CR-171828 c.1

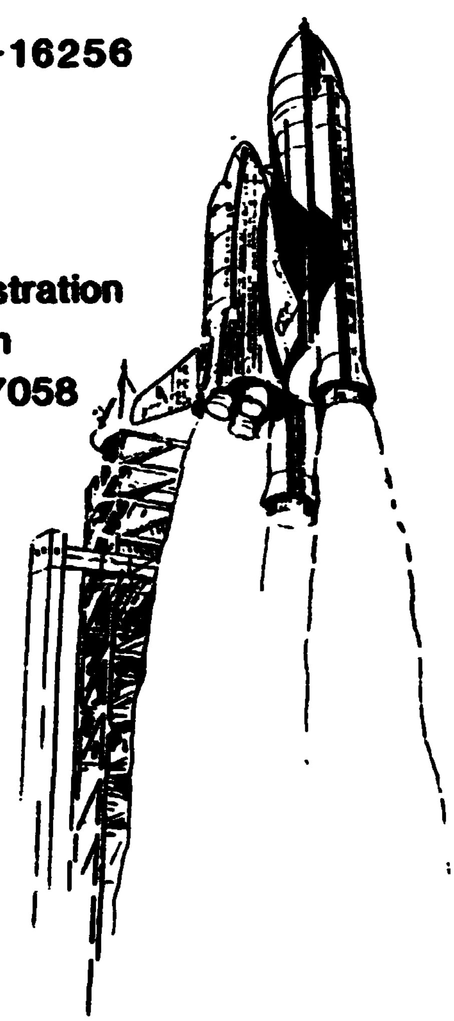
LMSC-HREC TR D867400-III

(NASA-CR-171828) HIGH ALTITUDE CHEMICALLY N85-15803
REACTING GAS PARTICLE MIXTURES. VOLUME 3:
COMPUTER CODE USER'S AND APPLICATIONS MANUAL
(Lockheed Missiles and Space Co.) 431 p Unclas
HC A19/MF A01 CSCL 04A G3/20 13006

HIGH ALTITUDE CHEMICALLY REACTING GAS PARTICLE MIXTURES
VOLUME III–COMPUTER CODE USER'S AND APPLICATIONS MANUAL

October 1984

CONTRACT NAS9-16256



Prepared for

National Aeronautics and Space Administration
Aerodynamic Systems Analysis Section
Johnson Space Center, Houston, TX 77058

by

S. D. Smith

Lockheed
Missiles & Space Company, Inc
Huntsville Research & Engineering Center

4800 Bradford Drive, Huntsville, AL 35807

FOREWORD

This document is Volume III of a three volume report describing the Reacting and Multi-Phase (RAMP2) computer code developed by the Computational Mechanics Section of Lockheed's Huntsville Research & Engineering Center, Huntsville, Alabama. Volume II provides a detailed description of all the elements used in the RAMP2 code. Volume I deals with the theory and numerical solution for the computer code, and Volume III is the program users and applications manual.

Documentation of the computer code was prepared in partial fulfillment of Contract NAS9-16256 with the NASA-Lyndon B. Johnson Space Center, Houston, Texas. The contracting officer's technical representative for this study was Mr. Barney B. Roberts (ET41).

The author acknowledges the efforts of Dr. Terry F. Greenwood of NASA-Marshall Space Flight Center and Mr. S.J. Robertson of Lockheed-Huntsville, both of whom contributed to the development of the RAMP2 code.

Companion documents to this report include a theory and numerical solution document for RAMP2 computer code; a computer program maintenance manual for RAMP2; a report which describes the modifications made to the NASA-Lewis TRAN72 computer code; the original documentation of the NASA-Lewis TRAN 72 computer code; and the original documentation of the Boundary Layer Integral Matrix (BLIMPJ) computer code. These documents are, respectively:

- "High Altitude Chemically Reacting Gas-Particle Mixtures - Volume I - A Theoretical Analysis and Development of the Numerical Solution," LMSC-HREC TR D867400-I.

- "High Altitude Chemically Reacting Gas-Particle Mixtures - Volume II - Program Manual for RAMP2," LMSC-HREC TR D867400-II.
- "User's Guide for TRAN72 Computer Code Modified for Use with RAMP and VOFMOC Flowfield Codes," LMSC-HREC TM D390409.
- Svehla, R.A., and B.J. McBride, "FORTRAN IV Computer Program for Calculation of Thermodynamics and Transport Properties of Complex Chemical Systems," NASA TN D-7056, January 1976.
- Evans, R.M., "Boundary Layer Integral Matrix Procedure BLIMP-J User's Manual," Aerotherm UM-75-64, July 1975.

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CONTENTS (Continued)

CONTENTS (Concluded)

1. INTRODUCTION AND SUMMARY

This document, Volume III, provides the details of how to input, use and apply the RAMP2 computer codes to accurately describe high altitude rocket exhaust plumes. The goal in developing RAMP2 was to produce computer code which would provide an engineering tool for calculating high altitude (orbital) rocket exhaust plumes. Additionally, the computer model includes the ability to analyze the major controlling phenomena (boundary layer, chemistry, two-phase flow, and free molecular flow) which influence the structure of the plume.

The contents of this volume along with the other two volumes (Refs. 1 and 2) are designed to enable the user to easily, efficiently, and accurately apply the RAMP2 codes to calculate rocket exhaust nozzle and plume flow fields to solve practical engineering design problems.

RAMP2 consists of three basic computational modules: the TRAN72 program for generating equilibrium thermodynamic and transport data, the RAMP2F code for solving the flow field and the BLIMPJ code used to calculate the nozzle boundary layer. Because of computer storage limitations the three programs must be executed separately; however, communication between the programs has been provided via temporary files so that except for separate executions they can be considered as one program.

Detailed descriptions of the TRAN72 (Ref. 3) and BLIMPJ (Ref. 4) have not been included, although Volume II contains a brief description of the subroutines of each of the codes. Section 4 of this volume contains information on how to use and input the TRAN72 code, and Section 5 contains a brief discussion of the BLIMPJ code. Complete descriptions of the two codes are available in Refs. 3 and 4.

Section 2 of this volume provides a discussion of the overall operation and interaction of the codes which make up the RAMP2 code along with run stream setups for both the Univac and CDC 7600 machines. Section 3 gives the capabilities of the programs and a discussion of the practical application of the program. Sections 4 and 5 discuss the use of the TRAN72 and BLIMPJ codes. A detailed input/output guide to the RAMP2F program is given in Section 6. Section 7 deals with program utilization including subsections on how to set up a case, a description of error messages and some problems that can be encountered and how to correct them. Section 8 details several sample cases including step-by-step description on how each case was input. Appendix A contains a reprint of a paper published in the 1983 Thermophysics Volume of the AIAA Progress Series. This paper summarizes the RAMP2F code and presents results of several applications of the program.

This report provides a compilation of the author's experience with the programs both during and following completion of the programs. It is hoped that the three volumes provide a clear description on how to use the programs. It is anticipated that through feedback from other users of the programs that the codes themselves as well as the documentation can be further improved for clarity.

2. GENERAL STRUCTURE AND OPERATION OF RAMP2

The three programs which make up the RAMP2 code (TRAN72, RAMP2F, and BLIMPJ) have been modified so as to interact as if they were a single code even though they are executed separately due to computer storage restrictions. This section describes the overall operation of the RAMP2 code, the interaction required by the three programs and finally gives run stream setups for using the programs on either the Univac 1100 or CDC 7600 systems. The overall commication of the three programs along with communications with other auxiliary programs is shown in Fig. 2-1.

2.1 OVERALL OPERATION OF RAMP2F CODE

The purpose of the RAMP2 code is to solve a rocket exhaust flow field in sufficient detail so that the plume may be used to adequately specify some design environment for systems which are influenced by the plume. For high altitude plumes an adequate definition of the plume requires the inclusion of chemistry and nozzle boundary layer effects. The TRAN72 program and BLIMPJ codes are included in the RAMP2 code along with the RAMP2F flowfield code to treat chemistry and boundary layer effects.

In general. in order to solve a high altitude plume the following steps are required. First, the TRAN72 program input data is prepared and executed to generate a data tape describing the thermodynamic characteristics of the post-combustion gases. Next the RAMP2F flowfield data are prepared and the nozzle flow field is solved using the TRAN72 program data tape as input. Then in order to adequately describe the nozzle boundary layer, the BLIMPJ code is executed using an input data file and flowfield tape generated by the RAMP2F nozzle solution. Finally the exhaust plume is generated by using the nozzle solution and boundary layer solution to generate an exit plane

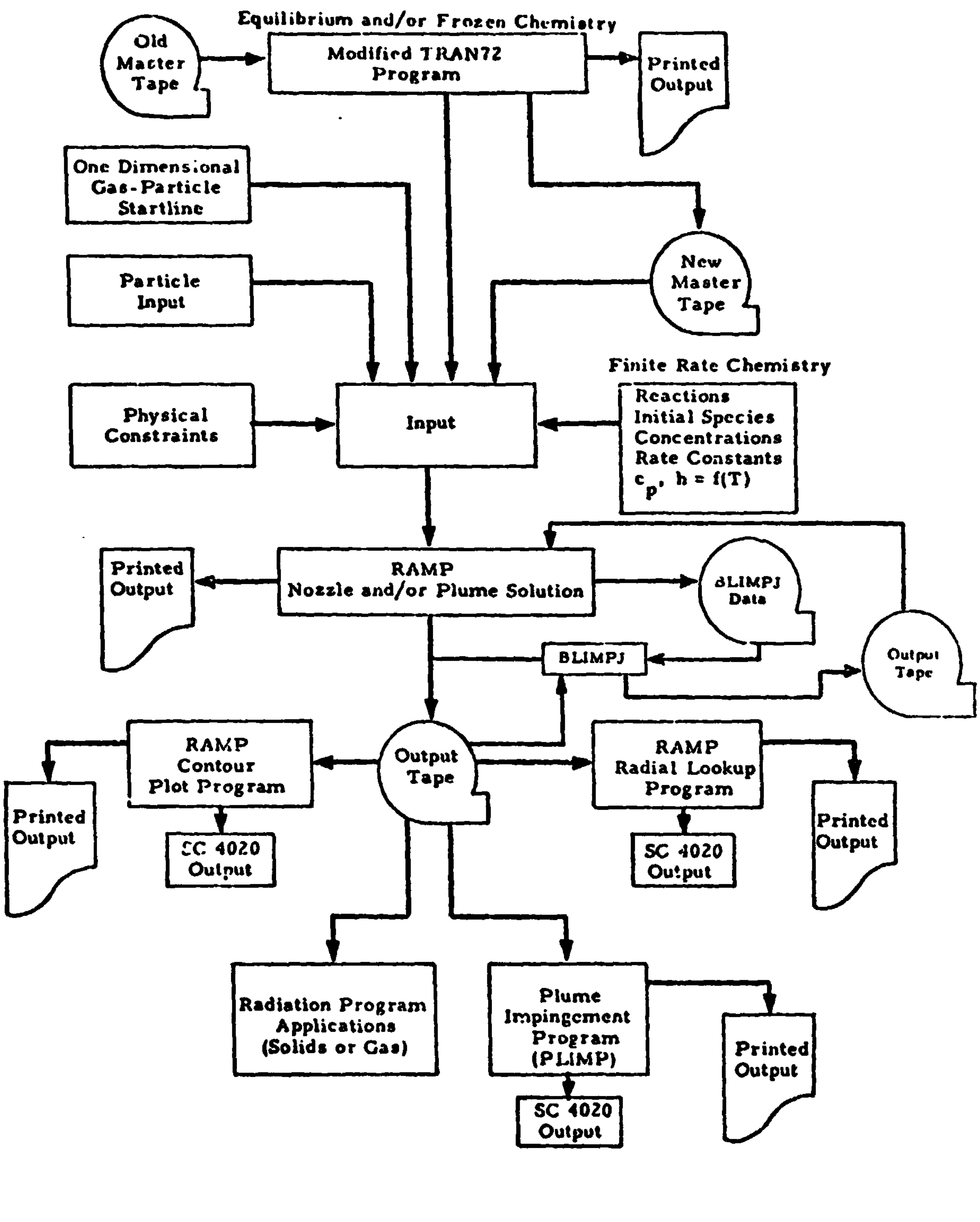


Fig. 2-1 Sequencing and Communication of the RAMP2 Programs with Auxiliary Codes

start line that is used to initiate the plume solution. Thus the generation of a high altitude plume can require up to four different executions of programs (TRAN72, RAMP2F, BLIMPJ, and RAMP2F) for the specification of the most detailed and accurate results. Physical input data are required only for the TRAN72 and first RAMP2F execution. All data required for the BLIMPJ code and second RAMP2F execution are generated internal to the program and/or communicated via data tapes or temporary files. Depending on the application, the problem or the level of sophistication required in the plume results it may not be necessary to run the TRAN72 or BLIMPJ codes. It is possible that a single RAMP2F calculation may be adequate.

As mentioned previously, the TRAN72 program generates thermodynamic data for the equilibrium/frozen post-combustion gases which are used in the flowfield calculations performed by RAMP2F. However, equilibrium/frozen thermodynamic data can be input via cards if the data were generated using some other method in which case it is not necessary to execute the TRAN72 program. It is also possible that the propellant for the motor might be an ideal gas (e.g., nitrogen jet) in which case the gas thermodynamic data can be input on a single card directly into the RAMP2F code. Finally, the user may decide that a finite rate or frozen chemistry solution is required in which case the reaction package and individual species thermodynamics are input directly into the RAMP2F code.

If the user has an application in which nozzle boundary layer effects are not important then it is not necessary to execute the BLIMPJ code.

If the user is not interested in boundary layer effects, then a single RAMP2F flowfield calculation starting at the throat or at the exit plane can be made to generate the exhaust flow field.

Thus numerous combinations of program executions are possible depending on what the user requires as results. Additionally, the TRAN72 program may be executed alone if the results are required for some use other than for RAMP2F. It is possible to execute the BLIMPJ as a stand-alone program but some minor program modifications are required to change the input file numbers and omit reference to flowfield data files that come from the RAMP2F nozzle solution.

2.2 INTERACTION OF THE CODES

The relationship of the three programs (TRAN72, RAMP2F, BLIMPJ) has been discussed in previous sections. The three programs communicate with each other via files (magnetic tape, FASTRAN, disk, mass storage, etc.). The files that the programs use are FORTRAN units 1,2,3,4,5 (card input), 6 (printed output), 7 (punched output) 8, 9, 10, 11, 12, and 13.

The TRAN72 program uses thermodynamic curve fit data and transport data as input from either cards or from FORTRAN Unit 4. The thermodynamic data of unit 4 which is included as a data set for the RAMP2 program is also used by the RAMP2F program for setting up the data file for a BLIMPJ nozzle boundary layer solution. The equilibrium/frozen gas thermochemistry results which are generated by the TRAN72 program are output on unit 10. These data are then used as input by the RAMP2F program for performing the nozzle and plume solutions.

The RAMP2F program generates numerous output files for its own use as well as by the BLIMPJ program. If the user has selected the option to generate a nozzle boundary layer, the input data file for the BLIMPJ code is generated by the RAMP2F nozzle solution and stored on unit 1. The RAMP2F code also stores data on FORTARN unit 2 for use by the BLIMPJ code. The data on FORTRAN Unit 2 is the coordinates the nozzle and flow properties of the nozzle wall points which are used as solution stations by the BLIMPJ code. The BLIMPJ code also output data on the same FORTRAN unit 2 for subsequent use by RAMP2F when a viscous plume is to be run after the nozzle boundary layer is generated. The flowfield results of the RAMP2F nozzle and plume solution are stored in Unit 3.

The flowfield data stored on FORTRAN Unit 3 is the final results of the RAMP2F nozzle and/or plume solution. These data can be used by other auxiliary programs for application of the plume data. The BLIMPJ program uses the nozzle flowfield data to match the boundary layer and inviscid flow properties at the boundary layer edge. If a complete nozzle, boundary layer, and plume solution are performed both the nozzle and plume results are put on Unit 3. If a single RAMP2F calculation is made with no subsequent exit plane restart (ITRCE = 0, card 5) then only the results for the single execution will be on the unit.

FORTRAN Unit 8 is the file on which the RAMP2F code stores a start line which is generated by the variable O/F or two-phase transonic module. If this file is used during the nozzle solution then it is also required for the subsequent viscous exit plume restart (ITRCE >0, card 1).

Units 9 and 11 are scratch files. Unit 10 contains the thermochemical properties of the equilibrium/frozen TRAN72 results. This file is required for the nozzle RAMP2F solution as well as for a subsequent viscous exit plane restart. This file is required only if ICON(1)=2, card 5.

An option of the RAMP2F code is the ability to generate an exit plane startline for the Standard Plume Flowfield (SPF) code (Ref. 5). Unit 12 contains exit plane data calculated during the RAMP2F nozzle run for generating an SPF start line (ISKPY > 0). If a viscous plume restart is to be performed unit 12 also contains the exit plane normal start line. Finally, if a viscous exit plane restart is to be performed unit 12 also contains the inviscid exit plane SPF startline. The data on unit 12 is used by the second RAMP2F plume restart to generate the exit plane startline for both the RAMP2F plume calculation as well as a viscous SPF start line. If a stand alone RAMP2F calculation is being made the unit 12 is only used if ISKPY = 0, card 5.

Unit 13 is used only to store the RAMP2F card input data. The purpose of this file is to store all the RAMP2F input data so that it will not have to be read in again if a subsequent viscous exit plane restart is selected. An exit plane restart using a viscous start line (ITRCE > 0), card 1) will require the input data on unit 13 that was saved for the RAMP2F nozzle solution.

In summary, if a viscous exit plane restart of a RAMP2F nozzle solution is to be performed then the data on FORTRAN units 2, 3, 4, 8, 10, 12, and 13 must be saved from the nozzle solution. A BLIMPJ calculation of the nozzle boundary layer requires the data on units 1, 2, and 3 from the RAMP2F nozzle solution. The communication of data between the three programs is summarized in Fig. 2-2.

2.3 RUN STREAM SETUP

This section illustrates run stream setups for the Univac 1108 EXEC 8 (Section 2.3.1) and CDC 7600 (Section 2.3.2) computers. Both runstreams assume that all three programs are executed to generate a exhaust plume which considers nozzle boundary layer effects. The RAMP2F programs can be executed individually depending on the user specified input data.

2.3.1 Univac 1108 EXEC 8 Runstream

Figure 2-3 presents the run stream setup for the Univac 1108. This run stream uses the programs and data which are retrieved from magnetic tape. These references to tape could be replaced with appropriate permanent files. This run stream also assumes that the executable instructions for the program have already been collected and stored on the tape as; A-TRAN72 program, TWOP-RAMP2F program, BLIMP-BLIMPJ program. The overlays for the RAMP2F and BLIMPJ programs can be found in Appendix A of Volume II of this report.

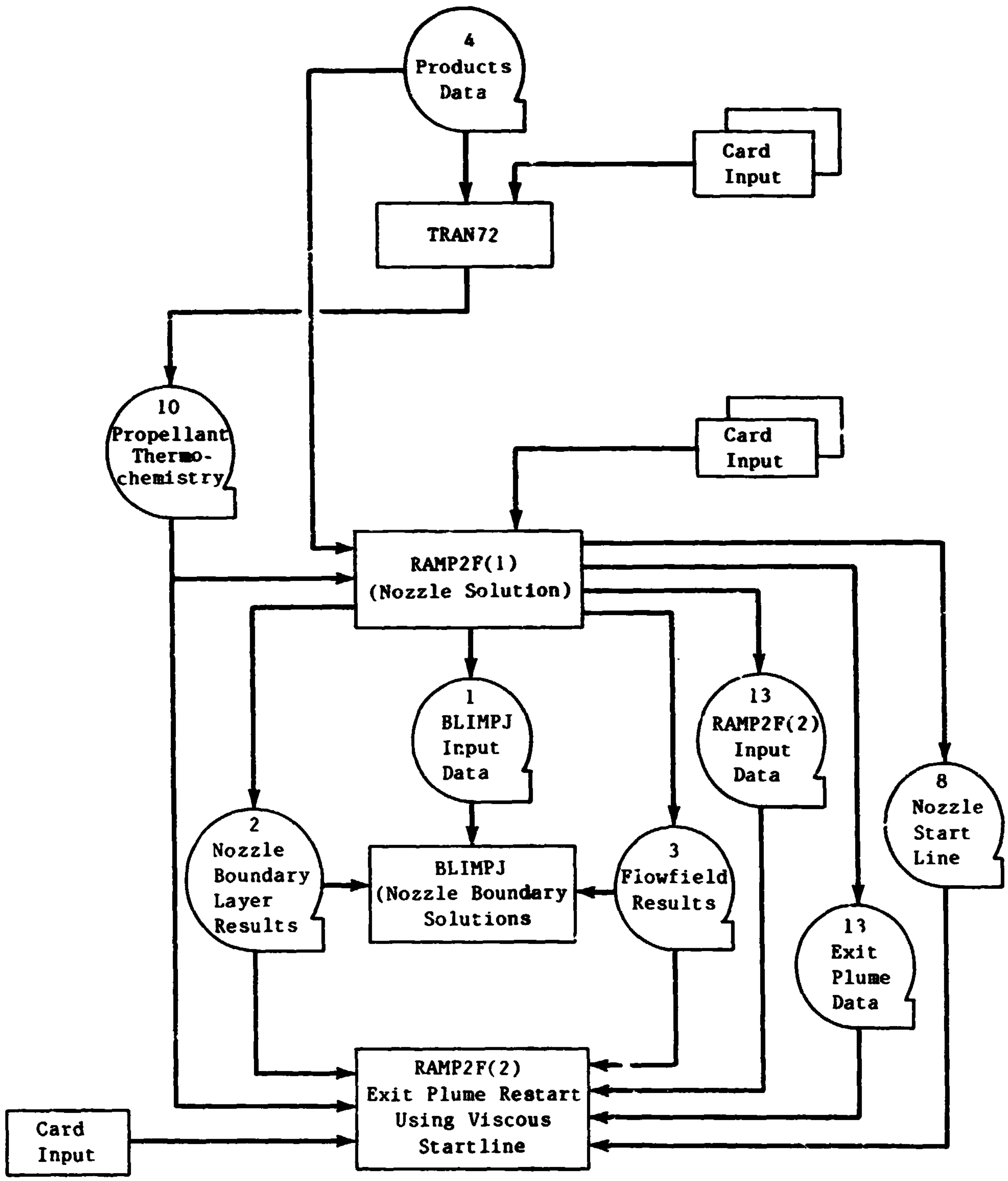


Fig. 2-2 Communication of Data Between the RAMP2 Programs

ORIGINAL PAGE IS
OF POOR QUALITY

```
@RUN                                        . RUN CONTROL CARD
@ASG,T 1,F///
@ASG,T PLT,F///
@USE 2,PLT
@ASG,T PLP,F///
@USE 3,PLP
@ASG,T PROD,F///
@USE 4,PROD
@ASG,T DUM,F///
@USE [illegible],DUM
@ASG,T [illegible],F
@ASG,T DAT,F
@USE [illegible]
@ASG,T 11,F
@ASG,T 12,F
@ASG,T PLIM,F///
@USE 15,PLIM
@FREE TPF$                                  . CORE ASSIGNMENT
@ASG,T TPF$,F///                            . CORE ASSIGNMENT
@ASG,TF STK,[illegible]                     . PROGRAM AND PRODUCT DATA TAPE
@MOVE STK,3                                 . MOVE TAPE TO 4 TH FILE
@COPY STK,PROD                              . COPY PRODUCTS DATA ONTO UNIT 4
@REWIND STK                                 . REWIND PROGRAM TAPE
@COPIN STK,TPF$                             . COPY TRAN72 PROGRAM INTO CORE
@XQT [illegible]                            . EXECUTE TRAN72 PROGRAM
    ................TRAN72 DATA....................
@[illegible]                                . [illegible]
@FREE TPF$                                  . CORE ASSIGNMENT
@ASG,T TPF$,F///                            . CORE ASSIGNMENT
@REWIND STK
@MOVE STK,1                                 . MOVE PROGRAM TAPE TO SECOND FILE
@COPIN STK,TPF$                             . COPY RAMP CODE INTO CORE
@COPIN STK,TPF$                             . COPY PLIMPJ CODE INTO CORE
@FREE STK                                   . RELEASE PROGRAM TAPE
@XQT [illegible]                            . EXECUTE RAMP CODE FOR NOZZLE SOLUTION
    ...................RAMP NOZZLE DATA.....................
@XQT [illegible]                            . EXL PLIMPJ CODE FOR NOZZLE BOUND LAYER
.   ............... PLIMPJ DATA IT CASE FOR RAMP OUTPUT FILE............
@XQT [illegible]                            . EXE RAMP FOR PART FL CALC + STARTLINE
    ........2 CARDS OF RAMP DATA FOR PARTICLE TRAJECTORY AND EXIT STARTLINE.......
    ........[illegible] DATA WAS LOADED ON UNIT 1[illegible] IN FIRST RAMP EXECUTION........
@FIN
@FIN
```

Fig. 2-3 Univac 1110 Runstream Setup for RAMP2

2.3.2 CDC 7600 Runstream

Figure 2-4 presents the runstream setup for the CDC 7600 system. The run stream uses permanent files for the programs and data files but tapes could be used instead. The segment loader cards for the RAMP2F and BLIMPJ codes can be found in Appendix A of Volume II of this report.

```
RUN CARD                                   • RUN CONTROL CARD
ATTACH([illegible])                        • TRANS72 PROGRAM FILE
REQUEST(TAPE1 [illegible])                 • ALLOCATE STORAGE FOR THERMOCHEMISTRY
ATTACH(TAPE[illegible])                    • TRANS72 PRODUCTS DATA FILE
[illegible]•                               • EXECUTE TRANS72 PROGRAM
CATALOG(TAPE1 [illegible])                 • SAVE THERMOCHEMICAL DATA PERMANENTLY
RETURN([illegible])                        • RELEASE TRANS72 PROGRAM FILE
ATTACH(OL[illegible])                      • RAMP2F PROGRAM FILE
REQUEST(TAPE[illegible])                   • ALLOCATE STORAGE FOR FLOWFIELD DATA
SEGLOAD•                                   • READ SEGMENT LOAD CARDS FOR RAMP2F
LOAD([illegible])                          • LOAD RAMP2F PROGRAM
EXECUTE•                                   • EXECUTE RAMP2F NOZZLE SOLUTION
RETURN(OL[illegible])                      • RELEASE RAMP2F PROGRAM FILE
ATTACH([illegible])                        • BLIMPJ PROGRAM FILE
SEGLOAD•                                   • READ SEGMENT LOAD CARDS FOR BLIMPJ
LOAD([illegible])                          • LOAD BLIMPJ PROGRAM
EXECUTE•                                   • EXECUTE BLIMPJ PROGRAM
RETURN([illegible])                        • RELEASE BLIMPJ PROGRAM
ATTACH(OL[illegible])                      • RAMP2F PROGRAM FILE
SEGLOAD•                                   • READ SEGMENT LOAD CARDS FOR RAMP2F
LOAD([illegible])                          • LOAD RAMP2F PROGRAM
EXECUTE                                    • EXECUTE RAMP2F FOR RESTART AT EXIT
CATALOG(TAPE[illegible])                   • SAVE RAMP2F FLOWFIELD DATA PERMANENTLY
•                                          • • CARDS ARE FILE SEPARATORS
   •••••   TRANS72 DATA   ••••
•
   •••••   RAMP2F SEGMENT LOADER CARDS SEE VOL II APPENDIX A   •••••
•
   •••••   RAMP2F DATA FOR NOZZLE SOLUTION                     •••••
•
   •••••   BLIMPJ SEGMENT LOAD CARDS SEE VOL II APPENDIX A     •••••
•
•
   •••••   [illegible] SEGMENT LOAD CARDS                      •••••
•
   •••••   RAMP2F DATA CARD FOR EXIT PLANE RESTART             •••••
•
```

Fig. 2-4 CDC 7600 Runstream Setup for RAMP2

3. CAPABILITIES AND APPLICATIONS

The RAMP2 program has a broad range of capabilities for treating the various phenomena which effect the characteristics of nozzle and exhaust plume flow fields. The ability of the RAMP2F code to treat single and two-phase flows has led to the application of the program to solve a wide range of problems. This section presents a list of capabilities of the program and summarizes some of the previous applications of the program.

3.1 CAPABILITIES

The RAMP computer program described in this document can be used to solve a wide variety of problems associated with real gas, supersonic, compressible flow. Some of the more important basic capabilities of the existing program are outlined below:

- The gas may be ideal or real. If the gas is real, frozen, equilibrium, or non-equilibrium, chemistry assumptions can be made. The effects of oxidizer/fuel gradients may be considered.
- Two-dimensional or axisymmetric flow problem geometries can be used.
- Both upper and lower boundaries can be solid or free. (A solid boundary can be approximated by either a conic or polynomial equation.) (Two-phase problems require the nozzle centerline as a lower boundary.)
- A nozzle wall may be curve fit with discrete points.
- Any number of expansion corners can be considered on either the upper or lower walls.
- Various methods for obtaining an initial start line are utilized.

1. The program will calculate a one-dimensional startline anywhere in the nozzle.

2. Data on a normal surface can be input at points across the flow field within the nozzle or in the plume.

3. An exit plane startline can be punched.

4. The program can be restarted from the startline punched in 3 above.

5. Single phase startline can be calcualted using a transonic solution which can handle ideal gas or equilibrium chemistry for both constant and variable oxidizer/fuel ratios.

6. Two-phase startline can be set up using a transonic solution.

- Hypersonic or quiescent approach flow options may be used.
- Exit to ambient pressure ratios from overexpanded to highly underexpanded are possible.
- Displacement of the axis of symmetry from the center of flow (i.e., the plug nozzle flow field) is possible for gas only cases.
- There is presently a maximum of 100 points on a normal and 100 input points.
- Reacting gas solutions which are in chemical equilibrium have been facilitated by modifying the TRAN72 (Refs. 3 and 6) computer program as described in Section 4 to provide binary tape and punched output of its equilibrium or frozen real gas calculations at any desired O/F ratio(s) or total enthalpy(s). The RAMP program has the capability of selecting the proper case from a large set of real gas properties cases stored on a master tape. Cases stored are uniquely identified by some characteristic of the particular gas under consideration. For example, a LOX/LH_2 system may be identified by the following:

Gas Type	Mixture Ratio	Chamber Pressure
O2/H2	O/F = 1.5 - 8.0	PC = 546.0

New cases of general interest may be added to the master tape; however, ad hoc cases should be prepared on a separate tape.

- Once the gas-particle flowfield solution has been obtained, the output tape may be used by the RAMP Radial Lookup Program (described in Appendix A of Ref. 7) which determines the radial variations of flowfield properties across the nozzle and plume flow fields at constant axial stations. The Plume Impingement Program (PLIMP) (Ref. 8) may also be run to determine the effects of the rocket exhaust plume on objects immersed in the plume.

- Two-dimensional or axisymmetric solutions are selected by simply loading a control word in the program input data. This integer (0 or 1) is then multiplied by the term containing (1/r) in the governing differential equation. By appropriate description of the flow boundaries, it is possible to change from a solid to free boundary on either the upper or lower walls. Conversely, it is not possible to change from a free to a solid boundary on either wall.
- A real gas nozzle boundary layer solution can be performed with no interface between the user and the RAMP code results. Frozen equilibrium chemistry with turbulent or laminar solution is possible.
- The effect of a nozzle wall boundary layer on particles which enter the boundary layer is treated.
- An exit plane startline can be generated for the SPF code which includes two phase flow and boundary layer effects. Additionally exit plane data are available for use in other codes.
- Multiple passes through the inviscid nozzle solution with the nozzle contour modified by the BLIMPJ solution displacement thickness is not possible.
- High altitude rarefied plumes may be treated with either continuum or sudden freeze free molecular flow assumptions.
- Nozzle shocks can be treated using a shock capturing methodology or can be treated isentropically using the streamline normal solution.
- Automatic exit plane restarts including boundary layer effects are possible following a nozzle and nozzle boundary layer solution.
- When the continuum treatment of rarefied plumes is used, the plume may be solved only to the point where the gas velocity reaches 99.9 percent of its limiting velocity. Near the gas limiting velocity numerical problems can lead to a termination of the solution.

3.2 APPLICATIONS

This section contains a list of problems for which the RAMP2F or RAMP codes have been applied. Where possible, references have been included which contain details of the analysis.

- Analyzed Space Shuttle RCS motor combustion chamber, nozzle and exhaust plume. Utilized equilibrium/frozen chemistry, variable O/F transonic solutin and boundary layer effects (Ref. 9).
- Space Shuttle Solid Rocket Motor
  - Equilibrium/frozen nozzle/plumes at various altitudes and operation conditions for base heating application (Ref. 10).
  - Sea level plume for Space Shuttle mobile launcher design environment (Ref. 11).
  - High altitude plume calculation including finite rate chemistry for application to range safety plume radar cross-section determination (Ref. 12).
- Space Shuttle separation motor nozzle/plume solutions for determination of stage separation impingement environments on Orbiter/ET combination (Ref. 13).
- Applied RAMP code to several small solid rocket motor nozzle and plume predictions to determine how best to apply RAMP code for making nozzle and plume calculations. Compared RAMP results with experimental nozzle and plume data (Ref. 14).
- Performed high attitude plume calculations for interim upper stage motor plumes. Particulate flow fields were to be used for determination of possible orbiter heat shield damage during various satellite deployment senarios (Ref. 15).
- Performed detailed combustion chamber and nozzle calculations and made comparisons with exit plane radiation measurements to determine the best analytic models for performing combustion chamber/nozzle calculations (Ref. 16).
- Used RAMP as a part of a code to compute the IR irradiance on a vehicle-born sensor arising from a plume emitted by a thruster on the vehicle in an exoatmospheric environment (Ref. 17).

4. USER INPUT/OUTPUT GUIDE FOR THE MODIFIED TRAN72 COMPUTER CODE

One option for the specification of the thermodynamic properties of the exhaust gases for the RAMP2F code is the utilization of the thermodynamic and transport data of rocket combustion gases which is generated by a modified version (Ref. 18) version of the NASA-Lewis TRAN72 (Ref. 3) computer program.

The TRAN72 computer program developed by NASA-Lewis (Ref. 3) was synthesized by combining a program for the transport properties calculation with the CEC 71 program (Ref. 6) for the thermodynamic properties calculation. The TRAN72 program was subsequently modified to meet the requirements of Lockheed's Reacting and Multi-Phase (RAMP) Computer Program. The requirements satisfied were: (1) calcuation of the theoretical rocket performance (for both equilibrium and frozen compositions) during a "gaseous-only" expansion, after a two-phase combustion chamber calculation, and (2) automated communication of these properties to the RAMP program.

The section describes the modifications which were made to the TRAN72 code, the input required to run the program, special considerations for using the code in conjunction with RAMP2F, and sample cases.

4.1 MODIFICATION OF THE TRAN72 PROGRAM FOR USE WITH THE RAMP2F PROGRAM

Modifications were made to the TRAN72 chemical equilibrium calculational scheme in order to generate thermochemical data consistent with the assumptions utilized in the RAMP program formulation. The assumptions being addressed in the RAMP program are:

- The total mass of the mixture is constant.
- The total energy of the mixture is constant.

- The gas obeys the perfect gas law and is either chemically frozen, in chemical non-equilibrium or in chemical equilibrium.
- There is no mass exchange between the phases.
- The particles are inert.

In the modified TRAN72 calculational scheme, the chamber calculations are performed initially with the condensed species considered. The total mass and total enthalpy of the mixture are then adjusted by removing the mass and enthalpy associated with the condensed species predicted to exist in the chamber after combustion. The total mass adjustment is made by removing the appropriate amount of mass of each of elements which comprise the condensed species that exist in the chamber. The total enthalpy is adjuted by removing the enthalpy associated with the condensed species that exist in the chamber. Next, the adjusted elemental mass balance relationships and the adjusted total enthalpy are referenced to the adjusted total mass of the mixture. All condensed species are then removed from the list of possible products being considered by the program. The chamber calculations and subsequent equilibrium chemistry expansion are then made with a gaseous-only composition. When the thermodynamic calculations are completed, the transport properties are calculted in the manner described in Ref. 3. The resultant equilibrium chemistry expansion and corresponding transport properties data are the case in which there is no heat transfer between the condensed and gaseous species during the equilibrium chemistry expansion process. To account for the effects of the heat transfer that does take place between the condensed and gaseous species as well as between the gas and the nozzle wall for cases involving a nozzle boundary layer, additional thermochemical data are required. To generate the required data, the total enthalpy of the gaseous-only mixture is perturbed (mass is held constant) and the thermochemical data calculational scheme is repeated. The total enthalpy is repeatedly perturbed, the result being an array of equilibrium expansion processes and corresponding transport properties, each with a different degree of heat transfer between the two phases.

Experience in thermodynamical modeling of rocket exhaust flows indicates that many chemical systems experience a transition from equilibrium to frozen chemistry during the expansion process. The standard TRAN72 program has an option to treat this problem. Under the pressure freeze option the chamber and initial expansion calculations are made assuming equilibrium chemistry. At a predetermined pressure ratio (chamber to local static), the chemistry of the system is frozen and the remainder of the expansion is completed with frozen chemistry. With this option, the transport properies are calculated as outlined in Ref. 3.

The thermochemical and transport data are communicated to the RAMP computer program automatically through the use of a magnetic tape (or rapid access storage, i.e., disk, FASTRAN, etc.). Creation of the data tape (or file) is accomplished by means of an additional subroutine (MOCDAT) added to the TRAN72 program. Logic is provided in this routine for creation of a new data tape (or file) and adding data to an existing Master data list. Each data case must be identified with a unique case name which is subsequently used by the RAMP (see card 9 of RAMP input guide) program to determine if thermodynamic data are available. An additional namelist has been added to the run stream to control use of the options available in the MOCDAT subroutine.

4.2 INPUT OF THE TRAN72 PROGRAM

The version of the TRAN72 program which is part of the RAMP2 set of computer programs contains all the options of the original program (Ref. 3), so that the user has the ability to generate thermodynamic data for purposes other than the RAMP2F code execution. This subsection describes the basic TRAN72 input data as well as the input control variables which were added to enable the modifications which were described in Section 4.1.

4.2.1 TRAN72/RAMP2F Input Variables

The modified TRAN72 program is used to generate thermodynamic and transport properties of the gaseous phase of the products of combustion being considered in a two-phase flow analysis. Control of the program function for this application is handled through three input groups: the reactant data cards, the $INPT2 namelist, and the $RKTINP namelist. A detailed description of the standard TRAN72 program input is given in Ref. 3. Thermodynamic data required for this application are calculated using the RKT option under the $INPT2 namelist. Selection of this option permits calculation of theoretical rocket performance for both equilibrium and frozen compositions during expansions. The variables MOC2P, PARTHT, QDOTP, and NQI have been added to the $INPT2 namelist. The MOC2P variable controls the selection of the two-phase flow analysis option (MOC2P=T). The variables PARTHT, QDOTP, and NQI control the selection (PARTHT=T) and use of the variable total enthalpy option when the effects of heat transfer between the condensed and gaseous species are to be determined in a two-phase flow analysis. When PARTHT=T, QDOTP is set equal to the amount by which the total enthalpy of the gaseous only mixture is to be perturbed. NQI is set equal to the number of QDOTP values input. The specific values of the ratio of chamber to local static pressures (P_c/P) at which thermodynamic and transport data are to be generated are input to the program in the $RKTINP namelist. The pressure freeze option is activated by setting the variable NFZ under the $RKTINP namelist equal to the number of the pressure ratio at which transition from equilibrium to frozen chemistry is to occur. (The chamber is considered to be number one, the throat number two, etc.). Freeze pressures may be the chamber value or any supersonic pressure. No provision is made for freeze pressures between chamber and throat. The parameters which are generally utilized by the RAMP program are local Mach number, static pressure and temperature, isentropic coefficient (gamma), molecular weight, entropy, Prandtl number, viscosity, specific heat at constant pressure and the total enthalpy (gas only). These parameters, with the exception of the total enthalpy, are calculated for each value of

(P_c/P) ratio by the program. A detailed description of the logic involed in the standard TRAN72 program computation is presented in flow chart form in Ref. 3. This information can be consulted for an in-depth understanding of the calculational scheme.

To automatically create a tape for communication with the RAMP program one of the two tape-write options must be selected (MOCT=T, or MOCTF=T) under the $INPT2 namelist. The MOCT variable is utilized when the thermochemical data are to be run completely under the equilibrium assumption. The MOCTF variable is utilized when the thermochemical data are to be run completely or partially frozen. If one of these options is selected an additional namelist, $TAPGEN, must be input to control the tape-write function and the input of the case name card. The $TAPGEN data are input after the $INPT2 data but prior to the case name card and $RKTINP namelist inputs. Table 4-1 summarizes the program variables added to the modified TRAN72 program.

4.2.2 TRAN72 Input Requirements

Table 4-2 presents complilation of the various input data utilized by the modified TRAN72 program. There are three basic types of input information: (1) code cards which specify what additional data will follow; (2) fixed format data associated with code cards, and; (3) namelist data associated with the namelist's code card The order in which the data are input is as shown in Table 4-2. Each execution of the TRAN72 program for use with the RAMP2F program requires: (2) thermodynamic data (from cards or tape); (2) reactants code card and REACTANTS data cards; (3) NAMELISTS code card and $INPT2, $RKTINP and $TAPGEN namelists and a case identifier card. Subsections 4.2.2.1 - 4.2.2.4 discuss each of the code cards and the associated data or namelists which must follow.

Table 4-1 ADDITIONAL INPUT VARIABLES
FOR MODIFIED* TRAN72 PROGRAM

$INPT2 NAMELIST					
Variable	Dimension	Type	Common Label	Value Before Read	Comment
MOCT	1	L	HREC	F	Selects tape-write option if true for equil. run.
MOC2P	1	L	HREC	F	Selects two-phase flow analysis option if true.
MOCTF	1	L	HREC	F	Selects tape-write option if true for frozen and pressure freeze options.
PARTHT	1	L	TWOPAS	F	Selects variable total enthalpy option if true for two-phase analysis run.
QDOTP**	26	R	TWOPAS	0.0	Set equal to the amount by which the total enthalpy of the gaseous-only mixture is to be perturbed.
NQI	1	I	TWOPAS	0	Set equal to the number of QDOTP values input.
$TAPGEN NAMELIST (NEW NAMELIST)****					
IREAD	1	I	-	1	If equal 0, new data added to master data tape list; if equal 1 data written on new data tape.
IO	1	I	-	8	Tape unit of old master tape list.
IN***	1	I	-	10	Tape unit of new data tape.
Case Name Card (New Input Card) Format: 6A4					

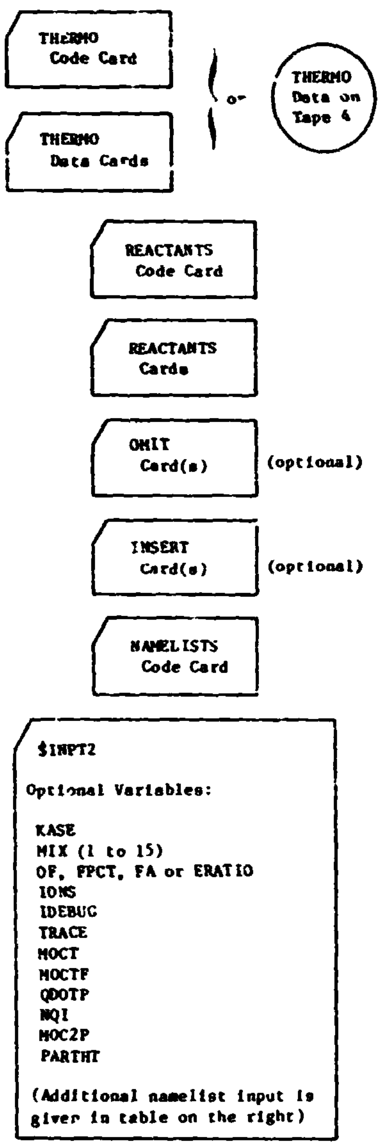
*Routines modified from the original TRAN72 program are: LINK, MAIN1 REACT, SEARCH, EQLBRM, ROCKET, RKTOUT, OUT1, TRANSP and OUT.

**The values of QDOTP must always be input in ascending order (from the most negative to the most positive).

***When running multiple cases, the data of the last case must always be placed on tape unit 10 if it is to be communicated automatically to the RAMP2F.

****$TAPGEN namelist and case name card are only required when MOCT or MOCTF are true.

Table 4-2 PROGRAM INPUT



Problem	Namelist	Variables	
		Required	Optional
Assigned temperature and pressure (TP)	INPT2	TP = .TRUE. T(1 to 26) P(1 to 26)	NSQM, PSIA, or MMHG
Assigned enthalpy and pressure (HP)	INPT2	HP = .TRUE. P(1 to 26)	NSQM, PSIA, or MMHG
Assigned entropy and pressure (SP)	INPT2	SP = .TRUE. SO(1) P(1 to 26)	NSQM, PSIA, or MMHG
Assigned temperature volume or density (TV)	INPT2	TV = .TRUE. T(1 to 26) V(1 to 26) RHO(1 to 26)	
Assigned internal energy and volume or density (UV)	INPT2	UV = .TRUE. V(1 to 26) or RHO(1 to 26)	
Assigned entropy and volume or density (SV)	INPT2	SV = .TRUE. V(1 to 26) or RHO(1 to 26) SO(1)	
Detonation (DETN)	INPT2	DETN = .TRUE. P(1 to 26) (initial gas)	NSQM, PSIA, or MMHG T(1 to 26) (initial gas)
Shock(SHOCK)	INPT2	SHOCK = .TRUE. P(1 to 13) T(1 to 13) (initial gas)	NSQM, PSIA, or MMHG
	SHKINP	U1(1 to 13) or MACH1 (1 to 13)	INCDEQ = .FALSE. or INCDFZ = .FALSE.
Rocket (RKT)	INPT2	RKT = .TRUE. P(1 to 26) (chamber pressures)	T(1 to 26) (chamber) NSQM, PSIA, or MMHG
	TAPGEN*		IO = 8 IN = 10 IREAD = 1
	RKTINP		EQL = .FALSE. or FROZ = .FALSE. PCP(1 to 22) SUPAR(1 to 13) SUBAR(1 to 13)

*Requires gas header card. TAPGEN namelist and gas header card are only used if MOCT or MOCTF are set = .TRUE.

4.2.2.1 THERMO Code Card and Thermodynamic/Transport Data

The thermodynamic and transport property data for possible chemical species can be read from cards or from tape (or mass storage). If the data are used from cards, the program will write these data on logical unit 4. During a computer run, the appropriate reaction product data consistent with each new set of REACTANTS cards will be automatically selected from tape 4 and stored in core.

THERMO and transport data may be read in from cards for each run. The program writes the THERMO and transport data on tape (or disk)4 as the cards are read. The data are written on tape with the same formats as the cards except that the THERMO code card and card numbers in column 80 are omitted.

When adding, removing, or changing data for various species on the tape, the whole set of THERMO and transport data cards must be included in the input for making a new tape.

The order and format of the input of the THERMO code card and thermodynamic and transport data are shown in Tables 4-3 and 4-4. The thermodynamic curve fit data (Table 4-3) is input, followed by the transport property data.

The thermodynamic properties (specific heats, enthalpy and entropy) of the species are specified on the thermo cards according to the following fourth order polynominal functions of temperature:

$$\frac{C_p}{R} = a_1 + a_2T + a_3T^2 + a_4T^3 + a_5T^4 \tag{1}$$

$$\frac{H_T^o}{RT} = a_1 + \frac{a_2}{2}T + \frac{a_3}{3}T^2 + \frac{a_4}{4}T^3 + \frac{a_5}{5}T^4 + \frac{a_6}{T} \tag{2}$$

Table 4-3 THERMODYNAMIC CARDS

Card Order	Contents*	Format	Card Column
1	THERMO	3A4	1 to 6
2	Temperature ranges for 2 sets of coefficients: lowest T, common T, and highest T	3F10.3	1 to 30
3	Species name Date Atomic symbols and formula Phase of species (S, L, or G for solid liquid, or gas, respectively) Temperature range Integer 1	3A4 2A3 4(A2.F3.0) A1 2F10.3 I15	1 to 12 19 to 24 25 to 44 45 46 to 65 80
4	Coefficient a_i (i = 1 to 5) in equations (1) to (3) (for upper temperature interval) Integer 2	5(E15.8) I5	1 to 75 80
5	Coefficients in eqs. (1) to (3) (a_6, a_7 for upper temperature interval, and a_1, a_2 and a_3 for lower) Integer 3	5(E15.8) I5	1 to 75 80
6	Coefficients in eqs. (1) to (3) (a_4, a_5, a_6, a_7 for lower temperature interval Integer 4	4(E15.8) I20	1 to 60 80
(a)	Repeat cards numbered 1 to 4 in cc 80 for each species		
(Final card)	END (Indicates end of thermodynamic data)	3A4	1 to 3

*Gaseous species and condensed species with only one condensed phase can be in any order. However, the sets for two or more condensed phases of the same species must be adjacent. If there are more than two condensed phases of a species, their sets must be either in increasing or decreasing order according to their temperature intervals

Table 4-4 TRANSPORT DATA

Card Type	Content[a]	Format	Column
1	Identification of interaction: chemical formula of species 1, chamical formula of species 2, number of temperatures in table (NTP), code to indicate type of data (1 for transport and 2 for relaxation), and number of rotational degrees of freedom.	2(3A4,6X), 2I5, F24.1	1 to 70
2[b]	Tables of data: either transport data (temperature, viscosity cross section, A^*, and B^*) or relaxation data (temperature, rotational collision number, vibrational collision number, and dimensionless vibirational heat capacity (C_{vib}/R)	4F10.4	1 to 40
3	End card to indicate end of transport data; LAST written in card columns 1 to 4	A4	1 to 4

[a] Identification of interaction is done by given chemical formula of particular species involved, whether they are the same or different. They may be specified in either order, inasmuch as the program assumes interaction A-B to be same as B-A. The number of rotational degrees of freedom is meaningful only for data of a pure species interaction of the type A-A). The temperature schedule is arbitrary if the number of temperatures is not more than the maximum of 20. In addition, the data should be ordered in either an increasing or decreasing function of temperature, in order that interpolation within the table be meaningful. As a matter of input convenience, the Hirschfelder-Eucken approximation is denoted by setting the collision number equal to 0.0. If the vibrational heat capacity is not specified ($C_{vib}/R = 0$), the program will calculate a value assuming that the electronic heat capacity is zero and that the rotational heat capacity is classical. For polar molecules A^* should be corrected for resonant exchange of internal energy.

[b] There are NTP cards of type 2; they are followed by a card of either type 1 or type 3.

$$\frac{S_T^o}{R} = a_1 \ln T + a_2 T + a_3 T^2 + \frac{a_4}{3} T^3 + \frac{a_5}{4} T^4 + a_7 \tag{3}$$

By definition

$$H_T^o = (\Delta H_f^o)_{298.15} + (H_T^o - H_{298.15}^o) \tag{4}$$

where ΔH_f^o is the heat of formation at T = 298.15°K.

The equations used in the program for calculating transport properties and sources for the necessary interaction data are discussed in Ref. 3.

4.2.2.2 Reactants Code Card and Data Cards

This set of cards is required for all problems. The first card in the set contains the reactants code card with the word REACTANTS punched in card columns 1 to 9. The last card in the set is blank. In between the first and last cards may be any number of cards up to a maximum of 15, one for each reactant species being considered. The cards for each reactant must give the chemical formula and the relative amount of the reactant. For some problems, enthalpy values are required. The format and contents of the cards are summarized in Table 4-5. A list of some sample REACTANTS cards is given in Table 4-6.

Relative Amounts of Reactants: The relative amounts of reactants may be specified in several ways. They may be specified in terms of moles, mole fraction, or mole percent (by keypunching M in card column 53).

For some cases, the relative amounts of the reactants are completely specified by the values on the REACTANTS cards. However, there are optional variables which may be set in namelist INPT2 that indicate relative amounts of total fuel to total oxidants. For this situation, each reactant must be

Table 4-5 REACTANTS CARDS

Order	Contents	Format	Card columns
First	REACTANTS	3A4	1 to 9
Any	One card for each reactant species (maximum 15). Each card contains:		
	(1) Atomic symbols and formula numbers (maximum 5 sets)[a]	5(A2, F7.5)	1 to 45
	(2) Relative weight[b] or number of moles	F7.5	46 to 52
	(3) Blank if (2) is relative weight or M if (2) is number of moles	A1	53
	(4) Enthalpy or internal energy[a], cal mole	F9.5	54 to 62
	(5) State: S, L, or G for solid, liquid or gas, respectively	A1	63
	(6) Temperature associated with enthalpy in (4)	F7.0	64 to 70
	(6a) J if (4) is in units of kJ/kg-mole and blank if (4) is in units of cal/g-mole	A1	71
	(7) F if fuel or O if oxidant	A1	72
	(8) Density in g cm^3 (optional)	F8.5	73 to 80
Last	Blank		

[a]Program will calculate the enthalpy or internal energy (4) for species in the THERMO data at the temperature (6) if zeros are punched in card columns 37 and 38. (See section Reactant enthalpy for additional information.)

[b]Relative weight of fuel in total fuels or oxidant in total oxidants. All reactants must be given either all in relative weights or all in number of moles.

Table 4-6 LIST OF REACTANTS CARDS FOR SOME OXIDANTS AND FUELS

Chemical	Chemical formula (card columns 1 to 45)	Percent (cc 46-52)	Assigned enthalpy, cal/mole (cc 54-62)	(a)	Temperature K (cc 64-71)	(b)	Density, g/cm^3 (cc 73-80)	References for assigned enthalpy	References for density
Acetonitrile	C 2. H 3. N 1.	100.	12600.	L	298.15	F	.7857	19	20
Acetylene	C 2. H 2.	100.	49272.	L	192.60	F	.61[illegible]	14 (series E)	14 (series E)
Air	N 1.56176 .41959 AR.009324C .000300	100.	-28.2	G	298.15	O		(c)	-----------
Aluminum	AL1.	100.	0.	S	298.15	F	2.702	reference element	20
Ammonia(g)	N 1. H 3.	100.	-10970.	G	298.15	F		8	-----------
Ammonia(l)	N 1. H 3.	100.	-17200.	L	239.7	F	.676	14 (series E)	14 (series E)
Ammonium perchlorate	N 1. H 4. CL1. O 4.	100.	-70690.	S	298.1	F	1.95	14 (series A)	14 (series A)
Aniline	C 6. H 7. N 1.	100.	7100.	L	298.15	F	1.02173	21	20
Argon	AR1.	100.	0.0	G	298.15	F		reference element	-----------
Benzene	C 6. H 6.	100.	+11719.	L	298.15	F	.8737	22	22
Beryllium	BE1.	100.	0.0	S	298.15	F	1.85	reference element	20
Butane	C 4. H 10.	100.	-36080.	L	272.65	F	.6012	22	20
1-butene	C 4. H 8.	100.	-5600.	L	266.9	F	.6253	22	22
Chlorine(g)	CL2.	100.	0.	G	298.15	O		reference element	-----------
Chlorine(l)	CL2.	100.	-5391.	L	239.09	O	1.56	14 (series E)	14 (series E)
Chlorine trifluoride(g)	CL1. F 3.	100.	-39000.	G	298.15	O		19	-----------
Chlorine trifluoride(l)	CL1. F 3.	100.	-45680.	L	284.55	O	1.8017	23	24
Cyanogen(g)	C 2. N 2.	100.	+73840.	G	298.15	F		19	-----------
Cyanogen(l)	C 2. N 2.	100.	67655.	L	252.00	F	.9537	8, 15, 18, 25	26
Diborane	B 2. H 6.	100.	697.	L	180.59	F	.4371	14 (series E)	14 (series E)
Ethane	C 2. H 6.	100.	-25008.	L	184.52	F	.5464	21, 22	22
Ethyl alcohol	C 2. H 6. O 1.	100.	-66373.	L	298.15	F	.7893	19	20
Ethylene	C 2. H 4.	100.	8100.	L	169.44	F	.5680	14 (series E)	14 (series E)
Ethylene oxide	C 2. H 4. O 1.	100.	-18843.	L	283.72	F	.8826	19, 21, 25	20
Ethylene polymer	C 1. H 2.	100.	-6100.	S[d]	298.15	F	.935	(d)	27
Fluorine(g)	F 2.	100.	0.	G	298.15	O		reference element	-----------
Fluorine(l)	F 2.	100.	-3098.	L	85.02	O	1.505	14 (series D)	14 (series D)
Graphite	C 1.	100.	0.	S	298.15	F	2.25	reference element	20
Helium	HE1.	100.	0.	G	298.15	F		reference element	-----------
Heptane	C 7. H 16.	100.	-53630.	L	298.15	F	.67951	22	22
Hydrazine	N 2. H 4.	100.	12100.	L	298.15	F	1.0036	19	28

[a] Phase S, solid, L, liquid, G, gas.
[b] Fuel, F; oxidant, O.
[c] Based on the following molar percents N_2 = 78.0881, O_2 = 20.9495, Ar = 0.9324, CO_2 = 0.0300
[d] Estimate based on paraffin hydrocarbon series

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Table 4-6 (Concluded)

Chemical	Chemical formula (card columns 1 to 45)	Percent (cc 46-52)	Assigned enthalpy, cal mole (cc 54-62)	(a)	Temperature, K (cc 64-71)	(b)	Density, g cm^{3} (cc 73-80)	References for assigned enthalpy	References for density
Hydrogen(g)	H 2.	100.	0.	G	298.15	F		reference element	------------
Hydrogen(l)	H 2.	100.	-2154.	L	20.27	F	.0709	14 (series D)	14 (series D)
Hydrogen peroxide	H 2. O 2.	100.	-44880.	L	298.15	O	1.437	14 (series C)	14 (series C)
IRFNA	H 1.572164 N 1.629450 O 4.695056 F .02499	100.	-64963.	L	298.15	O	1.48	(c)	(c)
JP-5, ASTMA1	C 1. H 1.9185	100.	-5393.	L	298.15	F	.807	(f)	(f)
JP-4, RP-1	C 1. H 1.9423	100.	-5430.	L	298.15	F	.773	(g)	29
Lithium(l)	LI 1.	100.	1714.1	L	453.69	F	.512	8	30
Lithium(s)	LI 1.	100.	0.	S	298.15	F	.534	reference element	20
Lithium perchlorate	LI 1. CL 1. O 4.	100.	-90880.	S	298.15	O	2.43	14 (series A)	14 (series A)
Methane(g)	C 1. H 4.	100.	-17895.	G	298.15	F		8	------------
Methane(l)	C 1. H 4.	100.	-21390.	L	111.66	F	.4239	14 (series E)	14 (series E)
Methyl alcohol	C 1. H 4. O 1.	100.	-57043.	L	298.15	F	.78659	19	31
Monomethyl hydrazine	C 1. H 6. N 2.	100.	12900.	L	298.15	F	.874	19	32
Nitric acid	H 1. N 1. O 3.	100.	-41463.	L	298.15	O	1.5027	14 (series C)	14 (series C)
Nitrogen(g)	N 2.	100.	0.0	G	298.15	F		reference element	------------
Nitrogen(l)	N 2.	100.	-2913.	L	77.35	F	.808	14 (series D)	14 (series D)
Nitrogen tetroxide	N 2. O 4.	100.	-6690.	L	298.15	O	1.431	14 (series C)	14 (series C)
Nitrogen trifluoride	N 1. F 3.	100.	-34103.	L	144.16	O	1.531	14 (series E)	14 (series E)
Nitromethane	C 1. H 3. N 1. O 2.	100.	-27030.	L	298.15	F	1.1371	14 (series A)	20
Octane	C 8. H 18.	100.	-59740.	L	298.15	F	.69867	22	22
Oxygen(g)	O 2.	100.0	0.0	G	298.15	O		reference element	------------
Oxygen(l)	O 2.	100.	-3102.	L	90.18	O	1.149	14 (series D)	14 (series D)
Oxygen difluoride	O 1. F 2.	100.	1869.	L	127.04	O	1.521	8, 14 (series E)	14 (series E)
Ozone(g)	O 3.	100.	34100.	G	298.15	O		8	------------
Ozone(l)	O 3.	100.	30310.	L	162.66	O	1.449	14 (series E)	14 (series E)
Pentaborane	B 5. H 9.	100.	7740.	L	298.15	F	.6183	14 (series A)	14 (series A)
Perchloryl fluoride	CL 1. O 3. F 1.	100.	-11350.	L	226.48	O	1.392	15, 19, 21	20
Propane	C 3. H 8.	100.	-30372.	L	231.08	F	.5808	21, 22	22
n-propyl nitrate	C 3. H 7. N 1. O 3.	100.	-51270.	L	298.15	F	1.0538	21	20
Toluene	C 7. H 8.	100.	2867.	L	298.15	F	.86230	22	22
Unsymmetrical dimethylhydrazine	C 2. H 8. N 2.	100.	+11900.	L	298.15	F	.783	14 (series A)	33

[a]Phase. S, solid; L, liquid; G, gas.
[b]Fuel, F, oxidant, O.
[c]Inhibited red fuming nitric acid based on following weight percents: $HNO_3(l)$ = 83.5, $N_2O_4(l)$ = 14, $H_2O(l)$ = 2, $HF(g)$ = 0.5
[f]Typical jet fuel having following properties: H/C weight ratio = 0.161, heat of combustion = 18 000 Btu/lb.
[g]Typical jet fuel having following properties: H/C weight ratio = 0.163, heat of combustion = 18 640 Btu/lb.

specified as a fuel or an oxidizer by keypunching an F or O, respectively, in column 72 of the REACTANTS card. The amounts given on the REACTANTS cards are relative to total fuel or total oxidant rather than total reactant.

There are four options in INPT2 for indicating relative amounts of total fuel to total oxidant. They include

1. Equivalence ratio (ERATIO is true)
2. Oxidant-to-fuel-weight ratio (OF is true)
3. Fuel percent by weight (FPCT is true)
4. Fuel-to-air or fuel-to-oxidant-weight ratio (FA is true).

For each option, the values are given in the MIX array of INPT2 (described in NAMELISTS Input Section). For cases involving just one fuel and one oxidant, the amounts of each (as given in columns 46 to 52) are shown as 100. This means that the oxidizer is 100 percent of the total oxidizers and the fuel is 100 percent of the total fuels. For cases which have more than one fuel, the percentage of each by weight relative to the total amount of fuels are specified in columns 46 to 52.

The purpose of the previous namelist variables is to permit using one set of reactant cards with any number of values (up to 15), of the variables such as oxidant to fuel ratio (OF = T).

Assigned enthalpy values for initial conditions are required for HP, RKT, DETN, and SHOCK problems. An assigned internal energy is required for the UV problem. These assigned values for the total reactant are calculated automatically by the program from the enthapies or internal energies of the individual reactants.

The values for the individual reactants are either keypunched on the REACTANTS cards or calculated from the THERMO data. The choice varies according to the type of problem as follows:

(1) RKT, UV, HP problems: Enthalpies or internal energies are taken from the REACTANTS cards unless zeros are punched in card columns 37 and 38. For each REACTANTS card with the "00" code, an enthalpy will be calculated for the species from the THERMO data for the temperature given in card columns 64 to 71.

(2) SHOCK problems: Enthalpies for all of the reactants are calculated from the THERMO data for the temperatures in the T schedule of namelist INPT2 (see Table 4-7). If enthalpy values are punched in card columns 64 to 71 (Table 4-6) they will be ignored. It is not necessary to punch zeros in card columns 37 and 38.

(3) DETN problems: If no T schedule is given in namelist INPT2, the option for calculating reactant enthalpies is the same as for RKT, UV, and HP problems. However, if a T schedule is given in INPT2, the enthalpies will be calculated from the THERMO data for the temperatures in the T schedule, the same as for the SHOCK problem.

The convention used by the program for specifying enthalpies is that

$$H_T = (\Delta H_f^o)_{298.15} + (H_T - H_{298.15})$$

where ΔH_f is the heat of formation. Since the program sums the individual enthalpies (assigned or computed) to obtain the resevoir total enthalpy, it is important that these values be at the same reference temperature (columns 64-71), however the fuel temperature may be different from the oxidant temperature.

Table 4-7 VARIABLES IN INPT2 NAMELIST

Variable	Dimension	Type	Common Label Read	Value Before	Definition and Comments
KASE	1	I	INDX	0	Optional assigned number associated with case
P	26	R	POINTS	0	Assigned pressures; chamber pressures for rocket problems; values in atm unless PSIA, NSQM or MMHG = T (see below)
NSQM	1	L	---	False	Values in P array are in N/m^2*
PSIA	1	L	---	False	Values in P array are in psia units*
MMHG	1	L	---	False	Values in P array are in mmHg units*
V	26	R	POINTS	0	Volume, cm^3/g
RHO	26	R	POINTS+(P)	0	Density, g/cm^3
T	26	R	POINTS	0	Assigned temperature, K
MIX	15	R	MISC+(OXF)	0	Values of equivalence ratios if ERATIO = T; oxidant-to-fuel weight ratio if OF = T; percent fuel by weight if FPCT = T; and fuel to air weight ratio if FA = T
ERATIO	1	L	MISC	False	Equivalence ratios are given in MIX*
OF	1	L	MISC	False	Oxidant-to-fuel weight ratios are given in MIX*

*If variable is set to be true.

+Equivalenced to variable given in parentheses.

Table 4-7 (Continued)

Variable	Dimension	Type	Common Label Read	Value Before	Definition and Comments
FPCT	1	L	MISC	False	Percent fuel by weight are given in MIX*
FA	1	L	---	False	Fuel to air weight ratios are given in MIX*
TRACE	1	R	MISC	0 (5.E-9 for SHOCK problem)	Option to print mole fractions ≥ TRACE in special E-format
IONS	1	L	INDX	False	Consider ionic species*
IDEBUG	1	I	INDX	0	Print intermediate output for all points indexed ≥ integer value
TP	1	L	INDX	False	Assigned temperature and pressure problem*
HP	1	L	INDX	False	Assigned enthalpy and pressure problem*
SP	1	L	INDX	False	Assigned entropy (SO) and pressure problem*
SO	1	R	MISC	0	Assigned entropy, cal/(g)(K)
TV	1	L	INDX	False	Assigned temperature and volume (or density) problem*
UV	1	L	INDX	False	Assigned internal energy and volume (or density) problem*
SV	1	L	INDX	False	Assigned entropy (SO) and volume (or density) problem*

*If variable is set to be true.

Table 4-7 (Concluded)

Variable	Dimension	Type	Common Label Read	Value Before	Definition and Comments
RKT	1	L		False	Rocket problem*
DETN	1	L	---	False	Detonation problem*
SHOCK	1	L	INDX	False	Shock problem*
SIUNIT	1	L	---	False	If true, the output tables will be in SI units
MOCT	1	L	HREC	F	Selects tape-write option if true for equil. run
MOC2P	1	L	HREC	F	Selects two-phase flow analysis option if ture
MOCTF	1	L	HREC	FD	Selects tape-write option if true for frozen and pressure freeze options
PARTHT	1	L	TWOPAS	F	Selects variable total enthalpy option if true for two-phase analysis run
QDOTP	26	R	TWOPAS	0.0	Set equal to the amount by which the total enthalpy of the gaseous-only mixture is to be perturbed.
NQI	1	I	TWOPAS	0	Set equal to the number of QDOTP values input

*If variable is set to be true.

When the program is calculating the individual reactant enthalpy or internal energy values from the THERMO data, the following two conditions are required:

1. The reactant must also be one of the species in the set of THERMO data. For example, $NH_3(g)$ is in the set of THERMO data but $NH_3(\ell)$ is not. Therefore, if $NH_3(g)$ is used as a reactant its enthalpy could be calculated automatically, but that of $NH_3(\ell)$ could not be.

2. The temperature T must be in the range $T_{low}/1.2 \leq T \leq T_{high} \times 1.2$ where T_{low} to T_{high} is the temperatre range of the THERMO data.

The only option that is used to produce the data required by the RAMP2F code is the RKT option. All other options which are discussed in this section are included to assist the users in preparing data for other applications or codes.

4.2.2.3 Omit and Insert Cards

As indicated in Table 4-2, OMIT and/or INSERT cards may follow the REACTANTS cards. Their inclusion is optional. They contain the names of particular species in the library of thermodynamic data for the specific purposes to be discussed. Each card contains the word OMIT (in card columns 1 to 4) or INSERT (in card columns 1 to 6) and the names of from one to four species starting in columns 16, 31, 46, and 61. The names must be exactly the same as they appear in the THERMO data.

<u>OMIT Cards:</u> These cards list species to be omitted from the THERMO data. If OMIT cards are not used, the program will consider as possible species all those species in the THERMO data which are consistent with the chemical system being considered. For some reactant combinations, notably the solid propellants, the number of possible reaction products may exceed the allotted storage (100 species). In this case, the only recourse is to

direct the program to ignore some of the possible products by listing their chemical symbols on OMIT cards. Some judgment, based partly on the relative amounts of the elements loaded into the chamber, is necessary in formulating the list of omitted species. Occasionally a trial run will be required.

Ocassionally it may be desired to specifically omit one or more species from considerations as possible species. This may be accomplished by means of OMIT cards.

INSERT Cards: These cards contain the names of condensed species only. They have been included as options for two reasons.

The first and more important reason for including the INSERT card option is that, in rare instances, it is impossible to obtain convergence for assigned enthalpy problems (HP or RKT) without the use of INSERT card. This occurs when, by considering gases only, the temperature becomes extremely low (say several degrees Kelvin). In these rare cases, the use of an INSERT card containing the name of the required condensed species will eliminate this kind of convergence difficulty. When this difficulty occurs, the following message is printed by the program: "LOW TEMPERATURE IMPLIES CONDENSED SPECIES SHOULD HAVE BEEN INCLUDED ON AN INSERT CARD."

The second and less important reason is that if one knows that one or several particular condensed species will be present among the final equilibrium compositions for the first assigned point, then a small amount of computer time can be saved by using an INSERT card. Condensed species whose chemical formulas are included on an INSERT card will be considered by the program during the initial iterations for the first assigned point. If the INSERT card were not used, only gaseous species will be considered during the initial iterations. However, after convergence, the program will automatically insert the appropriate condensed species and reconverge. For all other assigned points the inclusion of condensed species is handled automatically by the program. Therefore, it usually is immaterial whether or not INSERT cards are used for the purpose of saving computer time.

4.2.2.4 NAMELISTS Code Card and Namelist Input

As indicated in Table 4-2, the NAMELISTS code card preceeds the Namelist input. All problems require an INPT2 input. Rocket problems which are generating data for the RAMP2F code (MOCT = T or MOCTF = T) also require (immediately after the INPT2 namelist data) the namelist TAPGEN followed by a gas header card. Rocket and shock problems each require an additional set, namely, RKTINP and SHKINP. These additional sets simply follow INPT2 (or TAPGEN and header card) directly.

The variables in each namelist are listed in Table 4-1, 4-2, 4-7, 4-8, and 4-9. Table 4-2 indicates which variables are required and which are optional for the various types of problems. Tables 4-1, 4-7, 4-8, and 4-9 give a brief definition of each variable. Additional information about some of these variables follows:

Pressure Units: The program assumes the pressure in the P schedule to be in units of atmospheres unless either PSIA = T, NSQM = T, or MMHG = T.

Relative Amounts of Fuel(s) and Oxidizer(s): These quantities may be specified by assigning 1 to 15 values for either O/F, %F, F/A, or ER. If no value is assigned for any of these, the program assumes the relative amouts of fuel(s) and oxidizer(s) to be those specified on the REACTANTS cards. (See discussion in REACTANTS Cards section.)

Printing Mole Fractions of Trace Species: The program automatically prints compositions of species with mole fractions 5×10^{-6} in F-format for all problems except SHOCK. The TRACE option permits printing smaller mole fractions. If the variable TRACE is set to some positive value, mole fractions greater than or equal to this value will be printed. When this option is used, a special E-format for mole fraction output is used automatically. A TRACE value of 1.E-38 is the lowest value allowed by the program. For cases in which ionic species are requested a trace level of at least 1.E-10 is suggested.

Intermediate Output: Intermediate output will be listed for whatever point IDEBUG is set equal to and all following points. As an example, setting IDEBUG = 3 will result in intermediate output for all points except the first two. This should be avoided unless a problem with a particular case is encountered.

TP, HP, SP, TV, UV, or SV Problems: In these problems, from 1 to 26 values of T, P, and V (or RHO) may be assigned. However, only one value of entropy SO may be assigned in INPUT2 for the SP or SV problem. Only one value of enthalpy is permitted for the HP problem and only one value of internal energy is permitted for the UV problem. However, these values of enthalpy and internal energy are not assigned in INPT2 but are calculated by the program. In a TP problem, if 26 values of T and 26 values of P are assigned in INPUT2, properties will be calculted for the 676 possible P and T combinations. Similarly, up to 676 combinations can be calculated for a TV problem.

DETN Problem: Calculations will be made for all combinations of initial pressure P and initial temperature T. Initial temperatures may be specified in INPT2 namelist or on the REACTANTS card.

RKT Problem: At least one chamber pressure value P is required in INPT2, although as many as 26 chamber pressures may be assigned. A maximum of two can be used with the RAMP2F code. A complete set of calculations will be done for each chamber pressure. For cases where data is being generated for the RAMP2F code two chamber pressures should be input. One at the actual chamber pressure and another that is two orders of magnitude lower. The second chamber pressure corresponds to a different entropy level of the fluid which allows the RAMP2F program to account for thermodynamic changes due to variations in total pressure (two phase cases or boundary layer cases). The RKT problem requires the TAPGEN namelist and gas header card if MOCT=T or MOCTF=T. These data will follow the INPT2 namelist. All RKT cases requries the RKTINP namelist immediately following the INPT2 namelist on TAPGEN namelist and data card if they are present.

TAPGEN Namelist and Gas Header Card (RKT Problem Only): This namelist is required for RKT probems in whih the data is to be used by the RAMP2F program (MOCT=T or MOCTF=T). A list of variables and definitions are given in Table 4-1. Immediately after the TAPGEN namelist comes the gas header card which is written on the output tape.

RKTINP Namelist (RKT problem only): This namelist is required for RKT problems. It follows the INPT2 namelist. A list of variables and definitions is given in Table 4-8. All variables are optional, although ususally a pressure ratio schedule (PCP), an area ratio schedule (SUBAR) or (SUPAR), or some combination of these shedules will be assigned.

Pressure ratio and area ratio schedules must not include values for the chamber and throat inasmuch as these values are assigned or calculated automatically by the program. If both a pressure ratio schedule and an area ratio schedule are given in RKTINP, the pressure ratios will be calculted first. If both schedules are omitted, only chamber and throat conditions will be calculated.

The program will calculate both equilibrium and frozen performance unless RKTINP contains FROZ = F or EQL = F. If FROZ = F, only equilibrium performance will be calculated. If EQL = F, only frozen performance will be calculated.

To generate data for the RAMP2F code the pressure ratio option (PCP) option must be used. A maximum of 11 pressure ratios may be used on the PCP schedule since the chamber and throat conditions are calculated in addition

Table 4-8 VARIABLES IN RKTINP NAMELIST[a]

Variable	Dimension	Type	Common label	Value before read	Definition and comments
EQL	1	L	PERF	TRUE	Calculate rocket performance assuming equilibrium composition during expansion[b]
FROZ	1	L	PERF	TRUE	Calculate rocket performance assuming frozen composition during expansion[b]
PCP	22	R	PERF	0	Ratio of chamber pressure to exit pressure; list should not include values for the chamber and throat; storage allows for 22 values
SUBAR	13	R	PERF	0	Subsonic area ratios
SUPAR	13	R	PERF	0	Supersonic area ratios
TCEST	1	R	-----	3800	Optional initial chamber temperature estimate K. May be necessary when condensed species have been inserted on INSERT cards and 3800 K is far outside the range of the data for the inserted species
NFZ	1	I	-----	1	Option for freezing composition at throat (NFZ = 2) or a supersonic point (NFZ > 2) when FROZ = .true. An extra table is printed with equilibrium composition through point NFZ and frozen thereafter with the composition of point NFZ assumed. If NFZ > 2, only 13-NFZ additional exit points are allowed.

[a]Required for rocket problems only.
[b]Set variable false if these calculations are not desired.

to the PCP schedule and the RAMP2F code has a limitation of 13 pressure ratios for each input O/F (or enthalpy) and total pressure (entropy) table.

SHOCK Problem: The program requires a P and T schedule in INPT2 and either a U1 or MACH1 schedule in a second namelist SHKINP, which is described next. These values all refer to the unshocked gas and must correspond one to one with each other. The pressure and temperature schedules are limited to 13 values for SHOCK problems only. This corresponds to the 13-value limit for U1 or MACH1 schedules. For shock problems REACTANTS cards must be only for gaseous reactants that are also included as reaction species in the THERMO data. This permits the program to calculate enthalpy and specific heat values of the reactants from the THERMO data.

The SHKINP namelist follows the INPT2 namelist.

SHKINP Namelist (SHOCK Problem Only): A list of variables and definitions is given in Table 4-9. SHKINP must include from 1 to 13 values of either U1 or MACH1 of the unshocked gas. The program will calculate incident shock parameters assuming both equilibrium and frozen composition unless SHKINP contains either INCDEQ = F, or INCDFZ = F. If INCDEQ = F, only frozen composition will be used. If INCDFZ = F, only equilibrium composition will be used. In addition there are options for calculating reflected shock parameters. For each incident condition called for, reflected shock parameters will be calculated assuming either a frozen composition (REFLFZ = T), an equilibrium composition (REFLEQ = T), or both (REFLFZ = T, REFLEQ = T).

Table 4-9 VARIABLES IN SHKINP NAMELIST*

Variable	Dimension	Type	Value before read	Definition and comments
INCDEQ	1	L	TRUE	Calculate incident shock parameters assuming equilibrium compositions[b]
INCDFZ	1	L	TRUE	Calculate incident shock parameters assuming frozen compositions[b]
REFLEQ	1	L	FALSE	Calculate reflected shock parameters assuming equilibrium composition[c]
REFLFZ	1	L	FALSE	Calculate reflected shock parameters assuming composition frozen at incident composition[c]
U1	13	R	0	Shock velocity in m/sec (not required if values of MACH1 are listed)
MACH1	13	R	0	Ratio of shock velocity to the velocity of sound in the unshocked gas (not required if values of U1 are listed)

[a]Required for shock problems only.
[b]Set variable false if these calculations are not desired.
[c]If variable is set to be true.

4.3 SPECIAL CONSIDERATIONS FOR USING THE TRAN72 PROGRAM WITH RAMP2F

The user must select some of the input variables for the TRAN72 program to provide the most appropriate data to the RAMP2F program. Some of these data are: variable total enthalpy levels (two-phase and single-phase plumes with boundary layer), variable entropy levels (different total presures), the schedule of pressure ratios to perform the expansion and where to "freeze" the chemistry. There are some instances when the TRAN72 program can calculate poor thermodynamic data which will result in inaccurate flow fields or cause the RAMP2F code to error off. Each of these areas is discussed in the following subsections.

4.3.1 Use and Selection of the Variable Total Enthalpy Option (PARTHT = T)

The variable total enthalpy option of the TRAN72 program is used to produce thermodynamic tables that include variations due to differences in total enthalpy within the nozzle or plume. Two types of flow solutions require consideration of total enthalpy gradients. These cases are: two-phase nozzle and/or plume solutions and single or two-phase plume solutions which include nozzle boundary layer effects.

The work required to accelerate particles in two-phase motors combined with the heat exchange between the particle and gas phases is a non-isentropic expansion (see Appendix C of Vol. I). As a consequence, most solid rocket motor expansion processes result in a decrease in the gas total enthalpy as the flow expands. As a general rule of thumb, five total enthalpy tables can be used. Typical values of total enthalpy differences (QDOTP=) to input into the program for a 16 percent aluminium propellant are: -400, -150, -75, -40, 0.0 cal/gm. For less aluminized propellants the enthalpy variations need not be as great. Sample case 4 of Section 4.4 illustrates this option.

High altitude plumes for which nozzle boundary layers are considered require the use of multiple total enthalpy tables due to the total enthalpy gradients which exist across the boundary layer. The nozzle solution does not require total enthalpy tables (assuming constant O/F ratio) but the plume solution does. After the boundary layer has been calculated by the BLIMPJ program the user should examine the last station printed out by the BLIMPJ code. This station corresponds to the exit plane of the motor. The difference in total enthalpy between the first point (wall) and the last point (boundary layer edge) is the maximum QDOTP to input into the TRAN72 program. Eight or ten different QDOTPs should be considered with the range going from the most negative ($H_{T_\infty} - H_{T_w}$) to zero in even increments. Sample case 4-3 of Section 4.4 illustrates this option.

It should be noted that all entries in the QDOTP array must be monotomically increasing with the last (or first if the enthalpy at the wall is greater than freestream) entry being zero. The zero level corresponds to freestream (boundary layer edge) conditions. There is a maximum of 10 total enthalpy entries that can be used in the RAMP2F code.

4.3.2 Thermodynamic Variations with Total Pressure Losses

Two-phase nozzles and plumes require the consideration of variation in thermodynamics due to variations in total pressure (entropy) which occurs during the expansion process. This is accomplished by executing the TRAN72 program with two pressures input in the P schedule of the $INPT2 namelist. The first pressure should correspond to the actual motor chamber pressure. The second pressure should be a factor of 10 to 50 lower than the chamber pressure.

Two pressures can be run for all cases since the program will use the second table (total pressure) for gas only cases to calculate pitot pressure only. The RAMP2F program has a limit of two total pressure (entropy) tables per total enthalpy table.

4.3.3 Nozzle Freezing Points

Most rocket motors have a region in the flow where the chemical reactions go from fast (equilibrium) to slow (nearly frozen). In this transition region the mole fractions of the constituents change negligibly. If this region is shrunk to a point the freeze point has been reached.

For every rocket motor the location of the freeze point is a function of the expansion process and propellant composition. The only way to determine the actual freeze point is to calculate the flow field using a finite rate analysis. This can be done using a coupled analysis as is available in the RAMP2F code or an uncoupled analysis whereby the precalculated variation of flow properties along a given gas streamline is used as input to a one-dimensional finite rate program. The resulting variation in species mole fractions can be plotted as a function of pressure and the pressure at which there are negligible changes in the dominating specie mole fractions is the "freeze" pressure. This pressure ratio can then be input into the TRAN72 program and a set of tables can be generated for the RAMP2F program.

Previous calculations give some rules of thumb in determining freeze pressures for certain type motors and propellants. Typical large solid rocket motors using standard non-exotic propellant (Al, AP, PBAN, PBAA) chemically freeze at pressure ratios ($P_c/P = 5$) slightly downstream of the throat. Calculation of freeze pressures for a bipropellant motor (R4D, Ref. 19) operating at a 100 psia using MMH/N_2O_4, indicate that the freeze pressure ratio was 1000 for an O/F ratio of 3.07 and 2.5 for an O/F ratio of 1.24. For standard propellant systems a freeze pressure ratio of 20 is an estimate that can be used for calculating a nozzle and plume flow field.

For motors with exotic propellants or for cases in which the plume is to be used for applications which require an accurate representation of chemical species distributions, the flow field should be calculated using a finite rate chemistry analysis.

To use the freeze pressure option of the TRAN72 program the user should specify MOCTF=T on the $INPT2 namelist. Additionally, the freeze pressure ratio should be entered as a value in the PCP schedule of the $RKTINP namelist. Finally the number (NFZ) of the freeze pressure in the PCP schedule (including the chamber and throat pressure ratio) must be entered in the RKTINP namelist. An example of the pressure freeze opion is given in sample case 3 where the freeze pressure ratio is 2.

4.3.4 Care in the Use of TRAN72 Data with RAMP2F

The results of th TRAN72 program which are to be used with the RAMP2F program should be examined to see there are inflections in the variation of gamma with pressure. For some cases, gamma will start to decrease with expanding pressure (and decreasing temperature). These variations are probably not real but due to the application of the thermodynamic curve fits at low temperatures. The use of these data will result in difficulties for the RAMP2F flowfield program. For cases where this happens, and when the user is going to use equilibrium data only, the data should be rerun with the pressure ratios omitted from the PCP schedule beyond the pressure ratio where gamma starts decreasing significantly. For equilibrium/frozen cases the pressure ratio at which the flow is frozen should be decreased until there is no drop in gamma.

4.4 TRAN72 SAMPLE CASES

This section presents six sample cases which illustrate the use of the TRAN72 program. Each of the cases is discussed in Sections 4.4.1 through 4.4.6. Table 4-10 presents listings of the input data as well as some of the output results.

Table 4-10

EXAMPLE CASES OF REQUIRED INPUT AND OUTPUT OF TRAN72 PROGRAM FOR GENERATION OF THERMODYNAMIC DATA FOR RAMP2P PROGRAM

Case 1: Constant O/F, Equilibrium Chemistry

```
REACTANTS
H 2.0                                     100.    -763.3462L 140.    F
O 2.0                                     100.    -2770.146L 102.7   O
NAMELISTS
 $INPT2
  RKT=T,KASE=1,OF=T,MIX=6.113,P=2950.,30.,PSIA=T,MOCT=T
 $END
 $TAPGEN
  IREAD=1,IO=8,IN=10
 $END
  H2/O2 PC=2950
 $RKTINP
  PCP=5.,10.,20.,40.,100.,300.,500.,1000.,5000.,10000.
 $END
STOP
```

ORIGINAL PAGE IS
OF POOR QUALITY

Case 1 Output

```
REACTANTS
H   2.0000        .0000        .0000        .0000        .0000  100.0000      -163.35  L   140.000  F      .00000
O   2.0000        .0000        .0000        .0000        .0000  100.0000     -2770.15  L   102.700  O      .00000
NAMELISTS
$INPT2
KASE      =             +1
T         =       .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00
P         =       .29500000E+04,   .30000000E+02,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00
PSIA      =  T
MMHG      =  F
NSQM      =  F
V         =       .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00
RHO       =       .29500000E+04,   .30000000E+02,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00
ERATIO    =  F
OF        =  T
FPCT      =  F
FA        =  F
MIX       =       .61130000E+01,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00,   .00000000E+00,
                  .00000000E+00,   .00000000E+00,   .00000000E+00
TP        =  F
HP        =  F
SP        =  F
TV        =  F
UV        =  F
SV        =  F
RKT       =  T
SHOCK     =  F
```

```
DETN    =  F
OTTO    =  F
CR      =     .00000000E+00
SO      =     .00000000E+00
SO      =     .00000000E+00
IONS    =  F
IDEBUG  =              +0
TRACE   =     .00000000E+00
SIUNIT  =  F
EUNITS  =  F
TRNSPT  =  T
FROZN   =  F
PUNCH   =  F
NODATA  =  F
DIF     =  F
MOCP    =  F
MOCT    =  T
MOCTF   =  F
MOC2P   =  F
PARTHT  =  F
ODOTP   =     .00000000E+00,  .00000000E+00,  .00000000E+00,  .00000000E+00,
              .00000000E+00,  .00000000E+00,  .00000000E+00,  .00000000E+00,
              .00000000E+00,  .00000000E+00,  .00000000E+00,  .00000000E+00,
              .00000000E+00,  .00000000E+00,  .00000000E+00,  .00000000E+00,
              .00000000E+00,  .00000000E+00,  .00000000E+00,  .00000000E+00,
              .00000000E+00,  .00000000E+00,  .00000000E+00,  .00000000E+00,
              .00000000E+00,  .00000000E+00
NOI     =              +0

$END
$TAPGEN
IREAD   =              +1
IO      =              +8
IN      =             +10

$END

SPECIES BEING CONSIDERED IN THIS SYSTEM
    J 3/77  H          J 9/78  HO2          J 3/77  H2          L11/65  H2O(S)          L11/65  H2O(L)
    J 3/61  H2O        L 2/69  H2O2         J 3/77  O           J 6/77  OH              J 3/77  O2
    J 6/61  O3

                 LIST OF CONDENSED SPECIES FROM SEARCH
    H2O(S)       H2O(L)
$RKTINP
EQL     =  T
FROZ    =  T
SUBAR   =     .00000000E+00,  .00000000E+00,  .00000000E+00,  .00000000E+00,
              .00000000E+00,  .00000000E+00,  .00000000E+00,  .00000000E+00,
              .00000000E+00,  .00000000E+00,  .00000000E+00,  .00000000E+00,
              .00000000E+00
SUPAR   =     .00000000E+00,  .00000000E+00,  .00000000E+00,  .00000000E+00,
              .00000000E+00,  .00000000E+00,  .00000000E+00,  .00000000E+00,
              .00000000E+00,  .00000000E+00,  .00000000E+00,  .00000000E+00,
              .00000000E+00
PCP     =     .50000000E+01,  .10000000E+02,  .20000000E+02,  .40000000E+02,
              .10000000E+03,  .30000000E+03,  .50000000E+03,  .10000000E+04,
```

ORIGINAL PAGE IS OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

Case 1 Output (Cont'd)

```
              .50000000E+04,  .10000000E+05,  .00000000E+00,  .00000000E+00,
              .00000000E+00,  .00000000E+00,  .00000000E+00,  .00000000E+00,
              .20000000E+00,  .00000000E+00,  .00000000E+00,  .00000000E+00,
              .00000000E+00,  .00000000E+00
NFZ      =              1
$END

OF =    6.113000
                           EFFECTIVE FUEL        EFFECTIVE OXIDANT            MIXTURE
ENTHALPY                      HPP(2)                 HPP(1)                    HSUBO
(KG-MOL)(DEG K)/KG         -.19055043+03          -.43564722+02             -.64229097+02

KG-ATOMS/KG                   BOP(I,2)               BOP(I,1)                  BO(I)
         H                 .99209300+00           .00000000                 .13947603+00
         O                 .00000000              .62502343-01              .53715285-01

PT       H        O
 1    -8.860  -15.696     9.000
 2    -9.034  -16.035     4.000
PC/PT= 1.730131   T =   3474.91
 3    -9.356  -16.835     4.000
 4    -9.555  -17.518     4.000
 5    -9.738  -18.381     4.000
 6    -9.908  -19.474     4.000
 7   -10.118  -21.332     4.000
 8   -10.363  -24.284     3.000
 9   -10.476  -25.978     3.000
10   -10.631  -28.679     3.000
11   -11.000  -37.355     2.000
12   -11.168  -42.507     2.000
```

ORIGINAL PAGE IS
OF POOR QUALITY

Case 1 Output (Cont'd)

THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION

PC = 2950.0 PSIA
CASE NO. 1

CHEMICAL FORMULA	WT FRACTION (SEE NOTE)	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL H 2.00000	1.00000	-763.346	L	140.00	.0000
OXIDANT O 2.00000	1.00000	-2770.146	L	102.70	.0000

O/F= 6.1130 PERCENT FUEL= 14.0588 EQUIVALENCE RATIO= 1.2983 REACTANT DENSITY= .0000

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7381	5.0000	10.000	20.000	40.000	100.00	300.00	500.00	1000.00	5000.00	10000.0
P, ATM	200.73	115.49	40.147	20.073	10.037	5.0184	2.0073	.6691	.4015	.2007	.0401	.0201
T, DEG K	3688	3475	3086	2834	2580	2324	1998	1641	1490	1302	931	797
RHO, G/CC	9.0835-3	5.6053-3	2.2320-3	1.2252-3	6.7665-4	3.7658-4	1.7555-4	7.1274-5	4.7078-5	2.6941-5	7.5392-6	4.4006-6
H, CAL/G	-127.6	-413.4	-906.5	-1194.9	-1456.9	-1693.2	-1967.6	-2244.0	-2354.8	-2488.7	-2736.1	-2819.0
S, CAL/(G)(K)	4.0964	4.0964	4.0964	4.0964	4.0964	4.0964	4.0964	4.0964	4.0964	4.0964	4.0964	4.0964
M, MOL WT	13.693	13.839	14.077	14.192	14.270	14.313	14.334	14.339	14.339	14.339	14.339	14.339
(DLV/DLP)T	-1.02451	-1.01903	-1.00987	-1.00542	-1.00250	-1.00094	-1.00018	-1.00001	-1.00000	-1.00000	-1.00000	-1.00000
(DLV/DLT)P	1.4170	1.3435	1.1998	1.1186	1.0593	1.0243	1.0053	1.0005	1.0001	1.0000	1.0000	1.0000
CP, CAL/(G)(K)	1.9249	1.7766	1.4389	1.2170	1.0326	.9038	.8077	.7479	.7262	.6975	.6327	.6097
GAMMA (S)	1.1453	1.1453	1.1512	1.1608	1.1749	1.1908	1.2096	1.2277	1.2359	1.2479	1.2805	1.2942
SON VEL,M/SEC	1601.4	1546.3	1448.5	1388.2	1320.8	1260.0	1183.0	1080.7	1033.4	970.6	831.2	773.4
MACH NUMBER	.000	1.000	1.763	2.153	2.510	2.854	3.315	3.894	4.178	4.579	5.621	6.136
AE/AT		1.0000	1.5210	2.3672	3.8407	6.3589	12.583	28.897	42.646	72.378	246.07	415.03
CSTAR, FT/SEC		7699	7699	7699	7699	7699	7699	7699	7699	7699	7699	7699
CF		.659	1.008	1.274	1.421	1.542	1.672	1.793	1.840	1.894	1.991	2.022
IVAC,LB-SEC/LB		295.3	333.1	361.4	386.0	407.1	430.2	452.2	460.6	470.6	480.2	493.9
ISP, LB-SEC/LB		157.7	260.3	304.7	340.1	369.1	400.1	429.1	440.2	453.5	476.4	483.9

MOLE FRACTIONS

H	.03027	.02496	.01533	.00975	.00529	.00233	.00054	.00005	.00001	.00000	.00000	.00000
HO2	.00008	.00004	.00001	.00000	.00000	.00030	.00000	.00000	.00000	.00000	.00000	.00000
H2	.23801	.23429	.22940	.22826	.22829	.22887	.22950	.22973	.22975	.22976	.22976	.22976
H2O	.67886	.70069	.73551	.75178	.76215	.76744	.76978	.77022	.77024	.77024	.77024	.77024
H2O2	.00003	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
O	.00331	.00217	.00072	.00025	.00006	.00001	.00000	.00000	.00000	.00000	.00000	.00000
OH	.04571	.03526	.01802	.00961	.00412	.00134	.00018	.00001	.00000	.00000	.00000	.00000
O2	.00372	.00257	.00093	.00034	.00008	.00001	.00000	.00000	.00000	.00000	.00000	.00000

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN .50000-05 FOR ALL ASSIGNED CONDITIONS

H2O(S) H2O(L) O3

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

Case 1 Output (Cont'd)

TRANSPORT PROPERTIES OF ROCKET EXHAUST ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION

O/F= 6.1130 PERCENT FUEL= 14.0588 EQUIVALENCE RATIO= 1.2983 CHAMBER PRESSURE= 200.735 ATM

TEMP	VISCOSITY	MONATOMIC COND	INTERNAL COND	FROZEN COND	REACTION COND	EQUILIBRIUM COND	CP FROZ	CP EQ	PRANDTL FROZ	PRANDTL EQ	LEWIS NUMBER
DEG K	POISE	----	----	CAL/(CM)(SEC)(K)	----	----	CAL/(G)(K)		----	DIMENSIONLESS	----
3688	1112.X10-6	702.X10-6	895.X10-6	1597.X10-6	2460.X10-6	4057.X10-6	.8849	1.9249	.6162	.5278	1.3100
				NO TRANSPORT DATA WERE FOUND FOR THE SPECIES HO2							
				NO TRANSPORT DATA WERE FOUND FOR THE SPECIES H2O2							
3475	1068.	661.	848.	1510.	2077.	3587.	.8777	1.7766	.6212	.5292	1.3435
				NO TRANSPORT DATA WERE FOUND FOR THE SPECIES HO2							
3086	982.	589.	757.	1346.	1306.	2652.	.8619	1.4389	.6288	.5328	1.4493
2834	922.	546.	692.	1238.	838.	2076.	.8491	1.2170	.6324	.5405	1.5631
2580	858.	504.	619.	1123.	461.	1585.	.8338	1.0326	.6366	.5589	1.7221
2324	789.	464.	541.	1004.	209.	1214.	.8152	.9038	.6407	.5878	1.9187
1998	696.	412.	443.	855.	52.	907.	.7860	.8077	.6401	.6202	2.1928
1641	587.	353.	337.	689.	5.	694.	.7457	.7479	.6354	.6325	2.5002
1490	539.	327.	292.	619.	1.	620.	.7256	.7262	.6319	.6310	2.6098
1302	477.	293.	237.	530.	0.	530.	.6975	.6975	.6275	.6274	2.8567
931	397.	222.	137.	358.	0.	358.	.6327	.6327	.6133	.6133	
797	297.	193.	107.	300.	0.	300.	.6097	.6097	.6028	.6028	

CASE FOR QDOTP = -64.2 AND PC = 200.7 HAS BEEN COMPLETED AND WRITTEN ON TAPE UNIT10

Case 1 Output (Cont'd)

THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION

PC = 2950.0 PSIA
CASE NO. 1

CHEMICAL FORMULA	WT FRACTION (SEE NOTE)	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL H 2.00000	1.00000	-763.346	L	140.00	.0000
OXIDANT O 2.00000	1.00000	-2770.146	L	102.70	.0000

O/F= 6.1130 PERCENT FUEL= 14.0588 EQUIVALENCE RATIO= 1.2983 REACTANT DENSITY= .0000

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7713	5.0000	10.000	20.000	40.000	100.00	300.00	500.00	1000.00	5000.00	10000.0
P, ATM	200.73	113.33	40.147	20.073	10.037	5.0184	2.0073	.6691	.4015	.2007	.0401	.0201
T, DEG K	3688	3356	2818	2500	2211	1948	1638	1316	1183	1018	702	593
RHO, G/CC	9.0835-3	5.6356-3	2.3777-3	1.3401-3	7.5760-4	4.2980-4	2.0446-4	8.4851-5	5.6640-5	3.2206-5	9.5448-6	5.6493-6
H, CAL/G	-127.6	-419.6	-883.5	-1150.7	-1387.4	-1596.3	-1834.4	-2069.2	-2161.7	-2272.3	-2471.4	-2536.4
S, CAL/(G)(K)	4.0964	4.0964	4.0964	4.0964	4.0964	4.0964	4.0964	4.0964	4.0964	4.0964	4.0964	4.0964
M, MOL WT	13.693	13.693	13.693	13.693	13.693	13.693	13.693	13.693	13.693	13.693	13.693	13.693
CP, CAL/(G)(K)	.8849	.8736	.8493	.8299	.8082	.7842	.7497	.7056	.6846	.6561	.6046	.5888
GAMMA (S)	1.1962	1.1992	1.2061	1.2119	1.2189	1.2271	1.2400	1.2589	1.2690	1.2840	1.3159	1.3271
SON VEL,M/SEC	1636.6	1563.2	1436.5	1356.2	1279.1	1204.9	1110.7	1002.9	954.7	890.9	748.9	691.2
MACH NUMBER	.000	1.000	1.751	2.157	2.538	2.910	3.403	4.019	4.322	4.755	5.914	6.495
AE/AT		1.0000	1.4732	2.2467	3.5819	5.8465	11.901	28.757	37.698	63.98	208.41	347.33
CSTAR, FT/SEC		7575	7575	7575	7575	7575	7575	7575	7575	7575	7575	7575
CF		.677	1.089	1.267	1.406	1.518	1.637	1.746	1.787	1.838	1.918	1.945
IVAC,LB-SEC/LB		292.3	325.8	351.3	373.2	391.9	412.2	431.2	438.5	446.9	461.4	466.0
ISP, LB-SEC/LB		159.4	256.5	298.4	331.1	357.5	385.4	411.0	420.7	432.0	451.6	457.8

MOLE FRACTIONS

H	.03027	HO2	.00000	H2	.23801	H2O	.67806
H2O2	.00003	O	.00331	OH	.04571	O2	.00372

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN .50000-05 FOR ALL ASSIGNED CONDITIONS

H2O(S) H2O(L) O3

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

NO TRANSPORT DATA WERE FOUND FOR THE SPECIES HO2

NO TRANSPORT DATA WERE FOUND FOR THE SPECIES H2O2

TRANSPORT PROPERTIES OF ROCKET EXHAUST ASSUMING FROZEN COMPOSITION DURING EXPANSION

O/F= 6.1130 PERCENT FUEL= 14.0588 EQUIVALENCE RATIO= 1.2983 CHAMBER PRESSURE= 200.735 ATM

TEMP	VISCOSITY	MONATOMIC COND	INTERNAL COND	FROZEN COND	CP FROZ	PRANDTL FROZ
DEG K	POISE	----- CAL/(CM)(SEC)(K) ----			CAL/(G)(K)	
3688	1112.X10-6	702.X10-6	895.X10-6	1597.X10-6	.8849	.6162
	NO TRANSPORT DATA WERE FOUND FOR THE SPECIES HO2					
	NO TRANSPORT DATA WERE FOUND FOR THE SPECIES H2O2					
3356	1036.	655.	813.	1468.	.8736	.6168
	NO TRANSPORT DATA WERE FOUND FOR THE SPECIES HO2					
	NO TRANSPORT DATA WERE FOUND FOR THE SPECIES H2O2					
2818	907.	576.	671.	1247.	.8493	.6175
	NO TRANSPORT DATA WERE FOUND FOR THE SPECIES HO2					
	NO TRANSPORT DATA WERE FOUND FOR THE SPECIES H2O2					
2500	826.	527.	576.	1104.	.8299	.6210
	NO TRANSPORT DATA WERE FOUND FOR THE SPECIES HO2					
	NO TRANSPORT DATA WERE FOUND FOR THE SPECIES H2O2					
2211	748.	481.	490.	971.	.8082	.6228
	NO TRANSPORT DATA WERE FOUND FOR THE SPECIES HO2					
	NO TRANSPORT DATA WERE FOUND FOR THE SPECIES H2O2					
1948	674.	436.	415.	851.	.7842	.6209
	NO TRANSPORT DATA WERE FOUND FOR THE SPECIES HO2					
	NO TRANSPORT DATA WERE FOUND FOR THE SPECIES H2O2					
1638	581.	381.	326.	707.	.7497	.6162
	NO TRANSPORT DATA WERE FOUND FOR THE SPECIES HO2					
	NO TRANSPORT DATA WERE FOUND FOR THE SPECIES H2O2					
1316	479.	320.	235.	555.	.7056	.6085

Case 1 Output (Cont'd)

H2/O2 PC=2950 1 2

14 15

200.7 H O2	.0 HO2	.0 H2	.0 H2O	.0 H2O2	.0 O	.0 OH
.0	.0	.0	.0	.0	.0	.0
.6113000+01	.2007348+03	.3687805+04	.4096383+01	.1369321+02	.1145318+01	.0000000
.5277778+00	.1112387-02	.1924862+01	.4056995-02	-.1276336+03	-.1276338+03	.0000000
.3027482-01	.7963783-04	.2380141+00	.6788629+00	.2640450-04	.3310522-02	.4571382-01
.3717777-02						
.6113000+01	.1154889+03	.3474911+04	.4096383+01	.1383925+02	.1145272+01	.1000007+01
.5291871+00	.1068397-02	.1776623+01	.3586896-02	-.4133599+03	-.1276338+03	.0000000
.2496443-01	.4158912-04	.2342859+00	.7006913+00	.1358618-04	.2172292-02	.3525658-01
.2574427-02						
.6113000+01	.4014696+02	.3085692+04	.4096383+01	.1407659+02	.1151222+01	.1762521+01
.5328469+00	.9822482-03	.1438889+01	.2652443-02	-.9065423+03	-.1276338+03	.0000000
.1532836-01	.8804184-05	.2294846+00	.7355090+00	.3027250-05	.7207744-03	.1801628-01
.9291359-03						
6113000+01	.2007348+02	.2833766+04	.4096383+01	.1419202+02	.1160835+01	.2152758+01
.5404614+00	.9220765-03	.1216959+01	.2076242-02	-.1194930+04	-.1276338+03	.0000000
.9753854-02	.2279525-05	.2282606+00	.7517778+00	.9838792-06	.2531638-03	.9612050-02
.3394945-03						
.6113000+01	.1003674+02	.2579520+04	.4096383+01	.1426981+02	.1174875+01	.2509838+01
.5588689+00	.8576659-03	.1032588+01	.1584657-02	-.1456887+04	-.1276338+03	.0000000
.5290889-02	.4021916-06	.2282870+00	.7621541+00	.1946658-06	.6098190-04	.4122256-02
.8414866-04						
.6113000+01	.5018370+01	.2324432+04	.4096383+01	.1431277+02	.1190822+01	.2854351+01
.5877904+00	.7892582-03	.9037560+00	.1213522-02	-.1693155+04	-.1276338+03	.0000000
.2328688-02	.4377177-07	.2288699+00	.7674400+00	.3012892-07	.9079882-05	.1339476-02
.1281778-04						
.6113000+01	.2007348+01	.1997533+04	.4096383+01	.1433420+02	.1209584+01	.3314565+01
.6202442+00	.6962006-03	.8077407+00	.9066583-03	-.1967616+04	-.1276338+03	.0000000
.5374244-03	.0000000	.2294976+00	.7697798+00	.0000000	.3087119-06	.1844136-03
.4494433-06						
.6113000+01	.6691160+00	.1640514+04	.4096383+01	.1433898+02	.1227677+01	.3894250+01
.6324729+00	.5872530-03	.7479299+00	.6944552-03	-.2244032+04	-.1276338+03	.0000000
.4810672-04	.0000000	.2297292+00	.7702154+00	.0000000	.0000000	.7316276-05
.0000000						
.6113000+01	.4014696+00	.1490218+04	.4096383+01	.1433929+02	.1235912+01	.4177512+01
.6310269+00	.5390833-03	.7261740+00	.6203670-03	-.2354782+04	-.1276338+03	.0000000
.1175664-04	.0000000	.2297493+00	.7702378+00	.0000000	.0000000	.1124254-05
.0000000						
.6113000+01	.2007348+00	.1302067+04	.4096383+01	.1433937+02	.1247936+01	.4579402+01
.6274016+00	.4767344-03	.6975308+00	.5300225-03	-.2488750+04	-.1276338+03	.0000000
.1215360-05	.0000000	.2297553+00	.7702435+00	.0000000	.0000000	.5563927-07
.0000000						
.6113000+01	.4014696-01	.9305647+03	.4096383+01	.1433938+02	.1280487+01	.5620734+01
.6133098+00	.3474923-03	.6326549+00	.3584529-03	-.2736076+04	-.1276338+03	.0000000
.0000000	.0000000	.2297560+00	.7702440+00	.0000000	.0000000	.0000000
.0000000						
.6113000+01	.2007348-01	.7971360+03	.4096383+01	.1433938+02	.1294155+01	.6136015+01
.6028263+00	.2965383-03	.6096970+00	.2999180-03	-.2818951+04	-.1276338+03	.0000000
.0000000	.0000000	.2297559+00	.7702441+00	.0000000	.0000000	.0000000

Case 1 Output (Concluded)

14 14

H 2.0 .0	HO2 .0 .0	H2 .0 .0	H20 .0 .0	O .0 .0	OH .0 .0	O2 .0 .0
.6113000+01	.2041371+01	.3111267+04	.4781105+01	.1294957+02	.1117996+01	.0000000
.4699622+00	.9630494-03	.4100044+01	.8401835-02	-.1276333+03	-.1276338+03	.0000000
.7510917-01	.2727269-04	.2417708+00	.5895216+00	.1269936-01	.6842923-01	.1244047-01
.6113000+01	.1186903+01	.2983892+04	.4781105+01	.1314461+02	.1115885+01	.9999871+00
.4704454+00	.9376157-03	.3872005+01	.7717053-02	-.3793128+03	-.1276338+03	.0000000
.6682272-01	.1742541-04	.2376218+00	.6162384+00	.1001200-01	.5879431-01	.1049207-01
.611?000+01	.4082742+00	.2747955+04	.4781105+01	.1351053+02	.1114213+01	.1772623+01
.466?249+00	.8878669-03	.3272156+01	.6195398-02	-.8351589+03	-.1276338+03	.0000000
.5068245-01	.6354870-05	.2301976+00	.6663612+00	.5569156-02	.4050766-01	.6595211-02
.6113000+01	.2041371+00	.2600326+04	.4781105+01	.1373056+02	.1115866+01	.2158112+01
.4655261+00	.8544907-03	.2782893+01	.5108104-02	-.1105555+04	-.1276338+03	.0000000
.4024231-01	.2874096-05	.2264562+00	.6962013+00	.3338234-02	.2952270-01	.4236131-02
.6113000+0.	.1020685+00	.2451693+04	.4781105+01	.1392995+02	.1121378+01	.2503991+01
.4606824+00	.8187499-03	.2242130+01	.3984835-02	-.1357161+04	-.1276338+03	.0000000
.2982791-01	.1083715-05	.2241811+00	.7226539+00	.1681064-02	.1939543-01	.2259415-02
.6113000+01	.5103427-01	.2295379+04	.4781105+01	.1409919+02	.1133461+01	.2824672+01
.4509599+00	.7786403-03	.1705686+01	.2893752-02	-.1590507+04	-.1276338+03	.0000000
.1967152-01	.3035183-06	.2238769+00	.7441465+00	.6345386-03	.1078025-01	.8900355-03
.6113000+01	.2041371-01	.2063136+04	.4781105+01	.1425525+02	.1164350+01	.3226499+01
.4860230+00	.7146311-03	.1141457+01	.1678358-02	-.1870659+04	-.1276338+03	.0000000
.8171310-02	.2565118-07	.2262209+00	.7622422+00	.8051834-04	.3168124-02	.1169453-03
.6113000+01	.6804570-02	.1742573+04	.4781105+01	.1432855+02	.1210761+01	.3728556+01
.5806331+00	.6190958-03	.8147524+00	.8687238-03	-.2161546+04	-.1276338+03	.0000000
.1255336-02	.0000000	.2290841+00	.7694080+00	.1052898-05	.2500185-03	.1585116-05
.6113000+01	.4082742-02	.1590778+04	.4781105+01	.1433640+02	.1225925+01	.3990207+01
.6119057+00	.5714483-03	.7571888+00	.7071257-03	-.2279563+04	-.1276338+03	.0000000
.3672695-03	.0000000	.2295490+00	.7700352+00	.6280071-07	.4841562-04	.9678865-07
.6113000+01	.2041371-02	.1395289+04	.4781105+01	.1433901+02	.1240885+01	.4373943+01
.6257561+00	.5078629-03	.7145725+00	.5799462-03	-.2422866+04	-.1276338+03	.0000000
.4804487-04	.0000000	.2297278+00	.7702209+00	.0000000	.3250236-05	.0000000
.6113000+01	.4082742-03	.1009471+04	.4781105+01	.1433938+02	.1273299+01	.5375908+01
.6179668+00	.3748625-03	.6456449+00	.3916522-03	-.2688841+04	-.1276338+03	.0000000
.6024404-07	.0000000	.2297559+00	.7702441+00	.0000000	.0000000	.0000000
.6113000+01	.2041371-03	.8630361+03	.4781105+01	.1433938+02	.1287298+01	.5868068+01
.6083208+00	.3218498-03	.6209415+00	.3285272-03	-.2778402+04	-.1276338+03	.0000000
.0000000	.0000000	.2297560+00	.7702440+00	.0000000	.0000000	.0000000

Case 2: Bipropellant, Equilibrium Chemistry with a Freeze Point Variable O/F Ratio

```
REACTANTS
C 1.0    H 6.0    N 2.0                              100.    12900.    L 298.15 F .874
N 2.0    O 4.0                                       100.    -4660.    L 298.15 O 1.431

NAMELISTS
 $INPT2
   RKT=T,PSIA=T,P=153.,1.,MOCTF=T,OF=T,MIX=.8,.9,1.0,1.1,1.2,1.4,
   1.6,1.8,2.0,2.2
 $END
 $TAPGEN
  IREAD=1,IO=8,IN=10
 $END
 MMH/N2O4 PC=153
 $RKTINP
  PCP=3.35,3.38,5.,10.,30.,50.,150.,700.,2000.,8000.,50000.,NF2=3
 $END
STOP
```

Case 2 Output

THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION

PC = 153.0 PSIA

CHEMICAL FORMULA	WT FRACTION (SEE NOTE)	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL C 1.00000 H 6.00000 N 2.00000	1.00000	12900.00L	L	298.15	.8740
OXIDANT N 2.00000 O 4.00000	1.00000	-4680.00L	L	298.15	1.4310

O/F= .8000 PERCENT FUEL= 55.5556 EQUIVALENCE RATIO= 3.1205 REACTANT DENSITY= 1.0568

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.8298	3.3500	3.3800	5.0000	10.000	30.000	50.000	150.00	700.00	2000.00	6000.00	50000.0
P, ATM	10.411	5.6897	3.1078	3.0802	2.0822	1.0411	.3470	.2082	.0694	.0149	.0052	.0013	.0002
T, DEG K	1905	1733	1508	1505	1374	1169	938	878	791	697	636	562	461
RHO, G/CC	9.8118-4	6.1429-4	3.8558-4	3.8495-4	2.8361-4	1.6679-4	7.0002-5	4.5494-5	1.7399-5	4.4235-6	1.7497-6	5.1678-7	1.0216-7
H, CAL/G	132.9	-12.3	-138.9	-140.7	-213.6	-327.3	-474.8	-533.6	-647.0	-783.8	-864.3	-956.3	-1056.9
S, CAL/(G)(K)	3.3794	3.3794	3.3794	3.3794	3.3794	3.3794	3.3794	3.3794	3.3794	3.3794	3.3794	3.3794	3.3794
M, MOL WT	15.354	15.356	15.356	15.356	15.357	15.361	15.526	15.742	16.279	17.012	17.536	18.298	19.378
(DLV/DLP)T	-1.00012	-1.00006	-1.00006	-1.00006	-1.00010	-1.00066	-1.01883	-1.03544	-1.05652	-1.04781	-1.04555	-1.04663	-1.04467
(DLV/DLT)P	1.0023	1.0006	1.0004	1.0004	1.0009	1.0077	1.2826	1.5678	2.0600	1.8945	1.8392	1.8866	1.9373
CP, CAL/(G)(K)	.5856	.5690	.5582	.5581	.5540	.5623	1.1089	1.7231	3.1094	2.5969	2.3259	2.3279	2.4703
GAMMA (S)	1.2852	1.2948	1.3020	1.3021	1.3053	1.3037	1.2063	1.1691	1.1237	1.1282	1.1354	1.1356	1.1250
SON VEL, M/SEC	1175.5	1102.3	1031.2	1030.1	985.4	908.0	778.4	736.3	673.9	620.0	585.0	538.3	482.0
MACH NUMBER	.000	1.000	1.463	1.469	1.728	2.161	2.897	3.208	3.791	4.466	4.938	5.609	6.546
AE/AT		1.0000	1.1643	1.1686	1.4021	2.0687	4.2895	6.3022	15.234	55.268	133.96	434.01	2100.65
CSTAR, FT/SEC		5111	5111	5111	5111	5111	5111	5111	5111	5111	5111	5111	5111
CF		.708	.968	.971	1.093	1.260	1.448	1.516	1.640	1.778	1.854	1.938	2.026
IVAC, LB-SEC/LB		199.2	209.0	209.2	218.2	233.0	252.7	260.9	276.6	295.0	305.2	316.5	324.4
ISP, LB-SEC/LB		112.4	153.8	154.3	173.6	200.1	230.0	240.8	260.5	282.4	294.6	307.9	321.8

MOLE FRACTIONS

C(S)	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.01296	.04937	.06614	.07620	.08312
CH4	.00000	.00000	.00001	.00001	.00002	.00016	.00553	.01255	.02317	.02656	.03322	.04920	.07852
CO	.17621	.17421	.17115	.17109	.16828	.16092	.13924	.12521	.08679	.03411	.01351	.00285	.00027
CO2	.00893	.01095	.01402	.01407	.01688	.02415	.04246	.05206	.07084	.08497	.06460	.07314	.05233
H	.00030	.00006	.00001	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
H2	.45263	.45484	.45793	.45798	.46078	.46774	.47469	.46948	.45288	.42346	.39224	.33499	.24734
H2O	.10259	.10058	.09753	.09747	.09467	.08758	.07584	.07482	.06199	.10641	.13370	.17676	.23835
NH3	.00003	.00003	.00003	.00003	.00003	.00004	.00005	.00005	.00004	.00002	.00002	.00001	.00001
N2	.25929	.25932	.25933	.25933	.25934	.25941	.26219	.26583	.27135	.27311	.27657	.28485	.30006
OH	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN .50000-05 FOR ALL ASSIGNED CONDITIONS

C	CH	CH2	CH2O	CH3	CN	CNN	CN2	C2	C2H
C2H2	C2H4	C2H6	C2N	C2N2	C2O	C3	C3O2	C4	C4N2

Case 2 Output (Cont'd)

THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION

AFTER POINT 3

PC = 153.0 PSIA

CHEMICAL FORMULA				WT FRACTION (SEE NOTE)	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	C 1.00000	H 6.00000	N 2.00000	1.00000	12900.000	L	298.15	.8740
OXIDANT	N 2.00000	O 4.00000		1.00000	-4680.000	L	298.15	1.4310

O/F= .8000 PERCENT FUEL= 55.5556 EQUIVALENCE RATIO= 3.1205 REACTANT DENSITY= 1.0568

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.8298	3.3500	3.3800	5.0000	10.000	30.000	50.000	150.00	700.00	2000.00	8000.00
P, ATM	10.411	5.6897	3.1078	3.0802	2.0822	1.0411	.3470	.2082	.0694	.0149	.0052	.0013
T, DEG K	1985	1733	1508	1505	1371	1159	877	768	[illegible]	374	278	188
RHO, G/CC	9.8118-4	6.1429-4	3.8558-4	3.8497-4	2.8413-4	1.6817-4	7.4028-5	5.0766-5	2.2728-5	7.4510-6	3.5013-6	1.2972-6
H, CAL/G	132.9	-12.3	-138.9	-140.7	-213.5	-326.8	-470.7	-525.0	-619.6	-712.5	-756.4	-797.7
S, CAL/(G)(K)	3.3794	3.3794	3.3794	3.3794	3.3794	3.3794	3.3794	3.3794	3.3794	3.3794	3.3794	3.3794
M, MOL WT	15.354	15.356	15.356	15.356	15.356	15.356	15.356	15.356	15.356	15.356	15.356	15.356
CP, CAL/(G)(K)	.5856	.5690	.5582	.5471	.5400	.5237	.4997	.4901	.4752	.4637	.4568	.4535
GAMMA (S)	1.2852	1.2946	1.3020	1.3084	1.3152	1.3282	1.3445	1.3588	1.3743	1.3871	1.3929	1.3993
SON VEL,M/SEC	1175.5	1102.3	1031.2	1032.6	988.2	912.8	800.6	751.5	652.1	529.7	458.1	377.1
MACH NUMBER	.000	1.000	1.463	1.465	1.723	2.149	2.847	3.123	3.848	5.022	5.955	7.399
AE/AT		1.0000	1.1643	1.1685	1.3997	2.0530	4.0699	5.6847	11.873	34.166	70.893	1169.10
CSTAR, FT/SEC		5111	5111	5111	5111	5111	5111	5111	5111	5111	5111	5111
CF		.708	.968	.971	1.093	1.259	1.443	1.506	1.611	1.707	1.751	1.791
IVAC,LB-SEC/LB		199.2	209.0	209.2	218.1	232.6	250.7	257.3	268.5	279.0	263.8	288.3
ISP, LB-SEC/LB		112.4	153.8	154.3	173.6	200.0	229.2	239.3	255.9	271.2	278.2	284.6

MOLE FRACTIONS

C(S)	.00000	CH4	.00001	CO	.17115	CO2	.01402
H	.00001	H2	.45793	H2O	.09753	NH3	.00003
N2	.25933	OH	.00000				

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN .50000-05 FOR ALL ASSIGNED CONDITIONS

C(S)	C	CH	CH2	CH2O	CH3	CH4	CN	CNN	CN2
C2	C2H	C2H2	C2H4	C2H6	C2N	C2N2	C2O	C3	C3O2
C4	C4N2	C5	HCN	HCO	HNCO	HNO	HNO2	HNO3	HO2
H2N2	H2O(S)	H2O(L)	H2O2	N	NCO	NH	NH2	NO	NO2
NO3	N2H4	N2O	N2O4	N2O5	N3	O	O2	O3	

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

Case 2 Output (Cont'd)

TRANSPORT PROPERTIES OF ROCKET EXHAUST ASSUMING FROZEN COMPOSITION DURING EXPANSION

FROZEN AFTER POINT 3

O/F= .6000 PERCENT FUEL= 55.5556 EQUIVALENCE RATIO= 3.1205 CHAMBER PRESSURE= 10.411 ATM

TEMP	VISCOSITY	MONATOMIC COND	INTERNAL COND	FROZEN COND	CP FROZ	PRANDTL FROZ
DEG K	POISE	----- CAL/(CM)(SEC)(K)		----	CAL/(G)(K)	
1965	565.X10-6	386.X10-6	283.X10-6	669.X10-6	.5752	.4862
1733	515.	353.	241.	594.	.5625	.4877
1508	468.	322.	206.	528.	.5493	.4869
1505	467.	322.	205.	527.	.5491	.4869
1371	439.	302.	183.	485.	.5400	.4881
1159	391.	270.	148.	416.	.5237	.4896
877	323.	224.	107.	331.	.4997	.4871
768	294.	204.	93.	297.	.4901	.4840
572	238.	166.	70.	237.	.4752	.4776
374	173.	123.	49.	172.	.4637	.4672
278	137.	99.	37.	136.	.4588	.4616
188	97.	73.	22.	95.	.4535	.4629

CASE FOR QDOTP = 66.9 AND PC = 10.4 HAS BEEN COMPLETED AND WRITTEN ON TAPE UNIT10

Case 2 Output (Concluded)

THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION

AFTER POINT 3

PC = 153.0 PSIA

CHEMICAL FORMULA				WT FRACTION (SEE NOTE)	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	C 1.00000	H 6.00000	N 2.00000	1.00000	12900.000	L	298.15	.8740
OXIDANT	N 2.00000	O 4.00000		1.00000	-4680.000	L	298.15	1.4310

O/F= 2.2000 PERCENT FUEL= 31.2500 EQUIVALENCE RATIO= 1.1347 REACTANT DENSITY= 1.1933

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7276	3.3500	3.3800	5.0000	10.000	30.000	50.000	150.00	700.00	2000.00	8000.00	50000.0
P, ATM	10.411	6.0261	3.1078	3.0802	2.0822	1.0411	.3470	.2082	.0694	.0149	.0052	.0013	.0002
T, DEG K	3193	3038	2860	2856	2659	2340	1900	1720	1379	991	780	557	348
RHO, G/CC	6.9612-4	5.5223-4	3.0699-4	3.0476-4	2.2124-4	1.2571-4	5.1602-5	3.4201-5	1.4223-5	4.2393-6	1.8865-6	6.5991-7	1.6894-7
H, CAL G	52.5	-96.6	-265.2	-267.3	-359.9	-508.2	-707.2	-786.4	-931.9	-1087.2	-1166.6	-1245.4	-1315.4
S, CAL/(G)(K)	2.6495	2.8495	2.8495	2.8495	2.8495	2.8495	2.8495	2.8495	2.8495	2.8495	2.8495	2.8495	2.8495
M, MOL WT	22.551	22.846	23.185	23.185	23.185	23.185	23.185	23.185	23.185	23.185	23.185	23.185	23.185
CP, CAL/(G)(K)	1.5479	1.4751	1.3554	.4728	.4686	.4601	.4441	.4356	.4155	.3849	.3650	.3437	.3267
GAMMA (S)	1.1305	1.1284	1.1276	1.2214	1.2239	1.2289	1.2391	1.2450	1.2599	1.2865	1.3068	1.3322	1.3557
SON VEL,M/SEC	1153.6	1117.0	1075.5	1118.4	1080.3	1015.5	918.9	876.4	789.3	676.2	604.5	515.9	411.5
MACH NUMBER	.000	1.000	1.516	1.463	1.720	2.133	2.744	3.023	3.636	4.567	5.284	6.388	8.223
AE/AT		1.0000	1.2324	1.2371	1.5009	2.2652	4.7410	6.8070	15.111	47.115	102.37	283.63	1079.17
CSTAR, FT/SEC		5611	5611	5611	5611	5611	5611	5611	5611	5611	5611	5611	5611
CF		.653	.953	.957	1.086	1.267	1.474	1.549	1.678	1.806	1.868	1.927	1.978
IVAC,LB-SEC/LB		214.8	230.4	230.7	241.8	260.4	284.7	293.9	310.2	326.7	334.6	342.2	348.8
ISP, LB-SEC/LB		113.9	166.3	166.6	189.4	220.9	257.1	270.2	292.7	314.9	325.7	336.1	345.0

MOLE FRACTIONS

CH4	.00000	CO	.02859	CO2	.07867	H	.01354
HO2	.00002	H2	.05677	H2O	.39385	N	.00000
NO	.06638	N2	.32731	O	.00421	OH	.02876
O2	.01189						

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN .50000-05 FOR ALL ASSIGNED CONDITIONS

C(S)	C	CH	CH2	CH2O	CH3	CH4	CN	CNN	CN2
C2	C2H	C2H2	C2H4	C2H6	C2N	C2N2	C2O	C3	C3O2
C4	C4N2	C5	HCN	HCO	HNCO	HNO	HNO2	HNO3	H2N2
H2O(S)	H2O(L)	H2O2	NCO	NH	NH2	NH3	NO2	NO3	N2H4
N2O	N2O4	N2O5	N3	O3					

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

NO TRANSPORT DATA WERE FOUND FOR THE SPECIES HO2

Case 3: Bipropellant, Equilibrium/Frozen, Constant O/F with Variable Total Enthalpy Tables

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REACTANTS
C 1.0    H 6.0    N 2.0                              100.    12900.   L 298.15 F   .874
N 2.0    O 4.0                                       100.    -4680.   L 298.15 O  1.431
NAMELISTS
 $INPT2
   RKT=T,PSIA=T,P=110.,    MOCTF=T,OF=T,MIX=1.648,
  PARTHT=T,MOC2P=T,ODOTP=-1200.,-1100.,-950.,-750.,-600.,-450.,
  -300.,-150.,0.0,NOI=9$
 $TAPGEN
   IREAD=1,IO=8,IN=10$
 VERN OF=1.648 PC=110          MKS
 $RKTINP
  PCP=2.,5.,10.,20.,40.,100.,500.,NF2=3$
STOP
```

Case 3 Output

THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION

AFTER POINT 3

PC = 110.0 PSIA

ODOIP = -1200.0000 CAL/G

CHEMICAL FORMULA	WT FRACTION (SEE NOTE)	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL C 1.00000 H 6.00000 N 2.00000	1.00000	12900.000	L	298.15	.8740
OXIDANT N 2.00000 O 4.00000	1.00000	-4680.000	L	298.15	1.4310

O/F= 1.6480 PERCENT FUEL= 37.44 EQUIVALENCE RATIO= 1.5198 REACTANT DENSITY= 1.1539

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7580	2.0000	5.0000	10.000	20.000	40.000	100.00	500.00
P, ATM	7.4850	4.2578	3.7425	1.4970	.7485	.3743	.1871	.0749	.0150
T, DEG K	964	895	881	714	606	511	430	339	221
RHO, G/CC	2.0191-3	1.2590-3	1.1240-3	5.5499-4	3.2688-4	1.9364-4	1.1521-4	5.0335-5	1.7879-5
H, CAL/G	-1125.9	-1174.4	-1184.9	-1251.6	-1293.4	-1328.8	-1358.5	-1390.7	-1431.4
S, CAL/(G)(K)	2.4191	2.4191	2.4191	2.4191	2.4191	2.4191	2.4191	2.4191	2.4191
M, MOL WT	21.340	21.629	21.700	21.700	21.700	21.700	21.700	21.700	21.700
CP, CAL G)(K)	.8900	1.0483	1.0717	.3914	.3796	.3694	.3608	.3515	.3400
GAMMA (S)	1.1917	1.1788	1.1770	1.3054	1.3179	1.3296	1.3401	1.3523	1.3686
SON VEL,M/SEC	669.1	636.8	630.2	597.6	553.0	510.3	469.6	419.3	340.8
MACH NUMBER	.000	1.000	1.115	1.716	2.191	2.653	2.971	3.550	4.692
AE/AT		1.0000	1.0115	1.4095	2.0638	3.1656	4.9682	9.1977	27.937
CSTAR, FT/SEC		3116	3116	3116	3116	3116	3116	3116	3116
CF		.671	.740	1.080	1.247	1.372	1.469	1.567	1.689
IVAC,LB-SEC/LB		120.0	120.6	131.8	140.7	148.2	154.3	160.7	168.5
ISP, LB-SEC/LB		64.9	71.6	104.6	120.7	132.9	142.3	151.8	163.0

MOLE FRACTIONS

CH4	.01794	CO	.03260	CO2	.12733	H2	.19748
H2O	.29985	NH3	.00027	N2	.32452		

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN .50000-05 FOR ALL ASSIGNED CONDITIONS

C	CH	CH2	CH2O	CH3	CN	C4N	CN2	C2	C2H
C2H2	C2H4	C2H6	C2N	C2N2	C2O	C3	C3O2	C4	C4N2
CS	H	HCN	HCO	HNCO	HNO	HNO2	HNO3	HO2	H2N2
H2O2	N	NCO	NH	NH2	NO	NO2	NO3	N2H4	N2O
N2O4	N2O5	N3	O	OH	O2	O3			

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

Case 3 Output (Cont'd)

TRANSPORT PROPERTIES OF ROCKET EXHAUST ASSUMING FROZEN COMPOSITION DURING EXPANSION

FROZEN AFTER POINT 3

O/F: 1.6483 PERCENT FUEL: 37.7644 EQUIVALENCE RATIO: 1.5148 CHAMBER PRESSURE: 7.485 ATM

TEMP	VISCOSITY	MONATOMIC COND	INTERNAL COND	FROZEN COND	CP FROZ	PRANDTL FROZ
DEG K	POISE	----- CAL/(CM)(SEC)(K)		----	CAL/(G)(K)	
3040	882.x10-6	389.x10-6	394.x10-6	783.x10-6	.5114	.5766
2845	842.	363.	371.	733.	.5074	.5827
2798	832.	356.	365.	721.	.5063	.5841
2345	733.	315.	297.	611.	.4940	.5928
2046	664.	285.	252.	538.	.4830	.5965
1778	599.	258.	213.	471.	.4706	.5991
1540	539.	232.	178.	410.	.4571	.6008
1264	465.	201.	137.	337.	.4381	.6033
874	349.	152.	82.	233.	.4040	.6048

Case 3 Output (Cont'd)

THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION

AFTER POINT 3

PC = 110.0 PSIA

CLOIP = .0000 CAL/G

CHEMICAL FORMULA				WT FRACTION (SEE NOTE)	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	C 1.00000	H 6.00000	N 2.00000	1.00000	12900.000	L	298.15	.8740
OXIDANT	N 2.00000	O 4.00000		1.00000	-4680.000	L	298.15	1.4310

O/F= 1.6480 PERCENT FUEL= 37.7644 EQUIVALENCE RATIO= 1.5148 REACTANT DENSITY= 1.1534

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7490	2.0000	5.0000	10.000	20.000	40.000	100.00	500.00
P, ATM	7.4850	4.2796	3.7425	1.4970	.7485	.3743	.1871	.0749	.0150
T, DEG K	3040	2845	2798	2345	2046	1778	1540	1264	874
RHO, G/CC	6.1168-4	3.7729-4	3.3622-4	1.6044-4	9.1972-5	5.2899-5	3.0545-5	1.4882-5	4.3033-6
H, CAL/G	74.1	-85.5	-122.0	-348.5	-494.9	-622.5	-733.1	-856.6	-1020.9
S, CAL/(G)(K)	3.0565	3.0565	3.0565	3.0565	3.0565	3.0565	3.0565	3.0565	3.0565
M, MOL WT	20.382	20.582	20.624	20.624	20.624	20.624	20.624	20.624	20.624
CP, CAL/(G)(K)	1.1161	.9369	.8948	.4940	.4830	.4706	.4571	.4381	.4040
GAMMA (S)	1.1529	1.1620	1.1650	1.2423	1.2492	1.2574	1.2671	1.2819	1.3132
SON VEL,M/SEC	1195.6	1155.6	1146.3	1083.8	1015.0	949.4	886.9	808.3	680.3
MACH NUMBER	.000	1.000	1.117	1.735	2.160	2.543	2.931	3.453	4.449
AE/AT		1.0000	1.0124	1.4451	2.1725	3.4190	5.4923	10.499	33.471
CSTAR, FT/SEC		5707	5707	5707	5707	5707	5707	5707	5707
CF		.664	.736	1.081	1.254	1.398	1.494	1.604	1.740
IVAC,LB-SEC/LB		219.3	220.4	243.0	261.0	276.5	289.4	303.2	320.5
ISP, LB-SEC/LB		117.8	130.6	191.8	222.5	246.2	265.0	284.6	308.7

MOLE FRACTIONS

CO	.12886	CO2	.04019	H	.01659	HO2	.00000
H2	.15825	H2O	.33551	NO	.00125	N2	.30792
O	.00066	OH	.01019	O2	.00057		

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN .50000-05 FOR ALL ASSIGNED CONDITIONS

C	CH	CH2	CH2O	CH3	CH4	CN	CNN	CN2	C2
C2H	C2H2	C2H4	C2H6	C2N	C2N2	C2O	C3	C3O2	C4
C4N2	C5	HCN	HCO	HNCO	HNO	HNO2	HNO3	H2N2	H2O2
N	NCO	NH	NH2	NH3	NO2	NO3	N2H4	N2O	N2O4
N2O5	N3	O3							

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

NO TRANSPORT DATA WERE FOUND FOR THE SPECIES HO2

Case 3 Output (Cont'd)

TRANSPORT PROPERTIES OF ROCKET EXHAUST ASSUMING FROZEN COMPOSITION DURING EXPANSION

FROZEN AFTER POINT 3

O/F= 1.6480 PERCENT FUEL= 37.7644 EQUIVALENCE RATIO= 1.5148 CHAMBER PRESSURE= 7.485 ATM

TEMP	VISCOSITY	MONATOMIC COND	INTERNAL COND	FROZEN COND	CP FROZ	PRANDTL FROZ
DEG K	POISE	----- CAL/(CM)(SEC)(K)	----		CAL/(G)(K)	
964	381.X10-6	164.X10-6	106.X10-6	270.X10-6	.4178	.5902
895	360.	152.	96.	249.	.4108	.5946
881	355.	150.	94.	244.	.4092	.5961
714	300.	127.	71.	198.	.3914	.5927
606	262.	112.	57.	169.	.3796	.5898
511	227.	98.	46.	143.	.3694	.5852
430	194.	84.	37.	121.	.3608	.5797
339	156.	69.	27.	96.	.3515	.5706
221	101.	47	14.	61.	.3400	.5626

CASE FOR ODOTP = -1200.0 AND PC = 7.5 HAS BEEN COMPLETED AND WRITTEN ON TAPE UNIT10

Case 4: Solid Propellant, Equilibrium/Frozen with Variable Total Enthalpy Tables

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REACTANTS
C 6.694  H 10.089 O .278   N .264                 12.09   -12000.  S 298.15 F .09
C 6.15   H  6.97  O 1.17   N .03                   1.96   -28300.  S 298.15 F .0809
AL 1.0                                            16.       0.0    S 298.15 F .0975
N 1.0    H 4.0    O 4.0    CL 1.0                 69.6    70690.   S 298.15 F .0705
FE 2.0   O 3.0                                      .9   -197300.  S 298.15 F .185

OMIT          AL(S)         AL(L)         ALCL3(S)      ALCL3(L)
OMIT          CH3           CH4           COCL2         C2CL2
OMIT          ALN(S)        ALN           AL2CL6        AL2O2
OMIT          C2H6          C3O2          C4            C5
OMIT          CCL3          CCL4          CH            CH2
OMIT          FE(S)         FE(L)         FECL2(S)      FECL2(L)
OMIT          H2O(S)        H2O(L)        O2-           HCO+
OMIT          K2O2H2        NA2O2H2       NA2           NA2CL2
OMIT          NA(S)         NACL(S)       NAOH(S)       NA2O(S)
OMIT          NA(L)         NACL(L)       NAOH(L)       NA2O(L)
OMIT          K(S)          KCL(S)        KOH(S)        K2O(S)
OMIT          K(L)          KCL(L)        KOH(L)        K2
OMIT          ALCL+         ALCL2+        ALCL2-        ALO+
OMIT          ALOH+         ALOH-         ALO2-         AL2O+
OMIT          AL2O2+        AL+           H-            C+
OMIT          C-            C2-           CN+           CN-
OMIT          CH+           CO2           NAO-          HCO+
OMIT          NO+           NAH           FE03H3(S)     O3
OMIT          NO2-          N2O+          N3            HNCO
OMIT          NO2CL
NAMELISTS
 $INPT2
 KNT=T,PSIA=T,P=900.0,81.00,MOC2P=T,
   MOCTF=T,PARTHT=T,
 NOT=5,ODOTP=-400.,-150., 75.,-40.,0.0
 $END
 $TABGEP
     IREAD=1,IO=8,IN=10
 $END
   SEA LEVEL SRM PC=900        MKS          1    2
 $OUTINP
 EC2=10.,20.,40.,60.,100.,500.,1000.,5000.,10000.,50000.,NEZ=3
 $END
STOP
```

Case 4 Output

THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION

PC = 900.0 PSIA

	CHEMICAL FORMULA				WT FRACTION (SEE NOTE)	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	C 6.88400	H 10.08900	O .27800	N .26400	.12040	-17000.000	S	298.15	.0400
FUEL	C 6.15000	H 6.47000	O 1.17000	N .03000	.01960	-24300.000	S	298.15	.0409
FUEL	AL 1.00000				.16000	.000	S	298.15	.0975
FUEL	N 1.00000	H 4.00000	O 4.00000	CL 1.00000	.69600	-70690.000	S	298.15	.0706
FUEL	FE 2.00000	O 3.00000			.00400	-197300.000	S	298.15	.1850

O/F= .0000 PERCENT FUEL=100.0000 EQUIVALENCE RATIO= 1.6977 REACTANT DENSITY= .0666

	CHAMBER	THROAT	EXIT
PC/P	1.0000		
P, ATM	61.241		
T, DEG K	3416		
RHO, G/CC	6.2718-3		
H, CAL/G	-443.6		
S, CAL/(G)(K)	2.2671		
M, MOL WT	28.476		
(DLV/DLP)T	-1.01584		
(DLV/DLT)P	1.2780		
CP, CAL/(G)(K)	.8280		
GAMMA (S)	1.1387		
SON VEL,M/SEC	1065.7		

MOLE FRACTIONS

AL	.00007
ALCL	.00343
ALCL2	.00121
ALCL3	.00016
ALH	.00001
ALO	.00013
ALOCL	.00127
ALOH	.00031
ALO2	.00002
ALO2H	.00051
AL2O	.00002
AL2O3(L)	.07454
CO	.23188
COCL	.00001
CO2	.01609
CL	.01056
CLO	.00001
CL2	.00007
FE	.00037
FECL	.00005
FECL2	.00085

Case 4 Output (Cont'd)

```
FEO                 .00003
FEO2H2              .00002
H                   .03023
HCL                 .13614
HCN                 .00001
HCO                 .00002
H2                  .25950
H2O                 .14176
N                   .00001
NH2                 .00001
NH3                 .00001
NO                  .00057
N2                  .08198
O                   .00051
OH                  .00753
O2                  .00011
MASS OF ELEMENTS BEING REMOVED FOR TWO PHASE CALCULATION (KG OF SPECIE/KG OF MIXTURE)

                              C          .00000       .00000

                              H          .00000       .00000

                              O          .13577+00    .13577+00

                              N          .00000       .13577+00

                              AL         .15264+00    .28841+00

                              CL         .00000       .28841+00

                              FE         .00000       .28841+00

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN   .50000-05 FOR ALL ASSIGNED CONDITIONS

ALC       AL2O3(S)   AL4C3(S)   C(S)      C           CCL       CCL2       CH2O      CH3CL     CN
CNN       CN2        C2         C2H       C2H2        C2H4      C2N        C2N2      C2O       C3
C4N2      CL N       CLO2       CL2O      FECSO5(L)   FECSO5    FECL3(S)   FECL3(L)  FECL3     FEO(S)
FEC(L)    FEO2H (S)  FE2CL4     FE2O3(S)  FE3O4(S)    HALO      HNO        HNO2      HNO3      HO2
H2N2      H2O2       NCO        NH        NOCL        NO2       NO3        N2H4      N2O       N2O4
N2O5

NOTE. WEIGHT FRACTION OF FUEL ... TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS
     ADJUSTED VALUE OF HSUBO =     .21238+03 (KG-MOL)(DEG K)/KG
ELEMENTAL MASS VALUES AFTER TWO PHASE CORRECTION

                              C             .3[illegible]578-01
                              H             .5712070-01
                              O             .2226800-01
```

Case 4 Output (Cont'd)

THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION FOR TWO PHASE MOC CALCULATIONS

LBM CONDENSATES/LBM GAS =.40531

PC = 900.0 PSIA

ODOTP = -400.0000 CAL/G

	CHEMICAL FORMULA				WT FRACTION (SEE NOTE)	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	C 6.88400	H 10.08900	O .27800	N .26800	.12040	-12000.000	S	298.15	.0400
FUEL	C 6.15000	H 6.97000	O 1.17000	N .03000	.01960	-28300.000	S	298.15	.0408
FUEL	AL 1.00000				.16000	.000	S	298.15	.0975
FUEL	N 1.00000	H 4.00000	O 4.00000	CL 1.00000	.69600	-70690.000	S	298.15	.0705
FUEL	FE 2.00000	O 3.00000			.00400	-197300.000	S	298.15	.1850

O/F= .0000 PERCENT FUEL=100.0000 EQUIVALENCE RATIO= 1.6077 REACTANT DENSITY= .0664

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7920	10.000	20.000	40.000	60.000	100.00	500.00	1000.00	5000.00	10000.0	50000.0
P, ATM	61.241	34.174	6.1241	3.0621	1.5310	1.0207	.6124	.1225	.0612	.0122	.0061	.0012
T, DEG K	2851	2569	1892	1592	1371	1256	1125	808	707	580	506	432
RHO, G/CC	5.4343-3	3.3789-3	8.8003-4	4.9208-4	2.8568-4	2.0791-4	1.3821-4	3.8774-5	2.2177-5	5.8776-6	3.1034-6	7.773-7
H, CAL/G	22.0	-128.9	-487.0	-599.6	-696.6	-747.0	-804.5	-950.1	-999.7	-1092.6	-1126.2	-1194.3
S, CAL/(G)(K)	2.6659	2.6659	2.6659	2.6659	2.6659	2.6659	2.6659	2.6659	2.6659	2.6659	2.6659	2.6659
M, MOL WT	20.742	20.844	20.918	20.987	20.989	20.989	20.989	20.989	20.999	21.267	21.647	22.409
(DLV/DLP)T	-1.00380	-1.00256	-1.00034	-1.00005	-1.00001	-1.00001	-1.00001	-1.00012	-1.00017	-1.02175	-1.02750	-1.01335
(DLV/DLT)P	1.0670	1.0459	1.0072	1.0013	1.0002	1.0001	1.0001	1.0032	1.0034	1.4483	1.5067	1.2770
CP, CAL/(G)(K)	.5870	.5452	.4624	.4429	.4377	.4387	.4436	.4826	.4953	1.3189	1.6768	.9167
GAMMA (S)	1.2223	1.2326	1.2621	1.2728	1.2761	1.2753	1.2714	1.2452	1.2370	1.1452	1.1306	1.1663
SON VEL,M/SEC	1181.4	1123.9	959.9	895.9	832.4	796.5	757.8	631.3	588.5	491.7	468.8	431.5
MACH NUMBER	.000	1.000	2.150	2.546	2.986	3.185	3.493	4.518	4.968	6.211	6.612	7.391
AE/AT		1.0000	2.1680	3.3841	5.4207	7.2004	10.373	34.330	58.560	211.55	383.76	1531.75
CSTAR, FT/SEC		5361	5361	5361	5361	5361	5361	5361	5361	5361	5361	5361
CF		.688	1.263	1.396	1.501	1.552	1.600	1.745	1.789	1.860	1.897	1.952
IVAC,LB-SEC/LB		207.6	246.5	260.8	272.6	278.7	285.5	302.3	307.9	318.5	322.5	330.4
ISP, LB-SEC/LB		114.6	210.5	232.6	250.1	258.7	268.2	290.8	298.2	311.4	316.1	325.1

MOLE FRACTIONS

AL	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
ALCL	.00258	.00192	.00009	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
ALCL2	.00233	.00235	.00049	.00010	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000
ALCL3	.00123	.00228	.00736	.00793	.00803	.00804	.00804	.00804	.00805	.00815	.00829	.00862
ALO	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
ALOCL	.00120	.00102	.00008	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
ALOH	.00020	.00013	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
ALO2H	.00037	.00027	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
AL2O	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
CH3CL	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00003	.00004	.00006

Case 4 Output (Cont'd)

CO	.25815	.25348	.24603	.23929	.22983	.22191	.21036	.16055	.13687	.09607	.06711	.04305
CO2	.02042	.02219	.03142	.03829	.04817	.05569	.06724	.11708	.14085	.18615	.20989	.23744
C2H4	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00811	.01013	.02344
CL	.00244	.00114	.00004	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
CL2	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
FE	.00005	.00002	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
FECL	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
FECL2	.00139	.00144	.00148	.00148	.00148	.00148	.00147	.00122	.00066	.00004	.00002	.00000
FEO2H2	.00001	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
FE2CL4	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00013	.00041	.00073	.00075	.00079
H	.00674	.00315	.00011	.00002	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
HCL	.15545	.15501	.14842	.14776	.14766	.14765	.14765	.14767	.14772	.14958	.15224	.15814
HCN	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
HCO	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
H2	.29515	.29953	.31425	.32156	.33151	.33904	.35059	.40045	.42427	.45655	.45530	.44682
H2O	.16391	.16416	.15816	.15147	.14162	.13410	.12255	.07273	.04902	.01440	.01216	.01285
NH3	.00002	.00002	.00001	.00001	.00001	.00001	.00001	.00003	.00008	.00015	.00016	.00024
NO	.00006	.00002	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
N2	.09105	.09144	.09204	.09208	.09209	.09209	.09209	.09209	.09211	.19324	.0949[illegible]	.0985[illegible]
O	.00007	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00007	.00000	.00000	.00000
OH	.00114	.00040	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN .50000-05 FOR ALL ASSIGNED CONDITIONS

ALC	ALH	ALO2	C	CCL	CCL2	CH2O	CN	CNN	CN2
CUCL	C2	C2H	C2H2	C2N	C2N2	C2O	C3	CNN2	CLCN
CLO	CLO2	CL2O	FEC5O5	FECL3	FEO	HALO	HNO	HNO2	HNO3
HO2	H2N2	H2O2	N	NCO	NH	NH2	NOCL	NO2	NO3
N2H4	N2O	N2O4	N2O5	O2					

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

NO TRANSPORT DATA WERE FOUND FOR THE SPECIFS AL

NO TRANSPORT DATA WERE FOUND FOR THE SPECIFS CL

NO TRANSPORT DATA WERE FOUND FOR THE SPECIFS FE

NO TRANSPORT DATA WERE FOUND FOR THE SPECIFS ALCL

NO TRANSPORT DATA WERE FOUND FOR THE SPECIFS ALCL2

NO TRANSPORT DATA WERE FOUND FOR THE SPECIFS FECL2

NO TRANSPORT DATA WERE FOUND FOR THE SPECIFS ALCL3

NO TRANSPORT DATA WERE FOUND F [illegible] 'E SPECIFS ALOCL

NO TRANSPORT DATA WERE FOUND FO [illegible] SPECIFS ALO2H

THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION

AFTER POINT 3

PC = 900.0 PSIA

QDOTP = -900.0000 CAL/G

	CHEMICAL FORMULA				WT FRACTION (SEE NOTE)	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	C 6.88400	H 10.78900	O .27800	N .26400	.12040	-12000.000	S	298.15	.9400
FUEL	C 6.15000	H 6.97000	O 1.17000	N .03000	.01960	-28300.000	S	298.15	.0408
FUEL	AL 1.00000				.16000	.000	S	298.15	.0975
FUEL	N 1.00000	H 4.00000	O 4.00000	CL 1.00000	.64600	-70690.000	S	298.15	.0705
FUEL	FE 2.00000	O 3.00000			.00400	-197300.000	S	298.15	.1850

O/F= .0000 PERCENT FUEL=100.0000 EQUIVALENCE RATIO= 1.6977 REACTANT DENSITY= .0666

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7920	10.000	20.000	40.000	60.000	100.00	500.00	1000.00	5000.00	10000.0	50000.0
P, ATM	61.241	34.174	6.1241	3.0621	1.5310	1.0207	.6124	.1225	.0612	.0122	.0061	.0012
T, DEG K	2851	2569	1842	1583	1354	1233	1093	735	615	401	332	213
RHO, G/CC	5.4343-3	3.3789-3	8.4993-4	4.9465-4	2.8913-4	2.1165-4	1.4322-4	4.2608-5	2.5474-5	7.8136-6	4.7148-6	1.4079-6
H, CAL/G	22.0	-128.9	-487.0	-599.[illegible]	-698.5	-745.1	-801.8	-939.2	-983.4	-1059.8	-1083.8	-1124.7
S, CAL/(G)(K)	2.6659	2.6659	2.6659	2.6659	2.6659	2.6659	2.6659	2.6659	2.6659	2.6659	2.6659	2.6659
M, MOL WT	20.762	20.844	20.978	20.978	20.978	20.978	20.978	20.978	20.978	20.978	20.978	20.978
CP, CAL/(G)(K)	.5820	.5152	.4624	.4266	.4143	.4070	.3977	.3716	.3638	.3510	.34[illegible]	.3418
GAMMA (S)	1.2223	1.2326	1.2621	1.2855	1.2964	1.3033	1.3126	1.3421	1.3526	1.3696	1.3746	1.3834
SON VEL,M/SEC	1181.4	1123.9	959.9	897.9	834.0	798.0	758.1	625.2	578.[illegible]	466.4	425.3	382.0
MACH NUMBER	.000	1.000	2.150	2.539	2.938	3.175	3.481	4.536	5.053	6.451	7.152	9.058
AE/AT		1.0000	2.1649	3.3670	5.3607	7.0815	10.101	31.425	51.393	161.54	254.78	835.16
CSTAR, FT/SEC		5361	5361	5361	5361	5361	5361	5361	5361	5361	5361	5361
CF		.688	1.263	1.395	1.500	1.551	1.606	1.736	1.775	1.841	1.862	1.896
IVAC,LB-SEC/LB		207.6	246.5	260.6	272.[illegible]	278.0	284.5	299.7	304.3	312.2	314.6	318.7
ISP, LB-SEC/LB		114.6	210.5	232.5	249.9	258.4	267.7	289.2	295.8	306.8	310.2	315.9

MOLE FRACTIONS

AL	.00000	ALCL	.00009	ALCL2	.00049	ALCL3	.00736
ALO	.00000	ALOCL	.00008	ALOH	.00000	ALO2H	.00001
AL2O	.00000	CH3CL	.00000	CO	.24603	CO2	.03142
C2H4	.00000	CL	.00004	CL2	.00000	FE	.00000
FECL	.00000	FECL2	.00148	FEO2H2	.00000	FE2CL4	.00000
H	.00011	HCL	.14842	HCN	.00000	HCO	.00000
H2	.31425	H2O	.15816	NH3	.00001	NO	.00000
N2	.09204	O	.00000	OH	.00000		

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN .50000-05 FOR ALL ASSIGNED CONDITIONS

ALC	ALH	ALO2	C	CCl	CCL2	CH2O	CH3CL	CN	CNN
CN2	COCL	C2	C2H	C2H2	C2H4	C2N	C2N2	C3O	C3

THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION

AFTER POINT 3

PC = 900.0 PSIA

ODDIF = .0000 CAL/G

	CHEMICAL FORMULA								WT FRACTION (SEE NOTE)	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	C	6.88400	H	10.08900	O	.27800	N	.26400	.12040	-12000.000	S	298.15	.0400
FUEL	C	6.15000	H	6.97000	O	1.17000	N	.03000	.01960	-28390.000	S	298.15	.0408
FUEL	AL	1.00000							.16000	.000	S	298.15	.0975
FUEL	N	1.00000	H	4.00000	O	4.00000	CL	1.00000	.69[illegible]00	-70600.000	S	298.15	.07[illegible]6
FUEL	FE	2.00000	O	3.00000					.00900	-197300.000	S	298.15	.1850

O/F= .0000 PERCENT FUEL=100.0000 EQUIVALENCE RATIO= 1.6977 REACTANT DENSITY= .0566

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7680	10.000	20.000	40.000	60.000	100.00	500.00	1000.00	5000.00	10000.0	50000.0
P, ATM	61.241	34.638	6.1241	3.0621	1.5310	1.0207	.6124	.1225	.0612	.0122	.0061	.0012
T, DEG K	3416	3150	2369	2046	1760	1609	1433	979	824	542	450	296
RHO, G/CC	4.4273-3	2.7423-3	6.5630-4	3.8005-4	2.2087-4	1.6109-4	1.0847-4	3.1750-5	1.8869-5	5.7374-6	3.4556-6	1.0733-6
H, CAL/G	922.0	239.5	-219.6	-365.3	-498.9	-560.0	-630.1	-817.5	-873.0	-976.5	-1009.2	-1065.2
S, CAL/(G)(K)	2.7931	2.7931	2.7931	2.7931	2.7931	2.7931	2.7931	2.7931	2.7931	2.7931	2.7931	2.7931
M, MOL WT	20.263	20.464	20.833	20.833	20.833	20.833	20.833	20.833	20.833	20.833	20.833	20.833
CP, CAL/(G)(K)	.8809	.7780	.5490	.4451	.4335	.4270	.4179	.3886	.3771	.3579	.3528	.3454
GAMMA (S)	1.1867	1.1934	1.2316	1.2727	1.2817	1.2876	1.2957	1.3253	1.3386	1.3634	1.3705	1.3816
SON VEL, M/SEC	1289.7	1235.9	1079.1	1019.3	948.8	909.2	861.0	719.8	663.5	543.1	496.1	390.7
MACH NUMBER	.000	1.000	2.147	2.518	2.913	3.146	3.446	4.467	4.962	6.299	6.976	8.826
AE/AT		1.0000	2.2286	3.4742	5.5516	7.7542	10.531	33.197	54.563	172.67	283.40	895.07
CSTAR, FT/SEC		6007	6007	6007	6007	6007	6007	6007	6007	6007	6007	6007
CF		.675	1.266	1.402	1.510	1.563	1.621	1.756	1.798	1.868	1.890	1.927
IVAC, LB-SEC/LB		231.6	277.9	294.2	307.8	314.6	322.2	340.3	345.9	356.3	358.2	363.1
ISP, LB-SEC/LB		126.0	236.3	261.7	281.8	291.7	302.6	327.9	335.7	348.8	352.9	359.7

MOLE FRACTIONS

AL	.00000	ALCL	.00231	ALCL2	.00202	ALCL3	.00181
ALH	.00000	ALO	.00000	ALOCL	.00138	ALOH	.00014
ALO2	.00000	ALO2H	.00030	AL2O	.00000	CH3CL	.00000
CO	.25178	COCL	.00000	CO2	.02375	C2H4	.00000
CL	.00112	CLO	.00000	CL2	.00000	FE	.00002
FECL	.00000	FECL2	.00144	FEO	.00000	FEO2H2	.00000
FE2CL4	.00000	H	.00302	HCL	.15626	HCN	.00000
HCO	.00000	H2	.30072	H2O	.16218	N	.00000
NH2	.00000	NH3	.00000	NO	.00001	N2	.09140
O	.00000	OH	.00030	O2	.00000		

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN .50000-05 FOR ALL ASSIGNED CONDITIONS

Case 5: Equilibrium/Frozen Two-Phase Case Including Ions, Total Enthalpy and Entropy Variations

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REACTANTS
C 6.384  H 10.089 O .278   N .264              12.0786 -12000.  S 298.15 F .04
C 6.15   H  6.97  O 1.17   N .03                1.96   -28300.  S 298.15 F .0908
AL 1.0                                         16.       0.0    S 298.15 F .0975
N 1.0    H 4.0    O 4.0    CL 1.0              69.597  -70690.  S 298.15 F .0705
FE 2.0   O 3.0                                   .4    -197300. S 298.15 F .185
K 1.0                                           .0014       0.  G 298.15 F
NA1.0                                           .0030       0.  G 298.15 F

OMIT          H2O(S)        AL(S)         ALCL3(S)      ALN(S)
OMIT          H2O(L)        AL(L)         ALCL3(L)      C(S)
OMIT          NA(S)         NACL(S)       NAOH(S)       NA2O(S)
OMIT          NA(L)         NACL(L)       NAOH(L)       NA2O(L)
OMIT          K(S)          KCL(S)        KOH(S)        K2O(S)
OMIT          K(L)          KCL(L)        KOH(L)        C2
OMIT          ALH           ALCL          ALCL+         ALCL2
OMIT          ALCL2+        ALCL2-        ALCL*         ALO
OMIT          ALO+          ALOCL         ALOH          ALOH+
OMIT          ALOH-         ALO2          ALO2-         ALO2H
OMIT          AL2CL6        AL2O          AL2O+         AL2O2
OMIT          AL2O2+        ALN           AL+           H-
OMIT          C3            C4            C5            C+
OMIT          C-            C2-           CN+           CN-
OMIT          CH2O          C3O2          NO2-          N2O+
OMIT          O3            O2-           NCO+          CH2
OMIT          CNN           CH2           N3            NO2
OMIT          NO3           C2N           CCL3          CCL4
OMIT          K2O2H2        NA2OH2        NA2           NA2CL2
OMIT          CS(S)         CSCL(S)       CSOH(S)       CSOH(L)
OMIT          CS(L)         CSCL(L)       CS2           CS2CL2
OMIT          CS2O2H2
OMIT          AL4C3(S)      CN2           C2H6          FEO2H2(S)
OMIT          HNO2          KH            KO2(S)        K2CL2
OMIT          FEO2H2        KCN(S)        K2O2(S)       CH3CL
OMIT          COCL          C2H           C2O           CLCN
OMIT          FEO3H3(S)     HCO+          KCN(L)        K2CO3(S)
OMIT          CCL2          COCL2         C2H2          C4N2
OMIT          CLO           FECFO5(L)     FE2CL4        K2CO3(L)
OMIT          CLO2          H2+           KOH+          K2C2N2
OMIT          NCO           NA2C2N2       NAALO2(S)     NA2O
OMIT          NAALO2(S)     NA2O2(S)      NACN(S)       NA2O2(S)
OMIT          NACN(L)       NAO2(S)       NA2O2H2       NACN
OMIT          NA2CO3(S)     N2O5          NA2CO3(S)     NA2CO3(L)
NAMELISTS
 $INPT2
 RKT=T,PSIA=T,P=900.0,81.00,MOC2P=1,
   MOCTF=T,PARTHT=T,IONS=T,TRACE=1.E-10,
 NOI=5,ODOTP=-400.,-150.,-75.,-40.,0.0
 $END
 $TAPGEN
      IREAD=1,IO=8,IN=10
 $END
   SEA LEVEL SRM PC=900       MKS          1    2
 $RKTINP
                   PCP=10.,20.,40.,60.,100.,500.,1000.,5000,NFZ=3
 $END
STOP
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Case 5 Output

THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM COMPOSITION DURING EXPANSION FOR TWO PHASE MOC CALCULATIONS

LBM CONDENSATES/LBM GAS =.43292

PC = 900.0 PSIA

CODTP = -400.0000 CAL/G

	CHEMICAL FORMULA				WT FRACTION (SEE NOTE)	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	C 6.88400	H 10.08900	O .27800	N .26400	.12039	-12000.000	S	298.15	.0400
FUEL	C 6.15000	H 6.97000	O 1.17000	N .03000	.01960	-28300.000	S	298.15	.0606
FUEL	AL 1.00000				.16000	.000	S	298.15	.0975
FUEL	N 1.00000	H 4.00000	O 4.00000	CL 1.00000	.69597	-70690.000	S	298.15	.0705
FUEL	FE 2.00000	O 3.00000			.00400	-197300.000	S	298.15	.1850
FUEL	K 1.00000				.00001	.000	G	298.15	.0000
FUEL	NA 1.00000				.00003	.000	G	298.15	.0000

O/F= .0000 PERCENT FUEL=100.0000 EQUIVALENCE RATIO= 1.6977 REACTANT DENSITY= .0000

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7967	10.000	20.000	40.000	60.000	100.00	500.00	1000.00	5000.00
P, ATM	61.241	34.086	6.1241	3.0621	1.5310	1.0207	.6124	.1225	.0612	.0122
T, DEG K	2892	2599	1830	1574	1352	1237	1106	842	787	692
RHO, G/CC	5.2583-3	3.2677-3	8.3592-4	4.8591-4	2.8295-4	2.0623-4	1.3831-4	3.7058-5	2.0222-5	4.8226-6
H, CAL/G	75.5	-81.1	-447.5	-561.7	-659.8	-710.7	-768.6	-916.5	-969.5	-1077.5
S, CAL/(G)(K)	2.7007	2.7007	2.7007	2.7007	2.7007	2.7007	2.7007	2.7007	2.7007	2.7007
M, MOL WT	20.376	20.445	20.499	20.501	20.501	20.501	20.504	20.897	21.312	22.361
(DLV/DLP)T	-1.00313	-1.00141	-1.00005	-1.00002	-1.00003	-1.00007	-1.00035	-1.02950	-1.04686	-1.05977
(DLV/DLT)P	1.0604	1.0297	1.0012	1.0002	1.0003	1.0008	1.0045	1.5074	1.8586	2.2107
CP, CAL/(G)(K)	.5889	.5295	.4513	.4428	.4403	.4423	.4523	1.3043	1.9478	2.6634
GAMMA (S)	1.2741	1.2395	1.2743	1.2804	1.2824	1.2811	1.2752	1.1576	1.1344	1.1152
SON VEL,M/SEC	1201.9	1144.6	972.6	904.2	838.5	801.5	756.4	622.6	590.0	535.7
MACH NUMBER	.000	1.000	2.151	2.554	2.958	3.200	3.514	4.627	5.012	5.798
AE/AT		1.0000	2.1387	3.3333	5.3287	7.0708	10.175	35.031	62.543	249.67
CSTAR, FT/SEC		5443	5443	5443	5443	5443	5443	5443	5443	5443
CF		.690	1.261	1.392	1.495	1.546	1.602	1.737	1.782	1.872
IVAC,LB-SEC/LB		210.9	249.5	263.7	275.5	281.5	288.2	305.6	312.1	325.2
ISP, LB-SEC/LB		116.7	213.3	235.5	253.0	261.5	271.0	293.8	301.5	316.7

MOLE FRACTIONS

AL	1.0728-4	1.0772-4	1.0814-4	1.0814-4	1.0808-4	1.0802-4	1.0793-4	1.0955-4	1.1161-4	1.1684-4
ALO-	6.974 -8	6.647 -8	1.570 -8	.000 0	7.133-12	.000 0	9.281-15	.000 0	9.991-20	.000 0
CH	2.437-10	2.141-11	1.341-15	7.638-18	1.880-20	7.694-22	1.692-24	1.438-31	9.161-34	.000 0
CH3	7.174 -8	3.019 -8	2.572 -9	9.657-10	3.821-10	2.760-10	1.186-10	1.243-11	3.727-12	1.756-13
CH4	1.1937-7	1.0704-7	3.0690-7	9.4063-7	4.6924-6	1.5139-5	8.4599-5	9.6723-3	1.9774-2	4.5361-2
CN	2.566 -8	4.795 -9	6.766-12	2.106-13	3.792-15	2.759-16	7.662-18	1.454-22	4.634-24	2.577-27
CO	2.5563-1	2.5490-1	2.4653-1	2.3969-1	2.2981-1	2.2228-1	2.1068-1	1.6092-1	1.3747-1	8.5091-2
CO2	1.9104-2	2.0770-2	2.9881-2	3.6748-2	4.6621-2	5.4153-2	6.5724-2	1.1120-1	1.3012-1	1.7106-1

CO2-	1.839 -9	4.928-10	6.187-13	.000 0	5.452-19	.000 0	3.522-24	.000 0	2.071-34	.000 0
C2H4	5.409-12	2.747-12	1.643-12	2.844-12	8.241-12	1.986-11	7.887-11	2.720 -9	2.711 -9	9.302-10
CL	2.985 -3	1.406 -3	4.306 -5	5.644 -6	4.891 -7	9.535 -8	9.820 -9	1.239-11	2.031-12	5.304-14
CL-	1.086 -6	5.193 -7	5.137 -9	.000 0	4.069-14	.000 0	1.597-18	.000 0	7.783-27	.000 0
CL2	8.865 6	3.648 -6	8.712 -8	1.112 -6	9.862-10	1.996-10	2.211-11	3.423-14	5.495-15	1.287-16
E-	4.647 -9	1.249 -9	1.013-12	.000 0	3.799-19	.000 0	1.116-24	.000 0	2.122-35	.000 0
FE	5.212 -5	1.783 -5	9.178 -8	3.956 -9	8.053-11	5.919-12	1.530-13	2.700-18	1.281-19	2.543-22
FECL	1.213 -5	4.423 -6	3.984 -8	2.543 -9	9.209-11	9.976-12	4.511-13	4.732-17	3.032-18	1.335-20
FECL2	1.3944-3	1.4435-3	1.4706-3	1.4710-3	1.4711-3	1.4712-3	1.4715-3	1.4998-3	1.5295-3	1.6049-3
FECL3	1.5183-6	1.2768-6	7.4020-7	6.0[illegible]-7	5.1163-7	4.6893-7	4.2696-7	3.3524-7	2.9439-7	2.1922-7
FEO	2.462 -6	5.792 -7	5.874-10	9.817-12	6.779-14	2.372-15	2.169-17	1.724-23	3.538-25	1.341-28
H	7.759 -3	3.572 -3	1.031 -4	1.324 -5	1.128 -6	2.183 -7	2.231 -8	2.600-11	3.971-12	8.611-14
HALO	6.5330-7	5.7710-7	4.9133-7	5.1421-7	5.7804-7	6.3959-7	7.4903-7	1.2068-6	1.3413-6	1.6776-6
HCL	1.6710-1	1.6918-1	1.7097-1	1.7101-1	1.7102-1	1.7103-1	1.7105-1	1.7433-1	1.7779-1	1.8654-1
HCN	9.4931-6	4.7714-6	9.4149-7	5.1038-7	2.8627-7	2.0789-7	1.4182-7	3.6718-8	1.6858-8	2.1880-9
HCO	1.048 -5	3.818 -6	8.202 -8	1.146 -8	1.153 -9	2.624-10	3.469-11	6.924-14	9.086-15	1.031-16
HNCO	7.064 -7	3.658 -7	5.128 -8	2.213 -8	9.605 -9	5.843 -9	3.088 -9	3.834-10	1.531-10	1.632-11
HNO	1.309 -7	2.527 -8	2.674-11	6.167-13	7.228-15	3.821-16	6.561-18	3.530-23	1.071-24	8.062-28
HO2	5.779 -8	7.145 -9	8.302-13	4.969-15	1.103-17	1.879-19	6.515-22	3.097-29	2.805-31	2.026-35
H2	2.9767-1	3.0116-1	3.1186-1	3.1677-1	3.28[illegible]-1	3.3615-1	3.4755-1	3.6966-1	3.6398-1	3.4260-1
H2N2	2.592-10	5.389-11	1.687-13	9.356-15	3.569-16	4.385-17	2.565-18	4.778-22	3.013-23	7.879-26
H2O	1.5561-1	1.5545-1	1.4726-1	1.4041-1	1.3054-1	1.2303-1	1.1155-1	7.9060-2	7.3817-2	6.7527-2
H2O2	3.981 -8	6.980 -9	5.007-12	9.352-14	8.512-16	3.787-17	5.078-19	1.303-24	3.352-26	1.926-29
K	8.899 -8	4.443 -8	1.854 -9	2.806-10	2.861-11	6.199-12	7.323-13	1.265-15	2.147-16	5.727-18
K+	1.2552-6	4.5114-7	1.5696-8	.0000 0	7.1456-8	.0000 0	2.4276-7	.0000 0	1.4463-7	.0000 0
KCL	9.8617-6	9.9553-6	1.0501-5	1.[illegible]18-5	1.0518-5	1.0518-5	1.0520-5	1.0721-5	1.0934-5	1.1472-5
KO	1.637-10	2.693-11	1.091-14	1.278-16	6.322-19	1.[illegible]2-20	1.358-22	6.032-29	9.775-31	2.165-34
KOH	7.571 -8	3.811 -8	2.314 -9	4.879-10	7.789-11	7.31[illegible]-11	4.312-12	2.834-14	6.777-15	3.688-16
N	2.597 -7	3.628 -8	7.535-12	6.391-14	2.208-16	5.140-18	2.825-20	5.397-27	6.533-29	7.376-33
NH	2.890 -7	4.975 -8	3.354-11	1.088-13	5.440-15	7.424-1[illegible]	3.325-18	8.925-24	2.050-25	7.889-29
NH2	2.090 -6	6.654 -7	8.195 -9	8.311-10	5.979-11	1.081-11	1.045-12	8.810-16	9.563-17	8.373-19
NH3	2.3281-5	1.6829-5	9.1446-6	9.5681-6	9.0697-6	9.9480-6	1.1864-5	1.7082-5	1.4446-5	8.1697-6
NO	6.693 -5	1.773 -5	4.944 -8	1.702 -9	2.994-11	2.014-12	4.702-14	6.778-19	3.128-20	6.235-23
NOCL	6.405 -9	9.496-10	3.397-13	4.345-15	2.557-17	8.602-19	7.953-21	7.386-27	1.417-28	4.310-32
N2	9.1105-2	9.1445-2	9.1703-2	9.1710-2	9.1711-2	9.1713-2	9.1725-2	9.3482-2	9.5336-2	1.0003-1
N2O	9.014 -9	1.773 -9	2.137-12	5.406-14	7.150-16	4.117-17	8.002-19	6.674-24	2.380-25	2.576-28
NA	8.719 -7	4.740 -7	2.540 -8	4.479 -9	[illegible].475-10	1.335-10	1.864-11	5.284-14	1.037-14	3.745-16
NA+	5.015 -7	1.365 -7	1.361 -9	.000 0	1.443 -9	.000 0	1.425 -9	.000 0	5.344-11	.000 0
NACL	3.6489-5	3.7442-5	3.8305-5	3.8333-5	3.8334-5	3.8335-5	3.8340-5	3.9075-5	3.9850-5	4.1811-5
NAH	3.692 -8	1.465 -8	2.444-10	2.590-11	1.658-12	3.280-13	3.011-14	2.312-17	2.725-18	3.091-20
NAO	1.482 -9	2.734-10	1.612-17	2.357-15	1.515-17	5.247-19	4.906-21	4.433-27	8.848-29	3.022-32
NAOH	3.190 -7	1.618 -7	9.195 [illegible]	[illegible].900 -9	2.967-10	4.689-11	[illegible]86-11	9.827-14	2.309-14	1.213-15
O	2.036 -5	3.317 -6	8.764-10	[illegible].390-12	2.351-14	5.005-16	2.344-18	2.932-25	3.748-27	5.633-31
OH	1.276 -3	4.394 -4	3.545 -6	2.181 -7	7.591 -9	7.999-10	3.463-11	3.030-1[illegible]	2.310-16	1.282-18
OH-	4.631-10	7.140-11	6.266-15	.000 0	1.632-22	.000 0	4.711-29	.000 0	.000 0	.000 0
O2	4.325 -6	7.067 -7	1.833-10	1.500-12	4.522-15	9.180-17	3.964-19	3.913-26	5.008-28	8.249-32

ADDITIONAL PRODUCTS WHICH WERE CONSIDERED BUT WHOSE MOLE FRACTIONS WERE LESS THAN .10000-09 FOR ALL ASSIGNED CONDITIONS

ALC	C	CCL	CH+	C2CL2	C2N2	CL+	CL2O	FECSOS	H+
HNO3	H2-	KCN	KO-	K2	N+	N-	NO+	NO2CL	N2+
N2-	N2H4	N2O4	NAO-	NAOH+	O+	O-	OH+	O2+	

NOTE. WEIGHT FRACTION OF FUEL IN TOTAL FUELS AND OF OXIDANT IN TOTAL OXIDANTS

Case 6: Equilibrium/Frozen Monopropellant Hydrazine Model
with Total Enthalpy Variations

```
REACTANTS
H 2.0                                  00       .47   H 0.0    G 1200.  F
N 2.0                                  00       .30   N 0.0    G 1200.  F
UA1.0                                  00       .22   A 0.0    G 1200.  F
H 2.0    O 1.0                         00       .01   H 0.0    G 1200.  F
NAMELISTS
 $INPT2
   NASE=1,RKT=T,PSIA=T,MOCYF=T,P=180.0,1.0,       FPCT=T,MTX(1)=100.,
  PARTHT=T,NOI=7,DDOTP=-550.,-450.,-400.,-300.,-200.,-100.,0.0
 $END
 $TAPGEN
     IREAD=1,IC=8,IN=10
 $END
 HYDRAZINE 60  DISS
 $RKTINP
 PCP=3.,5.,10.,50.,100.,200.,500.,1000.,NFZ=2
 $END
STOP
```

Case 6 Output

THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION

AFTER POINT 2

PC = 180.0 PSIA

HO(R) = -550.0000 CAL/G

CASE NO. 1

	CHEMICAL FORMULA	MOLES	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	H 2.00000	.42000	64[illegible]0.553	G	1200.00	.0000
FUEL	N 2.00000	.30000	6[illegible]16.005	G	1200.00	.0000
FUEL	NA 1.00000	.22000	-382.026	G	1200.00	.0000
FUEL	H 2.00000 O 1.00000	.01000	-49553.348	G	1200.00	.0000

O/F = .0000 PERCENT FUEL=100.0000 EQUIVALENCE RATIO= 48.0000 REACTANT DENSITY= .0000

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.7694	3.0000	5.0000	10.000	50.000	100.00
P, ATM	12.248	6.9223	4.0827	2.4496	1.2248	.2450	.1225
T, DEG K	539	496	437	385	323	211	175
RHO, G/CC	4.2935-3	2.6714-3	1.7893-3	1.2180-3	7.2608-4	2.2210-4	1.3409-4
H, CAL/G	-215.0	-252.6	-283.7	-310.3	-341.2	-394.9	-411.8
S, CAL/(G)(K)	2.8527	2.8527	2.8527	2.8527	2.8527	2.8527	2.8527
M, MOL WT	15.371	15.713	15.713	15.713	15.713	15.713	15.713
CP, CAL/(G)(K)	1.7722	1.9066	.5180	.5058	.4917	.4686	.4619
GAMMA (S)	1.2079	1.1975	1.3230	1.3334	1.3463	1.3697	1.3770
SON VEL, M/SEC	590.9	560.7	553.1	521.3	479.7	391.2	357.0
MACH NUMBER	.000	1.000	1.371	1.712	2.147	3.136	3.594
AE/AT		1.0000	1.1042	1.3778	2.0076	5.4976	17.414
CSTAR, FT/SEC		2718	2718	2718	2718	2718	2718
CF		.677	.915	1.077	1.240	1.481	1.549
IVAC, LB-SEC/LB		104.9	108.4	114.3	121.7	134.4	138.2
ISP, LB-SEC/LB		57.2	77.3	91.0	104.8	125.1	130.8

MOLE FRACTIONS

H2	.28162	H2O	.01183	N2	.26330	NH3	.18348
NA	.26036						

Case 6 Output (Concluded)

THEORETICAL ROCKET PERFORMANCE ASSUMING FROZEN COMPOSITION DURING EXPANSION

AFTER POINT 2

PC = 190.0 PSIA

QOOIP = .0000 CAL/G
CASE NO. 1

CHEMICAL FORMULA		MOLES	ENERGY CAL/MOL	STATE	TEMP DEG K	DENSITY G/CC
FUEL	H 2.00000	.47000	6408.553	G	1200.00	.0000
FUEL	N 2.00000	.30000	6716.005	G	1200.00	.0000
FUEL	UA 1.00000	.22000	-382.026	G	1200.00	.0000
FUEL	H 2.00000 O 1.00000	.01000	-49553.348	G	1200.00	.0000

O/F= .0000 PERCENT FUEL=100.0000 EQUIVALENCE RATIO= 48.0000 REACTANT DENSITY= .0000

	CHAMBER	THROAT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT	EXIT
PC/P	1.0000	1.8251	3.0000	5.0000	10.000	50.000	100.00	200.00	500.00	1000.00
P, ATM	12.248	6.7108	4.0827	2.4496	1.2248	.2450	.1225	.0612	.0245	.0122
T, DEG K	1201	1052	940	835	708	472	393	326	254	209
RHO, G/CC	1.6514-3	1.0324-3	7.0275-4	4.7473-4	2.8022-4	8.4096-5	5.0457-5	3.0386-5	1.5618-5	9.4682-6
H, CAL/G	335.0	233.7	159.7	91.9	12.0	-128.3	-173.0	-210.2	-249.8	-273.7
S, CAL/(G)(K)	3.5666	3.5666	3.5666	3.5666	3.5666	3.5666	3.5666	3.5666	3.5666	3.5666
M, MOL WT	13.282	13.284	13.284	13.284	13.284	13.284	13.284	13.284	13.284	13.284
CP, CAL/(G)(K)	.6950	.6740	.6532	.6359	.6143	.5752	.5628	.5525	.5416	.5350
GAMMA (S)	1.2752	1.2868	1.2970	1.3076	1.3219	1.3515	1.3621	1.3713	1.3817	1.3882
SON VEL,M/SEC	979.0	920.6	873.8	826.8	765.2	631.6	578.8	529.2	468.6	426.6
MACH NUMBER	.000	1.000	1.386	1.725	2.148	3.117	3.562	4.036	4.721	5.291
AE/AT		1.0000	1.1167	1.4037	2.0633	5.7401	9.1362	14.644	27.511	44.478
CSTAR, FT/SEC		4284	4284	4284	4284	4284	4284	4284	4284	4284
CF		.705	.928	1.092	1.259	1.508	1.579	1.636	1.694	1.728
IVAC,LB-SEC/LB		166.8	173.1	182.8	195.1	216.1	222.4	227.6	232.9	236.1
ISP, LB-SEC/LB		93.9	123.5	145.4	167.6	200.8	210.2	217.8	225.6	230.1

MOLE FRACTIONS

H2	.46949	H2O	.01000	N2	.29990	NH3	.00050
UA	.22011						

OF POOR QUALITY
ORIGINAL PAGE IS

4.4.1 TRAN72 Sample Case 1

This particular case produces an equilibrium output tape for a hydrogen/oxygen propellant system such as is used for the Space Shuttle Main Engine. Two equilibrium tables are created for output to a tape or file for use by the RAMP2F program. Each table corresponds to an O/F ratio of 6.113. One table has a total pressure of 2950 psia while the other has a chamber pressure of 30.0 psia.

4.4.2 TRAN72 Sample Case 2

Sample Case 2 produces data for the Space Shuttle Reaction Control System engine. The propellants are MMH/N_2O_4. Variable O/F tables ranging from 0.8 to 2.2 are produced with a freeze point in each table at a pressure ratio of 3.35. Two total pressure tables for each O/F are generated.

4.4.3 TRAN72 Sample Case 3

This sample case demonstrates the use of the TRAN72 program to produce thermochemical data for a single phase case which includes boundary layer effects for a plume restart. The data for sample case 3 is for the Space Shuttle vernier motor which is a motor which uses MMH/N_2O_4 as a propellant system. The constant O/F option is used with nine different total enthalpy tables input to simulate the heat transfer losses through the boundary layer. A freeze pressure corresponding to a pressure ratio of 2 is selected for each table.

4.4.4 TRAN72 Sample Case 4

Sample Case 4 produces data for a equilibrium/frozen two-phase motor. The flow is frozen at a pressure ratio of 10. Five different total enthalpy tables are considered to account for heat transfer and drag effects between the particles and gas. The range of QDOTPs (total enthalpy losses) was selected for an inviscid two-phase solution that does not consider boundary layer effects. This particular propellant system (Space Shuttle solid rocket motor) would result in more than 100 species for the equilibrium calculations. The OMIT cards are used to delete the minor species so that the TRAN72 program limitation of 100 species is not exceeded.

4.4.5 TRAN72 Sample Case 5

Sample case 5 is identical to sample case 4 except that the IONS options is selected in addition to more OMIT cards. The IONS option is selected when the user is interested in electron and ion levels in the nozzle and plume. This option would be used if the application of the plume were for radar cross sections or plume/electromagnetic pulse (EMP) coupling calculations. The data for this case has a freeze point at a pressure ratio of 10. Electron and ion concentrations are very strongly affected by finite rate effects for most motors. The ionic chemistry diverges from equilibrium not far from the throat so that if accurate estimates of electron concentrations are required a knowledge of an appropriate freeze point or an a finite rate calcultion would be necessary.

4.4.6 TRAN72 Sample Case 6

Monopropellant (hydrazine) thrusters are used by many satellites. The thermochemical characteristics of the exhaust gases are strongly affected by the percentage ammonia dissociation for the particular propulsion system. If hydrazine were input to the TRAN72 by itself then the percent of ammonia dissociation probably would not be correct. A model of the hydrazine partially dissociated ammonia combustion has been developed. This model uses data published in Ref. 20. Figure 4-1 shows chamber temperature and molecular weight as a function of percent ammonia dissociation. Figure 4-2 presents the post-combustion mole fractions of H_2, N_2 and NH_3 as a function of percent ammonia dissociation. In addition to chamber pressure

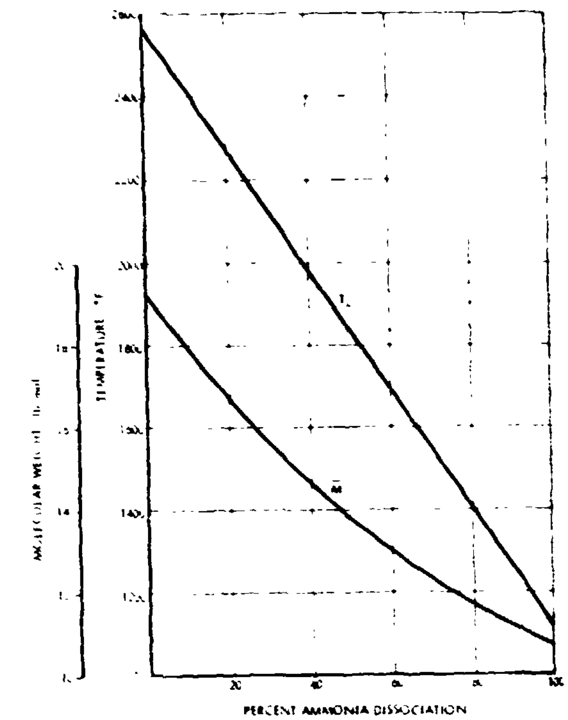


Fig. 4-1 Temperature and Molecular Weight versus Ammonia Dissociation-Anhydrous Hydrazine

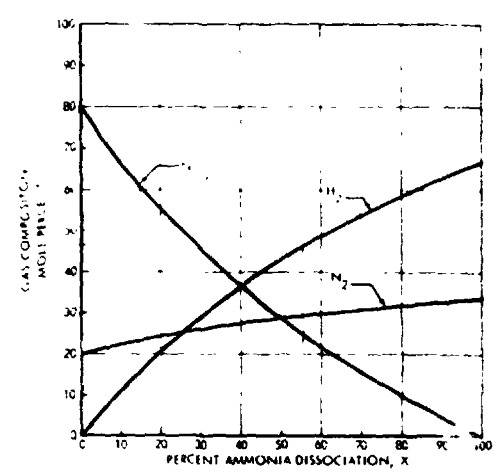


Fig. 4-2 Gas composition versus Ammonia-Anhydrous Hydrazine

one of the operating characteristics of each hydrazine motor is the specification of the percent ammonia dissociation. The first step in applying the hydrazine model is to determine the chamber temperature, species mole fractions (H_2,N_2,NH_3) using Figs. 4-1, 4-2 and the known percent ammonia dissociation. A species named UA is included on the thermodynamic data tape for the TRAN72/RAMP2 programs. The thermodynamic properties for UA (unreacting ammonia) are the same as ammonia (NH_3). By specifying the ammonia as UA the thermochemical characteristics of ammonia are considered for the propellant system while the ammonia is not allowed to dissociate further since the TRAN72 will carry UA as an inert. The reactants cards are prepared for N_2, H_2 and UA by inputting the mole fractions for each on the reactant's cards. The option whereby the program calculates the enthalpies of the reactants is used. Columns 37 and 38 are set to 0, the enthalpies are set to 0.0 and the combusiton chamber temperature (from Fig. 4-1) is input for each of the three reactants. The combustion chamber temperature must be input in degrees Kelvin so that the chamber temperature specified on Fig. 4-1 must be converted from degrees Fahrenheit to degrees Kelvin. The only other special input requirement is to set FPCT=T and MIX=100 on the $INPT2 namelist. The remaining input is the same as any standard case. The hydrazine decomposition products (N_2, H_2 and UA) are essentially frozen during the expansion so that the freeze option can be used with the freeze point set to either the chamber (NFZ=1) or throat (NFZ=2) stations. The data for this particular case produce tables for a nozzle and plume solution which does not include boundary layer effects. The data could be changed to include these effects if PARTHT was set to TRUE and QDOTPs were specified along with how many QDOT tables (NQI).

5. APPLICATION AND USE OF THE BLIMPJ MODULE

As has been previously mentioned, the BLIMPJ module is used to generate a nozzle boundary layer solution which can be used by a RAMP2F restart at the exit plane to generate a viscous plume. Preparation of the input data for the BLIMPJ program is performed by the RAMP2F nozzle solution calculation, and is stored on FORTRAN unit 1. The option in the nozzle run which enables the BLIMPJ data generation routine is IBL (Col. 34, Card 5). Section 5.1 discusses the BLIMPJ input variables which the user has control over. Section 5.2 discusses special considerations for using the BLIMPJ module as well as possible problems and suggested fixes.

5.1 USER OPTIONS FOR BLIMPJ MODULE

The input for the BLIMPJ module is generated by the RAMP2F nozzle solution. The user has three options in determining how the nozzle boundary layer solution will be performed. The user may specify type of boundary layer (turbulent or laminar), the chemistry assumption (equilibrium or frozen) and finally the wall boundary condition (specified wall temperature, adiabatic wall or wall steady state energy balance). The selection and use of these options are input on cards 41-44 for RAMP2F.

Through the use of KR7 (Card 41) the user may select whether the boundary layer is laminar or turbulent (following transition at a momentum Reynolds number of 250). KR7 also controls whether the chemistry is frozen or in equilibrium. The default values for the chemistry and type of boundary layer as a function of nozzle chemistry are given in Table 5-1. These default assumptions were chosen such that for most cases the properties at the boundary layer edge and the inviscid flowfield at the exit plane match very well.

Table 5-1

BLIMPJ BOUNDARY LAYER CHEMISTRY/TURBULENCE DEFAULT
USERS NOZZLE CHEMISTRY ASSUMPTION

Nozzle Chemistry Assumption	Default for BLIMPJ
Equilibrium/Frozen (ICON(1)=2)	Turbulent after transition. Frozen chemistry if the freeze pressure is greater than 70 percent of the lip pressure. The species distribution used are lip species. If the freeze pressure is less than 70 percent of the lip pressure or if the chemistry is equilibrium then equilibrium chemistry is used with the species in the combustion chamber being used to start solution.
Equilibrium (ICON(1)=2)	Turbulent after transition, equilibrium (combusion chamber species)
Gas Data from Cards (ICON(1)=1)	Turbulent after transition, frozen chemistry with species input by user via cards 41 of RAMP2F
Finite Rate (ICON(1)=3) or Frozen (ICON(1)=4)	Turbulent after transition, frozen chemistry using lip species distribution

The nozzle wall boundary condition is specified through the use of variable KR9 on card 41. The user can select the following: adiabatic wall, specified wall temperature or wall steady state energy balance. The default value in the program is the adiabatic wall option. In general the use of the adiabatic wall option will result in conservatively high estimates of nozzle exhaust mass flows in the backflow region of the plume. For cases where the user has access to experimental wall temperature distributions along the nozzle wall, the actual temperature distribution can be specified. The steady state energy balance option can be used for solid rocket motor cases. Built into the program is a typical wall material heat of formation for carbon/phenolic nozzle material. Future effort will include utilizing some of the other wall boundary conditions in the BLIMPJ code, so that such phenomena as nozzle wall ablation can be considered.

5.2 SPECIAL CONSIDERATIONS ON USING BLIMPJ MODULE

The BLIMPJ module is a very reliable program and the data that have generated by the RAMP2F nozzle solution have been structured to provide trouble-free execution of the BLIMPJ module. To date, only three areas have resulted in problems with the boundary layer solution. These are: (1) mismatch in properties between the boundary layer edge properties and the inviscid nozzle results when the boundary layer and exit plane startline are merged; (2) the boundary layer solution will not converge at the first solution station; and (3) for certain cases the program cannot reach a solution at a specified pressure on the nozzle wall.

The default chemistry option and total conditions which are used for the nozzle boundary layer solution are selected to provide the best match of inviscid/boundary layer edge properties. There are instances when an adequate match does not occur. The pressure distribution and resultant flow properties which are used as boundary layer edge properties are those which exist on the inviscid nozzle wall. In the uncoupled sense the actual boundary layer edge properties are actually somewhat displaced from the nozzle wall. As the boundary layer gets thicker, the actual edge properties differ from nozzle wall conditions. Built into the BLIMPJ program is an option which reruns the boundary layer solution using more appropriate edge conditions for certain cases. After the initial boundary layer solution is complete the BLIMPJ code checks to see if the nozzle wall static pressure is within 10 percent of the static pressure that exists at the edge of the boundary layer at the exit plane on the inviscid start line. If the match is satisfactory then the solution is terminated. However, if the match is not adequate the new edge properties (pressure) are determined based on the initial boundary layer edge location within the nozzle flow field and another boundary layer solution is performed. For gas only cases the same total conditions are used for the second solution. For two phase cases new total conditions (total enthalpy and total pressure) are calculated at the boundary layer edge. This is done due to the large entropy and total enthalpy gradients which can exist near the nozzle lip for solid motors.

Variable O/F nozzles in general have large O/F gradients near the nozzle wall due to film cooling. In the present version of the RAMP2 program no provisions have been made to change total conditions (O/F ratio, species, total enthalpy) for the second pass through the boundary layer. This deficiency will be corrected in the near future. It is possible to hardwire changes to the BLIMPJ program for these type cases. Until the deficiency is corrected users that require the inclusion of variable O/F effects in the boundary layer to better match the edge conditions should contact the author for guidance.

There is an option (NUNIPP, Card 41) to punch the BLIMPJ data on cards. The BLIMPJ data can then be modified and along with the flowfield data tape (tape 3), and tape 2 the BLIMPJ code can be run alone to alter the boundary layer solution to better match the boundary layer edge with the inviscid results. For 95 percent of the cases no special treatments are necessary to adequately match the boundary layer and inviscid results.

The selection of the solution stations for the nozzle boundary layer solution has been automated within the RAMP2F code to provide for a reliable and trouble-free execution of the BLIMPJ code. Subroutine WALPRP of the RAMP2F code (see Volume II, page 5-175) controls the selection of the solution station. To date, none of the cases that have been run have encountered problems in reaching a solution for the first station. However, if a particular case does not converge for the first solution station, subroutine WALPRP can be modified to change the distribution of solution stations or XSTART On Card 41 can be increased or decreased until a solution is obtained. Unless the nozzle being calculated is a very peculiar nozzle it is highly unlikely that this problem will be encountered.

A high area ratio two-phase case has encountered problems in performing the one-dimensional expansion from input total conditions to the pressure ratios at the solution stations input to the BLIMPJ code. Symptoms of this problem is either the error message 'STATE DOES NOT CONVERGE FOR KQ(5)=' or the summary of flow properties at the input pressure ratios shows oscillations in temperature at temperatures near 1000 K. This problem has been traced to mismatches in the thermodynamic curve fits for the two temperature ranges for which the thermo data for each species is curve fit. Should this problem occur, the user can set L=2 in BLIMPJ routines B14D, B14C, B14E. This problem will be corrected in the next version of the RAMP2F code.

Small, low thrust nozzles can have a boundary layers that comprise a large percentage of the mass flow of the nozzle at the exit plane. For these cases there can be a strong coupling between the boundary layer and the inviscid flow field. To account for this it is possible to iteratively solve for the boundary layer and flow field by using the boundary layer displacement thickness to alter the nozzle contour. To date this has not been incorporated into the RAMP2 codes but it will be included in the next version of the code.

6. RAMP2F INPUT/OUTPUT INSTRUCTIONS

This section outlines in detail the input to the RAMP2F flowfield code. The first subsection presents a card-by-card description of the input data. Section 6.2 presents a description of the printed output.

6.1 RAMP2F PROGRAM INPUT INFORMATION

This section presents a card-by-card description of the input data. These data are in general input in groups (i.e., control cards, boundary equations, gas thermodynamics, particle information, etc.). As the user utilizes the input guide each variable is explained, and the use of the various cards with given control variable options is explained. By referring to the sample cases of Section 8 the use and interaction of the various groups of cards for each type of problem will become clearer.

CARD 1 Overall Run Control Card Format: 16I5

Column	Parameter	Value	Description
5	ITRCE	0	All input data are coming from cards except as noted for ICON(1) and ICON(2). Input cards will be written on unit 13 for future use.
		1	RAMP code has already been executed for a nozzle, and all input data from nozzle run is on unit 13. Nozzle boundary layer has been completed, and the code will generate an exit plane start line which includes boundary layer and particles in the boundary layer (if present). All other data files (units 2,3,4,8,10,12,13) which were generated during the nozzle run must also have been saved and are used as input.
10	ISTART	0	Do not generate an exit plane start line that includes the boundary layer. Inviscid exit plane start lines are controlled by Card 5. ISTART > 0 implies that a nozzle boundary layer solution will be generated following a nozzle solution or has already been generat· if a plume restart at the exit plane is to be performed.
		1	Punch a viscous exit plane (or at any other boundary point based on ICON(6)) SPF startline.
		2	Generate a viscous normal start line at exit (streamline normal solution only) and restart plume solution at exit.

CARD 1 (Cont'd)

Column	Parameter	Value	Description
10	ISTART	3	Same as 2 plus punch a viscous SPF start line (see ISTART=1).
15	I.[illegible]STL (See Sec. [illegible].5)	0	Do not punch any viscous exit plane startlines.
		1	Print exit plane MOC ideal gas viscous start line (see Sec. 7.3) and ideal gas viscous exit plane normal startline (if ISTART=2 or 3).
		2	Print and punch ideal gas exit plane MOC and normal startline.

CARDS 2-4 — Problem Description — Format: 3(20A4)

Column	Parameter	Description
1-240	HEADER	Problem description may be put on three cards: however only the first 120 columns will be printed while all 240 characters will be written on the data tape. All three cards must be present even if blank.

CARD 5 — Run Control Card — Format: 16I5

Column	Parameter	Value	Description
5	ICON(1) Gaseous thermodynamic data control parameter	1	The gas composition is either chemically frozen and/or in chemical equilibrium. The gas properties are read directly from cards 10, 11, 12, and 13.
		2	Same as ICON(1)=1 except gas properties are read directly from a data tape mounted on FORTRAN unit 10 (from TRAN72).

CARD 5 (Cont'd)

Column	Parameter	Value	Description
5	ICON(1)	3	The gas composition is in chemical non-equilibrium. The gas properties are determined as a function of temperature in thermodynamic data tables input on card 15.
		4	Same as ICON(1)=3 except gas composition is chemically frozen.
8-9	NTAPE	N	If ICON(2)=2, tape unit number for start line if not input from cards. The program defaults to unit 5 (read cards) for ICON(2)=2. If ICON(2)=2 and a two-phase transonic solution is being performed NTAPE is the unit on which the transonic start line will be written. In this case the program defaults to unit 8.
10	ICON(2) Start line control parameter for gas only solution	0	Generate straight start line with Mach number given.
		1	Generate source startline with A/A^* given.
		2	Startline input from cards or tape.
		3	Not presently used.
		4	Generate constant O/F gaseous startline using gaseous transonic module. This option requires cards 20c,d,e; ICON(2)=4 for constant O/F cases only.
		5	Generate gaseous start line using gaseous transonic module for variable O/F nozzle. This option requires cards 20c,d,e.

CARD 5 (Cont'd)

Column	Parameter	Value	Description
10	Startline control parameter for gas-particle solution	0	Generate startline using transonic approximation.
		2	Startline input from cards.
13	ICON(3) (IFUD) Controls spacing of points on gas startline setup by program (1-D only)	0	Points are evenly spaced. This option should be used except for special cases
		1	Points are spaced according to a sine distribution.
14-15	ICON(3)	N	Number of startline points (100 maximum).** For gas only transonic cases the maximum number is 15 points.
16-20	ICON(4) Upper Boundary specification indicator	N	Number of upper boundary equations if specifying upper boundary with equations. (100 maximum, right adjust).

Option for ICON(4) when upper boundary is described by individual points and slopes

ICON(4) 1N000 + Number of discrete points (no boundary equation following last point)

2N000 + Number of discrete points + 1 (an upper boundary equation follows last point)

N number of points to use for Lagrangian integration (5 max).

If N is set to zero, a linear assumption will be made.

NOTE: If a nozzle is being run the throat must also be specified by discrete points.

** If particles are present and supersonic start line is generated by transonic approximation then total number of points on start line may be adjusted by transonic program depending on particle distributions.

CARD 5 (Cont'd)

Column	Parameter	Value	Description
21-25	ICON(5) Number of lower boundary equations	N	Lower boundary specification indicator. Same description and options as ICON(4).
27-28	ICON(6) (IFD)	N	N is the boundary equation number at which the SKIPPY start line is to be punched. The code uses the XMAX (see card 8) for this boundary equation as the station to punch. This is normally the lip equation.
29	ICON(6)(IUNIT)	0	Punch SPF start line
		1	Output SPF start line on unit 12.
30	ICON(6)(ISKPY)	0	Do not generate SPF start line
		1	Chemical system 1 SPF start line (see Table 6-1)
		2	Chemical system 2 SPF start line (see Table 6-1)
		3	Chemical system 3 SPF start line (see Table 6-1)
		4	Chemical system 4 SPF start line (see Table 6-1)
		5	Chemical system 5 SPF start line (see Table 6-1)
		6	Chemical system 6 SPF start line (see Table 6-1)
		7	Input chemical system via card
		8	Ideal gas SPF start line
33	ICAPTR	0	Streamline-normal solution
		1	Shock capturing numerical operator (Use only for nozzles)

Table 6-1

SPF CHEMICAL SYSTEMS

System 1 – Hydrogen/Oxygen

$H, H_2, H_2O, N_2, O, OH, O_2$

System 2 – Carbon/Hydrogen/Oxygen

$CO, CO_2, H, H_2, H_2O, N_2, O, CH, O_2$

System 3 – Carbon/Hydrogen/Oxygen/Chlorine

$Al_2O_3(S), CO, CO_2, Cl, Cl_2, H, H_2, H_2O, HCl, N_2, O, OH, O_2$

System 4 – Carbon/Hydrogen/Oxygen/Chlorine/Fluorine

$CO, CO_2, Cl, Cl_2, F, F_2, H, H_2, H_2O, HCl, HF, N_2, O, OH, O_2$

System 5 – Hydrogen/Oxygen/Boron

$BO, BO_2, B_2O_3, H, H_2, H_2O, HBO_2, N_2, O, OH, O_2$

System 6 – Hydrogen/Oxygen/Boron/Chlorine/Fluorine

$BF, BF_2, BF_3, BO, BOCl, BOF, BO_2, B_2O_3, CO, CO_2, Cl, Cl_2$
$F, F_2, H, H_2, H_2O, HBO_2, HCl, HF, N_2, O, OH, O_2$

CARD 5 (Cont'd)

Column	Parameter	Value	Description
34	IBL	0	Do not generate data for boundary layer calculation.
		1	Generate data for boundary layer calculation and store on unit 1.
35	ICON(7)	0	Two-dimensional flow problem geometry.
		1	Axisymmetric flow problem geometry.
38	ICON(8)(INOZ)	0	Perform calcuations until problem limits specified by card 22 are reached.
		1	Terminate solution when discontinuity in upper boundary equations are reached, i.e., lip is reached.
		2	Boundary layer is to be generated for plume restart at exit plane. Terminate nozzle solution at expansion corner (lip). This must be set if boundary layer is to be generated.
39	ICON(8) Data output control, used in conjunction with ICON(16)	0	Full printout, print every point on normal
		1	Print only boundary, shock, input, Prandtl-Meyer, and particle limiting streamline points.
40	ICON(8)	1	Print 1 line (R,X,M,θ,S and shock angle)
		2	Print above plus Mach angle, P, ρ, T, V
		3	Print all of above plus MWT, γ, TO*, PO*, S*.

CARD 5 (Cont'd)

Column	Parameter	Value	Description
43	ICON(9) Units indicator	0	Use English system of units.
		1	Use metric system of units.
			This option controls the units in which the flow field is calculated. The program assumes that the boundary equations are input in the same units as the units indicator (ICON(9)). This option will not override the units specifiation on cards 10 and 32 but will convert the units of the gas and particle thermodynamics to correspond to the units of this indicator.
44-45	ISPECS		Number of discrete particle sizes used to represent particle distribution (10 max). If gaseous only flow set equal to 0.
48-50	ICON(10)		Maximum iterations allowable for each point in flow field. If set to 0 program assumes value of 100.
51-55	ICON(11)		Case number printed at top of each page.
60	ICON(12)		Not presently used.
61	ICON(13)	0	Flowfield data will be output on FORTRAN unit 3. Must be set if generating boundary layer.
		1	Data will not be written on tape.
65	ICON(13)	0	Free molecular calcultions will not be considered.

CARD 5 (Cont'd)

Column	Parameter	Value	Description
65	ICON(13)	1	Free molecular calculations in all portions of flow field (including nozzle).
		2	Free molecular calculations will be considered in plume only following restart at exit plane with viscous starting line.
			NOTE: ICON(13) > 0 requires additional input from Card 24.
68-70	ICON(14)	0	No intermediate printout in solution iteration.
		N	Print intermediate results for N^{th} line.
71-75	ICON(15)	0	No intermediate printout.
		M	Print intermediate results from M^{th} point on each line from the N^{th} (ICON(14)) line on. Right adjust.
			Note: The use of ICON(14) and ICON(15) result in massive printout. This option is generally used only to debug program changes that result in errors.
76	ICON(16) (IPCH)	0	No punched cards output.
		1	Punch data line at nozzle exit.
77-78	ICON(16) (IOUT)	0	Print every line.
		N	Print every N^{th} line (use with ICON(8)).

CARD 5 (Cont'd)

Column	Parameter	Value	Description
79-80	ICON(16)		Time (SEC) before end of allotted run time when new startline is to be punched. Put 0 in column 79 if time less than 10 sec. The use of this option required the use of a system routine to monitor the CPU clock time.

CARD 6 — Finite Rate Chemistry* Run Control Card (Required if ICON(1)>2) — Format: 8I5

Column	Parameter	Value	Description
1-5	NT		Number of temperature points in thermodynamic data tables.
6-10	NS		Number of gaseous species (excluding 3rd bodies)
11-15	NM		Number of 3rd bodies.
16-20	NR		Number of reactions specified.
25	NPRINT	0	No intermediate printout in chemistry calculations.
		1	Echo print of input data.
		2	Print intermediate results of chemistry calculations.
30	ICTAPE	0	Species concentrations for start line read directly from cards.
		1	Species concentrations read directly from a TRAN72 data tape mounted on FORTRAN unit 10.

*A detailed description of the Finite Rate chemistry input requirements can be found in Section 7.1.2.3.

CARD 6 (Cont'd)

Column	Parameter	Value	Description
35	KGUP	≥ 2	Number of normals calculated before finite rate chemistry contributes to dS and dH.
40	IDIDO	0	Uniform species concentrations along start line.
		1	Non-uniform species concentrations along start line.

CARD 7 Nozzle Throat Radius Format: 2E10.4

Column	Parameter	Value	Description
1-10	RSTAR		Nozzle throat radius (ft or M depending on ICON(9)). If running a plume only, RSTAR can be left blank.
11-21	XSHIFT		XSHIFT is the distance from the nozzle throat to the center (X≠0) of the coordinate system for the wall equations. This is only necessary for two-phase cases where a transonic solution is desired and where X=0 at the nozzle throat. This distance is positive if the center of the coordinate system is downstream of the throat and negative if the center of the coordinate system is upstream of the throat. XSHIFT should be zero except for two-phase transonic cases. XSHIFT is input in feet or meters depending on ICON(9).

CARD 8 Upper Boundary Description

If ICON(4) < 10,000 use following Format (I1,3X,I1,5X,6E10.4).

CARD 8 (Cont'd)

Column	Parameter	Value	Description
1	IWALL(K,2)	1	Conic equation $R = A[(B+CX+DX^2)^{1/2}+E]$
	IWALL(K,2)	2	Polynomial equation $R = AX^4+BX^3+CX^2+DX+E$
		3	Free boundary equation $P = P_\infty(1+E_\infty X)(1+\gamma_\infty(M_\infty \sin(\theta_B - \theta_\infty))^2)$ (See page 6-15 for an example and description.)
5	ITRANS(K,2)	0	No discontinuity follows this equation.
		1	Expansion corner follows.
11-20	WALLCO(K,1,2)		Coefficient A or P_∞(psfa or N/m^2). (Units must be consistent with R in ft or m.)
21-30	WALLCO(K,2,2)		B or γ_∞
31-40	WALLCO(K,3,2)		C or M
41-50	WALLCO(K,4,2)		D or θ_∞(deg)
51-60	WALLCO(K,5,2)		E or E_∞
61-70	WALLCO(K,6,2)		Maximum value of X applicable to equation (feet if ICON(9)=0 meters if ICON(9)=1).

If ICON(4) > 10,000 use following format (I5,5X,3E10.4,I5,5X,3E10.4).

Column	Parameter	Value	Description
5	ITRANS(K,2)		Same as before.
11-20	WALLCO(K,3,2)		Axial position (X) of point K (ft or m).
21-30	WALLCO(K,1,2)		Radial position (R) of point K (ft or m).

CARD 8 (Cont'd)

Column	Parameter	Value	Description
31-40	WALLCO(K,2,2)		Wall angle (θ) at point K (deg)
45	ITRANS(K+1,2)		Same as before.
51-60	WALLCO(K+1,3,2)		X at point K+1 (ft or m).
61-70	WALLCO(K+1,1,2)		R at point K+1 (ft or m)
71-80	WALLCO(K+1,2,2)		θ at point K +1 (deg)

NOTE: Card 8, in the above format, is repeated for each equation until all necessary equations have been input. That is, repeat Card 8, in succession in order of increasing X, for K=1,2,...,ICON(4).

Repeat Card 8, in above format, in succession, and in order of increasing X, until all required points have been input.

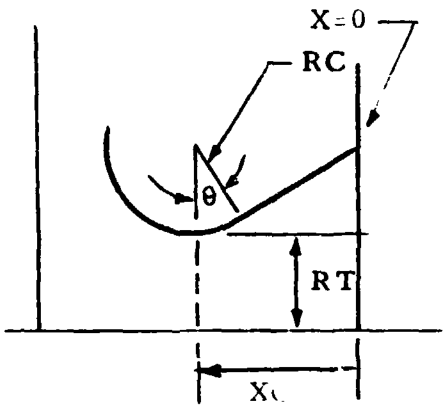
If ICON(4) > 20,000, the above format is used plus Card 8a must be input to define the boundary conditions downstream of the last discrete point.

CARD 8a (IF(ICON(4) >20,000))

Input boundary equation as per Card 8, ICON(14) <10,000.

CARD 9 Lower Boundary Description

The formats and options for card 9 are controlled by ICON(5) and are the same as for Card 8 (Upper Boundary) with the following exception: It is not possible to run a two-phase case with the lower boundary specified by points, therefore there is no Card 8a; (2) the indices of the parameters are (-,-,1) instead of (-,-,2), e.g., WALLCO(K,1,1) instead of WALLCO(K,1,2). A nozzle throat region showing the coefficients of a circular throat and free boundary are shown in the sketch on the following page.



RC = radius of curvature of the circular arc of the throat
RT = throat radius
XO = axial distance from the origin of the coordinate system to the throat
θ = throat divergence angle corresponding to the maximum value for which the throat conic equation applies

The conic equation for this case would have the following form:

A = -1 for an upper equation, +1 for a lower equation
-1 for this case)

$B = RC^2 - XO^2$

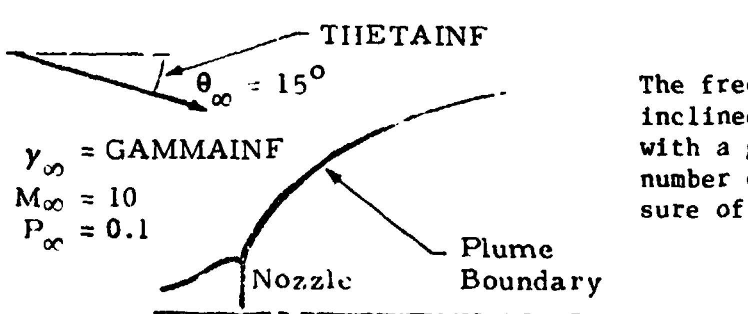
C = 2XO

D = -1

E = -(RC + RT)

Xmax = RC sin + XO

An example of a free boundary is shown in the sketch below.



The freestream approach flow is inclined at 15 deg to the plume with a gamma (γ) of 1.4, a Mach number of 10, and a static pressure of 0.1 psfa.

PINF = 0.1 (psfa)
E = 0 (No pressure variation with axial distance)
GAMMAINF = 1.4
MINF = 10
THETAINF = -15 deg

CARD 10 Gas Property Control Format: 6A4,5X,A3,6X,I2,3X,I2,5X,E10.4

This card is required whether gas data input by cards or tape.

Column	Parameter	Description
1-24	ALPHA(I)	Gas name for real gas on tape. If inputting gas data via cards, may be any name.
30-32	UNITS (Idependent of ICON(9))	ENG Input gas data with English units (cards only). MKS metric units (cards or tape).
39-40	IOF	Number of O/F or total enthalpy tables for gaseous only solution or number of gas total enthalpy tables for two-phase solution
44-45	IS	Number of entropy tables per IOF entry, 1 for gas, 2 maximum for gas chemical equilibrium solution.
51-60	HTREF	Total enthalpy (Btu/lbm or cal/gm (ICON(9)) of gas table corresponding to combustion chamber condition. HTREF is required to be input only for two-phase cases which use multiple total enthalpy tables input via cards. Input zero for all other cases. HTREF corresponds to the table generated by the TRAN72 program at QDOTP=0 (see Section 4).

CARD 11 Mixture Ratio or Total Enthalpy (This card is Not Used if ICON(1)≥2) Format: 2E10.4

*It is necessary to input ALPHA only for finite rate case (ICON(I)≥3).

CARD 11 (Cont'd)

Column	Parameter	Description
1-10	OFRAT(M)	For gaseous only flow input O/F ratio, for particle flow input gas total enthalpy (cal/gm for metric, Btu/lbm for English units specified by Card 10).
11-20	HO(M)	For gas only transonic case and for BL RESTART input total enthalpy (cal/gm for metric, Btu/lbm for English). If real gas get data from NASA-Lewis run. If ideal HO $= C_pT_o$ where $C_p = \gamma R/(\gamma - 1)$

CARD 12 — Entropy (This card is not used if ICON(1)$\geq$2) — Format E10.4,8X,I2

Column	Parameter	Description
1-10	STAB(M,I)	Entropy of gas (cal/gmK or Btu/lbm-R, units specified by Card 10).
19-20	IVTAB(M,I)	Number of Mach numbers for this entropy value (13 max).

CARD 13 — Gas Properties (This card is used if ICON(1)=1; units specified by Card 10) — Format: 8E10.4

Column	Parameter	Description
1-10	XSIDIM(1)	Mach number associated with above entropy.
11-20	XSIDIM(2)	Molecular weight of gas (gm/gm-mole or lbm/lb-mole).
21-30	XSIDIM(3)	Gamma (C_p/C_v)

CARD 13 (Cont'd)

31-40	XSIDIM(r)	Temperature (R or K)
41-50	XSIDIM(5)	Pressure (atm)
51-60	XSIDIM(6)	Prandtl number (dimensionless)
61-70	XSIDIM(7)	Absolute viscosity (poise)
71-80	XSIDIM(8)	Ideal gas (1 velocity cut per table) - viscosity temperature exponent. Real gas - C_p (cal/gm-K or Btu/lbm-R).

To illustrate the arrangement of cards 1, 2 and 3, let IOF=2 and IS=2; then the proper arrangement is:

Card 11
12
13(1-13 such cards)
12
13(1-13 such cards)
11
12
13(1-13 such cards)
12
13(1-13 such cards)

CARD 14 Gas Properties (This card is required if ICON(1) > 2) Format: 3E10.4

Column	Parameter	Default Value	Description
1-10	PR	0.7	Prandtl number (dimensionless).
11-20	VISO	1.0E-04	Absolute Viscosity (poise)
21-30	EX	0.6	Viscosity temperature Exponent.

CARD 15 Gas Thermodynamic Data
(The following cards are required if ICON(1)>2)

The following set of cards contain species thermodynamic data. The first card contains the species name, molecular weight, and heat of formation. The second and remaining cards contain the temperature and corresponding specific heat, entropy and enthalpy for that species. Two temperatures and corresponding thermodynamic data are placed on each card. the input table can contain up to a maximum of 30 temperature points. The data are input exactly as presented in the JANAF tables (Ref. 21) with the temperature points being the same for all species. Cards 15.1, 15.2, 15.3, etc., are repeated for each species. If a SPF start line is to be punched (0 ISKPY 7) then the species must be input in same order as they appear in Table 6-1. Section 7.1.3.2 contains thermodynamic and reaction data for typical propellant systems.

Card	Column	Description	Format
15.1	1-8	Name of first species (left adjusted)	2A4
	11-20	Molecular weight	E10.3
	21-30	Heat of formation, h_{298} (kcal/mole)	E10.3
15.2	1-10	First temperature point (K)	F10.4
	11-20	C_p (cal/mole-K)	F10.4
	21-30	S_i (cal/mole-K)	F10.4
	31-40	h_i-h_{298} (kcal/mole)	F10.4
	41-50	Second temperature point (K)	F10.4
	51-60	C_p (cal/mole-K)	F10.4
	61-70	S_i (cal/mole-K)	F10.4
	71-80	h_i-h_{298} (kcal/mole)	F10.4
15.3	1-10	Third temperature point	F10.4
		.	
		.	
		.	
		etc.	

CARD 16 Catalytic Species Weighting Factor Data
(The following cards are required if ICON(1)>2 and NM>0)

Card 16 (Cont'd)

The following set of cards specify the catalytic species (M1,M2,M3...) and their respective composition in terms of the species participating in the reactions. Weighting factors must be read in the same order in which the thermodynamic data sets are read.

Card	Column	Description	Format
16.1.1	1-3	AID(NS+1) - Name of first catalytic species (e.g., M1) (left adjusted)	2A4
16.1.2	1-5	WF(1,1) - Weighting factor of first species (for first catalytic species). Set weighting factor to zero for any reactant which does not contribute to the respective catalytic species.	16F5.2
	6-10	WF(1,2) - Weighting factor of second species contributing to first catalytic species.	
	.		
	.		
	.		
	75-80	WF(1,16) - Weighting factor of 16th species contributing to first catalytic species.	
16.1.3	1-5	WF(1,17) - Weighting factor of 17th species contributing to first catalytic species, etc.	16F5.2
16.2.1	1-8	AID(NS+2) - Name of second catalytic	2A4
16.2.2	1-5	WF(2,1) - Weighting factor of first species contributing to second catalytic species, etc.	16F5.2
16.NM.1	1-8	AID(NS+NM) - Name of last catalytic species, etc.	2A4

CARD 17 Chemical Reaction Mechanisms (The following cards are required if ICON(1)>2 and NR>0).

The following set of cards specifies the chemical reaction mechanisms for a particular problem, one card for each reaction. No particular order is required. Species names are left adjusted.

CARD 17 (Cont'd)

Card	Column	Description	Format
17.1	1-8	Species A	2A4
	9	+ sign	
	10-17	Species B (or M)	2A4
	18	+ sign	
	19-22	Blank (or M)	A4
	23	= sign	
	24-31	Species C	2A4
	32	+ sign (if needed)	
	33-40	Species D (or M)	2A4
	41	+ sign (if needed)	
	42-49	Species E (or M)	2A4
	50-51	Reaction type, 1 to 12	I2
	52	Rate constant type, 1 to 5	I1
	53-59	A, pre-exponential factor (cm-particle-sec units)	E7.1
	60-64	N, temperature exponent	F5.2
	65-74	B, activation energy (cal/mole)	F10.1
	75-80	M, temperature exponent	F6.2
17.2		Next reaction	
17.NR		Last reaction	

CARD 18 Startline Data Format: 7E10.3
(The following cards are requied
if ICON(1)>2 and ICTAPE=0)

CARD 18 (Cont'd)

The following cards contain the species mole fractions on the start-line. Mole fractions must be read in the same order in which the thermodynamic sets are read.

Card	Column	Description
18.1	1-10	Mole fraction of first species at the first point on the start line.
	. . .	
	61-70	Mole fraction of seventh species at the first point on the start line.
18.2	1-10	Mole fraction of eighth species at the first point on the start line.
	. . .	
	61-70	Mole fraction of the fourteenth species at the first point on the start line.

.
.
.
etc.

Cards 18.1 and 18.2, etc., are repeated for each point on the start-line. For a uniform start line (IDIDO=0), mole fractions are read for 1 point only.

CARD 19 — Chamber Condition Data (This is used if ICON(1) > 2 and ICTAPF=0) — Format: 2E10.4

Column	Parameter	Description
1-10	PC	Chamber pressure (atm)
11-20	TC	Chamber temperature (K)

CARDS 20 — Startline Data (This card is not used if ICON(2)=2 or for gas particle flow). — Format 8E10.4

Use Card 20a if ICON(1)≤2 and ICON(2)≤3. Use Card 20b if ICON(1)>2.
Use Cards 20c, d, e if ICON(2)≥4

Card	Column	Parameter	Description
20a	1-10	CORLIP(2)	Axial coordinate of upper limit of start line (ft or m, see Fig. 6-1)
	11-20	CORLIP(6)	Axial coordinate of lower limit of start-line (ft or m, see Fig. 6-1).
	21-30	CORLIP(4)	Mach number (ICON(2)=0) or A/A^* (ICON(2)=1) for startline
	31-40	CORLIP(5)	Entropy of start line (Btu/lbm/^{o}R or cal/gm/K)
	41-50	CORLIP(8)	Mixture ratio (O/F) of startline or total enthalpy (Btu/lbm or cal/gm) if a boundary layer solution is to be performed (IBL=1, Card 5)
20b*	1-10	CORLIP(2)	Axial coordinate of upper limit of start line (ft or m, see Fig. 6-1)
	11-20	CORLIP(6)	Axial coordinate of lower limit of start line (ft or m, see Fig. 6-1)
	21-30	CORLIP(4)	Mach number (ICON(2)=0) or A/A^* (ICON(2)=1) for start line
	31-40	P	Pressure for start line (atm)
	41-50	T	Temperature for start line (R or K)

*This card is used to input the gas startline information when the gas chemical non-equilibrium option is utilized in the solution.

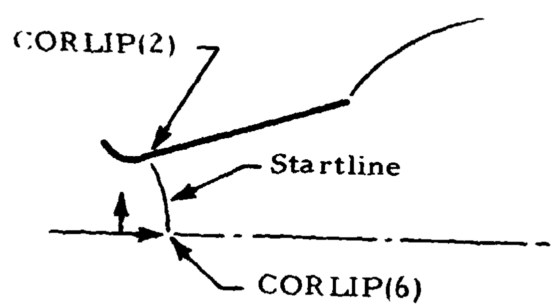


Fig. 6-1 Startline Geometric Set-Up

CARDS 20 (Cont'd)

20c	1-10	CORLIP(2)	Mass flow of nozzle (lbm/sec, gm/sec). If set = 0.0 then the average O/F ratio (CORLIP(8)) will be used to calculate the nozzle mass flow
	11-20	CORLIP(6)	Initial station to start transonic solution (ft,m) consistent with boundary equations. This station should be upstream of the point in the nozzle inlet where it begins to contract.
	21-30	CORLIP(4)	Axial position of nozzle throat (ft,m)
	31-40	CORLIP(5)	Area ratio at which to stop transonic solution should be ≥ 1.5. The default values is 1.5 if set to 0.0.
	41-50	CORLIP(8)	Engine mass average O/F ratio or total enthalpy (Btu/lbm or cal/gm)*
20d	1-5	IOFS	Number of tables of O/F ratio versus radial position on the initial station (CORLIP(6)) (Maximum of 20). If IOFS=1 then constant O/F case will be run using CORLIP(8) and card 20e is not used.

*For cases where ICON(2) = 5, the engine O/F ratio consistent with the gas thermo tables should be input. If ICON(2)=4, IBL=1 and multiple total enthalpy gas tables are input from TRAN72 results or from cards then the total enthalpy corresponding to the actual combustion chamber total conditions (QDOTP=0, see Section 4) should be input so that the proper table is used. If ICON(2)=4 and IBL=0 the code assumes the thermodynamic tables are input as a function of O/F so that CORLIP(8) should be set to the appropriate O/F ratio consistent with the table entries.

NOTE: Use card 20e when IOFS > 1. Points should be input starting at nozzle centerline and going toward wall. This card inputs O/F distribution on the transonic initial station (CORLIP(6)).

Card	Column	Parameter	Description
20e	1-10	OFST(I,1)	Radial position on transonic start line
	11-20	OFST(I,2)	O/F ratio at above radial coordinate on start line
	21-30	OFST(I+1,1)	R
	31-40	OFST(I+1,2)	O/F
	41-50	OFST(I+2,2)	R
	51-60	OFST(I+2,2)	O/F
	61-70	OFST(I+3,1)	R
	71-80	OFST(I+3,2)	O/F

NOTE: Use as many cards 20e as required to read in IOFS points.

CARD 21 Startline Data Format: 6E13.7

Do not use this card if ICON(2)≠2 or for gas-particle flow. Use feet if ICON(9)=0, meters if ICON(9)=1. Use card 21a if ICON(1) ≤2. Use Card 21b if ICON(1)>2.

Repeat this card in succession and in order of increasing R for 1=1,2,...ICON(3).

Card	Column	Parameter	Description
21a*	1-13	R	Radial coordinate (R) of point on startline (ft or m)

---

*Card 21a is used to input the gas start line information when the gas chemical equilibrium, frozen or ideal gas option is utilized in the solution (ICON(1) ≤ 2).

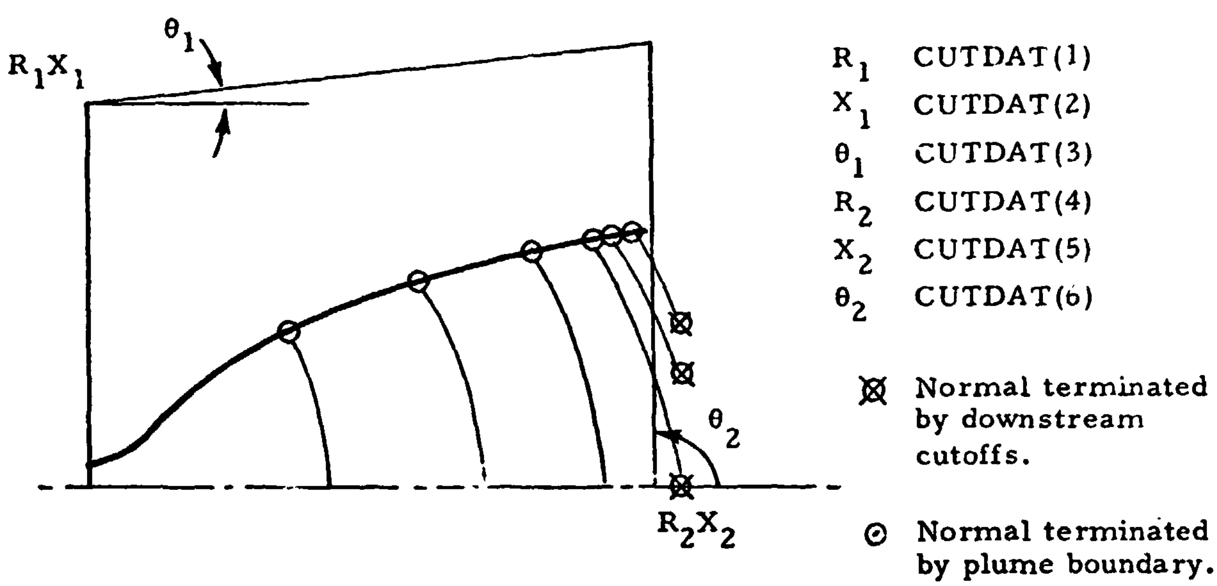
CARD 21a (Cont'd)

	14-26	X	Axial coordinate (X) of point I (ft or m)
	27-39	EM	Mach number at point I (dimensionless)
	40-52	THETA	Flow angle at point I (deg)
	53-65	S	Entropy at point I ($ft^2/sec^2/R$ or $m^2/sec^2/K$)
	66-78	OF	Mixture ratio at point I (O/F) or total enthalpy (ft^2/sec^2 or m^2/sec^2). O/F or H_T should be consistent with gas tables
21b*	1-13	R	Radial coordinate (R) of point I on startline (ft or m)
	14-26	X	Axial coordinate (X) of point I (ft or m)
	27-39	EM	Mach number at point I (dimensionless)
	40-52	THETA	Flow angle at point I (deg)
	53-65	T	Temperature at point I (R or K)
	66-78	P	Pressure at point I (atm)

CARD 22 — Cutoff Limits Data (See Fig. 6-2) — Format: 8E10.4

Column	Parameter	Description
1-10	CUTDAT(1)	Radial coordinate defining upper limit of calculation regime (ft or m)

*This card is used to input the gas startline information when the gas chemical non-equilibrium option is utilized in the solution (ICON(1) > 2).



NOTE: The normals must terminate on an upper boundary. Therefore, R_1, X_1, θ_1 must have values such that the cutoff box will always be above the plume or solid boundary. The code will attempt to fill up the cutoff box with normals until fewer than six points remain on the normal.

Fig. 6-2 Cutoff Limits

CARD 22 (Cont'd)

11-20	CUTDAT(2)	Axial coordinate defining upstream cutoff limit (ft or m)
21-30	CUTDAT(3)	Angle upper limit of calculation regime makes with horizontal (deg)
31-40	CUTDAT(4)	Radial coordinate defining downstream cutoff limit (ft or m)
41-50	CUTDAT(5)	Axial coordinate defining downstream cutoff limit (ft or m)
51-60	CUTDAT(6)	Angle downstream cutoff line makes with horizontal (deg)

CARD 23 Mesh Control (See Section 7.1.6) Format: 8E10.4

Column	Parameter	Description
1-10	STEP(3)	Interior point insertion criteria (ft or m)
11-20	STEP(6)	Axis point insertion criteria (ft or M)
21-30	STEP(9)	Particle limiting streamline insertion criteria
31-40	STEP(7)	Point deletion criteria
41-50	STEP(1)	Prandtl-Meyer integration step size (deg)
51-60	STEP(8)	Interpolation factor for calculating lower wall

CARD 24 Free-Molecular Control Variables (This card is not used if ICON(13)=0). Format: 5E10.4

Column	Parameter	Description
1-10	VIBNO	Reciprocal of the Knudsen number at which the vibrational energy mode thermally freezes

CARD 24 (Cont'd)

11-20	ROTNO	Reciprocal of the Knudsen number at which the rotational energy mode thermally freezes
21-30	TRANNO	Reciprocal of the Knudsen number at which the translational energy mode thermally freezes
31-40	CHARL	Characteristic length used in the Knudsen number calculation (normally the nozzle exit radius)
41-50	CONMM	Viscosity relation temperature exponent if not input in thermo tables.

Cards 25 through 37 are input only for two-phase solution.

CARD 25 Particle Solution Control Format: 16I5

(Use only if ISPECS>0)

Column	Parameter	Value	Description
4	IZO	0	Nozzle wall equations are referenced to the nozzle throat
		1	Nozzle wall equations are not referenced to throat
5	IWRITE (particle print flag)	0	1 line of print for each particle (V, θ, ΔM, h, ρ, ΔT)
		1	Above plus Re, ΔV, ΔT, viscosity, C_p, Pr
		2	All of above plus T_o, P_o, C_D/C_{DS}, Nu/Nus, A,B
6-10	IDRAG	0	Use drag table coded in Kliegel program (Ref. 22)
		1	Use C.J. Crowe drag table coded internal to program (Ref. 23)
		2	Henderson Drag Law (Ref. 24 recommended)

CARD 25 (Cont'd)

14-15	NSETS	0	Startline calculated by program (ICON(2)=2)
		N	Number of startline points at which particles are present for given start line. Must be input if ICON(2)=2. N $\leq$ ICON(3).
18	IPCHS	0	No punch.
		1	Punch start line from transonic program
20	IPFTOC	N	Where N is the number of different temperature/enthalpy tables to input which describe the temperature/enthalpy relationship for the particles. If only one type particle specie (i.e., Al_2O_3) then there is usually only one table input.
25	JTEM(1)	1	Particle temperature/enthalpy table to use for particle 1. The first table should always be for particle 1.
30 . . .	JTEM(M),M=2, ISPECS	0 . . .	Use Table 1 for the m^{th} particle size.
70		N	The particular particle temperature/enthalpy table used to describe this particular particle size.

CARD 26 Particle (if ISPECS > 0) Format: 8E10.4

Column	Parameter	Description
1-10	XMASSP	Ratio of particle total mass flow rate to gas mass flow rate

11-20	ACOMWL	Particle accommodation coefficient for impingement on nozzle wall. Ratio of particles which stick to the nozzle wall/ total particles which strike the nozzle wall. This variable is used only in the particle trajectory tracing through the boundary layer. If the particles hit the nozzle wall in the inviscid solution, ACOMWL is assumed to be 1.0
21-30	PWEGHT	The molecular weight of the particles. This variable is only used to set up a SPF two-phase start line. The SPF code allows only one type of particle.

CARD 27 Particle Mass Flow Rate Fractions (Use only if ISPECS>0) Format: 8E10.4

Column	Parameter	Description
1-10	PERTG(1)	Ratio of particle No. 1 mass flow rate to total particle mass flow rate.
11-20	PERTG(2)	Ratio of particle No. 2 mass flow rate to total particle mass flow rate
.	.	.
.	.	.
.	.	.
71-80	PERTG(ISPECS)	Ratio of particle No. ISPECS mass flow rate to total particle mass flow rate.

CARD 28 Particle Size (Use only if ISPECS>0) Format 8E10.4

Column	Parameter	Description
1-10	PSP(2,1)	Radius of particle No. 1 (microns)
.	.	.
.	.	.
.	.	.
	PSP(2,ISPECS)	Radius of particle No. ISPECS (microns)

CARD 29 Particle Mass Density — Format: 8E10.4
(Use only if ISPECS>0)

Column	Parameter	Description
1-10	PSP(1,1)	Mass density of particle No. 1 (lbm/ft^3, or kg/m^3)
.	.	.
.	.	.
.	.	.
	PSP(1,ISPECS)	Mass density of particle No. ISPECS lbm/ft^3, or kg/m^3).

CARD 30 Emissivity Data* — Format 8E10.4
(Use only if ISPECS>0)
(ε in Eq. 3.6 of Ref. 1)

Column	Parameter	Description
1-10	EMISS(1)	Emissivity of particle No. 1
.	.	.
.	.	.
.	.	.
	EMISS(ISPECS)	Emissivity of particle No. ISPECS

CARD 31 Accommodation Coefficients* — Format 8E10.4
(Use only if ISPECS >0)
(α in Eq.(3.6) of Ref. 1)

Column	Parameter	Description
1-10	ACC(1)	Accommodation coefficient of particle No. 1
.		.
.		.
.		.
	ACC(ISPECS)	Accommodation coefficient of particle No. ISPECS

*The emissivity and accommodation coefficients are used to determine the local energy exchange between the gas and particles via radiation. They normally produce negligible effects on solution and usually are set to 0 (zero).

CARD 32 Particle Equation of State (Use only if ISPECS > 0) (See Section 7.1.3.3 for explanation) — Format 6A4,I3,A4

Column	Parameter	Description
1-24	ALPHA	Particle name (any name)
28-30	UNIT (Independent of ICON(9))	ENG Data input in English units MKS Use metric units

CARD 33 Particle Data (Use only if ISPECS > 0) — Format: I3

Column	Parameter	Description
1-3	NPTM(I)	Number of temperature-enthalpy data points for this particle. If equal to 1, input liquid and solid heat capacities (see Card 34). Right adjust.

CARD 34 Particle Enthalpy Data (Use only if ISPECS > 0; units specified by Card 31) — Format: 7E10.4

1-10	TM(I)	Melting point temperature of particle No. I (R in English units, K in MKS units)
11-20	HS(I)	Enthalpy of solid phase of particle No. I at melting point temperature (Btu/lbm or cal/gm)
21-30	HM(I)	Enthalpy of liquid phase of particle No. I at melting point temperature (Btu/lbm or cal/gm)

---

*The emissivity and accommodation coefficients are used to determine the local energy exchange between the gas and particles via radiation. They normally produce negligible affects on solution and usually are set to 0 (zero).

CARD 34 (Cont'd)

Column	Parameter	Description
	If NPTM(I)=1, use following format.	
31-40	APHO(1,1,I)	Heat capacity of liquid phase of particle No.I (Btu/lbm-R or cal/gm-K).
41-50	APHO(1,2,I)	Heat capacity of solid phase of particle No. I (Btu/lbm-R or cal/gm-K).
	If NPTM(I) 1, use following format.	
31-40	APHO(1,1,I)	Temperature for T-H table for particle No. I (R or K).
41-51	APHO(1,2,I)	Enthalpy for T-H table for particle No. I (Btu/lbm or cal/gm).
51-60	APHO(2,1,I)	Second temperature in T-H table for particle No. I (R or K).
61-70	APHO(2,2,I)	Second enthalpy in T-H table for particle No. I.

The above format (APHO(J,1,I), APHO(J,2,I)) is continued on successive cards of format 7E10.4 for J=1,2,...,NPTM(I).

There are as many sets of cards 33 and 34 as there are different particle chemical species (IPFTOC, Card 25).

CARD 35* Input Startline (The following cards are required if ICON(2)=2 and ISPECS > 0)) — Format: 6E13.7

Use Card 35a if ICON(1) ≤ 2. Use Card 35b if ICON(1) > 2. Repeat this card for I=1,2,...ICON(3) starting at point on nozzle axis.

1-13	R	Radial coordinate of startline point I (ft or m).
14-26	X	Axial coordinate of startline point I (ft or m).
27-39	EM	Mach number at point I.

*This card is used when gas chemical equilibrium, frozen or ideal gas option is selected.

CARD 35a (Cont'd)

Column	Parameter	Description
40-52	THETA	Flow angle at point I (deg)
53-65	S	Entropy at point I (Btu/lbm-R or cal/gm-K)
66-78	OF	Gas total enthalpy (Btu/lbm or cal/gm).

CARD 35b

Column	Parameter	Description
1-13	R	Radial coordinate of startline point I (ft or m).
14-26	X	Axial coordinate of startline point I (ft or m).
27-39	EM	Mach number at point I.
40-52	THETA	Flow angle at point I (deg).
53-65	T	Temperature at point I (K)
66-78	P	Pressure at point I (atm)

CARD 36 Startline Particulate Data (the following cards are required if ICON(2)=2 and ISPECS > 0) Format: I5,5X,4E13.7

Column	Parameter	Description
5	J1	Particle number
11-23	H1	Particle enthalpy at point I (Btu/lbm or cal/gm)
14-36	RHO1	Particle density at point I (slug/ft^3 or kg/m^3)
37-49	U1	Particle axial velocity at point I (ft/sec or m/sec)

CARD 36 (Cont'd)

Column	Parameter	Description
50-62	V1	Particle radial velocity at point I (ft/sec or m/sec)

Card 36 is repeated for each discrete particle size at each point on the start line where particles are present, starting at the nozzle wall and going toward the axis (reverse order of Card 35). All particle sizes are input at each point starting with particle 1 to the number of particle sizes that exist at the particular point (See Table 7-7 for example).

CARD 37 Transonic Flow Data (Use only if ISPEC > 0 and ICON(2)≠2) Format: NAMELIST

Although there are many parameters that may be input via the namelist DATA, most of these have already been assigned values in the previous 36 input cards; and some of the parameters do not apply to the transonic calculation. Only those namelist parameters that could have a significant effect on the program are included below. The namelist data begins in Column 2 with $DATA. The last card begins in column 2 and contains only $END. Section 7.1.5.1 contains a discussion of the use of the transonic module. Figure 6-3 illustrates the variables required for input to the transonic module.

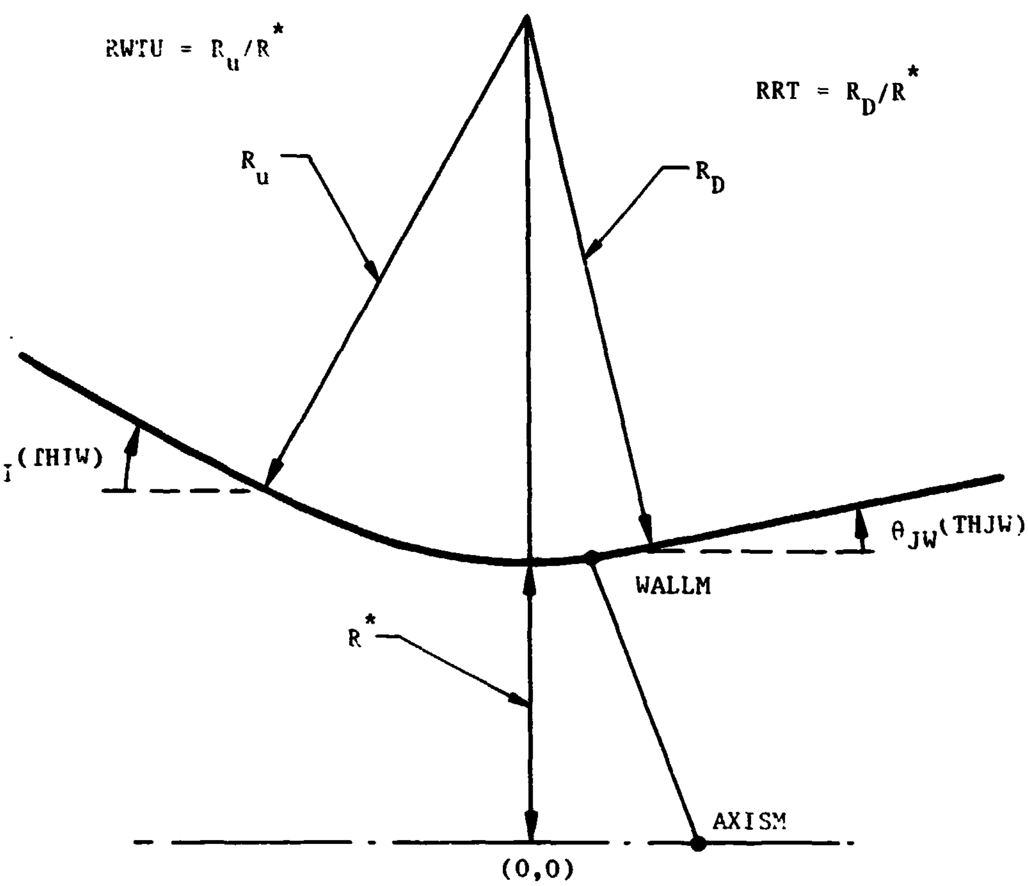


Fig. 6-3 Inlet and Throat Parameters for a Gas-Particle Transonic Solution (see Ref. 25)

Parameter	Description	Default Values
THID	Nozzle throat inlet angle (deg)	30.0
RRT	Throat downstream wall radius of curvature divided by the throat radius	2.0
RWTU	Throat upstream radius of curvature/ throat radius	2.0
THJW	Value of the nozzle wall angle downstream of the circular portion of the nozzle throat(RRT) in degrees	16.0
AXISM	The mach number on the start line on the nozzle centerline must be greater than 1	1.1
WALLM	The Mach number on the start line at the nozzle wall must be greater than 1.0	1.4

If ISKPY=7, read in cards 38,39 otherwise leave out.

CARD 38(If ISKPY=7(Card 5))   Format: I5

Column	Parameter	Description
1-5	INUM	Number of chemical species to be read in for this chemical system (maximum of 25)

CARD 39 Card 39 reads in the species names for chemical system which does not appear in Table 6-1   Format: 20A4

Column	Parameter	Description	
1-12 (Left Adjusted)	(SNAME(7,I, J),J=1,3)	Species name (consistent with JANNAF	3A4
13-24	I+1		3A4
25-36	.		3A4
37-48	.		3A4

CARD 39 (Cont'd)

49-60	.	3A4
61-72	(SNAME(7, I+7,J),J= 1,3)	3A4

Use as many cards 39 as required to read in INUM species.

If 1≤ISKPY≤7 and ICON(1)=1, card 40 is required, otherwise leave out.

CARD 40 Species mole fraction card for SPF start line — Format: 8E10.4

Column	Parameter	Description
1-10	SIFROZ(I)	Species mole fraction
11-21	SIFROZ(I+1)	Species mole fraction
.		.
.		.
.		.
71-80	SIFROZ(I+7)	Species mole fraction

As many species mole fractions must be read in as there are species in the particular chemical system (see Table 6-1). If ISKPY=7, there should be INUM species. The order must be the same as the species appearing in Table 6-1 or were read in under card 39. Use as many cards 40 as necessary to read in all species mole fractions (25 maximum).

Cards 41, 42, 43, and 44 may be required only if a boundary layer calculation is to be performed (IBL >0, card 5) otherwise they must be left out.

CARD 41 Boundary Layer Run Option Card Format: 5I5,5X,E10.5

This card must be input if IBL>0

Column	Parameter	Value	Description
1-5	KR7	0	Turbulent boundary layer, calculation starts off laminar and will trip to turbulent when the Reynolds number based on momentum thickness exceeds 250. The program will select whether the flow is frozen or in equilibrium.
		1	Laminar boundary layer, frozen chemistry
		2	Laminar boundary layer, equilibrium chemistry
		3	Turbulent boundary layer if momentum thickness Reynolds number exceeds 250. Equilibrium chemistry.
		4	Same as 3 except frozen chemistry
6-10	KR9	0	Adiabatic wall nozzle wall
		2	Specified wall temperature distribution. (Requires cards 44)
		4	Wall steady state energy balance (use for two-phase cases).
11-15	ITPTS	N	Where N is the number of wall points to input the nozzle wall temperature. This is used only if KR9=2 (25 max)
16-20	ISPEC	N	N is the number of chemical species in the boundary layer edge gas. This is required only if ICON(1)=1 (thermo data read from cards).

CARD 41 (Cont'd)

21-25	NUNIPP	0	Do not punch the BLIMPJ input data
		1	Punch the BLIMPJ input data
31-40	XSTART		Distance from the beginning of the boundary layer. Program defaults to 1/2 a throat radius.

CARD 42 Boundary Layer Edge Species Format: 4(2A4,2X,E10.4)

Column	Parameter	Description
1-8	SPECN(1)	Chemical species name (Left Adjusted)
11-20	SPECMF(1)	Species mole fraction
21-28	SPECN(2)	2nd chemical species name
31-40	SPECMF(2)	2nd chemical species mole fraction
.		
.		
.		

As many card 42 are used as are required to read in ISPEC species, 4 to a card.

CARD 43 Transport Property Card Format: 2E10.4

NOTE: This card is required only if ICON(1)=1 and the case being run is not a two-phase case (ICON(9)=0).

Column	Parameter	Description
1-10	XMU	Gas viscosity in the combustion chamber (poise)
11-20	PRFR	Turbulent Prandtl number

CARD(S) 44 Nozzle Wall Temperature Distribution Format: 8E10.4

Note: Card(s) 44 are only required if the wall temperature distribution option is selected (KR9=2). Input points starting from nozzle throat to the lip.

Column	Parameter	Description
1-10	TWA(1,1)	Axial coordinate of wall location (ft,m)
11-21	TWA(1,2)	Wall temperature at above location (deg R, deg K)

Input ITPTS pairs of location and temperature. Four pairs per card.

6.2 OUTPUT FORMAT

This section describes the printed output of the RAMP2F code. The program output is organized so that the initial pages contain the input data and the initial data surface. Each data surface thereafter is constructed along a "normal" to the streamlines which have been chosen to represent the flow expansion of the nozzle and exhaust plume. The computer code will treat a chemical equilibrium and/or frozen or chemical non-equilibrium flow expansion with or without the presence of particles; consequently typical printouts for each case are presented to demonstrate the output for each case. Numbered flags on the example printout sheets correspond to the numbered comments in the following description of the printout. The calculations are performed in either the English or metric system of units; hence units for both are given.

GROUP 1 - IDENTIFICATION

1 Computer code identification

2 Identifies gas-particle flow solution; does not occur for gaseous only case.

3 Case Number: Appears on each page - may be a maximum of five digits.

4 Problem Title: Identifies particular solution, appears on each page and may be 120 spaces.

GROUP 2 - PROGRAM CONTROL

5 These 16 parameters control the execution of program according to the options selected. (See Card 5 of the Input Guide for an explanation of the individual parameters.)

GROUP 3 - BOUNDARY EQUATIONS (See input guide for a detailed description)

6 Type Equation: Identifies the type of boundary equation selected.

7 ITRANS: Indicates whether a discontinuity follows this equation.

8 Equation Coefficients: Apply to upper and lower boundary equations.

9 MAX: Maximum value of x for which this equation applies.

GROUP 4 - GAS-PARTICLE MIXTURE IDENTIFICATION

10 Total Enthalpy (appears for gas-particle flow): Gas total enthalpy before it is perturbed.

11 Indicates number of discrete particles used to represent the particle distribution.

12 Gas Identification: Name (24 characteristics max.) which identifies the gas. If the gas data are stored on a magnetic tape, this is the name which is used to locate the gas data on the data tape (see Card 9 of the Input Guide).

GROUP 5 - GAS PROPERTIES

13 Total Enthalpy (appears for gas-particle flow): Gas total enthalpy for this table.

13 O/F Ratio (appears for gaseous only solution): O/F for this table.

14 Entropy: May be two maximum for each O/F or total enthalpy.

15 Gas Thermodynamics Data Velocity: May be 13 maximum for each entropy (ft/sec or m/sec).

16 Gas Constant: Value associated with particular velocity, etc., ($ft^2/sec^2/R$ or $m^2/sec^2/K$).

17 Isentropic Exponent: Value associated with particular velocity, etc.

18 Temperature: Value associated with particular velocity, etc., (R or K).

19 Pressure: Value associated with particular velocity, etc., (lbf/ft^2 or N/m^2).

Gas Transport Data: (does not appear for gaseous only solution).

20 Prandtl Number: Value associated with particular value of velocity, etc.

21 Viscosity: Value associated with particular value of velocity, etc.

22 Specific Heat at Constant Pressure: This parameter appears for real gas with multiple velocity values. If only one velocity is used the parameter printed is the viscosity exponent for the equation $= \mu_0 \, (T/T_0)^{exp}$.

GROUP 6 - PROBLEM LIMIT INFORMATION (see input guide)

23 R: Radial coordinate of upper cutoff (units consistent with boundary equations).

24 X: Axial coordinate of upper cutoff (units consistent with boundary equations).

25 THETA: Angle of upper cutoff line (deg).

26 R: Radial coordinate of lower cutoff (units consistent with boundary equations).

27 X: Axial coordinate of lower cutoff (units consistent with boundary equations.

28 Theta: Angle of lower cutoff line (deg).

GROUP 7 - PARTICLE DESCRIPTION (does not appear for gaseous only solution)

29 Particle Number: Number assigned to particular particle (10 max).

30 Particle Radius: Radius of the particle in microns.

31 Mass Density: Particle density (lbm/ft^3 or kgm/m^3).

33 Emissivity: Coefficient of emissivity for particle radiation to the surrounding medium.

33 Accommodation Coefficient: Accommodation coefficient for radiation from the surrounding medium to the particle.

34 $\dfrac{\dot{\omega}_{p_T}}{\dot{\omega}g_T}$ Particle percent loading relative to the gas.

35 $\dfrac{\dot{\omega}_{p_i}}{\dot{\omega}_{p_T}}$ Individual particle percentage relative to the total mass flow rate

36 UNITS: Units with which the particle temperature-enthalpy table will be input (see the input guide).

37 TMELT: Temperature of the particle during the phase change from liquid to solid (R or K).

38 HSOLID: Value of enthalpy at which the particle becomes a solid (ft^2/sec^2 or m^2/sec^2).

39 HLIQUID: Value of enthalpy at which the particle begins the transition from liquid to solid phase (ft^2/sec^2 or m^2/sec^2) constant specific heat analysis.

40 CPMELT: Value of the specific heat at constant pressure for the particle in the liquid state ($ft^2/sec^2/R$ or $m^2/sec^2/K$).

41 CPSOLID: Value of the specific heat at constant pressure for the particle in the solid state ($ft^2/sec^2/R$ or $m^2/sec^2/K$).

40 TP: Value of the particle temperature (R or K) (50 max). (Not shown)

41 HP: Value of particle enthalpy corresponding to 40 (50 max). (Not shown).

42 Re: Particle Reynolds number.

43 DRAG COEF: Particle drag coefficient parameter, f^j, corresponding to 42 .

GROUP 8 - GAS START LINE INFORMATION

44 R: Radial coordinate of the data point (units consistent with boundary equations).

45 X: Axial coordinate of the data point (units consistent with boundary equations).

46 M: Local value of the Mach number (must be > 1.0).

47 THETA: Local flow deflection angle (deg).

48 S: Local value of entropy level ($ft^2/sec^2/R$ or $m^2/sec^2/K$).

49 MACH ANGLE: Local value corresponding to M (deg).

50 Shock Angle: Local value of shock angle if point is a downstream shock point (deg).

51 H-TOTAL (gas-particle flow): Gas total enthalpy level (ft^2/sec^2 or m^2/sec^2).

51 O/F (gas only flow): Local value of O/F.

GROUP 9 - PARTICLE START LINE INFORMATION (does not appear for gaseous only solution)

52 POINT: Data point at which this particle is present.

53 SPECIE: Particle number for this data point.

54 U: Particle axial component of velocity (ft/sec or m/sec).

55 V: Particle radial component of velocity (ft/sec or m/sec).

56 θ: Particle streamline deflection angle (rad)

57 h: Particle enthalpy level (ft^2/sec^2 or m^2/sed^2)

58 ρ: Local particle concentration ($slug/ft^3$ or kgm/m^3)

GROUP 10 - MESH CONTROL CRITERIA (see input guide)

59 DLI: Point insert criteria for the nozzle-plume interior solution (units consistent with boundary equations).

60 DXA: Line insert criteria along the axis (units consistent with boundary equations).

61 DLM: Insert criteria near a particle limiting streamline (units consistent with the boundary equations).

62 DLD: Point delete criteria (units consistent with the boundary equations).

63 DEGPM: Incremental angle to be used in the numerical integration to define the Prandtl-Meyer expansion fan (deg).

64 F: Interpolation factor used in the axis point solution.

GROUP 11 - DATA LINE FLOW PROPERTIES

NOTE: The output format for all data surfaces are the same with each point type on the line being identified. Several different lines are shown to indicate typical line constructions.

65 Line: Line number; lines are numbered in ascending order.

66 Point: Indicates point number on the line.

67 Description: Indicates point type and flow regime. These options are:

Point Type	Output Format	Flow Regime	Output Format
a. Input	INPUT POINT	a. Continuum	CONTIN
b. Interior	INTER	b. Free Molecular	FREE
c. Wall	WALL		
d. Free boundary	FREEBD		
e. Prandtl-Meyer	PRN-MR		

NOTES: The point type and flow regime will appear in the appropriate combination to completely describe the data point.

Items 68 through 81 refer to gas conditions.

68 R: Radial coordinate of the data point (units consistent with the boundary equations)

69 X: Axial coordinate of the data point (units consistent with the boundary equations)

70 M: Local value of the Mach number

71 <u>θ:</u> Local flow deflection angle of the gas streamline (deg)

72 <u>S:</u> Local entropy level of the gas ($ft^2/sec^2/R$ or $m^2/sec^2/K$)

73 <u>V:</u> Local magnitude of the velocity (ft/sec or m/sec)

74 <u>H-TOTAL (gas-particle flow):</u> Gas total enthalpy level (ft^2/sec^2 or m^2/sec^2)

74 <u>O/F (gas only flow):</u> Local value of O/F

75 <u>Mach Angle:</u> Mach angle corresponding to the Mach number (deg)

76 <u>P:</u> Local pressure (lbf/in^2 or N/m^2)

77 <u>ρ:</u> Local density ($slug/ft^3$ or kgm/m^3)

78 <u>T:</u> Local static temperature (R or K)

79 <u>GAS CONST:</u> Local value of the gas constant ($ft^2/sec^2/R$ or $m^2/sec^2/K$)

80 <u>LOCAL GAMMA:</u> Local value of the isentropic exponent

81 <u>SHOCK ANGLE:</u> Local value of the downstream shockwave angle (deg)

NOTE: Items 82 through 88 refer to the particle properties. This printout does not appear for gas only flow.

82 <u>V:</u> Local magnitude of particle velocity (ft/sec or m/sec)

83 <u>θ:</u> Local particle streamline deflection angle (deg)

84 <u>DM:</u> Difference in Mach number between the gas and particle

85 <u>h:</u> Local particle enthalpy level (ft^2/sec^2 or m^2/sec^2)

86 <u>ρ:</u> Local particle concentration ($slug/ft^3$ or kgm/m^3)

87 <u>T:</u> Local particle temperature (R or K)

88 Indicates the data point is on a particle limiting streamline

GROUP 12 - INTEGRATED GAS AND PARTICLE MASS FLOW RATES

NOTE: The units of the flow rates depend on the units of the boundary equation. For the following units perform the indicated operation.

Units	Factor	
ft	1	slug/sec
M	1	kgm/sec

89 Gas mass flow rate

90 Particle total mass flow rate

91 Sum of the gas and particle mass flow rate

92 Particle percent loading relative to the gas (numerical integration results)

93 Particle percent loading relative to mixture

GROUP 13 - MOMENTUM INTEGRATION RESULTS

94 This is a calculation of the component of the net thrust due to the gas and particle momentum across the starting line.

FORCEX,FORCEY: Net axial and radial component of the thrust vector (lbf or N)

TORQZ: Net torque resulting from the thrust (ft-lb_f or m-N)

ISP: Specific impulse corresponding to FORCEX (lb_f-sec/lb_m)

95 This is the incremental gas and particle contribution to the thrust and torque vector

DELFXG,DELFYG: Net gaseous axial and radial component of the thrust vector (lb_f or N-m)

TORQZP: Net torque resulting from the gaseous contribution to the thrust vector (ft-lb_f or N-m)

DELFXP,DELFYP: Particle momentum contribution to the thrust vector (lb_f or N)

TORQZP: Net torque resulting from the particle contribution to the thrust vector (ft-lb_f or m-N)

Problem Solution Iteration Control

96 ITR: Number of iterations required for this point to converge within the convergence criteria

GROUP 14 - PRESSURE INTEGRATION RESULTS

97 This calculation is the thrust and torque resulting from the gas pressure acting on the nozzle wall.

FORCEX,FORCEY: Axial and radial component of the thrust (lb_f or N). This thrust vector includes the momentum and pressure contribution.

TORQZ: Net torque resulting from the thrust (ft-lbf or m-N)

DELFX,DELFY: Incremental force in the axial and radial directions resulting from the pressure acting on the nozzle wall (lbf or N)

ISP: Specific impulse corresponding to FORCEX (lbf-sec/lbm)

GROUP 15 - PERCENT CHANGE IN MASS FLOW RATE MOMENTUM ENERGY, AND ISP

NOTE: This is a comparison of the mass flow rate, momentum, energy and ISP relative to the mass flow rate, momentum, energy and ISP through the input (starting line) surface.

98 Percent change in the mass flow rate of the gas

99 Percent change in the mass flow rate of the particles

100 Percent change in the mass flow rate of the mixture

101 Percent change in the momentum of the gas

102 Percent change in the momentum of the particles

103 Percent change in the momentum of the mixture

104 Percent change in specific impulse

105 Percent change in the energy of the gas

106 Percent change in the energy of the particles

107 Percent change in the energy of the mixture

GROUP 16 - FREE MOLECULAR CONTROL PARAMETERS

108 VIBNO: Reciprocal of the Knudsen number at which the vibrational energy mode thermally freezes

109 ROTNO: Reciprocal of the Knudsen number at which the rotational energy mode thermally freezes

110 TRANNO: Reciprocal of the Knudsen number at which translational energy mode thermally freezes

111 CHARL: Characteristic length used in the mean free path calculation used to compute the local value of the Knudsen number (units consistent with the boundary equations)

112 GAMV: Value of the isentropic exponent to be used in the vibrationally frozen flow calculations

113 GAMR: Value of the isentropic exponent to be used in the rotationally frozen flow calculations.

113A Location on the normal where continuum flow assumptions are likely to start breaking down according to the Bird criteria (Ref. 26).

GROUP 17 - SPECIES THERMODYNAMIC AND REACTION DATA

114 These 7 parameters control the execution of the finite rate chemistry calculations according to the options selected. (See Card 5 of the Input Guide for an explanation of the individual parameters)

115 Prandtl number of the gas (dimensionless)

116 Absolute viscosity of the gas (poise)

117 Viscosity temperature exponent

118 Reaction number

119 Reaction being considered

120 A: Pre-exponential factor (cm-particle-sec)

121 N: Temperature exponent

122 B: Activation energy (cal/mole)

123 M: Temperature exponent

124 R-Type: Reaction type

125 K-Type: Rate constant type

126 Catalytic species being considered. (See Card(s) 14 for an explanation)

GROUP 18 - SPECIES MOLE FRACTIONS ON THE STARTLINE

127 Point: Indicates the point number on the startline

128 Corresponding species mole fractions at the point

129 Chamber pressure (atm)

130 Chamber temperature (K)

131 Species mole fractions at a point on the data surface

GROUP 19 - SINGLE PHASE TRANSONIC OUTPUT

132 Initial Station: Starting location for transonic solution (ft or m)

133 Throat Station: Location of nozzle throat (ft or m)

134 Final Station: Location to terminate transonic solution (ft or m)

135 Mass Flow: Mass flow rate for nozzle (slug/sec or kgm/sec)

136 Average O/F: Overall engine O/F ratio (variable O/F) or total enthalpy (constant O/F)

137 Throat Area: Area of nozzle throat (ft^2 or m^2)

138 Time Step: Integration step size for transonic solution (sec)

139-140 Table of O/F (or total enthalpy) as a function of local radius at initial station for transonic solution.

139 R: Radial location on initial station

140 O/F: O/F ratio or total enthalpy (constant O/F case) at the radial position (R on the initial station)

141 Line: Data surface number for transonic solution

142 Point: Point number at each data surface. Point 1 is on nozzle wall and last point is nozzle axis

143 R: Radial coordinate of point (ft or m)

144 X: Axial location of data surface (ft or m)

145 M: Mach number point

146 ANG: Flow angle point (deg)

147 O/F: O/F (or total enthalpy) (if total enthalpy, units are: ft^2/sec^2 or m^2/sec^2)

148 V: velocity (ft/sec or m/sec)

149 P: Static pressure (lbf/ft^2 or N/m)

150 T: Static temperature (R or K)

151 DENS: Density ($slugs/ft^3$ or kgm/m^3)

152 WDOT: Integrated mass flow across solution station (slug/sec or kgm/sec)

153 PTOT: Integrated momentum across station (lbf or N)

154 ISTEP: Time step number

Note: There are two printouts for step 1000. The first is for timestep 1000 while the second is for the timestep at which the best solution was obtained.

GROUP 20 - SUMMARY OF SPF STARTLINE DATA

155 Header which is output following nozzle solution summarizing SPF data. If no boundary layer solution is to follow then the inviscid SPF start line will be punched out instead of stored on Unit 12. A similar set of output will be displayed at beginning of a plume solution which includes the boundary layer.

156 SPF chemistry system - See Table 6-1 for species which are contained in each system

157-166 Exit plane mass flow averaged properties

157 Mass flow averaged exit plane molecular weight

158 Mass flow averaged exit plane specific heat ratio

159 Mass flow averaged exit plane viscosity (poise)

160 Mass flow averaged exit plane Prandtl number

161 Nozzle exit radius (ft)

162 Mass flow averaged exit plane static temperature (K)

163 Mass flow averaged exit plane density (gm/cc)

164 Mass flow averaged exit plane gas velocity (ft/sec)

165 Specie name

166 Mass flow averaged exit plane species mole fraction

167-172 SPF particle property data (for two phase cases only)

167 Particle species or size number

168 Location of particle limiting streamline on exit plane SPF start line

169 Particle radius (microns)

170 Particle specific heat (Btu/lbm/mole/^{o}R)

171 Particle mass density (gm/cc)

172 Particle molecular weight

173-183 Summarizes SPF exit plane startline properties

173 Non-dimensional (R/nozzle exit radius) radial coordinate of startline point

174 Axial component of gas velocity (ft/sec)

175 Radial component of gas velocity (ft/sec)

176 Static pressure (atm)

177 Static temperature (^{o}K)

178 Point number

179 Particle species (size) number

180 Axial component of particle velocity (ft/sec)

181 Radial component of particle velocity (ft/sec)

182 Particle density (gm/cc)

183 Particle temperature (K)

GROUP 21 - SUMMARY OF BLIMPJ DATA FILE

184 This is a printed listing of the card images which are prepared by the RAMP2F nozzle solution which are stored on unit 1. These data are printed out at the end of the RAMP2F nozzle solution. If the punch option (NUNIPP=1, Card 41) is selected these data will not be printed out

GROUP 22 - PARTICLE TRAJECTORY TRACING RESULTS

These results are printed out for two-phase restarts at the exit plane for cases which include the boundary layer. If any of the particles are found to penetrate the boundary layer then the program traces the particle trajectories to the exit plane so that particle property variations in the boundary layer may be included in the exit plane viscous start line.

185 This table summarizes the particle properties as they enter the boundary layer

186 Particle size number

187 Particle streamline number - The program traces nine different streamlines of a given particle size which enter the boundary layer at different locations down the boundary layer. The 10th point is the edge of the boundary layer at the exit plane

188 Radial location at which the particle enters the boundary layer (ft or m)

189 Axial location at which the particle enters the boundary layer (ft or m)

190 Particle velocity (ft/sec or m/sec)

191 Particle flow angle (deg)

192 Particle enthalpy (ft^2/sec^2 or m^2/sec^2)

193 Particle density ($slug/ft^3$ or kgm/m^3)

194 Particle temperature (R or K)

195 This table summarizes the particle properties at the particle streamlines of Table 180 except these results are at the exit plane after the particles were traced through the boundary layer.

GROUP 23 - IDEAL GAS EXIT START LINES

One of the options of the RAMP2F program is to print and/or punch an ideal gas start line for the Lockheed Method of Characteristic as well as for a RAMP2F exit restart. These start lines can only be punched for viscous exit plane restarts. See Vol. II, Appendix B for instructions on modifications to the MOC program for using this start line.

196 The exit plane mass flow averaged total pressure for MOC ideal gas start line (psfa)

197 The exit plane mass flow averaged total temperatures for MOC ideal gas start line (R)

198 The exit plane mass flow averaged specific heat ratio for MOC ideal gas startline

199 The exit plane mass flow averaged molecular weight for MOC ideal gas startline

200 Nozzle exit radius (ft)

201-206 Are exit plane startline point flow properties

201 R/RE, non-dimensional radial location in exit plane

202 X, axial location of exit plane. The program assumes exit plane is a 0.0

203 Mach number

204 Flow angle (deg)

205 Entropy ($ft^2/sec^2/R$)

206 Total enthalpy (ft^2/sec^2)

207-212 The exit plane normal ideal gas startline which could be used for a RAMP2F plane restart

207 Radial coordinate of startline point (ft or m)

208 Axial coordinate of startline point (ft or m)

209 Mach number

210 Flow angle (deg)

211 Entropy ($ft^2/sec^2/^oR$ or $m^2/sec^2/K$)

212 Total enthalpy (ft^2/sec^2 or m^2/sec^2)

Sample Printout
for Two-Phase Chemical Equilibrium Flow

Sample Printout for Two-Phase Chemical Equilibrium Flow

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM 1

GAS-PARTICLE FLOW SOLUTION 2

CASE NO. 1 3

PAGE 1

[illegible] SHUTTLE SEP MOTOR NOZZLE 4

Group 1

RUN CONTROL PARAMETERS 5

ICON(1)	ICON(2)	ICON(3)	ICON(4)	ICON(5)	ICON(6)	ICON(7)	ICON(8)
2	0	25	3	1	0	1	[illegible]2

ICON(9)	ICON(10)	ICON(11)	ICON(12)	ICON(13)	ICON(14)	ICON(15)	ICON(16)
0	25	1	1	0	0	0	[illegible]

FLOW CALCULATIONS ARE IN ENGLISH UNITS WITH THE R,X COORDINATES IN FEET

THE [illegible] FIELD DATA WILL BE WRITTEN ON TAPE

Group 2

UPPER BOUNDARY

6 TYPE	ITRANS 7	A 8	B 8	C 8	D 8	E 8	MAX 9
1	0	-.10[illegible]+01	.15340+00	.00000	-.1000[illegible]+01	-.52225+00	.14672+0[illegible]
[illegible]	1	.100[illegible]+01	.51561+01	.21824+01	-.1000[illegible]+01	-.21796+01	.74059+00
1	0	.[illegible]5290+01	.00000	.00000	.00000	.00[illegible]	.10000+04

LOWER BOUNDARY

TYPE	ITRANS	A	B	C	D	E	MAX
2	0	.00000	.00000	.00000	.00000	.00000	.[illegible]+04

Group 3

CHAMBER ENTHALPY = -.19610+00 10

THERE ARE 6 PARTICLE SPECIES PRESENT IN THE GAS-PARTICLE MIXTURE 11

Group 4

THE FOLLOWING GAS PROPERTIES IN ENGLISH UNITS ARE FOR SEP PROP PC=1ACD 12

REAL GAS PROPERTIES

H-TOTAL 13
-.20631+0[illegible]

S 14	V 15	H 16	GAMMA 17	T 18	P 19	PR 20	VIS 21	CP 22
-.17515+04								
	.00000	.19864+04	.12039+01	.40098+04	.18000+04	.5703[illegible]+00	.17610-05	.12302+05
	.32374+04	.19835+04	.121[illegible]+01	.3[illegible]603+04	.10111+04	.58520+00	.16373-05	.11652+05
	.51771+04	.19815+04	.12260+01	.36226+04	.36000+03	.60100+00	.14256-05	.10[illegible]5+05
	.[illegible]+0[illegible]	.19812+04	.12316+01	.3[illegible]+04	.10000+03	.50332+0[illegible]	.12739-05	.1[illegible]+05
	.[illegible]+0[illegible]	.19811+04	.12355+01	.27927+04	.50000+02	.60147+00	.11702-05	.10[illegible]+05
	.71778+04	.19811+04	.12376+01	.24957+04	.35000+02	.59727+00	.10564-05	.1[illegible]+05
	.7[illegible]+04	.19811+04	.12377+01	.20[illegible]+04	.18000+02	.58736+00	.92142-06	.10343+05
	.8[illegible]31+04	.19811+04	.12552+01	.16175+04	.60000+01	.64769+00	.76436-06	.3[illegible]+04

Group 5

Sample Printout for Two-Phase Chemical Equilibrium Flow

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 1

PAGE 7

SPACE SHUTTLE SEP MOTOR NOZZLE

REAL GAS PROPERTIES

H-TOTAL

S	V	R	GAMMA	T	P	PR	VIS	CP
-.17515+04								
	.84091+04	.19811+04	.12942+01	.14422+04	.36000+01	.58760+00	.49560-06	.97290+04
	.86241+04	.19811+04	.13062+01	.12789+04	.18000+01	.58589+00	.40075-06	.84559+04
	.89932+04	.19811+04	.13317+01	.83245+03	.36000+00	.58277+00	.42702-06	[illegible]
	.91091+04	.19811+04	.13913+01	.69912+03	.18000+00	.58035+00	.36311-06	[illegible]
	.93072+04	.19811+04	.13600+01	.46019+03	.36000-01	.57207+00	.23588-06	[illegible]
.94545+04								
	[illegible]	.19995+04	.11754+01	.46839+04	.80000+02	.50737+00	.17256-05	[illegible]
	.31967+04	.19905+04	.11920+01	.41074+04	.45254+02	.53093+00	.16219-05	.13454+05
	.51556+04	.19831+04	.12187+01	.36197+04	.16000+02	.58140+00	.14247-05	[illegible]
	.59941+04	.19816+04	.12286+01	.31911+04	.80000+01	.59755+00	.12954-05	.10726+05
	.64445+04	.19812+04	.12347+01	.28012+04	.40000+01	.60024+00	.11729-05	[illegible]
	.71663+04	.19811+04	.12374+01	.24537+04	.20000+01	.59719+00	.10591-05	.10334+05
	.77152+04	.19811+04	.12372+01	[illegible]	.80000+00	.58942+00	.92375-06	.10342+05
	.82163+04	.19811+04	.12850+01	.17230+04	.26667+00	.58798+00	[illegible]	.87341+04
	[illegible]	.19811+04	.12940+01	.14472+04	.16000+00	.58792+00	.69770-06	[illegible]
	[illegible]	.19811+04	.13060+01	.12333+04	.80000-01	.58718+00	.60789-06	[illegible]
	[illegible]	.19811+04	.13316+01	.83555+03	.16000-01	[illegible]	.43049-06	[illegible]
	[illegible]	.19811+04	.13412+01	.70177+03	.80000-02	.58081+00	.36441-06	[illegible]
	.93350+04	.19811+04	.13599+01	.46199+03	.16000-02	.57264+00	.23606-06	[illegible]

REAL GAS PROPERTIES

H-TOTAL
-.24125+08

S	V	R	GAMMA	T	P	PR	VIS	CP
-.84769+03								
	.00000	.19923+04	.11919+01	.51581+04	.18000+04	.55000+00	.18590-05	.13625+05
	.31540+04	.19967+04	.12032+01	.47059+04	.10145+04	.56677+00	.17326-05	.12372+05
	.51937+04	.19821+04	.12201+01	.39342+04	.36000+03	.59339+00	.15166-05	[illegible]
	.62562+04	.19814+04	.12277+01	.34668+04	.18000+03	.60145+00	.13793-05	[illegible]
	.69335+04	.19812+04	.12330+01	.30450+04	.90000+02	.60279+00	.12501-05	.10477+05
	.74773+04	.19811+04	.12364+01	.26690+04	.45000+02	.60017+00	.11302-05	.10370+05
	[illegible]	.19811+04	.12374+01	.22387+04	.18000+02	.59362+00	.98632-06	.10319+05
	[illegible]	.19811+04	.12791+01	.17727+04	.60000+01	.59495+00	.82327-06	[illegible]
	[illegible]	.19811+04	[illegible]	[illegible]	.36000+01	.59551+00	.75144-06	[illegible]
	[illegible]	.19811+04	[illegible]	.13527+04	.18000+01	.59562+00	.65929-06	[illegible]
	[illegible]	.19811+04	.13769+01	[illegible]	.36000+00	[illegible]	.47031-06	[illegible]
	[illegible]	.19811+04	[illegible]	[illegible]	[illegible]	.59212+00	.40011-06	[illegible]

Group 5 (Cont'd)

ORIGINAL PAGE IS OF POOR QUALITY

Sample Printout for Two-Phase Chemical Equilibrium Flow

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 1 PAGE 3

[illegible] SHUTTLE SRM MOTOR NOZZLE

ORIGINAL PAGE IS OF POOR QUALITY

Group 5 (Cont'd)

REAL GAS PROPERTIES

H-TOTAL

S	V	R	GAMMA	T	P	PR	VIS	CP
.53902+04								
	.000 0	.20140+04	.11597+01	.49404+04	.80000+02	.48389+00	[illegible]	[illegible]
	.32826+04	.20006+04	.11725+01	.45937+04	.45564+02	.49977+00	.17007-05	.14272+05
	[illegible]	.19862+04	.12045+01	[illegible]	.16000+02	.55046+00	.15120-05	[illegible]
	[illegible]	.19828+04	.12205+01	.34762+04	.80000+01	.58410+00	.13820-05	[illegible]
	.60348+04	.19815+04	[illegible]	.30614+04	.40000+01	.59829+00	.12552-05	[illegible]
	[illegible]	.19812+04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	.19811+04	.12378+01	[illegible]	[illegible]	.59379+00	.99120-06	[illegible]
	[illegible]	.19811+04	.12706+01	.17994+04	.26667+00	[illegible]	[illegible]	[illegible]
	.87565+04	.19811+04	.12876+01	.15793+04	.16000+00	[illegible]	[illegible]	[illegible]
	[illegible]	.19811+04	.12999+01	.13621+04	[illegible]	.59619+00	[illegible]	[illegible]
	[illegible]	.19811+04	.13266+01	.92762+03	[illegible]	.59440+00	[illegible]	[illegible]
	[illegible]	.19811+04	[illegible]	[illegible]	[illegible]	.53291+00	[illegible]	[illegible]
	[illegible]	.19811+04	.13560+01	.51576+03	.16000-02	.50770+00	[illegible]	[illegible]

REAL GAS PROPERTIES

H-TOTAL
-.21877+04

S	V	R	GAMMA	T	P	PR	VIS	CP
-.41765+03								
	[illegible]	.19965+04	.11856+01	[illegible]	.18000+04	.54000+00	[illegible]	[illegible]
	[illegible]	.19892+04	.11973+01	[illegible]	[illegible]	.55602+00	[illegible]	[illegible]
	[illegible]	.19830+04	.12164+01	[illegible]	.36000+03	.58723+00	[illegible]	[illegible]
	[illegible]	.19816+04	.12253+01	.36078+04	.18000+03	.59908+00	[illegible]	[illegible]
	[illegible]	.19812+04	.12315+01	.31720+04	.90000+02	.60267+00	[illegible]	[illegible]
	[illegible]	.19812+04	[illegible]	.27719+04	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	.19811+04	[illegible]	[illegible]	[illegible]	.59537+00	[illegible]	[illegible]
	[illegible]	.19811+04	[illegible]	.18517+04	.60000+01	.59771+00	[illegible]	[illegible]
	[illegible]	.19811+04	[illegible]	.16557+04	.36000+01	[illegible]	[illegible]	[illegible]
	[illegible]	.19811+04	.12974+01	.14161+04	[illegible]	.59725+00	[illegible]	[illegible]
	[illegible]	.19811+04	.13245+01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	.19811+04	.13312+01	.81309+03	.18000+00	.59714+00	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.59299+00	[illegible]	[illegible]
[illegible]								
	[illegible]	.20241+04	.11527+01	[illegible]	.90000+02	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	.11637+01	.47181+04	[illegible]	.48755+00	[illegible]	[illegible]
	[illegible]	[illegible]	.11957+01	[illegible]	.16000+02	.53284+00	[illegible]	.13086+05
	[illegible]	[illegible]	.12149+01	.36169+04	.80000+01	.57163+00	[illegible]	.11537+05

Sample Printout for Two-Phase Chemical Equilibrium Flow

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 1

PAGE 4

SPACE SHUTTLE SRM MOTOR NOZZLE

REAL GAS PROPERTIES

H-TOTAL

S	V	R	GAMMA	T	P	PR	VIS	CP
.58411+04								
	.70257+04	.19818+04	.12271+01	.31928+04	.40000+01	.59459+00	.12957-05	.10016+05
	.76987+04	.19813+04	.12342+01	.28041+04	.20000+01	.59763+00	.11730-05	.10467+05
	.81810+04	.19811+04	.12377+01	.23536+04	.80000+00	.59558+00	.10254-05	.10324+05
	.87227+04	.19811+04	.12754+01	.18680+04	.26667+00	.59820+00	.85829-06	.91605+04
	.89255+04	.19811+04	.12844+01	.16706+04	.16000+00	.59936+00	.78508-06	[illegible]
	.91505+04	.19811+04	.12968+01	.14292+04	.80000-01	.59994+00	.69025-06	.86620+04
	.95660+04	.19811+04	.13240+01	.97594+03	.16000-01	.59915+00	.49650-06	.81012+04
	.97939+04	.19811+04	.13343+01	.82199+03	.80000-02	.59810+00	.42283-06	.79129+04
	.99133+04	.19811+04	.13541+01	.54415+03	.16000-02	.59420+00	.28081-06	.75812+04

REAL GAS PROPERTIES

H-TOTAL
-.19419+08

S	V	R	GAMMA	T	P	PR	VIS	CP
.00000								
	.00000	.20017+04	.11798+01	.54686+04	.18000+04	.53040+00	.19346-05	.15475+05
	.34537+04	.19925+04	.11911+01	.50261+04	.10187+04	.54593+00	.18188-05	.13715+05
	.55738+04	.19840+04	.12121+01	.42383+04	.36000+03	.57942+00	.16030-05	.11671+05
	.64935+04	.19820+04	.12224+01	.37483+04	.18000+03	.59535+00	.14627-05	.11008+05
	.71907+04	.19813+04	.12297+01	.32794+04	.90000+02	.60190+00	.13287-05	.10643+05
	.77591+04	.19812+04	.12344+01	.28956+04	.45000+02	.60196+00	.12030-05	.10444+05
	.83575+04	.19811+04	.12376+01	.24304+04	.18000+02	.59704+00	.10513-05	.10327+05
	.89357+04	.19811+04	.12731+01	.19319+04	.60000+01	.60000+00	.88132-06	.92428+04
	.91111+04	.19811+04	.12819+01	.17790+04	.36000+01	.60158+00	.80732-06	.90137+04
	.93425+04	.19811+04	.12944+01	.14807+04	.18000+01	.60246+00	.71089-06	.87172+04
	.97616+04	.19811+04	.13220+01	.10132+04	.36000+00	.60236+00	.51232-06	.81391+04
	.99918+04	.19811+04	.13325+01	.85401+03	.18000+00	.60163+00	.43803-06	.79447+04
	.10115+05	.19811+04	.13527+01	.56614+03	.36000-01	.59865+00	.29237-06	.76037+04
.62828+04								
	.00000	.20345+04	.11470+01	.51490+04	.80000+02	.46684+00	.18474-05	.23667+05
	.33550+04	.20157+04	.11560+01	.48304+04	.45836+02	.47734+00	.17643-05	.20071+05
	.55345+04	.19924+04	.11861+01	.41947+04	.16000+02	.51537+00	.15901-05	.14185+05
	.61212+04	.19853+04	.12080+01	.37551+04	.80000+01	.55559+00	.14443-05	.12023+05
	.71405+04	.19824+04	.12232+01	.33245+04	.40000+01	.58776+00	.13162-05	[illegible]
	.77177+04	.19814+04	.12322+01	.29245+04	.20000+01	.59886+00	.12122-05	.10165+05
	.83252+04	.19812+04	.12373+01	.24564+04	.80000+00	.59708+00	.10600-05	.10112+05
	.89012+04	.19812+04	.12723+01	.19535+04	.26667+00	.60056+00	.88705-06	.92416+04
	.91145+04	.19812+04	.12811+01	.17488+04	.16000+00	.60228+00	[illegible]	[illegible]

Group 5 (Cont'd)

Sample Printout for Two-Phase Chemical Equilibrium Flow

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                SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                       GAS-PARTICLE FLOW SOLUTION
                                        CASE NO.    1                                               PAGE    5

SPACE SHUTTLE SEP MOTOR NOZZLE
                                             REAL GAS PROPERTIES
            H-TOTAL

     S            V           R          GAMMA         T           P           PR          VIS          CP
 .62928+04
             .93312+04   .19812+04   .12936+01   .14981+04   .80000-01   .60325+00   .71788-06   .47357+04  } Group 5
             .97449+04   .19812+04   .13213+01   .10259+04   .16000-01   .60338+00   .51801-06   .81821+04  } (Cont'd)
             .98332+04   .19812+04   .13313+01   .86491+03   .80000-02   .60275+00   .44317-06   .79557+04
             .1010A+05   .19812+04   .13522+01   .57369+03   .16000-02   .60006+00   .24629-06   .74113+04

                                          RUN CUTOFF INFORMATION
   (23)                                      (25)               (26)                            (28)
                  UPPER BOUNDARY                                         LOWER BOUNDARY
     .10003+04   X=   -.10003+24   THETA=   .00000     R=   .00000    X=   .10000+03   THETA=   .90000+02  } Group 6
         (29)      (30)   (24)     (31)                                      (27)
                                          PARTICLE PHYSICAL DATA
     SPECIE   RADIUS        MASS DENSITY       EMISSIVITY  (32) ACCM. COEFF.  (33)
        1     .11000+01      .25000+03          .00000          .00000
        2     .17000+01      .25000+03          .00000          .00000
        3     .25000+01      .25000+03          .00000          .00000
        4     .32000+01      .25000+03          .00000          .00000                          } Group 7
        5     .45000+01      .25000+03          .00000          .00000
        6     .65000+01      .25000+03          .00000          .00000
                                 (34)
     THE PARTICLES CONSTITUTE  3.31 PERCENT BY WEIGHT FLOW OF THE GAS-PARTICLE MIXTURE
               THE INDIVIDUAL PERCENTAGES ARE    .10   .20   .30   .20   .20   .10       (35)
     THE PARTICLE TEMPERATURE-ENTHALPY TABLE WILL BE READ IN WITH ENGLISH  (36)  UNITS

                        PARTICLE TEMPERATURE-ENTHALPY TABLE  (38)
                                  (37)
     PHASE CHANGE DATA ***  TMELT=  .41885+04 HSOLID=  .34010+08 HLIQUID=  .46520+08  (39)
                            CPMELT=     .85100+04  CPSOLID=     .81199+04
                                         (40)                   (41)
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Sample Printout for Two-Phase Chemical Equilibrium Flow

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

GAS-PARTICLE FLOW SOLUTION

CASE NO. 1

PAGE 6

SPACE SHUTTLE SEP MOTOR NOZZLE

PARTICLE DRAG TABLE

I	RE (42)	DRAG COEF (43)
1	.00003	.10000+01
2	.12500+01	.10000+01
3	.12550+01	.10000+01
4	.12600+01	.10010+01
5	.12650+01	.10020+01
6	.15820+01	.10630+01
7	.19950+01	.11410+01
8	.25100+01	.12240+01
9	.31600+01	.13160+01
10	.39800+01	.14120+01
11	.50100+01	.15170+01
12	.63100+01	.16250+01
13	.79500+01	.17450+01
14	.10000+02	.18740+01
15	.12600+02	.20260+01
16	.15920+02	.21840+01
17	.19950+02	.23640+01
18	.25100+02	.25550+01
19	.31600+02	.27600+01
20	.39800+02	.30030+01
21	.50100+02	.32520+01
22	.63100+02	.37520+01
23	.79500+02	.38240+01
24	.10000+03	.41550+01
25	.31600+03	.79000+01
26	.10000+04	.20030+02
27	.10[illegible]+04	.20[illegible]0+02
28	.10000+06	.20000+04

Group 7 (Cont'd)

ORIGINAL PAGE IS OF POOR QUALITY

Sample Printout for Two-Phase Chemical Equilibrium Flow

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 1

PAGE 12

...CE SHUTTLE SRM MOTOR NOZZLE

GASEOUS STARTING LINE INFO

R (44)	X (45)	M (46)	THETA (47)	S (48)	MACH ANGLE (49)	SHOCK ANGLE (50)	H-TOTAL (51)
.00000	.12847+00	.14166+01	.00000	.57051+02	.44904+02	.00000	-.19706+08
.58304-02	.12843+00	.14169+01	.45764+00	.57068+02	.44891+02	.00000	-.19707+08
.11661-01	.12833+00	.14178+01	.91650+00	.57120+02	.44863+02	.00000	-.19707+08
.17491-01	.12817+00	.14194+01	.13773+01	.57205+02	.44789+02	.00000	-.19707+08
.23321-01	.12794+00	.14217+01	.18428+01	.57325+02	.44700+02	.00000	-.19707+08
.29152-01	[illegible]	.14246+01	.23126+01	.57479+02	.44585+02	.00000	-.19707+08
.34982-01	[illegible]	.14281+01	.27893+01	.57670+02	.44445+02	.00000	-.19708+08
.40813-01	[illegible]	.14323+01	.32737+01	.57895+02	.44279+02	.00000	-.19708+08
.46643-01	[illegible]	.14373+01	.37676+01	.58157+02	.44087+02	.00000	-.19709+08
.52473-01	.12561+00	.14430+01	.42733+01	.58457+02	.43869+02	.00000	-.19709+08
.58314-01	[illegible]	.14494+01	.47923+01	.58775+02	.43624+02	.00000	-.19710+08
.64139-01	.12062+00	.14567+01	.53262+01	.59172+02	.43367+02	.00000	-.19711+08
.69969-01	[illegible]	.14649+01	.58741+01	.59591+02	.43053+02	.00000	-.19712+08
.75795-01	[illegible]	.14738+01	.64501+01	.60052+02	.42724+02	.00000	-.19712+08
.81625-01	.12204+00	.14839+01	.70444+01	.60558+02	.42369+02	.00000	-.19714+08
.87455-01	.12109+00	.14950+01	.76654+01	.61112+02	.41989+02	.00000	-.19715+08
.93286-01	[illegible]	.15073+01	.83145+01	.61715+02	.41544+02	.00000	-.19716+08
.10159+00	[illegible]	.15267+01	.92834+01	.62654+02	.40919+02	.00000	-.19718+08
.10945+00	[illegible]	.15358+01	.97115+01	.63082+02	.40426+02	.00000	-.19719+08
.12016+00	.11719+00	.15447+01	.10127+02	.63498+02	.40143+02	.00000	-.19720+08
.11497+00	.11572+00	.15654+01	.11039+02	.64441+02	.39703+02	.00000	-.19722+08
.12633+00	.11457+00	.15925+01	.11757+02	.65198+02	.39197+02	.00000	-.19724+08
.12737+00	[illegible]	.16100+01	.12849+02	.66371+02	.38398+02	.00000	-.19727+08
.13357+00	[illegible]	.16368+01	.13856+02	.67459+02	.37648+02	.00000	-.19730+08
.13991+00	[illegible]	.16675+01	.14943+02	.68637+02	.36808+02	.00000	-.19733+08
.14576+00	[illegible]	.16993+01	.16003+02	.69773+02	.36044+02	.00000	-.19737+08

Group 8

PARTICLE START LINE PROPERTIES

POINT (52)	SPECIE (53)	U (54)	V (55)	THETA (56)	ENTHALPY (57)	DENSITY (58)
1	1	.43867+04	.00000	.00000	.50821+08	.41806-04
1	2	.41994+04	.00000	.00000	.51228+08	.94862-04
1	3	.39440+04	.00000	.00000	.51674+08	.11244-03
1	4	.37884+04	.00000	.00000	.52027+08	.12661-03
1	5	.35389+04	.00000	.00000	.52563+08	.15260-03
1	6	.32769+04	.00000	.00000	.53218+08	.93531-04
2	1	.43873+04	.27314+02	.35670+00	.50819+08	.41782-04
2	2	.42009+04	.27201+02	.30280+00	.51229+08	.94617-04
2	3	.39465+04	.16340+02	.23787+00	.51677+08	.11238-03
2	4	.37900+04	.12[illegible]+02	.14956+00	.52033+08	.12653-03
2	5	.35391+04	.74544+01	.12168+00	.52573+08	.15248-03
2	6	.32773+04	.25972+01	.[illegible]28-01	.53233+08	.93430-04

Group 9

Sample Printout for Two-Phase Chemical Equilibrium Flow

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 1

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...CE SHUTTLE SFP MOTOR NOZZLE

POINT	SPECIE	U	V	THETA	ENTHALPY	DENSITY
3	1	.43891+04	.54725+02	.71435+00	.50815+08	.41730-04
3	2	.42018+04	.44489+02	.60664+00	.51229+08	.94683-04
3	3	.39481+04	.32146+02	.46649+00	.51685+08	.11220-03
3	4	.37905+04	.25174+02	.38053+00	.52048+08	.12630-03
3	5	.35406+04	.14941+02	.24179+00	.52601+08	.15214-03
3	6	.32786+04	.51141+01	.89371-01	.53277+08	.93137-04
4	1	.43921+04	.82332+02	.10739+01	.50808+08	.41637-04
4	2	.42047+04	.66947+02	.91217+00	.51220+08	.94465-04
4	3	.39509+04	.48387+02	.70159+00	.51698+08	.11192-03
4	4	.37930+04	.37890+02	.57233+00	.52071+08	.12575-03
4	5	.35427+04	.22491+02	.36374+00	.52644+08	.15161-03
4	6	.32808+04	.77209+01	.13484+00	.53342+08	.92682-04
5	1	.43961+04	.11024+03	.14364+01	.50797+08	.41510-04
5	2	.42089+04	.89660+02	.12204+01	.51227+08	.94173-04
5	3	.39548+04	.64315+02	.93895+00	.51712+08	.11154-03
5	4	.37966+04	.50758+02	.76596+00	.52098+08	.12548-03
5	5	.35458+04	.30138+02	.48699+00	.52496+08	.15092-03
5	6	.32838+04	.10384+02	.18122+00	.53423+08	.92113-04
6	1	.44019+04	.13856+03	.18029+01	.50782+08	.41354-04
6	2	.42141+04	.11272+03	.15321+01	.51223+08	.93817-04
6	3	.39598+04	.81516+02	.11793+01	.51726+08	.11109-03
6	4	.38011+04	.63827+02	.96200+00	.52126+08	.12495-03
6	5	.35498+04	.37916+02	.61198+00	.52748+08	.15015-03
6	6	.32877+04	.13127+02	.22876+00	.53497+08	.91193-04
7	1	.44088+04	.16740+03	.21744+01	.50763+08	.41171-04
7	2	.42209+04	.13622+03	.18984+01	.51214+08	.93518-04
7	3	.39660+04	.98557+02	.14235+01	.51736+08	.11063-03
7	4	.38067+04	.77147+02	.11610+01	.52149+08	.12439-03
7	5	.35549+04	.45862+02	.73917+00	.52791+08	.14937-03
7	6	.32924+04	.15958+02	.27771+00	.53559+08	.90873-04
8	1	.44171+04	.19687+03	.25523+01	.50738+08	.40963-04
8	2	.42288+04	.16024+03	.21701+01	.51200+08	.92784-04
8	3	.39735+04	.11402+03	.16724+01	.51738+08	.11009-03
8	4	.38137+04	.90765+02	.13635+01	.52160+08	.12382-03
8	5	.35608+04	.54014+02	.86906+00	.52815+08	.14865-03
8	6	.32980+04	.18894+02	.32824+00	.53589+08	.90394-04
9	1	.44269+04	.22718+03	.29376+01	.50708+08	.40744-04
9	2	.42380+04	.18490+03	.24982+01	.51179+08	.92535-04
9	3	.39822+04	.13397+03	.19269+01	.51727+08	.10960-03
9	4	.38207+04	.10473+03	.15702+01	.52155+08	.12332-03
9	5	.35688+04	.62415+02	.10022+01	.52810+08	.14807-03
9	6	.33044+04	.21845+02	.38050+00	.53579+08	.90070-04
10	1	.44383+04	.25940+03	.33320+01	.50670+08	.40515-04
10	2	.42486+04	.21030+03	.28337+01	.51140+08	.92086-04
10	3	.39923+04	.15252+03	.21870+01	.51701+08	.10915-03
10	4	.38291+04	.11909+03	.17814+01	.52128+08	.12292-03
10	5	.35744+04	.71108+02	.11390+01	.52768+08	.14771-03
10	6	.33117+04	.75119+02	.43459+00	.53502+08	.89991-04

Group 9 (Cont'd)

ORIGINAL PAGE IS OF POOR QUALITY

Sample Printout for Two-Phase Chemical Equilibrium Flow

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 1

SHUTTLE SRM MOTOR NOZZLE

POINT	SPECIE	U	V	THETA	ENTHALPY	DENSITY
11	1	.44514+04	.29075+03	.37360+01	.50624+08	.40275-04
11	2	.42505+04	.23656+03	.31778+01	.51106+08	.91592-04
11	3	.40038+04	.17176+03	.24563+01	.51456+08	.10898-03
11	4	.38386+04	.13394+03	.19860+01	.52075+08	.12260-03
11	5	.36961+04	.90184+02	.12803+01	.52681+08	.14763-03
11	6	.33198+04	.28 2+02	.49058+00	.53767+08	.96207-04
12	1	.44661+04	.329[illegible]	.41537+01	.50569+08	.40010-04
12	2	.42739+04	.261[illegible]+03	.35116+01	.51051+08	.91235-04
12	3	.40167+04	.1917[illegible]	.27334+01	.51508+08	.10894-03
12	4	.38591+04	.19[illegible]	.22295+01	.51988+08	.12755-03
12	5	.35271+04	.85572+02	.14765+01	.52547+08	.14787-03
12	6	.33280+04	.3106+02	.54849+00	.53169+08	.9 791-04
13	1	.44827+04	.35[illegible]+03	.46844+01	.50515+08	.39790-04
13	2	.42867+04	.29211+03	.38764+01	.50983+08	.90847-04
13	3	.40312+04	.21270+03	.35204+01	.51398+08	.10821-03
13	4	.39606+04	.165[illegible]+03	.24499+01	.51473+08	.12262-03
13	5	.36093+04	.95[illegible]+02	.14784+01	.52273+08	.14942-03
13	6	.33391+04	.35456+02	.60836+00	.52924+08	.91581-04
14	1	.45011+04	.34623+03	.50367+01	.50430+08	.39575-04
14	2	.33051+04	.32171+03	.42736+01	.50931+08	.90484-04
14	3	.40472+04	.23964+03	.33187+01	.51186+08	.10606-03
14	4	.38734+04	.18110+03	.26873+01	.51731+08	.12284-03
14	5	.36229+04	.10705+03	.17217+01	.52167+08	.14925-03
14	6	.33504+04	.39153+02	.67026+00	.52[illegible]+08	.92662-04
15	1	.45214+04	.43994+03	.54946+01	.50145+08	.39263-04
15	2	.43231+04	.35275+03	.46648+01	.50[illegible]+08	.90133-04
15	3	.40649+04	.257[illegible]+03	.36758+01	.51251+08	.10772-03
15	4	.38827+04	.1992[illegible]+03	.29140+01	.51566+08	.12310-03
15	5	.36376+04	.120[illegible]+03	.19722+01	.51950+08	.15028-03
15	6	.33[illegible]+04	.430[illegible]+02	.74[illegible]+00	.52931+08	.93861-04
16	1	.45[illegible]7+04	.475[illegible]+03	.[illegible]62+01	.50250+08	.[illegible]987-04
16	2	.43926+04	.38693+03	.50718+01	.51695+08	.89772-04
16	3	.40840+04	.28[illegible]+03	.39956+01	.51169+08	.10760-03
16	4	.39031+04	.2176[illegible]+03	.31921+01	.51901+08	.12359-03
16	5	.36538+04	.13[illegible]+03	.20759+01	.51760+08	.15137-03
16	6	.33774+04	.47167+02	.80011+00	.52315+08	.94983-04
17	1	.45678+04	.51911+03	.65835+01	.50144+08	.36597-04
17	2	.43639+04	.41955+03	.54961+01	.50577+08	.89367-04
17	3	.41049+04	.30[illegible]+03	.42962+01	.51253+08	.10770-03
17	4	.39205+04	.23732+03	.34[illegible]+01	.51219+08	.12794-03
17	5	.37702+04	.1497[illegible]	[illegible]7+01	[illegible]1+08	.15225-03
17	6	[illegible]	[illegible]	[illegible]	[illegible]	.9[illegible]-04
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]-04
18	3	.4[illegible]+04	.2[illegible]+03	.4[illegible]+01	[illegible]+08	.1[illegible]-03
18	4	.39996+04	.26[illegible]+03	.38774+01	.51126+08	.12[illegible]-03
18	5	.36963+04	.1[illegible]	.25737+01	.[illegible]2+08	.1[illegible]-03
18	6	.3[illegible]	[illegible]	.9[illegible]	[illegible]	.9[illegible]-04

Group 9 (Cont'd)

ORIGINAL PAGE IS OF POOR QUALITY

Sample Printout for Two-Phase Chemical Equilibrium Flow

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 1

PAGE 15

SPACE SHUTTLE SRB MOTOR NOZZLE

POINT	SPECIE	U	V	THETA	ENTHALPY	DENSITY
19	1	.46217+04	.61405+03	.75681+01	.49906+08	.37957-04
19	2	.44116+04	.49568+03	.64108+01	.50332+08	.88214-04
19	3	.41517+04	.36642+03	.50437+01	.50739+08	.10679-03
19	4	.39420+04	.28153+03	.40646+01	.51132+08	.12365-03
19	5	.37073+04	.17199+03	.26561+01	.51798+08	.15217-03
20	1	.46378+04	.64738+03	.78859+01	.49332+08	.37709-04
20	2	.44260+04	.51839+03	.66802+01	.50270+08	.87757-04
20	3	.41657+04	.36393+03	.52658+01	.50716+08	.10628-03
20	4	.39753+04	.29525+03	.42474+01	.51165+08	.12345-03
20	5	.37175+04	[illegible]	.21741-01	.52122+08	.15135-03
21	1	.46733+04	[illegible]	.85890+01	.49685+08	.37064-04
21	2	.44684+04	.56765+03	.72813-01	.50162+08	.86472-04
21	3	.41969+04	.42372+03	.57651+01	.50769+08	.10463-03
21	4	.40070+04	.32728+03	.46654+01	.51507+08	.12174-03
22	1	.47009+04	.75631+03	.91398+01	.49574+08	.36507-04
22	2	.44841+04	.61657+03	.77589+01	.50110+08	.85149-04
22	3	.42214+04	.45601+03	.61655+01	.50738+08	.10272-03
23	1	.47417+04	.83396+03	.99750+01	.49125+08	.35956-04
23	2	.45235+04	.67601+03	.84997+01	.50120+08	.82500-04
24	1	.47773+04	.90564+03	.10734+02	.49320+08	.34796-04

Group 9 (Cont'd)

THE MESH CONSTRUCTION WILL BE CONTROLED BY THE FOLLOWING VARIABLES
INTERIOR= .300-01 DX AXIS= .200-01 DL LIM= .150+00 DL DELETE= .100-02 DEG P.M.= .600+01 F= .650+00

Group 10

59 60 61 62 63 64

ORIGINAL PAGE IS OF POOR QUALITY

Sample Printout for Two-Phase Chemical Equilibrium Flow

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

GAS-PARTICLE FLOW SOLUTION

CASE NO. 1

PAGE 15

SPACE SHUTTLE SEP MOTOR NOZZLE

POINT	SPECIE	U	V	THETA	ENTHALPY	DENSITY
19	1	.46217+04	.61405+03	.75681+01	.49906+08	.37957-04
19	2	.44116+04	.49568+03	.64108+01	.50332+08	.88214-04
19	3	.41517+04	.36642+03	.50437+01	.50739+08	.10479-03
19	4	.39420+04	.28153+03	.40646+01	.51132+08	.12385-03
19	5	.37073+04	.17199+03	.26561+01	.51998+08	.15217-03
20	1	.46378+04	.64738+03	.78859+01	.49936+08	.37709-04
20	2	.44260+04	.51839+03	.66802+01	.50270+08	.87757-04
20	3	.41657+04	.38393+03	.52658+01	.50716+08	.10628-03
20	4	.39753+04	.29525+03	.42474+01	.51185+08	.12345-03
20	5	.37175+04	.18013+03	.27741+01	.52322+08	.15135-03
21	1	.46733+04	.70765+03	.85890+01	.49685+08	.37084-04
21	2	.44584+04	.56765+03	.72813+01	.50162+08	.86972-04
21	3	.41969+04	.42372+03	.57651+01	.50769+08	.10463-03
21	4	.40070+04	.32728+03	.46694+01	.51507+08	.12174-03
22	1	.47009+04	.75631+03	.91398+01	.49574+08	.36507-04
22	2	.44891+04	.61697+03	.77509+01	.50110+08	.85149-04
22	3	.42214+04	.45401+03	.61655+01	.50938+08	.10272-03
23	1	.47417+04	.83396+03	.99750+01	.49425+08	.35956-04
23	2	.45235+04	.67601+03	.84997+01	.50120+08	.82500-04
24	1	.47773+04	.90564+03	.10734+02	.49320+08	.34786-04

Group 9 (Cont'd)

THE MESH CONSTRUCTION WILL BE CONTROLED BY THE FOLLOWING VARIABLES

INTERIOR= .300-01 DK AXIS= .200-01 DL LIM= .150+00 DL DELETE= .100-02 DEG P.M.= .600+01 F= .650+00

59 60 61 62 63 64

Group 10

ORIGINAL PAGE IS OF POOR QUALITY

Sample Printout for Two-Phase Chemical Equilibrium Flow

```
                    SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                          GAS-PARTICLE FLOW SOLUTION
                                          CASE NO.    1                                            PAGE   21

65  SPACE SHUTTLE SFP MOTOR NOZZLE                                                                      74
LINE POINT  DSCRIP - REGIME       R  68        Z  69        M  70        THETA  71     ENTROPY 72    VELOCITY 73   M-TOTAL    ITR
     66      67              MACH ANGLE 75  PRESSURE 76  DENSITY 77  TEMPERATURE 78  GAS CONST 79  LOCAL GAMMA 80  SHOCK ANGLE 81
PARTICLE DATA
 SPECIE POINT  DESCRIPTION         V  82      THETA  83     D A  84        ENTHALPY  85    DENSITY  86      TEMPERATURE  87
   1    24  INPUT  - CONTIN    .13357+00     .11124+00    .16368+01     .13866+02     .87489+02    .92919+04    -.19930+00    0
                               .37658+02     .91134+03    .68525-02     .93569+04     .19851+04    .12093+01
PARTICLE DATA          88
   1    24 LIMIT STREAMLINE    .46292+04     .10734+02     .13289+00     .49320+00     .34286-04     .45174+04
------------------------------------------------------------------------------------------------------------------
   1    25  INPUT  - CONTIN    .13993+00     .10959+00    .16675+01     .14943+02     .88637+02    .93708+04    -.19733+00    0
                               .36848+02     .39136+03    .65735-02     .93199+04     .19848+04    .12101+01
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
------------------------------------------------------------------------------------------------------------------
   1    26  INPUT  - CONTIN    .14678+00     .10798+00    .16993+01     .16003+02     .89773+02    .94818+04    -.19537+00    0
                               .36049+02     .37152+03    .62942-02     .92031+04     .19895+04    .12109+01
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
------------------------------------------------------------------------------------------------------------------
   GAS MASS FLOW RATE =      .85715+02    PARTICLE MASS FLOW RATE =      .37352-01    MIXTURE MASS FLOW RATE =     .88950+02
                             89                  PARTICLE PERCENT LOADINGS             90                          91
                                                  RADIUS     LOADING
                                                 .11000+01   .99948+01
                                                 .17000+01   .20000+02
                                                 .25000+01   .20000+02
                                                 .32000+01   .20001+02
                                                 .45000+01   .20001+02
                                                 .65000+01   .99989+01
   PARTICLE PERCENT LOADING RELATIVE TO THE GAS =   .37744+01  PARTICLE PERCENT LOADING RELATIVE TO THE MIXTURE =   .36371+01
                                                            92                                                          93
                                         MOMENTUM INTEGRATION RESULTS
                                      FORCEX        FORCEY        TORQZ         ISP                    94
                                    -.18712+05     .00000        .00000       .20474+03
                 DELFXG        DELFYG        TORQZG        DELFXP        DELFYP        TORQZP         95
               .33778+03     .00000        .00000        .40047+03     .00000        .00000
```

Group 11

Group 12

Group 13

NOTES: (1) Typical printout for the startline data surface.
(2) Some points have been omitted for demonstration purposes.

Sample Printout for Two-Phase Chemical Equilibrium Flow

```
                 SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                         GAS-PARTICLE FLOW SOLUTION
                                              CASE NO,    1                                                    PAGE   27

   SPACE SHUTTLE SEP MOTOR NOZZLE

LINE POINT  DSCRIP - REGIME        R            X             M           THETA        ENTROPY       VELOCITY      M-TOTAL    ITR
                               MACH ANGLE    PRESSURE      DENSITY     TEMPERATURE   GAS CONST.    LOCAL GAMMA   SHOCK ANGLE
 PARTICLE DATA
 SPECIE POINT  DESCRIPTION         V           THETA           D M                    ENTHALPY      DENSITY       TEMPERATURE     (96)
  2    23  INTER  - CONTIN     .12853+00    .12060+00    .16501+01    .13697+02    .67676+02    .53263+04    -.19728+00    4
                               .37303+02    .40277+03    .67329-02    .93399+04    .19950+04    .12098+01
PARTICLE DATA
     1  23                     .491253+04    .10722+02    .12820+00    .49070+04    .55679-04    .49930+04
     2  23 LIMIT STREAMLINE    .466774+04    .92350+01    .20403+00    .49791+04    .70835-04    .45728+04
------------------------------------------------------------------------------------------------------------------------------------
  2    24  INTER  - CONTIN     .13512+00    .11912+00    .14794+01    .19787+02    .67000+02    .5901[illegible]+04    -.19730+00
                               .36599+02    .38918+03    .69733-02    .93041+04    .19897+04    .12109+01
PARTICLE DATA
     1  24 LIMIT STREAMLINE    .496890+04    .11591+02    .13949+00    .49970+04    .32596-04    .49704+04
------------------------------------------------------------------------------------------------------------------------------------
  2    25  INTER  - CONTIN     .14209+00    .11732+00    .17128+01    .16001+02    .68037+02    .54080+04    -.19733+00
                               .35722+02    .36379+03    .61855-02    .92686+04    .19893+04    .12112+01
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
------------------------------------------------------------------------------------------------------------------------------------
  2    26  WALL   - CONTIN     .14799+00    .11544+00    .17447+01    .17144+02    .69773+02    .90892+04    -.19737+00
                               .34971+02    .34909+03    .59177-02    .92312+04    .19890+04    .12120+01
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
------------------------------------------------------------------------------------------------------------------------------------
                                          PRESSURE INTEGRATION RESULTS                                 (97)
                                FORCEX       FORCEY        TORQZ         DELFX        DELFY          ISP
                              -.18118+05     .00000       .00000      -.10595+07     .00000       .30573+03
                                                                                                                    } Group 14

          PERCENT CHANGE IN MASS, MOMENTUM AND ENERGY NUMERICAL INTEGRATION FOR LINE  2 RELATIVE TO THE START LINE
         PERCENT CHANGE IN MASS FLOW, GAS =   -.[illegible]-01 (98) PARTICLE =  -.38287-01 (99) MIXTURE (103) =  -.15672-01 (100)
   PERCENT CHANGE IN MOMENTUM, GAS =   .75299+04 (101) PARTICLE =   .47907+00 (102) MIXTURE =  -.12303+01  ISP =  -.12198+01 (104)
          PERCENT CHANGE IN ENERGY, GAS =  -.[illegible]+02    PARTICLE =   .00037+00    MIXTURE =  -.02209-02
                                     (105)                          (106)                          (107)
                                                                                                                    } Group 15
```

NOTES: (1) Typical printout for a data surface inside the nozzle.
(2) Some points have been omitted for demonstration purposes.

Sample Printout for Two-Phase Chemical Equilibrium Flow

```
              SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                   GAS-PARTICLE FLOW SOLUTION
                                        CASE NO.    1                                          PAGE  169

  SPACE SHUTTLE SRB MOTOR NOZZLE

LINE POINT  DSCRIP - REGIME        R            Z             M            THETA        ENTROPY      VELOCITY     M-TOTAL     ITR
                               MACH ANGLE    PHI SURF      DENSITY      TEMPERATURE   GAS CONST.   LOCAL SOUND  SHOCK ANGLE
PARTICLE DATA
 SPECIE POINT  DESCRIPTION         V           THETA          D N                      ENTHALPY     DENSITY      TEMPERATURE

119     1  WALL    - CONTIN     .00000       .16756+01     .32346+01     .00000       [illegible]  [illegible]  [illegible]     2
                                .18069+02    .18060+02     .50693-03     .25970+04    .19812+04    .12365+01
PARTICLE DATA
  1        1                    .794676+04   .00000                     .80755-01     .27432+08    .21771-05    .27626+04
  2        1                    .781100+04   .00000                     .10784+00     .23086+08    .38481-05    .28407+04
  3        1                    .774027+04   .00000                     .15876+00     .25476+08    .43799-05    .31376+04
  4        1                    .760955+04   .00000                     .21497+00    [illegible]  [illegible]  [illegible]
  5        1                    .737590+04   .00000                     .34715+00     .33391+08    .69098-05    .91061+04
  6        1                    .675175+04   .00000                     .56499+00     .38867+08    .95327-05    .91885+04

118    17  FREEBD  - CONTIN     .10129+01    .95075+00     .83199+01     .69088+02    .69773+02    .10115+08    -.19737+00      2
                                .69037+01    .31449+01     .41942-05     .55160+01    .19811+04    .13527+01
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT

A NEW STREAMLINE HAS BEEN INSERTED ON LINE 117 BETWEEN POINTS  25 AND  26

119     1  WALL    - CONTIN     .00000       .16999+01     .32698+01     .00000       .66920+03    .81098+09    -.19653+00      3
                                .17834+02    .17077+02     .48396-03     .75451+04    .19812+04    .12367+01
PARTICLE DATA
  1        1                    .794744+04   .00000                     .84891+01     .27327+08    .20838+09    .27499+09
  2        1                    .790313+04   .00000                     .11225+00     .22983+08    .39363-05    .28305+09
  3        1                    .777129+04   .00000                     .14496+00    [illegible]  [illegible]  [illegible]
  4        1                    .762089+04   .00000                     .22489+00     .28107+08    .88977-05    .39419+09
  5        1                    .725636+04   .00000                     .34780+00     .33178+08    .63193+09    .90009+09
  6        1                    .674679+04   .00000                     .56590+00     .38764+08    .99699-05    .91885+09

119    17  FREEBD  - CONTIN     .10257+01    .95805+00    [illegible]    .89788+02    .69773+02    .10115+08    [illegible]
                                .69037+01    .31449+01     .91942-06     .55160+01    .19811+04    .13527+01
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT

                       POINT NO.  27 ON LINE 119 HAS BEEN DELETED

A NEW STREAMLINE HAS BEEN INSERTED ON LINE 119 BETWEEN POINTS  51 AND  52

A NEW STREAMLINE HAS BEEN INSERTED ON LINE 119 BETWEEN POINTS  53 AND  54
```

NOTES: (1) Typical printout for a data surface in the exhaust plume.
(2) Some points have been omitted for demonstration purposes.

Sample Printout for Two-Phase Chemical Equilibrium
Flow with Free Molecular Considerations

Sample Printout Two-Phase Chemical Equilibrium-Free Molecular

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 0 PAGE 1

SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

RUN CONTROL PARAMETERS

ICON(1)	ICON(2)	ICON(3)	ICON(4)	ICON(5)	ICON(6)	ICON(7)	ICON(8)
2	0	20	1	1	2	1	3

ICON(9)	ICON(10)	ICON(11)	ICON(12)	ICON(13)	ICON(14)	ICON(15)	ICON(16)
0	0	0	1	7	0	0	15070

FLOW CALCULATIONS ARE IN ENGLISH UNITS WITH THE R,X COORDINATES IN FEET

THE FLOW FIELD DATA WILL BE WRITTEN ON TAPE

UPPER BOUNDARY

TYPE	ITRANS	A	B	C	D	E	XEY
1	0	-.10000+01	.17290+00	.00000	-.10000+01	.52590+00	.15000+00
1	1	.10000+01	.23800+03	.15600+02	-.10000+01	-.15290+02	.27240+01
3	0	.10000-03	.00000	.00000	.00000	.00000	.10000+04

LOWER BOUNDARY

TYPE	ITRANS	A	B	C	D	E	XEY
2	0	.00000	.00000	.00000	.00000	.00000	.10000+04

CHAMBER ENTHALPY = .31568+08

THERE ARE 3 PARTICLE SPECIES PRESENT IN THE GAS-PARTICLE MIXTURE

THE FOLLOWING GAS PROPERTIES IN ENGLISH UNITS ARE FOR IUS-2 PC-800
REAL GAS PROPERTIES

H-TOTAL
-.89833+07

S	V	P	GAMMA	T	R	RP	VIS	CP
-.83652+04								
	.00000	.26450+04	.12801+01	.34853+04	.80000+02	.47762+00	.12467-05	.11841+05
	.32279+04	.26446+04	.12980+01	.30390+04	.47786+02	.48327+00	.11336-05	.11649+05
	.49849+04	.26400+04	.12913+01	.24190+04	.16000+03	.50087+00	.96772-06	.12462+05
	.57444+04	.26400+04	.13280+01	.20428+04	.80000+02	.48317+00	.86023-06	.10671+05
	.63137+04	.26400+04	.13425+01	.17162+04	.40000+02	.48311+00	.76049-06	.10355+05
	.65544+04	.26400+04	.13493+01	.15654+04	.27972+02	.48180+00	.71164-06	.10205+05
	.68744+04	.26400+04	.13594+01	.13525+04	.16000+02	.47936+00	.63932-06	.99926+04
	.71956+04	.26400+04	.13698+01	.11234+04	.80000+01	.47465+00	.55698-06	.97857+04
	.77139+04	.26400+04	.13852+01	.72250+03	.16000+01	.46557+00	.39244-06	.94995+04
.21628+04								
	.00000	.26465+04	.12815+01	.34769+04	.15000+02	.45653+00	.12446-05	.12184+05
	.32256+04	.26456+04	.12947+01	.30377+04	.81972+01	.47481+00	[illegible]	.11756+05
	.49828+04	.26454+04	.13046+01	.24081+04	.30000+01	.48544+00	.96447-06	.11337+05
	.57406+04	.26454+04	.13362+01	.20326+04	.15000+01	.48219+00	.85421-06	.10663+05

Sample Printout Two-Phase Chemical Equilibrium - Free Molecular

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SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                         GAS-PARTICLE FLOW SOLUTION
                         CASE NO.    D                                          PAGE    7

SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

                              RUN CUTOFF INFORMATION
          UPPER BOUNDARY                                          LOWER BOUNDARY
R=   .20000+05   X=   -.20000+05   THETA=   .00000   R=   .00000   X=   .10000+02   THETA=   .0 ....+0.

          VIBNO 108     ROTNO 109    TRANNO 110    CHARL 111    GAMV 112    GAMP 113
          .10000+03     .10000+02    .10000+00     .12711+01    .14000+01   .16667+01

                              PARTICLE PHYSICAL DATA
     SPECIE   RADIUS        MASS DENSITY    EMISSIVITY     ACCM. COEFF.
       1      .11500+01     .25000+03       .00000         .00000
       2      .30000+01     .25000+03       .00000         .00000
       3      .55000+01     .25000+03       .00000         .00000

   THE PARTICLES CONSTITUTE 31.50 PERCENT BY WEIGHT FLOW OF THE GAS-PARTICLE MIXTURE
          THE INDIVIDUAL PERCENTAGES ARE    .33   .33   .33
   THE PARTICLE TEMPERATURE-ENTHALPY TABLE WILL BE READ IN WITH ENGLISH     UNITS

                         PARTICLE TEMPERATURE-ENTHALPY TABLE

   PHASE CHANGE DATA *** TMELT=  .41880D+04 HSOLID=  .314355+04 HLIQUID=  .479496+04
                         CPMELT=  .85096+04 CPSOLID=  .80090+04
```

Group 16

Sample Printout Two-Phase Chemical Equilibrium - Free Molecular

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

GAS-PARTICLE FLOW SOLUTION

CASE NO. 0 PAGE 32

SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

LINE	POINT	DSCRIP - REGIME	R	X	M	THETA	ENTROPY	VELOCITY	H-TOTAL
			MACH ANGLE	PRESSURE	DENSITY	TEMPERATURE	GAS CONST.	LOCAL GAMMA	SHOCK ANGLE
			TO*	PO*	S*				
PARTICLE DATA									
SPECIE	POINT	DESCRIPTION	V	THETA	D M	ENTHALPY	DENSITY	TEMPERATURE	
1	41	INPUT - CONTIN	.12168+01	.27286+01	.28886+01	.16998+02	.56964+04	.90292+04	.26379+08
			.20253+02	.19300+01	.37305-04	.27899+04	.26708+04	.13115+01	
			.53760+04	.21028+02	.90911+04				
PARTICLE DATA									
NO PARTICLES ARE PRESENT AT THIS POINT,									
1	42	INPUT - CONTIN	.12246+01	.27262+01	.23995+01	.17036+02	.74855+04	.81869+04	.23678+08
			.24629+02	.19297+01	.31816-04	.32729+04	.26686+04	.13005+01	
			.52600+04	.19741+02	.95604+04				
PARTICLE DATA									
NO PARTICLES ARE PRESENT AT THIS POINT,									
1	43	INPUT - CONTIN	.12290+01	.27248+01	.17783+01	.17057+02	.94249+04	.63966+04	.18256+08
			.39217+02	.19296+01	.26572-04	.39396+04	.26594+04	.12350+01	
			.50519+04	.82453+01	.10096+05				
PARTICLE DATA									
NO PARTICLES ARE PRESENT AT THIS POINT,									
1	44	INPUT - CONTIN	.12304+01	.27244+01	.12648+01	.17064+02	.10370+05	.46682+04	.12435+08
			.52245+02	.19297+01	.24911-04	.41837+04	.26662+04	.12212+01	
			.48112+04	.47178+01	.10475+05				
PARTICLE DATA									
NO PARTICLES ARE PRESENT AT THIS POINT,									
1	45	INPUT - CONTIN	.12308+01	.27243+01	.10500+01	.17066+02	.10551+05	.38997+04	.99121+07
			.72247+02	.19297+01	.24487-04	.42560+04	.26663+04	.12156+01	
			.46973+04	.36782+01	.10551+05				
PARTICLE DATA									
NO PARTICLES ARE PRESENT AT THIS POINT,									
1	46	INPUT - CONTIN	.12314+01	.27241+01	.10500+01	.17069+02	.87565+04	.37361+04	.20769+07
			.72247+02	.19297+01	.27671-04	.37892+04	.26502+04	.12608+01	
			.42962+04	.37143+01	.87569+04				
PARTICLE DATA									
NO PARTICLES ARE PRESENT AT THIS POINT,									
1	47	PRN-MR - CONTIN	.12314+01	.27241+01	.12533+01	.21931+02	.87565+04	.43548+04	.20769+07
			.52930+02	.14953+01	.27637-04	.35964+04	.26498+04	.12710+01	
			.42958+04	.36602+01	.87960+04				

Notes: 1. Typical printout for a startline surface containing a Prandtl Meyer expansion.
2. Some points have been omitted for demonstration.

Sample Printout for Two-Phase Chemical Equilibrium - Free Molecular

```
SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                              GAS-PARTICLE FLOW SOLUTION
                              CASE NO.   0                                                  PAGE   76

SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

LINE POINT  DSCRIP - REGIME       P            X            M            THETA        ENTROPY      VELOCITY     H TOT.L     ITH
                              MACH ANGLE     PRESSURE     DENSITY      TEMPERATURE  GAS CONST.   LOCAL GAMMA  SHOCK ANGLE
                                 TO*           PO*          S*
PARTICLE DATA
 SPECIE POINT  DESCRIPTION        V            THETA        R M              ENTHALPY     DENSITY          TEMPERATURE

 52    57  INTER  - CONTIN    .12818+01    .27354+01    .43525+01    .89814+02    .87565+04    .86045+04    .20769+07    3
                              .13243+02    .11512-01    .58703-06    .10765+04    .26458+04    .13722+01
                              .42776+04    .28744+00    .15576+05
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT

 52    58  INTER  - CONTIN    .12816+01    .27300+01    .46770+01    .95068+02    .87565+04    .87364+04    .20769+07    3
                              .12343+02    .75209-02    .42682-06    .95903+03    .26458+04    .13746+01
                              .42776+04    .21673+00    .16327+05
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT

 52    59  INTER  - CONTIN    .12812+01    .27271+01    .48745+01    .97925+02    .87565+04    .88058+04    .20769+07    1
                              .11838+02    .58685-02    .35676-06    .89653+03    .26458+04    .13768+01
                              .42776+04    .18354+00    .16770+05
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
```

Points deleted for demonstration.

```
 52    71  INTER  - FREE M    .12610+01    .26891+01    .13711+02    .14006+03    .00000       .96277+04    .00000       1
                              .41877+01    .25673-06    .12498-09    .11180+03    .26458+04    .16670+01
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT

 52    72  INTER  - FREE M    .12594+01    .26877+01    .15657+02    .14260+03    .00000       .96533+04    .00000       1
                              .36619+01    .11696-06    .73857-10    .86185+02    .26458+04    .16670+01
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT

 52    73  FREERD - FREE M    .12586+01    .26871+01    .16763+02    .14368+03    .00000       .96641+04    .00000       1
                              .34200+01    .12603-06    .91028-10    .75355+02    .26458+04    .16670+01
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
CONTINUUM BREAKDOWN CRITERIA OF .05 MET BETWEEN POINTS   58 AND   59 AT X,R=   .12817+01   .27331+01

       PERCENT CHANGE IN MASS, MOMENTUM AND ENERGY NUMERICAL INTEGRATION FOR LINE 52 RELATIVE TO THE START LINE
      PERCENT CHANGE IN MASS FLOW, GAS =     -.50401+00    PARTICLE =    .64212-01  , MIXTURE =    -.32264+00
   PERCENT CHANGE IN MOMENTUM, GAS:  -.36411+01    PARTICLE =  -.19319+01    MIXTURE =  -.25852+01 ISP =  -.22646+01
         PERCENT CHANGE IN ENERGY, GAS =  -.65834+00    PARTICLE =   .21998+01    MIXTURE =  -.55060+00
```

113A

Note: Typical printout for a data surface in the exhaust plume.

Sample Printout for Single-Phase
Finite Rate Chemistry Flow

Sample Printout for Single-Phase Finite Rate Chemistry Flow

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 21

CASE 21 - SQUARE A/I CONE, O/F=2.2 , FINITE RATE, INVISCID, VAR O/F

RUN CONTROL PARAMETERS

ICON(1)	ICON(2)	ICON(3)	ICON(4)	ICON(5)	ICON(6)	ICON(7)	ICON(8)
3	2	21	2	1	0	1	3

ICON(9)	ICON(10)	ICON(11)	ICON(12)	ICON(13)	ICON(14)	ICON(15)	ICON(16)
[illegible]	50	21	1	[illegible]	0	0	[illegible]

FLOW CALCULATIONS ARE IN ENGLISH UNITS WITH THE R,Z COORDINATES IN FEET

THE FLOW FIELD DATA WILL BE WRITTEN ON TAPE

UPPER BOUNDARY

TYPE	ITRANS	A	B	C	D	E	MAX
[illegible]	1	.00000	.00000	.00000	.24795+00	.56731+01	.20517+01
[illegible]	0	.19000+02	.14000+01	.00000	.00000	.05000	.83333+01

LOWER BOUNDARY

TYPE	ITRANS	A	B	C	D	E	MAX
2	0	.00000	.00000	.00000	.00000	.00000	.83333+01

Sample Printout for Single-Phase Finite Rate Chemistry Flow

```
SPECIE THERMODYNAMIC AND REACTION DATA
NT,NS,NR,NM,ICTAPE,KGUP,IDIDO=  24   14   23    3    0    2    1   (114)
                           (115)
PRANDTL NUMBER =   .70000000D+00
BASE VISCOSITY =   .18651190-05  (116)
EXPONENT       =   .60000000D+00
                   (117)
                                (117)                                       (120)     (121)      (122)      (123)   (124)    (125)
   (118)        REACTIONS BEING CONSIDERED      KR=A*EXP(B/RT)*(NI/T)**N      A         N          B          M    R-TYPE   K-TYPE
    1    H     + OH    + M1    = H2O   + M1                                2.219+22    2.0         .0         .0      2        2
    2    O     + H     + M1    = OH    + M1                                7.260+16     .0         .0         .0      2        1
    3    O     + O     + M1    = O2    + M1                                1.379+18    1.0     -340.0         .0      2        4
    4    H     + H     + M2    = H2    + M2                                1.016+18    1.0         .0         .0      2        2
    5    CO    + O     + M3    = CO2   + M3                                7.260+14     .0    -4000.0         .0      2        3
    6    OH    + H             = H2    + O                                 8.435+09   -1.0    -7000.0         .0      1        4
    7    OH    + O             = H     + O2                                2.910+13     .0         .0         .0      1        1
    8    OH    + H2            = H2O   + H                                 6.025+06   -2.0    -2900.0         .0      1        4
    9    OH    + CO            = CO2   + H                                 6.627+06   -2.0     1400.0         .0      1        4
   10    OH    + OH            = H2O   + O                                 6.025+12     .0    -1100.0         .0      1        3
   11    CH4   + OH            = CH3   + H2O                               2.837+13     .0    -5000.0         .0      1        7
   12    CH4   + H             = CH3   + H2                                1.996+13     .0    -6000.0         .0      1        3
   13    CH4   + O             = CH3   + OH                                2.109+13     .0    -9100.0         .0      1        3
   14    CH3   + O             = CH2O  + H                                 6.627+13     .0         .0         .0      1        1
   15    CH2O  + OH            = CHO   + H2O                               6.422+11    -.5         .0         .0      1        2
   16    CH2O  + H             = CHO   + H2                                1.325+13     .0    -3800.0         .0      1        2
   17    CH2O  + O             = CHO   + OH                                9.690+10     .0         .0         .0      5        1
   18    CH2O  + M1            = CO    + H2    + M1                        2.109+16     .0   -36000.0         .0      1        3
   19    CHO   + OH            = CO    + H2O                               1.265+14     .0         .0         .0      1        1
   20    CHO   + H             = CO    + H2                                5.001+13     .0   -10000.0         .0      1        3
   21    CHO   + O             = CO    + OH                                1.265+14     .0         .0         .0      1        1
   22    CHO   + O2            = CO    + H                                 6.001+13     .0    -1600.0         .0      7        3
   23    CHO   + M1            = CO    + H     + M1                        7.230+13     .0   -16000.0         .0      5        3

         CATALYTIC SPECIES BEING CONSIDERED  (126)

    M1  = 1.00 C     , 1.00 CH4   , 1.00 CO    , 1.00 H2    , 3.00 H2O   , 1.00 NH3   , 1.00 N2    ,
          2.00 CO2   , 1.00 H     , 1.00 NO    , 1.00 OH    , 1.00 O     , 1.00 O2    , 1.00 CH3   ,
          1.00 CH2O  , 1.00 CHO   ,

    M2  = 1.00 C     , 1.00 CH4   , 1.00 CO    , 1.00 H2    ,10.00 H2O   , 1.00 NH3   , 1.00 N2    ,
          3.00 CO2   , 1.00 H     , 1.00 NO    , 2.00 OH    , 1.00 O     , 1.00 O2    , 1.00 CH3   ,
          1.00 CH2O  , 1.00 CHO   ,

    M3  = 1.00 C     , 1.00 CH4   , 1.50 CO    , 1.00 H2    ,10.00 H2O   , 1.00 NH3   , 1.00 N2    ,
          3.00 CO2   , 1.00 H     , 1.00 NO    , 1.00 OH    , 1.00 O     ,20.00 O2    , 1.00 CH3   ,
          1.00 CH2O  , 1.00 CHO   ,
```

Group 17

Sample Printout for Single-Phase Finite Rate Chemistry Flow

SPECIE MOLE FRACTIONS ON THE START LINE ARE READ FROM CARDS

POINT 127 128

POINT										
1	C .74780-01	CH4 .20780+00	CO .63820-03	H2 .43150+00	H2O .05700-03	NH3 .12570-02	N2 .28310+00	CO2 .56360-06	H .00000	NO .00000
1	OH .00000	O .00000	O2 .00000	CH3 .00000	CH2O .00000	CHO .00000				
2	C .79100-01	CH4 .18990+00	CO .63360-02	H2 .43860+00	H2O .64990-02	NH3 .11890-02	N2 .27820+00	CO2 .18310-03	H .00000	NO .00000
2	OH .00000	O .00000	O2 .00000	CH3 .00000	CH2O .00000	CHO .00000				
3	C .57070-01	CH4 .17970+00	CO .67990-01	H2 .47040+00	H2O .16650-01	NH3 .88840-03	N2 .26410+00	CO2 .16870-02	H .00000	NO .00000
3	OH .00000	O .00000	O2 .00000	CH3 .00000	CH2O .00000	CHO .00000				
4	C .00000	CH4 .27430-01	CO .16690+00	H2 .49510+00	H2O .60060-01	NH3 .35010-03	N2 .25730+00	CO2 .74110-02	H .12170-03	NO .28450-06
4	OH .22260-05	O .00000	O2 .00000	CH3 .00000	CH2O .00000	CHO .00000				
5	C .00000	CH4 .32960-06	CO .15740+00	H2 .31430+00	H2O .21750+00	NH3 .28520-04	N2 .28330+00	CO2 .21240-01	H .29960-02	NO .12950-03
5	OH .11510-02	O .27660-04	O2 .17390-04	CH3 .00000	CH2O .00000	CHO .00000				
6	C .00000	CH4 .00000	CO .12350+00	H2 .15270+00	H2O .39160+00	NH3 .45390-05	N2 .31050+00	CO2 .94060-01	H .10100-01	NO .22370-02
6	OH .11910-01	O .10340-02	O2 .18840-02	CH3 .00000	CH2O .00000	CHO .00000				
7	C .00000	CH4 .00000	CO .86030-01	H2 .65910-01	H2O .38640+00	NH3 .00000	N2 .32400+00	CO2 .71680-01	H .12700-01	NO .81070-02
7	OH .29160-01	O .39190-02	O2 .12170-01	CH3 .00000	CH2O .00000	CHO .00000				
8	C .00000	CH4 .00000	CO .58790-01	H2 .34920-01	H2O .38990+00	NH3 .00000	N2 .32850+00	CO2 .89300-01	H .96100-02	NO .14240-01
8	OH .39160-01	O .67750-02	O2 .33730-01	CH3 .00000	CH2O .00000	CHO .00000				

Group 18

NOTE: Some points hav : been omitted for demonstration purposes.

Sample Printout for Single-Phase Finite Rate Chemistry Flow

Group 18
(Cont'd)

```
20        OH            C             O2            CH3           CH2O          CHO
     .17030-02    .33800-04    .21280-04    .00000       .00000       .00900
2.        C             CH4           CO            H2            H2O           NH3           N2            CO2           H             NO
     .00000       .74950-07    .14680+00    .21720+00    .30120+00    .62950-05    .30130+00    .33710-01    .45300-02    .17100-03
21        OH            O             O2            CH3           CH2O          CHO
     .17030-02    .33800-04    .21280-04    .00000       .00000       .00 00
  STR PRESSURE (ATM) =   .1001+02 CHAMBER TEMPERATURE (DEG K) =   .3261+04
                    THERE ARE  0 PARTICLE SPECIES PRESENT IN THE GAS-PARTICLE MIXTURE
                                        RUN CUTOFF INFORMATION
                      UPPER BOUNDARY                                             LOWER BOUNDARY
  R=    .2500+01   X=    .00000      THETA=    .00000        R=    .00000      X=    .60000+00    THETA=    .00000+00
  ,
                  THE MESH CONSTRUCTION WILL BE CONTROLLED BY THE FOLLOWING VARIABLES
  DL INTERIOR=   .150-01 DY 1ELB=   .150-01 DL LIM=   .500    DL DELETE=   .100-04 DEG P.M.=   .000+01 DA   .275+00
```

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Sample Printout for Single-Phase Finite Rate Chemistry Flow

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SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                    GAS-PARTICLE FLOW SOLUTION                                      PAGE   2
                       CASE NO.   21

[illegible] - SOOLBF 6/1 CONE, O/F=2.2 , FINITE RATE, INVISCID, VAR O/F

LINE POINT  DESCRIP - REGIME      R             Y             M            THETA          ENTROPY        VELOCITY       P-TOTAL      ITR
                               MACH ANGLE     PRESSURE      DENSITY      TEMPERATURE    GAS CONST.     LOCAL GAMMA    SHOCK ANGLE
                                  TO.           PO.           S.

  1         INPUT  - CONTIN    .00000        .94167-02     .10274+01    .00000         .00000         .31052+04      .13274+[illegible]   0
                               .76745+02     .275[illegible]+03     .54912-02    .14993+04      .37993 04      .12660+01
                               .21650+04     .51429+03     .00000
CHEMICAL SPECIE MOLE FRACTIONS
[illegible]  [illegible]   CH4  2.0701-01   CO  6.3424-04   H2  4.3153-01   H2O  9.5705-04   NH3  1.2571-03   N2  [illegible]
CO2  5.[illegible]-06   H    0.0000      NO  0.0000      OH  0.0000      O    0.0000      O2   0.0000      CH3  0.0000
CH3C 0.0000     CHO  0.0000
------------------------------------------------------------------------------------------------------------------------------
  1     2   INPUT  - CONTIN    .19561-02     .94167-02     .10291+01    .74694+00      .00000         .31463+04      .12984+0[illegible]   0
                               .76336+02     .27440+03     .53672-02    .19242+04      .38250+04      .12712+01
                               .22006+04     .51479+03     .00000
CHEMICAL SPECIE MOLE FRACTIONS
[illegible]  7.5104-02   CH4  1.8991-01   CO  6.3343-03   H2  4.3862-0[illegible]   H2O  6.4443-03   NH3  1.1841-03   N2  2.7[illegible]-01
CO2  [illegible]   H    0.0000      NO  0.0000      OH  0.0000      O    0.0000      O2   0.0000      CH3  0.0000
CH3C [illegible]   CHO  0.0000
------------------------------------------------------------------------------------------------------------------------------
  1     3   INPUT  - CONTIN    .39127-02     .94167-02     .10238+01    .15011+01      .00000         .32426+04      .11275+08   1
                               .77629+02     .27475+03     .50759-02    .20735+04      .37591+04      .12870+01
                               .23854+04     .51502+03     .00000
CHEMICAL SPECIE MOLE FRACTIONS
[illegible]  5.7074-02   CH4  1.2471-01   CO  6.2444-02   H2  4.7043-01   H2O  1.6651-02   NH3  8.8846-04   N2  2.4512-01
CO2  [illegible]   H    0.0000      NO  0.0000      OH  0.0000      O    0.0000      O2   0.0000      CH3  0.0000
CH3C [illegible]   CHO  0.0000
------------------------------------------------------------------------------------------------------------------------------
  1     4   INPUT  - CONTIN    .58682-02     .94167-02     .10214+01    .22464+01      .00000         .35142+04      .69241+07   0
                               .78256+02     .27274+03     .41259-02    .26713+04      .33964+04      .13038+01
                               .30769+04     .51263+03     .00000
CHEMICAL SPECIE MOLE FRACTIONS
C    0.0000     CH4  [illegible]-02   CO  1.6692-01   H2  4.8514-01   H2O  6.0067-02   NH3  3.5014-06   N2  2.57[illegible]-01
CO2  7.9119-03   H    1.2171-04   NO  2.8451-07   OH  7.0268-06   O    0.0000      O2   0.0000      CH3  0.0000
CH3C 0.0000     CHO  0.0000
------------------------------------------------------------------------------------------------------------------------------
```

NOTES: (1) Typical printout for the startline data surface.
(2) Some points have been omitted for demonstration purposes.

Sample Printout for Single-Phase Finite Rate Chemistry Flow

```
SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SPEC. COMPUTER PROGRAM
                        GAS-PARTICLE FLOW SOLUTION
                             CASE NO.   21                                      PAGE    5

CASE 21 - SCCLSF 6/1 CONE, O/F=2.2 , FINITE RATE, [illegible], VAR O/F

LRI  POINT  DSCRIP - REGIME      R            X            M           THETA         ENTROPY        VELOCITY       N-TOTAL      ITP
                             MACH ANGLE    PRESSURE     DENSITY     TEMPERATURE    GAS CONST.     LOCAL GAMMA    SHOCK ANGLE
                                 TO.          PO.          SO.

 60     1   WALL    - CONTIN  .[illegible]   .62[illegible]  .20761+01  .00000      .91272-05     .5[illegible]     .[illegible]      3
                              .29496+02    .6[illegible]   .17351-02  .13026+04   .37993+04     .13[illegible]+01
                              .22[illegible]+04  .3536[illegible]  .00030
CHEMICAL SPECIE MOLE FRACTIONS        (131)
C     2.9785-02   CH4   2.0781-01   CO   6.3624-04   H2   4.3153-01   H2O   8.5705-04   NH3   1.2571-03   N2   [illegible]
CO2   5.[illegible]  H  3.[illegible]-19  HO  0.0000  OH  1.7397-25   O     3.9207-35   O2    0.0000      CH3  [illegible]-18
CH2O  5.[illegible]-19   CHO   1.[illegible]-18
------------------------------------------------------------------------------------------------------------------------------------
  3    21   [illegible]  - CONTIN  .[illegible]-01  .[illegible]  .12568+01  .15[illegible]+02  .77217+02  .67522+04  .3[illegible]+07  3
                              .[illegible]733+02   .70[illegible]  .10656-02  .37897+04   .25158+04     .12[illegible]+01
                              .55034+04    .3551[illegible]+03  .00030
CHEMICAL SPECIE MOLE FRACTIONS
C     [illegible]   CH4   [illegible]-03 , CO   1.[illegible]19-01   H2   2.1814-01   H2O   3.0192-01   NH3   8.3046-06   N2   3.[illegible]-01
CO2   3.39[illegible]-02   H   3.[illegible]-03   HO   1.7120-05   OH   6.3099-04   O   6.4868-06   O2   4.3406-05   CH3   1.92[illegible]
CH2O  2.5135-[illegible]   CHO   1.0[illegible]-05
------------------------------------------------------------------------------------------------------------------------------------
                                        PRESSURE INTEGRATION RESULTS
                         FORCEX        FORCEY        TORQZ         DELFX         DELFY          ISP
                       -.[illegible]+03   .00000        .00000      -.14807+01    .00000       .24229+03

 61     1   WALL    - CONTIN  .[illegible]0073  .64037-01  .20242+01   .00000      .91334-05     .52747+04     .[illegible]+09      3
                              .29606+02    .63144+02   .17445-02  .13778+04   .37993+04     .13019+01
                              .[illegible]2223+04   .34897+03  .00030
CHEMICAL SPECIE MOLE FRACTIONS
C     2.4785-02   CH4   2.[illegible]-01   CO   6.3824-04   H2   4.3153-01   H2O   8.5705-04   NH3   1.2571-03   N2   2.831[illegible]
CO2   5.[illegible]359-16   H   3.3767-17   HO   0.0000   CH   1.5902-25   O   2.5212-35   O2   0.0000   CH3   2.9542-1[illegible]
CH2O  5.[illegible]736-19   CHO   1.2075-18
------------------------------------------------------------------------------------------------------------------------------------
 61    21   WALL    - CONTIN  .52095-01    .57151-01    .19735+01   .15060+02   .78910+02     .67916+04     .34048+07      3
                              .[illegible]945+02    .68429+02   .10918-02  .37597+04   .25158+04     .12521+01
                              .[illegible]55+04     .35[illegible]+03  .00030
CHEMICAL SPECIE MOLE FRACTIONS
C     0.0000   CH4   .[illegible]635+[illegible]   CO   1.[illegible]-01   H2   2.1819-01   H2O   3.0190-01   NH3   8.3047-06   N2   3.[illegible]
CO2   3.3895-02   H   3.[illegible]-03   HO   1.71[illegible]-05   OH   6.1486-04   O   6.3040-06   O2   4.2352-05   CH3   1.9107-0[illegible]
CH2O  9.[illegible]   CHO   1.[illegible]
------------------------------------------------------------------------------------------------------------------------------------
                                        PRESSURE INTEGRATION RESULTS
                         FORCEX        FORCEY        TORQZ         DELFX         DELFY          ISP
                       -.[illegible]333+03  .00000     [illegible]   -.14[illegible]   .[illegible]   .24354+03
```

NOTES: (1) Typical printout for a data surface inside the nozzle.
(2) Some points have been omitted for demonstration purposes.

VARIABLE O/F TRANSONIC

132	INITIAL STATION	-.3423-01
133	THROAT STATION	.0000
134	FINAL STATION	.1734-01
135	MASS FLOW	.2545-02
136	AVERAGE O/F	.1397+11
137	THROAT AREA	.9168-03
138	TIME STEP	.1041-07

O/F DISTRIBUTION AT INITIAL STATION

139 R	140 O/F
.0000	.1397+11
.3333-01	.1397+11

SPACE SHUTTLE VERNIER NOZZLE A/A*=21 FREE MOLECULAR

141 LINE	142 POINT	143 R	144 X	145 M	146 ANG	147 O/F	148 V	149 P	150 T	151 DENS
1	1	.3333-01	-.3423-01	.1588+00	.0000	.1397+11	.6223+03	.1561+05	.5462+04	.1172-02
1	2	.3095-01	-.3423-01	.1588+00	.0000	.1397+11	.6223+03	.1561+05	.5462+04	.1172-02
1	3	.2857-01	-.3423-01	.1588+00	.0000	.1397+11	.6223+03	.1561+05	.5462+04	.1172-02
1	4	.2619-01	-.3423-01	.1588+00	.0000	.1397+11	.6223+03	.1561+05	.5462+04	.1172-02
1	5	.2381-01	-.3423-01	.1588+00	.0000	.1397+11	.6223+03	.1561+05	.5462+04	.1172-02
1	6	.2143-01	-.3423-01	.1588+00	.0000	.1397+11	.6223+03	.1561+05	.5462+04	.1172-02
1	7	.1905-01	-.3423-01	.1588+00	.0000	.1397+11	.6223+03	.1561+05	.5462+04	.1172-02
1	8	.1667-01	-.3423-01	.1588+00	.0000	.1397+11	.6223+03	.1561+05	.5462+04	.1172-02
1	9	.1429-01	-.3423-01	.1588+00	.0000	.1397+11	.6223+03	.1561+05	.5462+04	.1172-02
1	10	.1190-01	-.3423-01	.1588+00	.0000	.1397+11	.6223+03	.1561+05	.5462+04	.1172-02
1	11	.9524-02	-.3423-01	.1588+00	.0000	.1397+11	.6223+03	.1561+05	.5462+04	.1172-02
1	12	.7143-02	-.3423-01	.1588+00	.0000	.1397+11	.6223+03	.1561+05	.5462+04	.1172-02
1	13	.4762-02	-.3423-01	.1588+00	.0000	.1397+11	.6223+03	.1561+05	.5462+04	.1172-02
1	14	.2381-02	-.3423-01	.1588+00	.0000	.1397+11	.6223+03	.1561+05	.5462+04	.1172-02
1	15	.1397-08	-.3423-01	.1588+00	.0000	.1397+11	.6223+03	.1561+05	.5462+04	.1172-02

152 WDOT= .255-02 153 POUT= .158+01 154 ISTEP= 0

LINE	POINT	R	X	M	ANG	O/F	V	P	T	DENS
2	1	.3301-01	-.3042-01	.1631+00	-.9383+01	.1397+11	.6391+03	.1560+05	.5461+04	.1172-02
2	2	.3066-01	-.3042-01	.1631+00	-.8712+01	.1397+11	.6391+03	.1560+05	.5461+04	.1172-02
2	3	.2830-01	-.3042-01	.1631+00	-.8042+01	.1397+11	.6391+03	.1560+05	.5461+04	.1172-02
2	4	.2594-01	-.3042-01	.1631+00	-.7372+01	.1397+11	.6391+03	.1560+05	.5461+04	.1172-02
2	5	.2358-01	-.3042-01	.1631+00	-.6702+01	.1397+11	.6391+03	.1560+05	.5461+04	.1172-02
2	6	.2122-01	-.3042-01	.1631+00	-.6032+01	.1397+11	.6391+03	.1560+05	.5461+04	.1172-02
2	7	.1887-01	-.3042-01	.1631+00	-.5361+01	.1397+11	.6391+03	.1560+05	.5461+04	.1172-02
2	8	.1651-01	-.3042-01	.1631+00	-.4691+01	.1397+11	.6391+03	.1560+05	.5461+04	.1172-02
2	9	.1415-01	-.3042-01	.1631+00	-.4021+01	.1397+11	.6391+03	.1560+05	.5461+04	.1172-02
2	10	.1179-01	-.3042-01	.1631+00	-.3351+01	.1397+11	.6391+03	.1560+05	.5461+04	.1172-02
2	11	.9433-02	-.3042-01	.1631+00	-.2681+01	.1397+11	.6391+03	.1560+05	.5461+04	.1172-02
2	12	.7074-02	-.3042-01	.1631+00	-.2011+01	.1397+11	.6391+03	.1560+05	.5461+04	.1172-02
2	13	.4716-02	-.3042-01	.1631+00	-.1340+01	.1397+11	.6391+03	.1560+05	.5461+04	.1172-02
2	14	.2358-02	-.3042-01	.1631+00	-.6702+00	.1397+11	.6391+03	.1560+05	.5461+04	.1172-02
2	15	.2154-08	-.3042-01	.1631+00	-.5069-06	.1397+11	.6391+03	.1560+05	.5461+04	.1172-02

ORIGINAL PAGE IS OF POOR QUALITY

155 SUMMARY OF STANDARD PLUME FLOWFIELD CODE INPUT DATA WHIC WAS OUTPUT ON UNIT 12

CHEMISTRY SYSTEM 3 156

157	MOLECULAR WEIGHT	.18692+02
	SPECIFIC HEAT RATIO	.12737+01 158
159	VISCOSITY(POISE)	.66929-03
	PRANDTL NUMBER	.43820+00 160
161	NOZZLE EXIT RADIUS(FT)	.29605+01
	TEMPERATURE(DEG K)	.22850+04 162
163	DENSITY(GM/CF)	.34481-03
	VELOCITY(FT/SEC)	.74373+04 164

SPECIE 165	MOLE FRACTION 166	SPECIE	MOLE FRACTION
AL2O3(S)	.0000	CO	.2749+00
CO2	.9887-02	CL	.2324-02
CL2	.2073-05	H	.7771-02
H2	.3780+00	H2O	.8348-01
HCL	.1609+00	N2	.8180-01
O	.8049-05	OH	.1708-03
O2	.7403-06		

PARTICLE PHYSICAL DATA

SPECIE 167	LIMITING STREAMLINE 168	RADIUS (MICRON) 169	SPECIFIC HEAT (BTU/LBM/MOLE/DEG R) 170	MASS DENSITY (GM/CC) 171	MOL WEIGHT 172
1	19	.1150+01	.4209+02	.4005+01	.1020+03
2	17	.3000+01	.4209+02	.4005+01	.1020+03
3	14	.5500+01	.4209+02	.4005+01	.1020+03

ORIGINAL PAGE IS OF POOR QUALITY

GASEOUS STARTING LINE INFO

173 R/RC(ND)	174 U(FT/SEC)	175 V(FT/SEC)	176 P(ATM)	177 T(DEG K)
.0000	.6651+04	.0000	.4745+01	.2521+04
.4762-01	.6657+04	.2263+03	.4733+01	.2512+04
.9524-01	.6668+04	.4539+03	.4683+01	.2512+04
.1429+00	.6678+04	.6834+03	.4621+01	.2504+04
.1905+00	.6686+04	.9150+03	.4495+01	.2493+04
.2381+00	.6690+04	.1148+04	.4362+01	.2479+04
.2857+00	.6688+04	.1382+04	.4210+01	.2464+04
.3333+00	.6678+04	.1615+04	.4042+01	.2448+04
.3810+00	.6662+04	.1846+04	.3866+01	.2432+04
.4286+00	.6639+04	.2072+04	.3688+01	.2414+04
.4762+00	.6608+04	.2292+04	.3509+01	.2397+04
.5238+00	.6570+04	.2498+04	.3332+01	.2380+04
.5714+00	.6520+04	.2671+04	.3202+01	.2369+04
.5997+00	.6976+04	.2738+04	.3156+01	.2369+04
.6190+00	.6581+04	.2821+04	.3136+01	.2337+04
.6667+00	.6671+04	.2896+04	.3172+01	.2309+04
.6772+00	.6688+04	.2906+04	.3188+01	.2304+04
.7143+00	.6918+04	.3015+04	.3240+01	.2256+04
.7365+00	.6923+04	.3032+04	.3291+01	.2256+04
.7619+00	.7190+04	.3153+04	.3323+01	.2179+04
.8095+00	.7178+04	.3173+04	.3338+01	.2187+04
.8571+00	.7164+04	.3226+04	.3317+01	.2177+04
.9048+00	.7150+04	.3299+04	.3273+01	.2170+04
.9524+00	.7136+04	.3382+04	.3219+01	.2162+04
.1000+01	.7122+04	.3470+04	.3157+01	.2153+04

PARTICLE STARTING LINE PROPERTIES

178 POINT	179 SPECIE	180 U(FT/SEC)	181 V(FT/SEC)	182 DENSITY(GM/CC)	183 T(DEG K)
1	1	.6565+04	.0000	.8087-04	.2534+04
1	2	.6275+04	.0000	.1039-03	.2571+04
1	3	.5881+04	.0000	.1416-03	.262[illegible]+04
2	1	.6571+04	.2201+03	.7798-04	.253[illegible]+04
2	2	.6280+04	.2013+03	.1025-03	.2569+04
2	3	.5886+04	.1763+03	.1392-03	.2621+04
3	1	.6581+04	.4414+03	.7643-04	.2527+04
3	2	.6289+04	.4036+03	.1000-03	.2565+04
3	3	.5896+04	.3539+03	.1351-03	.2617+04
4	1	.6591+04	.6647+03	.7645-04	.2520+04
4	2	.6300+04	.6077+03	.9697-04	.2558+04
4	3	.5907+04	.5325+03	.1302-03	.2611+04
5	1	.6600+04	.8904+03	.7473-04	.2510+04
5	2	.6310+04	.8139+03	.9366-04	.2549+04
5	3	.5919+04	.7151+03	.1251-03	.2604+04
6	1	.6605+04	.1118+04	.7187-04	.2497+04
6	2	.6317+04	.1022+04	.9030-04	.2539+04
6	3	.5929+04	.9997+03	.1201-03	.2594+04

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Sample Printout of Data Set Prepared for BLIMPJ Boundary Layer

```
0200433210212000000   SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA
1
4
 .1549+01   .1558+01   .1577+01   .1614+01   .1674+01   .1734+01   .1794+01
 .1854+01   .1913+01   .1973+01   .2033+01   .2093+01   .2152+01   .2212+01
 .2272+01   .2332+01   .2391+01   .2451+01   .2511+01   .2570+01   .2630+01
 .2690+01   .2749+01   .2809+01   .2868+01   .2928+01   .2988+01   .3047+01
 .3107+01   .3166+01   .3226+01   .3280+01   .3345+01   .3405+01
2
 .0000      .2808-02   .6808-02   .1557-01   .2703-01   .4835-01   .1465+00
 .4154+00   .7219+00   .1000+01   .1203+01   .2500+01
0  .9500+00 1 1       .5000
 .0070      .5000-01   .1200+00   .2500+00   .3500+00   .4500+00   .6000+00
 .7500+00   .8500+00   .9500+00   .9800+00   .1000+01
 .1231+01
 .1077+01   .1586+01   .1595+01   .1611+01   .1638+01   .1665+01   .1692+01
 .1718+01   .1745+01   .1772+01   .1798+01   .1825+01   .1851+01   .1878+01
 .1905+01   .1931+01   .1958+01   .1984+01   .2010+01   .2037+01   .2063+01
 .2090+01   .2116+01   .2142+01   .2169+01   .2195+01   .2221+01   .2247+01
 .2273+01   .2300+01   .2326+01   .2352+01   .2378+01   .2404+01
 .1000+00  -.3780+03
 .3803+02
 .1136+04
 .0000
  .400+00   -.118+02    .168-01    .900+00    .900+00    .250+03
 .1136+04
 .2919+00
 .4020-06   .1580+01   .1000+01   .3560+03
20  101       300.000   1000.000   5000.000
  .375-03    .270+02    .761-02    .101+01    .697-05    .170+02
  .757-05    .160+02    .636-01    .180+02    .123-04    .300+02
  .275+00    .280+02    .918-06    .635+02    .990-02    .440+02
  .227-02    .355+02    .818-01    .280+02    .161+00    .365+02
  .227-05    .709+02    .158-04    .556+02    .115-05    .913+02
  .195-03    .127+03    .378+00    .202+01    .220-05    .290+02
  .379-05    .270+02    .378-01    .170+02
L                    J12/65AL 1.00 0.00 0.00 0.G    300.000   5000.000          1
  .25450650+01  -.75157512-04    .48674178-07  -.14045399-10    .15219285-14    2
  .38498957+05   .53100256+01    .27764983+01  -.12468495-02    .20733316-05    3
 -.15487769-08   .43185442-12    .38456100+05   .34202406+00                    4
                     J 3/77H  1.    0.    0.    0.G    300.000   5000.000          1
  .25000000+01   .00000000       .00000000      .00000000       .00000000       2
  .25474390+05  -.45989841+00    .25000000+01   .00000000       .00000000       3
  .00000000      .00000000       .25474390+05  -.45989841+00                    4
```

Printout for demonstration.

```
 .3156+00   .1836+00   .1878+00   .1808+00   .1774+00   .1738+00   .1700+01
 .1660+00   .1622+00   .1584+00   .1549+00   .1517+00   .1486+00   .1456+00
 .1426+00   .1394+00   .1361+00   .1326+00   .1291+00   .1255+00   .1219+00
 .1184+00   .1149+00   .1115+00   .1082+00   .1050+00   .1019+00   .9889-01
 .9599-01   .9321-01   .9052-01   .8792-01   .8542-01   .8300-01
```

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SUMMARY OF PARTICLE PROPERTIES
AS THEY ENTER THE BOUNDARY LAYER

PARTICLE SPECIE	STREAM-LINE	R	X	V	THETA	ENTHALPY	DENSITY	TEMPERATURE
186	187	188	189	190	191	192	193	194
1	1	.11156+01	.25276+01	.10196+05	.18629+02	.20502+08	.86288-05	.25599+04
1	2	.11222+01	.25495+01	.10201+05	.18566+02	.20460+08	.85160-05	.25546+04
1	3	.11287+01	.25713+01	.10206+05	.18502+02	.20421+08	.84105-05	.25497+04
1	4	.11352+01	.25931+01	.10210+05	.18438+02	.20383+08	.83072-05	.25450+04
1	5	.11417+01	.26149+01	.10215+05	.18374+02	.20344+08	.82044-05	.25402+04
1	6	.11481+01	.26368+01	.10219+05	.18309+02	.20306+08	.81013-05	.25354+04
1	7	.11545+01	.26586+01	.10223+05	.18245+02	.20271+08	.80064-05	.25310+04
1	8	.11609+01	.26804+01	.10227+05	.18181+02	.20236+08	.79125-05	.25266+04
1	9	.11672+01	.27023+01	.10231+05	.18116+02	.20201+08	.78186-05	.25222+04
1	10	.11736+01	.27241+01	.10235+05	.18052+02	.20166+08	.77248-05	.25179+04

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SUMMARY OF PARTICLE PROPERTIES
IN THE BOUNDARY LAYER AT THE NOZZLE EXIT PLANE

PARTICLE SPECIE	STREAM-LINE	R	X	V	THETA	ENTHALPY	DENSITY	TEMPERATURE
1	1	.11810+01	.27241+01	.10290+05	.18186+02	.19646+08	.73993-05	.24536+04
1	2	.11802+01	.27241+01	.10287+05	.18173+02	.19673+08	[illegible]	.24599+04
1	3	.11793+01	.27241+01	.10284+05	.18159+02	.19744+08	.75001-05	.24652+04
1	4	.11785+01	.27241+01	.10279+05	.18145+02	.19797+08	.75187-05	.24718+04
1	5	.11777+01	.27241+01	.10274+05	.18130+02	.19851+08	.75346-05	.24786+04
1	6	.11769+01	.27241+01	.10268+05	.18114+02	.19908+08	.75702-05	.24857+04
1	7	.11760+01	.27241+01	.10261+05	.18098+02	.19969+08	.76155-05	.24974+04
1	8	.11752+01	.27241+01	.10253+05	.18081+02	.20033+08	.76481-05	.25013+04
1	9	.11744+01	.27241+01	.10245+05	.18064+02	.20098+08	.76891-05	.25094+04
1	10	.11736+01	.27241+01	.10235+05	.18045+02	.20166+08	.77248-05	.25179+04

METHOD OF CHARACTERISTICS EXIT PLANE STARTLINE BASED ON MASS FLOW AVERAGED THERMODYNAMIC PROPERTIES

196	TOTAL PRESSURE(PSFA) -	.14063+05
197	TOTAL TEMPERATURE(R) -	.65638+04
198	SPECIFIC HEAT RATIO	.13262+01
199	MOLECULAR WEIGHT -	.18695+02
200	EXIT RADIUS(RE,FEET) -	.12314+01

R/RE	X	MACH NUMBER	FLOW ANGLE (DEG)	ENTROPY (FT**2/SEC**2/R)	TOTAL ENTHALPY (FT**2/SEC**2)
201	202	203	204	205	206
.00000	.00000	.25[illegible]+01	.[illegible]	.27[illegible]+04	.67[illegible]
.47619-01	.00000	.25802+01	.10305+01	.26999+04	.67190+08
.95238-01	.00000	.25881+01	.20500+01	.26738+04	.67223+08
.14286+00	.00000	.25982+01	.30466+01	.26428+04	.67269+08
.19048+00	.00000	.26100+01	.41081+01	.26076+04	.67325+08
.23810+00	.00000	.26234+01	.51208+01	.25679+04	.67390+08
.28571+00	.00000	.26378+01	.61195+01	.25235+04	.67458+08
.33333+00	.00000	.26521+01	.71010+01	.24777+04	.67530+08
.38095+00	.00000	.26652+01	.80609+01	.24353+04	.67607+08
.42857+00	.00000	.26768+01	.90065+01	.23954+04	.67675+08
.47619+00	.00000	.26848+01	.99525+01	.23670+04	.67726+08
.52381+00	.00000	.26858+01	.10895+02	.23627+04	.67765+08
.57143+00	.00000	.28228+01	.11882+02	.18772+04	.68483+08
.59546+00	.00000	.29778+01	.12454+02	.13394+04	.69367+08
.61905+00	.00000	.30615+01	.12878+02	.10598+04	.69837+08
.66667+00	.00000	.31681+01	.13630+02	.68541+03	.70473+08
.71429+00	.00000	.32569+01	.14328+02	.36204+03	.71008+08
.76190+00	.00000	.34239+01	.15009+02	-.24825+03	.71894+08
.79139+00	.00000	.35560+01	.15451+02	-.73186+03	.72465+08
.80952+00	.00000	.36051+01	.15634+02	-.92263+03	.72819+08
.85714+00	.00000	.36772+01	.16064+02	-.12405+04	.73272+08
.90476+00	.00000	.37657+01	.16482+02	-.16953+04	.73569+08
.95238+00	.00000	.40480+01	.16845+02	-.29213+04	.74460+08
.95905+00	.00000	.40940+01	.16897+02	-.33084+04	.74676+08
.96815+00	.00000	.38458+01	.16937+02	-.22478+04	.75216+08
.97515+00	.00000	.35775+01	.16962+02	-.12339+04	.74690+08
.98710+00	.00000	.28678+01	.17013+02	.13606+04	.71930+08
.99406+00	.00000	.23730+01	.17043+02	.30505+04	.68871+08
.99791+00	.00000	.17573+01	.17060+02	.47479+04	.63008+08
.99919+00	.00000	.12443+01	.17065+02	.55908+04	.56835+08
.99950+00	.00000	.10320+01	.17067+02	.57617+04	.54104+08
.10000+01	.00000	.10324+01	.17069+02	.42508+04	.47066+08

THE INVISCID PORTION OF THE START LINE WAS MOVED .28372 04 (FT/M) TO MATCH THE EDGE OF THE BOUNDARY LAYER

207	208	209	210	211			212
.0000	.2934+01	.2640+01	.0000	.2888+04	.0000	.0000	.67[illegible]+08
.3986-01	.2934+01	.2643+01	.6580+00	.2877+04	.0000	.0000	.6749+08
.7975-01	.2933+01	.2646+01	.1317+01	.2864+04	.0000	.0000	.6750+08
.1197+00	.2932+01	.2651+01	.1976+01	.2844+04	.0000	.0000	.6752+08
.1597+00	.2930+01	.2657+01	.2634+01	.2825+04	.0000	.0000	.6755+08
.1994+00	.2928+01	.2664+01	.3287+01	.2800+04	.0000	.0000	.6758+08
.2392+00	.2926+01	.2670+01	.3936+01	.2775+04	.0000	.0000	.6762+08
.2787+00	.2923+01	.2678+01	.4577+01	.2746+04	.0000	.0000	.6766+08
.3182+00	.2920+01	.2685+01	.5213+01	.2718+04	.0000	.0000	.6770+08
.3573+00	.2916+[illegible]	.269[illegible]	[illegible]+01	[illegible]95[illegible]	.000[illegible]	[illegible]	[illegible]74[illegible]

7. PROGRAM UTILIZATION

This section presents suggestions on how to prepare, as well as where to obtain, input data for the RAMP2F program. Areas covered for setting up the input data are: boundary equations, chemistry data, two-phase data, mesh control variables start line options, and free molecular data. Also included in this section are explanations of the various error messages, problems which may be encountered, and suggested remedies.

7.1 INPUT DATA PREPARATION

This subsection along with the instructions for setting up the sample cases provides the user with guidelines on how to prepare and obtain input data for the RAMP2F flowfield code. Input data areas covered are: boundary equations, chemistry data, two-phase data, mesh control variables, and start line options.

7.1.1 Boundary Equations

Probably the first step in setting up a problem along with determining the propellant is to determine what the geometric properties of the motor or other type problems are and then to specify the geometry in a form which is usable by the RAMP2F program. In general, the best source of motor geometric data is the motor manufacturer or the system integrator or customer. Some standard motor data can be found in Refs. 27 and 28. There are two basic types of boundary conditions which are either solid or free boundary equations. These two boundary conditions are used to specify both an upper and lower boundary for the problem.

Solid boundaries are used to describe the physical geometric boundaries (e.g., nozzle wall) and centerline. The solid boundaries can be specified by using polynomial or conic curve fits or by specifying coordinates (R,x) and local flow angle. When specifying the upper or lower boundaries, equations cannot be mixed with a point by point representation of the boundary except that a single equation can be input following a point by point representation of a fixed surface (i.e., free boundary equation following point representation of a nozzle wall or straight line following a point-by-point representation of a diffuser wall).

When using equations to specify an upper or lower boundary the user should take special care to ensure that the equations for each consecutive portion of the boundary match in both slopes (unless there is a actual discontinuity in slope) and location. The failure to do so may result in either the program "erroring off" or large variations in mass flow conservation. The example problems given in Section 8 present specific examples of utilizing equations to specify boundary conditions.

Figure 7-1 is a geometry typical of a liquid rocket motor. In this case it is desired to run the problem starting at the injector face and proceeding out into the plume. For this particular problem dimensions or angles a through i are known as well as ambient conditions. The upper boundary (nozzle wall and free boundary) will be specified using seven equations that have end points corresponding to points 1-7 on Fig. 7-1. The following seven steps are used to arrive at the seven upper boundary equations for this problem.

Step 1 (Equation 1)

A polynomial equation will be used to represent the first portion of the nozzle since the combustion chamber wall is a straight line. The coefficients of the polynomial are:

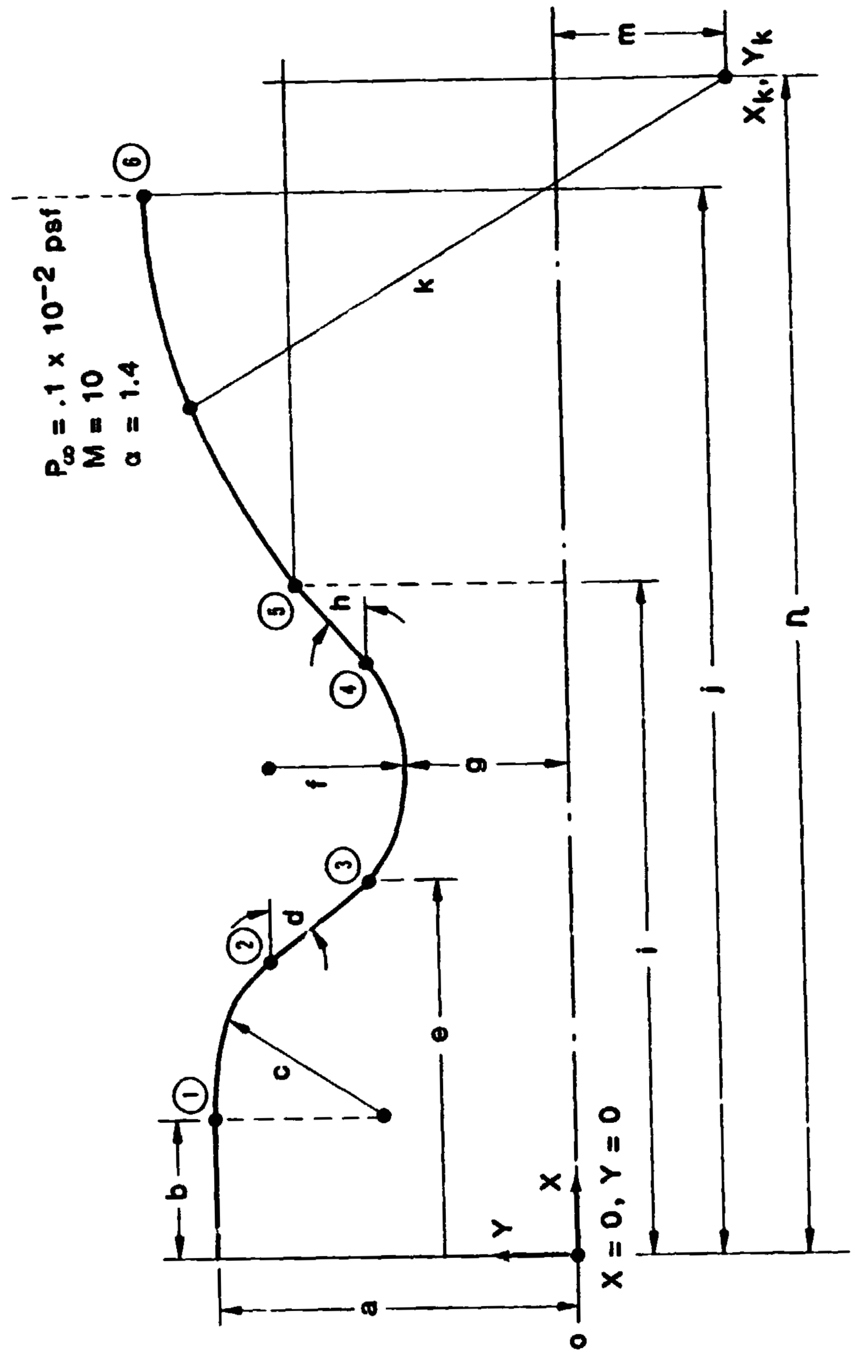

Fig. 7-1 Typical Liquid Rocket Motor Geometry

ITYPE = 2, ITRANS = 0

A = 0.0

B = 0.0

C = 0.0

D = 0.0 (slope is 0)

E = a

XMAX = b

Step 2 (Equation 2)

This portion of the combustion chamber starts at point 1 and can be represented using a conic equation (circle) of radius c whose center is at an axial position of b and a radial position of (a-c). Using the same methodology as was shown in Fig. 6-1 the coefficients of Eq. (2) are:

ITYPE = 1

ITRANS = 0

A = 0

B = c^2-b^2

C = 2b

D = -1.0

E = + (a-c)

XMAX = b + c sin(d)

Step 3 (Equation 3)

Equation (3) is a straight line at an angle of -d degrees which passes through points 2 and 3. The radial coordinate of point 2 is a - c*(1 - cos(d)). The axial coordinate is equal to XMAX for Eq. (2) which is b + c* sin(d). For this problem it is assumed that all the points 1-6 are perfectly matched as picked off drawings. Usually the drawings that the user will get to use to set up the problem do not have all the information needed so that some adjustments and engineering judgments must be made to match all the parts of the contour. The coefficients for Eq. (3) are:

ITYPE = 2

ITRANS = 0

A = 0.0

B = 0.0

C = 0.0

D = tan(d)

E = -tan(d) * x_2 + y_2

XMAX = e

Note: E is calculated from the slope of the line (-tan(d)) and the coordinates of point 2 , where x_2 = b + c sin(d) and y_2 = a - (1 - cos(d))*c.

Step 4

Equation (4) describes the throat using a circle with a radius of curvature of f whose center is at the coordinates, y = f + g, x = e + f sin(d). The coefficients for Eq. (4) are:

ITYPE = 1

ITRANS = 0

A = -1.0

B = f^2 - (e + f sin(d))^2

C = 2*(e + f sin(d))

D = -1.0

E = -(f + g)

XMAX = e + f sin(d) + f sin(h)

Step 5

Equation 5 describes the straight section of the nozzle that usually attaches the nozzle throat to the nozzle contour. A polynomial is used to describe the line that connects point 4 and 5 which is inclined at an h-degree angle. The coefficients are:

ITYPE = 2
ITRANS = 0
A = 0.0
B = 0.0
C = 0.0
D = tan(h)
E = $-\tan(h)*x_4 + y_4$
XMAX = i

Note: E is calculated from the slope of the line (tan(h)) and the coordinates of point 4 where:

x_4 = XMAX for Step 4 = e + f sin(d) + f sin(h)
y_4 = g + f(1 - cos(h))
$Y - Y_4 = m(Y - X_4)$ where: m is tan(h)

Step 6

Equation (6), which specifies the exit section of the nozzle, is described by a conic equation (circle) knowing the radius of curvature and the origin (X_k, Y_k) coordinates of the center of the circle. The coefficients of Eq.(6) are:

ITYPE = 1
ITRANS = 1 (an expansion corner exists at the exit)
A = +1.0

$B = k^2 - n^2$

$C = 2n$

$D = -1.0$

$E = - m$ (radial location of center of circle)

XMAX = j

Step 7

The last boundary equation is a free boundary or pressure boundary. As Fig. 7-1 shows the ambient pressure is 0.1×10^{-2} psfa, Mach number is 10, the flow is parallel to the nozzle axis and freestream specific heat ratio is 1.4. The coefficients for Eq. (7) are:

ITYPE = 3

ITRANS = 0

A = .1E - 02

B = 1.4

C = 10.0

D = 0.0

E = 0.0

XMAX = 1000.

Always set the XMAX for the last upper or lower boundary to a number which is greater than the problem cutoff limits.

The lower boundary for this problem is a straight line polynomial with ITYPE = 2, ITRANS = 0, coefficients A-E = 0.0 and XMAX = 1000.

The preceding example is one way to set up a problem. If some of the given information had been replaced with other data then the coefficients would still be the same, but the method of arriving at them would be different. In general, it is best to start setting up the geometry at the farthest upstream point where the solution is to begin and proceed to the downstream cutoffs. The boundary conditions should be as accurate as possible with no spatial or angular (unless they really exist) discontinuities between equations.

Many times the geometric data for the nozzle contour will be specified by a table of X,R coordinates. These data could be input to the program by curve fitting the data using one or more conic or polynomial equations or the X,R, θ option. Sample problem 1 in Section 8 is an example of setting up a problem in which the contour is specified by points. Unfortunately there are generally no flow angles specified with the tabulated points. If one were to use a spline fit for sections of the contour, previous experience indicates that in general the points specified to define a contour are not smooth enough to generate adequate curve fits using built in spline fit routines. For this reason the use of input X,R, and flow angle (θ) tables was selected as an option for the RAMP2F program. A brief description of setting up a nozzle contour using the X,R,θ option is presented in the following paragraphs. This discussion, along with sample case 1, should give the user an adequate understanding of one way to utilize this option.

Figure 7-2 shows a nozzle contour which was specified by a table of X,R coordinates. Normally a nozzle will have a throat region which is a circular arc. The first step in determining the flow angles that apply at each point is to determine for which points, a circular arc is applicable. Use simple geometric relationships to determine the radius of curvature of the throat region. From this, calculate the second derivative of the circle.

The next step is to use the remainder of the points along with the second derivative of the throat to construct a curve for the relationship of flow angle as a function of axial position (x). This is accomplished by calculating the slope of a straight line connecting each two contour points. This slope or flow angle is then the average flow angle between the two points and may be applied at the midpoint of the two contour points. Now

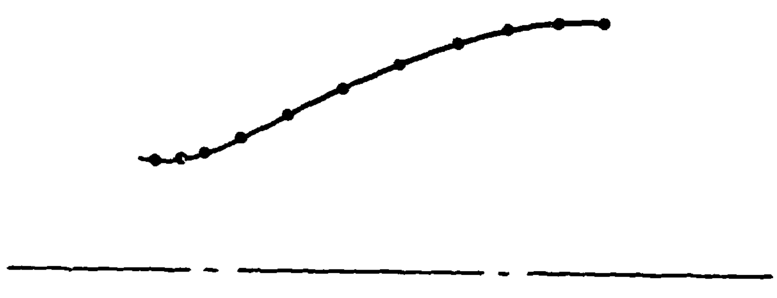

Fig. 7-2 Typical Tabulated Nozzle Contour

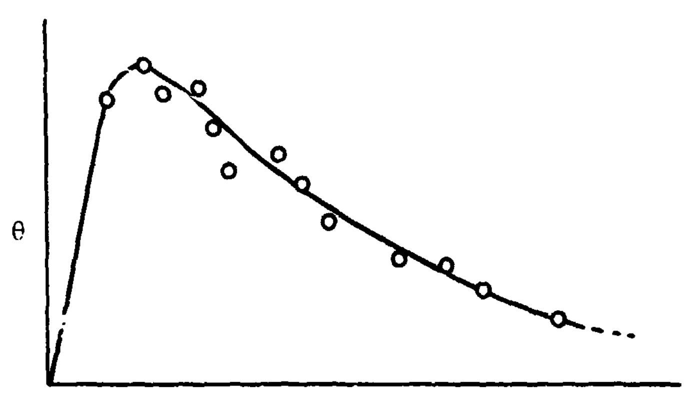

Fig. 7-3 Variation of Flow Angle as a Function of Distance from the Throat

plot each of the midpoints as a function of flow angle versus x. Figure 7-3 shows typical results. In general the points will not result in a smooth curve. To get a good representation of the variation of flow angle as a function of x, fair a curve through the plotted points and merge it with the throat region which ends at point (3) (Fig. 7-3). The variation of flow angle with x for the throat is a straight line since the second derivative of a circle is a constant. Some nozzles have the flow angle increasing beyond the throat region as is shown in Fig. 7-3, while others have straight walls for some distance before the merge into a contour (see sample problem 8-1). Sometimes it's necessary to plot the nozzle contour so that additional points may be picked off to better define the variation of flow angle with x. Now determine from the representation of flow angle versus x the flow angle at each of the contour points and input the X, R and θ's into the program. If the points are not close enough in the throat region and the flow angle varies more than approximately 5 deg add some more points. This can be done using the equation of the throat.

There are two ways to check to see how well the variation of flow angle is represented. The first is to check the mass flow conservation results that are output during the nozzle solution. If the tabulation of X, R and θ's are consistent you will see little oscillation or change in mass flow as the solution progresses down the nozzle. Typical mass flow conservation should be within 2 percent of the throat or startline mass flow. The other method is to recalculate the radial coordinates at each tabulated point. This is done by starting at the end of the throat region, and using the slope at the mid point of each two contour points and the assumption that a straight line connects them to recalculate the radial position at each point as you proceed down the nozzle. For example, say point (3) on Fig. 7-2 is the end of the throat. We know the coordinates at point (3) (X_3, R_3). The new coordinate for point (4) would be:

$$Y_4' = Y_3 + (X_4 - X_3) \tan\theta_{3-4}$$

C-3

Point (5) new radial coordinates would be:

$$Y_5' = Y_4' + (X_5 - X_4) \tan \theta_{4-5}$$

Using this same procedure the entire nozzle can be described out to the exit plane. If the θ vs X variation is a good representation of the nozzle, then the calculated coordinate of the nozzle lip should be very close to the actual nozzle exit radius. Previous calculations using this method have given good results and in many instances the Y' coordinates are the ones input into the program.

Nozzle geometric data are usually obtained from the engine manufacturer or from the organization that is integrating the motor into its particular system. At times, the information will be incomplete or not sufficiently detailed to specify the geometry using only the information which is given. In these cases, plot the geometry and use engineering judgment to determine the unknown variables.

7.1.2 Flowfield Chemistry

There are numerous chemistry assumptions which can be utilized by the RAMP2F program. The various assumptions are: (1) ideal gas (constant specific heat ratio and molecular weight); (2) equilibrium; (3) equilibrium/frozen (equilibrium with the species frozen at a specified pressure); (4) frozen (constant species distribution, varying specific heat ratio - from TRAN72 program); (5) frozen using input species thermodynamics; and (6) finite rate chemistry. The ability of the program allows the user a great deal of flexibility in applying the RAMP2 program to solve flow problems.

7.1.2.1 Ideal Gas

The ideal gas option assumes constant specific heat ratio, molecular weight, total temperature, and total pressure. This option can be used for any flow solution whether the gas is a true ideal gas or as an approximation of a real gas. The use of the ideal gas assumption for real gas problems will provide a fast, inexpensive calculation but the results will not be as accurate as a real gas calculation. Ideal gas solutions are suitable for trade studies where trends are more important than absolute values.

7.1.2.2 Equilibrium, Equilibrium/Frozen, or Frozen

The accurate treatment of the flowfield chemistry for most problems can be treated with some form of chemistry which results from calculations of the TRAN72 module of the RAMP2F program. Through the use of appropriate options (see Section 4) of the TRAN72, thermochemical data tables can be generated for the RAMP2F program which are either fully equilibrium, equilibrium with a pressure ratio in the table beyond which the species are frozen or chemically frozen from the combustion chamber. The selection of which option to use is a function of the user's particular problem although for most problems the equilibrium/frozen option is recommended since in most rocket motors the dominant species (for determination of global characteristics) freeze at some point in the nozzle (see Section 4). There are applications such as plume signatures and radar cross section where equilibrium/frozen chemistry is not adequate. For these applications the finite rate option could be used.

Setting up an equilibrium case requires certain data to be input to the TRAN72 program. These data are: chamber pressure, propellant system, propellant formulation, propellant temperature, propellant internal energy or enthalpy, freeze point (if applicable, see Section 4) and relative weights or moles of the individual reactants. There are numerous sources for these data.

Operating characteristics (chamber pressure, propellant types) for liquid motors can be found in Ref. 28. Corresponding data for solid motors are available in Ref. 27. Once the propellant system for a particular motor has been established, the particulars of the formulation required to use the TRAN72 program can be obtained from Ref. 29 for liquid motors and Ref. 30 for solid motors. In the event that the motor operating and propellant characteristics cannot be found from these manuals the engine manufacturer or system integration organization is the best alternate source.

7.1.2.3 Finite Rate Chemistry

Should the user require the use of the finite rate chemistry option, this section provides guidelines for using this option. The finite rate package can be used for a full finite rate calculation or a frozen option whereby the rates are not input and only the thermodynamic data tables are used to provide the necessary gas thermochemistry data.

Finite rate input information is input on cards 6 (control variables for finite rate calculations); card 13 (global gas properties), cards 14 (gas thermodynmaic data tables), cards 15 (catalytic species weighting factors), and cards 16 (reaction mechanisms). Additional startline information is discussed in Section 7.1.5.

The control variables for the finite rate package are input on card 6. NT is the number of temperature points in the thermodynamic data tables (cards 14) for each species. All tables must have the same number of points. NS is the number of gaseous species for the particular system, thus there will be NS tables of thermodynamic data (cards 14) required to be input. NM is the number of third bodies which are included in the reaction mechanism. NR is the number of reactions (input on cards 16) which make up the reaction package. In the event that the frozen option is utilized NM and NR should be set to zero. NPRINT is an intermediate print flag that should normally not be used. ICTAPE specifies whether the species mole fraction distributions are input for the starting line by the user or they are obtained from a data tape generated by the TRAN72 program for the particular propellant system. For starting finite rate cases in or near the throat, utilizing the TRAN72 results is recommended since for most high temperature motors the chemical equilibrium assumption up to the throat is valid. KGUP specifies the number of normals to calculate before the chemistry contributes to changes in enthalpy and entropy. Normally a value of 5 to 10 is input. This variable was incorporated to allow mismatches in the species distributions calculated using a finite rate analysis versus the species input for the start line. It is possible that bad mismatches could result in wild oscillations in the pressure and velocity field if the finite rate terms are included in the enthalpy and entropy calculations near the starting line. IDIDO specifies whether a single species distribution is applied to all points on the start line or if different distributions at each point are to be input.

The treatment of chemical non-equilibrium is handled in a completely general manner. The numerical model handles any chemical reaction or vibrational energy exchange mechanism as long as thermodynamic data for each participating species and rate constant data for each reaction are available. Twelve types of reaction or energy transfer mechanisms are considered as possible contributors to the calculation of the net rate of production, w_i, of each chemical species:

<u>Reaction Type</u>

(1,7)	$A + B \rightleftharpoons C + D$
(2,8)	$A + B + M \rightleftharpoons C + M$
(3,9)	$A + B \rightleftharpoons C + D + E$
(4,10)	$A + B \rightleftharpoons C$
(5,11)	$A + M \rightleftharpoons C + D + M$
(6,12)	$A + M \rightleftharpoons C + M$

Reaction types (7) through (12) correspond to reaction types (1) through (6), but proceed in the forward direction only.

The net rate of production for all reactions is given below in the form $w^{(j)} = RP^{(j)} - RM^{(j)}$, which are the symbols used in the computer program.

$$1.\ w^{(j)} = k_f\rho^2\ F_AF_B - \frac{k_f\rho^2\ F_CF_D}{K_p}$$

$$2.\ w^{(j)} = k_f\rho^3\ F_AF_BF_M - \frac{k_f\rho^2\ F_CF_M}{K_p\,\Re T}$$

$$3.\ w^{(j)} = k_f\rho^2\ F_AF_B - \frac{k_f\rho^3\ F_CF_DF_E\,\Re T}{K_p}$$

$$4.\ w^{(j)} = k_f\rho^2\ F_AF_B - \frac{k_f\rho F_C}{K_p\,\Re T}$$

$$5.\ w^{(j)} = k_f\rho^2\ F_AF_M - \frac{k_f\rho^3\ F_CF_DF_M\,\Re T}{K_p}$$

$$6.\ w^{(j)} = k_f{}^2\rho^2F_AF_M - \frac{k_f\rho^2\ F_CF_M}{K_p}$$

To reduce roundoff and truncation errors, $RP^{(j)}$ and $RM^{(j)}$ for each reaction are computed separately. All contributions to the molar rate of production of a given species are then computed and added algebraically to form $\dot{w}_j$. Since reaction types (7) through (12) proceed in the forward direction only, the second term on the right-hand sides of types 1 through 6 is disregarded in calculating the contributions to $\dot{w}_i$.

In reactions (2), (5), and (6) as well as in (8), (11), and (12), M denotes a third body species which can be specified. For these reactions the situation often occurs where for various third bodies the respective rate constants differ only by a constant multiplier. These multipliers can be considered as third body efficiencies or weighting factors. If such a case is encountered, the third body species mole mass ratio F_M becomes effectively a fictitious mole third body species, consisting of the weighted sum over all those species having a non-zero weighting factor, i.e.,

$$F_M = \sum_i f_i F_{M_i}$$

where f_i are the weighting factors.

The forward rate constant k_f is generally expressed in Arrhenius form. The equilibrium constant, K_p, is determined from the Gibbs free energy difference

$$\ln K_p = -\Delta G/\mathfrak{R}T$$

For speed in computation the rate constants are divided into five types:

Rate Constant Type

(1) $k_f = A$

(2) $k_f = AT^{-N}$

(3) $k_f = A\exp(B/\mathfrak{R}T)$

(4) $k_f = AT^{-N}\exp(B/\mathfrak{R}T)$

(5) $k_f = AT^{-N}\exp(B/\mathfrak{R}T^M)$

The thermodynamic properties required in the analysis include the specific heat, entropy, and enthalpy for each chemical species. Values of these properties as a function of temperature are obtainable from the JANAF thermochemical tables (Ref. 7) or other such sources. The Gibbs free energy used in determining the equilibrium constant is computed directly from the enthalpy, entropy, and temperature. The mixture specific heat at any point in the flow is given by:

$$c_p = \sum_{i=1}^{NS} c_{p_i}(T)\, F_i$$

The Prandtl number, viscosity (two phase) and viscosity exponent are input on card 13. In the event that a TRAN72 data tape is utilized (ICTAPE 0) the data input on card 13 is overridden by data obtained from the tape.

Tables 7-1 through 7-4 present some typical finite rate thermochemistry and reactions packages for typical rocket propellants. Table 7-1 represents a MMH/N_2O_4 bipropellant system. Table 7-2 shows a H_2/O_2 system. Table 7-3 gives a O_2/RP1 system. Table 7-4 is a chemistry package for a solid propellant system such as is used for the Space Shuttle SRMs. This particular package includes ionic species. If the user is not interested in radar cross sections, the ionic species and associated reactions can be omitted.

Table 7-1 MMH/N204 FINITE RATE CHEMISTRY DATA SET

24 16 3 23 0 0 2 1

C	12.001	0.0					
0.0	0.0	0.0	-.252	50.	.1975	.105	-.245
100.	.395	.210	-.238	150.	.7985	.465	-.199
200.	1.202	.720	-.160	250.	1.628	1.046	-.078
300.	2.054	1.372	.004	400.	2.851	2.075	.250
500.	3.496	2.784	.569	600.	4.038	3.471	.947
700.	4.440	4.126	1.372	800.	4.740	4.739	1.831
1000.	5.149	5.844	2.824	1200.	5.430	6.809	3.883
1400.	5.605	7.661	4.988	1600.	5.721	8.417	6.122
1800.	5.803	9.096	7.275	2000.	5.865	9.711	8.442
2300.	5.936	10.536	10.212	2600.	5.992	11.267	12.002
3000.	6.057	12.129	14.412	3300.	6.103	12.708	16.236
3600.	6.150	13.241	18.074	4000.	6.213	13.893	20.546
CH4	16.043	-17.895					
0.0	7.949	30.196	-2.396	50.	7.949	30.196	-1.9985
100.	7.949	35.706	-1.601	150.	7.975	38.924	-1.2004
200.	8.001	41.222	-.805	250.	8.268	43.011	-.40408
300.	8.535	44.543	.016	400.	9.680	47.144	.923
500.	11.076	49.953	1.960	600.	12.483	51.597	3.138
700.	13.813	53.622	4.454	800.	15.041	55.548	5.897
1000.	17.160	59.141	9.125	1200.	18.842	62.424	12.732
1400.	20.150	65.431	16.637	1600.	21.161	68.191	20.772
1800.	21.947	70.730	25.086	2000.	22.562	73.076	29.540
2300.	23.256	76.279	36.418	2600.	23.758	79.162	43.474
3000.	24.233	82.597	53.079	3300.	24.493	84.920	60.389
3600.	24.695	87.060	67.768	4000.	24.901	89.673	77.690
CO	28.010	-26.42					
0.	6.956	34.791	-2.072	50.	6.956	34.791	-1.7268
100.	6.956	39.613	-1.379	150.	6.9565	42.439	-1.0308
200.	6.95.	44.435	-0.683	250.	6.961	45.988	-.33515
300.	6.965	47.257	0.013	400.	7.013	49.265	0.711
500.	7.121	50.841	1.417	600.	7.276	52.152	2.137
700.	7.450	53.287	2.873	800.	7.624	54.293	3.627
1000.	7.931	56.028	5.183	1200.	8.168	57.496	6.794
1400.	8.346	58.769	8.446	1600.	8.480	59.893	10.130
1800.	8.583	60.898	11.836	2000.	8.664	61.807	13.561
2300.	8.756	63.024	16.175	2600.	8.825	64.102	18.813
3000.	8.895	65.370	22.357	3300.	8.937	66.220	25.032
3600.	8.973	66.999	27.719	4000.	9.014	67.946	31.316
CO2	44.0099	-94.054					
0.	6.981	37.919	-2.238	50.	6.981	37.919	-1.892
100.	6.981	42.758	-1.543	150.	7.358	45.598	-1.193
200.	7.734	47.769	-0.816	250.	8.315	49.658	-.414
300.	8.896	51.127	0.016	400.	9.877	53.830	0.958
500.	10.666	56.122	1.987	600.	11.310	58.126	3.087
700.	11.846	59.910	4.245	800.	12.293	61.522	5.453
1000.	12.980	64.344	7.984	1200.	13.466	66.756	10.632
1400.	13.815	68.859	13.362	1600.	14.074	70.722	16.152
1800.	14.269	72.391	18.987	2000.	14.424	73.903	21.857
2300.	14.600	75.931	26.212	2600.	14.739	77.730	30.613
3000.	14.873	79.848	36.535	3300.	14.956	81.270	41.010
3600.	15.030	82.579	45.508	4000.	15.119	84.162	51.538

Table 7-1 (Continued)

H	1.008	52.102					
0.	4.968	18.521	-1.481	50.	4.968	18.521	-1.2329
100.	4.968	21.965	-0.984	150.	4.968	23.979	-.7364
200.	4.968	25.408	-0.488	250.	4.968	26.517	-.2394
300.	4.968	27.423	0.009	400.	4.968	28.852	0.506
500.	4.968	29.961	1.003	600.	4.968	30.867	1.5
700.	4.968	31.632	1.996	800.	4.968	32.296	2.493
1000.	4.968	33.404	3.487	1200.	4.968	34.310	4.481
1400.	4.968	35.075	5.474	1600.	4.968	35.739	6.468
1800.	4.968	36.325	7.461	2000.	4.968	36.848	8.455
2300.	4.968	37.538	9.946	2600.	4.968	38.152	11.436
3000.	4.968	38.862	13.423	3300.	4.968	39.394	14.923
3600.	4.968	39.926	16.423	4000.	4.968	40.636	18.410
H2	2.016	0.					
0.	5.393	20.649	-2.024	50.	5.393	20.649	-1.535
100.	5.393	24.387	-1.265	150.	5.9555	26.726	-.9738
200.	6.518	28.520	-0.662	250.	6.706	30.011	-.327
300.	6.894	31.251	0.013	400.	6.975	33.247	0.707
500.	6.993	34.806	1.406	600.	7.009	36.082	2.106
700.	7.036	37.165	2.808	800.	7.087	38.107	3.519
1000.	7.219	39.702	4.944	1200.	7.390	41.033	6.404
1400.	7.600	42.187	7.902	1600.	7.823	43.217	9.446
1800.	8.016	44.150	11.030	2000.	8.195	45.004	12.651
2300.	8.432	46.160	15.157	2600.	8.639	47.213	17.708
3000.	8.859	48.465	21.210	3300.	9.0	49.6	23.000
3600.	9.3	50.8	25.00	4000.	9.4	53.0	28.000
H20	18.016	-57.798					
0.0	7.961	30.878	-2.367	50.	7.961	30.878	-1.979
100.	7.961	36.396	-1.581	150.	7.965	39.624	-1.1824
200.	7.969	41.516	-.784	250.	7.998	43.694	-.3856
300.	8.027	45.155	.015	400.	8.186	47.483	.825
500.	8.415	49.334	1.654	600.	8.676	50.891	2.509
700.	8.954	52.249	3.390	800.	9.246	53.464	4.300
1000.	9.851	55.591	6.209	1200.	10.444	57.440	8.240
1400.	10.987	59.092	10.384	1600.	11.462	60.591	12.630
1800.	11.869	61.965	14.964	2000.	12.214	63.234	17.373
2300.	12.634	64.971	21.103	2600.	12.965	66.540	24.945
3000.	13.304	68.420	30.201	3300.	13.503	69.698	34.223
3600.	13.669	70.880	38.300	4000.	13.850	72.330	43.805
NH3	17.03061	-10.97					
0.0	7.95	31.699	-2.404	50.	7.95	31.699	-2.0065
100.	7.950	37.210	-1.609	150.	8.2895	40.323	-1.2311
200.	8.064	42.740	-0.811	250.	8.295	44.552	-.4045
300.	8.526	46.085	.016	400.	9.241	48.633	.903
500.	10.036	50.780	1.867	600.	10.808	52.679	2.909
700.	11.538	54.400	4.027	800.	12.225	55.986	5.215
1000.	13.467	58.851	7.787	1200.	14.550	61.404	10.592
1400.	15.460	63.718	13.596	1600.	16.205	65.833	16.765
1800.	16.762	67.776	20.066	2000.	17.220	69.566	23.465
2300.	17.825	72.015	28.723	2600.	18.370	74.234	34.154
3000.	19.000	76.908	41.631	3300.	19.341	78.734	47.383
3600.	19.672	80.432	53.235	4000.	20.100	82.827	61.190
NO	30.008	21.58					
0.0	7.721	36.93	-2.197	50.0	7.721	36.934	-1.837
100.	7.721	42.286	-1.451	150.	7.496	45.353	-1.074
200.	7.271	47.477	-0.705	250.	7.202	49.085	-.3453
300.	7.132	50.392	.013	400.	7.157	52.444	.727
500.	7.287	54.053	1.448	600.	7.466	55.397	2.186
700.	7.655	56.562	2.942	800.	7.832	57.596	3.716
1000.	8.123	59.377	5.313	1200.	8.336	60.878	6.960
1400.	8.491	62.175	8.644	1600.	8.605	63.317	10.354
1800.	8.692	64.335	12.084	2000.	8.759	65.256	13.829
2300.	8.837	66.484	16.469	2600.	8.895	67.571	19.129
3000.	8.965	68.849	22.700	3300.	8.991	69.709	25.392
3600.	9.022	70.488	28.094	4000.	9.058	71.440	31.710

Table 7-1 (Continued)

N2	28.0134	0.0					
0.	6.956	33.348	-2.072	50.	6.956	33.348	-1.7268
100.	6.956	38.170	-1.379	150.	6.9565	40.99	-1.0308
200.	6.957	42.992	-0.683	250.	6.959	44.544	-.335
300.	6.961	45.813	0.013	400.	6.990	47.818	0.710
500.	7.069	49.386	1.413	600.	7.196	50.685	2.125
700.	7.350	51.806	2.853	800.	7.512	52.798	3.596
1000.	7.815	54.507	5.129	1200.	8.061	55.955	6.718
1400.	8.252	57.212	8.350	1600.	8.398	58.324	10.015
1800.	8.512	59.320	11.707	2000.	8.601	60.222	13.418
2300.	8.703	61.431	16.015	2600.	8.703	62.503	18.638
3000.	8.855	63.765	22.165	3300.	8.855	64.611	24.829
3600.	8.939	65.387	27.505	4000.	8.983	66.331	31.089
OH	17.0074	9.432					
0.0	7.798	30.321	-2.192	50.0	7.798	30.321	-1.8569
100.0	7.798	35.726	-1.467	150.0	7.577	38.837	-1.084
200.0	7.356	40.985	-.711	250.0	7.2605	42.61	-.3476
300.0	7.165	43.925	.013	400.0	7.087	45.974	.725
500.0	7.055	47.551	1.432	600.0	7.057	48.837	2.137
700.0	7.09	49.927	2.845	800.0	7.15	50.877	3.556
1000.0	7.332	52.491	5.003	1200.0	7.549	53.847	6.491
1400.0	7.766	55.027	8.023	1600.0	7.963	56.077	9.596
1800.0	8.137	57.025	11.207	2000.0	8.286	57.891	12.849
2300.0	8.472	59.062	15.364	2600.0	8.622	60.11	17.929
3000.0	8.78	61.355	21.411	3300.0	8.876	62.197	24.06
3600.0	8.959	62.973	26.735	4000.0	9.053	63.922	30.338
O	16.0	59.559					
0.0	5.666	28.539	-1.608	50.	5.666	28.539	-1.3633
100.	5.666	32.466	-1.080	150.	5.55	34.76	-.7976
200.	5.434	36.340	-.523	250.	5.3345	37.537	-.2542
300.	5.235	38.501	.010	400.	5.135	39.991	.528
500.	5.081	41.131	1.038	600.	5.049	42.054	1.544
700.	5.029	42.831	2.048	800.	5.015	43.501	2.550
1000.	4.999	44.619	3.552	1200.	4.990	45.529	4.551
1400.	4.984	46.298	5.548	1600.	4.981	46.963	6.544
1800.	4.979	47.550	7.540	2000.	4.978	48.074	8.536
2300.	4.980	48.770	10.029	2600.	4.986	49.381	11.524
3000.	5.004	50.096	13.522	3300.	5.025	50.573	15.026
3600.	5.050	51.012	16.537	4000.	5.091	51.546	18.565
O2	32.0	0.0					
0.0	6.958	36.572	-2.075	50.	6.958	36.572	-1.7289
100.	6.958	41.395	-1.381	150.	6.9595	44.216	-1.033
200.	6.961	46.218	-.685	250.	6.992	47.769	-.3379
300.	7.023	49.047	.013	400.	7.196	51.091	.724
500.	7.431	52.722	1.455	600.	7.670	54.098	2.210
700.	7.883	55.297	2.988	800.	8.063	56.361	3.786
1000.	8.336	58.192	5.427	1200.	8.527	59.729	7.114
1400.	8.674	61.055	8.835	1600.	8.800	62.222	10.583
1800.	8.916	63.265	12.354	2000.	9.029	64.21	14.149
2300.	9.194	65.483	16.882	2600.	9.354	66.62	19.664
3000.	9.551	67.973	23.446	3300.	9.682	68.889	26.331
3600.	9.799	69.737	29.254	4000.	9.932	70.776	33.201
CH3	15.03506	34.820					
0.	7.982	31.645	-2.487	50.	7.982	31.645	-2.091
100.	7.982	37.178	-1.692	150.	8.25	40.434	-1.2902
200.	8.518	42.846	-.871	250.	8.89	44.783	-.4368
300.	9.262	46.438	.017	400.	10.048	49.21	.983
500.	10.815	51.536	2.026	600.	11.541	53.572	3.144
700.	12.231	55.404	4.333	800.	12.888	57.08	5.589
1000.	14.09	60.088	8.29	1200.	15.109	62.75	11.213
1400.	15.939	65.144	14.321	1600.	16.602	67.317	17.578
1800.	17.129	69.304	20.953	2000.	17.548	71.131	24.422
2300.	18.028	73.618	29.762	2600.	18.38	75.851	35.226
3000.	18.716	78.506	42.649	3300.	18.901	80.299	48.293
3600.	19.045	81.95	53.986	4000.	19.194	83.965	61.635

Table 7-1 (Concluded)

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CH20     30.027      -27.700
  0.0        7.949      43.486      -2.395     50.        7.949      43.486     -1.9975
100.         7.949      43.479      -1.60     150.        7.978      46.697     -1.2036
200.         8.007      48.996      -.804     250.        8.241      50.789     -.[illegible]019
300.         8.475      52.313       .016     400.        9.385      54.869      .906
500.        10.46       57.077      1.898     600.       11.524      59.079     2.998
700.        12.505      60.931      4.20      800.       13.38       62.659     5.495
1000.       14.817      65.806      8.322    1200.       15.893      68.608    11.398
1400.       16.693      71.121     14.66     1600.       17.291      73.391    18.062
1800.       17.746      75.455     21.567    2000.       18.095      77.343    25.153
2300.       18.483      79.90      30.643    2600.       18.76       82.184    36.232
3000.       19.019      84.888     43.791    3300.       19.159      86.707    49.518
3600.       19.268      88.379     55.283    4000.       19.379      90.415    63.014
CHO      29.019      -2.900
  0.0        7.949      43.481      -2.387     50.        7.949      43.481     -1.99
100.         7.949      44.93       -1.593    150.        7.974      48.149     -1.1953
200.         7.999      50.447      -.796     250.        8.135      52.238     -.39515
300.         8.271      53.734       .015     400.        8.703      56.171      .863
500.         9.184      58.164      1.758     600.        9.66       59.881     2.70
700.        10.108      61.404      3.689     800.       10.518      62.781     4.72
1000.       11.216      65.206      6.896    1200.       11.758      67.301     9.196
1400.       12.172      69.196     11.591    1600.       12.489      70.793    14.059
1800.       12.732      72.279     16.582    2000.       12.921      73.63     19.148
2300.       13.133      75.452     23.058    2600.       13.286      77.071    27.022
3000.       13.43       78.983     32.367    3300.       13.508      80.267    36.408
3600.       13.569      81.445     40.47     4000.       13.631      82.878    45.911
M1
  1.0  1.0  1.0  2.0  1.0  1.0  6.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
M2
  1.0  1.0  1.0  3.0 20.0  2.5 10.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
M3
  1.0  1.0  1.5  3.0  1.0  1.0 10.0  1.0  1.0  1.0  1.0  1.0 20.0  1.0  1.0  1.0
H      +OH     +M1     =H20    +M1                     22 6.10-26 2.0      0.0
O      +H      +M1     =OH     +M1                     21 1.00-32 0.0      0.0
O      +O      +M1     =O2     +M1                     24 3.80-30 1.0   -390.0
H      +H      +M2     =H2     +M2                     22 2.80-30 1.0      0.0
CO     +O      +M3     =CO2    +M3                     23 2.00-33 0.0  -4000.0
OH     +H              =H2     +O                      14 1.40-14-1.0  -7000.0
OH     +O              =H      +O2                     11 4.00-11 0.0      0.0
OH     +H2             =H20    +H                      14 1.00-17-2.0  -2900.0
OH     +CO             =CO2    +H                      14 1.10-19-2.0   1600.0
OH     +OH             =H20    +O                      13 1.00-11 0.0  -1100.0
CH4    +OH             =CH3    +H20                    13 4.7 -11          -5000.0
CH4    +H              =CH3    +H2                     13 2.4 -11          -5000.0
CH4    +O              =CH3    +OH                     13 3.5 -11          -9100.0
CH3    +O              =CH20   +H                      11 1.1 -10
CH20   +OH             =CHO    +H20                    12 9.0 -13  -.5
CH20   +H              =CHO    +H2                     13 2.2 -11          -3800.0
CH20   +O              =CHO    +OH                     11 1.6 -13
CH20   +M1             =CO     +H2     +M1             53 3.5 -08         -35000.0
CHO    +OH             =CO     +H20                    11 2.1 -10
CHO    +H              =CO     +H2                     13 8.3 -11         -10000.0
CHO    +O              =CO     +OH                     11 2.1 -10
CHO    +O2             =CO     +H      +O2             73 8.3 -11          -1600.0
CHO    +M1             =CO     +H      +M1             53 1.2 -10         -15000.0
```

OR
OF PO

Table 7-2 H_2/O_2 FINITE RATE CHEMISTRY DATA SET

24 5 2 8 [illegible] 0 21 0

H	1.008	52.102					
0.	4.968	19.382	-1.481	50.	4.968	19.382	-1.233
100.	4.968	21.965	-0.984	150.	4.968	23.979	-0.736
200.	4.968	25.408	-0.488	250.	4.968	26.517	-0.239
300.	4.968	27.423	0.009	400.	4.968	28.852	0.506
500.	4.968	29.961	1.003	600.	4.968	30.867	1 5
700.	4.968	31.632	1.996	800.	4.968	32.296	2.493
1000.	4.968	33.404	3.457	1200.	4.968	34.310	4.481
1400.	4.968	35.075	5.474	1600.	4.968	35.739	6.468
1800.	4.968	36.325	7.461	2000.	4.968	36.848	8.455
2300.	4.968	37.539	9.946	2600.	4.968	38.152	11.436
3000.	4.968	38.862	13.423	3300.	4.968	39.394	14.923
3600.	4.968	39.926	16.423	4000.	4.968	40.636	18.410
H2	2.016	0.0					
0.	5.393	20.649	-1.804	50.	5.393	20.649	-1.535
100.	5.393	24.387	-1.265	150.	5.455	26.586	-0.994
200.	6.518	28.520	-0.662	250.	6.706	29.995	-0.331
300.	6.894	31.251	0.013	400.	6.975	33.247	0.707
500.	6.993	34.806	1.406	600.	7.009	36.082	2.106
700.	7.036	37.165	2.808	800.	7.087	38.107	3.514
1000.	7.219	39.702	4.944	1200.	7.330	41.033	6.404
1400.	7.600	42.187	7.902	1600.	7.923	43.217	9.446
1800.	8.016	44.150	11.030	2000.	8.195	45.004	12.651
2300.	8.432	46.160	15.157	2600.	8.639	47.213	17.708
3000.	8.859	4[illegible].465	21.210	3300.	9.0	49.6	23.300
3600.	9.3	50.8	25.00	4000.	9.4	53.0	28.0[illegible]
H2O	18.016	-57.798					
0.0	0.0	0.0	-2.367	50.	3.9805	18.198	-1.974
100.	7.961	36.396	-1.581	150.	7.965	39.156	-1.18
200.	7.969	41.916	- .784	250.	7.998	43.535	- .384
300.	8.027	45.155	.015	400.	8.186	47.483	.825
500.	8.415	49.334	1.654	600.	8.676	50.891	2.509
700.	8.954	52.249	3.390	800.	9.246	53.464	4.300
1000.	9.851	55.591	6.209	1200.	10.444	57.440	8.240
1400.	10.987	59.092	10.384	1600.	11.462	60.591	12.630
1800.	11.869	61.965	14.964	2000.	12.214	63.234	17.373
2300.	12.634	64.971	21.103	2600.	12.965	66.540	24.945
3000.	13.304	6[illegible].420	30.201	3300.	13.503	69.698	34.223
3600.	13.669	7[illegible].880	38.300	4000.	13.850	72.330	43.805
O	16.	59.559					
0.0	0.0	0.0	-1.608	50.	2.633	16.233	-1.354
100.	5.666	32.466	-1.080	150.	5.690	34.403	-.751
200.	5.434	36.340	-.523	250.	5.335	37.420	-.257
300.	5.235	38.501	.010	400.	5.135	39.991	.529
500.	5.081	41.131	1.036	600.	5.049	42.054	1.544
700.	5.029	42.831	2.048	800.	5.015	43.501	2.550
1000.	4.999	44.619	3.552	1200.	4.990	45.529	4.551
1400.	4.984	46.298	5.548	1600.	4.981	46.963	6.544
1800.	4.979	47.550	7.540	2000.	4.978	48.074	8.536
2300.	4.980	48.770	10.029	2600.	4.986	49.381	11.524
3000.	5.004	5[illegible].096	13.522	3300.	5.025	50.573	15.026
3600.	5.050	51.012	16.537	4000.	5.091	51.546	18.565
OH	17.008	9.73					
0.0	0.0	0.0	-2.107	50.	3.7835	17.926	-1.779
100.	7.567	35.852	-1.451	150.	7.488	38.436	-1.079
200.	7.309	41.021	- .707	250.	7.2215	42.891	- .347
300.	7.134	43.962	.013	400.	7.077	46.005	.724
500.	7.049	47.582	1.430	600.	7.053	48.867	2.134
700.	7.087	49.956	2.841	800.	7.148	50.906	3.553
1000.	7.329	52.52[illegible]	5.0	1200.	7.548	53.875	6.497
1400.	7.764	55.055	8.019	1600.	7.963	56.105	9.591
1800.	8.136	57.053	11.282	2000.	8.285	57.918	12.496
2300.	8.470	5[illegible].089	15.358	2600.	8.621	60.137	17.923

Table 7-2 (Concluded)

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3300.       9.778     61.342    21.474    3300.      8.973    62.223    24.252
3600.       8.355     62.930    26.726    4000.      9.146    65.947    30.327
02         32.          .0
  0.0       0.0         .0      -2.075      50.      3.479    24.701    -2.024
 100.       6.358     41.412    -1.381     150.      6.9595   43.809    -1.033
 200.       6.761     46.225    - .685     250.      6.992    47.641    - .336
 300.       7.723     49.354      .313     400.      7.196    51.097      .723
 500.       7.431     52.727     1.454     600.      7.670    54.103     2.210
 700.       7.883     55.312     2.987     800.      8.063    56.367     3.785
1000.       8.336     58.197     5.427    1200.      8.527    59.735     7.114
1400.       8.674     61.061     8.834    1600.      9.800    62.227    10.582
1800.       8.916     63.270    12.354    2000.      9.029    64.216    14.148
2300.       9.194     65.469    16.882    2600.      9.354    66.626    19.664
3300.       9.551     67.979    23.446    3300.      9.682    68.895    26.331
3600.       9.799     69.742    29.254    4000.      9.932    70.782    33.201
M1
  1.0   1.0   3.0   1.0   1.0   1.0
M2
 20.0   2.5  10.0   1.0   0.0   1.0
H        +OH      +M1  =H20     +M1                22 6.1-26 2.0        0.0
O        +H       +M1  =OH      +M1                21 2.0-32 0.0        0.0
O        +O       +M1  =O2      +M1                24 3.8-30 1.0     -340.0
H        +H       +M2  =H2      +M2                22 2.8-30 1.0        0.0
OH       +H            =H2      +O                 14 1.4-14-1.0    -7000.0
OH       +O            =H       +O2                11 4.0-11 0.0        0.0
OH       +H2           =H20     +H                 14 1.0-17-2.0    -2900.0
OH       +OH           =H20     +O                 13 1.0-11 0.0    -1100.0
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ORIGINAL PAGE IS OF POOR QUALITY

Table 7-3 O_2/RP1 FINITE RATE CHEMISTRY DATA SET

24 4 5 1[illegible] 21 0

CO	28.01	-26.42					
0.	6.956	39.613	-1.379	50.	6.956	39.613	-1.379
100.	6.956	39.613	-1.379	150.	6.956	42.024	-1.031
200.	6.957	44.435	-0.683	250.	6.961	45.946	-0.335
300.	6.965	47.257	0.013	400.	7.013	49.265	0.711
500.	7.121	50.841	1.417	600.	7.276	52.152	2.137
700.	7.450	53.287	2.873	800.	7.624	54.293	3.627
1000.	7.931	56.028	5.183	1200.	8.168	57.496	6.794
1400.	8.346	58.769	8.446	1600.	8.480	59.893	10.130
1800.	8.583	60.898	11.836	2000.	8.664	61.807	13.561
2300.	8.756	63.024	16.175	2600.	8.825	64.102	18.813
3000.	8.895	65.370	22.357	3300.	8.937	66.220	25.032
3600.	8.973	66.999	27.719	4000.	9.014	67.946	31.316
CO2	44.0099	-94.054					
0.	6.981	42.758	-1.543	50.	6.981	42.758	-1.543
100.	6.981	42.758	-1.543	150.	7.437	45.263	-1.179
200.	7.734	47.769	-0.816	250.	8.315	49.448	-0.400
300.	8.896	51.127	0.016	400.	9.877	53.830	0.958
500.	10.666	56.122	1.987	600.	11.310	58.126	3.087
700.	11.846	59.910	4.245	800.	12.293	61.522	5.453
1000.	12.980	64.344	7.984	1200.	13.466	66.756	10.632
1400.	13.815	68.859	13.362	1600.	14.074	70.722	16.152
1800.	14.269	72.391	18.987	2000.	14.424	73.903	21.857
2300.	14.690	75.931	26.212	2600.	14.734	77.730	30.613
3000.	14.973	79.846	36.535	3300.	14.956	81.270	41.010
3600.	15.030	82.574	45.509	4000.	15.119	84.162	51.538
H	1.008	52.102					
0.	4.969	19.382	-1.481	50.	4.969	19.382	-1.233
100.	4.968	21.965	-0.984	150.	4.968	23.975	-0.736
200.	4.968	25.4[illegible]	-0.488	250.	4.968	26.517	-0.239
300.	4.968	27.423	0.009	400.	4.968	28.852	0.506
500.	4.968	29.961	1.003	600.	4.968	30.867	1.5[illegible]
700.	4.968	31.632	1.996	800.	4.968	32.296	2.493
1000.	4.968	33.404	3.487	1200.	4.968	34.310	4.481
1400.	4.969	35.075	5.474	1600.	4.968	35.739	6.469
1800.	4.968	36.325	7.461	2000.	4.969	36.849	8.455
2300.	4.968	37.538	9.946	2600.	4.968	38.152	11.436
3000.	4.968	38.862	13.423	3300.	4.968	39.394	14.923
3600.	4.969	39.926	16.423	4000.	4.968	40.636	18.41[illegible]
H2	2.016	0.0					
0.	5.393	20.649	-1.994	50.	5.393	20.649	-1.535
100.	5.393	24.367	-1.265	150.	5.455	26.565	-0.994
200.	6.51[illegible]	28.520	-0.662	250.	6.706	29.955	-0.331
300.	6.894	31.251	0.013	400.	6.975	33.247	0.707
500.	6.993	34.806	1.406	600.	7.009	36.082	2.106
700.	7.036	37.165	2.808	800.	7.087	38.107	3.514
1000.	7.219	39.702	4.944	1200.	7.390	41.033	6.404
1400.	7.620	42.187	7.902	1600.	7.823	43.217	9.446
1800.	8.016	44.150	11.030	2000.	8.195	45.004	12.651
2300.	9.432	46.160	15.157	2600.	8.639	47.213	17.708
3000.	8.959	48.465	21.210	3300.	9.0	49.6	23.[illegible]
3600.	9.3	50.8	25.[illegible]	4000.	9.4	53.8	29.[illegible]
H2O	18.016	-57.798					
0.0	0.0	0.0	-2.367	50.	3.9805	18.199	-1.974
100.	7.961	36.396	-1.581	150.	7.965	39.156	-1.19
200.	7.969	41.916	- .784	250.	7.998	43.535	- .384
300.	8.027	45.155	.015	400.	8.186	47.483	.825
500.	8.415	49.334	1.654	600.	8.676	50.891	2.509
700.	8.954	52.249	3.390	800.	9.246	53.464	4.300
1000.	9.851	55.591	6.209	1200.	10.444	57.440	8.249
1400.	10.987	59.092	11.364	1600.	11.462	60.591	12.630
1800.	11.869	61.965	14.964	2000.	12.214	63.234	17.373
2300.	12.634	64.971	21.103	2600.	12.965	66.540	24.945
3000.	13.304	68.429	30.201	3300.	13.503	69.696	34.223
3600.	13.669	70.8[illegible]	38.300	4000.	13.850	72.33[illegible]	43.805

Table 7-3 (Concluded)

O	16.	59.559					
0.0	0.0	0.0	-1.606	50.	2.933	16.233	-1.354
100.	5.666	32.466	-1.360	150.	5.630	34.403	-.751
200.	5.434	36.346	-.523	250.	5.335	37.420	-.257
300.	5.235	38.571	.012	400.	5.135	39.991	.526
500.	5.061	41.131	1.038	600.	5.049	42.054	1.544
700.	5.029	42.821	2.046	800.	5.015	43.501	2.550
1000.	4.999	44.619	3.552	1200.	4.990	45.529	4.551
1400.	4.984	46.298	5.548	1600.	4.981	46.963	6.544
1800.	4.979	47.550	7.540	2000.	4.978	48.074	8.536
2300.	4.980	48.773	10.029	2600.	4.986	49.381	11.524
3000.	5.004	50.096	13.522	3300.	5.025	50.573	15.026
3600.	5.050	51.012	16.537	4000.	5.091	51.546	18.565
OH	17.008	9.33					
0.0	0.0	0.0	-2.167	50.	3.7835	17.976	-1.779
100.	7.567	35.652	-1.451	150.	7.460	38.426	-1.079
200.	7.309	41.021	-.737	250.	7.2215	42.851	-.347
300.	7.134	43.962	.013	400.	7.077	46.006	.724
500.	7.049	47.582	1.430	600.	7.053	48.867	2.134
700.	7.087	49.956	2.841	800.	7.148	50.966	3.553
1000.	7.329	52.520	5.0	1200.	7.546	53.875	6.477
1400.	7.764	55.055	8.018	1600.	7.963	56.105	9.591
1800.	8.136	57.057	11.202	2000.	8.265	57.918	12.496
2300.	8.479	59.059	15.358	2600.	8.621	60.137	17.923
3000.	8.776	61.352	21.424	3300.	8.873	62.223	24.052
3600.	8.955	62.995	26.726	4000.	9.046	63.947	30.327
O2	32.	0.0					
0.0	0.0	0.0	-2.075	50.	3.479	26.701	-1.728
100.	6.958	41.402	-1.381	150.	6.9595	43.808	-1.033
200.	6.961	45.225	-.685	250.	6.992	47.641	-.336
300.	7.023	49.054	.013	400.	7.196	51.097	.723
500.	7.431	52.727	1.454	600.	7.670	54.103	2.210
700.	7.883	55.302	2.987	800.	8.063	56.367	3.785
1000.	8.336	58.197	5.427	1200.	8.527	59.735	7.114
1400.	8.674	61.061	8.834	1600.	8.800	62.227	10.582
1800.	8.916	63.272	12.354	2000.	9.029	64.216	14.148
2300.	9.194	65.499	16.882	2600.	9.354	66.626	19.664
3000.	9.551	67.976	23.446	3300.	9.682	68.865	26.331
3600.	9.799	69.742	29.254	4000.	9.932	70.762	33.201

M1							
1.0	2.0	1.0	1.0	3.0	1.0	1.0	1.0
M2							
1.0	3.0	2.0	2.5	10.0	1.0	1.0	1.0
M3							
1.5	3.0	1.0	1.0	10.0	1.0	1.0	20.0

H	+OH	+M1	=H2O	+M1	22	6.1-26	2.0		0.0
O	+H	+M1	=OH	+M1	21	2.0-32	0.0		0.0
O	+O	+M1	=O2	+M1	24	3.8-30	1.0		-340.0
H	+H	+M2	=H2	+M2	22	2.8-31	1.0		0.0
CO	+O	+M3	=CO2	+M3	23	2.0-33	0.0		-4000.0
OH	+H		=H2	+O	14	1.4-14	-1.0		-7000.0
OH	+O		=H	+O2	11	4.0-11	0.0		0.0
OH	+H2		=H2O	+H	14	1.0-17	-2.0		-2900.0
OH	+CO		=CO2	+H	14	1.1-19	-2.0		1500.0
OH	+OH		=H2O	+O	13	1.0-11	0.0		-1100.0

Table 7-4 SOLID PROPELLANT FINITE RATE CHEMISTRY DATA SET

24 2.	3 24	0 1	21 0				
CO	28.01	-26.42					
0.	6.956	39.613	-1.379	50.	6.956	39.613	-1.379
100.	6.956	39.613	-1.379	150.	6.956	42.024	-1.031
200.	6.957	44.435	-0.683	250.	6.961	45.846	-0.335
300.	6.965	47.257	0.013	400.	7.013	49.265	0.711
500.	7.121	50.841	1.417	600.	7.276	52.152	2.137
700.	7.455	53.287	2.873	800.	7.624	54.293	3.627
1000.	7.931	56.026	5.183	1200.	8.168	57.496	6.794
1400.	8.346	58.769	8.446	1600.	8.480	59.893	10.130
1800.	8.583	60.899	11.836	2000.	8.664	61.807	13.561
2300.	8.756	63.024	16.175	2600.	8.825	64.102	18.813
3000.	8.895	65.374	22.357	3300.	8.937	66.220	25.032
3600.	8.973	66.999	27.719	4000.	9.014	67.946	31.316
CO2	44.0099	-94.054					
0.	6.981	42.758	-1.543	50.	6.981	42.758	-1.543
100.	6.981	42.758	-1.543	150.	7.407	45.263	-1.179
200.	7.734	47.769	-0.816	250.	8.315	49.448	-0.408
300.	8.896	51.127	0.016	400.	9.877	53.830	0.958
500.	10.566	56.122	1.987	650.	11.310	58.126	3.087
700.	11.846	59.917	4.245	800.	12.293	61.522	5.453
1000.	12.960	64.344	7.984	1200.	13.466	66.756	10.632
1400.	13.815	68.859	13.362	1600.	14.074	70.722	16.152
1800.	14.269	72.391	18.987	2000.	14.424	73.903	21.857
2300.	14.600	75.931	26.212	2600.	14.734	77.730	30.613
3000.	14.873	79.848	36.535	3300.	14.956	81.270	41.310
3600.	15.033	82.574	45.508	4000.	15.119	84.162	51.530
H	1.008	52.102					
0.	4.968	19.302	-1.481	50.	4.968	19.382	-1.233
100.	4.968	21.965	-0.984	150.	4.968	23.979	-0.736
200.	4.968	25.428	-0.488	250.	4.968	26.517	-0.239
300.	4.968	27.423	0.009	400.	4.968	28.852	0.506
500.	4.968	29.961	1.003	600.	4.968	30.867	1.5
700.	4.968	31.632	1.996	800.	4.968	32.296	2.493
1000.	4.968	33.404	3.487	1200.	4.968	34.310	4.481
1400.	4.968	35.075	5.474	1600.	4.968	35.739	6.468
1800.	4.968	36.325	7.461	2000.	4.968	36.848	8.455
2300.	4.968	37.539	9.946	2600.	4.968	38.152	11.436
3000.	4.968	38.862	13.423	3300.	4.968	39.394	14.923
3600.	4.968	39.926	16.423	4000.	4.968	40.636	18.410
H2	2.016	0.0					
0.	5.393	20.649	-1.804	50.	5.393	20.649	-1.535
100.	5.393	24.347	-1.265	150.	5.455	26.586	-0.994
200.	6.518	28.520	-0.662	250.	6.706	29.995	-0.331
300.	6.854	31.251	0.013	400.	6.975	33.247	0.707
500.	6.993	34.866	1.406	600.	7.009	36.082	2.106
700.	7.036	37.165	2.808	800.	7.087	38.107	3.514
1000.	7.219	39.702	4.944	1200.	7.390	41.033	6.404
1400.	7.620	42.187	7.792	1600.	7.823	43.217	9.446
1800.	8.016	44.153	11.030	2000.	8.195	45.004	12.651
2300.	8.432	46.166	15.157	2600.	8.639	47.213	17.738
3000.	8.859	48.465	21.210	3300.	9.0	49.6	23.030
3600.	9.2	50.8	25.00	4000.	9.4	53.0	28.000
H2O	18.016	-57.798					
0.	0.0	0.0	-2.367	50.	3.9865	18.198	-1.974
100.	7.961	36.396	-1.581	150.	7.965	39.156	-1.18
200.	7.969	41.916	- .784	250.	7.998	43.535	- .384
300.	8.027	45.155	.015	400.	8.186	47.483	.825
500.	8.415	49.334	1.654	600.	8.676	50.891	2.509
700.	8.954	52.249	3.390	800.	9.246	53.464	4.300
1000.	9.851	55.591	6.209	1200.	10.444	57.440	8.240

Table 7-4 (Continued)

1400.	10.987	59.092	10.384	1600.	11.462	60.591	12.630
1800.	11.869	61.965	14.964	2000.	12.214	63.234	17.373
2300.	12.634	64.971	21.103	2600.	12.965	66.540	24.905
3000.	13.384	69.420	30.201	3300.	13.503	69.698	34.223
3600.	13.669	70.085	38.300	4000.	13.858	72.338	43.005
O	16.	59.559					
0.0	0.0	0.0	-1.660	50.	2.833	16.233	-1.354
100.	5.666	32.466	-1.600	150.	5.608	34.403	-.751
200.	5.434	36.346	-.523	250.	5.335	37.420	-.257
300.	5.235	38.591	.010	400.	5.135	39.991	.520
500.	5.081	41.131	1.038	600.	5.049	42.054	1.544
700.	5.029	42.831	2.049	800.	5.015	43.501	2.550
1000.	4.999	44.619	3.552	1200.	4.996	45.529	4.551
1400.	4.984	46.298	5.548	1600.	4.981	46.963	6.544
1800.	4.979	47.556	7.546	2000.	4.978	48.074	8.536
2300.	4.980	48.773	10.829	2600.	4.986	49.381	11.524
3000.	5.004	50.096	13.522	3300.	5.025	50.573	15.026
3600.	5.058	51.012	16.537	4000.	5.091	51.546	18.565
OH	17.008	9.33					
0.0	0.0	0.0	-2.167	50.	3.7835	17.926	-1.779
100.	7.567	35.052	-1.451	150.	7.400	38.436	-1.079
200.	7.309	41.021	-.767	250.	7.2215	42.801	-.347
300.	7.134	43.962	.013	400.	7.077	46.006	.724
500.	7.049	47.582	1.430	600.	7.053	48.867	2.134
700.	7.087	49.956	2.841	800.	7.148	50.906	3.553
1000.	7.329	52.528	5.0	1200.	7.548	53.875	6.487
1400.	7.764	55.655	8.018	1600.	7.963	56.105	9.591
1800.	8.136	57.053	11.202	2000.	8.285	57.918	12.496
2300.	8.479	59.089	15.358	2600.	8.621	60.137	17.923
3000.	8.778	61.302	21.434	3300.	8.873	62.223	24.052
3600.	8.955	62.999	26.726	4000.	9.046	63.947	30.327
O2	32.	0.0					
0.0	0.0	0.0	-2.075	50.	3.479	20.701	-1.728
100.	6.958	41.402	-1.381	150.	6.9595	43.808	-1.033
200.	6.961	46.225	-.685	250.	6.992	47.641	-.336
300.	7.023	49.054	.013	400.	7.196	51.097	.723
500.	7.431	52.727	1.454	600.	7.670	54.183	2.210
700.	7.883	55.302	2.987	800.	8.063	56.367	3.785
1000.	8.336	58.197	5.427	1200.	8.527	59.735	7.114
1400.	8.674	61.061	8.834	1600.	8.800	62.227	10.582
1800.	8.916	63.270	12.354	2000.	9.029	64.216	14.140
2300.	9.194	65.489	16.882	2600.	9.354	66.626	19.664
3000.	9.551	67.978	23.446	3300.	9.682	68.895	26.331
3600.	9.799	69.742	29.254	4000.	9.932	70.782	33.201
CL	35.457	28.922					
0.	4.969	33.955	-1.002	50.	4.969	33.955	-1.002
100.	4.969	33.955	-1.002	150.	5.003	35.683	-0.752
200.	5.030	37.412	-0.503	250.	5.130	38.456	-0.256
300.	5.223	39.408	0.010	400.	5.376	41.013	0.540
500.	5.436	42.220	1.081	600.	5.445	43.212	1.625
700.	5.424	44.350	2.169	800.	5.389	44.772	2.170
1000.	5.314	45.967	3.700	1200.	5.249	46.930	4.836
1400.	5.197	47.735	5.880	1600.	5.156	48.426	6.915
1800.	5.125	49.031	7.943	2000.	5.101	49.570	8.966
2300.	5.073	50.281	10.492	2600.	5.053	50.902	12.011
3000.	5.034	51.623	14.020	3300.	5.024	52.103	15.537
3600.	5.016	52.539	17.043	4000.	5.007	53.067	19.047
CL2	70.906	0.0					
0.	7.001	45.150	-1.498	50.	7.001	45.150	-1.498
100.	7.001	45.150	-1.498	150.	7.228	47.653	-1.135

Table 7-4 (Continued)

200.	7.576	50.156	-0.772	250.	7.847	51.747	-0.378
300.	8.119	53.339	0.015	400.	8.437	55.724	0.845
500.	8.624	57.628	1.690	600.	8.741	59.212	2.567
700.	8.821	60.565	3.445	800.	8.878	61.747	4.331
1000.	8.956	63.737	6.115	1200.	9.010	65.375	7.912
1400.	9.051	66.767	9.718	1600.	9.086	67.978	11.532
1800.	9.117	69.050	13.352	2000.	9.149	70.813	15.179
2300.	9.203	71.295	17.931	2600.	9.268	72.427	20.701
3000.	9.374	73.762	24.429	3300.	9.461	74.658	27.255
3600.	9.546	75.485	30.166	4000.	9.645	76.496	33.945
HCL	36.465	-22.063					
0.	6.959	37.041	-1.379	50.	6.959	37.041	-1.379
100.	6.959	37.041	-1.379	150.	6.960	39.453	-1.031
200.	6.961	41.865	-0.683	250.	6.962	43.276	-0.335
300.	6.964	44.688	0.013	400.	6.973	46.693	0.710
500.	7.004	48.252	1.408	600.	7.069	49.534	2.112
700.	7.167	50.630	2.823	800.	7.289	51.595	3.546
1000.	7.559	53.253	5.030	1200.	7.819	54.652	6.569
1400.	8.043	55.875	8.155	1600.	8.229	56.691	9.783
1800.	8.382	57.540	11.445	2000.	8.509	58.830	13.135
2300.	8.666	60.630	15.711	2600.	8.778	61.099	18.327
3000.	8.902	62.364	21.864	3300.	8.976	63.216	24.546
3600.	9.041	64.000	27.249	4000.	9.115	64.956	30.881
N2	28.0134	0.0					
0.	6.956	38.170	-1.379	50.	6.956	38.170	-1.379
100.	6.956	38.170	-1.379	150.	6.956	40.586	-1.031
200.	6.957	42.992	-0.683	250.	6.959	44.402	-0.335
300.	6.961	45.813	0.013	400.	6.990	47.818	0.710
500.	7.069	49.386	1.413	600.	7.196	50.685	2.125
700.	7.350	51.806	2.853	800.	7.512	52.798	3.596
1000.	7.815	54.507	5.129	1200.	8.061	55.955	6.718
1400.	8.252	57.212	8.350	1600.	8.398	58.324	10.015
1800.	8.512	59.326	11.707	2000.	8.601	60.222	13.418
2300.	8.7[illegible]3	61.431	16.015	2600.	8.703	62.503	18.638
3000.	8.855	63.765	22.165	3300.	8.855	64.611	24.829
3600.	8.939	65.387	27.505	4000.	8.983	66.331	31.089
CL-	35.453	-55.9					
0.0	0.0	0.0	0.0	50.	4.968	36.658	0.0
100.0	4.968	36.658	0.0	150.	4.968	36.658	0.0
200.0	4.968	36.658	0.0	250.	4.968	36.658	0.0
300.0	4.968	36.658	0.0	400.	4.968	38.088	0.506
500.0	4.968	39.196	1.003	600.	4.968	40.102	1.500
700.0	4.968	40.868	1.996	800.	4.968	41.531	2.493
1000.0	4.968	42.640	3.487	1200.	4.968	43.546	4.481
1400.0	4.968	44.312	5.474	1600.	4.968	44.975	6.468
1800.0	4.968	45.560	7.461	2000.	4.968	46.084	8.455
2300.0	4.968	46.778	9.945	2600.	4.968	47.387	11.436
3000.0	4.968	48.098	13.423	3300.	4.968	48.572	14.914
3600.0	4.968	49.024	16.434	4000.	4.968	49.527	18.391
E	.0005488	0.0					
0.0	0.0	0.0	0.0	50.	4.968	5.019	0.0
100.0	4.968	5.019	0.0	150.	4.968	5.019	0.0
200.0	4.968	5.019	0.0	250.	4.968	5.019	0.0
300.0	4.968	5.019	0.009	400.	4.968	6.449	0.506
500.0	4.968	7.557	1.003	600.	4.968	8.463	1.500
700.0	4.968	9.229	1.996	800.	4.968	9.892	2.493
1000.0	4.968	11.001	3.487	1200.	4.968	11.906	4.480
1400.0	4.968	12.672	5.474	1600.	4.968	13.336	6.467
1800.0	4.968	13.921	7.461	2000.	4.968	14.444	8.455
2300.0	4.968	15.138	9.945	2600.	4.968	15.748	11.435
3000.0	4.968	16.458	13.423	3300.	4.968	16.932	14.913
3600.0	4.968	17.364	16.403	4000.	4.968	17.888	18.390

Table 7-4 (Continued)

K	39.1	21.31					
0.0	0.0	0.0	-1.481	50.	4.968	16.434	-1.282
100.0	4.968	32.869	-0.984	150.	4.968	34.091	-0.736
200.0	4.968	36.313	-0.488	250.	4.968	37.328	-0.248
300.0	4.968	38.327	0.009	400.	4.968	39.757	0.506
500.0	4.968	40.865	1.003	600.	4.968	41.771	1.500
700.0	4.968	42.537	1.996	800.	4.968	43.200	2.493
1000.0	4.968	44.369	3.487	1200.	4.968	45.215	4.481
1400.0	4.970	45.981	5.474	1600.	4.975	46.645	6.469
1800.0	4.988	47.231	7.465	2000.	5.013	47.758	8.465
2300.0	5.087	48.463	9.978	2600.	5.213	49.094	11.522
3000.0	5.489	49.857	13.658	3300.	5.802	50.394	15.349
3600.0	6.242	50.917	17.152	4000.	7.111	51.616	19.810
K+	39.1	122.896					
0.0	0.0	0.0	0.0	50.	4.968	36.950	0.0
100.0	4.968	36.950	0.0	150.	4.968	36.950	0.0
200.0	4.968	36.950	0.0	250.	4.968	36.950	0.0
300.0	4.968	36.950	.009	400.	4.968	38.379	0.506
500.0	4.968	39.488	1.003	600.	4.968	40.394	1.500
700.0	4.968	41.159	1.996	800.	4.968	41.823	2.493
1000.0	4.968	42.931	3.487	1200.	4.968	43.837	4.481
1400.0	4.968	44.603	5.474	1600.	4.968	45.267	6.468
1800.0	4.968	45.852	7.461	2000.	4.968	46.375	8.455
2300.0	4.968	47.070	9.945	2600.	4.968	47.679	11.436
3000.0	4.968	48.390	13.423	3300.	4.968	48.863	14.914
3600.0	4.968	49.295	16.404	4000.	4.968	49.819	18.391
KCL	74.555	-51.31					
0.0	0.0	0.0	-2.362	50.	7.576	48.122	-2.037
100.0	7.576	48.122	-1.652	150.	8.003	50.904	-1.248
200.0	8.436	53.687	-0.844	250.	8.578	55.428	-0.433
300.0	8.726	57.170	0.016	400.	8.857	59.701	0.896
500.0	8.930	61.685	1.786	600.	8.979	63.318	2.691
700.0	9.015	64.705	3.581	800.	9.046	65.911	4.484
1000.0	9.097	67.935	6.298	1200.	9.141	69.598	8.122
1400.0	9.182	71.010	9.995	1600.	9.221	72.238	11.795
1800.0	9.259	73.327	13.643	2000.	9.297	74.304	15.499
2300.0	9.353	75.607	18.296	2600.	9.408	76.758	21.110
3000.0	9.482	78.169	24.888	3300.	9.536	79.015	27.741
3600.0	9.591	79.847	30.610	4000.	9.664	80.862	34.461
NA	22.991	25.755					
0.0	0.0	0.0	-1.481	50.0	4.968	29.564	-1.247
100.0	4.968	31.286	-0.984	150.0	4.968	33.008	-0.736
200.0	4.968	34.735	-0.488	250.0	4.968	35.738	-0.24
300.0	4.968	36.745	0.009	400.0	4.968	38.174	0.506
500.0	4.968	39.282	1.003	600.0	4.968	40.188	1.5
700.0	4.968	40.954	1.996	800.0	4.968	41.617	2.493
1000.0	4.968	42.726	3.487	1200.0	4.968	43.632	4.481
1400.0	4.968	44.398	5.474	1600.0	4.968	45.061	6.468
1800.0	4.970	45.646	7.462	2000.0	4.973	46.170	8.456
2300.0	4.985	46.866	9.949	2600.0	5.013	47.478	11.448
3000.0	5.089	48.203	13.467	3300.0	5.184	48.690	15.007
3600.0	5.324	49.146	16.582	4000.0	5.604	49.721	18.763
NA+	22.991	145.755					
0.0	0.0	0.0	-1.481	50.0	4.968	28.186	-1.247
100.0	4.968	29.908	-0.984	150.0	4.968	31.630	-0.736
200.0	4.968	33.352	-0.488	250.0	4.968	34.360	-0.24
300.0	4.968	35.367	0.009	400.0	4.968	36.796	0.506
500.0	4.968	37.905	1.003	600.0	4.968	38.811	1.5
700.0	4.968	39.577	1.996	800.0	4.968	40.240	2.493
1000.0	4.968	41.349	3.487	1200.0	4.968	42.254	4.481
1400.0	4.968	43.020	5.474	1600.0	4.968	43.684	6.468
1800.0	4.968	44.269	7.461	2000.0	4.968	44.792	8.455
2300.0	4.968	45.487	9.945	2600.0	4.968	46.096	11.436
3000.0	4.968	46.807	13.423	3300.0	4.968	47.280	14.914
3600.0	4.968	47.712	16.404	4000.0	4.968	48.236	18.391

Table 7- 4 (Concluded)

NACL	58.448	-43.36					
0.0	0.0	0.0	-2.258	50.0	6.624	43.558	-1.948
100.0	7.265	46.224	-1.597	150.0	7.707	48.891	-1.210
200.0	8.148	51.557	-0.822	250.0	8.353	53.254	-0.403
300.0	8.558	54.950	0.016	400.0	8.749	57.441	0.882
500.0	8.854	59.466	1.763	600.0	8.921	61.026	2.652
700.0	8.969	62.405	3.546	800.0	9.006	63.605	4.445
1000.0	9.064	65.622	6.252	1200.0	9.110	67.270	8.070
1400.0	9.152	68.686	9.896	1600.0	9.190	69.910	11.730
1800.0	9.227	70.995	13.572	2000.0	9.263	71.969	15.421
2300.0	9.315	73.267	18.208	2600.0	9.367	74.412	21.010
3000.0	9.435	75.757	24.770	3300.0	9.485	76.659	27.608
3600.0	9.536	77.486	30.461	4000.0	9.602	78.495	34.289

M1

1.0 2.0 1.0 1.0 3.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0

M2

1.0 3.0 20.0 1.0 10.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0

M3

1.5 3.0 1.0 1.0 10.0 1.0 1.0 20.0 1.0 1.0 1.0 1.0

H	+OH	+M1	=H2O	+M1	22	6.1-26	2.0	0.0
O	+H	+M1	=OH	+M1	21	2.0-32	0.0	0.0
O	+O	+M1	=O2	+M1	24	3.8-30	1.0	-340.0
H	+H	+M2	=H2	+M2	22	2.8-30	1.0	0.0
CO	+O	+M3	=CO2	+M3	23	2.0-33	0.0	-4000.0
H	+CL	+M1	=HCL	+M1	22	1.1-31	1.0	0.0
CL	+CL	+M1	=CL2	+M1	24	4.3-31	1.0	1250.0
OH	+H		=H2	+O	14	1.4-14	-1.0	-7000.0
OH	+O		=H	+O2	11	4.0-11	0.0	0.0
OH	+H2		=H2O	+H	14	1.0-17	-2.0	-2900.0
OH	+CO		=CO2	+H	14	1.1-19	-2.0	1600.0
OH	+OH		=H2O	+O	13	1.0-11	0.0	-1100.0
OH	+HCL		=H2O	+CL	14	1.0-14	-1.0	-1000.0
O	+HCL		=OH	+CL	13	2.0-12	0.0	-4500.0
H	+CL2		=HCL	+CL	13	2.0-10	0.0	-2400.0
CL	+H2		=HCL	+H	13	8.0-11	0.0	-5260.0
K	+HCL		=KCL	+H	13	6.0-10	0.0	-5000.0
NA	+HCL		=NACL	+H	13	5.0-10	0.0	-8000.0
K+	+E	+M1	=K	+M1	24	2.0-22	1.5	
NA+	+E	+M1	=NA	+M1	24	1.5-20	2.0	
K+	+CL-		=K	+CL	14	1.0-08	0.5	
NA+	+CL-		=NA	+CL	14	3.0-08	0.5	
CL	+E	+M1	=CL-	+M1	21	3.0-30	0.0	
HCL	+E		=H	+CL-	13	1.0-08	0.0	-20000.0

7.1.3 Two-Phase Data

Input data required for two phase flow solutions include: particle sizes and weight distributions, thermodynamics (specific heats, melt temperature, and heat of fusion), mass density and drag laws. This section discusses each of these types of data, suggests what values can be used to input aluminized solid propellant cases, and supplies additional sources of particle information.

7.1.3.1 Mean Particle Size

Unless a mean particle size or distribution is given for a particular motor the first piece of information which is required for two-phase cases is a mass mean particle size. Numerous methods have been proposed and used for determining the mean particle size for a given motor/propellant combination. Reference 25 provides an excellent discussion of the various methods of determining mean particle size. Reference 25 recommends a mean particle size correlation that can be used. This correlation is:

$$D_{43} = 3.6304\, D_t^{0.2932} \left(1 - e^{-0.0008163\,\varepsilon_c P_c \tau}\right)$$

where:

D_{43}	=	mass-weighted average diameter (microns)
D_t	=	nozzle throat diameter (in.)
ε_c	=	A_2O_3 concentration in chamber (g-mol/100 g)
P_c	=	chamber pressure (psia)
τ	=	average chamber residence time (msec)

An alternative and very simple correlation of mean particle size correlation of Delaney (Ref. 31) can also be used:

$$D_m = 4D_t^{.3}$$

where D_m is the mean particle diameter in microns and D_t is the throat diameter in inches. Delaney's correlation has been shown to be invalid for throat diameters less than approximately .083 ft, so that the user can use the previous correlation or the following correlation obtained from Ref. 32 for motors which have diameters less than .083 ft:

$$D_p = 0.454\ (P_c)^{1/3}\ (\xi)^{1/3}\ [1 - e^{-0.004\ L^*}]\ (1 + 0.045\ D_t)$$

D_p = mass mean particle diameter (microns)

ξ = mole fraction of condensed phase

L = chamber volume parameter (in.)

D_t = nozzle throat diameter (in.)

P_c = chamber pressure (psia)

7.1.3.2 Particle Size Distribution

For many calculations in which no particle impingement on the wall is anticipated, one particle size at the mean size can be used. However, for plume calculations a knowledge of the particle size distribution is necessary.

Delaney (Ref. 31) showed that the distribution of particles for smaller motors ($D_t \leq 3.5$ in.) followed a log normal distribution (Fig. 7-4). For the large motors ($D_t \geq 3.5$ in.) the data indicate that the size distribution follows a normal distribution (Fig. 7-5). To use these distributions, move the curves up or down to the mean size at the 50 percent coordinate, then divide the curve into five or six sections corresponding to a

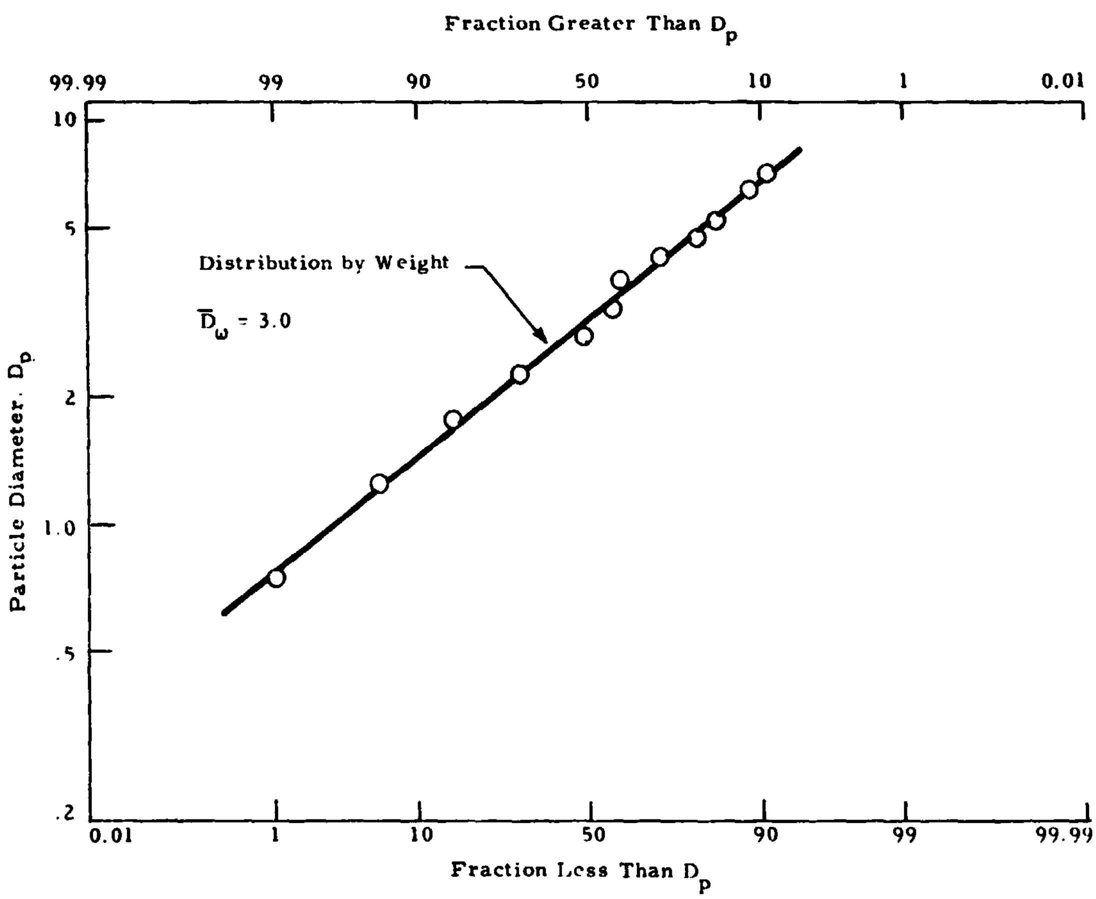


Fig. 7-4 Log Normal Particle Size Distribution from HI 5 PC Motor

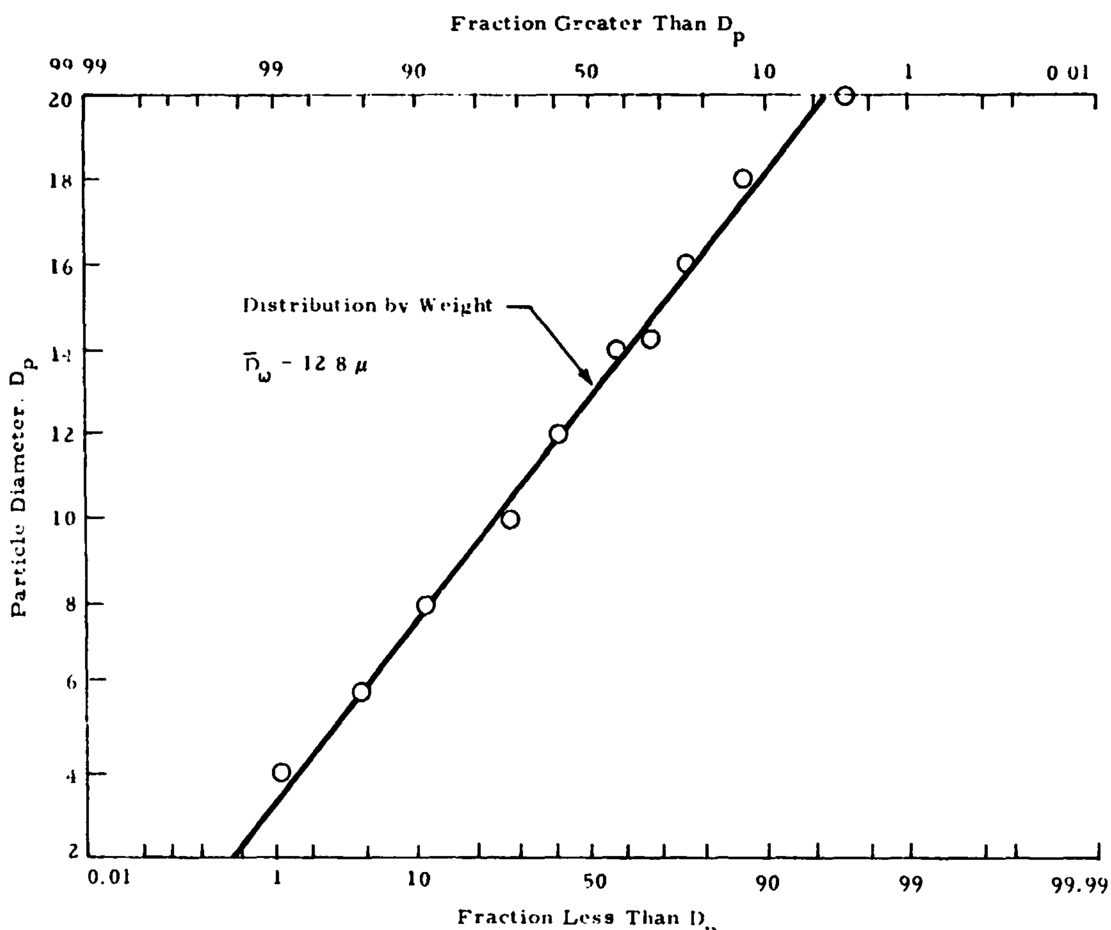


Fig. 7-5 Normal Particle Size Distribution from AGC 260-2 Motor

percentage of the total particle mass and determine the mean size that goes with each of these sections. Table 7-5 gives an example of the size distribution (for six discrete sizes) which was determined from the curve in Fig. 7-4. As was the case for the mean size, if a particle size distribution is known for a given motor it may be input directly into the program.

Table 7-5

LOG NORMAL PARTICLE SIZE DISTRIBUTION
FOR HI 5 PC MOTOR

Particle Diameter (microns)	Percent Total Particle Mass Flow
1.2	10
1.9	20
2.65	20
3.5	20
5.0	20
8.0	10

7.1.3.3 Particle Mass Density

Mass density for aluminum oxide is different for solid and liquid phases. Reference 33 shows the mass density of liquid aluminum oxide (Al_2O_3) to be 188 lbm/ft^3. The mass density of solid Al_2O_3 is 250 lbm/ft^3. For cases where the particle temperatures will be higher than the melting temperature for most of the flow field, the liquid mass density should be used. In cases where the particle temperature will be below the melting temperature (i.e., plumes) the solid mass density should be used. Should the propellant formulation result in solids other than aluminum oxide, Ref. 34 can be consulted for the appropriate mass density.

7.1.3.4 Particle Thermodynamics

The solution of the governing equations for the gas-particle system requires a relationship between particle temperature and enthalpy. There are two methods in the RAMP2F whereby the user may supply this information. The first method is an "ideal" simulation of the variation of temperature with enthalpy and the second method is to input tables of temperature versus enthalpy directly.

The ideal approximation of the variation of particle temperature versus enthalpy assumes that the specific heat capacity of the particulate is a constant for the solid phase and another constant for the liquid phase. Another requirement of this method is a knowledge of the melt temperature, the enthalpy of the solid at the melt temperature and the enthalpy of the liquid phase of the particle at the melt temperature. Figure 7-6 is a graphical example of the ideal approximation for Al_2O_3 using the values of the necessary input data (see Table 7-6) for Al_2O_3. The important aspects of this variation are: (1) the solid phase enthalpy at the melt temperature must be equal to product of the heat capacity of the solid phase and the melt temperature, and (2) the difference between the enthalpies of the liquid and solid phases at the melt temperature must be equal to the heat of fusion of the particle.

Table 7-6
Al_2O_3 THERMODYNAMIC DATA

Liquid A $_2O_3$ Specific Heat (C_{p_ℓ})	.34 Btu/lbm°R)
Solid A $_2O_3$ Specific Heat (C_{p_s})	.32 Btu/lbm°R
Enthalpy of Solid Phase of Al_2O_3 at Melting Temperature	1340.16 Btu/lbm
Enthalpy of Liquid Phase of Al_2O_3 at Melting Temperature	1839.96 Btu/lbm
Melting Temperature	4188°R

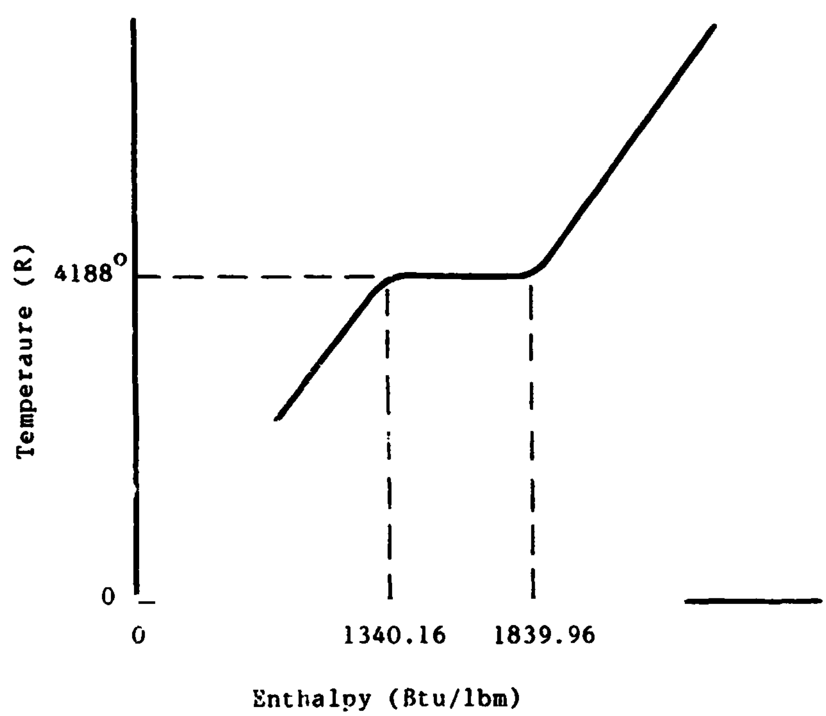


Fig. 7-6 Ideal Approximation of Al_2O_3 Temperature Variation as Function of Enthalpy

A good source of data for the necessary data (T_m, C_{p_ℓ} , C_{p_s} and ΔHf) for particles other than Al_2O_3 is Ref. 21.

The other option for inputting the variation of particle temperature versus enthalpy is to input a table of particle enthalpies and temperatures. The advantage of this method is that variations in particle heat capacity for each of the phases may be included in the tables. These data may be obtained from Ref. 21. The only constraint on using this method is that two entries must be made at the meet temperature. One at the solid phase and one at the liquid phase. As with the ideal approximation, the difference in enthalpies between the two phases must be equal to the heat of fusion. If the liquid and solid phase tables are referenced to a different enthalpy then a constant may be added or subtracted from the liquid enthalpies in order to get the correct heat of fusion. The tables should be input with the temperature monotomically increasing.

7.1.3.5 Particle Drag Law

There are three drag laws preently built into the RAMP2F program. The drag laws will be referred to as Kliegel (Ref. 22), Crowe (Ref. 23), and Henderson (Ref. 24). The recommended drag law to use for two-phase calculations is the Henderson drag law. Previous studies (Ref. 35) have shown that the Kleigel correlation is satisfactory for the flow regimes encountered in nozzles but overpredicts the drag on particles in Mach number/ Reynolds number regimes encountered in high altitude plumes. For nozzles the Kliegel method can be used since it is more economical in computer time but it should not be used for high altitude plumes where particle trajectory locations are important. Reference 25 provides additional discussions of various drag laws.

7.1.4 Startline Options

There are numerous startline options available within the RAMP2F. The user selectable startline option for single phase flow are: input start line, program set up one-dimensional start line based on given area ratio or Mach number, and constant O/F or variable O/F transonic start line. From two-phase cases the start line may be input or calculated by the program using the two-phase transonic module (Ref. 25). Section 7.1.4.1 discusses the input for the various startline options for single phase cases and Section 7.1.4.2 discusses the two-phase startline options.

7.1.4.1 Single Phase Start Lines

The startline options for single phase cases range in complexity from one-dimensional to the most detailed variable O/F transonic start lines. Input requirements for each of the start line options are fairly straightforward and will be discussed in the following paragraphs.

As mentioned previously, the RAMP2F program uses data surfaces which are constructed along normals to streamline (regular characteristic mode) or vertical surfaces (shock capturing mode). When inputting a startline or setting up a one-dimensional start line, the shape of the start line should be consistent with the method of solution. For streamline normal solutions of diverging flows the axial coordinate of the centerline points (first point on start line) must be downstream of the wall point(last point on the start line). If the data surface is too far from a true normal provisions have been made in the program to alter the solution techniuqe to compensate. Figure 7-7 shows the construction of data surfaces if the input surface is a true normal, and Fig. 7-8 shows the construction of data surfaces if the start line is far from a normal. For shock capturing solutions the start line should be a vertical surface (x = constant), but if the input start line is not a vertical surface then the construction of data surfaces will proceed as shown in Fig. 7-9.

The start lines which are input by the user are either generated by previous RAMP2F calcualtions or are generated from some other source. The input requirements for each start line point are straightforward and are explained in Section 6. The only care which should be taken in inputting the start line is that the entropy and O/F (or total enthalpy) must be consistent with the thermodynamic data tables. One should keep in mind that the reference entropy level for each O/F or total enthalpy gas table is zero which corresponds to the combustion chamber pressure. If an entropy level for a start line is input at a value other than zero then a head loss (decreased total pressure) or head gain (increased total pressure) must have been introduced at the start line.

One-dimensional start lines require the user to input the axial coordinates of the start line at the upper and lower boundary, the Mach number or area ratio of the entropy level, and the O/F ratio (total enthalpy) of the start line. If the start line is input at the throat the axial coordinate of the start line at the wall and centerline should be the same (since the flow angle along the start line is zero). If the start line is at the exit plane of the motor the axial coordinate of the startline on the wall should correspond to the lip (X_{lip}). Using trigonometric relationships and the assumption that the flow is sourcelike at the exit the coordinate at the centerline is:

$$X_{CL} = X_{LIP} + R_{LIP}\left(\frac{1}{\sin\theta_{LIP}} - \frac{1}{\tan\theta_{LIP}}\right)$$

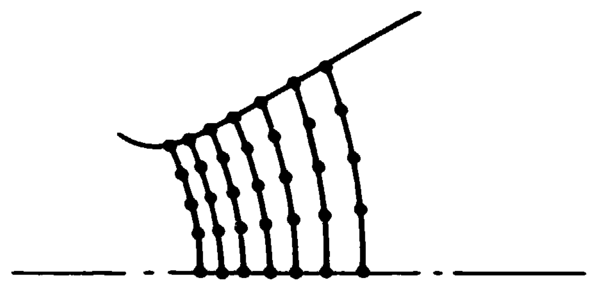


Fig. 7-7 Data Surface Construction for a True Input Normal (Streamline Normal Solution)

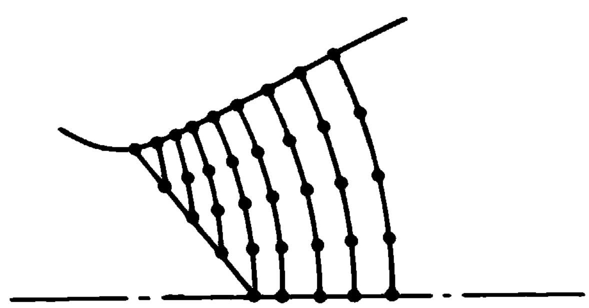


Fig. 7-8 Data Surface Construction for a Non-Normal Startline (Streamline Normal Solution)

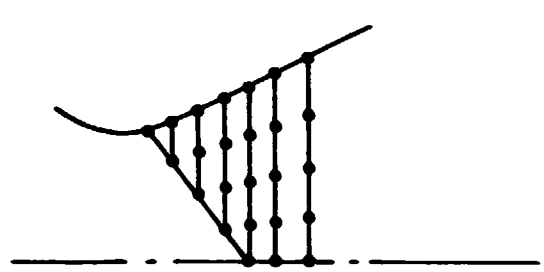


Fig. 7-9 Data Surface Construction for a Non-Vertical Startline (Shock Capturing Solution)

The Mach number of the start line must be greater than 1.0 and should be consistent with the geometry of the motor. The area ratio must be greater than 1.0 and, like the Mach number, should be consistent with the geometry. The entropy level of the start line should, in general, be 0.0 unless it is desired to change the total conditions of the start line relative to the input gas thermodynamic tables. The O/F or total enthalpy of the start line must be input consistent with the thermodynamic table O/F or total enthalpy. If there is only one O/F or total enthalpy table then the value input does not effect the solution. If there are more than one total enthalpy or O/F ratio thermo table then the input value for the start line should correspond to the table corresponding to the O/F or total enthalpy desired on the start line.

When letting the program set up a startline for a finite rate (or frozen, ICON(1)=4) case, the user may input the species distribution, or the user may elect to let the program determine the species on the start line from an input TRAN72 data tape. In either case, the same distribution will be applied at all startline points. The species values that are selected from the thermo data tape are taken to be those at the throat for the last O/F or total enthalpy on the data tape. This limitation will be eliminated on a future version of the program.

The single phase transonic module provides the final option for single phase start lines. This module utilizes a time dependent finite difference method to solve the nozzle flow field in the combustion chamber/throat region of the nozzle. From this flowfield solution a start line is set up for the nozzle/plume solution. The transonic module can be run for options ICON(1) = 1 or 2 only, not for finite rate cases (ICON(1) >2). This limitation will be eliminated in future versions of the code. Results of an equilibrium/frozen transonic solution could be used to input a start line for a finite rate case.

The single phase transonic module can be used for constant or variable O/F solutions. To generate a variable O/F solution requires the input of radial variations in O/F ratio at the initial station (usually the entrance) to the convergent section of the nozzle). The determintion of an O/F distribution across the start line is not straightforward. One method is to use the injector oxidizer and fuel mass flow rates at various different rings of the injector to determine a step function O/F distribution. A parabolic fit of this step function could then be input to the program. Another example of determining O/F distributions can be found in Ref. 19.

Input requirements for a transonic case are: the axial station at which to start the solution, the axial location of the throat, the area ratio to terminate the solution, the mass flow rate of the nozzle (optional) and an engine mass averaged O/F ratio. The initial station for the solution is normally chosen as the entrance to the convergent section of the nozzle, although any station may be chosen. The area ratio at which to terminate the solution is used to establish the axial station at which to terminate the solution. If the user inputs a value of 0.0, the program assumes a value of 1.5 for the area ratio. The program sets up a start line from the transonic solution by locating Mach 1.15 on the axis and Mach 1.55 on the wall. The area ratio at which the solution is terminated must be great enough so that the flow at the axis of the nozzle can accelerate above Mach 1.15. The distribution of stations upstream and downstream of the throat has been set up for standard type motor geometries. If a non-standard nozzle is to be run (i.e., long entrance, short throat) or short entrance, long throat or large variations in upstream and downstream throat radius of curvature ratios then tne initial and final stations may have to be adjusted to obtain an adequate solution. An adequate solution is obtained when the entropy levels on the start line are within ± 1000 $ft^2/sec^2/R$.

The O/F ratio (or total enthalpy) that is input is used by the program to obtain the proper thermodynamic data from the input tables. For constant O/F ratio cases which have multiple total enthalpy tables which will be used following the boundary layer solution, it is necessary to input the total enthalpy of the table which corresponds to combustion chamber conditions. For constant O/F and variable O/F cases, input the mass flow average O/F ratio of the motor (i.e., overall operating O/F ratio). The mass flow averaged O/F or enthalpy will be used to calculate the mass flow rate of the motor if the input mass flow rate is set to 0.0. The recommended option is to set the mass flow to zero and let the program calculate the mass flow.

7.1.4.2 Two-Phase Startline Options

There are two basic options for two-phase startlines. They are: input the start line or let the program set it up using the transonic module. The same comments which were made about the construction of single phase start lines apply to two-phase start lines except that in general entropy levels on the start line are not zero since the heat transfer and drag losses are associated with accelerating particles from the combustion chamber through the throat. When inputting the particle properties along the start line the user must input the number (NSETS, Card 25) of gas points at which there are particles present. The particle properties at each point must be input starting with the point nearest the nozzle wall and proceeding to the centerline. The particle properties at each point must be input for each particle size group. Table 7-7 presents an example of an input two-phase start line where there are six particle sizes, 29 startline points and 29 points at which there are particles present.

Input data required by the two-phase transonic module is the inlet angle upstream of the throat, the upstream and downstream radii of curvature and the nozzle wall angle at the end of the throat conical section. The two-phase transonic module is capable of analyzing only one type of nozzle inlet geometry. The nozzle must have a conical inlet attached tangentially to a circular arc. At the nozzle throat plane, this upstream circular arc is attached tangentially to a downstream circular arc. Earlier versions of the program required the inlet entrance angle to be less than approximately 45 deg, only one circular arc was allowed at the nozzle throat and the

Table 7-7 EXAMPLE OF TWO-PHASE INPUT STARTLINE (29 POINTS, NSET = 29)

.0000000	.1383401+02	.2486349+01	.0000000	.3090802+04	.1670527+08
~~.3257065+00~~	~~.1383335+02~~	~~.2484953+01~~	~~.2331746+00~~	~~.3074026+04~~	~~.1671626+08~~
.6491177+00	.1383132+02	.2486105+01	.4874691+00	.3046929+04	.1673897+08
.9673735+00	.1382783+02	.2480324+01	.7698359+00	.3012545+04	.1677226+08
~~.1279088+01~~	~~.1382276+02~~	~~.2472419+01~~	~~.1091418+01~~	~~.2972797+04~~	~~.1681118+08~~
.1583427+01	.1381600+02	.2463339+01	.1456106+01	.2929917+04	.1685200+08
.1880053+01	.1380741+02	.2453524+01	.1861467+01	.2884979+04	.1688790+08
.2168971+01	.1379691+02	.2443062+01	.2300018+01	.2839095+04	.1691263+08
.2450390+01	.1378447+02	.2431944+01	.2763011+01	.2794363+04	.1692428+08
.2724663+01	.1377008+02	.2419779+01	.3242429+01	.2751240+04	.1691634+08
~~.2991061+01~~	~~.1375370+02~~	~~.2406786+01~~	~~.3731407+01~~	~~.2718655+04~~	~~.1688769+08~~
.3252904+01	.1373565+02	.2392788+01	.4225366+01	.2672652+04	.1683398+08
.3507698+01	.1371572+02	.2377887+01	.4720753+01	.2637637+04	.1675502+08
.3756713+01	.1369457+02	.2361836+01	.5214193+01	.2606082+04	.1665323+08
.4000238+01	.1367080+02	.2344801+01	.5704946+01	.2579448+04	.1653689+08
.4238489+01	.1364598+02	.2326920+01	.6191477+01	.2556638+04	.1640583+08
~~.4471595+01~~	~~.1361976+02~~	~~.2308382+01~~	~~.6672197+01~~	~~.2537202+04~~	~~.1626393+08~~
.4699584+01	.1359207+02	.2289464+01	.7145702+01	.2519457+04	.1611040+08
.4922342+01	.1356323+02	.2270734+01	.7610958+01	.2508952+04	.1594069+08
.5139703+01	.1353331+02	.2252678+01	.8065115+01	.2479348+04	.1575006+08
.5445107+01	.1348813+02	.2306990+01	.8765643+01	.2246431+04	.1645667+08
.5776207+01	.1342471+02	.2374882+01	.9553713+01	.1946862+04	.1722644+08
~~.5930366+01~~	~~.1339432+02~~	~~.2447496+01~~	~~.9926885+01~~	~~.1634890+04~~	~~.1770778+08~~
.6038969+01	.1337270+02	.2508424+01	.1016547+02	.1338253+04	.1781953+08
.6080003+01	.1336531+02	.2531523+01	.1024855+02	.1295668+04	.1772629+08
.6133913+01	.1335451+02	.2564825+01	.1034289+02	.1013100+04	.1753190+08
.6159234+01	.1334986+02	.2578839+01	.1038977+02	.9235659+03	.1739845+08
.6206842+01	.1334003+02	.2606155+01	.1045436+02	.7456412+03	.1712184+08
~~.6236000+01~~	~~.1333523+02~~	~~.2615850+01~~	~~.1049000+02~~	~~.6795271+03~~	~~.1702620+08~~

1	.2824822+08	.1568279-04	.8221250+04	.1673941+04
1	.2842661+08	.1555424-04	.8205057+04	.1661741+04
2	.3033925+08	.3019810-04	.8094814+04	.1733182+04
1	.2875967+08	.1531500-04	.8174611+04	.1643137+04
2	.3087807+08	.2986991-04	.8061363+04	.1713792+04
~~1~~	~~.2692756+08~~	~~.1519261-04~~	~~.8159844+04~~	~~.1632929+04~~
2	.3115433+08	.2970713-04	.8044369+04	.1703357+04
3	.3532940+08	.2958706-04	.7942589+04	.1747236+04
1	.2927933+08	.1496368-04	.8113595+04	.1607961+04
2	.3186508+08	.2941963-04	.7996918+04	.1677792+04
3	.3614520+08	.2944126-04	.7892528+04	.1720408+04
~~1~~	~~.2953810+08~~	~~.1480343-04~~	~~.8077890+04~~	~~.1588373+04~~
2	.3241208+08	.2922095-04	.7958511+04	.1658048+04
3	.3675401+08	.2933639-04	.7854295+04	.1699688+04
4	.3916663+08	.3082717-04	.7751996+04	.1730724+04
1	.3018470+08	.1446790-04	.7964107+04	.1529464+04
2	.3427381+08	.2882174-04	.7842945+04	.1599995+04
~~3~~	~~.3816494+08~~	~~.2913266-04~~	~~.7739683+04~~	~~.1641252+04~~
4	.4027675+08	.3067009-04	.7638903+04	.1672403+04
5	.4187140+08	.3281177-04	.7518696+04	.1701539+04
1	.3103271+08	.1410942-04	.7807043+04	.1444839+04
2	.3652528+08	.2836218-04	.7689419+04	.1519200+04
3	.3972851+08	.2884465-04	.7592791+04	.1562790+04
~~4~~	~~.4184341+08~~	~~.3338564-04~~	~~.7499675+04~~	~~.1596921+04~~
5	.4275531+08	.3741874-04	.7388996+04	.1630382+04
6	.4388468+08	.2198300-04	.7247472+04	.1662695+04
1	.3249609+08	.1326365-04	.7648728+04	.1307832+04
2	.3817490+08	.2692044-04	.7549333+04	.1395083+04
3	.4069955+08	.2754583-04	.7472585+04	.1448248+04
~~4~~	~~.4208496+08~~	~~.2896367-04~~	~~.7398257+04~~	~~.1490946+04~~
5	.4317468+08	.3073485-04	.7307629+04	.1533012+04
6	.4414775+08	.2302460-04	.7186720+04	.1573720+04

Table 7-7 (Continued)

1	.3431260+08	.1256937-04	.7517033+04	.1189197+04
2	.3946182+08	.2564694-04	.7436045+04	.1287836+04
3	.4143550+08	.2632660-04	.7372457+04	.1349506+04
4	.4255973+08	.2759732-04	.7319751+04	.1399391+04
5	.4347847+08	.2915797-04	.7246034+04	.1448569+04
6	.4433490+08	.1827239-04	.7141994+04	.1495825+04
1	.3295575+08	.1187976-04	.7574074+04	.1146577+04
2	.3862121+08	.2433001-04	.7492938+04	.1243121+04
3	.4082361+08	.2504725-04	.7433534+04	.1306874+04
4	.4207853+08	.2624020-04	.7374581+04	.1357793+04
5	.4314189+08	.2770527-04	.7299006+04	.1407433+04
6	.4405071+08	.1693874-04	.7192179+04	.1454262+04
1	.3211508+08	.1121580-04	.7631330+04	.1089350+04
2	.3776174+08	.2304115-04	.7550018+04	.1195980+04
3	.4020399+08	.2378158-04	.7489643+04	.1261720+04
4	.4159482+08	.2490923-04	.7429266+04	.1313662+04
5	.4272599+08	.2631377-04	.7351647+04	.1363577+04
6	.4376861+08	.1573448-04	.7241877+04	.1409903+04
1	.3158886+08	.1059681-04	.7688046+04	.1035755+04
2	.3688861+08	.2161407-04	.7606585+04	.1146602+04
3	.3956189+08	.2256831-04	.7545080+04	.1214274+04
4	.4111385+08	.2364125-04	.7483110+04	.1266991+04
5	.4235520+08	.2500771-04	.7403275+04	.1316933+04
6	.4349242+08	.1466679-04	[illegible]	.1362521+04
1	.3122226+08	.1001040-04	[illegible]	.9801184+03
2	.3602627+08	.2066755-04	.7661849+04	.1095198+04
3	.3897509+08	.2143051-04	[illegible]	.1164576+04
4	.4064853+08	.2245760-04	.7535341+04	.1217780+04
5	.4199866+08	.2379905-04	.7453150+04	.1267426+04
6	.4322841+08	.1373258-04	.7377107+04	.1311979+04
1	.3093467+08	.9476732-05	.7796751+04	.9226520+03
2	.3520635+08	.1961039-04	.7715031+04	.1041892+04
3	.3890357+08	.2037961-04	.7650786+04	.1112640+04
4	.4021279+08	.2136862-04	.7585210+04	.1165964+04
5	.4166625+08	.2269266-04	.7500582+04	.1219935+04
6	.4298327+08	.1292354-04	.7381297+04	.1258111+04
1	.3070086+08	.8989716-05	.7847339+04	.8634758+03
2	.3445666+08	.1864456-04	.7765444+04	.9867362+03
3	.3788434+08	.1941945-04	.7699612+04	.1058410+04
4	.3981770+08	.2037772-04	.7632097+04	.1111412+04
5	.4136565+08	.2168937-04	.7544976+04	.1159284+04
6	.4276205+08	.1222862-04	.7422464+04	.1200718+04
1	.3049877+08	.8547621-05	.7894763+04	.8027114+03
2	.3376342+08	.1776749-04	.7812615+04	.9297397+03
3	.3743254+08	.1854907-04	.7745058+04	.1001784+04
4	.3947373+08	.1948408-04	.7675531+04	.1053962+04
5	.4114372+08	.2078746-04	.7585937+04	.1100258+04
6	.4256909+08	.1163563-04	.7460253+04	.1139574+04
1	.3031832+08	.8147764-05	.7938746+04	.7465109+03
2	.3325132+08	.1697426-04	.7856216+04	.8708961+03
3	.3705543+08	.1776498-04	.7786811+04	.9426164+03
4	.3918568+08	.1868445-04	.7715248+04	.9934007+03
5	.4096318+08	.1998368-04	.7623232+04	.1037596+04
6	.4240625+08	.1113252-04	.7494468+04	.1074418+04
1	.3014767+08	.7786836-05	.7979268+04	.6771418+03
2	.3287463+08	.1625874-04	.7896132+04	.8102064+03
3	.3675617+08	.1706233-04	.7824764+04	.8807398+03
4	.3895540+08	.1797420-04	.7751148+04	.9204908+03
5	.4070570+08	.1927365-04	.7656808+04	.9710167+03
6	.4227444+08	.1070812-04	.7525074+04	.1004969+04

Table 7-7 (Concluded)

ORIGINAL PAGE IS
OF POOR QUALITY

1	.2998755+06	.7461462-05	.9016467+04	.6129453+03
2	.3262966+06	.1561497-04	.7932367+04	.7476288+03
3	.3653132+08	.1643616-04	.7858940+04	.8159236+03
4	.3870848+08	.1734838-04	.7783267+04	.8619426+03
5	.4056996+08	.1865274-04	.7686736+04	.9001895+03
6	.4217280+08	.1035271-04	.7552155+04	.9309207+03
1	.2983522+08	.7168124-05	.8050735+04	.5462756+03
2	.3246326+08	.1503721-04	.7965157+04	.6829726+03
3	.3637593+08	.1588156-04	.7889497+04	.7477738+03
4	.3866765+06	.1680167-04	.7611771+04	.7902696+03
5	.4047331+06	.1811610-04	.7713152+04	.8247090+03
6	.4209982+08	.1005765-04	.7575895+04	.8518418+03
1	.2968793+08	.6904589-05	.8082245+04	.4834751+03
2	.3236720+08	.1452246-04	.7994413+04	.6158808+03
3	.3626207+06	.1539597-04	.7916398+04	.6758263+03
4	.3860155+08	.1633058-04	.7836700+04	.7130619+03
5	.4041217+08	.1766023-04	.7736079+04	.7441319+03
6	.4205294+08	.9817186-05	.7596400+04	.7673134+03
1	.2955085+08	.6669584-05	.8111273+04	.4186304+03
2	.3232412+08	.1406951-04	.8020247+04	.5455893+03
3	.3623937+08	.1497786-04	.7939727+04	.5992967+03
4	.3854458+08	.1593267-04	.7858202+04	.6322534+03
5	.4036104+08	.1728170-04	.7755679+04	.6578037+03
6	.4202837+08	.9625675-05	.7613866+04	.6768086+03
1	.2942465+08	.6463715-05	.8137774+04	.3535129+03
2	.3232340+08	.1367981-04	.8042577+04	.4709476+03
3	.3623738+08	.1462795-04	.7959427+04	.5171285+03
4	.3863946+06	.1560764-04	.7876175+04	.5443978+03
5	.4037424+08	.1697878-04	.7772031+04	.5649676+03
6	.4202208+08	.9479864-05	.7628323+04	.5798498+03
1	.2931473+08	.6289510-05	.8161178+04	.2874492+03
2	.3235217+08	.1335814-04	.8061773+04	.3894613+03
3	.3626443+08	.1434915-04	.7975172+04	.4282308+03
4	.3855613+08	.1535615-04	.7890454+04	.4494633+03
5	.4038524+08	.1675139-04	.7784989+04	.4650638+03
6	.4202932+08	.9377258-05	.7639726+04	.4760019+03
1	.2922715+08	.6150608-05	.8180335+04	.2194508+03
2	.3239731+08	.1311465-04	.8077950+04	.2999241+03
3	.3630526+08	.1414444-04	.7986468+04	.3316653+03
4	.3854411+08	.1517924-04	.7900746+04	.3468170+03
5	.4040524+08	.1659928-04	.7794288+04	.3577690+03
6	.4204362+08	.9315675-05	.7647915+04	.3651396+03
1	.2916854+08	.6049623-05	.8193816+04	.1466596+03
2	.3246571+08	.1295432-04	.8089322+04	.2040235+03
3	.3635313+08	.1401385-04	.[illegible]3086+04	.2270131+03
4	.3861849+06	.1507533-04	.7906727+04	.2365655+03
5	.4043072+08	.1651920-04	.7799745+04	.2433215+03
6	.4206266+08	.9291857-05	.7652659+04	.2477445+03
1	.2914492+08	.5985039-05	.8200271+04	.7484052+02
2	.3252320+08	.1286704-04	.8094574+04	.1030626+03
3	.3640448+08	.1395013-04	.7995096+04	.1152318+03
4	.3865674+08	.1503525-04	.7908364+04	.1198375+03
5	.4046067+08	.1650087-04	.7801211+04	.1230221+03
6	.4206562+08	.9298963-05	.7653814+04	.1250737+03
1	.2915311+08	.5946519-05	.8199571+04	.0000000
2	.3256938+08	.1282621-04	.8093726+04	.0000000
3	.3644820+08	.1392883-04	.7993298+04	.0000000
4	.3869078+08	.1503287-04	.7906341+04	.0000000
5	.4048720+08	.1651610-04	.7799266+04	.0000000
6	.4210721+08	.9320678-05	.7651902+04	.0000000

radius of this arc needed to be greater than approximately twice the nozzle throat radius. The two-phase transonic module now allows inlet angles to be as steep as 50 deg. Two circular arcs are now used to define the nozzle throat. The arc upstream of the throat plane can have a radius as small as half the value of the throat radius. The arc downstream of the throat plane can have a radius as small as one tenth the value of the throat radius. The ATA module can analyze gas-particle flow containing particle groups of arbitrarily small diameter. Earlier versions of the module required particle diameters to be greater than approximatley one-half micron. Also, the upstream value of the wall radius ratio can be different than the downstream value. Many inlets are not conical (i.e., submerged nozzle). The user should approximate the inlet angle for these type nozzles to best approximate the angle that the bulk of the particles will be constrained within.

The start line is attached to the wall and centerline using input (or default) values of Mach number. The default values (1.1 on centerline, 1.4 on wall) have been established to obtain a good startline shape for standard type motors. If a case is run in which the start line is inclined improperly (i.e., $X_{wall} > X_{CL}$) then AXISM and WALLM may be adjusted to alter the start line.

7.1.5 Mesh Control Variables

This subsection discusses each of the mesh control parameters which the program utilizes. The function of each of these parameters is discussed in relation to potential mesh control problems in construction of a typical flow solution.

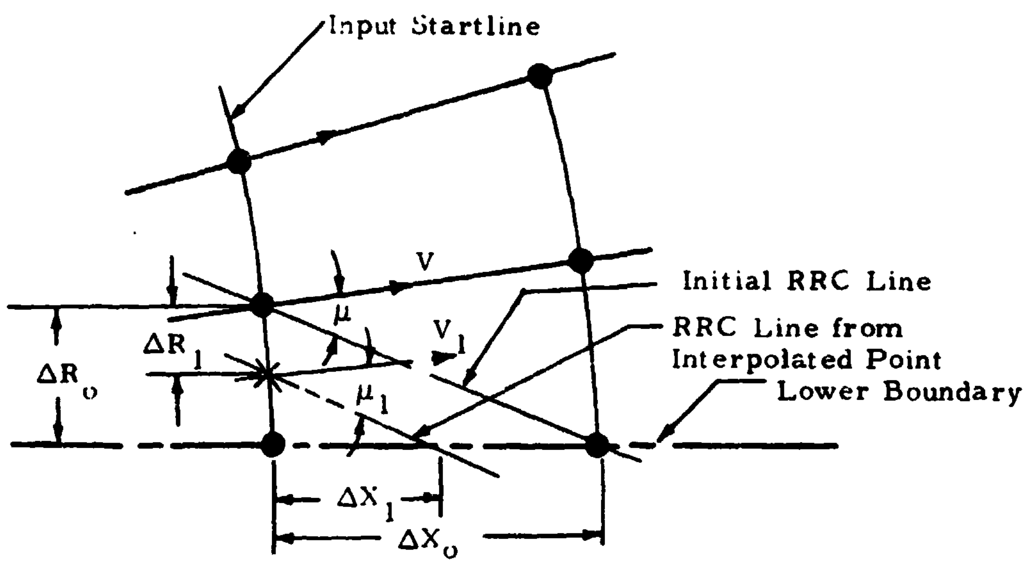
Control of the insertion of interior points and the deletion of points on a known data surface is the function of subroutine CHECK. CHECK is normally called from subroutine PHASE1 after a line has been completed unless a special circumstance is encountered where a point needs to be inserted or deleted due to streamline crossings. The axial step control is performed by PHASE1.

7.1.5.1 Lower Wall Interpolation Factor (STEP(8))

Characteristic theory governs the construction of the initial data point on a new surface. The maximum axial step at the lower boundary is determined by the intersection of the right-running characteristic (RRC) emanating from the first interior point on the normal and the lower boundary. The RRC is inclined at the local characteristic angle $(\theta - \mu)$ toward the lower boundary. The axial step downstream of the known data surface is determined by the intersection of the RRC line (which is located a factor of STEP(8) (≤ 1.0) of the distance between the axis point and first interior point) with the lower boundary. Details of this construction are noted in the sketch on the following page.

Consequently, STEP(8) is the primary parameter which controls the mesh construction and also has a significant impact on program run time. The radial point spacing on the start or previous line also helps to determine the initial axial step. The closer the point spacing the smaller the axial step.

Step size also affects the conservation of mass flow, momentum and energy. Most cases will maintain good mass flow conservation. However, there can be cases where poor mass flow conservation is observed. In these instances, normally there is an error in the input data. If no error is detected it may be necessary to take smaller step sizes to maintain the particle mass flow conservation. Gaseous cases with larger gradients across the flow field may also require smaller steps and more mesh points in order to conserve mass flow.



ΔX_1 = Initial Axial Step

ΔR_o = Initial Radial Point Spacing

ΔX_o = Maximum Initial Axial Step

μ = Local Characteristic Angle

V = Local Velocity

The ΔRRC Step ΔX_1 is given by:

$\Delta R_1 = \Delta R_o [1 - \text{STEP}(8)]$

$\Delta X_1 \cong \Delta R_o * \text{STEP}(8) * \tan(\pi/2 - \mu_1)$

7.1.5.2 Axis Point Insertion Criteria (STEP(6))

The axis point insertion control parameter, STEP(6), limits the maximum axial step between data surfaces. If the data surface location between axis points for any reason exceeds STEP(6), the interpolation factor for the lower wall solution (STEP(8)) will be multiplied by 0.8. This results in a smaller axial step. The new axis point will be recomputed until it is less than a distance of STEP(6) away from the known axis point.

Typical values for STEP(6) are: 0.1 throat radii for two-phase nozzle flow problems, 0.1 exit radii for two-phase plume flow problems and 0.2 throat/radius for gas only nozzle solution and 0.2 exit radius for gas only plume flows.

7.1.5.3 Interior Point Insertion Criteria (STEP(3))

The purpose of the point insertion capability is to provide control of the streamline spacing in a rapidly expanding flow. Insertion of a streamline is accomplished in the following manner. The distance along a normal line between two grid points is computed in subroutine CHECK. If this distance exceeds STEP(3) a new streamline will be inserted midway between the two existing points. The new streamline point will be retained as the solution progresses.

7.1.5.4 Particle Limiting Streamline Insertion Criteria (STEP(9))

This parameter provides for control of streamline spacing on a data surface based on the entropy difference between two streamlines. This option is only used for two-phase flow cases and then only between a particle limiting streamline and the adjoining gas streamline. STEP(9) is the maximum allowable percentage change in entropy near a particle limiting streamline. The procedure is to first calculate the entropy difference (ΔS) between the particle limiting streamline and the adjacent streamline, above or below the particle limiting streamline. If ΔS is greater than STEP(9) times the entropy level of the limiting streamline then a new streamline point will be inserted midway between the two points. The procedure is identical to the interior point insertion scheme once the program has determined that a point should be added.

This mesh control parameter is utilized to avoid large entropy gradients near limiting streamlines. There will naturally be an entropy gradient, from a region where particles are present to a gas-only region, across a limiting streamline. However, use of the STEP(9) control can minimize the chance of encountering numerical difficulties near limiting streamlines in two-phase flow problems.

7.1.5.5 Prandtl-Meyer Integration (STEP(1))

This parameter controls the number of mesh points which are distributed through the Prandtl-Meyer expansion. STEP(1) is the size of the integration step in degrees that is used to numerically integrate the Prandtl-Meyer function. STEP(1) then becomes the number of degrees between mesh points in the expansion fan.

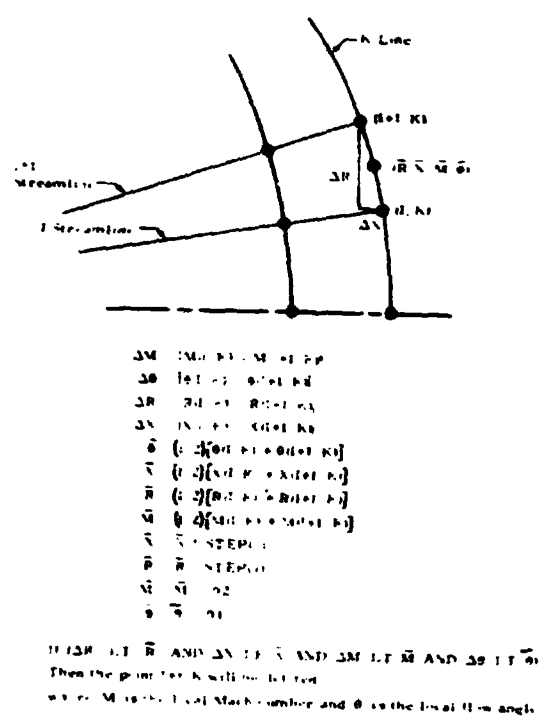
7.1.5.6 Point Deletion Criteria (STEP(7))

The purpose of this mesh control parameter is to limit the spacing of adjacent streamline points on a normal to a minimum value. When streamlnes begin to converge the solution can encounter numerical difficulty when computing locations of intersections of characteristic lines with normals to streamlines.

The procedure is to determine the radial and axial spacing, the Mach number difference and flow angle differences between two consecutive points on a normal ($\Delta R, \Delta X, \Delta M, \Delta\theta$). The average R,X, Mach number and flow angle for the two points are calculated ($\bar{R}$, $\bar{X}$, $\bar{M}$, $\bar{\theta}$). R and X are multiplied by

STEP(7) and $\bar{M}$ and $\bar{\theta}$ are multiplied by built-in values. If ΔR and ΔX are less than the average locations ($\bar{R}$ and $\bar{X}$) times STEP(7) and ΔM and $\Delta\theta$ are less than the average values ($\bar{M}$ and $\bar{\theta}$) times the built-in values then one of the two points will be deleted. This procedure is shown in the sketch below.

The program will not delete the following types of points: upper or lower boundary, free boundary, Prandtl-Meyer, shock, slipline, or limiting streamlines. Normally, the I point is deleted.



7.1.5.7 Finite Rate Chemistry Mesh Controls

The mesh control parameters for a finite rate chemistry case are the same as in the previous sections with the following exception.

The lower wall interpolation factor, STEP(8), is overriden by the "CFL" condition which requires that the Mach lines from any new point must intersect the base line between the base point and either of its neighboring points. This condition is assured by the equation

$$CFL = \Delta_N \sqrt{M^2 - 1}$$

where Δ_N is the normal distance between any two adjacent points on the base line and M is the Mach number. CFL is the maximum distance along the streamline through the base point the new point may extend and still ensure that the Mach lines intersect the adjacet points. This distance is calculated for each point on the base line and the minimum distance is used for the entire new line.

7.1.5.8 Recommended Mesh Control Variables

Table 7-8 presents a set of recommended values for the mesh control variables. This set of mesh control values has been found by the author to be general for most of the cases which have been run. However, there probably will be cases where the run time or conservation of mass flow, energy and momentum will be unsatisfactory and adjustments to the mesh will be required. As the user becomes familiar with the code and runs more cases, changes in the mesh control variables and the resulting effect on the flow solution will become apparent.

Table 7-8

RECOMMENDED MESH CONTROL VALUES

	Nozzle-Gas	Nozzle-Two-Phase	Plume – Low Altitude Two-Phase	Plume – Low Altitude Gas Only	Plume – High Altitude Two-Phase	Plume – High Altitude Gas Only
STEP(1), Prandtl-Meyer Control	4.0	4.0	4.0	4.0	6.0	6.0
STEP(3), Interior Insertion	0.1 R_T	0.1 R_T	0.1 R_E	0.2 R_E	0.3 R_E	0.5 R_E
STEP(6), Axis Insertion	0.2 R_T	0.1 R_T	0.1 R_E	0.2 R_E	0.2 R_E	0.3 R_E
STEP(7), Delete Criteria	0.001	0.001	0.005	0.005	0.005	0.005
STEP(8), Axis Point Interpolation	0.9	0.7	0.5	0.7	0.7	0.8
STEP(9), Limiting Streamline	1000.0	0.2	0.2	1000.0	0.2	1000.0

R_T = Throat Radius

R_E = Exit Radius

NOTE: If no limiting streamline, axis insertion, or interior insertion control is desired input a large number (~ 1000). If no deletion is desired use an extremely small number (1.E-5).

7.1.5.9 Mesh Spacing Effect on Run Time and Conservation Equations

Run time is significantly affected by the point density for two reasons: (1) the computer run time is a direct function of the number of points on the normals, i.e., for the same number of normal surfaces and twice the number of points on each normal there will be a factor of two differences in run time, (2) the more points on a given normal, the smaller will be the step size which will result in more execution time, i.e., twice as many points on a surface will result in the maximum axial step having one-half the length. This coupled with twice the points on the normal will result in four times as much computer time.

Coupled with conserving run time is the necessity that the solution be numerically valid, i.e., conserve mass, momentum, and energy. The conservation functions for numerical solutions of the type employed by the RAMP program are somewhat controlled by the mesh spacing. For flows which contain large gradients in flow properties it is desirable to have more mesh points to avoid any large errors in mass flow, system energy and momentum. Thus, there is some happy medium or parity between run time and system conservation.

7.1.5.10 Point Spacing

The type of solution which the RAMP code employs lends itself to uniformly spaced points on each data surface. However, particular flow solutions which have large radial gradients require close point spacing in the region of the large gradients. For these cases, smaller axial steps are necessary.

7.2 EXPLANATION OF ERROR MESSAGES AND OTHER MESSAGES

This section lists the messages that can be output by the program and describes what the messages mean to the solution. Comments are also included on how to change the input data to correct problems in the solution which cause improper terminations.

1. Previously noted errors have propagated to lower boundary or problem limits have been reached. Case terminated.

   The program has terminated properly, the problem limits set by the user have been reached or another error which has been identified via a message has been encountered.

2. Lower boundary solution will not converge.

   The program is unable to obtain a solution at the lower boundary within the user specified number of iterations. The code will back up the line a maximum of 10 times to try to obtain a solution. If no solution is reached then the execution will terminate.

3. Interior solution will not converge.

   The program is unable to obtain a solution for an interior point within the user specified number of iterations. The code will back up and take a smaller step. If the point still will not converge after backing up 10 times then the solution will be terminated.

   Possible causes of this problem are:

   - Input error in boundary equations
   - Numerical difficulties due to large point spacing in regions of steep gradients. Use more points or take smaller steps.
   - If this occurs early in the solution, the start line may not be physically or numerically suited to the problem. Check the start line.
   - Check for obvious errors in thermodynamic data.

4. Upper boundary solution will not converge.

   The program is unable to obtain a solution at the upper boundary. Causes and fixes are same as item 3.

5. ITSUB will not converge in RGMOFP.

   Real gas solution of Mach number as a function of pressure will not converge within present number of iterations. Check the thermodynamic tables for errors and also the plume boundary conditions.

6. ITSUB will not converge in RGVOFM.

   Real gas solution of velocity as a function of Mach number will not converge within present number of iterations. Check the thermodynamic tables for errors. For two-phase, real gas cases with a startline input from cards, be sure all the input Mach numbers fall within the thermodynamic table entries.

7. ITSUB WNC in THETPM

   Unable to balance the last Prandtl-Meyer point pressure with the back pressure at the free boundary or flow angle at a solid boundary, within the preset number of iterations. This can be caused by poor thermodynamic table construction or incompatible plume boundary conditions.

8. ITSUB WNC in AOASTR

   Unable to balance the mass flow at input A/A^* with mass flow at throat within the preset number of iterations. Check thermodynamic tables.

9. ITSUB WNC in TURN

   Unable to turn the flow through a specified turning angle within the preset number of iterations. Usually caused by flow going subsonic.

10. ITSUB WNC in OVEREX

    Unable to turn the flow through a specified turning angle to match the plume boundary pressure within the preset number of iterations. Usually caused by the flow going subsonic.

11. The following case cannot be found on the master tape.

    The program is unable to find the desired gas case among the cases present on the master tape. This is usually caused by the gas header card not matching any of the header cards which appear on the tape, or the wrong tape was mounted.

12. ITSUB WNC in HYPER

Program is unable to find a velocity which will give the ambient boundary conditions within the number of preset iterations. Can be caused by trying to expand the flow too far or having bad thermodynamic tables.

13. Subsonic Mach number encountered in TOFV.

The characteristic theory utilizes Mach number in the definition of Mach angle ($\sqrt{M^2 - 1}$) and is limited to supersonic flow. Possible causes for this message are:

- Flow went subsonic.
- Error occurs in boundary equations.
- Error occurs in other input data.
- A situation is encountered which the code is unable to handle.

14. Negative velocity encountered in TOFV.

Something has happened during the solution which has resulted in a negative velocity being calculated. Probable causes are:

- Error occurs in boundary equations
- Error occurs in gas thermodynamic data
- Mesh problem is caused by too large a step in a region of steep gradients. Try taking smaller steps.
- Program limitation.

15. ITSUB does not converge in PHYSOL.

Subroutine PHYSOL is unable to determine the characteristic intersection with the known data surface within the preset number of iterations. This is usually caused by too small a mesh size or a data surface that has been input, which is not a true normal.

16. Two straight lines in INRSCT are parallel.

Subroutine INRSCT's function is to determine the intersection of two straight lines. If two lines are found to be parallel this message is printed out. Usually caused by some inconsistency in the input data.

17. Characteristic lines diverge; last P-M point set free molecular.

    Subroutine MOCSOL is unable to intersect right and left running lines while constructing the normal around a Prandtl-Meyer expansion. This is usually caused by trying to take too large a step past an expansion corner.

18. MOCSOL will not converge.

    MOCSOL is unable to find the intersection of two characteristic lines within the preset number of iterations.

19. A problem with a RRC intersection with line X has been encountered. The line will be recalculated.

    This is the result of either an interior solution taking too many iterations or a situation where the program is unable to intersect the right-running characteristic from the new point to the known data surface. The program will back up and take a smaller step for a maximum of 10 iterations. If the same problem is still encountered, the case will be terminated. This is usually caused by an error in a boundary equation, a start line which is not a normal or a poor point spacing.

20. Particle limiting streamline intersects with the boundary.

    This message occurs whenever a particle limiting streamline intersects a boundary (solid or free). The solution proceeds while assuming all mass which intersects the boundary passes on through.

21. Point number X on line Y has been deleted.

    This message is printed whenever a point is thrown out because it did not satisfy the mesh control criteria or whenever a gas and particle streamline cross.

22. A new streamline has been inserted on line Y between points X and Z.

    This message will appear each time a point is added on a line due to mesh control criteria being exceeded between two points.

23. Due to gas-particle streamline crossing the point X has been replaced.

    This message occurs for two-phase cases whenever a gas and particle limiting streamline cross. The gas streamline is thrown out.

24. You are trying to throw out point X, the point is a wall limiting streamline or free boundary point. You probably have an error in your input.

    This error message is usually caused by an error in the start line or an error in the boundary equations. Check your input data.

25. Could not find M = point in BL, EDGE Mach No. is .

    When merging the boundary layer results with the inviscid results at the exit plane the program searches for Mach = 1.05 in the boundary layer results. If the program cannot find M = 1.05 this messge is printed out. Check the boundary layer results. If this error message occurs there is an error in the RAMP2F code or the boundary layer results are inviscid.

26. Cound not find boundary layer edge on start line.

    The edge of the boundary layer could not be matched with inviscid normal. Error in code or boundary layer results. Contact author.

27. The inviscid portion of start line was moved _____(ft/m) to match edge of boundary layer.

    In order to satisfactorily patch the boundary layer results with the exit plane inviscid start line the exit plane normal is moved slightly. This is a normal message and can be ignored.

28. Bound cannot find positive argument for conic equation.

    There is an error in your boundary equation coefficients for conic equation. Check your input.

29. Temperature of ______ is out of range in CHEM, the solution is flushed.

    A temperature has been calculated during a finite rate solution which is out of range of the thermodynamic tables. Check your thermo data tables for errors, check for errors in your start line or, take smaller steps.

30. Error (FIXIL-WALL) - XMACH.LE.1.0

    Error in two-phase transonic solution. Cannot find suspension Mach number on nozzle wall. Check geometry and transonic input data for errors.

31. Error (FIXIL-AXIS) - XMACH.LE.1.0

    Error in two-phase transonic solution. Cannot find supersonic Mach number on nozzle axis. Check geometry and transonic input data for errors.

32. Error*** Species data from tape do not agree with card input

    The TRAN72 data tape input to the program does not match the species input for the finite rate calculation. Check TRAN72 results and thermo data input to RAMP2F.

33. *****Error***** input parameter too large

    Input parameter for finite rate case (Card 6) exceeds dimension limits of program. Check input.

34. Cannot find wall Mach number of ____________

    The gas transonic module looks for a Mach number of 1.55 to anchor the start line to the nozzle wall. If the solution does not have a Mach number this high on the nozzle wall, the wall Mach number (1.55) is decreased until the start line can be anchored to the wall. If no Mach number on the wall is found after four tries the solution is terminated. Check your transonic input data for errors or check nozzle geometry for errors. If no errors are found increase the downstream solution area ratio input on Card 20e.

35. Cannot find axis Mach number of

    Same as above except for axis Mach number of 1.15.

36. The point ______ could not be found on start line; Could not locate limit streamline on start line or, PUNEX cannot find INDX limit streamline.

    Routine (RUNEX) which generates exit plane SPF start line cannot find the limiting streamline. Check particle size distribution for errors. Check geometry. If no errors are found, contact author.

37. Temperature is out of range for startline enthalpy.

    When setting up a finite rate start line within the program the program looks up enthalpy using input thermo tables and a known temperature for the start line (as input by user). If the program is unable to locate a set of points in the table which bracket the startline temperature this message is output. Check your input start line and thermo tables for errors.

38. The starting point of particle streamline tracing through boundary layer for particle _____ is beyond exit or particle ___ is upstream of the limiting streamline intersection with Bl.

    Program has encountered difficulties in establishing starting points for tracing particle trajectories through the boundary layer. Check input geometry and starting line for errors.

39. ITSUB WNC in mass

    The gaseous transonic module uses the location of the nozzle throat (M=1.0) and an input value of mass averaged O/F ratio or total enthalpy to calculate the engine mass flow. If this error message occurs check your thermo data tables, nozzle geometry and card 20C for errors or inconsistencies.

40. ITSUB WNC in start for downstream boundary area ratio

    During initialization of the gas transonic solution the program establishes the downstream limit of the transonic solution based on the input geometry, location of throat and downstream area ratio. This error message indicates an error in one or more of these data. The code also uses the XMAX for the last upper solid boundary to establish an increment to start the iteration. If the XMAX for the last boundary is too big this error message is possible. Decrease the XMAX or change subroutine STARTV (SAVE(2)=DX) to SAVE(2) = 10*DX.

41. ITSUB WNC in start

    The initialization routine (STARTV) for the gas transonic routine could not converge for a particular station. Check your input data (Card 20c, d or geometry) for errors. If the station on which this occurs is not the upstream limit station the results of the transonic calculation are valid.

42. Temperature is out of range for T=F(H) iteration in THERM1 or temperature out of range for T = ____ or ITSUB WNC in TOFH, T, H2, ABIFF

    Indicates error in temperature or enthalpy lookup for finite rate case. Check your input start line and thermo tables for error or decrease step size.

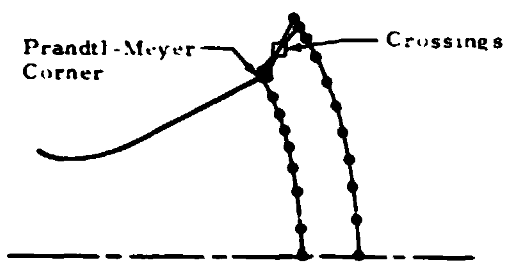
7.3 PROBLEMS COMMONLY ENCOUNTERED AND SUGGESTED FIXES

This section is intended to aid the user in utilizing the program and avoiding some common problems. Also included are some general comments on inputting the code.

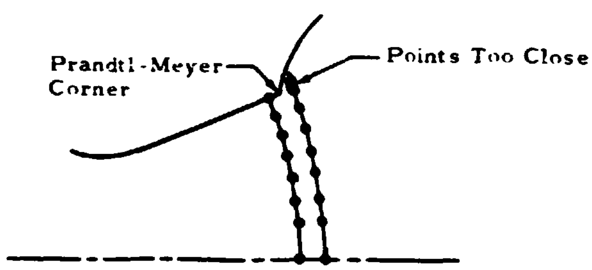
The following is a list of hints to the user:

- The numerical scheme which the program utilizes lends itself to evenly spaced points. Therefore, when setting up a start line try to ensure that the points are as evenly spaced as possible. The only exception to this rule is in the vicinity of large gradients in flow properties, (e.g., Prandtl-Meyer corners). The points in this region should be closer together, and smaller axial steps should be taken.

- In the region immediately downstream of a Prandtl-Meyer expansion it is necessary for the program to patch together a characteristic mesh with the streamline normal mesh (Section 6.9, Vol. I). This mesh construction can result in two unique problems. First, if the first normal beyond the corner is too far downstream of expansion, it is possible for the code to be unable to intersect characteristic lines. This normally will only occur for high altitude cases. To fix this, take a small step. If too large a step is taken at lower altitudes, streamlines may cross which can result in a subsonic Mach number or negative velocity message. To correct, take smaller steps. On the other hand, if the first normal downstream of the corner is too close to the lip the points in the fan may be too close together. This may cause problems with characteristic line intersections with previous data surfaces and result in excessive iterations or no convergence of points in this region. It may also result in the necessity to take too small a step in order to proceed with the solution. To correct this problem, a slightly larger step must be taken so that the first normal is farther downstream of the corner. Shown on the following page are sketches of normals which are too close and too far from expansion corners.



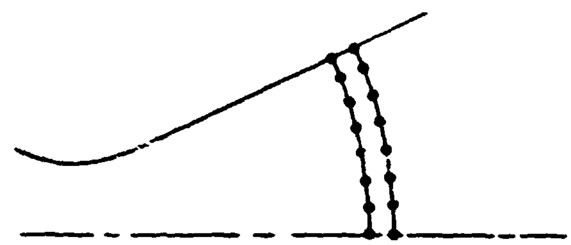
Normal Too Far Downstream
of Expansion Corner



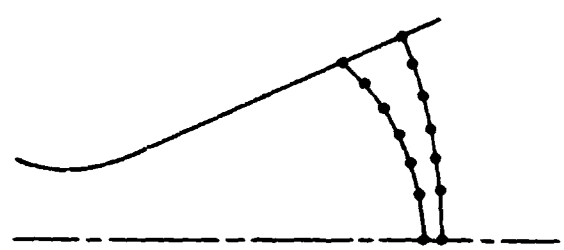
Normal Too Close to Expansion
Corner

- The two-phase transonic module requires the Mach number at the interaction of the start line with the axis (AXISM) and the nozzle wall (WALLM). Default values of 1.1 for AXISM and 1.4 for WALLM are used in the program. These values have been chosen to provide the best start line for most standard nozzles. In the event that your particular geometry results in a start line that produces results, that go subsonic or produce a start line that is inclined backwards (i.e., x increasing from centerline to wall) different values of AXISM and WALLM may be input on Card 37.

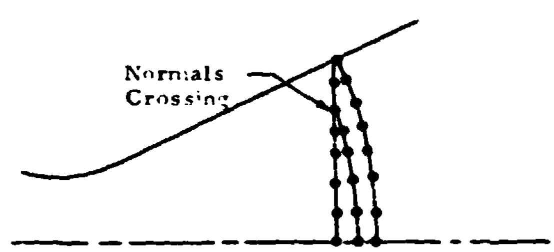
- Since the program uses streamlines and normals to streamlines (except for shock capturing solutions) to construct the mesh it is always assumed that each data surface is a true normal. If a start line is input which is not a normal, it is possible to encounter difficulties in getting the solution started. Shown on the following page are three sketches of candidate initial data surfaces.



Sketch A – True Normal

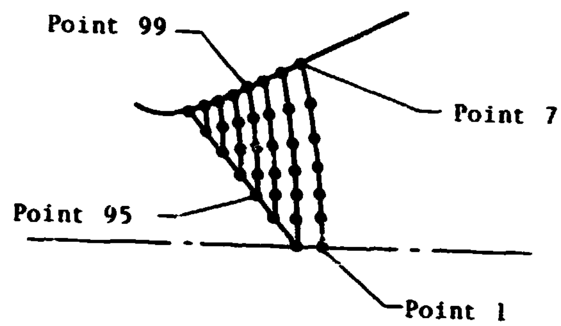


Sketch B – Normal Inclined Too Much



Sketch C – Normal Not Inclined Enough

The program checks the start line to see if the start line is inclined too much to the flow (see sketch B above). In the event that the startline is inclined too much, a different mesh construction technique is used just downstream of the start line (see sketch on following page). Also, the numbering system is changed for the points on each data surface. The last point is identified as point 99 and the remaining points numbers decrease to 99-N+1 where N is the number of pooints on the normal. After the normals move off the startline Point 1 is the axis point and the wall point is 1+N-1.



Sketch A is true normal, Sketch B is inclined too much and Sketch C is not inclined enough. In the case of the data surface which is inclined too much the code will probably have trouble finding the characteristic line intersections with this surface during the next line's solution. When the code is unable to obtain an intersection with the new data surface after backing up 10 times, the case is terminated. A normal which is not inclined enough will result in normal lines crossing as shown in Sketch C. The solution will usually have no trouble in obtaining a solution for the new data surface although several lines may overlap. To fix both of these cases, regenerate the start line so the normal line is a true normal.

- A large percentage of problems encountered is due to errors in the boundary equations. These errors can result in messages being printed out such as subsonic Mach number, negative velocity, or possible systems error messages due to bad interpolation factors. If any anomalies are encountered while the code is solving an upper boundary point, the following are some of the errors to look for:

   a. A discontinuity in boundary equations where the equations are supposed to match.

   b. The boundary equations are not in the same units as the start line.

   c. The start line does not fall on the first boundary equation.

   d. For two-phase cases the input throat radius is not consistent with the throat equation.

   e. There is an error in the equation itself.

- Care should be taken in selecting the particle size distribution for any particular case. If the particle sizes are too large for the motor being analyzed then the lags are too great, thereby compromising the results. If the sizes are too small, then the particles may try to thermally and tranlationally equilibrate with the gas which may result in numerical problems. (A discussion on how the author determines mean sizes and distributions is contained in Section 7.1.3.2 of this volume.)

- If the user is interested only in such things as nozzle wall pressure and initial plume expansion angle then a single particle size having the mean size for the motor is sufficient for good results. However, if the user is interested in two-phase impingement, then a good distribution is necessary in order to get satisfactory impingement results. Section 7.1.3.2 contains a discussion of particle distribution.

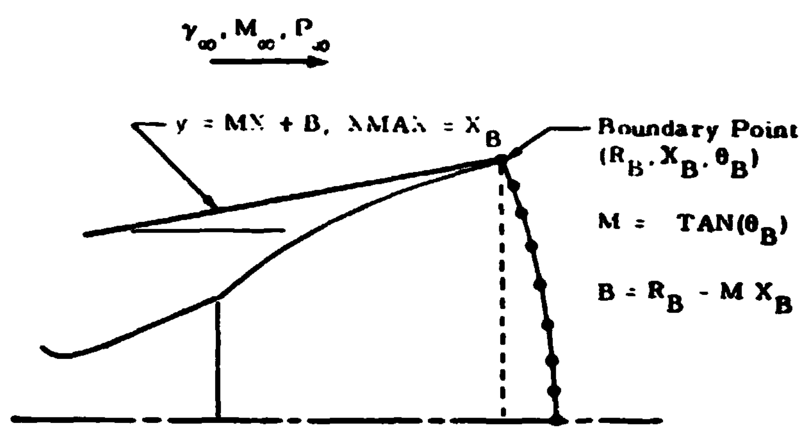
- There are some specific do's and don'ts associated with inputting a start line with cards. The following hints are what to be careful of when setting up a case where the startline is read from cards.

  a. Make sure that the number of gaseous startline points corresponds to the value input on Card 5 (ICON(3)).

  b. The gaseous startline points should be input starting from the nozzle centerline and proceeding to the upper boundary. The particle properties should be input starting with the first point nearest the upper boundary which has particles present and inputting the particle data down to the nozzle centerline. For each point the particles should be input from the smallest size (particle 1) up to the largest size (particle 6). The same particle number must always be used for each specific size.

  c. A common mistake users make is to forget to input the number of gas points (NSETS, Card 25) which have particles present. This only applies to two-phase cases.

  d. Whenever a restart is used it is necessary that the last point on the start line (upper boundary point) be a point on the first boundary equation. The first boundary equation must also be a type 1 or 2 boundary (conic or polynomial). Therefore, all boundary equations prior to the one which applies at the boundary startline point, must be removed and ICON(4) adjusted accordingly. Cases which are trying to be restarted in the plume require a fictitious boundary for the first equation. This equation consists of a straight line which passes through the boundary point and has the same slope. The next boundary equation should be the original free boundary equation. A sketch describing this requirement is shown below.



Fictitious Boundary for Plume Restart

e. The Mach number which is input on the startline cards must be within the thermodynamic table entries for two-phase cases which utilize equilibrium tables with multiple enthalpy and entropy tables. This is normally a problem only for high altitude plume restarts. If this is ever encountered, contact the author for a temporary change to the program so that gas velocity may be read in instead of Mach number.

- If gas thermodynamic data are coming from tape be sure to set ICON(1) = 2 (Card 5) and also use exactly the same gas header card (Card 10) as was used by the TRAN72 program to generate the tape.

- For gas data coming from cards be sure that the units of the gas properties are consistent with the units identified on the gas header card (Card 11).

- The entropy and total enthalpy levels of any start lines input to the program must be consistent with the gas thermodynamic tables. This is generally only important in two-phase cases. If the start line was punched by the program on a previous run and the same gas thermodynamic tables are used then the gas entropy and total enthalpy levels are consistent. However, if the start line is generated by some other code, care should be taken to enter the entropy and total enthalpy to obtain the correct static gas properties (P, ρ, T). For ideal gas two-phase cases the total enthalpy is calculated as follows:

$$H_T = C_p \, T_{OL}$$

where C_p is the ideal gas C_p defined as $C_p = \gamma R/(\gamma-1)$ and T_{OL} is the local total temperature including any two-phase losses. T_O and P_o are the combustion chamber total temperature and pressure. The static pressure is calculated via the following relationship:

$$P = \frac{P_o \, (T_{OL}/T_O)^{\gamma/\gamma-1}}{e^{S/R} \left(1 + \frac{(\gamma-1)}{2} M^2\right)^{\gamma/\gamma-1}}$$

The local static temperature is calculated using the local total temperature.

For equilibrium chemistry two-phase cases, the head loss due to the difference in total temperature between local and chamber conditions is accounted for by the change in entropy level between the total enthalpy tables. It is therefore necessary to use two entropy tables and more than one total enthalpy table for two-phase equilibrium cases. The user must also be sure that the gas total enthalpy at any point in the plume will never exceed that of the highest total enthalpy table ($\Delta H = 0$) or be less than the lowest total enthalpy table ($H_T = - \Delta H$ max). A ΔH_T of -300 cal/gm is probably the largest heat loss that need be used in the modified TRAN72 program for two-phase cases.

- For finite rate chemistry cases the following precautions should be taken

  1. Be sure that the order in which the chemical species names appear are the same for the thermodynamic data tables, the startline mole fractions and the catalytic species.

  2. Be sure that the temperatures in the data tables are the same for each species and that the number of temperatures are the same.

  3. Be sure that the enthalpies and entropies are referenced to the same temperature for each species.

  4. The program is set up to "freeze" the chemistry on the start line and will keep the chemistry frozen until a complete normal has been computed. It is recommended that the start line should be as near to a normal as possible.

  5. The run time for a finite rate chemistry case is much longer than for an equilibrium case.

8. SAMPLE PROBLEMS

This section contains seven sample problems which are designed to aid the user in familiarization and preparation of input data for the RAMP2F code. Each sample case will consist of a description of the problem, a listing of the input, selected parts of the output, and in some cases, a detailed description of the development of the input data. All cases which include a boundary layer and plume restart calculation require an execution of the BLIMPJ module followed by a RAMP2F execution. The BLIMPJ execution requires no card input. The second RAMP2F execution requires card 1 with a "1" in Column 5.

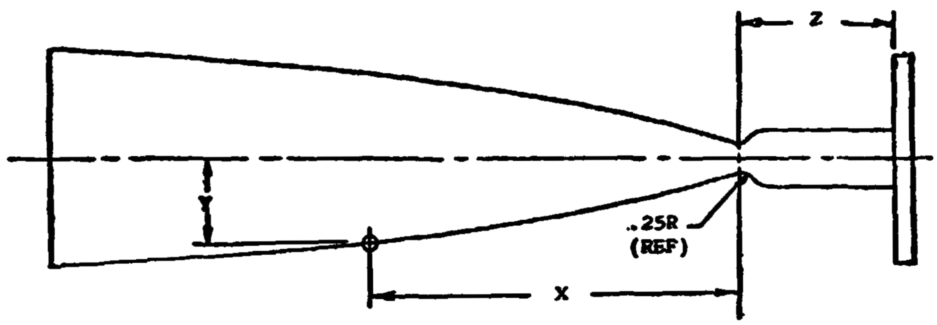
8.1 SAMPLE PROBLEM 1 - SPACE SHUTTLE VERNIER MOTOR

The Space Shuttle Vernier Reaction Control System (VRCS) motor is a 25 lb thrust bipropellant motor which has the following geometric and operating characteristics:

Throat Radius	0.01708333 ft
Area Ratio	20.7
Chamber Pressure	110 psia
Propellant	
Fuel	Monomethylhydrazine (MMH)
Oxidizer	N_2O_4
O/F Ratio	1.648

Figure 8-1 presents the detail of the nozzle and combustion chamber geometry. This is typical of what the nozzle/plume modelers can expect to have to work with to set up the input for calculating a nozzle plume flow field.

The first step, and usually the most difficult, is specifying the nozzle geometry. Solid boundaries can be input in two basic ways: (1) analytic functions (conic or polynomial equations), or (2) point



Z = Chamber Length to ℄ Throat = 2.165 to 2.265 inches

X in.	Y (Coated) in.
.000	0.205
.500	0.328
1.000	0.452
1.500	0.568
2.000	0.677
2.500	0.776
3.000	0.867
3.500	0.952
4.000	1.030
4.500	1.097
5.000	1.158
5.500	1.214
6.000	1.264
6.500	1.309
7.000	1.347
7.500	1.385
8.000	1.422
8.500	1.456
9.000	1.488
9.500	1.516
10.000	1.536

(NOZZLE CONTOUR - REF. ONLY)

Fig. 8-1 Vernier Motor Nozzle Contour

specification (R,X,θ). For simple geometries analytic functions are easiest. Many nozzles do not lend themselves to be easily defined by equations,and the specification of X, R and θ is necessary.

The geometry for the vernier nozzle was generated in two steps. First the geometry downsteam of the throat was determined in the same manner as the first sample problem in Section 7. Finally,the geometry from the combustion chamber to the throat was specified.

The first step in specifying the nozzle geometry downstream of the throat was to use the tabulated points given in Fig. 8-1 to determine the variation of flow angle versus distance from the throat. By assuming straight lines between each two consecutive points and applying the slope of the straight line at the midpoint of the points, Fig. 8-2 can be constructed. The throat section is a straight line determined from the throat radius of curvature. The area is "faired in" from the end of the throat section to the first plotted point. The maximum angle at which to apply the circular arc portion of the throat was estimated to provide a smooth transition to the contour. In many cases the location of this point is a specified contour point. In some cases it would be necessary to plot the nozzle contour using the points and from the plot pick off additional points to aid in the specification of the variation in flow angle with X. In general, more points than were specified downstream of the circular arc portion of the throat are necessary, but since the vernier engine contour is so well behaved only the points given in Fig. 8-1 were used. The location of the contour from the throat to the end of the circular arc were determined knowing the radius of curvature and throat radius. The points were specified every two degrees in flow angle. A tabulation of the points and flow angle is given in Table 8-1.

The determination of the geometry of the nozzle upstream of the throat required some scaling from Fig. 8-1. The diameter of the combustion chamber

Table 8-1 TABULATED NOZZLE CONTOUR FOR SPACE SHUTTLE VERNIER ENGINE

Axial Distance from Throat (ft) x	Radial Distance from Centerline (ft) R	Flow Angle (deg) θ	
-.03422505	.03333333	0.0	
-.03300388	.03330135	-3.0	
-.03178605	.03320551	-6.0	
-.0301733	.03297885	-10.0	
-.0281859	.03253826	-15.0	
-.0262446	.03192616	-20.0	
-.0243639	.03114718	-25.0	$x = x_c + r_1 \sin\theta$
-.02255838	.03020726	-30.0	$R = R_c - r_1 (1 - \cos\theta)$
-.0208416	.02911355	-35.0	
-.01922667	.0278744	-40.0	
-.0177259	.0264991	-45.0	
-.01614389	.0247484	-50.79658	
-.014731	.02318527	-45.0	
-.0133914	.0219574	-40.0	
-.0119495	.020850999	-35.0	
-.01041667	.01987447	-30.0	
-.00880454	.019035254	-25.0	
-.00712542	.018339737	-20.0	
-.00539206	.0177932	-15.0	
-.00361767	.017399838	-10.0	
-.00217767	.01719746	-6.0	
-.00109033	.01711188	-3.0	
0.0	.0170833	0.0	
.000727083	.0170960	2.0	
.00145325	.0171341	4.0	
.00217767	.0171974	6.0	$x = r_2 \sin\theta$
.00289942	.0172861	8.0	
.003617667	.0173998	10.0	$R = R_T + r_2 (1 - \cos\theta)$
.0043315	.0175386	12.0	
.00504	.0177022	14.0	
.00666667	.0181137	14.4	
.00833333	.0185456	14.65	
.01166667	.0194216	14.8	
.01666667	.0207427	14.8	
.04166667	.02733333	14.35	
.0833333	.0376667	13.57	
.125	.04733333	12.72	
.1666667	.05641667	11.81	
.2083333	.0646667	10.8	
.25	.07225	9.95	
.2854167	.078270833	9.5	

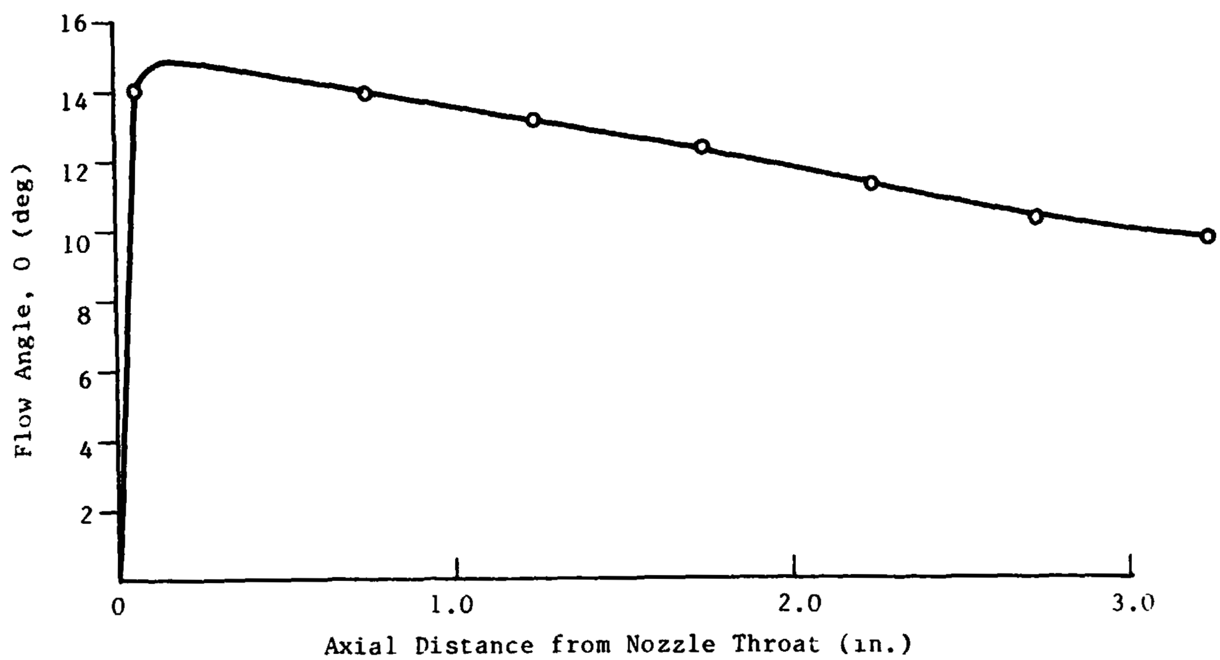


Fig. 8-2 Nozzle Wall Flow Angle vs Axial Distance for Space Shuttle Vernier Engine

was determined to be 0.8 in. and the distance from the throat at the beginning of the contraction was approximately 0.41 in. Next the contour of the combustion chamber is plotted on graph paper. A circular arc was used to take the contour from the combustion chamber to the throat circular arc. A circle with a radius of 0.28 in. was used. Figure 8-3 shows a layout of the combustion chamber/throat region. The two circles must match exactly. At the intersection of the two circles the flow angle is the same. Using this equality, the angle at the intersection can be determined from the following:

$$R_c - r_1 (1 - \cos\theta) = R_T + r_2 (1 - \cos\theta)$$

By substitution of the known 'mensions given on Fig. 8-3 the attach angle is found to be 50.796586 deg. he exact distance from the point of contraction to the throat is determined to be .4107006 in. using the following relationship.

$$x_c = r_1 \sin\theta + r_2 \sin\theta$$

Now that a complete description of the combustion chamber throat region has been determined (two circles), the points describing the region were determined and are tabulated in Table 8-1.

The propellant for the vernier motor is MMH/N_2O_4. Equilibrium/frozen chemistry was selected for this problem. The TRAN72 data for this system are shown in sample case 3 of Section 4 of this report. Since a boundary layer is important for applications of the vernier plume, the variable total enthalpy option was selected. The range of total enthalpy was determined knowing the nozzle wall temperature and making several TRAN72

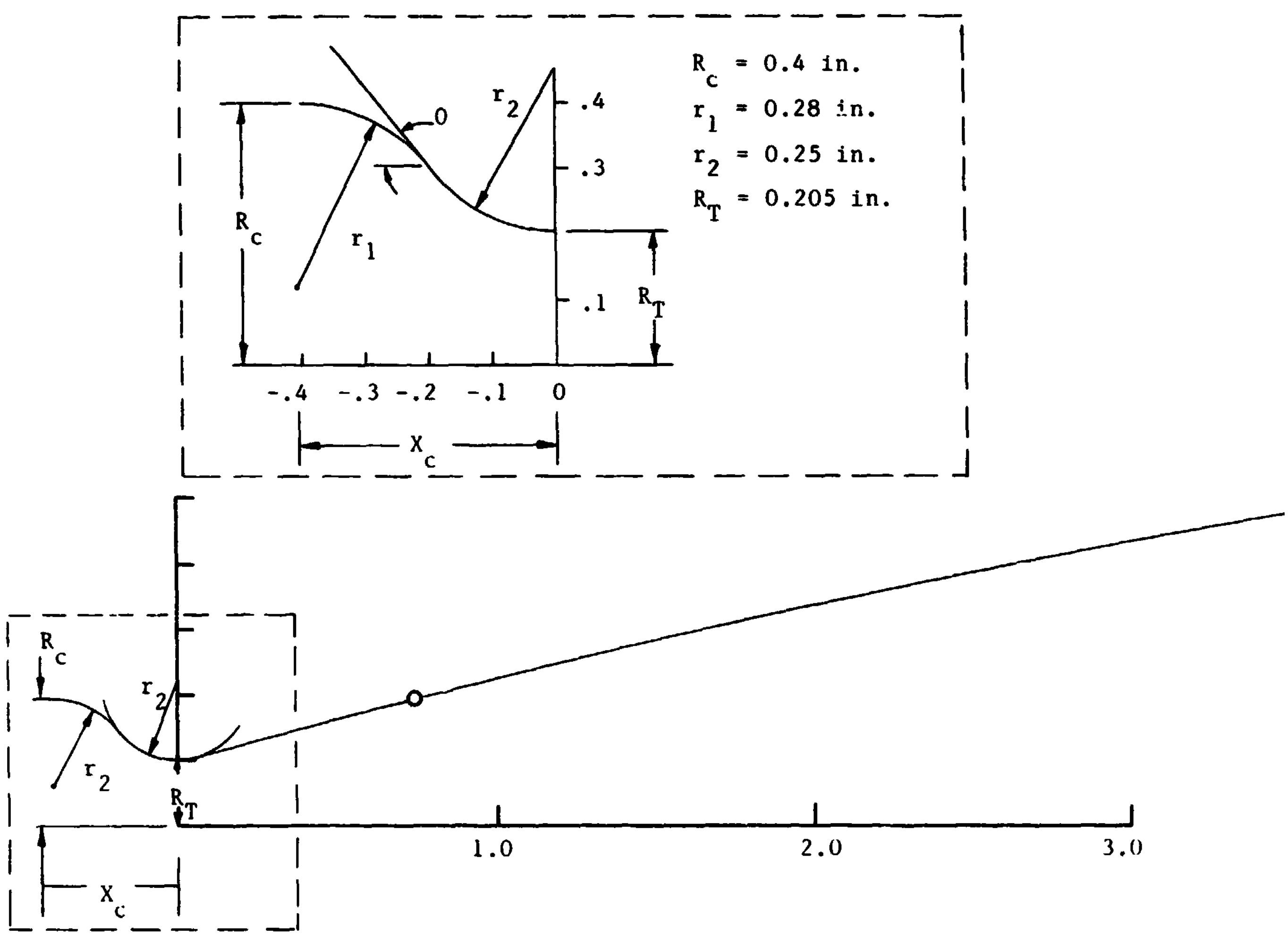


Fig. 3-3 Vernier Engine Combustion Chamber Geometry

calculations until the lip wall temperature was obtained for the bounding set of total enthalpies. The nozzle wall temperature boundary conditions for the vernier motor were based on the Space Shuttle RCS measured wall temperature data discussed in sample problem 2. A constant wall temperature of 2300 R was used. The adiabatic wall option could be used but the resulting wall temperature would be too high. Another source of wall temperature data would be the engine manufacturer. The flow was initially estimated to freeze at a pressure ratio (P_c/P) of 2. Using the results from Ref. 19 and the O/F ratio of 1.648 a better freeze pressure ratio would be 3.2. However, the effect on the nozzle and plume results due to this minor variation is insignificant so that the original estimate of freeze pressure was used.

The single phase transonic module was utilized to generate a supersonic start line. Since the usual use of the vernier flowfield calculation is the plume at relatively large distance from the nozzle, the transonic effects are negligible. However, for purposes of demonstration, the transonic calculation is included. Input data required by the transonic module are: the axial location of the throat (0.0), the station to start the solution (-0.03822505 ft), the entrance to the converging section, and the total enthalpy (133.344668 Btu/lbm) of the combustion products at the combustion chamber total temperature. Total enthalpy is input instead of O/F ratio since multiple total enthalpy tables are input. The enthalpy was obtained from the TRAN72 results for the QDOTP = 0.0 table. The remainder of the data input for this case is fairly straightforward.

SAMPLE PROBLEM I INPUT DATA

```
Card
1
2          SPACE SHUTTLE VERNIER NOZZLE  A/A*R..
3
4
5          2     4    1.2 .42      1  1  2     11   2                          1      0              1 57.
7    ..17083333 0..
           0      -. 342205.5..3333333  ..                         -..3330388..3330135  -3..
           0      -.031786.5..332.661  -6..                        -..301733 ..3297885  -1
                  -. 251859  . 32...2. -1...                       -..262446 . 3192616  -2
                  -. 243659  . 311471. -25.                        -..2255838..3020726  -30.
                  -. 208416  . 2911355 -3..                        -..01922667.0278744  -40.
                  -..0177259 . 264.41  -45.                        -..01614389..247484  -50.79658
           0      -..014731  ..231..27 -45.                        -..0133914 . 219574  -40.
                  -..119455  . 2.65.0.0-35.                        -..01041667..1987447 -30.
                  -.. 68 454. 1...5254-25.                         -..0712542. 18339737-20.
8          0      -.0053.206..0177932  -15.              0         -..00361767..17399838-10.
           0      -..0217767..1713744  -6.                         -..00109033..01711188 -3.
           0       0..       ..17083333 0..                        ..000727083..0170960  2.0
                  ..01145325 ..0171341  4..                        ..0217767 ..0171974  6.0
           0      ..00289-42 . 172.61                              ..003617667..0173998  10.0
                  ..043315   ..175..   12..                        ..0504    ..0177022  14.
                  ..066667   . 1.113.  14.4                        ..0833333 ..0185456  14.65
           0      ..01166667 ..194.16  14..                        ..01666667 . 207427  14.8
           0      ..04166667 ..0273333 14.35                       ..0833333  ..376667  13.57
           0      .125       . 4.3333  12.72          0            .1666667  ..5641667  11.81
           0      .20833333 ..646..67  10..           0            .25       ..37225    9.95
           1      .2854167  ..7.27...3 ..
8a   3     0      .1       -.04                                               1000.
9    2     0                                                                  1000.
10     VERN OF=1.648 PC=11.          PPS
20c  0..          -...342205.5  .         ..           133.344668
20d        1
22   10.          -1...      ...        .         2..        9 .
23   ..026  0     ...6        1 ..         ..              ..      .5
41                 2       2        1
44   0..           23  .        ..         ..   .
```

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SAMPLE PROBLEM 1 OUTPUT

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 1

SPACE SHUTTLE VERNIER NOZZLE 4/A4:21

RUN CONTROL PARAMETERS

ICON(1)	ICON(2)	ICON(3)	ICON(4)	ICON(5)	ICON(6)	ICON(7)	ICON(8)
2	0	15	40007	1	41	1	202

ICON(9)	ICON(10)	ICON(11)	ICON(12)	ICON(13)	ICON(14)	ICON(15)	ICON(16)
0	[illegible]	[illegible]	1	0	[illegible]	0	12570

FLOW CALCULATIONS ARE IN ENGLISH UNITS WITH THE X,R COORDINATES IN FEET

THE FLOW FIELD DATA WILL BE WRITTEN ON TAPE

UPPER BOUNDARY POINTS

TYPE	ITRANS.	X	R	THETA
2	[illegible]	-.30225-01	.33333-01	.00000
[illegible]	0	-.9350-01	.33301-01	-.52360-01
2	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	-.30173-01	.32970-01	-.17453+00
2	[illegible]	[illegible]	.32538-01	[illegible]
[illegible]	[illegible]	-.26245-01	.31920-01	-.34907+00
2	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	-.22950-01	.30207-01	-.52360+00
2	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	-.19227-01	.27870-01	-.69813+00
2	[illegible]	[illegible]	[illegible]	[illegible]
2	1	-.16144-01	.24740-01	-.80657+00
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	-.13341-01	.21957-01	-.69813+00
2	[illegible]	[illegible]	[illegible]	[illegible]
2	0	-.10917-01	.19276-01	-.52360+00
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	-.71250-02	.14390-01	-.34907+00
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	-.30177-02	.17690-01	-.17453+00
2	[illegible]	[illegible]	[illegible]	[illegible]
2	0	-.10043-02	.17112-01	-.52360-01
[illegible]	[illegible]	.13000	[illegible]	.00000
[illegible]	0	.72720-03	.17190-01	.34907-01
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	.21777-02	.17197-01	.13672+00
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	0	.36177-02	.17600-01	.17453+00
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	.56060-02	.17762-01	.20943+00
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	.83333-02	.14540-01	.25560+00
2	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	.16667-01	.27103-01	.25431+00
[illegible]	[illegible]	[illegible]	.27333-01	[illegible]

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 2

SPACE SHUTTLE VERNIER NOZZLE 4/A4:21

UPPER BOUNDARY POINTS

TYPE	ITRANS	X	R	THETA			
[illegible]	0	.83333-01	.37667-01	.23600+00			
[illegible]	[illegible]	.12500+00	.47333-01	.22201+00			
[illegible]	0	.16667+00	.56417-01	.20612+00			
2	[illegible]	.20833+00	.64667-01	.18850+00			
2	1	.25000+00	.77250-01	.17366+00			
2	[illegible]	.28562+00	.78271-01	.16581+00			
3	0	.00000	.17000-04	.00000			
0	0	[illegible]	.00003	.00000	.00000	.00000	.00000

LOWER BOUNDARY

TYPE	ITRANS	A	B	C	D	E	MAX
2	0	.00000	.30000	.00000	.00000	.00000	.10000+04

THERE ARE 0 PARTICLE SPECIES PRESENT IN THE GAS-PARTICLE MIXTURE

THE FOLLOWING GAS PROPERTIES IN ENGLISH UNITS ARE FOR VERN OF=1.648 PC=110

REAL GAS PROPERTIES

O/F
-.50730+00

S	V	R	GAMMA	T	P
.30000					
	.00000	.23296+04	.11917+01	.17350+04	.11000+03
	.20091+04	.22903+04	.11778+01	.16109+04	.62573+02
	.23099+04	.22907+04	.11770+01	.15651+04	.55000+02
	.33641+04	.22907+04	.13059+01	.12852+04	.22000+02
	.38835+04	.22907+04	.13179+01	.10900+04	.11000+02
	.42740+04	.22907+04	.13296+01	.92003+03	.55000+01
	.45771+04	.22907+04	.13401+01	.77317+03	.27500+01
	.48829+04	.22907+04	.13573+01	.61040+03	.11000+01
	.52452+04	.22907+04	.13686+01	.39859+03	.22000+00

REAL GAS PROPERTIES

O/F
-.66226+04

S	V	R	GAMMA	T	P
.00000					
	.00000	.23770+04	.12497+01	.20306+04	.11000+03
	.23019+04	.23669+04	.12327+01	.18160+04	.61451+02
	.24085+04	.23668+04	.12249+01	.17874+04	.55000+02
	.34239+04	.23698+04	.13166+01	.14425+04	.22000+02

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SAMPLE PROBLEM 1 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 1

SPACE SHUTTLE VERNIER NOZZLE A/A*=21

REAL GAS PROPERTIES

O/F

S	V	R	GAMMA	T	P
.30000					
	.41912+04	.23698+04	.13198+01	.12229+04	.11000+02
	.46103+04	.23698+04	.13306+01	.10317+04	.55000+01
	.49355+04	.23698+04	.13418+01	.86671+03	.27500+01
	.52637+04	.23698+04	.13528+01	[illegible]	.11000+01
	.56526+04	.23698+04	.13607+01	.44457+03	.22000+00

REAL GAS PROPERTIES

O/F
-.39486+00

S	V	R	GAMMA	T	P
.00000					
	.00000	.23734+04	.12517+01	.26074+04	.11000+03
	.26216+04	.23734+04	.12532+01	.23105+04	.68073+02
	.28264+04	.23734+04	.12533+01	.22828+04	.55000+02
	.41123+04	.23734+04	.12097+01	.19494+04	.22000+02
	.47476+04	.23734+04	.13017+01	.15779+04	.11000+02
	.52278+04	.23734+04	.13168+01	.13390+04	.55000+01
	.56022+04	.23734+04	.13290+01	.11308+04	.27500+01
	.59815+04	.23734+04	.13431+01	.89776+03	.11000+01
	.64333+04	.23734+04	.13614+01	.58997+03	.22000+00

REAL GAS PROPERTIES

O/F
-.36454+00

S	V	R	GAMMA	T	P
.00000					
	.00000	.23736+04	.12432+01	.37555+04	.11000+03
	.29748+04	.23735+04	.12478+01	.29881+04	.61816+02
	.32126+04	.23735+04	.12485+01	.29265+04	.55000+02
	.44811+04	.23735+04	.12712+01	.24165+04	.22000+02
	.50128+04	.23735+04	.12830+01	.20792+04	.11000+02
	.54848+04	.23735+04	.12981+01	.17798+04	.55000+01
	.60468+04	.23735+04	.13095+01	.15148+04	.27500+01
	.66529+04	.23735+04	.13208+01	.12182+04	.11000+01
	.73888+04	.23735+04	.13510+01	.80739+03	.22000+00

REAL GAS PROPERTIES

O/F
-.23696+00

S	V	R	GAMMA	T	P
.00000					
	.00000	.23745+04	.12378+01	.39005+04	.11000+03

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE [illegible]

SPACE SHUTTLE VERNIER NOZZLE A/A*=21

REAL GAS PROPERTIES

O/F

S	V	R	GAMMA	T	P
.30000					
	.32097+04	.23738+04	.12406+01	.39075+04	.61221+02
	.34679+04	.23737+04	.12418+01	.36157+04	.55000+02
	.50591+04	.23737+04	.12603+01	.28360+04	.22000+02
	.58554+04	.23737+04	.12787+01	.24530+04	.11000+02
	.64681+04	.23737+04	.12826+01	.21110+04	.55000+01
	.69491+04	.23737+04	.12957+01	.18071+04	.27500+01
	.74366+04	.23737+04	.13137+01	.14591+04	.11000+01
	.80325+04	.23737+04	.13428+01	.98807+03	.22000+00

REAL GAS PROPERTIES

O/F
-.16938+00

S	V	R	GAMMA	T	P
.00000					
	.00000	.23743+04	.12147+01	.44084+04	.11600+03
	.34045+04	.23753+04	.12286+01	.39717+04	.61659+02
	.36965+04	.23749+04	.12390+01	.38908+04	.55000+02
	.53999+04	.23749+04	.12570+01	.32455+04	.22000+02
	.62551+04	.23749+04	.12613+01	.28173+04	.11600+02
	.69109+04	.23749+04	.12719+01	.24350+04	.55000+01
	.74300+04	.23749+04	.12839+01	.20944+04	.27500+01
	.79652+04	.23749+04	.13075+01	.17021+04	.11000+01
	.86172+04	.23749+04	.13379+01	.11552+04	.22000+00

REAL GAS PROPERTIES

O/F
-.11179+00

S	V	R	GAMMA	T	P
.00000					
	.00000	.23798+04	.11900+01	.48671+04	.11600+03
	.35666+04	.23807+04	.12082+01	.44223+04	.61676+02
	.38956+04	.23795+04	.12119+01	.43351+04	.55000+02
	.57006+04	.23795+04	.12463+01	.36270+04	.22000+02
	.66084+04	.23795+04	.12545+01	.31572+04	.11000+02
	.73062+04	.23795+04	.12640+01	.27374+04	.55000+01
	.78601+04	.23795+04	[illegible]	.23630+04	.27500+01
	.84331+04	.23795+04	.12916+01	.19304+04	.11000+01
	.91355+04	.23795+04	.13234+01	.17222+04	.22000+00

REAL GAS PROPERTIES

O/F
-.34206-07

S	V	R	GAMMA	T	P
.00000					
	.00000	.24101+04	.11677+01	.51979+04	.11000+03

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 5

SPACE SHUTTLE VERNIER NOZZLE A/A*=21

REAL GAS PROPERTIES

O/F

.3[illegible]

S	V	R	GAMMA	T	P
	.36998+04	.23935+00	.11831+01	.60106+04	.62917+02
	[illegible]	[illegible]	[illegible]	[illegible]	.55000+02
	.59562+04	.23906+00	.12031+01	.39573+04	.22000+02
	[illegible]	[illegible]	[illegible]	[illegible]	.11000+02
	.76421+04	.23906+00	.12593+01	.29972+04	.55000+01
	[illegible]	[illegible]	[illegible]	[illegible]	.27500+01
	.88297+04	.23906+00	.12850+01	.21256+04	.11000+01
	[illegible]	[illegible]	[illegible]	[illegible]	.22000+00

REAL GAS PROPERTIES

O/F

.33370+07

S	V	R	GAMMA	T	P
	.00000	.24385+00	.11529+01	.54712+04	.11000+03
	[illegible]	[illegible]	[illegible]	[illegible]	.62893+02
	.42822+04	.24182+00	.11650+01	.50359+04	.55000+02
	[illegible]	[illegible]	[illegible]	[illegible]	.22000+02
	.71545+04	.24182+00	.12492+01	.36819+04	.11000+02
	[illegible]	[illegible]	[illegible]	[illegible]	.55000+01
	.85259+04	.24182+00	.12671+01	.27716+04	.27500+01
	[illegible]	[illegible]	[illegible]	[illegible]	.11000+01
	.99303+04	.24182+00	.13112+01	.15718+04	.22000+00

VARIABLE O/F TRANSONIC

INITIAL STATION	-.3023-01
THROAT STATION	.0000
FINAL STATION	.1734-01
MASS FLOW	.2595-02
AVERAGE O/F	.3336+07
THROAT AREA	.9164-03
TIME STEP	.1001-07

O/F DISTRIBUTION AT INITIAL STATION

R	O/F
.0000	.3336+07
.1000+01	.3336+07

SPACE SHUTTLE VERNIER NOZZLE A/A*=21

LINE	POINT	R	X	M	ANG	O/F	V	P	T	DENS
1	1	.3391-01	-.3023-01	.1500+00	.0000	.3370+07	.6223+03	.1561+05	.5462+00	.1172-02
1	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	3	.2857-01	-.3023-01	.1500+00	.0000	.3370+07	.6223+03	.1561+05	.5462+00	.1172-02
1	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	5	.2391-01	-.3023-01	.1500+00	.0000	.3370+07	.6223+03	.1561+05	.5462+00	.1172-02
1	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	7	.1975-01	-.3023-01	.1500+00	.0000	.3370+07	.6223+03	.1561+05	.5462+00	.1172-02
1	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	9	.1420-01	-.3023-01	.1500+00	.0000	.3370+07	.6223+03	.1561+05	.5462+00	.1172-02
1	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	11	.9574-02	-.3023-01	.1500+00	.0000	.3370+07	.6223+03	.1561+05	.5462+00	.1172-02
1	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	13	.4762-02	-.3023-01	.1500+00	.0000	.3370+07	.6223+03	.1561+05	.5462+00	.1172-02
1	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	15	.1391-08	-.3023-01	.1500+00	.0000	.3370+07	.6223+03	.1561+05	.5462+00	.1172-02

WDOT= .255-07 PDOT= .150+01 ISTEP= 0

LINE	POINT	R	X	M	ANG	O/F	V	P	T	DENS
2	1	.3391-01	-.3002-01	.1631+00	-.9303+01	.3370+07	.6391+03	.1560+05	.5461+00	.1172-02
2	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	3	[illegible]	-.3002-01	.1631+00	-.8002+01	.3370+07	.6391+03	.1560+05	.5461+00	.1172-02
2	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	5	.2356-01	-.3002-01	.1631+00	-.6702+01	.3370+07	.6391+03	.1560+05	.5461+00	.1172-02
2	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	7	.1807-01	-.3002-01	.1631+00	-.5361+01	.3370+07	.6391+03	.1560+05	.5461+00	.1172-02
2	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	9	.1415-01	-.3002-01	.1631+00	-.4021+01	.3370+07	.6391+03	.1560+05	.5461+00	.1172-02
2	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	11	.9433-02	-.3002-01	.1631+00	-.2681+01	.3370+07	.6391+03	.1560+05	.5461+00	.1172-02
2	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	13	.4716	-.3002-01	.1631+00	-.1340+01	.3370+07	.6391+03	.1560+05	.5461+00	.1172-02
2	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	15	.2150-09	-.3002-01	.1631+00	-.5069-06	.3370+07	.6391+03	.1560+05	.5461+00	.1172-02

WDOT= .255-07 PDOT= .163+01 ISTEP= 0

LINE	POINT	R	X	M	ANG	O/F	V	P	T	DENS
3	1	.3244-01	-.2662-01	.1772+00	-.1903+02	.3370+07	.6999+03	.1555+05	.5459+00	.1169-02
3	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	3	.2787-01	-.2662-01	.1772+00	-.1614+02	.3370+07	.6999+03	.1555+05	.5459+00	.1169-02
3	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	5	.2299-01	-.2662-01	.1772+00	-.1360+02	.3370+07	.6999+03	.1555+05	.5459+00	.1169-02
3	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	7	.1811-01	-.2662-01	.1772+00	-.1082+02	.3370+07	.6999+03	.1555+05	.5459+00	.1169-02
3	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	9	.1373-01	-.2662-01	.1772+00	-.8158+01	.3370+07	.6999+03	.1555+05	.5459+00	.1169-02
3	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	11	.9156-02	-.2662-01	.1772+00	-.5430+01	.3370+07	.6999+03	.1555+05	.5459+00	.1169-02
3	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	13	.4570-02	-.2662-01	.1772+00	-.2719+01	.3370+07	.6999+03	.1555+05	.5459+00	.1169-02
3	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	15	.1926-09	-.2662-01	.1772+00	-.1387-[illegible]	.3370+07	.6999+03	.1555+05	.5459+00	.1169-02

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

SPACE SHUTTLE VERNIER NOZZLE 8/10:21

LINE	POINT	R	X	M	ANG	U/F	V	P	T	DENS
1	1	.3333-01	-.3623-01	.1500+01	.0000	.3370+07	.6223+03	.1561+05	.5462+04	.1172-02
1	2	.3095-01	-.3623-01	.1500+01	.0000	.3370+07	.6223+03	.1561+05	.5462+04	.1172-02
1	3	.2857-01	-.3623-01	.1500+01	.0000	.3370+07	.6223+03	.1561+05	.5462+04	.1172-02
1	4	.2619-01	-.3623-01	.1500+01	.0000	.3370+07	.6223+03	.1561+05	.5462+04	.1172-02
1	5	.2381-01	-.3623-01	.1500+01	.0000	.3370+07	.6223+03	.1561+05	.5462+04	.1172-02
1	6	.2143-01	-.3623-01	.1500+01	.0000	.3370+07	.6223+03	.1561+05	.5462+04	.1172-02
1	7	.1905-01	-.3623-01	.1500+01	.0000	.3370+07	.6223+03	.1561+05	.5462+04	.1172-02
1	8	.1667-01	-.3623-01	.1500+01	.0000	.3370+07	.6223+03	.1561+05	.5462+04	.1172-02
1	9	.1429-01	-.3623-01	.1500+01	.0000	.3370+07	.6223+03	.1561+05	.5462+04	.1172-02
1	10	.1190-01	-.3623-01	.1500+01	.0000	.3370+07	.6223+03	.1561+05	.5462+04	.1172-02
1	11	.9524-02	-.3623-01	.1500+01	.0000	.3370+07	.6223+03	.1561+05	.5462+04	.1172-02
1	12	.7143-02	-.3623-01	.1500+01	.0000	.3370+07	.6223+03	.1561+05	.5462+04	.1172-02
1	13	.4762-02	-.3623-01	.1500+01	.0000	.3370+07	.6223+03	.1561+05	.5462+04	.1172-02
1	14	.2381-02	-.3623-01	.1500+01	.0000	.3370+07	.6223+03	.1561+05	.5462+04	.1172-02
1	15	.1907-08	-.3623-01	.1500+01	.0000	.3370+07	.6223+03	.1561+05	.5462+04	.1172-02

WDOT= .255-02 PDOT= .950+01 ISTEP= 926

LINE	POINT	R	X	M	ANG	U/F	V	P	T	DENS
2	1	.3331-01	-.3062-01	.1291+01	-.9384+01	.3370+07	.5870+03	.1597+05	.5482+04	.1194-02
2	2	.3100-01	-.3062-01	.1400+01	-.1283+02	.3370+07	.5526+03	.1594+05	.5480+04	.1193-02
2	3	.2897-01	-.3062-01	.1514+01	-.1360+02	.3370+07	.5927+03	.1591+05	.5477+04	.1191-02
2	4	.2594-01	-.3062-01	.1620+01	-.1444+02	.3370+07	.6305+03	.1581+05	.5470+04	.1185-02
2	5	.2154-01	-.3062-01	.1703+01	-.1443+02	.3370+07	.6834+03	.1570+05	.5465+04	.1178-02
2	6	.2174-01	-.3062-01	.1850+01	-.1453+02	.3370+07	.7205+03	.1559+05	.5461+04	.1171-02
2	7	.1887-01	-.3062-01	.1956+01	-.1453+02	.3370+07	.7664+03	.1553+05	.5450+04	.1167-02
2	8	.1651-01	-.3062-01	.2056+01	-.1467+02	.3370+07	.8051+03	.1544+05	.5455+04	.1161-02
2	9	.1415-01	-.3062-01	.2150+01	-.1395+02	.3370+07	.8429+03	.1534+05	.5449+04	.1153-02
2	10	.1179-01	-.3062-01	.2262+01	-.1126+02	.3370+07	.8697+03	.1500+05	.5440+04	.1138-02
2	11	.9433-02	-.3062-01	.2372+01	-.8494+01	.3370+07	.9266+03	.1484+05	.5429+04	.1122-02
2	12	.7076-02	-.3062-01	.2479+01	-.5601+01	.3370+07	.9641+03	.1462+05	.5419+04	.1108-02
2	13	.4716-02	-.3062-01	.2506+01	[illegible]	.3370+07	.9920+03	.1405+05	.5412+04	.1097-02
2	14	.2358-02	-.3062-01	.2591+01	-.1650+01	.3370+07	.1018+04	.1435+05	.5404+04	.1091-02
2	15	.2150-04	-.3062-01	.2607+01	.0000	.3370+07	.1016+04	.1432+05	.5406+04	.1089-02

WDOT= .122-02 PDOT= .230-01 ISTEP= 926

LINE	POINT	R	X	M	ANG	U/F	V	P	T	DENS
3	1	.3230-01	-.2662-01	.1692+01	-.1403+02	.3370+07	.6507+03	.1575+05	.5469+04	.1184-02
3	2	.2976-01	-.2662-01	.1732+01	-.1686+02	.3370+07	.6790+03	.1573+05	.5467+04	.1180-02
3	3	.2707-01	-.2662-01	.1705+01	-.1706+02	.3370+07	.6994+03	.1565+05	.5464+04	.1175-02
3	4	.2514-01	-.2662-01	.1819+01	-.1755+02	.3370+07	.7128+03	.1563+05	.5462+04	.1173-02
3	5	.2404-01	-.2662-01	.1859+01	-.1646+02	.3370+07	.7403+03	.1556+05	.5460+04	.1169-02
3	6	.2240-01	-.2662-01	.1903+01	-.1600+02	.3370+07	.7456+03	.1567+05	.5456+04	.1163-02
3	7	.1613-01	-.2662-01	.1935+01	-.1273+02	.3370+07	.7579+03	.1562+05	.5458+04	.1160-02
3	8	.1592-01	-.2662-01	.1937+01	-.1255+02	.3370+07	.7586+03	.1558+05	.5456+04	.1164-02
3	9	.1377-01	-.2662-01	.1915+01	-.1327+02	.3370+07	.7500+03	.1563+05	.5461+04	.1170-02
3	10	.1100-01	-.2662-01	.1905+01	-.1374+02	.3370+07	.7460+03	.1575+05	.5467+04	.1181-02
3	11	.9150-02	-.2662-01	.1915+01	-.1261+02	.3370+07	.7511+03	.1577+05	.5468+04	.1182-02
3	12	.6867-02	-.2662-01	.1966+01	-.9803+01	.3370+07	[illegible]	.1564+05	.5465+04	.1177-02
3	13	.4570-02	-.2662-01	.1992+01	-.6595+01	.3370+07	.7766+03	.1557+05	.5460+04	.1170-02
3	14	.2284-02	-.2662-01	.2009+01	-.3225+01	.3370+07	.7670+03	.1558+05	.5456+04	.1164-02
3	15	.1976-08	-.2662-01	.2020+01	.0000	.3370+07	.7699+03	.1555+05	.5455+04	.1162-02

SPACE SHUTTLE VERNIER NOZZLE 8/10:21

LINE	POINT	R	X	M	ANG	U/F	V	P	T	DENS
	2	.1442-01	.1734-01	.1750+01	.1026+02	.3370+07	.6421+04	.3096+04	.4178+04	.2985-03
27	3	.1191-01	.1734-01	.1767+01	.1025+02	.3370+07	.6248+04	.2985+04	.4172+04	.2988-03
27	4	.1644-01	.1734-01	.1793+01	.1446+02	.3370+07	.6316+04	.2079+04	.4142+04	.2883-03
27	5	.1494-01	.1734-01	.1797+01	.1472+02	.3370+07	.6333+04	.2876+04	.4141+04	.2881-03
27	6	.1345-01	.1734-01	.1705+01	.1368+02	.3370+07	.6303+04	.2951+04	.4163+04	.2901-03
27	7	.1195-01	.1734-01	.1758+01	.1222+02	.3370+07	.6235+04	.3094+04	.4202+04	.3056-03
27	8	.1046-01	.1734-01	.1720+01	.1150+02	.3370+07	.6132+04	.3209+04	.4252+04	.3210-03
27	9	.8965-02	.1734-01	.1693+01	.8897+01	.3370+07	.6055+04	.3473+04	.4285+04	.3315-03
27	10	.7471-02	.1734-01	.1663+01	.7867+01	.3370+07	.5966+04	.3503+04	.4323+04	.3439-03
27	11	.5977-02	.1734-01	.1642+01	.5916+01	.3370+07	.5907+04	.3717+04	.4353+04	.3542-03
27	12	.4483-02	.1734-01	.1625+01	.3598+01	.3370+07	.5862+04	.3867+04	.4387+04	.3650-03
27	13	.2988-02	.1734-01	.1610+01	.2101+01	.3370+07	.5837+04	.4009+04	.4417+04	.3766-03
27	14	.1494-02	.1734-01	.1608+01	.9237+00	.3370+07	.5825+04	.4113+04	.4439+04	.3844-03
27	15	.1091-08	.1734-01	.1606+01	.0000	.3370+07	.5821+04	.4151+04	.4447+04	.3873-03

WDOT= .256-02 PDOT= .150+02 ISTEP= 926

STARTING LINE INFO

R	X	M	THETA	S	MACH ANGLE	SHOCK ANGLE	U/F
.95508-09	.69107-02	.15170+01	.00000	-.72353+02	.60245+02	.00000	.33370+07
.12457-02	.67602-02	.11464+01	.24211+00	-.67196+02	.60720+02	.00000	.33370+07
.25855-02	.65023-02	.11435+01	.61609+00	-.20970+02	.60975+02	.00000	.33370+07
.38697-02	.64452-02	.11492+01	.97610+00	.16431+02	.60920+02	.00000	.33370+07
.51082-02	.62800-02	.11477+01	.10509+01	.40031+02	.60617+02	.00000	.33370+07
.64430-02	.61331-02	.11563+01	.16402+01	.45099+02	.59863+02	.00000	.33370+07
.76003-02	.59706-02	.11670+01	.22416+01	.39216+02	.58967+02	.00000	.33370+07
.89502-02	.58236-02	.11856+01	.25476+01	.33407+02	.57521+02	.00000	.33370+07
.10287-01	.56699-02	.12651+01	.34731+01	.30620+02	.56081+02	.00000	.33370+07
.11458-01	.55166-02	.12371+01	.39897+01	.25431+02	.53931+02	.00000	.33370+07
.12703-01	.53644-02	.12640+01	.57135+01	.13608+02	.52457+02	.00000	.33370+07
.13963-01	.52127-02	.13219+01	.58773+01	.88069+01	.49162+02	.00000	.33370+07
.15174-01	.50613-02	.13677+01	.80700+01	-.31069+01	.46982+02	.00000	.33370+07
.16413-01	.49105-02	.14060+01	.95439+01	-.13728+02	.43053+02	.00000	.33370+07
.17638-01	.47606-02	.15513+01	.13211+02	-.57931+02	.40074+02	.00000	.33370+07

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 6

SPACE SHUTTLE VERNIER NOZZLE A/A*=21

RUN CUTOFF INFORMATION

	UPPER BOUNDARY			LOWER BOUNDARY		
-2 .10000+13	R= -.10000+03	THETA= .00000	R= .00000	R= .20000+02	THETA= .90000+02	

THE MESH CONSTRUCTION WILL BE CONTROLLED BY THE FOLLOWING VARIABLES

DL INTERIOR= .261-02 DL AXIS= .630-02 DL LIP= .100+03 DL DELETE= .500-02 DEG P.M.= .500+01 F= .500+00

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 7

SPACE SHUTTLE VERNIER NOZZLE A/A*=21

LINE	POINT	DISCRIP - REGIME	R / MACH ANGLE	Z / PRESSURE	W / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
1	1	INPUT - CONTIN	.95506-04 .60495+02	.69187-02 .59321+02	.11519+01 .69975-03	.00000 .99999+00	-.72353+02 .29102+00	.43226+04 .11697+01	.33378+07	0
1	2	INPUT - CONTIN	.12957-02 .60770+02	.67682-02 .56352+02	.11969+01 .69925-03	.20211+00 .59015+00	-.57196+02 .29102+00	.43035+04 .11698+01	.33378+07	0
1	3	INPUT - CONTIN	.25055-02 .60975+02	.66023-02 .53725+02	.11976+01 .64139-03	.61909+00 .59090+00	-.20978+02 .29102+00	.42938+04 .11686+01	.33378+07	0
1	4	INPUT - CONTIN	.38697-02 .60920+02	.64452-02 .52057+02	.11902+01 .63100-03	.97039+00 .59091+00	.16031+02 .29102+00	.42968+04 .11687+01	.33378+07	0
1	5	INPUT - CONTIN	.51402-02 .60617+02	.62688-02 .51196+02	.11977+01 .62255-03	.10509+01 .99999+00	.40031+02 .29102+00	.43081+04 .11692+01	.33378+07	0
1	6	INPUT - CONTIN	.64910-02 .59463+02	.61371-02 .51054+02	.11563+01 .61608-03	.16402+01 .99096+00	.45099+02 .29102+00	.43308+04 .11703+01	.33378+07	0
1	7	INPUT - CONTIN	.76403-02 .58567+02	.59780-02 .59084+02	.11670+01 .61087-03	.27010+01 .49766+00	.30210+02 .29102+00	.43756+04 .11718+01	.33378+07	0
1	8	INPUT - CONTIN	.89582-02 .57521+02	.50236-02 .49026+02	.11050+01 .60087-03	.25476+01 .49502+00	.33607+02 .29102+00	.44390+04 .11743+01	.33378+07	0
1	9	INPUT - CONTIN	.10297-01 .56481+02	.56699-02 .49628+02	.17051+01 .58931-03	.39731+01 .49300+00	.39820+02 .29102+00	.45066+04 .11770+01	.33378+07	0
1	10	INPUT - CONTIN	.11978-01 .53931+02	.55160-02 .46722+02	.12371+01 .57003-03	.39007+01 .48901+00	.45031+02 .29102+00	.46162+04 .11813+01	.33378+07	0
1	11	INPUT - CONTIN	.12703-01 .52157+02	.53644-02 .45677+02	.12600+01 .55966-03	.52135+01 .48511+00	.13000+02 .29192+00	.47207+04 .11859+01	.33378+07	0
1	12	INPUT - CONTIN	.13593-01 .49142+02	.52127-02 .41898+02	.13218+01 .52394-03	.58773+01 .47822+00	.08069+01 .29102+00	.49402+04 .11925+01	.33378+07	0
1	13	INPUT - CONTIN	.15179-01 .46482+02	.50615-02 .39932+02	.13677+01 .49090-03	.89706+01 .47226+00	-.31069+01 .29102+00	.50512+04 .11969+01	.33378+07	0
1	14	INPUT - CONTIN	.16613-01 .43453+02	.49105-02 .36284+02	.14698+01 .46671-03	.95034+01 .45928+00	-.13726+02 .29102+00	.53623+04 .12106+01	.33378+07	0
1	15	INPUT - CONTIN	.17678-01 .40474+02	.47696-02 .33979+02	.15573+01 .47662-03	.11211+02 .44725+00	-.57931+02 .29102+00	.56362+04 .12219+01	.33378+07	0

THE MASS FLOW RATE IS = .81421-01

MOMENTUM INTEGRATION RESULTS

FORCEX	FORCEY	TORGZ	ISP
-.45193+02	.00000	.00000	.22392+03

ORIGINAL PAGE IS OF POOR QUALITY

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 3 PAGE 8

SPACE SHUTTLE VERNIER NOZZLE 8/4/71

LINE	POINT	DESCRIP - REGIME	M MACH ANGLE	X PRESSURE	R DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
2	99	INPUT - CONTIN	.16413-01 .41453+02	.49105-02 .34206+02	.19646+01 .44601-03	.95434+01 .45928+00	-.13730+02 .29102+00	.53623+00 .12106+01	.33378+07	0
4	100	INPUT - CONTIN	.17630-01 .40276+02	.47646-02 .30424+02	.15535+01 .40642-03	.13211+02 .44725+00	-.57931+02 .29102+00	.56362+00 .12219+01	.33378+07	0

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.18193+02	.00000	.00000	.00000	.00000	.22342+03

LINE	POINT	DESCRIP - REGIME	M MACH ANGLE	X PRESSURE	R DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
3	50	INPUT - CONTIN	.15179-01 .46982+02	.59615-02 .39934+02	.13677+01 .49894-03	.80790+01 .47222+00	-.31069+01 .29102+00	.50512+00 .11989+01	.33378+07	0

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.18193+02	.00000	.00000	.00000	.00000	.22342+03

LINE	POINT	DESCRIP - REGIME	M MACH ANGLE	X PRESSURE	R DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
4	47	INPUT - CONTIN	.13943-01 .44162+02	.52127-02 .41898+02	.13218+01 .52344-03	.50773+01 .47872+00	.08469+01 .29102+00	.49002+00 .11925+01	.33378+07	0

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.18193+02	.00000	.00000	.00000	.00000	.22342+03

LINE	POINT	DESCRIP - REGIME	M MACH ANGLE	X PRESSURE	R DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
5	46	INPUT - CONTIN	.12703-01 .32657+02	.51644-02 .45137+02	.12684+01 .55466-03	.52135+01 .48511+00	.13606+02 .29102+00	.47287+00 .11859+01	.33378+07	0

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.18193+02	.00000	.00000	.00000	.00000	.22342+03

LINE	POINT	DESCRIP - REGIME	M MACH ANGLE	X PRESSURE	R DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
6	45	INPUT - CONTIN	.11450-01 .53431+02	.55166-02 .46772+02	.12371+01 .57083-03	.39097+01 .48961+00	.25431+02 .29102+00	.46162+00 .11813+01	.33378+07	0

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.18193+02	.00000	.00000	.00000	.00000	.22342+03

LINE	POINT	DESCRIP - REGIME	M MACH ANGLE	X PRESSURE	R DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
7	44	INPUT - CONTIN	.10207-01 .56481+02	.56699-02 .49628+02	.12151+01 .59971-03	.36731+01 .49360+00	.30820+02 .29102+00	.45066+00 .11770+01	.33378+07	0

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.18193+02	.00000	.00000	.00000	.00000	.22342+03

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 93

SPACE SHUTTLE VERNIER NOZZLE 8/4/71

LINE	POINT	DESCRIP - REGIME	M MACH ANGLE	X PRESSURE	R DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
128	1	WALL - CONTIN	.00000 .13474+02	.27600+00 .36614+00	.41618+01 .12456-04	.00000 .17565+00	-.72353+02 .29102+00	.97343+00 .13053+01	.33378+07	2
128	46	WALL - CONTIN	.75111-01 .14498+02	.26741+00 .50673+00	.38897+01 .16893-04	.97287+01 .19265+00	-.57931+02 .29102+00	.95484+00 .12970+01	.33378+07	2

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.25439+02	.00000	.00000	-.19962-01	.00000	.31240+03

LINE	POINT	DESCRIP - REGIME	M MACH ANGLE	X PRESSURE	R DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
129	1	WALL - CONTIN	.00000 .13925+02	.27717+00 .35783+00	.41555+01 .12235-04	.00000 .17473+00	-.72353+02 .29102+00	.97403+00 .13057+01	.33378+07	2
129	46	WALL - CONTIN	.75751-01 .14886+02	.27059+00 .53315+00	.39029+01 .16616-04	.96803+01 .19170+00	-.57931+02 .29102+00	.95508+00 .12982+01	.33378+07	2

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.25455+02	.00000	.00000	-.19894-01	.00000	.31265+03

A NEW STREAMLINE HAS BEEN INSERTED ON LINE 129 BETWEEN POINTS 35 AND 36

LINE	POINT	DESCRIP - REGIME	M MACH ANGLE	X PRESSURE	R DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
130	1	WALL - CONTIN	.00000 .13875+02	.28037+00 .34976+00	.41690+01 .12072-04	.00000 .17382+00	-.72353+02 .29102+00	.97542+00 .13061+01	.33378+07	2
130	47	WALL - CONTIN	.76490-01 .14795+02	.27381+00 .52184+00	.39161+01 .16343-04	.96475+01 .19076+00	-.57931+02 .29102+00	.95692+00 .12986+01	.33378+07	2

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.25479+02	.00000	.00000	-.19846-01	.00000	.31289+03

LINE	POINT	DESCRIP - REGIME	M MACH ANGLE	X PRESSURE	R DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
131	1	WALL - CONTIN	.00000 .13627+02	.28361+00 .34191+00	.41843+01 .11813-04	.00000 .17292+00	-.72353+02 .29102+00	.97639+00 .13065+01	.33378+07	2
131	47	WALL - CONTIN	.76451-01 .14744+02	.27707+00 .51079+00	.39293+01 .16076-04	.96061+01 .18983+00	-.57931+02 .29102+00	.95799+00 .12990+01	.33378+07	2

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.25496+02	.00000	.00000	-.19799-01	.00000	.31310+03

LINE	POINT	DESCRIP - REGIME	M MACH ANGLE	X PRESSURE	R DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
132	1	WALL - CONTIN	.00000 .13379+02	.28687+00 .33427+00	.41997+01 .11616-04	.00000 .17203+00	-.72353+02 .29102+00	.97735+00 .13068+01	.33378+07	2

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

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SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

                                   CASE NO.   0                                              PAGE   44

SPACE SHUTTLE VERNIER NOZZLE  A/A*=21

LINE POINT  DSCRIP - REGIME        Q            X            M            THETA        ENTROPY       VELOCITY     O/F         ITR
                                   MACH ANGLE   PRESSURE     DENSITY      TEMPERATURE  GAS CONST.    LOCAL GAMMA  SHOCK ANGLE

132   47  WALL   - CONTIN         .77411-01    .28056+00    .39625+01    .95642+01    -.57931+02    .95896+04    .33378+07    2
                                   .19693+02   .50000+00    .15033-04    .18891+04    .29102+04     .12994+01

                                      PRESSURE INTEGRATION RESULTS
                                  FORCEX       FORCEY       TORQZ        DELFX         DELFY        ISP
                                 -.27518+02    .00000       .00000      -.19752-01     .00000       .31339+03

A NEW STREAMLINE HAS BEEN INSERTED ON LINE 133 BETWEEN POINTS  37 AND  38

133    1  WALL   - CONTIN          .00000       .29026+00    .42129+01    .00000       -.72353+02    .97030+04    .33378+07    2
                                   .19731+02    .32609+00    .11411-04    .17115+04    .29102+04     .13072+01

133   48  WALL   - CONTIN          .77470-01    .28369+00    .39557+01    .95219+01    -.57931+02    .95997+04    .33378+07    2
                                   .19603+02    .48996+00    .15556-04    .18799+04    .29102+04     .12999+01

                                      PRESSURE INTEGRATION RESULTS
                                  FORCEX       FORCEY       TORQZ        DELFX         DELFY        ISP
                                 -.25530+02    .00000       .00000      -.19704-01     .00000       .31362+03

134    1  WALL   - CONTIN          .00000       .29356+00    .42271+01    .00000       -.72353+02    .97924+04    .33378+07    2
                                   .19684+02    .31971+00    .11218-04    .17020+04    .29102+04     .13076+01

134   48  WALL   - CONTIN          .78471-01    .28562+00    .39630+01    .95000+01    -.57931+02    .96000+04    .33378+07    2
                                   .19610+02    .48360+00    .15014-04    .18708+04    .29102+04     .13001+01

                                      PRESSURE INTEGRATION RESULTS
                                  FORCEX       FORCEY       TORQZ        DELFX         DELFY        ISP
                                 -.25596+02    .00000       .00000      -.10012-01     .00000       .31370+03

        PERCENT CHANGE IN MASS, MOMENTUM AND ENERGY NUMERICAL INTEGRATION FOR LINE134 RELATIVE TO THE START LINE
  THE PERCENT CHANGE IN MASS FLOW IS :        .110458+01
 PERCENT CHANGE IN MOMENTUM IS :    .13741+01     ISP :   -.98364+00
 PERCENT CHANGE IN ENERGY IS :    .00000
EXIT PLANE NORMAL START LINE

           .00000u       .2919188+00   .4220145+01   .0000000     -.7235314+02   .33378u0+07
           .1637861-02   .2919156+00   .4718691+01   .7242057+00  -.6957172+02   .33378u0+07
           .3276226-02   .2919060+00   .4717396+01   .4487677+00  -.6479630+02   .33378u0+07
           .4911260-02   .2919490+00   .4215596+01   .6724065+00  -.6099311+02   .33378u0+07
           .6545392-02   .2916677+00   .4213940+01   .8946751+00  -.5719591+02   .33378u0+07
           .8171923-02   .2916391+00   .4249654+01   .1113731+01  -.4917453+02   .33378u0+07
           .9797608-02   .2918095+00   .4265579+01   .1331519+01  -.3916501+02   .33378u0+07
           .1141147-01   .2917639+00   .4201056+01   .1546763+01  -.3006521+02   .33378u0+07
           .1302391-01   .2917174+00   .4196246+01   .1758055+01  -.2097821+02   .33378u0+07
           .1462609-01   .2916655+00   .4191493+01   .1965399+01  -.1169053+02   .33378u0+07
           .1621436-01   .2916787+00   .4185605+01   .2169822+01  -.2032619+01   .33378u0+07
           .1779268-01   .2915456+00   .4179773+01   .2369569+01   .7005493+01   .33378u0+07
           .1936790-01   .2914775+00   .4173615+01   .2566005+01   .1693059+02   .33378u0+07
           .2093013-01   .2914669+00   .4169397+01   .2757729+01   .2243733+02   .33378u0+07
           .2248085-01   .2913272+00   .4162194+01   .2945030+01   .2944407+02   .33378u0+07
           .2412671-01   .2912456+00   .4155697+01   .3178036+01   .3463773+02   .33378u0+07
           .2556049-01   .2911592+00   .4149325+01   .3307301+01   .4043190+02   .33378u0+07
           .2708605-01   .2910687+00   .4143677+01   .3481399+01   .4182494+02   .33378u0+07
           .2867511-01   .2909763+00   .4134023+01   .3652007+01   .4289779+02   .33378u0+07
           .3019493-01   .2908764+00   .4131354+01   .3817580+01   .4305269+02   .33378u0+07
           .3160195-01   .2907764+00   .4125597+01   .3979937+01   .4509877+02   .33378u0+07
           .3909631-01   .2906660+00   .4119724+01   .4138563+01   .4356565+02   .33378u0+07
           .3456906-01   .2905598+00   .4113607+01   .4294624+01   .4209966+02   .33378u0+07
           .3603179-01   .2904479+00   .4107364+01   .4446948+01   .4061421+02   .33378u0+07
           .3749283-01   .2903324+00   .4160972+01   .4597538+01   .3921617+02   .33378u0+07
           .3893307-01   .2902167+00   .4099455+01   .4745079+01   .3769092+02   .33378u0+07
           .4037193-01   .2900930+00   .4081653+01   .4891611+01   .3628694+02   .33378u0+07
           .4179220-01   .2899730+00   .4081477+01   .5030531+01   .3476845+02   .33378u0+07
           .4321173-01   .2898431+00   .4079610+01   .5181257+01   .3340716+02   .33378u0+07
           .4461101-01   .2897145+00   .4067457+01   .5324469+01   .3266917+02   .33378u0+07
           .4630965-01   .2895823+00   .4061046+01   .5464495+01   .3210368+02   .33378u0+07
           .4739166-01   .2894463+00   .4059914+01   .5611929+01   .3136032+02   .33378u0+07
           .4917353-01   .2893107+00   .4047753+01   .5756671+01   .3081991+02   .33378u0+07
           .5012437-01   .2891729+00   .4041510+01   .5894734+01   .2936631+02   .33378u0+07
           .5147531-01   .2890315+00   .4035354+01   .6044824+01   .2817060+02   .33378u0+07
           .5281079-01   .2888684+00   .4029390+01   .6190560+01   .2667520+02   .33378u0+07
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SAMPLE PROBLEM 1 OUTPUT (Cont'd)

.5616600-01	.2887818+00	.4025404+01	.6330619+01	.2563097+02	.3337800+07
.5505807-01	.2885994+00	.4018227+01	.6485609+01	.2203589+02	.3337800+07
.5676954-01	.2884615+00	.4011043+01	.6636103+01	.1968292+02	.3337800+07
.5936054-01	.2881342+00	.4001573+01	.6960702+01	.1380808+02	.3337800+07
.6188979-01	.2878209+00	.3993835+01	.7207157+01	.1130709+02	.3337800+07
.6459357-01	.2874950+00	.3985101+01	.7563938+01	.8006901+01	.3337800+07
.6634756-01	.2871621+00	.3970360+01	.7888165+01	.2009983+01	.3337800+07
.6929059-01	.2868167+00	.3972486+01	.8224575+01	-.3106936+01	.3337800+07
.7162049-01	.2864726+00	.3967639+01	.8555416+01	-.8024076+01	.3337800+07
.7395510-01	.2861180+00	.3962705+01	.8889088+01	-.1372767+02	.3337800+07
.7618870-01	.2857599+00	.3962461+01	.9208230+01	-.3583293+02	.3337800+07
.7827083-01	.2854167+00	.3963026+01	.9500009+01	-.5793090+02	.3337800+07

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.25558+02	.00000	.00000	-.10072-01	.00000	.31307+03

A NEW STREAMLINE HAS BEEN INSERTED ON LINE 133 BETWEEN POINTS 59 AND 60
ISSUE WAS IN HYPER
000100000000 000000000000

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 98

SPACE SHUTTLE VERNIER NOZZLE A/A*:21

LINE	POINT	DSCRIP - REGIME	P / MACH ANGLE	X / PRESSURE	M / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
133	46	INTER - CONTIN	.73675-01	.24639+00	.39559+01	.89097+01	-.13728+02	.95999+04	.33378+07	3
			.14663+02	.48041+00	.15269-04	.18797+04	.24102+04	.12999+01		
133	47	INTER - CONTIN	.75825-01	.24004+00	.39557+01	.92207+01	-.35033+02	.95997+04	.33378+07	3
			.14663+02	.46699+00	.15614-04	.18799+04	.24102+04	.12999+01		
133	48	WALL - CONTIN	.77478-01	.24369+00	.39557+01	.95219+01	-.57931+02	.95997+04	.33378+07	3
			.14669+02	.45946+00	.15556-04	.18799+04	.24102+04	.12999+01		
133	49	INPUT - CONTIN	.78271-01	.28542+00	.39630+01	.95000+01	-.57931+02	.96054+04	.33378+07	0
			.14616+02	.48368+00	.15414-04	.18748+04	.24102+04	.13001+01		
133	50	PRN-MR - CONTIN	.78471-01	.28542+00	.42663+01	.14500+02	-.57931+02	.98179+04	.33378+07	0
			.13556+02	.29890+00	.10636-04	.16790+04	.24102+04	.13086+01		
133	51	PRN-MR - CONTIN	.78471-01	.28542+00	.46190+01	.19499+02	-.57931+02	.10018+05	.33378+07	0
			.12504+02	.17761+00	.71364-05	.14870+04	.24102+04	.13132+01		
133	52	PRN-MR - CONTIN	.78471-01	.28542+00	.50319+01	.24499+02	-.57931+02	.10206+05	.33378+07	0
			.11463+02	.10099+00	.46423-05	.12997+04	.24102+04	.13132+01		
133	53	PRN-MR - CONTIN	.78471-01	.28542+00	.55066+01	.29498+02	-.57931+02	.10379+05	.33378+07	0
			.10463+02	.54634-01	.29078-05	.11225+04	.24102+04	.13132+01		
133	54	PRN-MR - CONTIN	.78471-01	.28542+00	.60583+01	.34498+02	-.57931+02	.10540+05	.33378+07	0
			.95109+01	.27903-01	.17432-05	.95635+03	.24102+04	.13132+01		
133	55	PRN-MR - CONTIN	.78471-01	.28542+00	.67092+01	.39498+02	-.57931+02	.10687+05	.33378+07	0
			.85718+01	.13319-01	.99255-06	.80172+03	.24102+04	.13132+01		
133	56	PRN-MR - CONTIN	.78471-01	.28542+00	.74913+01	.44497+02	-.57931+02	.10821+05	.33378+07	0
			.76712+01	.58640-02	.53142-06	.65926+03	.24102+04	.13132+01		
133	57	PRN-MR - CONTIN	.78471-01	.28542+00	.84516+01	.49497+02	-.57931+02	.10942+05	.33378+07	0
			.67452+01	.23399-02	.26379-06	.52955+03	.24102+04	.13132+01		
133	58	PRN-MR - CONTIN	.78471-01	.28542+00	.96676+01	.54496+02	-.57931+02	.11049+05	.33378+07	0
			.59403+01	.82593-03	.11985-06	.41310+03	.24102+04	.13132+01		
133	59	PRN-MR - CONTIN	.78471-01	.28542+00	.11242+02	.57496+02	-.57931+02	.11142+05	.33378+07	0
			.51473+01	.24003-03	.47937-07	.31678+03	.24102+04	.13132+01		
133	60	PRN-MR - CONTIN	.78471-01	.28542+00	.13392+02	.64490+02	-.57931+02	.11222+05	.33378+07	0
			.47673+01	.60935-04	.16949-07	.27186+03	.24102+04	.13132+01		

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 99

SPACE SHUTTLE VERNIER NOZZLE A/A*:21

LINE	POINT	DSCRIP - REGIME	P / MACH ANGLE	X / PRESSURE	M / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
133	61	PRN-MR - CONTIN	.78471-01	.28542+00	.16512+02	.69495+02	-.57931+02	.11289+05	.33378+07	0
			.34721+01	.11057-04	.44733-08	.14768+03	.24102+04	.13132+01		
133	62	PRN-MR - CONTIN	.78471-01	.28542+00	.21497+02	.74494+02	-.57931+02	.11342+05	.33378+07	0
			.26725+01	.12834-05	.86770-09	.84365+02	.24102+04	.13132+01		
133	63	PRN-MR - CONTIN	.78471-01	.28542+00	.30478+02	.79493+02	-.57931+02	.11381+05	.33378+07	0
			.18475+01	.69409-07	.94096-10	.44071+02	.24102+04	.13132+01		

PREVIOUSLY NOTED ERRORS HAVE PROPAGATED TO LOWER BOUNDARY, OR PROBLEM LIMITS HAVE BEEN REACHED. CASE TERMINATED.
77777777777 77777777777

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

SUMMARY OF STANDARD PLUME FLOWFIELD CODE INPUT DATA WHICH WAS OUTPUT ON UNIT 12

CHEMISTRY SYSTEM 2

MOLECULAR WEIGHT	.20620+02
SPECIFIC HEAT RATIO	.13018+01
VISCOSITY(POISE)	.34122-03
PRANDTL NUMBER	.60423+00
NOZZLE EXIT RADIUS(FT)	.78269-01
TEMPERATURE(DEG R)	.10192+04
DENSITY(GM/CC)	.71982-05
VELOCITY(FT/SEC)	.96492+04

SPECIE	MOLE FRACTION	SPECIE	MOLE FRACTION
CO	.1269+00	CO2	[illegible]-01
H	.1659-01	H2	[illegible]+00
H2O	.3355+00	N2	[illegible]+00
O	.6616-03	OH	.10[illegible]-01
O2	.5723-01		

GASEOUS STARTING LINE INFO

R/RE(ND)	U(FT/SEC)	V(FT/SEC)	P(ATM)	T(DEG R)
.0000	.9765+04	.0000	.2298-01	.9579+03
.4167-01	.9767+04	.7902+02	.2301-01	.9588+03
.8333-01	.9764+04	.1575+03	.2306-01	.9601+03
.1250+00	.9757+04	.2349+03	.2316-01	.9620+03
.1667+00	.9749+04	.3108+03	.2331-01	.9658+03
.2083+00	.9739+04	.3846+03	.2350-01	.9694+03
.2500+00	.9728+04	.4562+03	.2374-01	.9734+03
.2917+00	.9717+04	.5251+03	.2403-01	.9773+03
.3333+00	.9705+04	.5911+03	.2439-01	.9816+03
.3750+00	.9693+04	.6543+03	.2481-01	.9857+03
.4167+00	.9680+04	.7146+03	.2529-01	.9900+03
.4583+00	.9667+04	.7723+03	.2583-01	.9945+03
.5000+00	.9653+04	.8281+03	.2645-01	.9994+03
.5417+00	.9638+04	.8827+03	.2706-01	.1005+04
.5833+00	.9622+04	.9370+03	.2772-01	.1010+04
.6250+00	.9606+04	.9918+03	.2843-01	.1015+04
.6667+00	.9590+04	.1048+04	.2907-01	.1020+04
.7083+00	.9574+04	.1106+04	.2972-01	.1025+04
.7500+00	.9558+04	.1166+04	.3035-01	.1029+04
.7917+00	.9542+04	.1228+04	.3093-01	.1034+04
.8333+00	.9527+04	.1294+04	.3145-01	.1037+04
.8750+00	.9512+04	.1364+04	.3189-01	.1040+04
.9167+00	.9497+04	.1438+04	.3227-01	.1042+04
.9583+00	.9484+04	.1512+04	.3260-01	.1042+04
.1000+01	.9473+04	.1587+04	.3292-01	.1042+04

ORIGINAL PAGE IS
OF POOR QUALITY

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

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          JANNAF BOUNDARY LAYER INTEGRAL MATRIX PROCEDURE

                    BLIMP-J  MOD 2  JULY 1975

     AEROTHERM CORP.  AEROTHERM DIV.,MT. VIEW,CALIF.

CASE     SPACE SHUTTLE VERNIER NOZZLE  A/A*=21

     CONTROL NUMBERS  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20

                      1  3  2  0  0  4  3  3  7  1  0  2  1  2  0  0  0  0  0  0

  U/UE TO        NODAL PT.                          ETA VALUES
  NORM. ETA      AT WHICH
                 ETA NORM.
  9.900-01       10          0.000     2.876-03  6.808-03  1.557-02  2.703-02  4.835-02  1.065-01  4.154-01  7.219-01
                             1.000+00  1.293+00  2.500+00

CASE                      1.00000+00

TOTAL ENTHALPY, H/LB      1.33300+02

TOTAL PRESSURE, ATM       7.85100+00

INCID. RAD FLUX, B/SF2    0.00000

  CEBECI-SMITH TURB. MODEL

  MIXING LENGTH CONSTANT    :  4.000-01
  SUBLAYER CONSTANT, VAP    :  1.180+01
  CLAUSER NUMBER            :  1.680-02

  TURBULENT PRANDTL NUMBER  :  9.000-01

  TURBULENT SCHMIDT NUMBER  :  9.000-01
  TRANSITION MOM.THICK.RE   :  2.500+02

     CASE  1 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

     VISCOSITY LAW   MU=(  .629-06*T**   .158+01)/(   .170+01*T+   .356+03)

     PRANDTL NUMBER  PR=   .399+00+   .000   *T+    .000   +    .000   *T**   .000

     TEMP. IN DEG. R      VISCOSITY IN LBM/S-FT

                                         MIXTURE CURVE FIT CONSTANTS (DEG K)

 300.00    .36371974+01   -.1399192-03    .12953039-05   -.38353117-09   -.95402938-13   -.13955813+05    .10660942+01
 1000.00   .29160279+01    .19054599-07   -.59091876-06    .89061822-10   -.51649651-14   -.13766611+05    .67659089+01


          FLUID MIXTURE

        COMPONENT             MOLE        MASS
                              FRACTION    FRACTION

   CO                         .1289+00    .1751+00

   CO2                        .4018-01    .8575-01

   H                          .1659-01    .8075-03

   H2                         .1579+00    .1547-01

   H2O                        .3358+00    .2912+00

   NO                         .1249-02    .1814-02

   N2                         .3079+00    .4181+00

   O                          .6617-03    .5133-03

   OH                         .1120-01    .9906-02

   O2                         .5717-03    .8873-03

  MOLECULAR WEIGHT =  20.6185424
```

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

STAGNATION SOLUTION
EDGE CONDITIONS

TEMPERATURE	:	.5730+04 DEG R
PRESSURE	:	.7051+01 ATMOSPHERES
GAMMA	:	.1231+01
ENTHALPY	:	.1333+03 BTU/LBM
ENTROPY	:	.2903+01 BTU/LBM-DEG R
CP-FROZEN	:	.5142+00 BTU/LBM-DEG R
DENSITY	:	.3068-01 LBM/FT3
VISCOSITY	:	.6178-04 LBM/S-FT

EDGE CONDITIONS

IS	WALL LENGTH FEET	TEMP DEG-R	CP FROZEN B/LB-R	STATIC PRESSURE ATM	DENSITY L3/FT	VISCOSITY LB/FS	VELOCITY F/S	ENTHALPY B/LB	ENTROPY B/LB-R	MACH NO.
1	1.230-02	4.447+03	4.979-01	2.219+00	1.315-02	5.185-05	5.768+03	-5.173+02	2.903+00	1.571+00
2	1.475-02	4.373+03	4.967-01	1.992+00	1.226-02	5.120-05	5.867+03	-5.541+02	2.903+00	1.622+00
3	1.754-02	4.312+03	4.957-01	1.766+00	1.157-02	5.082-05	5.994+03	-5.842+02	2.903+00	1.668+00
4	2.365-02	4.179+03	4.933-01	1.545+00	1.017-02	4.978-05	6.262+03	-6.498+02	2.903+00	1.770+00
5	3.178-02	3.948+03	4.898-01	1.127+00	8.056-03	4.795-05	6.700+03	-7.631+02	2.903+00	1.907+00
6	4.212-02	3.718+03	4.837-01	9.322-01	6.319-03	4.607-05	7.106+03	-8.750+02	2.903+00	2.126+00
7	5.144-02	3.511+03	4.793-01	6.244-01	5.021-03	4.433-05	7.450+03	-9.751+02	2.903+00	2.291+00
8	6.175-02	3.325+03	4.742-01	4.772-01	4.052-03	4.274-05	7.742+03	-1.064+03	2.903+00	2.443+00
9	7.12[illegible]-02	3.163+03	4.696-01	3.736-01	3.335-03	4.131-05	7.985+03	-1.149+03	2.903+00	2.580+00
10	7.935-02	3.022+03	4.654-01	2.995-01	2.798-03	4.005-05	8.189+03	-1.206+03	2.903+00	2.709+00
11	8.[illegible]-02	2.899+03	4.615-01	2.443-01	2.389-03	3.892-05	8.361+03	-1.263+03	2.903+00	2.815+00
12	9.734-02	2.792+03	4.580-01	2.037-01	2.073-03	3.792-05	8.507+03	-1.312+03	2.903+00	2.916+00
13	1.072-01	2.698+03	4.547-01	1.742-01	1.821-03	3.703-05	8.633+03	-1.355+03	2.903+00	3.007+00
14	1.165-01	2.615+03	4.517-01	1.565-01	1.625-03	3.623-05	8.741+03	-1.393+03	2.903+00	3.089+00
15	1.257-01	2.543+03	4.490-01	1.340-01	1.465-03	3.552-05	8.834+03	-1.425+03	2.903+00	3.163+00
16	1.357-01	2.479+03	4.465-01	1.179-01	1.337-03	3.490-05	8.914+03	-1.454+03	2.903+00	3.230+00
17	1.442-01	2.423+03	4.443-01	1.054-01	1.230-03	3.434-05	8.984+03	-1.479+03	2.903+00	3.290+00
18	1.535-01	2.374+03	4.423-01	9.622-02	1.142-03	3.384-05	9.045+03	-1.501+03	2.903+00	3.345+00
19	1.627-01	2.329+03	4.405-01	8.909-02	1.068-03	3.339-05	9.099+03	-1.520+03	2.903+00	3.394+00
20	1.72[illegible]-01	2.290+03	4.388-01	8.16[illegible]-02	1.005-03	3.298-05	9.146+03	-1.537+03	2.903+00	3.439+00
21	1.812-01	2.253+03	4.372-01	7.47[illegible]-02	9.486-04	3.260-05	9.191+03	-1.554+03	2.903+00	3.482+00
22	1.[illegible]-01	2.218+03	4.357-01	7.[illegible]-02	8.980-04	3.224-05	9.232+03	-1.569+03	2.903+00	3.523+00
23	1.997-01	2.185+03	4.343-01	6.592-02	8.517-04	3.189-05	9.271+03	-1.583+03	2.903+00	3.563+00
24	2.787-01	2.153+03	4.328-01	6.167-02	8.069-04	3.156-05	9.308+03	-1.597+03	2.903+00	3.602+00
25	2.179-01	2.122+03	4.314-01	5.763-02	7.693-04	3.123-05	9.344+03	-1.610+03	2.903+00	3.641+00
26	2.272-01	2.092+03	4.301-01	5.[illegible]-02	7.3[illegible]-04	3.091-05	9.379+03	-1.623+03	2.903+00	3.679+00
27	2.364-01	2.062+03	4.287-01	5.[illegible]-02	6.965-04	3.059-05	9.413+03	-1.636+03	2.903+00	3.717+00
28	2.456-01	2.033+03	4.273-01	4.774-02	6.63[illegible]-04	3.027-05	9.446+03	-1.649+03	2.903+00	3.755+00
29	2.[illegible]47-01	2.004+03	4.259-01	4.402-02	6.314-04	2.996-05	9.479+03	-1.661+03	2.903+00	3.[illegible]3+00
30	2.610-01	1.976+03	4.246-01	4.[illegible]-02	6.01[illegible]-04	2.965-05	9.510+03	-1.673+03	2.903+00	3.[illegible]+00
31	2.[illegible]-01	1.947+03	4.232-01	3.947-02	5.723-04	2.933-05	9.542+03	-1.685+03	2.903+00	3.871+00
32	2.[illegible]22-01	1.920+03	4.219-01	3.70[illegible]-02	5.453-04	2.902-05	9.573+03	-1.697+03	2.903+00	3.909+00
33	2.[illegible]14-01	1.893+03	4.205-01	3.4[illegible]-02	5.206-04	2.873-05	9.602+03	-1.708+03	2.903+00	3.946+00
34	3.[illegible]36-01	1.868+03	4.192-01	3.291-02	4.978-04	2.844-05	9.630+03	-1.719+03	2.903+00	3.983+00

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

ORIGINAL PAGE IS OF POOR QUALITY

AXIAL DISTANCE, FEET	.00000	.13997-02	.42040-02	.98219-02	.18840-01	.27872-01	.36895-01	.45926-01
	.54944-01	.63994-01	.72996-01	.82029-01	.91045-01	.10008+00	.10910+00	.11814+00
	.12716+00	.13618+00	.14521+00	.15428+00	.16329+00	.17234+00	.18139+00	.19026+00
	.19931+00	.20837+00	.21744+00	.22652+00	.23542+00	.24450+00	.25360+00	.26252+00
	.27161+00	.28053+00						
WALL LENGTH, FEET	.13360-01	.14745-01	.17644-01	.23451-01	.32777-01	.42119-01	.51445-01	.60750-01
	.70045-01	.79354-01	.88645-01	.97937-01	.10719+00	.11647+00	.12573+00	.13500+00
	.14424+00	.15348+00	.16277+00	.17200+00	.18122+00	.19044+00	.19967+00	.20872+00
	.21794+00	.22716+00	.23639+00	.24561+00	.25466+00	.26389+00	.27311+00	.28216+00
	.29138+00	.30044+00						
RADIUS, FEET	.17627-01	.17985-01	.18793-01	.20189-01	.22513-01	.24954-01	.27311-01	.29565-01
	.31803-01	.34040-01	.36278-01	.38464-01	.40565-01	.42649-01	.44750-01	.46833-01
	.48832-01	.50813-01	.52777-01	.54741-01	.56671-01	.58465-01	.60258-01	.62035-01
	.63828-01	.65570-01	.67244-01	.68884-01	.70523-01	.72112-01	.73649-01	.75186-01
	.76723-01	.78261-01						
RI,LLB/S 1002	.16076-07	.17806-07	.21314-07	.28671-07	.40897-07	.53006-07	.64883-07	.76097-07
	.86703-07	.96874-07	.10651-06	.11586-06	.12487-06	.13365-06	.14224-06	.15074-06
	.15913-06	.16748-06	.17582-06	.18422-06	.19262-06	.20104-06	.20947-06	.21775-06
	.22619-06	.23461-06	.24300-06	.25133-06	.25994-06	.26762-06	.27570-06	.28351-06
	.29136-06	.29896-06						
PRESSURE RATIO	.26370+00	.24180+00	.22500+00	.19170+00	.14350+00	.10600+00	.79530-01	.60780-01
	.47590-01	.38150-01	.31240-01	.26110-01	.22190-01	.19170-01	.16610-01	.14950-01
	.13450-01	.12230-01	.11220-01	.10380-01	.96420-02	.89880-02	.83970-02	.78580-02
	.73660-02	.69090-02	.64810-02	.60810-02	.57090-02	.53630-02	.50280-02	.47230-02
	.44470-02	.41920-02						
STATIC PRESSURE, ATM	.20703+01	.18984+01	.17665+01	.15050+01	.11266+01	.83221+00	.62439+00	.47718+00
	.37363+00	.29952+00	.24527+00	.20499+00	.17421+00	.15050+00	.13198+00	.11737+00
	.10560+00	.96018-01	.88098-01	.81493-01	.75699-01	.70565-01	.65925-01	.61693-01
	.57831-01	.54243-01	.50882-01	.47742-01	.44821-01	.42105-01	.39475-01	.37080-01
	.34913-01	.37911-01						
EDGE VELOCITY, F/S	.57075+04	.58669+04	.59941+04	.67618+04	.66998+04	.71056+04	.74497+04	.77416+04
	.79850+04	.81890+04	.83619+04	.85074+04	.86331+04	.87410+04	.88341+04	.89141+04
	.89840+04	.90450+04	.90989+04	.91464+04	.91905+04	.92311+04	.92707+04	.93081+04
	.93436+04	.93776+04	.94127+04	.94461+04	.94786+04	.95102+04	.95423+04	.95728+04
	.96017+04	.96296+04						
BETAV	.61704+00	.33418+00	.19415+00	.33526+00	.42746+00	.46894+00	.47618+00	.48008+00
	.46510+00	.44538+00	.42331+00	.40002+00	.37828+00	.35206+00	.32433+00	.29808+00
	.27582+00	.25391+00	.23211+00	.21746+00	.21144+00	.20595+00	.20679+00	.20486+00
	.20126+00	.20467+00	.20872+00	.21380+00	.21485+00	.21974+00	.23610+00	.22463+00
	.21951+00	.22705+00						
BETAP	.61704+00	.33418+00	.19415+00	.33526+00	.42746+00	.46894+00	.47818+00	.48008+00
	.46510+00	.44598+00	.42331+00	.40302+00	.37828+00	.35206+00	.32433+00	.29808+00
	.27582+00	.25391+00	.23211+00	.21746+00	.21144+00	.20595+00	.20679+00	.20486+00
	.20126+00	.20467+00	.20872+00	.21380+00	.21485+00	.21974+00	.23010+00	.22463+00
	.21951+00	.22705+00						
INCID RAD.FLUX, W/SF2	.00000	.00000	.00000	.00300	.00700	.00000	.00600	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00070
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000						
FLUX NORM. PARAM.,LB/SF2	.38282+00	.35149+00	.31915+00	.26722+00	.20617+00	.15841+00	.12573+00	.10160+00
	.64075-01	.70984-01	.61096-01	.53434-01	.47306-01	.42448-01	.38583-01	.35465-01
	.32857-01	.30690-01	.28868-01	.27336-01	.25952-01	.24646-01	.23446-01	.22336-01
	.21303-01	.20310-01	.19343-01	.18418-01	.17551-01	.16718-01	.15887-01	.15128-01
	.14434-01	.13790-01						
WALL TEMPERATURE,DEG-R	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04
	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04
	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04
	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04	.23000+04
	.23000+04	.23000+04						
COMP FLUX, LB/SF2	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000						
COMP FLUX, LB/SF2	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000						
COMP FLUX, LB/SF2	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000						

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

STATION 1 - - - - - - - - - - - AXIAL POSITION .00000 FEET - - - - - - -

ITERATED VALUES DAMP MAX.LIN MAX.ERRORS IN CONSERVATION EQS.

ITS	TIME	ALPH	FPPW	DAMP	MAX.LIN ERROR		MOMENTUM		ENERGY
1	.000	3.600	.6176	.2769	2.+00	12	-2.4+00	1	-1.8+03
2	.000	3.240	.5612	.3769	1.+00	12	-1.4+00	1	-1.2+03
3	.000	2.916	.5885	.5741	7.-01	12	-1.1+00	1	-7.4+02
4	.000	2.629	.6771	1.000	3.-01	12	-5.1-01	1	-2.9+02
5	.000	2.509	.6900	1.000	9.-06	11	-3.7-02	10	2.1+01
6	.000	2.578	.6907	1.000	2.-07	12	-6.3-06	10	-6.1-01

ALPHA	RADIUS FEET	PRESSURE ATM	EDGE VEL. F/S	ZETAP	BETAV	HEAT FLUXES--B/SF2 DIFFUSIONAL	TOT ENTH	PERAD	QCOND
2.578+00	1.763-02	2.070+00	5.308+03	6.170-01	6.170-01	5.257+02	5.257+02	0.000	5.262+02

WALL SHEAR LBF/F2	MASS FLUXES LB/SF2 MECHANICAL REMOVAL	PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS DIFFUSIVE FLUXES LB/SF2 FOR
5.776+01	0.000	0.000	0.000	0.000	0.000

MOM TRANS COEFF. CF/2	HEAT TRANS COEFF. ST NO.	BLOWING PARAMETERS (NORM. BY RHOEUE*ST) FOR PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS TRANSFER COEFFICIENTS. CM. FOR
4.340-03	4.205-03	0.000	0.000	0.000	0.000

MOMENTUM THICKNESS. THETA FEET	DISPLACE. THICKNESS. DELSTAR FEET	EFFECTIVE BODY DISPLACE. FEET	ENTHALPY THICKNESS. LAMBDA FEET	REYNOLDS NUMBER PER FOOT	MASS THICKNESS FOR FEET
5.769-05	3.350-05	3.350-05	1.117-04	1.447+06	0.000

TOTAL HEAT TO WALL B/S	THRUST LOSS (LBF)	TOTAL WALL AREA (F2)	ACCELLERATION PARAMETER-R	INVISCID MASS IN BL LB/S	TOTAL MASS IN BL LB/S
0.000	4.880-02	0.000	1.603-05	6.118-03	6.118-03

NODAL INFORMATION

ETA	DISTANCE FROM WALL FEET	F	U/UE	FPP	SHEAR LBF/F2	G, TOTAL ENTHALPY B/LB	GP B/LB	GPP B/LB	STATIC ENTHALPY B/LB	TEMP DEG-R
0.000	0.000	0.000	0.000	6.907-01	5.776+01	-1.533+03	4.448+02	4.272+02	-1.533+03	2.300+03
2.008-03	5.085-07	1.407-05	4.992-03	6.869-01	5.761+01	-1.530+03	4.479+02	4.249+02	-1.530+03	2.307+03
6.408-03	1.736-06	1.061-04	1.209-02	6.871-01	5.738+01	-1.525+03	4.521+02	4.191+02	-1.525+03	2.318+03
1.557-02	2.990-06	5.541-04	2.756-02	6.831-01	5.689+01	-1.515+03	4.619+02	4.103+02	-1.515+03	2.340+03
2.763-02	4.961-06	1.666-03	4.766-02	6.774-01	5.623+01	-1.501+03	4.739+02	3.954+02	-1.502+03	2.369+03
4.835-02	4.977-06	5.304-03	8.462-02	6.670-01	5.499+01	-1.474+03	4.956+02	3.336+02	-1.479+03	2.422+03
1.465-01	2.855-05	4.746-02	2.462-01	6.105-01	4.907+01	-1.338+03	5.400+02	1.115+02	-1.378+03	2.648+03
4.159-01	9.003-05	3.490-01	6.026-01	4.178-01	3.178+01	-9.793+02	6.577+02	-1.032+02	-1.146+03	3.151+03
7.219-01	1.720-04	9.330-01	8.486-01	2.099-01	1.888+01	-4.471+02	5.124+02	-2.854+02	-4.156+02	3.634+03
1.000+00	2.456-04	1.584+00	9.500-01	7.831-02	5.487+00	-1.530+02	3.083+02	-2.714+02	-7.401+02	3.995+03
1.203+00	3.216-04	2.06?+00	9.769-01	3.237-02	2.24?+00	-2.366+01	1.869+02	-1.396+02	-6.469+02	4.185+03
2.500+00	7.695-04	5.428+00	1.000+00	0.000	0.000	1.331+02	0.000	2.765+01	-5.173+02	4.447+03

DISTANCE FROM WALL FEET	DENSITY RHO LB/F3	VISCOSITY MU LB/FS	SPECIFIC HEAT B/LB-R	THERMAL COND. B/SF-R	PRANDTL NUMBER	MODIFIED SCHMIDT NUMBER	MOLECULAR WEIGHT	MACH NUMBER	RHOSQ*EPS /RHOE*MUE	TURB NT PRANDTL NO
0.000	2.761-02	3.309-05	4.392-01	3.641-05	3.992-01	3.992-01	2.062+01	0.000	0.000	0.000
5.085-07	2.733-02	3.316-05	4.395-01	3.651-05	3.992-01	3.992-01	2.062+01	1.067-02	0.000	0.000
1.736-06	2.722-02	3.327-05	4.400-01	3.667-05	3.992-01	3.992-01	2.062+01	2.578-02	0.000	0.000
2.990-06	2.698-02	3.350-05	4.409-01	3.700-05	3.992-01	3.992-01	2.062+01	5.853-02	0.000	0.000
4.961-06	2.667-02	3.379-05	4.421-01	3.743-05	3.992-01	3.992-01	2.062+01	1.006-01	0.000	0.000
8.977-06	2.613-02	3.431-05	4.443-01	3.829-05	3.992-01	3.992-01	2.062+01	1.768-01	0.000	0.000
2.855-05	2.277-02	3.655-05	4.529-01	4.186-05	3.992-01	3.992-01	2.062+01	4.934-01	0.000	0.000
9.003-05	1.855-02	4.121-05	4.693-01	4.849-05	3.992-01	3.992-01	2.062+01	1.112+00	0.000	0.000
1.720-04	1.608-02	4.530-05	4.820-01	5.478-05	3.992-01	3.992-01	2.062+01	1.463+00	0.000	0.000
2.556-04	1.463-02	4.833-05	4.898-01	5.930-05	3.992-01	3.992-01	2.062+01	1.565+00	0.000	0.000
3.213-04	1.397-02	4.983-05	4.934-01	6.159-05	3.992-01	3.992-01	2.062+01	1.577+00	0.000	0.000
7.695-04	1.315-02	5.105-05	4.979-01	6.068-05	3.992-01	3.992-01	2.062+01	1.565+00	0.000	0.000

REFIT CALLED

I	ETA(I)	U/UE	G(I,1)	SP(I,1,1)	SP(I,1,2)	SP(I,1,3)	SP(I,1,4)	SP(I,1,5)	SP(I,1,6)	SP(I,1,7)	SP(I,1,8)
1	0.000	0.000	-1.533+03	1.000+00							
2	2.637-02	5.000-02	-1.499+03	0.000							
3	6.911-02	1.200-01	-1.447+03	0.000							
4	1.489-01	2.500-01	-1.335+03	0.000							
5	2.152-01	3.500-01	-1.234+03	0.000							
6	2.877-01	4.500-01	-1.120+03	0.000							
7	4.130-01	6.000-01	-9.134+02	0.000							
8	5.728-01	7.499-01	-6.577+02	0.000							
9	7.245-01	8.501-01	-4.036+02	0.000							
10	1.000+00	9.500-01	-1.530+02	6.557-02							
11	1.279+00	9.814-01	-1.668+01	3.291-02							
12	2.500+00	1.000+00	1.333+02	2.307+03							

SAMPLE PROBLEM I OUTPUT (Cont'd)

STATION 2 - - - - - - - - - - - - AXIAL POSITION [illegible] FEET

ITERATED VALUES DAMP MAX.LIN MAX.ERRORS IN CONSERVATION EQS.

ITS	TIME	ALPH	TPPW		F JOB	MOMENTUM		ENERGY
1	.300	2.590	.6570	.9999	6.-46 10	7.4-02	4	-8.2-01
2	.500	2.611	.6249	1.0030	3.-64 10	4.0-02	9	-4.1-01
3	.800	2.611	.6249	1.0030	1.-07 11	1.5-03	8	4.9-01

ALPHA	RADIUS FEET	PRESSURE ATM	EDGE VEL. F/S	BETAP	BETAV	HEAT FLUXES B/SF-S DIFFUSIONAL	TOT COND	QFRAD	QCOND
2.6 +00	1.799-02	1.890+00	[illegible]	3.392-01	3.392-01	4.549+02	4.549+02	0.000	4.551+02

MW SUB AW LBM/FT2	MASS FLUXES LB/SF2 MECHANICAL REMOVAL	PY-OL G/S	CHAR	TOTAL GAS	ELEMENTAL MASS DIFFUSIVE FLUXES LB/SF2 FOR
4.9[illegible]+01	0.000	0.000	0.000	0.000	0.000

MOM TRANS COEFF. LB/F2	HEAT TRANS COEFF. ST NO.	BLOWING PARAMETERS (NORM. BY MOMENTUM) FOR PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS TRANSFER COEFFICIENTS. CM. FOR
3.797-03	3.796-03	0.000	0.000	0.000	0.000

MOMENTUM THICKNESS, THETA FEET	DISPLACE. THICKNESS, DELSTAR FEET	EFFECTIVE BODY DISPLACE. FEET	ENTHALPY THICKNESS, LAMBDA FEET	REYNOLDS NUMBER PER FOOT	MASS THICKNESS FOR [illegible] FEET
6.406-05	4.119-05	4.119-05	1.201-04	1.407+06	0.000

TOTAL HEAT TO WALL B/S	THRUST LOSS (LBF)	TOTAL WALL AREA (F2)	ACCELERATION PARAMETER-K	INVISCID [illegible] IN BL LB/S	TOTAL MASS IN BL LB/S
7.9[illegible]-02	7.100-02	1.617-04	7.901-06	6.490-03	6.490-03

NODAL INFORMATION

ETA	DISTANCE FROM WALL FEET	F	U/UE	FPP	SHEAR LBF/F2	G, TOTAL ENTHALPY B/LB	GP B/LB	GPP B/LB	STATIC ENTHALPY B/LB	TEMP DEG-R
0.000	0.000	0.000	0.000	6.200-01	4.[illegible]+01	-1.533+03	4.713+02	3.460+02	-1.533+03	2.380+03
2.037-02	5.777-06	1.780-03	4.665-02	6.109-01	4.421+01	-1.501+03	4.900+02	3.500+02	-1.502+03	2.370+03
6.911-02	1.03[illegible]-05	1.309-02	1.219-01	6.001-01	[illegible].697+01	-1.451+03	4.859+02	3.166+02	-1.460+03	2.406+03
1.049-01	3.212-05	4.612-02	2.355-01	5.827-01	4.395+01	-1.393+03	5.505+02	2.030+02	-1.501+03	2.460+03
2.152-01	4.776-05	9.567-02	3.336-01	5.[illegible]-01	4.107+01	-1.299+03	5.926+02	1.687+02	-1.321+03	2.[illegible]73+03
2.077-01	6.571-05	1.680-01	4.361-01	5.165-01	3.761+01	-1.129+03	6.705+02	5.506+01	-1.259+03	2.908+03
4.[illegible]-01	9.760-05	3.[illegible]-01	5.876-01	4.215-01	3.066+01	-9.217+02	6.828+02	-1.106+02	-1.159+03	3.122+03
5.120-01	1.039-04	6.154-01	7.022-01	3.130-01	2.191+01	-6.429+02	5.966+02	-2.762+02	-1.092+03	3.371+03
7.265-01	1.[illegible]-04	9.[illegible]-01	8.061-01	2.107-01	1.001+01	-4.[illegible]+02	5.070+02	-2.798+02	-9.360+02	3.591+03
1.000+00	2.464-04	1.521+00	9.5[illegible]-01	1.814-02	5.707+00	-1.520+02	3.059+02	-2.721+02	-7.724+02	3.937+03
1.2[illegible]+00	3.61[illegible]-04	2.162+00	9.920-01	2.867-02	1.071+00	-8.929+00	1.730+02	-1.316+02	-6.717+02	4.135+03
2.[illegible]+00	6.865-04	5.070+00	1.000+00	0.000	0.000	1.333+02	0.000	2.680+01	-5.561+02	4.377+03

DISTANCE FROM WALL FEET	DENSITY RHO LB/F3	VISCOSITY MU LB/FS	SPECIFIC HEAT F/LB-R	THERMAL COND. B/SF-R	PRANDTL NUMBER	MODIFIED SCHMIDT NUMBER	MOLECULAR WEIGHT	MACH NUMBER	RHOSCHMPS [illegible]	TURBULENT PRANDTL NO
0.000	2.330-02	5.109-05	4.392-01	5.001-05	3.997-01	3.992-01	2.062+01	0.000	0.000	0.000
5.772-06	2.762-02	3.100-05	4.921-01	5.767-05	3.997-01	3.992-01	2.062+01	4.991-02	0.000	0.000
1.036-05	2.179-02	3.47[illegible]-05	4.96[illegible]-01	5.00[illegible]-05	3.997-01	3.992-01	2.062+01	2.372-01	0.000	0.000
3.212-05	2.036-02	3.497-05	6.526-01	4.13[illegible]-05	3.997-01	3.992-01	2.062+01	4.857-01	0.000	0.000
4.776-05	1.933-02	3.779-05	4.52[illegible]-01	4.329-05	3.997-01	3.992-01	2.062+01	6.724-01	0.000	0.000
6.571-05	1.793-02	3.901-05	4.618-01	4.5[illegible]-05	3.997-01	3.992-01	2.062+01	8.556-01	0.000	0.000
9.069-05	1.716-02	4.095-05	4.665-01	4.936-05	3.997-01	3.992-01	2.062+01	1.120+00	0.000	0.000
1.439-04	1.590-02	4.316-05	4.750-01	5.137-05	3.997-01	3.992-01	2.062+01	1.364+00	0.000	0.000
1.699-04	1.4[illegible]2-02	4.501-05	4.810-01	5.423-05	3.997-01	3.992-01	2.062+01	1.500+00	0.000	0.000
2.004-04	1.3[illegible]-02	4.700-05	4.885-01	5.809-05	3.997-01	3.997-01	2.062+01	1.6[illegible]2+00	0.000	0.000
3.610-04	1.296-02	4.993-05	4.925-01	6.092-05	3.997-01	3.997-01	2.062+01	1.636+00	0.000	0.000
8.605-04	1.226-02	5.120-05	4.967-01	6.301-05	3.997-01	3.997-01	2.062+01	1.622+00	0.000	0.000

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

STATION 3 - - - - - - - - - - - AXIAL POSITION .70053,0E FEET

ITERATED VALUES DAMP N-R LIN MAX.ERRORS IN CONSERVATION EQS.

ITS	TIME	ALPH	FPPW		ERROR	MOMENTUM	ENERGY
1	.240	2.703	.7553	.9999	6.-C0 13	-5.7-02 10	-1.5-02
2	.000	2.740	.75851	.0000	6.-L0 13	-7.9-02 10	-7.7-01
3	.000	2.360	.75851	.0000	6.-L0 14	-0.3-05 10	-7.0-07

ALPHA	RADIUS FEET	PRESSURE ATM	EDGE VEL. F/S	DEJAR	DEJAV	HEAT FLUXES..B/SF. DIFFUSIONAL	TOT ENTH	RERAD	RECONV
2.380+00	7.026-02	3.201-02	9.630+03	2.270-01	2.270-01	9.018+00	9.01+00	0.000	9.018+00

WALL SHEAR LBF/FT2	MASS FLUXES LB/SF2 MECHANICAL REMOVAL	PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS DIFFUSIVE FLUXES LB/SF2 FOR
2.958+00	0.000	0.000	0.000	0.000	0.000

MOM TRANS COEFF. CF/2	HEAT TRANS COEFF. ST NO.	BLOWING PARAMETERS (NORM. BY RHOE*UE*ST) FOR PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS TRANSFER COEFFICIENTS, CM, FOR
2.063-03	1.180-03	0.000	0.000	0.000	0.000

MOMENTUM THICKNESS, THETA FEET	DISPLACE. THICKNESS, DELSTAR FEET	EFFECTIVE DISPLACE. FEET	ENTHALPY THICKNESS, LAMBDA FEET	REYNOLDS NUMBER PER FOOT	MASS THICKNESS FOR FEET
8.252-04	2.707-03	2.707-03	1.202-03	1.609+05	0.000

TOTAL HEAT TO WALL B/S	THRUST LOSS (LBF)	TOTAL WALL AREA (FT2)	ACCELERATION PARAMETER-K	INVISCID MASS IN BL LB/S	TOTAL MASS IN BL LB/S
3.996+00	1.790-01	9.081 02	1.802-06	2.037-02	2.037-02

NODAL INFORMATION

ETA	DISTANCE FROM WALL FEET	F	U/UE	FPP	SHEAR LBF/FT2	G, TOTAL ENTHALPY B/LB	GP B/LB	GPP B/LB	STATIC ENTHALPY B/LB	TEMP DEG-R
0.000	0.000	0.000	0.000	7.585-01	2.958+00	-1.533+03	2.286+02	1.260+03	-1.531+03	2.380+03
2.037-02	1.778-04	1.777-03	5.066-02	7.027-01	2.079+00	-1.511+03	3.737+02	1.167+03	-1.515+03	2.340+03
6.911-02	6.261-04	1.009-02	1.719-01	7.162-01	2.769+00	-1.969+03	4.949+02	9.323+02	-1.096+03	2.397+03
1.469-01	9.317-04	4.571-02	2.571-01	6.603-01	2.535+00	-1.360+03	6.619+02	6.601+02	-1.079+03	2.025+03
2.152-01	1.359-03	9.152-02	3.522-01	6.109-01	2.342+00	-1.207+03	7.667+02	5.120+02	-1.077+03	2.026+03
2.877-01	1.836-03	1.631-01	4.526-01	5.525-01	2.179+00	-1.109+03	8.379+02	4.009+01	-1.049+03	2.001+03
4.130-01	2.591-03	3.211-01	6.027-01	4.509-01	1.755+00	-8.556+02	8.629+02	-7.885+02	-1.527+03	2.319+03
5.728-01	3.535-03	5.800-01	7.501-01	3.260-01	1.262+00	-5.073+02	7.761+02	-9.959+02	-1.569+03	2.171+03
7.265-01	4.176-03	8.900-01	8.930-01	2.219-01	9.729-01	-3.065+02	5.771+02	-9.913+02	-1.691+03	2.050+03
1.060+00	5.700-03	1.460+00	9.500-01	8.137-02	1.549-01	-3.177+01	2.509+02	-2.817+02	-1.705+03	1.900+03
1.229+00	6.970-03	1.992+00	9.827-01	7.157-02	1.740-01	4.332+01	1.017+02	-8.056+01	-1.722+03	1.859+03
2.500+00	1.313-02	5.910+00	1.000+00	0.000	0.000	1.333+02	0.000	2.139+01	-1.719+03	1.868+03

DISTANCE FROM WALL FEET	DENSITY RHO LB/F3	VISCOSITY MU LB/FS	SPECIFIC HEAT B/LB-R	THERMAL COND. B/SF-R	PRANDTL NUMBER	MODIFIED SCHMIDT NUMBER	MOLECULAR WEIGHT	MACH NUMBER	RHO*MU/RHOE*MUE	TURBULENT PRANDTL NO
0.000	4.090-04	3.309-05	4.397-01	1.691-05	3.992-01	3.992-01	2.067+01	0.000	1.000	0.000
1.730-04	3.971-04	3.356-05	4.469-01	3.700-05	3.992-01	3.992-01	2.067+01	1.815-01	0.000	0.000
4.211-04	[illegible]	3.306-05	4.427-01	3.763-05	3.992-01	3.992-01	2.062+01	4.317-01	0.000	0.000
9.312-04	[illegible]	3.036-05	4.469-01	3.824-05	3.992-01	3.992-01	2.062+01	8.083-01	0.000	0.000
1.154-03	[illegible]	3.037-05	4.409-01	3.876-05	3.992-01	3.992-01	2.062+01	1.741+00	0.000	0.000
1.819-03	3.470-04	3.012-05	4.436-01	3.790-05	3.992-01	3.992-01	2.062 01	1.607+00	0.000	0.000
2.592-03	4.216-04	3.323-05	4.790-01	3.661-05	3.992-01	3.992-01	2.062+01	2.169+00	0.000	0.000
3.515-03	6.575-04	3.175-05	4.337-01	3.469-05	3.992-01	3.992-01	2.062+01	2.783+00	0.000	0.000
4.176-03	4.537-04	3.090-05	4.281-01	3.266-05	3.992-01	3.992-01	2.062+01	3.236+00	0.000	0.000
5.799-03	4.990-04	2.980-05	4.709-01	3.037-05	3.992-01	3.992-01	2.062+01	3.752+00	0.000	0.000
6.928-03	4.999-04	2.819-05	4.188-01	2.923-05	3.992-01	3.992-01	2.062+01	3.919+00	0.000	0.000
1.313-02	4.974-04	2.849-05	4.192-01	2.987-05	3.992-01	3.992-01	2.062+01	3.981+00	0.000	0.000

ORIGINAL PAGE IS OF POOR QUALITY

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

STATION SUMMARY FOR SPACE SHUTTLE ORBITER NOZZLE [illegible]

NEW CONTOUR INFORMATION

		INPUT INVISCID CONTOUR NEW WALL CONTOUR-NORM. BY THROAT RADIUS= [illegible] FEET		INPUT WALL CONTOUR NEW INVISCID CONTOUR-NORM. BY THROAT RADIUS= .17000-01 FEET	
STATION NO.	DISPLACEMENT THICKNESS FEET	AXIAL COORDINATE	RADIAL COORDINATE	AXIAL COORDINATE	RADIAL COORDINATE
1	3.39675-05	0.00000	1.03396+00	0.00000	1.01000+00
2	4.11976-05	4.13535-02	1.05574+00	8.75508-02	1.05066+00
3	5.31691-05	2.95607-01	1.09802+00	2.97163-01	1.09198+00
4	6.53675-05	5.79419-01	1.18592+00	5.76192-01	1.17000+00
5	9.46966-05	1.10165+00	1.32636+00	1.10947+00	1.31546+00
6	1.46114-04	1.62995+00	1.46814+00	1.63371+00	1.45396+00
7	1.65466-04	2.15767+00	1.60834+00	2.16256+00	1.58964+00
8	2.13112-04	2.68567+00	1.74311+00	2.69191+00	1.71889+00
9	2.69679-04	3.21309+00	1.87728+00	3.22767+00	1.84972+00
10	3.31702-04	3.74123+00	2.01196+00	3.75657+00	1.97419+00
11	4.01496-04	4.26829+00	2.19608+00	4.27955+00	2.10120+00
12	4.76395-04	4.79606+00	2.27911+00	4.80910+00	2.22889+00
13	5.57985-04	5.32307+00	2.40679+00	5.33789+00	2.34372+00
14	6.47565-04	5.85115+00	2.53366+00	5.86805+00	2.46039+00
15	7.30623-04	6.37775+00	2.66165+00	6.39716+00	2.57835+00
16	8.19966-04	6.90579+00	2.79078+00	6.92736+00	2.69572+00
17	9.11623-04	7.43323+00	2.91112+00	7.45632+00	2.80698+00
18	1.00906-03	7.96054+00	3.03292+00	7.98579+00	2.91758+00
19	1.09675-03	8.48817+00	3.15235+00	8.51547+00	3.02725+00
20	1.18806-03	9.01777+00	3.27298+00	9.04720+00	3.13702+00
21	1.27972-03	9.54687+00	3.39127+00	9.57623+00	3.24973+00
22	1.37990-03	1.00796+01	3.50196+00	1.01059+01	3.35969+00
23	1.47066-03	1.06032+01	3.61296+00	1.06367+01	3.45394+00
24	1.56677-03	1.11216+01	3.72203+00	1.11577+01	3.54197+00
25	1.66875-03	1.16503+01	3.83289+00	1.16883+01	3.64116+00
26	1.77317-03	1.21908+01	3.94095+00	1.22197+01	3.73705+00
27	1.88119-03	1.27106+01	4.04592+00	1.27506+01	3.82958+00
28	1.99719-03	1.32417+01	4.14697+00	1.32828+01	3.91793+00
29	2.11909-03	1.37609+01	4.25077+00	1.38057+01	4.00773+00
30	2.23803-03	1.42926+01	4.35107+00	1.43378+01	4.09293+00
31	2.37103-03	1.48205+01	4.44909+00	1.48708+01	4.17516+00
32	2.50683-03	1.53050+01	4.54669+00	1.53990+01	4.25736+00
33	2.64692-03	1.58766+01	4.64990+00	1.59287+01	4.33920+00
34	2.78773-03	1.63970+01	4.74282+00	1.64524+01	4.42118+00

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

SUMMARY OF STANDARD PLUME FLOWFIELD CODE INPUT DATA INCLUDING THE BOUNDARY LAYER

CHEMISTRY SYSTEM 2

MASS FLOW AVERAGED PROPERTIES(SPECIES ARE INVISCID AVERAGES)

MOLECULAR WEIGHT	.20623+02
SPECIFIC HEAT RATIO	.13049+01
VISCOSITY(POISE)	.00000
PRANDTL NUMBER	.00000
NOZZLE EXIT RADIUS(FT)	.70269-01
TEMPERATURE(DEG R)	.10304+04
DENSITY(GM/CC)	.78870-05
VELOCITY(FT/SEC)	.96707+04

SPECIE	MOLE FRACTION	SPECIE	MOLE FRACTION
CO	.1289+00	CO2	.8819-01
H	.1659-01	H2	.1502+00
H2O	.3355+00	N2	.3079+00
O	.6616-03	OH	.1019-01
O2	.5723-03		

GASEOUS STARTING LINE INFO

R/RL(ND)	U(FT/SEC)	V(FT/SEC)	P(ATM)	T(DEG R)
.0000	.9769+04	.0000	.2298-01	.9579+03
.4167-01	.9767+04	.7961+02	.2301-01	.9580+03
.8333-01	.9764+04	.1575+03	.2306-01	.9601+03
.1250+00	.9757+04	.2349+03	.2316-01	.9620+03
.1667+00	.9749+04	.3100+03	.2331-01	.9656+03
.2083+00	.9739+04	.3846+03	.2350-01	.9690+03
.2500+00	.9728+04	.4562+03	.2374-01	.9734+03
.2917+00	.9717+04	.5251+03	.2403-01	.9773+03
.3333+00	.9705+04	.5911+03	.2439-01	.9816+03
.3750+00	.9693+04	.6543+03	.2481-01	.9857+03
.4167+00	.9680+04	.7146+03	.2529-01	.9900+03
.4583+00	.9667+04	.7723+03	.2583-01	.9945+03
.5000+00	.9653+04	.8290+03	.2643-01	.9999+03
.5417+00	.9638+04	.8827+03	.2706-01	.1005+04
.5833+00	.9622+04	.9370+03	.2772-01	.1010+04
.6250+00	.9606+04	.9918+03	.2840-01	.1015+04
.6667+00	.9590+04	.1048+04	.2907-01	.1020+04
[illegible]	.9574+04	.1106+04	.2972-01	.1075+04
.7500+00	.9558+04	.1166+04	.3035-01	.1029+04
.7917+00	.9542+04	.1228+04	.3093-01	.1034+04
.8333+00	.9527+04	.1294+04	.3145-01	.1037+04
.8750+00	.9512+04	.1364+04	.3189-01	.1090+04
.9167+00	.9497+04	.1438+04	.3227-01	.1047+04
.9181+00	.9346+04	.1417+04	.3316-01	.1039+04
.9326+00	.9040+04	.1396+04	.3312-01	.1057+04
.9509+00	.8073+04	.1275+04	.3307-01	.1190+04
.9617+00	.7131+04	.1181+04	.3303-01	.1207+04
.9739+00	.5723+04	.9290+03	.3300-01	.1286+04
.9839+00	.4300+04	.7063+03	.3297-01	.1334+04
.9899+00	.3307+04	.5536+03	.3295-01	.1348+04
.9926+00	.2831+04	.4698+03	.3294-01	.1348+04
.1000+01	.2560+04	.4290+03	.3292-01	.1106+04

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

METHOD OF CHARACTERISTICS EXIT PLANE STARTLINE BASED ON MASS FLOW AVERAGED THERMODYNAMIC PROPERTIES

TOTAL PRESSURE(PSFA) - .10695+05
TOTAL TEMPERATURE(R) - .61000+04
SPECIFIC HEAT RATIO - .13009+01
MOLECULAR WEIGHT - .28623+02
EXIT RADIUS(RE,FEET) - .30271-01

R/RE	Y	MACH NUMBER	FLOW ANGLE (DEG)	ENTROPY (FT**2/SEC**2/R)	TOTAL ENTHALPY (FT**2/SEC**2)
.00000	.00000	.42022+01	.00000	-.19610+03	.65700+08
.41667-01	.00000	.41990+01	.46349+00	-.19853+03	.65700+08
.83333-01	.00000	.41655+01	.92623+00	-.18070+03	.65700+08
.12500+00	.00000	.41876+01	.13793+01	-.16251+03	.65707+08
.16667+00	.00000	.41784+01	.18260+01	-.14413+03	.65706+08
.20833+00	.00000	.41677+01	.22616+01	-.12573+03	.65706+08
.25000+00	.00000	.41550+01	.26846+01	-.10607+03	.65705+08
.29167+00	.00000	.41441+01	.30930+01	-.94470+02	.65704+08
.33333+00	.00000	.41316+01	.34855+01	-.88470+02	.65703+08
.37500+00	.00000	.41197+01	.38616+01	-.87549+02	.65702+08
.41667+00	.00000	.41071+01	.42216+01	-.87919+02	.65701+08
.45833+00	.00000	.40996+01	.45679+01	-.84598+02	.65700+08
.50000+00	.00000	.40800+01	.49030+01	-.90394+02	.65699+08
.54167+00	.00000	.40653+01	.52330+01	-.94115+02	.65698+08
.58333+00	.00000	.40500+01	.55620+01	-.96313+02	.65697+08
.62500+00	.00000	.40340+01	.58950+01	-.98653+02	.65696+08
.66667+00	.00000	.40206+01	.62353+01	-.10279+03	.65695+08
.70833+00	.00000	.40073+01	.65837+01	-.10806+03	.65694+08
.75000+00	.00000	.39956+01	.69520+01	-.11550+03	.65693+08
.79167+00	.00000	.39947+01	.73349+01	-.11952+03	.65692+08
.83333+00	.00000	.39740+01	.77369+01	-.12458+03	.65692+08
.87500+00	.00000	.39670+01	.81621+01	-.13261+03	.65691+08
.91667+00	.00000	.39622+01	.86075+01	-.14021+03	.65691+08
.91808+00	.00000	.39132+01	.86226+01	-.28098+03	.64199+08
.93257+00	.00000	.37453+01	.87779+01	-.52992+02	.61669+08
.95109+00	.00000	.32234+01	.89740+01	.74071+03	.54005+08
.96172+00	.00000	.27679+01	.90901+01	.13390+04	.48736+08
.97388+00	.00000	.21579+01	.92703+01	.20011+04	.40952+08
.98392+00	.00000	.15083+01	.93279+01	.23906+04	.34549+08
.98997+00	.00000	.12102+01	.93915+01	.24990+04	.31767+08
.99248+00	.00000	.10907+01	.94737+01	.24967+04	.29923+08
.10000+01	.00000	.10623+01	.95000+01	.44094+03	.29167+08

THE INVISCID PORTION OF THE START LINE WAS MOVED .26653-02 (FEET) TO MATCH THE EDGE OF THE BOUNDARY LAYER

.0000	.2919+00	.4220+01	.0000	-.1971+03	.0000	.0000	.6546+08
.1634-02	.2919+00	.4219+01	.2463+00	-.1911+03	.0000	.0000	.6546+08
.3276-02	.2919+00	.4217+01	.4947+00	-.1876+03	.0000	.0000	.6546+08
.4911-02	.2919+00	.4216+01	.6721+00	-.1839+03	.0000	.0000	.6546+08
.6545-02	.2919+00	.4213+01	.8946+00	-.1801+03	.0000	.0000	.6546+08
.8172-02	.2919+00	.4210+01	.1119+01	-.1717+03	.0000	.0000	.6547+08
.9797-02	.2918+00	.4206+01	.1332+01	-.1676+03	.0000	.0000	.6547+08
.1141-01	.2918+00	.4201+01	.1546+01	-.1614+03	.0000	.0000	.6548+08
.1302-01	.2917+00	.4196+01	.1750+01	-.1465+03	.0000	.0000	.6548+08
.1462-01	.2917+00	.4191+01	.1965+01	-.1356+03	.0000	.0000	.6548+08
.1621-01	.2916+00	.4186+01	.2176+01	-.1263+03	.0000	.0000	.6549+08
.1779-01	.2916+00	.4182+01	.2376+01	-.1170+03	.0000	.0000	.6549+08
.1937-01	.2915+00	.4179+01	.2566+01	-.1070+03	.0000	.0000	.6550+08
.2093-01	.2914+00	.4168+01	.2776+01	-.1020+03	.0000	.0000	.6550+08
.2249-01	.2914+00	.4162+01	.2946+01	-.9615+02	.0000	.0000	.6551+08
.2403-01	.2913+00	.4156+01	.3128+01	-.9015+02	.0000	.0000	.6552+08
.2556-01	.2912+00	.4149+01	.3307+01	-.8917+02	.0000	.0000	.6552+08
.2709-01	.2911+00	.4144+01	.3491+01	-.8335+02	.0000	.0000	.6553+08
.2861-01	.2910+00	.4139+01	.3652+01	-.8272+02	.0000	.0000	.6553+08
.3010-01	.2909+00	.4132+01	.3816+01	-.8161+02	.0000	.0000	.6554+08
.3160-01	.2908+00	.4126+01	.3990+01	-.8067+02	.0000	.0000	.6555+08
.3309-01	.2907+00	.4120+01	.4115+01	-.8219+02	.0000	.0000	.6555+08
.3457-01	.2906+00	.4114+01	.4245+01	-.8916+02	.0000	.0000	.6556+08
.3603-01	.2905+00	.4107+01	.4447+01	-.8579+02	.0000	.0000	.6556+08
.3749-01	.2904+00	.4101+01	.4598+01	-.9735+02	.0000	.0000	.6557+08
.3893-01	.2902+00	.4094+01	.4745+01	-.9909+02	.0000	.0000	.6558+08
.4037-01	.2901+00	.4088+01	.4892+01	-.9170+02	.0000	.0000	.6558+08
.4179-01	.2900+00	.4081+01	.5017+01	-.9243+02	.0000	.0000	.6559+08
.4321-01	.2899+00	.4075+01	.5191+01	-.9471+02	.0000	.0000	.6559+08
.4461-01	.2897+00	.4068+01	.5324+01	-.9497+02	.0000	.0000	.6560+08
.4601-01	.2896+00	.4061+01	.5468+01	-.9576+02	.0000	.0000	.6561+08
.4739-01	.2895+00	.4054+01	.5612+01	-.9671+02	.0000	.0000	.6561+08
.4877-01	.2893+00	.4049+01	.5757+01	-.9747+02	.0000	.0000	.6562+08
.5012-01	.2892+00	.4042+01	.5900+01	-.9915+02	.0000	.0000	.6563+08
.5148-01	.2891+00	.4035+01	.6045+01	-.1006+03	.0000	.0000	.6563+08
.5281-01	.2889+00	.4029+01	.6191+01	-.1022+03	.0000	.0000	.6564+08
.5415-01	.2888+00	.4023+01	.6338+01	-.1037+03	.0000	.0000	.6564+08
.5546-01	.2886+00	.4018+01	.6486+01	-.1068+03	.0000	.0000	.6565+08
.5677-01	.2885+00	.4013+01	.6636+01	-.1098+03	.0000	.0000	.6566+08
.5937-01	.2882+00	.4008+01	.6791+01	-.1119+03	.0000	.0000	.6566+08
.6139-01	.2878+00	.3998+01	.7207+01	-.1162+03	.0000	.0000	.6567+08
.6439-01	.2875+00	.3985+01	.7584+01	-.1215+03	.0000	.0000	.6568+08
.6685-01	.2872+00	.3970+01	.7888+01	-.1277+03	.0000	.0000	.6569+08
.6920-01	.2866+00	.3972+01	.8225+01	-.1319+03	.0000	.0000	.6570+08
.7162-01	.2865+00	.3867+01	.8555+01	-.1399+03	.0000	.0000	.6571+08
.7198-01	.2865+00	.3919+01	.8606+01	-.2778+03	.0000	.0000	.6410+08
.7309-01	.2862+00	.3753+01	.8765+01	-.4876+02	.0000	.0000	.6176+08
.7453-01	.2861+00	.3237+01	.8960+01	.7053+03	.0000	.0000	.5505+08
.7533-01	.2859+00	.2789+01	.9082+01	.1303+04	.0000	.0000	.4903+08
.7626-01	.2858+00	.2170+01	.9214+01	.2006+04	.0000	.0000	.4121+08
.7702-01	.2856+00	.1602+01	.9373+01	.2393+04	.0000	.0000	.3471+08
.7748-01	.2855+00	.1281+01	.9387+01	.2501+04	.0000	.0000	.3117+08
.7770-01	.2855+00	.1050+01	.9419+01	.2498+04	.0000	.0000	.2950+08
.7827-01	.2854+00	.1050+01	.9500+01	.4410+03	.0000	.0000	.2922+08

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 7

SPACE SHUTTLE VERNIER NOZZLE [illegible]

LINE	POINT	DSCRIP - REGIME	[illegible] MACH ANGLE	[illegible] PRESSURE	[illegible] DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
1	1	INPUT - CONTIN	.00000 .13107+02	.29196+00 .32322+00	.92201+01 .11312-04	.00000 .17070+04	-.72352+02 .29102+04	.97878+00 .13074+01	.13965+11	0
1	2	INPUT - CONTIN	.16379-02 .13711+02	.29196+00 .32335+00	.92169+01 .11312-04	.22027+00 .17070+04	-.68578+02 .29102+04	.97876+00 .13074+01	.13965+11	0
1	3	INPUT - CONTIN	.37762-02 .13716+02	.29193+00 .32360+00	.92170+01 .11319-04	.44075+00 .17067+04	-.64799+02 .29102+04	.97860+00 .13073+01	.13965+11	0
1	4	INPUT - CONTIN	.49113-02 .13722+02	.29191+00 .32400+00	.92156+01 .11321-04	.62190+00 .17094+04	-.66992+02 .29102+04	.97898+00 .13073+01	.13965+11	0
1	5	INPUT - CONTIN	.67959-02 .13729+02	.29189+00 .32457+00	.92139+01 .11333-04	.89005+00 .17111+04	-.57195+02 .29102+04	.97870+00 .13072+01	.13965+11	0
1	6	INPUT - CONTIN	.81719-02 .13742+02	.29196+00 .32530+00	.92094+01 .11302-04	.11137+01 .17135+04	-.98170+02 .29102+04	.97800+00 .13071+01	.13965+11	0
1	7	INPUT - CONTIN	.97976-02 .13756+02	.29183+00 .32619+00	.92055+01 .11357-04	.13315+01 .17160+04	-.39166+02 .29102+04	.97701+00 .13070+01	.13965+11	0
1	8	INPUT - CONTIN	.11911-01 .13771+02	.29179+00 .32776+00	.92012+01 .11375-04	.15900+01 .17188+04	-.30065+02 .29102+04	.97751+00 .13069+01	.13965+11	0
1	9	INPUT - CONTIN	.13024-01 .13787+02	.29174+00 .32849+00	.91962+01 .11399-04	.17500+01 .17218+04	-.20979+02 .29102+04	.97719+00 .13068+01	.13965+11	0
1	10	INPUT - CONTIN	.14620-01 .13804+02	.29169+00 .32990+00	.91911+01 .11426-04	.19654+01 .17250+04	-.11699+02 .29102+04	.97684+00 .13066+01	.13965+11	0
1	11	INPUT - CONTIN	.16214-01 .13822+02	.29163+00 .33108+00	.91856+01 .11458-04	.21690+01 .17284+04	-.24338+01 .29102+04	.97640+00 .13065+01	.13965+11	0
1	12	INPUT - CONTIN	.17793-01 .13842+02	.29157+00 .33323+00	.91798+01 .11495-04	.23696+01 .17320+04	.70092+01 .29102+04	.97606+00 .13063+01	.13965+11	0
1	13	INPUT - CONTIN	.19360-01 .13863+02	.29150+00 .33517+00	.91736+01 .11536-04	.25660+01 .17359+04	.16430+02 .29102+04	.97567+00 .13062+01	.13965+11	0
1	14	INPUT - CONTIN	.20916-01 .13882+02	.29143+00 .33720+00	.91683+01 .11585-04	.27577+01 .17396+04	.27037+02 .29102+04	.97579+00 .13060+01	.13965+11	0
1	15	INPUT - CONTIN	.22489-01 .13902+02	.29135+00 .33959+00	.91621+01 .11643-04	.29940+01 .17431+04	.27499+02 .29102+04	.97489+00 .13059+01	.13965+11	0

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 8

SPACE SHUTTLE VERNIER NOZZLE [illegible]

LINE	POINT	DSCRIP - REGIME	[illegible] MACH ANGLE	[illegible] PRESSURE	[illegible] DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
1	16	INPUT - CONTIN	.24029-01 .13923+02	.29127+00 .34208+00	.91559+01 .11698-04	.31289+01 .17470+04	.34630+02 .29102+04	.97446+00 .13057+01	.13965+11	0
1	17	INPUT - CONTIN	.25565-01 .13944+02	.29118+00 .34476+00	.91493+01 .11762-04	.33074+01 .17512+04	.40832+02 .29102+04	.97401+00 .13055+01	.13965+11	0
1	18	INPUT - CONTIN	.27087-01 .13965+02	.29109+00 .34767+00	.91430+01 .11836-04	.34814+01 .17547+04	.41876+02 .29102+04	.97363+00 .13053+01	.13965+11	0
1	19	INPUT - CONTIN	.28605-01 .13985+02	.29100+00 .35069+00	.91380+01 .11915-04	.36522+01 .17584+04	.42049+02 .29102+04	.97323+00 .13052+01	.13965+11	0
1	20	INPUT - CONTIN	.30105-01 .14006+02	.29090+00 .35391+00	.91319+01 .11998-04	.38176+01 .17623+04	.43953+02 .29102+04	.97281+00 .13050+01	.13965+11	0
1	21	INPUT - CONTIN	.31661-01 .14028+02	.29080+00 .35737+00	.91256+01 .12086-04	.39799+01 .17663+04	.45099+02 .29102+04	.97237+00 .13048+01	.13965+11	0
1	22	INPUT - CONTIN	.33086-01 .14048+02	.29069+00 .36089+00	.91197+01 .12181-04	.41386+01 .17702+04	.43565+02 .29102+04	.97196+00 .13047+01	.13965+11	0
1	23	INPUT - CONTIN	.34568-01 .14069+02	.29058+00 .36460+00	.91136+01 .12280-04	.42994+01 .17740+04	.42100+02 .29102+04	.97153+00 .13045+01	.13965+11	0
1	24	INPUT - CONTIN	.36032-01 .14091+02	.29047+00 .36850+00	.91070+01 .12382-04	.44469+01 .17781+04	.40613+02 .29102+04	.97109+00 .13043+01	.13965+11	0
1	25	INPUT - CONTIN	.37492-01 .14114+02	.29036+00 .37250+00	.91009+01 .12487-04	.45975+01 .17823+04	.39216+02 .29102+04	.97064+00 .13041+01	.13965+11	0
1	26	INPUT - CONTIN	.38933-01 .14136+02	.29024+00 .37659+00	.90945+01 .12594-04	.47451+01 .17865+04	.37690+02 .29102+04	.97018+00 .13040+01	.13965+11	0
1	27	INPUT - CONTIN	.40371-01 .14160+02	.29012+00 .38079+00	.90878+01 .12704-04	.48918+01 .17908+04	.36207+02 .29102+04	.96972+00 .13038+01	.13965+11	0
1	28	INPUT - CONTIN	.41792-01 .14183+02	.29000+00 .38509+00	.90813+01 .12815-04	.50365+01 .17951+04	.34768+02 .29102+04	.96925+00 .13036+01	.13965+11	0
1	29	INPUT - CONTIN	.43212-01 .14207+02	.28987+00 .38937+00	.90746+01 .12928-04	.51813+01 .17994+04	.33602+02 .29102+04	.96877+00 .13034+01	.13965+11	0
1	30	INPUT - CONTIN	.44611-01 .14231+02	.28974+00 .39371+00	.90679+01 .13040-04	.53245+01 .18039+04	.32645+02 .29102+04	.96829+00 .13032+01	.13965+11	0

SAMPLE PROBLEM I OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 9

SPACE SHUTTLE VERNIER NOZZLE A/A*=21

LINE	POINT	DESCRIP - REGIME	R / MACH ANGLE	X / PRESSURE	M / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
1	31	INPUT - CONTIN	.44410-01	.28967+00	.47611+01	.54685+01	.32104+02	.96780+00	.13965+11	0
			.19255+02	.39810+00	.13152-04	.18884+04	.24102+04	.13030+01		
1	32	INPUT - CONTIN	.47392-01	.28907+00	.40544+01	.56119+01	.31361+02	.96732+00	.13965+11	0
			.19279+02	.40247+00	.13265-04	.18178+04	.24102+04	.13028+01		
1	33	INPUT - CONTIN	.48779-01	.28934+00	.40478+01	.57567+01	.30070+02	.96684+00	.13965+11	0
			.19303+02	.40687+00	.13377-04	.18172+04	.24102+04	.13026+01		
1	34	INPUT - CONTIN	.50124-01	.28920+00	.40412+01	.58997+01	.29364+02	.96634+00	.13965+11	0
			.19326+02	.41144+00	.13494-04	.18216+04	.24102+04	.13024+01		
1	35	INPUT - CONTIN	.51475-01	.28906+00	.40350+01	.60[illegible]+01	.28171+02	.96591+00	.13965+11	0
			.19348+02	.41573+00	.13604-04	.18257+04	.24102+04	.13022+01		
1	36	INPUT - CONTIN	.52611-01	.28691+00	.40291+01	.61906+01	.26675+02	.96597+00	.13965+11	0
			.19370+02	.41992+00	.13712-04	.18297+04	.24102+04	.13021+01		
1	37	INPUT - CONTIN	.54196-01	.28677+00	.40232+01	.63309+01	.25431+02	.96504+00	.13965+11	0
			.19391+02	.42411+00	.13819-04	.18336+04	.24102+04	.13019+01		
1	38	INPUT - CONTIN	.55458-01	.2885[illegible]	.40180+01	.64856+01	.22936+02	.96466+00	.13965+11	0
			.19410+02	.42821+00	.13926-04	.18371+04	.24102+04	.13017+01		
1	39	INPUT - CONTIN	.56776-01	.28807+00	.40129+01	.66341+01	.19627+02	.96428+00	.13965+11	0
			.19429+02	.43223+00	.14030-04	.18406+04	.24102+04	.13016+01		
1	40	INPUT - CONTIN	.59369-01	.28816+00	.40031+01	.69407+01	.13808+02	.96357+00	.13965+11	0
			.19465+02	.44003+00	.14235-04	.18471+04	.24102+04	.13013+01		
1	41	INPUT - CONTIN	.61640-01	.28784+00	.39918+01	.72472+01	.11307+02	.96286+00	.13965+11	0
			.19[illegible]0+02	.44724+00	.14416-04	.18536+04	.24102+04	.13010+01		
1	42	INPUT - CONTIN	.64394-01	.2875[illegible]+00	.39851+01	.75639+01	.88066+01	.96221+00	.13965+11	0
			.19533+02	.45601+00	.14590-04	.18595+04	.24102+04	.13008+01		
1	43	INPUT - CONTIN	.66648-01	.28719+00	.39783+01	.78882+01	.20498-01	.96169+00	.13965+11	0
			.19556+02	.46019+00	.14708-04	.18642+04	.24102+04	.13005+01		
1	44	INPUT - CONTIN	.6929[illegible]-01	.28684+00	.39723+01	.82796+01	-.31071+01	.96124+00	.13965+11	0
			.19584+02	.46576+00	.14894-04	.18683+04	.24102+04	.13004+01		
1	45	INPUT - CONTIN	.71626-01	.2865[illegible]+00	.39673+01	.85559+01	-.84291+01	.96086+00	.13965+11	0
			.19599+02	.47[illegible]67+00	.15021-04	.18716+04	.24102+04	.13002+01		

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 10

SPACE SHUTTLE VERNIER NOZZLE A/A*=21

LINE	POINT	DESCRIP - REGIME	R / MACH ANGLE	X / PRESSURE	M / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
1	46	INPUT - CONTIN	.73980-01	.28647+00	.39190+01	.86065+01	.11706+03	.94829+00	.15863+07	0
			.19783+02	.48363+00	.15461-04	.18728+04	.24051+04	.12997+01		
1	47	INPUT - CONTIN	.73693-01	.28678+00	.37526+01	.87495+01	.36958+03	.92257+00	-.88539+06	0
			.15455+02	.48373+00	.14929-04	.19457+04	.23981+04	.12959+01		
1	48	INPUT - CONTIN	.74497-01	.28605+00	.32365+01	.89690+01	.28722+04	.83505+00	-.76732+07	0
			.17997+02	.48365+00	.13817-04	.21785+04	.23036+04	.12832+01		
1	49	INPUT - CONTIN	.75327-01	.28591+00	.27830+01	.90818+01	.47760+04	.74911+00	-.13699+08	0
			.21052+02	.48369+00	.12437-04	.2355[illegible]+04	.23171+04	.12750+01		
1	50	INPUT - CONTIN	.76256-01	.28575+00	.21696+01	.92139+01	.79473+04	.60279+00	-.21911+08	0
			.27465+02	.48371+00	.11473-04	.25578+04	.23741+04	.12688+01		
1	51	INPUT - CONTIN	.77023-01	.28563+00	.16029+01	.93228+01	.95550+04	.45567+00	-.27750+08	0
			.38619+02	.48369+00	.10081-0[illegible]	.26968+04	.23736+04	.12633+01		
1	52	INPUT - CONTIN	.77477-01	.28555+00	.12914+01	.93872+01	.10794+05	.35589+00	-.31223+08	0
			.53664+02	.48369+00	.10693-04	.27572+04	.23735+04	.12556+01		
1	53	INPUT - CONTIN	.77703-01	.28551+00	.10500+01	.99199+01	.11397+05	.32179+00	-.32753+08	0
			.72297+02	.48369+00	.10509-04	.27819+04	.23735+04	.12507+01		
1	54	INPUT - CONTIN	.78271-01	.28542+00	.10503+31	.95000+01	.11346+05	.27843+00	-.38373+08	0
			.72297+02	.48369+00	.12907-34	.23652+04	.23735+04	.12526+01		

THE MASS FLOW RATE IS = .771060-01

MOMENTUM INTEGRATION RESULT

FORCEX	FORCEY	TORQZ	I.C
-.23672+02	.0000	.00000	.30701+01

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 19

SPACE SHUTTLE VERNIER NOZZLE A/A*=21

LINE	POINT	DSCRIP - REGIME	Y / MACH ANGLE	X / PRESSURE	R / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
2	46	INTER - CONTIN	.72070-01 .19760+02	.20712+00 .47002+00	.39252+01 .15363-04	.85475+01 .18685+04	.11284+05 .24051+04	.94872+04 .12999+01	.15863+07	2
2	47	INTER - CONTIN	.71196-01 .15443+02	.20695+00 .48150+00	.37559+01 .14876-04	.87684+01 .19037+04	.76958+05 .23981+04	.97280+04 .12955+01	-.84530+06	2
2	48	INTER - CONTIN	.74605-01 .17901+02	.20673+00 .48171+00	.32396+01 .13359-04	.89784+01 .21761+04	.20722+04 .23036+04	.83576+04 .12833+01	-.16732+07	2
2	49	INTER - CONTIN	.75937-01 .21076+02	.20660+00 .48481+00	.27871+01 .12379-04	.91239+01 .23529+04	.97760+04 .23771+04	.79956+04 .12760+01	-.13699+08	3
2	50	INTER - CONTIN	.76378-01 .27372+02	.20645+00 .47918+00	.21750+01 .11386-04	.93794+01 .25527+04	.73470+04 .23741+04	.60318+04 .12690+01	-.21071+09	3
2	51	INTER - CONTIN	.77137-01 .30614+02	.20632+00 .48369+00	.16020+01 .10801-04	.93220+01 .26968+04	.95550+04 .23736+04	.45567+04 .12633+01	-.27759+08	1
2	52	INTER - CONTIN	.77592-01 .53666+02	.20675+00 .48369+00	.12010+01 .10693-04	.93872+01 .27572+04	.10799+05 .23735+04	.35504+04 .12556+01	-.31223+08	1
2	53	INTER - CONTIN	.77819-01 .72298+02	.20621+00 .48369+00	.10500+01 .10509-04	.94199+01 .27819+04	.11397+05 .23735+04	.30179+04 .12507+01	-.32753+08	1
2	54	WALL - CONTIN	.78271-01 .72292+02	.20542+00 .48369+00	.10500+01 .12907-04	.95000+01 .23652+04	.11346+05 .23739+04	.27893+04 .12526+01	-.30373+08	1

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.23672+02	.00000	.00000	.00000	.00000	.30701+03

PERCENT CHANGE IN MASS, MOMENTUM AND ENERGY NUMERICAL INTEGRATION FOR LINE 2 RELATIVE TO THE START LINE

THE PERCENT CHANGE IN MASS FLOW IS = .252199-02

PERCENT CHANGE IN MOMENTUM IS = -.52860+00 ISP = -.53111+00

PERCENT CHANGE IN ENERGY IS = .00000

EXIT PLANE NORMAL START LINE

.0000000	.2919436+00	.4222118+01	.0000002	-.7235160+02	.1396535+11
.1637467-02	.2919462+00	.4219865+01	.2242746+00	-.6857036+02	.1396535+11
.3276230-02	.2919345+00	.4217371+01	.4487471+00	-.6478912+02	.1396535+11
.4911256-02	.2919145+00	.4215565+01	.6719755+00	-.6299270+02	.1396535+11
.6545361-02	.2918922+00	.4213996+01	.8940487+00	-.5719527+02	.1396535+11
.8171908-02	.2918637+00	.4209653+01	.1113727+01	-.4817373+02	.1396535+11
.9796991-02	.2918290+00	.4205570+01	.1331590+01	-.3916567+02	.1396535+11
.1141199-01	.2917705+00	.4201035+01	.1546606+01	-.3006473+02	.1396535+11
.1302308-01	.2917420+00	.4196201+01	.1758021+01	-.2097057+02	.1396535+11
.1462070-01	.2916901+00	.4191078+01	.1965008+01	-.1169903+02	.1396535+11
.1621430-01	.2916325+00	.4185589+01	.2169013+01	-.2033792+01	.1396535+11
.1779266-01	.2915700+00	.4179759+01	.2369570+01	.7004222+01	.1396535+11
.1936796-01	.2915121+00	.4173672+01	.2566007+01	.1602979+02	.1396535+11
.2093606-01	.2914295+00	.4169033+01	.2757719+01	.2293601+02	.1396535+11
.2240083-01	.2913510+00	.4162179+01	.2945029+01	.2899303+02	.1396535+11
.2402070-01	.2912701+00	.4155805+01	.3128033+01	.3963777+02	.1396535+11
.2556409-01	.2911837+00	.4149318+01	.3307370+01	.4003172+02	.1396535+11
.2708604-01	.2910935+00	.4143026+01	.3481308+01	.4102503+02	.1396535+11
.2860511-01	.2909988+00	.4138019+01	.3652005+01	.4209859+02	.1396535+11
.3012493-01	.2909009+00	.4131993+01	.3817571+01	.4395255+02	.1396535+11
.3160106-01	.2907990+00	.4125594+01	.3979932+01	.4509078+02	.1396535+11
.3308631-01	.2906936+00	.4119718+01	.4138569+01	.4356519+02	.1396535+11
.3456810-01	.2905843+00	.4113671+01	.4294622+01	.4209957+02	.1396535+11
.3663180-01	.2904725+00	.4107355+01	.4446943+01	.4061312+02	.1396535+11
.3749244-01	.2903569+00	.4100916+01	.4597513+01	.3921598+02	.1396535+11
.3893308-01	.2902392+00	.4099452+01	.4745066+01	.3769017+02	.1396535+11
.4037143-01	.2901180+00	.4087999+01	.4891790+01	.3629659+02	.1396535+11
.4179229-01	.2899946+00	.4081229+01	.5036523+01	.3476809+02	.1396535+11
.4321171-01	.2898677+00	.4079600+01	.5181256+01	.3349739+02	.1396535+11
.4461101-01	.2897390+00	.4067059+01	.5320963+01	.3264956+02	.1396535+11
.4640964-01	.2896069+00	.4061058+01	.5460984+01	.3219908+02	.1396535+11
.4739165-01	.2894728+00	.4054911+01	.5611916+01	.3134067+02	.1396535+11
.4877352-01	.2893353+00	.4047751+01	.5756661+01	.3082441+02	.1396535+11
.5013976-01	.2891979+00	.4041154+01	.5899729+01	.2936572+02	.1396535+11
.5149751-01	.2890561+00	.4035010+01	.6099606+01	.2817122+02	.1396535+11

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

.5781079-01	.2889129+00	.4020100+01	.6190550+01	.2667978+02	.1396535+11
.5919696-01	.2887663+00	.4023271+01	.6350011+01	.2509113+02	.1396535+11
.5595807-01	.2886189+00	.4018010+01	.6495690+01	.2243571+02	.1396535+11
.567895[illegible]	.2884681+00	.4017913+01	.6636099+01	.1962319+02	.1396535+11
.5936651-01	.2881567+00	.4003280+01	.6980702+01	.1380031+02	.1396535+11
.6168980-01	.2878450+00	.3993820+01	.7247170+01	.1130796+02	.1396535+11
.6439359-01	.2875190+00	.3985092+01	.7563900+01	.8006609+01	.1396535+11
.6689750-01	.2871866+00	.3970265+01	.7888169+01	.2099771+01	.1396535+11
.6929059-01	.2868040+00	.3972139+01	.8229575+01	-.3107063+01	.1396535+11
.7162049-01	.2864972+00	.3967258+01	.8555915+01	-.8928113+01	.1396535+11
.7197992-01	.2864694+00	.3919036+01	.8606966+01	.1120611+03	.1586397+07
.7309296-01	.2862832+00	.3757585+01	.8764599+01	.7695821+03	-.8953865+06
.7499707-01	.2860902+00	.3236536+01	.8963991+01	.2822296+04	-.7673157+07
.7532654-01	.2859094+00	.2703777+01	.9081801+01	.9776037+04	-.1369882+08
.7625627-01	.2857530+00	.2169603+01	.9213861+01	.7347039+04	-.2191077+08
.7702301-01	.2856255+00	.1602375+01	.9322765+01	.9555025+04	-.2775890+08
.7707699-01	.2855095+00	.1491377+01	.9387225+01	.1070385+05	-.3122319+08
.7770311-01	.2855117+00	.1049970+01	.9419369+01	.1139739+05	-.3275331+08
.7827083-01	.2854167+00	.1050000+01	.9500000+01	.1130550+05	-.3837303+08

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.23672+07	.00000	.00000	.00000	.00000	.30701+03

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

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                SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

                                         CASE NO.   0                                              PAGE  26

 SPACE SHUTTLE VERNIER NOZZLE  A/A*=21

LINE POINT  DSCRIP  REGIME        C            P            H            THETA        ENTROPY      VELOCITY       Q/T       ITR
                               MACH ANGLE    PRESSURE     DENSITY      TEMPERATURE   GAS CONST.   LOCAL GAMMA   SHOCK ANGLE

  2   75  INTER  - CONTIN     .78576-01    .28578+00    .89568+01    .12096+03    .11396+05    .71007+04    -.30373+00    4
                              .64830+01    .25872-04    .78745-08    .10034+03    .23734+04    .13586+01

  2   76  INTER  - CONTIN     .78559-01    .28525+00    .16392+02    .12580+03    .11396+05    .71605+04    -.30373+00    4
                              .55487+01    .85751-05    .34967-08    .10879+03    .23734+04    .13584+01

  2   77  INTER  - CONTIN     .78539-01    .28572+00    .17369+02    .13062+03    .11396+05    .72190+04    -.30373+00    4
                              .46373+01    .23689-05    .13620-08    .10552+03    .23734+04    .13602+01

  2   78  INTER  - CONTIN     .78510-01    .28520+00    .15355+02    .13567+03    .11396+05    .72638+04    -.30373+00    4
                              .37339+01    .44459-06    .47013-09    .69320+02    .23734+04    .13602+01

  2   79  INTER  - CONTIN     .78494-01    .28517+00    .20175+02    .14032+03    .11396+05    .72993+04    -.30373+00    4
                              .28409+01    .63960-07    .95702-10    .40549+02    .23734+04    .13602+01

  2   80  FREEBD - CONTIN     .78482-01    .28516+00    .19951+02    .14032+03    .11396+05    .72981+04    -.30373+00    4
                              .28730+01    .69501-07    .10173-09    .41451+02    .23734+04    .13602+01

          PERCENT CHANGE IN MASS, MOMENTUM AND ENERGY NUMERICAL INTEGRATION FOR LINE  2 RELATIVE TO THE START LINE
   THE PERCENT CHANGE IN MASS FLOW IS =       .319722-01
  PERCENT CHANGE IN MOMENTUM IS =  -.56260+00     ISP =  -.62442+00
  PERCENT CHANGE IN ENERGY IS =     .00000

  3    1  WALL   - CONTIN     .00000       .29329+02    .92257+01    .00000      -.72352+02    .97915+04     .13965+11    2
                              .13689+02    .32030+00    .11236-04    .17036+04    .24102+04    .13076+01

  3   80  FREEBD - CONTIN     .78622-01    .28499+01    .19953+02    .14020+03    .11396+05    .72982+04    -.30373+00    2
                              .28727+01    .69445-07    .10167-09    .41442+02    .23734+04    .13602+01

                                     POINT NO.  45 ON LINE   3 HAS BEEN DELETED

 A NEW STREAMLINE HAS BEEN INSERTED ON LINE   2 BETWEEN POINTS  49 AND  50

 A NEW STREAMLINE HAS BEEN INSERTED ON LINE   2 BETWEEN POINTS  53 AND  54

  4    1  WALL   - CONTIN     .00000       .29396+00    .92285+01    .00000      -.72352+02    .97933+04     .13965+11    2
                              .13674+02    .31898+00    .11198-04    .17019+04    .24102+04    .13076+01

  4   81  FREEBD - CONTIN     .78621-01    .28475+00    .19953+02    .14110+03    .11396+05    .72982+04    -.30373+00    1
                              .28727+01    .69445-07    .10167-09    .41442+02    .23734+04    .13602+01

 A NEW STREAMLINE HAS BEEN INSERTED ON LINE   3 BETWEEN POINTS  51 AND  52

 A NEW STREAMLINE HAS BEEN INSERTED ON LINE   3 BETWEEN POINTS  56 AND  57

  5    1  WALL   - CONTIN     .00000       .29444+00    .92313+01    .00000      -.72352+02    .97952+04     .13965+11    2
                              .13676+02    .31758+00    .11160-04    .17002+04    .24102+04    .13077+01

                SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

                                         CASE NO.   0                                              PAGE  27

 SPACE SHUTTLE VERNIER NOZZLE  A/A*=21

LINE POINT  DSCRIP - REGIME       Q            P            H            THETA        ENTROPY      VELOCITY       Q/T       ITR
                               MACH ANGLE    PRESSURE     DENSITY      TEMPERATURE   GAS CONST.   LOCAL GAMMA   SHOCK ANGLE

  5   83  FREEBD - CONTIN     .79028-01    .28449+00    .19953+02    .14140+03    .11396+05    .72982+04    -.30373+00    1
                              .28727+01    .69445-07    .10167-09    .41442+02    .23734+04    .13602+01

 A NEW STREAMLINE HAS BEEN INSERTED ON LINE   4 BETWEEN POINTS  50 AND  51

  6    1  WALL   - CONTIN     .00000       .29532+00    .92341+01    .00000      -.72352+02    .97970+04     .13965+11    2
                              .13661+02    .31619+00    .11122-04    .16985+04    .24102+04    .13078+01

  6   84  FREEBD - CONTIN     .79244-01    .28422+00    .19953+02    .14156+03    .11396+05    .72982+04    -.30373+00    1
                              .28727+01    .69445-07    .10167-09    .41442+02    .23734+04    .13602+01

 A NEW STREAMLINE HAS BEEN INSERTED ON LINE   5 BETWEEN POINTS  48 AND  49

  7    1  WALL   - CONTIN     .00000       .29600+00    .92369+01    .00000      -.72352+02    .97989+04     .13965+11    2
                              .13652+02    .31481+00    .11085-04    .16968+04    .24102+04    .13079+01

  7   85  FREEBD - CONTIN     .79467-01    .28394+00    .19953+02    .14176+03    .11396+05    .72982+04    -.30373+00    1
                              .28727+01    .69445-07    .10167-09    .41442+02    .23734+04    .13602+01

 A NEW STREAMLINE HAS BEEN INSERTED ON LINE   6 BETWEEN POINTS  50 AND  51

  8    1  WALL   - CONTIN     .00000       .29668+00    .92397+01    .00000      -.72352+02    .98007+04     .13965+11    2
                              .13643+02    .31344+00    .11048-04    .16951+04    .24102+04    .13079+01

  8   86  FREEBD - CONTIN     .79696-01    .28365+00    .19953+02    .14192+03    .11396+05    .72982+04    -.30373+00    1
                              .28727+01    .69445-07    .10167-09    .41442+02    .23734+04    .13602+01

                                     POINT NO.  85 ON LINE   8 HAS BEEN DELETED

  9    1  WALL   - CONTIN     .00000       .29736+00    .92425+01    .00000      -.72352+02    .98025+04     .13965+11    2
                              .13633+02    .31208+00    .11011-04    .16934+04    .24102+04    .13080+01

  9   85  FREEBD - CONTIN     .79930-01    .28335+00    .19953+02    .14206+03    .11396+05    .72982+04    -.30373+00    2
                              .28727+01    .69445-07    .10167-09    .41442+02    .23734+04    .13602+01

 10    1  WALL   - CONTIN     .00000       .29805+00    .92453+01    .00000      -.72352+02    .98043+04     .13965+11    2
                              .13624+02    .31072+00    .10974-04    .16917+04    .24102+04    .13081+01

 10   85  FREEBD - CONTIN     .80169-01    .28304+00    .19953+02    .14217+03    .11396+05    .72982+04    -.30373+00    2
                              .28727+01    .69445-07    .10167-09    .41442+02    .23734+04    .13602+01

                                     POINT NO.  56 ON LINE  10 HAS BEEN DELETED

                                     POINT NO.  56 ON LINE  10 HAS BEEN DELETED

 11    1  WALL   - CONTIN     .00000       .29873+00    .92481+01    .00000      -.72352+02    .98061+04     .13965+11    2
                              .13615+02    .30936+00    .10937-04    .16900+04    .24102+04    .13082+01
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ORIGINAL PAGE IS OF POOR QUALITY

SAMPLE PROBLEM 1 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 98

SPACE SHUTTLE VERNIER NOZZLE 4/30/73

LINE	POINT	DSCRIP - REGIME	B / MACH ANGLE	P / PRESSURE	M / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/I / SHOCK ANGLE	TIP
205	1	WALL - CONTIN	.00000 .26589+01	.17213+02 .12355-05	.21561+02 .84918-09	.00000 .87499+02	-.72352+02 .24102+04	.11393+05 .13132+01	.13965+11	2
205	77	FREEND - CONTIN	.14158+02 .20727+01	-.84933+01 .69445-07	.19953+02 .10167-09	.11969+03 .41442+02	.11396+05 .23734+04	.72982+04 .13602+01	-.30373+08	2
206	1	WALL - CONTIN	.00000 .26405+01	.17567+02 .11685-05	.21707+02 .80907-09	.00000 .86289+02	-.72352+02 .24102+04	.11394+05 .13132+01	.13965+11	2
206	77	FREEND - CONTIN	.14480+02 .20727+01	-.85907+01 .69445-07	.19953+02 .10167-09	.11941+03 .41442+02	.11396+05 .23734+04	.72982+04 .13602+01	-.30373+08	2

A NEW STREAMLINE HAS BEEN INSERTED ON LINE 205 BETWEEN POINTS 44 AND 45

LINE	POINT	DSCRIP - REGIME	B / MACH ANGLE	P / PRESSURE	M / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/I / SHOCK ANGLE	TIP
207	1	WALL - CONTIN	.00000 .26226+01	.17910+02 .11047-05	.21854+02 .77520-09	.00000 .85141+02	-.72352+02 .24102+04	.11395+05 .13132+01	.13965+11	2

POINT NO. 44 ON LINE 207 HAS BEEN DELETED

POINT NO. 44 ON LINE 207 HAS BEEN DELETED

LINE	POINT	DSCRIP - REGIME	B / MACH ANGLE	P / PRESSURE	M / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/I / SHOCK ANGLE	TIP
207	1	WALL - CONTIN	.00000 .26047+01	.18304+02 .10440-05	.22004+02 .74252-09	.00000 .84000+02	-.72352+02 .24102+04	.11396+05 .13132+01	.13965+11	2
206	76	FREEND - CONTIN	.15150+02 .20727+01	-.88910+01 .69445-07	.19953+02 .10167-09	.11413+03 .41442+02	.11396+05 .23734+04	.72982+04 .13602+01	-.30373+08	2

A NEW STREAMLINE HAS BEEN INSERTED ON LINE 207 BETWEEN POINTS 43 AND 44

PREVIOUSLY NOTED ERRORS HAVE PROPAGATED TO LOWER BOUNDARY, OR PROBLEM LIMITS HAVE BEEN REACHED. CASE TERMINATED.

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00000000L700 C000C0000000

   PUNCH CARDS FOR LINE 207

.0000000    .1830789+02 .2200425+02 .0000000     -.7235160+02 .1396535+11
.1833C05+00 .1830294+02 .2199664+02 .5953982+00 -.6857636+02 .1396535+11
.3726709+00 .1829999+02 .2199559+02 .1276069+01 -.6474912+02 .1396535+11
.5571631+00 .1829507+02 .2199571+02 .1816369+01 -.6099220+02 .1396535+11
.7437066+00 .1828817+02 .2199737+02 .2422433+01 -.5719527+02 .1396535+11
.9296624+00 .1827932+02 .2199451+02 .3029122+01 -.4817373+02 .1396535+11
.1115926+01 .1826847+02 .2199317+02 .3637141+01 -.3916567+02 .1396535+11
.1301517+01 .1825569+02 .2199356+02 .4243505+01 -.3006473+02 .1396535+11
.1487539+01 .1824089+02 .2199586+02 .4851907+01 -.2097857+02 .1396535+11
.1672562+01 .1822421+02 .2199853+02 .5457369+01 -.1169903+02 .1396535+11
.1858052+01 .1820549+02 .2200373+02 .6065538+01 -.2031792+01 .1396535+11
.2042296+01 .1818487+02 .2200937+02 .6671791+01 .7004222+01 .1396535+11
.2270264+01 .1816217+02 .2201129+02 .7281197+01 .1692979+02 .1396535+11
.2413390+01 .1813752+02 .2203069+02 .7890784+01 .2243681+02 .1396535+11
.2599423+01 .1811072+02 .2204605+02 .8503340+01 .2099383+02 .1396535+11
.2769732+01 .1808200+02 .2206298+02 .9115099+01 .3963777+02 .1396535+11
.2971196+01 .1805106+02 .2208184+02 .9731584+01 .4003172+02 .1396535+11
.3157519+01 .1801806+02 .2210491+02 .1039912+02 .9182583+01 .1396535+11
.3395250+01 .1798272+02 .2213690+02 .1097796+02 .4280854+02 .1396535+11
.3537667+01 .1794533+02 .2216755+02 .1159628+02 .4395255+02 .1396535+11
.3721650+01 .1790546+02 .2220028+02 .122267 2 .4509878+02 .1396535+11
.3911437+01 .1786323+02 .2223021+02 .1286195+02 .4356519+02 .1396535+11
.4103153+01 .1781833+02 .2227882+02 .1350492+02 .4209957+02 .1396535+11
.4295004+01 .1777111+02 .2232192+02 .1419971+02 .4061312+02 .1396535+11
.4469097+01 .1772101+02 .2236768+02 .1480445+02 .3921598+02 .1396535+11
.4663157+01 .1766851+02 .2241626+02 .1546162+02 .3769017+02 .1396535+11
.4829426+01 .1761288+02 .2246875+02 .1612972+02 .3628654+02 .1396535+11
.5077110+01 .1755956+02 .2252372+02 .1680297+02 .3476809+02 .1396535+11
.5277383+01 .1749270+02 .2258172+02 .1748806+02 .3340234+02 .1396535+11
.5470151+01 .1742819+02 .2264313+02 .1817827+02 .3266456+02 .1396535+11
.5682339+01 .1735975+02 .2270881+02 .1888333+02 .3210968+02 .1396535+11
.5867879+01 .1728863+02 .2277906+02 .1959113+02 .3136067+02 .1396535+11
.6097253+01 .1721197+02 .2285653+02 .2031762+02 .3082011+02 .1396535+11
.6306189+01 .1713306+02 .2293574+02 .2105832+02 .2936572+02 .1396535+11
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ORIGINAL PAGE
OF POOR QUALITY

SAMPLE PROBLEM 1 OUTPUT (Concluded)

.6519554+01	.1709928+02	.2302239+02	.2181035+02	.2812122+02	.1396535+11
.6735290+01	.1696130+02	.2311610+02	.2257483+02	.2667878+02	.1396535+11
.6956126+01	.1696768+02	.2321880+02	.2336281+02	.2503113+02	.1396535+11
.7178588+01	.1676974+02	.2333130+02	.2416158+02	.2293571+02	.1396535+11
.7467297+01	.1666517+02	.2305462+02	.2498787+02	.1962319+02	.1396535+11
.7891091+01	.1643058+02	.2379612+02	.2674809+02	.1300831+02	.1396535+11
.8467105+01	.1616238+02	.2410575+02	.2863295+02	.1130796+02	.1396535+11
.8969715+01	.1583869+02	.2459109+02	.3075699+02	.8806604+01	.1396535+11
.9617216+01	.1543426+02	.2527875+02	.3322059+02	.2849771+01	.1396535+11
.1065674+02	.1462892+02	.2580982+02	.3771259+02	.1195073+04	.6983468+10
.1170027+02	.1392358+02	.2639112+02	.4220449+02	.1120411+03	.1586[illegible]47+07
.1239871+02	.1315918+02	.2810177+02	.4496657+02	.7695821+03	-.8453865+06
.1299713+02	.1253249+02	.2831170+02	.4760163+02	.1869532+04	-.9259272+07
.1361777+02	.1101781+02	.2890081+02	.5056813+02	.2672296+04	-.7673157+07
.1469386+02	.1121179+02	.2878302+02	.5303718+02	.3849267+04	-.1068599+08
.1452888+02	.1060898+02	.2949652+02	.5537265+02	.4776037+04	-.1369882+08
.1530122+02	.9382913+01	.2970262+02	.6005072+02	.6091464+04	-.1755979+08
.1558428+02	.8876676+01	.3015113+02	.6187060+02	.6695691+04	-.1998270+08
.1586021+02	.8339250+01	.3049082+02	.6377409+02	.7347039+04	-.2191077+08
.1619768+02	.7727129+01	.3109935+02	.6591810+02	.7881326+04	-.2299780+08
.1691956+02	.7085139+01	.3141175+02	.6811708+02	.8946659+04	-.2458883+08
.1669457+02	.6350567+01	.3202215+02	.7061687+02	.8901329+04	-.2617107+08
.1695794+02	.5599164+01	.3263719+02	.7331127+02	.9555025+04	-.2775890+08
.1727438+02	.4395626+01	.3399473+02	.7735877+02	.1013384+05	-.2999102+08
.1750931+02	.3108402+01	.3508953+02	.8140582+02	.1068973+05	-.3393202+08
.1757498+02	.2598868+01	.3561958+02	.8320286+02	.1099736+05	-.3615753+08
.1763762+02	.1992868+01	.3589278+02	.8495296+02	.1133145+05	-.3837303+08
.1769791+0	1013373+01	.3750777+02	.8877208+02	.1139550+05	-.3837303+08
.1770759+02	.4103905+00	.3848863+02	.8998190+02	.113 116+05	-.3837303+08
.1769608+02	-.2189950+00	.3937678+02	.9205139+02	.1139550+05	-.3837303+08
.1768090+02	-.1479190+01	.4111807+02	.9607106+02	.1139550+05	-.3837303+08
.1745987+02	-.2552368+01	.4285257+02	.9960560+02	.1139550+05	-.3837303+08
.1726631+02	-.3578450+01	.4460871+02	.1020275+03	.1139550+05	-.3837303+08
.1703514+02	-.4432864+01	.4628969+02	.1050089+03	.1139550+05	-.3837303+08
.1677276+02	-.5276222+01	.4795096+02	.1087120+03	.1139550+05	-.3837303+08
.1649507+02	-.6038050+01	.4956863+02	.1113039+03	.1139550+05	-.3837303+08
.1618036+02	-.6791559+01	.5128936+02	.1139933+03	.1139550+05	-.3837303+08
.1584283+02	-.7507266+01	.[illegible]259191+02	.1165045+03	.1139550+05	-.3837303+08
.1550295+02	-.8171204+01	.4991478+02	.1177110+03	.1139550+05	-.3837303+08
.1528672+02	-.8590799+01	.2836182+02	.1159377+03	.1139550+05	-.3837303+08
.1520305+02	-.8775224+01	.2209122+02	.1148052+03	.1139550+05	-.3837303+08
.1517219+02	-.8892714+01	.2072770+02	.1193391+03	.1139550+05	-.3837303+08
.1519954+02	-.8893439+01	.1995305+02	.1191251+03	.1139550+05	-.3837303+08

8.2 SAMPLE PROBLEM 2 - SPACE SHUTTLE REACTION CONTROL SYSTEM (RCS) MOTOR

The Space Shuttle Reaction Control System (RCS) engine is a 920 lb thrust motor used for attitude control and minor orbit changes. It may be used during retrieval and deployment of payloads and satellites so that a detailed characterization of the plume is necessary to determine RCS plume induced environments. The RCS motor is a bipropellant motor and has the following characteristics:

Throat Radius	0.08508333 ft
Area Ratio (Unscarfed)	22.1
Chamber Pressure	153.0
Propellants	
Fuel	Monomethylhydrazine (MMH)
Oxidizer	N_2O_4
O/F Ratio	1.63

The method used to determine the RCS geometric input data is essentially the same as was used to set up the vernier engine. A layout of the RCS geometry is shown in Fig. 8-4. A tabulation of the nozzle contour points from the throat to the exit plane is given in Table 8-2. The origin of the geometry for the RCS motor was taken to be the throat so that the tabulated values in Table 8-2 were shifted so the x = 0 at the throat. The data given in Fig. 8-4 and Table 8-2 were subsequently converted from inches to feet for input to the program. The chamber/transonic (to throat) geometry is made up of two circular arcs (as seen from Fig. 8-4). Unlike the vernier engine, enough information is given in Fig. 8-4 so that the location and angle at which the two circles intersect can be solved as in the vernier engine without any scalng. The geometry of the RCS motor from the throat to the exit plane is calculated in the same manner as the vernier engine. The radius of curvature downstream of the throat and the contour points are given and used to construct a curve of flow angle versus axial location (assuming straight line sections between contour points). A

Table 8-2 SPACE SHUTTLE REACTION CONTROL NOZZLE CONTOUR

Axial Distance from Throat, (in x	Radius (in.) y
3.585	1.021
3.720	1.059
3.826	1.126
3.959	1.210
4.091	1.294
4.200	1.365
4.340	1.455
4.459	1.530
4.585	1.609
4.720	1.693
4.828	1.760
4.944	1.830
5.085	1.913
5.585	2.201
6.585	2.720
7.585	3.166
8.585	3.560
9.585	3.909
10.585	4.211
11.585	4.489
12.585	4.729
12.885	4.799

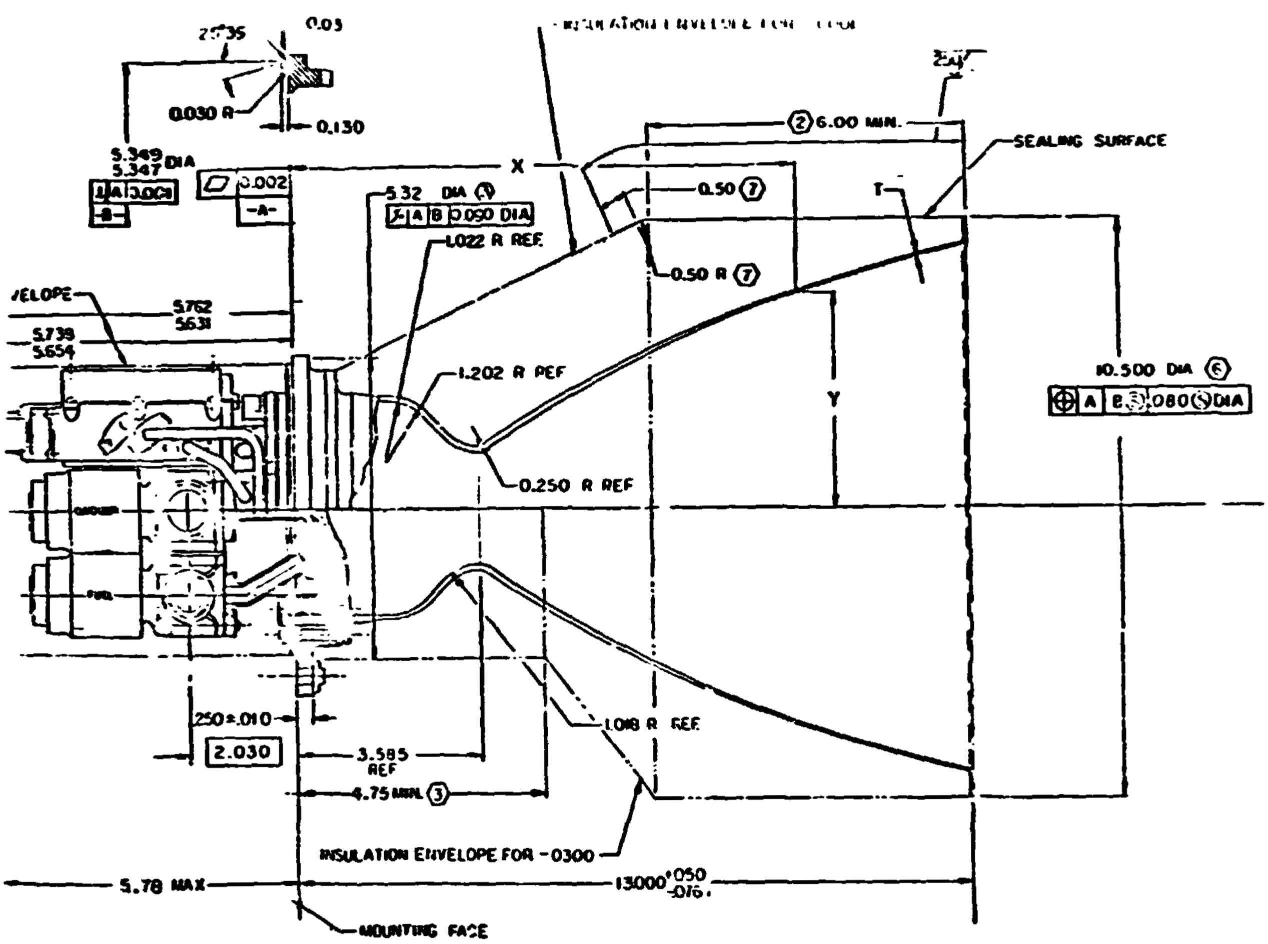

Fig. 8-4 Shuttle Reaction Control System Rocket Motor

C-4

listing of the resultant point-by-point representation of the RCS geometry is given in the listing of the data for the RCS motor (Case 8-2). The development of these data are left to the user as an exercise in setting up geometric data as was done in the Vernier motor (Case 8-1).

Some rocket engine combustion chamber geometries have a conical section between the two circular arcs upstream of the nozzle throat. The solution procedure for the boundary points must be modified to include the conical portion. The slope of the linear section is determined by the motor contour but as an example of the procedure an inclination (θ_{line}) of -30 deg is used (Fig. 8-5).

From the geometry it can be shown that $\theta_1 = \theta_2 = \theta_{line}$. In Region 1

$$X_1 = 1.022 \sin\theta_1 = 1.022 \sin 30$$
$$X_1 = 0.510$$
$$R_1 = 1.865 - 1.022\ (1 - \cos\theta_1)$$
$$R_1 = 1.865 - 1.022\ (1 - \cos 30)$$
$$R_1 = 1.728078$$

From the equation of a line through X_1 and R_1, the value of b

$$R_1 = \tan\theta_1\ X_1 + b$$
$$1.728078 = [\tan(-30)]\ 0.51 + b$$
$$b = 2.0225266$$

In Region 2 for $\theta_2 = 30$ deg,

$$R_2 = 1.021 + 1.018\ (1 - \cos\theta_2)$$
$$R_2 = 1.021 + 1.018\ (1 - \cos 30)$$
$$R_2 = 1.1.57386$$

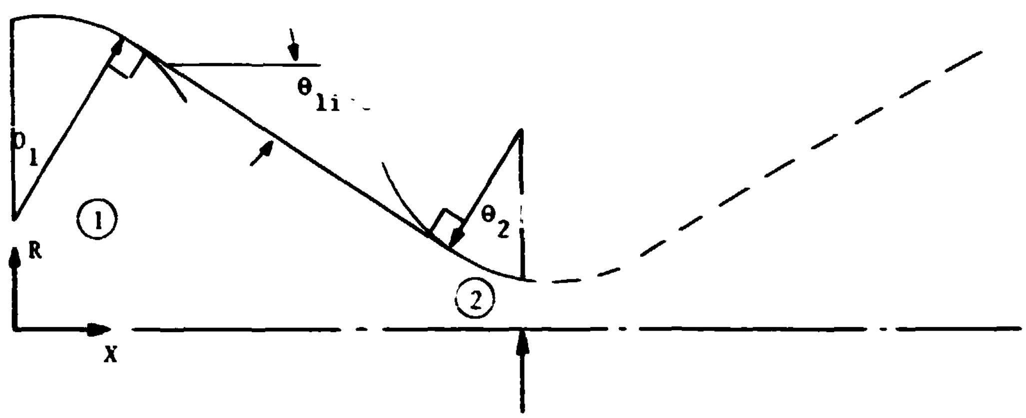

Fig. 8-5 Motor Geometry with Linear Section

Reapplying the equation of a line, determine X_2,

$$R_2 = \tan\theta_2 X_2 + 2.0225266$$
$$1.157386 = [\tan(-30)]\ X_2 + 2.0225266$$
$$X_2 = 1.498466.$$

The R and X values in Regions 1 and 2 for $\theta < 30$ deg are calculated by incrementing from 0 to 30 deg.

For the RCS example shown here there was no linear section in the contour. The linear section addition was shown as an example for setting up cases where there is a conical section upstream of the throat.

The thermodynamic properties of the combusted propellants were determined using the TRAN72 program. These data are prepared using sample case 2 of Section 4. A variable O/F calculation was made with O/F ratios ranging from 0.8 on the wall to 2.2 on the nozzle axis. The O/F distribution used at the entrance to the contraction upstream of the throat is shown in Fig. 8-6. The results of Ref. 19 were used to infer this O/F distribution for the RCS motor. The RCS motor is film-cooled so that the O/F ratio near the wall at the injector is on the order of 0.1 to 0.2. The O/F ratio on the centerline is approximately 2.2. Reference 19 shows that the wall film does not hold the same O/F ratio through the transonic region. An estimate of 0.8 was selected. Using 0.8 at the wall and 2.2 on the axis a parabolic distribution of O/F was assumed and then slightly modified so that the integrated (over the inlet area) O/F ratio matched the overall O/F ratio (1.63) for the motor. This O/F distribution was then imposed on the transonic solution.

A freeze pressure ratio of 3.35 was estimated based on an overall O/F ratio of 1.63 and pressure freeze results of Ref. 19. A pressure ratio of 3.38 was included in the TRAN72 calculation to give a sharp break from equilibrium to frozen thermochemistry.

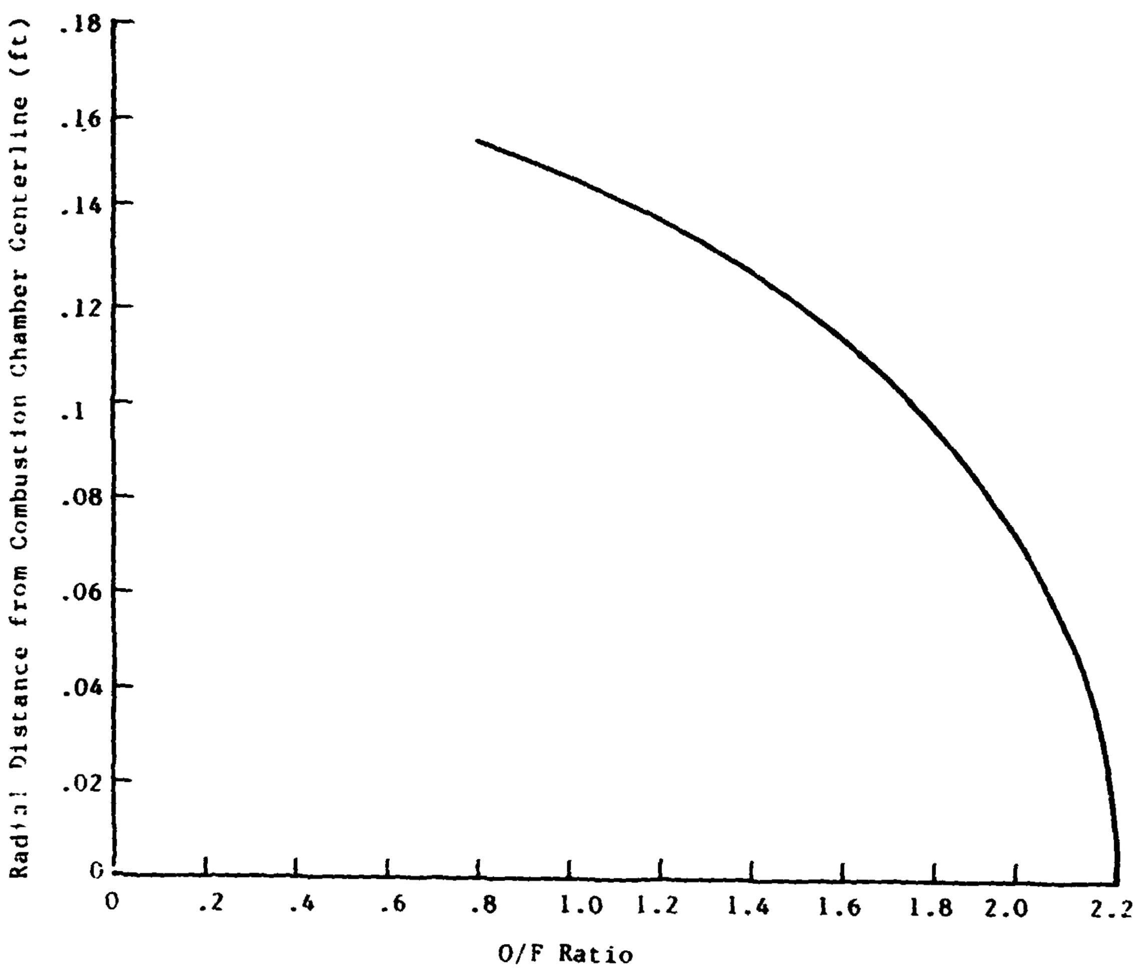

Fig. 8-6 Space Shuttle RCS Motor O/F Ratio Distribution at End of Combustion Chamber

The nozzle wall temperature distribution used as a boundary conditions for the boundary layer calculation is shown in Fig. 8-7. Two measured data points (from the engine manufacturers) are shown on the figure. A linear variation through these two points was assumed.

The output for the RCS motor consists of the results of the nozzle and boundary layer solution and the beginning of the plume restart which includes the boundary layer. The program will continue with an equilibrium plume calculation but the results will not be correct because the program cannot presently treat both total enthalpy and O/F variations for equilibrium chemistry. To calculate a plume, the ideal gas startline which is generated by the restart can be used initiate another plume calculation. This start line has the correct temperature, Mach number and pressure distributions but utilizes constant gamma, molecular weight, and total conditions.

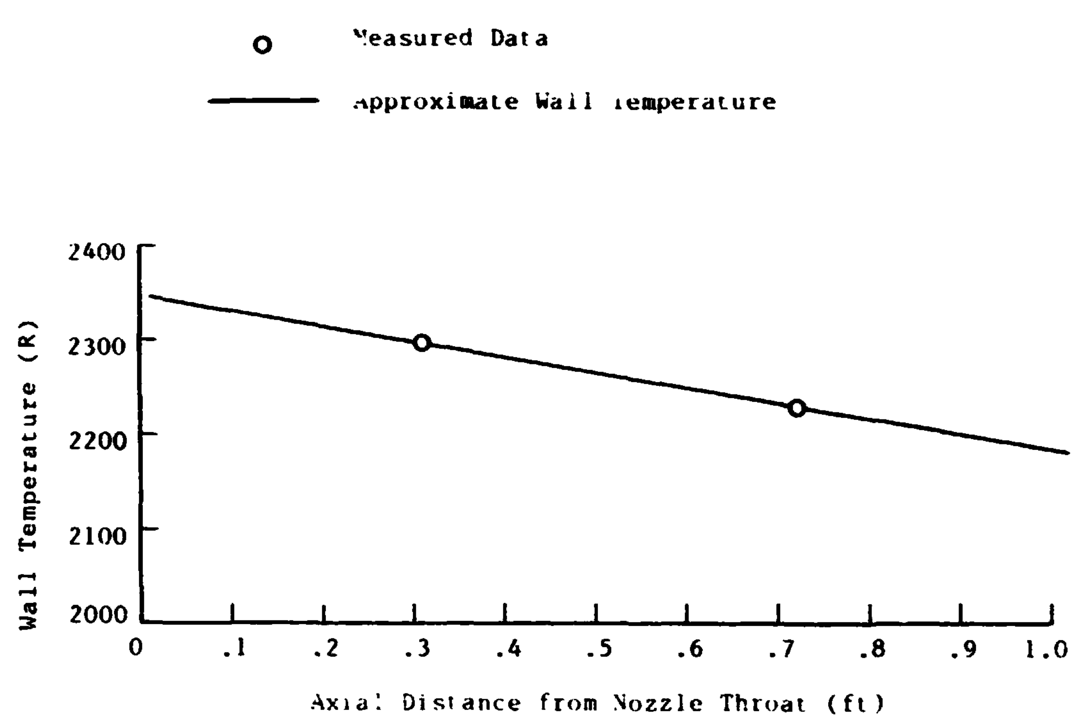

Fig. 8-7 Space Shuttle RCS Motor Nozzle Wall Temperature

SAMPLE PROBLEM 2 INPUT DATA

Card					
1	[illegible] [illegible]				
2	RCS RCS VARIABLE [illegible]				
3					
4					
5	[illegible] 5	152 61	. 6 1[illegible] 2[illegible]	[illegible] 1[illegible]	612576
7	.0[illegible]5[illegible]3333				
8		-.13771[illegible]	.1[illegible]417 .	-.134747	.155365 -2.00[illegible]
		-.131778	.1[illegible] -4.	-.128817	.15455[illegible] -6.[illegible]
		-.125566	.1[illegible]7 -[illegible].	-.12257	.154128-15.[illegible]
		-.117115	.152[illegible]7-14.	-.1114[illegible]1	.151248-16.[illegible]
		-.1[illegible]1[illegible]	.14[illegible]-2[illegible].	-.1[illegible]3[illegible]	.146797-26.[illegible]
		-.[illegible]	.144 7-3 .	-.[illegible]5887	.14[illegible]14-75.0[illegible]
		-.[illegible]75	.1[illegible]4 1-4 .	-.[illegible]77457	.17[illegible]472-45.[illegible]
		-.[illegible]7247[illegible]	.1[illegible]4[illegible] 4-5 .	-.[illegible]65725	.121181-54.1[illegible]
		-.[illegible]4[illegible]	.1[illegible] 7-5 .	-.[illegible]	.1[illegible]97[illegible]-45.[illegible]
		-.[illegible]4-3[illegible]	.1[illegible]4[illegible]1-4 .	-.[illegible]4[illegible]	.1[illegible]425-75.[illegible]
		-.[illegible]4[illegible]417	.[illegible]44 -3 .	-.[illegible]37155	.[illegible]93665-26.[illegible]
		-.[illegible]3177[illegible]	.[illegible]12[illegible]1-22.	-.[illegible]6215	.[illegible]55275-18.[illegible]
		-.[illegible]2[illegible]3	.[illegible]7-1[illegible].	-.[illegible]14731	.[illegible]66372-1[illegible]
		-.[illegible]11[illegible]7	.[illegible]-[illegible].	-.[illegible]5667	.[illegible]95548 -6.[illegible]
		-.[illegible]5[illegible]1[illegible]	.[illegible]57[illegible] -4.	-.[illegible]9561	.[illegible]85135 -2.[illegible]
		.[illegible]	.[illegible] .[illegible]	.[illegible]33	.[illegible]1.[illegible] 2.2924[illegible]
		.[illegible]16[illegible]7	.[illegible] 4.[illegible]	.[illegible]3333	.[illegible]5535 5.216[illegible]
		.[illegible]	.[illegible] 17.[illegible]	.[illegible]6667	.[illegible]86275 18.66[illegible]
		.[illegible]5333	.[illegible] 23.[illegible]7 3	.1[illegible]	.[illegible]57640 28.655[illegible]
		.[illegible]1[illegible]41[illegible]	.[illegible]7 7[illegible] 3[illegible]. 27[illegible]	.[illegible]1125	.[illegible]5363 3[illegible].3275[illegible]
		.[illegible]2[illegible]83	.[illegible] 31.[illegible]	.[illegible]31167	.1[illegible]633 32.55[illegible]
		.[illegible]42167	.1[illegible]7[illegible] 32.[illegible]27[illegible]	.[illegible]5125[illegible]	.11375[illegible] 32.843[illegible]
		.[illegible]62[illegible]17	.1[illegible]1[illegible] 3[illegible].[illegible]4[illegible]	.[illegible]72833	.12758[illegible] 32.4563[illegible]
		.[illegible]83333	.17[illegible]3 32.1[illegible]	.[illegible]94567	.141[illegible]3 31.736[illegible]
		.1[illegible]3583	.14[illegible]7 31.467[illegible]	.1172[illegible]	.152[illegible] 31.[illegible]26[illegible]
		.125[illegible]	.157417 3[illegible].5[illegible]3	.166667	.157417 29.94[illegible]
		.25[illegible]	.226667 25.5594[illegible]	.333333	.263833 23.145[illegible]
		.416667	.295657 2[illegible].4 5[illegible]	.5[illegible]	.325750 17.875[illegible]
		.583333	.35[illegible]917 15.722[illegible]	.666667	.374083 14.0363[illegible]
		.75[illegible]	.394[illegible]3 13.17[illegible] 1	.775[illegible]	.369917 13.116[illegible]
8a	3	.74565 -25	[illegible]. . [illegible].	.[illegible] 1[illegible]	
9	2	[illegible].	[illegible]. . [illegible].	[illegible].[illegible] 1[illegible].	[illegible].

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SAMPLE PROBLEM 2 INPUT DATA (Concluded)

10	MMH/N2O4 FC=153							
20c	0.0	-.13771[illegible]	[illegible]	.641427	1.6[illegible]			
20d	11							
20e	0.0	2.?	.15[illegible]	2.1[illegible]	.31[illegible]34	2.17	.47[illegible]	2.12
	.[illegible]6376[illegible]7	[illegible].[illegible]4	.7[illegible]7	1.[illegible]	.[illegible]5641	1.[illegible]1	.111[illegible]12	1.64
	.1275213	1.42	.[illegible]474[illegible]	1.[illegible]	.1[illegible]4167	.[illegible]		
22	1[illegible].	-1[illegible].	.[illegible]	.	1.[illegible]	[illegible].		
23	.[illegible]12	.[illegible]	1.	.[illegible]	[illegible].	.[illegible]		
41		[illegible]	[illegible]	.1[illegible]				
44	0.0	234[illegible].	.[illegible]	[illegible].	.4	2[illegible].	.[illegible]	224[illegible].
	.775	222[illegible].						

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SAMPLE PROBLEM 2 OUTPUT

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 1

RCS RCS VARIABLE O/F TRANSONIC NOZZLE SOLUTION

RUN CONTROL PARAMETERS

ICON(1)	ICON(2)	ICON(3)	ICON(4)	ICON(5)	ICON(6)	ICON(7)	ICON(8)
2	5	15	20061	1	60	1	203

ICON(9)	ICON(10)	ICON(11)	ICON(12)	ICON(13)	ICON(14)	ICON(15)	ICON(16)
0	0	0	1	0	0	0	12570

FLOW CALCULATIONS ARE IN ENGLISH UNITS WITH THE R,X COORDINATES IN FEET

THE FLOW FIELD DATA WILL BE WRITTEN ON TAPE

UPPER BOUNDARY POINTS

TYPE	ITRANS	X	R	THETA
2	0	-.13772+00	.15542+00	.00000
2	0	-.13475+00	.15536+00	-.34907-01
2	0	-.13178+00	.15521+00	-.69813-01
2	0	-.12882+00	.15495+00	-.10472+00
2	0	-.12587+00	.15459+00	-.13963+00
2	0	-.12293+00	.15412+00	-.17453+00
2	0	-.11712+00	.15289+00	-.24435+00
2	0	-.11190+00	.15125+00	-.31416+00
2	0	-.10581+00	.14921+00	-.38397+00
2	0	-.10038+00	.14680+00	-.45379+00
2	0	-.95136-01	.14401+00	-.52360+00
2	0	-.89870-01	.14081+00	-.61087+00
2	0	-.82975-01	.13565+00	-.69813+00
2	0	-.77497-01	.13097+00	-.78540+00
2	0	-.72478-01	.12499+00	-.87266+00
2	0	-.68725-01	.12018+00	-.95993+00
2	0	-.64986-01	.11539+00	-.87266+00
2	0	-.59986-01	.10993+00	-.78540+00
2	0	-.54530-01	.10993+00	-.69813+00
2	0	-.48658-01	.10493+00	-.61087+00
2	0	-.42417-01	.96449-01	-.52360+00
2		-.37109-01	.93669-01	-.45379+00
2	0	-.31779-01	.91261-01	-.38397+00
2	0	-.26215-01	.89235-01	-.31416+00
2	0	-.20523-01	.87603-01	-.24435+00
2	0	-.14731-01	.86472-01	-.17453+00
2	0	-.11807-01	.85909-01	-.13963+00
2	0	-.88610-02	.85540-01	-.10472+00
2	0	-.59180-02	.85290-01	-.69813-01
2	0	-.29610-02	.85135-01	-.34907-01
2	0	.00000	.85083-01	.00000
2	0	.83300-03	.85100-01	.58010-01
2	0	.16670-02	.85150-01	.83086-01
2	0	.33330-02	.85356-01	.16069+00
2	0	.50000-02	.85692-01	.24237+00

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 2

RCS RCS VARIABLE O/F TRANSONIC NOZZLE SOLUTION

UPPER BOUNDARY POINTS

TYPE	ITRANS	X	R	THETA			
2	0	.66670-02	.86175-01	.32573+00			
2	0	.83330-02	.86825-01	.41152+00			
2	0	.10000-01	.87642-01	.52065+00			
2	0	.10918-01	.87875-01	.52364+00			
2	0	.11250-01	.88383-01	.52932+00			
2	0	.20883-01	.93833-01	.55680+00			
2	0	.31167-01	.10083+00	.56863+00			
2	0	.42167-01	.10783+00	.57426+00			
2	0	.51250-01	.11375+00	.57392+00			
2	0	.62917-01	.12125+00	.57038+00			
2	0	.72933-01	.12750+00	.56647+00			
2	0	.83333-01	.13408+00	.56039+00			
2	0	.94583-01	.14108+00	.55390+00			
2	0	.10358+00	.14667+00	.54920+00			
2	0	.11325+00	.15258+00	.54151+00			
2	0	.12500+00	.15942+00	.53377+00			
2	0	.16667+00	.18392+00	.50518+00			
2	0	.25000+00	.22667+00	.45360+00			
2	0	.33333+00	.26383+00	.40396+00			
2	0	.41667+00	.29667+00	.35413+00			
2	0	.50000+00	.32525+00	.31198+00			
2	0	.58333+00	.35092+00	.27440+00			
2	0	.66667+00	.37408+00	.24958+00			
2	0	.75000+00	.39408+00	.22986+00			
2	1	.77500+00	.39992+00	.22892+00			
3	0	.74905-05	.00000	.00000	.00000	.00000	.10000+06

LOWER BOUNDARY

TYPE	ITRANS	A	B	C	D	E	MAX
2	0	.00000	.00000	.00000	.00000	.00000	.10000+04

THERE ARE 0 PARTICLE SPECIES PRESENT IN THE GAS-PARTICLE MIXTURE

THE FOLLOWING GAS PROPERTIES IN ENGLISH UNITS ARE FOR MMH/N2O4 PC=153

REAL GAS PROPERTIES

O/F
.80000+00

S	W	R	GAMMA	T	P
.00000					
	.00000	.32375+04	.12452+01	.35738+04	.15300+03
	.36162+04	.32371+04	.12940+01	.31200+04	.83616+07

SAMPLE PROBLEM 2 OUTPUT (Cont'd)

VARIABLE O/F TRANSONIC

INITIAL STATION	-.1377+00
THROAT STATION	.0000
FINAL STATION	.3696-01
MASS FLOW	.8770-01
AVERAGE O/F	.1630+01
THROAT AREA	.2274-01
LINE STEP	.5108-01

O/F DISTRIBUTION AT INITIAL STATION

R	O/F
.0000	.2200+01
.1594-01	.2198+01
.3188-01	.2170+01
.4782-01	.2120+01
.6376-01	.2040+01
.7970-01	.1930+01
.9564-01	.1810+01
.1116+00	.1640+01
.1275+00	.1420+01
.1435+00	.1120+01
.1554+00	.8000+00

RCS RCS VARIABLE O/F TRANSONIC NOZZLE SOLUTION

LINE	POINT	R	X	M	ANG	O/F	V	P	T	DENS		
1	1	.1554+00	-.1377+00	.1707+00	.6769-04	.8000+00	.6570+03	.2162+05	.3559+04	.1877-02	.6570+03	.7761-03
1	2	.1443+00	-.1377+00	.1740+00	.6285-04	.1097+01	.6947+03	.2162+05	.4504+04	.1677-02	.6947+03	.7621-03
1	3	.1332+00	-.1377+00	.1763+00	.5802-04	.1313+01	.7050+03	.2162+05	.4995+04	.1624-02	.7050+03	.7139-03
1	4	.1221+00	-.1377+00	.1782+00	.5310-04	.1495+01	.7075+03	.2162+05	.5306+04	.1611-02	.7075+03	.6560-03
1	5	.1110+00	-.1377+00	.1799+00	.4835-04	.1646+01	.7062+03	.2162+05	.5494+04	.1616-02	.7062+03	.5959-03
1	6	.9991-01	-.1377+00	.1801+00	.4351-04	.1764+01	.7032+03	.2162+05	.5595+04	.1628-02	.7032+03	.5340-03
1	7	.8881-01	-.1377+00	.1806+00	.3868-04	.1861+01	.6999+03	.2162+05	.5651+04	.1643-02	.6999+03	.4725-03
1	8	.7771-01	-.1377+00	.1808+00	.3384-04	.1944+01	.6967+03	.2162+05	.5686+04	.1657-02	.6967+03	.4115-03
1	9	.6661-01	-.1377+00	.1811+00	.2901-04	.2020+01	.6936+03	.2162+05	.5713+04	.1672-02	.6936+03	.3512-03
1	10	.5551-01	-.1377+00	.1812+00	.2417-04	.2081+01	.6909+03	.2162+05	.5721+04	.1685-02	.6909+03	.2915-03
1	11	.4440-01	-.1377+00	.1813+00	.1934-04	.2131+01	.6887+03	.2162+05	.5728+04	.1696-02	.6887+03	.2325-03
1	12	.3330-01	-.1377+00	.1813+00	.1450-04	.2166+01	.6871+03	.2162+05	.5733+04	.1703-02	.6871+03	.1739-03
1	13	.2220-01	-.1377+00	.1813+00	.9670-05	.2187+01	.6862+03	.2162+05	.5736+04	.1708-02	.6862+03	.1150-03
1	14	.1110-01	-.1377+00	.1814+00	.4835-05	.2199+01	.6856+03	.2162+05	.5737+04	.1710-02	.6856+03	.5786-04
1	15	.1796-08	-.1377+00	.1814+00	.3002-11	.2200+01	.6856+03	.2162+05	.5737+04	.1711-02	.6856+03	.3593-10

WDOT= .878-01 PDOT= .612+02 ISTEP= 0

2	1	.1540+00	-.1224+00	.1754+00	-.1035+02	.8000+00	.6750+03	.2160+05	.3558+04	.1875-02	.6750+03	-.1213+03
2	2	.1430+00	-.1224+00	.1788+00	-.9613+01	.1097+01	.7130+03	.2160+05	.4503+04	.1676-02	.7130+03	-.1192+03
2	3	.1320+00	-.1224+00	.1812+00	-.8874+01	.1313+01	.7243+03	.2160+05	.4994+04	.1623-02	.7243+03	-.1117+03
2	4	.1210+00	-.1224+00	.1831+00	-.8134+01	.1495+01	.7270+03	.2160+05	.5305+04	.1610-02	.7270+03	-.1029+03
2	5	.1100+00	-.1224+00	.1843+00	-.7395+01	.1646+01	.7256+03	.2160+05	.5493+04	.1615-02	.7256+03	-.9339+02
2	6	.9901-01	-.1224+00	.1851+00	-.6655+01	.1764+01	.7225+03	.2160+05	.5594+04	.1627-02	.7225+03	-.8374+02
2	7	.8801-01	-.1224+00	.1855+00	-.5916+01	.1861+01	.7191+03	.2160+05	.5651+04	.1641-02	.7191+03	-.7412+02
2	8	.7701-01	-.1224+00	.1858+00	-.5176+01	.1944+01	.7159+03	.2160+05	.5686+04	.1656-02	.7159+03	-.6459+02
2	9	.6601-01	-.1224+00	.1861+00	-.4437+01	.2020+01	.7127+03	.2160+05	.5712+04	.1670-02	.7127+03	-.5513+02
2	10	.5500-01	-.1224+00	.1862+00	-.3697+01	.2081+01	.7099+03	.2160+05	.5721+04	.1683-02	.7099+03	-.4578+02
2	11	.4400-01	-.1224+00	.1862+00	-.2958+01	.2131+01	.7076+03	.2160+05	.5727+04	.1694-02	.7076+03	-.3651+02
2	12	.3300-01	-.1224+00	.1863+00	-.2218+01	.2166+01	.7060+03	.2160+05	.5732+04	.1702-02	.7060+03	-.2733+02
2	13	.2200-01	-.1224+00	.1863+00	-.1479+01	.2187+01	.7050+03	.2160+05	.5735+04	.1706-02	.7050+03	-.1820+02
2	14	.1100-01	-.1224+00	.1864+00	-.7395+00	.2199+01	.7045+03	.2160+05	.5737+04	.1709-02	.7045+03	-.9097+01
2	15	.3260-08	-.1224+00	.1864+00	-.3669-06	.2200+01	.7044+03	.2160+05	.5737+04	.1709-02	.7044+03	-.4510-05

WDOT= .878-01 PDOT= .629+02 ISTEP= 0

3	1	.1497+00	-.1071+00	.1912+00	-.2107+02	.8000+00	.7353+03	.2152+05	.3555+04	.1870-02	.7353+03	-.2644+03
3	2	.1390+00	-.1071+00	.1949+00	-.1956+02	.1097+01	.7776+03	.2152+05	.4500+04	.1671-02	.7776+03	-.2604+03
3	3	.1283+00	-.1071+00	.1975+00	-.1806+02	.1313+01	.7891+03	.2152+05	.4991+04	.1618-02	.7891+03	-.2446+03
3	4	.1176+00	-.1071+00	.1995+00	-.1655+02	.1495+01	.7920+03	.2152+05	.5302+04	.1605-02	.7920+03	-.2257+03
3	5	.1069+00	-.1071+00	.2009+00	-.1505+02	.1646+01	.7905+03	.2152+05	.5491+04	.1609-02	.7905+03	-.2053+03
3	6	.9623-01	-.1071+00	.2017+00	-.1354+02	.1764+01	.7872+03	.2152+05	.5592+04	.1622-02	.7872+03	-.1844+03
3	7	.8554-01	-.1071+00	.2022+00	-.1204+02	.1861+01	.7835+03	.2152+05	.5649+04	.1636-02	.7835+03	-.1634+03
3	8	.7484-01	-.1071+00	.2025+00	-.1053+02	.1944+01	.7800+03	.2152+05	.5684+04	.1651-02	.7800+03	-.1426+03
3	9	.6415-01	-.1071+00	.2028+00	-.9030+01	.2020+01	.7765+03	.2152+05	.5710+04	.1665-02	.7765+03	-.1219+03
3	10	.5346-01	-.1071+00	.2029+00	-.7525+01	.2081+01	.7734+03	.2152+05	.5719+04	.1678-02	.7734+03	-.1013+03
3	11	.4277-01	-.1071+00	.2030+00	-.6020+01	.2131+01	.7710+03	.2152+05	.5725+04	.1688-02	.7710+03	-.8085+02
3	12	.3208-01	-.1071+00	.2030+00	-.4515+01	.2166+01	.7692+03	.2152+05	.5730+04	.1696-02	.7692+03	-.6055+02
3	13	.2138-01	-.1071+00	.2031+00	-.3010+01	.2187+01	.7681+03	.2152+05	.5733+04	.1701-02	.7681+03	-.4033+02
3	14	.1069-01	-.1071+00	.2031+00	-.1505+01	.2199+01	.7675+03	.2152+05	.5735+04	.1703-02	.7675+03	-.2016+02
3	15	.4059-08	-.1071+00	.2031+00	-.7337-06	.2200+01	.7675+03	.2152+05	.5735+04	.1704-02	.7675+03	-.9020-05

SAMPLE PROBLEM 2 OUTPUT (Cont'd)

RCS HCS VARIABLE O/F TRANSONIC NOZZLE SOLUTION

WDOT: .877-01 POUT: .608+02 ISTEP: 0

LINE	POINT	R	X	M	ANG	O/F	V	P	T	RHOS		
4	1	.1419+00	-.9101-01	.2252+00	-.3265+02	.0000+00	.8655+03	.2133+05	.3540+04	.1857-02	.8655+03	-.4670+03
4	2	.1318+00	-.9101-01	.2296+00	-.3032+02	.1097+01	.9151+03	.2133+05	.4494+04	.1659-02	.9151+03	-.4621+03
4	3	.1216+00	-.9101-01	.2326+00	-.2790+02	.1313+01	.9209+03	.2133+05	.4903+04	.1606-02	.9209+03	-.4356+03
4	4	.1115+00	-.9101-01	.2350+00	-.2544+02	.1495+01	.9324+03	.2133+05	.5295+04	.1592-02	.9324+03	-.4037+03
4	5	.1013+00	-.9101-01	.2366+00	-.2332+02	.1646+01	.9306+03	.2133+05	.5485+04	.1597-02	.9306+03	-.3685+03
4	6	.9121-01	-.9101-01	.2376+00	-.2099+02	.1764+01	.9268+03	.2133+05	.5586+04	.1609-02	.9268+03	-.3320+03
4	7	.8108-01	-.9101-01	.2382+00	-.1866+02	.1861+01	.9225+03	.2133+05	.5643+04	.1623-02	.9225+03	-.2951+03
4	8	.7094-01	-.9101-01	.2385+00	-.1633+02	.1944+01	.9183+03	.2133+05	.5676+04	.1637-02	.9183+03	-.2581+03
4	9	.6081-01	-.9101-01	.2389+00	-.1399+02	.2020+01	.9142+03	.2133+05	.5705+04	.1652-02	.9142+03	-.2211+03
4	10	.5067-01	-.9101-01	.2390+00	-.1166+02	.2081+01	.9106+03	.2133+05	.5719+04	.1665-02	.91 +03	-.1841+03
4	11	.4054-01	-.9101-01	.2391+00	-.9329+01	.2131+01	.9077+03	.2133+05	.5721+04	.1675-02	.9077+03	-.1471+03
4	12	.3040-01	-.9101-01	.2392+00	-.6997+01	.2166+01	.9056+03	.2133+05	.5725+04	.1683-02	.9056+03	-.1103+03
4	13	.2027-01	-.9101-01	.2392+00	-.4665+01	.2187+01	.9044+03	.2133+05	.5728+04	.1687-02	.9044+03	-.7354+02
4	14	.1013-01	-.9101-01	.2392+00	-.2332+01	.2199+01	.9037+03	.2133+05	.5730+04	.1690-02	.9037+03	-.3677+02
4	15	.8265-08	-.9101-01	.2392+00	-.1521-05	.2200+01	.9036+03	.2133+05	.5730+04	.1690-02	.9036+03	-.2390-04

WDOT: .877-01 POUT: .806+02 ISTEP: 0

5	1	.1294+00	-.7651-01	.3024+00	-.4590+02	.0000+00	.1159+04	.2070+05	.3527+04	.1820-02	.1159+04	-.8335+03
5	2	.1202+00	-.7651-01	.3082+00	-.4270+02	.1097+01	.1226+04	.2070+05	.4469+04	.1624-02	.1226+04	-.8314+03
5	3	.1109+00	-.7651-01	.3122+00	-.3941+02	.1313+01	.1245+04	.2070+05	.4962+04	.1572-02	.1245+04	-.7902+03
5	4	.1017+00	-.7651-01	.3154+00	-.3613+02	.1495+01	.1249+04	.2070+05	.5276+04	.1558-02	.1249+04	-.7366+03
5	5	.9243-01	-.7651-01	.3176+00	-.3284+02	.1646+01	.1247+04	.2070+05	.5467+04	.1562-02	.1247+04	-.6764+03
5	6	.8318-01	-.7651-01	.3189+00	-.2956+02	.1764+01	.1242+04	.2070+05	.5570+04	.1573-02	.1242+04	-.6127+03
5	7	.7394-01	-.7651-01	.3197+00	-.2628+02	.1861+01	.1236+04	.2070+05	.5628+04	.1587-02	.1236+04	-.5473+03
5	8	.6470-01	-.7651-01	.3202+00	-.2299+02	.1944+01	.1231+04	.2070+05	.5664+04	.1601-02	.1231+04	-.4807+03
5	9	.5546-01	-.7651-01	.3207+00	-.1971+02	.2020+01	.1225+04	.2070+05	.5691+04	.1615-02	.1225+04	-.4132+03
5	10	.4621-01	-.7651-01	.3208+00	-.1642+02	.2081+01	.1221+04	.2070+05	.5700+04	.1627-02	.1221+04	-.3451+03
5	11	.3697-01	-.7651-01	.3210+00	-.1314+02	.2131+01	.1217+04	.2070+05	.5707+04	.1637-02	.1217+04	-.2765+03
5	12	.2773-01	-.7651-01	.3211+00	-.9853+01	.2166+01	.1214+04	.2070+05	.5712+04	.1645-02	.1214+04	-.2077+03
5	13	.1849-01	-.7651-01	.3212+00	-.6569+01	.2187+01	.1212+04	.2070+05	.5715+04	.1649-02	.1212+04	-.1387+03
5	14	.9243-02	-.7651-01	.3212+00	-.3284+01	.2199+01	.1211+04	.2070+05	.5717+04	.1652-02	.1211+04	-.6940+02
5	15	.7334-08	-.7651-01	.3212+00	-.1201-05	.2200+01	.1211+04	.2070+05	.5717+04	.1652-02	.1211+04	-.2707-04

WDOT: .878-01 PDOT: .108+03 ISTEP: 0

6	1	.1113+00	-.6121-01	.4335+00	-.4627+02	.0000+00	.1651+04	.1955+05	.3479+04	.1736-02	.1651+04	-.1192+04
6	2	.1033+00	-.6121-01	.4414+00	-.4292+02	.1097+01	.1747+04	.1955+05	.4412+04	.1547-02	.1747+04	-.1190+04
6	3	.9537-01	-.6121-01	.4469+00	-.3962+02	.1313+01	.1774+04	.1955+05	.4913+04	.1495-02	.1774+04	-.1131+04
6	4	.8742-01	-.6121-01	.4515+00	-.3632+02	.1495+01	.1782+04	.1955+05	.5231+04	.1480-02	.1782+04	-.1055+04
6	5	.7947-01	-.6121-01	.4540+00	-.3302+02	.1646+01	.1779+04	.1955+05	.5426+04	.1482-02	.1779+04	-.9693+03
6	6	.7152-01	-.6121-01	.4562+00	-.2971+02	.1764+01	.1772+04	.1955+05	.5533+04	.1492-02	.1772+04	-.8783+03
6	7	.6358-01	-.6121-01	.4579+00	-.2641+02	.1861+01	.1764+04	.1955+05	.5592+04	.1505-02	.1764+04	-.7847+03
6	8	.5563-01	-.6121-01	.4586+00	-.2311+02	.1944+01	.1756+04	.1955+05	.5630+04	.1518-02	.1756+04	-.6893+03
6	9	.4768-01	-.6121-01	.4593+00	-.1981+02	.2020+01	.1748+04	.1955+05	.5658+04	.1531-02	.1748+04	-.5925+03
6	10	.3974-01	-.6121-01	.4595+00	-.1651+02	.2081+01	.1742+04	.1955+05	.5667+04	.1542-02	.1742+04	-.4949+03
6	11	.3179-01	-.6121-01	.4598+00	-.1321+02	.2131+01	.1736+04	.1955+05	.5675+04	.1552-02	.1736+04	-.3966+03
6	12	.2384-01	-.6121-01	.4599+00	-.9905+01	.2166+01	.1732+04	.1955+05	.5680+04	.1559-02	.1732+04	-.2980+03

RCS HCS VARIABLE O/F TRANSONIC NOZZLE SOLUTION

LINE	POINT	R	X	M	ANG	O/F	V	P	T	RHOS		
27	2	.9676-01	.3646-01	.2311+01	.1969+02	.9603+00	.7052+04	.1771+04	.2353+04	.2494-03	.6950+04	.4008+04
27	3	.8932-01	.3646-01	.2115+01	.2758+02	.1127+01	.6856+04	.2425+04	.2922+04	.2938-03	.6815+04	.3146+04
27	4	.8187-01	.3646-01	.1909+01	.2164+02	.1260+01	.6531+04	.3318+04	.3423+04	.3597-03	.6511+04	.2404+04
27	5	.7443-01	.3646-01	.1691+01	.1744+02	.1420+01	.6064+04	.4711+04	.4025+04	.4582-03	.6051+04	.1818+04
27	6	.6699-01	.3646-01	.1561+01	.1270+02	.1561+01	.5737+04	.5673+04	.4438+04	.5215-03	.5744+04	.1461+04
27	7	.5954-01	.3646-01	.1461+01	.1009+02	.1703+01	.5342+04	.6871+04	.4809+04	.6045-03	.5366+04	.9351+03
27	8	.5210-01	.3646-01	.1389+01	.6988+01	.1611+01	.5080+04	.7652+04	.5013+04	.6622-03	.5121+04	.8180+03
27	9	.4466-01	.3646-01	.1323+01	.5359+01	.1913+01	.4829+04	.8390+04	.5142+04	.7213-03	.4885+04	.4510+03
27	10	.3721-01	.3646-01	.1278+01	.1696+01	.2001+01	.4651+04	.8847+04	.5233+04	.7590-03	.4736+04	.2998+03
27	11	.2977-01	.3646-01	.1241+01	.2800+01	.2078+01	.4503+04	.9234+04	.5277+04	.7954-03	.4610+04	.2200+03
27	12	.2233-01	.3646-01	.1217+01	.1721+01	.2137+01	.4406+04	.9606+04	.5313+04	.8288-03	.4493+04	.1323+03
27	13	.1489-01	.3646-01	.1201+01	.8380+00	.2175+01	.4344+04	.1000+05	.5343+04	.8625-03	.4370+04	.6353+02
27	14	.7443-02	.3646-01	.1192+01	.2263+00	.2196+01	.4319+04	.1032+05	.5369+04	.8891-03	.4288+04	.1709+02
27	15	.2794-08	.3646-01	.1189+01	.0000	.2200+01	.4305+04	.1044+05	.5370+04	.8987-03	.4255+04	.0000

WDOT: .879-01 PDOT: .496+03 ISTEP:1000

SUM OF ERROR = .32699+11 MIN SUM OF ERROR = .29190+11 AT STATION 886

STARTING LINE INFO

R	X	M	THETA	S	MACH ANGLE	SHOCK ANGLE	O/F
.50992-08	.32760-01	.11506+01	.00000	-.23499+02	.60359+02	.00000	.22000+01
.71739-02	.30535-01	.11290+01	.64025-01	.15663+01	.62340+02	.00000	.21965+01
.14152-01	.28364-01	.11124+01	.33499+00	.50434+02	.64020+02	.00000	.21782+01
.20992-01	.26250-01	.11025+01	.66536+00	.91617+02	.65096+02	.00000	.21464+01
.27551-01	.24193-01	.10987+01	.86431+00	.10011+03	.65532+02	.00000	.20982+01
.33987-01	.22190-01	.11031+01	.60697+00	.96952+02	.65036+02	.00000	.20346+01
.40259-01	.20238-01	.11137+01	.60459+00	.74310+02	.63079+02	.00000	.19653+01
.46377-01	.18334-01	.11341+01	.42786+00	.54728+02	.61852+02	.00000	.18827+01
.52397-01	.16476-01	.11501+01	.43177+00	.45298+02	.60397+02	.00000	.17980+01
.58171-01	.14663-01	.11752+01	.86092+00	.22173+02	.58308+02	.00000	.17000+01
.63855-01	.12894-01	.11491+01	.17997+01	-.11906+01	.56874+02	.00000	.15900+01
.69406-01	.11167-01	.12526+01	.10582+01	-.26288+02	.52973+02	.00000	.14498+01
.74919-01	.94522-02	.12703+01	.44458+01	-.45699+02	.51969+02	.00000	.12952+01
.80429-01	.77358-02	.14514+01	.51473+01	-.94446+02	.43551+02	.00000	.10947+01
.85089-01	.60470-02	.15744+01	.16172+02	-.51015+03	.39432+02	.00000	.80000+00

RUN CUTOFF INFORMATION

UPPER BOUNDARY: R= .10000+03 X= -.10000+03 THETA= .00000

LOWER BOUNDARY: R= .00000 X= .15000+01 THETA= .90000+02

THE MESH CONSTRUCTION WILL BE CONTROLLED BY THE FOLLOWING VARIABLES

DL INTERIOR= .120-01 ON AXIS= .120-01 DL LIM= .100+03 DL DELETE= .500-02 DEG P.M.= .500+01 F= .850+00

SAMPLE PROBLEM 2 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 11

RCS RCS VARIABLE O/F TRANSONIC NOZZLE SOLUTION

LINE	POINT	DSCRIP - REGIME	R MACH ANGLE TD*	X PRESSURE PO*	H DENSITY S*	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITN
1	1	INPUT - CONTIN	.58902-08	.12768-01	.11504+01	.00000	-.23499+02	.41790+04	.22600+01	0
			.60359+02	.75608+02	.93330-03	.53853+04	.21662+04	.11282+01		
			.57471+04	.15910+03	-.15129+02					
1	2	INPUT - CONTIN	.71739-02	.30535-01	.11290+01	.64025-01	.15661+01	.41030+04	.21965+01	0
			.67380+02	.76659+02	.94313-03	.53970+04	.21687+04	.11283+01		
			.57461+04	.15253+03	.66183+01					
1	3	INPUT - CONTIN	.19152-01	.28369-01	.11129+01	.33499+00	.50434+02	.40527+04	.21782+01	0
			.64020+02	.76400+02	.93548-03	.54021+04	.21761+04	.11290+01		
			.57397+04	.14924+03	.53870+02					
1	4	INPUT - CONTIN	.20942-01	.26250-01	.11025+01	.66536+00	.91617+02	.40206+04	.21964+01	0
			.65096+02	.75807+02	.72404-03	.54002+04	.21876+04	.11302+01		
			.57322+04	.14651+03	.44215+02					
1	5	INPUT - CONTIN	.27551-01	.24193-01	.10987+01	.66931+00	.10613+03	.40296+04	.20982+01	0
			.65532+02	.75543+02	.91537-03	.53910+04	.22044+04	.11320+01		
			.57245+04	.14547+03	.11053+03					
1	6	INPUT - CONTIN	.33981-01	.22190-01	.11031+01	.60677+00	.26952+02	.40631+04	.20346+01	0
			.65036+02	.75500+02	.90900-03	.53731+04	.22260+04	.11344+01		
			.57169+04	.14626+03	.59695+02					
1	7	INPUT - CONTIN	.40259-01	.20230-01	.11137+01	.68959+00	.19310+02	.41199+04	.19653+01	0
			.63879+02	.75231+02	.90138-03	.53361+04	.22573+04	.11385+01		
			.56991+04	.14776+03	.77980+02					
1	8	INPUT - CONTIN	.46377-01	.18334-01	.11391+01	.42786+00	.54720+02	.42140+04	.18827+01	0
			.61652+02	.73690+02	.88295-03	.52695+04	.22871+04	.11455+01		
			.56668+04	.14897+03	.60646+02					
1	9	INPUT - CONTIN	.52397-01	.16976-01	.11501+01	.03177+00	.45290+02	.42933+04	.17988+01	0
			.60397+02	.72587+02	.86497-03	.52023+04	.23231+04	.11530+01		
			.56313+04	.14950+03	.53965+02					
1	10	INPUT - CONTIN	.58171-01	.14663-01	.11752+01	.86092+00	.22173+02	.44039+04	.17008+01	0
			.58308+02	.70700+02	.84579-03	.50644+04	.23766+04	.11665+01		
			.55505+04	.15075+03	.35419+02					
1	11	INPUT - CONTIN	.63855-01	.12829-01	.11991+01	.17947+01	-.11906+01	.44922+04	.15900+01	0
			.54874+02	.69266+02	.83314-03	.49369+04	.24398+04	.11822+01		
			.58524+04	.15198+03	.16208+02					

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 12

RCS RCS VARIABLE O/F TRANSONIC NOZZLE SOLUTION

LINE	POINT	DSCRIP - REGIME	R MACH ANGLE TD*	X PRESSURE PO*	H DENSITY S*	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITN
1	12	INPUT - CONTIN	.69406-01	.11163-01	.12526+01	.18982+01	-.26208+02	.47000+04	.14498+01	0
			.52973+02	.64219+02	.79231-03	.45992+04	.25377+04	.12063+01		
			.52562+04	.15219+03	.10032+02					
1	13	INPUT - CONTIN	.19915-01	.95522-02	.12701+01	.49958+01	-.56992+02	.47649+04	.12952+01	0
			.51469+02	.62098+02	.79081-03	.47419+04	.26657+04	.12311+01		
			.49740+04	.15347+03	-.81933+01					
1	14	INPUT - CONTIN	.80429-01	.77358-02	.14514+01	.51973+01	-.94496+02	.52153+04	.10947+01	0
			.43551+02	.48653+02	.68658-03	.35695+04	.28587+04	.12654+01		
			.45116+04	.19855+03	.69033+02					
1	15	INPUT - CONTIN	.85984-01	.60020-02	.15744+01	.16772+02	-.51015+03	.52374+04	.00000+00	0
			.39432+02	.45061+02	.76893-03	.26070+04	.32370+04	.13114+01		
			.15730+04	.16060+03	-.15865+03					

THE MASS FLOW RATE IS = .282533+01

MOMENTUM INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	ISP
-.61835+03	.00000	[illegible]	.21886+03

SAMPLE PROBLEM 2 OUTPUT (Cont'd)

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                 SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

                                        CASE NO.    0                                              PAGE   13

RCS RCS VARIABLE O/F TRANSONIC NOZZLE SOLUTION

LINE POINT  DSCRIP - REGIME       R            X            M            THETA        ENTROPY      VELOCITY      O/F       ITH
                              MACH ANGLE    PRESSURE     DENSITY     TEMPERATURE   GAS CONST.   LOCAL GAMMA  SHOCK ANGLE
                                 T0*          P0*          S0*

  2    99  INPUT  - CONTIN     .80429-01    .72358-02    .19519+01    .51973+01   -.99996+02    .52153+04    .10947+01    0
                               .43551+02    .40653+02    .40650-03    .35695+04    .28587+04    .17654+01
                               .45116+04    .19855+03    .89033+02

  2   100  WALL   - CONTIN     .86190-01    .65467-02    .16986+01    .10310+02   -.51015+03    .59180+04    .80000+00    6
                               .37342+02    .40228+02    .70522-03    .25376+04    .32370+04    .13153+01
                               .35738+04    .15525+03   -.47211+02

                                            PRESSURE INTEGRATION RESULTS
                                 FORCEX       FORCEY       TORQZ        DELFX        DELFY         ISP
                               -.61887+03    .00000       .00000     -.51926+00    .00000       .21904+03

  3    98  INPUT  - CONTIN     .74914-01    .99522-02    .12783+01    .49958+01   -.56992+02    .47699+04    .12952+01    0
                               .51469+02    .62098+02    .79081-03    .42419+04    .26657+04    .12311+01
                               .49240+04    .15347+03   -.81933+L

  3   100  WALL   - CONTIN     .86462-01    .74037-02    .17643+01    .20837+02   -.51015+03    .56779+04    .80000+00    7
                               .34528+02    .33564+02    .61950-03    .24298+04    .32370+04    .13166+01
                               .35335+04    .14590+03    .15383+03

                                            PRESSURE INTEGRATION RESULTS
                                 FORCEX       FORCEY       TORQZ        DELFX        DELFY         ISP
                               -.61980+03    .00000       .00000     -.92898+00    .00000       .21937+03

  4    97  INPUT  - CONTIN     .69806-01    .11167+01    .12526+01    .18882+01   -.26208+02    .47000+04    .19498+01    0
                               .52973+02    .64219+02    .79231-03    .45992+04    .25377+04    .12063+01
                               .52562+04    .15239+03    .10432+02

  4   100  WALL   - CONTIN     .86797-01    .82623-02    .18701+01    .23370+02   -.51015+03    .59033+04    .80000+00    6
                               .37322+02    .28325+02    .54045-03    .23315+04    .32370+04    .13201+01
                               .35730+04    .13673+03    .36392+03

                                            PRESSURE INTEGRATION RESULTS
                                 FORCEX       FORCEY       TORQZ        DELFX        DELFY         ISP
                               -.62061+03    .00000       .00000     -.81296+00    .00000       .21946+03

  5    96  INPUT  - CONTIN     .63855-01    .12694-01    .11991+01    .17947+01   -.11906+01    .44922+04    .15500+01    0
                               .56874+02    .69266+02    .83314-03    .49069+04    .24396+04    .11822+01
                               .54524+04    .15198+03    .16208+02

  5   100  WALL   - CONTIN     .87210-01    .91188-02    .19201+01    .25985+02   -.51015+03    .61098+04    .80000+00    5
                               .30993+02    .24058+02    .47757-03    .22405+04    .32170+04    .13231+01
                               .35724+04    .12722+03    .59898+03


                 SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

                                        CASE NO.    0                                              PAGE   46

RCS RCS VARIABLE O/F TRANSONIC NOZZLE SOLUTION

LINE POINT  DSCRIP - REGIME       R            X            M            THETA        ENTROPY      VELOCITY      O/F       ITH
                              MACH ANGLE    PRESSURE     DENSITY     TEMPERATURE   GAS CONST.   LOCAL GAMMA  SHOCK ANGLE
                                 T0*          P0*          S0*

 93     1  WALL   - CONTIN     .00000       .77664+00    .97607+01    .00000      -.23499+02    .10238+05    .22000+01    2
                               .12125+02    .16482+00    .66344-05    .16686+04    .21440+04    .12927+01
                               .51009+04    .47083+01    .77504+04

 93    51  WALL   - CONTIN     .38690+00    .71968+00    .38596+01    .13361+02   -.51015+03    .82381+04    .80000+00    3
                               .15020+02    .11765+01    .51086-04    .10245+04    .32370+04    .13744+01
                               .35610+04    .23007+02    .61352+04

                                            PRESSURE INTEGRATION RESULTS
                                 FORCEX       FORCEY       TORQZ        DELFX        DELFY         ISP
                               -.85910+03    .00000       .00000     -.99920+00    .00000       .30230+03

A NEW STREAMLINE HAS BEEN INSERTED ON LINE  92 BETWEEN POINTS  17 AND  18

 94     1  WALL   - CONTIN     .00000       .78576+00    .97812+01    .00000      -.23499+02    .10240+05    .22000+01    2
                               .17073+02    .15985+00    .64797-05    .16569+04    .21440+04    .12933+01
                               .50963+04    .46079+01    .78003+04

 94    52  WALL   - CONTIN     .38921+00    .72938+00    .3[illegible]+01    .13286+02   -.51015+03    .82479+04    .80000+00    3
                               .14952+02    .11481+01    .50189-04    .10176+04    .32370+04    .13747+01
                               .35609+04    .22651+02    .61857+04

                                            PRESSURE INTEGRATION RESULTS
                                 FORCEX       FORCEY       TORQZ        DELFX        DELFY         ISP
                               -.85509+03    .00000       .00000     -.99227+00    .00000       .30263+03

 95     1  WALL   - CONTIN     .00000       .79502+00    .98018+01    .00000      -.23499+02    .10259+05    .22000+01    2
                               .17020+02    .15502+00    .63202-05    .16454+04    .21440+04    .12940+01
                               .50921+04    .45083+01    .78501+04

 95    52  WALL   - CONTIN     .39155+00    .73923+00    .38892+01    .13223+02   -.51015+03    .82582+04    .80000+00    3
                               .14880+02    .11188+01    .49260-04    .10104+04    .32370+04    .13749+01
                               .35604+04    .22281+02    .62390+04

                                            PRESSURE INTEGRATION RESULTS
                                 FORCEX       FORCEY       TORQZ        DELFX        DELFY         ISP
                               -.85598+03    .00000       .00000     -.93911+00    .00000       .30296+03

 96     1  WALL   - CONTIN     .00000       .80493+00    .98225+01    .00000      -.23499+02    .10270+05    .22000+01    2
                               .11968+02    .15033+00    .61798-05    .16338+04    .21440+04    .12946+01
                               .50879+04    .44109+01    .79005+04
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SAMPLE PROBLEM 2 OUTPUT (Cont'd)

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SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTING PROGRAM

                                   CASE NO.   0                                        PAGE  47

RCS ACS VARIABLE O/F TRANSONIC NOZZLE SOLUTION

LINE POINT  DSCRIP - REGIME      Q            X            R            THETA        ENTROPY      VELOCITY     O/F         ITR
                                 MACH ANGLE   PRESSURE     DENSITY      TEMPERATURE  GAS CONST.   LOCAL GAMMA  SHOCK ANGLE
                                 IOQ          POQ          SQ

 96   52  WALL  - CONTIN      .39390+00    .7? .?+00    .40136+01    .13123+02    -.51015+03   .82685+04    .80000+00    3
                              .14804+02    .10000+01    .40290-04    .10020+04    .32370+04    .13752+01
                              .35602+09    .21092+02    .42959+09

                                        PRESSURE INTEGRATION RESULTS
                              FORCEX       FORCEY       TORQZ        DELFX        DELFY        ISP
                             -.85690+03    .00000       .00000       -.92962+00   .00000       .36369+03

A NEW STREAMLINE HAS BEEN INSERTED ON LINE  95 BETWEEN POINTS  19 AND  20

 97    1  WALL  - CONTIN      .00000       .81390+00    .40430+01    .00000       -.23499+02   .10286+05    .22000+01    2
                              .11915+02    .14576+00    .60395-05    .16223+04    .21440+04    .12952+01
                              .0632?+09    .83150+01    .29509+08

 97   53  WALL  - CONTIN      .39620+00    .35939+00    .39389+01    .13150+02    -.51015+03   .82880+04    .80000+00    3
                              .14722+02    .10567+01    .47263-04    .99459+03    .32370+04    .13755+01
                              .35605+09    .21082+02    .43579+09

                                        PRESSURE INTEGRATION RESULTS
                              FORCEX       FORCEY       TORQZ        DELFX        DELFY        ISP
                             -.85201+03    .00000       .00000       -.90959+00   .00000       .30361+03

 98    1  WALL  - CONTIN      .00000       .82370+00    .40403+01    .00000       -.23499+02   .10291+05    .22000+01    2
                              .11063+02    .14132+00    .50979-05    .16109+04    .21440+04    .12950+01
                              .50795+09    .82213+01    .80015+09

 98   53  WALL  - CONTIN      .39960+00    .36971+00    .39569+01    .13127+02    -.51015+03   .82923+04    .80000+00    3
                              .14441+02    .10254+01    .46246-04    .98637+03    .32370+04    .13758+01
                              .35600+09    .21073+02    .40192+09

                                        PRESSURE INTEGRATION RESULTS
                              FORCEX       FORCEY       TORQZ        DELFX        DELFY        ISP
                             -.85071+03    .00000       .00000       -.90159+00   .00000       .30325+03

 99    1  WALL  - CONTIN      .00000       .83356+00    .40053+01    .00000       -.23499+02   .10301+05    .22000+01    2
                              .11812+02    .13701+00    .57533-05    .15995+04    .21440+04    .12964+01
                              .50753+09    .81290+01    .80523+08

 99   53  WALL  - CONTIN      .39992+00    .72500+00    .39676+01    .13116+02    -.51015+03   .82903+04    .80000+00    3
                              .14590+02    .10095+01    .45729-04    .98211+03    .32370+04    .13760+01
                              .35603+09    .20862+02    .40572+09

                                        PRESSURE INTEGRATION RESULTS
                              FORCEX       FORCEY       TORQZ        DELFX        DELFY        ISP
                             -.85916+03    .00000       .00000       -.8534?+00   .00000       .30909+03

THE PERCENT CHANGE IN MASS FLOW IS =     .171165+00
PERCENT CHANGE IN MOMENTUM IS =    .12903+03    ISP =    .20650+00
PERCENT CHANGE IN ENERGY IS =    .00000
EXIT PLANE NORMAL START LINE
```

.0000000	.9286759+00	.4874887+01	.0000000	-.2349945+02	.2200000+01
.7090059-02	.8286467+00	.4873697+01	.4712641+00	-.2036482+02	.2199566+01
.1419920-01	.8285591+00	.4872239+01	.9427931+00	-.1723019+02	.2199132+01
.2130722-01	.8284130+00	.4870516+01	.1413334+01	-.1409556+02	.2198698+01
.2841060-01	.8282046+00	.4868494+01	.1881717+01	-.1096093+02	.2198265+01
.3551391-01	.8279463+00	.4866001+01	.2347730+01	-.7829131+01	.2197831+01
.4260945-01	.8276267+00	.4863130+01	.2810290+01	-.4697334+01	.2197397+01
.4967958-01	.8272514+00	.4859817+01	.3267452+01	-.1565528+01	.2196963+01
.5673013-01	.8268205+00	.4855976+01	.3719232+01	.1566273+01	.2196529+01
.6355780-01	.8263514+00	.4850895+01	.4150897+01	.7653111+01	.2194243+01
.7036389-01	.8258323+00	.4845196+01	.4573267+01	.1374549+02	.2191958+01
.7712234-01	.8252673+00	.4838619+01	.4984870+01	.1983562+02	.2189672+01
.8386376-01	.8246556+00	.4831118+01	.5384632+01	.2594159+02	.2187367+01
.9053386-01	.8240045+00	.4822471+01	.5766502+01	.3203957+02	.2185101+01
.9717998-01	.8233120+00	.4812370+01	.6130219+01	.3817580+02	.2182815+01
.1037377+00	.8225080+00	.4800781+01	.6470190+01	.4426127+02	.2180530+01
.1102644+00	.8218295+00	.4787340+01	.6786683+01	.5043424+02	.2178244+01
.1165119+00	.8210709+00	.4772613+01	.7061488+01	.5537308+02	.2174265+01
.1227326+00	.8202869+00	.4755361+01	.7305203+01	.6063144+02	.2170287+01
.1287936+00	.8194986+00	.4736407+01	.7516341+01	.6529995+02	.2166308+01
.1348405+00	.8186917+00	.4713943+01	.7684671+01	.7046481+02	.2162329+01
.1464648+00	.8170996+00	.4663191+01	.7913096+01	.8122149+02	.2154372+01
.1575520+00	.8155507+00	.4604097+01	.7990979+01	.9161721+02	.2146415+01
.1678432+00	.8141066+00	.4543914+01	.7964216+01	.9562596+02	.2134365+01
.1775720+00	.8127527+00	.4484812+01	.7902076+01	.9964935+02	.2122314+01
.1867318+00	.8114047+00	.4430469+01	.7462101+01	.1038?5?+03	.2110263+01

ORIGINAL PAGE IS
OF POOR QUALITY

SAMPLE PROBLEM 2 OUTPUT (Cont'd)

.1034613+00	.8102783+00	.9381954+01	.7873896+01	.1001289+03	.2098711+01
.2036932+00	.8091358+00	.9382C89+01	.7939183+01	.1052318+03	.2002318+01
.2114618+00	.8080163+00	.9380954+01	.8096078+01	.1021285+03	.2060087+01
.2142889+00	.8069590+00	.9270363+01	.8178933+01	.9951893+02	.2050589+01
.2262602+00	.8058054+00	.9288185+01	.8326227+01	.9605280+02	.2038641+01
.2339223+00	.8042877+00	.9215931+01	.8475061+01	.9408751+02	.2017231+01
.2410098+00	.8037223+00	.9188069+01	.8673575+01	.9253825+02	.1999991+01
.2477578+00	.8026985+00	.9169980+01	.8762178+01	.8169936+02	.1982612+01
.2585590+00	.8014353+00	.9198356+01	.8897739+01	.7930961+02	.1965282+01
.2609980+00	.8006188+00	.9117095+01	.9119600+01	.6789733+02	.1999887+01
.2679953+00	.7995808+00	.9092910+01	.9132881+01	.6952909+02	.1929011+01
.2735209+00	.7986078+00	.9069996+01	.9238530+01	.5821117+02	.1903326+01
.2795851+00	.7976169+00	.9095681+01	.9322187+01	.5972801+02	.1882798+01
.2911081+00	.7953059+00	.9008111+01	.9506958+01	.5010806+02	.1890792+01
.3019938+00	.7938753+00	.3957062+01	.9671014+01	.9529709+02	.1798899+01
.3122076+00	.7921128+00	.3922990+01	.9830261+01	.3891995+02	.1799896+01
.3219228+00	.7904124+00	.3891279+01	.1000366+02	.2217320+02	.1700040+01
.3312061+00	.7881593+00	.3862569+01	.1010859+02	.1552982+02	.1645913+01
.3401369+00	.7871370+00	.3839678+01	.1039909+02	-.1190798+01	.1589977+01
.3485257+00	.7855829+00	.3822176+01	.1061916+02	-.9986593+01	.1519899+01
.3560522+00	.7840037+00	.3808992+01	.1085087+02	-.2620780+02	.1449820+01
.3697162+00	.7820765+00	.3791733+01	.1112103+02	-.1131739+02	.1372999+01
.3724086+00	.7809019+00	.3790993+01	.1143281+02	-.5699223+02	.1295177+01
.3790916+00	.7794125+00	.3796527+01	.1177070+02	-.6093658+02	.1199962+01
.3869230+00	.7780222+00	.3813501+01	.1215829+02	-.9999579+02	.1079707+01
.3938431+00	.7763856+00	.3859176+01	.1265919+02	-.1767379+03	.9973535+00
.3999170+00	.7750000+00	.3867618+01	.1311600+02	-.5101491+03	.0000000+00

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	FORCEZ	DELFY	DELFY	ISP
-.85902+03	.00000	.00000	-.45345+00	.00000	.38925+03

SAMPLE PROBLEM 2 OUTPUT (Concluded)

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JANNAF BOUNDARY LAYER INTEGRAL MATRIX PROCEDURE

        BLIMP-J  MOD 2  JULY 1975

   ACUREX CORP.  AEROTHERM DIV..MTN. VIEW,CALIF.

CASE   [illegible] TRANSONIC NOZZLE SOLUTION

   CONTROL NUMBERS  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20
                    1  0  2  0  0  4  3  1  2  1  0  2  1  2  0  0  0  0  0  0

 NUM. ID      NODAL PT.                    ETA VALUES
 NORM. ETA    AT WHICH
              ETA NORM.
 9.500-01        10      0.000   2.400-03  6.000-03  1.557-02  2.703-02  4.035-02  1.065-01  4.150-01  7.219-01
                         1.000+00  1.201+00  2.500+00

CASE                     1.00000+00

TOTAL ENTHALPY, B/LB     2.1930+02

TOTAL PRESSURE, ATM      1.0270+01

INCID. RAD FLUX, B/SF2   0.00000

  CEBECI-SMITH TURB. MODEL

  MIXING LENGTH CONSTANT     =  4.4000-01
  SUBLAYER CONSTANT, YAP     =  2.1000+01
  CLAUSER NUMBER             =  1.6800-02

  TURBULENT PRANDTL NUMBER   =  9.0000-01

  TURBULENT SCHMIDT NUMBER   =  9.0000-01
  TRANSITION MOM.THICK.RE    =  2.5000+02

  CASE  1

     VISCOSITY LAW   MU=1   .363-04  [illegible]  .150  [illegible]  .300  [illegible]  .356+03

     PRANDTL NUMBER  PR=  .875+00   .000   +100   .000   +   .000   +100   .000

     TEMP. IN DEG. R     VISCOSITY IN LBM/S-FT

                         MIXTURE CP[illegible] CONSTANTS (DEG R)

  300.00   .33740145+01   .90402500-03   -.18133020-05   .25155300-08   -.10305725-11   -.60187110+03   .35349959+00
 1000.00   .29776310+01   .12745905-02   -.35063330-06   .50816913-10   -.27650333-14   -.66655023+03   .75002606+01
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EDGE CONDITIONS

IS	WALL LENGTH FEET	TEMP DEG-R	CP FROZEN B/LB-R	STATIC PRESSURE ATM	DENSITY LB/F3	VISCOSITY LB/FS	VELOCITY F/S	ENTHALPY B/LB	ENTROPY B/LB-R	MACH NO.
1	1.127-01	2.518+03	5.919-01	1.067+00	2.567-02	2.900-05	5.487+03	-3.621+02	3.172+00	1.690+00
2	1.760-01	2.065+03	5.240-01	1.420+00	1.440-02	2.610-05	6.430+03	-5.000+02	3.172+00	2.161+00
3	1.850-01	1.947+03	5.139-01	1.000+00	1.172-02	2.503-05	6.711+03	-6.463+02	3.172+00	2.310+00
4	2.040-01	1.839+03	5.123-01	8.440-01	9.879-03	2.380-05	6.910+03	-7.164+02	3.172+00	2.450+00
5	2.335-01	1.755+03	5.879-01	7.028-01	8.544-03	2.289-05	7.089+03	-7.493+02	3.172+00	2.577+00
6	2.626-01	1.683+03	5.050-01	6.100-01	7.617-03	2.227-05	7.199+03	-7.957+02	3.172+00	2.660+00
7	2.911-01	1.623+03	5.941-01	5.297-01	6.859-03	2.167-05	7.303+03	-8.259+02	3.172+00	2.746+00
8	3.205-01	1.566+03	4.994-01	4.621-01	6.190-03	2.109-05	7.399+03	-8.541+02	3.172+00	2.829+00
9	3.490-01	1.512+03	4.967-01	4.039-01	5.600-03	2.051-05	7.490+03	-8.811+02	3.172+00	2.912+00
10	3.772-01	1.461+03	4.942-01	3.535-01	5.084-03	1.999-05	7.575+03	-9.066+02	3.172+00	2.993+00
11	4.051-01	1.412+03	4.919-01	3.100-01	4.626-03	1.957-05	7.653+03	-9.309+02	3.172+00	3.075+00
12	4.329-01	1.370+03	4.899-01	2.771-01	4.250-03	1.901-05	7.721+03	-9.512+02	3.172+00	3.144+00
13	4.605-01	1.332+03	4.881-01	2.492-01	3.930-03	1.859-05	7.781+03	-9.698+02	3.172+00	3.212+00
14	4.877-01	1.295+03	4.864-01	2.239-01	3.633-03	1.813-05	7.839+03	-9.880+02	3.172+00	3.280+00
15	5.147-01	1.263+03	4.850-01	2.091-01	3.399-03	1.782-05	7.888+03	-1.003+03	3.172+00	3.338+00
16	5.410-01	1.235+03	4.836-01	1.870-01	3.199-03	1.751-05	7.931+03	-1.017+03	3.172+00	3.393+00
17	5.685-01	1.208+03	4.826-01	1.710-01	3.007-03	1.720-05	7.972+03	-1.030+03	3.172+00	3.447+00
18	5.950-01	1.184+03	4.816-01	1.665-01	2.840-03	1.692-05	8.000+03	-1.041+03	3.172+00	3.490+00
19	6.217-01	1.165+03	4.804-01	1.511-01	2.725-03	1.670-05	8.030+03	-1.051+03	3.172+00	3.535+00
20	6.481-01	1.146+03	4.800-01	1.427-01	2.607-03	1.648-05	8.065+03	-1.060+03	3.172+00	3.576+00
21	6.743-01	1.128+03	4.793-01	1.319-01	2.495-03	1.626-05	8.092+03	-1.068+03	3.172+00	3.616+00
22	7.005-01	1.112+03	4.787-01	1.273-01	2.403-03	1.608-05	8.115+03	-1.076+03	3.172+00	3.650+00
23	7.266-01	1.099+03	4.782-01	1.217-01	2.326-03	1.592-05	8.135+03	-1.082+03	3.172+00	3.683+00
24	7.524-01	1.083+03	4.775-01	1.150-01	2.230-03	1.573-05	8.158+03	-1.090+03	3.172+00	3.717+00
25	7.783-01	1.070+03	4.770-01	1.101-01	2.162-03	1.557-05	8.176+03	-1.096+03	3.172+00	3.749+00
26	8.041-01	1.058+03	4.766-01	1.057-01	2.099-03	1.542-05	8.195+03	-1.102+03	3.172+00	3.777+00
27	8.298-01	1.044+03	4.760-01	1.007-01	2.027-03	1.526-05	8.215+03	-1.108+03	3.172+00	3.810+00
28	8.559-01	1.031+03	4.756-01	9.619-02	1.959-03	1.510-05	8.234+03	-1.115+03	3.172+00	3.843+00
29	8.814-01	1.019+03	4.751-01	9.244-02	1.901-03	1.496-05	8.251+03	-1.120+03	3.172+00	3.872+00
30	9.070-01	1.008+03	4.747-01	8.840-02	1.843-03	1.481-05	8.268+03	-1.126+03	3.172+00	3.902+00
31	9.325-01	9.929+02	4.742-01	8.375-02	1.772-03	1.463-05	8.289+03	-1.133+03	3.172+00	3.940+00
32	9.580-01	9.768+02	4.736-01	7.890-02	1.697-03	1.443-05	8.312+03	-1.140+03	3.172+00	3.982+00
33	9.827-01	9.599+02	4.730-01	7.368-02	1.618-03	1.421-05	8.337+03	-1.149+03	3.172+00	4.029+00
34	1.000+00	9.405+02	4.723-01	6.870-02	1.535-03	1.397-05	8.364+03	-1.150+03	3.172+00	4.082+00

ORIGINAL PAGE IS
OF POOR QUALITY

SAMPLE PROBLEM 2 OUTPUT (Cont'd)

AXIAL DISTANCE, FEET	.00000	.37650-02	.11495-01	.26900-01	.51672-01	.76300-01	.10180+00	.12505+00
	.15051+00	.17536+00	.20007+00	.22475+00	.24945+00	.27424+00	.29907+00	.32366+00
	.34845+00	.37316+00	.39793+00	.42265+00	.44737+00	.47213+00	.49682+00	.52150+00
	.54634+00	.57135+00	.59570+00	.62003+00	.64551+00	.67018+00	.69500+00	.71901+00
	.74300+00	.76660+00						
WALL LENGTH, FEET	.17271+00	.17600+00	.18501+00	.20402+00	.23340+00	.26264+00	.29176+00	.32058+00
	.34900+00	.37716+00	.40507+00	.43209+00	.46050+00	.48760+00	.51473+00	.54170+00
	.56458+00	.59505+00	.62160+00	.64805+00	.67426+00	.70044+00	.72658+00	.75245+00
	.77831+00	.80400+00	.82979+00	.85540+00	.88103+00	.90645+00	.93240+00	.95600+00
	.98267+00	.10002+01						
RADIUS, FEET	.06616-01	.07567-01	.92227-01	.10193+00	.11704+00	.13309+00	.14900+00	.16135+00
	.17765+00	.19100+00	.20385+00	.21670+00	.22912+00	.24018+00	.25116+00	.26222+00
	.27217+00	.28107+00	.29165+00	.30004+00	.30952+00	.31811+00	.32642+00	.33411+00
	.34166+00	.34900+00	.35636+00	.36295+00	.36900+00	.37639+00	.38235+00	.38831+00
	.39409+00	.39990+00						
XI,LB/S **2	.53602-05	.54617-05	.56094-05	.59221-05	.64583-05	.70043-05	.77140-05	.84317-05
	.91002-05	.99677-05	.10759-04	.11565-04	.12304-04	.13195-04	.14695-04	.14625-04
	.15641-04	.16453-04	.17271-04	.19100-04	.18922-04	.19750-04	.20505-04	.21415-04
	.22245-04	.23076-04	.23685-04	.24745-04	.25544-04	.26302-04	.27192-04	.27904-04
	.20730-04	.29476-04						
PRESSURE RATIO	.21490+00	.10810+00	.76129-01	.60550-01	.49250-01	.42750-01	.37120-01	.32300-01
	.24273-01	.20772-01	.21790-01	[illegible]	.17460-01	.15690-01	.14300-01	.13163-01
	.12120-01	.11250-01	.10590-01	.99610-02	.93860-02	.89106-02	.85270-02	.80040-02
	.77140-02	.74070-02	.70540-02	.67370-02	.64650-02	.61950-02	.58640-02	.55290-02
	.51779-02	.48140-02						
STATIC PRESSURE, ATM	[illegible]	.14206+01	.13062+01	.66405+00	.78206+00	.61CC4+00	.52070+00	.46206+00
	.43341+00	.35367+00	.31094+00	.27712+00	.24915+00	.22310+00	.20080+00	.18770+00
	.19265+00	.16654+00	.15112+00	.14223+00	.13394+00	.12726+00	.12168+00	.11530+00
	.11360+00	.10570+00	.10073+00	.96137-01	.92256-01	.88463-01	.83751-01	.79890-01
	.73076-01	.68696-01						
EDGE VELOCITY, F/S	.54076+04	.64394+04	.67115+04	.69175+04	.70900+04	.71680+04	.73632+04	.73903+04
	.74903+04	.75740+04	.76532+04	.77250+04	.77809+04	.79391+04	.79081+04	.70306+04
	.70716+04	.80070+04	.80365+04	.80647+04	.80921+04	.81150+04	.81340+04	.81570+04
	.81780+04	.81951+04	.82151+04	.82302+04	.82560+04	.82670+04	.82800+04	.83110+04
	.83367+04	.83635+04						
BETAW	.19655-02	.94353-01	-.12132-01	.68794+00	.37040+00	.31875+00	.30397+00	.28778+00
	.27902+00	.27455+00	.25703+00	.23302+00	.23156+00	.22576+00	.19404+00	.18953+00
	.14007+00	.16376+00	.14391+00	.15436+00	.14452+00	.11928+00	.12979+00	.14179+00
	.11725+00	.12410+00	.14873+00	.12799+00	.12117+00	.14776+00	.14206+00	.20970+00
	.24141+00	.26394+00						
BETAP	.19655-02	.94353-01	-.12132-01	.60794+00	.37040+00	.31875+00	.30397+00	.28778+00
	.27902+00	.27455+00	.25703+00	.23002+00	.23156+00	.22576+00	.19404+00	.18953+00
	.14007+00	.16376+00	.14391+00	.15436+00	.14452+00	.11928+00	.12979+00	.14179+00
	.11725+00	.12410+00	.14073+00	.12799+00	.12117+00	.14776+00	.14206+00	.20970+00
	.24141+00	.26394+00						
INCID RAD-FLUX, B/SF2	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000						
FLUX NORM. PARAM.,LB/SF2	.11024+00	.64085-01	.53777-01	.48142-01	.45048-01	.43428-01	.41118-01	.38470-01
	.35719-01	.32929-01	.30204-01	.28187-01	.26177-01	.24216-01	.22640-01	.21350-01
	.23066-01	.18965-01	.18147-01	.17320-01	.16520-01	.15875-01	.15335-01	.14662-01
	.14897-01	.13632-01	.13083-01	.12565-01	.12135-01	.11695-01	.11140-01	.10562-01
	.99624-02	.93374-02						
WALL TEMPERATURE,DEG-R	.23440+04	.23430+04	.23420+04	.23400+04	.23360+04	.23320+04	.23280+04	.23240+04
	.23200+04	.23160+04	.23120+04	.23080+04	.23050+04	.23010+04	.22970+04	.22940+04
	.22900+04	.22860+04	.22820+04	.22780+04	.22740+04	.22700+04	.22660+04	.22610+04
	.22570+04	.22530+04	.22490+04	.22450+04	.22410+04	.22370+04	.22310+04	.22200+04
	.22260+04	.22220+04						
COMP FLUX, LB/SF2	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000						
COMP FLUX, LB/SF2	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000						
COMP FLUX, LB/SF2	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000						

SAMPLE PROBLEM 2 OUTPUT (Cont'd)

PRIOR LAMINAR SOLUTION AFTER TRANSITION. TURBULENCE WILL BE INCLUDED AND SOLUTION CONTINUED

ITS	ITERATED VALUES TIME	ALPH	FPPW	DAMP	MAX LIN ERROR	MAX ERRORS IN CONSERVATION EQS. MOMENTUM		ENERGY	
2	.000	2.350	.7087	.1650	4.-01	11	-2.2+01	1	-1.7+02
3	.000	2.309	1.0900	.0950	3.-01	11	-2.1+01	11	-1.5+02
4	.000	2.112	1.0105	.7497	2.-01	11	-1.0+01	11	-1.3+02
5	.000	1.931	2.0702	.0775	4.-02	11	-1.2+01	11	-9.0+01
6	.000	1.766	3.0076	.0400	2.-02	11	-7.9+00	11	-5.5+01
7	.000	1.615	3.5975	.0610	1.-02	11	-4.8+00	7	-3.7+01
8	.330	1.470	4.0366	.5550	6.-03	11	-2.6+00	8	-3.0+01
9	.000	1.350	4.3033	.0469	3.-03	11	-1.1+00	6	-2.3+01
10	.000	1.314	4.4433	1.0030	4.-04	11	-1.2-01	9	-6.7+00
11	.000	1.315	4.4444	1.0300	6.-06	11	-3.9-03	8	6.7-01

ALPHA	RADIUS FEET	PRESSURE ATM	EDGE VEL. F/S	BETAP	BETAU	HEAT FLUXES--B/SF2 DIFFUSIONAL	TOT ENTH	RERAD	QCOND
1.315+00	4.602-02	3.367+00	5.447-03	1.044-01	1.044-01	5.287-01	5.287-01	0.000	5.286-01

WALL SHEAR LBF/F2	MASS FLUXES LB/SF2 MECHANICAL REMOVAL	PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS DIFFUSIVE FLUXES LB/SF2 FOR
4.525-01	0.000	0.000	0.000	0.000	0.000

MOM TRANS COEFF. CF/2	HEAT TRANS COEFF. ST NO.	BLOWING PARAMETERS (NORM. BY RHOE*UE*ST) FOR PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS TRANSFER COEFFICIENTS, CM, FOR
3.548-03	5.433-03	0.000	0.000	0.000	0.000

MOMENTUM THICKNESS, THETA FEET	DISPLACE. THICKNESS, DELSTAR FEET	EFFECTIVE BODY DISPLACE. FEET	ENTHALPY THICKNESS, LAMBDA FEET	REYNOLDS NUMBER PER FOOT	MASS THICKNESS FOR FEET
4.937-05	1.423-05	1.423-05	1.077-04	4.727+06	0.000

TOTAL HEAT TO WALL B/S	THRUST LOSS (LBF)	TOTAL WALL AREA (F2)	ACCELERATION PARAMETER-K	INVISCID MASS IN BL LB/S	TOTAL MASS IN BL LB/S
0.000	5.914-01	0.000	1.103-05	6.154-02	6.154-02

NODAL INFORMATION

ETA	DISTANCE FROM WALL FEET	F	U/UE	FPP	SHEAR LBF/F2	G, TOTAL ENTHALPY B/LB	GP B/LB	GPP B/LB	STATIC ENTHALPY B/LB	TEMP DEG-R
0.000	0.000	0.000	0.000	4.444+00	4.525-01	-4.514+02	2.233+02	1.222+04	-4.514+02	2.344+03
2.020-03	9.324-07	1.215-05	1.429-02	4.302+00	4.404-01	-4.505+02	2.445+02	1.159+04	-4.507+02	2.345+03
4.020-03	2.261-06	1.761-04	3.911-02	4.293+00	4.232-01	-4.489+02	3.294+02	1.044+04	-4.499+02	2.347+03
1.557-02	5.175-06	9.372-04	4.744-02	4.098+00	7.855-01	-4.445+02	4.497+02	8.696+03	-4.491+02	2.349+03
2.723-02	4.946-06	2.480-03	1.473-01	3.843+00	7.764-01	-4.367+02	5.807+02	6.161+03	-4.497+02	2.347+03
4.415-02	1.404-05	8.250-03	2.405-01	3.300+00	6.489+01	-4.180+02	7.534+02	5.111+02	-4.551+02	2.337+03
1.465-01	4.779-05	6.374-02	5.737-01	1.659+00	3.237-01	-3.165+02	8.194+02	-1.438+03	-5.144+02	2.226+03
4.154-01	1.285-04	3.305-01	4.918-01	1.350-01	2.701+00	-1.229+02	2.756+02	-1.595+02	-4.003+02	2.043+03
7.219-01	2.203-04	7.745-01	4.302-01	5.864-02	1.150+00	-2.438+01	2.136+02	-8.636+01	-5.447+02	2.164+03
1.003+00	3.076-04	1.350+00	9.500-01	4.944-02	4.427-01	4.787+01	1.018+02	-1.093+02	-4.948+02	2.261+03
1.203+00	3.735-04	1.306+00	9.422-01	4.102-02	8.086-01	4.260+01	1.540+02	-5.867+01	-4.640+02	2.328+03
2.500+00	8.222-04	2.909+00	1.000+00	0.000	0.000	2.393+02	0.000	-1.219+02	-3.621+02	2.510+03

DISTANCE FROM WALL FEET	DENSITY RHO LB/F3	VISCOSITY MU LB/FS	SPECIFIC HEAT B/LB-R	THERMAL COND. B/SF-R	PRANDTL NUMBER	MODIFIED SCHMIDT NUMBER	MOLECULAR WEIGHT	MACH NUMBER	RHOSQ*EPS /RHOE*MUE	TURBULENT PRANDTL NO
0.000	2.749-02	2.839-05	5.353-01	3.199-05	4.751-01	4.751-01	1.534+01	0.000	0.000	0.000
9.324-07	2.747-02	2.840-05	5.353-01	3.201-05	4.751-01	4.751-01	1.534+01	2.424-02	0.000	9.000-01
2.261-06	2.745-02	2.842-05	5.354-01	3.202-05	4.751-01	4.751-01	1.534+01	6.775-02	0.000	9.000-01
5.175-06	2.744-02	2.843-05	5.355-01	3.204-05	4.751-01	4.751-01	1.534+01	1.514-01	0.000	9.000-01
8.946-06	2.745-02	2.842-05	5.354-01	3.203-05	4.751-01	4.751-01	1.534+01	2.551-01	0.000	9.000-01
1.606-05	2.757-02	2.833-05	5.350-01	3.190-05	4.751-01	4.751-01	1.534+01	4.314-01	0.000	9.000-01
4.779-05	2.895-02	2.736-05	5.303-01	3.054-05	4.751-01	4.751-01	1.534+01	1.019+00	0.000	9.000-01
1.285-04	3.124-02	2.590-05	5.230-01	2.851-05	4.751-01	4.751-01	1.534+01	1.440+00	0.000	9.000-01
2.203-04	2.971-02	2.685-05	5.278-01	2.983-05	4.751-01	4.751-01	1.534+01	1.673+00	0.000	9.000-01
3.076-04	2.848-02	2.768-05	5.314-01	3.099-05	4.751-01	4.751-01	1.534+01	1.674+00	0.000	9.000-01
3.735-04	2.777-02	2.819-05	5.343-01	3.170-05	4.751-01	4.751-01	1.534+01	1.676+00	0.000	9.000-01
8.222-04	2.567-02	2.980-05	5.419-01	3.399-05	4.751-01	4.751-01	1.534+01	1.678+00	0.000	9.000-01

REFIT CALLED

I	ETA(I)	U/UE	SP(1,I)	SP(1,I,1)	SP(1,I,2)	SP(1,I,3)	SP(1,I,4)	SP(1,I,5)	SP(1,I,6)	SP(1,I,7)	SP(1,I,8
1	0.000	0.000	-4.514+02	1.000+00							
2	8.747-03	5.001-02	-4.481+02	0.000							
3	2.172-02	1.200-01	-4.465+02	0.000							
4	4.869-02	2.501-01	-4.176+02	0.000							
5	7.273-02	3.499-01	-3.937+02	0.000							
6	1.000-01	4.501-01	-3.646+02	0.000							
7	1.508-01	5.999-01	-3.041+02	0.000							
8	2.433-01	7.534-01	-2.234+02	0.000							
9	3.317-01	8.434-01	-1.649+02	0.000							
10	1.000+00	9.500-01	4.787-01	3.490-01							
11	1.573+00	9.781-01	1.594+02	6.870-02							
12	2.500+00	1.000+00	2.393+02	2.345+03							

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS OF POOR QUALITY

SAMPLE PROBLEM 2 OUTPUT (Cont'd)

STATION 36 - - - - - - - - - - - AXIAL POSITION .70666+00 FEET - - - - - -

ITERATED VALUES DAMP MAX.LIN MAX.ERRORS IN CONSERVATION EQS.

ITS	TIME	ALPH	FPPW		ERROR	MOMENTUM		ENERGY
1	.000	5.379	2.1150	.4999	5.-07 12	-1.3+00	11	6.9-01
2	.000	5.379	2.1346	1.0000	5.-07 12	-6.6-01	11	3.5-01
3	.000	5.378	2.1346	1.0000	5.-07 13	-4.6-03	11	3.7-01

ALPHA	RADIUS FEET	PRESSURE ATM	EDGE VEL. F/S	BETAP	BETAU	HEAT FLUXES--B/SF2 DIFFUSIONAL	TOT ENTH	REVRD	RCONV
5.370+00	3.999-01	6.070-02	8.364+03	2.639-01	2.639-01	8.675+00	8.675+00	0.000	8.675+00

WALL SHEAR LBF/F2	MASS FLUXES LB/SF2 MECHANICAL REMOVAL	PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS DIFFUSIVE FLUXES LB/SF2 FOR
4.290+00	0.000	0.000	0.000	0.000	0.000

MOM TRANS COEFF. CF/2	HEAT TRANS COEFF. ST NO.	BLOWING PARAMETERS (NORM. BY RHOE*UE*ST) FOR PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS TRANSFER COEFFICIENTS, CM, FOR
1.246-03	8.943-04	0.000	0.000	0.000	0.000

MOMENTUM THICKNESS, THETA FEET	DISPLACE. THICKNESS, DELSTAR FEET	EFFECTIVE BODY DISPLACE. FEET	ENTHALPY THICKNESS, LAMBDA FEET	REYNOLDS NUMBER PER FOOT	MASS THICKNESS FOR FEET
1.170-03	6.795-03	6.795-03	1.553-03	9.108+05	0.000

TOTAL HEAT TO WALL B/S	THRUST LOSS (LBF)	TOTAL WALL AREA (F2)	ACCELERATION PARAMETER-K	INVISCID MASS IN BL LB/S	TOTAL MASS IN BL LB/S
2.470+01	7.137+00	1.404+00	1.397-07	5.941-01	5.941-01

NODAL INFORMATION

ETA	DISTANCE FROM WALL FEET	F	U/UE	FPP	SHEAR LBF/F2	G, TOTAL ENTHALPY B/LB	CP B/LB	CPP B/LB	STATIC ENTHALPY B/LB	TEMP DEG-R
0.000	0.000	0.000	0.000	2.135+00	4.290+00	-5.164+02	5.330+02	6.474+03	-5.164+02	2.222+03
4.565-03	8.709-05	6.402-04	9.217-02	2.121+00	4.251+00	-5.013+02	6.967+02	6.369+03	-5.051+02	2.241+03
1.130-02	2.109-04	3.701-03	1.249-01	2.090+00	4.203+00	-4.735+02	9.159+02	4.288+03	-4.953+02	2.262+03
2.359-02	4.546-04	1.677-02	2.593-01	1.884+00	4.099+00	-4.319+02	1.201+03	-7.491+02	-4.958+02	2.261+03
3.478-02	6.693-04	3.553-02	3.611-01	1.505+00	4.013+00	-3.312+02	1.153+03	-3.776+03	-5.134+02	2.220+03
4.970-02	9.491-04	4.075-02	4.616-01	1.004+00	3.909+00	-2.509+02	8.587+02	-2.414+03	-5.486+02	2.161+03
9.020-02	1.663-03	1.079-01	6.117-01	3.756-01	3.679+00	-1.230+02	3.256+02	-3.887+02	-6.456+02	1.976+03
2.098-01	3.505-03	6.386-01	7.604-01	8.762-02	3.210+00	5.993+00	7.587+01	-2.055+01	-8.018+02	1.670+03
4.585-01	6.770-03	1.721+00	8.527-01	5.062-02	2.546+00	8.912+01	4.053+01	-1.069+01	-9.267+02	1.420+03
1.000+00	1.252-02	4.167+00	9.500-01	1.627-02	1.311+00	1.850+02	1.744+01	-3.930+00	-1.076+03	1.113+03
1.416+00	1.630-02	6.525+00	9.787-01	4.416-03	6.403-01	2.165+02	1.067+01	-3.206+00	-1.122+03	1.016+03
2.500+00	2.521-02	1.231+01	1.000+00	0.000	0.000	2.393+02	0.000	-3.803-01	-1.156+03	9.505+02

DISTANCE FROM WALL FEET	DENSITY RHO LB/F3	VISCOSITY MU LB/FS	SPECIFIC HEAT B/LB-R	THERMAL COND. B/SF-R	PRANDTL NUMBER	MODIFIED SCHMIDT NUMBER	MOLECULAR WEIGHT	MACH NUMBER	RHOSQ*EPS /RHOE*MUE	TURBULENT PRANDTL NO
0.000	6.496-04	2.733-05	5.301-01	3.049-05	4.751-01	4.751-01	1.534+01	0.000	0.000	0.000
8.709-05	6.434-04	2.751-05	5.313-01	3.075-05	4.751-01	4.751-01	1.534+01	1.407-01	1.321-04	9.000-01
2.109-04	6.381-04	2.760-05	5.318-01	3.090-05	4.751-01	4.751-01	1.534+01	3.356-01	4.078-03	9.000-01
4.546-04	6.384-04	2.767-05	5.318-01	3.097-05	4.751-01	4.751-01	1.534+01	6.968-01	7.248-02	9.000-01
6.693-04	6.479-04	2.738-05	5.309-01	3.056-05	4.751-01	4.751-01	1.534+01	9.772-01	2.712-01	9.000-01
9.491-04	6.678-04	2.679-05	5.275-01	2.970-05	4.751-01	4.751-01	1.534+01	1.267+00	7.694-01	9.000-01
1.663-03	7.305-04	2.518-05	5.190-01	2.741-05	4.751-01	4.751-01	1.534+01	1.751+00	3.181+00	9.000-01
3.505-03	8.640-04	2.215-05	5.094-01	2.352-05	4.751-01	4.751-01	1.534+01	2.397+00	1.420+01	9.000-01
6.770-03	1.016-03	1.955-05	4.923-01	2.026-05	4.751-01	4.751-01	1.534+01	2.854+00	1.979+01	9.000-01
1.252-02	1.297-03	1.608-05	4.787-01	1.621-05	4.751-01	4.751-01	1.534+01	3.573+00	3.223+01	9.000-01
1.630-02	1.420-03	1.492-05	4.750-01	1.497-05	4.751-01	4.751-01	1.534+01	3.846+00	2.791+01	9.000-01
2.521-02	1.535-03	1.397-05	4.723-01	1.389-05	4.751-01	4.751-01	1.534+01	4.081+00	0.000	9.000-01

SAMPLE PROBLEM 2 OUTPUT (Cont'd)

SUMMARY OF STANDARD PLUME FLOWFIELD CODE INPUT DATA INCLUDING THE BOUNDARY LAYER

CHEMISTRY SYSTEM 2

MASS FLOW AVERAGED PROPERTIES(SPECIES ARE INVISCID AVERAGES)

MOLECULAR WEIGHT	.19334+02
SPECIFIC HEAT RATIO	.13113+01
VISCOSITY(POISE)	.00000
PRANDTL NUMBER	.00000
NOZZLE EXIT RADIUS(FT)	.39992+00
TEMPERATURE(DEG R)	.10147+04
DENSITY(GM/CC)	.11643-04
VELOCITY(FT/SEC)	.93852+04

SPECIE	MOLE FRACTION	SPECIE	MOLE FRACTION
CO	.1264+00	CO2	.4412-01
H	.6030-02	H2	.1930+00
H2O	.3101+00	N2	.3040+00
O	.9240-03	OH	.8867-02
O2	.2037-02		

GASEOUS STARTING LINE INFO

R/RE(ND)	U(FT/SEC)	V(FT/SEC)	P(ATM)	T(DEG R)
.0000	.1024+05	.0000	.1120-01	.9282+03
.4167-01	.1023+05	.7133+02	.1125-01	.9285+03
.8333-01	.1022+05	.4251+03	.1130-01	.9296+03
.1250+00	.1021+05	.6333+03	.1134-01	.9312+03
.1667+00	.1019+05	.8350+03	.1141-01	.9332+03
.2083+00	.1017+05	.1029+04	.1153-01	.9363+03
.2500+00	.1015+05	.1208+04	.1176-01	.9414+03
.2917+00	.1012+05	.1359+04	.1217-01	.9489+03
.3333+00	.1008+05	.1471+04	.1292-01	.9617+03
.3750+00	.1004+05	.1533+04	.1415-01	.9816+03
.4167+00	.9995+04	.1535+04	.1613-01	.1026+04
.4583+00	.9946+04	.1507+04	.1875-01	.1039+04
.5000+00	.9900+04	.1496+04	.2162-01	.1068+04
.5417+00	.9859+04	.1521+04	.2445-01	.1091+04
.5833+00	.9820+04	.1566+04	.2729-01	.1111+04
.6250+00	.9775+04	.1614+04	.3036-01	.1124+04
.6667+00	.9726+04	.1654+04	.3389-01	.1133+04
.7083+00	.9675+04	.1684+04	.3799-01	.1143+04
.7500+00	.9619+04	.1710+04	.4261-01	.1151+04
.7917+00	.9541+04	.1731+04	.4771-01	.1139+04
.8333+00	.9454+04	.1758+04	.5304-01	.1117+04
.8750+00	.9322+04	.1792+04	.5836-01	.1061+04
.9167+00	.9133+04	.1833+04	.6344-01	.9765+03
.9583+00	.8612+04	.1881+04	.6721-01	.8288+03
.9594+00	.8031+04	.1717+04	.6946-01	.5681+03
.9690+00	.7760+04	.1695+04	.6929-01	.6194+03
.9836+00	.6955+04	.1567+04	.6901-01	.7695+03
.9920+00	.6198+04	.1421+04	.6885-01	.9284+03
.9967+00	.4903+04	.1153+04	.6876-01	.1096+04
.9985+00	.3760+04	.8735+03	.6873-01	.1201+04
.9990+00	.3147+04	.7318+03	.6872-01	.1226+04
.1000+01	.2908+04	.6775+03	.6870-01	.1048+04

SAMPLE PROBLEM 2 OUTPUT (Concluded)

METHOD OF CHARACTERISTICS EXIT PLANE STARTLINE BASED ON MASS FLOW AVERAGED THERMODYNAMIC PROPERTIES

TOTAL PRESSURE(PSFA)	=	.14739+04
TOTAL TEMPERATURE(R)	=	.56027+04
SPECIFIC HEAT RATIO	=	.13113+01
MOLECULAR WEIGHT	=	.16336+02
EXIT RADIUS(RE,FEET)	=	.39992+00

R/RE	X	MACH NUMBER	FLOW ANGLE (DEG)	ENTROPY (FT**2/SEC**2/RF)	TOTAL ENTHALPY (FT**2/SEC**2)
.00000	.00000	.43129+01	.00000	.26490+06	.70682+08
.41667-01	.00000	.43107+01	.11990+01	.20764+06	.70686+08
.83333-01	.00000	.43080+01	.23009+01	.20836+06	.70690+08
.12500+00	.00000	.43001+01	.35405+01	.20907+06	.70696+08
.16667+00	.00000	.42904+01	.46867+01	.20987+06	.70519+08
.20833+00	.00000	.42895+01	.57744+01	.29065+06	.70530+08
.25000+00	.00000	.42750+01	.67787+01	.29138+06	.70556+08
.29167+00	.00000	.42534+01	.76515+01	.29123+06	.70591+08
.33333+00	.00000	.42170+01	.83032+01	.29039+06	.70642+08
.37500+00	.00000	.41611+01	.90032+01	.28916+06	.70700+08
.41667+00	.00000	.40880+01	.87291+01	.28461+06	.70788+08
.45833+00	.00000	.40057+01	.86139+01	.27877+06	.70863+08
.50000+00	.00000	.39332+01	.85972+01	.27143+06	.70944+08
.54167+00	.00000	.38764+01	.87495+01	.26315+06	.71026+08
.58333+00	.00000	.38293+01	.90633+01	.25471+06	.71109+08
.62500+00	.00000	.37936+01	.93737+01	.23936+06	.70985+08
.66667+00	.00000	.37621+01	.96493+01	.22328+06	.70759+08
.70833+00	.00000	.37203+01	.98761+01	.20359+06	.70511+08
.75000+00	.00000	.36960+01	.10079+02	.17671+06	.70176+08
.79167+00	.00000	.36882+01	.10281+02	.13790+06	.69215+08
.83333+00	.00000	.36935+01	.10537+02	.89307+03	.68010+08
.87500+00	.00000	.37413+01	.10984+02	.90192+02	.65736+08
.91667+00	.00000	.38266+01	.11765+02	-.12197+06	.62926+08
.95833+00	.00000	.40178+01	.12067+02	-.29466+06	.56751+08
.95961+00	.00000	.44142+01	.12079+02	-.71592+06	.44509+08
.96897+00	.00000	.40967+01	.12320+02	-.61795+06	.43616+08
.98362+00	.00000	.32572+01	.12656+02	-.35402+06	.40009+08
.99196+00	.00000	.26789+01	.12910+02	-.17794+06	.38316+08
.99660+00	.00000	.19817+01	.13031+02	.38403+02	.34483+08
.99851+00	.00000	.14301+01	.13078+02	.10110+06	.30860+08
.99974+00	.00000	.11034+01	.13092+02	.12594+06	.29160+08
.10000+01	.00000	.11843+01	.13116+02	-.46376+03	.24089+08

THE INVISCID PORTION OF THE START LINE WAS MOVED .12160-03 (FT/M) TO MATCH THE EDGE OF THE BOUNDARY LAYER

.0000	.8288+00	.4875+01	.0000	.2886+06	.0000	.0000	.8169+08
.7099-02	.8288+00	.4874+01	.4713+00	.2898+06	.0000	.0000	.8159+08
.1420-01	.8287+00	.4872+01	.9428+00	.2901+06	.0000	.0000	.8168+08
.2131-01	.8285+00	.4871+01	.1413+01	.2894+06	.0000	.0000	.8166+08
.2841-01	.8283+00	.4868+01	.1882+01	.2897+06	.0000	.0000	.8166+08
.3551-01	.8281+00	.4866+01	.2348+01	.2900+06	.0000	.0000	.8148+08
.4261-01	.8277+00	.4863+01	.2816+01	.2902+06	.0000	.0000	.8168+08
.4968-01	.8274+00	.4860+01	.3267+01	.2905+06	.0000	.0000	.8160+08
.5674-01	.8269+00	.4856+01	.3719+01	.2907+06	.0000	.0000	.8156+08
.6356-01	.8265+00	.4851+01	.4150+01	.2910+06	.0000	.0000	.8166+08
.7036-01	.8260+00	.4845+01	.4573+01	.2913+06	.0000	.0000	.8165+08
.7712-01	.8254+00	.4839+01	.4985+01	.2916+06	.0000	.0000	.8163+08
.8386-01	.8248+00	.4831+01	.5385+01	.2918+06	.0000	.0000	.8162+08
.9053-01	.8241+00	.4822+01	.5767+01	.2921+06	.0000	.0000	.8161+08
.9710-01	.8234+00	.4812+01	.6130+01	.2923+06	.0000	.0000	.8160+08
.1037+00	.8227+00	.4801+01	.6470+01	.2925+06	.0000	.0000	.8159+08
.1103+00	.8220+00	.4787+01	.6787+01	.2927+06	.0000	.0000	.8159+08
.1165+00	.8212+00	.4773+01	.7061+01	.2925+06	.0000	.0000	.8157+08
.1227+00	.8204+00	.4755+01	.7305+01	.2922+06	.0000	.0000	.8155+08
.1288+00	.8196+00	.4736+01	.7516+01	.2919+06	.0000	.0000	.8154+08
.1348+00	.8188+00	.4714+01	.7685+01	.2917+06	.0000	.0000	.8153+08
.1465+00	.8172+00	.4663+01	.7913+01	.2909+06	.0000	.0000	.8151+08
.1576+00	.8157+00	.4604+01	.7991+01	.2897+06	.0000	.0000	.8150+08
.1678+00	.8142+00	.4544+01	.7964+01	.2871+06	.0000	.0000	.8145+08
.1776+00	.8129+00	.4485+01	.7902+01	.2837+06	.0000	.0000	.8137+08
.1867+00	.8116+00	.4430+01	.7862+01	.2804+06	.0000	.0000	.8127+08
.1955+00	.8104+00	.4382+01	.7878+01	.2772+06	.0000	.0000	.8116+08
.2037+00	.8093+00	.4342+01	.7939+01	.2730+06	.0000	.0000	.8105+08
.2117+00	.8081+00	.4306+01	.8046+01	.2690+06	.0000	.0000	.8092+08
.2193+00	.8071+00	.4270+01	.8179+01	.2652+06	.0000	.0000	.8080+08
.2268+00	.8060+00	.4244+01	.8326+01	.2615+06	.0000	.0000	.8067+08
.2339+00	.8049+00	.4216+01	.8475+01	.2577+06	.0000	.0000	.8053+08
.2410+00	.8038+00	.4188+01	.8624+01	.2540+06	.0000	.0000	.8039+08
.2478+00	.8028+00	.4165+01	.8762+01	.2467+06	.0000	.0000	.8008+08
.2546+00	.8018+00	.4140+01	.8898+01	.2398+06	.0000	.0000	.7976+08
.2610+00	.8007+00	.4117+01	.9020+01	.2321+06	.0000	.0000	.7939+08
.2674+00	.7997+00	.4092+01	.9133+01	.2248+06	.0000	.0000	.7903+08
.2735+00	.7987+00	.4070+01	.9231+01	.2173+06	.0000	.0000	.7866+08
.2796+00	.7977+00	.4046+01	.9322+01	.2101+06	.0000	.0000	.7830+08
.2911+00	.7958+00	.4000+01	.9506+01	.1961+06	.0000	.0000	.7748+08
.3019+00	.7940+00	.3957+01	.9672+01	.1822+06	.0000	.0000	.7686+08
.3122+00	.7922+00	.3922+01	.9834+01	.1568+06	.0000	.0000	.7546+08
.3219+00	.7905+00	.3891+01	.1000+02	.1316+06	.0000	.0000	.7408+08
.3312+00	.7889+00	.3863+01	.1019+02	.1044+06	.0000	.0000	.7256+08
.3401+00	.7873+00	.3840+01	.1039+02	.7456+03	.0000	.0000	.7096+08
.3485+00	.7857+00	.3822+01	.1061+02	.2795+03	.0000	.0000	.6835+08
.3569+00	.7841+00	.3808+01	.1086+02	-.1982+03	.0000	.0000	.6581+08
.3647+00	.7826+00	.3792+01	.1112+02	-.7355+03	.0000	.0000	.6287+08
.3726+00	.7810+00	.3795+01	.1143+02	-.1440+06	.0000	.0000	.5950+08
.3798+00	.7795+00	.3797+01	.1178+02	-.2296+06	.0000	.0000	.5538+08
.3844+00	.7786+00	.3847+01	.1208+02	-.7158+06	.0000	.0000	.4636+08
.3880+00	.7778+00	.3574+01	.1233+02	-.6177+06	.0000	.0000	.3601+08
.3936+00	.7765+00	.2854+01	.1270+02	-.3538+06	.0000	.0000	.3488+08
.3960+00	.7757+00	.2357+01	.1291+02	-.1778+06	.0000	.0000	.3373+08
.3986+00	.7753+00	.1752+01	.1303+02	.3996+02	.0000	.0000	.3162+08
.3993+00	.7751+00	.1267+01	.1308+02	.1012+06	.0000	.0000	.2926+08
.3995+00	.7751+00	.1050+01	.1309+02	.1259+06	.0000	.0000	.2806+08
.3999+00	.7750+00	.1050+01	.1312+02	-.4635+03	.0000	.0000	.2393+08

8.3 SAMPLE PROBLEM 3 - SPACE SHUTTLE MAIN ENGINE

The Space Shuttle main engine is a throttelable pump fed hydrogen/oxygen system which produces on the order of 470,000 lb thrust and has the following characteristics:

Throat Radius	0.429475 ft
Area Ratio	77.5
Chamber Pressure	Variable
Propellant	
Fuel	H_2
Oxidizer	O_2
O/F Ratio	6.1

This sample problem analyzes the nozzle flow field starting from the throat assuming a sonic start line. The chemistry is assumed to be equilibrium throughout the nozzle. The TRAN72 input data are shown in Sample Case 1 of Section 4 of this report except that the second total pressure was 5.4 instead of 30. This difference in the TRAN72 data only slightly changes the pitot pressure calculation. For constant O/F or total enthalpy the second total pressure table is not used for any of the other calculations.

The nozzle geometry is specified using the point specification option of inputting the solid boundaries. The method of determination of the point input is the same as was used to set up sample cases 8.1 and 8.2. The remainder of the input data is very straightforward since only the nozzle is calculated, and neither a boundary layer nor plume restart was performed.

In the event that a boundary layer solution is desired, Ref. 4 contains a sample case which specifies the SSME nozzle wall temperature distribution required for a boundary layer calculation. The boundary layer for the SSME is fairly small compared to exit radius and probably would not significally affect the plume for the low altitude operating regime of the engine.

SAMPLE PROBLEM 3 INPUT DATA

Card							
1	1						
2	SCML NOZZLE PC=2[illegible]5						
3							
4	2	3[illegible]2.[illegible]9[illegible]	1[illegible]98[illegible]1	1[illegible]2[illegible]3	1[illegible]		12570
5	.429475	[illegible]					
7							
8	.000000	.429475	.[illegible]	.005876	.429577	.998390	
	.011744	.42[illegible]	3.[illegible]	.017598	.430397	4.998060	
	.023433	.431113	7.[illegible]826	.029234	.432132	8.998500	
	.035[illegible]	.433154	11.[illegible]1[illegible]	.041728	.434476	12.998240	
	.046[illegible]5	.435496	14.[illegible]7[illegible]	.052[illegible]24	.437715	17.000690	
	.057581	.43[illegible]62[illegible]	1[illegible]	.063[illegible]67	.441774	21.001140	
	.069476	.444[illegible]3	23.[illegible]14[illegible]	.0738[illegible]1	.446514	25.[illegible]3330	
	.07[illegible]3[illegible]	.449[illegible]1	26.99323	.081620	.450587	28.518229	
	.084177	.45[illegible]	29.5[illegible]11[illegible]	.086709	.453521	31.492370	
	.0[illegible]5214	.455[illegible]7	31.5[illegible]624	.091652	.456675	32.496800	
	.094143	.458267	33.49[illegible]	.096664	.459921	34.499210	
	.[illegible]9[illegible]956	.461627	3[illegible].49977	.101318	.463375	36.501860	
	.1[illegible]7369	.46753[illegible]	36.[illegible]6[illegible]4	.214778	.547821	36.652040	
	.322116	.6[illegible]59[illegible]	36.[illegible]2[illegible]	.429475	.702261	35.4174[illegible]0	
	.536644	.776942	34.[illegible]2[illegible]94	.644212	.849979	34.224965	
	.751551	.921446	33.64954	.85895	.991379	33.076580	
	.966319	1.[illegible]5782	32.51535	1.073697	1.126621	31.965120	
	1.181[illegible]56	1.19242	31.42349	1.288425	1.256642	30.885100	
	1.395754	1.319544	3[illegible].365[illegible]2	1.503163	1.381154	29.846830	
	1.610531	1.441456	2[illegible].3364[illegible]	1.7179[illegible]	1.5[illegible]621	28.839770	
	1.825269	1.555544	2[illegible].3462[illegible]	1.932677	1.6153[illegible]2	27.862060	
	2.[illegible]40[illegible]6	1.67[illegible]	27.38731	2.147375	1.725429	26.913510	
	2.254744	1.776[illegible]	26.4558[illegible]	2.362112	1.871232	26.002790	
	2.469481	1.882557	25.549[illegible]7	2.576851	1.932880	25.115017	
	2.684219	1.962221	24.67747	2.791588	2.[illegible]7[illegible]682	24.248670	
	2.899956	2.[illegible]7[illegible]	23.5315[illegible]	3.016325	2.124510	23.417510	
	3.113694	2.17[illegible]5	23.[illegible]41[illegible]	3.221[illegible]63	2.2146[illegible]	22.606140	
	3.328431	2.259636	22.[illegible]644	3.4358[illegible]	2.3[illegible]1613	21.814670	
	3.543169	2.343763	21.4376[illegible]	3.651537	2.385[illegible]5	21.054340	
	3.757906	2.42562	2[illegible].6745[illegible]	3.865275	2.465359	20.310180	
	3.972644	2.5[illegible]43[illegible]5	19.94679	4.080[illegible]13	2.542537	19.590440	
	4.187381	2.5[illegible]	19.23654	4.29475[illegible]	2.616739	18.885730	

ORIGINAL PAGE IS OF POOR QUALITY

SAMPLE PROBLEM 3 INPUT DATA (Concluded)

Card							
8	4.4[illegible]2219	2.6[illegible]7[illegible]	1[illegible].54732	4.5[illegible]	2.6[illegible]7[illegible]	18.2[illegible]67[illegible]
	4.72[illegible]225	2.71[illegible]64[illegible]	17.[illegible]447[illegible]	4.9[illegible]63	2.822[illegible]	16.8[illegible]7[illegible]10
	5.1537[illegible]	2.[illegible]4[illegible]	16.27[illegible]74[illegible]	5.368437	2.9466[illegible]	15.66346[illegible]
	5.583175	3.[illegible]5[illegible]4	15.[illegible]61720	5.797912	3.0611[illegible]	14.48298[illegible]
	6.[illegible]1265[illegible]	3.114[illegible]	13.[illegible]2[illegible]990	6.227387	3.166461	13.36[illegible]69[illegible]
	6.442125	3.[illegible]15[illegible]5	12.[illegible]21[illegible]7[illegible]	6.656662	3.263272	12.30[illegible]4[illegible]
	6.6716[illegible]	3.3[illegible]621	11.[illegible]	7.08637[illegible]	3.3[illegible]2[illegible]1[illegible]	11.30[illegible]31[illegible]
	7.3[illegible]1.75	3.392432	1[illegible].[illegible]11[illegible]	7.515813	3.43311[illegible]	1[illegible].338790
	7.73[illegible]55[illegible]	3.470945	[illegible].874[illegible]6[illegible]	7.945288	3.5[illegible]7[illegible]14	9.422410
	8.[illegible]52656	3.524394	[illegible].19466[illegible]	8.160[illegible]25	3.54136[illegible]	8.97963[illegible]
	8.267394	3.5579[illegible]7	[illegible].76[illegible]	8.374763	3.574[illegible]	8.542610
	8.5[illegible]	3.6[illegible]5[illegible]	[illegible].124[illegible]	8.69[illegible]	3.62[illegible]	7.91233[illegible]
	[illegible].[illegible]4227	3.6[illegible]454[illegible]	7.7[illegible]96[illegible]	8.9116[illegible]5	3.648[illegible]	7.50324[illegible]
	[illegible].[illegible]1[illegible]75	3.[illegible]4[illegible]1	7.3[illegible]4[illegible]	[illegible].233712	3.6[illegible]74	6.[illegible]4331
	9.341[illegible]1	3.[illegible]1476	[illegible].71512[illegible]	[illegible].4484[illegible]	3.7137[illegible]	6.52146[illegible]
	[illegible].[illegible]631[illegible]	3.7[illegible]7211	6.141[illegible]	9.77[illegible]556	3.7484[illegible]	[illegible].05472[illegible]
	[illegible].[illegible]77[illegible]25	3.7[illegible]	5.76[illegible]6[illegible]	1[illegible].1[illegible]61[illegible]	3.7[illegible]84[illegible]	5.3092[illegible]

Card							
							1 [illegible].
8a	3	1[illegible].					2 [illegible].
9	2						
10	H2/O2/H20 EQUIV			[illegible]S	1 2		
					[illegible].113		
20a	0.[illegible]	.	1.[illegible]1	.		[illegible].	2.
22	4[illegible].[illegible]	[illegible].	.	.	15[illegible].		
23	.25	.[illegible]	1[illegible].	.[illegible]	7.	.[illegible]	

SAMPLE PROBLEM 3 OUTPUT

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 1

SSME NOZZLE PC=2850

RUN CONTROL PARAMETERS

ICON(1)	ICON(2)	ICON(3)	ICON(4)	ICON(5)	ICON(6)	ICON(7)	ICON(8)
2	0	30	20059	1	98	1	203

ICON(9)	ICON(10)	ICON(11)	ICON(12)	ICON(13)	ICON(14)	ICON(15)	ICON(16)
0	0	0	1	0	0	0	12570

FLOW CALCULATIONS ARE IN ENGLISH UNITS WITH THE R,X COORDINATES IN FEET

THE FLOW FIELD DATA WILL BE WRITTEN ON TAPE

UPPER BOUNDARY POINTS

TYPE	ITRANS	X	R	THETA
2	0	.00000	.42947+00	.00000
2	0	.50760-02	.42958+00	.17425-01
2	0	.11766-01	.42988+00	.52372-01
2	0	.17590-01	.43040+00	.87233-01
2	0	.23430-01	.43111+00	.12220+00
2	0	.29234-01	.43203+00	.15705+00
2	0	.35003-01	.43315+00	.19202+00
2	0	.40728-01	.43448+00	.22686+00
2	0	.46405-01	.43600+00	.26176+00
2	0	.52024-01	.43772+00	.29672+00
2	0	.57581-01	.43963+00	.33162+00
2	0	.63067-01	.44173+00	.36654+00
2	0	.68476-01	.44403+00	.40143+00
2	0	.73801-01	.44651+00	.43639+00
2	0	.79038-01	.44918+00	.47112+00
2	0	.81620-01	.45058+00	.49756+00
2	0	.84177-01	.45203+00	.51489+00
2	0	.86709-01	.45352+00	.53219+00
2	0	.89214-01	.45506+00	.54989+00
2	0	.91692-01	.45663+00	.56718+00
2	0	.94143-01	.45826+00	.58467+00
2	0	.96564-01	.45992+00	.60212+00
2	0	.98956-01	.46163+00	.61959+00
2	0	.10132+00	.46337+00	.63708+00
2	0	.10737+00	.46793+00	.64523+00
2	0	.21474+00	.54782+00	.63970+00
2	0	.32211+00	.62591+00	.62881+00
2	0	.42947+00	.70226+00	.61815+00
2	0	.53684+00	.77696+00	.60774+00
2	0	.64421+00	.84998+00	.59734+00
2	0	.75158+00	.92145+00	.58730+00
2	0	.85895+00	.99138+00	.57730+00
2	0	.96632+00	.10598+01	.56750+00
2	0	.10737+01	.11268+01	.55790+00
2	0	.11811+01	.11926+01	.54864+00

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 2

SSME NOZZLE PC=2850

UPPER BOUNDARY POINTS

TYPE	ITRANS	X	R	THETA
2	0	.12884+01	.12566+01	.53905+00
2	0	.13958+01	.13195+01	.52497+00
2	0	.15032+01	.13812+01	.52093+00
2	0	.16105+01	.14415+01	.51202+00
2	0	.17179+01	.15006+01	.50335+00
2	0	.18253+01	.15585+01	.49473+00
2	0	.19326+01	.16153+01	.48628+00
2	0	.20400+01	.16709+01	.47800+00
2	0	.21474+01	.17254+01	.46973+00
2	0	.22547+01	.17789+01	.46176+00
2	0	.23621+01	.18312+01	.45383+00
2	0	.24695+01	.18826+01	.44592+00
2	0	.25768+01	.19329+01	.43834+00
2	0	.26842+01	.19822+01	.43070+00
2	0	.27916+01	.20306+01	.42322+00
2	0	.28990+01	.20780+01	.41070+00
2	0	.30063+01	.21245+01	.40871+00
2	0	.31137+01	.21701+01	.40150+00
2	0	.32211+01	.22148+01	.39455+00
2	0	.33284+01	.22586+01	.38761+00
2	0	.34358+01	.23016+01	.38079+00
2	0	.35432+01	.23438+01	.37409+00
2	0	.36505+01	.23851+01	.36747+00
2	0	.37579+01	.24256+01	.36091+00
2	0	.38653+01	.24654+01	.35448+00
2	0	.39726+01	.25043+01	.34814+00
2	0	.40800+01	.25425+01	.34192+00
2	0	.41874+01	.25800+01	.33578+00
2	0	.42947+01	.26167+01	.32962+00
2	0	.44021+01	.26528+01	.32371+00
2	0	.45095+01	.26881+01	.31777+00
2	0	.47242+01	.27566+01	.30621+00
2	0	.49390+01	.28225+01	.29491+00
2	0	.51537+01	.28858+01	.28398+00
2	0	.53684+01	.29467+01	.27338+00
2	0	.55832+01	.30051+01	.26288+00
2	0	.57979+01	.30611+01	.25278+00
2	0	.60127+01	.31149+01	.24297+00
2	0	.62274+01	.31665+01	.23335+00
2	0	.64421+01	.32159+01	.22396+00
2	0	.66569+01	.32633+01	.21483+00
2	0	.68716+01	.33086+01	.20594+00
2	0	.70863+01	.33520+01	.19723+00
2	0	.73011+01	.33935+01	.18870+00
2	0	.75158+01	.34331+01	.18045+00
2	0	.77305+01	.34709+01	.17235+00

SAMPLE PROBLEM 3 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 3

SSME NOZZLE PC=2450

UPPER BOUNDARY POINTS

TYPE	ITRANS	X	R	THETA			
2	0	.79453+01	.35070+01	.16465+00			
2	0	.80527+01	.35244+01	.16042+00			
2	0	.81600+01	.35414+01	.15672+00			
2	0	.82674+01	.35579+01	.15291+00			
2	0	.83748+01	.35740+01	.14910+00			
2	0	.85895+01	.36051+01	.14180+00			
2	0	.86969+01	.36200+01	.13810+00			
2	0	.88042+01	.36345+01	.13456+00			
2	0	.89116+01	.36487+01	.13096+00			
2	0	.90190+01	.36625+01	.12748+00			
2	0	.92337+01	.36888+01	.12050+00			
2	0	.93411+01	.37015+01	.11720+00			
2	0	.94484+01	.37138+01	.11382+00			
2	0	.96632+01	.37372+01	.10720+00			
2	0	.97706+01	.37484+01	.10393+00			
2	0	.98779+01	.37593+01	.10067+00			
2	1	.10103+02	.37800+01	.94235-01			
3	0	.10000+03	.00000	.00000	.00000	.00000	.10000+04

LOWER BOUNDARY

TYPE	ITRANS	A	B	C	D	E	MAX
2	0	.00000	.00000	.00000	.00000	.00000	.20000+04

STARTING LINE INFO

X	R	M	THETA	S	MACH ANGLE	SHOCK ANGLE	O/P
.00000	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.14809-01	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.29619-01	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.44428-01	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.59238-01	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.74047-01	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.88857-01	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.10367+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.11848+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.13329+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.14809+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.16290+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.17771+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.19252+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.20733+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.22214+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.23695+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.25176+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.26657+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.28138+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.29619+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.31100+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.32581+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.34062+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.35543+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.37024+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.38505+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 5

SSME NOZZLE PC=2450

STARTING LINE INFO

X	R	M	THETA	S	MACH ANGLE	SHOCK ANGLE	O/P
.39986+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.41467+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07
.42947+00	.00000	.10100+01	.00000	.00000	.81932+02	.00000	-.57507+07

RUN CUTOFF INFORMATION

UPPER BOUNDARY						LOWER BOUNDARY					
R=	.40000+02	X=	.00000	THETA=	.00000	R=	.00000	X=	.15000+04	THETA=	.90000+02

THE MESH CONSTRUCTION WILL BE CONTROLED BY THE FOLLOWING VARIABLES

DL INTERIOR= .250+00 DL AXIS= .350+00 DL LINE= .100+03 DL DELETE= .500-02 DEG P.M.= .300+01 F= .800+00

ORIGINAL PAGE IS
OF POOR QUALITY

SAMPLE PROBLEM 3 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 6

SSME NOZZLE PC=2850

LINE	POINT	DSCRIP - REGIME	R / MACH ANGLE / TO*	X / PRESSURE / PO*	W / DENSITY / S*	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
1	1	INPUT - CONTIN	.00000	.00000	.10100+01	.00000	.00000	.51197+04	-.5 507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	2	INPUT - CONTIN	.14809-01	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	3	INPUT - CONTIN	.29619-01	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	4	INPUT - CONTIN	.44428-01	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	5	INPUT - CONTIN	.59238-01	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	6	INPUT - CONTIN	.74047-01	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	7	INPUT - CONTIN	.88857-01	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	8	INPUT - CONTIN	.10367+00	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	9	INPUT - CONTIN	.11848+00	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	10	INPUT - CONTIN	.13329+00	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	11	INPUT - CONTIN	.14809+00	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 7

SSME NOZZLE PC=2850

LINE	POINT	DSCRIP - REGIME	R / MACH ANGLE / TO*	X / PRESSURE / PO*	W / DENSITY / S*	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
1	12	INPUT - CONTIN	.16290+00	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	13	INPUT - CONTIN	.17771+00	.00000	.10100+01	.00000	.00000	.51197+04	-. [illegible]7+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	14	INPUT - CONTIN	.19252+00	0000	.10100+01	.00000	.00000	.51197+[illegible]	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	15	INPUT - CONTIN	.20733+00	.00000	.10100+01	.00000	.00000	.51197+0[illegible]	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	16	INPUT - CONTIN	.22214+00	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+0[illegible]	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	17	INPUT - CONTIN	.23695+00	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	18	INPUT - CONTIN	.25176+00	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	19	INPUT - CONTIN	.26657+00	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	20	INPUT - CONTIN	.28138+00	.00000	.10100+01	.00000	.00000	.51197+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					
1	21	INPUT - CONTIN	.29619+00	.00000	.10100+01	.00000	.00000	.511[illegible]7+04	.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.1[illegible]+01		
			.66380+04	.29500+04	.36813-02					
1	22	INPUT - CONTIN	.31100+00	.00000	.10100+01	.00000	.00000	.511[illegible]+04	-.57507+07	0
			.81932+02	.16793+04	.10779-01	.62474+04	.35910+04	.11454+01		
			.66380+04	.29500+04	.36813-02					

SAMPLE PROBLEM 3 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 8

SSME NOZZLE PC:2950

LINE	POINT	DSCRIP - REGIME	X MACH ANGLE T0*	R PRESSURE P0*	P DENSITY S*	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
1	23	INPUT - CONTIN	.32581+00 .81932+02 .66380+04	.00000 .16793+04 .29500+04	.10100+01 .10779-01 .36813-02	.00000 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	0
1	24	INPUT - CONTIN	.34062+00 .81932+02 .66380+04	.00000 .16793+04 .29500+04	.10100+01 .10779-01 .36813-02	.00000 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	0
1	25	INPUT - CONTIN	.35543+00 .81932+02 .66380+04	.00000 .16793+04 .29500+04	.10100+01 .10779-01 .36813-02	.00000 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	0
1	26	INPUT - CONTIN	.37024+00 .81932+02 .66380+04	.00000 .16793+04 .29500+04	.10100+01 .10779-01 .36813-02	.00000 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	0
1	27	INPUT - CONTIN	.3[illegible]+00 [illegible] .66[illegible]+04	.00000 .16793+04 .29500+04	.10100+01 .10779-01 .36813-02	.00000 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	0
1	28	INPUT - CONTIN	.39986+00 .81932+02 .66380+04	.00000 .16793+04 .29500+04	.10100+01 .10779-01 .36813-02	.00000 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	0
1	29	INPUT - CONTIN	.41467+00 .81932+02 .66380+04	.00000 .16793+04 .29500+04	.10100+01 .10779-01 .36813-02	.00000 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	0
1	30	INPUT - CONTIN	.42947+00 .81932+02 .66380+04	.00000 .16793+04 .29500+04	.10100+01 .10779-01 .36813-02	.00000 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	0

THE MASS FLOW RATE IS = .102683+04

MOMENTUM INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	ISP
-.30393+06	.00000	.00000	.26532+03

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 9

SSME NOZZLE PC:2950

LINE	POINT	DSCRIP - REGIME	X MACH ANGLE T0*	R PRESSURE P0*	P DENSITY S*	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
2	1	WALL - CONTIN	.00000 .81932+02 .66380+04	.16794-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	.00000 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	2	INTER - CONTIN	.14809-01 .81932+02 .66380+04	.16794-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96825-07 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	3	INTER - CONTIN	.29619-01 .81932+02 .66380+04	.16794-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96825-07 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	4	INTER - CONTIN	.44428-01 .81932+02 .66380+04	.16794-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96825-07 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	5	INTER - CONTIN	.59238-01 .81932+02 .66380+04	.16794-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96825-07 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	6	INTER - CONTIN	.74047-01 .81932+02 .66380+04	.16794-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96825-07 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	7	INTER - CONTIN	.88857-01 .81932+02 .66380+04	.16794-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96825-07 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	8	INTER - CONTIN	.10367+00 .81932+02 .66380+04	.16794-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96825-07 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	9	INTER - CONTIN	.11848+00 .81932+02 .66380+04	.16794-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96825-07 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	10	INTER - CONTIN	.13329+00 .81932+02 .66380+04	.16794-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96825-07 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	11	INTER - CONTIN	.14809+00 .81932+02 .66380+04	.16794-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96825-07 .62676+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1

SAMPLE PROBLEM 3 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 10

SSME NOZZLE PC=2050

LINE	POINT	DSCRIP - REGIME	R MACH ANGLE TO*	X PRESSURE PO*	M DENSITY SO	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	D/F SHOCK ANGLE	ITR
2	12	INTER - CONTIN	.16290+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	13	INTER - CONTIN	.17771+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	14	INTER - CONTIN	.19252+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	15	INTER - CONTIN	.20733+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	16	INTER - CONTIN	.22214+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	17	INTER - CONTIN	.23695+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	18	INTER - CONTIN	.25176+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	19	INTER - CONTIN	.26657+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	20	INTER - CONTIN	.28138+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	21	INTER - CONTIN	.29619+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	22	INTER - CONTIN	.31100+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 11

SSME NOZZLE PC=2050

LINE	POINT	DSCRIP - REGIME	R MACH ANGLE TO*	X PRESSURE PO*	M DENSITY SO	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	D/F SHOCK ANGLE	ITR
2	23	INTER - CONTIN	.32581+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	24	INTER - CONTIN	.34062+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	25	INTER - CONTIN	.35543+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	26	INTER - CONTIN	.37024+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	27	INTER - CONTIN	.38505+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	28	INTER - CONTIN	.39986+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	29	INTER - CONTIN	.41467+00 .81932+02 .66380+04	.16799-02 .16793+04 .29500+04	.10100+01 .10779-01 .40494-02	-.96025-07 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1
2	30	WALL - CONTIN	.42950+00 .74766+02 .66380+04	.16437-02 .16319+04 .29498+04	.10756+01 .10515-01 .21525+00	.27922+00 .62273+04	.00000 .35847+04	.52941+04 .11456+01	-.57507+07	7

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DFLFY	ISP
-.30305+06	.00000	.00000	-.10365+02	.00000	.29539+03

PERCENT CHANGE IN MASS, MOMENTUM AND ENERGY NUMERICAL INTEGRATION FOR LINE 2 RELATIVE TO THE START LINE
THE PERCENT CHANGE IN MASS FLOW IS : .11730-01
PERCENT CHANGE IN MOMENTUM IS : .10646-01 ISP : -.51730-02
PERCENT CHANGE IN ENERGY IS : .00000

LINE	POINT	DSCRIP - REGIME	R MACH ANGLE TO*	X PRESSURE PO*	M DENSITY SO	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	D/F SHOCK ANGLE	ITR
3	1	WALL - CONTIN	.00000 .81932+02 .66380+04	.33509-02 .16793+04 .29500+04	.10100+01 .10779-01 .46175-02	.00000 .62474+04	.00000 .35910+04	.51197+04 .11454+01	-.57507+07	1

SAMPLE PROBLEM 3 OUTPUT (Cont'd)

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                SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

                                           CASE NO.   0                                              PAGE   76

 SSME NOZZLE PC:2950

LINE POINT  DSCRIP - REGIME      R            X            M           THETA        ENTROPY      VELOCITY      O/F        ITR
                             MACH ANGLE    PRESSURE     DENSITY     TEMPERATURE   GAS CONST.   LOCAL GAMMA  SHOCK ANGLE
                                T0*          P0*          S*

 48     1  WALL   - CONTIN    .00000       .96520-01    .10555+01    .00000       .00000       .53333+04   -.57507+07     1
                              .71363+02    .15970+00    .10175-01    .62176+04    .35871+04    .11057+01
                              .66390+04    .29494+04    .70010+00

 48    30  WALL   - CONTIN    .44340+00    .67190-01    .17063+01    .22525+02    .00000       .87118+04   -.57507+07     4
                              .34936+02    .60616+03    .44352-02    .55711+04    .35375+04    .11511+01
                              .65930+04    .23752+04    .76045+03

                                           PRESSURE INTEGRATION RESULTS
                                FORCEX       FORCEY       TORQZ        DELFX        DELFY        ISP
                              -.30872+06    .00000       .00000      -.23089+03    .00003       .30007+03

 49     1  WALL   - CONTIN    .00000       .10063+00    .10603+01    .00000       .00000       .53557+04   -.57507+07     3
                              .70540+02    .15896-04    .10276-01    .62848+04    .3 347+04    .11050+01
                              .66390+04    .29492+04    .44291+00

 49    30  WALL   - CONTIN    .44440+00    .69452-01    .17690+01    .23347+02    .00000       .84836+04   -.57597+07     4
                              .34684+02    .58207+03    .42784-02    .55468+04    .35384+04    .11514+01
                              .65896+04    .22375+04    .81679+03

                                           PRESSURE INTEGRATION RESULTS
                                FORCEX       FORCEY       TORQZ        DELFX        DELFY        ISP
                              -.30896+06    .00000       .00000      -.23910+03    .00000       .30030+03

 50     1  WALL   - CONTIN    .00000       .10498+00    .10650+01    .00000       .00000       .53797+04   -.57507+07     3
                              .69870+02    .15803+04    .10276-01    .62048+04    .35867+04    .11054+01
                              .66390+04    .29990+04    .11996+01

 50    30  WALL   - CONTIN    .44557+00    .71279-01    .17944+01    .24243+02    .00003       .84909+04   -.57507+07     4
                              .34869+02    .55934+03    .41368-02    .55108+04    .35248+04    .11527+01
                              .65861+04    .22902+04    .87656+03

                                           PRESSURE INTEGRATION RESULTS
                                FORCEX       FORCEY       TORQZ        DELFX        DELFY        ISP
                              -.30921+06    .00000       .00000      -.24967+03    .00000       .30054+03

 51     1  WALL   - CONTIN    .00000       .10936+00    .10709+01    .00000       .00000       .54053+04   -.57507+07     3
                              .69515+02    .15705+04    .10172-01    .62045+04    .35858+04    .11059+01
                              .66390+04    .29407+04    .15091+01

 51    30  WALL   - CONTIN    .44670+00    .74160-01    .18197+01    .25183+02    .00000       .85961+04   -.57507+07     4
                              .34336+02    .57601+03    .39884-02    .54891+04    .35269+04    .11527+01
                              .65023+04    .22570+04    .94015+03

                                           PRESSURE INTEGRATION RESULTS
                                FORCEX       FORCEY       TORQZ        DELFX        DELFY        ISP
                              -.30946+06    .00000       .00000      -.24984+03    .00000       .30079+03

                SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

                                           CASE NO.   0                                              PAGE   81

 SSME NOZZLE PC:2950

LINE POINT  DSCRIP - REGIME      R            X            M           THETA        ENTROPY      VELOCITY      O/F        ITR
                             MACH ANGLE    PRESSURE     DENSITY     TEMPERATURE   GAS CONST.   LOCAL GAMMA  SHOCK ANGLE
                                T0*          P0*          S*

104     1  WALL   - CONTIN    .00000       .10129+02    .56683+01    .00000       .00000       .15351+05   -.57507+07     2
                              .10161+02    .55235+00    .13901-04    .16505+04    .34666+04    .12819+01
                              .55630+04    .22104+02    .10140+05

104    30  WALL   - CONTIN    .37660+01    .99402+01    .42203+01    .56527+01    .00000       .14211+05   -.57507+07     2
                              .13707+02    .54736+01    .86010-04    .26415+04    .34666+04    .12373+01
                              .59462+04    .11883+03    .11675+05

                                           PRESSURE INTEGRATION RESULTS
                                FORCEX       FORCEY       TORQZ        DELFX        DELFY        ISP
                              -.47472+06    .00000       .00000      -.52192+03    .00000       .46192+03

105     1  WALL   - CONTIN    .00000       .10394+02    .54566+01    .00000       .00000       .15395+05   -.57507+07     2
                              .10183+02    .5 161+00    .14078-04    .16565+04    .34666+04    .12815+01
                              .55650+04    .22444+02    .10093+05

105    30  WALL   - CONTIN    .37800+01    .10103+02    .42335+01    .53902+01    .00000       .14226+05   -.57507+07     1
                              .13663+02    .53481+01    .84619-04    .26316+04    .34666+04    .12377+01
                              .59424+04    .11685+03    .11738+05

                                           PRESSURE INTEGRATION RESULTS
                                FORCEX       FORCEY       TORQZ        DELFX        DELFY        ISP
                              -.47500+06    .00000       .00000      -.27409+03    .00000       .46169+03

          PERCENT CHANGE IN MASS, MOMENTUM AND ENERGY NUMERICAL INTEGRATION FOR LINE105 RELATIVE TO THE START LINE
   THE PERCENT CHANGE IN MASS FLOW IS :      -.476321-01
  PERCENT CHANGE IN MOMENTUM IS :    .24924+03     ISP :    .20243+01
   PERCENT CHANGE IN ENERGY IS :     .00000
EXIT PLANE NORMAL START LINE

           .6000000     .1027293+02  .5661674+01  .0000000     .0000000    -.5750719+07
           .2301342+00  .1027334+02  .5627610+01 -.1983518+00  .0000000    -.5750719+07
           .4687518+00  .1027424+02  .5557808+01 -.2479560+00  .0000000    -.5750719+07
           .6838680+00  .1027477+02  .5485219+01 -.3500930-01  .0000000    -.5750719+07
           .8866190+00  .1027405+02  .5425431+01  .4410773+00  .0000000    -.5750719+07
           .1080580+01  .1027153+02  .5373992+01  .1052477+01  .0000000    -.5750719+07
           .1267287+01  .1026709+02  .5323067+01  .1670029+01  .0000000    -.5750719+07
           .1446621+01  .1026099+02  .5268638+01  .2229717+01  .0000000    -.5750719+07
           .1617952+01  .1025365+02  .5209555+01  .7685530+01  .0000000    -.5750719+07
```

SAMPLE PROBLEM 3 OUTPUT (Cont'd)

.1700770+01	.1029550+02	.5196256+01	.3049956+01	.0000000	-.5750719+07
.1934954+01	.1023691+02	.5079055+01	.3315172+01	.0000000	-.5750719+07
.2080532+01	.1022726+02	.5011702+01	.3502013+01	.0000000	-.5750719+07
.2218150+01	.1021969+02	.4943133+01	.3624970+01	.0000000	-.5750719+07
.2347929+01	.1021130+02	.4875957+01	.3704050+01	.0000000	-.5750719+07
.2430442+01	.1020330+02	.4811597+01	.3766373+01	.0000000	-.5750719+07
.2580492+01	.1019569+02	.4750914+01	.3823394+01	.0000000	-.5750719+07
.2694670+01	.1018826+02	.4694261+01	.3887856+01	.0000000	-.5750719+07
.2801898+01	.1018109+02	.4641526+01	.3969120+01	.0000000	-.5750719+07
.2902730+01	.1017397+02	.4592339+01	.4051013+01	.0000000	-.5750719+07
.2999676+01	.1016702+02	.4547181+01	.4149154+01	.0000000	-.5750719+07
.3093195+01	.1016015+02	.4505043+01	.4256307+01	.0000000	-.5750719+07
.3183616+01	.1015333+02	.4465197+01	.4369073+01	.0000000	-.5750719+07
.3271118+01	.1014654+02	.4427366+01	.4485589+01	.0000000	-.5750719+07
.3356295+01	.1013979+02	.4391043+01	.4615600+01	.0000000	-.5750719+07
.3439659+01	.1013304+02	.4358300+01	.4752260+01	.0000000	-.5750719+07
.3519502+01	.1012622+02	.4326117+01	.4890627+01	.0000000	-.5750719+07
.3597206+01	.1011947+02	.4295026+01	.5031039+01	.0000000	-.5750719+07
.3674929+01	.1011253+02	.4266272+01	.5179726+01	.0000000	-.5750719+07
.3746999+01	.1010507+02	.4242643+01	.5301157+01	.0000000	-.5750719+07
.3780849+01	.1010261+02	.4233509+01	.5399240+01	.0000000	-.5750719+07

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.47527+06	.00000	.00000	-.27409+03	.00000	.46195+03

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 62

SSME NOZZLE PC=2050

LINE	POINT	DSCRIP - REGIME	X MACH ANGLE TO*	R PRESSURE PO*	M DENSITY S*	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	O/F SHOCK ANGLE	ITR
199	1	WALL - CONTIN	.00000	.10129+02	.56603+01	.00000	.00000	.15351+05	-.57507+07	2
			.10161+02	.55235+00	.11903-04	.16505+04	.34666+04	.12819+01		
			.55630+04	.22100+02	.18140+05					
199	2	INTER - CONTIN	.23862+00	.10129+02	.56320+01	-.13693+00	.00000	.15333+05	-.57507+07	2
			.10226+02	.58021+00	.14483-04	.16688+04	.34666+04	.12808+01		
			.55714+04	.22946+02	.17999+05					
199	3	INTER - CONTIN	.46935+00	.10130+02	.55584+01	-.15915+00	.00000	.15292+05	-.57507+07	2
			.10364+02	.64585+00	.15717-04	.17064+04	.34666+04	.12790+01		
			.55899+04	.24898+02	.17697+05					
199	4	INTER - CONTIN	.68393+00	.10130+02	.54810+01	.51351-01	.00000	.15247+05	-.57507+07	2
			.10512+02	.72370+00	.17200-04	.17488+04	.34666+04	.12770+01		
			.56095+04	.27096+02	.17356+05					
199	5	INTER - CONTIN	.88597+00	.10129+02	.54177+01	.52974+00	.00000	.15209+05	-.57507+07	2
			.10637+02	.79499+00	.18526-04	.17826+04	.34666+04	.12754+01		
			.56256+04	.29048+02	.17084+05					
199	6	INTER - CONTIN	.10779+01	.10126+02	.53695+01	.11412+01	.00000	.15177+05	-.57507+07	2
			.10743+02	.86758+00	.19725-04	.18123+04	.34666+04	.12739+01		
			.56392+04	.30803+02	.16855+05					
199	7	INTER - CONTIN	.12630+01	.10122+02	.53173+01	.17725+01	.00000	.15144+05	-.57507+07	2
			.10848+02	.92936+00	.20962-04	.18416+04	.34666+04	.12725+01		
			.56523+04	.32605+02	.16673+05					
199	8	INTER - CONTIN	.14409+01	.10115+02	.52592+01	.23448+01	.00000	.15109+05	-.57507+07	2
			.10961+02	.10084+01	.22340-04	.18733+04	.34666+04	.12710+01		
			.56662+04	.34629+02	.16399+05					
199	9	INTER - CONTIN	.16111+01	.10100+02	.52010+01	.28261+01	.00000	.15071+05	-.57507+07	2
			.11085+02	.11019+01	.23945-04	.19083+04	.34666+04	.12691+01		
			.56813+04	.36967+02	.16145+05					
199	10	INTER - CONTIN	.17729+01	.10099+02	.51306+01	.32091+01	.00000	.15024+05	-.57507+07	2
			.11222+02	.12172+01	.25667-04	.19467+04	.34666+04	.12675+01		
			.56974+04	.39657+02	.15873+05					
199	11	INTER - CONTIN	.19204+01	.10090+02	.50773+01	.34991+01	.00000	.14982+05	-.57507+07	2
			.11366+02	.13409+01	.28017-04	.19881+04	.34666+04	.12656+01		
			.57194+04	.42707+02	.15596+05					

SAMPLF PROBLEM 3 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 63

SSME NOZZLE PC:2050

LINE	POINT	DSCRIP - REGIME	R / MACH ANGLE / TO*	X / PRESSURE / PO*	M / DENSITY / S*	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
144	12	INTER - CONTIN	.20715+01	.10081+02	.50061+01	.37068+01	.00000	.14930+05	-.57507+07	2
			.11573+02	.14887+01	.30436-04	.70320+04	.34666+04	.12633+01		
			.57370+04	.46111+02	.15289+05					
144	13	INTER - CONTIN	.22087+01	.10072+02	.49303+01	.38679+01	.00000	.14883+05	-.57507+07	2
			.11683+02	.16558+01	.33106-04	.20776+04	.34666+04	.12611+01		
			.57496+04	.49039+02	.14989+05					
144	14	INTER - CONTIN	.23382+01	.10063+02	.48716+01	.39420+01	.00000	.14831+05	-.57507+07	2
			.11845+02	.18800+01	.35948-04	.21278+04	.34666+04	.12598+01		
			.57673+04	.53876+02	.14693+05					
144	15	INTER - CONTIN	.24604+01	.10054+02	.48079+01	.40130+01	.00000	.14779+05	-.57507+07	2
			.12076+02	.20382+01	.39022-04	.21667+04	.34666+04	.12566+01		
			.57893+04	.57985+02	.14487+05					
144	16	INTER - CONTIN	.25764+01	.10046+02	.47467+01	.40757+01	.00000	.14729+05	-.57507+07	2
			.12162+02	.22670+01	.42153-04	.22183+04	.34666+04	.12544+01		
			.58004+04	.62241+02	.14135+05					
144	17	INTER - CONTIN	.26864+01	.10038+02	.46898+01	.41432+01	.00000	.14680+05	-.57507+07	2
			.12312+02	.24636+01	.45336-04	.22572+04	.34666+04	.12522+01		
			.58155+04	.66527+02	.13880+05					
144	18	INTER - CONTIN	.27914+01	.10031+02	.46368+01	.42213+01	.00000	.14634+05	-.57507+07	2
			.12455+02	.26852+01	.48535-04	.22982+04	.34666+04	.12502+01		
			.58296+04	.70806+02	.13692+05					
144	19	INTER - CONTIN	.28920+01	.10023+02	.45874+01	.43103+01	.00000	.14589+05	-.57507+07	2
			.12591+02	.29115+01	.51786-04	.23373+04	.34666+04	.12483+01		
			.58420+04	.75062+02	.13419+05					
144	20	INTER - CONTIN	.29886+01	.10016+02	.45421+01	.44098+01	.00000	.14546+05	-.57507+07	2
			.12718+02	.31421+01	.55010-04	.23777+04	.34666+04	.12469+01		
			.58559+04	.79364+02	.13276+05					
144	21	INTER - CONTIN	.30818+01	.10009+02	.44997+01	.45157+01	.00000	.14505+05	-.57507+07	2
			.12840+02	.33772+01	.58299-04	.24062+04	.34666+04	.12457+01		
			.58674+04	.83665+02	.13005+05					
144	22	INTER - CONTIN	.31719+01	.10001+02	.44578+01	.46324+01	.00000	.14466+05	-.57507+07	2
			.12957+02	.36151+01	.61586-04	.24484+04	.34666+04	.12446+01		
			.58786+04	.87935+02	.12816+05					

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 64

SSME NOZZLE PC:2050

LINE	POINT	DSCRIP - REGIME	R / MACH ANGLE / TO*	X / PRESSURE / PO*	M / DENSITY / S*	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
144	23	INTER - CONTIN	.32591+01	.99982+01	.44216+01	.47467+01	.00000	.14427+05	-.57507+07	2
			.13071+02	.38598+01	.64921-04	.24897+04	.34666+04	.12437+01		
			.58893+04	.92237+02	.12636+05					
144	24	INTER - CONTIN	.33438+01	.99870+01	.43857+01	.48728+01	.00000	.14390+05	-.57507+07	2
			.13180+02	.41061+01	.68236-04	.24996+04	.34666+04	.12428+01		
			.58995+04	.96486+02	.12463+05					
144	25	INTER - CONTIN	.34259+01	.99800+01	.43522+01	.50117+01	.00000	.14355+05	-.57507+07	2
			.13286+02	.43507+01	.71592-04	.25279+04	.34666+04	.12419+01		
			.59089+04	.10063+03	.12309+05					
144	26	INTER - CONTIN	.35063+01	.99728+01	.43197+01	.51498+01	.00000	.14320+05	-.57507+07	2
			.13385+02	.46023+01	.74882-04	.25557+04	.34666+04	.12404+01		
			.59181+04	.10482+03	.12149+05					
144	27	INTER - CONTIN	.35837+01	.99657+01	.42892+01	.52893+01	.00000	.14287+05	-.57507+07	2
			.13482+02	.48531+01	.78069-04	.25823+04	.34666+04	.12395+01		
			.59267+04	.10893+03	.12004+05					
144	28	INTER - CONTIN	.36609+01	.99585+01	.42595+01	.54376+01	.00000	.14255+05	-.57507+07	2
			.13578+02	.51108+01	.81180-04	.26088+04	.34666+04	.12386+01		
			.59351+04	.11308+03	.11862+05					
144	29	INTER - CONTIN	.37324+01	.99516+01	.42325+01	.55787+01	.00000	.14225+05	-.57507+07	2
			.13666+02	.53578+01	.84563-04	.26325+04	.34666+04	.12377+01		
			.59427+04	.11701+03	.11733+05					
144	30	WALL - CONTIN	.37808+01	.10103+02	.42375+01	.53992+01	.00000	.14226+05	-.57507+07	2
			.13643+02	.53641+01	.84619-04	.26314+04	.34666+04	.12377+01		
			.59424+04	.11685+03	.11738+05					
144	31	PRN-MR - CONTIN	.37808+01	.10103+02	.43825+01	.81000+01	.00000	.14387+05	-.57507+07	2
			.13180+02	.41289+01	.68542-04	.25023+04	.34666+04	.12426+01		
			.59004+04	.96876+02	.12498+05					
144	32	PRN-MR - CONTIN	.37808+01	.10103+02	.45394+01	.10801+02	.00000	.14584+05	-.57507+07	2
			.12776+02	.31570+01	.55270-04	.23769+04	.34666+04	.12468+01		
			.58562+04	.79639+02	.13193+05					
144	33	PRN-MR - CONTIN	.37808+01	.10103+02	.47085+01	.13502+02	.00000	.14696+05	-.57507+07	2
			.12242+02	.23988+01	.44243-04	.22578+04	.34666+04	.12528+01		
			.58105+04	.65087+02	.13964+05					

SAMPLE PROBLEM 3 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 65

SSME NOZZLE PC=2850

LINE	POINT	DSCRIP - REGIME	R / MACH ANGLE / TP*	X / PRESSURE / PO*	W / DENSITY / S*	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
144	34	PRN-MR - CONTIN	.37800+01	.10103+02	.49899+01	.16202+02	.00000	.14985+05	-.57507+07	2
			.11802+02	.17889+01	.35195-04	.21113+04	.34666+04	.12599+01		
			.57626+04	.52731+02	.14772+05					
144	35	PRN-MR - CONTIN	.37800+01	.10103+02	.50822+01	.18923+02	.00000	.14989+05	-.57507+07	2
			.11358+02	.13226+01	.27713-04	.19896+04	.34666+04	.12657+01		
			.57171+04	.42277+02	.15625+05					
144	36	PRN-MR - CONTIN	.37800+01	.10103+02	.52803+01	.21604+02	.00000	.15129+05	-.57507+07	2
			.10900+02	.96595+00	.21597-04	.18542+04	.34656+04	.12718+01		
			.56500+04	.33525+02	.16575+05					
144	37	PRN-MR - CONTIN	.37800+01	.10103+02	.55092+01	.24305+02	.00000	.15263+05	-.57507+07	2
			.10458+02	.69638+00	.18644-04	.17329+04	.34666+04	.12777+01		
			.56029+04	.26275+02	.17476+05					

PREVIOUSLY NOTED ERRORS HAVE PROPAGATED TO LOWER BOUNDARY, OR PROBLEM LIMITS HAVE BEEN REACHED. CASE TERMINATED.

SAMPLE PROBLEM 3 OUTPUT (Concluded)

SUMMARY OF STANDARD PLUME FLOWFIELD CODE INPUT DATA WHICH WAS OUTPUT ON UNIT 1?

CHEMISTRY SYSTEM I

MOLECULAR WEIGHT	.14770+02
SPECIFIC HEAT RATIO	.12497+01
VISCOSITY(POISE)	[illegible]
PRANDTL NUMBER	.62620+00
NOZZLE EXIT RADIUS(FT)	[illegible]
TEMPERATURE(DEG R)	.12977+04
DENSITY(SLUG/FT3)	.28608-06
VELOCITY(FT/SEC)	.14580+05

SPECIE	MOLE FRACTION	SPECIE	MOLE FRACTION
H	.6078-05	H2	.2298+00
H2O	.7702+00	N2	.0000
O	.0000	OH	.3526-06
O2	.0000		

GASEOUS STARTING LINE INFO

R/RE(ND)	U(FT/SEC)	V(FT/SEC)	P(ATM)	T(DEG R)
.0000	[illegible]	.0000	.3755-01	.9147+03
.4167-01	.1534+05	-.2192+02	.3880-01	.9215+03
.8333-01	.1532+05	-.3455+02	[illegible]	.9340+03
.1250+00	.1529+05	-.3685+02	.4403-01	.9486+03
.1667+00	.1526+05	.4773+01	.4798-01	.9656+03
.2083+00	.1523+05	.8376+02	.5105-01	.9814+03
.2500+00	.1520+05	.1985+03	.5563-01	.9960+03
.2917+00	.1517+05	.3290+03	.5935-01	.1010+04
.3333+00	.1514+05	.4701+03	.6333-01	.1023+04
.3750+00	.1510+05	.6020+03	.6804-01	.1039+04
.4167+00	.1506+05	.7185+03	.7371-01	.1056+04
.4583+00	.1502+05	.8165+03	.8062-01	.1076+04
.5000+00	.1497+05	.8976+03	.8910-01	.1099+04
.5417+00	.1491+05	.9496+03	.9987-01	.1124+04
.5833+00	.1485+05	.9856+03	.1121+00	[illegible]
.6250+00	.1479+05	.1005+04	.1274+00	.1184+04
.6667+00	.1472+05	.1018+04	.1457+00	[illegible]
.7083+00	.1465+05	.1032+04	.1654+00	.1250+04
.7500+00	.1458+05	.1052+04	.1880+00	[illegible]
.7917+00	.1451+05	.1080+04	.2125+00	.1317+04
.8333+00	.1444+05	.1117+04	.2398+00	.1347+04
.8750+00	.1437+05	.1160+04	.2686+00	.1378+04
.9167+00	.1430+05	.1213+04	.2996+00	.1408+04
.9583+00	.1423+05	.1277+04	.3329+00	.1437+04
.1000+01	.1416+05	.1366+04	.3690+00	.1462+04

8.4 SAMPLE PROBLEM 4 - SPACE SHUTTLE HIGH PERFORMANCE MOTOR (HPM)

The two Space Shuttle High Performance Motors (HPMs) provide approximately 3 million pounds of thrust each to the Space Shuttle vehicle during its initial ascent. The HPMs are solid rocket motors which burn an aluminized solid propellant. The HPM motor has the following characteristics:

Throat Radius	2.244167 ft
Area Ratio	7.72
Propellant	See case 4 of Section 4
Chamber Pressure	See Fig. 8-8
Nozzle Contour	See Table 8-3

The geometry for the nozzle contour was generated from the tabulated contour points (Table 8-3) in the same manner as the RCS and vernier engines. The upstream and downstream throat radii of curvature were determined from the tabulated contour to be 1.15 and 0.5 throat radii, respectively. The inlet angle was chosen to be 42 deg based on the contour and the nozzle attach angle was 24.6 deg. These data were required as input for the transonic module.

The equilibrium/frozen chemistry used to perform the calculation is shown in Sample Case 4 of Section 4.

The two-phase data for this case were obtained from the recommended data of Section 7 of this report. The mean particle size was based on the correlation with throat size and the distribution of size was based on a six particle normal type distribution. The particle equation of state was the ideal gas approximation for Al_2O_3.

This particular case solved the nozzle flow field only and generated exit plane inviscid start lines for the SPF code and a RAMP2F restart. This case could be restarted at the exit plane with the RAMP2F start line so that a plume could be calculated.

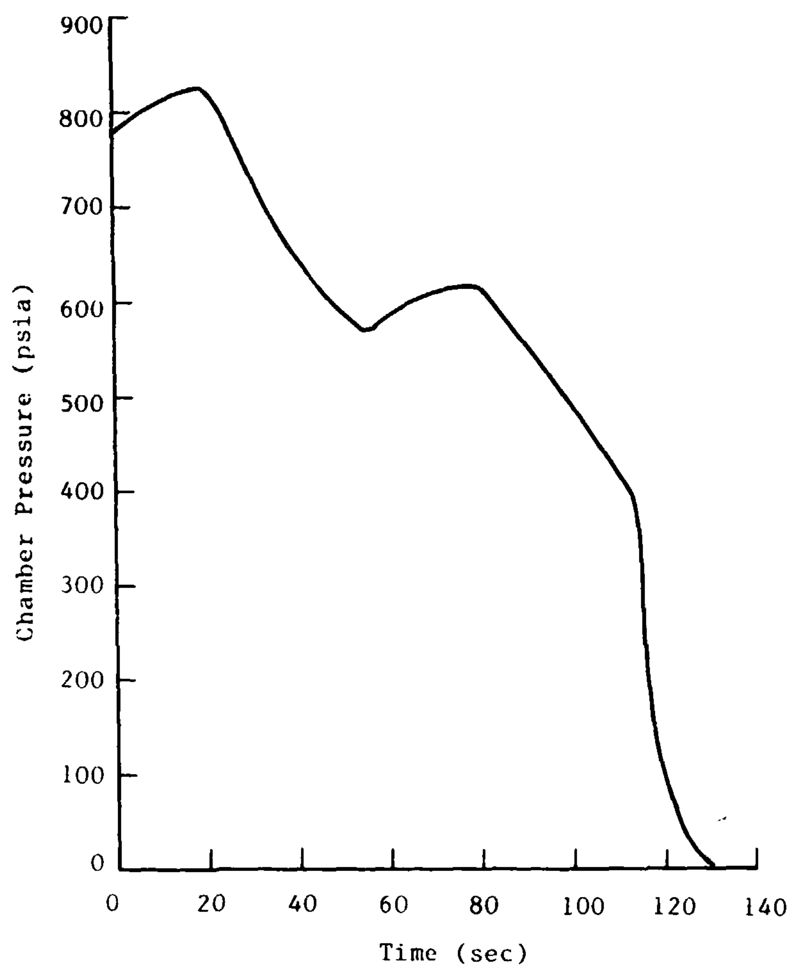

Fig. 8-8 Space Shuttle HPM Chamber Pressure Time History

Table 8-3 SPACE SHUTTLE HIGH PERFORMANCE MOTOR (HPM) NOZZLE COORDINATES

Inlet X (in.)	Inlet Y (in.)		Exit X	Exit Y
-24.598	42.700		0.561	28.942
-24.498	42.000		1.122	26.977
-24.181	41.050		1.683	27.036
-23.700	39.930		2.244	27.118
-22.550	37.850		2.804	27.225
-21.850	36.750		3.365	27.357
-20.888	35.424		3.926	27.515
-19.350	33.820		4.487	27.699
-18.400	33.036		5.048	27.911
-17.317	32.269		5.609	28.153
-16.000	31.470		11.129	30.680
-15.000	30.955		15.270	32.576
-14.000	30.490		19.410	31.472
-13.000	30.064		22.521	35.887
-12.000	29.670		26.518	37.666
-11.000	29.310		31.135	39.661
-10.000	28.975		36.270	41.803
-9.000	28.625		41.865	44.046
-8.000	28.300		51.027	47.528
-7.000	28.000		61.027	51.076
-6.000	27.700		71.794	54.630
-5.000	27.400		83.278	58.142
-4.000	27.290		95.439	61.579
-3.000	27.145		103.907	63.814
-2.000	27.035		112.654	65.997
-1.000	26.960		121.677	68.123
0.000	26.930	Throat	130.970	70.185
			135.716	71.192
			140.526	72.181
			143.695	72.822
			145.403	73.152
			150.342	74.105
			154.153	74.820

SAMPLE PROBLEM 4 INPUT DATA

Card									
1		.	3	2					
2		SPACE SHUTTL[illegible] NOZZLE ACTUAL GEOMETRY							
3									
4									
5		.	3[illegible]2[illegible]55	1[illegible]54[illegible]5	1	[illegible]3	6	1[illegible] 25	1 12575
7	2.24416667	0.							

Card									
8			.0[illegible]	2.244167	1.		.1[illegible]563[illegible]5	2.2443375	1.
			.3[illegible]1[illegible] 14	2.244[illegible]	2.		.7827267	2.2460	4.
			.1172[illegible]54	2.25[illegible]313[illegible]	6.		.15616393	2.255[illegible]867	8.
			.1[illegible]4.4775	2.2612137[illegible]	10.		.2332942[illegible]	2.2686867	12.
			.27[illegible]4[illegible]5	2.2774[illegible]7[illegible]	14.		.3[illegible]9288[illegible]0	2.2876342	16.
			.3467426[illegible]7	2.29[illegible]	18.		.3[illegible]3775[illegible]8	2.3118367	20.
			.42[illegible]339[illegible]3	2.325[illegible]72[illegible]	22.		.45639242	2.3411758	24.
			.4671[illegible]175	2.346[illegible]1[illegible]	24.6		1.63715	2.9[illegible]1625	24.6
			1.7[illegible]4[illegible]	2.9[illegible]	24.4[illegible]24		1.[illegible]5[illegible]175	2.9[illegible]9[illegible]	24.2765
			2.[illegible]5375	3.[illegible]7[illegible]5	24.[illegible]146		2.2[illegible]6[illegible]	3.1466	23.[illegible]127
			2.41265	3.2275[illegible]33	23.3795		2.61[illegible]175	3.3122417	23.[illegible]2[illegible]4
			2.[illegible]143333	3.3[illegible]25	22.[illegible]43[illegible]		3.[illegible]367667	3.49[illegible]1333	22.2526
			3.2646167	3.5[illegible]2425	21.[illegible]5[illegible]3		3.5[illegible]1575	3.6764587	21.439
			3.7471[illegible]17	3.771[illegible]33	21.[illegible]217		4.[illegible]111[illegible]7	3.9683917	2[illegible].[illegible]
			4.263[illegible]417	3.9457417	20.1754		4.[illegible]27[illegible]3	4.[illegible]636917	19.7455
			4.[illegible]417	4.16[illegible]667	19.3[illegible]		5.[illegible]43[illegible]	4.26[illegible]6167	1[illegible].99[illegible]7
			5.[illegible]6	4.3[illegible]	18.471[illegible]		5.[illegible]45[illegible]	4.4577333	18.[illegible]482
			5.[illegible]664[illegible]3	4.5[illegible]	17.[illegible]7[illegible]		6.3[illegible]16667	4.653[illegible]167	17.2[illegible]39
			6.52[illegible]33	4.7511[illegible]33	16.7[illegible]5[illegible]		6.[illegible]444417	4.8479417	16.384
			7.275[illegible]3	4.[illegible]44	15.[illegible]75[illegible]		7.613[illegible]	5.[illegible]392587	15.5732
			8.3[illegible]6[illegible]7	5.2[illegible]7[illegible]17	14.77[illegible]2		8.66[illegible]576	5.31[illegible]	14.3888
			9.[illegible]219167	5.41[illegible]25	14.[illegible]3[illegible]		9.7[illegible]525	5.5[illegible]9667	13.6222
			[illegible].761	5.5[illegible]5	13.2456		1[illegible].139333	5.6776917	12.8733
			10.523[illegible]83	5.7641[illegible]3	12.5[illegible]63		1[illegible].[illegible]125	5.8492	12.1434
			11.3[illegible]7417	5.[illegible]32[illegible]	11.7654		11.7[illegible]7917	6.[illegible]151167	11.4326
			11.[illegible]74583	6.[illegible]6[illegible]25	11.[illegible]24		12.116917	6.[illegible]96	11.1
			12.52[illegible]5	6.1754167	10.74	1	12.846[illegible]93	6.235	10.4[illegible]
8a	3	[illegible]	2115.					1[illegible]0.	
9	2	[illegible]						1[illegible]0.	

SAMPLE PROBLEM INPUT DATA (Concluded)


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25                                    1
26     .4[illegible]         .4          1 1.[illegible]
27     .1          .2          .[illegible]        .2          .[illegible]        .1
28     3.15        4.7         5.[illegible]       [illegible].[illegible]      [illegible].1[illegible]     [illegible].7
29     25[illegible].      25[illegible].     2[illegible].     25[illegible].    2[illegible].    2[illegible].
30
31     AL2O[illegible] EQ. OF STATE         1[illegible]
32       1
33     41[illegible].      134[illegible].1[illegible]   [illegible].[illegible]   .34         .3[illegible]
34      $DATA
37      TH[illegible]=42.,[illegible]=.[illegible],[illegible]=1.1[illegible],[illegible]=[illegible]4.[illegible],[illegible]=1,[illegible]=.1,[illegible]=.1,[illegible]=[illegible].[illegible],
         CA[illegible]=.7[illegible]
        $END
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SAMPLE PROBLEM 4 OUTPUT

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 25 PAGE 1

SPACE SHUTTLE HPM NOZZLE ACTUAL GEOMETRY

RUN CONTROL PARAMETERS

ICON(1)	ICON(2)	ICON(3)	ICON(4)	ICON(5)	ICON(6)	ICON(7)	ICON(8)
2	0	30	20055	1	54	1	3

ICON(9)	ICON(10)	ICON(11)	ICON(12)	ICON(13)	ICON(14)	ICON(15)	ICON(16)
0	15	25	1	0	0	0	12575

FLOW CALCULATIONS ARE IN ENGLISH UNITS WITH THE R,X COORDINATES IN FEET

THE FLOW FIELD DATA WILL BE WRITTEN ON TAPE

UPPER BOUNDARY POINTS

TYPE	ITRANS	X	R	THETA
2	0	.00000	.22442+01	.00000
2	0	.19583-01	.22443+01	.17453-01
2	0	.39160-01	.22449+01	.34907-01
2	0	.78273-01	.22469+01	.69813-01
2	0	.11729+00	.22503+01	.10472+00
2	0	.15616+00	.22551+01	.13963+00
2	0	.19485+00	.22612+01	.17453+00
2	0	.23329+00	.22687+01	.20944+00
2	0	.27146+00	.22775+01	.24435+00
2	0	.30929+00	.22876+01	.27925+00
2	0	.34674+00	.22991+01	.31416+00
2	0	.38378+00	.23118+01	.34907+00
2	0	.42034+00	.23259+01	.38397+00
2	0	.45639+00	.23412+01	.41888+00
2	0	.46710+00	.23460+01	.42935+00
2	0	.16372+01	.28816+01	.42935+00
2	0	.17541+01	.29350+01	.42730+00
2	0	.18952+01	.29990+01	.42270+00
2	0	.20538+01	.30701+01	.41913+00
2	0	.22268+01	.31466+01	.41306+00
2	0	.24126+01	.32276+01	.40803+00
2	0	.26102+01	.33122+01	.40178+00
2	0	.28187+01	.33999+01	.39521+00
2	0	.30368+01	.34901+01	.38938+00
2	0	.32646+01	.35824+01	.38136+00
2	0	.35016+01	.36765+01	.37418+00
2	0	.37472+01	.37719+01	.36690+00
2	0	.40011+01	.38684+01	.35952+00
2	0	.42630+01	.39657+01	.35213+00
2	0	.45327+01	.40637+01	.34465+00
2	0	.48099+01	.41621+01	.33724+00
2	0	.50944+01	.42606+01	.32981+00
2	0	.53860+01	.43592+01	.32239+00
2	0	.56845+01	.44577+01	.31500+00
2	0	.59664+01	.45559+01	.30766+00

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 25 PAGE 2

SPACE SHUTTLE HPM NOZZLE ACTUAL GEOMETRY

UPPER BOUNDARY POINTS

TYPE	ITRANS	X	R	THETA			
2	0	.63017+01	.46538+01	.30037+00			
2	0	.66201+01	.47512+01	.29311+00			
2	0	.69444+01	.48479+01	.28595+00			
2	0	.72759+01	.49440+01	.27884+00			
2	0	.76131+01	.50393+01	.27180+00			
2	0	.83087+01	.52271+01	.25795+00			
2	0	.86609+01	.53195+01	.25113+00			
2	0	.90219+01	.54108+01	.24440+00			
2	0	.93885+01	.55010+01	.23775+00			
2	0	.97619+01	.55900+01	.23118+00			
2	1	.10139+02	.56777+01	.22468+00			
2	0	.10523+02	.57641+01	.21828+00			
2	0	.10913+02	.58492+01	.21199+00			
2	0	.11307+02	.59329+01	.20464+00			
2	0	.11708+02	.60151+01	.19954+00			
2	0	.11975+02	.60685+01	.19552+00			
2	0	.12117+02	.60960+01	.19373+00			
2	0	.12528+02	.61754+01	.18745+00			
2	1	.12846+02	.62350+01	.18709+00			
3	0	.21160+04	.00000	.00000	.00000	.00000	.10000+04

LOWER BOUNDARY

TYPE	ITRANS	A	B	C	D	E	MAX
2	0	.00000	.00000	.00000	.00000	.00000	.10000+04

CHAMBER ENTHALPY = .19015+08

THERE ARE 6 PARTICLE SPECIES PRESENT IN THE GAS-PARTICLE MIXTURE

THE FOLLOWING GAS PROPERTIES IN ENGLISH UNITS ARE FOR SEA LEVEL SRM PC=900
REAL GAS PROPERTIES

H-TOTAL
.99250+06

S	V	P	GAMMA	T	P	PR	VIS	CP
-.31842+04								
.00000	.23942+04	.12223+01	.51326+04	.90000+03	.40871+00	.17143-05	.19632+05
.36849+04	.23849	.12326+01	.46246+04	.50223+03	.44920+00	.15023-05	.13613+05
.67705+04	.23696	.12671+01	.33158+04	.90000+02	.51009+00	.12588-05	.11562+05
.74799+04	.23696	.12855+01	.28487+04	.45000+02	.50677+00	.11309-05	.10678+05
.80384+04	.23656	.12964+01	.20368+04	.22500+02	.50676+00	.10123-05	.10371+05
.83118+04	.23695+04	.13013+01	.22192+04	.15000+02	.51006+00	.99683-06	.10188+05
.86110+04	.23696+04	.13126+01	.19678+04	.90000+01	.51176+00	.96852-06	.99854+04
.95040+04	.23696+04	.13471+01	.13224+04	.18000+01	.52579+00	.84493-06	.97021+04

SAMPLE PROBLEM 4 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

GAS-PARTICLE FLOW SOLUTION

CASE NO. 25 PAGE 6

SPACE SHUTTLE MPM NOZZLE ACTUAL GEOMETRY

REAL GAS PROPERTIES

H-TOTAL

S	V	R	GAMMA	T	P	MR	VIS	CF
.39724+04								
	.74657+04	.24016+04	.12053+01	.42194+04	.81000+01	.36635+00	.14904-05	.16291+[illegible]
	.83125+04	.24016+04	.12755+01	.36394+04	.47500+01	.50856+00	.13423-05	.11130+[illegible]
	.89635+04	.24016+04	.12847+01	.31274+04	.29250+01	.51140+00	.12050-05	.10845+[illegible]
	.92827+04	.24016+04	.12907+01	.28566+04	.13500+01	.51227+00	.11308-05	.10677+[illegible]
	.96326+04	.24016+04	.12994+01	.25430+04	.61000+00	.51355+00	.10410-05	.10447+[illegible]
	.10447+05	.24016+04	.13293+01	.17310+04	.16200+00	.51675+00	.78847-06	.97206+04
	.10898+05	.24016+04	.13423+01	.14550+04	.81000-01	.51311+00	.69111-06	.94261+04
	.11119+05	.24016+04	.13668+01	.95901+03	.16200-01	.50856+00	.49525-06	.89576+04
	.11249+05	.24016+04	.13737+01	.79102+03	.81000-02	.50055+00	.42361-06	.87369+04
	.11466+05	.24016+04	.13845+01	.50800+03	.16200-02	.49347+00	.28548-06	.81558+04

RUN CUTOFF INFORMATION

UPPER BOUNDARY LOWER BOUNDARY

R= .10000+07 X= .14000+03 THETA= .00000 R= .00000 X= .20000+02 THETA= .90000+02

PARTICLE PHYSICAL DATA

SPECIE	RADIUS	MASS DENSITY	EMISSIVITY	ACCM. COEFF.
1	.31500+01	.25000+03	.00000	.00000
2	.47000+01	.25000+03	.00000	.00000
3	.59700+01	.25000+03	.00000	.00000
4	.69500+01	.25000+03	.00000	.00000
5	.81000+01	.25000+03	.00000	.00000
6	.97000+01	.25000+03	.00000	.00000

THE PARTICLES CONSTITUTE 40.07 PERCENT BY WEIGHT FLOW OF THE GAS-PARTICLE MIXTURE

THE INDIVIDUAL PERCENTAGES ARE .11 .20 .20 .20 .17 .11

THE PARTICLE TEMPERATURE-ENTHALPY TABLE WILL BE READ IN WITH ENGLISH UNITS

PARTICLE TEMPERATURE-ENTHALPY TABLE

PHASE CHANGE DATA *** TMELT= .41850+04 HSOLID= .33541?+08 HLIQUID= .46051?+08

CPMELT= .85096+04 CPSOLID= .80090+04

SAMPLE PROBLEM 4 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE MOCK COMPUTER PROGRAM

GAS-PARTICLE FLOW SOLUTION

CASE NO. [illegible] PAGE [illegible]

SPACE SHUTTLE MPM NOZZLE ACTUAL CONTOUR

GAS STARTING

I	P	X	R	THETA	S	RHO

K	J	M-P	MACH-P	U-P	V-P

GASEOUS STARTING LINE INFO

X	Y	M	THETA	S	MACH ANGLE	SHOCK ANGLE	P-TOTAL
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

PARTICLE START LINE PROPERTIES

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

SAMPLE PROBLEM 4 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

GAS-PARTICLE FLOW SOLUTION

CASE NO. 25 PAGE 1

SPACE SHUTTLE HPM NOZZLE ACTUAL GEOMETRY

LINE	POINT	DESCRIP - REGIME	X / MACH ANGLE / ZC*	R / PRESSURE / PO*	W / DENSITY / ρ*	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	MU-TOTAL / SHOCK ANGLE	ITN
	1	INPUT - CONTIN								
	2	INPUT - CONTIN								
	3	INPUT - CONTIN								

PARTICLE DATA

SPECIE POINT DESCRIPTION | U | THETA | D M | ENTHALPY | DENSITY | TEMPERATURE

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

GAS-PARTICLE FLOW SOLUTION

CASE NO. 25 PAGE 1

SPACE SHUTTLE HPM NOZZLE ACTUAL GEOMETRY

LINE	POINT	DESCRIP - REGIME	X / MACH ANGLE / ZC*	R / PRESSURE / PO*	W / DENSITY / ρ*	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	MU-TOTAL / SHOCK ANGLE	ITN
	99	INPUT - CONTIN								
	100	WALL - CONTIN								

PARTICLE DATA

NO PARTICLES ARE PRESENT AT THIS POINT

PRESSURE INTEGRATION RESULTS

FORCEX | FORCEY | TORQZ | DELFX | DELFY | ISP

	98	INPUT - CONTIN							

PARTICLE DATA

1 98 LIMIT STREAMLINE

	113	WALL - CONTIN							

PARTICLE DATA

NO PARTICLES ARE PRESENT AT THIS POINT

PRESSURE INTEGRATION RESULTS

FORCEX | FORCEY | TORQZ | DELFY | DELFX | ISP

	97	INPUT - CONTIN							

PARTICLE DATA

1 97

2 97 LIMIT STREAMLINE

SAMPLE PROBLEM 4 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

GAS-PARTICLE FLOW SOLUTION

CASE NO. 25

[illegible]

PRESSURE INTEGRATION RESULTS

[illegible]

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

GAS-PARTICLE FLOW SOLUTION

CASE NO. 25

[illegible]

PRESSURE INTEGRATION RESULTS

[illegible]

SAMPLE PROBLEM 4 OUTPUT (Cont'd)

```
SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                               GAS-PARTICLE FLOW SOLUTION
                                      CASE NO.  75                                        PAGE  176

SPACE SHUTTLE HPM NOZZLE ACTUAL GEOMETRY

LINE POINT  DSCRIP _ REGIME        X            R            M          THETA       ENTROPY      VELOCITY     M-TOTAL   ITN
                              MACH ANGLE    PRESSURE     DENSITY    TEMPERATURE   GAS CONST.   LOCAL GAMMA  SHOCK ANGLE
                                 TO*           PO*          S*
PARTICLE DATA
SPECIE POINT  DESCRIPTION          X          THETA          D M                  ENTHALPY      DENSITY     TEMPERATURE

 14    29  INTER  - CONTIN    [illegible]  .12666+02  .25391+01  .10103+02  .13221+04  .83632+04  .17763+04   5
                              [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
                              [illegible]  .19263+03  [illegible]
PARTICLE DATA
   1   29                     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
   2   29                     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
   3   29                     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
   4   29                     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]

 14    30  INTER  - CONTIN    [illegible]  .12637+02  [illegible]  .10209+02  [illegible]  [illegible]  .17666+04   5
                              [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
                              [illegible]  [illegible]  .36651+04
PARTICLE DATA
   1   30                     [illegible]  [illegible]  [illegible]  .26651+06  .16201+04  [illegible]
   2   30                     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
   3   30                     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
   4   30  LIMIT STREAMLINE   [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]

 14    31  INTER  - CONTIN    [illegible]  [illegible]  [illegible]  .10272+02  [illegible]  [illegible]  .17537+04   5
                              [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
                              [illegible]  [illegible]  [illegible]
PARTICLE DATA
   1   31                     [illegible]  .11250+02  [illegible]  [illegible]  [illegible]  [illegible]
   2   31                     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
   3   31                     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]

 14    32  INTER  - CONTIN    [illegible]  [illegible]  [illegible]  .10325+02  [illegible]  [illegible]  .17357+04   5
                              [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
                              [illegible]  [illegible]  [illegible]
PARTICLE DATA
   1   32                     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
   2   32                     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
   3   32  LIMIT STREAMLINE   [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]

 14    33  INTER  - CONTIN    [illegible]  [illegible]  [illegible]  .10372+02  [illegible]  .85382+04  [illegible]   5
                              [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
                              [illegible]  [illegible]  [illegible]
PARTICLE DATA
   1   33                     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
   2   33                     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                               GAS-PARTICLE FLOW SOLUTION
                                      CASE NO.  75                                        PAGE  177

SPACE SHUTTLE HPM NOZZLE ACTUAL GEOMETRY

LINE POINT  DSCRIP _ REGIME        X            R            M          THETA       ENTROPY      VELOCITY     M-TOTAL   ITN
                              MACH ANGLE    PRESSURE     DENSITY    TEMPERATURE   GAS CONST.   LOCAL GAMMA  SHOCK ANGLE
                                 TO*           PO*          S*
PARTICLE DATA
SPECIE POINT  DESCRIPTION          X          THETA          D M                  ENTHALPY      DENSITY     TEMPERATURE

 14    34  INTER  - CONTIN    [illegible]  .17811+02  [illegible]  .10434+02  [illegible]  [illegible]  [illegible]
                              [illegible]  [illegible]  .42206-01  .38073+04  [illegible]  [illegible]
                              [illegible]  .21650+03  .31755+04
PARTICLE DATA
   1   34                     [illegible]  [illegible]  [illegible]  .27760+06  .16939-06  [illegible]
   2   34  LIMIT STREAMLINE   [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]

 14    35  WALL   - CONTIN    [illegible]  [illegible]  [illegible]  .10490+02  [illegible]  [illegible]  [illegible]   5
                              [illegible]  [illegible]  [illegible]  .33793+04  [illegible]  [illegible]
                              [illegible]  [illegible]  .30493+04
PARTICLE DATA
   1   35                     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]

 14    36  PIN-MN - CONTIN    [illegible]  [illegible]  [illegible]  .18125+02  .52735+03  [illegible]  [illegible]   5
                              [illegible]  [illegible]  .35576-03  .32080+04  [illegible]  .12810+01
                              [illegible]  [illegible]  .34520+04
PARTICLE DATA
   1   36                     [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]

 14     7  PIN-MN - CONTIN    .62350+01  [illegible]  [illegible]  .17760+02  .52735+03  .90030+04  [illegible]   5
                              [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  .12893+01
                              [illegible]  .16385+03  .30533+04
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
```

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OF POOR QUALITY

SAMPLE PROBLEM 4 OUTPUT (Concluded)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 25 PAGE 190

SPACE SHUTTLE MPM NOZZLE ACTUAL GEOMETRY

LINE POINT DSCRIP - REGIME	X / MACH ANGLE / THO	R / PRESSURE / PHO	U / DENSITY / SO	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	MUTUAL / SHOCK ANGLE
PARTICLE DATA: SPECIE POINT DESCRIPTION	X	THETA	D M	ENTHALPY	DENSITY	TEMPERATURE	
195 1 WALL - CONTIN	.00000	.19626+02	[illegible]	.00000	[illegible]	.79600+04	.17663+04
	.25988+02	[illegible]	.16716-03	.38610+04	.24932+04	.12499+01	
	.36792+04	.83633+02	.56075+04				
PARTICLE DATA 1 1	[illegible]	.00000	[illegible]	[illegible]	.76553-05	[illegible]	
2 1	.18716+04	.00000	.97580-02	[illegible]	.18746-04	[illegible]	
3 1	[illegible]	.00003	.17765-01	[illegible]	.14785-04	[illegible]	
4 1	[illegible]	.00000	[illegible]	.33785+08	.15163-04	[illegible]	
5 1	.17502+04	.00000	[illegible]	[illegible]	.15762-04	[illegible]	
6 1	.17677+04	.00000	[illegible]	[illegible]	.83799-05	.41880+04	
195 31 FREEBD - CONTIN	.76580+01	[illegible]	[illegible]	.60223+01	[illegible]	[illegible]	.16621+04
	[illegible]	[illegible]	[illegible]	.30577+04	.23846+04	.12838+01	
	.57791+04	.16172+03	.38552+04				
PARTICLE DATA 1 31	[illegible]	[illegible]	.76319-02	[illegible]	.13325-04	[illegible]	
2 31	[illegible]	[illegible]	[illegible]	.75722+08	.17937-04	[illegible]	
196 1 WALL - CONTIN	.00000	.19656+02	[illegible]	.00000	[illegible]	.79060+04	.17656+04
	.25950+02	[illegible]	.18671-03	.38609+04	.24932+04	.12499+01	
	.36741+04	[illegible]	.56153+04				
PARTICLE DATA 1 1	[illegible]	.00000	[illegible]	[illegible]	.74770-05	[illegible]	
2 1	[illegible]	.00000	[illegible]	[illegible]	.18700-04	[illegible]	
3 1	.18666+04	.00005	.17773-01	.31687+08	.14734-04	.39566+04	
4 1	[illegible]	[illegible]	[illegible]	.33685+08	.15099-04	[illegible]	
5 1	.17535+04	.00003	.45099-01	[illegible]	.15684-04	[illegible]	
6 1	.17680+04	.00000	.66585+01	.38720+08	.83320-05	.41880+04	
196 31 FREEBD - CONTIN	.76773+01	[illegible]	.29517+01	.74619+01	[illegible]	.89702+04	.16626+04
	[illegible]	[illegible]	[illegible]	.30580+04	.23846+04	.12838+01	
	.57741+04	[illegible]	.38557+04				
PARTICLE DATA 1 31	[illegible]	[illegible]	[illegible]	.29673+08	.13271-04	[illegible]	
2 31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 25 PAGE 191

SPACE SHUTTLE MPM NOZZLE ACTUAL GEOMETRY

LINE POINT DSCRIP - REGIME	X / MACH ANGLE / THO	R / PRESSURE / PHO	U / DENSITY / SO	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	MUTUAL / SHOCK ANGLE
PARTICLE DATA: SPECIE POINT DESCRIPTION	X	THETA	D M	ENTHALPY	DENSITY	TEMPERATURE	
196 1 WALL - CONTIN	.00000	[illegible]	[illegible]	.00000	.38576+04	.79080+04	.17665+04
	.25992+02	[illegible]	.16626-03	.38610+04	.24933+04	.12500+01	
	.36741+04	.83511+02	.56226+04				
PARTICLE DATA 1 1	[illegible]	[illegible]	[illegible]	.30941+08	.76188-05	[illegible]	
2 1	.18751+04	.00000	[illegible]	[illegible]	.18666-04	[illegible]	
3 1	[illegible]	.00000	.17762-01	.31652+08	.14666-04	[illegible]	
4 1	[illegible]	.00000	.24887-01	.33586+08	.15037-04	[illegible]	
5 1	.17563+04	[illegible]	.44868-01	.36774+08	.15607-04	[illegible]	
6 1	.17681+04	.00000	.66799+01	.38657+08	.82870-05	.41880+04	
196 31 FREEBD - CONTIN	.76700+01	.19660+02	[illegible]	.77722+01	[illegible]	.89698+04	[illegible]
	.19988+02	[illegible]	[illegible]	.30580+04	.23846+04	.12838+01	
	.57791+04	.16166+03	.38562+04				
PARTICLE DATA 1 31	.89986+04	.55965+01	.69220-02	.29670+08	.13219-04	[illegible]	
2 31	.88756+04	.10615+02	.23595+01	.75118+08	.17800-04	.31237+04	

PREVIOUSLY COMPUTED SHOCKS HAVE PROPAGATED TO LOWER BOUNDARY, OR PROBLEM LIMITS HAVE BEEN REACHED. CASE TERMINATED.
1101000010001 000000000000

PUNCH CARDS FOR LINE 195

.00000000	.22078787+02	.23272°6+01	.00000000	.38576320+04	.17766°26+08
.262°7°6+00	.22088500+02	.23249576+01	.12488689+00	.38893196+04	.17478009+08
.52657987+00	.20087637+02	.23333670+01	.25083500+00	.37259115+04	.17749127+08
.79°50888+00	.20086100+02	.23380884+01	.37785°°°+00	.36°01036+04	.17500773+08
.10599397+01	.22008913+02	.23433370+01	.50832°°+00	.37773339+04	.17°180°+08
.13191827+01	.20081517+02	.23522368+01	.63°2193°+00	.37373866+04	.17524027+08
.15815551+01	.20078200+02	.2359°°7+01	.77569°°+00	.37000°00+04	.17527°°+08
.18444444+01	.20074380+02	.23079990+01	.8°°5180+00	.36°7373+04	.17527879+08
.21068491+01	.2006°°°+02	.23768°50+01	.10°7137°+01	.36210983+04	.1752329°+08
.23698151+01	.20069°°+02	.2385°°3+01	.1°°°°°+01	.3°8°676+04	.17°1878+08

8.5 SAMPLE PROBLEM 5 - SECOND STAGE IUS MOTOR

The second stage Interim Upper Stage (IUS) motor is used as part of the vehicle which propels payloads from a low earth orbit to a geosynchronous orbit. The second stage motor is a solid propellant motor producing an average of 17,300 lbf of thrust. The nozzle is contoured with an area ratio of 49.3:1 without the extendable section and 181.1:1 with the extension. The area ratio of 49.3:1 geometry was used for this demonstration case. A summary of the characteristics of the motor is:

Throat Radius	.17529 ft
Area Ratio	49.3:1
Propellant	HTPB:AP:Al
Chamber Pressure	800 (chosen to correspond to chamber pressure two-thirds the way through burn)
Nozzle Contour	2 Circular Arcs.

The potential uses of the IUS plume are for payload contamination, radiation heating environments, and potential particulate impingement on the Space Shuttle vehicle during deployment. For these reasons, the boundary layer option was selected so that the plume backflow region could be calculated.

The IUS nozzle geometry was represented with two circular arcs. The throat region is represented with a circular arc that had a radius of .3505833 ft and an origin of x = 0, r = .525875 ft. The throat region is applied out to a flow angle of 26.25 deg. Attached to the throat is another circular arc whose radius is 17.28712174 ft and whose origin is at x = 7.79824555 ft, r = -15.2943622 ft. The nozzle exit is at x = 2.7240833 ft at a flow angle of 17.069 deg.

The inlet angle to the throat is chosen to be 30 deg and the upstream and downstream radii of curvature is taken to be 2 throat radii. The limiting nozzle angle for the transonic region was taken to be 20 deg. It should have been 26.25 deg but has no effect on the transonic solution as long as the transonic calculation can locate the nozzle wall Mach number for the startline before the flow expands to 20 deg.

The equilibrium/frozen chemistry option was selected for this case. the chemistry was frozen at a chamber/local pressure ratio of 5. Solid motors of this type typically freeze the dominant species at relatively low pressure ratios. A listing of the input data for the IUS TRAN72 calculation follows this discussion.

The ideal approximation of the Al_2O_3 equation of state was taken from Section 7.1.3.4. The particle size and distributions were taken from Ref. 36.

The nozzle boundary layer solution was generated assuming a wall steady state energy balance with the built in heat of fusion for typical solid motor wall materials.

This particular case predicts that the 1.15 micron radius particles penetrate the boundary layer. A summary of the particle properties in the boundary layer is contained in the sample printout for this case. Additionally, the free molecular option was selected for this case. The characteristic length used in determining the Knudsen number was the exit radius (1.2314 ft) of the motor.

SAMPLE PROBLEM 5 TRAN72 INPUT DATA

```
REACTANTS
C 17.6    H 24.6  [illegible]                                    [illegible]1294        13550.S 298.15 F
FE 2.0    O 3.0                                                  [illegible]6.   -1577[illegible].S 298.15 F
C 22.0    H 42.0    O 4.                                         [illegible]1 6  -31160.0  S 298.15 F
N 1.      H 4.      O 4.      CL 1.                              [illegible]67594 -7065.0  S 298.15 F
AL 1.0                                                           [illegible]1[illegible]          .0  S 298.15 F

OMIT        H2O(S)        AL(S)         ALCL3(S)      ALN(S)
OMIT        H2O(L)        AL(L)         ALCL3(L)      C(S)
OMIT        NA(S)         NACL(S)       NAOH(S)       NA2O(S)
OMIT        NA(L)         NACL(L)       NAOH(L)       NA2O(L)
OMIT        K(S)          KCL(S)        KOH(S)        K2O(S)
OMIT        K(L)          KCL(L)        KOH(L)        O2
OMIT        ALH           ALCL          ALCL+         ALCL2
OMIT        ALCL2+        ALCL2-        ALCL3         ALO
OMIT        ALO+          ALOCL         ALOH          ALOH+
OMIT        ALOH-         ALO2          ALO2-         ALO2H
OMIT        AL2CL6        ALO-          AL2O +        AL2O2
OMIT        AL2O2+        ALN           AL+           H-
OMIT        C3            C4            C5            C+
OMIT        C-            C2-           CN+           CN-
OMIT        CH2O          C3O2          NO2-          N2O+
OMIT        C2            C2-           NO+           CN2
OMIT        CNN           CH4           N3            NO2
OMIT        NO3           C2N           CCL3          CCL4
OMIT        K2O2H2        NA2O2H2       NA2           NA2CL2
OMIT        CCL           CH            C2H4          C2H
OMIT        C2H2          C2H6          C2N2          C2O
OMIT        HNO           HNO2          HO2           H2O2
OMIT        KO            NOCL          NCO           CL2O
OMIT        CCL2          COCL2         C2CL2         CLO2
OMIT        HNO3          K2            NC2CL         N2H4
OMIT        N2O4
```

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SAMPLE PROBLEM 5 INPUT DATA (Concluded)

```
NAMELISTS
 $INPT2
 RKT=T,PSIA=T,P=560.,30,15.00,TRNSPT=T,MOC2P=T,MOCP=F,
   MOCTF=T,FARTHT=T,
  NGI=10,DDOTP=-900.,-800.,-700.,-600.,-500.,-400.,-300.,-200.,-100.,0.,
  TRACE=1.E-5
 $END
 $TAPGEN
      IREAD=1,IO=8,IN=1
 $END
 IUS-2 PC=6.                 MKS
 $RKTINP
  PCP=5.,1 .,2.,26.6,5.,10.,5..,          NFZ=3
 $END
STOP
```

LOCKHEED-HUNTSVILLE RESEARCH & ENGINEERING CENTER

SAMPLE PROBLEM 5 INPUT DATA

```
Card
 1        .    3    3
 2    SECONC STAGE IUS NOZZLE/PLUME PC=     PSIA
 3
 4      2       2.     3     1   2'3    11  2.3     7                     1"    2          15170
 5   .175291667 ...
 7   1    .      -1.        .122" 1673 0.       -1.        -.525675  .155 .4
 8   1    1      1.         228. 15764215.5564511 -1.        -15.2-43622.724 P333
 8   3           ....1                                                  101..
 8   2                                                                  10...
 9    IUS-2 PC=..                   ..S
10   2.....      -2....     ...     ...       1 .        ...
22   ..5         ..4        .3      .0.5      5.         .7
23   1...        1..        ..      1.2314     ..
24                             1
25   .515        .5         1 1...
26   .333        .333       .334
27   1.15        3.         5.5
28   256..       25...      25..      25 .      25..      25..      25..
29
30
31   AL2C3 EQ. OF STATE           1ENC
32    1
33   4186.       134..16     183..56  .34       .32
34    $DATA
35     THID=3...PRT=2..RWTL=2...THJW=2 ..IWALL=1.EL=.1.DP=1..ETVI=3.5
41    $ENC
        L     4
```

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SAMPLE PROBLEM 5 OUTPUT

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 0 PAGE 1

SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

RUN CONTROL PARAMETERS

ICON(1)	ICON(2)	ICON(3)	ICON(4)	ICON(5)	ICON(6)	ICON(7)	ICON(8)
2	0	20	3	1	2	1	203

ICON(9)	ICON(10)	ICON(11)	ICON(12)	ICON(13)	ICON(14)	ICON(15)	ICON(16)
0	0	0	1	2	0	0	15070

FLOW CALCULATIONS ARE IN ENGLISH UNITS WITH THE R,Z COORDINATES IN FEET

THE FLOW FIELD DATA WILL BE WRITTEN ON TAPE

UPPER BOUNDARY

ITYPE	ITRANS	A	B	C	D	E	MAX
1	0	-.10000+01	.17291+00	.00000	-.10000+01	-.52580+00	.15500+00
1	1	.10000+01	.23804+03	.15596 02	-.10008+01	-.15294+02	.27241+01
3	0	.10000-03	.00000	.00000	.00000	.00000	.10000+04

LOWER BOUNDARY

ITYPE	ITRANS	A	B	C	D	E	MAX
2	0	.00000	.00000	.00000	.00000	.00000	.10000+04

CHAMBER ENTHALPY = .31568+08

THERE ARE 3 PARTICLE SPECIES PRESENT IN THE GAS-PARTICLE MIXTURE

THE FOLLOWING GAS PROPERTIES IN ENGLISH UNITS ARE FOR IUS-2 PC=800
REAL GAS PROPERTIES

W-TOTAL
-.89833+07

S	H	R	GAMMA	T	P	PR	VIS	CP
-.83652+04								
	.00000	.26450+04	.12891+01	.38853+04	.80000+03	.47762+00	.12467-05	.11841+05
	.32279+04	.26446+04	.12960+01	.30394+04	.43706+03	.48377+00	.11336-05	.11649+05
	.49849+04	.26400+04	.12913+01	.24190+04	.16000+03	.50087+00	.96772-06	.12462+05
	.57444+04	.26400+04	.13290+01	.20420+04	.80000+02	.49313+00	.86073-06	.10671+05
	.63137+04	.26400+04	.13425+01	.17162+04	.40000+02	.48311+00	.76049-06	.10355+05
	.65544+04	.26400+04	.13493+01	.15654+04	.27072+02	.48190+00	.71164-06	.10205+05
	.69744+04	.26400+04	.13599+01	.13525+04	.16000+02	.47836+00	.63932-06	.99926+04
	.71956+04	.26400+04	.13698+01	.11239+04	.80000+01	.47465+00	.55618-06	.97857+04
	.77139+04	.26400+04	.13852+01	.72250+03	.16000+01	.46557+00	.39244-06	.94995+04
.21628+04								
	.00000	.26465+04	.12815+01	.38769+04	.15000+02	.45653+00	.12996-05	.17189+05
	.32256+04	.26456+04	.12947+01	.30377+04	.81972 01	.47691+00	.11330-05	.11656+05
	.49828+04	.26456+04	.13046+01	.24081+04	.30000+01	.48544+00	.96427-06	.11737+05
	.57406+04	.26456+04	.13307+01	.20326+04	.15000+01	.46719+00	.85691-06	.10663+05

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 0 PAGE 9

SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

GAS STARTLINE

I	R	Z	M	THETA	S	WTG
I	J	W-P	RHO-P	U-P	V-P	

GASEOUS STARTING LINE INFO

R	Z	M	THETA	S	MACH ANGLE	SHOCK ANGLE	W-TOTAL
.00000	.12433+00	.10584+01	.00000	.49454+03	.70880+02	.00000	.30349+08
.93272-02	.12271+00	.10532+01	.50921+00	.49045+03	.71631+02	.00000	.30358+08
.18754-01	.12108+00	.10505+01	.10468+01	.48765+03	.72167+02	.00000	.30365+08
.28132-01	.11946+00	.10488+01	.16144+01	.48618+03	.72457+02	.00000	.30368+08
.37509-01	.11784+00	.10487+01	.22300+01	.48608+03	.72476+02	.00000	.30369+08
.46886-01	.11622+00	.10502+01	.28835+01	.48742+03	.72213+02	.00000	.30365+08
.56263-01	.11459+00	.10535+01	.35812+01	.49027+03	.71666+02	.00000	.30359+08
.65640-01	.11297+00	.10586+01	.43237+01	.49473+03	.70846+02	.00000	.30348+08
.75017-01	.11135+00	.10657+01	.51099+01	.50093+03	.69777+02	.00000	.30333+08
.84395-01	.10972+00	.10749+01	.59375+01	.50901+03	.68485+02	.00000	.30314+08
.93772-01	.10810+00	.10864+01	.68023+01	.51913+03	.66999+02	.00000	.30291+08
.10315+00	.10648+00	.11001+01	.76983+01	.53149+03	.65348+02	.00000	.30261+08
.11253+00	.10485+00	.11160+01	.86179+01	.54630+03	.63559+02	.00000	.30226+08
.12190+00	.10323+00	.11362+01	.95513+01	.56382+03	.61654+02	.00000	.30185+08
.13128+00	.10161+00	.11588+01	.10486+02	.58434+03	.59654+02	.00000	.30137+08
.14008+00	.99987-01	.11853+01	.11431+02	.60840+03	.57527+02	.00000	.30079+08
.15217+00	.97993-01	.12216+01	.12502+02	.64259+03	.54996+02	.00000	.29999+08
.15991+00	.96740-01	.12579+01	.13151+02	.66744+03	.53257+02	.00000	.29941+08
.17151+00	.94646-01	.12980+01	.14141+02	.71522+03	.50393+02	.00000	.29828+08
.17817+00	.93494-01	.13290+01	.14619+02	.74521+03	.48804+02	.00000	.29758+08
.18754+00	.91871-01	.13773+01	.15192+02	.79707+03	.46556+02	.00000	.29647+08

PARTICLE START LINE PROPERTIES

POINT	SPECIE	U	V	PSI	ENTHALPY	DENSITY
1	1	.40482+04	.00000	.00000	.57610+08	.69083-03
1	2	.35116+04	.00000	.00000	.58269+08	.10407-02
1	3	.30958+04	.00000	.00000	.58894+08	.14295-02
2	1	.40797+04	.26548+01	.65074-03	.57656+08	.69337-03
2	2	.34945+04	.56736+00	.16236-03	.58310+08	.10482-02
2	3	.30301+04	-.89206+00	-.29990-03	.58929+08	.14453-02
3	1	.40660+04	.10885+02	.26771-02	.57688+08	.69465-03
3	2	.34845+04	.23263+01	.66819-03	.58339+08	.10531-02
3	3	.30179+04	-.36576+01	-.12120-02	.58953+08	.14559-02
4	1	.40571+04	.25212+02	.62141-02	.57708+08	.69465-03
4	2	.34726+04	.53880+01	.15516-02	.58356+08	.10553-02
4	3	.30093+04	-.84715+01	-.28151-02	.58968+08	.14615-02
5	1	.40532+04	.46295+02	.11421-01	.57713+08	.69380-03
5	2	.34680+04	.98939+01	.28579-02	.58361+08	.10548-02
5	3	.30046+04	-.15556+02	-.51174-02	.58972+08	.14619-02
6	1	.40544+04	.74911+02	.18475-01	.57703+08	.69087-03

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SAMPLE PROBLEM 5 OUTPUT (Cont'd)

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              SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                        GAS-PARTICLE FLOW SOLUTION
                                        CASE NO.   0                                            PAGE  11

 SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

LINE POINT  DSCRIP - REGIME      R            X            M           THETA       ENTROPY      VELOCITY     M-TOTAL   ITR
                               MACH ANGLE   PRESSURE     DENSITY     TEMPERATURE  GAS CONST.   LOCAL GAMMA  SHOCK ANGLE
                                  TO0          P00          S0
 PARTICLE DATA
 SPECIE POINT  DESCRIPTION       V            THETA         D M         ENTHALPY     DENSITY      TEMPERATURE

   1    1  INPUT  - CONTIN    .00000       .12833+00    .10580+01    .00000       .49450+03    .49803+00    .30349+00    0
                              .70980+02    .32010+03    .31839-02    .55162+00    .26908+00    .12073+01
                              .60767+00    .62167+03    .49510+03
 PARTICLE DATA
   1    1                     .409817+00   .00000        .90269-01    .57610+00    .60083-03    .55463+00
   2    1                     .351160+00   .00000        .22083+00    .50269+00    .10807-02    .56730+00
   3    1                     .304582+00   .00000        .33886+00    .50899+00    .14295-02    .56972+00
-------------------------------------------------------------------------------------------------------------------------
   1    2  INPUT  - CONTIN    .93772-02    .12271+00    .10537+01    .50921+00    .49045+03    .49625+00    .30350+00    0
                              .71631+02    .33088+03    .32041-02    .55218+00    .26910+00    .12071+01
                              .60775+00    .62299+03    .49095+03
 PARTICLE DATA
   1    2                     .407960+00   .37284-01    .90308-01    .57656+00    .69737-03    .55517+00
   2    2                     .349889+00   .93025-02    .22856+00    .50310+00    .10402-02    .56286+00
   3    2                     .303006+00   -.16860-01   .33823+00    .50920+00    .14453-02    .57013+00
-------------------------------------------------------------------------------------------------------------------------
   1    3  INPUT  - CONTIN    .18754-01    .12108+00    .10505+01    .10088+01    .48765+03    .49503+00    .30365+00    0
                              .77167+02    .33233+03    .32102-02    .55256+00    .26911+00    .12070+01
                              .60779+00    .62390+03    .48807+03
 PARTICLE DATA
   1    3                     .406598+00   .15339+00    .90716-01    .57608+00    .69465-03    .55556+00
   2    3                     .348147+00   .30284-01    .22869+00    .50339+00    .10531-02    .56320+00
   3    3                     .301786+00   -.69441-01   .33812+00    .50953+00    .14559-02    .57047+00
-------------------------------------------------------------------------------------------------------------------------
   1    4  INPUT  - CONTIN    .28132-01    .11946+00    .10488+01    .16189+01    .48618+03    .49439+00    .30368+00    0
                              .72452+02    .33323+03    .32256-02    .55277+00    .26912+00    .12069+01
                              .60782+00    .62437+03    .48656+03
 PARTICLE DATA
   1    4                     .405718+00   .35604+00    .91261-01    .57700+00    .69465-03    .55578+00
   2    4                     .347261+00   .88099-01    .22922+00    .50356+00    .10553-02    .56340+00
   3    4                     .300928+00   -.16130+00   .33857+00    .50969+00    .14615-02    .57059+00
-------------------------------------------------------------------------------------------------------------------------
   1    5  INPUT  - CONTIN    .37509-01    .11789+00    .10482+01    .22300+01    .48608+03    .49430+00    .30369+00    0
                              .72476+02    .33329+03    .32261-02    .55278+00    .26912+00    .12069+01
                              .60782+00    .62440+03    .48646+03
 PARTICLE DATA
   1    5                     .405347+00   .65440+00    .92034-01    .57717+00    .69390-03    .55584+00

              SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                        GAS-PARTICLE FLOW SOLUTION
                                        CASE NO.   0                                            PAGE  12

 SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

LINE POINT  DSCRIP - REGIME      R            X            M           THETA       ENTROPY      VELOCITY     M-TOTAL   ITR
                               MACH ANGLE   PRESSURE     DENSITY     TEMPERATURE  GAS CONST.   LOCAL GAMMA  SHOCK ANGLE
                                  TO0          P00          S0
 PARTICLE DATA
 SPECIE POINT  DESCRIPT.         V            THETA         D M         ENTHALPY     DENSITY      TEMPERATURE

   1    6  INPUT  - CONTIN    .46886-01    .11622+00    .10502+01    .28835+01    .48742+03    .49493+00    .30365+00    0
                              .72213+02    .33[illegible]+03  .32109-02    .55260+00    .26912+00    .12069+01
                              .60780+00    .62[illegible]+03  .48783+03
 PARTICLE DATA
   1    6                     .405502+00   .10505+01    .93040-01    .57703+00    .69007-03    .55573+00
   2    6                     .346770+00   .26452+00    .23167+00    .50353+00    .10516-02    .56337+00
   3    6                     .300433+00   -.40022+00   .34130+00    .50965+00    .14572-02    .57055+00
-------------------------------------------------------------------------------------------------------------------------
   1    7  INPUT  - CONTIN    .56263-01    .11459+00    .10535+01    .35812+01    .49027+03    .49617+00    .30359+00    0
                              .71666+02    .33075+03    .32052-02    .55220+00    .26910+00    .12071+01
                              .60775+00    .62305+03    .49076+03
 PARTICLE DATA
   1    7                     .406241+00   .15709+01    .94276-01    .57678+00    .68707-03    .55544+00
   2    7                     .347209+00   .39976+00    .23366+00    .50332+00    .10459-02    .56312+00
   3    7                     .300624+00   -.71686+00   .34366+00    .50946+00    .14475-02    .57033+00
-------------------------------------------------------------------------------------------------------------------------
   1    8  INPUT  - CONTIN    .65690-01    .11292+00    .10586+01    .43232+01    .49473+03    .49811+00    .30348+00    0
                              .70046+02    .32807+03    .31830-02    .55159+00    .26907+00    .12073+01
                              .60762+00    .62161+03    .49538+03
 PARTICLE DATA
   1    8                     .407509+00   .22259+01    .95723-01    .57637+00    .68201-03    .55496+00
   2    8                     .348110+00   .55684+00    .23623+00    .50296+00    .10372-02    .56270+00
   3    8                     .301328+00   -.10115+01   .34675+00    .50915+00    .14326-02    .56997+00
-------------------------------------------------------------------------------------------------------------------------
   1    9  INPUT  - CONTIN    .75017-01    .11135+00    .10657+01    .51099+01    .50093+03    .50079+00    .30333+00    0
                              .69777+02    .32437+03    .31529-02    .55074+00    .26904+00    .12076+01
                              .60746+00    .61959+03    .50183+03
 PARTICLE DATA
   1    9                     .409612+00   .30090+01    .97396-01    .57579+00    .67568-03    .55427+00
   2    9                     .349935+00   .74919+00    .23961+00    .50246+00    .10260-02    .56211+00
   3    9                     .301749+00   -.11717+01   .35234+00    .50882+00    .14126-02    .56950+00
-------------------------------------------------------------------------------------------------------------------------
   1   10  INPUT  - CONTIN    .84395-01    .10972+00    .10799+01    .59375+01    .50901+03    .45926+00    .30314+00    0
                              .68485+02    .31960+03    .31129-02    .54963+00    .26899+00    .12080+01
                              .60742+00    .61696+03    .51032+03
 PARTICLE DATA
   1   10                     .412384+00   .39354+01    .99086-01    .57501+00    .66908-03    .55135+00
```

SAMPLE PROBLEM 5 OUTPUT (Cont'd)

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          SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                      GAS-PARTICLE FLOW SOLUTION
                                          CASE NO.    0                                              PAGE   13

  SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

LINE POINT  DSCRIP - REGIME        R             X             M          THETA        ENTROPY      VELOCITY     M-TOTAL   ITR
                               MACH ANGLE     PRESSURE      DENSITY    TEMPERATURE   GAS CONST.   LOCAL GAMMA   SHOCK ANGLE
                                  TO*           PO*           S*
PARTICLE DATA
 SPECIE POINT  DESCRIPTION         V            THETA          D M          ENTHALPY       DENSITY          TEMPERATURE

 1    11  INPUT  - CONTIN      .93273-01     .10810+00     .10864+01    .68023+01    .51913+03    .45857+04    .30291+08   0
                               .66999+02     .31372+03     .30690-02    .54824+04    .26894+04    .12085+01
                               .60729+04     .61364+03     .52110+03
PARTICLE DATA
   1   11                      .415121+04     .45133+01       .10292+00      .57916+08       .65922-03       .55235+04
   2   11                      .351951+04     .11079+01       .25258+00      .58123+08       .99542-03       .56067+04
   3   11                      .303394+04    -.13116+01       .36761+00      .58782+08       .13572-02       .56891+04
------------------------------------------------------------------------------------------------------------------------------

 1    12  INPUT  - CONTIN      .10315+00     .10649+00     .11003+01    .76903+01    .53149+03    .46377+04    .30261+08   0
                               .65348+02     .30667+03     .30052-02    .54 54+04    .26887+04    .12091+01
                               .60702+04     .60956+03     .53451+03
PARTICLE DATA
   1   12                      .418553+04     .50979+01       .10728+00      .57309+08       .64909-03       .55110+04
   2   12                      .354027+04     .13176+01       .26036+00      .58034+08       .97613-03       .55962+04
   3   12                      .304423+04    -.13526+01       .37805+00      .58719+08       .13719-02       .5 766+04
------------------------------------------------------------------------------------------------------------------------------

 1    13  INPUT  - CONTIN      .11253+00     .10485+00     .11168+01    .86119+01    .54 20+03    .46993+04    .30226+08   0
                               .63559+02     .29840+03     .29360-02    .54450+04    .268 9+04    .12097+01
                               .60675+04     .60462+03     .55095+03
PARTICLE DATA
   1   13                      .422293+04     .56963+01       .11235+00      .57179+08       .63769-03       .54957+04
   2   13                      .356242+04     .15301+01       .27015+00      .57933+08       .95915-03       .55843+04
   3   13                      .305691+04    -.13706+01       .39033+00      .58699+08       .12819-02       .56678+04
------------------------------------------------------------------------------------------------------------------------------

 1    14  INPUT  - CONTIN      .12190+00     .10323+00     .11362+01    .95513+01    .56382+03    .47712+04    .30185+08   0
                               .61654+02     .28888+03     .28559-02    .54209+04    .26870+04    .12106+01
                               .60143+04     .59819+03     .57097+03
PARTICLE DATA
   1   14                      .427654+04     .62985+01       .11780+00      .57025+08       .62507-03       .54776+04
   2   14                      .358958+04     .17512+01       .28139+00      .57812+08       .92948-03       .55701+04
   3   14                      .307427+04    -.13748+01       .40911+00      .58552+08       .12358-02       .56570+04
------------------------------------------------------------------------------------------------------------------------------

 1    15  INPUT  - CONTIN      .13128+00     .10161+00     .11588+01    .10906+02    .58939+03    .48590+04    .30137+08   0
                               .59654+02     .27806+03     .27645-02    .53976+04    .26859+04    .12115+01
                               .60606+04     .59163+03     .59527+03
PARTICLE DATA
   1   15                      .433029+04     .68811+01       .12201+00      .56851+08       .61108-03       .54 72+04

          SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                      GAS-PARTICLE FLOW SOLUTION
                                          CASE NO.    0                                              PAGE   14

  SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

LINE POINT  DSCRIP - REGIME        R             X             M          THETA        ENTROPY      VELOCITY     M-TOTAL   ITR
                               MACH ANGLE     PRESSURE      DENSITY    TEMPERATURE   GAS CONST.   LOCAL GAMMA   SHOCK ANGLE
                                  TO*           PO*           S*
PARTICLE DATA
 SPECIE POINT  DESCRIPTION         V            THETA          D M          ENTHALPY       DENSITY          TEMPERATURE

 1    16  INPUT  - CONTIN      .14068+00     .99987-01     .11853+01    .11931+02    .60880+03    .49508+04    .30079+08   0
                               .57577+02     .26563+03     .26588-02    .53590+04    .26846+04    .12126+01
                               .60560+04     .58305+03     .62549+03
PARTICLE DATA
   1   16                      .439466+04     .74632+01       .13315+00      .56692+08       .59550-03       .54326+04
   2   16                      .355920+04     .21291+01       .30921+00      .57510+08       .87134-03       .55366+04
   3   16 LIMIT STREAMLINE     .312299+04    -.10847+01       .43762+00      .58316+08       .11280-02       .56297+04
------------------------------------------------------------------------------------------------------------------------------

 1    17  INPUT  - CONTIN      .15217+00     .97993-01     .12216+01    .12502+02    .64259+03    .50415+04    .29999+08   0
                               .54946+02     .24927+03     .25185-02    .53124+04    .26829+04    .12141+01
                               .60495+04     .57089+03     .66962+03
PARTICLE DATA
   1   17                      .448166+04     .80959+01       .14419+00      .56355+08       .57548-03       .53989+04
   2   17 LIMIT STREAMLINE     .371229+04     .22936+01       .32915+00      .57286+08       .83152-03       .55083+04
------------------------------------------------------------------------------------------------------------------------------

 1    18  INPUT  - CONTIN      .15941+00     .96790-01     .12479+01    .13151+02    .66794+03    .51754+04    .29981+08   0
                               .53257+02     .23781+03     .24194-02    .52782+04    .26817+04    .12151+01
                               .60496+04     .56172+03     .70387+03
PARTICLE DATA
   1   18                      .454337+04     .84505+01       .15241+00      .56148+08       .56167-03       .53796+04
------------------------------------------------------------------------------------------------------------------------------

 1    19  INPUT  - CONTIN      .17151+00     .94696-01     .12980+01    .14141+02    .71527+03    .53514+04    .29828+08   0
                               .50393+02     .21707+03     .22782-02    .52123+04    .26774+04    .12172+01
                               .60399+04     .54360+03     .77411+03
PARTICLE DATA
   1   19 LIMIT STREAMLINE     .466135+04     .89665+01       .16736+00      .55748+08       .53691-03       .53275+04
------------------------------------------------------------------------------------------------------------------------------

 1    20  INPUT  - CONTIN      .17817+00     .93494-01     .13290+01    .14619+02    .74521+03    .54588+04    .29750+08   0
                               .48804+02     .20499+03     .21306-02    .51709+04    .26779+04    .12184+01
                               .60287+04     .53194+03     .82115+03
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
------------------------------------------------------------------------------------------------------------------------------

 1    21  INPUT  - CONTIN      .18754+00     .91871-01     .13773+01    .15192+02    .79242+03    .56237+04    .29647+08   0
                               .46554+02     .18692+03     .19701-02    .51058+04    .26758+04    .12203+01
                               .60186+04     .51319+03     .89979+03
```

SAMPLE PROBLEM 5 OUTPUT (Cont'd)

```
                         PARTICLE PERCENT LOADINGS
                          RADIUS      LOADING
                         .11500+01   .33296+02

                         .30000+01   .33273+02

                         .55000+01   .33031+02

 PARTICLE PERCENT LOADING RELATIVE TO THE GAS :   .50877+02   PARTICLE PERCENT LOADING RELATIVE TO THE MIXTURE :   .33721+02

                         MOMENTUM INTEGRATION RESULTS
                  FORCEX        FORCEY        TORQZ         ISP
                -.19119+05     .00000        .00000        .19796+03
        DELFXG        DELFYG        TORQZG        DELFXP        DELFYP        TORQZP
       .11404+05     .00000        .00000        .27145+04     .00000        .00000

         SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                         GAS-PARTICLE FLOW SOLUTION
                         CASE NO.  0                                              PAGE  15

 SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

LINE POINT  DSCRIP - REGIME      R            X            A           THETA       ENTROPY     VELOCITY     N-TOTAL  ITR
                            MACH ANGLE     PRESSURE     DENSITY     TEMPERATURE  GAS CONST.  LOCAL GAMMA  SHOCK ANGLE
                               TO*           PO*          SO*
PARTICLE DATA
 SPECIE POINT  DESCRIPTION       V            THETA         D M.        ENTHALPY     DENSITY       TEMPERATURE

  2    99  INPUT  - CONTIN   .17812+00    .93898-01    .13290+01    .19619+02    .19521+03    .59588+09    .29750+08   0
                             .44804+02    .20489+03    .21306-02    .51709+04    .26779+04    .12184+01
                             .60287+04    .53194+03    .82115+03
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
------------------------------------------------------------------------------------------------------------------

  2   100  INPUT  - CONTIN   .18754+00    .91871-01    .13773+01    .15192+02    .79292+03    .54237+04    .29647+08   0
                             .46556+02    .18692+03    .19701-02    .51058+04    .26758+04    .12203+01
                             .60186+04    .51319+03    .89979+03
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
------------------------------------------------------------------------------------------------------------------

                         PRESSURE INTEGRATION RESULTS
                  FORCEX        FORCEY        TORQZ         DELFX         DELFY         ISP
                -.19119+05     .00000        .00000        .00000        .00000        .19796+03

  3    98  INPUT  - CONTIN   .17151+00    .94646-01    .12980+01    .19191+02    .71522+03    .53519+04    .29828+08   0
                             .50393+02    .21707+03    .22382-02    .52123+04    .26799+04    .12172+01
                             .60349+04    .54360+03    .77411+03
PARTICLE DATA
    1    98 LIMIT STREAMLINE  .466135+04    .89665+01    .16736+00    .55748+08    .53691-03    .53275+04
------------------------------------------------------------------------------------------------------------------

                         PRESSURE INTEGRATION RESULTS
                  FORCEX        FORCEY        TORQZ         DELFX         DELFY         ISP
                -.19119+05     .00000        .00000        .00000        .00000        .19796+03

  4    97  INPUT  - CONTIN   .15941+00    .96740-01    .12479+01    .13151+02    .66794+03    .51754+04    .29941+08   0
                             .53257+02    .23781+03    .29199-02    .52782+04    .26817+04    .12151+01
                             .60466+04    .56172+03    .70387+03
PARTICLE DATA
    1    97                   .454337+04    .84505+01    .15241+00    .56148+08    .56167-03    .53746+04
------------------------------------------------------------------------------------------------------------------

                         PRESSURE INTEGRATION RESULTS
                  FORCEX        FORCEY        TORQZ         DELFX         DELFY         ISP
                -.19119+05     .00000        .00000        .00000        .00000        .19796+03

  5    96  INPUT  - CONTIN   .15217+00    .97997-01    .11716+01    .12702+02    .64259+03    .50815+04    .29999+04   0

    2    96 LIMIT STREAMLINE  .371229+04    .22936+01    .32915+00    .57284+08    .83162+03    .55083+04

                         PRESSURE INTEGRATION RESULTS
                  FORCEX        FORCEY        TORQZ         DELFX         DELFY         ISP
                -.19119+05     .00000        .00000        .00000        .00000        .19796+03
```

SAMPLE PROBLEM 5 OUTPUT (Cont'd)

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                 SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                        GAS-PARTICLE FLOW SOLUTION
                                        CASE NO.    0                                          PAGE   82

SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

LINE POINT  DSCRIP - REGIME      R            X            M           THETA        ENTROPY      VELOCITY     H-TOTAL    ITR
                             MACH ANGLE    PRESSURE     DENSITY     TEMPERATURE   GAS CONST.   LOCAL GAMMA  SHOCK ANGLE
                                TO*          PO*          S*
PARTICLE DATA
 SPECIE POINT  DESCRIPTION       U           THETA          D M          ENTHALPY        DENSITY        TEMPERATURE

141     1  WALL   - CONTIN   .00000       .29055+01    .26337+01    .00000       .12182+04    .84106+04    .21850+08    3
                             .27315+02    .17629+01    .23308-04    .29290+04    .26638+04    .13070+01
                             .51846+04    .11532+02    .98956+04
PARTICLE DATA
    1     1                  .831757+04     .00000        .29121-01      .31665+08      .51812-05      .39537+04
    2     1                  .780971+04     .00000        .18972+00      .42565+08      .98296-05      .41880+04
    3     1                  .688589+04     .00000        .41744+00      .46399+08      .19285-04      .42289+04
----------------------------------------------------------------------------------------------------------------------

141     2  INTER  - CONTIN   .39378-01    .29053+01    .26366+01    .63896+00    .12667+04    .84160+04    .21863+08    1
                             .22248+02    .12630+01    .23333-04    .29262+04    .26630+04    .13071+01
                             .51053+04    .11558+02    .98919+04
PARTICLE DATA
    1     2                  .832204+04     .60979+00      .29102-01      .31629+08      .51733-05      .39490+04
    2     2                  .780828+04     .67660+00      .19039+00      .42548+08      .97993-05      .41880+04
    3     2                  .688861+04     .69065+00      .47851+00      .46309+08      .19230-04      .42277+04
----------------------------------------------------------------------------------------------------------------------

141     3  IN. R  - CONTIN   .78785-01    .29046+01    .26402+01    .12711+01    .21931+04    .84222+04    .21882+08    1
                             .[illegible]+02  .12671+01    .23362-04    .29220+04    .26636+04    .13072+01
                             .51861+04    .11589+02    .98878+04
PARTICLE DATA
    1     3                  .832920+04     .12031+01      .29297-01      .31591+08      .51634-05      .39444+04
    2     3                  .781275+04     .13563+01      .19119+00      .42532+08      .97859-05      .41880+04
    3     3                  .689219+04     .13817+01      .47976+00      .46278+08      .19156-04      .42265+04
----------------------------------------------------------------------------------------------------------------------

141     4  INTER  - CONTIN   .11876+00    .29035+01    .26452+01    .19082+01    .71790+04    .76320+04    .21908+08    1
                             .22213+02    .12634+01    .23905-04    .29180+04    .26638+04    .13[illegible]+01
                             .51873+04    .11633+02    .98821+04
PARTICLE DATA
    1     4                  .833819+04     .19267+01      .29434-01      .31529+08      .51517-05      .39366+04
    2     4                  .781889+04     .2[illegible]+01      .19234+00      .42505+08      .96880-05      .41880+04
    3     4                  .6897[illegible]      .20740+01      .48189+00      .46362+08      .19070-04      .42785+04
----------------------------------------------------------------------------------------------------------------------

141     5  INTER  - CONTIN   .15772+00    .29020+01    .26505+01    .25552+01    .71537+04    .84421+04    .21939+08    1
                             .22146+02    .12638+01    .23452-04    .29130+04    .26638+04    .13079+01
                             .51887+04    .11682+02    .98782+04
PARTICLE DATA
    1     [illegible]                  .[illegible]+04     .[illegible]+01      .[illegible]-01      .31665+08      .[illegible]-05      .39[illegible]+04

                 SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                        GAS-PARTICLE FLOW SOLUTION
                                        CASE NO.    0                                          PAGE   89

SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

LINE POINT  DSCRIP - REGIME      R            X            M           THETA        ENTROPY      VELOCITY     H-TOTAL    ITR
                             MACH ANGLE    PRESSURE     DENSITY     TEMPERATURE   GAS CONST.   LOCAL GAMMA  SHOCK ANGLE
                                TO*          PO*          S*
PARTICLE DATA
 SPECIE POINT  DESCRIPTION       U           THETA          D M          ENTHALPY        DENSITY        TEMPERATURE

141    40  INTER  - CONTIN   .11978+01    .27099+01    .41667+01    .17056+02    .79521+03    .10564+05    .29758+08    3
                             .13887+02    .19306+01    .58175-04    .17957+04    .26612+04    .13651+01
                             .51719+04    .43607+02    .76788+04
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
----------------------------------------------------------------------------------------------------------------------

141    41  WALL   - CONTIN   .12313+01    .27291+01    .41365+01    .17069+02    .79242+03    .10576+05    .29647+08    1
                             .13990+02    .19709+01    .58016-04    .18133+04    .26612+04    .13444+01
                             .55708+04    .43868+02    .76426+04
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
----------------------------------------------------------------------------------------------------------------------

141    42  PDW-RR - CONTIN   .12314+01    .27291+01    .44870+01    .21872+02    .79242+03    .10749+05    .29647+08    3
                             .12077+02    .11927+01    .40429-04    .15963+04    .26612+04    .13509+01
                             .55078+04    .31290+02    .85907+04
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
----------------------------------------------------------------------------------------------------------------------

141    43  PDW-RR - CONTIN   .12314+01    .27291+01    .48095+01    .26676+02    .79242+03    .10944+05    .29647+08    1
                             .11789+02    .68963+00    .26889-04    .13878+04    .26612+04    .13546+01
                             .54378+04    .21536+02    .96852+04
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
----------------------------------------------------------------------------------------------------------------------

141    44  PDW-RR - CONTIN   .12319+01    .27291+01    .53790+01    .31478+02    .79242+03    .11132+05    .29647+08    1
                             .10719+02    .37881+00    .17254-04    .11880+04    .26612+04    .13546+01
                             .53690+04    .19261+02    .10816+05
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
----------------------------------------------------------------------------------------------------------------------

141    45  PDW-RR - CONTIN   .12314+01    .27291+01    .59479+01    .36283+02    .79242+03    .11301+05    .29647+08    1
                             .96777+01    .19546+00    .10562-04    .10013+04    .26612+04    .13546+01
                             .53498+04    .89572+01    .17112+05
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
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SAMPLE PROBLEM 5 OUTPUT (Cont'd)

SUMMARY OF STANDARD PLUME FLOWFIELD CODE INPUT DATA WHICH WAS OUTPUT ON UNIT 12

CHEMISTRY SYSTEM 3

MOLECULAR WEIGHT	.18649+02
SPECIFIC HEAT RATIO	.13269+01
VISCOSITY(POISE)	.84672-03
PRANDTL NUMBER	.98169+00
NOZZLE EXIT RADIUS(FT)	.12319+01
TEMPERATURE(DEG R)	.12090+04
DENSITY(GM/CC)	.19750-04
VELOCITY(FT/SEC)	.96357+04

SPECIE	MOLE FRACTION	SPECIE	MOLE FRACTION
AL2O3(S)	.0000	CO	.2740+00
CO2	.1000-01	CL	.3319-02
CL2	.1746-05	H	.1110-01
H2	.3762+00	H2O	.8249-01
HCL	.1596+00	N2	.8162-01
O	.1502-09	OH	.4969-03
O2	.1383-05		

PARTICLE PHYSICAL DATA

SPECIE	LIMITING STREAMLINE	RADIUS (MICRON)	SPECIFIC HEAT (BTU/LBM/MOLE/DEG R)	MASS DENSITY (GM/CC)	MOL WEIGHT
1	29	.1150+01	.9016+02	.4005+01	.1020+03
2	19	.3000+01	.9016+02	.4005+01	.1020+03
3	14	.5500+01	.9016+02	.4005+01	.1020+03

GASEOUS STARTING LINE INFO

R/RE(NO)	U(FT/SEC)	V(FT/SEC)	P(ATM)	T(DEG R)
.0000	.8366+04	.0000	.9787-01	.1655+04
.4762-01	.8374+04	.1960+03	.9785-01	.1652+04
.9524-01	.8384+04	.2926+03	.9770-01	.1648+04
.1429+00	.8395+04	.4397+03	.9727-01	.1643+04
.1905+00	.8407+04	.5874+03	.9714-01	.1637+04
.2381+00	.8419+04	.7355+03	.9699-01	.1631+04
.2857+00	.8429+04	.8836+03	.9684-01	.1624+04
.3333+00	.8438+04	.1031+04	.9679-01	.1618+04
.3810+00	.8441+04	.1176+04	.9672-01	.1612+04
.4286+00	.8439+04	.1320+04	.9682-01	.1607+04
.4762+00	.8427+04	.1463+04	.9693-01	.1604+04
.5238+00	.8397+04	.1604+04	.9705-01	.1606+04
.5714+00	.8619+04	.1805+04	.9740-01	.1573+04
.5934+00	.8831+04	.1936+04	.9790-01	.1466+04
.6190+00	.8957+04	.2046+04	.9688-01	.1475+04
.6667+00	.9074+04	.2197+04	.9740-01	.1385+04
.7143+00	.9117+04	.2374+04	.9851-01	.1368+04
.7619+00	.9352+04	.2511+04	.1001+00	.1287+04
.7905+00	.9526+04	.2643+04	.1016+00	.1225+04
.8095+00	.9583+04	.2699+04	.1026+00	.1205+04
.8571+00	.9653+04	.2749+04	.1040+00	.1181+04
.9048+00	.9723+04	.2884+04	.1119+00	.1147+04
.9524+00	.9962+04	.3019+04	.1235+00	.1094+04
.9592+00	.1001+05	.3041+04	.1255+00	.1027+04
.1000+01	.1007+05	.3095+04	.1341+00	.1007+04

PARTICLE START LINE PROPERTIES

POINT	SPECIE	U(FT/SEC)	V(FT/SEC)	DENSITY(GM/CC)	T(DEG R)
1	1	.8273+04	.0000	.2990-05	.2237+04
1	2	.7742+04	.0000	.5724-05	.2327+04
1	3	.6826+04	.0000	.1126-04	.2360+04
2	1	.8281+04	.1463+03	.2981-05	.2231+04
2	2	.7791+04	.1452+03	.5684-05	.2327+04
2	3	.6829+04	.1303+03	.1120-04	.2359+04
3	1	.8290+04	.2931+03	.2968-05	.2226+04
3	2	.7752+04	.2906+03	.5632-05	.2327+04
3	3	.6829+04	.2607+03	.1111-04	.2359+04
4	1	.8300+04	.4404+03	.2953-05	.2214+04
4	2	.7757+04	.4362+03	.5554-05	.2327+04
4	3	.6834+04	.3912+03	.1100-04	.2355+04
5	1	.8311+04	.5882+03	.2937-05	.2207+04
5	2	.7762+04	.5820+03	.5480-05	.2327+04
5	3	.6842+04	.5216+03	.1089-04	.2353+04
6	1	.8322+04	.7367+03	.2922-05	.2195+04
6	2	.7767+04	.7278+03	.5395-05	.2327+04
6	3	.6846+04	.6519+03	.1080-04	.2350+04

SAMPLE PROBLEM 5 OUTPUT (Cont'd)

STAGNATION SOLUTION
EDGE CONDITIONS

TEMPERATURE : .6500+04 DEG R
PRESSURE : .3700-02 ATMOSPHERES
GAMMA : .1266+01
ENTHALPY : .1104+04 BTU/LBM
ENTROPY : .2037+01 BTU/LBM-DEG R
CP-FROZEN : .5061+00 BTU/LBM-DEG R
DENSITY : .1997-02 LBM/FT3
VISCOSITY : .6212-04 LBM/S-FT

EDGE CONDITIONS

IS	WALL LENGTH FEET	TEMP DEG-R	CP FROZEN B/LB-R	STATIC PRESSURE ATM	DENSITY LB/FT3	VISCOSITY LB/FS	VELOCITY F/S	ENTHALPY B/LB	ENTROPY B/LB-R	MACH NO.
1	1.295-01	5.167+03	4.929-01	1.272+01	6.309-02	5.354-05	5.809+03	5.112+02	2.037+00	1.392+00
2	1.932-01	5.099+03	4.922-01	1.701+01	6.031-02	5.314-05	5.937+03	4.800+02	2.037+00	1.470+00
3	2.212-01	4.869+03	4.892-01	9.662+00	5.085-02	5.156-05	6.905+03	3.699+02	2.037+00	1.776+00
4	2.744-01	4.546+03	4.838-01	6.539+00	3.749-02	4.870-05	7.121+03	1.717+02	2.037+00	1.920+00
5	3.136-01	4.139+03	4.784-01	4.627+00	2.862-02	4.639-05	7.657+03	1.320+01	2.037+00	2.030+00
6	4.675-01	3.800+03	4.735-01	3.741+00	2.373-02	4.421-05	8.096+03	-1.249+02	2.037+00	2.212+00
7	5.615-01	3.601+03	4.687-01	2.493+00	1.772-02	4.230-05	8.447+03	-2.408+02	2.037+00	2.407+00
8	6.567-01	3.391+03	4.642-01	1.919+00	1.447-02	4.060-05	8.730+03	-3.382+02	2.037+00	2.555+00
9	7.400-01	3.214+03	4.601-01	1.516+00	1.209-02	3.918-05	8.964+03	-4.207+02	2.037+00	2.691+00
10	8.039-01	3.067+03	4.563-01	1.227+00	1.027-02	3.789-05	9.159+03	-4.912+02	2.037+00	2.814+00
11	9.336-01	2.923+03	4.528-01	1.009+00	8.832-03	3.671-05	9.328+03	-5.536+02	2.037+00	2.929+00
12	1.026+00	2.805+03	4.496-01	8.463-01	7.724-03	3.568-05	9.470+03	-6.070+02	2.037+00	3.032+00
13	1.119+00	2.702+03	4.466-01	7.227-01	6.848-03	3.477-05	9.591+03	-6.532+02	2.037+00	3.127+00
14	1.211+00	2.609+03	4.439-01	6.265-01	6.127-03	3.393-05	9.698+03	-6.944+02	2.037+00	3.217+00
15	1.303+00	2.526+03	4.414-01	5.455-01	5.529-03	3.316-05	9.797+03	-7.317+02	2.037+00	3.298+00
16	1.394+00	2.450+03	4.390-01	4.804-01	5.021-03	3.246-05	9.879+03	-7.649+02	2.037+00	3.371+00
17	1.486+00	2.380+03	4.367-01	4.259-01	4.590-03	3.180-05	9.955+03	-7.953+02	2.037+00	3.444+00
18	1.577+00	2.317+03	4.347-01	3.825-01	4.226-03	3.120-05	1.002+04	-8.226+02	2.037+00	3.511+00
19	1.668+00	2.261+03	4.327-01	3.459-01	3.916-03	3.066-05	1.008+04	-8.471+02	2.037+00	3.579+00
20	1.767+00	2.208+03	4.309-01	3.144-01	3.644-03	3.014-05	1.014+04	-8.698+02	2.037+00	3.634+00
21	1.849+00	2.159+03	4.292-01	2.871-01	3.403-03	2.966-05	1.019+04	-8.909+02	2.037+00	3.691+00
22	1.941+00	2.115+03	4.276-01	2.640-01	3.198-03	2.922-05	1.024+04	-9.096+02	2.037+00	3.744+00
23	2.032+00	2.075+03	4.261-01	2.444-01	3.015-03	2.881-05	1.028+04	-9.271+02	2.037+00	3.793+00
24	2.121+00	2.038+03	4.248-01	2.273-01	2.856-03	2.844-05	1.032+04	-9.429+02	2.037+00	3.840+00
25	2.211+00	2.003+03	4.235-01	2.122-01	2.713-03	2.808-05	1.036+04	-9.576+02	2.037+00	3.884+00
26	2.302+00	1.971+03	4.223-01	1.992-01	2.587-03	2.776-05	1.039+04	-9.711+02	2.037+00	3.926+00
27	2.391+00	1.942+03	4.211-01	1.876-01	2.474-03	2.745-05	1.042+04	-9.835+02	2.037+00	3.965+00
28	2.480+00	1.914+03	4.201-01	1.773-01	2.371-03	2.716-05	1.045+04	-9.951+02	2.037+00	4.002+00
29	2.570+00	1.887+03	4.190-01	1.678-01	2.276-03	2.689-05	1.047+04	-1.006+03	2.037+00	4.039+00
30	2.659+00	1.863+03	4.181-01	1.594-01	2.191-03	2.663-05	1.050+04	-1.016+03	2.037+00	4.073+00
31	2.749+00	1.841+03	4.172-01	1.522-01	2.116-03	2.640-05	1.052+04	-1.026+03	2.037+00	4.104+00
32	2.836+00	1.821+03	4.164-01	1.457-01	2.048-03	2.618-05	1.054+04	-1.034+03	2.037+00	4.133+00
33	2.926+00	1.801+03	4.156-01	1.397-01	1.985-03	2.597-05	1.056+04	-1.042+03	2.037+00	4.162+00

**** STATE DOES NOT CONVERGE FOR NO+S?: 1 *****

34	3.015+00	1.783+03	4.148-01	1.341-01	1.926-03	2.577-05	1.058+04	-1.050+03	2.037+00	4.189+00

SAMPLE PROBLEM 5 OUTPUT (Cont'd)

PRIOR LAMINAR SOLUTION AFTER TRANSITION. TURBULENCE WILL BE INCLUDED AND SOLUTION CONTINUED

ITERATED VALUES DAMP. MAX.LIN MAX.ERRORS IN CONSERVATION EQS.

ITS	TIME	ALPH	FPPW	DAMP	ERROR	MOMENTUM	ENERGY
2	.000	2.103	.0902	.1650	2.-01 12	-2.9-01 11	-1.8+02
3	.000	2.161	.0065	.4950	2.-01 12	-2.0-01 11	-1.5+02
4	.000	2.331	.9360	1.0000	9.-02 12	-8.9-02 11	-7.6+01
5	.000	2.035	.9358	1.0000	8.-07 12	4.0-03 11	4.4+00
6	.000	2.035	.9354	1.0000	1.-07 12	5.8-06 8	4.2-02

ALPHA	RADIUS FEET	PRESSURE ATM	EDGE VEL. F/S	BETAP	BETAU	HEAT FLUXES, B/SF2 DIFFUSIONAL	TOT ENTH	QERAD	QCOND
2.035+00	1.076-01	1.272+01	5.809+03	9.605-01	9.605-01	4.466+01	4.466+01	4.466+01	4.466+01

WALL SHEAR LBF/F2	MASS FLUXES LB/SF2 MECHANICAL REMOVAL	PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS DIFFUSIVE FLUXES LB/SF2 FOR
7.851+01	0.000	0.000	0.000	0.000	0.000

MOM TRANS COEFF. CF/2	HEAT TRANS COEFF. ST NO.	BLOWING PARAMETERS (NORM. BY RHOE*UE*ST) FOR PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS TRANSFER COEFFICIENTS, CM, FOR
5.831-04	2.461-04	0.000	0.000	0.000	0.000

MOMENTUM THICKNESS, THETA FEET	DISPLACE. THICKNESS, DELSTAR FEET	EFFECTIVE BODY DISPLACE. FEET	ENTHALPY THICKNESS, LAMBDA FEET	REYNOLDS NUMBER PER FOOT	MASS THICKNESS FOR FEET
7.785-05	2.075-04	2.075-04	8.827-05	6.833+06	0.000

TOTAL HEAT TO WALL B/S	THRUST LOSS (LBF)	TOTAL WALL AREA (F2)	ACCELERATION PARAMETER-K	INVISCID MASS IN BL LB/S	TOTAL MASS IN BL LB/S
0.000	-5.216-01	0.000	1.832-02	9.252-01	9.252-01

NODAL INFORMATION

ETA	DISTANCE FROM WALL FEET	F	U/UE	FPP	SHEAR LBF/F2	G, TOTAL ENTHALPY B/LB	CP B/LB	CPP B/LP	STATIC ENTHALPY B/LB	TEMP DEG-R
0.000	0.000	0.000	0.000	9.354-01	3.851+01	6.889+02	5.655+01	8.336+02	6.889+02	5.520+03
2.808-03	1.400-06	1.525-05	5.338-03	9.325-01	3.839+01	6.887+02	6.132+01	8.244+02	6.887+02	5.521+03
6.808-03	3.398-06	8.951-05	1.291-02	9.285-01	3.822+01	6.893+02	6.802+01	8.071+02	6.891+02	5.522+03
1.557-02	7.767-06	4.667-04	2.938-02	9.198-01	3.786+01	6.906+02	8.241+01	7.799+02	6.900+02	5.523+03
2.703-02	1.349-05	1.401-03	5.069-02	9.079-01	3.737+01	6.927+02	1.006+02	7.363+02	6.910+02	5.525+03
4.835-02	2.413-05	4.467-03	8.960-02	8.862-01	3.648+01	6.978+02	1.325+02	6.830+02	6.920+02	5.526+03
1.465-01	7.316-05	3.939-02	2.565-01	7.850-01	3.231+01	7.359+02	2.490+02	1.819+02	6.916+02	5.527+03
4.154-01	2.065-04	2.835-01	6.113-01	5.121-01	2.120+01	8.992+02	5.092+02	-1.074+02	6.478+02	5.418+03
7.214-01	3.555-04	7.975-01	8.998-01	2.577-01	1.054+01	1.079+03	2.282+02	-2.448+02	5.931+02	5.320+03
1.000+00	4.885-04	1.761+00	9.500-01	1.015-01	4.250+00	1.169+03	8.577+01	-1.555+02	5.617+02	5.264+03
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

DISTANCE FROM WALL FEET	RHO LB/F3	MU LB/FS	HEAT P/LB-R	COND. B/SF-R	NUMBER	SCHMIDT NUMBER	WEIGHT	NUMBER	PHORETIC	PRANDTL NO
0.000	5.899-02	5.594-05	4.969-01	9.618-05	2.890-01	2.890-01	1.869+01	0.000	0.000	0.000
1.400-06	5.898-02	5.595-05	4.969-01	9.619-05	2.890-01	2.890-01	1.869+01	7.165-03	0.000	9.000-01
3.398-06	5.897-02	5.595-05	4.969-01	9.620-05	2.890-01	2.890-01	1.869+01	1.733-02	0.000	9.000-01
7.767-06	5.895-02	5.596-05	4.969-01	9.622-05	2.890-01	2.890-01	1.869+01	3.965-02	0.000	9.000-01
1.349-05	5.893-02	5.598-05	4.969-01	9.625-05	2.890-01	2.890-01	1.869+01	6.809-02	0.000	9.000-01
2.413-05	5.890-02	5.599-05	4.970-01	9.629-05	2.890-01	2.890-01	1.869+01	1.202-01	0.000	9.000-01
7.316-05	5.892-02	5.598-05	4.970-01	9.621-05	2.890-01	2.890-01	1.869+01	3.442-01	0.000	9.000-01
2.065-04	5.987-02	5.591-05	4.960-01	9.510-05	2.890-01	2.890-01	1.869+01	8.769-01	0.000	9.000-01
3.555-04	6.111-02	5.460-05	4.940-01	9.363-05	2.890-01	2.890-01	1.869+01	1.161+00	0.000	9.000-01
4.885-04	6.185-02	5.426-05	4.941-01	9.277-05	2.890-01	2.890-01	1.869+01	1.305+00	0.000	9.000-01
5.848-04	6.220-02	5.407-05	4.938-01	9.238-05	2.890-01	2.890-01	1.869+01	1.350+00	0.000	9.000-01
1.192-03	6.308-02	5.358-05	4.929-01	9.139-05	2.890-01	2.890-01	1.869+01	1.387+00	0.000	9.000-01

REFIT CALLED

I	ETA(I)	U/UE	G(I,1)	SP(I,1,1)	SP(I,1,2)	SP(I,1,3)	SP(I,1,4)	SP(I,1,5)	SP(I,1,6)	SP(I,1,7)	SP(I,1,8)
1	0.000	0.000	6.889+02	1.000+00							
2	2.666-02	5.000-02	6.927+02	0.000							
3	4.538-02	1.200-01	7.027+02	0.000							
4	1.425-01	2.500-01	7.339+02	0.000							
5	2.075-01	3.500-01	7.602+02	0.000							
6	2.790-01	4.500-01	8.095+02	0.000							
7	4.097-01	6.000-01	8.919+02	0.000							
8	5.677-01	7.500-01	9.977+02	0.000							
9	7.223-01	8.501-01	1.079+03	0.000							
10	1.000+00	9.500-01	1.169+03	1.000+00							
11	1.229+00	9.829-01	1.195+03	1.391-01							
12	2.500+00	1.000+00	1.189+03	5.521-01							

SAMPLE PROBLEM 5 OUTPUT (Cont'd)

STATION 30 ------ AXIAL POSITION 2.6332+01 FEET

ITERATED VALUES DAMP MAX.LIN MAX.ERRORS IN CONSERVATION EQS.

ITS	TIME	ALPH	EPPW		ERROR	MOMENTUM		ENERGY
1	.000	6.796	2.6079	.9999	5.-07 13	6.5-01	10	4.0+02
2	.000	6.806	2.6030	1.0000	5.-07 13	3.2-01	10	2.0+02
3	.000	6.806	2.6030	1.0000	1.-06 16	5.8-04	10	-2.8-01

ALPHA	RADIUS FEET	PRESSURE ATM	EDGE VEL. F/S	BETAP	BETAV	HEAT FLUXES--B/SF2 DIFFUSIONAL	TOT ENTH	RERAD	CCOND
6.806+00	1.231+00	1.391-01	1.058+04	1.091-01	1.091-01	1.630+01	1.630+01	1.630+01	1.630+01

WALL SHEAR LBF/F2	MASS FLUXES LB/SF2 MECHANICAL REMOVAL	PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS DIFFUSIVE FLUXES LB/SF2 FOR
6.291+00	0.000	0.000	0.000	0.000	0.000

MOM TRANS COEFF. CF/2	HEAT TRANS COEFF. ST NO.	BLOWING PARAMETERS INORM. BY RHOE*UE*STI FOR PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS TRANSFER COEFFICIENTS. CM. FOR
9.396-04	7.295-04	0.000	0.000	0.000	0.000

MOMENTUM THICKNESS. THETA FEET	DISPLACE. THICKNESS. DELSTAR FEET	EFFECTIVE BODY DISPLACE. FEET	ENTHALPY THICKNESS. LAMBDA FEET	REYNOLDS NUMBER PER FOOT	MASS THICKNESS FOR FEET
2.637-03	1.727-02	1.727-02	2.018-03	7.904+05	0.000

TOTAL HEAT TO WALL B/S	THRUST LOSS (LBF)	TOTAL WALL AREA (F2)	ACCELERATION PARAMETER-K	INVISCID MASS IN BL LB/S	TOTAL MASS IN BL LB/S
0.000	9.416-01	1.324+01	2.422-08	6.639+00	6.639+00

NODAL INFORMATION

ETA	DISTANCE FROM WALL FEET	F	U/UE	FPP	SHEAR LBF/F2	G, TOTAL ENTHALPY B/LB	GP B/LB	GPP B/LB	STATIC ENTHALPY B/LB	TEMP DEG-R
0.000	0.000	0.000	0.000	2.603+00	6.291+00	8.669+01	6.409+02	2.156+04	8.669+01	6.291+03
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.276+00	[illegible]	[illegible]	2.096+04	[illegible]	[illegible]
5.606-03	2.922-04	2.627-03	1.166-01	2.577+00	6.253+00	1.271+02	1.599+03	1.369+04	1.067+02	6.332+03
[illegible]	[illegible]	1.132-02	[illegible]	[illegible]	6.206+00	2.011+02	[illegible]	-2.686+03	1.065+02	[illegible]
2.202-02	[illegible]	2.791-02	3.619-01	1.685+00	6.152+00	3.577+02	2.182+03	[illegible]	[illegible]	6.292+03
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4.972-02	2.973-03	1.961-01	6.130-01	3.039-01	5.866+00	7.311+02	6.275+02	-6.151+02	-1.081+02	[illegible]
1.326-01	[illegible]	[illegible]	7.670-01	[illegible]	5.165+00	9.635+02	[illegible]	-2.022+01	[illegible]	[illegible]
9.520-01	1.562-02	2.229+00	9.590-01	3.765-02	4.027+00	1.058+03	[illegible]	-8.011+00	-5.908+02	[illegible]
1.200+00	[illegible]	5.627+00	9.500-01	1.169-02	[illegible]	1.158+03	1.129+01	-2.216+00	-8.586+02	[illegible]
1.377+00	3.787-02	9.799+00	9.769-01	7.530-03	1.177+00	1.179+03	5.818+00	-2.665+00	-9.637+02	2.036+03
[illegible]	5.938-02	1.569+01	1.000+00	0.000	0.000	1.188+03	0.000	[illegible]	-1.050+03	1.763+03

DISTANCE	DENSITY	VISCOSITY	[illegible]	[illegible]	PRANDTL	MOLECULAR	MOLECULAR	MACH	[illegible]	TURBULENT
2.922-04	[illegible]	9.781-05	9.817-01	7.970-05	2.890-01	2.890-01	1.869+01	3.208-01	5.666-03	9.000-01
[illegible]	[illegible]	9.781-05	9.817-01	7.969-05	2.890-01	2.890-01	1.869+01	6.751-01	1.028-01	9.000-01
[illegible]	7.999-06	9.752-05	9.911-01	7.911-05	2.890-01	2.890-01	1.869+01	9.611-01	3.916-01	9.000-01
[illegible]	8.100-06	[illegible]	9.796-01	7.771-05	2.890-01	2.890-01	1.867+01	1.266+00	1.162+00	9.000-01
[illegible]	[illegible]	[illegible]	9.761-01	7.297-05	2.890-01	2.890-01	1.869+01	1.777+00	5.305+00	9.000-01
[illegible]	1.036-03	9.007-05	9.626-01	6.910-05	2.890-01	2.890-01	1.869+01	2.307+00	2.828+01	9.000-01
1.562-02	1.209-03	3.600-05	9.505-01	5.612-05	2.890-01	2.890-01	1.869+01	2.886+00	3.318+01	9.000-01
2.965-02	1.536-03	3.000-05	9.318-01	4.563-05	2.890-01	2.890-01	1.867+01	3.578+00	5.357+01	9.000-01
3.787-02	1.687-03	2.862-05	9.267-01	4.176-05	2.890-01	2.890-01	1.869+01	3.837+00	6.636+01	9.000-01
5.938-02	1.926-03	2.577-05	9.369-01	3.700-05	2.890-01	2.890-01	1.869+01	4.187+00	0.000	9.000-01

SAMPLE PROBLEM 5 OUTPUT (Cont'd)

STATION SUMMARY FOR SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

NEW CONTOUR INFORMATION

		INPUT INVISCID CONTOUR		INPUT WALL CONTOUR	
		NEW WALL CONTOUR-NORM. BY		NEW INVISCID CONTOUR-NORM. BY	
		THROAT RADIUS:	.17530+00 FEET	THROAT RADIUS:	.17530+00 FEET
STATION NO.	DISPLACEMENT THICKNESS FEET	AXIAL COORDINATE	RADIAL COORDINATE	AXIAL COORDINATE	RADIAL COORDINATE
1	2.07961-04	0.00000	1.0[illegible]+00	0.00000	1.06802+00
2	1.97757-04	7.45150-02	1.09308+00	7.41513-02	1.09092+00
3	2.29503-04	2.25013-01	1.1972[illegible]+00	2.25877-01	1.18679+00
4	3.69583-04	5.25123-01	1.28890+00	5.26909-01	1.28510+00
5	6.58201-04	1.00613+00	1.52637+00	1.01003+00	1.51963+00
6	9.68160-04	1.48818+00	1.75998+00	1.49396+00	1.75002+00
7	1.32062-03	1.97109+00	1.99085+00	1.97832+00	1.97715+00
8	1.77153-03	2.45407+00	2.21795+00	2.46263+00	2.20005+00
9	2.15889-03	2.93610+00	2.44318+00	2.94693+00	2.42082+00
10	2.61796-03	3.41773+00	2.66660+00	3.43007+00	2.63790+00
11	3.11707-03	3.89905+00	2.88922+00	3.91364+00	2.85178+00
12	3.63775-03	4.38111+00	3.09999+00	4.39785+00	3.06201+00
13	4.17296-03	4.863[illegible]+00	3.31283+00	4.88232+00	3.26917+00
14	4.73005-03	5.34466+00	3.52280+00	5.36549+00	3.47320+00
15	5.30599-03	5.82720+00	3.72989+00	5.85080+00	3.67411+00
16	5.90179-03	6.30899+00	3.93670+00	6.33482+00	3.87192+00
17	6.51427-03	6.79077+00	4.13530+00	6.81896+00	4.06662+00
18	7.13603-03	7.27276+00	4.33375+00	7.30329+00	4.25925+00
19	7.76090-03	7.75491+00	4.52819+00	7.78760+00	4.44686+00
20	8.39708-03	8.24160+00	4.72167+00	8.27622+00	4.63213+00
21	9.03778-03	8.71898+00	4.91106+00	8.75261+00	4.81898+00
22	9.70069-03	9.20199+00	5.09780+00	9.23999+00	4.99970+00
23	1.03465-02	9.68748+00	5.28233+00	9.72854+00	5.17167+00
24	1.09968-02	1.01664+01	5.46277+00	1.02080+01	5.34523+00
25	1.16325-02	1.06426+01	5.64133+00	1.06081+01	5.51667+00
26	1.22771-02	1.11129+01	5.81709+00	1.11702+01	5.68991+00
27	1.29165-02	1.16120+01	5.98949+00	1.16612+01	5.85051+00
28	1.35608-02	1.20703+01	6.15906+00	1.21446+01	6.01298+00
29	1.41939-02	1.25769+01	6.32532+00	1.26286+01	6.17228+00
30	1.49320-02	1.30599+01	6.49028+00	1.31139+01	6.32972+00
31	1.54858-02	1.35408+01	6.65178+00	1.35989+01	6.48922+00
32	1.60952-02	1.40106+01	6.81062+00	1.40753+01	6.63598+00
33	1.66594-02	1.45059+01	6.96569+00	1.45621+01	6.78811+00
34	1.72712-02	1.49927+01	7.11917+00	1.50502+01	6.93093+00

SAMPLE PROBLEM 5 OUTPUT (Cont'd)

SUMMARY OF PARTICLE PROPERTIES
AS THEY ENTER THE BOUNDARY LAYER

PARTICLE SPECIE	STREAM-LINE	R	X	V	THETA	ENTHALPY	DENSITY	TEMPERATURE
1	1	.11176+01	.25329+01	.10204+05	.18638+02	.20731+08	.85931-05	.25889+04
1	2	.11240+01	.25541+01	.10209+05	.18575+02	.20689+08	.84844-05	.25832+04
1	3	.11303+01	.25753+01	.10213+05	.18517+02	.20651+08	.83853-05	.25784+04
1	4	.11367+01	.25966+01	.10217+05	.18450+02	.20613+08	.82966-05	.25737+04
1	5	.11430+01	.26178+01	.10221+05	.18387+02	.20575+08	.81870-05	.25690+04
1	6	.11493+01	.26391+01	.10225+05	.18325+02	.20537+08	.80891-05	.25644+04
1	7	.11555+01	.26603+01	.10229+05	.18262+02	.20502+08	.79989-05	.25599+04
1	8	.11617+01	.26816+01	.10233+05	.18199+02	.20468+08	.79088-05	.25556+04
1	9	.11679+01	.27029+01	.10236+05	.18136+02	.20434+08	.78187-05	.25513+04
1	10	.11741+01	.27241+01	.10240+05	.18073+02	.20399+08	.77287-05	.25470+04

SUMMARY OF PARTICLE PROPERTIES
IN THE BOUNDARY LAYER AT THE NOZZLE EXIT PLANE

PARTICLE SPECIE	STREAM-LINE	R	X	V	THETA	ENTHALPY	DENSITY	TEMPERATURE
1	1	.11813+01	.27241+01	.10292+05	.18196+02	.19850+08	.74236-05	.24785+04
1	2	.11805+01	.27241+01	.10290+05	.18184+02	.19900+08	.74409-05	.24847+04
1	3	.11797+01	.27241+01	.10286+05	.18171+02	.19954+08	.75117-05	.24915+04
1	4	.11788+01	.27241+01	.10282+05	.18159+02	.20010+08	.75425-05	.24984+04
1	5	.11780+01	.27241+01	.10277+05	.18144+02	.20068+08	.75570-05	.25057+04
1	6	.11773+01	.27241+01	.10271+05	.18129+02	.20178+08	.75914-05	.25132+04
1	7	.11764+01	.27241+01	.10265+05	.18115+02	.20193+08	.76363-05	.25213+04
1	8	.11756+01	.27241+01	.10257+05	.18099+02	.20240+08	.76616-05	.25296+04
1	9	.11748+01	.27241+01	.10249+05	.18083+02	.20328+08	.76929-05	.25382+04
1	10	.11741+01	.27241+01	.10240+05	.18067+02	.20399+08	.77287-05	.25470+04

SAMPLE PROBLEM 5 OUTPUT (Cont'd)

GASEOUS STARTING LINE INFO

R/RE(NO)	U(FT/SEC)	V(FT/SEC)	P(ATM)	T(DEG R)
.0000	.8366+04	.0000	.9747-01	.1655+04
.4762-01	.8374+04	.1460+03	.9745-01	.1652+04
.9524-01	.8384+04	.2926+03	.9738-01	.1648+04
.1429+00	.8395+04	.4397+03	.9727-01	.1643+04
.1905+00	.8407+04	.5874+03	.9714-01	.1637+04
.2381+00	.8419+04	.7355+03	.9699-01	.1631+04
.2857+00	.8429+04	.8836+03	.9684-01	.1624+04
.3333+00	.8438+04	.1031+04	.9674-01	.1618+04
.3810+00	.8441+04	.1176+04	.9672-01	.1612+04
.4286+00	.8439+04	.1320+04	.9682-01	.1607+04
.4762+00	.8427+04	.1463+04	.9693-01	.1604+04
.5238+00	.8397+04	.1604+04	.9705-01	.1606+04
.5714+00	.8619+04	.1805+04	.9740-01	.1533+04
.5934+00	.8871+04	.1936+04	.9746-01	.1466+04
.6190+00	.8957+04	.2044+04	.9688-01	.1425+04
.6667+00	.9074+04	.2197+04	.9740-01	.1385+04
.7143+00	.9117+04	.2324+04	.9851-01	.1368+04
.7619+00	.9352+04	.2511+04	.1001+00	.1287+04
.7905+00	.9526+04	.2643+04	.1016+00	.1225+04
.8095+00	.9583+04	.2694+04	.1026+00	.1205+04
.8571+00	.9653+04	.2749+04	.1060+00	.1181+04
.9048+00	.9723+04	.2884+04	.1119+00	.1147+04
.9524+00	.9947+04	.3019+04	.1235+00	.1094+04
.9593+00	.1001+05	.3041+04	.1256+00	.1078+04
.9689+00	.9861+04	.3004+04	.1348+00	.1132+04
.9753+00	.9608+04	.2932+04	.1347+00	.1243+04
.9872+00	.8676+04	.2655+04	.1344+00	.1579+04
.9941+00	.7759+04	.2379+04	.1343+00	.1885+04
.9979+00	.6198+04	.1902+04	.1342+00	.2157+04
.9992+00	.4578+04	.1405+04	.1341+00	.2372+04
.9995+00	.3828+04	.1175+04	.1341+00	.2369+04
.1000+01	.3572+04	.1097+04	.1341+00	.2062+04

PARTICLE START LINE PROPERTIES

POINT	SPECIE	U(FT/SEC)	V(FT/SEC)	DENSITY(GM/CC)	T(DEG R)
1	1	.8273+04	.0000	.2980-05	.2237+04
1	2	.7742+04	.0000	.5721-05	.2327+04
1	3	.6826+04	.0000	.1126-04	.2360+04
2	1	.8281+04	.1463+03	.2980-05	.2233+04
2	2	.7747+04	.1452+03	.5683-05	.2327+04
2	3	.6829+04	.1303+03	.1120-04	.2359+04
3	1	.8290+04	.2931+03	.2967-05	.2226+04
3	2	.7752+04	.2906+03	.5626-05	.2327+04
3	3	.6834+04	.2607+03	.1111-04	.2358+04
4	1	.8300+04	.4404+03	.2951-05	.2218+04
4	2	.7757+04	.4362+03	.5556-05	.2327+04
4	3	.6838+04	.3912+03	.1100-04	.2355+04

SUMMARY OF STANDARD PLUME FLOWFIELD CODE INPUT DATA INCLUDING THE BOUNDARY LAYER

CHEMISTRY SYSTEM 3

MASS FLOW AVERAGED PROPERTIES(SPECIES ARE INVISCID AVERAGES)

MOLECULAR WEIGHT	.18651+02
SPECIFIC HEAT RATIO	.13258+01
VISCOSITY(POISE)	.44672-03
PRANDTL NUMBER	.48169+00
NOZZLE EXIT RADIUS(FT)	.12314+01
TEMPERATURE(DEG R)	.13345+04
DENSITY(GM/CC)	.18757-04
VELOCITY(FT/SEC)	.95082+04

SPECIE	MOLE FRACTION	SPECIE	MOLE FRACTION
AL2O3(S)	.0000	CO	.2740+00
CO2	.1008-01	CL	.3319-02
CL2	.1786-05	H	.1110-01
H2	.3762+00	H2O	.8294-01
HCL	.1596+00	N2	.4162-01
O	.1502-04	OH	.4969-03
O2	.1383-05		

PARTICLE PHYSICAL DATA

SPECIE	LIMITING STREAMLINE	RADIUS (MICRON)	SPECIFIC HEAT (BTU/LBM/MOLE/DEG R)	MASS DENSITY (GM/CC)	MOL WEIGHT
1	24	.1150+01	.4016+02	.4005+01	.1020+03
2	19	.3000+01	.4016+02	.4005+01	.1020+03
3	14	.5500+01	.4016+02	.4005+01	.1020+03

SAMPLE PROBLEM 5 OUTPUT (Cont'd)

POINT	SPECIE	U(FT/SEC)	V(FT/SEC)	DENSITY(GM/CC)	T(DEG K)
5	1	.8311+04	.5882+03	.2935-05	.2207+04
5	2	.7762+04	.5820+03	.5977-05	.2322+04
5	3	.6842+04	.5216+03	.1084-04	.2353+04
6	1	.8322+04	.7167+03	.2920-05	.2195+04
6	2	.7767+04	.7278+03	.5392-05	.2327+04
6	3	.6846+04	.6519+03	.1079-04	.2350+04
7	1	.8332+04	.8057+03	.2907-05	.2181+04
7	2	.7771+04	.8737+03	.5304-05	.2327+04
7	3	.6850+04	.7822+03	.1073-04	.2346+04
8	1	.8340+04	.1035+04	.2898-05	.2165+04
8	2	.7773+04	.1019+04	.5216-05	.2327+04
8	3	.6853+04	.9123+03	.1072-04	.2341+04
9	1	.8344+04	.1183+04	.2896-05	.2149+04
9	2	.7774+04	.1165+04	.5131-05	.2327+04
9	3	.6855+04	.1042+04	.1080-04	.2337+04
10	1	.8343+04	.1331+04	.2902-05	.2133+04
10	2	.7771+04	.1309+04	.5053-05	.2327+04
10	3	.6054+04	.1172+04	.1101-04	.2332+04
11	1	.8332+04	.1476+04	.2918-05	.2117+04
11	2	.7763+04	.1452+04	.4987-05	.2327+04
11	3	.6850+04	.1301+04	.1140-04	.2327+04
12	1	.8309+04	.1618+04	.2944-05	.2105+04
12	2	.7744+04	.1593+04	.4939-05	.2327+04
12	3	.6833+04	.1431+04	.1203-04	.2327+04
13	1	.8507+04	.1876+04	.2911-05	.209[illegible]+04
13	2	.7827+04	.1764+04	.4855-05	.2327+04
13	3	.6897+04	.1574+04	.1277-04	.2327+04
14	1	.8682+04	.1948+04	.2896-05	.2005+04
14	2	.7907+04	.1856+04	.4816-05	.2327+04
14	3	.6957+04	.1696+04	.1310-04	.2327+04
15	1	.8800+04	.2060+04	.2929-05	.1950+04
15	2	.7988+04	.1957+04	.4802-05	.2327+04
16	1	.8921+04	.2226+04	.3029-05	.1872+04
16	2	.8298+04	.2127+04	.4831-05	.2327+04
17	1	.8969+04	.2368+04	.3145-05	.1819+04
17	2	.8159+04	.2281+04	.4906-05	.2327+04
18	1	.9143+04	.2567+04	.3234-05	.1731+04
18	2	.8290+04	.2462+04	.4955-05	.2327+04
19	1	.9337+04	.2763+04	.3304-05	.1672+04
19	2	.8392+04	.2581+04	.4921-05	.2327+04
20	1	.7389+04	.2765+04	.3385-05	.1641+04
21	1	.9460+04	.2890+04	.3611-05	.1581+04
22	1	.9528+04	.3011+04	.3825-05	.1520+04
23	1	.9728+04	.3177+04	.3979-05	.1418+04
24	1	.9777+04	.3215+04	.3828-05	.1377+04

ORIGINAL PAGE IS
OF POOR QUALITY

SAMPLE PROBLEM 5 OUTPUT (Cont'd)

METHOD OF CHARACTERISTICS EXIT PLANE STARTLINE BASED ON MASS FLOW AVERAGED THERMODYNAMIC PROPERTIES

TOTAL PRESSURE(PSFA) - .13986+05
TOTAL TEMPERATURE(R) - .65706+04
SPECIFIC HEAT RATIO - .13258+01
MOLECULAR WEIGHT - .18653+02
EXIT RADIUS(RE,FEET) - .12314+01

R/RE	X	MACH NUMBER	FLOW ANGLE (DEG)	ENTROPY (FT**2/SEC**2/R)	TOTAL ENTHALPY (FT**2/SEC**2)
.00000	.00000	.25778+01	.00000	.26584+04	.67301+08
.47619-01	.00000	.25878+01	.99915+00	.26413+04	.67326+08
.95238-01	.00000	.25912+01	.19988+01	.26170+04	.67364+08
.14286+00	.00000	.26006+01	.29981+01	.25870+04	.67415+08
.19048+00	.00000	.26115+01	.39966+01	.25527+04	.67476+08
.23810+00	.00000	.26238+01	.49931+01	.25193+04	.67546+08
.28571+00	.00000	.26371+01	.59839+01	.24729+04	.67623+08
.33333+00	.00000	.26502+01	.69659+01	.24310+04	.67703+08
.38095+00	.00000	.26671+01	.79335+01	.23920+04	.67781+08
.42857+00	.00000	.26719+01	.88908+01	.23571+04	.67848+08
.47619+00	.00000	.26777+01	.98515+01	.23360+04	.67892+08
.52381+00	.00000	.26799+01	.10812+02	.23453+04	.67894+08
.57143+00	.00000	.28206+01	.11830+02	.18273+04	.68688+08
.59338+00	.00000	.29604+01	.12365+02	.13494+04	.69490+08
.61905+00	.00000	.30520+01	.12865+02	.10519+04	.70020+08
.66667+00	.00000	.31453+01	.13612+02	.73222+03	.70623+08
.71429+00	.00000	.31893+01	.14300+02	.56909+03	.70976+08
.76190+00	.00000	.33853+01	.15030+02	-.14395+03	.71999+08
.79048+00	.00000	.35413+01	.15505+02	-.71182+03	.72778+08
.80952+00	.00000	.35964+01	.15700+02	-.92092+03	.73063+08
.85714+00	.00000	.36665+01	.16114+02	-.12271+04	.73525+08
.90476+00	.00000	.37551+01	.16520+02	-.16085+04	.73818+08
.95238+00	.00000	.40399+01	.16858+02	-.29702+04	.74549+08
.95931+00	.00000	.40900+01	.16905+02	-.31803+04	.74752+08
.96839+00	.00000	.38417+01	.16942+02	-.23236+04	.75232+08
.97533+00	.00000	.35735+01	.16970+02	-.13113+04	.74713+08
.98720+00	.00000	.28636+01	.17017+02	.12902+04	.71981+08
.99412+00	.00000	.23695+01	.17045+02	.29813+04	.68941+08
.99773+00	.00000	.17504+01	.17061+02	.46807+04	.63124+08
.99920+00	.00000	.12436+01	.17064+02	.55261+04	.56986+08
.99950+00	.00000	.10316+01	.17067+02	.56983+04	.54264+08
.10000+01	.00000	.10370+01	.17069+02	.41903+04	.47724+08

THE INVISCID PORTION OF THE START LINE WAS MOVED .21935-04 (FT/R) TO MATCH THE EDGE OF THE BOUNDARY LAYER

.0000	.2933+01	.2639+01	.0000	.2831+04	.0000	.0000	.6763+08
.3968-01	.2933+01	.2642+01	.6347+00	.2822+04	.0000	.0000	.6764+08
.7940-01	.2932+01	.2645+01	.1271+01	.2809+04	.0000	.0000	.6766+08
.1192+00	.2931+01	.2650+01	.1907+01	.2791+04	.0000	.0000	.6768+08
.1588+00	.2930+01	.2656+01	.2544+01	.2771+04	.0000	.0000	.6771+08
[illegible]	[illegible]	.2662+01	.3177+01	.2748+04	.0000	.0000	[illegible]
.3985+00	.2911+01	.2698+01	.6297+01	.2608+04	.0000	.0000	.6792+08
.4330+00	.2907+01	.2705+01	.6904+01	.2578+04	.0000	.0000	.6802+08
.4715+00	.2902+01	.2712+01	.7511+01	.2548+04	.0000	.0000	.6807+08
.5095+00	.2897+01	.2717+01	.8112+01	.2520+04	.0000	.0000	.6812+08
.5470+00	.2891+01	.2722+01	.8716+01	.2495+04	.0000	.0000	.6817+08
.5850+00	.2885+01	.2725+01	.9315+01	.2478+04	.0000	.0000	.6820+08
.6220+00	.2879+01	.2726+01	.9911+01	.2468+04	.0000	.0000	.6823+08
.6596+00	.2872+01	.2722+01	.1050+02	.2467+04	.0000	.0000	.6824+08
.6967+00	.2865+01	.2716+01	.1108+02	.2475+04	.0000	.0000	.6824+08
.7250+00	.2859+01	.2824+01	.1157+02	.2068+04	.0000	.0000	.6876+08
.7608+00	.2852+01	.3010+01	.1229+02	.1402+04	.0000	.0000	.6973+08
.7879+00	.2845+01	.3093+01	.1273+02	.1113+04	.0000	.0000	.7017+08
.8160+00	.2839+01	.3135+01	.1306+02	.9562+03	.0000	.0000	.7042+08
.8420+00	.2833+01	.3176+01	.1339+02	.8015+03	.0000	.0000	.7068+08
.8775+00	.2824+01	.3201+01	.1382+02	.6926+03	.0000	.0000	.7089+08
.9130+00	.2818+01	.3224+01	.1425+02	.5863+03	.0000	.0000	.7109+08
.9438+00	.2808+01	.3337+01	.1465+02	.1591+03	.0000	.0000	.7161+08
.9685+00	.2801+01	.3444+01	.1501+02	-.2508+03	.0000	.0000	.7210+08
.9957+00	.2794+01	.3561+01	.1538+02	-.7167+03	.0000	.0000	.7251+08
.1013+01	.2789+01	.3605+01	.1555+02	-.8983+03	.0000	.0000	.7277+08
.1043+01	.2790+01	.3640+01	.1579+02	-.1071+04	.0000	.0000	.7290+08
.1074+01	.2771+01	.3674+01	.1603+02	-.1241+04	.0000	.0000	.7321+08
.1119+01	.2760+01	.3725+01	.1636+02	-.1539+04	.0000	.0000	.7339+08
.1137+01	.2753+01	.3787+01	.1653+02	-.1878+04	.0000	.0000	.7345+08
.1152+01	.2748+01	.3853+01	.1669+02	-.2204+04	.0000	.0000	.7354+08
.1162+01	.2745+01	.3917+01	.1670+02	-.2503+04	.0000	.0000	.7364+08
.1171+01	.2743+01	.3977+01	.1675+02	-.2770+04	.0000	.0000	.7379+08
.1185+01	.2738+01	.4074+01	.1686+02	-.3196+04	.0000	.0000	.7410+08
.1195+01	.2735+01	.4124+01	.1691+02	-.3404+04	.0000	.0000	.7431+08
.1196+01	.2735+01	.3837+01	.1691+02	-.2321+04	.0000	.0000	.7592+08
.1201+01	.2733+01	.3578+01	.1699+02	-.1309+04	.0000	.0000	.7479+08
.1217+01	.2729+01	.2886+01	.1700+02	.1293+04	.0000	.0000	.7260+08
.1225+01	.2726+01	.2397+01	.1704+02	.2983+04	.0000	.0000	.6970+08
.1229+01	.2725+01	.1777+01	.1706+02	.4681+04	.0000	.0000	.6377+08
.1230+01	.2724+01	.1265+01	.1706+02	.5526+04	.0000	.0000	.5730+08
.1231+01	.2724+01	.1050+01	.1707+02	.5698+04	.0000	.0000	.5455+08
.1231+01	.2724+01	.1050+01	.1707+02	.4190+04	.0000	.0000	.4747+08

SAMPLE PROBLEM 5 OUTPUT (Cont'd)

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                 SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                          GAS-PARTICLE FLOW SOLUTION
                                          CASE NO.    0                                                 PAGE    9

 SECOND STAGE IUS NOZZLE/PLUME PC=400 PSIA

LINE POINT  DSCRIP - REGIME        R            X             M            THETA         ENTROPY       VELOCITY      H-TOTAL    ITR
                               MACH ANGLE    PRESSURE      DENSITY      TEMPERATURE    GAS CONST.    LOCAL GAMMA   SHOCK ANGLE
                                  TO*           PO*          S*
PARTICLE DATA
 SPECIE POINT  DESCRIPTION        V            THETA          O M           ENTHALPY       DENSITY       TEMPERATURE

  1    1  INPUT  - CONTIN      .00000       .29331+01    .26388+01     .00000        .72390+04     .84169+04     .21819+08    0
                               .22268+02    .12399+01    .22941-04     .29218+04     .26637+04     .13072+01
                               .51818+04    .11365+02    .99305+04
PARTICLE DATA
   1    1                      .832407+04      .00000        .29094-01       .31583+08      .50461-05      .39434+04
   2    1                      .781381+04      .00000        .18907+00       .42525+08      .96558-05      .41880+04
   3    1                      .689473+04      .00000        .47721+00       .46375+08      .18935-04      .42259+04
-------------------------------------------------------------------------------------------------------------------------

  1    2  INPUT  - CONTIN      .39684-01    .29329+01    .26417+01     .63474+00     .72275+04     .84223+04     .21832+08    0
                               .22242+02    .12400+01    .22865-04     .29189+04     .26637+04     .13073+01
                               .51824+04    .11391+02    .99264+04
PARTICLE DATA
   1    2                      .832935+04      .64034+00      .29154-01       .31546+08      .50882-05      .39384+04
   2    2                      .781781+04      .67559+00      .18973+00       .42509+08      .96210-05      .41880+04
   3    2                      .689766+04      .68459+00      .47828+00       .46365+08      .18881-04      .42247+04
-------------------------------------------------------------------------------------------------------------------------

  1    3  INPUT  - CONTIN      .79398-01    .29322+01    .26453+01     .12707+01     .72138+04     .84290+04     .21851+08    0
                               .22211+02    .12401+01    .22994-04     .29155+04     .26638+04     .13074+01
                               .51833+04    .11421+02    .99227+04
PARTICLE DATA
   1    3                      .833572+04      .12822+01      .29266-01       .31509+08      .50784-05      .39342+04
   2    3                      .782189+04      .13522+01      .19052+00       .42492+08      .95738-05      .41880+04
   3    3                      .690099+04      .13400+01      .47953+00       .46354+08      .18809-04      .42235+04
-------------------------------------------------------------------------------------------------------------------------

  1    4  INPUT  - CONTIN      .11918+00    .29311+01    .26503+01     .19074+01     .71987+04     .84383+04     .21877+08    0
                               .22167+02    .12404+01    .23037-04     .29107+04     .26638+04     .13075+01
                               .51845+04    .11465+02    .99170+04
PARTICLE DATA
   1    4                      .834472+04      .19253+01      .29390-01       .31447+08      .50670-05      .39264+04
   2    4                      .782807+04      .20305+01      .19167+00       .42465+08      .95165-05      .41880+04
   3    4                      .690602+04      .20715+01      .48126+00       .46334+08      .18725-04      .42214+04
-------------------------------------------------------------------------------------------------------------------------

  1    5  INPUT  - CONTIN      .15895+00    .29296+01    .26556+01     .25440+01     .71793+04     .84484+04     .21908+08    0
                               .22120+02    .12408+01    .23084-04     .29057+04     .26638+04     .13076+01
                               .51858+04    .11513+02    .99111+04
PARTICLE DATA
   1    5                      .835580+04      .25678+01      .2956 -01       .31344+08      .50556-05      .39186+04

                 SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                          GAS-PARTICLE FLOW SOLUTION
                                          CASE NO.    0                                                 PAGE   17

 SECOND STAGE IUS NOZZLE/PLUME PC=400 PSIA

LINE POINT  DSCRIP - REGIME        R            X             M            THETA         ENTROPY       VELOCITY      H-TOTAL    ITR
                               MACH ANGLE    PRESSURE      DENSITY      TEMPERATURE    GAS CONST.    LOCAL GAMMA   SHOCK ANGLE
                                  TO*           PO*          S*
PARTICLE DATA
 SPECIE POINT  DESCRIPTION        V            THETA          O M           ENTHALPY       DENSITY       TEMPERATURE

  1   42  INPUT  - CONTIN      .12314+01    .22781+01    .10500+01     .17069+02     .87221+04     .33387+04     .21701+07    0
                               .72247+02    .19710+01    .28215-04     .37955+04     .26502+04     .12604+01
                               .43025+04    .37933+01    .87227+04
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
-------------------------------------------------------------------------------------------------------------------------
 GAS MASS FLOW RATE =       .47903+02    PARTICLE MASS FLOW RATE =      .23495+02    MIXTURE MASS FLOW RATE =      .71398+02
                                           PARTICLE PERCENT LOADINGS
                                              RADIUS       LOADING
                                            .11500+01    .33619+02

                                            .30000+01    .31507+02

                                            .55000+01    .34873+02

 PARTICLE PERCENT LOADING RELATIVE TO THE GAS =   .49046+02   PARTICLE PERCENT LOADING RELATIVE TO THE MIXTURE =   .32901+02

                                         MOMENTUM INTEGRATION RESULTS
                                   FORCEX        FORCEY         TORQZ          ISP
                                -.20530+05      .00000        .00000       .28754+03
                       DELFXG         DELFYG         TORQZG         DELFXP         DELFYP         TORQZP
                     .14716+05       .00000         .00000        .58138+04       .00000         .00000
```

SAMPLE PROBLEM 5 OUTPUT (Cont'd)

```
                SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                          GAS-PARTICLE FLOW SOLUTION
                                             CASE NO.   0                                              PAGE   50

 SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

LINE POINT  DESCRIP - REGIME       X              R              M            THETA         ENTROPY       VELOCITY       H-TOTAL    ITR
                              MACH ANGLE      PRESSURE       DENSITY      TEMPERATURE    GAS CONST.    LOCAL GAMMA    SHOCK ANGLE
                                 TO*            PO*            SO
 PARTICLE DATA
 SPECIE POINT  DESCRIPTION         V            THETA           D M           ENTHALPY       DENSITY                    TEMPERATURE

   2    67  INTER  - CONTIN   .12319+01      .27238+01      .82666+01      .12397+03     .87223+04     .93921+04     .21701+07    2
                              .69480+01      .20075-03      .30793-07      .35394+01     .26458+04     .13784+01
                              .42812+04      .17898-01      .22989+05
 PARTICLE DATA
 NO PARTICLES ARE PRESENT AT THIS POINT
 ------------------------------------------------------------------------------------------------------------------------

   2    68  INTER  - CONTIN   .12319+01      .27238+01      .96286+01      .12888+03     .87223+04     .94820+04     .21701+07    2
                              .59614+01      .70650-04      .14461-07      .26591+03     .26458+04     .13784+01
                              .42812+04      .84614-02      .24952+05
 PARTICLE DATA
 NO PARTICLES ARE PRESENT AT THIS POINT
 ------------------------------------------------------------------------------------------------------------------------

   2    69  INTER  - CONTIN   .12318+01      .27238+01      .11908+02     .13327+03     .87223+04     .95590+04     .21701+07    2
                              .49936+01      .20354-04      .58356-08     .18983+03     .26458+04     .13784+01
                              .42812+04      .35110-02      .27325+05
 PARTICLE DATA
 NO PARTICLES ARE PRESENT AT THIS POINT
 ------------------------------------------------------------------------------------------------------------------------

   2    70  INTER  - CONTIN   .12318+01      .27237+01      .14140+02     .13866+03     .87223+04     .96230+04     .21701+07    2
                              .40410+01      .45858-05      .19794-08     .12609+03     .26458+04     .13784+01
                              .42832+04      .12074-02      .30166+05
 PARTICLE DATA
 NO PARTICLES ARE PRESENT AT THIS POINT
 ------------------------------------------------------------------------------------------------------------------------

   2    71  INTER  - CONTIN   .12317+01      .27237+01      .18988+02     .14354+03     .87223+04     .96740+04     .21701+07    2
                              .31005+01      .69309-06      .50249-09     .75070+02     .26458+04     .13784+01
                              .42832+04      .31010-03      .33785+05
 PARTICLE DATA
 NO PARTICLES ARE PRESENT AT THIS POINT
 ------------------------------------------------------------------------------------------------------------------------

   2    72  FREERD - CONTIN   .12317+01      .27237+01      .16379+02     .14374+03     .87223+04     .96739+04     .21701+07    2
                              .31020+01      .69551-06      .50376-09     .75141+02     .26458+04     .13784+01
                              .42832+04      .31098-03      .33778+05
 PARTICLE DATA
 NO PARTICLES ARE PRESENT AT THIS POINT
 ------------------------------------------------------------------------------------------------------------------------

                SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                          GAS-PARTICLE FLOW SOLUTION
                                             CASE NO.   0                                              PAGE   55

 SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

LINE POINT  DESCRIP - REGIME       X              R              M            THETA         ENTROPY       VELOCITY       H-TOTAL    ITR
                              MACH ANGLE      PRESSURE       DENSITY      TEMPERATURE    GAS CONST.    LOCAL GAMMA    SHOCK ANGLE
                                 TO*            PO*            SO
 PARTICLE DATA
 SPECIE POINT  DESCRIPTION         V            THETA           D M           ENTHALPY       DENSITY                    TEMPERATURE

  11     1  WALL   - CONTIN   .00000         .30411+01      .26803+01      .00000        .72450+04     .88187+04     .21810+08    1
                              .22256+02      .12333+01      .22835-04      .29197+04     .26637+04     .13073+01
                              .51809+04      .11317+02      .99906+04
 PARTICLE DATA
     1     1                  .832591+04     .00000         .29099-01      .31560+08     .50722-04     .39905+04
     2     1                  .781643+04     .00000         .18889+00      .42514+08     .96069-05     .41880+04
     3     1                  .689737+04     .00000         .87716+00      .46368+08     .18836-04     .42251+04
 ------------------------------------------------------------------------------------------------------------------------

  11    83  FREERD - FREE M   .17336+01      .27211+01      .16808+02      .14375+03     .00000        .96739+04     .00000       1
                              .34109+01      .66889-06      .48179-09      .75110+02     .26458+04     .14670+01
 PARTICLE DATA
 NO PARTICLES ARE PRESENT AT THIS POINT
 ------------------------------------------------------------------------------------------------------------------------
 CONTINUUM BREAKDOWN CRITERIA OF .05 MET BETWEEN POINTS   56 AND   57 AT X,R=  .12350+01  .27278+01

  A NEW STREAMLINE HAS BEEN INSERTED ON LINE  10 BETWEEN POINTS  63 AND  64

  A NEW STREAMLINE HAS BEEN INSERTED ON LINE  10 BETWEEN POINTS  53 AND  54

                                 POINT NO.  61 ON LINE  11 HAS BEEN DELETED

                                 POINT NO.  62 ON LINE  11 HAS BEEN DELETED

  A NEW STREAMLINE HAS BEEN INSERTED ON LINE  10 BETWEEN POINTS  62 AND  63

                                 POINT NO.  64 ON LINE  11 HAS BEEN DELETED

  12     1  WALL   - CONTIN   .00000         .30419+01      .26808+01      .00000        .72456+04     .88189+04     .21809+08    1
                              .22255+02      .12327+01      .22825-04      .29195+04     .26637+04     .13073+01
                              .51808+04      .11313+02      .99816+04
 PARTICLE DATA
     1     1                  .832612+04     .00000         .29099-01      .31557+08     .50698-04     .39402+04
     2     1                  .781669+04     .00000         .18887+00      .42513+08     .96021-05     .41880+04
     3     1                  .689752+04     .00000         .87715+00      .46367+08     .18827-04     .42251+04
 ------------------------------------------------------------------------------------------------------------------------

  12    83  FREERD - FREE M   .17339+01      .27207+01      .16808+02      .14375+03     .00000        .96739+04     .00000       1
                              .34109+01      .63759-06      .46201-09      .75110+02     .26458+04     .14670+01
 PARTICLE DATA
 NO PARTICLES ARE PRESENT AT THIS POINT
```

SAMPLE PROBLEM 5 OUTPUT (Concluded)

```
              SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                        GAS-PARTICLE FLOW SOLUTION
                                        CASE NO.    0                                               PAGE   93

 SECOND STAGE IUS NOZZLE/PLUME PC-800 PSIA

LINE POINT  DSCRIP - REGIME        R            X             W          THETA        ENTROPY      VELOCITY     M-TOTAL   ITR
                               MACH ANGLE    PRESSURE      DENSITY    TEMPERATURE   GAS CONST.   LOCAL GAMMA   SHOCK ANGLE
                                  10*          F0*          5*
PARTICLE DATA
 SPECIE POINT  DESCRIPTION          V           THETA          D M          ENTHALPY       DENSITY        TEMPERATURE

 56    1  WALL   - CONTIN     .00000       .30087+01     .26510+01     .00000       .72836+04     .84319+04     .21184+08     1
                              .22161+02    .11871+01     .22096-04     .29045+04    .26637+04     .13076+01
                              .51750+04    .10980+02     .10013+05
PARTICLE DATA
     1     1                  .813926+04   .00000        .29130-01     .31394+08    .89038-05     .30199+04
     2     1                  .783507+04   .00000        .18765+00     .42433+08    .92649-05     .41880+04
     3     1                  .691588+04   .00000        .47676+00     .46319+08    .18148-04     .42194+04
-------------------------------------------------------------------------------------------------------------------------

 56   74  FREERD - FREE M     .12554+01    .26914+01     .16808+07     .14375+03    .00000        .96739+04    .00000       1
                              .34109+01    .13763-06     .99726-10     .75110+02    .26458+04     .16670+01
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
-------------------------------------------------------------------------------------------------------------------------
CONTINUUM BREAKDOWN CRITERIA OF .05 MET BETWEEN POINTS    57 AND   58 AT X,R:   .12758+01   .27335+01

 A NEW STREAMLINE HAS BEEN INSERTED ON LINE  55 BETWEEN POINTS  40 AND  41

                          POINT NO.  63 ON LINE  56 HAS BEEN DELETED

 57    1  WALL   - CONTIN     .00000       .30052+01     .26522+01     .00000       .72923+04     .84224+04     .21737+08     3
                              .22151+02    .11820+01     .22014-04     .29028+04    .26637+04     .13077+01
                              .51743+04    .10943+02     .10021+05
PARTICLE DATA
     1     1                  .830075+04   .00000        .29133-01     .31376+08    .88853-05     .39176+04
     2     1                  .783715+04   .00000        .18751+00     .42424+08    .92772-05     .41880+04
     3     1                  .691753+04   .00000        .47672+00     .46319+08    .18072-04     .42188+04
-------------------------------------------------------------------------------------------------------------------------

 57   74  FREERD - FREE M     .12581+01    .26877+01     .16808+02     .14375+03    .00000        .96739+04    .00000       1
                              .34109+01    .12492-06     .90521-10     .75110+02    .26458+04     .16670+01
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
-------------------------------------------------------------------------------------------------------------------------
CONTINUUM BREAKDOWN CRITERIA OF .05 MET BETWEEN POINTS    58 AND   59 AT X,R:   .12808+01   .27341+01

 58    1  WALL   - CONTIN     .00000       .30118+01     .26534+01     .00000       .72921+04     .84399+04     .21729+08     3
                              .22196+02    .11770+01     .21933-04     .29011+04    .26637+04     .13077+01
                              .51736+04    .10906+02     .10029+05
PARTICLE DATA
     1     1                  .814224+04   .00000        .29131-01     .31358+08    .88867-05     .39153+04

              SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                        GAS-PARTICLE FLOW SOLUTION
                                        CASE NO.    0                                               PAGE  124

 SECOND STAGE IUS NOZZLE/PLUME PC=800 PSIA

LINE POINT  DSCRIP - REGIME        R            X             W          THETA        ENTROPY      VELOCITY     M-TOTAL   ITR
                               MACH ANGLE    PRESSURE      DENSITY    TEMPERATURE   GAS CONST.   LOCAL GAMMA   SHOCK ANGLE
                                  10*          F0*          5*
PARTICLE DATA
 SPECIE POINT  DESCRIPTION          V           THETA          D M          ENTHALPY       DENSITY        TEMPERATURE

 193   1  WALL   - CONTIN     .00000       .10112+02     .35332+01     .00000       .93604+04     .92098+04     .17091+08     5
                              .16441+02    .92132-01     .24137-05     .19102+04    .26573+04     .13386+01
                              .49616+04    .15159+01     .14497+05
PARTICLE DATA
     1     1                  .502833+04   .00000        .69626-01     .25149+08    .58657-06     .31900+04
     2     1                  .875264+04   .00000        .17539+00     .38402+08    .97142-06     .41880+04
     3     1                  .803054+04   .00000        .45242+00     .43927+08    .16838-05     .41880+04
-------------------------------------------------------------------------------------------------------------------------

 193  55  FREERD - FREE M     .48672+01   -.22273+01     .16808+02     .14375+03    .00000        .96739+04    .00000       1
                              .34109+01    .26668-09     .19329-12     .75110+02    .26458+04     .16670+01
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
-------------------------------------------------------------------------------------------------------------------------
CONTINUUM BREAKDOWN CRITERIA OF .05 MET BETWEEN POINTS    53 AND   54 AT X,R:   .59992+01   .73145+01

PREVIOUSLY NOTED ERRORS HAVE PROPAGATED TO LOWER BOUNDARY, OR PROBLEM LIMITS HAVE BEEN REACHED.  CASE TERMINATED.
     0000000000000 0000000000000
-------------------------------------------------------------------------------------------------------------------------
          PUNCH CARDS FOR LINE  192

          .0000000     .1011162+02  .3533237+01  .0000000     .9360443+04  .1709102+08

          .1132286+00  .1011078+02  .3537815+01  .8498166+00  .9347392+04  .1710881+08

          .2268198+00  .1010825+02  .3545052+01  .1700042+01  .9332235+04  .1712888+08

          .3409527+00  .1010412+02  .3555775+01  .2550256+01  .9311633+04  .1715188+08

          .4556374+00  .1009806+02  .3568764+01  .3397979+01  .9290246+04  .1717636+08

          .5705378+00  .1009039+02  .3584606+01  .4238800+01  .9265401+04  .1720025+08

          .6864458+00  .1008095+02  .3602633+01  .5076277+01  .9240603+04  .1722363+08

          .8028312+00  .1006976+02  .3623307+01  .5905387+01  .9213427+04  .1724435+08

          .9207336+00  .1005671+02  .3645994+01  .6732781+01  .9187276+04  .1726296+08

          .1039272+01  .1004144+02  .3670857+01  .7559075+01  .9160317+04  .1727666+08
```

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8.6 SAMPLE PROBLEM 6 - SPACE SHUTTLE HIGH PERFORMANCE MOTOR WITH FINITE RATE CHEMISTRY

Sample Case 6 utilizes the same data as Sample Case 4 for the HPM nozzle solution except that the finite rate chemistry option was selected. The finite rate package used for this case was taken from Table 7-4 of Section 7. This chemistry package was selected because the plume was to be used in range safety radar cross-section calculations which require the treatment of the ionic species and their reactions. A boundary layer calculation was not selected since its effect is minimal on plume characteristics at low altitude. For this reason, the nozzle and plume were calculated in a single run and did not require a restart at [illegible] plane.

The transonic module was executed to generate a supersonic start line. Additionally, the option (ICTAPE=1, Card 6) which has the program determine the species distribution on the start line was selected. This option requires the TRAN72 program to be run for the particular motor propellant as if an equilibrium or equilibrium/frozen calculation were to be performed. The TRAN72 data used to input this case are shown in Sample Case 5 of Section 4.

SAMPLE PROBLEM 6 INPUT DATA

```
1            3    2
2      SPACE SHUTTL HPM NOZZLE  TUAL GEOMETRY FINITE RATE
3
4
5      3        3.2   55    1          1     3     6    15    25    1                  12575
6     24    2        3    24                     21
7   2.24416667 0.0
8      0    0.0        2.244167   1.0                        .1958705 2.2443775 1.
            .0316.14   2.24415    2.0                        .7827257 2.2465    4.
            .1172855F  2.2513150  6.                         .15616383 2.2556867 8.
            .1944775   2.2612133  10.                        .23329425 2.2666867 12.
            .2714565   2.2774575  14.                        .3192880  2.2876342 16.
            .3467483   2.249      18.                        .383775   2.3118367 20.
            .42 33983  2.325725   22.                        .45639242 2.3411758 24.
            .4671 175  2.346      24.6                       1.62715   2.881625  24.6
            1.754      2.575      24.4824                    1.855175  2.9989583 24.2765
            2.5375     3.7        24.146                     2.2268    3.1466    23.7123
            2.41265    3.22733    23.3785                    2.61917   3.3122417 23.274
            2.5143333  3.309625   22.6435                    3.367667  3.491333  22.2526
            3.2646167  3.562425   21.5                       3.5.1575  3.6764583 21.439
            3.7471917  3.771233   21.0217                    4.011167  3.8683917 20.599
            4.2630417  3.9657417  20.1754                    4.5327 83 4.0636917 19.7495
            4.99417    4.162 667  19.3226                    5.43633   4.2616167 18.8967
            5.306      4.3 2333   18.4715                    5.684533  4.457733  18.3482
            5.9564 3   4.555      17.6275                    6.3 16667 4.6538167 17.2299
            6.62 33    4.751 3    16.7152                    6.9444417 4.9479417 16.3844
            7.2759 3   4.944      15.0766                    7.613125  5.1392583 15.5732
            8.3 6667   5.227 17   14.7752                    8.6 9275  5.3195    14.7888
            9.219167   5.41 25    14.3                       9.38525   5.5029667 13.6222
            9.761      5.5 5      13.2456                    10.135333 5.6776917 12.8733
            10.523 3   5.7641 83  12.5063                    10.9125   5.8492    12.1434
            11.307417  5.932 833  11.7854                    11.707917 6.0151167 11.4326
            11.974583  6.063525   11.2024                    12.116917 6.096     11.1
            12.5265    6.1754167  10.74                 1    12.846 83 6.235     10.49
8a  3       2116.                                                    1 00.
9   2                                                                1 0.
10    SEA LEVEL SKM PC=3            MKS
14  0.5         30 06         6
```


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SAMPLE PROBLEM 6 INPUT DATA (Cont'd)

Card								
15	CO	2[illegible].[illegible]1	-26.42					
	0.	6.956	39.612	-1.37[illegible]	[illegible].	6.956	39.613	-1.379
	100.	6.956	39.613	-1.37[illegible]	150.	6.956	42.024	-1.031
	200.	6.957	44.435	-0.683	250.	6.961	45.846	-0.335
	300.	6.965	47.257	0.013	400.	7.013	49.265	0.711
	500.	7.121	50.841	1.417	600.	7.276	52.152	2.137
	700.	7.450	53.297	2.873	800.	7.624	54.293	3.627
	1000.	7.931	56.02[illegible]	5.163	1200.	8.168	57.496	6.794
	1400.	8.346	58.76[illegible]	8.446	1600.	8.460	59.893	10.13[illegible]
	1800.	8.563	6[illegible].8[illegible]	11.836	2[illegible].	8.664	61.807	13.561
	2300.	8.756	63.024	16.175	2600.	8.825	64.102	18.813
	3000.	8.895	65.37[illegible]	22.357	3300.	8.937	66.221	25.032
	3600.	8.973	66.[illegible]	27.719	4[illegible].	9.014	67.946	31.316
15	CO2	44.[illegible]	-94.[illegible]					
	0.	6.[illegible]1	42.75[illegible]	-1.543	5[illegible].	6.981	42.758	-1.543
	100.	6.[illegible]	42.75	-1.543	15[illegible].	7.417	45.263	-1.173
	200.	7.734	47.7[illegible]	-0.[illegible]16	25[illegible].	8.315	49.448	-0.43[illegible]
	300.	8.[illegible]56	51.127	0.[illegible]16	4[illegible].	9.[illegible]77	53.83[illegible]	[illegible].9[illegible]
	500.	1[illegible].666	56.12[illegible]	1.[illegible]7	6[illegible].	11.31[illegible]	58.126	3.[illegible]7
	700.	11.[illegible]46	5[illegible].[illegible]1	4.245	[illegible].	12.[illegible]93	61.[illegible]22	5.453
	1000.	12.[illegible]	64.344	7.[illegible]4	12[illegible].	13.466	66.756	1[illegible].632
	1400.	13.[illegible]15	6[illegible].[illegible]5[illegible]	13.35[illegible]	1[illegible].	14.[illegible]74	7[illegible].722	16.152
	1800.	14.269	72.[illegible]	1[illegible].[illegible]7	2[illegible].	14.424	73.9[illegible]3	21.857
	2300.	14.6[illegible]	75.[illegible]31	26.212	26[illegible].	14.734	77.73[illegible]	3[illegible].613
	3000.	14.[illegible]73	7[illegible].[illegible]4[illegible]	36.[illegible]	33[illegible].	14.956	[illegible]1.27[illegible]	41.[illegible]1[illegible]
	3600.	15.[illegible]3[illegible]	[illegible]2.574	45.5[illegible]	4[illegible].	15.11[illegible]	[illegible].162	51.5[illegible]
15	H	1.[illegible]	52.1[illegible]					
	[illegible].	4.968	1[illegible].3[illegible]	-1.4[illegible]1	5[illegible].	4.968	19.382	-1.2[illegible]
	100.	4.968	21.[illegible]65	-0.[illegible]4	15[illegible].	4.968	23.976	-0.736
	200.	4.968	25.4[illegible]	-0.488	25[illegible].	4.968	26.517	-0.239
	300.	4.968	27.4[illegible]	[illegible].[illegible]	4[illegible].	4.968	28.852	0.506
	500.	4.968	29.9[illegible]1	1.[illegible]3	6[illegible].	4.968	30.867	1.5
	700.	4.968	31.632	1.9[illegible]	[illegible].	4.968	32.296	2.493
	1000.	4.968	33.4[illegible]4	3.4[illegible]7	1200.	4.968	34.31[illegible]	4.491
	1400.	4.968	35.[illegible]7[illegible]	5.474	16[illegible].	4.968	35.739	6.468
	1800.	4.968	36.325	7.461	2[illegible].	4.968	36.848	8.455
	2300.	4.968	37.53	9.946	26[illegible].	4.968	38.152	11.436
	3000.	4.968	3[illegible].[illegible]	13.42[illegible]	33[illegible].	4.968	39.394	14.927
	3600.	4.968	3[illegible].926	16.423	4[illegible].	4.968	40.636	18.41[illegible]

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SAMPLE PROBLEM 6 INPUT DATA (Cont'd)

Card								
	H2	2.016	[illegible]					
	0.	5.393	2[illegible].644	-1.[illegible]4	50.	5.3[illegible]3	20.645	-1.535
	100.	5.393	24.387	-1.265	150.	5.455	26.586	-0.994
	200.	6.518	28.52[illegible]	-0.682	250.	6.716	29.995	-0.331
	300.	6.894	31.251	[illegible].013	400.	6.975	33.247	0.737
	500.	6.993	34.[illegible]	1.4[illegible]5	600.	7.0[illegible]	36.082	2.166
15	700.	7.036	37.165	2.3[illegible]8	800.	7.087	38.167	3.514
	1000.	7.219	39.7[illegible]2	4.944	1200.	7.39[illegible]	41.037	6.4[illegible]4
	1400.	7.6[illegible]	42.187	7.9[illegible]2	1600.	7.827	43.217	9.446
	1800.	8.[illegible]16	44.15	11.[illegible]3	2000.	8.195	45.004	12.651
	2300.	8.432	46.16[illegible]	15.157	2600.	8.635	47.213	17.7[illegible]8
	3000.	9.[illegible]59	[illegible]	21.21	3300.	9.	49.6	23.[illegible]
	3600.	9.3	[illegible]	25.[illegible]	4000.	9.4	[illegible]	29.[illegible]
	H2O	18.016	-57.7[illegible]					
	0.	0.	0.	-2.367	50.	[illegible]	[illegible]	-1.974
	100.	7.961	36.396	-1.583	150.	7.965	39.156	-1.18
	200.	7.969	41.716	-.784	250.	7.996	43.535	-.384
	300.	8.027	[illegible]	.015	400.	8.186	47.483	.825
	500.	8.415	49.334	1.[illegible]4	600.	8.676	[illegible].891	2.509
15	700.	8.954	52.249	3.39[illegible]	800.	9.246	53.464	4.3[illegible]9
	1000.	9.651	55.391	6.2[illegible]9	1200.	10.444	57.44[illegible]	8.240
	1400.	10.[illegible]67	[illegible]	10.3[illegible]4	1600.	11.462	6[illegible].591	12.630
	1800.	11.669	61.[illegible]	14.964	2000.	12.214	6[illegible].2[illegible]4	17.373
	2300.	12.634	64.971	21.1[illegible]3	2600.	12.965	66.54[illegible]	24.945
	3000.	13.3[illegible]4	6[illegible].42[illegible]	30.2[illegible]1	3300.	13.513	6[illegible].696	34.223
	3600.	13.669	71.[illegible]	38.3[illegible]	4000.	13.853	72.33[illegible]	43.805
	O	16.	59.559					
	0.	0.	0.	-1.6[illegible]8	50.	2.833	16.233	-1.354
	100.	5.666	32.466	-1.[illegible]	150.	5.6[illegible]	34.4[illegible]3	-.751
	200.	5.434	36.34[illegible]	-.523	250.	5.335	37.42[illegible]	-.257
	300.	5.235	[illegible]	.01[illegible]	400.	5.135	39.991	.528
	500.	5.081	41.131	1.038	600.	5.045	42.054	1.544
15	700.	5.029	42.331	2.048	800.	5.015	43.501	2.550
	1000.	4.999	44.619	3.552	1200.	4.990	45.529	4.551
	1400.	4.954	46.28[illegible]	5.54[illegible]	1600.	4.981	46.963	6.544
	1800.	4.979	47.55	7.54[illegible]	2000.	4.978	48.074	8.536
	2300.	4.98[illegible]	48.77	10.[illegible]	2600.	4.986	49.3[illegible]1	11.524
	3000.	5.004	50.[illegible]	13.522	3300.	5.025	5[illegible].573	15.026
	3600.	5.050	51.[illegible]	16.[illegible]77	4000.	5.091	51.546	18.065

SAMPLE PROBLEM 6 INPUT DATA (Cont'd)

Card								
	OH	17.[illegible]	9.3[illegible]					
	0.	0.	0.	-2.[illegible]7	5[illegible].	3.783[illegible]	17.926	-1.779
	100.	7.567	3[illegible]	-1.4[illegible]1	15[illegible].	7.45[illegible]	3[illegible].436	-1.079
	200.	7.[illegible]	41.[illegible]	-.7[illegible]7	25[illegible].	7.[illegible]15	4[illegible].[illegible]1	-.347
	300.	7.134	43.[illegible]	.[illegible]13	4[illegible].	7.[illegible]77	46.[illegible]	.724
15	500.	7.[illegible]49	47.5[illegible]	1.47[illegible]	6[illegible].	7.[illegible]53	4[illegible].867	2.134
	700.	7.[illegible]87	4[illegible].[illegible]56	2.[illegible]4[illegible]	[illegible]	7.14[illegible]	[illegible].9[illegible]6	3.[illegible]53
	1000.	7.2[illegible]	[illegible]	5.	1[illegible].	7.[illegible]4[illegible]	[illegible].67[illegible]	6.487
	1400.	7.764	[illegible]	[illegible].1[illegible]	1[illegible].	7.[illegible]63	56.1[illegible]	9.591
	1[illegible].	[illegible].136	[illegible]7.[illegible]5[illegible]	11.[illegible]7	2[illegible].	[illegible].2[illegible]	[illegible]7.91[illegible]	12.496
	23[illegible].	[illegible].47[illegible]	[illegible]	15.[illegible]	2[illegible].	[illegible].62[illegible]	6[illegible].137	17.923
	3[illegible].	[illegible].77[illegible]	[illegible]1.[illegible]	[illegible]1.4[illegible]4	[illegible].	[illegible].[illegible]7[illegible]	6[illegible].[illegible]23	24.052
	36[illegible].	[illegible]	[illegible]	[illegible]6.7[illegible]	4[illegible].	[illegible].146	67.947	3[illegible].327
	O2	32.	[illegible].					
	0.	0.	0.	-2.[illegible]78	5.[illegible]	3.47[illegible]	2[illegible].7[illegible]1	-1.728
	100.	[illegible].[illegible]	41.4[illegible]	-1.[illegible]1	15[illegible].	6.[illegible]	43.[illegible]	-1.033
	200.	6.[illegible]61	4[illegible].22[illegible]	-.[illegible]85	25[illegible].	6.[illegible]9[illegible]	47.641	-.336
	300.	7.[illegible]23	4[illegible].[illegible]54	.[illegible]13	4[illegible].	7.15[illegible]	51.[illegible]97	.723
	500.	7.431	5[illegible].7[illegible]7	1.454	[illegible].	7.[illegible]67	54.10[illegible]	2.210
15	700.	7.[illegible]3	5[illegible].[illegible]	2.[illegible]7	[illegible].	8.[illegible]67	56.367	3.785
	1[illegible].	[illegible].336	5[illegible].1[illegible]	5.427	12[illegible].	8.527	59.725	7.114
	140[illegible].	[illegible].674	61.[illegible]	8.[illegible]34	16[illegible].	8.80[illegible]	62.227	10.582
	18[illegible].	[illegible].516	6[illegible].27	12.354	2[illegible]00.	9.029	64.216	14.148
	230[illegible].	9.194	6[illegible].4[illegible]	16.[illegible]	26[illegible].	9.354	66.626	19.664
	3[illegible].	9.551	67.97[illegible]	23.446	330[illegible].	9.662	68.895	26.331
	36[illegible].	9.799	6[illegible].74[illegible]	29.254	4[illegible].	9.932	7[illegible].782	33.201
	CL	35.457	2[illegible].[illegible]					
	0.	4.969	3[illegible].[illegible]	-1.[illegible]2	[illegible].	4.969	33.955	-1.032
	100.	4.96[illegible]	3[illegible].[illegible]	-1.[illegible]2	15[illegible].	5.[illegible]	35.6[illegible]	-0.752
	200.	5.[illegible]3[illegible]	37.41[illegible]	-[illegible].5[illegible]3	[illegible].	5.13[illegible]	3[illegible].45[illegible]	-0.256
	300.	5.223	3[illegible].4[illegible]	[illegible].[illegible]1[illegible]	4[illegible].	5.27[illegible]	41.[illegible]1[illegible]	0.540
15	500.	5.436	4[illegible].2[illegible]	1.[illegible]1	[illegible].	5.449	43.212	1.625
	700.	5.424	44.[illegible]5	2.16[illegible]	[illegible].	5.269	44.772	2.170
	1[illegible].	5.314	45.[illegible]67	3.7[illegible]	12[illegible].	5.[illegible]4[illegible]	46.93[illegible]	4.836
	1400.	5.197	47.72[illegible]	5.[illegible]	16[illegible].	5.15[illegible]	4[illegible].426	6.915
	1800.	5.125	4[illegible].[illegible]31	7.[illegible]43	[illegible].	5.1[illegible]1	49.[illegible]7	8.966
	230[illegible].	5.[illegible]73	5[illegible].2[illegible]	1[illegible].4[illegible]2	[illegible].	5.[illegible]53	5[illegible].9[illegible]2	12.011
	3[illegible].	5.[illegible]34	51.[illegible]	14.[illegible]	[illegible].	5.[illegible]4	5[illegible].1[illegible]	15.537
	36[illegible].	5.[illegible]16	5[illegible].[illegible]7	17.[illegible]43	4[illegible].	5.[illegible]17	5[illegible].[illegible]67	1[illegible].[illegible]47

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SAMPLE PROBLEM 6 INPUT DATA (Cont'd)

Card								
15	CL2	70.906	[illegible]					
	0.	7.[illegible]1	45.15	-1.4[illegible]	50.	7.[illegible]1	45.15	-1.498
	100.	7.[illegible]1	45.15	-1.4[illegible]	150.	7.228	47.693	-1.135
	200.	7.576	5[illegible].150	-0.772	250.	7.847	51.747	-0.378
	300.	8.119	53.33[illegible]	0.015	400.	8.437	55.724	0.845
	500.	8.624	57.62[illegible]	1.698	600.	8.741	59.212	2.567
	700.	8.821	6[illegible].56[illegible]	3.445	800.	8.878	61.747	4.331
	1000.	8.956	63.737	6.115	1200.	9.0[illegible]	65.375	7.912
	1400.	9.051	66.767	9.718	1600.	9.086	67.978	11.532
	1800.	9.117	6[illegible].[illegible]5	13.352	2000.	9.149	7[illegible].013	15.179
	2300.	9.2[illegible]3	71.255	17.931	2600.	9.268	72.427	20.701
	3000.	9.374	73.76	24.429	3300.	9.461	74.659	27.255
	3600.	9.546	75.415	30.106	4[illegible].	9.646	76.496	33.945
15	HCL	36.465	-22.[illegible]63					
	0.	6.959	37.041	-1.379	50.	6.959	37.041	-1.379
	100.	6.959	37.041	-1.379	150.	6.960	39.453	-1.031
	200.	6.961	41.865	-0.683	250.	6.962	43.276	-0.335
	300.	6.964	44.688	0.013	400.	6.973	46.693	0.710
	500.	7.004	48.252	1.408	600.	7.069	49.534	2.112
	700.	7.167	50.63	2.823	800.	7.289	51.595	3.546
	1000.	7.559	53.25	5.030	1200.	7.819	54.652	6.569
	1400.	8.043	55.875	8.155	1600.	8.229	56.691	9.783
	1800.	8.382	57.94	11.445	2000.	8.509	58.830	13.135
	2300.	8.660	60.03	15.711	2600.	8.776	61.095	18.327
	3000.	8.902	62.364	21.864	3300.	8.976	63.216	24.546
	3600.	9.041	64.[illegible]	27.249	4000.	9.115	64.976	30.881
15	N2	28.[illegible]134	[illegible]					
	0.	6.956	38.17[illegible]	-1.379	5[illegible].	6.956	3[illegible].17[illegible]	-1.379
	100.	6.956	3[illegible].17	-1.37[illegible]	1[illegible].	6.956	4[illegible].556	-1.031
	200.	6.957	42.[illegible]	-0.[illegible]	250.	6.959	44.4[illegible]2	-0.335
	300.	6.961	45.[illegible]1[illegible]	0.[illegible]13	4[illegible].	6.9[illegible]	47.816	0.719
	500.	7.[illegible]69	4[illegible].3[illegible]	1.413	600.	7.196	5[illegible].64[illegible]	2.125
	700.	7.35[illegible]	51.[illegible]	2.853	800.	7.512	52.798	3.596
	1000.	7.815	54.5[illegible]7	5.129	1200.	8.[illegible]61	55.955	6.718
	1400.	8.252	57.21[illegible]	8.35	1600.	8.358	58.324	10.015
	1800.	8.512	59.32	11.7[illegible]7	2[illegible].	[illegible]	6[illegible].22[illegible]	13.418
	2300.	[illegible].7[illegible]3	61.4[illegible]	[illegible]	[illegible]	[illegible].7[illegible]	[illegible]	18.6[illegible]
	3000.	[illegible]	63.7[illegible]	[illegible]2.1[illegible]	[illegible]	8.955	64.611	24.829
	3600.	[illegible]	6[illegible].[illegible]7	27.[illegible]	4[illegible].	[illegible]	6[illegible].731	31.[illegible]

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SAMPLE PROBLEM 6 INPUT DATA (Cont'd)

Card								
	CL-	3[illegible].453	[illegible]					
	[illegible]	[illegible]	[illegible]	[illegible]	5[illegible].	4.968	36.658	0.[illegible]
	100.	4.968	36.[illegible]	[illegible]	1[illegible].	4.968	36.658	0.[illegible]
	200.	4.968	36.[illegible]	[illegible]	25.	4.968	36.658	0.[illegible]
	300.	4.96[illegible]	36.65[illegible]	[illegible]	4[illegible].	4.968	38.[illegible]68	0.506
	500.	4.968	39.196	1.[illegible]7	6[illegible].	4.968	40.132	1.5[illegible]
15	700.	4.96[illegible]	[illegible]	1.996	[illegible]	4.968	41.571	2.493
	1000.	4.96[illegible]	42.64	3.457	12[illegible].	4.968	43.546	4.481
	1400.	4.968	44.31[illegible]	5.474	16[illegible].	4.96[illegible]	44.975	6.468
	1800.	4.96[illegible]	45.5[illegible]	7.461	[illegible]	4.96[illegible]	46.[illegible]84	8.455
	2300.	4.968	46.77[illegible]	9.945	2[illegible].	4.968	47.387	11.436
	3000.	4.961	48.[illegible]	13.423	33[illegible].	4.968	48.572	14.914
	3600.	4.968	49.[illegible]4	16.4[illegible]4	4[illegible].	4.968	49.527	18.391
	E	[illegible]5E4[illegible]	[illegible]					
	0.	[illegible]	[illegible]	[illegible]	5.	4.968	5.[illegible]19	0.[illegible]
	100.	4.968	5.[illegible]1[illegible]	[illegible]	15.	4.968	5.[illegible]19	0.[illegible]
	200.	4.968	5.[illegible]1[illegible]	[illegible]	25.	4.968	5.019	0.[illegible]
	300.	4.96[illegible]	5.[illegible]1[illegible]	[illegible]	4[illegible].	4.968	6.449	0.506
	500.	4.968	7.557	1.[illegible]3	6[illegible].	4.968	8.463	1.5[illegible]
15	700.	4.968	9.22[illegible]	1.996	[illegible]	4.968	9.872	2.493
	1000.	4.96[illegible]	11.[illegible]	3.457	1[illegible].	4.968	11.9[illegible]6	4.48[illegible]
	1400.	4.96[illegible]	12.672	5.474	16[illegible].	4.968	13.376	6.467
	1800.	4.968	13.921	7.461	[illegible]	4.968	14.444	8.455
	2300.	4.96[illegible]	15.13[illegible]	9.945	2[illegible].	4.968	15.768	11.475
	3000.	4.968	16.451	13.423	33[illegible].	4.968	16.932	14.913
	3600.	4.96[illegible]	17.364	16.4[illegible]3	4[illegible].	4.967	17.868	18.39[illegible]
	K	34.1	2[illegible].31					
	0.	[illegible]	[illegible]	-1.4[illegible]1	5.	4.968	36.434	-1.282
	100.	4.96[illegible]	32.[illegible]	-[illegible].964	15[illegible].	4.968	34.[illegible]1	-0.736
	200.	4.96[illegible]	36.312	-[illegible].49[illegible]	25.	4.968	37.72[illegible]	-0.248
	300.	4.968	38.327	[illegible]	4[illegible].	4.968	39.757	0.506
	500.	4.968	40.[illegible]	1.[illegible]3	6[illegible].	4.968	41.77[illegible]	1.5[illegible]
15	700.	4.96[illegible]	42.537	[illegible]1.996	[illegible]	4.967	43.2[illegible]	2.493
	1000.	4.968	44.[illegible]	3.457	12[illegible].	4.968	45.215	4.481
	1400.	4.975	45.981	5.474	16[illegible].	4.975	46.645	6.469
	1800.	4.988	47.231	7.465	2[illegible].	5.013	47.758	8.465
	2300.	5.067	48.413	9.978	26[illegible].	5.213	49.[illegible]	11.522
	3000.	5.489	49.877	13.655	33[illegible].	5.612	50.354	15.349
	3600.	6.242	50.917	17.152	4[illegible].	7.111	51.616	19.81[illegible]

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SAMPLE PROBLEM 6 INPUT DATA (Cont'd)

Card								
	K+	39.1	122.[illegible]					
	0.0	0.0	0.0	0.0	50.	4.968	36.951	0.0
	100.0	4.968	36.95	0.0	150.	4.968	36.950	0.0
	200.0	4.968	36.950	0.0	250.	4.968	36.950	0.0
	300.0	4.968	36.950	[illegible]	400.	4.968	38.379	0.556
	500.0	4.968	39.4[illegible]	1.003	600.	4.968	40.394	1.530
15	700.0	4.968	41.159	1.996	800.	4.968	41.823	2.493
	1000.0	4.968	42.931	3.487	1200.	4.968	43.837	4.481
	1400.0	4.968	44.613	5.474	1600.	4.968	45.267	6.468
	1800.0	4.968	45.952	7.461	2000.	4.968	46.375	8.455
	2300.0	4.968	47.17	9.945	2600.	4.968	47.675	11.436
	3000.0	4.968	48.36	13.423	3300.	4.968	48.863	14.914
	3600.0	4.968	49.2[illegible]	16.404	4000.	4.968	49.915	18.391
	KCL	74.555	-51.31					
	0.0	0.0	0.0	-2.762	50.	7.576	48.122	-2.107
	100.0	7.576	48.122	-1.652	150.	8.063	50.974	-1.248
	200.0	8.43	53.677	-0.844	250.	8.578	55.428	-0.43
	300.0	8.726	57.17	0.016	400.	8.857	59.751	0.866
	500.0	8.93	61.06	1.766	600.	8.975	63.318	2.691
15	700.0	9.015	64.76	3.581	800.	9.046	65.911	4.484
	1000.0	9.097	67.935	6.25	1200.	9.141	69.508	8.122
	1400.0	9.172	71.01	9.995	1600.	9.221	72.238	11.795
	1800.0	9.259	73.327	13.643	2000.	9.297	74.314	15.499
	2300.0	9.353	75.67	18.29	2600.	9.41	76.758	21.11
	3000.0	9.482	78.1	24.8	3300.	9.536	79.015	27.741
	3600.0	9.591	79.47	31.61	4000.	9.664	80.862	34.461
	NA	22.991	25.755					
	0.0	0.0	0.0	-1.411	50.	4.968	29.564	-1.247
	100.0	4.968	31.26	-0.954	150.	4.968	33.008	-0.736
	200.0	4.968	34.73	-0.44	250.	4.968	35.738	-0.24
	300.0	4.968	36.746	0.0	400.	4.968	38.174	0.506
	500.0	4.968	39.28	1.003	600.	4.968	41.188	1.5
15	700.0	4.968	40.954	1.996	800.	4.968	41.617	2.493
	1000.0	4.968	42.726	3.497	1200.	4.968	43.632	4.481
	1400.0	4.968	44.395	5.474	1600.	4.968	45.061	6.468
	1800.0	4.97	45.64	7.462	2000.	4.973	46.17	8.456
	2300.0	4.985	46.86	9.94	2600.	5.013	47.478	11.448
	3000.0	5.05	48.2	13.467	3300.	5.184	49.69	15.007
	3600.0	5.324	49.146	16.582	4000.	5.614	49.721	18.763

OF POOR QUALITY

SAMPLE PROBLEM 6 INPUT DATA (Cont'd)

Card								
15	NA+	22.991	145.755					
	0.0	0.	[illegible]	-1.481	5[illegible]	4.968	29.186	-1.247
	100.	4.968	29.[illegible]	-0.[illegible]4	150.	4.968	31.67[illegible]	-0.736
	200.	4.968	33.302	-0.4[illegible]	2[illegible]	4.968	34.36[illegible]	-.24
	300.	4.968	35.367	[illegible]	4[illegible]	4.968	36.796	0.536
	500.	4.968	37.9[illegible]	1.[illegible]	[illegible]	4.968	38.911	1.5
	700.	4.968	39.577	1.9[illegible]	[illegible]	4.968	40.241	2.493
	1000.0	4.968	41.349	3.487	1200.	4.968	42.254	4.481
	1400.	4.968	43.[illegible]2	5.474	1600.	4.968	43.684	6.468
	1800.	4.968	44.269	7.461	2000.	4.968	44.792	8.455
	2300.	4.965	45.457	9.948	2600.	4.968	46.096	11.436
	3000.	4.966	46.8[illegible]7	13.423	3300.	4.968	47.28[illegible]	14.914
	3600.	4.968	47.712	16.4[illegible]4	4000.	4.968	48.236	18.391
15	NACL	58.448	-43.36					
	0.0	0.	0.[illegible]	-2.29[illegible]	50.	6.824	43.558	-1.949
	100.	7.265	46.224	-1.557	150.	7.717	48.891	-1.219
	200.	8.148	51.557	-0.822	250.	8.353	53.254	-0.403
	300.	8.55[illegible]	54.55	[illegible]	400.	8.749	57.441	0.882
	500.	8.854	59.416	1.763	600.	8.921	61.026	2.652
	700.	8.969	62.415	3.546	800.	9.106	63.695	4.445
	1000.0	9.[illegible]4	65.622	6.282	1200.	9.111	67.278	8.070
	1400.	9.152	69.686	[illegible]	1600.	9.19[illegible]	69.91[illegible]	11.730
	1800.	9.227	70.955	13.572	2000.	9.263	71.969	15.421
	2300.	9.315	73.267	18.268	2600.	9.367	74.412	21.010
	3000.	9.435	75.757	24.770	3300.	9.485	76.658	27.608
	3600.	9.536	77.466	30.461	4000.	9.602	78.495	34.289

Card																	
16	M1																
		1.0	2.	1.0	1.0	3.	1.	1.	1.0	1.	1.	1.0	1.	1.0	1.0	1.0	1.0
		1.	1.	1.0	1.0												
16	M2																
		1.0	3.0	2[illegible]	1.0	1.0	1.	1.	1.0	1.	1.	1.0	1.0	1.0	1.0	1.0	1.0
		1.0	1.	1.0	1.0												
16	M3																
		1.5	3.	1.	1.	1.	1.	1.	2[illegible]	1.	1.	1.0	1.0	1.0	1.0	1.0	1.0
		1.	1.	1.0	1.0												

Card									
17	H	+OH	+M1	=H2O	+M1	22	6.1-26	2.0	0.0
	O	+H	+M1	=OH	+M1	21	2.0-32	[illegible]	0.0
	O	+O	+M1	=O2	+M1	24	3.8-3[illegible]	1.0	-341[illegible]
	H	+H	+M2	=H2	+M2	22	2.6-3[illegible]	1.0	0.0
	CO	+O	+M3	=CO2	+M3	23	[illegible]-33	[illegible]	-4[illegible]00.0

SAMPLE PROBLEM 6 INPUT DATA (Concluded)

```
Card
      H        +CL     +M1  =HCL     +M1                 22 1.1-31 1.0       0.0
      CL       +CL     +M1  =CL2     +M1                 24 4.3-31 1.0    1250.0
      OH       +H           =H2      +O                  14 1.4-14-1.0   -7000.0
      OH       +O           =H       +O2                 11 4.0-11 0.0       0.0
      OH       +H2          =H2O     +H                  14 1.0-17-2.0   -2500.0
      OH       +CO          =CO2     +H                  14 1.1-19-2.0    1600.0
      OH       +OH          =H2O     +O                  13 1.0-11 0.0   -1100.0
      OH       +HCL         =H2O     +CL                 14 1.0-14-1.0   -1000.0
17    O        +HCL         =OH      +CL                 13 2.0-12 0.0   -4500.0
      H        +CL2         =HCL     +CL                 13 2.0-11 0.0   -2400.0
      CL       +H2          =HCL     +H                  13 8.0-11 0.0   -5260.0
      K        +HCL         =KCL     +H                  13 6.0-10 0.0   -5100.0
      NA       +HCL         =NACL    +H                  13 5.0-10 0.0   -8100.0
      K+       +E      +M1  =K       +M1                 24 2.0-22 1.5
      NA+      +E      +M1  =NA      +M1                 24 1.5-2[illegible] 2.0
      K+       +CL-         =K       +CL                 14 1.0-08 0.5
      NA+      +CL-         =NA      +CL                 14 3.0-08 0.5
      CL       +E      +M1  =CL-     +M1                 21 3.0-3[illegible] 0.0
      HCL      +E           =H       +CL-                13 1.0-08 0.0  -20000.0
22    100.       -100.       0.0         0.0         20.0        90.
23    .5         .2          .2          .005        4.          .4
25                              1
26    .40068     .4          1.1.96
27    .1         .2          .2          .2          .2          .1
28    3.15       4.7         5.9         6.65        8.15        9.7
29    250.       250.        250.        250.        250.        250.
30
31
32    AL203 EQ. OF STATE            1[illegible]
33      1
      4188.      134[illegible].16    1[illegible]3[illegible].[illegible]      .34         .32
34     $DATA
35      THID=42.,RFT=.5,RLTH=1.15,THJW=24.6,IWALL=1,DL=.1,DR=.1,DTWI=3.5,
        CARM=.75
       $END
```


OF POOR QUALITY

SAMPLE PROBLEM 6 OUTPUT

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 25 PAGE 1

SPACE SHUTTLE MPM NOZZLE ACTUAL GEOMETRY FINITE RATE

RUN CONTROL PARAMETERS

ICON(1)	ICON(2)	ICON(3)	ICON(4)	ICON(5)	ICON(6)	ICON(7)	ICON(8)
1	[illegible]	30	200[illegible]	1	0	1	3

ICON(9)	ICON(10)	ICON(11)	ICON(12)	ICON(13)	ICON(14)	ICON(15)	ICON(16)
0	1[illegible]	25	1	0	0	0	12575

FLOW CALCULATIONS ARE IN ENGLISH UNITS WITH THE X,R COORDINATES IN FEET

THE FLOW FIELD DATA WILL BE WRITTEN ON TAPE

UPPER BOUNDARY POINTS

TYPE	ITRANS	X	R	THETA
2	0	.00000	.22402+01	.00000
2	0	.19583-01	.22403+01	.17453-01
2	0	.39160-01	.22409+01	.34907-01
2	0	.78273-01	.22464+01	.69813-01
2	0	.11729+00	.22503+01	.10472+00
2	0	.15614+00	.22551+01	.13963+00
2	0	.19465+00	.22612+01	.17453+00
2	0	.23329+00	.22687+01	.20944+00
2	0	.27166+00	.22775+01	.24435+00
2	0	.30929+00	.22876+01	.27925+00
2	0	.34674+00	.22991+01	.31416+00
2	0	.38372+00	.23116+01	.34907+00
2	0	.42034+00	.23259+01	.38397+00
2	0	.45639+00	.23412+01	.41888+00
2	0	.46710+00	.23460+01	.42935+00
2	0	.16372+01	.28016+01	.42935+00
2	0	.17561+01	.29350+01	.42730+00
2	0	.18957+01	.29990+01	.42370+00
2	0	.20538+01	.30701+01	.41913+00
2	0	.22263+01	.31966+01	.41306+00
2	0	.24126+01	.32276+01	.40603+00
2	0	.26102+01	.33122+01	.40170+00
2	0	.28169+01	.33999+01	.39521+00
2	0	.30326+01	.34901+01	.38838+00
2	0	.32644+01	.35824+01	.38136+00
2	0	.35014+01	.36765+01	.37410+00
2	0	.37472+01	.37719+01	.36690+00
2	0	.40011+01	.38684+01	.35957+00
2	0	.42630+01	.39657+01	.35213+00
2	0	.45327+01	.40637+01	.34465+00
2	0	.48099+01	.41621+01	.33726+00
2	0	.50944+01	.42608+01	.32981+00
2	0	.53360+01	.43592+01	.32230+00
2	0	.56845+01	.44577+01	.31500+00
2	0	.59664+01	.45559+01	.30764+00

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 25 PAGE 2

SPACE SHUTTLE MPM NOZZLE ACTUAL GEOMETRY FINITE RATE

UPPER BOUNDARY POINTS

TYPE	ITRANS	X	R	THETA			
2	0	.63017+01	.46538+01	.30037+00			
2	0	.66201+01	.47512+01	.29313+00			
2	0	.69499+01	.48497+01	.28595+00			
2	0	.72757+01	.49490+01	.27889+00			
2	0	.76131+01	.50391+01	.27180+00			
2	0	[illegible]	.52271+01	.25795+00			
2	0	.86609+01	.53195+01	.25113+00			
2	0	.90219+01	.54100+01	.24440+00			
2	0	.93866+01	.55010+01	.23777+00			
2	0	.97610+01	.55900+01	.23119+00			
2	0	.10139+02	.56777+01	.22460+00			
2	0	.10529+02	.57641+01	.21820+00			
2	0	.10913+02	.58492+01	.21194+00			
2	0	.11307+02	.59329+01	.20569+00			
2	0	.11708+02	.60151+01	.19950+00			
2	0	.11975+02	.60685+01	.19557+00			
2	0	.12113+02	.60960+01	.19323+00			
2	0	.12529+02	.61754+01	.18705+00			
2	1	.12896+02	.62350+01	.18309+00			
3	0	.21160+04	.00000	.00000	.00000	.00000	.10000+04

LOWER BOUNDARY

TYPE	ITRANS	A	B	C	U	E	MAX
2	0	.00000	.00000	.00000	.00000	.00000	.10000+04

SAMPLE PROBLEM 6 OUTPUT (Cont'd)

SPECIE THERMODYNAMIC AND REACTION DATA
LT,NS,NR,NN,ICTYPE,DGUP,IG,ID: 24 24 24 3 1 21 [illegible]

PRANDTL NUMBER : .53000000+00
MASS VISCOSITY : .17?31606-0?
EXPONENT : .63000000+00

		REACTIONS BEING CONSIDERED				A	N	B		F-TYPE	B-TYPE
1	H	+ OH	+ M1	= H2O	+ M1	[illegible]	2.0	.0	.0	2	[illegible]
2	O	+ H	+ M1	= OH	+ M1	7.260+15	.0	.0	.0	2	1
3	O	+ O	+ M1	= O2	+ M1	[illegible]	1.0	-340.0	.0	2	6
4	H	+ H	+ M2	= H2	+ M2	1.016+18	1.0	.0	.0	2	2
5	CO	+ O	+ M3	= CO2	+ M3	7.260+14	.0	-4000.0	.0	2	1
6	H	+ CL	+ M1	= HCL	+ M1	3.903+16	1.0	.0	.0	2	2
7	CL	+ CL	+ M1	= CL2	+ M1	1.561+17	1.0	1250.0	.0	2	6
8	OH	+ H		= H2	+ O	8.035+09	-1.0	-7000.0	.0	1	6
9	OH	+ O		= H	+ O2	7.410+13	.0	.0	.0	1	7
10	OH	+ H2		= H2O	+ H	6.021+06	-2.0	-2900.0	.0	1	6
11	OH	+ CO		= CO2	+ H	6.627+36	-2.0	1,400.0	.0	1	6
12	OH	+ OH		= H2O	+ O	6.025+12	.0	-1100.0	.0	1	1
13	OH	+ HCL		= H2O	+ CL	6.025+09	-1.0	-1000.0	.0	1	6
14	O	+ HCL		= OH	+ CL	1.20?+12	.0	-4500.0	.0	1	1
15	H	+ CL2		= HCL	+ CL	1.20?+14	.0	-2900.0	.0	1	1
16	CL	+ H2		= HCL	+ H	4.820+13	.0	-5260.0	.0	1	1
17	K	+ HCL		= KCL	+ H	[illegible].615+14	.0	-5000.0	.0	1	1
18	NA	+ HCL		= NACL	+ H	[illegible].012+14	.0	-8000.0	.0	1	1
19	K+	+ E	+ M1	= K	+ M1	7.760+25	1.5	.0	.0	2	6
20	NA+	+ E	+ M1	= NA	+ M1	5.4??+2?	2.0	.0	.0	2	6
21	K+	+ CL-		= K	+ CL	6.??+15	.5	.0	.0	1	6
22	NA+	+ CL-		= NA	+ CL	1.807+16	.5	.0	.0	1	6
23	CL	+ E	+ M1	= CL-	+ M1	1.000+18	.0	.0	.0	2	1
24	HCL	+ E		= H	+ CL-	6.025+15	.0	-20000.0	.0	1	1

CATALYTIC SPECIES BEING CONSIDERED

M1	= 1.00 CO	+ 1.00 CO2	+ 1.00 H	+ 1.00 H2	+ 3.00 H2O	+ 1.00 O	+ 1.00 OH +
	1.00 O2	+ 1.00 CL	+ 1.00 CL2	+ 1.00 HCL	+ 1.00 N2	+ 1.00 CL-	+ 1.00 E +
	1.00 K	+ 1.00 K+	+ 1.00 KCL	+ 1.00 NA	+ 1.00 NA+	+ 1.00 NACL	+
M2	= 1.00 CO	+ 3.00 CO2	+ ?.00 H	+ 1.00 H2	+ 10.00 H2O	+ 1.00 O	+ 1.00 OH +
	1.00 O2	+ 1.00 CL	+ 1.00 CL2	+ 1.00 HCL	+ 1.00 N2	+ 1.00 CL-	+ 1.00 E +
	1.00 K	+ 1.00 K+	+ 1.00 KCL	+ 1.00 NA	+ 1.00 NA+	+ 1.00 NACL	+
M3	= 1.?0 CO	+ 3.00 CO2	+ 1.00 H	+ 1.00 H2	+ 1?.00 H2O	+ 1.00 O	+ 1.00 OH +
	20.00 O2	+ 1.00 CL	+ 1.00 CL2	+ 1.00 HCL	+ 1.00 N2	+ 1.00 CL-	+ 1.00 E +
	1.00 K	+ 1.00 K+	+ 1.00 KCL	+ 1.00 NA	+ 1.00 NA+	+ 1.00 NACL	+

SPECIE MOLE FRACTIONS ON THE START LINE ARE

CO	CO2	H	H2	H2O	O	OH	O2	CL	CL2
.5343+00	.17550-01	.23?2-01	.29?29+00	.1?057+00	.2?0?1-0?	.4?86?-02	.5?13?-0?	.8?011-02	.17?1?-0?

HCL	K2	CL-	E	K	K+	KCL	N2	NA+	NACL
.5439+00	.8?743-01	.4?711-05	.?0069-07	.19?11-05	.27225-05	.22869-05	.22606-05	.16884-05	.3?09?-0?

THERE ARE 6 PARTICLE SPECIES PRESENT IN THE GAS-PARTICLE MIXTURE

RUN CUTOFF INFORMATION

	UPPER BOUNDARY					LOWER BOUNDARY					
R:	.1?0??+0?	X:	-.1??00+03	THETA:	.00000	R:	.?0000	X:	.70000+02	THETA:	.90000+02

PARTICLE PHYSICAL DATA

SPECIE	RADIUS	MASS DENSITY	EMISSIVITY	ACCM. COEFF.
1	.31?00+01	.25000+03	.00000	.00000
2	.47?00+01	.25000+03	.00000	.00000
3	.59??0+01	.25000+03	.00000	.00000
4	.69??0+01	.25000+03	.00000	.00000
5	.81??0+01	.25000+03	.00000	.00000
6	.97000+01	.25000+03	.00000	.00000

THE PARTICLES CONSTITUTE ?0.0? PERCENT BY WEIGHT ?? OF THE GAS-PARTICLE MIXTURE
THE INDIVIDUAL PERCENTAGES ARE .?0 .20 .20 .20 .20 .10
THE PARTICLE TEMPERATURE-ENTHALPY TABLE WILL BE READ IN WITH ENGLISH UNITS

PARTICLE TEMPERATURE-ENTHALPY TABLE

PHASE CHANGE DATA *** TMELT: .?1?00+04 HSOLID: .335?19+04 HLIQUID: .46?5?0+04
CPMELT: .85096+0? CPSOLID: .80090+0?

SAMPLE PROBLEM 6 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

GAS-PARTICLE FLOW SOLUTION

CASE NO. 75 PAGE 3

SPACE SHUTTLE HP= NOZZLE ACTUAL GEOMETRY FINITE RATE

PARTICLE DRAG TABLE

I	RE	DRAG COEF
1	.00000	.10000+01

DATA				
CAPM =	.75000000E+00			
CPL =	.65498144E+04			
CPS =	.20090031E+04			
FR =	.59657681E+00			
FL =	.10000000E+00			
FN =	.10000000E+02			
DTVI =	.35000000E+01			
FA =	.10000000E-02			
FA =	.00000000E+00,	.50000000E+00,	.10000000E+01,	.12500000E+01,
	.10000000E+01,	.12550000E+01,	.10000000E+01,	.12400000E+01,
	.13010000E+01,	.12650000E+01,	.10020000E+01,	.15020000E+01,
	.10610000E+01,	.19950000E+01,	.11410000E+01,	.25100000E+01,
	.17240000E+01,	.31600000E+01,	.13150000E+01,	.39600000E+01,
	.18120000E+01,	.50100000E+01,	.15170000E+01,	.63100000E+01,
	.16200000E+01,	.79500000E+01,	.17600000E+01,	.10000000E+02,
	.18340000E+01,	.12600000E+02,	.20260000E+01,	.15920000E+02,
	.21660000E+01,	.19900000E+02,	.21640000E+01,	.25100000E+02,
	.25550000E+01,	.31600000E+02,	.27400000E+01,	.39900000E+02,
	.30000000E+01,	.50100000E+02,	.32520000E+01,	.63100000E+02,
	.35300000E+01,	.79500000E+02,	.38250000E+01,	.10000000E+03,
	.41500000E+01,	.31600000E+03,	.39000000E+01,	.10000000E+04,
	.20000000E+02,	.10010000E+04,	.20020000E+02,	.10000000E+06,
	.20000000E+04,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.30000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
GAMMA =	.11669403E+01			
[illegible] =	.12677218E-04			
HPL =	.46056997E+00			
HPS =	.33541073E+00			
IMAX =	5			
N1 =	100			
N2 =	1			
PC =	.69999967E+03			
P_d =	.30000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.30000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.30000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.30000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.30000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.30000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.30000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.30000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.30000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.00000000E+00,	.00000000E+00,	.00000000E+00,	.00000000E+00,
	.22491670E+01,	.22443375E+01,	.22448510E+01,	.22469070E+01,
	.22503133E+01,	.22550667E+01,	.22712133E+01,	.22686867E+01,
	.22774975E+01,	.22876342E+01,	.22990450E+01,	.23118367E+01,
	.23278725E+01,	.23411758E+01,	.23460109E+01,	.24916250E+01,
	.29350000E+01,	.29989583E+01,	.30700500E+01,	.31466000E+01,
	.32275833E+01,	.33122417E+01,	.33999258E+01,	.34901358E+01,
	.35829250E+01,	.36766583E+01,	.37718833E+01,	.38683917E+01,
	.39657617E+01,	.40636917E+01,	.41621667E+01,	.42606167E+01,
	.43592333E+01,	.44577333E+01,	.45559510E+01,	.46536167E+01,
	.47511033E+01,	.48479417E+01,	.49440000E+01,	.50392593E+01,
	.52276917E+01,	.53195600E+01,	.54108250E+01,	.55008667E+01,
	.55849953E+01,	.56776917E+01,	.57681367E+01,	.58497000E+01,
	.60327833E+01,	.60151167E+01,	.60685750E+01,	.60960000E+01,

SAMPLE PROBLEM 6 OUTPUT (Cont'd)

```
REFINING OF TWO PHASE NOZZLE PROGRAM
                         GAS-PARTICLE FLOW (THEORY)

R BAR 1.1[illegible]      WDG  [illegible]        EQUILIBRIUM CONDITIONS.

ONE DIMENSIONAL FLOW
ZU  -3.9142    ZMAX  -1.93592    DZ  .00200    UD  355.795    TPIO  6199.867    AD  98.7453

  -1.9359    DZ  .00E304    A/AT  1.92628    UG  1157.379    TG  6152.454
   UP(I)      TP(I)      R(I)      L(I)      I=1,...6
  1116.399   6157.541   .96463    .97688    1089.466   6154.138   .96966   .05992
  1057.466   6159.984   .92235    .94625    1049.715   6155.553   .90701   .93910
  1030.581   6156.199   .89C49    .92039    1007.777   6157.023   .87777   .90283
UO   .337071.E0   USC  .30333.E0   ZSINM  -.12667.+01
K BAR = 1.1465715     WDG CONST LAG = 9161.0730
CD19.CD1.CD.DL.TI.CELT     .99213   .96321   .99199     -.028912 -.031797

WDG  968[illegible]      WDP(I)  364.1376    728.2752    728.2752    728.2752    728.2752    364.1376

ONE DIMENSIONAL FLOW
ZU  -3.4201    ZMAX  -1.93592    DZ  .00200    UD  355.795    TPIO  6199.867    AD  95.0752

  -1.9359    DZ  .00E292    A/AT  1.92578    UG  1161.876    TG  6152.005
   UP(I)      TP(I)      R(I)      L(I)      I=1,...6
  1120.598   6153.192   .96952    .97665    1092.695   6153.997   .99050   .05065
  1071.378   6154.609   .92215    .94690    1055.536   6155.224   .90679   .93378
  1034.369   6155.877   .89025    .91988    1011.407   6156.700   .87051   .90246
UO   .339005.E0   USC  .30738.E0   ZSINM  -.126675+01
K BAR = 1.1469[illegible]     WDG CONST LAG = 9161.9796
CD19.CD1.CD.DL.TI.CELT     .99213   .96612   .9971[illegible]     -.026012 -.0[illegible]79

WDG  968[illegible]      WDP(I)  364.1696    728.3793    728.3793    728.3793    728.3793    364.1696
PARTICLE LAG VALUES AT INTERCEPT POSITIONS ON THE MOC INITIAL LINE.
```

J	I	R(U)	R(V)	L	P
1	1	.9598[illegible]	.78732	.96[illegible]	.[illegible]
1	2	.93061	.65403	.95793	.97796
1	3	.91[illegible]	.55720	.93661	.9[illegible]7[illegible]
1	4	.89033	.48057	.92755	.9[illegible]51
1	5	.87766	.41[illegible]92	.90[illegible]99	.95170
1	6	.85920	.33[illegible]52	.88067	.9[illegible]

J	I	R(U)	R(V)	L	P
2	1	.94759	.75[illegible]	.96[illegible]	.[illegible]
2	2	.91[illegible]	.60[illegible]	.94020	.67176
2	3	.9[illegible]	.[illegible]	.9[illegible]189	.[illegible]
2	4	.87[illegible]7	.43[illegible]2	.91553	.[illegible]
2	5	.95[illegible]	.36726	.98491	.[illegible]
2	6	.93[illegible]	.29639	.8[illegible]	.[illegible]

J	I	R(U)	R(V)	L	P
3	1	.9[illegible]	.47[illegible]	.95[illegible]	.9[illegible]
3	2	.86997	.52197	.91903	.[illegible]
3	3	.9[illegible]	.42765	.89117	.[illegible]
3	4	.84797	.36[illegible]3	.87[illegible]	.77[illegible]
3	5	.8[illegible]998	.29869	.8[illegible]	.78[illegible]
3	6	.81035	.23[illegible]	.81991	.77[illegible]

J	I	R(U)	R(V)	L	P
4	1	.89[illegible]	.51501	.90[illegible]6	.97192
4	2	.85[illegible]	.3[illegible]	.86[illegible]9	.94[illegible]63
4	3	.83[illegible]	.27769	.83537	.93[illegible]
4	4	.81[illegible]	.21[illegible]	.81716	.92232
4	5	.79[illegible]	.15989	.78766	.91122
4	6	.77732	-.01106	.75920	.89911

SAMPLE PROBLEM 6 (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HU[illegible] MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 75 PAGE 4

SPACE SHUTTLE HPP NOZZLE ACTUAL GEOMETRY FINITE RATE

GAS STARTLINE

X	R	THETA	T	P

GASEOUS STARTING LINE INFO

R	X	M	THETA	S	MACH ANGLE	SHOCK ANGLE	H-TOTAL
.00000	.14417+01	.10509+01	.00000	.00000	.72100+02	.00000	.20515+04
.76253-01	.14046+01	.10436+01	.35692+00	.00000	.73383+02	.00000	.20482+04
.15251+00	.13662+01	.10371+01	.72950+00	.00000	.74620+02	.00000	.20452+04
.22876+00	.13285+01	.10315+01	.11203+01	.00000	.75793+02	.00000	.20427+04
.30501+00	.12907+01	.10268+01	.15316+01	.00000	.76873+02	.00000	.20405+04
.38126+00	.12529+01	.10230+01	.19649+01	.0000	.77872+02	.00000	.20388+04
.45752+00	.12152+01	.10201+01	.24217+01	.00000	.78596+02	.00000	.20375+04
.53377+00	.11774+01	.10182+01	.29027+01	.00000	.79143+02	.00000	.20366+04
.61002+00	.11397+01	.10173+01	.34066+01	.00000	[illegible]	.00000	.20362+04
.68628+00	.11019+01	.10175+01	.39393+01	.00000	.79369+02	.00000	.20362+04
.76253+00	.10642+01	.10187+01	.44985+01	.00000	.79005+02	.00000	.20368+04
.83878+00	.10264+01	.1021[illegible]+01	.50734+01	.00000	.78338+02	.00000	.20379+04
.91503+00	.98867+00	.10246+01	.56750+01	.00000	.77484+02	.00000	.20395+04
.99129+00	.95092+00	[illegible]+01	.62975+01	.00000	.76264+02	.00000	.20417+04
.10675+01	.91317+00	.10355+01	.69349+01	.00000	.74896+02	.00000	.20445+04
.11438+01	.87541+00	.10430+01	.75966+01	.00000	.73495+02	.00000	.20479+04
.12200+01	.83766+00	.10518+01	.82675+01	.00000	.71940+02	.00000	.20520+04
.12963+01	.79991+00	.10621+01	.89497+01	.00000	.70306+02	.00000	.20566+04
.13726+01	.76215+00	.10740+01	.96344+01	.00000	.6[illegible]+02	.00000	.20623+04
.14488+01	.72440+00	.10874+01	.10322+02	.00000	.66868[illegible]	.00000	.20687+04
.15251+01	.68665+00	.11026+01	.11005+02	.00000	.65090+02	.00000	.20758+04
.16013+01	.64889+00	.11195+01	.11677+02	.00000	.63284+02	.00000	.20840+04
.16776+01	.61114+00	.11383+01	.12336+02	.00000	.61440+02	.00000	.20930+04
.17538+01	.57339+00	.11592+01	.12966+02	.00000	.59621+02	.00000	.21032+04
.18301+01	.53563+00	.11821+01	.13567+02	.00000	.57773+02	.00000	.21145+04
.19063+01	.49788+00	.12073+01	.14129+02	.00000	.55920+02	.00000	.21257+04
[illegible]	.46264+00	[illegible]+01	.14860+02	.00000	.54211+02	.00000	.21423+04
.20589+01	.42925+00	.12596+01	.15019+02	.00000	.52551+02	.00000	.21467+04
[illegible]+01	.4169[illegible]+00	[illegible]699+01	.15157+02	.00000	.51947+02	.00000	.21509+04
.20951+01	.40440+00	.12807+01	.15290+02	.00000	.51339+02	.00000	.21553+04
.21279+01	.38769+00	.12957+01	.15455+02	.00000	.50517+02	.00000	[illegible]+04
.21812+01	.36186+00	.13200+01	.15679+02	.00000	[illegible]253+02	.00000	.21715+04
.22113+01	.34697+00	[illegible]+01	.15790+02	.00000	[illegible]326+02	.00000	.21776+04
.22876+01	.30911+00	.13736+01	.15991+02	.00000	[illegible]9+02	.00000	.21940+04

PARTICLE START LINE PROPERTIES

POINT	SPECIE	U	V	PSI	ENTHALPY	DENSITY
1	1	[illegible]+04	.00000	.00000	.57872+04	.18653-03
1	2	[illegible]5+04	.00000	.00000	.57968+04	.48890-03
1	3	[illegible]273+04	.00000	.00000	.58044+04	.43557-03
1	4	.34666+04	.00000	.00000	.58111+04	.45329-03
1	5	.37998+04	.00000	.00000	.58189+04	.43136-03
1	6	.37277+04	.00000	.00000	.58201+04	.24635-03
2	1	.40911+04	.10489+01	.35082-[illegible]	.57990+04	.18307-03
2	2	.39768+04	.12265+01	.39882-03	.58036+04	.41027-03
2	3	.39993+04	.10696+01	.27405-03	.58110+04	.43732-03
2	4	.38365+04	.99516+00	.24636-03	.55177+04	.47956-03
2	5	.37708+04	.81974+00	.21729-03	[illegible]255+04	.48392-03
2	6	.36987+04	.67868+00	.19369-03	.58357+04	.25612-03

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO. 75 PAGE 5

SPACE SHUTTLE HPP NOZZLE ACTUAL GEOMETRY FINITE RATE

POINT	SPECIE	U	V	PSI	ENTHALPY	DENSITY
3	1	.40565+04	.58084+01	.14319-[illegible]	.58030+04	.18796-03
3	2	.39517+04	.49858+01	.12617-[illegible]	.58093+04	.41326-03
3	3	.38739+04	.43419+01	.11213-[illegible]	.58169+04	.43873-03
3	4	.38110+04	.39471+01	.10082-[illegible]	.58236+04	.48132-03
3	5	.37453+04	.33376+01	.88929-03	.58314+04	.44605-03
3	6	.36693+04	.27589+01	.75187-03	.58416+04	.25760-03
4	1	.40387+04	.17315+02	.33001-02	.57052+04	.18777-03
4	2	.39295+04	.11429+02	.29086-02	.58144+04	.41201-03
4	3	.38512+04	.99583+01	.25856-02	.58220+04	.43980-03
4	4	.37892+04	.88075+01	.23250-02	.58287+04	.47275-03
4	5	.37224+04	.76351+01	.20511-02	.58365+04	.48774-03
4	6	.36465+04	.63204+01	.17344-02	.58467+04	.25881-03
5	1	.40158+04	.24169+02	.69184-02	.58096+04	.18792-03
5	2	.39190+04	.20746+02	.59056-02	.58187+04	.41208-03
5	3	.38313+04	.18075+02	.47177-02	.58263+04	.44059-03
5	4	.37681+04	.15987+02	.42027-02	.58330+04	.46380-03
5	5	.37021+04	.13859+02	.37034-02	.58409+04	.48898-03
5	6	.36261+04	.11480+02	.31657-02	.58511+04	.25975-03
6	1	.39997+04	.38626+02	.96569-02	.58132+04	.18794-03
6	2	.38933+04	.33156+02	.85159-02	.58222+04	.41265-03
6	3	.38142+04	.28887+02	.75736-02	.58298+04	.44094-03
6	4	.37507+04	.25550+02	.68120-02	.58366+04	.46946-03
6	5	.36846+04	.22149+02	.60111-02	.58445+04	.48979-03
6	6	.36097+04	.18367+02	.50846-02	.58548+04	.24080-03
7	1	.39867+04	.56975+02	.14290-01	.58159+04	.18783-03
7	2	.38796+04	.48976+02	.17605-01	.58249+04	.41258-03
7	3	.37999+04	.42610+02	.11213-01	.58326+04	.44101-03
7	4	.37361+04	.37647+02	.10087-01	.58394+04	.46473-03
7	5	.36699+04	.32670+02	.89021-02	.58473+04	.49015-03
7	6	.35938+04	.27062+02	.75299-02	.58576+04	.26077-03
8	1	.39748+04	.79510+02	.19996-01	.58178+04	.18779-03
8	2	.38649+04	.68266+02	.17643-01	.58268+04	.41210-03
8	3	.37856+04	.59478+02	.15698-01	.58345+04	.44670-03
8	4	.37245+04	.52696+02	.14173-01	.58413+04	.46462-03
8	5	.36590+04	.45604+02	.12466-01	.58493+04	.49008-03
8	6	.35818+04	.37775+02	.10596-01	.58597+04	.26087-03
9	1	.39700+04	.10663+03	.20[illegible]2-01	.58188+04	.18727-03
9	2	.38612+04	.91526+02	[illegible]699-01	.58278+04	.41186-03
9	3	.37673+04	.79781+02	[illegible]091-01	.58355+04	.44011-03
9	4	.37158+04	.70530+02	[illegible]979-01	.58424+04	.46411-03
9	5	.36990+04	.61111+02	.16354-01	.58505+04	.49456-03
9	6	.35726+04	.50615+02	.14175-01	.58611+04	.26640-03

SAMPLE PROBLEM 6 OUTPUT (Cont'd)

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                 SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                        GAS-PARTICLE FLOW SOLUTION
                                               CASE NO.  [illegible]                                      PAGE  [illegible]

SPACE SHUTTLE HPP NOZZLE ACTUAL GEOMETRY FINITE RATE

LINE POINT  DESCRIP - REGIME        X            Y            M           THETA       ENTROPY      VELOCITY     M-TOTAL   ITS
                               MACH ANGLE    PRESSURE      DENSITY     TEMPERATURE  GAS CONST.   LOCAL GAMMA   SHOCK ANGLE
                                  IO*          PO*           SO
PARTICLE DATA
SPECIE POINT  DESCRIPTION           V            META          D M          ENTHALPY      DENSITY      TEMPERATURE

  1    1  INPUT  - CONTIN      [illegible]  .19917+01   .10509+01   .00000      .00003      .93996+04   [illegible]
                               .73180+02   [illegible]  .40067-02   .55613+04   .24997+04   .12675+01
                               .63675+04   [illegible]  .10000
PARTICLE DATA
   1   1                       .410963+04   [illegible]      .44037-01    .57872+08    [illegible]   [illegible]
   2   1                       .400945+04   .00300           .93340-01    .57968+08    [illegible]   [illegible]
   3   1                       .392727+04   .00300           .11176+01    .58044+08    .03557-03     [illegible]
   4   1                       .384456+04   .00100           .12675+00    .58111+08    .05729-03     [illegible]
   5   1                       .379883+04   .00700           .14262+00    .58189+08    .06134-03     [illegible]
   6   1                       .372266+04   .00300           .16060+00    .58291+08    .25035-03     .56264+04
CHEMICAL SPECIE MOLE FRACTIONS
CO    2.5392-01  CO2  1.7589-02  H    2.4027-02  H2   2.8984-01  H2O  1.5085-01  O    2.4087-04  OH   [illegible]
[illegible] 5.0226-05  CL   8.9180-03  CL2  1.7066-05  HCL  1.5969-01  N2   8.9914-02  CL-  6.2792-06  F    [illegible]
[illegible] [illegible]  NA+  2.7327-06  NCL  7.3003-06  NA   7.2650-06  NA+  1.6920-06  NACL 3.3109-05
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  1    2  INPUT  - CONTIN      [illegible]  [illegible]  .17936+01   .35642+00   .00000      [illegible]  [illegible]
                               .73383+02   .39971+03   .40057-02   .55672+04   .24907+04   .12625+01
                               .63653+04   [illegible]  .00000
PARTICLE DATA
   1   2                       .404112+04   .24760-01    .60369-01    .57947+08    .18727-03     [illegible]
   2   2                       .397675+04   .17671-01    .93299-01    .58030+08    .01027-03     [illegible]
   3   2                       .389947+04   .15702-01    .11181+00    .58119+08    .03732-03     .56051+04
   4   2                       .393868+04   [illegible]  [illegible]  .58177+08    .05950-03     [illegible]
   5   2                       .377076+04   [illegible]  .14257+00    .58255+08    .06392-03     [illegible]
   6   2                       .369976+04   [illegible]  .16069+00    .58357+08    .25617-03     [illegible]
CHEMICAL SPECIE MOLE FRACTIONS
CO    2.5392-01  CO2  1.7589-02  H    2.4027-02  H2   2.8984-01  H2O  1.5085-01  O    2.4087-04  OH   [illegible]
[illegible] 5.0226-05  CL   8.9180-03  CL2  1.7066-05  HCL  1.5969-01  N2   8.9914-02  CL-  6.2792-06  [illegible] 5.0966-[illegible]
[illegible] 1.9969-07  NA+  2.7327-06  NCL  7.3003-06  NA   7.2650-06  NA+  1.6920-06  NACL 3.3109-05
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                 SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                        GAS-PARTICLE FLOW SOLUTION
                                               CASE NO.  [illegible]                                      PAGE  23

SPACE SHUTTLE HPP NOZZLE ACTUAL GEOMETRY FINITE RATE

LINE POINT  DESCRIP - REGIME        X            Y            M           THETA       ENTROPY      VELOCITY     M-TOTAL   ITS
                               MACH ANGLE    PRESSURE      DENSITY     TEMPERATURE  GAS CONST.   LOCAL GAMMA   SHOCK ANGLE
                                  IO*          PO*           SO
PARTICLE DATA
SPECIE POINT  DESCRIPTION           V            THETA         D M          ENTHALPY      DENSITY      TEMPERATURE

       30  INPUT  - CONTIN     [illegible]  .40000+03   .12607+01   .15296+02   .00000      [illegible]  .21553+04
                               .51336+02   [illegible]  [illegible]  .52967+04   .24907+04   .12604+01
                               .69912+04   .65919+03   .00000
PARTICLE DATA
   1   30                      .442768+04   .94000+01    .18039+00    .56127+08    [illegible]   [illegible]
   2   30                      .422336+04   .69737+01    .24466+00    .56692+08    .34091-03     [illegible]
   3   30  LIMIT STREAMLINE    .427731+04   .52111+01    .78262+00    .56752+08    .36124-03     .56653+04
CHEMICAL SPECIE MOLE FRACTIONS
CO    2.5392-01  CO2  1.7589-02  H    2.4027-02  H2   2.8984-01  H2O  1.5085-01  O    2.4087-04  OH   [illegible]
[illegible] 5.0226-05  CL   8.9180-03  CL2  1.7066-05  HCL  1.5969-01  N2   8.9914-02  CL-  6.2792-06  F    5.0966-06
[illegible] 1.9969-07  NA+  2.7327-06  NCL  7.3003-06  NA   7.2650-06  NA+  1.6920-06  NACL 3.3109-05
-----------------------------------------------------------------------------------------------------------------------

  1   31  INPUT  - CONTIN      .21299+01   .38769+03   [illegible]  .15655+02   .00000      .57830+04   .21618+04
                               [illegible]  .25669+03   .28093-02   .52787+04   .24907+04   .12605+01
                               .69578+04   .65313+03   .00000
PARTICLE DATA
   1   31                      .[illegible]+04  [illegible]  .19338+00   .56[illegible]+08  .35330-03   [illegible]
   2   31  LIMIT STREAMLINE    .423926+04   .66701+01    .75622+00    .56917+08    .33930-03     [illegible]
CHEMICAL SPECIE MOLE FRACTIONS
CO    2.5392-01  CO2  1.7589-02  H    2.4027-02  H2   2.8984-01  H2O  1.5085-01  O    2.4087-04  OH   [illegible]
[illegible] 5.0226-05  CL   8.9180-03  CL2  1.7066-05  HCL  1.5969-01  N2   8.9914-02  CL-  6.2792-06  F    5.0966-06
[illegible] 1.9969-07  NA+  2.7327-06  NCL  7.3003-06  NA   7.2650-06  NA+  1.6920-06  NACL 3.3109-05
-----------------------------------------------------------------------------------------------------------------------

  1   32  INPUT  - CONTIN      .21812+01   [illegible]  .13207+01   .15679+02   .00000      .53675+04   .21715+04
                               [illegible]  .20551+03   .27041-02   .52697+04   .24907+04   .12609+01
                               .69670+04   .64307+03   .00000
PARTICLE DATA
   1   32  LIMIT STREAMLINE    .472366+04   .62558+01    [illegible]  .56567+08    .15059-03     .53909+04
CHEMICAL SPECIE MOLE FRACTIONS
CO    2.5392-01  CO2  1.7589-02  H    2.4027-02  H2   2.8984-01  H2O  1.5085-01  O    2.4087-04  OH   [illegible]
[illegible] 5.0226-05  CL   8.9180-03  CL2  1.7066-05  HCL  1.5969-01  N2   8.9914-02  CL-  6.2792-06  F    5.0966-06
[illegible] 1.9969-07  NA+  2.7327-06  NCL  7.3003-06  NA   7.2650-06  NA+  1.6920-06  NACL 3.3109-05
-----------------------------------------------------------------------------------------------------------------------

  1   33  INPUT  - CONTIN      [illegible]  [illegible]  [illegible]  .15770+02   .00000      [illegible]  .21776+04
                               [illegible]  [illegible]  .21917-02   .52317+04   .24907+04   .12609+01
                               [illegible]  [illegible]  .00000
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
CHEMICAL SPECIE MOLE FRACTIONS
CO    2.5392-01  CO2  1.7589-02  H    2.4027-02  H2   2.8984-01  H2O  1.5085-01  O    2.4087-04  OH   [illegible]
[illegible] 5.0226-05  CL   8.9180-03  CL2  1.7066-05  HCL  1.5969-01  N2   8.9914-02  CL-  6.2792-06  F    5.0966-06
[illegible] [illegible]  NA+  2.7327-06  NCL  7.3003-06  NA   7.2650-06  NA+  1.6920-06  NACL 3.3109-05
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OF POOR QUALITY

SAMPLE PROBLEM 6 OUTPUT (Cont'd)

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              SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                         GAS-PARTICLE FLOW SOLUTION
                                         CASE NO.  75                                                       PAGE  [illegible]

SPACE SHUTTLE MPP NOZZLE ACTUAL GEOMETRY FINITE RATE

LINE POINT  DESCRIP - REGIME        R            X             M            THETA        ENTROPY      VELOCITY     H-TOTAL   ITE
                                MACH ANGLE    PRESSURE      DENSITY      TEMPERATURE   GAS CONST.   LOCAL GAMMA  SHOCK ANGLE
                                   IQ            PO*           S*
PARTICLE DATA
SPECIE POINT  DESCRIPTION          V             THETA          D M           ENTHALPY       DENSITY        TEMPERATURE

 1    34  INPUT  - CONTIN     .22676+01    .30911+03    .11736+01    .15991+02    .00000    .55518+04    .21990+04
                              .46719+02    .22294+03    .24011-02    .51033+04    .24907+04   .12673+01
                              .69957+04    .61952+01    .00000
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
CHEMICAL SPECIE MOLE FRACTIONS
CO   2.5362-01  CO2  1.7584-02  H    2.4027-02  H2   2.8998-01  H2O  1.5065-01  O    2.4083-06  OH   6.8357-05
CL   5.0226-05  CL   8.9100-03  CL2  1.2066-05  HCL  1.5949-01  N2   8.9918-02  CL-  6.2792-06  E    5.0966-06
N    1.9949-07  N+   2.7327-06  NCL  7.3033-06  NA   2.2650-06  NA+  1.6920-06  NACL 3.3108-05
-----------------------------------------------------------------------------------------------------------------------
  GAS MASS FLOW RATE =   .93767+04   PARTICLE MASS FLOW RATE =   .36508+04   MIXTURE MASS FLOW RATE =   .13026+05
                                        PARTICLE PERCENT LOADINGS
                                          RADIUS     LOADING
                                        .31590+01   .90018+01

                                        .47390+01   .20004+02

                                        .59070+01   .20001+02

                                        .69560+01   .20023+02

                                        .81590+01   .20000+02

                                        .97070+01   .99803+01

PARTICLE PERCENT LOADING RELATIVE TO THE GAS =   .38935+02   PARTICLE PERCENT LOADING RELATIVE TO THE MIXTURE =   .28026+02

                                        MOMENTUM INTEGRATION RESULTS
                               FORCEX         FORCEY        TORQZ          ISP
                             -.25787+07      .00000        .00000        .19779+03
                     DELFXG         DELFYG        TORQZG         DELFXP         DELFYP         TORQZP
                   -.21341+07      .00000        .00000        -.43759+06      .00000        .00000

              SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                         GAS-PARTICLE FLOW SOLUTION
                                         CASE NO.  75                                                       PAGE  25

SPACE SHUTTLE MPP NOZZLE ACTUAL GEOMETRY FINITE RATE

LINE POINT  DESCRIP - REGIME        R            X             M            THETA        ENTROPY      VELOCITY     H TOTAL   ITE
                                MACH ANGLE    PRESSURE      DENSITY      TEMPERATURE   GAS CONST.   LOCAL GAMMA  SHOCK ANGLE
                                   IQ*           PO*           S*
PARTICLE DATA
SPECIE POINT  DESCRIPTION          V             THETA          D P           ENTHALPY       DENSITY        TEMPERATURE

 .    99  INPUT  - CONTIN     .22111+01    .39697+03    .17387+01    .15756+02    .00000    .56173+04    .21776+04
                              .46576+02    .23993+01    .22617-02    .57312+04    .24907+04   .12699+01
                              .69677+04    .67675+03    .00000
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
CHEMICAL SPECIE MOLE FRACTIONS
CO   2.5362-01  CO2  1.7584-02  H    2.4027-02  H2   2.8998-01  H2O  1.5065-01  O    2.4083-06  OH   6.8357-05
CL   5.0226-05  CL   8.9100-03  CL2  1.2066-05  HCL  1.5949-01  N2   8.9918-02  CL-  6.2792-06  E    5.0966-06
N    1.9949-07  N+   2.7327-06  NCL  7.3033-06  NA   2.2650-06  NA+  1.6920-06  NACL 3.3108-05
-----------------------------------------------------------------------------------------------------------------------

 .    100  WALL  - CONTIN     .22919+01    .37339+03    .13933+01    .16753+02    .00000    .56155+04    .21963+04
                              .45867+02    .216 7+03    .24275-02    .51533+04    .24907+04   .12676+01
                              .69017+04    .61674+03    .00000
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
CHEMICAL SPECIE MOLE FRACTIONS
CO   2.5362-01  CO2  1.7584-02  H    2.4027-02  H2   2.8998-01  H2O  1.5065-01  O    2.4083-06  OH   6.8357-05
CL   5.0226-05  CL   8.9100-03  CL2  1.2066-05  HCL  1.5949-01  N2   8.9918-02  CL-  6.2792-06  E    5.0966-06
N    1.9949-07  N+   2.7327-06  NCL  7.3033-06  NA   2.2650-06  NA+  1.6920-06  NACL 3.3108-05
-----------------------------------------------------------------------------------------------------------------------

                                        PRESSURE INTEGRATION RESULTS
                     FORCEX         FORCEY         TORQZ          DELFX          DELFY          ISP
                   -.25787+07      .00000        .00000        -.14815+06      .00000        .19799+03

 3    98  INPUT  - CONTIN     .21812+01    .38190+03    .17200+01    .15679+02    .00000    .53615+04    .21115+04
                              .49203+02    .28551+03    .27081-02    .57092+04    .24907+04   .12690+01
                              .69617+04    .69375+03    .00000
PARTICLE DATA
     1    98 LIMIT STREAMLINE     .45236+04        .91158+03        .20752+06        .55967+04        .15055+03        .53407+04
CHEMICAL SPECIE MOLE FRACTIONS
CO   2.5362-01  CO2  1.7584-02  H    2.4027-02  H2   2.8998-01  H2O  1.5065-01  O    2.4083-06  OH   6.8357-05
CL   5.0226-05  CL   8.9170-03  CL2  1.2066-05  HCL  1.5949-01  N2   8.9918-02  CL-  6.2792-06  E    5.0966-06
N    1.9949-07  N+   2.7327-06  NCL  7.3033-06  NA   2.2650-06  NA+  1.6920-06  NACL 3.3108-05
-----------------------------------------------------------------------------------------------------------------------

 3    100  WALL  - CONTIN     .22936+01    .37899+03    .14011+01    .17747+02    .00000    .56395+04    .21572+04
                              .45577+02    .21911+03    .24878-02    .51520+04    .24858+04   .12688+01
                              .69918+04    .61515+03    .00000
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
CHEMICAL SPECIE MOLE FRACTIONS
CO   2.5320-01  CO2  1.8573-02  H    2.2193-02  H2   2.9173-01  H2O  1.5129-01  O    1.5717-06  OH   3.9676-05
CL   4.9257-05  CL   8.8690-03  CL2  8.5717-06  HCL  1.6045-01  N2   9.0990-02  CL-  5.8699-06  E    4.8912-06
N    2.0916-07  N+   2.5332-06  NCL  7.5151-06  NA   2.3991-06  NA+  1.6799-06  NACL 3.3756-05
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                                        PRESSURE INTEGRATION RESULTS
                     FORCEX         FORCEY         TORQZ          DELFX          DELFY          ISP
                   -.27799+07      .00000        .00000        -.75166+03      .00000        .19809+03
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SAMPLE PROBLEM 6 OUTPUT (Cont'd)

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                SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                          GAS-PARTICLE FLOW SOLUTION
                                          CASE NO.   75                                              PAGE  [illegible]

SPACE SHUTTLE HPP NOZZLE ACTUAL CLOPLIST FINITE RATE

LINE POINT  DSCRIP - REGIME      P              T              RHO            THETA          ENTROPY        VELOCITY       M.TOTAL
                             MACH ANGLE      PRESSURE        DENSITY       TEMPERATURE     GAS CONST.     LOCAL GAMMA    SHOCK ANGLE
                                 X0*            P0*            S0
PARTICLE DATA
 SPECIE POINT  DESCRIPTION       V             THETA            D M            ENTHALPY        DENSITY       TEMPERATURE

 [illegible]  WALL  - CONTIN  [illegible]   .23752+01     .18360+01     .23900+02     .15909+03     .69305+04     .19060+04
                             .37993+07     .10056+03     .130E0-07     .65670+04     .24553+04     .12660+01
                             .66998+04     .49150+03     .00090
PARTICLE DATA
13 PARTICLES ARE PRESENT AT THIS POINT
CHEMICAL SPECIE MOLE FRACTIONS
CO   [illegible]  CO2  [illegible]  H    6.6774-03  H2   [illegible]  H2O  1.5441-01  O    1.0995-05  OH   [illegible]
O2   [illegible]  CL   2.6550-03  CL2  [illegible]  HCL  1.6843-01  N2   9.1212-02  CL-  1.7034-06  F    [illegible]
N    8.0361-10  N+   8.6003-07  NCL  [illegible]    NA   [illegible]  NA+  2.0419-07  NACL 3.6660-05

                                          PRESSURE INTEGRATION RESULTS
                         FORCEX         FORCEY          TORQZ          DELFX          DELFY           ISP
                       -.24026+07       .00000         .00000       -.68550+06       .00000        .27782+03

 [illegible]  1  WALL  - CONTIN   .00000      .32879+03     .16351+01     .00000        .11393+04     .63159+04     .19090+04
                             .37763+07     .11258+03     .13796-07     .67073+04     .26471+04     .12650+01
                             .64875+04     .91684+03     .00000
PARTICLE DATA
    1   1                      .609723+04      .00000       .70852-01     .51764+04     .67972-09     .98617+04
    2   1                      .58676+04       .00000       .11604+00     .52197+04     .15761-03     .99103+04
    3   1                      .572867+04      .00000       .15203+00     .52510+04     .17527-03     .99670+04
    4   1                      [illegible]     .00000       .18809+00     .52769+04     .19190-03     .99774+04
    5   1                      .546523+04      .00000       .22069+00     .53049+04     .20998-03     .50101+04
    6   1                      .528721+04      .00000       .26632+00     .53396+04     .11020-03     .50112+04
CHEMICAL SPECIE MOLE FRACTIONS
CO   [illegible]  CO2  2.7184-02  H    1.0215-02  H2   2.9801-01  H2O  1.5408-01  O    7.9378-05  OH   1.3636-03
O2   [illegible]  CL   4.0119-03  CL2  [illegible]  HCL  1.6661-01  N2   9.0959-02  CL-  1.5795-06  F    [illegible]
N    1.1563-07  N+   1.2596-06  NCL  8.9765-06  NA   1.2637-04  NA+  6.3028-07  NACL 3.5803-05

                SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                          GAS-PARTICLE FLOW SOLUTION
                                          CASE NO.   75                                              PAGE  [illegible]

SPACE SHUTTLE HPP NOZZLE ACTUAL CLOPLIST FINITE RATE

LINE POINT  DSCRIP - REGIME      P              T              RHO            THETA          ENTROPY        VELOCITY       M.TOTAL
                             MACH ANGLE      PRESSURE        DENSITY       TEMPERATURE     GAS CONST.     LOCAL GAMMA    SHOCK ANGLE
                                 X0*            P0*            S0
PARTICLE DATA
 SPECIE POINT  DESCRIPTION       V             THETA            D M            ENTHALPY        DENSITY       TEMPERATURE

 [illegible]  1  WALL  - CONTIN  [illegible]   .13979+02     .23040+01     .00000        [illegible]   [illegible]   [illegible]
                             .25723+07     .13567+02     .20567-03     .38760+04     .26696+04     .12733+01
                             .66679+04     .92978+03     .00000
PARTICLE DATA
    1   1                      .601164+04      [illegible]    -.23579-03    .30936+04     [illegible]   [illegible]
    2   1                      [illegible]     [illegible]    .16376-01     .33607+04     .33101-06     [illegible]
    3   1                      .382772+04      [illegible]    .39201-01     .37055+04     .16080-06     [illegible]
    4   1                      .381635+04      [illegible]    [illegible]   .39180+04     .19463-06     [illegible]
    5   1                      .371964+04      [illegible]    .43972-01     .40700+04     .21991-06     [illegible]
    6   1                      .356336+04      .00000        .12037+00     .42269+04     .11857-06     [illegible]
CHEMICAL SPECIE MOLE FRACTIONS
CO   [illegible]  CO2  [illegible]  H    3.6307-03  H2   3.0556-01  H2O  1.5167-01  O    1.9996-06  OH   2.5164-06
O2   [illegible]  CL   1.9913-03  CL2  5.6848-07  HCL  1.7073-01  N2   9.1831-02  CL-  4.8684-07  F    1.9533-10
N    5.2669-08  N+   5.1782-07  NCL  9.6749-06  NA   [illegible]  NA+  6.7006-08  NACL [illegible]

    NO SOLUTION AT THE POINT IS THE LINE WILL BE RECALCULATED USING A SMALLER STEP LENGTH

        A PROBLEM WITH A HPC INTERSECTION WITH LINE [illegible] HAS BEEN ENCOUNTERED. THE LINE WILL BE RECALCULATED

 [illegible]  1  WALL  - CONTIN  [illegible]   .13365+02     .23065+01     .00000        .38110+04     .60112+04     .19090+04
                             .25714+02     .13551+02     .20561-03     .38767+04     .26669+04     .12733+01
                             .66671+04     .92993+03     .00000
PARTICLE DATA
    1   1                      .803166+04      [illegible]    -.13900-03    .30931+04     [illegible]   .39620+04
    2   1                      .795708+04      [illegible]    .16770-01     .33539+04     [illegible]   .91877+04
    3   1                      .777620+04      [illegible]    .78027-01     .37101+04     .16593-06     .91880+04
    4   1                      .776461+04      [illegible]    [illegible]   .39137+04     .19933-06     .91880+04
    5   1                      .771632+04      [illegible]    .44709-01     .40779+04     .21572-06     .91880+04
    6   1                      .759073+04      .00000        .12097+00     .42274+04     .11906-06     .91880+04
CHEMICAL SPECIE MOLE FRACTIONS
CO   2.5121-01  CO2  [illegible]  H    3.6620-03  H2   3.0556-01  H2O  1.5196-01  O    1.9519-06  OH   [illegible]
O2   4.1363-07  CL   1.9976-03  CL2  [illegible]  HCL  1.7073-01  N2   9.1031-02  CL-  4.0771-07  F    1.5560-10
N    [illegible]  N+   5.1029-07  NCL  [illegible]  NA   [illegible]  NA+  6.7110-08  NACL 3.6093-05

 [illegible]  37  WALL  - CONTIN  [illegible]   [illegible]    [illegible]   [illegible]   [illegible]   [illegible]   [illegible]
                             [illegible]    [illegible]    [illegible]   [illegible]   [illegible]   .12850+01
                             [illegible]    [illegible]    .00000
PARTICLE DATA
    1  37                      [illegible]     [illegible]    [illegible]   [illegible]   .17066-06     [illegible]
CHEMICAL SPECIE MOLE FRACTIONS
CO   2.4917-01  CO2  2.7014-02  H    [illegible]  H2   [illegible]  H2O  1.4939-01  O    2.3373-07  OH   [illegible]
O2   5.3365-07  CL   6.6073-03  CL2  1.6047-07  HCL  [illegible]  N2   9.1572-02  CL-  2.3014-07  F    6.7661-10
N    2.6133-08  N+   [illegible]  NCL  1.0097-05  NA   [illegible]  NA+  2.2807-14  NACL [illegible]

                                          PRESSURE INTEGRATION RESULTS
                         FORCEX         FORCEY          TORQZ          DELFX          DELFY           ISP
                       -.31927+07       .00000         .00000       -.19744+06       .00000        .27199+03

        PERCENT CHANGE IN MASS, MOMENTUM AND ENERGY NUMERICAL INTEGRATION FOR LINE [illegible] RELATIVE TO THE START LINE
            PERCENT CHANGE IN MASS FLOW, GAS = -.31071+01   PARTICLE = .12570+01   MIXTURE = -.19099+01
      PERCENT CHANGE IN MOMENTUM, GAS = [illegible]   PARTICLE = .99618+02   MIXTURE = -.30315+01  ISP = [illegible]
              PERCENT CHANGE IN ENERGY, GAS = -.18760+02   PARTICLE = .99779+01   MIXTURE = -.13907+02
EXIT PLANE NORMAL START LINE

        .20600E6     .1333197+02   .2296909+01   .00000      .3073930+04   .9223705+00

        [illegible]  [illegible]   .2300526+01   .1201780+00  [illegible]   .9216328+00
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SAMPLE PROBLEM 6 OUTPUT (Cont'd)

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                    SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                          GAS-PARTICLE FLOW SOLUTION
                                               CASE NO.  [illegible]                                      PAGE  [illegible]

  SPACE SHUTTLE HPM NOZZLE ACTUAL GEOMETRY FINITE RATE

LINE POINT  DESCRIP - REGIME        R            X            M           THETA       ENTROPY      VELOCITY     M-TOTAL   ITR
                                MACH ANGLE    PRESSURE     DENSITY     TEMPERATURE  GAS CONST.  LOCAL GAMMA   SHOCK ANGLE
                                   TOP          POA          SO
PARTICLE DATA
 SPECIE POINT  DESCRIPTION          V           THETA         D M                    ENTHALPY     DENSITY      TEMPERATURE

154     1  WALL    - CONTIN     .[illegible]    .13263+02    .23056+01    .00000       .38000+00    .80121+04    .19015+04
                                .23130+02    .13546+03    .20560-03    .38718+00    .20696+06    .12773+01
                                .65511+00    .53103+03    .00000
PARTICLE DATA
   1     1                      .601166+04   .00000       .13717-03                 .30923+08    .81730-05    .36411+04
   2     1                      .765066+04   .00000       .17751-01                 .33679+08    .11326-04    .61480+04
   3     1                      .383258+04   .00000       .40360-01                 .37765+08    .16481-04    .61480+04
   4     1                      .380785+04   .00000       .63015-01                 .39721+08    .20096-04    .61980+04
   5     1                      .771162+04   .00000       .86610-01                 .40848+08    .21763-04    .61980+04
   6     1                      .756953+04   .00000       .12307+00                 .42172+08    .32015-04    .61980+04
CHEMICAL SPECIE MOLE FRACTIONS
CO    2.5119-01  CO2   2.6806-02  H    3.6441-03  H2   3.0558-01  H2O   1.5100-01  O     1.9517-06  OH    [illegible]
[ ]   9.1355-07  CL    1.9999-03  CL2  5.6192-07  HCL  1.7602-01  N2    9.1930-02  CL-   6.8836-07  F     1.6723-05
N     5.2650-08  N+    5.1901-07  NCL  9.6777-06  NA   6.6750-07  NA+   6.7357-08  NACL  3.6901-05
------------------------------------------------------------------------------------------------------------------------------

                    SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                          GAS-PARTICLE FLOW SOLUTION
                                               CASE NO.  75                                          PAGE  2[illegible]

  SPACE SHUTTLE HPM NOZZLE ACTUAL GEOMETRY FINITE RATE

LINE POINT  DESCRIP - REGIME        R            X            M           THETA       ENTROPY      VELOCITY     M-TOTAL   ITR
                                MACH ANGLE    PRESSURE     DENSITY     TEMPERATURE  GAS CONST.  LOCAL GAMMA   SHOCK ANGLE
                                   TOP          POA          SO
PARTICLE DATA
 SPECIE POINT  DESCRIPTION          V           THETA         D M                    ENTHALPY     DENSITY      TEMPERATURE

154    35  INTER   - CONTIN     .61571+01    .12781+02    .25550+01    .10866+02    .56217+03    .85339+04    .19689+04
                                .23678+02    .23651+02    .39013-03    .35695+00    .20957+00    .12771+01
                                .67696+00    .15780+03    .00000
PARTICLE DATA
   1    35                      .887233+04   .11961+02    .10882-01                 .28705+08    .11961-04    .35685+04
   2    35  LIMIT STREAMLINE    .857606+04   .12069+02    .52782-01                 .29599+08    .30617-04    .36057+04
CHEMICAL SPECIE MOLE FRACTIONS
CO    2.4967-01  CO2   2.6875-02  H    1.6709-03  H2   3.0887-01  H2O   1.4998-01  O     2.5292-07  OH    6.9660-[illegible]
[ ]   5.2634-06  CL    6.4805-04  CL2  1.0789-07  HCL  1.7107-01  N2    9.1560-02  CL-   2.3736-07  F     6.3780-11
N     2.6984-08  N+    3.0526-07  NCL  1.0091-05  NA   3.6215-07  NA+   2.0761-08  NACL  3.7361-05
------------------------------------------------------------------------------------------------------------------------------

154    36  INTER   - CONTIN     .61655+01    .12775+02    .26075+01    .17659+02    .58029+03    .86221+04    .19656+04
                                .22615+02    .23680+02    .39605-03    .35160+00    .20957+00    .12781+01
                                .68075+00    .20833+03    .00000
PARTICLE DATA
   1    36                      .870833+04   .11850+02    .35527-01                 .28613+08    .13884-04    .35722+04
CHEMICAL SPECIE MOLE FRACTIONS
CO    2.4969-01  CO2   2.6802-02  H    1.6351-03  H2   3.0885-01  H2O   1.4997-01  O     2.8790-07  OH    8.[illegible]
[ ]   6.1766-06  CL    6.4813-04  CL2  2.1272-07  HCL  1.7107-01  N2    9.1560-02  CL-   2.6172-07  F     5.8722-11
N     2.6172-08  N+    3.0876-07  NCL  1.0080-05  NA   3.6631-07  NA+   3.0700-08  NACL  3.7378-05
------------------------------------------------------------------------------------------------------------------------------

154    37  WALL    - CONTIN     .62350+01    .12896+02    .27013+01    .17690+02    .62869+03    .88145+04    .20058+04
                                .21327+02    .23684+02    .40947-03    .34029+00    .20956+00    .12800+01
                                .68270+00    .21949+03    .00000
PARTICLE DATA
   1    37                      .866736+04   .11508+02    .51829-01                 .27857+08    .11580-04    .36761+04
CHEMICAL SPECIE MOLE FRACTIONS
CO    2.4910-01  CO2   2.7976-02  H    1.5669-03  H2   3.0900-01  H2O   1.4939-01  O     2.3303-07  OH    6.6815-[illegible]
[ ]   5.3365-06  CL    6.6018-04  CL2  1.4097-07  HCL  1.7110-01  N2    9.1572-02  CL-   2.3059-07  F     6.0963-11
N     2.6133-08  N+    3.7026-07  NCL  1.0097-05  NA   3.5123-07  NA+   2.7407-08  NACL  3.7376-05
------------------------------------------------------------------------------------------------------------------------------

154    38  PRN-PR  - CONTIN     .62350+01    .12896+02    .28395+01    .18159+02    .62869+03    .90386+04    .20058+04
                                .20639+02    .18693+02    .33637-03    .32295+00    .20956+00    .12832+01
                                .68751+00    .18852+03    .00000
PARTICLE DATA
   1    38                      .866736+04   .11508+02    .12117+00                 .27857+08    .11580-04    .36781+04
CHEMICAL SPECIE MOLE FRACTIONS
CO    2.4910-01  CO2   2.7[illegible]   H    1.5669-03  H2   3.0908-01  H2O   1.4939-01  O     2.3303-07  OH    6.6815-[illegible]
[ ]   5.3365-06  CL    6.6018-04  CL2  1.4097-07  HCL  1.7110-01  N2    9.1572-02  CL-   2.3059-07  F     6.0963-11
N     2.6133-08  N+    3.7026-07  NCL  1.0097-05  NA   3.5123-07  NA+   2.7407-08  NACL  3.7376-05
------------------------------------------------------------------------------------------------------------------------------

                    SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
                                          GAS-PARTICLE FLOW SOLUTION
                                               CASE NO.  75                                          PAGE  [illegible]

  SPACE SHUTTLE HPM NOZZLE ACTUAL GEOMETRY FINITE RATE

LINE POINT  DESCRIP - REGIME        R            X            M           THETA       ENTROPY      VELOCITY     M-TOTAL   ITR
                                MACH ANGLE    PRESSURE     DENSITY     TEMPERATURE  GAS CONST.  LOCAL GAMMA   SHOCK ANGLE
                                   TOP          POA          SO
PARTICLE DATA
 SPECIE POINT  DESCRIPTION          V           THETA         D M                    ENTHALPY     DENSITY      TEMPERATURE

155    70  PRN-PR  - CONTIN     .62350+01    .12896+02    .29831+01    .17728+02    .62869+03    .92441+04    .20058+04
                                .19592+02    .18203+02    .27367-03    .30175+00    .20956+00    .12849+01
                                .69113+00    .14503+03    .00000
PARTICLE DATA
NO PARTICLES ARE PRESENT AT THIS POINT
CHEMICAL SPECIE MOLE FRACTIONS
CO    2.4910-01  CO2   2.7976-02  H    1.5669-03  H2   3.0908-01  H2O   1.4939-01  O     2.3303-07  OH    6.6815-[illegible]
[ ]   5.3365-06  CL    6.6018-04  CL2  1.4097-07  HCL  1.7110-01  N2    9.1572-02  CL-   2.3059-07  F     6.0963-11
N     2.6133-03  N+    3.0026-07  NCL  1.0097-05  NA   3.5123-07  NA+   2.7403-08  NACL  3.7376-05
------------------------------------------------------------------------------------------------------------------------------
```

SAMPLE PROBLEM 6 OUTPUT (Concluded)

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SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO.  75                                                                PAGE  [illegible]

SPACE SHUTTLE MPP NOZZLE ACTUAL GEOMETRY FINITE RATE

LINE POINT  DSCRIP - REGIME   MACH ANGLE   PRESSURE   DENSITY   THETA        ENTROPY    VELOCITY     M-TOTAL
                              TOO          POO        SO        TEMPERATURE  GAS CONST. LOCAL GAMMA  SHOCK ANGLE
PARTICLE DATA
SPECIE POINT  DESCRIPTION        V          THETA      D M        ENTHALPY    DENSITY     TEMPERATURE

21.   1 WALL   - CONTIN   [illegible] rows of values
PARTICLE DATA
  1  1  ...
  2  1  ...
  3  1  ...
  4  1  ...
  5  1  ...
  6  1  ...
CHEMICAL SPECIE MOLE FRACTIONS
CO  ...  CO2 ...  H ...  H2 ...  H2O ...  O ...  OH ...
O2  ...  CL  ...  CL2 ... HCL ... N2 ...  CL- ... E ...
N   ...  N+  ...  HCL ... NO ... NO+ ... HACL ...

21.  33 FREE - CONTIN   [illegible] rows of values
PARTICLE DATA
  1  33  ...
  2  33  ...
CHEMICAL SPECIE MOLE FRACTIONS
CO  ...  CO2 ...  H ...  H2 ...  H2O ...  O ...  OH ...
O2  ...  CL  ...  CL2 ... HCL ... N2 ...  CL- ... E ...
N   ...  N+  ...  HCL ... NO ... NO+ ... HACL ...

211   1 WALL   - CONTIN   [illegible] rows of values
PARTICLE DATA
  1  1  ...
  2  1  ...
  3  1  ...
  4  1  ...
  5  1  ...
  6  1  ...
CHEMICAL SPECIE MOLE FRACTIONS
CO  ...  CO2 ...  H ...  H2 ...  H2O ...  O ...  OH ...
O2  ...  CL  ...  CL2 ... HCL ... N2 ...  CL- ... E ...
N   ...  N+  ...  HCL ... NO ... NO+ ... HACL ...

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM
GAS-PARTICLE FLOW SOLUTION
CASE NO.  75                                                                PAGE  [illegible]

SPACE SHUTTLE MPP NOZZLE ACTUAL GEOMETRY FINITE RATE

LINE POINT  DSCRIP - REGIME   MACH ANGLE   PRESSURE   DENSITY   THETA        ENTROPY    VELOCITY     M-TOTAL
                              TOO          POO        SO        TEMPERATURE  GAS CONST. LOCAL GAMMA  SHOCK ANGLE
PARTICLE DATA
SPECIE POINT  DESCRIPTION        V          THETA      D M        ENTHALPY    DENSITY     TEMPERATURE

21.  33 FREE - CONTIN   [illegible] rows of values
PARTICLE DATA
  1  33  ...
  2  33  ...
CHEMICAL SPECIE MOLE FRACTIONS
CO  ...  CO2 ...  H ...  H2 ...  H2O ...  O ...  OH ...
O2  ...  CL  ...  CL2 ... HCL ... N2 ...  CL- ... E ...
N   ...  N+  ...  HCL ... NO ... NO+ ... HACL ...

PARTICULATE NOTED ERRORS HAVE PROPAGATED TO LOWER BOUNDARY, OR PROBLEM LIMITS HAVE BEEN REACHED.  CASE TERMINATED.
 300000000000 000000000000

     PUNCH CARDS FOR LINE  211

     .3300000    .2040000+02  .2310560+01  .0000000     .2169970+04  .8156720+00
     .2657070+00 .2000000+02  .2320007+01  .1000003+00  .2160575+04  .8157020+00
     .5726307+00 .2000700+02  .2327030+01  .2965075+00  .2160963+04  .8161100+00
     .7007330+00 .2200570+02  .2333010+01  .4000036+00  .2156070+04  .8166227+00
     .1066053+01 .2070320+02  .2340775+01  .5927773+00  .2150519+04  .8172916+00
     .1133067+01 .2000017+02  .2340300+01  .7005550+00  .2143970+04  .8180570+00
     .1600750+01 .2037630+02  .2356000+01  .8905300+00  .2137090+04  .8100715+00
     .1967107+01 .2007107+02  .2360700+01  .1006761+01  .2129900+04  .8196713+00
     .2133116+01 .2006662+02  .2373050+01  .1215600+01  .2122200+04  .8199007+00
     .2390076+01 .2000553+02  .2303095+01  .1013031+01  .2110201+04  .8103035+00
     .2663051+01 .2005301+02  .2303547+01  .1667190+01  .2105276+04  .8169050+00
     .2929127+01 .2000000+02  .2405774+01  .1990020+01  .2705175+04  .8115590+00
     .3100977+01 .2603001+02  .2400066+01  .2130060+01  .2603327+05  .8072077+00
     .3067197+01 .2002230+02  .2036057+01  .2936131+01  .2069677+04  .7002062+00
```

8.7 SAMPLE PROBLEM 7 - MONOPROPELLANT MOTOR

Small monopropellant thrusters are typically used for satellite attitude control. These motors impinge on some of the spacecraft surfaces and can cause local heating and unwanted cancellation of control moments. This particular sample case calculates the nozzle, boundary layer, and exhaust plume (including the boundary layer effects). The boundary layer is included since most of the impinged surfaces for monopropellant motors are typically in the backflow region of the plume where the boundary layer dominates.

The particular motor produces 10 lbf of thrust. A summary of the motor characteristics is as follows:

Throat	.008333 ft
Area Ratio	50
Propellant	Hydrazine
Chamber Pressure	180 psia

The geometry for this motor was specified using the point specification. The throat section is a circular arc whose radius is .015 ft. The points in the throat region were calculated from the specified circular arc in the same fashion as was used to set up sample problem 1. The remainder of the nozzle contour was generated using the same procedure as Sample Problem 1.

The equilibrium/frozen chemistry option using the TRAN72 results was selected. The monopropellant chemistry model described in Section 4.4.6 was used to set up the TRAN72 data. The TRAN72 data shown are Sample Case 6 of Section 4.

The nozzle solution was initiated at the throat assuming Mach = 1.02. The nozzle wall temperature for the BLIMPJ boundary calculation was taken to be constant at 1000 R.

'is particular case required the boundary layer to be calculated twi e. This was performed internal to the BLIMPJ program because after the first calculation the boundary layer was sufficiently thick so that the pressure at the edge of the boundary layer differed from the lip pressure by more than 10 percent.

SAMPLE PROBLEM 7 INPUT DATA

Card

1
2 A/A*=5 .HYDRAZINE MOTOR CATALYST PARTICULATES
3
4
5 2 252 [illegible] 1 11 2.2 1 1257[illegible]
7 .10533333

8

.[illegible]	. [illegible]328	.[illegible]	.	.[illegible]523	.018742	2.00[illegible]
.[illegible]1 4[illegible]	.[illegible]637	4.[illegible]	[illegible]	.[illegible]156[illegible]	.0FF416	6.[illegible]
.[illegible]	. [illegible]47[illegible]	[illegible]		.[illegible]2677	.0[illegible]8561	10.[illegible]
.[illegible]3119	.[illegible]66[illegible]1	12.[illegible]		.[illegible]3629	.[illegible]8779	14.[illegible]
.[illegible]4135	.[illegible]914	1[illegible].[illegible]		.[illegible]4635	.[illegible]9067	18.[illegible]
.[illegible]13[illegible]	. [illegible]23[illegible]	2[illegible]		.[illegible]5619	.[illegible]9426	22.[illegible]
.[illegible]1 1	. [illegible]67	24.[illegible]		.[illegible]5776	.[illegible]9981	26.[illegible]
.[illegible]7 [illegible]7	. 1 111	2[illegible].17[illegible]		.[illegible]75[illegible]	.[illegible]1034[illegible]	29.4[illegible]
.[illegible]333	. 1 50[illegible]	3[illegible]		.[illegible]1[illegible]	.[illegible]11856	32.23[illegible]
.[illegible]15273	. 1404[illegible]	34.1[illegible]		.[illegible]16667	. 16352	35.[illegible]
.[illegible]	. 1[illegible]6[illegible]	3[illegible]		.[illegible]23333	. 21[illegible]7	37.92[illegible]
.[illegible]2[illegible]667	. 23161	31.[illegible]		.[illegible]3[illegible]	.[illegible]25175	28.55[illegible]
.[illegible]33333	.[illegible]2611	26.5[illegible]		.[illegible]36667	.[illegible]28413	24.9[illegible]
.[illegible]4[illegible]	.[illegible]13	23.72[illegible]		.[illegible]47333	.[illegible]31747	22.7[illegible]
.[illegible]4[illegible]667	. [illegible]27.3	21.53		.[illegible]	.[illegible]3402[illegible]	21.16[illegible]
.[illegible]	. [illegible]29[illegible]	2[illegible].4[illegible]		.[illegible]56667	. 36516	19.76[illegible]
.[illegible]6[illegible]	. 3767[illegible]	1[illegible].12[illegible]		.[illegible]63333	.[illegible]38828	18.5[illegible]
.[illegible]66667	. 3[illegible]24	17.[illegible]		.[illegible]7[illegible]	.[illegible]4[illegible]8[illegible]	17.33[illegible]
.[illegible]73337	. 4[illegible]	15.75[illegible]		.[illegible]76667	.[illegible]4295	16.24[illegible]
.[illegible]	. 4[illegible]46	1[illegible].74[illegible]	.	.[illegible]83333	.[illegible]4467	15.28[illegible]
.[illegible]86667	.[illegible]45767	14.[illegible]3		.[illegible]	.[illegible]46635	14.4[illegible]
.[illegible]3333	. 47477	13.[illegible]		.[illegible]96667	. 4829[illegible]	13.57[illegible]
.1[illegible]	. 4[illegible]	13.21		.103333	.[illegible]49663	12.9[illegible]
.1[illegible]6667	. [illegible]0616	12.54[illegible]		.11[illegible]	.[illegible]51347	12.23[illegible]
.113333	.[illegible]5[illegible]5[illegible]	11.92[illegible]		.116667	.[illegible]52752	11.620000
.12[illegible]	.[illegible]53426	11.33		.123333	.[illegible]54007	11.060000
.126667	. 5473[illegible]	1[illegible].79[illegible]		.13[illegible]	.[illegible]5358	10.540000
.133333	.[illegible]55971	1[illegible].31[illegible]		.136667	.056571	10.350000
.14[illegible]	.[illegible]571[illegible]	[illegible].9[illegible]	.	.143333	.[illegible]57733	9.720000
.146667	.[illegible]5-259	9.55[illegible]	1	.147917	.[illegible]5[illegible]	9.460000

ORIGINAL PAGE IS OF POOR QUALITY

SAMPLE PROBLEM 7 INPUT DATA (Concluded)

8a	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	HY[illegible]AZINE 6 [illegible]							
20a	[illegible]	[illegible]	[illegible]					
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
41		[illegible]		[illegible]				
44	[illegible]	[illegible]	[illegible]	[illegible]				

OF POOR QUALITY

SAMPLE PROBLEM 7 OUTPUT

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 1

A/A*=50,HYDRAZINE MOTOR CATALYST PARTICULATES

RUN CONTROL PARAMETERS

ICON(1)	ICON(2)	ICON(3)	ICON(4)	ICON(5)	ICON(6)	ICON(7)	ICON(8)
2	0	25	20001	1	0	1	202

ICON(9)	ICON(10)	ICON(11)	ICON(12)	ICON(13)	ICON(14)	ICON(15)	ICON(16)
0	0	0	1	3	0	0	12570

FLOW CALCULATIONS ARE IN ENGLISH UNITS WITH THE R,X COORDINATES IN FEET

THE FLOW FIELD DATA WILL BE WRITTEN ON TAPE

UPPER BOUNDARY POINTS

TYPE	ITRANS	X	R	THETA
2	0	.00000	.83330-02	.00000
2	0	.52300-03	.83920-02	.34907-01
2	0	.10460-02	.83700-02	.69813-01
2	0	.15580-02	.84160-02	.10472+00
2	0	.20000-02	.84790-02	.13963+00
2	0	.26770-02	.85610-02	.17453+00
2	0	.31190-02	.86610-02	.20944+00
2	0	.36290-02	.87790-02	.24435+00
2	0	.41350-02	.89140-02	.27925+00
2	0	.46350-02	.90670-02	.31416+00
2	0	.51300-02	.92380-02	.34907+00
2	0	.56190-02	.94260-02	.38397+00
2	0	.61010-02	.96300-02	.41888+00
2	0	.65760-02	.98510-02	.45379+00
2	0	.70830-02	.10111-01	.49166+00
2	0	.75000-02	.10340-01	.51313+00
2	0	.83330-02	.10876-01	.53756+00
2	0	.10000-01	.11856-01	.56252+00
2	0	.13333-01	.14005-01	.59516+00
2	0	.16667-01	.16352-01	.61139+00
2	0	.20000-01	.18699-01	.61137+00
2	0	.23333-01	.21007-01	.59202+00
2	0	.26667-01	.23151-01	.54879+00
2	0	.30000-01	.25075-01	.49829+00
2	0	.33333-01	.26811-01	.46251+00
2	0	.36667-01	.28411-01	.43459+00
2	0	.40000-01	.29913-01	.41397+00
2	0	.43333-01	.31303-01	.37619+00
2	0	.46667-01	.32713-01	.38775+00
2	0	.50000-01	.34078-01	.36831+00
2	0	.53333-01	.35296-01	.35709+00
2	0	.56667-01	.36516-01	.34488+00
2	0	.60000-01	.37692-01	.33371+00
2	0	.63333-01	.38878-01	.32789+00
2	0	.66667-01	.39920-01	.31741+00

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 2

A/A*=50,HYDRAZINE MOTOR CATALYST PARTICULATES

UPPER BOUNDARY POINTS

TYPE	ITRANS	X	R	THETA			
2	0	.70000-01	.40980-01	.30297+00			
2	0	.73333-01	.42072-01	.29304+00			
2	0	.76667-01	.42950-01	.28399+00			
2	0	.80000-01	.43906-01	.27471+00			
2	0	.83333-01	.44870-01	.26669+00			
2	0	.86667-01	.45787-01	.25883+00			
2	0	.90000-01	.46635-01	.25133+00			
2	0	.93333-01	.47477-01	.24400+00			
2	0	.96667-01	.48296-01	.23689+00			
2	0	.10000+00	.49090-01	.23056+00			
2	0	.10333+00	.49863-01	.22515+00			
2	0	.10667+00	.50615-01	.21921+00			
2	0	.11000+00	.51347-01	.21395+00			
2	0	.11333+00	.52078-01	.20804+00			
2	0	.11667+00	.52752-01	.20281+00			
2	0	.12000+00	.53478-01	.19775+00			
2	0	.12333+00	.54087-01	.12203+00			
2	0	.12667+00	.54730-01	19832+00			
2	1	.13000+00	.55358-01	.18396+00			
2	0	.13333+00	.55971-01	.17994+00			
2	0	.13667+00	.56571-01	.17593+00			
2	0	.14000+00	.57158-01	.17279+00			
2	0	.14333+00	.57733-01	.16965+00			
2	0	.14667+00	.58289-01	.16668+00			
2	1	.19792+00	.58508-01	.16511+00			
3	0	.10000+06	.00000	.00000	.00000	.00000	.10000+04

LOWER BOUNDARY

TYPE	ITRANS	A	B	C	D	E	MAX
2	0	.00000	.00000	.00000	.00000	.00000	.10000+04

THERE ARE 0 PARTICLE SPECIES PRESENT IN THE GAS-PARTICLE MIXTURE

THE FOLLOWING GAS PROPERTIES IN ENGLISH UNITS ARE FOR HYDRAZINE 60 DISS
REAL GAS PROPERTIES

O/F
.96890+07

S	V	P	GAMMA	T	R
.00000					
	.00000	.32393+04	.12379+01	.96196+03	.18000+03
	.18395+04	.31636+04	.11775+01	.89317+03	.10173+03

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 3

A/A9:50,HYDRAZINE MOTOR CATALYST PARTICULATES

REAL GAS PROPERTIES

O/F

S	V	R	GAMMA	T	P
.00000					
	.74872+04	.31636+04	.13230+01	.78650+03	.60000+02
	.79283+04	.31636+04	.13314+01	.69323+03	.36000+02
	.73711+04	.31636+04	.13463+01	.58144+03	.18000+02
	.80244+04	.31636+04	.13697+01	.38016+03	.36000+01
	.82090+04	.31636+04	.13770+01	.31486+03	.18000+01
.17668+05					
	.00000	.35922+04	.11928+01	.72070+03	.10000+01
	.16577+04	.34696+04	.11762+01	.67450+03	.56991+00
	.72561+04	.34696+04	.13599+01	.58594+03	.33333+00
	.76518+04	.34696+04	.13671+01	.51133+03	.20000+00
	.30455+04	.34696+04	.13757+01	.42380+03	.10000+00
	.76190+04	.34696+04	.13903+01	.27127+03	.20000-01

REAL GAS PROPERTIES

O/F

-.51833+07

S	V	P	GAMMA	T	P
.00000					
	.00000	.34965+04	.12379+01	.10761+04	.18000+03
	.70308+04	.34269+04	.12209+01	.98566+03	.10044+03
	.27296+04	.34269+04	.13311+01	.86735+03	.60000+02
	.32053+04	.34269+04	.13469+01	.76277+03	.36000+02
	.36870+04	.34269+04	.13529+01	.63804+03	.18000+02
	.43958+04	.34269+04	.13751+01	.41503+03	.36000+01
	.45955+04	.34269+04	.13822+01	.34307+03	.18000+01
	.47541+04	.34269+04	.13881+01	.28292+03	.90000+00
.18927+05					
	.00000	.37299+04	.13216+01	.89933+03	.10000+01
	.19324+04	.37040+04	.12789+01	.78828+03	.55054+00
	.25454+04	.37040+04	.13615+01	.69065+03	.33333+00
	.29870+04	.37040+04	.13665+01	.60246+03	.20000+00
	.34268+04	.37040+04	.13769+01	.49906+03	.10000+00
	.40676+04	.37040+04	.13921+01	.31907+03	.20000-01

REAL GAS PROPERTIES

O/F

-.29305+07

S	V	P	GAMMA	T	P
.00000					
	.00000	.35984+04	.12611+01	.11519+04	.18000+03
	.71382+04	.35380+04	.12462+01	.10420+04	.10030+03
	.24513+04	.35380+04	.13337+01	.91761+03	.60000+02
	.33529+04	.35390+04	.13422+01	.80640+03	.36000+02

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 4

A/A9:50,HYDRAZINE MOTOR CATALYST PARTICULATES

REAL GAS PROPERTIES

O/F

S	V	R	GAMMA	T	P
.00000					
	.38558+04	.35380+04	.13549+01	.67397+03	.18000+02
	.45943+04	.35380+04	.13766+01	.43774+03	.36000+01
	.48023+04	.35380+04	.13832+01	.36165+03	.18000+01
	.49674+04	.35380+04	.13896+01	.29808+03	.90000+00
.19226+05					
	.00000	.37414+04	.13339+01	.10444+04	.10000+01
	.21119+04	.37360+04	.13320+01	.89625+03	.58019+00
	.27383+04	.37360+04	.13555+01	.79089+03	.33333+00
	.32127+04	.37360+04	.13631+01	.69069+03	.20000+00
	.36859+04	.37360+04	.13722+01	.57322+03	.10000+00
	.43171+04	.37360+04	.13888+01	.36770+03	.20000-01
	.45705+04	.37360+04	.13943+01	.30254+03	.10000-01

REAL GAS PROPERTIES

O/F

.15152+07

S	V	R	GAMMA	T	P
.00000					
	.00000	.37081+04	.12993+01	.13658+04	.18000+03
	.23858+04	.36830+04	.12893+01	.11988+04	.98630+02
	.31382+04	.36830+04	.13122+01	.10605+04	.60000+02
	.36835+04	.36830+04	.13417+01	.93235+03	.36000+02
	.42343+04	.36830+04	.13535+01	.77968+03	.18000+02
	.50450+04	.36830+04	.13755+01	.50697+03	.36000+01
	.52734+04	.36830+04	.13830+01	.41898+03	.18000+01
	.54548+04	.36830+04	.13892+01	.34541+03	.90000+00
.19816+05					
	.00000	.37437+04	.13177+01	.13393+04	.10000+01
	.23987+04	.37435+04	.13296+01	.11522+04	.58023+00
	.31078+04	.37435+04	.13352+01	.10208+04	.33333+00
	.36895+04	.37435+04	.13481+01	.89576+03	.20000+00
	.41919+04	.37435+04	.13591+01	.74736+03	.10000+00
	.49882+04	.37435+04	.13795+01	.48394+03	.20000-01
	.52127+04	.37435+04	.13864+01	.39943+03	.10000-01
	.53909+04	.37435+04	.13922+01	.32890+03	.50000-02

REAL GAS PROPERTIES

O/F

.60808+07

S	V	P	GAMMA	T	P
.00000					
	.00000	.37347+04	.12980+01	.13299+04	.18000+03
	.26276+04	.37293+04	.13072+01	.14174+04	.98007+02

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 6

A/A*=50.HYDRAZINE MOTOR CATALYST PARTICULATES

REAL GAS PROPERTIES

O/F

S	V	P	GAMMA	T	P
.00000					
	.70200+04	.37421+04	.12868+01	.18941+04	.98623+02
	.39731+04	.37421+04	.12970+01	.16929+04	.60000+02
	.46787+04	.37421+04	.13076+01	.15036+04	.36000+02
	.53927+04	.37421+04	.13219+01	.12737+04	.18000+02
	.64591+04	.37421+04	.13515+01	.84880+03	.36000+01
	.67636+04	.37421+04	.13621+01	.70734+03	.18000+01
	.70068+04	.37421+04	.13713+01	.58728+03	.90000+00
	.72567+04	.37421+04	.13817+01	.45705+03	.36000+00
	.74038+04	.37421+04	.13882+01	.37695+03	.18000+00
.19454+05					
	.00000	.37440+04	.12754+01	.21600+04	.10000+01
	.39231+04	.37440+04	.12871+01	.18928+04	.56784+00
	.39728+04	.37440+04	.12972+01	.16916+04	.33333+00
	.46783+04	.37440+04	.13078+01	.15024+04	.20000+00
	.53921+04	.37440+04	.13221+01	.12725+04	.10000+00
	.64581+04	.37440+04	.13517+01	.84788+03	.20000-01
	.67625+04	.37440+04	.13622+01	.70651+03	.10000-01
	.70056+04	.37440+04	.13714+01	.58658+03	.50000-02
	.72553+04	.37440+04	.13818+01	.45648+03	.20000-02
	.74023+04	.37440+04	.13883+01	.37647+03	.10000-02

STARTING LINE INFO

R	X	M	THETA	S	MACH ANGLE	SHOCK ANGLE	O/F
.00000	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.34721-03	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.69442-03	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.10416-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.13888-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.17360-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.20833-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.24305-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.27777-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.31249-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.34721-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.38193-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.41665-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.45137-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.48609-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.52081-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.55553-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.59025-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.62497-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.65970-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.69442-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.72914-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 7

A/A*=50.HYDRAZINE MOTOR CATALYST PARTICULATES

STARTING LINE INFO

R	X	M	THETA	S	MACH ANGLE	SHOCK ANGLE	O/F
.76386-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.79858-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08
.83330-02	.00000	.10200+01	.00000	.00000	.78637+02	.00000	.15092+08

RUN CUTOFF INFORMATION

UPPER BOUNDARY						LOWER BOUNDARY					
R=	.30000+00	X=	-.10000+00	THETA=	.00000	R=	.00000	X=	.30000+00	THETA=	.90000+02

THE MESH CONSTRUCTION WILL BE CONTROLLED BY THE FOLLOWING VARIABLES

DL INTERIOR= .300-02 DX AXIS= .800-03 DL LIM= .100+03 DP DELETE= .500-02 DEG P.M.= .500+01 F= .900+00

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 1 PAGE 8

A/A*=50, HYDRAZINE MOTOR CATALYST PARTICULATES

LINE	POINT	DSCRIP - REGIME	Q / MACH ANGLE	X / PRESSURE	Y / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
1	1	INPUT - CONTIN	.00000	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	2	INPUT - CONTIN	.34721-03	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	3	INPUT - CONTIN	.69442-03	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	4	INPUT - CONTIN	.10416-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	5	INPUT - CONTIN	.13889-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	6	INPUT - CONTIN	.17360-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	7	INPUT - CONTIN	.20833-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	8	INPUT - CONTIN	.24305-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	9	INPUT - CONTIN	.27777-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	10	INPUT - CONTIN	.31249-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	11	INPUT - CONTIN	.34721-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	12	INPUT - CONTIN	.38193-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	13	INPUT - CONTIN	.41665-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	14	INPUT - CONTIN	.45137-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	15	INPUT - CONTIN	.48609-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 1 PAGE 9

A/A*=50, HYDRAZINE MOTOR CATALYST PARTICULATES

LINE	POINT	DSCRIP - REGIME	Q / MACH ANGLE	X / PRESSURE	Y / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
1	16	INPUT - CONTIN	.52081-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	17	INPUT - CONTIN	.55553-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	18	INPUT - CONTIN	.59025-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	19	INPUT - CONTIN	.62497-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	20	INPUT - CONTIN	.65970-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	21	INPUT - CONTIN	.69442-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	22	INPUT - CONTIN	.72914-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	23	INPUT - CONTIN	.76386-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	24	INPUT - CONTIN	.79858-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
1	25	INPUT - CONTIN	.83330-02	.00000	.10200+01	.00000	.00000	.30731+04	.15092+08	0
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		

THE MASS FLOW RATE IS = .29589-01

MOMENTUM INTEGRAL RESULTS

FORCEX	FORCEY	TORQZ	ISP
-.70835+01	.00000	.00000	.16683+03

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 10

A/A*=50,HYDRAZINE MOTOR CATALYST PARTICULATES

LINE	POINT	DSCRIP - REGIME	R / MACH ANGLE	X / PRESSURE	M / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
2	1	WALL - CONTIN	.00000	.62799-04	.10200+01	.00000	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	2	INTER - CONTIN	.34721-03	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	3	INTER - CONTIN	.69442-03	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	4	INTER - CONTIN	.10416-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	5	INTER - CONTIN	.13888-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	6	INTER - CONTIN	.17360-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	7	INTER - CONTIN	.20833-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	8	INTER - CONTIN	.24305-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	9	INTER - CONTIN	.27777-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	10	INTER - CONTIN	.31249-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	11	INTER - CONTIN	.34721-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	12	INTER - CONTIN	.38193-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	13	INTER - CONTIN	.41665-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	14	INTER - CONTIN	.45137-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	15	INTER - CONTIN	.48609-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 11

A/A*=50,HYDRAZINE MOTOR CATALYST PARTICULATES

LINE	POINT	DSCRIP - REGIME	R / MACH ANGLE	X / PRESSURE	M / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
2	16	INTER - CONTIN	.52081-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	17	INTER - CONTIN	.55553-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	18	INTER - CONTIN	.59025-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	19	INTER - CONTIN	.62497-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	20	INTER - CONTIN	.65970-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.126[illegible]		
2	21	INTER - CONTIN	.69442-02	.62799-04	.10200+01	-.11434-06	.00000	.3[illegible]	.15092[illegible]	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.1[illegible]01		
2	22	INTER - CONTIN	.72914-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	23	INTER - CONTIN	.76386-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	24	INTER - CONTIN	.79858-02	.62799-04	.10200+01	-.11434-06	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
2	25	WALL - CONTIN	.83381-02	.62080-04	.10063+01	.23380+00	.00000	.31267+04	.15092+08	5
			.73996+02	.94142+02	.19328-02	.18743+04	.37421+04	.12879+01		

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.70843+01	.00000	.00000	.76774-03	.00000	.16685+03

PERCENT CHANGE IN MASS, MOMENTUM AND ENERGY NUMERICAL INTEGRATION FOR LINE 2 RELATIVE TO THE START LINE
THE PERCENT CHANGE IN MASS FLOW IS = .222681-01
PERCENT CHANGE IN MOMENTUM IS = .34275-01 ISP = -.96527-02
PERCENT CHANGE IN ENERGY IS = .00000

LINE	POINT	DSCRIP - REGIME	R / MACH ANGLE	X / PRESSURE	M / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
3	1	WALL - CONTIN	.00000	.12560-03	.10200+01	.00000	.00000	.30731+04	.15092+08	1
			.78637+02	.96392+02	.19685-02	.18843+04	.37421+04	.12873+01		
3	25	WALL - CONTIN	.83351-02	.12370-03	.10558+01	.47112+00	.00000	.31674+04	.15092+08	5
			.71283+02	.92438+02	.19057-02	.18666+04	.37421+04	.12884+01		

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.12850+01	.00000	.00000	-.73987-03	.00000	.16687+03

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 40

A.40:50.HYDRAZINE MOTOR CATALYST PARTICULATES

LINE	POINT	DESCRIP - REGIME	M / MACH ANGLE	P / PRESSURE	R / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	LTG
[illegible]	1	WALL - CONTIN	.00000	.15422+00	.70997+01	.00000	.00000	.76736+00	.15692+00	2
			.80801+01	.20513-01	.90685-05	.22995+03	.37921+00	.13002+01		
278	36	WALL - CONTIN	.58507-01	.14791+00	.46529+01	.99606+01	.00000	.72358+00	.15092+00	2
			.12917+02	.39296+00	.32301-04	.46819+03	.37921+00	.13000+01		

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.99097+01	.00000	.00000	-.20861-02	.00000	.23039+03

LINE	POINT	DESCRIP - REGIME	M / MACH ANGLE	P / PRESSURE	R / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	LTG
[illegible]	1	WALL - CONTIN	.00000	.15502+00	.71149+01	.00000	.00000	.76753+00	.15092+00	2
			.80797+01	.27995-01	.90389-05	.22982+03	.37921+00	.13002+01		
279	36	WALL - CONTIN	.58509-01	.14792+00	.46525+01	.99608+01	.00000	.72358+00	.15092+00	2
			.12917+02	.39298+00	.32250-04	.46812+03	.37921+00	.13000+01		

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.99097+01	.00000	.00000	-.27790-04	.00000	.23039+03

PERCENT CHANGE IN MASS, MOMENTUM AND ENERGY NUMERICAL INTEGRATION FOR LINE279 RELATIVE TO THE START LINE

THE PERCENT CHANGE IN MASS FLOW IS : .8801780+01

PERCENT CHANGE IN MOMENTUM IS : -.15479+03 ISP : -.55495+00

PERCENT CHANGE IN ENERGY IS : .00000

EXIT FLOW NORMAL START LINE

.0000000	.1542320+00	.7099807+01	.0000000	.0000000	.1509210+00
.2179195-02	.1542163+00	.7099367+01	.8213820+00	.2090093-04	.1509210+00
.4358032-02	.1541695+00	.7097301+01	.1642300+01	.0000000	.1509210+00
.6539601-02	.1540917+00	.7095627+01	.2463277+01	.2090083-04	.1509210+00
.8718353-02	.1539829+00	.7093010+01	.3201279+01	.0000000	.1509210+00
.1089677-01	.1538419+00	.7089371+01	.4094367+01	-.4673004-02	.1509210+00
.1306008-01	.1536711+00	.7084264+01	.4906967+01	.0000000	.1509210+00
.1522031-01	.1534710+00	.7077249+01	.5657007+01	.2090083-04	.1509210+00
.1737187-01	.1532415+00	.7067276+01	.6470827+01	.0000000	.1509210+00
.1950070-01	.1529846+00	.7052676+01	.7232687+01	-.9075165-02	.1509210+00
.2162040-01	.1527027+00	.7033194+01	.7943967+01	.0000000	.1509210+00
.2371760-01	.1523969+00	.6993920+01	.8576447+01	-.2601801-01	.1509210+00
.2576676-01	.1520809+00	.6932600+01	.9067550+01	.0000000	.1509210+00
.2773992-01	.1517619+00	.6827613+01	.9301030+01	-.1052112+00	.1509210+00
.2960590-01	.1514592+00	.6655309+01	.9125031+01	.0000000	.1509210+00
.3120060-01	.1511993+00	.6011590+01	.8952007+01	-.5009403+00	.1509210+00
.3277267-01	.1509916+00	.6135907+01	.7959000+01	.0000000	.1509210+00
.3403160-01	.1508370+00	.5900669+01	.6537010+01	-.4420921+01	.1509210+00
.3517905-01	.1507127+00	.5717694+01	.5801737+01	.0000000	.1509210+00
.3727761-01	.1505071+00	.5463385+01	.5296517+01	.0000000	.1509210+00
.3911972-01	.1503370+00	.5319686+01	.5290319+01	.0000000	.1509210+00
.4089106-01	.1501765+00	.5229650+01	.5435506+01	.0000000	.1509210+00
.4249905-01	.1500152+00	.5148972+01	.5710719+01	.0000000	.1509210+00
.4409803-01	.1498505+00	.5002536+01	.6010133+01	.0000000	.1509210+00
.4566153-01	.1496819+00	.5023072+01	.6331029+01	.0000000	.1509210+00
.4718041-01	.1495076+00	.4969134+01	.6657070+01	.0000000	.1509210+00
.4868255-01	.1493208+00	.4918950+01	.6988003+01	.0000000	.1509210+00
.5019650-01	.1491950+00	.4872203+01	.7322730+01	.0000000	.1509210+00
.5156203-01	.1489562+00	.4828529+01	.7650197+01	.0000000	.1509210+00
.5299350-01	.1487623+00	.4787657+01	.7996444+01	.0000000	.1509210+00
.5438040-01	.1485632+00	.4749784+01	.8381581+01	.0000000	.1509210+00
.5579602-01	.1483586+00	.4715360+01	.8700584+01	.0000000	.1509210+00
.5769372-01	.1481970+00	.4684659+01	.9076457+01	.0000000	.1509210+00
.5850800-01	.1479170+00	.4652461+01	.9460000+01	.0000000	.1509210+00

PRESSURE INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	DELFX	DELFY	ISP
-.99097+01	.00000	.00000	-.27790-04	.00000	.23039+03

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 6 PAGE 89

[illegible] CATALYST PARTICULATES

LINE	POINT	DESCRIP - REGIME	R MACH ANGLE	X PRESSURE	Y DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	P/[illegible] SHOCK ANGLE	ITR
[illegible]	1	WALL - CONTIN	.00000 .80807+01	.15422+00 .20813-01	.70907+01 .48605-05	.00000 .22925+03	.00000 .37921+00	.76736+00 .13002+01	.15092+00	1
[illegible]	2	INTER - CONTIN	[illegible] .80900+01	[illegible] .20875-01	[illegible] .40620-05	[illegible] .22907+03	[illegible] .37921+00	[illegible] .13002+01	.15092+00	1
[illegible]	3	INTER - CONTIN	.43679-02 [illegible]	.15416+00 .20850-01	.70912+01 [illegible]	.16424+01 .22903+03	.00000 .37921+00	.76735+00 .13002+01	.15092+00	1
[illegible]	4	INTER - CONTIN	[illegible] .81827+01	[illegible] .20896-01	[illegible] .40777-05	[illegible] .22913+03	[illegible] .37921+00	[illegible] .1300 01	.15092+00	1
[illegible]	5	INTER - CONTIN	.87177-02 .81052+01	.15397+00 .20880-01	.70929+01 .48791-05	.32013+01 .22920+03	.00000 .37921+00	.76731+00 .13002+01	.15092+00	1
[illegible]	6	INTER - CONTIN	[illegible] .81897+01	[illegible] .20841-01	[illegible] .40918-05	[illegible] .22949+03	[illegible] .37921+00	[illegible] .13002+01	[illegible]	1
[illegible]	7	INTER - CONTIN	.13057-01 [illegible]	.15360+00 [illegible]	.70041+01 [illegible]	.49818+01 [illegible]	.00000 .37921+00	.76722+00 [illegible]	.15092+00	1
[illegible]	8	INTER - CONTIN	[illegible] .81231+01	[illegible] .20979-01	[illegible] .49301-05	[illegible] .22919+03	[illegible] .37921+00	[illegible] .13002+01	[illegible]	1
[illegible]	9	INTER - CONTIN	.17371-01 [illegible]	.15323+00 [illegible]	.77671+01 [illegible]	.64791+01 [illegible]	.00000 .37921+00	.76705+00 [illegible]	.15092+00	1
[illegible]	10	INTER - CONTIN	[illegible] .81516+01	[illegible] .20401-01	[illegible] .50169-05	[illegible] .22762+03	[illegible] .37921+00	[illegible] .13002+01	[illegible]	1
[illegible]	11	INTER - CONTIN	.21627-01 [illegible]	.15269+00 [illegible]	.70190+01 [illegible]	.79441+01 [illegible]	.00000 .37921+00	.76687+00 [illegible]	.15092+00	1
[illegible]	12	INTER - CONTIN	[illegible] .87297+01	[illegible] .31299-01	[illegible] .57161-05	[illegible] .23109+03	[illegible] .37921+00	[illegible] .13002+01	[illegible]	1
[illegible]	13	INTER - CONTIN	.29764-01 [illegible]	.15277+00 [illegible]	.69325+01 [illegible]	.90670+01 [illegible]	.00000 .37921+00	.76560+00 .13002+01	.15092+00	1
[illegible]	14	INTER - CONTIN	[illegible] .89221+01	[illegible] .36947-01	[illegible] .58273-05	[illegible] .26175+03	[illegible] .37921+00	[illegible] .13002+01	[illegible]	1
[illegible]	15	INTER - CONTIN	[illegible] [illegible]	[illegible] [illegible]	[illegible] [illegible]	.91261+01 .25270+03	.00000 .37921+00	.76291+00 .13002+01	.15092+00	1

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 6 PAGE 90

[illegible] CATALYST PARTICULATES

LINE	POINT	DESCRIP - REGIME	R MACH ANGLE	X PRESSURE	Y DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	P/[illegible] SHOCK ANGLE	ITR
[illegible]	16	INTER - CONTIN	.31200-01 .80720+01	.15119+00 [illegible]	.66117+01 .17050-05	.00063+01 .27001+03	-.50000+00 .37921+00	.75005+00 .13002+01	.15092+00	1
[illegible]	17	INTER - CONTIN	[illegible] .93793+01	[illegible] .72132-01	[illegible] .95302-05	[illegible] .39100+03	.00000 .37921+00	.75502+00 .13002+01	.15092+00	1
[illegible]	18	INTER - CONTIN	.14631-01 [illegible]	.15093+00 .92253-01	.59078+01 [illegible]	.65390+01 [illegible]	-.46280+01 .37921+00	.75193+00 .13002+01	.15092+00	1
[illegible]	19	INTER - CONTIN	[illegible] .10060+02	[illegible] [illegible]	.57197+01 .13239-04	.98831+01 [illegible]	.00000 .37921+00	.74883+00 .13002+01	.15092+00	1
[illegible]	20	INTER - CONTIN	.37277-01 [illegible]	.15050+00 [illegible]	.54630+01 .15970-04	.37075+01 [illegible]	.00000 .37921+00	.74398+00 .13002+01	.15092+00	1
[illegible]	21	INTER - CONTIN	[illegible] .10035+02	[illegible] .17970+00	[illegible] .17946-04	[illegible] [illegible]	.00000 .37921+00	[illegible] .13002+01	.15092+00	1
[illegible]	22	INTER - CONTIN	.40800-01 .11035+02	.15017+00 .19457+00	.52246+01 .19427-04	.54362+01 .30519+03	.00000 .37921+00	.73880+00 .13075+01	.15092+00	1
[illegible]	23	INTER - CONTIN	[illegible] .11199+02	.15001+00 .21293+00	.51989+01 .20770-04	[illegible] .39492+03	.00000 .37921+00	.73711+00 .13067+01	.15092+00	1
[illegible]	24	INTER - CONTIN	.44098-01 .11344+02	.14994+00 .23079+00	.50270+01 .21976-04	.60161+01 .40370+03	.00000 .37921+00	.73558+00 .13060+01	.15092+00	1
[illegible]	25	INTER - CONTIN	.45661-01 .11407+02	[illegible] .24708+00	.50229+01 .23170-04	.61320+01 .41103+03	.00000 .37921+00	.73381+00 .13054+01	.15092+00	1
[illegible]	26	INTER - CONTIN	.47187-01 .11610+02	.14990+00 .26440+00	.49691+01 .24255-04	.64540+01 .41907+03	.00000 .37921+00	.73261+00 .13047+01	.15092+00	1
[illegible]	27	INTER - CONTIN	[illegible] .11790+02	.14932+00 .28116+00	[illegible] .25376-04	[illegible] .42670+03	.00000 .37921+00	.73128+00 .13042+01	.15092+00	1
[illegible]	28	INTER - CONTIN	.50145-01 .11099+02	.14910+00 .29794+00	.48722+01 .26435-04	.71271+01 .43359+03	.00000 .37921+00	.73001+00 .13036+01	.15092+00	1
[illegible]	29	INTER - CONTIN	[illegible] .11953+02	[illegible] .31445+00	[illegible] .27480-04	[illegible] .44016+03	.00000 .37921+00	.72879+00 [illegible]	.15092+00	1
[illegible]	30	INTER - CONTIN	.53007-01 .12054+02	.14876+00 .33091+00	.47476+01 .28520-04	.74960+01 .44687+03	.00000 .37921+00	.72761+00 .13025+01	.15092+00	1

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 6 PAGE 91

[illegible] HYDRAZINE MOTOR CATALYST PARTICULATES

LINE POINT	DESCRIP - REGIME	R / MACH ANGLE	X / PRESSURE	Y / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	G/I / SHOCK ANGLE	ITR
[illegible] 31	INTER - CONTIN	[illegible]	.10876+00	[illegible]	.07471+01	.00003	.72653+00	.15092+00	3
		.12159+02	.19122+00	.27516-09	.95291+03	.37921+09	.13820+01		
[illegible] 32	INTER - CONTIN	.55705-01	.10835+00	[illegible]	.87010+01	.00000	.72551+00	.15092+00	3
		.12244+02	.36244+00	.30619-09	.95798+03	.37921+09	.13816+01		
[illegible] 33	INTER - CONTIN	.57C0?-01	.10816+00	[illegible]	.09771+01	.00003	.72457+00	.15092+00	3
		.12326+02	.37679+00	.31192-09	.96285+03	.37921+09	.13812+01		
[illegible] 34	WALL - CONTIN	.58509-01	.10792+00	.94525-01	.99670+01	.00000	.72358+00	.15092+00	3
		.12417+02	.39290+00	.32250-09	.96812+03	.37921+09	.13808+01		
[illegible] 35	FAN-ME - CONTIN	.50509-01	.10792+00	.50712-01	.13808+02	.00000	.73539+00	.15092+00	3
		.11161+02	.23222+00	.22229-09	.90960+03	.37921+09	.13808+01		
[illegible] 36	FAN-ME - CONTIN	.58509-01	.10792+00	.55722-01	.18227+02	.00000	.76621+00	.15092+00	3
		.12329+02	.17050+00	.10593-09	.30960+03	.37921+09	.13802+01		
37	FAN-ME - CONTIN	.59500-01	.10792+00	.61767-01	.22675+02	.00000	.75617+00	.15092+00	3
		.93201-01	.62330-01	.92929-05	.20869+03	.37921+09	.13802+01		
[illegible] 38	FAN-ME - CONTIN	.59509-01	.10752+00	.68924-01	.27013+02	.00000	.76522+00	.15092+00	3
		.87619+01	.39372-01	.57770-05	.23775+03	.37921+09	.13802+01		
[illegible] 39	FAN-ME - CONTIN	[illegible]	.10792+00	.77767-01	.31401+02	.00000	.77335+00	.15092+00	3
		.73899-01	.15671-01	.31661-05	.17896+03	.37921+09	.13082+01		
[illegible] 40	FAN-ME - CONTIN	.59500-01	.10752+00	.88421-01	.35750+02	.00000	.78058+00	.15092+00	3
		.44609+01	.49360-02	.14670-05	.19051+03	.37921+09	.13802+01		
[illegible] 41	FAN-ME - CONTIN	.59500-01	.10792+00	.10370+02	.42170+02	.00000	.78609+00	.15092+00	3
		.55500-01	.21118-02	.79769-06	.11153+03	.37921+09	.13802+01		
[illegible] 42	FAN-ME - CONTIN	.59520-01	.10792+00	.12316+02	.49566+02	.00000	.79229+00	.15092+00	3
		.44577+01	.65413-03	.37370-06	.79646+02	.37921+09	.13802+01		

[illegible] ERRORS HAVE PROPAGATED TO LOWER BOUNDARY, OR PROBLEM LIMITS HAVE BEEN REACHED. CASE TERMINATED.
??????????? CCCCCCCCCCC

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

```
        [illegible] BOUNDARY LAYER INTEGRAL MATRIX PROCEDURE

              [illegible] JULY 1975

   ACUREX CORP.  AEROTHERM DIV., MT. VIEW, CALIF.

[illegible]  [illegible] HYDRAZINE MOTOR CATALYST PARTICULATES

   CONTROL NUMBERS  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20
                    1  0  2  0  0  4  3  1  2  1  0  2  1  2  0  0  0  0  0  0

 [illegible]       NODAL PT.                        ETA VALUES
 NORM. ETA         AT WHICH
                   ETA NORM.
 [illegible]       10        0.000    2.050-03  6.000-03  1.357-02  2.703-02  4.835-02  7.665-02  8.156-01  7.210-01
                             1.000+00  1.2[illegible]+00  2.500+00

[illegible]                      1.00000+03

TOTAL ENTHALPY, B/LB       6.27000+02

TOTAL PRESSURE, ATM        1.27500+01

INIT. RAD FLUX, B/SF2      0.00000

   CEBECI-SMITH TURB. MODEL

   MIXING LENGTH CONSTANT    :  4.0000-01
   SUBLAYER CONSTANT, VAP    :  1.1000+01
   CLAUSER NUMBER            :  1.6800-02

   TURBULENT PRANDTL NUMBER  :  9.0000-01

   TURBULENT SCHMIDT NUMBER  :  9.0000-01
   TRANSITION MOM.THICK.RE   :  2.5000+02

      CASE   1

      VISCOSITY LAW   [illegible]

      PRANDTL NUMBER  [illegible]

      TEMP. IN DEG. R     VISCOSITY IN LBM/S-FT

                              MIXTURE CURVE FIT CONSTANTS (DEG R)

[illegible]   .31726522+01   .79115794-03   -.19616151-06   .52183882-09   -.39783467-12   -.25573205+09   .12220564+00
[illegible]   .2[illegible]+01   .20991901-07   -.63571360-06   .07546640-10   -.56661915-14   -.20111760+04   .26992811+01


           FLUID MIXTURE

      COMPONENT        MOLE        MASS
                     FRACTION    FRACTION

   H2                .9692+00   .7136-01

   H2O               .1001-01   .1316-01

   N2                .3002+00   .6127+00

   NH3               .9971-01   .6369-01

   [illegible]       .2201+00   .2817+00

  MOLECULAR WEIGHT =  13.[illegible]
```

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

STAGNATION SOLUTION
EDGE CONDITIONS

TEMPERATURE = .2161+04 DEG R
PRESSURE = .1225+02 ATMOSPHERES
GAMMA = .1275+01
ENTHALPY = .8029+03 BTU/LBM
ENTROPY = .3402+01 BTU/LBM-DEG R
CP-FROZEN = .6731+00 BTU/LBM-DEG R
DENSITY = .1631+00 LBM/FT3
VISCOSITY = .2525-04 LBM/S-FT

EDGE CONDITIONS

	WALL LENGTH FEET	TEMP DEG-R	CP FROZEN B/LB-R	STATIC PRESSURE ATM	DENSITY LB/FT3	VISCOSITY LB/FS	VELOCITY F/S	ENTHALPY B/LB	ENTROPY B/LB-R	MACH NO.
1	1.000-02	1.989+03	6.701-01	6.560+00	6.331-02	2.200-05	3.070+03	4.101+02	3.402+00	1.025+00
2	1.770-02	1.930+03	6.633-01	5.950+00	5.903-02	2.215-05	3.966+03	3.630+02	3.402+00	1.176+00
3	3.222-02	1.807+03	6.527-01	4.027+00	4.340-02	2.104-05	3.997+03	2.030+02	3.402+00	1.399+00
4	3.520-02	1.429+03	6.209-01	1.976+00	2.515-02	1.852-05	4.926+03	1.102+02	3.402+00	1.870+00
5	4.200-02	1.090+03	5.971-01	6.519-01	1.080-02	1.497-05	5.809+03	-8.967+01	3.402+00	2.545+00
6	4.440-02	9.771+02	5.822-01	3.447-01	6.762-03	1.300-05	6.204+03	-1.856+02	3.402+00	2.919+00
7	5.2[illegible]1-02	8.181+02	5.720-01	2.127-01	4.720-03	1.166-05	6.530+03	-2.486+02	3.402+00	3.216+00
8	5.707-02	7.672+02	5.679-01	1.665-01	3.907-03	1.101-05	6.640+03	-2.776+02	3.402+00	3.367+00
9	6.355-02	7.661+02	5.670-01	1.656-01	3.932-03	1.100-05	6.642+03	-2.782+02	3.402+00	3.366+00
10	6.897-02	7.630+02	5.676-01	1.630-01	3.887-03	1.096-05	6.649+03	-2.800+02	3.402+00	3.376+00
11	7.415-02	7.461+02	5.661-01	1.498-01	3.652-03	1.074-05	6.685+03	-2.896+02	3.402+00	3.432+00
12	7.937-02	7.255+02	5.643-01	1.367-01	3.379-03	1.047-05	6.720+03	-3.013+02	3.402+00	3.501+00
13	8.450-02	7.021+02	5.623-01	1.191-01	3.086-03	1.016-05	6.777+03	-3.145+02	3.402+00	3.583+00
14	8.959-02	6.815+02	5.605-01	1.065-01	2.847-03	9.889-06	6.820+03	-3.260+02	3.402+00	3.657+00
15	9.466-02	6.630+02	5.589-01	9.413-02	2.637-03	9.641-06	6.850+03	-3.363+02	3.402+00	3.726+00
16	9.975-02	6.460+02	5.574-01	8.723-02	2.456-03	9.410-06	6.892+03	-3.458+02	3.402+00	3.792+00
17	1.047-01	6.308+02	5.561-01	7.981-02	2.301-03	9.231-06	6.923+03	-3.543+02	3.402+00	3.853+00
18	1.097-01	6.165+02	5.549-01	7.332-02	2.163-03	9.029-06	6.952+03	-3.622+02	3.402+00	3.912+00
19	1.147-01	6.039+02	5.539-01	6.781-02	2.047-03	8.831-06	6.977+03	-3.692+02	3.402+00	3.965+00
20	1.197-01	5.916+02	5.528-01	6.203-02	1.935-03	8.659-06	7.001+03	-3.760+02	3.402+00	4.018+00
21	1.246-01	5.799+02	5.518-01	5.897-02	1.834-03	8.495-06	7.024+03	-3.824+02	3.402+00	4.071+00
22	1.295-01	5.690+02	5.509-01	5.452-02	1.743-03	8.342-06	7.046+03	-3.884+02	3.402+00	4.120+00
23	1.344-01	5.590+02	5.501-01	5.107-02	1.662-03	8.199-06	7.065+03	-3.940+02	3.402+00	4.168+00
24	1.392-01	5.490+02	5.492-01	4.779-02	1.583-03	8.057-06	7.085+03	-3.995+02	3.402+00	4.216+00
25	1.442-01	5.389+02	5.484-01	4.464-02	1.507-03	7.917-06	7.104+03	-4.050+02	3.402+00	4.266+00
26	1.490-01	5.300+02	5.476-01	4.199-02	1.441-03	7.794-06	7.121+03	-4.099+02	3.402+00	4.311+00
27	1.539-01	5.213+02	5.469-01	3.954-02	1.380-03	7.659-06	7.138+03	-4.146+02	3.402+00	4.355+00
28	1.587-01	5.132+02	5.462-01	3.737-02	1.327-03	7.543-06	7.154+03	-4.191+02	3.402+00	4.398+00
29	1.636-01	5.052+02	5.455-01	3.526-02	1.269-03	7.424-06	7.169+03	-4.234+02	3.402+00	4.441+00
30	1.684-01	4.976+02	5.449-01	3.337-02	1.220-03	7.314-06	7.183+03	-4.276+02	3.402+00	4.483+00
31	1.732-01	4.902+02	5.443-01	3.158-02	1.172-03	7.209-06	7.197+03	-4.316+02	3.402+00	4.525+00
32	1.781-01	4.827+02	5.437-01	2.987-02	1.127-03	7.099-06	7.211+03	-4.357+02	3.402+00	4.567+00
33	1.829-01	4.751+02	5.430-01	2.820-02	1.075-03	6.987-06	7.226+03	-4.398+02	3.402+00	4.612+00
34	1.877-01	4.682+02	5.425-01	2.670-02	1.039-03	6.880-06	7.239+03	-4.436+02	3.402+00	4.653+00

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

FRIZO LAMINAR SOLUTION AFTER TRANSITION. TURBULENCE WILL BE INCLUDED AND SOLUTION CONTINUED

ITERATED VALUES DAMP MAX.LIN MAX.ERRORS IN CONSERVATION EQS.

ITS	TIME	ALPH	FPPW	DAMP	ERROR		MOMENTUM		ENERGY
1	.000	2.329	1.0798	.1650	1.-01	11	-3.3+00	1	-4.4+01
2	.000	2.230	2.3052	.4958	9.-02	11	-2.9+00	1	-3.6+01
3	.000	2.117	2.3635	1.0000	4.-02	11	-1.5+00	1	-1.0+01
4	.000	2.106	2.3711	1.0000	5.-07	12	-4.7-02	8	-2.8+00
5	.000	2.105	2.3711	1.0000	1.-07	12	1.4-03	10	-2.5-02

ALPHA	RADIUS FEET	PRESSURE ATM	EDGE VEL. F/S	BETAP	BETAU	HEAT FLUXES--B/SF2 DIFFUSIONAL	TOT ENTH	QERAD	QCOND
2.105+00	8.333-03	6.560+00	3.074+03	1.142+01	1.142+01	1.005+02	1.005+02	0.000	1.009+02

WALL SHEAR LBF/F2	MASS FLUXES LB/SF2 MECHANICAL REMOVAL	PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS DIFFUSIVE FLUXES LB/SF2 FOR
7.557-01	0.000	0.000	0.000	0.000	0.000

MOM TRANS COEFF. CF/2	HEAT TRANS COEFF. ST NO.	BLOWING PARAMETERS (MDPH. BY ONECONE+STI FOR PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS TRANSFER COEFFICIENTS. CM, FOR
3.794-03	1.243-03	0.000	0.000	0.000	0.000

MOMENTUM THICKNESS, THETA FEET	DISPLACE. THICKNESS, DELSTAR FEET	EFFECTIVE BODY DISPLACE. FEET	ENTHALPY THICKNESS, LAMBDA FEET	REYNOLDS NUMBER PER FOOT	MASS THICKNESS FOR FEET
2.634-05	-8.599-06	-8.599-06	7.464-05	8.527+06	0.000

TOTAL HEAT TO WALL B/S	THRUST LOSS (LBF)	TOTAL WALL AREA (F2)	ACCELERATION PARAMETER-K	INVISCID MASS IN BL LB/S	TOTAL MASS IN BL. LB/S
0.000	3.199-02	0.000	2.233-05	4.035-03	4.035-03

LOCAL INFORMATION

ETA	DISTANCE FROM WALL FEET	F	U/UE	FPP	SHEAR LBF/F2	G, TOTAL ENTHALPY B/LB	CP B/LB	CPP B/LB	STATIC ENTHALPY B/LB	TEMP DEG-R
0.000	0.000	0.000	0.000	2.371+00	7.557-01	-1.410+02	2.098+02	1.063+03	-1.430+02	1.000+03
2.000-03	2.636-07	4.129-05	1.392-02	2.341+00	6.963-01	-1.412+02	2.961+02	1.010+03	-1.413+02	1.001+03
6.400-03	6.403-07	2.409-04	3.345-02	2.297+00	6.830-01	-1.387+02	3.096+02	9.230+02	-1.389+02	1.007+03
1.557-02	1.471-06	1.243-03	7.494-02	2.237+00	6.530-01	-1.329+02	3.216+02	7.846+02	-1.340+02	1.015+03
3.743-02	2.567-06	3.679-03	1.266-01	2.217+00	6.157-01	-1.249+02	3.406+02	5.795+02	-1.280+02	1.025+03
4.035-02	4.633-06	1.137-02	2.146-01	1.894+00	5.464-01	-1.091+02	3.466+02	9.288+01	-1.179+02	1.043+03
1.965-01	1.452-05	8.091-02	5.250-01	9.702-01	2.840-01	-7.137+01	3.457+02	-1.475+02	-7.966+01	1.107+03
4.159-01	4.470-05	4.870-01	8.230-01	1.531-01	4.749-03	1.633+02	3.722+02	-9.278+01	3.523+01	1.296+03
7.219-01	8.567-05	1.096+00	9.340-01	9.560-02	2.716-02	7.303+02	2.429+02	-1.292+02	1.847+02	1.539+03
1.040+00	1.277-04	1.550+00	9.500-01	6.192-02	1.841-02	4.500+02	1.468+02	-1.772+02	2.884+02	1.694+03
1.263+00	1.607-04	2.001+00	9.715-01	3.527-02	1.030-02	5.109+02	1.129+02	-9.670+01	3.403+02	1.773+03
2.540+00	3.871-04	4.716+00	1.000+00	0.000	0.000	6.029+02	0.000	1.437+01	4.141+02	1.800+03

DISTANCE FROM WALL FEET	DENSITY RHO LB/F3	VISCOSITY MU LB/FS	SPECIFIC HEAT B/LB-R	THERMAL COND. B/SF-R	PRANDTL NUMBER	MODIFIED SCHMIDT NUMBER	MOLECULAR WEIGHT	MACH NUMBER	ONESOHEPS CONSTANT	TURBULENT PRANDTL NO
0.000	1.191-01	1.383-05	5.888-01	1.433-05	5.001-01	5.001-01	1.328+01	0.000	0.000	0.000
2.636-07	1.190-01	1.390-05	5.891-01	1.638-05	5.001-01	5.001-01	1.328+01	1.900-02	0.000	9.000-01
6.403-07	1.185-01	1.395-05	5.855-01	1.499-05	5.001-01	5.001-01	1.328+01	4.576-02	0.000	9.000-01
1.471-06	1.175-01	1.405-05	5.902-01	1.658-05	5.001-01	5.001-01	1.328+01	1.021-01	0.000	9.000-01
2.567-06	1.166-01	1.416-05	5.912-01	1.670-05	5.001-01	5.001-01	1.328+01	1.716-01	0.000	9.000-01
4.633-06	1.144-01	1.436-05	5.927-01	1.702-05	5.001-01	5.001-01	1.328+01	2.880-01	0.000	9.000-01
1.452-05	1.028-01	1.509-05	5.987-01	1.806-05	5.001-01	5.001-01	1.328+01	6.617-01	0.000	9.000-01
4.470-05	9.208-02	1.719-05	6.164-01	2.117-05	5.001-01	5.001-01	1.328+01	1.001+00	0.000	9.000-01
8.567-05	7.728-02	1.956-05	6.382-01	2.492-05	5.001-01	5.001-01	1.328+01	1.015+00	0.000	9.000-01
1.277-04	7.091-02	2.110-05	6.534-01	2.757-05	5.001-01	5.001-01	1.328+01	1.018+00	0.000	9.000-01
1.607-04	6.728-02	2.181-05	6.603-01	2.883-05	5.001-01	5.001-01	1.328+01	1.019+00	0.000	9.000-01
3.871-04	6.331-02	2.299-05	6.701-01	3.061-05	5.001-01	5.001-01	1.328+01	1.020+00	0.000	9.000-01

REFIT CALLED

	ETA(I)	U/UE	G(I,I)	SP(I,I,1)	SP(I,I,2)	SP(I,I,3)	SP(I,I,4)	SP(I,I,5)	SP(I,I,6)	SP(I,I,7)	SP(I,I,8)
1	0.000	0.000	-1.410+02	1.000+00							
2	1.024-02	4.996-02	-1.365+02	0.000							
3	2.558-02	1.202-01	-1.262+02	0.000							
4	5.765-02	2.498-01	-1.019+02	0.000							
5	9.570-02	3.505-01	-2.918+01	0.000							
6	1.220-01	4.409-01	-5.119+01	0.000							
7	1.865-01	5.018-01	8.813+00	0.000							
8	3.050-01	7.469-01	8.942+01	0.000							
9	5.012-01	8.551-01	2.169+02	0.000							
10	1.040+00	9.500-01	4.308+02	5.131-02							
11	1.318+00	9.810-01	5.815+02	2.479-02							
12	2.540+00	1.000+00	6.029+02	1.003+01							

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

STATION 39 - - - - - - - - - - AXIAL POSITION .19779+00 FEET

ITERATED VALUES DAMP MAX.LIM MAX.ERRORS IN CONSERVATION EQS.

ITN	TIME	ALPH	FPPW		ERROR	MOMENTUM		ENERGY
1	.000	4.255	1.9226	.999	2.-07	11 -8.2-01	8	-1.4+02
	.000	4.251	1.92491.0000		5.-07	11 -4.1-01	8	-8.8+01
3	.000	4.251	1.92491.0000		2.-07	11 4.5-09	9	1.6-31

ALPHA	RADIUS	PRESSURE	EDGE VEL.	RETPP	RETAY	HEAT FLUXES--B/SF2			
	FEET	ATM	F/S			DIFFUSIONAL	TOT ENTH	RERAD	QCOND
4.251+00	5.053-02	2.674-02	7.239+03	1.491-01	1.491-01	7.069+00	7.069+00	0.000	7.069+00

WALL	MASS FLUXES LB/SF2				ELEMENTAL MASS DIFFUSIVE FLUXES LB/SF2 FOR
SHEAR	MECHANICAL	PYROL	CHAR	TOTAL GAS	
LBF/F2	REMOVAL	GAS			
3.187+00	0.000	0.000	0.000	0.000	0.000

MOM TRANS	HEAT TRANS	BLOWING PARAMETERS			ELEMENTAL MASS TRANSFER COEFFICIENTS,
COEFF.	COEFF.	(NORM. BY RHOE*UE*ST) FOR			CM. FOR
CF/2	ST NO.	PYROL GAS	CHAR	TOTAL GAS	
1.484-03	1.401-01	0.000	0.000	0.000	0.000

MOMENTUM	DISPLACE.	EFFECTIVE	ENTHALPY	REYNOLDS	MASS THICKNESS FOR
THICKNESS,	THICKNESS,	BODY	THICKNESS,	NUMBER	
THETA	DELSTAR	DISPLACE.	LAMBDA	PER FOOT	
FEET	FEET	FEET	FEET		FEET
4.132-04	2.278-03	2.278-03	6.293-04	1.093+06	0.000

TOTAL HEAT	THRUST	TOTAL	ACCELERATION	INVISCID	TOTAL
TO WALL	LOSS	WALL AREA	PARAMETER-K	MASS IN BL	MASS IN BL
B/S	(LBF)	(F2)		LB/S	LB/S
7.263-01	2.061-01	3.797-02	3.221-07	1.738-02	1.738-02

LOCAL INFORMATION

ETA	DISTANCE FROM WALL	F	U/UE	FPP	SHEAR	G, TOTAL ENTHALPY	GP	GPP	STATIC ENTHALPY	TEMP
	FEET				LBF/F2	B/LB	B/LB	B/LB	B/LB	DEG-R
0.000	0.000	0.000	0.000	1.925+00	3.187+00	-1.410+02	3.958+02	2.163+03	-1.433+02	1.000+03
4.792-03	4.971-05	8.834-04	5.007-02	1.916+00	3.158+00	-1.277+02	4.713+02	2.059+03	-1.303+02	1.021+03
2.262-02	1.716-04	5.131-03	1.202-01	1.399+00	3.115+00	-1.016+02	5.740+02	1.667+03	-1.164+02	1.044+03
4.265-02	2.639-04	2.305-02	2.510-01	1.319+00	3.029+00	-3.878+01	7.325+02	5.200+02	-1.047+02	1.065+03
6.168-02	3.835-04	4.751-02	3.516-01	1.168+00	2.958+00	2.216+01	7.765+02	-8.508+02	-1.072+02	1.060+03
9.438-02	5.248-04	8.698-02	4.522-01	9.168-01	2.876+00	9.293+01	6.929+02	-1.417+03	-1.210+02	1.037+03
1.359-01	8.294-04	2.038-01	6.024-01	9.550-01	2.721+00	2.146+02	7.821+02	-5.170+02	-1.691+02	9.555+02
2.571-01	1.458-03	5.601-01	7.533-01	1.704-01	2.788+00	3.389+02	1.157+02	-4.831+01	-2.544+02	8.071+02
4.790-01	2.431-03	1.320+00	9.978-01	6.998-02	1.822+00	4.265+02	7.013+01	-1.901+01	-3.257+02	6.820+02
1.000+00	4.267-03	3.370+00	9.500-01	2.229-02	9.235-01	5.352+02	2.003+01	-5.984+00	-4.092+02	5.312+02
1.781+00	5.920-03	4.894+00	9.769-01	1.362-02	4.855-01	5.728+02	1.034+01	-7.430+00	-4.300+02	4.931+02
2.760+00	8.565-03	9.626+00	1.000+00	0.000	0.000	6.029+02	0.000	-2.817-01	-4.436+02	4.662+02

DISTANCE FROM WALL	DENSITY RHO	VISCOSITY MU	SPECIFIC HEAT	THERMAL COND.	PRANDTL NUMBER	MODIFIED SCHMIDT NUMBER	MOLECULAR WEIGHT	MACH NUMBER	RHOSQ*EPS /RHOE*RHUE	TURBULENT PRANDTL NO
FEET	LB/F3	LB/FS	B/LB-R	B/SF-R						
0.000	4.064-04	1.387-05	5.888-01	1.637-05	5.001-01	5.001-01	1.328+01	0.000	0.000	0.000
4.971-05	4.762-04	1.412-05	5.908-01	1.664-05	5.001-01	5.001-01	1.328+01	1.807-01	4.757-05	9.000-01
1.716-04	4.653-04	1.438-05	5.929-01	1.705-05	5.001-01	5.001-01	1.328+01	3.806-01	2.017-03	9.000-01
2.639-04	4.568-04	1.461-05	5.948-01	1.738-05	5.001-01	5.001-01	1.328+01	7.074-01	3.485-02	9.000-01
3.835-04	4.587-04	1.457-05	5.944-01	1.731-05	5.001-01	5.001-01	1.328+01	1.105+00	1.331-01	9.000-01
5.248-04	4.690-04	1.430-05	5.922-01	1.697-05	5.001-01	5.001-01	1.328+01	1.436+00	3.057-01	9.000-01
8.294-04	5.093-04	1.335-05	5.848-01	1.560-05	5.001-01	5.001-01	1.328+01	1.989+00	1.573+00	9.000-01
1.458-03	6.026-04	1.157-05	5.715-01	1.317-05	5.001-01	5.001-01	1.328+01	2.495+00	6.747+00	9.000-01
2.431-03	7.132-04	8.884-06	5.605-01	1.109-05	5.001-01	5.001-01	1.328+01	3.288+00	1.000+01	9.000-01
4.267-03	9.156-04	7.802-06	5.477-01	8.599-06	5.001-01	5.001-01	1.328+01	4.157+00	1.649+01	9.000-01
5.920-03	9.869-04	7.297-06	5.885-01	7.891-06	5.001-01	5.001-01	1.328+01	4.491+00	1.927+01	9.000-01
8.565-03	1.039-03	6.880-06	5.425-01	7.462-06	5.001-01	5.001-01	1.328+01	4.653+00	0.000	9.000-01

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

STATION 39 - - - - - - - - - - AXIAL POSITION .19729+00 FEET - - - - - -

ITERATED VALUES DAMP MAX.LIM MAX.ERRORS IN CONSERVATION EQS.

ITS	TIME	ALPH	FPPW		ERROR	MOMENTUM		ENERGY
1	.000	9.255	1.9226	.9999	2.-02	11 -8.2-01	8	-1.6+02
2	.000	9.251	1.92491	.0000	5.-07	11 -9.1-01	8	-8.0+01
3	.000	9.251	1.92491	.0000	2.-07	13 9.5-04	9	1.6-01

ALPHA	RADIUS	PRESSURE	EDGE VEL.	BETAP	BETAV	HEAT FLUXES--B/SF2			
	FEET	ATM	F/S			DIFFUSIONAL	TOT ENTH	RERAD	QCOND
9.251+00	5.851-02	2.674-02	7.239+03	1.691-01	1.691-01	7.869+00	7.869+00	0.000	7.869+00

WALL	MASS FLUXES LB/SF2				ELEMENTAL MASS DIFFUSIVE FLUXES LB/SF2 FOR
SHEAR	MECHANICAL	PYROL	CHAR	TOTAL GAS	
LBF/F2	REMOVAL	GAS			
3.187+00	0.000	0.000	0.000	0.000	0.000

MOM TRANS	HEAT TRANS	BLOWING PARAMETERS			ELEMENTAL MASS TRANSFER COEFFICIENTS,
COEFF.	COEFF.	(NORM. BY RHOEUE*ST) FOR			CM. FOR
CF/2	ST NO.	PYROL GAS	CHAR	TOTAL GAS	
1.484-03	1.403-03	0.000	0.000	0.000	0.000

MOMENTUM	DISPLACE.	EFFECTIVE	ENTHALPY	REYNOLDS	MASS THICKNESS FOR
THICKNESS,	THICKNESS,	BODY	THICKNESS,	NUMBER	
THETA	DELSTAR	DISPLACE.	LAMBDA	PER FOOT	
FEET	FEET	FEET	FEET		FEET
4.122-04	2.278-03	2.278-03	6.290-04	1.093+06	0.000

TOTAL HEAT	THRUST	TOTAL	ACCELERATION	INVISCID	TOTAL
TO WALL	LOSS	WALL AREA	PARAMETER-R	MASS IN BL	MASS IN BL .
B/S	(LBF)	(F2)		LB/S	LB/S
7.203-01	2.061-01	1.757-02	1.221-07	1.738-02	1.738-02

LOCAL INFORMATION

ETA	DISTANCE FROM WALL	F	U/UE	FPP	SHEAR	G, TOTAL ENTHALPY	GP	GPP	STATIC ENTHALPY	TEMP
	FEET				LBF/F2	B/LB	B/LB	B/LB	B/LB	DEG-R
0.000	0.000	0.000	0.000	1.425+00	3.187+00	-3.410+02	3.950+02	2.143+03	-1.030+02	1.000+03
4.292-03	4.971-05	8.034-04	5.007-02	1.418+00	3.158+00	-1.277+02	4.713+02	2.059+03	-1.303+02	1.021+03
2.002-02	1.216-04	5.171-03	1.202-01	1.399+00	3.115+00	-1.016+02	5.740+02	1.647+03	-1.160+02	1.044+03
4.265-02	2.634-04	2.305-02	2.510-01	1.319+00	3.029+00	-3.870+01	7.325+02	5.200+02	-1.047+02	1.065+03
6.168-02	3.835-04	4.751-02	3.516-01	1.168+00	2.958+00	2.216+01	7.745+02	-8.508+02	-1.072+02	1.060+03
9.438-02	5.248-04	8.648-02	4.522-01	9.164-01	2.876+00	9.293+01	6.924+02	-1.417+03	-1.210+02	1.037+03
1.359-01	8.294-04	2.038-01	6.024-01	4.550-01	2.721+00	2.106+02	3.021+02	-5.170+02	-1.691+02	9.555+02
2.571-01	1.458-03	5.603-01	7.533-01	1.306-01	2.368+00	3.309+02	1.157+02	-4.031+01	-2.549+02	8.071+02
4.707-01	2.431-03	1.320+00	8.978-01	6.998-02	1.622+00	4.265+02	7.013+01	-1.901+01	-3.257+02	6.820+02
1.000+00	4.267-03	3.330+00	9.500-01	2.229-02	9.235-01	5.352+02	2.003+01	-5.984+00	-4.092+02	5.312+02
1.381+00	5.420-03	4.894+00	9.789-01	1.347-02	4.855-01	5.720+02	1.434+01	-7.430+00	-4.300+02	4.931+02
2.500+00	8.565-03	9.626+00	1.000+00	0.000	0.000	6.029+02	0.000	-2.817-01	-4.436+02	4.682+02

DISTANCE FROM WALL	DENSITY RHO	VISCOSITY MU	SPECIFIC HEAT	THERMAL COND.	PRANDTL NUMBER	MODIFIED SCHMIDT NUMBER	MOLECULAR WEIGHT	MACH NUMBER	RHOSQ*EPS /RHOE*MUE	TURBULENT PRANDTL NO
FEET	LB/F3	LB/FS	B/LB-R	B/SF-R						
0.000	4.869-04	1.387-05	5.888-01	1.437-05	5.001-01	5.001-01	1.320+01	0.000	0.000	0.000
4.971-05	4.762-04	1.412-05	5.908-01	1.468-05	5.001-01	5.001-01	1.320+01	1.607-01	6.757-05	9.000-01
1.216-04	4.657-04	1.438-05	5.929-01	1.705-05	5.001-01	5.001-01	1.320+01	3.806-01	2.017-03	9.000-01
2.634-04	4.568-04	1.461-05	5.948-01	1.738-05	5.001-01	5.001-01	1.320+01	7.874-01	3.485-02	9.000-01
3.835-04	4.587-04	1.457-05	5.944-01	1.731-05	5.001-01	5.001-01	1.320+01	1.105+00	1.333-01	9.000-01
5.248-04	4.690-04	1.430-05	5.922-01	1.697-05	5.001-01	5.001-01	1.320+01	1.436+00	3.857-01	9.000-01
8.294-04	5.090-04	1.334-05	5.848-01	1.560-05	5.001-01	5.001-01	1.320+01	1.989+00	1.573+00	9.000-01
1.458-03	6.026-04	1.152-05	5.715-01	1.317-05	5.001-01	5.001-01	1.320+01	2.695+00	6.747+00	9.000-01
2.431-03	7.132-04	9.494-06	5.605-01	1.109-05	5.001-01	5.001-01	1.320+01	3.288+00	1.000+01	9.000-01
4.267-03	9.156-04	7.802-06	5.477-01	8.594-06	5.001-01	5.001-01	1.320+01	4.157+00	1.649+01	9.000-01
5.420-03	9.868-04	7.287-06	5.445-01	7.891-06	5.001-01	5.001-01	1.320+01	4.481+00	1.927+01	9.000-01
8.565-03	1.039-03	6.880-06	5.425-01	7.462-06	5.001-01	5.001-01	1.320+01	4.653+00	0.000	9.000-01

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

EDGE CONDITIONS

IS	WALL LENGTH FEET	TEMP DEG-R	CP FROZEN B/LB-R	STATIC PRESSURE ATM	DENSITY LB/FT	VISCOSITY LB/FS	VELOCITY F/S	ENTHALPY B/LB	ENTROPY B/LB-R	MACH NO.
1	3.000-02	1.889+03	6.701-01	6.559+00	6.331-02	2.286-05	3.075+03	4.191+02	3.402+00	1.025+00
2	3.074-02	1.815+03	6.647-01	5.551+00	5.582-02	2.222-05	3.430+03	3.679+02	3.402+00	1.159+00
3	3.282-02	1.723+03	6.559-01	4.415+00	4.659-02	2.137-05	3.897+03	3.073+02	3.402+00	1.333+00
4	3.528-02	1.659+03	6.312-01	2.123+00	2.656-02	1.976-05	4.447+03	1.337+02	3.402+00	1.725+00
5	4.268-02	1.519+03	6.275-01	1.893+00	2.939-02	1.832-05	4.973+03	1.091+02	3.402+00	1.887+00
6	4.640-02	1.372+03	6.235-01	1.665+00	2.208-02	1.793-05	5.105+03	8.234+01	3.402+00	1.966+00
7	5.221-02	1.320+03	6.190-01	1.437+00	1.974-02	1.744-05	5.249+03	5.264+01	3.402+00	2.055+00
8	5.797-02	1.270+03	6.140-01	1.212+00	1.736-02	1.688-05	5.404+03	1.969+01	3.402+00	2.157+00
9	6.355-02	1.210+03	6.083-01	9.933-01	1.491-02	1.623-05	5.573+03	-1.728+01	3.402+00	2.277+00
10	6.893-02	1.137+03	6.015-01	7.734-01	1.237-02	1.543-05	5.767+03	-6.122+01	3.402+00	2.426+00
11	7.419-02	1.095+03	5.930-01	5.515-01	5.592-03	1.439-05	6.001+03	-1.149+02	3.402+00	2.630+00
12	7.937-02	9.161+02	5.812-01	3.290-01	6.532-03	1.287-05	6.309+03	-1.920+02	3.402+00	2.945+00
13	8.450-02	6.806+02	5.609-01	1.060-01	2.831-03	9.878-06	6.622+03	-3.269+02	3.402+00	3.482+00
14	8.958-02	6.620+02	5.588-01	9.558-02	2.628-03	9.627-06	6.860+03	-3.368+02	3.402+00	3.730+00
15	9.466-02	6.418+02	5.571-01	8.515-02	2.413-03	9.353-06	6.901+03	-3.481+02	3.402+00	3.809+00
16	9.975-02	6.265+02	5.556-01	7.680-02	2.239-03	9.115-06	6.936+03	-3.578+02	3.402+00	3.879+00
17	1.047-01	6.097+02	5.543-01	7.036-02	2.099-03	8.911-06	6.965+03	-3.660+02	3.402+00	3.940+00
18	1.097-01	5.930+02	5.530-01	6.389-02	1.955-03	8.691-06	6.997+03	-3.747+02	3.402+00	4.009+00
19	1.147-01	5.822+02	5.520-01	5.931-02	1.852-03	8.527-06	7.020+03	-3.812+02	3.402+00	4.060+00
20	1.197-01	5.698+02	5.510-01	5.474-02	1.749-03	8.357-06	7.044+03	-3.880+02	3.402+00	4.117+00
21	1.246-01	5.566+02	5.498-01	5.025-02	1.642-03	8.169-06	7.070+03	-3.951+02	3.402+00	4.180+00
22	1.295-01	5.462+02	5.490-01	4.690-02	1.562-03	8.017-06	7.090+03	-4.010+02	3.402+00	4.229+00
23	1.344-01	5.353+02	5.481-01	4.356-02	1.480-03	7.860-06	7.111+03	-4.070+02	3.402+00	4.281+00
24	1.392-01	5.264+02	5.473-01	4.097-02	1.415-03	7.732-06	7.128+03	-4.118+02	3.402+00	4.329+00
25	1.442-01	5.171+02	5.465-01	3.838-02	1.350-03	7.597-06	7.146+03	-4.169+02	3.402+00	4.377+00
26	1.490-01	5.073+02	5.457-01	3.579-02	1.283-03	7.455-06	7.165+03	-4.223+02	3.402+00	4.430+00
27	1.539-01	4.987+02	5.450-01	3.362-02	1.226-03	7.328-06	7.181+03	-4.270+02	3.402+00	4.477+00
28	1.587-01	4.904+02	5.443-01	3.164-02	1.174-03	7.208-06	7.197+03	-4.315+02	3.402+00	4.523+00
29	1.636-01	4.833+02	5.437-01	2.999-02	1.129-03	7.102-06	7.210+03	-4.355+02	3.402+00	4.565+00
30	1.684-01	4.758+02	5.431-01	2.834-02	1.087-03	6.992-06	7.225+03	-4.395+02	3.402+00	4.608+00
31	1.732-01	4.680+02	5.424-01	2.669-02	1.032-03	6.876-06	7.239+03	-4.437+02	3.402+00	4.655+00
32	1.781-01	4.609+02	5.418-01	2.525-02	9.966-04	6.770-06	7.252+03	-4.475+02	3.402+00	4.698+00
33	1.829-01	4.535+02	5.412-01	2.381-02	9.550-04	6.659-06	7.266+03	-4.515+02	3.402+00	4.749+00
34	1.877-01	4.471+02	5.407-01	2.262-02	9.203-04	6.564-06	7.278+03	-4.550+02	3.402+00	4.785+00

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

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PRIOR LAMINAR SOLUTION AFTER TRANSITION. TURBULENCE WILL BE INCLUDED AND SOLUTION CONTINUED

   ITERATED VALUES    DAMP  MAX.LIN  MAX.ERRORS IN CONSERVATION EQS.
ITS  TIME    ALPH   FPPW           ERROR    MOMENTUM      ENERGY
 2    .000 2.329 1.8388  .1450  1.-01 11 -1.0+00   1 -4.3+01
 3    .000 2.230 2.0293  .4950  4.-02 11 -2.5+00   1 -3.6+01
 4    .000 2.118 2.2876 1.0000  8.-02 11 -1.8+00   1 -1.8+01
 5    .000 2.107 2.2966 1.0000  7.-03 12 -5.7-02   8 -1.9+00
 6    .000 2.107 2.2966 1.0000  1.-03 12  1.2-03  10 -1.5-02

  ALPHA     RADIUS    PRESSURE  EDGE VEL.   BETAP      BETAV              HEAT FLUXES--B/SF2
            FEET      ATM       F/S                               DIFFUSIONAL TOT ENTH  BERAD      QCOND
  2.102+00  8.333-03  4.559+00  3.075+01  1.068+01  1.068+01  1.800+02  1.800+02  0.000      1.800+02

   WALL       MASS FLUXES LB/SF2                     ELEMENTAL MASS DIFFUSIVE FLUXES LB/SF2 FOR
   SHEAR   MECHANICAL  PYROL        CHAR     TOTAL GAS
   LBF/F2   REMOVAL     GAS
   6.836+01  0.000      0.000      0.000     0.000      0.000

  MOM TRANS HEAT TRANS      BLOWING PARAMETERS       ELEMENTAL MASS TRANSFER COEFFICIENTS,
   COEFF,    COEFF.    (NORM. BY RHOE*UE*STI FOR               CH,  EQ6
   CF/2       ST NO.   PYROL GAS    CHAR    TOTAL GAS
   3.425-01  1.280-01  0.000      0.000      0.000      0.000

  MOMENTUM  DISPLACE. EFFECTIVE ENTHALPY  REYNOLDS  MASS THICKNESS FOR
  THICKNESS THICKNESS   BODY   THICKNESS.  NUMBER
   THETA     DELSTAR  DISPLACE.  LAMBDA   PER FOOT
   FEET       FEET      FEET      FEET                 FEET
  2.645-05 -8.102-06 -8.102-06  7.443-05  8.527+06  0.000

  TOTAL HEAT    THRUST        TOTAL    ACCELERATION  INVISCID     TOTAL
   TO WALL       LOSS       WALL AREA  PARAMETER-K  MASS IN BL  MASS IN BL
    B/S         (LBF)        (F2)                     LB/S        LB/S
   2.263-01    3.166+02    3.197+02     2.081-05    8.030-03    1.030-01

NODAL INFORMATION
   ETA     DISTANCE      F          U/UE       FPP       SHEAR    G, TOTAL     FP        GPP      STATIC     TEMP
           FROM WALL                                               ENTHALPY                      ENTHALPY
            FEET                                         LBF/F2     B/LB      B/LB      B/LB      B/LB     DEG-R
   0.000    0.000      0.000      0.000      2.297+00  6.836+01 -1.830+02  2.890+02  9.995+02 -1.830+02  1.000+03
  2.802-03  2.638-07  4.003-05  1.350-02  2.268+00  6.748+01 -1.812+02  2.949+02  9.549+02 -1.813+02  1.003+03
  6.868-03  6.809-07  2.339-04  3.285-02  2.228+00  6.628+01 -1.787+02  3.030+02  8.728+02 -1.789+02  1.007+03
  1.557-02  1.472-06  1.208-03  7.276-02  2.139+00  6.351+01 -1.730+02  3.191+02  7.473+02 -1.740+02  1.015+03
  2.741-02  2.569-06  3.527-03  1.230-01  2.023+00  5.996+01 -1.251+02  3.371+02  5.603+02 -1.279+02  1.026+03
  4.935-02  4.638-06  1.107-02  2.091-01  1.809+00  5.747+01 -1.093+02  3.623+02  1.058+02 -1.176+02  1.043+03
  1.865-01  1.855-05  8.706-02  4.922-01  9.777-01  2.860+01 -3.216+01  3.842+02 -1.827+02 -7.883+01  1.108+03
  4.154-01  4.478-05  4.821-01  8.205-01  1.638-01  4.850+00  1.626+02  1.033+02 -9.485+01  3.549+01  1.296+03
  7.719-01  8.559-05  1.081+00  9.081-01  9.519-02  2.828+00  3.367+02  2.921+02 -1.285+02  1.895+02  1.533+03
  1.000+00  1.278-04  1.586+00  9.500-01  6.191-02  1.841+00  4.595+02  1.468+02 -1.269+02  2.881+02  1.694+03
  1.203+00  1.609-04  1.997+00  9.715-01  3.925-02  1.037+00  5.183+02  1.125+02 -9.668+01  3.401+02  1.773+03
  2.500+00  3.875-04  4.715+00  1.000+00  0.000     0.000     6.029+02  0.000     1.834+01  4.141+02  1.888+03

  DISTANCE  DENSITY   VISCOSITY SPECIFIC  THERMAL   PRANDTL   MODIFIED  MOLECULAR   MACH    RHOSQEPS TURBULENT
  FROM WALL   RHO        MU       HEAT      COND.    NUMBER    SCHMIDT    WEIGHT    NUMBER  /RHOE*MUE PRANDTL NO
    FEET     LB/F3     LB/FS    B/LB-R    B/SF-R              NUMBER
  0.000     1.193-01  1.387-05  5.848-01  1.631-05  5.001-01  5.001-01  1.328+01  0.000     0.000      0.000
  2.638-07  1.190-01  1.390-05  5.891-01  1.638-05  5.001-01  5.001-01  1.328+01  1.851-02  0.000      9.000-01
  6.809-07  1.185-01  1.395-05  5.895-01  1.644-05  5.001-01  5.001-01  1.328+01  4.839-02  0.000      9.000-01
  1.472-06  1.175-01  1.405-05  5.902-01  1.658-05  5.001-01  5.001-01  1.328+01  9.915-02  0.000      9.000-01
  2.569-06  1.163-01  1.416-05  5.912-01  1.674-05  5.001-01  5.001-01  1.328+01  1.668-01  0.000      9.000-01
  4.638-06  1.144-01  1.437-05  5.928-01  1.703-05  5.001-01  5.001-01  1.328+01  2.813-01  0.000      9.300-01
  1.855-05  1.077-01  1.510-05  5.988-01  1.809-05  5.001-01  5.001-01  1.328+01  6.500-01  0.000      9.000-01
  4.478-05  9.204-02  1.715-05  6.164-01  2.114-05  5.001-01  5.001-01  1.328+01  9.966-01  0.000      9.000-01
  8.559-05  7.780-02  1.956-05  6.387-01  2.498-05  5.001-01  5.001-01  1.328+01  1.015+00  0.000      9.000-01
  1.278-04  7.092-02  2.110-05  6.533-01  2.756-05  5.001-01  5.001-01  1.328+01  1.018+00  0.000      9.000-01
  1.609-04  6.728-02  2.183-05  6.601-01  2.882-05  5.001-01  5.001-01  1.328+01  1.020+00  0.000      9.000-01
  3.875-04  6.331-02  2.284-05  6.701-01  3.041-05  5.001-01  5.001-01  1.328+01  1.020+00  0.000      9.000-01

  REFIT CALLED

 I   ETA(I)      U/UE      G(1,I)   SP(1,I,1)  SP(1,I,2)  SP(1,I,3)  SP(1,I,4)  SP(1,I,5)  SP(1,I,6)  SP(1,I,7)  SP(1,I,8)

 1   0.000       0.000     -1.830+02  1.000+00
 2   1.058-02    4.996-02  -1.363+02  0.000
 3   2.633-02    1.200-01  -1.255+02  0.000
 4   5.938-02    2.498-01  -1.009+02  0.000
 5   8.925-02    3.505-01  -7.773+01  0.000
 6   1.255-01    4.489-01  -4.901+01  0.000
 7   2.010-01    6.015-01   1.107+01  0.000
 8   3.112-01    7.470-01   9.238+01  0.000
 9   5.065-01    8.596-01   2.196+02  0.000
10   1.000+00    9.500-01   4.585+02  5.131-02
11   1.317+00    9.808-01   5.436+02  2.262-02
12   2.500+00    1.000+00   6.029+02  1.003+03
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SAMPLE PROBLEM 7 OUTPUT (Cont'd)

STATION 39 - - - - - - - - - - - AXIAL POSITION .19789+00 FEET - - - - - - -

ITERATED VALUES DAMP MAX.LIN. MAX.ERRORS IN CONSERVATION EQS.

ITS	TIME	ALPH	EPPW		ERROR		MOMENTUM		ENERGY
1	.000	9.229	1.7347	.9999	2.-07	19	1.9-01	10	-1.9+02
	.700	9.232	1.72771	.0000	5.-07	19	1.7-01	10	-9.7+01
2	.000	9.232	1.72771	.0000	2.-07	19	-1.5-08	10	8.5-01

ALPHA	RADIUS FEET	PRESSURE ATM	EDGE VEL. F/S	BETAP	BETAX	HEAT FLUXES--B/SF2 DIFFUSIONAL	TOT ENTH	RERAD	QCOND
9.232+00	5.851-02	2.262-02	1.270+01	2.388-01	2.388-01	6.069+00	6.069+00	0.000	6.069+00

WALL SHEAR LBF/F2	MASS FLUXES LB/SF2 MECHANICAL REMOVAL	PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS DIFFUSIVE FLUXES LB/SF2 FOR
2.789+00	0.000	0.000	0.000	0.000	0.000

MOM TRANS COEFF. CF/2	HEAT TRANS COEFF. ST NO.	BLOWING PARAMETERS (NORM. BY RHOE*UE*ST) FOR PYROL GAS	CHAR	TOTAL GAS	ELEMENTAL MASS TRANSFER COEFFICIENTS, CM, FOR
1.837-03	1.215-03	0.000	0.000	0.000	0.000

MOMENTUM THICKNESS THETA FEET	DISPLACE. THICKNESS DELSTAR FEET	EFFECTIVE BODY DISPLACE. FEET	ENTHALPY THICKNESS LAMBDA FEET	REYNOLDS NUMBER PER FOOT	MASS THICKNESS FOR FEET
5.365-04	2.507-03	2.507-03	9.781-04	1.021+06	0.000

TOTAL HEAT TO WALL B/S	THRUST LOSS (LBF)	TOTAL WALL AREA (F2)	ACCELERATION PARAMETER-K	INVISCID MASS IN BL LB/S	TOTAL MASS IN BL LB/S
1.212+00	2.501-01	7.595-02	3.026-07	2.068-02	2.068-02

LOCAL INFORMATION

ETA	DISTANCE FROM WALL FEET	F	U/UE	FPP	SHEAR LBF/F2	G, TOTAL ENTHALPY B/LB	GP B/LB	GPP B/LB	STATIC ENTHALPY B/LB	TEMP DEG-R
0.000	0.000	0.000	0.000	1.720+00	2.789+00	-1.430+02	9.261+02	3.172+03	-1.430+02	1.000+03
6.239-03	5.187-05	6.010-04	4.548-32	1.717+00	2.759+00	-1.306+02	5.099+02	3.063+03	-1.324+02	1.017+03
1.493-02	1.259-04	3.433-03	1.083-01	1.695+00	2.725+00	-1.098+02	6.226+02	2.608+03	-1.222+02	1.035+03
3.140-02	2.672-04	1.504-02	2.240-01	1.623+00	2.656+00	-6.005+01	8.044+02	1.340+03	-1.131+02	1.050+03
4.536-02	3.879-04	3.103-02	3.158-01	1.483+00	2.595+00	-1.019+01	8.836+02	-5.919+02	-1.157+02	1.046+03
6.251-02	5.344-04	5.762-02	4.138-01	1.216+00	2.520+00	5.238+01	8.406+02	-2.070+03	-1.287+02	1.024+03
1.050-01	8.775-04	1.483-01	5.766-01	5.945-01	2.395+00	1.701+02	9.680+02	-7.547+02	-1.816+02	9.340+02
2.142-01	1.629-03	4.623-01	7.469-01	1.426-01	2.000+00	3.059+02	1.195+02	-5.422+01	-2.843+02	7.555+02
4.371-01	2.676-03	1.219+00	8.958-01	6.692-02	1.593+00	3.946+02	6.435+01	-1.599+01	-3.621+02	6.166+02
1.000+00	5.333-03	3.380+00	9.500-01	2.060-02	7.840-01	5.136+02	3.156+01	-4.038+00	-4.412+02	4.726+02
1.380+00	6.719-03	4.934+00	9.777-01	1.384-02	4.331-01	5.592+02	2.506+01	-9.468+00	-4.521+02	4.529+02
2.560+00	1.090-02	9.645+00	1.000+00	0.000	0.000	6.029+02	0.000	-1.110+00	-4.553+02	4.471+02

DISTANCE FROM WALL FEET	DENSITY RHO LB/F3	VISCOSITY MU LB/FS	SPECIFIC HEAT B/LB-R	THERMAL COND. B/SF-R	PRANDTL NUMBER	MODIFIED SCHMIDT NUMBER	MOLECULAR WEIGHT	MACH NUMBER	RHO*EPS /RHOE*MUE	TURBULENT PRANDTL NO
0.000	4.115-04	1.387-05	5.888-01	1.637-05	5.001-01	5.001-01	1.328+01	0.000	0.000	0.000
5.187-05	4.095-04	1.407-05	5.909-01	1.661-05	5.001-01	5.001-01	1.328+01	1.464-01	4.462-05	9.000-01
1.259-04	3.975-04	1.428-05	5.921-01	1.690-05	5.001-01	5.001-01	1.328+01	3.462-01	1.316-03	9.000-01
2.672-04	3.917-04	1.445-05	5.935-01	1.715-05	5.001-01	5.001-01	1.328+01	7.110-01	2.239-02	9.000-01
3.879-04	3.933-04	1.440-05	5.931-01	1.708-05	5.001-01	5.001-01	1.328+01	1.004+00	8.789-02	9.000-01
5.344-04	4.018-04	1.415-05	5.910-01	1.672-05	5.001-01	5.001-01	1.328+01	1.324+00	2.736-01	9.000-01
8.775-04	4.405-04	1.309-05	5.826-01	1.525-05	5.001-01	5.001-01	1.328+01	1.935+00	1.358+00	9.000-01
1.629-03	5.447-04	1.086-05	5.669-01	1.232-05	5.001-01	5.001-01	1.328+01	2.773+00	7.264+00	9.000-01
2.676-03	6.673-04	9.007-06	5.549-01	9.994-06	5.001-01	5.001-01	1.328+01	3.462+00	1.252+01	9.000-01
5.333-03	8.707-04	6.945-06	5.428-01	7.538-06	5.001-01	5.001-01	1.328+01	4.424+00	2.131+01	9.000-01
6.719-03	9.096-04	6.643-06	5.411-01	7.189-06	5.001-01	5.001-01	1.328+01	4.651+00	1.736+01	9.000-01
1.090-02	9.203-04	6.560-06	5.407-01	7.097-06	5.001-01	5.001-01	1.328+01	4.784+00	0.000	9.000-01

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

STATION SUMMARY FOR 4/44=50.HYDRAZINE MOTOR CATALYST PARTICULATES

NEW CONTOUR INFORMATION

		INPUT INVISCID CONTOUR		INPUT WALL CONTOUR	
		NEW WALL CONTOUR-NORM. BY		NEW INVISCID CONTOUR-NORM.BY	
		THROAT RADIUS:	.83330-02 FEET	THROAT RADIUS:	.83330-02 FEET
STATION NO.	DISPLACEMENT THICKNESS FEET	AXIAL COORDINATE	RADIAL COORDINATE	AXIAL COORDINATE	RADIAL COORDINATE
1	-8.10167-06	0.00000	9.99026-01	0.00000	1.00097+00
2	-6.57793-06	8.89953-02	1.00121+00	8.89598-02	1.00279+00
3	-4.53934-06	2.66120-01	1.01984+00	2.66010-01	1.02059+00
4	2.09633-06	6.21542-01	1.11174+00	6.21667-01	1.11076+00
5	2.22411-05	1.19100+00	1.42035+00	1.19353+00	1.41565+00
6	3.65455-05	1.76097+00	1.80165+00	1.76583+00	1.79435+00
7	5.43613-05	2.33116+00	2.20235+00	2.33863+00	2.19165+00
8	7.13145-05	2.90101+00	2.59506+00	2.91068+00	2.58094+00
9	9.32800-05	3.47036+00	2.98655+00	3.48244+00	2.97745+00
10	1.18257-04	4.04048+00	3.25253+00	4.05379+00	3.22747+00
11	1.55493-04	4.61047+00	3.52489+00	4.62632+00	3.49111+00
12	1.97426-04	5.17937+00	3.77773+00	5.19826+00	3.73427+00
13	4.39053-04	5.73801+00	4.03776+00	5.77797+00	3.94029+00
14	5.64000-04	6.30250+00	4.27213+00	6.35132+00	4.14587+00
15	6.42714-04	6.87357+00	4.49046+00	6.92642+00	4.34558+00
16	7.23559-04	7.44878+00	4.69813+00	7.50515+00	4.53387+00
17	7.98558-04	8.01623+00	4.89595+00	8.07660+00	4.71435+00
18	8.87844-04	8.58780+00	5.08475+00	8.65102+00	4.88175+00
19	9.63516-04	9.15007+00	5.26560+00	9.21749+00	5.04940+00
20	1.04653-03	9.72759+00	5.43792+00	9.79540+00	5.19608+00
21	1.14293-03	1.02942+01	5.60528+00	1.03668+01	5.34072+00
22	1.22721-03	1.08647+01	5.76356+00	1.09388+01	5.47844+00
23	1.32400-03	1.14360+01	5.91722+00	1.15125+01	5.60870+00
24	1.41084-03	1.19979+01	6.06449+00	1.20779+01	5.73551+00
25	1.50490-03	1.25731+01	6.20709+00	1.26532+01	5.85421+00
26	1.61047-03	1.31368+01	6.34657+00	1.32214+01	5.96943+00
27	1.71322-03	1.37149+01	6.48022+00	1.37987+01	6.07778+00
28	1.81917-03	1.42806+01	6.60982+00	1.43688+01	6.18218+00
29	1.91907-03	1.48886+01	6.73488+00	1.49389+01	6.28312+00
30	2.02612-03	1.54175+01	6.85681+00	1.55099+01	6.37919+00
31	2.14578-03	1.59870+01	6.97625+00	1.60802+01	6.46975+00
32	2.25954-03	1.65569+01	7.09193+00	1.66522+01	6.55807+00
33	2.38636-03	1.71221+01	7.20611+00	1.72245+01	6.64183+00
34	2.50748-03	1.76975+01	7.31767+00	1.77982+01	6.72473+00

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 8

A/A-50,HYDRAZINE MOTOR CATALYST PARTICULATES

LINE	POINT	DSCRIP - REGIME	R / MACH ANGLE	X / PRESSURE	R / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/I / SHOCK ANGLE	ITR
1	1	INPUT - CONTIN	.00000	.15471+00	.70785+01	.00000	.00000	.76736+04	.15092+08	0
			.80981+01	.28416-01	.48609-05	.22495+03	.37421+04	.13882+01		
1	2	INPUT - CONTIN	.21192-02	.15429+00	.70781+01	.82130+00	.20981-04	.76736+04	.15092+08	0
			.80996+01	.28470-01	.48623-05	.22498+03	.37421+04	.13882+01		
1	3	INPUT - CONTIN	.43580-02	.15424+00	.70971+01	.16426+01	.00000	.76735+04	.15092+08	0
			.80998+01	.28473-01	.48655-05	.22504+03	.37421+04	.13882+01		
1	4	INPUT - CONTIN	.65396-02	.15416+00	.70954+01	.24633+01	.20981-04	.76733+04	.15092+08	0
			.81018+01	.28499-01	.48711-05	.22514+03	.37421+04	.13882+01		
1	5	INPUT - CONTIN	.87184-02	.15406+00	.70927+01	.32813+01	.00000	.76730+04	.15092+08	0
			.81048+01	.28567-01	.48795-05	.22529+03	.37421+04	.13882+01		
1	6	INPUT - CONTIN	.10897-01	.15392+00	.70891+01	.40984+01	-.46730-02	.76727+04	.15092+08	0
			.81090+01	.28664-01	.48914-05	.22550+03	.37421+04	.13882+01		
1	7	INPUT - CONTIN	.13060-01	.15374+00	.70840+01	.49010+01	.00000	.76722+04	.15092+08	0
			.81149+01	.28797-01	.49077-05	.22579+03	.37421+04	.13882+01		
1	8	INPUT - CONTIN	.15220-01	.15354+00	.70770+01	.56971+01	.20981-04	.76715+04	.15092+08	0
			.81230+01	.28982-01	.49305-05	.22620+03	.37421+04	.13882+01		
1	9	INPUT - CONTIN	.17377-01	.15332+00	.70670+01	.64780+01	.00000	.76704+04	.15092+08	0
			.81345+01	.29249-01	.49631-05	.22678+03	.37421+04	.13882+01		
1	10	INPUT - CONTIN	.19509-01	.15306+00	.70524+01	.72327+01	-.90752-02	.76690+04	.15092+08	0
			.81515+01	.29644-01	.50113-05	.22763+03	.37421+04	.13882+01		
1	11	INPUT - CONTIN	.21624-01	.15278+00	.70299+01	.79440+01	.00000	.76667+04	.15092+08	0
			.81777+01	.30263-01	.50865-05	.22895+03	.37421+04	.13882+01		
1	12	INPUT - CONTIN	.23718-01	.15247+00	.69927+01	.85764+01	-.26918-01	.76629+04	.15092+08	0
			.82208+01	.31293-01	.52126-05	.23110+03	.37421+04	.13882+01		
1	13	INPUT - CONTIN	.25767-01	.15215+00	.69324+01	.90676+01	.00000	.76564+04	.15092+08	0
			.82936+01	.33126-01	.54287-05	.23481+03	.37421+04	.13882+01		
1	14	INPUT - CONTIN	.27740-01	.15184+00	.68279+01	.93218+01	-.10521+00	.76450+04	.15092+08	0
			.84221+01	.36552-01	.58276-05	.24136+03	.37421+04	.13882+01		
1	15	INPUT - CONTIN	.29605-01	.15153+00	.66549+01	.91270+01	.00000	.76251+04	.15092+08	0
			.86421+01	.43091-01	.65529-05	.25271+03	.37421+04	.13882+01		

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 0 PAGE 9

A/A-50,HYDRAZINE MOTOR CATALYST PARTICULATES

LINE	POINT	DSCRIP - REGIME	R / MACH ANGLE	X / PRESSURE	R / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/I / SHOCK ANGLE	ITR
1	16	INPUT - CONTIN	.31289-01	.15127+00	.64115+01	.84520+01	-.50094+00	.75945+04	.15092+08	0
			.89729+01	.58653-01	.77866-05	.27059+03	.37421+04	.13882+01		
1	17	INPUT - CONTIN	.32731-01	.15101+00	.61359+01	.78590+01	.00000	.75560+04	.15092+08	0
			.93795+01	.72144-01	.95104-05	.29191+03	.37421+04	.13882+01		
1	18	INPUT - CONTIN	.34032-01	.15071+00	.59003+01	.65374+01	-.44289+01	.75192+04	.15092+08	0
			.97571+01	.92299-01	.11361-04	.31262+03	.37421+04	.13882+01		
1	19	INPUT - CONTIN	.35174-01	.15039+00	.57195+01	.58817+01	.00000	.74883+04	.15092+08	0
			.10067+02	.11182+00	.13041-04	.32907+03	.37421+04	.13882+01		
1	20	INPUT - CONTIN	.37278-01	.150[illegible]8+00	.54634+01	.52865+01	.00000	.74398+04	.15092+08	0
			.10587+02	.19815+00	.15970-04	.35697+03	.37421+04	.13882+01		
1	21	INPUT - CONTIN	.37120-01	.15081+00	.53198+01	.52403+01	.00000	.74100+04	.15092+08	0
			.10835+02	.17475+00	.17950-04	.37354+03	.37421+04	.13882+01		
1	22	INPUT - CONTIN	.40841-01	.15075+00	.52245+01	.54355+01	.00000	.73888+04	.15092+08	0
			.11015+02	.19860+00	.19490-04	.38521+03	...121+04	.13875+01		
1	23	INPUT - CONTIN	.42898-01	.15008+00	.51467+01	.57107+01	.00000	.73710+04	.15092+08	0
			.11197+02	.21288+00	.20742-04	.39495+03	.37421+04	.13867+01		
1	24	INPUT - CONTIN	.44098-01	.14992+00	.50827+01	.67141+01	.00000	.73550+04	.15092+08	0
			.11386+02	.23039+00	.21960-04	.40372+03	.37421+04	.13860+01		
1	25	INPUT - CONTIN	.45662-01	.14976+00	.50233+01	.63118+01	.00000	.73401+04	.15092+08	0
			.11492+02	.24753+00	.23127-04	.41195+03	.37421+04	.13854+01		
1	26	INPUT - CONTIN	.47189-01	.14958+00	.49697+01	.65575+01	.00000	.73260+04	.15092+08	0
			.11612+02	.26885+00	.24258-04	.41989+03	.37421+04	.13847+01		
1	27	INPUT - CONTIN	.48683-01	.14940+00	.49188+01	.69888+01	.00000	.73127+04	.15092+08	0
			.11737+02	.28121+00	.25359-04	.42672+03	.37421+04	.13842+01		
1	28	INPUT - CONTIN	.50146-01	.14922+00	.48730+01	.73227+01	.00000	.73000+04	.15092+08	0
			.11888+02	.29729+00	.26436-04	.43321+03	.37421+04	.13836+01		
1	29	INPUT - CONTIN	.51583-01	.14903+00	.48283+01	.76583+01	.00000	.72879+04	.15092+08	0
			.11957+02	.31480+00	.27452-04	.44070+03	.37421+04	.13830+01		
1	30	INPUT - CONTIN	.52017-01	.14970+00	.46514+01	.77717+01	.68269+03	.71105+04	.13997+08	[illegible]
			.12815+02	.33250+00	.28271-04	.45265+03	.37915+04	.13798+01		

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 6 PAGE 15

A/A*=50, HYDRAZINE MOTOR CATALYST PARTICULATES

LINE	POINT	DSCRIP - REGIME	R / MACH ANGLE	X / PRESSURE	M / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
1	31	INPUT - CONTIN	.53945-01	.14876+00	.44245+01	.81426+01	.16499+04	.69094+04	.12855+08	0
			.13062+02	.34579+00	.28178-04	.97233+03	.37400+04	.13802+01		
1	32	INPUT - CONTIN	.55869-01	.19836+00	.39628+01	.87731+01	.65957+04	.61551+04	.98766+07	0
			.16785+02	.36832+00	.22982-04	.61781+03	.37378+04	.13690+01		
1	33	INPUT - CONTIN	.57099-01	.19815+00	.27735+01	.99973+01	.10563+05	.54472+04	.76502+07	0
			.21113+02	.37985+00	.19335-04	.75785+03	.37328+04	.13505+01		
1	34	INPUT - CONTIN	.57890-01	.19801+00	.19149+01	.92862+01	.15590+05	.92108+04	.92569+07	0
			.31120+02	.38670+00	.15785-04	.95074+03	.37105+04	.13426+01		
1	35	INPUT - CONTIN	.58174-01	.19797+00	.13242+01	.93742+01	.18746+05	.30351+04	.13112+07	0
			.98791+02	.38929+00	.14290-04	.10691+04	.36785+04	.13272+01		
1	36	INPUT - CONTIN	.58301-01	.19795+00	.10550+01	.99066+01	.19879+05	.29062+04	-.39893+05	0
			.72247+02	.39099+00	.13777-04	.11254+04	.36312+04	.12850+01		
1	37	INPUT - CONTIN	.58505-01	.19792+00	.10500+01	.94600+01	.19222+05	.22089+04	-.35786+07	0
			.72247+02	.39291+00	.15973-04	.10193+04	.35060+04	.12494+01		

THE MASS FLOW RATE IS = .40412-01

MOMENTUM INTEGRATION RESULTS

FORCEX	FORCEY	TORQZ	ISP
-.91894+01	.00000	.00000	.22695+03

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 6 PAGE 16

A/A*=50, HYDRAZINE MOTOR CATALYST PARTICULATES

LINE	POINT	DSCRIP - REGIME	R / MACH ANGLE	X / PRESSURE	M / DENSITY	THETA / TEMPERATURE	ENTROPY / GAS CONST.	VELOCITY / LOCAL GAMMA	O/F / SHOCK ANGLE	ITR
1	31	INPUT - CONTIN	.53945-01	.14876+00	.44245+01	.81426+01	.16499+04	.69094+04	.12855+08	0
			.13062+02	.34579+00	.28178-04	.97233+03	.37400+04	.13802+01		
1	32	INPUT - CONTIN	.55869-01	.19836+00	.39628+01	.87731+01	.65957+04	.61551+04	.98766+07	0
			.16785+02	.36832+00	.22982-04	.61781+03	.37378+04	.13690+01		
1	33	INPUT - CONTIN	.57099-01	.19815+00	.27735+01	.99973+01	.10563+05	.54472+04	.76502+07	0
			.21113+02	.37985+00	.19335-04	.75785+03	.37328+04	.13505+01		
1	34	INPUT - CONTIN	.57890-01	.19801+00	.19149+01	.92862+01	.15590+05	.92108+04	.92569+07	0
			.31120+02	.38670+00	.15785-04	.95074+03	.37105+04	.13426+01		
1	35	INPUT - CONTIN	.58174-01	.19797+00	.13242+01	.93742+01	.18746+05	.30351+04	.13112+07	0
			.98791+02	.38929+00	.14290-04	.10691+04	.36785+04	.13272+01		
1	36	INPUT - CONTIN	.58301-01	.19795+00	.10550+01	.99066+01	.19879+05	.29062+04	-.39893+05	0
			.72247+02	.39099+00	.13777-04	.11254+04	.36312+04	.12850+01		
1	37	INPUT - CONTIN	.58505-01	.19792+00	.10500+01	.94600+01	.19222+05	.22089+04	-.35786+07	0
			.72247+02	.39291+00	.15973-04	.10193+04	.35060+04	.12494+01		
1	38	PRN-MR - CONTIN	.58508-01	.19792+00	.12357+01	.19257+02	.19222+05	.25779+04	-.35786+07	0
			.53769+02	.30375+00	.13148-04	.94818+03	.35060+04	.13007+01		
1	39	PRN-MR - CONTIN	.58508-01	.19792+00	.13896+01	.19093+02	.19222+05	.28452+04	-.35786+07	0
			.96029+02	.29270+00	.11117-04	.89693+03	.35060+04	.13331+01		
1	40	PRN-MR - CONTIN	.58508-01	.19792+00	.15921+01	.23850+02	.19222+05	.30769+04	-.35786+07	0
			.40395+02	.19398+00	.94005-05	.84753+03	.35060+04	.13381+01		
1	41	PRN-MR - CONTIN	.58508-01	.19792+00	.16995+01	.28697+02	.19222+05	.32865+04	-.35786+07	0
			.36168+02	.15397+00	.79112-05	.79930+03	.35060+04	.13422+01		
1	42	PRN-MR - CONTIN	.58508-01	.19792+00	.18480+01	.33993+02	.19222+05	.34835+04	-.35786+07	0
			.32760+02	.12074+00	.66119-05	.75176+03	.35060+04	.13466+01		
1	43	PRN-MR - CONTIN	.59508-01	.19792+00	.20043+01	.38290+02	.19222+05	.36621+04	-.35786+07	0
			.29896+02	.93762-01	.54796-05	.70344+03	.35060+04	.13510+01		
1	44	PRN-MR - CONTIN	.58508-01	.19792+00	.21717+01	[illegible]	.19222+05	.38339+04	-.35786+07	0
			.27417+02	.71677-01	.44476-05	[illegible]	.35060+04	.13553+01		
1	45	PRN-MR - CONTIN	.58508-01	.19792+00	.23474+01	.48793+02	.19222+05	.39953+04	-.35786+07	0
			.25214+02	.53810-01	.36370-05	.60751+03	.35060+04	.13600+01		

SAMPLE PROBLEM 7 OUTPUT (Cont'd)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 6 PAGE 22

AZ50:50-HYDRAZINE MOTOR CATALYST PARTICULATES

LINE	POINT	DESCRIP - REGIME	S MACH ANGLE	X PRESSURE	R DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	C/I SHOCK ANGLE	ITR
1	46	FAN-MR - CONTIN	.58599-01 .23238+02	.14792+00 .17671-01	.25347+01 .29103-05	.52670+02 .55292+03	.19222+05 .35060+09	.41405+09 .13890+01	-.35786+07	0
1	47	FAN-MR - CONTIN	.58509-01 .21493+02	.14792+00 .28670-01	.27159+01 .29931-05	.57922+02 .51317+03	.19222+05 .35060+09	.42534+09 .13690+01	-.35786+07	6
1	48	FAN-MR - CONTIN	.58508-01 .19282+02	.14792+00 .12223-01	.29539+01 .17771-05	.62273+02 .46737+03	.19222+05 .35060+09	.44379+09 .13731+01	-.35786+07	6
1	49	FAN-MR - CONTIN	.58508-01 .18251+02	.14792+00 .13918-01	.31370+01 .13529-05	.67028+02 .42251+03	.19222+05 .35060+09	.45806+09 .13772+01	-.35786+07	6
[illegible]	50	FAN-MR - CONTIN	.58508-01 .16801+02	.14792+00 .93068-02	.34595+01 .10169-05	.73817+02 .37872+03	.19222+05 .35060+09	.46827+09 .13813+01	-.35786+07	6
1	51	FAN-MR - CONTIN	.58508-01 .15429+02	.14752+00 .60267-02	.37589+01 .73793-06	.76613+02 .33548+03	.19222+05 .35060+09	.47911+09 .13849+01	-.35786+07	6
1	52	FAN-MR - CONTIN	.58508-01 .14119+02	.14792+00 .37658-02	.40358+01 .52575-06	.81910+02 .29916+03	.19222+05 .35060+09	.49044+09 .13876+01	-.35786+07	0
1	53	FAN-MR - CONTIN	.58508-01 .12867+02	.14752+00 .22581-02	.44912+01 .36357-06	.86237+02 .25487+03	.19222+05 .35060+09	.50619+09 .13892+01	-.35786+07	0
1	54	FAN-MR - CONTIN	.58598-01 .11661+02	.14792+00 .12873-02	.49476+01 .24227-06	.91003+02 .21229+03	.19222+05 .35060+09	.50957+09 .13892+01	-.35786+07	6
1	55	FAN-MR - CONTIN	.58508-01 .10507+02	.14752+00 .69992-03	.54976+01 .15567-06	.95600+02 .18321+03	.19222+05 .35060+09	.51799+09 .13892+01	-.35786+07	6

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. 6 PAGE 2[illegible]

AZ50:50-HYDRAZINE MOTOR CATALYST PARTICULATES

LINE	POINT	DESCRIP - REGIME	S MACH ANGLE	X PRESSURE	R DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	C/I SHOCK ANGLE	ITR
2	45	INTER - CONTIN	.58659-01 .19767+02	.14878+00 .20129-01	.29569+01 .17711-05	.62225+02 .46678+03	.19222+05 .35060+09	.44326+09 .13732+01	-.35786+07	4
2	46	INTER - CONTIN	.58665-01 .19225+02	.14805+00 .13838-01	.31767+01 .13473-05	.67008+02 .42196+03	.19222+05 .35060+09	.45629+09 .13772+01	-.35786+07	4
2	47	INTER - CONTIN	.58679-01 .16779+02	.14803+00 .92996-02	.34663+01 .10255-05	.71795+02 .37762+03	.19222+05 .35060+09	.45846+09 .13819+01	-.35786+07	4
2	48	INTER - CONTIN	.58681-01 .15404+02	.14801+00 .59804-02	.37691+01 .73373-06	.76592+02 .33477+03	.19222+05 .35060+09	.47992+09 .13849+01	-.35786+07	4
2	49	INTER - CONTIN	.58686-01 .14499+02	.14799+00 .37313-02	.41365+01 .52232-06	.81367+02 .29391+03	.19222+05 .35060+09	.49063+09 .13876+01	-.35786+07	4
2	50	INTER - CONTIN	.58687-01 .12841+02	.14797+00 .22375-02	.44995+01 .36093-06	.86159+02 .25412+03	.19222+05 .35060+09	.50057+09 .13892+01	-.35786+07	4
2	51	INTER - CONTIN	.58690-01 .11637+02	.14795+00 .12723-02	.49575+01 .24072-06	.90944+02 .21708+03	.19222+05 .35060+09	.50975+09 .13892+01	-.35786+07	4
2	52	INTER - CONTIN	.58690-01 .10489+02	.14793+00 .68573-03	.54956+01 .15419-06	.95739+02 .18253+03	.19222+05 .35060+09	.51814+09 .13892+01	-.35786+07	4
2	53	FREEBD - CONTIN	.58687-01 .10507+02	.14790+00 .69992-03	.54976+01 .15560-06	.95702+02 .18321+03	.19222+05 .35060+09	.51799+09 .13892+01	-.35786+07	4

PERCENT CHANGE IN MASS, MOMENTUM AND ENERGY NUMERICAL INTEGRATION FOR LINE 2 RELATIVE TO THE START LINE
THE PERCENT CHANGE IN MASS FLOW IS : .29599-01
PERCENT CHANGE IN MOMENTUM IS : -.21102+00 ISP : -.79678+00
PERCENT CHANGE IN ENERGY IS : .00000

LINE	POINT	DESCRIP - REGIME	S MACH ANGLE	X PRESSURE	R DENSITY	THETA TEMPERATURE	ENTROPY GAS CONST.	VELOCITY LOCAL GAMMA	C/I SHOCK ANGLE	ITR
3	1	WALL - CONTIN	.00000 .80869+01	.15692+00 .28195-01	.71090+01 .98275-05	.00000 .22935+03	.00000 .37921+09	.76747+09 .13882+01	.15692+08	2
3	53	FREEBD - CONTIN	.56799-01 .10507+02	.14789+00 .69995-03	.54936+01 .15558-06	.95692+02 .18321+03	.19222+05 .35060+09	.51799+09 .13892+01	-.35786+07	2

A NEW STREAMLINE HAS BEEN INSERTED ON LINE 2 BETWEEN POINTS [illegible] AND 35

A NEW STREAMLINE HAS BEEN INSERTED ON LINE 2 BETWEEN POINTS 35 AND 36

A NEW STREAMLINE HAS BEEN INSERTED ON LINE 2 BETWEEN POINTS 38 AND 39

A NEW STREAMLINE HAS BEEN INSERTED ON LINE 2 BETWEEN POINTS [illegible] AND 35

SAMPLE PROBLEM 7 OUTPUT (Concluded)

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. [illegible] PAGE 38

[illegible]

LINE	POINT	DESCRIP. - REGION	MACH ANGLE	PRESSURE	DENSITY	TEMPERATURE	GAS CONST.	LOCAL GAMMA	SHOCK ANGLE	ITR.
66	50	FREE [illegible] - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-.35786+07	2

POINT NO. [illegible] ON LINE [illegible] HAS BEEN DELETED

LINE	POINT	DESCRIP. - REGION	MACH ANGLE	PRESSURE	DENSITY	TEMPERATURE	GAS CONST.	LOCAL GAMMA	SHOCK ANGLE	ITR.
67	1	WALL - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
67	53	FREE [illegible] - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-.35786+07	2
68	1	WALL - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
68	53	FREE [illegible] - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-.35786+07	2
69	1	WALL - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
69	53	FREE [illegible] - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-.35786+07	2

POINT NO. [illegible] ON LINE [illegible] HAS BEEN DELETED

LINE	POINT	DESCRIP. - REGION	MACH ANGLE	PRESSURE	DENSITY	TEMPERATURE	GAS CONST.	LOCAL GAMMA	SHOCK ANGLE	ITR.
70	1	WALL - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
70	52	FREE [illegible] - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-.35786+07	2
71	1	WALL - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
71	52	FREE [illegible] - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-.35786+07	2
72	1	WALL - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
72	5[illegible]	FREE [illegible] - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-.35786+07	2

POINT NO. [illegible] ON LINE [illegible] HAS BEEN DELETED

POINT NO. [illegible] ON LINE [illegible] HAS BEEN DELETED

LINE	POINT	DESCRIP. - REGION	MACH ANGLE	PRESSURE	DENSITY	TEMPERATURE	GAS CONST.	LOCAL GAMMA	SHOCK ANGLE	ITR.
73	1	WALL - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
73	5[illegible]	FREE [illegible] - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2

SUPERSONIC FLOW ANALYSIS USING THE LOCKHEED-HUNTSVILLE MULTIPLE SHOCK COMPUTER PROGRAM

CASE NO. [illegible] PAGE 39

[illegible]

LINE	POINT	DESCRIP. - REGION	MACH ANGLE	PRESSURE	DENSITY	TEMPERATURE	GAS CONST.	LOCAL GAMMA	SHOCK ANGLE	ITR.
74	1	WALL - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
74	[illegible]	FREE [illegible] - CONTIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2

PREVIOUSLY NOTED ERRORS HAVE PROPAGATED TO LOWER BOUNDARY, OR PROBLEM LIMITS HAVE BEEN REACHED. CASE TERMINATED.

[illegible]

PUNCH CARDS FOR LINE [illegible]

[illegible]

9. CONCLUSIONS AND RECOMMENDATIONS

A computer code has been developed which can be used to model the dominant phenomena which effect the prediction of liquid and solid rocket nozzle and orbital (as well as low alttude) plume flow fields. With a single computer run it is possible for the designer to predict a high altitude plume starting from the combustion chamber. This code is intended to be a user-oriented design tool that will allow rocket nozzle/plume calculations that can range from the simplest preliminary design calculations to final design predictions.

The emphasis in developing this tool was to require very little user interface and data manipulation which has previously been required to adequately treat such influences as nozzle boundary layer, two-phase and variable O/F transonic startlines, boundary layer effects on particulates entering the boundary layer, and the transition from continuum to free molecular flow. Development of the program to this stage also allows the RAM2F code to generate an exit plane startline for both single and two phase motors which will interface with the JANNAF Standardized Plume Flowfield (SPF) Code.

The program is being used to generate nozzle and plume data for numerous applications such as:

- Gas/Gas-Particle Impingement (Heat-Transfer-Loads)
- Rocket Nozzle Performance (Thrust, I_{sp})
- IR Signatures (Radiating Species)
- RF Attenuation (Electron Densities)
- Plume Radiation (Radiative Heat Transfer Gas/Particles)
- Vehicle Base Pressure
- Base Heating (Convection-Recirculation), and
- Flowfield Properties for Contamination Predictions.

This three-volume report describes the program and is intended to provide the user the necessary information to use the code. It is anticipated that there may be some areas of the operation of the code that are not discussed in sufficient depth. Through feedback from the user the documentation will be periodically updated to reflect the experience of the various users. Additionally, coding errors which are uncovered will also be periodically dessiminated to users.

The code has been checked out and compared with a wide range of data. Validation of the program in the low density area of the plume has been verified with limited amounts of data. High altitude (vacuum) plume data are still required to further verify the applicability and range of use of the RAMP2F code. As these data become available the code will be further verified or modified to improve its applicability.

10. REFERENCES

1. Smith, S.D., "High Altitude Supersonic Flow of Chemically Reacting Gas-Particle Mixtures - Volume I - A Theoretical Analysis and Development of the Numerical Solution," LMSC-HREC TR D867400-I, Lockheed Missiles & Space Company, Huntsville, Ala., October 1984.

2. Smith, S.D., "High Altitude Supersonic Flow of Chemically Reacting Gas-Particle Mixtures - Volume II - RAMP2 - Program Manual for RAMP2," LMSC-HREC TR D867400-II, Lockheed Missiles & Space Company, Huntsville, Ala., October 1984.

3. Svehla, R.A., and B.J. McBride, "FORTRAN IV Computer Program for Calculation of Thermodynamics and Transport Properties of Complex Chemical Systems," NASA TN D-7056, January 1976.

4. Evans, R.M., "Boundary Layer Integral Matrix Procedure BLIMP-J User's Manual," Aerotherm UM-75-64, July 1975.

5. Dash, S.M., H.S. Pergament, and R.D. Thorpe, "A Modular Approach for the Coupling of Viscous and Inviscid Processes in Exhaust Plume Flows," 17th Aerospace Sciences Meeting, New Orleans, January 1979.

6. Gordon, S., and B.J. McBride, "Computer Program for Calculation of Complex Chemical Equilibrium Compositions, Rocket Performance, Incident and Reflected Shocks, and Chapman-Jouget Detonations," NASA SP-273, Lewis Research Center, Cleveland, Ohio, 1968.

7. Penny, M.M. et al., "Supersonic Flow of Chemically Reacting Gas-Particle Mixtures-Volume II-RAMP, A Comptuer for Analysis of Chemically Reacting Gas-Particle Flows," LMSC-HREC TR D496555-II, Lockheed Missiles & Space Company, Huntsville, Ala., January 1976.

8. Penny, M.M., and C.J. Wojciechowski, "User's Manual and Description of a Computer Program for Calculating Heating Rates, Forces and Moments Acting on Bodies Immersed in Rocket Exhaust Plumes," LMSC-HREC D162867-II, Lockheed Missiles & Space Company, Huntsville, Ala., March 1971.

9. Alred, J.W., "Flowfield Description of the Reaction Control System Jets of the Space Shuttle Orbiter," AIAA Paper 83-1548, AIAA 18th Thermophysics Conference, Montreal, June 1983.

10. Smith, S.D., "Space Shuttle Solid Rocket Motor (SRM) Exhaust Plume Definitions - Sea Level to SRB Separation," LMSC-HREC TM D496879, Lockheed Missiles & Space Company, Huntsville, Ala., August 1976.

11. Smith, S.D., "Space Shuttle Solid Rocket Motor Sea Level Exhaust Plume Definition, LMSC-HREC TM D784045, Lockheed Missiles & Space Company, Huntsville, Ala., January 1981.

12. Boynton, F.P., and P.S. Rajadeknar, "Plume Interference with Space Shuttle Range Safety Signals," JANNAF 11th Plume Technology Mgt., CPIA Pub 306, Redstone Arsenal, Ala., May 1979.

13. Smith, S.D., "Definition of the Space Shuttle $A/A^* = 5.83$, 2% Aluminum Separation Motor Plume Flow Field," LMSC-HREC TN D496599, Lockheed Missiles & Space Company, Huntsville, Ala., November 1975.

14. Tevepaugh, J.A., S.D. Smith, and M.M. Penny, "Assessment of Analytical Techniques for Predicting Solid Propellant Exhaust Plumes," AIAA Paper 77-711, AIAA 10th Fluid and Plasamadynamics Conference, Albuquerque, June 1977.

15. Smith, S.D., "Definition of Solid Particle Plume Flow Fields of the Space Shuttle Interim Upper Stage (IUS, SSUS-A, SSUS-D) Solid Booster Motors," LMSC-HREC TN D568087, Lockheed Missiles & Space Company, Huntsville, Ala., November 1977.

16. Ring, L.R., "Evaluation of Combustion/Nozzle Gasdynamic Models for Liquid Rocket Engine Applications," AFRPL-TR-77-46, Air Force Rocket Propulsion Laboratory, Edwards, Calif., July 1977.

17. Curtis, J.T., J.R. Moselle, and P.V. Marrone, "Plume Interference Prediction (PID) Code: User's Manual and Test and Evaluation Manual, KC 5900 A-6, Vol. I, Calspan Corporation, Buffalo, N.Y., April 1977.

18. Sulyma, P.R., and L.R. Baker, Jr., "User's Guide for TRAN72 Computer Code Modified for Use with RAMP and VOFMOC Flowfield Codes," LMSC-HREC TM D390409, Lockheed Missiles & Space Company, Huntsville, Ala., October 1974.

19. Ratliff, A.W. et al., "Analysis of Exhaust Plumes from Skylab Configuration R-4D Attitude Control Motors," LMSC-HREC D162171, Lockheed Missiles & Space Company, Huntsville, Ala., March 1970.

20. "Monopropellant Hydrazine Design Data," Rocket Research Corporation, Seattle, Wash.

21. JANNAF Thermochemical Tables, Second Edition, NSRDS-NBS37, U.S. Dept. of Commerce, National Bureau of Standards, Washington, D.C., June 1971.

22. Kliegel, J.R., and G.R. Nickerson, "Axisymmetric Two-Phase Perfect Gas Performance Program - Vol. I," NASA CR 92069, April 1967.

23. Crowe, C.J., "Drag Coefficient of Particles in a Rocket Nozzle," AIAA J., Vol. 5, No. 5, May 1967.

24. Henderson, C.B., "Drag Coefficients of Spheres in Continuum and Rarefied Flows," AIAA J., Vol. 14, No. 6, June 1976, pp. 707-708.

25. Nickerson, G.R. et al., "A Computer Program for the Prediction of Solid Propellant Rocket Motor Performance," Vol. II, AFPRL TR-80-34, Software and Engineering Associates, Santa Ana, Calif., April 1981.

26. Bird, G.A., "Breakdown of Translational and Rotational Equilibrium in Gaseous Expansions," AIAA J., Vol. 8, November 1970, pp. 1998-2003.

27. Brown, R.D., ed., CPIA/M1 Rocket Motor Manual (U), JHU Applied Physics Laboratory," Silver Spring, Md., August 1974 (CONFIDENTIAL).

28. Cadwallader, E.A., ed., CPIA/M5 Revised Liquid Propellant Engine Manual (U), JHU Applied Physics Laboratory, Silver Spring, Md., August 1972 - Excluded GDS (CONFIDENTIAL).

29. Cadwallader, E.A., ed., CPIA/M4 Liquid Propellant Manual (U), JHU Applied Physics Laboratory, Silver Spring, Md., July 1970 (CONFIDENTIAL).

30. Brown, R.D., ed., CPIA/M2 Solid Propellant Manual (U), JHU Applied Physics Laboratory, Silver Spring, Md., August 1974, Excluded GDS, (CONFIDENTIAL).

31. Delaney, L.J., "Particle Characteristics in Two-Phase Plumes," Rocket Plume Phenomena Specialists Meeting, Aerospace Corp., San Bernadino, Calif., July 1968.

32. Coats, D.E. et al., "A Computer Program for the Prediction of Solid Propellant Rocket Motor Performance, Vol. I," AFRPL-TR-75-36, Wright-Patterson AFB, Ohio, July 1975.

33. Rasmussen, J.J., and R.P. Nelson, "Surface Tension of Molten Al_2O_3," Vol. 54, No. 8, J. American Ceramic Soc.

34. CRC Handbook of Chemistry and Physics.

35. Smith, S.D, "Sensitivity Analysis of the Solid Particle Plume Flow Fields of the Space Shuttle Interim Upper Stages Due to Uncertainty in Particle Size Distributions and Drag Forces," LMSC-HREC TN D568223, Lockheed Missiles & Space Company, Huntsville, Ala., March 1978.

36. Girata, P.T., and W.K. McGregor, "Particle Sampling of Solid Rocket Motor Exhausts in High-Altitude Test Cells," AIAA Paper 83-0245, presented at 21st Aerospace Sciences Meeting, Reno, January 1983.

Appendix A

IMPROVEMENTS IN ROCKET ENGINE NOZZLE AND HIGH ALTITUDE PLUME COMPUTATIONS

Improvements in Rocket Engine Nozzle and High Altitude Plume Computations

S.D. Smith*

Lockheed-Huntsville Research & Engineering Center
Huntsville, Alabama

Abstract

A knowledge of the structure of high altitude rocket exhaust plumes is necessary to solve on-orbit plume induced problems such as plume impingement heating, contamination, plume induced forces, and moments and base heating. Rocket exhaust flowfields are very complicated and are governed by many phenomena. Many simplifying assumptions are made to enable one to compute exhaust flows. However, many of these simplifying assumptions can compromise and invalidate the results, depending on the application for which the flowfield is intended. The purpose of this paper is to describe a computer code which allows the user to eliminate many of the simplifying assumptions and treat most of the phenomena which govern nozzle/plume solutions. Additionally, this code requires little or no interaction between the code and the user for the solution of a nozzle flowfield from the combustion chamber to the exhaust plume (including the backflow region).

Introduction

Rocket exhaust flowfields are very complicated and are governed by many phenomena. Many simplifying assumptions are made to enable one to compute exhaust flows. However, many of these simplifying assumptions can compromise and invalidate the results, depending on the application for which the flowfield is intended. Numerous codes are available that treat many of the governing phenomena, but no single code is available that treats reacting single- and multi-phase flows including boundary-layer effects as an integral part of the solution. Thus, previously it was

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Presented as Paper 83-1547 at the AIAA 18th Thermophysics Conference, Montreal, Canada, June 1-3, 1983.

*Staff Engineer, Computational Mechanics Section.

necessary to use a multitude of codes to treat a nozzle/plume flow in detail. It is therefore desirable from both computational and economic standpoints to have a single code that can treat all the dominant phenomena in a rocket nozzle/plume flowfield. Additionally, it is possible to perform calculations which may range from the most simple (as for preliminary design studies) to the most complex as required for final design.

This paper will describe a nozzle plume flowfield code that has capabilities which do not presently exist in a single computer code. The RAMP code[1,2] which was developed by Lockheed under government funding was chosen as the basic code from which to work. The basic RAMP employs modular construction and has the following capabilities: 1) Two-phase with two-phase transonic solution, 2) Two-phase, reacting gas (chemical equilibrium, reaction kinetics), supersonic inviscid nozzle/plume solution, and is 3) Operational for inviscid solutions at both high and low altitudes.

During the course of the study the following capabilities have been added to the code:[3] 1) Direct interface with JANNAF SPF code,[4] 2) Shock capturing finite difference numerical operator, 3) Two-phase, equilibrium/frozen, boundary-layer analysis, 4) Variable oxidizer-to-fuel ratio transonic solution, 5) Improved two-phase transonic solution, 6) Two-phase real gas semiempirical nozzle boundary layer expansion, 7) Continuum limit criteria, and, 8) Sudden freeze free molecular calculation beyond the continuum limit.

Most of the above capabilities already exist in other computer codes. These codes were incorporated into the RAMP code to enhance its usefulness.

Future efforts to improve the code will be directed toward the following: 1) Simplified input, 2) More rigorous treatment of the boundary-layer/Prandtl-Meyer fan interaction, 3) Interface with plume impingement models, 4) Documentation, and 5) Verification of the applicability of the model in the backflow region.

This paper presents the present status of the code and presents some results of plume calculations for bipropellant and solid propellant motors.

RAMP Improvements

JANNAF Standard Plume Flowfield (SPF) Code Interface

To perform a plume calculation, the SPF code[4] requires nozzle exit properties as initial conditions. The RAMP code was modified to punch or put on tape exit plane data in the format that the SPF code uses. The code will punch data for both single- and two-phase cases.

Shock-Capturing Finite Difference Operator

It is desirable to have the capability to treat shocks that can occur in some nozzles. The original RAMP code has the logic for computing any number of right or left-running shocks using shock fitting techniques. This logic was partially verified under previous efforts. Shock capturing schemes require no special equations or program logic and are reliable. For most nozzle flows, existing shock capturing techniques are sufficiently powerful to treat the shocks. Additionally, in order to directly interface with the SPF code, it would be desirable to use a shock capturing numerical operator.

For the above reasons, a shock capturing algorithm was added to the code. The methodology, equations, and grid system which was incorporated into the code is identical to the SPF code.[4] To obtain more information on the scheme the reader should consult Ref. 4.

Equilibrium/Frozen Boundary-Layer Analysis

Nozzle boundary layers are known to influence certain regions of nozzle flow and high altitude exhaust plumes.[5,6,7] For nozzle designers, the nozzle boundary layer is important in determining the thermal loads to the nozzle, performance losses due to heat transfer and effects on the nozzle pressure distribution due to the displacement thickness effect on the inviscid flow structure. For spacecraft designers the nozzle boundary layer is important because of its effect on the exhaust plume. At high altitudes the nozzle boundary layer causes the plume to expand to large angles (approximately 180 deg). In these backflow regions, spacecraft and sensitive surfaces are subjected to unwanted contamination, forces, moments, and heating rates. For some applications the radiative properties of the expanded boundary-layer flow is important. Thus, it is easy to see that for many applications the nozzle wall boundary layer is an important factor.

The BLIMPJ boundary-layer code[8] was chosen for the solution of the nozzle wall boundary layer. BLIMPJ is a JANNAF standard boundary-layer code for determining boundary-layer effects on the performance of a rocket engine. The BLIMPJ code can treat nozzle flows for equilibrium or frozen chemistry, uses the JANNAF standard thermochemistry curve fits and has numerous ways to handle the nozzle wall boundary conditions that allow it to treat liquid engines as well as solid motors with and without ablative walls.

For most rocket motors the boundary layer is fairly thin (approximately 5-10% of exit diameter) and the resultant effect on inviscid flow properties is minimal. For these cases one pass through the inviscid nozzle solution and boundary-layer calculation is adequate. The boundary-layer results are then superimposed on the inviscid nozzle solution and an exit plane start line with boundary-layer effects is generated which can be used to perform a plume expansion.

Some low pressure or low thrust motors have boundary layers which contain a significant portion of the total mass flow of the system. In these cases the entire solution should be iterated by making two passes through the inviscid nozzle and boundary-layer calculations. After the initial nozzle and bounday-layer solution has been completed, the nozzle solutions will be calculated with the actual wall contour adjusted by the local displacement thickness which was determined from the boundary-layer calculation. The boundary-layer solution will then be rerun using the new edge conditions from the second nozzle calculation. The results will then be superimposed on the original nozzle contour and second flowfield solution, and an exit startline will be output or saved.

Particle Tracing Through Boundary Layer

Any particulate matter (Al_2O_3-solids or unburned propellant droplets in liquid motors) which might enter the nozzle wall boundary layer could be influenced by the boundary layer to expand into the backflow region. Thus, there may be certain motor/nozzle configurations in which it is necessary to track particles through the boundary layer in order to obtain the most accurate representation of the nozzle flow properties at the exit plane.

Lockheed-Huntsville added a particle streamline tracing module into the nozzle code. The code which was used as the basic building block of this module was used in predicting the IUS, SSUS particle distributions published in Ref. 9. This code uses initial particle properties (velocity flow angle temperature and density) and traces the particles through a known flowfield. This option is user-selectable.

Boundary Layer Expansion at Lip

Once a fully supersonic startline has been generated at the exit plane, the flow can be expanded around the lip using a Prandtl-Meyer expansion. The main problem with generating the startline is the treatment of the subsonic portions of the boundary layer and the boundary-layer lip interaction.

The present version of the code uses the replacement layer treatment of the subsonic portion of the boundary layer. This method conserves the mass of the subsonic flow using mass averaged properties at a slightly supersonic value, which results in a layer of constant properties near the wall. As experience is gained using the code, further effort will be spent on the treatment of the lip region so that more accurate predictions may be made in the lip dominated backflow region of the plume.

Variable Oxidizer-to-Fuel Ratio Transonic Solution

Solution of the subsonic transonic region of a liquid[10] rocket engine can vary in complexity from a simple one-dimensional variable O/F streamtube analysis to the most detailed model such as that of the distributed energy release (DER) model.[11] The streamtube analysis performs a multizone, one-dimensional calculation to the sonic point given a known O/F distribution just downstream of the injection face. The DER program is a complex model which is initiated upstream of the injector face and continues the solution up through the sonic line. The DER code was used to initiate nozzle solutions in Ref. 12 but is not particularly easy to use or input and requires a good bit of experience of the user to successfully execute. For these reasons it will not be utilized in the nozzle code. On the other hand, a one-dimensional streamtube analysis does not account for two-dimensional effects. A time-dependent scheme[13] is a compromise between these two schemes. The approach includes the radial momentum equation which results in a set of mixed partial differential equations. The solution procedure is an unsteady time-dependent finite-difference technique with equilibrium chemistry. This technique has both the equilibrium and variable O/F chemistry option and has been utilized[14,15] previously with excellent results. This code has been incorporated into the RAMP code as a module and has been executed for all combinations of ideal and equilibrium chemistry, constant, and variable O/F distributions.

Improved Two-Phase Transonic Solution

The original transonic module which was incorporated into the RAMP code could handle throat radii of curvature to throat radius ratios above 1.5. Many solid motors have radii of curvature ratios smaller than 1. To alleviate this limitation the improved approximate transonic module was taken from the new standard performance prediction program (SPP)[16] and put into the RAMP code.

Continuum Limit Criteria

There have been numerous studies over the past several years concerning methods of determining where continuum flow breaks down and free molecular flow begins. Examples of these criteria are the Knudsen number criteria, criteria based on Mach and Reynolds number, and the breakdown parameter as proposed by G. A. Bird.[17]

The present version of the code uses a Knudsen number criteria of 10 to check for free molecular flow transition. The code does keep track of the continuum breakdown criteria and locates the surface in the plume where the breakdown criteria of 0.05 is located. In the future the appropriate data at this surface will be stored so that this information may be passed along to a full Monte Carlo solution.

Free Molecular Flow Option

A sudden freeze free molecular flow option has been incorporated into the code. Once the Knudsen number criteria of 10 has been exceeded the flow is frozen. (Specific heat ratio, molecular weight, velocity and temperature along a gas streamline is held constant.) At this point the streamline is assumed to expand at a constant flow angle and the density varies according to the streamtube area. This option allows the calculations to be performed in the backflow region (>90 deg) of the plume. Numerous cases have been run for several hundred nozzle exit diameters.

Future Improvements

Input Simplification

Much of the input that is required by the RAMP code requires that the user have access to such things as particle size correlations, thermochemical curve fits, particle thermodynamics, reaction rate packages, and a step size control. Defaults for this information will be built into the code or stored on external files much as is done in the SPP code. The user will have the option to override these data. Additionally, the NASA-Lewis CEC program[18] will be put into the RAMP code as a module to facilitate generating the thermodynamic data necessary to perform a plume restart from an exit plane startline that includes a nozzle wall boundary layer. It is anticipated that input simplifications will make the RAMP code much easier and more reliable to use.

Boundary-Layer-Lip Interaction Model

Near the nozzle lip, the subsonic and a part of the supersonic portions of the boundary layer are influenced by the expansion process.[19,20,21] For highly underexpanded flows, the sonic line has been found to attach to the lip[19] so that the flow at the wall must rapidly accelerate when it gets near the lip and the static pressure rapidly decreases. For overexpanded flows the subsonic flow merely stays subsonic as it negotiates the lip so that downstream flow conditions can feed back up into the boundary layer.

These are exact solutions to the corner flow problem. Bird[19] uses a direct simulation Monte Carlo method. He set his model up to compute the entire nozzle starting at the region near the throat. He predicts the attachment of the sonic line for underexpanded nozzles. Baum[21] uses a finite-difference method along with boundary-layer equations to describe the subsonic portion of the boundary layer. His application was for base flow about blunt bodies and compares well with data. Finally, the GIM code[22] can be used to exactly solve the corner problem. All three of these methods are very complex and are outside the scope of this effort.

A more practical approach to adequately handling the lip problem is to develop a model of this region using integral relations, matched asymptotic or other semiempirical techniques. One of these methods will be selected and will be included in the nozzle/plume code. There are existing published calculations of the lip region using Monte Carlo techniques. These results will be used to verify the model. Additional comparisons will be made using experimental data which exist for the lip dominated portion of the exhaust plume. The resultant model will provide a reliable, accurate representation of the boundary-layer-lip interaction zone.

Plume Contamination Model Surface Chemical Species Determination

Specification of the amount and type of plume exhaust products at a surface immersed in a rocket plume is important for determination of spacecraft surface degradation. After an adequate representation of the characteristics of the exhaust plume has been performed it is necessary to relate the spatial characteristics of the plume to a surface that is immersed in the plume.

Under previous studies, Lockheed-Huntsville developed the Lockheed plume impingement code.[23] This program will provide forces, moments, and heating rates to bodies immersed in the exhaust plume generated by the Lockheed method-of-characteristics program.[24]

The plume impingement program (PLIMP) will be modified so that it can use the results of the RAMP2 code to predict forces, moments, and heating rates due to plume impingement. Additionally, the PLIMP code will be modified to determine the types and amounts of plume species at any given location of a body immersed in the exhaust plume. Since the RAMP2 code has the capability of predicting free molecular flow properties, the PLIMP code will be modified so that free molecular flow data can be used to predict plume impingement surface characteristics (forces, moments, heating rates, and species distributions).

Present Program Capabilities

The present form of the RAMP code allows the user to perform a detailed nozzle and plume solution starting in the combustion chamber of the nozzle and proceeding several hundred nozzle diameters into the plume. The program will perform a first-order characterization of the backflow region of the plume. Any appropriate combination of the following capabilities may be used to perform the nozzle and plume solution:

(1) Single- or two-phase nozzles and plumes can be treated.

(2) The gas may be ideal or real. If the gas is real; frozen, equilibrium, or non-equilibrium chemistry assumptions can be made. The effects of oxidizer/fuel gradients may be considered.

(3) Two-dimensional or axisymmetric flow problem geometries can be used.

(4) Both upper and lower boundaries can be solid or free.

(5) Reacting gas solutions which are in chemical equilibrium have been facilitated by modifying the TRAN72[18] computer program as described in Sec. 2 of Ref. 2 to provide binary tape and punched output of its equilibrium or frozen real gas calculations at any desired O/F ratio(s) or total enthalpy(s).

(6) Hypersonic or quiescent approach flow options may be used.

(7) Exit to ambient pressure ratios from over expanded to highly under expanded are possible.

(8) A real gas nozzle boundary layer solution can be performed with no interface between the user and the RAMP code results. A frozen, equilibrium chemistry, turbulent or laminar solution is possible.

(9) The effect of a nozzle wall boundary layer on particles which enter the boundary layer is treated.

(10) An exit plane start line can be generated for the SPF code which includes two-phase flow and boundary-layer effects. Additionally exit plane data are available for use in other codes.

(11) Fuel striations (variable O/F) can be treated starting at the entrance to the nozzle throat region.

(12) The code will handle the two-phase transonic region for nozzles with throat radius of curvature to throat radius ratios of 0.5.

(13) Free molecular flow region is treated using a source flow approximation.

(14) Once the gas-particle flowfield solution has been obtained, the output tape may be used by the RAMP radial lookup program (described in Appendix A of Ref. 2) which determines the radial variations of flowfield properties across the nozzle and plume flowfields at constant axial stations. The plume impingement program (PLIMP)[23] may also be run to determine the effects of the rocket exhaust plume on objects immersed in the plume.

Backflow Model Applicability

The emphasis on the program development has been to provide an engineering tool that allows the designer to perform a detailed nozzle solution for most conceivable combustion chamber/nozzle/propellant combinations followed by a plume solution including the backflow region. The backflow region is calculated using as starting conditions the nozzle/boundary-layer solution at the exit plane and proceeding to perform the plume solution using either a continuum or continuum/sudden freeze free molecular approximation.

Previous studies[25,26] have shown that the continuum approximation (to within a few degrees of the limiting expansion angle) does fairly well for predicting mass flux distributions but Mach number and temperature distributions in the high Mach number (backflow) regions are not well characterized. For applications where contaminant mass fluxes are of interest the continuum approach is probably adequate. The "sudden freeze" source flow plume model that is presently in the program is a first order approximation of a collisionless plume. Temperature and Mach number predictions are more appropriate than continuum predictions for the backflow regions beyond the freeze line if the freeze line is adequately predicted. In order to establish how best to use the continuum or sudden freeze models which are presently in the code comparisons of program predictions with experimental data (other than QCM measurements) and flight data are necessary.

Examples of results of a continuum and continuum/sudden freeze free molecular calculation are shown in Figs. 1 and 2. Both plume solutions were initiated from an exit plane startline of a detailed solution of the Space Shuttle Vernier RCS nozzle.

Figure 1 presents contour plots of static pressure for the continuum assumption, while Fig. 2 presents static pressure plots for the continuum/sudden freeze assumption for the Vernier motor plume. A comparison of the two figures shows that pressure in the continuum region of both calculations are the same while pressure in the free molecular region is higher than that predicted by continuum theory.

Results

To date a multitude of problems has been solved using the RAMP code. However, three particular exhaust plumes have been selected to demonstrate the applicability of the new version of the code. These cases are: a 5-lbf bipropellant motor, the Space Shuttle reaction control system (RCS) motor and an early candidate first stage interim upper stage (IUS) solid motor.

The 5-lbf bipropellant motor was used in a plume contamination test program[27] performed at AEDC. Part of the experimental data consisted of a survey of plume mass flux as a function of angle off the nozzle centerline. A comparison was made with the experimental data using results of a RAMP solution. Figure 3 presents the analytic and experimental results of normalized mass flux as a function of angle measured from the nozzle centerline. The analytic results compare very well with the measurements out to 150 deg. The flowfield solution was initiated at the nozzle throat assuming equilibrium chemistry at a constant oxidizer-to-fuel ratio. The thermochemistry was frozen chemically at a local/chamber pressure ratio of 0.2. Once the nozzle flowfield was completed, the boundary-layer module was executed and predicted laminar boundary-layer conditions at the exit plume. The boundary-layer results were merged with the inviscid exit plane conditions and the plume solution was performed. The plume solution considered variations in total enthalpy due to boundary layer effects. A Knudsen number of 10 was used to determine where the plume went free molecular.

An accurate description of the Space Shuttle RCS motor is important due to the effect of the RCS exhaust on the large number of various payloads which will be placed in orbit by the Space Shuttle. The RCS motor is a bipropellant motor producing 870 lbf of thrust with a 20:1 area ratio contoured nozzle. The injector pattern of the combustion chamber was designed to produce an overall oxidizer-to-fuel ratio of 1.6, while providing film cooling of the combustion chamber walls. The injector pattern results in a distribution of O/F ratio across the inlet of the nozzle. Previous studies[14] have shown that O/F distributions can have a significant effect on the above characteristics. The RCS O/F distribution was inferred from the injector flow pattern and applied at the inlet to the throat region. The transonic module was utilized to give a supersonic start line downstream of the throat. Equilibrium chemistry was used in the solution with chemical freeze points specified as a function of O/F ratio and local static pressure. The pressure to freeze the flow was determined from previous studies[14] which utilized finite rate chemistry results. The remainder of the solution was performed identically to the 5-lbf bipropellant motor except that a turbulent boundary layer was predicted and the plume was calculated via an ideal gas approximation (including total enthalpy variations) since the code presently cannot handle both variations in O/F ratio and total enthalpy.

Figure 4 presents density contour plots of the RCS exhaust plume plots of the RCS exhaust plume assuming the continuum flow approximation throughout the plume. Reference 28 presents a detailed definition of the RCS plume. Figure 5 shows a comparison of plume pitot pressure survey data with the results of the RCS plume calculations assuming both constant and variable O/F distributions. The constant O/F assumption results in an overprediction of the pitot pressure while the variable O/F results compare very well with the data. The effects of variable O/F ratio will be even more pronounced in the backflow region of the plume ($>$ 90 deg) where the O/F ratio is considerably lower than the mean value of the motor.

The interim upper stage (IUS) is used to boost payloads from near Earth orbit to higher orbits. This stage uses solid rocket motors as propulsion. From a payload and stage design standpoint, it is necessary to define the exhaust plume. The RAMP code is especially suited to calculating the IUS exhaust plume including all the driving phenomena: equilibrium/frozen thermochemistry with total enthalpy variations, two-phase flow, nozzle wall boundary layer, and free molecular flow. Figure 6 presents contour plots for Mach number in the exhaust plume. Also Knudsen number of 10 included in this figure is the continuum breakdown surface corresponding to the Bird breakdown criteria of 0.05 and the boundary beyond which free molecular flow is treated. A more complete definition of the first-stage IUS plume will be published soon.

Conclusions

A computer code has been described which can be used to model the dominant phenomena which affect the prediction of a rocket nozzle and orbital plume flowfield. With a single computer run it is possible for the designer to predict a high altitude plume starting back in the combustion chamber. Further work is planned to verify the results of plume calculations to orbital and high altitude applications. The final version of the code will be a user-oriented design tool that will allow rocket nozzle/plume calculations that can range from the most simple preliminary design calcuations to final design predictions.

Acknowledgment

This work was performed under Co.tract NAS9-16256 for the National Aeronautics and Space Administration, Johnson Space Center, Houston, Texas.

References

[1]Penny, M. M. et al., "Supersonic Flow of Chemically Reacting Gas-Particle Mixtures-Volume I-A Theoretical Analysis and Development of the Numerical Solution," LMSC-HREC TR D496555-I, Lockheed Missiles & Space Company, Huntsville, Ala., Jan. 1976.

[2]Penny, M. M. et al., "Supersonic Flow of Chemically Reacting Gas-Particle Mixtures-Volume II-RAMP, a Computer for Analysis of Chemically Reacting Gas-Particle Flows," LMSC-HREC TR D496555-II, Lockheed Missiles & Space Company, Huntsville, Ala., Jan. 1976.

[3]Smith, S. D., "Improvement of Rocket Engine Plume Analysis Techniques-Final Report," LMSC-HREC TR D784753, Lockheed Missiles & Space Co., Huntsville, Ala., Jan. 1982.

[4]Dash, S. M., Pergament, H. S. and Thorpe, R. D.,"A Modular Approach for the Coupling of Viscous and Inviscid Processes in Exhaust Plume Flows," 17th Aerospace Sciences Meeting, New Orleans, La., Jan. 1979.

[5]Penny, M. M., "Analytical Data for the APS R-1E Engine Plume Impingement Forces and Moments on the S-IVB Protuberances and the OWS Panels (Small Version), LMSC-HREC D148628, Lockheed Missiles & Space Company, Huntsville, Ala., Jan. 1969.

[6]Boynton, F. P., "Exhaust Plumes from Nozzles with Wall Boundary Layers," Journal of Spacecraft and Rockets, Vol. 5, Oct. 1968, pp. 1143-1147.

[7]Simons, G. A., "Effect of Nozzle Boundary Layers on Rocket Exhaust Plumes," AIAA Journal, Vol. 10, Nov. 1972, pp. 1534-1535.

[8]Evans, R. M., "BLIMP-J User's Manual," UM-75-64, Aerotherm, Mountain View, Calif., July 1975.

[9]Smith, S. D., "Definition of Solid Particle Plume Flowfields of the Space Shuttle Interim Upper Stage (IUS, SSUS-A, SSUS-D) Solid Booster Motors," LMSC-HREC TN D568087, Lockheed Missiles & Space Company, Huntsville, Ala., Nov. 1977.

[10]Prozan, R. J., "Striated Combustion Solution," LMSC-HREC A791356, Lockheed Missiles & Space Company, Huntsville, Ala., May 1968.

[11]Combs, L. P., "Liquid Rocket Performance Computer Model with Distributed Energy Release," NASA CR-11462, June 1972.

[12]Ring, L. R., "Evaluation of Combustion/Nozzle Gasdynamic Models for Liquid Rocket Engine Applications," AFRPL-TR-77-46, Air Force Rocket Propulsion Laboratory, Edwards, Calif., July 1977.

[13]Stephens, J. T., and Ratliff, A. W., "Studies of Rocket Engine Combustion Chamber Geometry Using an Equilibrium Reacting Gas Transonic Flow Program," LMSC-HREC A784898, Lockheed Missiles & Space Company, Huntsville, Ala., Nov. 1967.

[14]Ratliff, A. W. et al., "Analysis of Exhaust Plumes from Skylab-Configuration R-4D Attitude Control Motors," LMSC-HREC D162171, Lockheed Missiles & Space Company, Huntsville, Ala., March 1970.

[15]Ring. L. R. et al., "Analysis and Correlation of High Altitude Rocket Exhaust Plume Experimental Data," JANNAF 7th Plume Technology Meeting, Huntsville, Ala., April 1973.

[16]Nickerson, G. R. et al., "Solid Rocket Motor Performance Predictions Using the Improved SPP Computer Model," 16th JANNAF Combustion Meet- ing, Monterey, Calif., Sept. 1979.

[17]Bird, G. A., "Breakdown of Translational and Rotational Equilibrium in Gaseous Expansions," AIAA Journal, Vol. 8, Nov. 1970, pp. 1998-2003.

[18]Gordon, S., and McBride, B. J., "Computer Program for Calculation of Complex Chemical Equilibrium Compositions, Rocket Performance, Incident and Reflected Shocks, and Chapman-Jouget Detonations," NASA SP-273, Lewis Research Center, Cleveland, Ohio, 1968.

[19]Bird, G. A., "The Nozzle Lip Problem," Rarefied Gas Dynamics: Proceedings of the 9th International Symposium, Vol. 1, 1974, pp. A.22-1-A.22-8.

[20]Wiernbaum, S., "Rapid Expansion of a Supersonic Boundary Layer and Its Application to the Near Wake," AIAA Journal, Vol. 4, 1966, pp. 217-226.

[21]Baum, E., "An Interaction Model of a Supersonic Laminar Boundary Layer on Sharp and Backward Facing Steps," AIAA Journal, Vol. 6, March 1966, pp. 440-447.

[22]Spradley, L. W., and Pearson, M. L., "GIM Code User's Manual for the STAR-100 Computer," NASA CR-3157, Nov. 1979.

[23]Penny, M. M., and Wojciechowski, C. J., "User's Manual and Description of a Computer Program for Calculating Heating Rates, Forces and Moments Acting on Bodies Immersed in Rocket Exhaust Plumes," LMSC-HREC D162867-II, Lockheed Missiles & Space Company, Huntville, Ala., March 1971.

[24]Smith, S. D., and Ratliff, A. W., "User's Manual-Variable O/F Ratio Method of Characteristics Program for Nozzle and Plume Analysis," LMSC-HREC D162220-IV, Lockheed Missiles & Space Company, Huntsville, Ala., June 1971.

[25]Guernsey, Carl S., "Effects of Translational Nonequilibrium on Vacuum Plume Expansions," JANNAF 13th Plume Technology Meeting, Houston, Texas, April 1982.

[26]Chirivella, J. E., and C. S. Guernsey, "Nozzle Lip Flow and Self-Scattering Molecular Collisilns as Contributors to Plume Backflow," JANNAF 13th Plume Technology Meeting, Houston, Texas, April 1982.

[27]Alt, R. E., "Bipropellant Engine Plume Contamination Program-Vol. I; Chamber Measurements - Phase I," AEDC-TR-79-28, Arnold Engineering Development Center, Arnold Air Force Station, Tenn., Dec. 1979.

[28]Alred, J. W., "Flowfield Description of the Reaction Control System Jets of the Space Shuttle Orbiter," AIAA Paper 83-1548, AIAA 18th Thermophysics Conference, Montreal, Canada, June 1983.

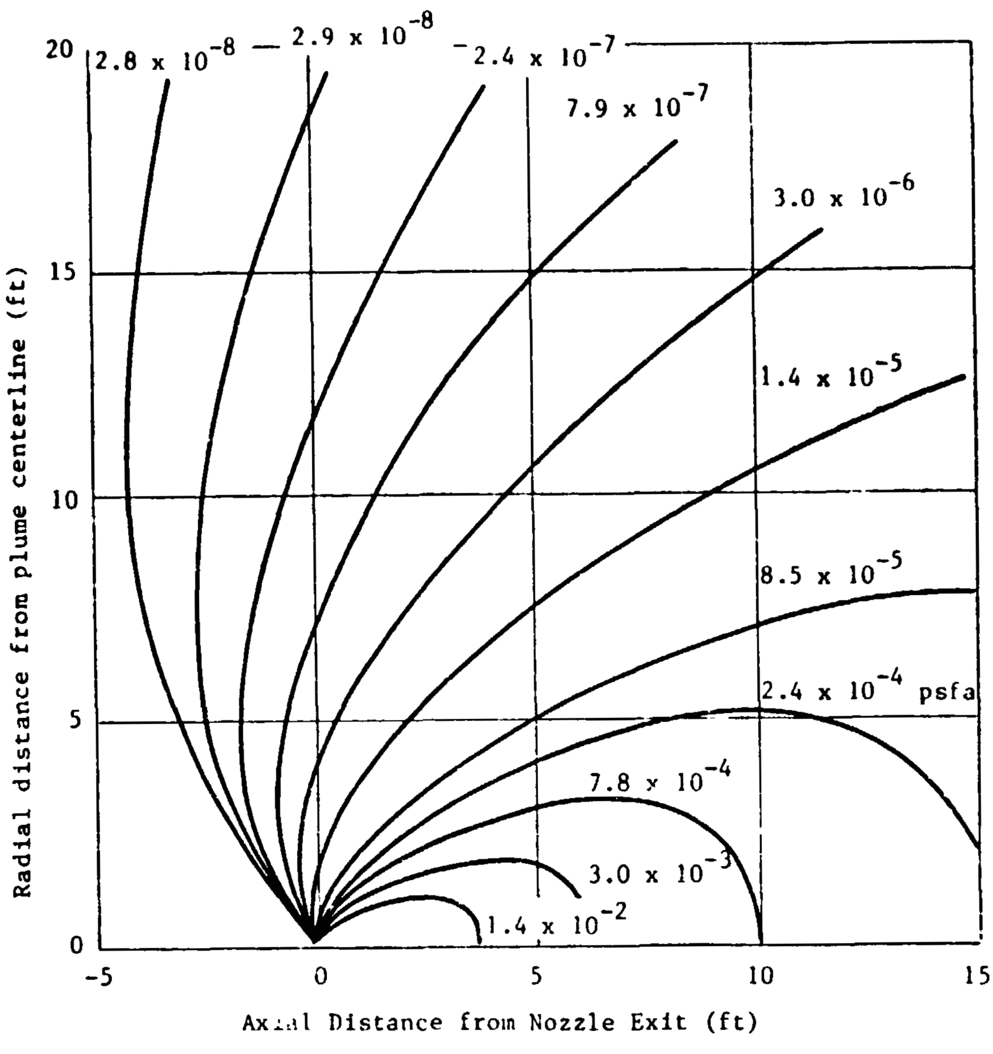

Fig. 1 Space Shuttle vernier motor continuum plume static pressure contours.

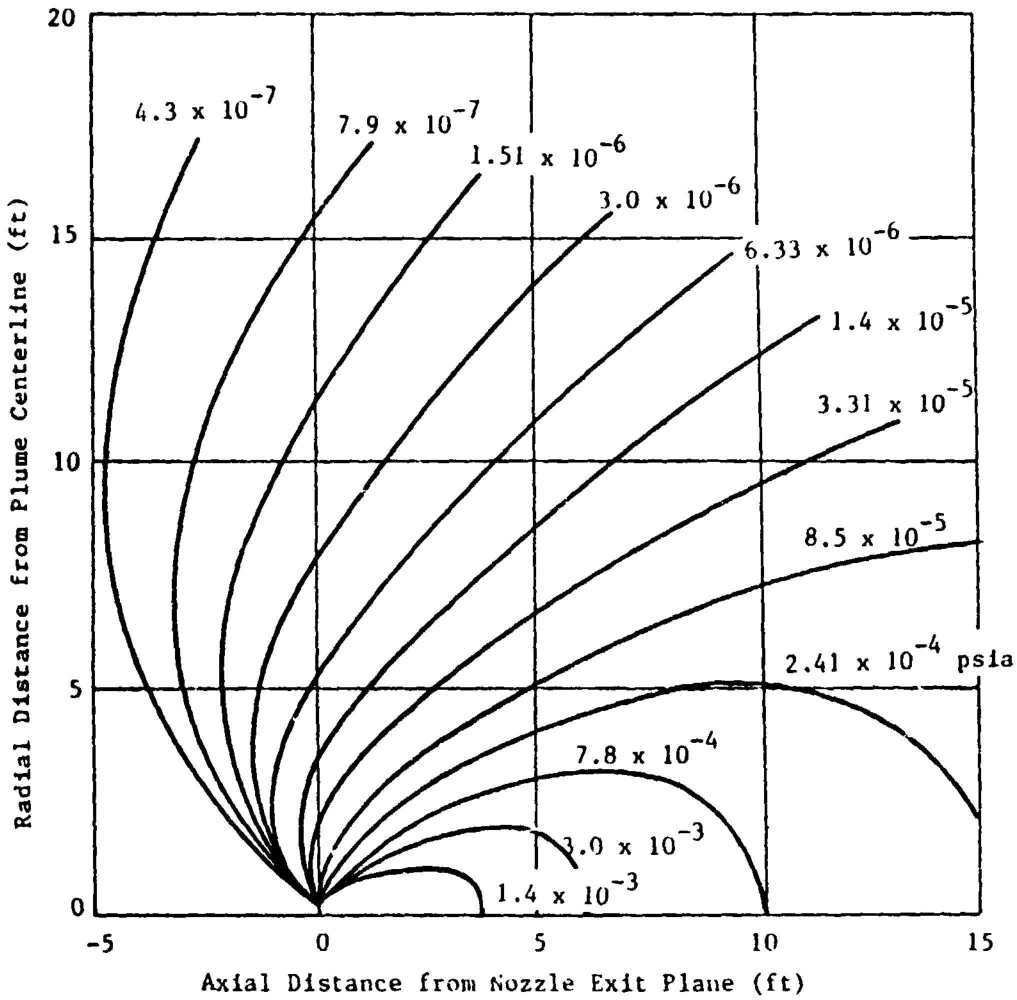

Fig. 2 Space Shuttle vernier motor free molecular plume static pressure contours.

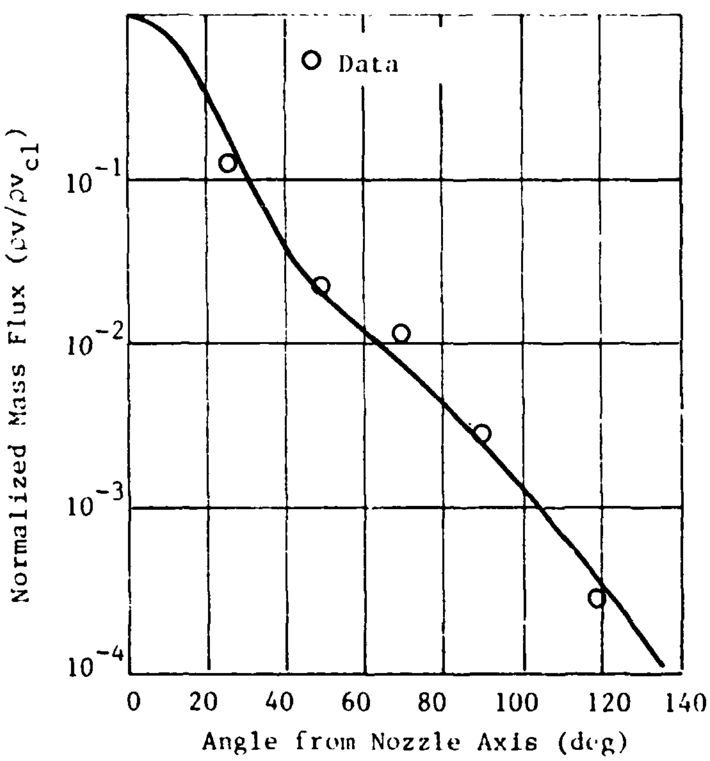

Fig. 3 Mass flux normalized by centerline mass flux versus angle from plume centerline for 5 lbf bipropellant motor.

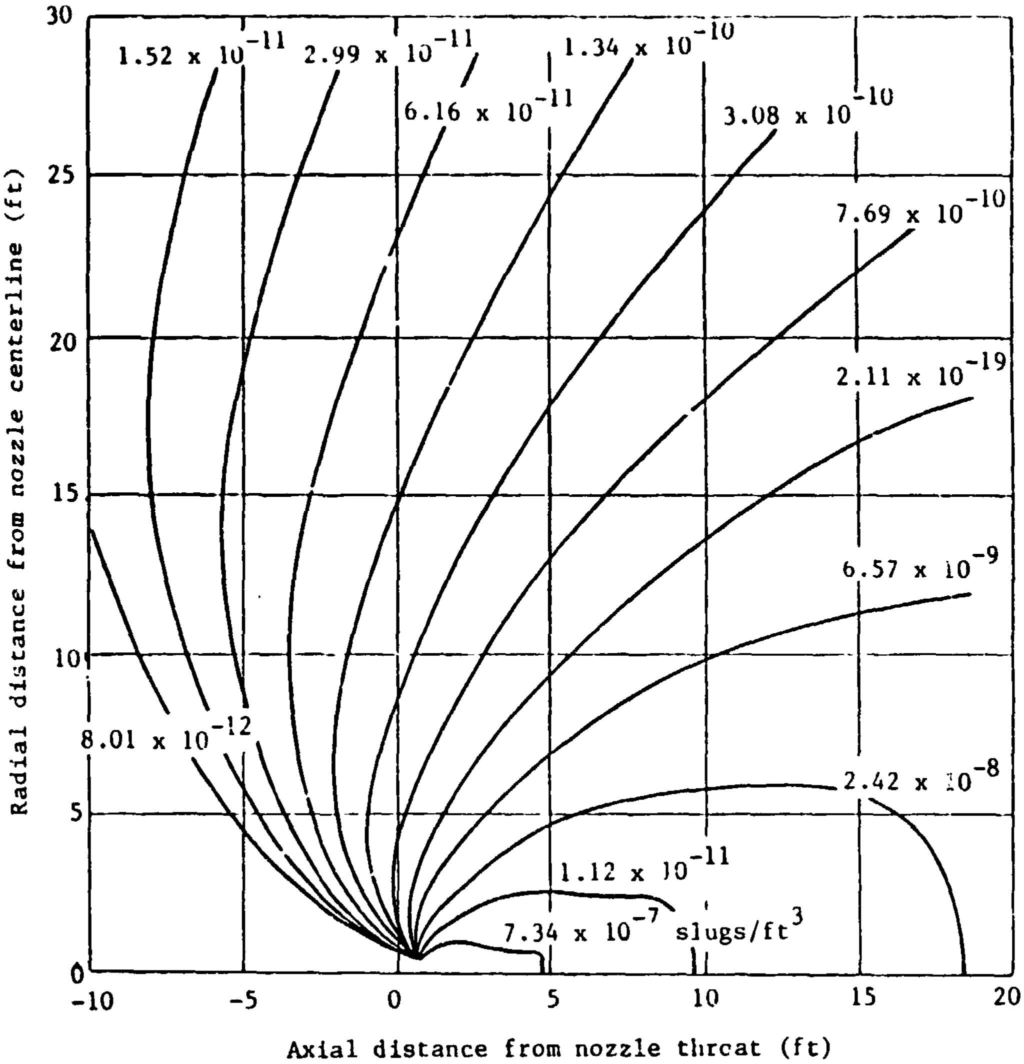

Fig. 4 Space Shuttle RCS motor exhaust plume density contours.

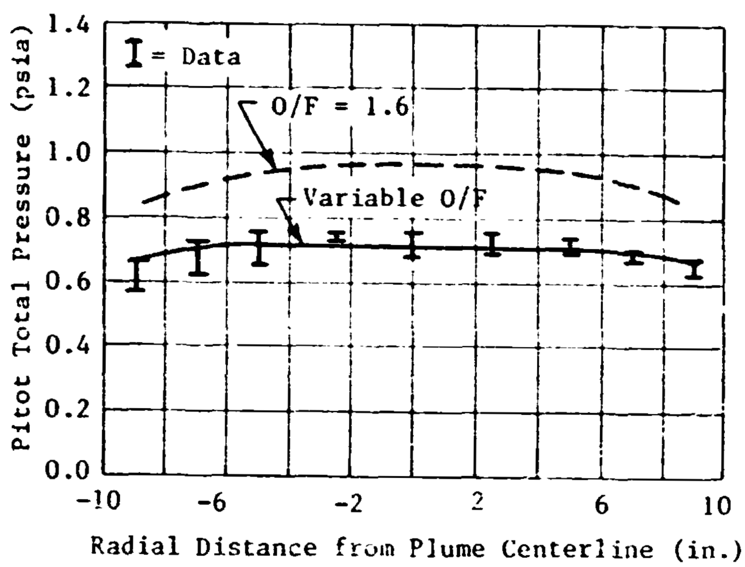

Fig. 5 Comparison of RAMP calculation for Space Shuttle RCS motor plume with pitot pressure survey taken at 45 in. from nozzle exit plane.

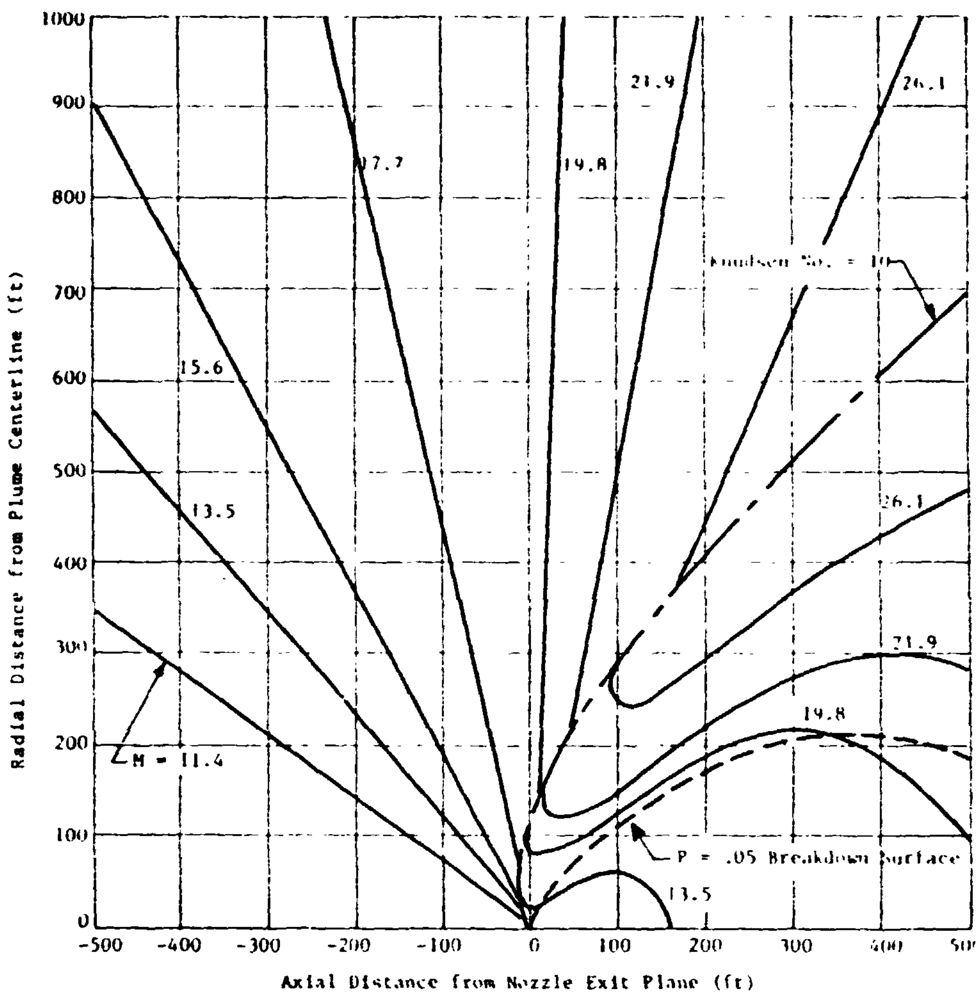

Fig. 6 Large Boeing motor exhaust plume Mach number contours.