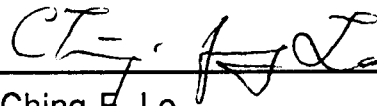


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A PROTOTYPE EXPERT SYSTEM  
FOR DIFFUSER PERFORMANCE EVALUATION  
OF BLOWDOWN TYPE WIND TUNNELS

A Thesis  
Presented for the  
Master of Science  
Degree  
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Gary W. Jarrell  
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## ABSTRACT

The purpose of this research was to develop a prototype expert system built around the Diffuser Performance Program written by Mr. Bob Bauer of Calspan Corporation. The Diffuser Performance Program predicts the performance of the diffuser section of a blowdown type wind tunnel. The expert system was intended to have two main capabilities; assist the user in understanding the program inputs and assigning correct values to them, then execute the Diffuser Program and provide an interpretation of the diffuser's performance in text and graphical formats.

This thesis describes the components, structure and capabilities of the Diffuser Expert System. A brief synopsis of the Diffuser Performance Program is included with complete charts of the variables and equations. The structure of the expert system is described with each of the component program's function identified. And finally, the results of the expert system and their potential value to a user are discussed.

A final section of this thesis outlines future work that would be necessary to bring the expert system from the prototype level to an actual operating system.

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## LIST OF SYMBOLS

|          |                                       |
|----------|---------------------------------------|
| $A$      | area                                  |
| $Alt$    | altitude                              |
| $C$      | Crocco number                         |
| $C_D$    | wall drag coefficient                 |
| $C_P$    | specific heat at constant pressure    |
| $C_V$    | specific heat at constant temperature |
| $D$      | diameter                              |
| $DF$     | differential force (thrust)           |
| $F$      | force (momentum plus pressure)        |
| $h$      | nondimensional heat released          |
| $k$      | normalized mass flow                  |
| $L$      | diffuser gap                          |
| $m$      | mass flow                             |
| $M$      | Mach number                           |
| $P$      | pressure                              |
| $r$      | radial dimension                      |
| $T$      | temperature                           |
| $X$      | axial dimension                       |
| $\delta$ | boundary layer thickness              |
| $\gamma$ | ratio of specific heats               |

## **Superscripts**

\* throat area

## **Subscripts**

|     |                                                                    |
|-----|--------------------------------------------------------------------|
| A   | engine fuel afterburning                                           |
| B   | free jet diffuser region                                           |
| BE  | free jet diffuser minimum area region                              |
| B1  | jet pump diffuser region                                           |
| B1E | jet pump diffuser minimum area region                              |
| b1  | engine base                                                        |
| b2  | jet stretcher base                                                 |
| b4  | jet pump base                                                      |
| C   | chamber region                                                     |
| E   | external region                                                    |
| i   | engine inlet on test body                                          |
| j   | radial gap between nozzle exit and jet<br>stretcher inlet          |
| N   | nozzle                                                             |
| N1  | nozzle parameter solution for diffuser<br>exhausting to atmosphere |
| P   | jet stretcher porous wall                                          |

### Subscripts Continued

|    |                                                           |
|----|-----------------------------------------------------------|
| S  | model, support structure and free jet<br>diffuser surface |
| S1 | jet pump region surface                                   |
| S2 | jet pump diffuser surface                                 |
| t  | total or stagnation condition                             |
| W  | water cooling spray                                       |
| WS | water saturated                                           |
| 1  | test body engine exit                                     |
| 2  | region between test body and jet stretcher                |
| 3  | gap between jet stretcher and free jet<br>diffuser        |
| 4  | jet pump                                                  |
| 5  | jet pump region                                           |

## I. INTRODUCTION

### Background

A FORTRAN computer program was developed by Mr. Bob Bauer of Calspan Corporation for analyzing the general performance and starting conditions of the diffuser section of blowdown type aerodynamic test units. The Diffuser Performance Program is used for predicting the performance of an existing diffuser section with a proposed test article. It can also be used in the design of a new diffuser. The program is complex and requires an extensive set of inputs that include geometric, thermodynamic and fluid mechanical parameters. Execution of the program results in another large set of output variables. The large amount of numerical information produced and required by the program makes it difficult and tedious to use. A user of the program must fully understand the theory behind the program and acquire a lot of background knowledge before he can use the program effectively. Artificial Intelligence (AI) techniques was used to provide some of the knowledge required to use the Diffuser Program.

Artificial Intelligence is defined as behavior by a machine, that if performed by a human being, would be called intelligent [1]. The branch of AI applied in this project is Expert Systems. Expert systems are defined as a computerized advisory program

that attempts to imitate or substitute the reasoning processes and knowledge of human experts in solving specific types of problems [1]. It was believed that developing an expert system to substitute for the knowledge base required to use the Diffuser Program would be beneficial. Such an expert system would allow persons not familiar with the Diffuser Program to use it without extensive consultation with human experts. The consultation is time consuming and an expert is not always available. The expert system could also be used as a training tool for a user not familiar with diffuser characteristics. A final benefit in building a Diffuser Expert System would be to preserve the human expertise so that it would not be lost.

### Objective

To better understand the requirements for a Diffuser Expert System, a description of a typical session using the Diffuser Performance Program was obtained. The user assembles a list of the input parameter values and enters them into the program. If the program is being used to check the performance of an existing test unit and test article, the input values are those for the existing equipment. If the program is being used to help design a test unit, the input parameter values are picked as per the test unit specifications. The program is run and the output parameters are interpreted and evaluated. If necessary, the

inputs are altered according to the output evaluation and the program rerun. The process is repeated until usable answers are obtained.

Figure 1.<sup>1</sup> shows the proposed data path through the Diffuser Expert System. The data path closely resembles the path presently being used when the Diffuser Program is run. Expert system programs are inserted at the steps where a human expert would normally be. The expert system to assemble the inputs would have the following functions:

- Ask the user for the necessary inputs.
- Ask questions and make decisions about the initial diffuser configuration.
- Set reasonable default values to input parameters not needed from the user.
- Set limits to input parameters where required.
- Explain each input parameter when requested.
- Suggest reasonable values for parameters when requested.
- Assemble input data in data files.

---

<sup>1</sup> All figures may be found in Appendix A

The expert system to interpret the outputs would have the following functions:

- Check that the inputs make sense with respect to the outputs.
- Provide a general interpretation of the diffusers performance.
- Identify diffuser flow irregularities and suggest remedies.

### Approach

To develop a Diffuser Expert System, it was first necessary to gain a working knowledge of the Diffuser Performance Program. Most of the literature found on the program dealt only with the development of the equations that describe the diffuser. There is very little written information on the variable definitions or the program's usage. A majority of the knowledge was gained through interviews with the program's developer, Mr. Bauer. Condensing a small part of the many years of Mr. Bauer's experience into the expert system proved to be the major task of this research.

The second aspect to the expert system was the transformation of the knowledge gained into software. The expert shell was the key to this transformation and its selection

was important. An expert shell was needed with a flexible programming language and with the ability to call and share data with external programs. The expert shell's flexibility would be important in developing the user interface. The user interface was desired to be menu driven, with all functions of the expert system accessible from a central main menu. The expert shell would have to interact with external programs easily because all interaction with the Diffuser Program would be done through external programs. The external programs would read the Diffuser Program's input and output data files. This was necessary because it was desired that no modifications would be made to the Diffuser Program. The Diffuser Program is mature and has been used for many years by people who have gained confidence in its outputs. Any changes to the program would shake that confidence.

## II. DIFFUSER PERFORMANCE PROGRAM

### Diffuser Flow Development

A blowdown type wind tunnel is defined for this thesis as one that exhausts to atmosphere, either directly or through an exhauster plant. Blowdown wind tunnels are used primarily to allow testing of larger models than is possible in a closed loop wind tunnel and in testing of engines where products of combustion must be exhausted. Figure 2. shows a sketch of a representative blowdown wind tunnel. The major components include: the free jet nozzle where the process flow is accelerated to supersonic speeds, the test chamber where the model is mounted, and the diffuser section where deceleration of the process gas and pressure recovery is performed. Other components can include: a jet pump which provides an extra stage of compression in the process flow and a jet stretcher which is an aerodynamically tailored device which replaces a known streamline with a boundary layer corrected wall and provides interference free flow at the engine inlets [2]. A jet stretcher is typically used with a model where the engine inlet is far downstream of the nose.

Blowdown type wind tunnels are used to simulate high altitude conditions at supersonic speeds. The wind tunnel

achieves these conditions by accelerating the process gas from stagnation conditions to supersonic flow through the converging/diverging nozzle. The resulting free jet entrains surrounding gas in the test chamber through turbulent mixing along the boundary layer, and transports it to the diffuser exit. The action of removing gas from the test chamber causes the chamber pressure to decrease, thereby simulating a higher altitude. The amount of chamber gas entrainment is a function of the momentum of the free jet which is also directly related to the pressure ratio across the test unit.

Figure 3. illustrates the flow development in a blowdown wind tunnel. The curve shown in the illustration is a standard format for representing a diffuser's performance. The performance curve is typically on a log-log scale of  $P_C/P_{tN}$  vs.  $P_B/P_{tN}$ , where  $P_{tN}$  is the nozzle total pressure,  $P_C$  is the test unit chamber pressure, and  $P_B$  is the diffuser discharge pressure. The performance curve shows the relationship of the overall test unit pressure ratio with the nondimensional chamber pressure. The curve shown is representative of a diffuser with good performance. The curve initially lies along the line where  $P_C = P_B$ , showing very little pump down of the test chamber. As test unit pressure ratio increases the curve acquires a near vertical slope, showing large drops in chamber pressure for small changes in test unit pressure ratio.

To discuss the flow development of a blowdown test unit, four operating points were selected on the performance curve for illustration in Fig. 3. For simplification, a basic test unit was used with only a nozzle, a test chamber and a diffuser. A pressure profile is also shown in Fig. 3. for each operating point. The pressure profile was produced by assuming no friction in the diffuser, adiabatic flow, and  $P_B$  is held constant while  $P_{tN}$  is increased to move down the performance curve.

Point A was selected high on the curve at  $P_C/P_{tN}$  equal to .528 and where the chamber pressure is essentially equal to the diffuser discharge pressure. At this point the the flow has reached sonic velocity in the throat, but the chamber pressure is high enough to cause the flow to separate from the nozzle wall as shown in Fig. 3. Since the sonic flow is not expanding, supersonic flow is not achieved and pressure in the diffuser is equal to the exit pressure. As  $P_{tN}$  is increased and the diffuser operating point moves down the curve, the flow begins to attach to the nozzle wall and shocks form in the nozzle.

Point B is selected at the labeled Diffuser Started region of the curve. Diffuser Started is defined as the point where there are no disturbances from the nozzle exit which influence the test body flow field of interest [3]. At this operating point the flow reaches supersonic speeds but the chamber pressure is still greater than the nozzle exit pressure. Oblique shocks form at the nozzle exit to compress the flow. Pressure recovery in the

diffuser section is achieved by the free jet "shocking down" to reach subsonic speeds and match pressure at the exit. Model aerodynamic testing can be performed with the diffuser operating near the labeled starting point. In this region the test rhombus is shortened by the oblique shocks originating at the nozzle exit, but the diffuser will operate with the smallest value of nozzle total pressure for a given constant diffuser exit pressure. Increasing  $P_{tN}$  moves the diffuser operating point further down the curve, lengthens the test rhombus and moves the "shocking down" process further down the duct.

The sketch for Point C illustrates the flow at the nozzle design point where the chamber pressure and nozzle exit pressure are equal. At this point, the free jet comes straight out of the nozzle and there are no shocks at the nozzle exit. Again, the free jet "shocks down" further down in the diffuser to match pressures at the exit.

Point D illustrates an operating point where the chamber pressure is less than the nozzle exit pressure. Expansion waves form to expand the flow and match the static and chamber pressures. Increasing  $P_{tN}$  moves the diffuser operating point down the performance curve until the labeled Base Pressure Limit is reached. This pressure limit is the lowest theoretical value for the chamber pressure and is found by assuming an isentropic expansion of the flow from the nozzle throat area to the diffuser area. Typically rocket testing is performed near this operating

point because it represents the highest altitude simulation possible for a given diffuser configuration.

### Diffuser Performance Program Overview

The equations describing the performance of a diffuser was developed by Mr. R.C. Bauer by applying fluid mechanics conservation laws to the control volumes shown in Figure 2. The Diffuser Performance Program is based on these equations and is programmed in Fortran for use on IBM compatible personal computers. The diffuser analysis is divided into two parts 1) general performance and 2) diffuser starting conditions. The general performance analysis determines the relationship between the nozzle total pressure  $P_{tN}$ , the chamber pressure  $P_C$ , and the exhaust pressure  $P_B$ . The starting conditions analysis relates the nozzle total pressure to the maximum chamber pressure at which the system will operate in a steady state started condition [3].

The calculations of diffuser performance can be made with the diffuser in a variety of configurations. A sketch of a diffuser system with the major configuration components is shown in Figure 2. The basic diffuser modeled consists of a nozzle, a test chamber and a diffuser ducting section. A test article can be inserted into the test chamber and the effects of drag and blockage can be simulated. An engine can be added to the test

article and the effects of thermal and momentum additions to the flow can be simulated. Another configuration is the addition of a jet pump and jet pump diffuser that are used to increase the performance of a diffuser. A jet stretcher can also be added to provide an interference free flow field over the model [2].

Miscellaneous additions to the diffuser simulation can be included, such as a cooling water spray, a test chamber leak from atmosphere, and cooler coils between the free jet diffuser and jet pump regions. The possible configurations of the diffuser are specified by the values of the Diffuser Program inputs. The inputs are set to default values to simulate the absence of a configuration structure, or specified a value depending on the configuration desired.

The diffuser performance equations were developed in the early seventies to model a jet stretcher system. The analysis was subsequently expanded to model Control Volume I shown in Fig. 2. The equations were first transformed into FORTRAN code to run on IBM mainframe computers by Wilbur Armstrong, formerly of Calspan Corp. The equations and computer code for Control Volumes II and III (Fig. 2) were added in later years . Other minor additions, such as fuel afterburning, were also added. The resulting Diffuser Performance Program was then converted to run on a desktop personal computer during the middle 1980's, also by Wilbur Armstrong. A menu driven interface to enter the input variables was also added by John Felderman of Calspan Corp.

in 1988. The evolution of the equations and computer code over many years is mostly responsible for the sometimes confusing nomenclature. As a reference aid the Diffuser Program variables and their definitions are included in Appendix B and a complete listing of the equations are in Appendix C.

### Definition of Diffuser Starting Conditions

A definition and method for calculating the diffuser starting condition can be found in Reference 4. A diffuser and jet stretcher system is defined to be operating in a started condition when there are no disturbances from the nozzle and jet stretcher exits which influence the test body flow field of interest. These disturbances are produced by a chamber pressure,  $P_C$ , that is different from either the nozzle or jet stretcher exit static pressure, excessive blockage in the diffuser preventing the establishment of supersonic flow, or a nozzle exit boundary layer thickness that exceeds the radial distance between the nozzle exit and the jet stretcher inlet. The later two disturbances can be eliminated by properly designing the jet stretcher for blockage and the range of test Reynolds numbers. The first disturbance is eliminated by reducing the chamber pressure to a sufficiently low level for starting.

An unstarted flowfield exists when the chamber pressure is greater than the maximum allowable chamber pressure required

for the boundary layer to be attached at the nozzle exit. At some point in the steady-state starting process the chamber pressure will become equal to this maximum allowable chamber pressure. At this point, both the nozzle and jet stretcher are flowing full. However, the system is unstarted because of the upstream feedback of the chamber pressure in the nozzle boundary layer caused by an adverse pressure gradient. For the system to be started, all of the compression waves produced by the high-pressure feedback must be intercepted by the jet stretcher. This will occur at a chamber pressure that is less than that for boundary layer separation.

To quantitatively determine the chamber pressure for starting,  $(P_C)_{\text{start}}$ , it is necessary to analytically represent; 1) boundary layer separation pressure ratio, 2) high-pressure feedback in a boundary layer at the nozzle and jet stretcher exits, and 3) allowable feedback distance in the nozzle boundary layer where disturbances can originate and still be intercepted by the jet stretcher. The above analytical relations are produced with experimental data, nozzle geometry, and linear relationships. Their combination produces the following equation [4] for starting chamber to nozzle exit pressure ratio:

$$\left(\frac{P_C}{P_N}\right)_s = 1 + \frac{(M_N - 1)}{5 \left(\frac{\delta_N}{r_N}\right)} \left[ \left(1 - \frac{r_j}{r_N} - \frac{\delta_N^*}{r_N}\right) (M_N^2 - 1)^{1/2} - \frac{X_j}{r_N} \right] \quad (1)$$

Which applies in the following range:  $M_N \geq \left(\frac{P_C}{P_N}\right)_s \geq 1.0$

For  $\left(\frac{P_C}{P_N}\right)_s > M_N$ , the starting value is  $\left(\frac{P_C}{P_N}\right)_s = M_N$

For  $\left(\frac{P_C}{P_N}\right)_s < 1.0$ , the system will not start since the allowable feedback distance is less than zero.

A diffuser without a jet stretcher is a simplified subset of the starting analysis. If no jet stretcher is needed, default values are picked for the geometry variables so that the right side of the starting pressure equation is equal to  $M_N$ .

### Diffuser General Performance

The Diffuser Performance Program can be used to predict problems with a diffuser's performance. The overriding concern is if the minimum attainable chamber pressure is reached before the diffuser has reached the chamber pressure for starting. The minimum chamber pressure is determined by either diffuser choking, free jet pluming or base flow phenomena [4]. Diffuser choking can occur on control volume surfaces 3, 5, B, and B1 as shown in Fig. 2. and can be caused by excess drag of the model and support surfaces, excessive chamber inleakage, area restrictions in the diffuser, etc. The jet plume limit is reached at a chamber pressure, less than the nozzle exit pressure, where the nozzle

free jet plumes to a diameter larger than the diffuser diameter and pump down of the test chamber has stopped. The base flow limit occurs when a nozzle plume is attaching to the inside of the diffuser sufficiently downstream of the diffuser entrance so as not to interfere with the recompression process. Of the above limits, only diffuser choking is predictable by the control volume analysis used to develop the performance equations.

### Data Files

Inputs for the Diffuser Performance Program are stored in a data file called BAUER.DOC. A BASIC program MENU.BAS was provided with the Diffuser Program to allow for changes to the input data file BAUER.DOC. The program divides the inputs into six categories such as engine variables, jet pump variables, etc. The variables are accessed through a menu driven user interface. The variables are displayed on the screen along with a definition and a field on the same line for accepting keyboard value inputs. An example of a MENU.BAS input screen is provided in Figure 4.

Several problems were seen with the MENU.BAS program. The definitions are very sketchy and even omitted in some cases. Many of the variables were not placed under the correct categories. All variables were left in the non-dimensional form used by Mr. Bauer during development of the equations. In some cases, such as a ratio of chamber pressure to nozzle total

pressure, non-dimensional variables makes sense. However, it was felt that the non-dimensional variables caused some unnecessary calculations on the program users part. Also, the number of decimal places accepted and saved by MENU.BAS were not appropriate in many cases to the type of variable. Another problem is caused by limitations in the BASIC program language. The limitation will not allow zero to be entered as a variable value. Entering zero will cause the variable to be left unchanged. This problem can be circumvented by entering a very small number, on the order of  $1 \times 10^{-6}$ .

The Diffuser Program outputs are saved in two ASCII data files; PRIN6.DOC and PRIN8.DOC. PRIN6.DOC contains the results for the test chamber and free jet diffuser regions. PRIN8.DOC contains the results for the jet pump and jet pump diffuser region. PRIN8.DOC is only created if a jet pump has been included in the diffuser configuration. Examples of the PRIN6.DOC and PRIN8.DOC files are included in Figures 5. and 6. The output data files are divided into three sections. The input variable names and values are relisted in the first section. The second section contains miscellaneous calculated parameters such as mass flows, Mach numbers etc. for different regions in the diffuser. The third section is a tabulated listing of selected parameters calculated for ten user input values of  $P_C/P_{tN}$ . It is possible for the Bauer calculations to be stopped short of the full ten  $P_C/P_{tN}$  values. This happens when a value of unity is calculated for Mach

number at region 3, 5 , B, or B1, (Fig. 2.) signifying that the region has reached sonic velocity and is choked. Referring to Figure 5, the last value at the bottom of the  $P_C/P_{tN}$  tabulation is the point where nozzle starting occurs based on the criteria set forth in the definition of diffuser starting section in this thesis. The program sets  $P_C/P_N$  starting to  $M_N$  and works backward to calculate a corresponding  $P_C/P_{tN}$ . Miscellaneous messages may be printed after the end of the  $P_C/P_{tN}$  tabulation. The data line after the STARTED heading contains the value of  $P_C/P_{tN}$  where the complete diffuser will start. The program calculates a  $P_C/P_N$  starting point from Equation 1. and uses it to work backward and calculate a corresponding  $P_C/P_{tN}$ . If a jet stretcher is not included in the configuration, the two started points will be equal. Also listed in the third section under the heading STARTED WHEN EXHAUSTING TO ATMOSPHERE is the point where the diffuser will operate started if exhausting to atmosphere which is typical of the majority of blowdown type test units. The section of data printout after the atmospheric start in PRIN6.DOC was a late add-on for when the Diffuser Program was used to simulate a jet engine, not a test facility, and is beyond the scope of this project.

### III. THE DIFFUSER EXPERT SYSTEM

#### Expert System Construction Tools

The Diffuser Expert System was developed using IBM personnel computer compatible software. VP-Expert version 2.0, a rule-based expert shell developed by Paperback Software, was used to represent the knowledge base. VP-Expert was chosen for its low cost, flexibility and ability to interact with external programs. External programs, which were necessary to supplement the capabilities of VP-Expert, were developed using the Basic language because the MENU.BAS program, supplied with the Diffuser Performance Program for modifying the inputs, was written in Basic. Microsoft QuickBasic, a Basic language editor and compiler was selected for its low cost, availability and its ability to compile BASIC code for quicker execution as compared to using a BASIC interpreter.

#### Expert System Architecture

Six major VP-Expert programs control the various aspects of the Diffuser Expert System. The program DIFFUSER.KBS is the main controller and presents the user the available options such as, build an input data file, run the Diffuser Program and printout the expert system analysis results. The option selected branches

the user to one of the other five VP-Expert programs. A chart of the expert system structure is shown in Fig. 7. The chart shows the program interaction with each other and the data files. Definitions for all the programs shown on the chart are included in Figure 8. Execution of DIFFUSER.KBS will produce the menu shown in Figure 9. To select the required option, press the arrow keys to move the cursor to the number and press ENTER.

Selecting Option 1, Create New Data File For Inputs, will build a new input data file by modifying the existing BAUER.DOC file. As shown in Fig. 7, the major program run with this option is the VP-Expert program INPUTS.KBS. INPUTS first prompts the user for the basic inputs needed for any consultation. The program then asks the user a string of questions on the diffuser configuration. For an explanation about a question being asked, the backslash key can be pressed and "WHY?" selected from the VP-Expert function key choices. Depending on the users answers, INPUTS.KBS either calls external programs to set default values to variables, or calls external programs to prompt the user for more inputs. The changes are then saved to the BAUER.DOC input file. The external programs were modeled after the supplied MENU.BAS program to save development time. However, major changes where made. The majority of the variables were made dimensional to reduce the number of calculations required from the user. Also, a partial definition of each variable is given. Care should be taken not to run this option twice on the same

BAUER.DOC input data file. Answering the configuration questions differently can completely change the input variable values.

Selecting Option 2, Use Old Data File for Inputs, lists all data files in the present directory with a .DAT extension and asks for a selection. The selection is then copied onto BAUER.DOC and will be used in the next execution of the Diffuser Program. This allows a built input file that has been saved with a .DAT extension to be used at a later time.

Entering Option 3, Quick Change of Input File, will execute the VP-Expert file MENU.KBS that calls the original MENU.BAS program. The program is very useful when only one variable is to be changed. It allows "what if" analysis without going through the lengthy configuration question process of Option 1. No improvements have been made to the MENU.BAS program used in this option.

Option 4, Run Diffuser Program, will execute the OUTPUTS.KBS VP-Expert file that runs the Diffuser Program and contains the inference engine for analysis of the outputs. A copy of OUTPUTS.KBS is included in Appendix D. This option takes the longest to execute because it calls many external programs. OUTPUTS runs the Diffuser Program, corrects several input variables based on the outputs, and evaluates the diffuser performance. Passing data back and forth between the Diffuser Program output data files and OUTPUTS.KBS is accomplished using the VP-Expert commands SAVEFACTS and LOADFACTS [5].

SAVEFACTS and LOADFACTS read and produce data files that are built with one variable per line in the format Variable=Value CNF n. The confidence factor n, is always set to one hundred, or complete certainty, since numeric variables are being dealt with. The communication loop between the output and input data files and OUTPUTS can be seen in Fig. 7. Getting data from the Diffuser Program output files PRIN6.DOC is accomplished by the external program P6READ. P6READ reads selected variables from the data file, and copies the data into the file P6OUT in the required LOADFACTS format. The VP-Expert command LOADFACTS is used to read P6OUT into the VP-Expert file OUTPUTS. To get input changes made by OUTPUTS into the Diffuser Program input data file, SAVEFACTS is used to produce the file OUTDAT. The external program OUTREAD is called to read the few variable values that are needed from OUTDAT, and makes the changes to the Diffuser Program input data file. Interaction between PRIN8.DOC and the VP-Expert programs are not provided, therefore no analysis of the outputs for the jet pump and jet pump diffuser regions are possible.

In summary, a typical sequence of communications between the OUTPUTS VP-Expert file and the Diffuser Program data file PRIN6.DOC would execute like the following. A rule in the OUTPUTS file compares the Mach number at the nozzle exit,  $M_N$ , to the Mach number at region 2,  $M_2$ , and finds them unequal. The rule then sets  $M_N$  equal to  $M_2$  and executes the command SAVEFACTS.

The external program OUTREAD is then called to read the new value of  $M_N$  from the file OUTDAT created by the SAVEFACTS command. OUTREAD then modifies the value of  $M_N$  in the Bauer input data file. The Diffuser Program is then executed by the VP-Expert rule, and a new output data file PRIN6.DOC is created. The external program P6READ is called to read in data from PRIN6 and the data loaded into the data file P6OUT. The Rule then executes the LOADFACTS command to load the file P6OUT into the OUTPUTS file for evaluation to continue.

Once all needed corrections are made to the inputs, OUTPUTS.KBS then selects twenty values for  $P_C/P_{tN}$ . The Diffuser Program is called and  $P_B/P_{tN}$  values are calculated for each of the twenty points. The data is saved in PLOT.DOC and used by the external program PERCRV.EXE to produce a plot of  $P_C/P_{tN}$  vs.  $P_B/P_{tN}$ . An example of the plot is shown in Fig. 10.

After the plot is produced, OUTPUTS.KBS then analysis the outputs. Presently, OUTPUTS is looking for these things:

- does the free jet diffuser choke, if so, then why?
- does the free jet diffuser choke before the it has started and flowing full?
- how is the diffuser performance, i.e. how well is the chamber pressure pumped down?

The text file RESULTS is generated providing a written analysis of the diffuser's performance based on the answers to the above questions.

Options 5, 6 and 7 allow a review of the resultant files created by the last execution of Option 4. As shown in Fig. 7, these options either rerun the PERCRV program to display the performance curve, or run the shareware program LIST which allows a user to display and search an ASCII data file.

Option 8, Printout of Results, will printout the resultant files created by the latest execution of Option 4. The files include; the plot of  $P_C/P_{tN}$  vs.  $P_B/P_{tN}$ , the analysis file RESULTS that contains the interpretation of outputs, and the PRIN6.DOC file produced by the Diffuser Program.

#### IV. EXPERT SYSTEM RESULTS

A cornerstone of the Diffuser Expert System analysis is the plot generated of  $P_C/P_{IN}$  vs.  $P_B/P_{IN}$  an example of which is in Figure 10. The plot is generated from twenty points calculated by two calls of the Diffuser Program from OUTPUT.KBS. Much information about the diffuser's performance can be obtained by analysis of the plot. Labeled on the plot are the points where the diffuser is started and where the nozzle is operating at it's design point.

A choked diffuser system can also be seen from the performance curve. A choked diffuser is represented by an abrupt horizontal line from the minimum point on the performance curve to the  $P_C$  axis where  $P_B$  is zero. A performance curve for a choked diffuser is included in Figure 11. Of interest if a diffuser has choked is whether the performance curve has reached the nozzle starting level. If it does not, measures should be taken to improve the minimum  $P_C$  level that can be reached.

An evaluation of a diffuser's efficiency can be determined from the performance curve. An efficient diffuser that provides good pumping action on the chamber pressure will have a near vertical performance curve in the diffuser started and nozzle design regions. A poorly performing diffuser will have a performance curve that lies on a  $P_C$  equals  $P_B$  line ( $45^\circ$  slope),

signifying that little pumping action is being done on the chamber pressure.

The evaluation of the Diffuser Program outputs is produced in text form by the program OUTPUTS.KBS in the file RESULTS. An example of the RESULTS is shown in Figure 12. The first few lines of RESULTS are miscellaneous messages placed there by OUTPUTS showing when iteration was necessary, values of certain calculated variables, etc. The RESULTS file then contains an evaluation of the diffusers performance, i.e. whether or not the diffuser has choked before starting, the operating point when exhausting to atmosphere, etc. The last part of RESULTS gives reasons for the diffusers choking in the order of probability. Some steps are also given that might alleviate the diffuser choking problem.

## V. CONCLUDING REMARKS

Most of the original objectives for the part of the Diffuser Expert System that assists in assembling the inputs were met. The expert system will ask the user for all inputs that are absolutely required by the Diffuser Program. The expert system will then ask questions on the diffuser configuration and give an explanation of the choices when needed. Depending on the configuration, the expert system will set variable defaults or ask values for parameters as required. When input variable values are asked, they have been logically grouped and an on-screen definition is provided for each one. Also, the input variables are entered in dimensional form, the expert system does the calculations to put the variables in the non-dimensional format required by the Diffuser Program.

The objectives for the expert system that analyzes the Diffuser Program outputs were basically met. The expert system checks several of the inputs and will change them based on output parameter values. Diffuser performance knowledge is then represented in graphical and text form. Much of the knowledge is contained in the diffuser performance curve now produced by the expert system instead of hand plotted. It shows diffuser efficiency, the diffuser starting region, and diffuser choking. The same knowledge is recorded in text format in the RESULTS file.

Also included in the RESULTS file is a heirarchical list of diffuser choke reasons and possible remedies. Much expansion of the knowledge base must be accomplished; however, for the expert system to reach it's potential. Particularly an expansion of the knowledge base to include performance analysis for diffusers with a jet pump.

Some other benefits to a user of the Diffuser Expert System were not originally part of the objectives. Using the expert system is much more interactive than using the original Diffuser Program. The user can create or change the input file, run the Diffuser Program and review the results all without leaving the expert system. After satisfactory results have been obtained, the user can then request a printout of the output files. Also, past input files can be saved to create a library of diffuser configurations and these files can be recalled from inside the expert system.

Some of the expert system requirements remain to be refined. To assist the user, an input parameter definition is displayed on the input screens; however, the size of the screen limits the extent of the definition possible. A suggestion of reasonable values and limits for each parameter are also not show because of the same size limitation. Using the MENU.BAS program as a model for entering input values, while cutting front end development time, restricted programming options. No simple method for displaying variable limits or suggesting

reasonable values could be found. It is felt that the best way to address the problems would be to provide parameter information in "pop up" form that would only be available when the user needs it. A possible method for displaying this information would be to use the VP-Expert command HYPERTEXT. HYPERTEXT allows text to be dynamically linked to a word or object displayed on the computer screen [6]. The text is displayed in a window when the word or object is selected by a mouse. To use this feature, screens would have to be built inside VP-Expert for keyboard input of the variables. The executable files used for this function would be eliminated. The variable names displayed in the input screens would be linked with text that gives a complete description, limits and suggested values for the variable.

Some other suggestions have been made to improve the present Diffuser Expert System prototype to a more useful product. An upgraded expert system should provide out-of-range checking on input variables as values are assigned to them. The system would interactively recognize unrealistic variable values and notify the user to change them. Another upgrade would be to link the expert system to an intelligent hypertext system. The hypertext system would provide to the user a tutorial on the gas dynamics and fluid mechanics of the diffuser. The tutorial could be coupled with illustrations, similar to Fig. 3, to convey to the user the diffuser operating regions and the testing performance expected.

All discussed upgrades to the Diffuser Expert System can be done using VP-Expert capabilities. However, newer and more capable software products have been brought to market and the possibility of using them should be investigated. One additional hardware requirement to using hypertext would be that computer systems that can run the expert system would be limited to those with a mouse.

## LIST OF REFERENCES

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## APPENDIXES

## APPENDIX A

### FIGURES

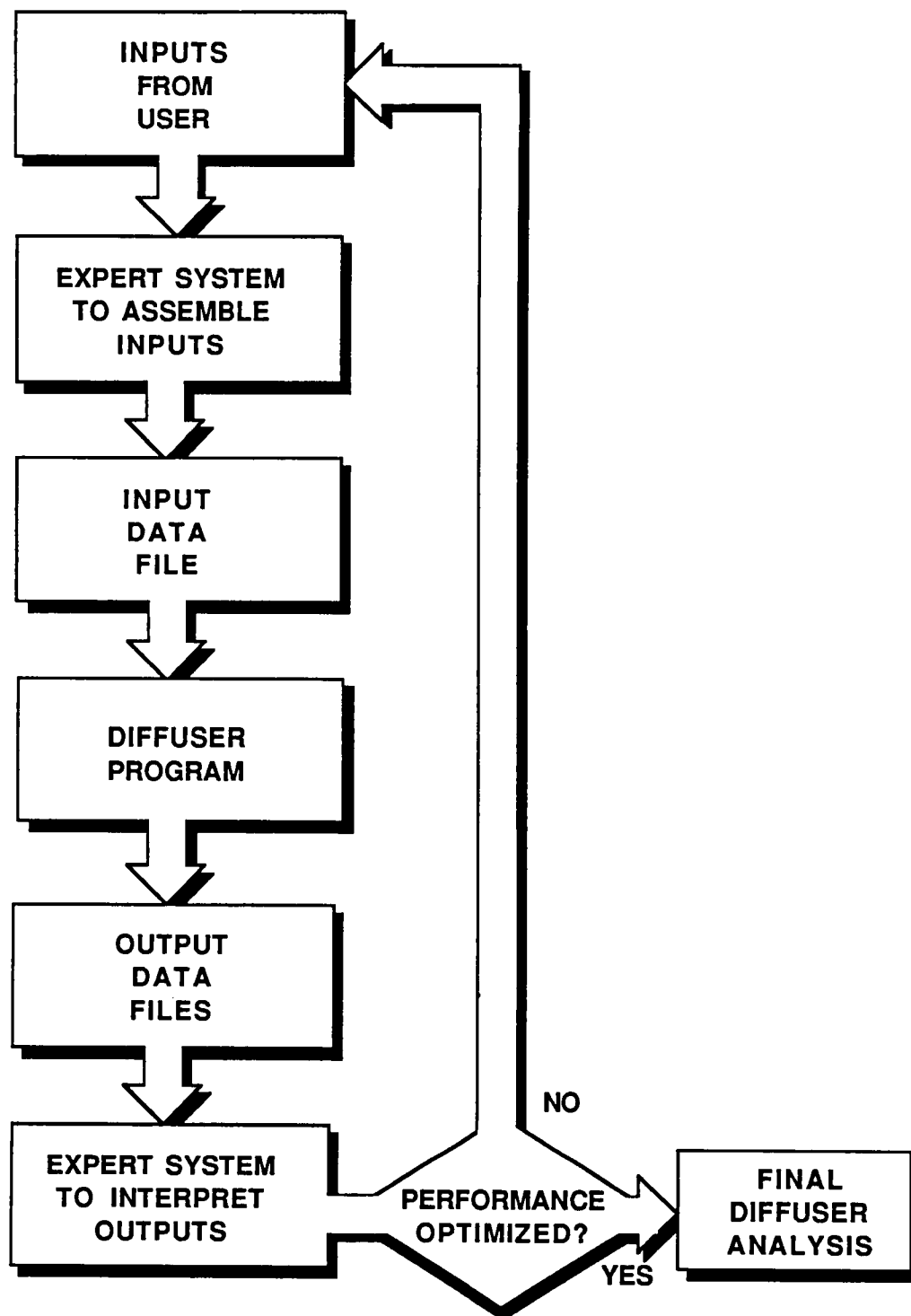
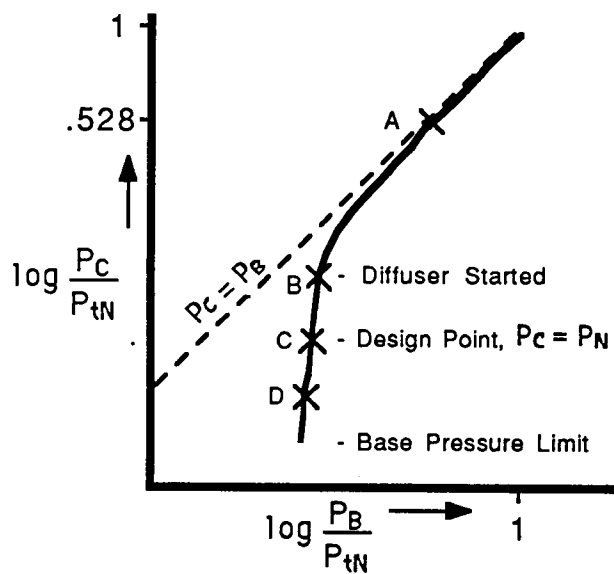


Figure1. Flow of Data Through the Diffuser Expert System





Assumptions:

- no friction losses
- adiabatic
- $T_t$  constant

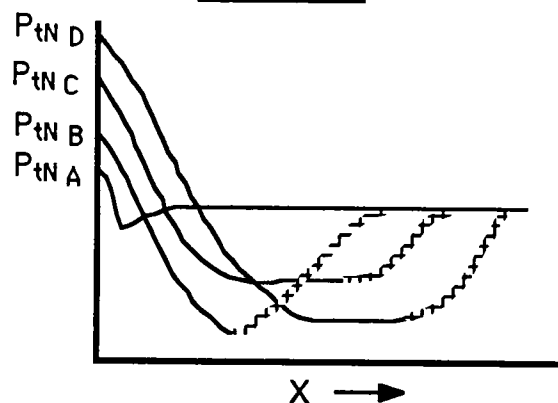
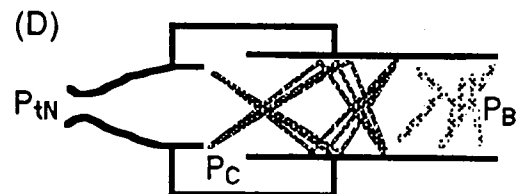
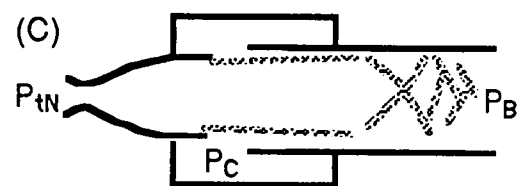
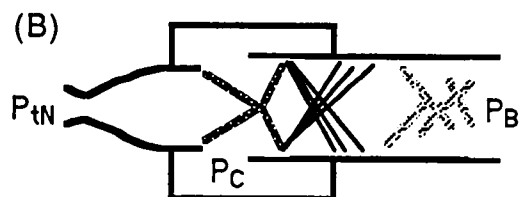
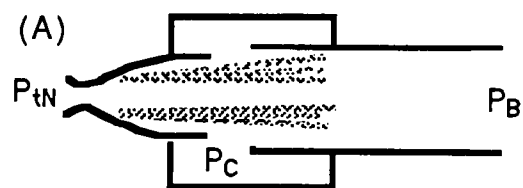


Figure 3. Diffuser Flow Development

# RESERVOIR & GEOMETRY CONDITIONS

|                                 |                   |                      |      |
|---------------------------------|-------------------|----------------------|------|
| RESERVOIR TOTAL PRESSURE        | (PTN)             | PSIA, DEFAULT: 100   | ?    |
| RESERVOIR TOTAL TEMPERATURE     | (TTN)             | DEG R, DEFAULT: 1500 | ?    |
| RESERVOIR SPECIFIC HEAT         | (CPN) FT#/SLUG-R, | DEFAULT: 6479        | ?    |
| RESERVOIR GAMMA                 | (GAM-N)           | , DEFAULT: 1.4       | 1.36 |
| NOZZLE EXIT MACH NUMBER         | (MN)              | , DEFAULT: 4         | ?    |
| NOZZLE EXIT: GAMMA              | (GAMMA 2)         | , DEFAULT: 1.4       | ?    |
| NOZZLE EXIT: SPECIFIC HEAT      | (CP2/CPN)         | , DEFAULT: 1         |      |
| NOZZLE EXIT: TEMPERATURE        | (TT2/TTN)         | , DEFAULT: 1         |      |
| NOZZLE THROAT AREA              | (AN*)             | SQ FT, DEFAULT: .024 |      |
| NOZZLE EXIT AREA                | (A2/AN*)          | , DEFAULT: 12.5      |      |
| DIFFUSER THROAT AREA            | (AB/AN*)          | , DEFAULT: 20.37     |      |
| DISTANCE BTWN NOZZLE & DIFFUSER | (L/DB)            | , DEFAULT: .4        |      |
| (AB/AN)* - (A2/AN*) =           | (A3/AN*)          | , DEFAULT: 7.87      |      |

ENTER '1' TO ACCEPT DEFAULTS; '0' TO MAKE CHANGES

Figure 4. Sample MENU.EXE Screen for Accepting Input  
Parameter Changes to the File BAUER.DOC

APTU-II M=4.0 Dn=32"

## INPUT

|                     |                     |                     |                     |                      |
|---------------------|---------------------|---------------------|---------------------|----------------------|
| PT1/PTN= .0000E+00  | TT1/TTN= 1.0000E+00 | CP1/CPN= 1.0000E+00 | GAMMA1= 1.3400E+00  | A1/AN*= 1.0000E+00   |
| A1/A1*= 1.0000E+00  | KJ= 1.0000E-15      | KE= .0000E+00       | KP= .0000E+00       | PT2/PTN= 1.0000E+00  |
| GAMMA2= 1.3400E+00  | A2/AN*= 1.0710E+01  | CP2/CPN= 1.0000E+00 | CDS= .0000E+00      | L/DB= 1.0000E+00     |
| AB/AN*= 4.7060E+01  | AI/AN*= 1.0000E+00  | AS/AN*= 2.4000E+00  | GAMMA= 1.3400E+00   | AB1/AN*= .0000E+00   |
| PB1/P2= 1.0000E+00  | AB2/AN*= .0000E+00  | MN= 3.7800E+00      | TT2/TTN= 1.0000E+00 | CPP/CPN= 1.0000E+00  |
| TTP/TTN= 1.0000E+00 | CPE/CPN= 1.0000E+00 | TTE/TTN= 1.0000E+00 | GAMMA= 1.3400E+00   | GAMMAE= 1.3400E+00   |
| CPJ/CPN= 1.0000E+00 | TTJ/TTN= 1.0000E+00 | A3/AN*= 3.6350E+01  | GAMMAJ= 1.3400E+00  | ABE/AN*= 4.7050E+01  |
| RJ/RN= 8.0000E-01   | XJ/RN= -1.0000E+00  | DN/RN= 2.0000E-01   | PTN= 1.0000E+03     | DN*/RN= 2.0000E-01   |
| AS1/AN*= 1.0000E+00 | AB1/AN*= 8.7900E+01 | A4/AN*= 3.5642E+01  | AB4/AN*= 5.2013E+00 | A4/A4*= 2.5000E+01   |
| AS2/AN*= 1.0000E+00 | CP5/CPN= 1.0000E+00 | G5/GB= 1.0000E+00   | TT5/TTN= 1.0000E+00 | G4= 1.3300E+00       |
| CP4/CPN= 1.0300E+00 | TT4/TTN= 1.1800E+00 | CDS1= .0000E+00     | CDS2= .0000E+00     | PT4/PTN= -1.0000E+01 |
| AM*= 4.1720E-01     | CPN= 6.7550E+03     | TTN= 1.7000E+03     | HA= .0000E+00       | HAM= .0000E+00       |
| KW= 1.0000E-01      | KWS= .0000E+00      | KA= 2.0000E+00      | TBA/TTN= 2.0000E+00 | KI= .0000E+00        |
| A1E/AN*= 8.7900E+01 | MT= -1.0000E+00     |                     |                     |                      |

## 0 CONSTANT OUTPUT

|                     |                     |                     |                     |                     |
|---------------------|---------------------|---------------------|---------------------|---------------------|
| C1= 3.8118E-01      | C2= 8.4169E-01      | CT3/CTN= 1.0000E+00 | G3/GN= 1.0000E+00   | G3= 1.3400E+00      |
| CP3/CPN= 1.0000E+00 | TT3/TTN= 1.0000E+00 | M1/MN= .0000E+00    | M2/MN= 1.0000E+00   | M3/MN= 1.0000E-15   |
| MI/MN= 9.3371E-02   | H= 1.0066E+00       | CTB/CTN= 7.2133E-01 | CPB/CPN= 1.0683E+00 | TTB/TTN= 6.7520E-01 |
| GB/GN= 9.9529E-01   | GB= 1.3337E+00      | F1/PAN*= .0000E+00  | F2/PAN*= 1.6768E+00 | F1/PAN*= 1.5657E-01 |
| FS/PAN*= .0000E+00  | P2/PT2= 7.7686E-03  | M1= 1.0000E+00      | M2= 3.7807E+00      | PN/PTN= 7.7767E-03  |
| CP5/CPN= 1.0683E+00 | G5= 1.3337E+00      | TT5/TTN= 6.7520E-01 | C4= 8.8084E-01      | P4/PT4= 2.4110E-03  |
| M4= 4.5806E+00      |                     |                     |                     |                     |

| PC/PTN     | PEX/PTN    | P3/P2      | PB/PTN     | PC/PN      | PB/PC      | M3         | M8         |
|------------|------------|------------|------------|------------|------------|------------|------------|
| 8.8900E-03 | 3.7135E-02 | 1.1443E+00 | 3.5004E-02 | 1.1432E+00 | 3.9376E+00 | 2.9179E-16 | 2.9884E-01 |
| 7.7800E-03 | 3.6224E-02 | 1.0015E+00 | 3.4031E-02 | 1.0004E+00 | 4.3743E+00 | 3.3342E-16 | 3.0722E-01 |
| 6.9250E-03 | 3.5520E-02 | 8.9141E-01 | 3.3277E-02 | 8.9048E-01 | 4.8054E+00 | 3.7458E-16 | 3.1408E-01 |
| 6.0730E-03 | 3.4817E-02 | 7.8174E-01 | 3.2520E-02 | 7.8092E-01 | 5.3550E+00 | 4.2714E-16 | 3.2127E-01 |
| 5.2210E-03 | 3.4111E-02 | 6.7206E-01 | 3.1758E-02 | 6.7136E-01 | 6.0830E+00 | 4.9684E-16 | 3.2884E-01 |
| 4.3690E-03 | 3.3403E-02 | 5.6239E-01 | 3.0991E-02 | 5.6180E-01 | 7.0936E+00 | 5.9373E-16 | 3.3684E-01 |
| 3.5170E-03 | 3.2692E-02 | 4.5272E-01 | 3.0217E-02 | 4.5225E-01 | 8.5921E+00 | 7.3756E-16 | 3.4531E-01 |
| 2.6650E-03 | 3.1979E-02 | 3.4305E-01 | 2.9437E-02 | 3.4269E-01 | 1.1046E+01 | 9.7336E-16 | 3.5428E-01 |
| 1.8130E-03 | 3.1262E-02 | 2.3337E-01 | 2.8649E-02 | 2.3313E-01 | 1.5803E+01 | 1.4308E-15 | 3.6383E-01 |
| 9.6100E-04 | 3.0543E-02 | 1.2370E-01 | 2.7852E-02 | 1.2357E-01 | 2.8984E+01 | 2.6993E-15 | 3.7401E-01 |
| 2.9371E-02 | 5.3596E-02 | 3.7807E+00 | 5.2172E-02 | 3.7768E+00 | 1.7764E+00 | 8.8319E-17 | 2.0131E-01 |

## 0 P3/P2 GREATER THAN M2

## 0 STARTED

|                 |                  |                 |            |            |            |            |            |
|-----------------|------------------|-----------------|------------|------------|------------|------------|------------|
| 2.9371E-02      | 5.3596E-02       | 3.7807E+00      | 5.2172E-02 | 3.7768E+00 | 1.7764E+00 | 8.8319E-17 | 2.0131E-01 |
| PC = 2.9371E+01 | PEX = 5.3596E+01 | PB = 5.2172E+01 |            |            |            |            |            |

## 0 STARTING WHEN EXHAUSTING TO ATMOSPHERE

|                    |                  |                 |                 |                 |                |                 |
|--------------------|------------------|-----------------|-----------------|-----------------|----------------|-----------------|
| PC/PTN= 2.9396E-02 | PTN1= 2.8739E+02 | PN1= 2.2350E+00 | ALT= 4.4180E+04 | LMN= 2.1944E+02 | M8= 2.0116E-01 | LMW= 2.1944E+01 |
|--------------------|------------------|-----------------|-----------------|-----------------|----------------|-----------------|

## 0 FAILED TO START WHEN EXHAUSTING TO ATMOSPHERE

|                     |                     |                 |            |            |            |            |
|---------------------|---------------------|-----------------|------------|------------|------------|------------|
| FOR MBE= 2.7555E-01 | PTB/PC= 3.23425E+00 | WSC= .00000E+00 |            |            |            |            |
| 1.2356E-02          | 3.9962E-02          | 1.5905E+00      | 3.8001E-02 | 1.5888E+00 | 3.0756E+00 | 2.0994E-16 |

Figure 5. Sample PRIN6.DOC Output File for the Free Jet Diffuser  
Produced by BAUER.EXE

1

## JET PUMP ADDITIONS TO DIFFUSER PROGRAM NO. 2

APTU-II M=4.0 Dn=32"

## INPUT

|                     |                     |                     |                     |                      |
|---------------------|---------------------|---------------------|---------------------|----------------------|
| PT1/PTN= .0000E+00  | TT1/TTN= 1.0000E+00 | CP1/CPN= 1.0000E+00 | GAMMA1= 1.3400E+00  | A1/AN*= 1.0000E+00   |
| A1/A1*= 1.0000E+00  | KJ= 1.0000E-15      | KE= .0000E+00       | KP= .0000E+00       | PT2/PTN= 1.0000E+00  |
| GAMMA2= 1.3400E+00  | A2/AN*= 1.0710E+01  | CP2/CPN= 1.0000E+00 | COS= .0000E+00      | L/OB= 1.0000E+00     |
| AB/AN*= 4.7060E+01  | A1/AN*= 1.0000E+00  | AS/AN*= 2.4000E+00  | GAMMA= 1.3400E+00   | AB1/AN*= .0000E+00   |
| PB1/P2= 1.0000E+00  | AB2/AN*= .0000E+00  | MN= 3.7800E+00      | TT2/TTN= 1.0000E+00 | CPP/CPN= 1.0000E+00  |
| TTP/TTN= 1.0000E+00 | CPE/CPN= 1.0000E+00 | TTE/TTN= 1.0000E+00 | GAMMAJ= 1.3400E+00  | GAMMAE= 1.3400E+00   |
| CPJ/CPN= 1.0000E+00 | TTJ/TTN= 1.0000E+00 | A3/AN*= 3.6350E+01  | GAMMAJ= 1.3400E+00  | ABE/AN*= 4.7050E+01  |
| RJ/RN= 8.0000E-01   | XJ/RN= -1.0000E+00  | DN/RN= 2.0000E-01   | PTN= 1.0000E+03     | DN*/RN= 2.0000E-01   |
| AS1/AN*= 1.0000E+00 | AB1/AN*= 8.7900E+01 | A4/AN*= 3.5642E+01  | AB4/AN*= 5.2013E+00 | A4/A4*= 2.5000E+01   |
| AS2/AN*= 1.0000E+00 | CPS/CPB= 1.0000E+00 | G5/G6= 1.0000E+00   | TT5/TTB= 1.0000E+00 | G4= 1.3300E+00       |
| CP4/CPN= 1.0300E+00 | TT4/TTN= 1.1800E+00 | COS1= .0000E+00     | COS2= .0000E+00     | PT4/PTN= -1.0000E+00 |
| AN*= 4.1720E-01     | CPN= 6.7550E+03     | TTN= 1.7000E+03     | HA= .0000E+00       | HAN= .0000E+00       |
| KW= 1.0000E-01      | KWS= .0000E+00      | KA= 2.0000E+00      | TBA/TTN= 2.0000E+00 | KI= .0000E+00        |
| A1E/AN*= 8.7900E+01 | MT= -1.0000E+00     |                     |                     |                      |

## D CONSTANT OUTPUT

|                     |                     |                     |                     |                     |
|---------------------|---------------------|---------------------|---------------------|---------------------|
| C1= 3.8118E-01      | C2= 8.4169E-01      | CT3/CTN= 1.0000E+00 | G3/GN= 1.0000E+00   | G3= 1.3400E+00      |
| CP3/CPN= 1.0000E+00 | TT3/TTN= 1.0000E+00 | M1/MN= .0000E+00    | M2/MN= 1.0000E+00   | M3/MN= 1.0000E-15   |
| M1/MN= 9.3371E-02   | H= 1.0066E+00       | CTB/CTN= 7.2133E-01 | CPB/CPN= 1.0683E+00 | TTB/TTN= 6.7520E-01 |
| GB/GN= 9.9529E-01   | GB= 1.3337E+00      | F1/PAN*= .0000E+00  | F2/PAN*= 1.6768E+00 | F1/PAN*= 1.5657E-01 |
| FS/PAN*= .0000E+00  | P2/PT2= 7.7686E-03  | M1= 1.0000E+00      | M2= 3.7807E+00      | PN/PTN= 7.7767E-03  |
| CPS/CPN= 1.0683E+00 | G5= 1.3337E+00      | TT5/TTN= 6.7520E-01 | C4= 8.8084E-01      | P4/PT4= 2.4110E-03  |
| M4= 4.5806E+00      |                     |                     |                     |                     |

| PC/PTN | PB1/PTN | PTB1/PTN | PT4/PTN | K4 | M5 | MB1 | PB1/PB | TTB1/TTN | GB1 | PT5/PTB | CB1/CPN | M55 |
|--------|---------|----------|---------|----|----|-----|--------|----------|-----|---------|---------|-----|
|--------|---------|----------|---------|----|----|-----|--------|----------|-----|---------|---------|-----|

|            |            |            |            |            |       |       |            |            |        |            |            |       |
|------------|------------|------------|------------|------------|-------|-------|------------|------------|--------|------------|------------|-------|
| 8.8900E-03 | 3.5942E-01 | 3.9789E-01 | 1.4522E+01 | 1.8942E+01 | .2987 | .3934 | 1.0268E+01 | 1.1536E+00 | 1.3302 | 1.0002E+00 | 1.0319E+00 | .1658 |
| 7.7803E-03 | 3.4938E-01 | 3.8687E-01 | 1.4119E+01 | 1.8415E+01 | .3071 | .3939 | 1.0266E+01 | 1.1529E+00 | 1.3302 | 1.0002E+00 | 1.0320E+00 | .1598 |
| 6.9250E-03 | 3.4160E-01 | 3.7833E-01 | 1.3806E+01 | 1.8007E+01 | .3140 | .3944 | 1.0265E+01 | 1.1523E+00 | 1.3302 | 1.0002E+00 | 1.0320E+00 | .1631 |
| 6.0730E-03 | 3.3380E-01 | 3.6977E-01 | 1.3492E+01 | 1.7598E+01 | .3211 | .3948 | 1.0264E+01 | 1.1517E+00 | 1.3302 | 1.0002E+00 | 1.0321E+00 | .1665 |
| 5.2210E-03 | 3.2595E-01 | 3.6116E-01 | 1.3176E+01 | 1.7186E+01 | .3287 | .3952 | 1.0263E+01 | 1.1511E+00 | 1.3302 | 1.0002E+00 | 1.0321E+00 | .1701 |
| 4.3690E-03 | 3.1804E-01 | 3.5248E-01 | 1.2858E+01 | 1.6770E+01 | .3367 | .3957 | 1.0262E+01 | 1.1504E+00 | 1.3302 | 1.0002E+00 | 1.0322E+00 | .1738 |
| 3.5170E-03 | 3.1008E-01 | 3.4374E-01 | 1.2537E+01 | 1.6352E+01 | .3452 | .3962 | 1.0261E+01 | 1.1497E+00 | 1.3302 | 1.0002E+00 | 1.0322E+00 | .1777 |
| 2.6650E-03 | 3.0204E-01 | 3.3492E-01 | 1.2213E+01 | 1.5930E+01 | .3541 | .3967 | 1.0260E+01 | 1.1489E+00 | 1.3302 | 1.0002E+00 | 1.0323E+00 | .1818 |
| 1.8130E-03 | 2.9394E-01 | 3.2602E-01 | 1.1886E+01 | 1.5503E+01 | .3637 | .3972 | 1.0260E+01 | 1.1481E+00 | 1.3302 | 1.0002E+00 | 1.0323E+00 | .1862 |
| 9.6100E-04 | 2.8575E-01 | 3.1704E-01 | 1.1556E+01 | 1.5072E+01 | .3738 | .3978 | 1.0259E+01 | 1.1473E+00 | 1.3302 | 1.0002E+00 | 1.0324E+00 | .1908 |
| 2.9371E-02 | 5.3700E-01 | 5.9264E-01 | 2.1645E+01 | 2.8231E+01 | .2012 | .3874 | 1.0293E+01 | 1.1620E+00 | 1.3301 | 1.0002E+00 | 1.0313E+00 | .1071 |

## D STARTED

|            |            |            |            |            |       |       |            |            |        |            |            |       |
|------------|------------|------------|------------|------------|-------|-------|------------|------------|--------|------------|------------|-------|
| 2.9371E-02 | 5.3700E-01 | 5.9264E-01 | 2.1645E+01 | 2.8231E+01 | .2012 | .3874 | 1.0293E+01 | 1.1620E+00 | 1.3301 | 1.0002E+00 | 1.0313E+00 | .1071 |
| 2.9371E+01 | 5.3700E+02 | 5.9264E+02 | 2.1645E+04 |            |       |       |            |            |        |            |            |       |

## D STARTING WHEN EXHAUSTING TO ATMOSPHERE

|                    |                   |                 |                 |                 |                 |
|--------------------|-------------------|-----------------|-----------------|-----------------|-----------------|
| PC/PTN= 2.9396E-02 | PTN1= 2.7922E+01  | PN1= 2.1714E-01 | ALT= 9.2497E+04 | LMN= 2.1309E+01 | LM4= 6.0182E+02 |
| LMT= 6.2313E+02    | V5/V4= 7.1612E-02 | PT4= 6.0460E+02 | K4= 2.8243E+01  | MB1= 3.8739E-01 | M55= 1.0710E-01 |
| LMW= 2.1309E+00    | FBI= 1.2003E+05   | DF= 1.1721E+05  | FM= 2.8128E+03  |                 |                 |

Figure 6. Sample PRIN8.DOC Output File for the Jet Pump Addition  
Produced by BAUER.EXE

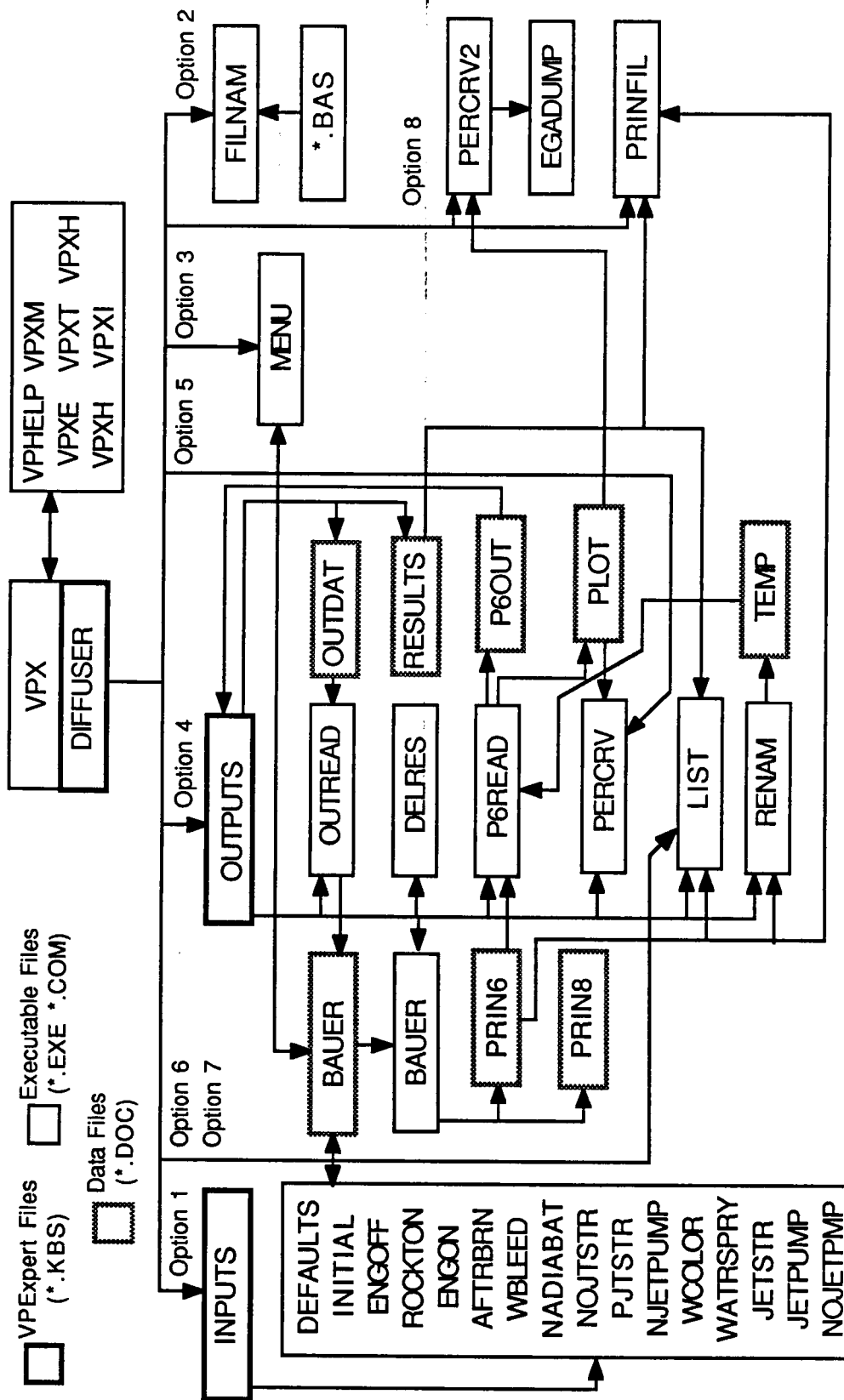


Figure 7. Diffuser Expert System Program Call Chart

### VP-Expert Programs

|              |                                     |
|--------------|-------------------------------------|
| DIFFUSER.KBS | Driver program, displays main menu. |
| INPUTS.KBS   | Assembles inputs.                   |
| OUTPUTS.KBS  | Interprets outputs.                 |

### Executable Programs

|                |                                                                  |
|----------------|------------------------------------------------------------------|
| AFTERBRN.EXE   | Accepts variables for simulating engine afterburn.               |
| BAUER.EXE      | Diffuser math model.                                             |
| BRUN45.EXE     | QuickBasic library routines.                                     |
| DEFAULTS.EXE   | Sets variable default values.                                    |
| DELRES.EXE     | Deletes file RESULTS to allow a new one to be built.             |
| EGADUMP.EXE    | Library routine that dumps EGA graphics to printer.              |
| ENGOFF.EXE     | Sets variable default values for engine not running.             |
| ENGON.EXE      | Accepts variables for engine running.                            |
| FILNAM.EXE     | Renames PRIN6.DOC to TEMP.DOC for retention.                     |
| INITIAL.EXE    | Accepts values for required input variables.                     |
| JETPUMP.EXE    | Accepts variables for a jet pump simulation.                     |
| JETSTR.EXE     | Accepts variables for simulating a jet stretcher.                |
| LIST.COM       | Displays ASCII data files on computer screen                     |
| MENU.EXE       | Original variable input routine provided with BAUER.EXE.         |
| NADIABATIC.EXE | Accepts variables for non-adiabatic flow.                        |
| NJETPUMP.EXE   | Sets variable defaults for no jet pump.                          |
| NOJETPMP.EXE   | Sets variable defaults for a non-optimum jet pump.               |
| NOJTSTR.EXE    | Sets variable defaults for no jet stretcher.                     |
| OUTREAD.EXE    | Reads input modifications by OUTPUTS.KBS and corrects BAUER.DOC. |

Figure 8. Diffuser Expert System Files

|              |                                                                                |
|--------------|--------------------------------------------------------------------------------|
| PERCRV.EXE   | Produces diffuser performance plot.                                            |
| PERCRV2.EXE  | Produces diffuser performance plot and prints it.                              |
| PJTSTR.EXE   | Accepts defaults for simulating a porous jetstretcher.                         |
| PRINFIL.EXE  | Prints RESULTS and PRIN6.DOC.                                                  |
| P6READ.EXE   | Reads PRIN6.DOC and reforms for use by OUTPUTS.KBS.                            |
| RENAM.EXE    | Renames PRIN6.DOC to TEMP.DOC for holding.                                     |
| ROCKTON.EXE  | Accepts variables for when engine is a rocket.                                 |
| WATRSPRY.EXE | Accepts variables for simulating a cooling waterspray.                         |
| WBLEED.EXE   | Accepts variables for simulating chamber leaks.                                |
| WCOLER.EXE   | Accepts variables for simulating a cooler before the jet pump diffuser region. |
| VPX.EXE      | VP-Expert development tool, VPXE, VPXH, VPXM, VPXT, VPXI are supporting files. |

### Data Files

|           |                                                                        |
|-----------|------------------------------------------------------------------------|
| BAUER.DOC | Input file for BAUER.EXE.                                              |
| OUTDAT    | Output file from OUTPUTS.KBS for modifying BAUER.DOC with OUTREAD.EXE. |
| PLOT.DOC  | Contains data for diffuser performance curve.                          |
| PRIN6.DOC | Output file from BAUER.EXE.                                            |
| PRIN8.DOC | Jet pump output file from BAUER.EXE.                                   |
| P6OUT     | Output file from P6READ.EXE to form readable by OUTPUTS.KBS.           |
| RESULTS   | Contains OUTPUTS.KBS analysis results.                                 |
| TEMP.DOC  | Holding file for one copy of PRIN6.DOC.                                |

Figure 8 (con't). Diffuser Expert System Files

MENU OPTIONS ARE

- 1 - CREATE NEW DATA FILE FOR INPUTS
- 2 - USE OLD DATA FILE FOR INPUTS
- 3 - QUICK CHANGE OF INPUT DATA
- 4 - RUN DIFFUSER PROGRAM
- 5 - REVIEW PERFORMANCE CURVE
- 6 - REVIEW OUTPUT DATA FILE
- 7 - REVIEW DIFFUSER ANALYSIS
- 8 - PRINT REPORT
- X - EXIT CONSULTATION

PICK AN OPTION

1  
4  
7

2  
5  
8

3  
6  
X

Figure 9. Sample of the Main Menu for the Diffuser Expert System

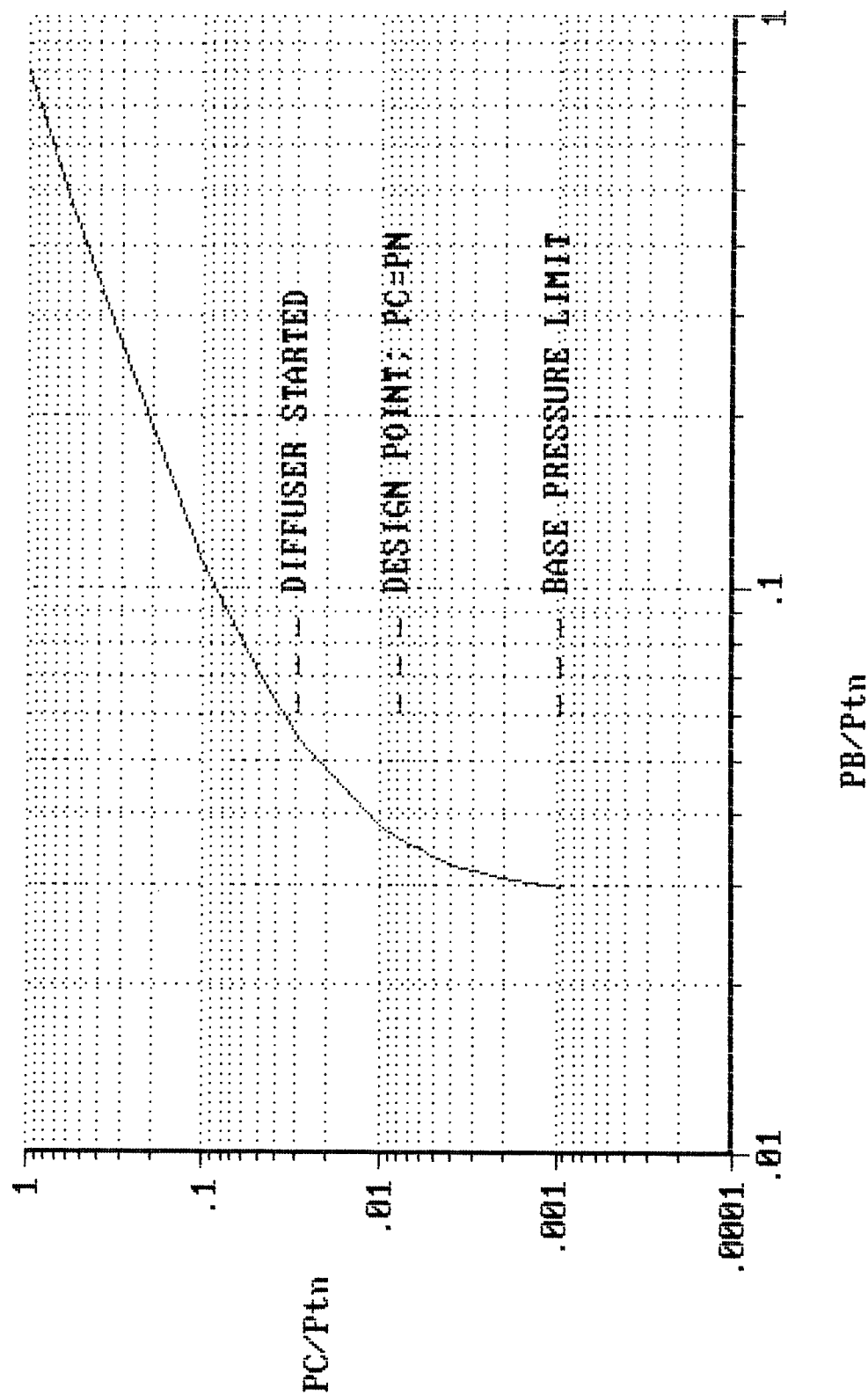


Figure 10. Sample of a Diffuser Performance Curve

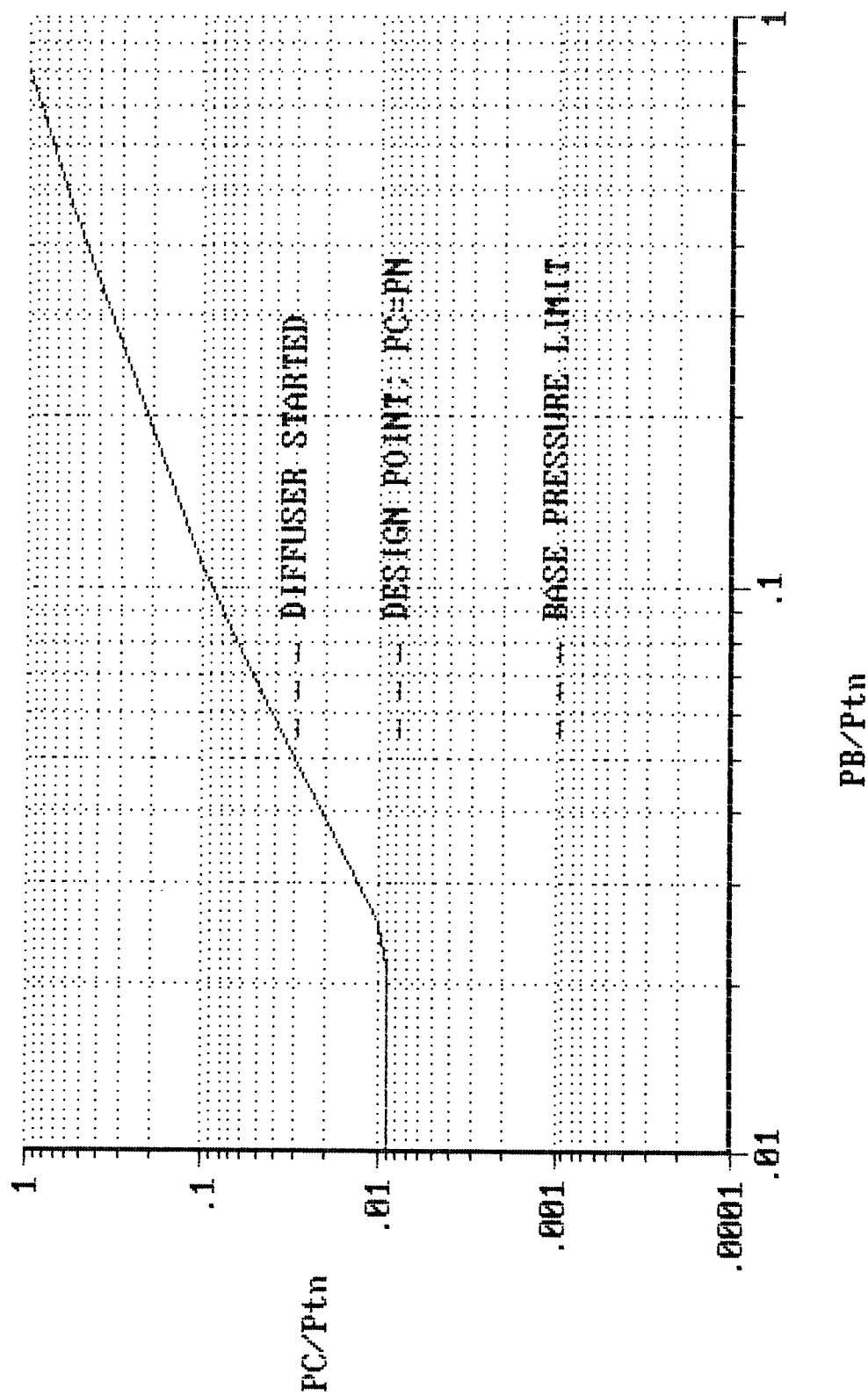


Figure 11. Sample of a Diffuser Performance Curve Showing a Choked Diffuser

THE SATURATED WATER SPRAY FLOW; ZKWS=0.299010

THE SUGGESTED CHAMBER PRESSURE RATIOS ARE

PC/PTN[1]=1

PC/PTN[2]=0.775000

PC/PTN[3]=0.550000

PC/PTN[4]=0.325000

PC/PTN[5]=.1

PC/PTN[6]=0.082000

PC/PTN[7]=0.064000

PC/PTN[8]=0.046000

PC/PTN[9]=0.028000

PC/PTN[10]=.01"

PC/PTN[11]=0.008888

PC/PTN[12]=0.007777

PC/PTN[13]=0.006925

PC/PTN[14]=0.006073

PC/PTN[15]=0.005221

PC/PTN[16]=0.004369

PC/PTN[17]=0.003517

PC/PTN[18]=0.002665

PC/PTN[19]=0.001813

PC/PTN[20]=0.000961

AN/AN\* = 47.131207, ZRATIO=1.001513"

#### DIFFUSER ANALYSIS

The diffuser performance curve is along the PC-PB line in the diffuser started region. This shows a diffuser with a poor pumpdown of the chamber. SLOPE = 0.525586

The diffuser flow has started and is flowing full

Most testing should be done around the diffuser started chamber pressure of PC/PTN= 0.0293. In this region of the performance curve the test rhombus is shortened, but the diffuser will operate with the smallest value of PTN for a constant PB.

The diffuser will operate in the started conditions while exhausting to atmosphere at:

PTN = 278.83 psia    PB = 15 psia    MB = 0.229    PN = 2.168 psia  
Simulated Altitude = 44811 Ft

The Nozzle will operate at it's design point (PC=PN) at:    PC/PTN=0.007777

The diffuser has choked for the following reasons:

- Diffuser choking at exit (MB=1.0), diffuser minimum area  
ABE/AN\* = 26.00 is less than the diffuser area AB/AN\* = 47.06.

The reduction in area can cause the diffuser to choke.

- Diffuser choking at exit (MB=1.0), the model drag is too large;  
Either the diffuser area must be increased or the model size decreased.  
Either the diffuser area must be increased or the model size decreased.

Figure 12. Sample of the RESULTS File Produced by the Diffuser  
Expert System

APPENDIX B  
DIFFUSER PERFORMANCE PROGRAM  
VARIABLE DEFINITIONS

| Variable                | Definition                                                                                                                  | Program Name | Units |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------------|--------------|-------|
| $A_1 / A_1^*$           | Area ratio test body engine nozzle                                                                                          | A1/A1*       |       |
| $A_1 / A_N^*$           | Nondimensional area of test body engine exit                                                                                | A1/AN*       |       |
| $A_{B1E} / A_N^*$<br>48 | Nondimensional minimum area of the jet pump diffuser exit                                                                   | A1E/AN*      |       |
| $A_2 / A_N^*$           | Nondimensional area between test body and jet stretcher at the engine inlet. Nozzle exit area if there is no jet stretcher. | A2/AN*       |       |
| $A_3 / A_N^*$           | Nondimensional area of gap between jet stretcher and diffuser                                                               | A3/AN*       |       |
| $A_4 / A_4^*$           | Area ratio jet pump nozzle                                                                                                  | A4/A4*       |       |
| $A_4 / A_N^*$           | Nondimensional area of jet pump nozzle exit                                                                                 | A4/AN*       |       |

| Variable         | Definition                                                | Program Name          | Units |
|------------------|-----------------------------------------------------------|-----------------------|-------|
| $A_B / A_N^*$    | Nondimensional area of free jet diffuser exit             | AB/AN*                |       |
| $A_{B1} / A_N^*$ | Nondimensional area of the jet pump diffuser exit         | AB1/AN*               |       |
| $A_{b1} / A_N^*$ | Nondimensional area of test article base                  | AB1/AN*<br>(repeated) |       |
| $A_{b2} / A_N^*$ | Nondimensional area of jet stretcher base                 | AB2/AN*               |       |
| $A_{b4} / A_N^*$ | Nondimensional area of jet pump nozzle base               | AB4/AN*               |       |
| $A_{BE} / A_N^*$ | Nondimensional minimum area of the free jet diffuser exit | ABE/AN*               |       |
| $A_i / A_N^*$    | Nondimensional area of test article engine inlet          | AI/AN*                |       |

| Variable           | Definition                                                                     | Program Name | Units  |
|--------------------|--------------------------------------------------------------------------------|--------------|--------|
| ALT                | Altitude simulated in test cell based on the Standard Atmosphere and using PN1 | ALT          | ft     |
| $A_N^*$            | Free jet nozzle throat area                                                    | $A_N^*$      | $ft^2$ |
| $A_s^* / A_N^*$    | Nondimensional reference area of free jet diffuser surface, model, and support | $AS/AN^*$    |        |
| $A_{s1}^* / A_N^*$ | Nondimensional reference area of jet pump region surface                       | $AS1/AN^*$   |        |
| $A_{s2}^* / A_N^*$ | Nondimensional reference area of jet pump diffuser surface                     | $AS2/AN^*$   |        |
| $C_1$              | Crocco number at test article engine exit (Egn. 2. Appendix C)                 | $C_1$        |        |
| $C_2$              | Crocco number at region 2 between model and jet stretcher (Eqn. 3 App. C)      | $C_2$        |        |

| Variable         | Definition                                                                      | Program Name | Units |
|------------------|---------------------------------------------------------------------------------|--------------|-------|
| $C_4$            | Crocco number of jet pump flow (Eqn. 44 App. C)                                 | C4           |       |
| $C_{PB1}/C_{PN}$ | Nondimensional specific heat at the jet pump diffuser exit (Eqn. 64 App. C)     | CB1/CPN      |       |
| $C_{DS}$         | Drag coefficient of free jet diffuser surface, model, and support               | CDS          |       |
| $C_{DS1}$        | Drag coefficient of jet pump region                                             | CDS1         |       |
| $C_{DS2}$        | Drag coefficient of jet pump diffuser surface                                   | CDS2         |       |
| $C_{P1}/C_{PN}$  | Nondimensional specific heat at test article engine exit                        | CP1/CPN      |       |
| $C_{P2}/C_{PN}$  | Nondimensional specific heat region between test article body and jet stretcher | CP2/CPN      |       |

| Variable        | Definition                                                                                                          | Program Name | Units |
|-----------------|---------------------------------------------------------------------------------------------------------------------|--------------|-------|
| $C_{P3}/C_{PN}$ | Nondimensional specific heat at jet stretcher gap (Eqn. 7 App. C)                                                   | CP3/CPN      |       |
| $C_{P4}/C_{PN}$ | Nondimensional specific heat jet pump reservoir                                                                     | CP4/CPN      |       |
| $C_{P5}/C_{PB}$ | Specific heat jet pump diffuser divided by Specific heat free jet diff. exit (set to zero for no jet pump printout) | CP5/CPB      |       |
| $C_{P5}/C_{PN}$ | Nondimensional specific heat jet pump region (Eqn. 43 App. C)                                                       | CP5/CPN      |       |
| $C_{PB}/C_{PN}$ | Nondimensional specific heat at the free jet diffuser exit (Eqn. 16 App. C)                                         | CPB/CPN      |       |
| $C_{PE}/C_{PN}$ | Nondimensional specific heat of the external bleed flow                                                             | CPE/CPN      |       |
| $C_{Pi}/C_{PN}$ | Nondimensional specific heat at radial gap between nozzle exit and jet stretcher inlet                              | CPJ/CPN      |       |

| Variable                              | Definition                                                                            | Program Name | Units             |
|---------------------------------------|---------------------------------------------------------------------------------------|--------------|-------------------|
| $C_{PN}$                              | Nozzle reservoir specific heat at constant pressure                                   | CPN          | ft-lb/slug-°<br>R |
| $C_{PP}/C_{PN}$                       | Nondimensional specific heat of flow through the jet stretcher porous wall            | CPP/CPN      |                   |
| $\frac{C_{P3} T_{t3}}{C_{PN} T_{tN}}$ | Nondimensional total enthalpy at the diffuser gap (Eqn. 4 App. C)                     | CT3/CTN      |                   |
| $\frac{C_{PB} T_{tB}}{C_{PN} T_{tN}}$ | Nondimensional total enthalpy at the free jet diffuser exit (Eqn. 15 App. C)          | CTB/CTN      |                   |
| $D_B$                                 | Free jet diffuser exit diameter                                                       | DB           | f t               |
| DF                                    | Thrust difference between jet pump diffuser exit and free jet nozzle (Eqn. 78 App. C) | DF           | lb f              |
| $\delta_N^*/r_N$                      | Boundary layer displacement thickness of free jet nozzle/ radius free jet nozzle exit | DN*/RN       |                   |

| Variable           | Definition                                                                                                           | Program Name | Units |
|--------------------|----------------------------------------------------------------------------------------------------------------------|--------------|-------|
| $\delta_N/r_N$     | Total boundary layer thickness at free jet nozzle exit/<br>radius free jet nozzle exit                               | DN/RN        |       |
| $F_1/P_{tN} A_N^*$ | Nondimensional flow momentum at test article engine exit (Eqn. 20 App. C)                                            | F1/PAN*      |       |
| $F_2/P_{tN} A_N^*$ | Nondimensional flow momentum in the region between the test article and jet stretcher (Eqn. 21 App. C)               | F2/PAN*      |       |
| $F_{B1}$           | Flow momentum at jet pump diffuser exit for the case where the diffuser is exhausting to atmosphere (Eqn. 76 App. C) | FB1          | lbf   |
| $F_i/P_{tN} A_N^*$ | Nondimensional flow momentum at the test article engine inlet (Eqn. 23 App. C)                                       | FI/PAN*      |       |
| $F_N$              | Flow momentum at free jet nozzle exit for the case where the diffuser is exhausting to atmosphere (Eqn. 77 App. C)   | FN           | lbf   |
| $F_s/P_{tN} A_N^*$ | Nondimensional friction momentum (drag) for the free jet diffuser (Eqn. 24 App. C)                                   | FS/PAN*      |       |

| Variable            | Definition                                                                                                     | Program Name | Units |
|---------------------|----------------------------------------------------------------------------------------------------------------|--------------|-------|
| $\gamma_3$          | Specific heat ratio at the gap between the jet stretcher exit and the free jet diffuser inlet (Eqn. 6 App. C)  | G3           |       |
| $\gamma_3/\gamma_N$ | Specific heat ratio at the jet stretcher gap divided by the nozzle specific heat ratio (Eqn. 5 App. C)         | G3/GN        |       |
| $\gamma_4$          | Specific heat ratio of jet pump reservoir                                                                      | G4           |       |
| $\gamma_5$          | Specific heat ratio in the jet pump region (Eqn. 44 App. C)                                                    | G5           |       |
| $\gamma_5/\gamma_B$ | Specific heat ratio for the jet pump region flow/<br>specific heat ratio for the free jet diffuser exit region | G5/GB        |       |
| $\gamma_1$          | Specific heat ratio at test article engine exit                                                                | GAMMA1       |       |
| $\gamma_2$          | Specific heat ratio for the region between test body and jet stretcher                                         | GAMMA2       |       |

| Variable            | Definition                                                                                                                 | Program Name | Units |
|---------------------|----------------------------------------------------------------------------------------------------------------------------|--------------|-------|
| $\gamma_E$          | Specific heat ratio of external bleed flow                                                                                 | GAMMAE       |       |
| $\gamma_j$          | Specific heat ratio for the gap between nozzle exit and jet stretcher inlet                                                | GAMMAJ       |       |
| $\gamma_N$          | Specific heat ratio for the free jet nozzle reservoir                                                                      | GAMMAN       |       |
| $\gamma_P$          | Specific heat ratio for jet stretcher porous wall flow                                                                     | GAMMAP       |       |
| $\gamma_B$          | Specific heat ratio for the free jet diffuser exit region (Eqn. 19 App. C)                                                 | GB           |       |
| $\gamma_{B1}$       | Specific heat ratio at jet pump diffuser exit (Eqn. 66 App. C)                                                             | GB1          |       |
| $\gamma_B/\gamma_N$ | Specific heat ratio for the free jet diffuser exit divided by the free jet nozzle reservoir specific heat (Eqn. 18 App. C) | GBOGN        |       |

| Variable          | Definition                                                                                                                | Program Name | Units |
|-------------------|---------------------------------------------------------------------------------------------------------------------------|--------------|-------|
| H                 | Nondimensional mass flow sum of control volume 1 (Eqn. 14 App. C)                                                         | H            |       |
| $h_A$             | Afterburning energy released per slug of engine exhaust divided by $C_p$ and $T_t$ of the nozzle reservoir.               | HA           |       |
| $h_{AM}$          | Nondimensional maximum heat released for fuel afterburning limited by amount of oxygen available                          | HAM          |       |
| $\frac{m_4}{m_N}$ | Mass flow from jet pump divided by free jet nozzle mass flow (Eqn. 61 App. C)                                             | K4           |       |
| $k_A$             | Value of $M_1/M_N$ at which all oxygen in $M_N$ (nozzle flow) is consumed by afterburn of the fuel in $M_1$ (engine flow) | KA           |       |
| $k_E$             | Ratio of mass flow external bleed to nozzle mass flow                                                                     | KE           |       |
| $k_i$             | Fraction of engine mass flow bled from engine inlet before entering combustion chamber                                    | KI           |       |

| Variable | Definition                                                                                                   | Program Name | Units   |
|----------|--------------------------------------------------------------------------------------------------------------|--------------|---------|
| $k_j$    | Ratio of jet stretcher gap mass flow (reintroduced at area 3) to free jet nozzle mass flow (Eqn. 1 App. C)   | KJ           |         |
| $k_P$    | Ratio of jet stretcher porous wall mass flow to free jet nozzle mass flow                                    | KP           |         |
| $k_W$    | Ratio of water spray mass flow to free jet nozzle mass flow (if set to -1 KWS is calculated by program)      | KW           |         |
| $k_{WS}$ | Saturated ratio of water spray mass flow to free jet nozzle mass flow (Eqn. 17 App. C)                       | KWS          |         |
| $L/D_B$  | Distance from jet stretcher to free jet diffuser/Diameter of free jet diffuser                               | L/DB         |         |
| $m_4$    | Mass flow leaving the jet pump nozzle for the case of the diffuser exhausting to atmosphere (Eqn. 82 App. B) | LM4          | lbm/sec |
| $m_N$    | Mass flow leaving the free jet nozzle for the case of the diffuser exhausting to atmosphere (Eqn. 81 App. C) | LMN          | lbm/sec |

| Variable                | Definition                                                                                                                                 | Program Name | Units   |
|-------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|--------------|---------|
| $\dot{m}_T$             | Total mass flow through diffuser calculated by Diffuser Performance Program (Eqn. 84 App. C)                                               | LMT          | lbm/sec |
| $\dot{m}_w$             | Water spray mass flow for the case of the diffuser exhausting to atmosphere (Eqn. 83 App. C)                                               | LMW          | lbm/sec |
| $M_1$                   | Mach number engine exit (Eqn. 30 App. C)                                                                                                   | M1           |         |
| $\dot{m}_1 / \dot{m}_N$ | Nondimensional mass flow at the test article engine exit (Eqn. 10 App. C)                                                                  | M1/MN        |         |
| $M_2$                   | Mach number at area A2 between test article and jet stretcher or nozzle exit Mach number if there is no jet stretcher (Equation 31 App. C) | M2           |         |
| $\dot{m}_2 / \dot{m}_N$ | Mass flow area between test article and jet stretcher/free jet nozzle mass flow (Eqn. 11 App. C)                                           | M2/MN        |         |
| $M_3$                   | Mach number at gap between jet stretcher and free jet diffuser (Eqn. 32 App. C)                                                            | M3           |         |

| Variable  | Definition                                                                                  | Program Name | Units |
|-----------|---------------------------------------------------------------------------------------------|--------------|-------|
| $m_3/m_N$ | Mass flow jet stretcher gap/ free jet nozzle mass flow (Eqn. 12 App. C)                     | M3/MN        |       |
| $M_4$     | Mach number of flow leaving jet pump (Eqn. 48 App. C)                                       | M4           |       |
| $M_5$     | Mach number of flow in jet pump region (Eqn. 74 App. C)                                     | M5           |       |
| $M_{5S}$  | Drag area (AS1) corrected Mach number at region 5 in the jet pump diffuser (Eqn. 89 App. C) | M5S          |       |
| $M_B$     | Mach number free jet diffuser exit (Eqn. 34 App. C)                                         | MB           |       |
| $M_{B1}$  | Mach number jet pump diffuser exit (Eqn. 75 App. C)                                         | MB1          |       |
| $m_i/m_N$ | Mass flow test article engine inlet/ free jet nozzle mass flow (Eqn. 13 App. C)             | MI/MN        |       |

| Variable          | Definition                                                                                        | Program Name | Units   |
|-------------------|---------------------------------------------------------------------------------------------------|--------------|---------|
| $M_N$             | Free jet nozzle exit Mach number                                                                  | MN           |         |
| $\dot{m}_{TOTAL}$ | Total mass flow (set to -1 forces Diffuser Performance Program to calculate)                      | MT           | lbm/sec |
| $P_2/P_{t2}$      | Pressure area between test article and jet stretcher / total pressure of same (Eqn. 25 App. C)    | P2/PT2       |         |
| $P_3/P_2$         | Jet stretcher gap pressure/ Pressure area between test article and jet stretcher (Eqn. 41 App. C) | P3/P2        |         |
| $P_4/P_{t4}$      | Pressure at jet pump exit/total pressure of same (Eqn. 47 App. C)                                 | P4/PT4       |         |
| $P_B/P_C$         | Pressure free jet diffuser exit/ Pressure chamber (Eqn. 42 App. C)                                | PB/PC        |         |
| $P_B/P_{tN}$      | Nondimensional pressure free jet diffuser exit (Eqn. 36 App. C)                                   | PB/PTN       |         |

| Variable        | Definition                                                                                 | Program Name | Units |
|-----------------|--------------------------------------------------------------------------------------------|--------------|-------|
| $P_{b1}/P_2$    | Pressure test article engine base/Pressure region between test body and jet stretcher      | PB1/P2       |       |
| $P_{B1}/P_B$    | Pressure jet pump diffuser exit/ Pressure free jet diffuser exit (Eqn. 73 App. C)          | PB1/PB       |       |
| $P_{B1}/P_{tN}$ | Pressure jet pump diffuser exit/ Free jet nozzle reservoir total pressure (Eqn. 72 App. C) | PB1/PTN      |       |
| $P_C/P_N$       | Pressure chamber/ Pressure free jet nozzle exit (Eqn. 38 App. C)                           | PC/PN        |       |
| $P_C/P_{tN}$    | Non-dimensional test cell pressures                                                        | PC/PTN       |       |
| $P_{tB}/P_{tN}$ | Nondimensional total pressure free jet diffuser exit (Eqn. 35, 36 App. C)                  | PEX/PTN      |       |
| $P_N/P_{tN}$    | Free jet nozzle pressure ratio (Eqn. 37 App. C)                                            | PN/PTN       |       |

| Variable         | Definition                                                                                                                       | Program Name | Units |
|------------------|----------------------------------------------------------------------------------------------------------------------------------|--------------|-------|
| $P_{N1}$         | Free jet nozzle exit pressure for solution where diffuser is exhausting to atmospheres (Eqn. 80 App. C)                          | PN1          | psia  |
| $P_{t1}/P_{tN}$  | Nondimensional total pressure engine exit                                                                                        | PT1/PTN      |       |
| $P_{t2}/P_{tN}$  | Nondimensional total pressure between test body and jet stretcher                                                                | PT2/PTN      |       |
| $P_{t4}$         | Total pressure of the jet pump reservoir for the case where the diffuser is exhausting to atmosphere (Eqn. 86 App. C)            | PT4          | psia  |
| $P_{t4}/P_{tN}$  | Nondimensional total pressure of jet pump reservoir (if set to -1 program will calculate optimum, $P5=P4$ ) (Eqn. 55, 56 App. C) | PT4/PTN      |       |
| $P_{t5}/P_{tB}$  | Total pressure jet pump region/ Total pressure free jet diffuser exit (Eqn. 57 App. C)                                           | PT5/PTB      |       |
| $P_{tB1}/P_{tN}$ | Nondimensional total pressure jet pump diffuser exit (Eqn. 70 App. C)                                                            | PTB1/PTN     |       |

| Variable         | Definition                                                                                                                 | Program Name | Units |
|------------------|----------------------------------------------------------------------------------------------------------------------------|--------------|-------|
| $P_{tN}$         | Free jet nozzle reservoir total pressure                                                                                   | PTN          | psia  |
| $P_{tN1}$        | Free jet nozzle reservoir total pressure ( $P_{tN}$ ) for case where diffuser is exhausting to atmosphere (Eqn. 79 App. C) | PTN1         | psia  |
| $r_j/r_N$        | Radius of jet stretcher inlet/Radius of free jet nozzle exit                                                               | RJ/RN        |       |
| $r_N$            | Radius free jet nozzle exit                                                                                                | RN           |       |
| $T_{tBA}/T_{tN}$ | Nondimensional maximum temperature due to fuel afterburning                                                                | TBA/TTN      |       |
| $T_{t1}/T_{tN}$  | Nondimensional total temperature at test article engine exit                                                               | TT1/TTN      |       |
| $T_{t2}/T_{tN}$  | Nondimensional total temperature between test body and jet stretcher                                                       | TT2/TTN      |       |

| Variable         | Definition                                                                                       | Program Name | Units |
|------------------|--------------------------------------------------------------------------------------------------|--------------|-------|
| $T_{t3}/T_{tN}$  | Nondimensional total temperature gap between jet stretcher and free jet diffuser (Eqn. 8 App. C) | TT3/TTN      |       |
| $T_{t4}/T_{tN}$  | Nondimensional jet pump reservoir total temperature                                              | TT4/TTN      |       |
| $T_{t5}/T_{tB}$  | Total temperature jet pump region/total temperature free jet diffuser exit                       | TT5/TTB      |       |
| $T_{t5}/T_{tN}$  | Nondimensional total temperature jet pump region (Eqn. 45 App. C)                                | TT5/TTN      |       |
| $T_{tB}/T_{tN}$  | Nondimensional total temperature at free jet diffuser exit (Eqn. 17 App. C)                      | TTB/TTN      |       |
| $T_{tB1}/T_{tN}$ | Nondimensional total temperature jet pump diffuser exit (Eqn. 68 App. C)                         | TTB1/TTN     |       |
| $T_{tE}/T_{tN}$  | Nondimensional total temperature external bleed flow                                             | TTE/TTN      |       |

| Variable        | Definition                                                                                                                 | Program Name | Units |
|-----------------|----------------------------------------------------------------------------------------------------------------------------|--------------|-------|
| $T_{ij}/T_{tN}$ | Nondimensional total temperature radial gap between free jet nozzle exit and jet stretcher inlet                           | TTJ/TTN      |       |
| $T_{tN}$        | Free jet nozzle reservoir total temperature                                                                                | TTN          | °R    |
| $T_{tp}/T_{tN}$ | Nondimensional total temperature of flow through jet stretcher porous wall                                                 | TTP/TTN      |       |
| $V_5/V_4$       | Flow velocity in jet pump region/flow velocity of jet pump plume (Needs to be small for jet pump to work) (Eqn. 85 App. C) | V5/V4        |       |
| $X_j/r_N$       | Linear distance from free jet nozzle exit to jet stretcher inlet/ radius free jet nozzle exit                              | XJ/RN        |       |

APPENDIX C  
DIFFUSER PERFORMANCE PROGRAM  
EQUATIONS

The conservation laws were applied based on the following assumptions (References 2, 3 and 4):

- The test body is at zero angle of attack.
- The test facility nozzle provides one-dimensional supersonic flow approaching the test vehicle.
- The test body engine inlets are located at least 5 body diameters from the nose, therefore, the flow conditions on the control volume surface 2 are one-dimensional.
- The bow shock wave from the test vehicle falls outside the facility nozzle exit, therefore, the total stream thrust on surface 2 equals the total stream thrust that would exist at the nozzle exit plane without the presence of the test vehicle.
- The test body engine exhaust is one-dimensional.
- For a typical test body, the jet stretcher is cylindrical beyond the engine inlets.
- The flow conditions over surface 3 of the control volume are one-dimensional.
- The cylindrical diffuser is of sufficient length to allow complete mixing; therefore, the flow conditions at the diffuser exit (surface B of the control volume) are one-dimensional.
- All the gases are perfect.
- The flow field within the chamber is the low velocity recirculating type; therefore, the chamber pressure,  $P_C$ ,

is the total pressure of the flow on surface 3 of the control volume.

- There are no regions of flow separation in the nozzle or jet stretcher.

The diffuser performance equations are developed in terms of Crocco number (  $C$  ) instead of Mach number. Crocco number is defined by:

$$C^2 = \frac{V^2}{2 C_p T_t}$$

and is related to the Mach number by:

$$M = \left( \frac{2}{\gamma - 1} \right)^{1/2} \frac{C}{(1 - C^2)^{1/2}}$$

The Crocco number has an upper limit of one. It was used as an equation basis because it is based on stagnation temperature, not static temperature as is Mach number. Stagnation temperature is easier to calculate than static temperature, and it does not change unless the flow is nonadiabatic.

Determine  $k_j$  from:

$$K_j = 1 - \frac{\left(\frac{r_j}{r_N}\right)^2}{\left(1 - \frac{\delta_N^*}{r_N}\right)^2} \quad (1)$$

Determine the maximum positive value of  $C_1$  from:

$$\left(1 - C_1^2\right)^{\frac{1}{\gamma_1 - 1}} C_1 = \frac{A_1^*}{A_1} \left(\frac{2}{\gamma_1 + 1}\right)^{\frac{1}{\gamma_1 - 1}} \left[\frac{\gamma_1 - 1}{\gamma_1 + 1}\right]^{1/2} \quad (2)$$

Determine the maximum positive value of  $C_2$  from:

$$\begin{aligned} \left(1 - C_2^2\right)^{\frac{1}{\gamma_2 - 1}} C_2 = & \left(\frac{P_{tN}}{P_{t2}}\right) \left(\frac{A_N^*}{A_2}\right) \sqrt{\left(\frac{C_{p2}}{C_{pN}}\right) \left(\frac{T_{t2}}{T_{tN}}\right)} \left(\frac{\gamma_2 - 1}{\gamma_2}\right) \dots \\ & \left[\frac{\gamma_N}{(\gamma_N^2 - 1)^{1/2}}\right] \left(\frac{2}{\gamma_N + 1}\right)^{\frac{1}{\gamma_N - 1}} [1 - k_j - k_P] \end{aligned} \quad (3)$$

Determine  $\left(\frac{C_{p3} T_{t3}}{C_{pN} T_{tN}}\right)$  from:

$$\left(\frac{C_{p3} T_{t3}}{C_{pN} T_{tN}}\right) = \frac{k_j \left(\frac{C_{pj}}{C_{pN}}\right) \left(\frac{T_{tj}}{T_{tN}}\right) + \left(\frac{C_{pp}}{C_{pN}}\right) \left(\frac{T_{tP}}{T_{tN}}\right) \left[\frac{k_P + |k_P|}{2}\right] + \left(\frac{C_{pE}}{C_{pN}}\right) \left(\frac{T_{tE}}{T_{tN}}\right) \left[\frac{k_E + |k_E|}{2}\right]}{k_j + \left[\frac{k_P + |k_P|}{2}\right] + \left[\frac{k_E + |k_E|}{2}\right]} \quad (4)$$

Determine  $\left(\frac{\gamma_3}{\gamma_N}\right)$  from:

$$\left(\frac{\gamma_3}{\gamma_N}\right) = \frac{k_j \left(\frac{C_{Pj}}{C_{PN}}\right) + \left(\frac{C_{PP}}{C_{PN}}\right) \left[\frac{k_P + |k_P|}{2}\right] + \left(\frac{C_{PE}}{C_{PN}}\right) \left[\frac{k_E + |k_E|}{2}\right]}{k_j \left(\frac{C_{Pj}}{C_{PN}}\right) \left(\frac{\gamma_N}{\gamma_j}\right) + \left(\frac{C_{PP}}{C_{PN}}\right) \left(\frac{\gamma_N}{\gamma_P}\right) \left[\frac{k_P + |k_P|}{2}\right] + \left(\frac{C_{PE}}{C_{PN}}\right) \left(\frac{\gamma_N}{\gamma_E}\right) \left[\frac{k_E + |k_E|}{2}\right]} \quad (5)$$

Determine  $\gamma_3$  from:

$$\gamma_3 = \left(\frac{\gamma_3}{\gamma_N}\right) \gamma_N \quad (6)$$

Determine  $\frac{C_{P3}}{C_{PN}}$  from:

$$\frac{C_{P3}}{C_{PN}} = \frac{k_j \left(\frac{C_{Pj}}{C_{PN}}\right) + \left(\frac{C_{PP}}{C_{PN}}\right) \left[\frac{k_P + |k_P|}{2}\right] + \left(\frac{C_{PE}}{C_{PN}}\right) \left[\frac{k_E + |k_E|}{2}\right]}{k_j + \left[\frac{k_P + |k_P|}{2}\right] + \left[\frac{k_E + |k_E|}{2}\right]} \quad (7)$$

Determine  $\frac{T_{13}}{T_{1N}}$  from:

$$\frac{T_{13}}{T_{1N}} = \frac{\left(\frac{C_{P3}}{C_{PN}} \frac{T_{13}}{T_{1N}}\right)}{\left(\frac{C_{P3}}{C_{PN}}\right)} \quad (8)$$

Determine the maximum positive value of  $C_3$  from:

$$(1 - C_3^2)^{\frac{1}{\gamma_3 - 1}} C_3 = \left( \frac{P_{tN}}{P_C} \right) \left[ \frac{A_N^*}{A_3 + 4 \left( \frac{L}{D_B} \right) A_B} \right] \sqrt{\left( \frac{C_{p3}}{C_{pN}} \right) \left( \frac{T_{t3}}{T_{tN}} \right)} \dots$$

$$\left( \frac{\gamma_3 - 1}{\gamma_3} \right) \left[ \frac{\gamma_N}{(\gamma_N^2 - 1)^{1/2}} \right] \left( \frac{2}{\gamma_N + 1} \right)^{\frac{1}{\gamma_N - 1}} [k_j + k_E + k_P]$$
(9)

Determine  $\frac{m_1}{m_N}$  from:

$$\frac{m_1}{m_N} = \frac{\left( \frac{P_{t1}}{P_{tN}} \right) \left( \frac{A_1^*}{A_N^*} \right)}{\sqrt{\left( \frac{C_{p1}}{C_{pN}} \right) \left( \frac{T_{t1}}{T_{tN}} \right)}} \left( \frac{\gamma_N + 1}{2} \right)^{\frac{1}{\gamma_N - 1}} \left( \frac{2}{\gamma_1 + 1} \right)^{\frac{1}{\gamma_1 - 1}} \left[ \frac{\gamma_N^2 - 1}{\gamma_1^2 - 1} \right]^{1/2} \left( \frac{\gamma_1}{\gamma_N} \right)$$
(10)

Determine  $\frac{m_2}{m_N}$  from:

$$\frac{m_2}{m_N} = 1 - k_j - k_P$$
(11)

Determine  $\frac{m_3}{m_N}$  from:

$$\frac{m_3}{m_N} = k_j + k_E + k_P$$
(12)

Determine  $\frac{m_i}{m_N}$  from:

$$\frac{m_i}{m_N} = (1 - k_j - k_P) \left( \frac{A_i}{A_N^*} \right) \left( \frac{A_N^*}{A_2} \right)$$
(13)

Determine  $H$  from:

$$H = \frac{m_1}{m_N} - \frac{m_i}{m_N} + \frac{m_2}{m_N} + \frac{m_3}{m_N} + k_W + k_i \frac{m_i}{m_N} \quad (14)$$

Determine  $h_{AM}$  by:

For  $\frac{m_1}{m_N} \geq k_A$  (lack of oxygen)

$$h_{AM} = \frac{K_A h_A}{\left(\frac{m_1}{m_N}\right)}$$

For  $\frac{m_1}{m_N} < k_A$  (excess oxygen)

$$h_{AM} = h_A$$

If calculated  $\frac{T_{tB}}{T_{tN}} \leq \frac{T_{tBA}}{T_{tN}}$  then use  $h_{AM}$

If calculated  $\frac{T_{tB}}{T_{tN}} > \frac{T_{tBA}}{T_{tN}}$  then determine

$$h_{AM} \text{ for } \frac{T_{tB}}{T_{tN}} = \frac{T_{tBA}}{T_{tN}}$$

Determine  $\left(\frac{C_{PB} T_{tB}}{C_{PN} T_{tN}}\right)$  from:

$$\begin{aligned} \left(\frac{C_{PB} T_{tB}}{C_{PN} T_{tN}}\right) = & \frac{\frac{m_1}{m_N} \left(\frac{C_{P1} T_{t1}}{C_{PN} T_{tN}}\right) + \left[\frac{m_2}{m_N} - \frac{m_i}{m_N}\right] \left(\frac{C_{P2} T_{t2}}{C_{PN} T_{tN}}\right) + \left(\frac{C_{P3} T_{t3}}{C_{PN} T_{tN}}\right) \left(\frac{m_3}{m_N}\right)}{H} \\ & + \frac{\frac{m_1}{m_N} h_{AM} + \left(\frac{m_i}{m_N}\right) k_i \left(\frac{C_{P2} T_{t2}}{C_{PN} T_{tN}}\right) + k_W \left[\frac{2.073 \times 10^7}{C_{PN} T_{tN}}\right]}{H} \end{aligned} \quad (15)$$

Determine  $\frac{C_{PB}}{C_{PN}}$  from:

$$\frac{C_{PB}}{C_{PN}} = \frac{\frac{m_1}{m_N} \left( \frac{C_{P1}}{C_{PN}} \right) + \left[ \frac{m_2}{m_N} - \frac{m_i}{m_N} \right] \left( \frac{C_{P2}}{C_{PN}} \right) + \left( \frac{C_{P3}}{C_{PN}} \right) \left( \frac{m_3}{m_N} \right)}{H} + \frac{k_i \left( \frac{m_i}{m_N} \right) \left( \frac{C_{P2}}{C_{PN}} \right) + k_W \left[ \frac{1.14 \times 10^4}{C_{PN}} \right]}{H} \quad (16)$$

Determine  $\frac{T_{tB}}{T_{tN}}$  from:

$$\frac{T_{tB}}{T_{tN}} = \frac{\left( \frac{C_{PB} T_{tB}}{C_{PN} T_{tN}} \right)}{\left( \frac{C_{PB}}{C_{PN}} \right)} \quad (17)$$

condition:

1. for  $k_W > 0.0$  and  $T_{tB} < 520 \text{ }^\circ\text{R}$

make  $T_{tB} = 520 \text{ }^\circ\text{R}$  and solve equations 15 ,16  
and 17 for a  $k_W = k_{WS}$  (saturated condition)  
and printout

2. for  $k_W < 0.0$

determine  $k_{WS}$  as in condition 1 and use in  
calculations

Determine  $\frac{\gamma_B}{\gamma_N}$  from:

$$\frac{\gamma_B}{\gamma_N} = \frac{\frac{m_1}{m_N} \left( \frac{C_{P1}}{C_{PN}} \right) + \left[ \frac{m_2}{m_N} - \frac{m_i}{m_N} \right] \left( \frac{C_{P2}}{C_{PN}} \right) + \left( \frac{C_{P3}}{C_{PN}} \right) \left( \frac{m_3}{m_N} \right)}{\frac{m_1}{m_N} \left( \frac{C_{P1}}{C_{PN}} \right) \left( \frac{\gamma_N}{\gamma_1} \right) + \left[ \frac{m_2}{m_N} - \frac{m_i}{m_N} \right] \left( \frac{C_{P2}}{C_{PN}} \right) \left( \frac{\gamma_N}{\gamma_2} \right) + \left( \frac{C_{P3}}{C_{PN}} \right) \left( \frac{m_3}{m_N} \right) \left( \frac{\gamma_N}{\gamma_3} \right)} \dots$$

$$\frac{+ k_i \left( \frac{m_i}{m_N} \right) \left( \frac{C_{P2}}{C_{PN}} \right) + k_W \left[ \frac{1.14 \times 10^4}{C_{PN}} \right]}{+ k_i \left( \frac{m_i}{m_N} \right) \left( \frac{C_{P2}}{C_{PN}} \right) \left( \frac{\gamma_N}{\gamma_2} \right) + k_W 8.764 \times 10^8 \left( \frac{\gamma_N}{C_{PN}} \right)} \quad (18)$$

Determine  $\gamma_B$  from:

$$\gamma_B = \left( \frac{\gamma_B}{\gamma_N} \right) \gamma_N \quad (19)$$

Determine  $\frac{F_1}{P_{tN} A_N^*}$  from:

$$\frac{F_1}{P_{tN} A_N^*} = \left( \frac{P_{t1}}{P_{tN}} \right) \left( \frac{A_1}{A_N^*} \right) (1 - C_1^2)^{\frac{1}{\gamma_1 - 1}} \left[ 1 + \left( \frac{\gamma_1 + 1}{\gamma_1 - 1} \right) C_1^2 \right] \quad (20)$$

Determine  $\frac{F_2}{P_{tN} A_N^*}$  from:

$$\frac{F_2}{P_{tN} A_N^*} = \left( \frac{P_{t2}}{P_{tN}} \right) \left( \frac{A_2}{A_N^*} \right) (1 - C_2^2)^{\frac{1}{\gamma_2 - 1}} \left[ 1 + \left( \frac{\gamma_2 + 1}{\gamma_2 - 1} \right) C_2^2 \right] \quad (21)$$

Determine  $\frac{F_3}{P_{tN} A_N^*}$  from:

$$\frac{F_3}{P_{tN} A_N^*} = \left( \frac{P_C}{P_{tN}} \right) \left( \frac{A_3}{A_N^*} \right) (1 - C_3^2)^{\frac{1}{\gamma_3 - 1}} \left[ 1 + \left( \frac{\gamma_3 + 1}{\gamma_3 - 1} \right) C_3^2 \right] \quad (22)$$

Determine  $\frac{F_i}{P_{tN} A_N^*}$  from:

$$\frac{F_i}{P_{tN} A_N^*} = \frac{F_2}{P_{tN} A_N^*} \left( \frac{A_i}{A_N^*} \right) \left( \frac{A_N^*}{A_2} \right) \quad (23)$$

Determine  $\frac{F_s}{P_{tN} A_N^*}$  from:

$$\frac{F_s}{P_{tN} A_N^*} = C_{DS} \left( \frac{P_{t2}}{P_{tN}} \right) \left( \frac{A_s}{A_N^*} \right) \left( \frac{\gamma_2}{\gamma_2 - 1} \right) \left( 1 - C_2^2 \right)^{\frac{1}{\gamma_2 - 1}} C_2^2 \quad (24)$$

Determine  $\frac{P_2}{P_{t2}}$  from:

$$\frac{P_2}{P_{t2}} = \left( 1 - C_2^2 \right)^{\frac{\gamma_2}{\gamma_2 - 1}} \quad (25)$$

Determine  $\frac{P_3}{P_C}$  from:

$$\frac{P_3}{P_C} = \left( 1 - C_3^2 \right)^{\frac{\gamma_3}{\gamma_3 - 1}} \quad (26)$$

Determine  $G$  from:

$$G = \frac{F_1}{P_{tN} A_N^*} + \left( \frac{P_{b1}}{P_2} \right) \left( \frac{P_2}{P_{t2}} \right) \left( \frac{P_{t2}}{P_{tN}} \right) \left( \frac{A_{b1}}{A_N^*} \right) - \frac{F_i}{P_{tN} A_N^*} + \frac{F_2}{P_{tN} A_N^*} + \left( \frac{P_3}{P_C} \right) \left( \frac{P_C}{P_{tN}} \right) \left( \frac{A_{b2}}{A_N^*} \right) + \frac{F_3}{P_{tN} A_N^*} - \frac{F_s}{P_{tN} A_N^*} \quad (27)$$

Determine the subsonic solution for  $C_B$  from:

$$C_B = \frac{1}{2} \left( \frac{G}{H} \right) \sqrt{\left( \frac{C_{PN}}{C_{PB}} \right) \left( \frac{T_{tN}}{T_{tB}} \right) \left( \frac{\gamma_B}{\gamma_B + 1} \right) \left[ \frac{(\gamma_N^2 - 1)^{1/2}}{\gamma_N} \right] \left( \frac{\gamma_N + 1}{2} \right)^{\frac{1}{\gamma_N - 1}}} \\ - \frac{1}{2} \sqrt{\left( \frac{G}{H} \right)^2 \left( \frac{C_{PN}}{C_{PB}} \right) \left( \frac{T_{tN}}{T_{tB}} \right) \left( \frac{\gamma_B}{\gamma_B + 1} \right)^2 \left[ \frac{(\gamma_N^2 - 1)}{\gamma_N^2} \right] \left( \frac{\gamma_N + 1}{2} \right)^{\frac{2}{\gamma_N - 1}} - 4 \left( \frac{\gamma_B - 1}{\gamma_B + 1} \right)}$$

(28)

Determine  $\frac{P_{tB}}{P_{tN}}$  from:

$$\frac{P_{tB}}{P_{tN}} = \frac{G}{\left( \frac{A_B}{A_N} \right) (1 - C_B^2)^{\frac{1}{\gamma_B - 1}} \left[ 1 + \left( \frac{\gamma_B + 1}{\gamma_B - 1} \right) C_B^2 \right]}$$

(29)

Determine  $M_1$  from:

$$M_1 = \left( \frac{2}{\gamma_1 - 1} \right)^{1/2} \frac{C_1}{(1 - C_1^2)^{1/2}}$$

(30)

Determine  $M_2$  from:

$$M_2 = \left( \frac{2}{\gamma_2 - 1} \right)^{1/2} \frac{C_2}{(1 - C_2^2)^{1/2}}$$

(31)

Determine  $M_3$  from:

$$M_3 = \left( \frac{2}{\gamma_3 - 1} \right)^{1/2} \frac{C_3}{(1 - C_3^2)^{1/2}}$$

(32)

Determine  $\frac{P_3}{P_{tN}}$  from:

$$\frac{P_3}{P_{tN}} = \left( \frac{P_3}{P_C} \right) \left( \frac{P_C}{P_{tN}} \right)$$

(33)

Determine  $M_B$  from:

$$M_B = \left( \frac{2}{\gamma_B - 1} \right)^{1/2} \frac{C_B}{(1 - C_B^2)^{1/2}} \quad (34)$$

Condition: if  $A_{BE} \neq A_B$  then assume an isentropic expansion/contraction and calculate a new  $M_B$ .

Determine  $\frac{P_B}{P_{tB}}$  from:

$$\frac{P_B}{P_{tB}} = (1 - C_B^2)^{\gamma_B / (\gamma_B - 1)} \quad (35)$$

Determine  $\frac{P_B}{P_{tN}}$  from:

$$\frac{P_B}{P_{tN}} = \left( \frac{P_B}{P_{tB}} \right) \left( \frac{P_{tB}}{P_{tN}} \right) \quad (36)$$

Determine  $\frac{P_N}{P_{tN}}$  from:

$$\frac{P_N}{P_{tN}} = \left[ 1 + \left( \frac{\gamma_N - 1}{2} \right) M_N^2 \right]^{-\frac{\gamma_N}{\gamma_N - 1}} \quad (37)$$

Determine  $\frac{P_C}{P_N}$  from:

$$\frac{P_C}{P_N} = \left( \frac{P_C}{P_{tN}} \right) \left( \frac{P_{tN}}{P_N} \right) \quad (38)$$

Determine  $\frac{P_C}{P_2}$  from:

$$\frac{P_C}{P_2} = \left( \frac{P_C}{P_{tN}} \right) \left( \frac{P_{tN}}{P_2} \right) \left( \frac{P_{tN}}{P_{t2}} \right) \quad (39)$$

Determine  $\left(\frac{P_C}{P_N}\right)_{\text{Start}}$  from:

$$\left(\frac{P_C}{P_N}\right)_{\text{Start}} = \frac{(M_N - 1) \left[ \left( 1 - \frac{\delta_N^*}{r_N} - \frac{r_j}{r_N} \right) (M_N^2 - 1)^{1/2} - \frac{x_j}{r_N} \right]}{5 \left( \frac{\delta_N}{r_N} \right)} + 1.0 \quad (40)$$

after  $\left(\frac{P_C}{P_N}\right)_{\text{Start}}$  is calculated all parameters which correspond to this value is determined. These will be the values for the system to start if the following conditions apply:

$$MB \leq 1.0$$

$$M3 \leq 1.0$$

$$\frac{P_3}{P_2} \geq 1.0$$

$$\left(\frac{P_C}{P_N}\right)_{\text{Start}} \geq 1.0$$

$$\frac{\delta_N}{r_N} \leq \left( 1 - \frac{r_j}{r_N} \right)$$

$$\left(\frac{P_C}{P_N}\right)_{\text{Start}} > M_N \text{ then make } \left(\frac{P_C}{P_N}\right)_{\text{Start}} = M_N$$

$$\frac{P_3}{P_2} \leq M_2$$

if the last condition is violated then determine the started conditions based on  $\frac{P_3}{P_2} = M_2$ .

Determine  $\frac{P_3}{P_2}$  from:

$$\frac{P_3}{P_2} = \left( \frac{P_{t2}}{P_2} \right) \left( \frac{P_{tN}}{P_{t2}} \right) \left( \frac{P_C}{P_{tN}} \right) \left( \frac{P_3}{P_C} \right) \quad (41)$$

Determine  $\frac{P_B}{P_C}$  from:

$$\frac{P_B}{P_C} = \left( \frac{P_{tN}}{P_C} \right) \left( \frac{P_B}{P_{tN}} \right) \quad (42)$$

Determine  $\frac{C_{P5}}{C_{PN}}$  from:

$$\frac{C_{P5}}{C_{PN}} = \left( \frac{C_{P5}}{C_{PB}} \right) \left( \frac{C_{PB}}{C_{PN}} \right) \quad (43)$$

Determine  $\gamma_5$  from:

$$\gamma_5 = \left( \frac{\gamma_5}{\gamma_B} \right) \gamma_B \quad (44)$$

Determine  $\frac{T_{t5}}{T_{tN}}$  from:

$$\frac{T_{t5}}{T_{tN}} = \left( \frac{T_{t5}}{T_{tB}} \right) \left( \frac{T_{tB}}{T_{tN}} \right) \quad (45)$$

Determine  $C_4$  from:

$$\left( 1 - C_4^2 \right)^{\frac{1}{\gamma_4 - 1}} C_4 = \frac{A_4^*}{A_4} \left( \frac{2}{\gamma_4 + 1} \right)^{\frac{1}{\gamma_4 - 1}} \left[ \frac{\gamma_4 - 1}{\gamma_4 + 1} \right]^{1/2} \quad (46)$$

Determine  $\frac{P_4}{P_{t4}}$  from:

$$\frac{P_4}{P_{t4}} = \left( 1 - C_4^2 \right)^{\frac{\gamma_4}{\gamma_4 - 1}} \quad (47)$$

Determine  $M_4$  from:

$$M_4 = \left( \frac{2}{\gamma_4 - 1} \right)^{1/2} \frac{C_4}{(1 - C_4^2)^{1/2}} \quad (48)$$

Determine  $\frac{F_{S1}}{P_{tN} A_N^*}$  from:

$$\begin{aligned} \frac{F_{S1}}{P_{tN} A_N^*} = C_{DS1} & \left( \frac{P_{tB}}{P_{tN}} \right) \left( \frac{A_{S1}}{A_N^*} \right) \left( \frac{\gamma_B}{\gamma_B - 1} \right) (1 - C_B^2)^{\frac{1}{\gamma_B - 1}} C_B^2 \\ & + \left( \frac{P_B}{P_{tN}} \right) P_{tN} A_N^* \left( \frac{A_4}{A_N^*} + \frac{A_{b4}}{A_N^*} \right) \end{aligned} \quad (49)$$

Define  $G_1$  as:

$$G_1 = G + \left( \frac{P_B}{P_{tB}} \right) \left( \frac{P_{tB}}{P_{tN}} \right) \left( \frac{A_{B1}}{A_N^*} - \frac{A_B}{A_N^*} \right) - \left( \frac{F_{S1}}{P_{tN} A_N^*} \right) \quad (50)$$

Determine the subsonic solution of  $C_5$  from:

$$\begin{aligned} C_5 = \frac{1}{2} \left( \frac{G_1}{H} \right) & \sqrt{\left( \frac{C_{PN}}{C_{P5}} \right) \left( \frac{T_{tN}}{T_{t5}} \right)} \left( \frac{\gamma_5}{\gamma_5 + 1} \right) \left[ \frac{(\gamma_N^2 - 1)^{1/2}}{\gamma_N} \right] \left( \frac{\gamma_N + 1}{2} \right)^{\frac{1}{\gamma_N - 1}} \\ & - \frac{1}{2} \sqrt{\left( \frac{G_1}{H} \right)^2 \left( \frac{C_{PN}}{C_{P5}} \right) \left( \frac{T_{tN}}{T_{t5}} \right) \left( \frac{\gamma_5}{\gamma_5 + 1} \right)^2 \left[ \frac{(\gamma_N^2 - 1)}{\gamma_N^2} \right] \left( \frac{\gamma_N + 1}{2} \right)^{\frac{2}{\gamma_N - 1}} - 4 \left( \frac{\gamma_5 - 1}{\gamma_5 + 1} \right)} \end{aligned} \quad (51)$$

Determine  $\frac{P_{t5}}{P_{tN}}$  from:

$$\frac{P_{t5}}{P_{tN}} = \frac{G_1}{\left( \frac{A_{B1}}{A_N^*} - \frac{A_4}{A_N^*} - \frac{A_{b4}}{A_N^*} \right) (1 - C_5^2)^{\frac{1}{\gamma_5 - 1}} \left[ 1 + \left( \frac{\gamma_5 + 1}{\gamma_5 - 1} \right) C_5^2 \right]} \quad (52)$$

Determine  $\frac{P_5}{P_{t5}}$  from:

$$\frac{P_5}{P_{t5}} = \left(1 - C_5^2\right)^{\frac{\gamma_5}{\gamma_5 - 1}} \quad (53)$$

Determine  $\frac{P_5}{P_{tN}}$  from:

$$\frac{P_5}{P_{tN}} = \left(\frac{P_5}{P_{t5}}\right) \left(\frac{P_{t5}}{P_{tN}}\right) \quad (54)$$

If  $\frac{P_{t4}}{P_{tN}} = -1$  calculate optimum jet pump option, assume  $P_5 = P_4$

Determine  $\frac{P_{t4}}{P_{tN}}$  from:

$$\frac{P_{t4}}{P_{tN}} = \frac{\left(\frac{P_5}{P_{t5}}\right) \left(\frac{P_{t5}}{P_{tN}}\right)}{\frac{P_4}{P_{t4}}} \quad (55)$$

If  $\frac{P_{t4}}{P_{tN}} \neq -1$  then

Determine  $\frac{P_5}{P_4}$  from:

$$\frac{P_5}{P_4} = \left(\frac{P_5}{P_{t5}}\right) \left(\frac{P_{t5}}{P_{tN}}\right) \left(\frac{P_{tN}}{P_{t4}}\right) \left(\frac{P_{t4}}{P_4}\right) \quad (56)$$

Determine  $\frac{P_{t5}}{P_{tB}}$  from:

$$\frac{P_{t5}}{P_{tB}} = \left(\frac{P_{t5}}{P_{tN}}\right) \left(\frac{P_{tN}}{P_{tB}}\right) \quad (57)$$

Determine  $\frac{F_{S2}}{P_{tN} \dot{A}_N^*}$  from:

$$\frac{F_{S2}}{P_{tN} \dot{A}_N^*} = C_{DS2} \left( \frac{P_{t5}}{P_{tN}} \right) \left( \frac{A_{S2}}{\dot{A}_N^*} \right) \left( \frac{\gamma_5}{\gamma_5 - 1} \right) (1 - C_5^2)^{\frac{1}{\gamma_5 - 1}} C_5^2 \quad (58)$$

Determine  $\frac{F_4}{P_{tN} \dot{A}_N^*}$  from:

$$\frac{F_4}{P_{tN} \dot{A}_N^*} = \left( \frac{P_{t4}}{P_{tN}} \right) \left( \frac{A_4}{\dot{A}_N^*} \right) (1 - C_4^2)^{\frac{1}{\gamma_4 - 1}} \left[ 1 + \left( \frac{\gamma_4 + 1}{\gamma_4 - 1} \right) C_4^2 \right] \quad (59)$$

Define  $G_2$  as:

$$G_2 = G_1 + \frac{F_4}{P_{tN} \dot{A}_N^*} + \frac{P_5 A_{b4}}{P_{tN} \dot{A}_N^*} - \frac{F_{S2}}{P_{tN} \dot{A}_N^*} \quad (60)$$

Determine  $\frac{m_4}{m_N}$  from:

$$\frac{m_4}{m_N} = \frac{\left( \frac{P_{t4}}{P_{tN}} \right) \left( \frac{\dot{A}_4}{\dot{A}_N^*} \right) \left( \frac{A_4}{\dot{A}_N^*} \right)}{\sqrt{\left( \frac{C_{p4}}{C_{pN}} \right) \left( \frac{T_{t4}}{T_{tN}} \right)}} \left( \frac{\gamma_N + 1}{2} \right)^{\frac{1}{\gamma_N - 1}} \left( \frac{2}{\gamma_4 + 1} \right)^{\frac{1}{\gamma_4 - 1}} \left[ \frac{\gamma_N^2 - 1}{\gamma_4^2 - 1} \right]^{\frac{1}{2}} \left( \frac{\gamma_4}{\gamma_N} \right) \quad (61)$$

Define  $H_1$  as:

$$H_1 = H + \frac{m_4}{m_N} \quad (62)$$

Define  $k_4$  as  $\frac{m_4}{m_N}$

Determine  $\frac{C_{PB1} T_{tB1}}{C_{PN} T_{tN}}$  from:

$$\frac{C_{PB1} T_{tB1}}{C_{PN} T_{tN}} = \left( \frac{k_4}{H + k_4} \right) \left( \frac{C_{P4} T_{t4}}{C_{PN} T_{tN}} \right) + \left( \frac{H}{H + k_4} \right) \left( \frac{C_{P5} T_{t5}}{C_{PN} T_{tN}} \right) \quad (63)$$

Determine  $\frac{C_{PB1}}{C_{PN}}$  from:

$$\frac{C_{PB1}}{C_{PN}} = \left( \frac{k_4}{H + k_4} \right) \left( \frac{C_{P4}}{C_{PN}} \right) + \left( \frac{H}{H + k_4} \right) \left( \frac{C_{P5}}{C_{PN}} \right) \quad (64)$$

Determine  $\frac{C_{VB1}}{C_{VN}}$  from:

$$\frac{C_{VB1}}{C_{VN}} = \left( \frac{k_4}{H + k_4} \right) \left( \frac{C_{P4}}{C_{PN}} \right) \left( \frac{\gamma_N}{\gamma_4} \right) + \left( \frac{H}{H + k_4} \right) \left( \frac{C_{P5}}{C_{PN}} \right) \left( \frac{\gamma_N}{\gamma_5} \right) \quad (65)$$

Determine  $\frac{\gamma_{B1}}{\gamma_N}$  from:

$$\frac{\gamma_{B1}}{\gamma_N} = \frac{\left( \frac{C_{PB1}}{C_{PN}} \right)}{\left( \frac{C_{VB1}}{C_{VN}} \right)} \quad (66)$$

Determine  $h_{AM1}$  as follows:

For  $\frac{m_1}{m_N} \geq k_A k_4$  (lack of oxygen)

$$h_{AM1} = \frac{k_A k_4}{\left( \frac{m_1}{m_N} \right)} (h_A - h_{AM}) \quad (67)$$

For  $\frac{m_1}{m_N} < k_A k_4$  (excess oxygen)

$$h_{AM1} = h_A - h_{AM}$$

If calculated  $\frac{T_{tB1}}{T_{tN}} \leq \frac{T_{tBA}}{T_{tN}}$  then use  $h_{AM1}$

If calculated  $\frac{T_{tB1}}{T_{tN}} > \frac{T_{tBA}}{T_{tN}}$  then make  $\frac{T_{tB1}}{T_{tN}} = \frac{T_{tBA}}{T_{tN}}$

Determine  $\frac{T_{tB1}}{T_{tN}}$  from:

$$\frac{T_{tB1}}{T_{tN}} = \frac{k_4 \left( \frac{T_{t4}}{T_{tN}} \right) \left( \frac{C_{P4}}{C_{PN}} \right) + H \left( \frac{T_{t5}}{T_{tN}} \right) \left( \frac{C_{P5}}{C_{PN}} \right) + \left( \frac{m_1}{m_N} \right) h_{AM1}}{k_4 \left( \frac{C_{P4}}{C_{PN}} \right) + H \left( \frac{C_{P5}}{C_{PN}} \right)} \quad (68)$$

Determine the subsonic solution of  $C_{B1}$  from:

$$C_{B1} = \frac{1}{2} \left( \frac{G_2}{H_1} \right) \sqrt{\left( \frac{C_{PN}}{C_{PB1}} \right) \left( \frac{T_{tN}}{T_{tB1}} \right) \left( \frac{\gamma_{B1}}{\gamma_{B1}-1} \right) \left[ \frac{(\gamma_N^2 - 1)^{1/2}}{\gamma_N} \right] \left( \frac{\gamma_N + 1}{2} \right)^{\frac{1}{\gamma_N - 1}}} \\ - \frac{1}{2} \sqrt{\left( \frac{G_2}{H_1} \right)^2 \left( \frac{C_{PN}}{C_{PB1}} \right) \left( \frac{T_{tN}}{T_{tB1}} \right) \left( \frac{\gamma_{B1}}{\gamma_{B1}-1} \right)^2 \left[ \frac{(\gamma_N^2 - 1)}{\gamma_N^2} \right] \left( \frac{\gamma_N + 1}{2} \right)^{\frac{2}{\gamma_N - 1}} - 4 \left( \frac{\gamma_{B1} + 1}{\gamma_{B1} - 1} \right)} \quad (69)$$

Determine  $\frac{P_{tB1}}{P_{tN}}$  from:

$$\frac{P_{tB1}}{P_{tN}} = \frac{G_2}{\left( \frac{A_{B1}}{A_N} \right) \left( 1 - C_{B1}^2 \right)^{\frac{1}{\gamma_{B1} - 1}} \left[ 1 + \left( \frac{\gamma_{B1} + 1}{\gamma_{B1} - 1} \right) C_{B1}^2 \right]} \quad (70)$$

Determine  $\frac{P_{B1}}{P_{tB1}}$  from:

$$\frac{P_{B1}}{P_{tB1}} = \left( 1 - C_{B1}^2 \right)^{\gamma_{B1} / (\gamma_{B1} - 1)} \quad (71)$$

Determine  $\frac{P_{B1}}{P_{tN}}$  from:

$$\frac{P_{B1}}{P_{tN}} = \left( \frac{P_{B1}}{P_{tB1}} \right) \left( \frac{P_{tB1}}{P_{tN}} \right) \quad (72)$$

Determine  $\frac{P_{B1}}{P_B}$  from:

$$\frac{P_{B1}}{P_B} = \left( \frac{P_{B1}}{P_{tN}} \right) \left( \frac{P_{tN}}{P_B} \right) \quad (73)$$

Determine  $M_5$  from:

$$M_5 = \left( \frac{2}{\gamma_5 - 1} \right)^{1/2} \frac{C_5}{(1 - C_5^2)^{1/2}} \quad (74)$$

Determine  $M_{B1}$  from:

$$M_{B1} = \left( \frac{2}{\gamma_{B1} - 1} \right)^{1/2} \frac{C_{B1}}{(1 - C_{B1}^2)^{1/2}} \quad (75)$$

Condition: if  $A_{BE1} \neq A_{B1}$  then assume an isentropic expansion/contraction and calculate a new  $M_{B1}$ .

Determine  $F_{B1}$  from:

$$F_{B1} = P_{tN1} \left( \frac{P_{tB1}}{P_{tN}} \right) A_{B1} (1 - C_{B1}^2)^{\frac{1}{\gamma_{B1} - 1}} \left[ 1 + \left( \frac{\gamma_{B1} + 1}{\gamma_{B1} - 1} \right) C_{B1}^2 \right] \quad (76)$$

Determine  $F_N$  from:

$$F_N = \frac{F_2}{P_{tN} A_N^*} P_{tN1} A_N^* \quad (144) \quad (77)$$

Determine  $DF$  from:

$$DF = F_{B1} - F_N \quad (78)$$

Determine  $P_{tN1}$  from:

$$P_{tN1} = \frac{15}{\left(\frac{P_B}{P_{tN}}\right)} \quad (\text{without jet pump}) \quad (79)$$

$$P_{tN1} = \frac{15}{\left(\frac{P_{B1}}{P_{tN}}\right)} \quad (\text{with jet pump})$$

Determine  $P_{N1}$  from:

$$P_{N1} = \left(\frac{P_N}{P_{tN}}\right) P_{tN1} \quad (80)$$

Determine  $m_N$  from:

$$m_N = \frac{(9265) P_{tN1} A_N^*}{\sqrt{2} C_{PN} T_{tN}} \left(\frac{2}{\gamma_N + 1}\right)^{\frac{1}{\gamma_N - 1}} \left[\frac{\gamma_N}{(\gamma_N^2 - 1)^{1/2}}\right] \quad (81)$$

Determine  $m_4$  from:

$$m_4 = m_N k_4 \quad (82)$$

Determine  $m_W$  from:

$$\begin{aligned} m_W &= m_N K_W \\ \text{or if } k_W &= -1 \text{ (calculate saturated case)} \\ \text{then} \\ m_W &= m_N K_{Ws} \end{aligned} \quad (83)$$

Determine  $m_T$  from:

$$m_T = m_N + m_4 \quad (84)$$

Determine  $\frac{V_5}{V_4}$  from:

$$\frac{V_5}{V_4} = \left( \frac{M_5}{M_4} \right) \left[ \frac{\left( \frac{T_{t5}}{T_{tB}} \right) \left( \frac{T_{tB}}{T_{tN}} \right)}{\left( \frac{T_{t4}}{T_{tN}} \right)} \left[ \frac{\gamma_B \left( \frac{\gamma_5}{\gamma_B} \right) - 1}{\gamma_4 - 1} \right] \left[ \frac{\left( \frac{C_{p5}}{C_{pB}} \right) \left( \frac{C_{pB}}{C_{pN}} \right)}{\left( \frac{C_{p4}}{C_{pN}} \right)} \right] \left[ \frac{1 + \left( \frac{\gamma_4 - 1}{2} \right) M_4^2}{1 + \left[ \frac{\gamma_B \left( \frac{\gamma_5}{\gamma_B} \right) - 1}{2} \right] M_5^2} \right] \right]^{1/2} \quad (85)$$

Determine  $P_{t4}$  from:

$$P_{t4} = \left( \frac{P_{t4}}{P_{tN}} \right) P_{tN1} \quad (86)$$

Determine  $\frac{A_5^*}{A_5}$  from:

$$\frac{A_5^*}{A_5} = \left( \frac{\gamma_5 + 1}{2} \right)^{\frac{\gamma_5 + 1}{2(\gamma_5 - 1)}} M_5 \left[ 1 + \left( \frac{\gamma_5 + 1}{2} \right) M_5^2 \right]^{-\left[ \frac{\gamma_5 + 1}{2(\gamma_5 - 1)} \right]} \quad (87)$$

Determine  $\frac{A_5^*}{A_{5S}}$  from:

$$\frac{A_5^*}{A_{5S}} = \left( \frac{A_5^*}{A_5} \right) \left( \frac{\frac{A_{B1}}{A_N^*} - \frac{A_4}{A_N^*} - \frac{A_{b4}}{A_N^*}}{\frac{A_{B1}}{A_N^*} - \frac{A_{S1}}{A_N^*}} \right) \quad (88)$$

Determine  $M_{5S}$  from:

$$\frac{A_5^*}{A_{5S}} = \left( \frac{\gamma_5 + 1}{2} \right)^{\frac{\gamma_5 + 1}{2(\gamma_5 - 1)}} M_{5S} \left[ 1 + \left( \frac{\gamma_5 + 1}{2} \right) M_{5S}^2 \right]^{-\left[ \frac{\gamma_5 + 1}{2(\gamma_5 - 1)} \right]} \quad (89)$$

APPENDIX D  
DIFFUSER EXPERT SYSTEM  
PROGRAM  
OUTPUTS.KBS

!portion of the diffuser expert system that reads in outputs from Bauer.exe  
!and makes decisions based on their values.

EXECUTE;  
ENDOFF;  
RUNTIME;

#### ACTIONS

XDUM=1  
YDUM=1  
ZDUM=1  
ZCOUNT=1  
MACHC1=1           !put here to hold a place in outdat  
CLS  
CLROFF  
CALL DELRES,""       !deletes RESULTS and PLOT.DOC  
CLRON  
CALL BAUER,""  
CLROFF  
CALL P6READ,""  
CLRON  
LOADFACTS P6OUT  
  
!    CALCULATE CONSTANTS FOR ISENTROPIC EXPANSION CALCULATIONS  
  
    ZA=((YGAMMAN-1)/2)  
    ZB=((YGAMMAN+1)/2)  
    ZC=((YGAMMAN+1)/(2\*(YGAMMAN-1)))  
    ZD=(YGAMMAN/(YGAMMAN-1))  
  
!    CORRECT INPUTS WHERE NEEDED  
  
    RESET ZCORRECTMN  
    FIND ZCORRECTMN  
  
!    LOOP TO FIND THE CORRECT MASS FLOW IN AND OUT OF THE ENGINE  
  
    ZCOUNT=20  
    WHILETRUE ZCOUNT=20 THEN  
        RESET ZCORRECTMASS1  
        RESET ZDUMMY22  
        RESET ZDUMNT23  
        FIND ZCORRECTMASS1  
    END

```

RESET ZMAXIMUMKW
FIND ZMAXIMUMKW
RESET ZCORRECTPRESS
FIND ZCORRECTPRESS

```

```

! LOOP TO FIND THE BASE PRESSURE LIMIT

```

```

ZCOUNT = 20
ZMACH = (MN)
RESET ZBASEPRESS
WHILETRUE ZCOUNT = 20 THEN
  RESET ZBASEPRESS
  ZMACH=(ZMACH+.05)
  ZADAN=(@EXP(@LOG(1/ZMACH)+ZC*(@LOG((1+ZA*ZMACH*ZMACH)/ZB))))
  ZRATIO=(ZADAN/YABOAN)
  FIND ZBASEPRESS
END
FDISPLAY RESULTS,"AN/AN* = {ZADAN}, ZRATIO={ZRATIO}~"

```

```

CLROFF
CALL P6READ,""
CLRON
LOADFACTS P6OUT
RESET ZCALCCHECK
FIND ZCALCCHECK
CALL PERCRV,"" !displays performance curve
CCALL LIST,"PRIN6.DOC" !displays output data file
RESET ANALYSIS
RESET FJDCHOKE
RESET FJDCHOKEREASON
RESET STARTED
RESET EFFICIENCY
FIND ANALYSIS
SORT FJDCHOKEREASON

```

```

CLS
WOPEN 1,0,0,22,79,7
ACTIVE 1
DISPLAY " DIFFUSER ANALYSIS"
FDISPLAY RESULTS,"

```

```

DIFFUSER ANALYSIS

```

```

RESET EFFICIENCYTEXT
FIND EFFICIENCYTEXT
RESET FFULLTEXT
FIND FFULLTEXT

```

```

RESET CHOKETEXT
FIND CHOKETEXT

!   loop to find choke reason text in order of probability

WHILEKNOWN FJDCHOKEREASON1
  RESET FJDCHOKEREASON1
  POP FJDCHOKEREASON, FJDCHOKEREASON1
  RESET FJDCHOKEREASONTTEXT
  FIND FJDCHOKEREASONTTEXT
END
DISPLAY"
Analysis complete - strike any key to quit~"

CHAIN DIFFUSER
;

!   RULE PORTION OF THE EXPERT SYSTEM THAT CORRECTS ERRORS IN THE INPUTS
!-----

RULE 20
IF      YKP = 0.0      AND
      M2 < (.95*MN) OR
      M2 > (1.05*MN)
THEN
  MN = (M2)
  PC10 = 0.010000
  PC09 = 0.040000
  PC08 = 0.060000
  PC07 = 0.080000
  PC06 = 0.100000
  PC05 = 0.200000
  PC04 = 0.400000
  PC03 = 0.600000
  PC02 = 0.800000
  PC01 = 1.000000
  SAVEFACTS OUTDAT
  CLROFF
  CALL OUTREAD,"
  CLRON
  CALL BAUER,"
  CLROFF
  CALL P6READ,"
  CLRON
  LOADFACTS P6OUT
  FDISPLAY RESULTS,"IT WAS NECESSARY TO SET MN=M2={MN}"
  ZCORRECTMN = YES

```

ELSE ZCORRECTMN = YES

;

RULE 22

IF M1OMN > 0.0 AND  
M1OMN > 0.0 AND  
M1OMN < (.99\*(M1OMN-XYKI\*M1OMN)) OR  
M1OMN > (1.01\*(M1OMN-XYKI\*M1OMN))  
THEN XXPT1OPTN = (((M1OMN-XYKI\*M1OMN)/M1OMN)\*XXPT1OPTN)  
FDISPLAY RESULTS,"CALCULATED VALUE OF PT1/PTN= {XXPT1OPTN}~"  
ZDUMMY22=YES  
ELSE ZCORRECTMASS1=YES  
ZCOUNT=1  
ZDUMMY22=NO  
ZDUMMY23=NO

;

RULE 23

IF ZDUMMY22=YES AND  
XXPT1OPTN>1.0  
THEN XXPT1OPTN=1.0  
XYKI = 0.000000  
PC10 = 0.010000  
PC09 = 0.040000  
PC08 = 0.060000  
PC07 = 0.080000  
PC06 = 0.100000  
PC05 = 0.200000  
PC04 = 0.400000  
PC03 = 0.600000  
PC02 = 0.800000  
PC01 = 1.000000  
SAVEFACTS OUTDAT  
CLROFF  
CALL OUTREAD,""  
CLRON  
CALL BAUER,""  
CLROFF  
CALL P6READ,""  
CLRON  
LOADFACTS P6OUT  
ZKI=((M1OMN-M1OMN)/M1OMN)  
XYKI=(XYKI+ZKI)  
WOPEN 2,0,0,11,79,7  
ACTIVE 2  
DISPLAY"While iterating on engine exit total pressure (PT1) to mass  
balance the engine, PT1 reached the limiting case of being equal

to the nozzle total pressure (PTN). To make up the mass difference,  
a value of the engine bleed flow, KI={XYKI} was calculated."

ZDUMMY23=YES

;

RULE 23A

IF ZDUMMY23=YES AND  
ZPREFERENCE=CONTINUE

THEN PC10 = 0.010000  
PC09 = 0.040000  
PC08 = 0.060000  
PC07 = 0.080000  
PC06 = 0.100000  
PC05 = 0.200000  
PC04 = 0.400000  
PC03 = 0.600000  
PC02 = 0.800000  
PC01 = 1.000000

SAVEFACTS OUTDAT

CLROFF

CALL OUTREAD,""

CLRON

CALL BAUER,""

CLROFF

CALL P6READ,""

CLRON

LOADFACTS P6OUT

FDISPLAY RESULTS,"IT WAS NECESSARY TO SET PT1/PTN=1.0 AND

CALCULATE A KI={XYKI} TO MASS BALANCE THE ENGINE"

ZCORRECTMASS1 = YES

ZCOUNT=1

;

RULE 23D

IF ZPREFERENCE=STOP\_ANALYSIS

THEN CHAIN DIFFUSER

;

RULE 23C

IF ZDUMMY22=YES AND  
XXPT10PTN<=1.0

THEN PC10 = 0.010000  
PC09 = 0.040000  
PC08 = 0.060000  
PC07 = 0.080000  
PC06 = 0.100000  
PC05 = 0.200000

```

PCD4 = 0.400000
PCD3 = 0.600000
PCD2 = 0.800000
PCD1 = 1.000000
SAVEFACTS OUTDAT
CLROFF
CALL OUTREAD,""
CLRON
CALL BAUER,""
CLROFF
CALL P6READ,""
CLRON
LOADFACTS P6OUT
FDISPLAY RESULTS,"IT WAS NECESSARY TO ITERATE ON PT1/PTN TO MAKE
M1/MN=M1/MN"
ZDUMMY23=NO
ZCORRECTMASS1=NO
;

RULE 25
IF      XKWS = 0.0
THEN    ZKWSAVE=(XKWS)
        XXKW=(-1.000000)
        PCD10 = 0.010000
        PCD9 = 0.040000
        PCD8 = 0.060000
        PCD7 = 0.080000
        PCD6 = 0.100000
        PCD5 = 0.200000
        PCD4 = 0.400000
        PCD3 = 0.600000
        PCD2 = 0.800000
        PCD1 = 1.000000
        SAVEFACTS OUTDAT
        CLROFF
        CALL OUTREAD,""
        CLRON
        CALL BAUER,""
        CLROFF
        CALL P6READ,""
        CLRON
        LOADFACTS P6OUT
        ZKWS=(XKWS)
        XXKW=(ZKWSAVE)
        SAVEFACTS OUTDAT
        CLROFF
        CALL OUTREAD,""

```

```

        CLRON
        FDISPLAY RESULTS,"THE SATURATED WATER SPRAY FLOW; ZKWS={ZKWS}"
        ZMAXIMUMKW=YES
ELSE
        ZKWS={XKWS}
        ZMAXIMUMKW=YES
;

RULE 28
IF      PNOPTN >.1
THEN    PC05=(PNOPTN)
        ZDUMMY28=FOUND
ELSE    PC05=.1
        ZDUMMY28 = FOUND
;

RULE 29
IF      PNOPTN >.01
THEN    PC10=(PNOPTN)
        ZDUMMY29=FOUND
ELSE    PC10=.01
        ZDUMMY29 = FOUND
;

RULE 30
IF      ZDUMMY28 = FOUND AND
        ZDUMMY29 = FOUND
THEN    PC01 = 1
        ZSTEP=((PC01-PC05)/4)
        PC02 = (PC01-ZSTEP)
        PC03 = (PC02-ZSTEP)
        PC04 = (PC03-ZSTEP)
        ZSTEP=((PC05-PC10)/5)
        PC09 = (PC10+ZSTEP)
        PC08 = (PC09+ZSTEP)
        PC07 = (PC08+ZSTEP)
        PC06 = (PC07+ZSTEP)
        FDISPLAY RESULTS,"THE SUGGESTED CHAMBER PRESSURE RATIOS ARE"
        FDISPLAY RESULTS,"PC/PTN[1]={PC01}"
        FDISPLAY RESULTS,"PC/PTN[2]={PC02}"
        FDISPLAY RESULTS,"PC/PTN[3]={PC03}"
        FDISPLAY RESULTS,"PC/PTN[4]={PC04}"
        FDISPLAY RESULTS,"PC/PTN[5]={PC05}"
        FDISPLAY RESULTS,"PC/PTN[6]={PC06}"
        FDISPLAY RESULTS,"PC/PTN[7]={PC07}"
        FDISPLAY RESULTS,"PC/PTN[8]={PC08}"
        FDISPLAY RESULTS,"PC/PTN[9]={PC09}"

```

```

        FDISPLAY RESULTS,"PC/PTN[10]={PC10}~"
        SAVEFACTS OUTDAT
        CLROFF
        CALL OUTREAD,""
        CLRON
        CALL BAUER,""
        CALL RENAM,""
        ZCORRECTPRESS=FOUND
ELSE    ZCORRECTPRESS=FOUND
;

RULE 35
IF      PC10>(PNOPTN) AND
        PNOPTN>.001
THEN    PC01=(PC10-((PC10-PNOPTN)/2))
        PC02=(PNOPTN)
        ZDUMMY35=YES
;

RULE 36
IF      PC10<(PNOPTN)
THEN    PC01=(PC10)
        PC02=.01
        ZDUMMY35=YES
;

RULE 37
IF      PNOPTN<.001
THEN    PC02=.001
        PC01=(PC10-((PC10-PC02)/2))
        ZDUMMY35=YES
;

RULE 38
IF      PC10=(PNOPTN)
THEN    PC01=.01
        PC02=.009
        ZDUMMY35=YES
;

RULE 40
IF      ZDUMMY35=YES AND
        ZRATIO >.98
THEN    PC10 = (@EXP(ZD*@LOG(1/(1+ZA*ZMACH*ZMACH))))
        ZSTEP= ((PC02-PC10)/8)
        PC03 = (PC02-ZSTEP)
        PC04 = (PC03-ZSTEP)

```

```

PC05 = (PC04-ZSTEP)
PC06 = (PC05-ZSTEP)
PC07 = (PC06-ZSTEP)
PC08 = (PC07-ZSTEP)
PC09 = (PC08-ZSTEP)
FDISPLAY RESULTS,"PC/PTN[11]={PC01}"
FDISPLAY RESULTS,"PC/PTN[12]={PC02}"
FDISPLAY RESULTS,"PC/PTN[13]={PC03}"
FDISPLAY RESULTS,"PC/PTN[14]={PC04}"
FDISPLAY RESULTS,"PC/PTN[15]={PC05}"
FDISPLAY RESULTS,"PC/PTN[16]={PC06}"
FDISPLAY RESULTS,"PC/PTN[17]={PC07}"
FDISPLAY RESULTS,"PC/PTN[18]={PC08}"
FDISPLAY RESULTS,"PC/PTN[19]={PC09}"
FDISPLAY RESULTS,"PC/PTN[20]={PC10}"
SAVEFACTS OUTDAT
CLROFF
CALL OUTREAD,""
CLRON
CALL BAUER,""
ZCOUNT=1
ZBASEPRESS = FOUND
ELSE ZBASEPRESS = REDO
;

RULE 49
IF YSTARTCALC = NO
THEN WOPEN 3,0,0,11,79,7
ACTIVE 3
DISPLAY "The BAUER program was unable to calculate a diffuser
flow starting point. Therefore no started region will be show on the
diffuser performance curve.

Strike any key to continue.""
ZCALCCHECK = PROBLEM
ELSE ZCALCCHECK = OK
;

! RULE PORTION OF EXPERT SYSTEM THAT ANALYSIS RESULTS OF BAUER PROGRAM
!-----

RULE 2000
IF XJORN >= 0.0 AND
M3>.98
THEN FJDCHOKEREASON=INTERNAL CNF 50
;

```

```

RULE 2010
IF      MB>.98 AND
        XXXW>0.01 AND
        XXXW<(.8*ZKWS)
THEN    FJDCHOKEREASON=WATERSPRAY CNF 50
;

```

```

RULE 2011
IF      MB>.98 AND
        XXXW>(.8*ZKWS)
THEN    FJDCHOKEREASON=WATERSPRAY CNF 80
;

```

```

RULE 2020
IF      MB>.98 AND
        XASDAN > 0.0 AND
        XCDS > 0.0
THEN    FJDCHOKEREASON=DRAG CNF 50
;

```

```

RULE 2030
IF      MB>.98 AND
        YABEDAN<(.9*YABOAN) AND
        YABEDAN>(.5*YABOAN)
THEN    FJDCHOKEREASON=AREA CNF 50
;

```

```

RULE 2031
IF      MB>.98 AND
        YABEDAN<(.5*YABOAN)
THEN    FJDCHOKEREASON=AREA CNF 80
;

```

```

RULE 2100
IF      MB>.98 OR
        M3>.98
THEN    FJDCHOKE=YES
ELSE    FJDCHOKE=NO
;

```

```

RULE 2201
IF      FJDCHOKE = YES AND
        PCS < (1.5*PC)
THEN    STARTED = NO
ELSE    STARTED = YES
;

```

```

RULE 2210
IF      FJDCHOKE=NO
THEN    FJDCHOKEREASON=NONE
;

RULE 2220
IF      YKE>0.0 AND
        YKE<.3 AND
        M3>.98
THEN    FJDCHOKEREASON=INTERNAL_W_EXTERNALBLEED CNF 50
;

RULE 2221
IF      YKE>=.3 AND
        M3>.98
THEN    FJDCHOKEREASON=INTERNAL_W_EXTERNALBLEED CNF 90
;

RULE 2225
IF      YKP>0.0 AND
        YKP<.5 AND
        M3>.98
THEN    FJDCHOKEREASON=INTERNAL_W_POROUSJETSTR CNF 50
;

RULE 2228
IF      YKP>=.5 AND
        M3>.98
THEN    FJDCHOKEREASON=INTERNAL_W_POROUSJETSTR CNF 80
;

RULE 2230
IF      YKE>0.0 AND
        YKE<.5 AND
        MB>.98
THEN    FJDCHOKEREASON=EXTERNALBLEED CNF 50
;

RULE 2231
IF      YKE>=0.5 AND
        MB>.98
THEN    FJDCHOKEREASON=EXTERNALBLEED CNF 90
;

RULE 2240
IF      STARTED = NO
THEN    EFFICIENCY = NULL

```

;

RULE 2250

IF        STARTED = YES AND  
          YSLOPE>45  
THEN      EFFICIENCY = GOOD  
;

RULE 2260

IF        STARTED = YES AND  
          YSLOPE<6.3  
THEN      EFFICIENCY = POOR  
;

RULE 2270

IF        STARTED = YES AND  
          YSLOPE>6.3 AND  
          YSLOPE<45  
THEN      EFFICIENCY=OK  
;

RULE 2280

IF        MB>.98 AND  
          M10MN> 0.0 AND  
          XXKW<.04 AND  
          YTT10TTN> 1.0  
THEN      FJDCHOKEREASON=THERMAL CNF 50  
;

RULE 2281

IF        MB>.98 AND  
          M10MN> 0.0 AND  
          XXKW>0.04 AND  
          YTT10TTN> 1.0  
THEN      FJDCHOKEREASON=THERMAL CNF 30  
;

RULE 2290

IF        MB>.98 AND  
          XYKI > 0.0 AND  
          XYKI < 0.5  
THEN      FJDCHOKEREASON=ENGINE\_BLEED CNF 50  
;

RULE 2291

IF        MB > .98 AND  
          XYKI >= 0.5

```
THEN      FJDCHOKEREASON=ENGINE_BLEED CNF 80
;
```

```
RULE 2300
```

```
IF        MB>.98 AND
          M10MN>0.0 AND
          YHAM>0.0
THEN      FJDCHOKEREASON=AFTERBURN CNF 50
;
```

```
RULE 5000
```

```
IF        FJDCHOKE <> UNKNOWN AND
          FJDCHOKEREASON <> UNKNOWN AND
          STARTED <> UNKNOWN AND
          EFFICIENCY <> UNKNOWN
THEN      ANALYSIS = COMPLETE
;
```

```
! RULE PORTION OF THE EXPERT SYSTEM THAT SELECTS WORDING FOR DISPLAY
```

```
!-----
```

```
RULE 6000
```

```
IF        FJDCHOKE = YES
THEN      ACTIVE 1
DISPLAY"
```

```
The diffuser has choked for the following reasons:"
```

```
FDISPLAY RESULTS,"
```

```
The diffuser has choked for the following reasons:"
```

```
      CHOKETEXT = ASSIGNED
```

```
ELSE      ACTIVE 1
          DISPLAY"
```

```
The diffuser did not choke"
```

```
      FDISPLAY RESULTS,"
```

```
The diffuser did not choke"
```

```
      CHOKETEXT = ASSIGNED
```

```
;
```

```
RULE 6010
```

```
IF        FJDCHOKE = NO
THEN      FJDCHOKEREASONTEXT = NONE
;
```

```
RULE 6100
```

```
IF        STARTED = NO
THEN      ACTIVE 1
          FORMAT PCS, 7.4
```

```

FORMAT PC, 7.4
FORMAT PBOPTNS, 7.4
FORMAT PBOPTN, 7.4
DISPLAY"The diffuser has choked before the nozzle flow can start
        and develop fully

```

```

diffuser started at    PC/PTN={PCS}      PB/PTN={PBOPTNS}
diffuser choked at    PC/PTN={PC}       PB/PTN={PBOPTN}

```

Strike any key to continue to choke analysis ..."

```

FDISPLAY RESULTS,"The diffuser has choked before the nozzle flow can start
        and develop fully

```

```

Diffuser started at    PC/PTN={PCS}      PB/PTN={PBOPTNS}
Diffuser choked at    PC/PTN={PC}       PB/PTN={PBOPTN}"

```

```

ELSE
    FFULLTEXT = ASSIGNED
    FORMAT PTN1, 7.2
    FORMAT PN1, 8.3
    FORMAT YMBA, 6.3
    FORMAT ALT, 7.0
    FORMAT PCS, 7.4
    FORMAT PC, 7.4
    FORMAT PBOPTNS, 7.4
    FORMAT PBOPTN, 7.4

```

```

DISPLAY"
The diffuser flow has started and is flowing full

```

Most testing should be done around the diffuser started chamber pressure of PC/PTN={PCS}. In this region of the performance curve the test rhombus is shortened, but the diffuser will operate with the smallest value of PTN for a given PB.

The diffuser will operate in the started conditions while exhausting to atmosphere at:

```

PTN = {PTN1} psia  PB = 15 psia  MB = {YMBA}  PN = {PN1} psia
Simulated Altitude = {ALT} Ft

```

The Nozzle will operate at it's design point (PC=PN) at: PC/PTN={PNOPTN}

Strike any key to continue to choke analysis..."

FDISPLAY RESULTS,"The diffuser flow has started and is flowing full

Most testing should be done around the diffuser started chamber pressure of  $PC/PTN=\{PCS\}$ . In this region of the performance curve the test rhombus is shortened, but the diffuser will operate with the smallest value of  $PTN$  for a constant  $PB$ .

The diffuser will operate in the started conditions while exhausting to atmosphere at:

$PTN = \{PTN1\}$  psia    $PB = 15$  psia    $MB = \{YMBA\}$     $PN = \{PN1\}$  psia  
Simulated Altitude =  $\{ALT\}$  Ft

The Nozzle will operate at it's design point ( $PC=PN$ ) at:  $PC/PTN=\{PNOPTN\}$ "

FFULLTEXT = ASSIGNED

;

RULE 6110

IF        FJDCHOKEREASON1=INTERNAL

THEN      ACTIVE 1

          FORMAT XKJ, 8.4

DISPLAY"- Internal choking ( $M3=1.0$ ) at Region 3 with a Jet Stretcher bypass flow of  $KJ = \{XKJ\}$ . To reduce choking and achieve a lower  $PC$ , enlarge  $L$ , the distance between the Jet Stretcher exit and the diffuser entrance, or increase  $A3$ , the radial area between the Jet Stretcher and the diffuser."

FDISPLAY RESULTS,"- Internal choking ( $M3=1.0$ ) at Region 3 with a Jet Stretcher bypass flow of  $KJ = \{XKJ\}$ . To reduce choking and achieve a lower  $PC$ , enlarge  $L$ , the distance between the Jet Stretcher exit and the diffuser entrance, or increase  $A3$ , the radial area between the Jet Stretcher and the diffuser."

          FJDCHOKEREASONTEXT=ASSIGNED

;

RULE 6120

IF        FJDCHOKEREASON1=WATERSPRAY

THEN      ACTIVE 1

          FORMAT XXKW, 8.3

          FORMAT ZKWS, 8.3

DISPLAY" - Diffuser choking at exit ( $MB=1.0$ ), waterspray mass flow to nozzle mass flow ratio,  $KWN$ , is excessive.  $KWN = \{XXKW\}$  should be 10% to 20% of the flow saturation value of  $KWN = \{ZKWS\}$ ."

FDISPLAY RESULTS," - Diffuser choking at exit ( $MB=1.0$ ), waterspray mass flow to nozzle mass flow ratio,  $KWN$ , is excessive.  $KWN = \{XXKW\}$  should be 10% to 20%

of the flow saturation value of KWN = {ZKWS}."

FJDCHOKEREASONTEXT=ASSIGNED

;

RULE 6130

IF FJDCHOKEREASON1=AREA

THEN ACTIVE 1

FORMAT YABOAN, 6.2

FORMAT YABEOAN, 6.2

DISPLAY" - Diffuser choking at exit (MB=1.0), diffuser minimum area  
ABE/AN\* = {YABEOAN} is less than the diffuser area AB/AN\* = {YABOAN}.  
The reduction in area can cause the diffuser to choke."

FDISPLAY RESULTS," - Diffuser choking at exit (MB=1.0), diffuser minimum area  
ABE/AN\* = {YABEOAN} is less than the diffuser area AB/AN\* = {YABOAN}.  
The reduction in area can cause the diffuser to choke."

FJDCHOKEREASONTEXT=ASSIGNED

;

RULE 6140

IF FJDCHOKEREASON1=DRAG

THEN ACTIVE 1

FORMAT XCDS, 7.3

FORMAT XASOAN, 8.3

DISPLAY"- Diffuser choking at exit (MB=1.0), the model drag is too large;  
Either the diffuser area must be increased or the model size decreased."

FDISPLAY RESULTS,"- Diffuser choking at exit (MB=1.0), the model drag is too large;  
Either the diffuser area must be increased or the model size decreased."

FJDCHOKEREASONTEXT=ASSIGNED

;

RULE 6150

IF FJDCHOKEREASON1=EXTERNALBLEED

THEN ACTIVE 1

FORMAT YKE, 8.5

DISPLAY" - Diffuser choking at exit (MB=1.0), external bleed flow to nozzle  
mass flow ratio, KE, is excessive. The nozzle is having to pump too much  
mass flow out of the test chamber. KE = {YKE} should be reduced."

FDISPLAY RESULTS," - Diffuser choking at exit (MB=1.0), external bleed flow to nozzle  
mass flow ratio, KE, is excessive. The nozzle is having to pump too much  
mass flow out of the test chamber. KE = {YKE} should be reduced."

FJDCHOKEREASONTEXT=ASSIGNED

;

```

RULE 6160
IF      FJDCHOKEREASON1=INTERNAL_W_EXTERNALBLEED
THEN    ACTIVE 1
        FORMAT YKE, 8.5
DISPLAY" - Diffuser choking at area between jet stretcher and diffuser (M3=1.0),
external bleed flow to nozzle mass flow ratio, KE, is excessive.
The nozzle is having to pump too much mass flow out of the test chamber.
KE = {YKE} should be reduced, or the area A3 increased by enlarging the diffuser."

FDISPLAY RESULTS,"- Diffuser choking at area between jet stretcher and diffuser (M3=1.0),
external bleed flow to nozzle mass flow ratio, KE, is excessive.
The nozzle is having to pump too much mass flow out of the test chamber.
KE = {YKE} should be reduced, or the area A3 increased by enlarging the diffuser."
        FJDCHOKEREASONTXT=ASSIGNED
;

RULE 6161
IF      FJDCHOKEREASON1=INTERNAL_W_POROUSJETSTR
THEN    ACTIVE 1
        FORMAT YKP, 8.5
DISPLAY" - Diffuser choking at area between jet stretcher and diffuser (M3=1.0),
porous jet stretcher flow to nozzle mass flow ratio, KP, is excessive.
The nozzle is having to pump too much mass flow out of the test chamber.
KP = {YKP} should be reduced, or enlarge L, the distance between the jet
stretcher exit and the diffuser entrance, or increase AB to increase A3,
the radial area between the jet stretcher and the diffuser."

FDISPLAY RESULTS,"- Diffuser choking at area between jet stretcher and diffuser (M3=1.0),
external bleed flow to nozzle mass flow ratio, KE, is excessive.
The nozzle is having to pump too much mass flow out of the test chamber.
KE = {YKE} should be reduced, or enlarge L, the distance between the jet
stretcher exit and the diffuser entrance, or increase AB to increase A3,
the radial area between the jet stretcher and the diffuser."
        FJDCHOKEREASONTXT=ASSIGNED
;

RULE 6162
IF      FJDCHOKEREASON1=ENGINE_BLEED
THEN    ACTIVE 1
        FORMAT XYKI, 8.5
DISPLAY" - Diffuser choking at exit (MB=1.0),
engine bleed flow to engine mass flow ratio, KI, is excessive.
Too much momentum is being lost by mass spilling out of the engine inlet.
KI = {XYKI} should be reduced, or the diffuser area increased."

FDISPLAY RESULTS," - Diffuser choking at exit (MB=1.0),

```

engine bleed flow to engine mass flow ratio, KI, is excessive.  
Too much momentum is being lost by mass spilling out of the engine inlet.  
KI = {XYKI} should be reduced, or the diffuser area increased."

FJDCHOKEREASONTEXT=ASSIGNED

;

RULE 6170

IF        EFFICIENCY = NULL  
THEN     EFFICIENCYTEXT = NONE

;

RULE 6180

IF        EFFICIENCY = GOOD  
THEN     ACTIVE 1

DISPLAY "The diffuser performance curve is a near vertical line in the  
diffuser started region. This shows a diffuser with a good, efficient  
pumpdown of the chamber. SLOPE = {YSLOPE}"

FDISPLAY RESULTS,"The diffuser performance curve is a near vertical line in the  
diffuser started region. This shows a diffuser with a good, efficient  
pumpdown of the chamber. SLOPE = {YSLOPE}"

EFFICIENCYTEXT=ASSIGNED

;

RULE 6190

IF        EFFICIENCY = POOR  
THEN     ACTIVE 1

DISPLAY "The diffuser performance curve is along the PC=PB line in the  
diffuser started region. This shows a diffuser with a poor  
pumpdown of the chamber. The diffuser efficiency might be improved by  
decreasing the diffuser area, AB. SLOPE = {YSLOPE}"

FDISPLAY RESULTS,"The diffuser performance curve is along the PC=PB line in the  
diffuser started region. This shows a diffuser with a poor  
pumpdown of the chamber. SLOPE = {YSLOPE}"

EFFICIENCYTEXT=ASSIGNED

;

RULE 6200

IF        EFFICIENCY = OK  
THEN     ACTIVE 1

DISPLAY "The diffuser performance curve is between the PC=PB line  
and a near vertical line in the diffuser started region. This shows  
a diffuser with an OK pumpdown of the chamber. SLOPE = {YSLOPE}"

FDISPLAY RESULTS,"The diffuser performance curve is between the PC=PB line

and a near vertical line in the diffuser started region. This shows a diffuser with an OK pumpdown of the chamber. SLOPE = {YSLOPE}"

EFFICIENCYTEXT=ASSIGNED

;

RULE 6210

IF FJDCHOKEREASON1=THERMAL

THEN ACTIVE 1

FORMAT XCDS, 7.3

FORMAT XASOAN, 8.3

DISPLAY"- Diffuser choking at exit (MB=1.0), the model engine is operating, introducing heat into the diffuser and possibly causing thermal choking. Possible solutions are; enlarge the diffuser area, or add a small amount of water spray, KW, less than the saturated value of KWS = {ZKWS}, for cooling."

FDISPLAY RESULTS,"- Diffuser choking at exit (MB=1.0), the model engine is operating, introducing heat into the diffuser and possibly causing thermal choking. Possible solutions are; enlarge the diffuser area, or add a small amount of water spray, KW, less than the saturated value of KWS = {ZKWS}, for cooling."

FJDCHOKEREASONTEXT=ASSIGNED

;

RULE 6210

IF FJDCHOKEREASON1=AFTERBURN

THEN ACTIVE 1

FORMAT YHAM, 7.3

DISPLAY"- Diffuser choking at exit (MB=1.0), the model engine is operating with afterburning downstream of the test article, introducing heat energy into the diffuser of the value HA = {YHAM} and possibly causing thermal choking. Possible solutions are; enlarge the diffuser area, or add a small amount of water spray, KW, less than the saturated value of KWS = {ZKWS}, for cooling."

FDISPLAY RESULTS,"- Diffuser choking at exit (MB=1.0), the model engine is operating with afterburning downstream of the test article, introducing heat energy into the diffuser of the value HA = {YHAM} and possibly causing thermal choking. Possible solutions are; enlarge the diffuser area, or add a small amount of water spray, KW, less than the saturated value of KWS = {ZKWS}, for cooling."

FJDCHOKEREASONTEXT=ASSIGNED

;

ASK ZSUGGESTEDPC : "Do you wish to run the simulation with suggested values

of test cell and nozzle reservoir pressure ratios?";

CHOICES ZSUGGESTEDPC : YES, NO;

ASK ZPREFERENCE: "Do you wish to continue with PT10PTN=1.0 and the  
calculated KI, or stop the analysis?

INDICATE PREFERENCE:";

CHOICES ZPREFERENCE : CONTINUE, STOP\_ANALYSIS;

PLURAL: FJDCHOKEREASON;

PLURAL: FJDCHOKEREASONTXT;

APPENDIX E  
DIFFUSER PERFORMANCE PROGRAM  
SETUP

## Program Setup and System Requirements

The Diffuser Expert System will run on an IBM compatible PC with the following:

- MS-DOS Version 2.0 or higher
- 512k of RAM free of memory resident programs
- A hard disk
- EGA Graphics
- Epson command set compatible printer

To run the Diffuser Expert System, create a dedicated directory on the hard disk and copy the entire contents of the three program disks into it. Type VPX DIFFUSER to start the program. The menu shown in Fig. 9. will appear when the program executes. The menu reappears after successful completion of a selected option.

## VITA

Gary W. Jarrell was born in Manchester, Tennessee, on April 29, 1962. He was educated in the Tullahoma school system, attending East Lincoln Elementary, East Middle, and Tullahoma High School, graduating in 1980. The same year he entered The University of Tennessee in Knoxville and in June of 1985 received a Bachelor of Science degree in Mechanical Engineering. While attending The University of Tennessee, he began the Co-Operative Program, working at Arvin/Calspan, an operating contractor for the Arnold Engineering Development Center, Arnold Air Force Station, Tennessee. After graduation from The University of Tennessee, he began working at Arvin/Calspan in July of 1985. He is currently working as a Plant Engineer with the Plant Operations Group.

The author began employer sponsored graduate study at The University of Tennessee Space Institute, Tullahoma, Tennessee, in 1985. He received a Master of Science degree with a major in Mechanical Engineering from The University of Tennessee, Knoxville in 1991.

Gary is currently living in Tullahoma, Tennessee, with his wife, the former Direnda Harrelson, and their son, Clay.