NASA Technical Memorandum 106310

Transient Ejector Analysis (TEA) Code User's Guide

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December 1993

NASA

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SUMMARY

A FORTRAN computer program for the semianalytic prediction of unsteady thrust augmenting ejector performance has been developed, based on a theoretical analysis for ejectors. That analysis blends classic self-similar turbulent jet descriptions with control-volume mixing region elements. Division of the ejector into an inlet, diffuser, and mixing region allowed flexibility in the modelling of the physics for each region. In particular, the inlet and diffuser analyses are simplified by a quasi-steady-analysis, justified by the assumption that pressure is the forcing function in those regions. Only the mixing region is assumed to be dominated by viscous effects.

The present work provides an overview of the code structure, a description of the required input and output data file formats, and the results for a test case. Since there are limitations to the code for applications outside the bounds of the test case, the user should consider TEA as a research code (not as a production code), designed specifically as an implementation of the proposed ejector theory. Program error flags are discussed, and some diagnostic routines are presented.

CODE OVERVIEW

TEA is a FORTRAN computer program (TEA.FOR), designed for batch execution, which reads an input file (TEA.DAT) to obtain the necessary program data (ejector geometry, primary nozzle conditions, free-stream conditions), solution control options, and file output requests for print and plot files (TEA.OUT and TEA.PLT, respectively). An overview of the TEA.FOR program follows; the required TEA.DAT input file structure is the subject of the next section.

The main program simply serves to open the necessary I/O files and instructs the processing of input data, after which the governing equations are solved.[1]

A total of three subroutines are contained in the TEA.FOR file;[2] they are

DIP - Data Input Processor
MEC - Main Execution Control
SPC - Single Point Calculation

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[1] The solution procedure can be influenced by input file specifications.

[2] Appendix B provides a complete listing of the TEA.FOR file. Some idea of complexity is given by code length: the code is 731 lines long, divided into 21 lines for the main program, 164 for the DIP, 57 for the MEC, and 569 for the SPC. Programming style leans toward clarity rather than conciseness. The development platform for this code was a VAX 8800; the code has not been tested on other platforms.

Figure 1 illustrates that the SPC routine is called by the MEC routine. Although the primary purpose of this document is to provide instructions for preparation of the TEA.DAT file (read by the DIP), some brief remarks on each program module are helpful in interpreting the overall program structure.

Module Descriptions

Data input processor. — The data input processor (DIP) is designed to obtain baseline ejector engineering information, free-stream properties, solution control options, and printout and plot control parameters from the input data file and place this information in COMMON blocks; the use of COMMON blocks reduces (or eliminates) the need for READ statements in other program subroutines.

Input data is read from TEA.DAT according to a macro command sequence. The DIP echoes essential program data (specified and default) so the user can conveniently identify incomplete or incorrect input data. In the interest of clarity, the DIP routine was not written as compactly as possible; this is an overriding perspective throughout the code. For ease of use, all data has a free-format structure — the user need only demarcate values with a comma, rather than be concerned with the customary Hollerith and data format (e.g., 2F12.3).

Main execution control. — The main execution control (MEC) routine provides the basic service of feeding the single point calculation (SPC) subroutine argument list with the information needed to compute ejector thrust at a specified point in time. Although it may appear the MEC is a trivial routine to include, it facilitates development of an SPC that is void of I/O for the time-dependent primary flow conditions.

A previously mentioned aspect of the DIP and MEC subroutine structure is the absence of subroutine calls — all information is transmitted through COMMON blocks. While this may not be the most effective programming practice,[3] it is an approach that met the simulation specifications at the time the code was under development.

Single point computation. — The single point computation (SPC) subroutine is the focal point of the TEA program and provides the code implementation of the transient ejector theory given by Drummond (ref. 1). Execution of the SPC routine is controlled by the MEC, since the SPC is structured to be a "drop-in" module for integration in, for instance, an aircraft engine simulation. The SPC is the largest program subroutine, consuming almost two-thirds of the overall TEA code (see lines 243-731 of the listing in Appendix B).

Information for the SPC routine is transmitted primarily through COMMON blocks. This influence on the TEA computer program was the result of a requirement that the SPC argument list include only the primary flow conditions (m , $T_{1P,0}$, P_{1P}) at a given time t, and return thrust and augmentation ratio (T , ϕ) for a real-time component-level-model engine simulation.[4] This requirement is clearly simulation specific, but does provide module parameter inputs consistent with information

[3] The COMMON block chalkboard approach to programming can make program error tracking during diagnostics a difficult process.

[4] As discussed by Drummond (ref. 1), the motivating factor behind the development of the transient ejector theory was the need to develop a high-fidelity propulsion system simulation for the Advanced Short Take-Off and Landing (ASTOVL) development program.

typically available to an engine simulation code.[5] Although alternate simulation requirements may result in the need for a different SPC argument list, the modular code structure remains quite convenient.

Comment cards in the SPC routine mark out blocks of calculations corresponding with calculation steps in the theory; an outline of the SPC solution procedure is shown in figure 2.

Within the SPC module, there exists a decision branch between quasi-steady and transient flow calculations, based on the value of an execution mode switch, MODE, in the SPC argument list; this points to an important aspect of an ejector mixing region analysis. Since it is expected that transient ejector performance predictions are kicked-off from an assigned initial condition (there can be more than one initial condition of interest), there is a need for a built-in initialization routine for the field variables. A quasi-steady solution to the governing equations is associated with a value of MODE=0; such a solution does not invoke time derivatives in the analysis and provides, by default, a series of steady-state flow computations. When MODE=1, a transient solution is invoked which reflects the implementation of the proposed transient ejector theory.

System of units. — Few applications in engineering analysis appear to be exempt from the need to clarify the system of units involved in calculations. Typically, confusion extends from translating back and forth between force, mass, and pressure; the usual remark is that a consistent system of units must be used in analysis, and that certainly is the case here. In the present work, the Engineering English system of units is used.

With the backdrop that the current work represents a research code, the use of the Engineering English system was appropriate for the system simulation during the code development period (in which this code was ultimately intended to be compatible with a propulsion system simulation that used a similar unit system; the Metric system was not appropriate for the simulation application).

The Engineering English system is based on four fundamental units for length, force, time, and mass. Units of length are in feet (ft), units of time are in seconds (s), units of force are in pounds-force (lb_f), and units of mass are in pounds-mass (lb_m). Compatibility of units is provided by the introduction of the gravitational constant g_c = 32.174 into Newton's law (g_c is numerically, but not dimensionally equal to the gravitational constant). Although the work of Drummond (ref. 1) provides extensive examples on the appropriate units for each variable involved in the analysis, the following summary is relevant to input file preparation:

Description	Mnemonic	Value = Units
Temperature	T	= ^oR
Pressure	P	= lb_f/ft^2
Velocity	V	= ft/s
Density	RHO	= lb_m/ft^3
Mass flowrate	MDOT	= lb_m/s
Specific heat ratio	GAMMA	1.4 = non-dim
Gas constant	RBAR	1715.66 = ft^2/s^2R
Angle of attack	ALPHA	= degrees

[5] This leads to certain calculations that normal ejector codes would not have a requirement for, or the use of (e.g., a total pressure versus static pressure specification at the secondary inlet).

In principle, there is nothing to prevent the user from using, say, the Absolute MKS system of units (g_c has a value of unity) since equations involving the value of g_c do so symbolically. Illustrations of this are shown in lines 118 and 122 of the SPC routine — g_c is set at the top of the SPC module (line 67) and could be reassigned as desired.

INPUT DATA FILE PREPARATION

Typical File Structure

Data processing for the TEA.FOR program involves extensive use of macro commands; macros are keywords placed in the input file which permit a flexible input data file structure. Appendix A provides an example[6] input file structure.

Although the macro command structure can be perceived as a somewhat clumsy programming practice, the result is a very lucid input file structure. Another benefit to the macro approach is that the blocks of data are not required to be placed in any particular order, and in some cases they need not appear at all (as long as the program defaults are acceptable to the user). A subtle feature of the macro command approach is that the program will ignore any lines that do not begin with a recognized keyword — as such, the user can include as many descriptive comment cards as desired at the top of the file for a full description of the case study at hand.[7]

Macro Commands and Options

Within the data input processor (DIP), solution instructions, data input, and data output specifications are read from the TEA.DAT file through a macro command structure. As mentioned previously, COMMON statements are extensively used as placeholders in memory to shuttle data from one routine to another. Except for the SPC, none of the subroutines have argument lists since the necessary information is provided by the COMMON statements. For this type of data transfer, sub-program macros are very useful.

Data to be processed within the DIP block is subdivided according to a logical characterization of the data to be handled. Currently, eight keywords are used in the subdivision of data:

'BACK' PRESSURE	Back pressure specification for ejector discharge (optional)
'CASE'	Case banner for printed output (optional)
'COEF' FICIENT	Empirical coefficients for mixing and entrainment
'DISP' LAY	Display control for printed and plotted output (optional)
'FREE' STREAM	Free-stream fluid properties
'GEOM' ETRY	Geometry of the ejector
'PRIM' ARY	Primary nozzle discharge conditions
'STOP'	Stop command for data input processing (optional)

[6] This file corresponds with the test case to be discussed later; for now, however, it is the file structure rather than the numbers themselves that are of interest.

[7] After several weeks pass, it is easy to forget why a particular case was of interest.

Quotes around the first four letters of each keyword are used to indicate the minimum portion of the word to be included for data file preparation. Only four of the eight data blocks are essential to include in the input file; optional sets are marked accordingly. Except for STOP, which (if used) must be the last keyword encountered in the DIP data block, the keywords and associated data can occur in any sequence desired. Descriptions of the input parameters associated with each macro command are given below (in alphabetical order).

BACK: Ejector back-pressure (optional). — Aircraft installation aerodynamics often dictate that the back pressure of an installed ejector may be different than atmospheric; to accommodate this, the BACK block allows the prescription of a nonatmospheric exit pressure.

Line	Variable	Description
1	'BACK'	Keyword for back pressure input block
2	'PBACK'	Value for ejector back pressure [Default: PBACK=PINF]

This data block is optional if the back pressure is equal to that of the ambient since the program default is to assign the backpressure to the value of the free-stream static pressure (as specified and discussed later in the FREE stream block). PBACK has units of $lb_f/ft.^2$

CASE: Banner for printed output (optional). — The descriptive banner is the header for printed output. This data block is composed of two lines:

Line	Variable	Description
1	'CASE'	Keyword for banner input block
2	'RUNID'	Banner for printed output [Default: RUNID='TEA']

The CASE block is optional; the program provides a default banner of TEA if this data block is omitted.

COEF: Coefficients for solution type, mixing, kinetic energy entrainment. — As discussed in the work of Drummond (refs.1 and 2) the ejector theory implemented in this work employs two empirical constants, the flow mixing effectiveness, BETA (ß), and the coefficient for the kinetic energy transfer function, CSIGMA (C_s).

Line	Variable	Description
1	'COEF'	Keyword for coefficient data block
2	'TITLE'	Comment line with descriptive titles for variables on next line
3	'ITYPE',	Type of solution desired (0 = Steady; 1 = Transient)
	'BETA',	Mixing effectiveness factor (1.0 < BETA < 2.0)
	'CSIGMA'	Kinetic energy coefficient (0.0 < CSIGMA < 1.0)

In the interest of making direct comparisons between quasi-steady and full transient flows, this block introduces the option of enforcing a quasi-steady flow assumption. What essentially happens is that the steady-flow initialization routine is invoked for all point calculations emanating from the MEC. The default integer has a value of ITYPE=1 and marks the full transient flow as the execution mode; a value of 0 eliminates time derivatives to provide the quasi-steady option (ITYPE sets the value of the MODE parameter discussed previously in the SPC overview).

DISP: Printout of intermediate computations (optional). — For detailed investigations of transient performance calculation results, three parameters can be set to control printed output and plot file information.

Line	Variable	Description
1	'DISP'	Keyword for display data block
2	'TITLE'	Comment line with descriptive titles for variables on next line
3	'ICHECK',	Integer for printed calculation output [Default: ICHECK=100]
	'INDEX',	Indexing for printout loops [Default: INDEX=1]
	'IPLOT'	Index for plotfile data [Default: IPLOT=0]

Values of ICHECK can range between 0 and 1000, where 0 provides no printed output at all, 50 provides only a print summary from the DIP and MEC routines, and a value of 100 (the default) provides detailed listing of SPC results as each time step calculation is completed.[8] For diagnostic applications, ICHECK = 500 provides detailed velocity initialization data, and at ICHECK = 1000, self-similar profiles and secondary velocities are printed for every iteration within each time step. The INDEX parameter is useful if the program has operated on, for instance, 500 primary nozzle states, and it is desired to only printout every 10th computed result; INDEX must have a value greater than or equal to 1. The IPLOT parameter dictates whether a plot file is to be created, and the intervals at which data is written to the plot file. For the default value of IPLOT = 0, no data is stored in the TEA .PLT file. For IPLOT = 1, primary flowrate, thrust, and thrust augmentation are stored at each time interval; for values of IPLOT = N, every Nth data point is stored (much like the INDEX function).

Plot file output parameters are controlled by the WRITE statement at lines 231-235 in the code. At present, only parameters passed through the SPC argument list are amenable to place in the plot file; other parameters could be used if the appropriate WRITE statements were written to replace the existing segment of code.

FREE: Free-stream fluid properties (optional). — Characteristic (free-stream) flow properties and thermodynamic data are contained in the FREE stream data block.

Line	Variable	Description	
1	'FREE'	Keyword for free-stream data block	
2	'TITLE'	Comment line with descriptive titles for variables on next line	
3	'TINF',	Free-stream static temperature	[= 530°R; default value]
	'PINF',	Free-stream static pressure	[= 2116.8 lb_f/ft^2]
	'GAMMA',	Specific heat ratio	[= 1.4 nondim]
	'RBAR',	Universal gas constant	[= 1715.66 ft^2/s^2R]
	'UINF',	Free-stream velocity	[= 0.0 ft/s]
	'ALPHA'	Angle of attack	[= 90.0 deg]

To simplify the implementation of the ejector theory, the primary and secondary ejector streams are assumed to have the same gas composition (this is not a restriction of the theory).

[8] The rationale for the ICHECK values of 0, 50, 100 (instead of 1, 2, 3) extends from the prototype code effort to interface with the airframe simulation.

GEOM: Ejector geometric characteristics. — Geometric approximations for the ejector are contained in the GEOM data block. All numeric data must be proceeded by a title. Data is expected in the following order:

Line	Variable	Description
1	'GEOM'	Keyword geometric data input block
2	'TITLE'	Comment line with descriptive titles for variables on next line
3	'X0,Y0'	Inlet (station 0) x- and y-dimensions
4	'TITLE'	Comment line with descriptive titles for variables on next line
5	'X1,Y1,	Primary nozzle (Stn 1) x- and y-dimensions x-section
	NX1,NY1'	Number of nozzles in the x-,y- directions
6	'TITLE'	Comment line with descriptive titles for variables on next line
7	'X2,Y2'	Secondary flow (station 2) x- and y-dimensions
8	'TITLE'	Comment line with descriptive titles for variables on next line
9	'X3,Y3'	Mixing region (station 3) x- and y-dimensions
10	'TITLE'	Comment line with descriptive titles for variables on next line
11	'X4,Y4'	Diffuser exit (station 4) x- and y-dimensions
12	'TITLE'	Comment line with descriptive titles for variables on next line
13	'Z1,NZ1'	Total mixing region length and number of finite volumes

Figure 3 illustrates the expected geometric layout of the ejector; specific data was shown previously in Appendix A.

PRIM: Primary nozzle discharge conditions. — This block specifies the primary nozzle discharge velocities and thermodynamic properties.

Line	Variable	Description
1	'PRIM'	Keyword for primary nozzle data block
2	'TYPE'	Keyword for nature of data to follow:
		'SPEC' -> Data specified for every t
		'STEP' -> Step function specification

If TYPE = 'SPEC', then the following input data sequence is expected:

Line	Variable	Description
3	'TITLE'	Comment line with descriptive titles for variables on next line
4,...N	'T(I),	Time stamp
	DMPDT(I),	Primary flowrate
	T1P0(I),	Stagnation temperature
	P1P(I)'	Static pressure
N+1	0	Number(s) or character(s) to trigger end of record

Note that there are four data values on each of the 4,...N lines to simulate the primary nozzle conditions as a function of time. The N+1 reading must be a number or letter format that will terminate input by triggering an error in the READ loop (a simple single value of '0' works fine; see Appendix A).

If TYPE = 'STEP', then the following input data sequence is expected:

Line	Variable	Description
3	'TITLE'	Descriptive comment for variable list
4	'T(1)	Starting time
	DMPDT(1)	Starting primary flowrate
	T1P0(1)	Starting stagnation temperature
	P1P(1)'	Starting static pressure
5	'TITLE'	Comment line with descriptive titles for variables on next line
6	'Z1TIME'	Time at which step-change occurs
	'Z1DMDT'	New primary flowrate
	'Z1T1P0'	New stagnation temperature
	'Z1P1P'	New static pressure
7	'TITLE'	Comment line with descriptive titles for variables on next line
8	'TSTEP,N'	Time-step size and number of time steps to take

STOP Statement (optional). — The end of input data is marked by the presence of the QUIT card.

Line	Variable	Description
1	'STOP'	Keyword to exit DIP routine

ILLUSTRATIVE CASE

Background

Research on design methodologies for integrated aircraft and flight control systems requires accurate subsystem component simulations. In principle, these simulations must mimic steady-state and transient component effects. Of particular interest in recent years is the development of real-time simulations for short take-off vertical landing (STOVL) aircraft.[9] The thrust augmenting ejector shown in figure 4 is considered a potentially valuable propulsion subsystem element for the powered-lift aspect of STOVL aircraft.

Steady-flow ejector performance predictions are typically the centerpiece of an ejector design cycle, and transient flow behavior is most often described through a quasi-steady flow approximation. The latter essentially assumes away the transient behavior issue since the conjecture is the ejector will instantaneously provide whatever thrust is demanded.

To establish the validity of the quasi-steady flow assumption, one must be able to quantify the elapsed time for the ejector to adapt to a new thrust level, and establish that the ejector delay is less than the control system update period. In air-breathing propulsion systems, this assessment can take the form of a comparison between the ejector frequency response and that of the propulsion control system; see figure 5. The purpose of the TEA program is to assist in the assessment of the ejector response rate; the specific case study used to examine the STOVL response rate is presented next.

[9] For more extensive details on the simulation of interest, see Drummond (ref. 2), or Drummond and Ouzts (ref. 5).

Characteristic Test Case

In the absence of appropriate[10] data from transient flow ejector experiments or from advanced time-dependent CFD calculations, verification that the proposed ejector analysis can provide reasonable thrust predictions must be left to engineering judgement. Because of this, a familiar forcing function must be used. In the present work, the system response to a step-function input is not only a characteristic transient case study, but the scenario is coincident with typical STOVL ejector application. For demonstration purposes the ejector system response to a step-change in primary nozzle flowrate from 18.7 to 21.85 lb_m/sec is chosen because (1) experimental steady-state data at each of these operating points is available, and (2) the 17 percent change in primary flowrate is beyond the small-perturbation range; this exercises the system nonlinearities. Two versions of the TEA.DAT input file were prepared[11] for this case study and are given in Appendix C.

Geometric approximations for the ejector inlet, mixing region, and diffuser are presented in table I note the 3-D to 2-D conversion required for the primary nozzle area. This conversion in nozzle geometry is required so that the input data will be consistent with the mathematical formulation of the ejector mixing layer.

Results

For the mixing region, a finite-volume length of 0.18 ft and a characteristic mixing region velocity of 500 ft/s, the characteristic time step for computations is approximately 0.4 ms. To avoid infringing on this stability limit a computational time step of 0.1 ms was chosen; 100 time steps provided the necessary interval for examination of the step-function test case.

A detailed listing of the program printout is given in Appendix D, though the results for each of the 100 time steps are not shown (for brevity).

The empirical coefficient in the transient analysis (required for calibration of the primary-to-secondary kinetic energy exchange mechanism), was selected to match the asymptotic thrust prediction with the quasi-steady value at the new set point. Figure 6 illustrates the predicted ejector thrust profile for a coefficient C_σ of approximately 0.25. It appears the 2 millisecond residence time of the flow (elapsed time for the primary nozzle flow to reach the diffuser exit plane) is slightly less than the 3 millisecond interval for the thrust to reach a new maximum. Oscillations in thrust after that point appear to settle out in about 5 milliseconds.

An (initially) unexpected feature of the thrust profile is the dip in thrust immediately following the step-change in primary nozzle efflux. Examination of the field variable profiles reveals this is not a numerical problem, but that the increase in static pressure associated with the instantaneous change in driving flow temporarily impedes the secondary flow. After a short period, the secondary flow kinetic energy builds to overcome this effect and then continues in the intuitively expected manner.

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[10] A test was conducted by Drummond (ref. 3). specifically to collect transient ejector data, but the forcing function had a characteristic time much greater than the time scale of interest in simulation validation.

[11] The file identifier 'TEA .DAT' is hard-coded into the program for simplicity in program development. As such, the examples given in Appendix C are titled CASE1.DAT and CASE2.DAT, for which it is assumed the user will rename the case of interest to be TEA.DAT, prior to execution. The user can automate this process through a simple command language script.

Discussion

Steady-state ejector performance is well-known to be highly sensitive to design conditions, so it should come as no surprise that the transient performance prediction task is as much an art as it is a science. Some aspects of the illustrative test case runs are useful to discuss.

Entrainment coefficient variation. — A critical step in the implementation of the transient ejector theory is the identification of the appropriate value of the empirical entrainment coefficient C_s. For a known ejector step-function response, the desired C_s value is the one that provides a match between the predicted asymptote and the known thrust at the second state. As an example, thrust predictions for various C_s values are shown in figure 8; this chart illustrates the idea that the TEA code was not designed to provide the optimal prediction of steady-state ejector performance[12] — rather, that the code focuses on analysis of transient flow characteristics. (Figure 7 differs slightly from figure 6 in thrust prediction due to a slight modification in the implementation of the theory; figure 7 is the more recent result).

Back pressure effects. — It is possible for several physical reasons that the ejector backpressure will differ from the (upstream) ambient as, for instance, in the case of installation effects or curved mixing regions (asymmetric mixing region). To this end, a performance feature to explore is backpressure limits. The principal goal of increasing the backpressure for any parametric investigation is to establish the threshold at which the mixing region discharge energy is inadequate to overcome the back pressure — in that situation the program notifies the user that a fatal error has occurred (see Appendix A). For the illustrative test case, the backpressure cannot exceed 5 percent over ambient. Error codes are discussed further in the ERROR CODES AND EXECUTION PROBLEMS section.

Performance sensitivity to nozzle geometry. — Ejector performance is very sensitive to ejector geometry. In particular, performance is most readily influenced by the primary nozzle discharge area. For the baseline case, a 20-percent increase in the primary nozzle area yields a 14-percent decrease in primary nozzle discharge velocity, but a 20-percent decrease in the primary nozzle area causes some difficulty in initialization of the program. As illustrated in Appendix A, the initialization difficulty is presented to the user through an error message for a negative entrained velocity. However, during the initialization process, a simple fix is to reset the entrained kinetic energy to a small positive number. This patch seems to work well in the few cases it has been invoked.

A point to be made here is that the ejector transient flow solution involves a highly complex solution logic, and that to encounter an error is not so much a reflection that the input data is incorrect, but that an idiosyncrasy with the solution method may have been encountered.

The discussion in the next section suggests that previous problems encountered with execution have been fixed by altering input data values. Recommendations for algorithm changes or improvements to the theory are outside the scope of this work.

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[12] But a sample routine is included to initialize the transient flow calculation procedure.

ERROR CODES AND EXECUTION PROBLEMS

Error Codes

At several points in the previous discussion, it has been noted that program execution may terminate under certain conditions. Five types of errors are currently flagged by the computer; although one could easily inspect the code and potentially identify many more diagnostic flags, those included presently extend from execution experiences with the test case described earlier. Error codes, the current flag location (given by the SPC line number), and a brief description of the problem are given below:

Error code	SPC line number	Description of problem
001	272	Imaginary value ($B^2 - 4AC < 0$ in the quadratic equation) has been computed for the centerline velocity during initialization of the field variables. If ICHECK has been set to 500, then the XCHECK2 routine will assist in the diagnostics by printing a listing of the variables related to the calculation.
002	416	A negative value for the nominal velocity V* has been computed (V* is equal to the entrained velocity V_e cubed). In this case, rates of change in KE have diminished entrainment rates to unrealistically low (negative) levels. The XCHECK3 routine is automatically invoked as a first pass at fixing the problem. (This was discussed in the test case description; see Performance Sensitivity to Nozzle Geometry).
003	448	Unrealistic value for density, the value is less than zero.
004	449	Unrealistic value for density, the value is greater than one.
005	452	Unrealistic value for temperature, the value is less than zero.
006	466	Stagnation pressure at station 4 is less than the static pressure; this results in an unrealistic discharge exit velocity. Either the ejector back pressure is too high or the inlet Mach number is too low.

These problems are generally symptomatic of the divergence of the transient solution.

Execution Problems

Unrealistic or divergent transient flow solutions may be the result of one of the following:

(1) An incorrect starting solution (check input data file),
(2) Too large a time step (modify the input data time history), or
(3) An inappropriate expression for the function for exchange of kinetic energy between the primary and secondary fluid streams.

The last item is an important one since the entrainment function relies heavily on the assigned value of CSIGMA (see line 185 in SPC). More details on this function and its origin are described in Drummond (refs. 2 and 4).

Optional Debug Routines

Appendix B includes four routines that may be useful for printout of intermediate information during the debugging process. These routines are invoked through INCLUDE statements (to simplify their omission or modification, if desired); typically, these diagnostic routines are unnecessary if the program executes without error.

Routine name	SPC line number	Description
XCHECK1	203	Printout of self-similar profile coefficient values
XCHECK2	273	Printout of data involved in the centerline velocity calculation; used in conjunction with SPC error code number 1.
XCHECK3	417	Corrective procedure for negative V* result; used in conjunction with SPC error code number 2.
XCHECK4	494	Entrained velocity error and discharge mass error printouts, used to monitor convergence of a solution at a given time step.

CONCLUSION

Understanding and quantifying ejector fluid-dynamic characteristics is central to design decisions involved in propulsion system applications. The present work provides instructions for a FORTRAN computer program implementation of a semianalytic prediction of unsteady thrust augmenting ejector performance developed by Drummond (ref. 1). That analysis blends classic self-similar turbulent jet descriptions with control-volume mixing region elements. Division of the ejector into an inlet, diffuser, and mixing region allowed flexibility in the modelling of the physics for each region.

An overview of the code structure, a description of the required input and output data file formats, and the results for a test case were presented. It is emphasized that there are limitations to the code for applications outside the bounds of the test case, so the user should consider TEA as a research code designed specifically as a test of the proposed ejector theory. For program applications outside the test case bounds, some error flags and diagnostic routines are presented and discussed.

TEA.DAT: SAMPLE

```
C---------------------------------------------------------------------------------------------CASE1.DAT---
C
C       Case study input file for TEA.FOR transient ejector analysis
C       routine. Here a single step function is prescribed that
C       corresponds with one of the DeHaviland/PLF tests run in June 1987.
C       This file assumes that the default BACK and DISP parameters in the TEA.FOR
C       source code are appropriate.
C
C------------------------------------------------------------------------------------------------------------
CASE banner.
   Test #2, Step change in primary flow for 87 DHC ejector design.

GEOMetric approximation for the ejector.
XO            YO
0009.36000,   0001.25000
X1            Y1            NX1    NY1
0000.10801,   0000.10801,   00012, 00003
X2            Y2
0000.78000,   0000.34700
X3            Y3
0009.36000,   0001.04100
X4            Y4
0009.36000,   0001.87500
Z1            NZ
0000.90000,   00005

COEFficients for solution execution.
1TYPE         BETA          CSIGMA
00001,        0001.0550,    0000.30000

FREE stream fluid conditions.
TINF          PINF          GAMMA         RBAR          UNIF          ALPHA
0542.80000,   2067.84000,   0001.40000,   1714.54130,   0000.00000,   0090.00000

PRIMary nozzle discharge conditions.
SPECify states at each time step.
T             MDOT1P        T1P0          P1P
0000.00010,   0018.70000,   0769.70000,   2219.78000
0000.00020,   0018.70000,   0769.70000,   2219.78000
0000.00030,   0018.70000,   0769.70000,   2219.78000
0000.00040,   0018.70000,   0769.70000,   2219.78000
0000.00050,   0018.70000,   0769.70000,   2219.78000
0000.00060,   0021.85000,   0760.60000,   2250.92000
0000.00070,   0021.85000,   0760.60000,   2250.92000
0000.00080,   0021.85000,   0760.60000,   2250.92000
0

C------------------------------------------------------------------------------------------------------------
```

```
ARIEL$ RUN TEA

     $$$ TEA  FATAL ERROR #    6,     $$$
%MTH-F-SQUROONEG, square root of negative value
   user PC 000242C1
%TRACE-F-TRACEBACK, symbolic stack dump follows
module name          routine name          line


SPC                  SPC                    396
MEC                  MEC                     38
TEA                  TEA                     16
ARIEL$
```

```
ARIEL$ RUN TEA

     $$$ TEA FATAL ERROR #    2,     $$$


     ***  ERROR DURING CALCULATIONS FOR T =     0.00040

          DKE        =    976309.563
          DKEOLD     =   2096179.500
          SIGMA      =        71.929
          PLOSS      =     11389.766
          ENERGY1S   =   1076481.875
          CHANGE     =  -1119870.000
          VSTAR      =  -1261377.625

     *** PROCEED W/ CHANGE = -0.999ENERGY1S

     *** NEW VSTAR IS =            31295.961

 FORTRAN STOP
 ARIEL$
```

APPENDIX B - TEA PROGAM LISTING

```
C TEA.FOR: Transient Ejector Analysis - Ver.2.1                    15-AUG-91
C=================================================================
C                                                       Revised: 15-Feb-93
C Colin K. Drummond
C Propulsion Systems Division
C NASA Lewis Research Center
C Ref: "A Control-Volume Method for Analysis of Unsteady Thrust
C        Augmenting Ejector Flows," NASA CR-182203.
C=================================================================
      PROGRAM TEA
C
      OPEN (UNIT= 5,  FILE= 'TEA.DAT',STATUS= 'OLD')     ! Input data file
      OPEN (UNIT= 6,  FILE= 'TEA.OUT',STATUS= 'NEW')     ! Output data file
      OPEN (UNIT=10,  FILE= 'TEA.PLT', STATUS= 'NEW')    ! Plot data file
      CALL DIP            ! Data Input Processor
      CALL MEC            ! Main Execution Control
      CLOSE (UNIT= 5)
      CLOSE (UNIT= 6)
      CLOSE (UNIT=10)
      STOP
      END
```

APPENDIX B - TEA PROGAM LISTING

```
C=====================================================================
      SUBROUTINE DIP
C
C        Data Input Processor (DIP)
C---------------------------------------------------------------------
      PARAMETER      (M=5000)
      CHARACTER*80   RUNID
      CHARACTER*4    TITLE(20)
      DIMENSION      T(M),DMPDT(M),T1P0(M),P1P(M)
      COMMON /CHECK/ ICHECK,INDEX
      COMMON /COEFX/ BETA,CSIGMA
      COMMON /ITYPE/ ITYPE
      COMMON /PLOTS/ IPLOT
      COMMON /LIST1/ X0,      Y0,
     &               X1,      Y1,      NX1,     NY1,
     &               X2,      Y2,
     &               X3,      Y3,
     &               X4,      Y4,
     &               Z1,      NZ1,     DZ
      COMMON /LIST2/ GAMMA,   RBAR,    TINF,    PINF,    PBACK
      COMMON /LIST3/ ALPHA,   UINF
      COMMON /FLOW1/ ISW,     N,       T,       DMPDT,   T1P0,    P1P
      COMMON /FLOW2/ Z1TIME,  Z1DMDT,  Z1T1P0,  Z1P1P,   TSTEP
C
C.....DEFAULT DATA
      ALPHA  =   90.00  ! Angle of attack of aircraft
      GAMMA  =    1.40  ! Specific heat ratio
      ICHECK =  100     ! Print detailed time step output
      INDEX  =    1     ! Print every I=1 times
      IPLOT  =    0     ! No plotted output
      ITYPE  =    1     ! Full transient solution (= 0, steady-state)
      PINF   = 2067.84  ! Free-stream pressure, lbf/ft2 (14.7 psia)
      PBACK  = PINF
      RBAR   = 1714.54  ! Gas constant for AIR, ft2/s2R
      RUNID  = 'TEA'    ! Default RUNID
      TINF   =  542.80  ! Free-stream temperature, R (70degF)
      UINF   =    0.0   ! Free-stream velocity, ft/s (stationary ejector)
C
C.....READ INPUT DECK
   10 READ (5,'(20A4)',END=200) TITLE
         IF (TITLE(1).EQ.'BACK') GO TO 100
         IF (TITLE(1).EQ.'CASE') GO TO 110
         IF (TITLE(1).EQ.'COEF') GO TO 120
         IF (TITLE(1).EQ.'DISP') GO TO 130
         IF (TITLE(1).EQ.'FREE') GO TO 140
         IF (TITLE(1).EQ.'GEOM') GO TO 150
         IF (TITLE(1).EQ.'PRIM') GO TO 160
         IF (TITLE(1).EQ.'STOP') GO TO 200
       GO TO 10
C
C.....BACK pressure path to read PBACK specification.
C     *** Note: This is ONLY needed if PBACK.NE.PINF
  100 READ (5,*) PBACK
      GO TO 10
C
C.....CASE path to read RUNID banner.
  110 READ (5,'(A)') RUNID
```

```
      GO TO 10
C
C.....COEFFicients path to read solution limits and coefficients
  120 READ (5,*)
      READ (5,*) ITYPE,BETA,CSIGMA
      GO TO 10
C
C.....DISPlay path for printout and plotting options.
  130 READ (5,*)
      READ (5,*) ICHECK,INDEX,IPLOT
      GO TO 10
C
C.....FREE stream path to read flow properties.
  140 READ (5,*)
      READ (5,*) TINF,PINF,GAMMA,RBAR,UINF,ALPHA
      PBACK = PINF
      GO TO 10
C
C.....GEOMetry path to read baseline ejector geometry.
  150 READ (5,*)
      READ (5,*) X0,Y0
      READ (5,*)
      READ (5,*) X1,Y1,NX1,NY1
      READ (5,*)
      READ (5,*) X2,Y2
      READ (5,*)
      READ (5,*) X3,Y3
      READ (5,*)
      READ (5,*) X4,Y4
      READ (5,*)
      READ (5,*) Z1,NZ1
      GO TO 10
C
C.....PRIMary path for specification of primary nozzle state.
  160 READ (5,'(20A4)') TITLE
      IF(TITLE(1).EQ.'SPEC') GO TO 161
      IF(TITLE(1).EQ.'STEP') GO TO 164
C     --- Read step-by-step nozzle condition matrix ---
  161 ISW = 0
      READ (5,*)
      DO 162 I=1,M
      READ (5,*,ERR=163) T(I),DMPDT(I),T1P0(I),P1P(I)
  162 CONTINUE
  163 N = I-1
      K = N
      GO TO 10
C     --- Read parameters for generating a step function ---
  164 ISW = 1
      READ (5,*)
      READ (5,*) T(1),DMPDT(1),T1P0(1),P1P(1)
      READ (5,*) Z1TIME, Z1DMDT, Z1T1P0, Z1P1P
      READ (5,*)
      READ (5,*) TSTEP,N
      K = 1
      GO TO 10
C
C.....STOP reading data and print data summary (if ICHECK.GE.50)
```

```
  200 IF (ICHECK.LT.50) GO TO 999
      WRITE (6,700) RUNID,ICHECK,X0,Y0,X1,Y1,NX1,NY1,X2,Y2,
     &              X3,Y3,X4,Y4,Z1,NZ1,BETA,CSIGMA,TINF,PINF,
     &              GAMMA,RBAR,UINF,ALPHA,PBACK
      IF (ISW.EQ.0) THEN
         WRITE (6,706)
         WRITE (6,'((7X,I3,4(2X,F10.5)))')
     &         ((I,T(I),DMPDT(I),T1P0(I),P1P(I)),I=1,K)
      ENDIF
      IF (ISW.EQ.1)
     &   WRITE (6,705) T(1),DMPDT(1),T1P0(1),P1P(1),
     &                 Z1TIME,Z1DMDT,Z1T1P0,Z1P1P,TSTEP
      WRITE (6,703) N
      IF (ITYPE.EQ.0) WRITE (6,704)
      GO TO 999
C.....
  700 FORMAT(//,20X,'***** TEA INPUT *****',///3X,A,
     &      //,5X,'CHECK PRINT LEVEL IS ',I3,
     &      //,5X,'EJECTOR GEOMETRIC CHARACTERISTICS,'
     &       /,7X,'X0 = ',F10.5,5X,'Y0 = ',F10.5,
     &       /,7X,'X1 = ',F10.5,5X,'Y1 = ',F10.5,
     &       /,7X,'NX1= ',I5,10X,'NY1= ',I5,
     &       /,7X,'X2 = ',F10.5,5X,'Y2 = ',F10.5,
     &       /,7X,'X3 = ',F10.5,5X,'Y3 = ',F10.5,
     &       /,7X,'X4 = ',F10.5,5X,'Y4 = ',F10.5,
     &       /,7X,'Z1 = ',F10.5,5X,'NZ = ',I5,5X,
     &      //,5X,'MIXING LOSS CORRECTION FACTOR',
     &       /,7X,'BETA =  ',F10.5,
     &      //,5X,'KINETIC ENERGY MIXING COEFFICIENT',
     &       /,7X,'CSIGMA = ',F10.5
     &      //,5X,'FREE-STREAM THERMODYNAMIC PROPERTIES',
     &       /,7X,'STATIC TEMPERATURE  = ',F10.5,' DEG-RANKINE',
     &       /,7X,'STATIC PRESSURE     = ',F10.5,' LB-F/FT3',
     &       /,7X,'SPECIFIC HEAT RATIO = ',F10.5,
     &       /,7X,'GAS CONSTANT, AIR   = ',F10.5,' FT2/S2-R',
     &       /,7X,'FREESTREAM VELOCITY = ',F10.5,' FT/S',
     &       /,7X,'ANGLE-OF-ATTACK     = ',F10.5,' DEGREES',
     &      //,5X,'EJE BACK PRESSURE IS ',F10.5,' LBF/FT2',
     &      //,5X,'PRIMARY NOZZLE DATA',/)
  703 FORMAT(//5X,'PROGRAM WILL OPERATE ON ',I5,' DATA SETS')
  704 FORMAT(//5X,'QUASI-STEADY SOLUTION INVOKED')
  705 FORMAT(   7X,'STEP FUNCTION FOR PRIMARY NOZZLE DISCHARGE',
     &         /,7X,' T  ',4X,' DMPDT',7X,'T1P0  ',5X,' P1P',4X,
     &         /,6X,'(sec)',4X,'(lbm/s)',5X,'(degR)',4X,'(lbf/ft2)',
     &         /,4(2X,F10.5),/,4(2X,F10.5),//,9X,'TSTEP = ',F10.5)
  706 FORMAT(
     &7X,'DATA',7X,' T  ',4X,' DMPDT',7X,'T1P0  ',5X,' P1P',4X,/,
     &7X,'SET#',6X,'(sec)',4X,'(lbm/s)',5X,'(degR)',4X,'(lbf/ft2)')
  999 RETURN
      END
```

```
C======================================================================
      SUBROUTINE MEC
C
C         Main Execution Control (MEC) Routine
C----------------------------------------------------------------------
C
      PARAMETER (M=5000)
      COMMON /CHECK/ ICHECK,L
      COMMON /ITYPE/ ITYPE
      COMMON /PLOTS/ IPLOT
      COMMON /LAST1/ TLAST
      COMMON /FLOW1/ ISW,    N,      T,      DMPDT,  T1P0,   P1P
      COMMON /FLOW2/ Z1TIME, Z1DMDT, Z1T1P0, Z1P1P,  TSTEP
      DIMENSION T(M),DMPDT(M),T1P0(M),P1P(M),THRUST(M),PHI(M)
C
C---LOOP ON SPC ROUTINE FOR SPECIFIED PRIMARY FLOW DRIVER
      MODE  = 0
      TLAST = T(1)
      DO 20 I=1,N
         IF (I.EQ.1) GO TO 20
         MODE  = 1
         TLAST = T(I-1)
         IF (ISW.EQ.1) GO TO 5
         TSTEP = T(I)-T(I-1)
         GO TO 15
C        --- STEP FUNCTION OPERATION ---
    5    T(I)     = T(I-1) + TSTEP
         IF (T(I).GE.Z1TIME) GO TO 6
            T1P0(I)  = T1P0(1)
            P1P(I)   = P1P(1)
            DMPDT(I) = DMPDT(1)
         GO TO 15
    6       T1P0(I)  = Z1T1P0
            P1P(I)   = Z1P1P
            DMPDT(I) = Z1DMDT
         GO TO 15
   15    IF (ITYPE.EQ.0) MODE=0
   20 CALL SPC(T(I),DMPDT(I),T1P0(I),P1P(I),THRUST(I),PHI(I),MODE)
C
C---PRINT TO TEXT AND PLOT FILES AS REQUESTED
      IF (ICHECK.GE.50) THEN
       WRITE(6,100)
       WRITE(6,'((2X,4(2X,F10.5)))')
     &  (((T(I)*1000.0),DMPDT(I),THRUST(I),PHI(I)),I=1,N,L)
      ENDIF
      IF (IPLOT.GT.0) THEN
       WRITE(10,109)
       WRITE(10,'((2X,4(2X,F10.5)))')
     &  (((T(I)*1000.0),DMPDT(I),THRUST(I),PHI(I)),I=1,N,IPLOT)
      ENDIF
C
  100 FORMAT(1H1/,14X,5(1H*),' SOLUTION PROFILE ',5(1H*),
     &     //7X,'   T    ',4X,' DMpDT ',6X,'THRUST',8X,'PHI',
     &       /7X,'(m-sec)',4X,'(lbm/s)',6X,' (lb)',/)
  109 FORMAT(7X,'   T    ',4X,' DMpDT ',6X,'THRUST',8X,'PHI')
  199 RETURN
      END
```

APPENDIX B - TEA PROGAM LISTING

```
C======================================================================
      SUBROUTINE SPC(T,DMPDT,T1P0,P1P,THRUST,PHI,MODE)
C
C        Single Point Calculation (SPC) Routine
C----------------------------------------------------------------------
C
      COMMON /CHECK/ ICHECK, INDEX
      COMMON /COEFX/ BETA,   CSIGMA
      COMMON /LAST1/ TLAST
      COMMON /LIST1/ X0,     Y0,
     &               X1,     Y1,     NX1,    NY1,
     &               X2,     Y2,
     &               X3,     Y3,
     &               X4,     Y4,
     &               Z1,     NZ1,    DZ
      COMMON /LIST2/ GAMMA,  RBAR,   TINF,   PINF,   PBACK
      COMMON /LIST3/ ALPHA,  U
      COMMON /LIST4/ E,      F,      G
      COMMON /LIST5/ P1S,    T1S,    V1S,    D1S,    Z1S
      COMMON /LIST6/ PE,     TE,     VE,     RE
      COMMON /LIST7/ PM,     TM,     VM,     RM
      COMMON /LIST8/ DRDT,   DEDT,   DKEOLD, VENEW,  DVE
C
      DIMENSION   B(50),     BSTAR(50), E(15,50),  F(15,50),
     & G(15,50),  PE(50),    PM(50),    RE(50),    RM(50),
     & TE(50),    TM(50),    VE(50),    VM(50),    XIHAT(50), Z(50),
     & BI(50),    BII(50),   DRDT(50),  DPDT(50),  DEDT(50), DVDT(50)
      REAL*8 V1P,V1S,R2,THETA1,DZ,B,BI,BII,THETA2,XIHAT
      REAL*8 SURGE,DELTA,DM3DT,DM4DT,D1S,D1P,A1S,A1PT
      REAL*8 T1S,C1S,PE,PM,VE,VM,RE,RM,DMSDT
      REAL*8 BVALUE,CVALUE,B24AC,C8
      REAL*8 DM1DT,FLUXP,FLUXM,FLUXMI,FLUXMJ
C
C---INTERNAL FUNCTION DEFINITIONS
C
      CP(G,R)  = R*G/(G-1.0)
      F2(G,Z)  = 1.0 + 0.5*(G-1.0)*Z*Z
      F3(G,Z)  = F2(G,Z)**(G/(G-1.0))
      FZ0(PM,PE,E1,E2) = PM*E1 + PE*E2
      FZ1(RM,RE,VM,VE,C1,C2,C3,C4) =
     &    RM*VM*C1 + RE*VM*C2 + RM*VE*C3 + RE*VE*C4
      FZ2(RM,RE,VM,VE,G1,G2,G3,G4,G5,G6) =
     &    RM*G1*VM*VM + RM*G2*VE*VE + RM*G3*VE*VM +
     &    RE*G4*VM*VM + RE*G5*VE*VE + RE*G6*VE*VM
      FZETA(Z,C1,C2,C3,C4) = C1*Z**4. + C2*Z**2.5 + C3*Z + C4
      FPZETA(Z,C1,C2,C3)   = 4.*C1*Z**3. + 2.5*C2*Z**1.5 + C3
      FPPZETA(Z,C1,C2)     = 12.*C1*Z**2. + 3.75*C2*Z**0.5
      GFT(T)=1.3825+0.10173*T*(1.-1.5638*T*(1.0-.4016*T*(1.-.1304*T)))
      H1G(Z) = (4531. + 1309.*Z**10. - 9240.*Z**8.5 + 22440.*Z**7.
     &        -19040.*Z**5.5)/13090.0
      H2G(Z) = (729. + 1122.*Z**10. -  7920.*Z**8.5 + 22440.*Z**7.
     &        -32640.*Z**5.5 + 25245.*Z**4. - 8976.*Z**2.5)/ 3740.0
      H3G(Z) = (2727. - 3927.*Z**10. + 27720.*Z**8.5 - 72930.*Z**7.
     &        +85680.*Z**5.5 - 39270.*Z**4.)/13090.0
      H4G(Z) = ( 6561. - 2618.*Z**10. + 18480.*Z**8.5 - 56100.*Z**7.
     &        +95200.*Z**5.5 - 98175.*Z**4. + 62832.*Z**2.5
     &        -26180.*Z)/26180.0
```

```
      H1L(Z) = -(H1G(Z) - 4531.0/13090.0)
      H2L(Z) = -(H2G(Z) -  729.0/ 3740.0)
      H3L(Z) = -(H3G(Z) - 2727.0/13090.0)
      H4L(Z) = -(H4G(Z) - 6561.0/26180.0)
C
C---GLOBAL PARAMETER INITIALIZATION
C
      ITN   = 0
      LIMIT = 50
      GC    = 32.174
      W     = Y2
      SCALE = FLOAT(NX1)*FLOAT(NY1)
      N     = NZ1+1
      DZ    = Z1/FLOAT(NZ1)
C
C---CONDITIONS FOR FREE-STREAM
C
   10 ALPHAR = ALPHA*3.1415/180.0
      VINF   = U*SIN(ALPHAR)
      DUyDT  = DUDT*SIN(ALPHAR)
      DINF   = PINF/(RBAR*TINF/GC)
      POINF  = PINF+0.5*VINF*VINF*DINF/GC
      TOINF  = TINF+0.5*VINF*VINF/CP(GAMMA,RBAR)
      AINF   = X0*Y0
      DMIDT  = AINF*VINF*DINF
C
C---EVALUATE PRIMARY NOZZLE CONDITIONS
C
      A1P = X1*Y1
      A1PT= A1P*FLOAT(NX1)*FLOAT(NY1)
      ZZ0 = GAMMA/(GAMMA-1.0)
      ZZ1 = (GAMMA-1.0)/GAMMA
      ZZ2 = (GAMMA+1.0)/2.0
      ZZ3 = 2.0*GAMMA*(GAMMA+1.0)
      ZZ4 = (DMPDT/(A1PT*PBACK*GC))**2.0
      ZZ4 = ZZ4*T1P0*RBAR*(GAMMA-1.0)/(2.0*GAMMA)
      PRN = (0.5+0.5*SQRT(1.0+4.0*ZZ4))**ZZ0
      XPRN= ZZ2**ZZ0
C
C   CHECK FOR CHOKED FLOW....
      IF (PRN.LT.XPRN) GO TO 17
C
C      CHOKED NOZZLE FLOW OPERATIONS...
         P1P0    = 1.88076*(DMPDT/A1PT)*SQRT(T1P0)
         PRN     = P1P0/PBACK
         Z1P     = 1.0
         P1P     = P1P0/F3(GAMMA,Z1P)
         YPRN    = P1P0/P1P
         FORCE1P= DMPDT*(2.0/GC)*SQRT((T1P0*RBAR)/ZZ3)
         FORCE1P= FORCE1P*(GAMMA + 1.0 - XPRN/PRN)
         GO TO 19

C      SUBSONIC NOZZLE COMPUTATIONS...
   17    ZZ4     = (DMPDT/(A1PT*P1P*GC))**2.0
         ZZ4     = ZZ4*T1P0*RBAR*(GAMMA-1.0)/(2.0*GAMMA)
         YPRN    = (0.5+0.5*SQRT(1.0+4.0*ZZ4))**ZZ0
         Z1P     = SQRT((2.0/(GAMMA-1.0))*(YPRN**ZZ1 - 1.0))
```

```
            P1PO    = P1P*YPRN
            PRN     = P1PO/PBACK
            PRN     = AMAX1(1.,PRN)
            FORCE1P= DMPDT*(SQRT(T1PO))/GC
            FORCE1P= FORCE1P*SQRT((2.*RBAR*ZZO)*(1.0-(1./PRN)**ZZ1))
   19 CONTINUE
      T1P = T1PO/F2(GAMMA,Z1P)
      D1P = P1P/(T1P*RBAR/GC)
      C1P = SQRT(GAMMA*RBAR*T1P)
      V1P = Z1P*C1P
      DMPDT = D1P*V1P*A1PT
C
C---PREDICT SECONDARY FLOW PROPERTIES
C
      A1S = (X3*Y3)-A1PT
      P1SO=POINF
      T1SO=TOINF
C   STATION 1-S INITIAL VELOCITY ESTIMATE
      IF (MODE.EQ.0)  V1S = 1.0
      IF (MODE.EQ.1)  V1S = VENEW
C   ITERATE ON ACTUAL SOLUTION
   20 ITN = ITN + 1
      T1S = T1SO - 0.5*(V1S**2.0)/CP(GAMMA,RBAR)
      P1S = P1SO*(T1S/T1SO)**(GAMMA/(GAMMA-1.0))
      D1S = P1S/(RBAR*T1S/GC)
      DMSDT = D1S*V1S*A1S
      ER    = DMSDT/DMPDT
      ENERGY1S = 0.5*D1S*V1S**3.0
C
C---MIXING REGION PREDICTIONS
C
      AREA3 = X3*Y3
      DM1DT = DMPDT + DMSDT
      PM(1) = P1P
      PE(1) = P1S
      RM(1) = D1P/GC
      RE(1) = D1S/GC
      VM(1) = V1P
      VE(1) = V1S
C
C--- VIRTUAL GRID INITIALIZATION
C
      R2         = V1S/V1P
      THETA1     = DATAN(0.4*(1-R2)*(0.416+0.134*R2)/(1+R2))
      BI(1)      = A1P/(W*2.0)
      BI(2)      = BI(1) - DZ*DTAN(THETA1)
         IF(BI(2).LE.0.0) BI(2)=0.0
      BII(1)     = BI(1)
      BMAX       = X2/2.0
C
C   COMPUTE OUTER JET EXPANSION ANGLE
      C1     = BI(2)*D1P*V1P + (BMAX-BI(2))*D1S*V1S
      C2     = 0.45*D1P*V1P + 0.55*D1P*V1S - D1S*V1S
      B(2)   = ((DM1DT/(2.0*SCALE*W))-C1)/C2
      BII(2)= B(2)+BI(2)
      THETA2= DATAN ((BII(2)-BII(1))/DZ)
C
```

```
C   COMPUTE FINAL GRID BOUNDARIES
      DO 34 I = 2,N
         Z(I) = DZ*FLOAT(I-1)
         BI(I)  = BI(1) - Z(I)*DTAN(THETA1)
           IF(BI(I).LE.0.0) BI(I)=0.0
         BII(I) = BII(1) + Z(I)*DTAN(THETA2)
           IF(BII(I).GT.BMAX) BII(I)=BMAX
         B(I)   = BII(I) - BI(I)
         XIHAT(I) = (BMAX-BI(I))/B(I)
   34 CONTINUE
C
C   COMPUTE SIGMA
C     SIGMA = CSIGMA*Z(N)*144.0/(1.0+Z1P)
      SIGMA = CSIGMA*(((1.0+0.23*Z1P)*12.0/Z(N))**2.0)
C
C   COMPUTE SELF-SIMILAR PROFILE INTEGRALS FOR THE NEW JET
      DO 37 I=2,N
         BIB    = BI(I)/B(I)
         E(I,1) = BIB      + 1.00
         E(I,2) = XIHAT(I) - 1.00
         F(I,1) = BIB      + 0.45
         F(I,2) = 0.0
         F(I,3) = 0.55
         F(I,4) = XIHAT(I) - 1.0
         G(I,1) = (BIB + 243.0/770.0)
         G(I,2) = (320.0/770.0)
         G(I,3) = (414.0/1540.0)
         G(I,4) = 0.0
         G(I,5) = (XIHAT(I) - 1.0)
         G(I,6) = 0.0
   37 CONTINUE
         INCLUDE 'XCHECK1.FOR'
C
C---SKIP FINITE VOLUME INITIALIZATION IF MODE > 0
C
      IF (MODE.EQ.1) GO TO 40
C
C---INITIALIZATION OF FIELD VARIABLES
C
      DO 39 I = 1,N-1
         J = I+1
         RE(J) = RE(I)
         PE(J) = PE(I)
         DO 38 K=1,3
            VE(J) = VE(I)
            C8 = 0.5*VE(I)*VE(I)
     &         + GAMMA/(GC*(GAMMA-1.0))*(PE(I)/RE(I)-PE(J)/RE(J))
            IF(C8.GT.0.0) VE(J) = SQRT(2*C8)
         IF (I.EQ.1) THEN
            FLUXRI = RM(I)*VM(I)*A1PT + RE(I)*VE(I)*A1S
            FLUXPI = PM(I)*VM(I)*A1PT + PE(I)*VE(I)*A1S
            FLUXMI = (PM(I)+RM(I)*VM(I)*VM(I))*A1PT
     &             + (PE(I)+RE(I)*VE(I)*VE(I))*A1S
         ELSE
            FLUXRI = 2.0*SCALE*W*B(I)*
     &       FZ1(RM(I),RE(I),VM(I),VE(I),F(I,1),F(I,2),F(I,3),F(I,4))
            FLUXPI = 2.0*SCALE*W*B(I)*
```

```
     &       FZ1(PM(I),PE(I),VM(I),VE(I),F(I,1),F(I,2),F(I,3),F(I,4))
            FLUXMI = 2.0*SCALE*W*B(I)*(
     &       FZ2(RM(I),RE(I),VM(I),VE(I),G(I,1),G(I,2),G(I,3),G(I,4),
     &                                  G(I,5),G(I,6))
     &      +FZ0(PM(I),PE(I),E(I,1),E(I,2)))
         ENDIF
      C1 = (G(J,3)+G(J,6))/(G(J,1)+G(J,4))
      C2 = (F(J,1)+F(J,2))/(G(J,1)+G(J,4))
      C3 = (G(J,2)+G(J,5))/(G(J,1)+G(J,4))
      C4 = (E(J,1)+E(J,2))/(G(J,1)+G(J,4))
      C5 = (F(J,3)+F(J,4))/(G(J,1)+G(J,4))
      BVALUE= VE(J)*C1 - (FLUXMI/FLUXRI)*C2
      CVALUE= VE(J)*VE(J)*C3 + (FLUXPI/FLUXRI)*C4
     &                       - VE(J)*(FLUXMI/FLUXRI)*C5
      B24AC = (BVALUE**2.0) - 4.0*CVALUE
         IF (B24AC.LT.0.0) THEN
             WRITE(*,900) 1
             INCLUDE 'XCHECK2.FOR'
         ENDIF
      VM(J) = -0.5*(BVALUE+DSQRT(B24AC))
      C6 = FLUXRI/(2.0*SCALE*W*B(J)*(F(J,1)+F(J,2)))
      C7 = VE(J)*(F(J,3)+F(J,4))/(F(J,1)+F(J,2))
      C8 = FLUXPI/(2.0*SCALE*W*B(J)*(F(J,1)+F(J,2)))
      RM(J) = C6/(VM(J)+C7)
      RE(J) = RM(J)
      PM(J) = C8/(VM(J)+C7)
      PE(J) = PM(J)
   38 CONTINUE
   39 CONTINUE
C
C---DERIVATIVE ESTIMATES
C
   40 DT    = T-TLAST
C
C  ...SKIP DERIVATIVE COMPUTATIONS IF DT=0
      IF(DT.LE.0.0) GO TO 43
C
C  ...NO DERIVATIVES ARE NEEDED FOR QUASI-STEADY FLOW
      IF(MODE.EQ.0) GO TO 43
C
C  ...PROCEED WITH DERIVATIVE COMPUTATIONS
      DO 42 I = 1,N-1
          J = I+1
C
C          ...UPDATE ENTRAINED VELOCITY
         VE(J) = VE(I)
         C8 = 0.5*VE(I)*VE(I)
     &        + GAMMA/(GC*(GAMMA-1.0))*(PE(I)/RE(I)-PE(J)/RE(J))
         IF(C8.GT.0.0) VE(J) = SQRT(2.0*C8)

C
C          ...COMPUTE STATION 'I' FLUXES
         IF (I.EQ.1) THEN
            FLUXRI = DM1DT/(2.0*SCALE*W*GC)
            FLUXMI = ((A1PT*(P1P+D1P*V1P*V1P/GC))
     &               +(A1S*(P1S+D1S*V1S*V1S/GC)))/(2.0*SCALE*W)
            FLUXPI = ((A1PT*P1P*V1P)+(A1S*P1S*V1S))/(2.0*SCALE*W)
```

```
               ELSE
                 FLUXRI = B(I)*FZ1(RM(I),RE(I),VM(I),VE(I),
     &                    F(I,1),F(I,2),F(I,3),F(I,4))
                 FLUXMI = B(I)*(FZ2(RM(I),RE(I),VM(I),VE(I),
     &                    G(I,1),G(I,2),G(I,3),G(I,4),
     &                    G(I,5),G(I,6))
     &                   +FZO(PM(I),PE(I),E(I,1),E(I,2)))
                 FLUXPI = B(I)*FZ1(PM(I),PE(I),VM(I),VE(I),
     &                    F(I,1),F(I,2),F(I,3),F(I,4))
               ENDIF
C
C              ... COMPUTE STATION 'J' FLUXES ...
               FLUXRJ = B(J)*FZ1(RM(J),RE(J),VM(J),VE(J),
     &                  F(J,1),F(J,2),F(J,3),F(J,4))
               FLUXMJ = B(J)*(FZ2(RM(J),RE(J),VM(J),VE(J),
     &                  G(J,1),G(J,2),G(J,3),G(J,4),
     &                  G(J,5),G(J,6))
     &                  +FZO(PM(J),PE(J),E(J,1),E(J,2)))
               FLUXPJ = B(J)*FZ1(PM(J),PE(J),VM(J),VE(J),
     &                  F(J,1),F(J,2),F(J,3),F(J,4))
C
C              ... COMPUTE PRIMARY FLOW DERIVATIVES ...
               DEDT(I) = DVE/DT
               DRDT(I) = (FLUXRI - FLUXRJ)/(BMAX*DZ)
               DPDT(I) = (FLUXPI - FLUXPJ)/(BMAX*DZ)
               CDVDT   = 0.0
               C1 = (F(J,3)+F(J,4))/(F(J,1)+F(J,2))
               C2 = C1*DEDT(I)*CDVDT - (DRDT(I)/RM(J))*(VM(J)+VE(J)*C1)
               DVDT(I) = (FLUXMI - FLUXMJ)/(B(J)*DZ) - C2
C
C              ... ADVANCE PRIMARY FLOW FORWARD IN TIME ...
               RM(J) = RM(J) + DRDT(I)*DT
               RE(J) = RM(J)
               PM(J) = PM(J) + DPDT(I)*DT
               PE(J) = PM(J)
               VM(J) = VM(J) + DVDT(I)*DT
   42 CONTINUE
C
C  COMPUTE THE JET STREAMLINE
   43 DO 45 J = 2,N
               ISTOP= 0
               ZETA = BI(1)/B(J)
               C1 = 0.25*(VM(J)-VE(J))
               C2 = 0.80*(VE(J)-VM(J))
               C3 = VM(J)
               C4 = (RE(1)/RE(J))*((BMAX-BI(1))/B(J))*V1S
     &              - C1 - C2 - C3 - ((BMAX/B(J)) - 1.)*VE(J)
   44          ISTOP = ISTOP + 1
               C5 = FZETA(ZETA,C1,C2,C3,C4)/FPZETA(ZETA,C1,C2,C3)
               C6 = 1- FZETA(ZETA,C1,C2,C3,C4)*FPPZETA(ZETA,C1,C2)
     &              /FPZETA(ZETA,C1,C2,C3)**2.0
               DELTA = -C5/C6
               ZETA  = ZETA + DELTA
               BSNEW = ZETA*B(J)
               IF (BSNEW.GE.BMAX) THEN
                  BSTAR(J) = BMAX
                  GO TO 45
```

```
            ENDIF
            IF((ABS(DELTA).GE.0.000001).AND.(ISTOP.LT.50)) GO TO 44
            BSTAR(J) = BSNEW
   45 CONTINUE
C
C---KINETIC ENERGY EXCHANGE
C
      ZETA  = BSTAR(N)/B(N)
      ZSTAR = BMAX/B(N)
      C1 = (H1G(ZETA) - (0.55 + 0.25*ZETA**4.-0.8*ZETA**2.5))
     &      *VE(N)**3.0
      C2 = (H3G(ZETA) - (0.45-(0.25*ZETA**4.-0.8*ZETA**2.5+ZETA)))
     &      *VM(N)*VE(N)**2.0
      C3 = H2G(ZETA)*VE(N)*VM(N)**2.0
      C4 = H4G(ZETA)*VM(N)**3.0
      DKE  = B(N)*RM(N)*GC*(C1+C2+C3+C4)
      C1 = H1L(ZETA)*VE(N)**3. + H2L(ZETA)*VE(N)*VM(N)**2.
     &   + H3L(ZETA)*VM(N)*VE(N)*2. + H4L(ZETA)*VM(N)**3.
      C2 = (0.25*ZETA**4. - 0.8*ZETA**2.5 + ZETA)*VM(N)**3.
     &   + (-0.25*ZETA**4. + 0.8*ZETA**2.5)*VE(N)*VM(N)**2.
      PLOSS  = -B(N)*RM(N)*GC*(C1-C2)
      DKE    = DKE + SIGMA*PLOSS
      CHANGE = DKE - DKEOLD
      VSTAR  = ((ENERGY1S+CHANGE)/(0.5*D1S))
        IF(VSTAR.LT.0.0) THEN
          WRITE(*,900) 2
          INCLUDE 'XCHECK3.FOR'
        ENDIF
      VENEW  = (ABS(VSTAR))**(1./3.)
      DVE    = VENEW-V1S
      DKEOLD = DKE
C
C---ASSIGN MIXING REGION EXIT CONDITIONS
C
      ZZZ  = (2.0*SCALE*W*B(N))/AREA3
      V3   = ZZZ*(0.45*VM(N) + (XIHAT(N)-0.45)*VE(N))
      D3   = RM(N)*GC
        IF (D3.LT.0.0) WRITE(*,900) 3
        IF (D3.GE.1.0) WRITE(*,900) 4
      P3   = PM(N)
      T3   = P3/(RBAR*D3/GC)
        IF (T3.LT.0.0) WRITE(*,900) 5
      C3   = SQRT(GAMMA*RBAR*T3)
      Z3   = V3/C3
      P30  = P3*F3(GAMMA,Z3)
      T30  = T3*F2(GAMMA,Z3)
      DM3DT= D3*V3*AREA3
C
C---DIFFUSER PREDICTIONS
C
   50 AREA4 = X4*Y4
      P40   = P30
      T40   = T30
        IF(MODE.EQ.0) THEN
          P4 = PBACK
            IF(P40.LT.P4) WRITE(*,900) 6
          Z4 = SQRT((2.0/(GAMMA-1.0))
```

```
     &              *(((P40/P4)**((GAMMA-1.0)/GAMMA))-1.0))
          T4 = T40/F2(GAMMA,Z4)
          D4 = P4/(RBAR*T4/GC)
          C4 = SQRT(GAMMA*RBAR*T4)
          V4 = Z4*C4
        ELSE
          C1 = 0.5/(GAMMA-1.0)
          C2 = (GAMMA/(GAMMA-1.0))*GC*AREA4*P30/DM3DT
          C3 = CP(GAMMA,RBAR)*T30
          V4 = (C2-SQRT(C2*C2-4.0*C1*C3))/(2.0*C1)
          D4 = DM3DT/(V4*AREA4)
          P4 = P40 - 0.5*D4*V4*V4/GC
          T4 = T40 - 0.5*V4*V4/CP(GAMMA,RBAR)
          C4 = SQRT(GAMMA*RBAR*T4)
       ENDIF
       DM4DT = D4*V4*AREA4
C
C--- CHECK FOR CONTINUITY
C
       EPSILON = 0.00005
       SURGE = (DM4DT - DM3DT)/(D1S*A1S)
       IF(MODE.EQ.1) GO TO 70
       IF (ABS(SURGE).LE.EPSILON) THEN
          GO TO 70
        ELSE
          V1S = V1S + SURGE
          INCLUDE 'XCHECK4.FOR'
          IF(ITN.LT.LIMIT) GO TO 20
       ENDIF
C---THRUST AND THRUST AUGMENTATION RESULTS
C
   70 THRUST = (DM4DT*(V4/(BETA**2.)-VINF)/(GC))
     &         + AREA4*(PBACK-PINF)
       PHI    = THRUST/FORCE1P
C
C---PRINT OPTION
C
       IF(ICHECK.LT.100) GO TO 999
       WRITE (6,200) T
       WRITE (6,201) AINF,  A1PT,  A1S,   AREA3, AREA4,
     &               VINF,  V1P,   V1S,   V3,    V4,
     &               PINF,  P1P,   P1S,   P3,    P4,
     &               POINF, P1PO,  P1SO,  P30,   P40,
     &               TINF,  T1P,   T1S,   T3,    T4,
     &               TOINF, T1PO,  T1SO,  T30,   T40,
     &               DINF,  D1P,   D1S,   D3,    D4,
     &               DMIDT, DMPDT, DMSDT, DM3DT, DM4DT
       WRITE (6,202) PRN,   XPRN
       IF(MODE.EQ.0) WRITE (6,203) SURGE, ITN, LIMIT
       WRITE (6,204)
       WRITE (6,207)((I,Z(I),BI(I),BII(I),BSTAR(I)),I=2,N)
       WRITE (6,206)
       WRITE (6,207)((I,RM(I),PM(I),VM(I),VE(I)),I=1,N)
       WRITE (6,208)
       WRITE (6,207)((I,DRDT(I),DPDT(I),DVDT(I),DEDT(I)),I=1,N-1)
       WRITE (6,209) THETA1,THETA2,BI(1),BMAX
       WRITE (6,210) THRUST,FORCE1P,PHI
```

```
      200 FORMAT(1H1,/,19X,'***** SINGLE POINT CALCULATION *****',
     &            /,29X,'T = ',F8.5,' sec'/)
      201 FORMAT( /,3X,'FIELD VARIABLE PROFILE:',/
     & /,3X,'Station -> Infinity',6X,'1P',10X,'1S',10X,
     &      '3           4',/,
     & /,3X,'AREA    ',2X,5(F10.5,2X),'FT',
     & /,3X,'V       ',2X,5(F10.5,2X),'FT/S',
     & /,3X,'P       ',2X,5(F10.5,2X),'LBF/FT2',
     & /,3X,'PO      ',2X,5(F10.5,2X),'LBF/FT2',
     & /,3X,'T       ',2X,5(F10.5,2X),'DEG-R',
     & /,3X,'TO      ',2X,5(F10.5,2X),'DEG-R',
     & /,3X,'RHO     ',2X,5(F10.5,2X),'LBM/FT3',
     & /,3X,'MDOT    ',2X,5(F10.5,2X),'LBM/S')
      202 FORMAT(7X,'NOTES:',/10X,'Nozzle Pressure Ratio is ',F8.5,
     & '  (Choked NPR is ',F8.5,' )')
      203 FORMAT( 10X,'Station 3-4 SURGE error is ',F12.8,
     &/,10X,'Solution obtained in ',I3,' iterations, limit is ',I3)
      204 FORMAT(/,3X,'FINITE VOLUME PROFILE',//,5X,'Station      Z',
     &10X,'B,inner',7X,'B,outer',8X,'B,jsl ')
      206 FORMAT(/,5X,'Station',4X,'Rho',11X,'P',13X,'Vm',12X,'Ve')
      207 FORMAT(6X,I3,2X,E12.5,2X,E12.5,2X,E12.5,2X,E12.5)
      208 FORMAT(//,5X,
     &'Element  D(Rho)/DT     D(P)/DT        D(Vm)/DT     D(Ve)/DT')
      209 FORMAT(7X,'NOTES:',
     & /10X,'Inner jet expansion, Theta1 ',F8.5,' radians',
     & /10X,'Outer jet expansion, Theta2 ',F8.5,' radians',
     & /10X,'Initial jet with, B0, ',F8.5,' Ft',
     & /10X,'Allowable jet width, Bmax, ',F8.5,' Ft')
      210 FORMAT( /,3X,'PREDICTED THRUST AND PERFORMANCE:',
     &        //,5X,'Total ejector thrust       = ',F12.5,' Lb',
     &         /,5X,'Isentropic primary thrust = ',F12.5,' Lb',
     &         /,5X,'Thrust augmentation ratio = ',F12.5)
      900 FORMAT(/5X,'$$$ TEA FATAL ERROR # ',I2,', $$$'/)
      999 RETURN
          END
```

APPENDIX B - TEA PROGAM LISTING

```
C=================================================================
C      XCHECK1.FOR
C-----------------------------------------------------------------
C      PRINT MIXING REGION DATA FOR DEBUG CHECKS
C-----------------------------------------------------------------
 1000 IF(ICHECK.LT.1000) GO TO 1020
          WRITE(6,1010) T,ITN
          WRITE(6,1011)
          DO 1001 I=2,N
 1001        WRITE(6,1012) (I,(E(I,J),J=1,2))
          WRITE(6,1013)
          DO 1002 I=2,N
 1002        WRITE(6,1014) (I,(F(I,J),J=1,4))
          WRITE(6,1015)
          DO 1003 I=2,N
 1003        WRITE(6,1016) (I,(G(I,J),J=1,6))
 1010 FORMAT(1H1,/10X,'*** T = ',F10.5,'  ITN = ',I5)
 1011 FORMAT(/,33X,'> SELF-SIMILAR PROFILE EVALUATION <',
     &       /,3X,'Z-POINT   E(1)       E(2)')
 1012 FORMAT(5X,I2,1X,2(3X,F7.3))
 1013 FORMAT(/,3X,'Z-POINT   F(1)       F(2)       F(3)       ',
     &                      'F(4)')
 1014 FORMAT(5X,I2,1X,4(3X,F7.3))
 1015 FORMAT(/,3X,'Z-POINT   G(1)       G(2)       G(3)       ',
     &                      'G(4)       G(5)       G(6)')
 1016 FORMAT(5X,I2,1X,6(3X,F7.3))
 1020 CONTINUE
```

```
C======================================================================
C     XCHECK2.FOR
C----------------------------------------------------------------------
C     PRINT VELOCITY INITIALIZATION DATA FOR DEBUG CHECKS
C----------------------------------------------------------------------
 2000 IF(ICHECK.LT.500) GO TO 2060
      WRITE(6,2010) T,I,J
      WRITE(6,2020) C1,C2,C3,C4,C5
      WRITE(6,2050) THETA1,THETA2
      WRITE(6,2030) FLUXRI,FLUXMI,FLUXPI
      WRITE(6,2040) VE(J),BVALUE,CVALUE,B24AC
 2010 FORMAT(///,5X,'*** T = ',F7.4,' ; I = ',I2,' J = ',I2)
 2020 FORMAT(/,5X,'C1',8X,'C2',8X,'C3',8X,'C4',8X,'C5',
     &/,5X,5(F10.4,2X))
 2030 FORMAT(/2X,'FLUXRI = ',E12.4,
     &       /2X,'FLUXMI = ',E12.4,/2X,'FLUXPI = ',E12.4)
 2040 FORMAT(/2X,'VE(J) = ',F10.4,/
     &        2X,'B = ',E12.4,' C = ',E12.4,' B24AC = ',E12.4)
 2050 FORMAT(/5X,'THETA1 = ',F10.5,' THETA2 = ',F10.5)
 2060 CONTINUE
C======================================================================
```

APPENDIX B - TEA PROGAM LISTING

```
C=================================================================
C     XCHECK3.FOR
C-----------------------------------------------------------------
C     KINETIC ENERGY EXCHANGE ERRORS
C        Print out all kinetic energy information if the program bombs.
C        This error by resetting the KE-CHANGE and re-computing VSTAR
C-----------------------------------------------------------------
      WRITE(*,*)
      WRITE(*,'(/5X,38H*** ERROR DURING CALCULATIONS FOR T = ,
     &          F10.5)') T
      WRITE(*,'(/10X,10HDKE      = ,F15.3,/10X,10HDKEOLD  = ,F15.3,
     &         /10X,10HSIGMA    = ,F15.3,/10X,10HPLOSS   = ,F15.3,
     &         /10X,10HENERGY1S= ,F15.3,/10X,10HCHANGE  = ,F15.3,
     &         /10X,10HVSTAR    = ,F15.3)')
     &     DKE,DKEOLD,SIGMA,PLOSS,ENERGY1S,CHANGE,VSTAR
      CHANGE = -0.999*ENERGY1S
      WRITE(*,'(/5X,38H*** PROCEED W/ CHANGE = -0.999ENERGY1S)')
      VSTAR  = ((ENERGY1S+CHANGE)/(0.5*D1S))
      WRITE(*,'(/5X,19H*** NEW VSTAR IS = ,F15.3//)') VSTAR
C=================================================================
```

```
C=====================================================================
C     XCHECK4.FOR
C---------------------------------------------------------------------
C      PRINT ENTRAINED VELOCITY AND SURGE FOR ITERATIVE PROCESS
C---------------------------------------------------------------------
 4000 IF(ICHECK.LT.1000) GO TO 4020
      WRITE(6,4010) V1S,SURGE
 4010 FORMAT(/,5X,'V1S = ',F10.3,'    SURGE = ',F10.3)
 4020 CONTINUE
C----------------------------------------------------------------------
```

APPENDIX C - TEST CASE INPUT LISTINGS

```
C---------------------------------------------------------------- CASE1.DAT ---
C
C      Case study input file for TEA.FOR transient ejector analysis
C      routine. Here, a single step function is prescribed that
C      corresponds with one of the STOVL ejector tests run in June 1987.
C      This file assumes the default BACK and DISP parameters in the TEA.FOR
C      source code are appropriate.
C
C------------------------------------------------------------------------------

CASE banner.
  Test for step change in primary flow for STOVL ejector design.

GEOMetric approximation for the ejector.
X0          Y0
0009.36000, 0001.25000
X1          Y1          NX1    NY1
0000.10801, 0000.10801, 00012, 00003
X2          Y2
0000.78000, 0000.34700
X3          Y3
0009.36000, 0001.04100
X4          Y4
0009.36000, 0001.87500
Z1          NZ
0000.90000, 00005

COEFficients for solution execution.
ITYPE       BETA        CSIGMA
00001,      0001.0550,  0000.30000

PRIMary nozzle discharge conditions.
SPECify states at each time step.
T           MDOT1P      T1PO        P1P
0000.00010, 0018.70000, 0769.70000, 2219.78000
0000.00020, 0018.70000, 0769.70000, 2219.78000
0000.00030, 0018.70000, 0769.70000, 2219.78000
0000.00040, 0018.70000, 0769.70000, 2219.78000
0000.00050, 0018.70000, 0769.70000, 2219.78000
0000.00060, 0021.85000, 0760.60000, 2250.92000
0000.00070, 0021.85000, 0760.60000, 2250.92000
0000.00080, 0021.85000, 0760.60000, 2250.92000
0

C------------------------------------------------------------------------------
```

APPENDIX C - TEST CASE INPUT LISTINGS

```
C------------------------------------------------------------------- CASE2.DAT ---
C
C     This case study has the same basic conditions as CASE1.DAT, but includes
C     the use of some optional macros.
C
C--------------------------------------------------------------------------------

CASE banner.
 Test for step change in primary flow for STVOL ejector design.

DISPlay parameters for printing and plotting output.
ICHECK      INDEX       IPLOT
00100,      00001,      00001

GEOMetric approximation for the ejector.
X0          Y0
0009.36000, 0001.25000
X1          Y1          NX1    NY1
0000.10801, 0000.10801, 00012, 00003
X2          Y2
0000.78000, 0000.34700
X3          Y3
0009.36000, 0001.04100
X4          Y4
0009.36000, 0001.87500
Z1          NZ
0000.90000, 00005

COEFficients for solution execution.
ITYPE       BETA        CSIGMA
00001,      0001.0550,  0000.30000

FREE stream fluid conditions.
TINF        PINF        GAMMA       RBAR        UINF        ALPHA
0542.80000, 2067.84000, 0001.40000, 1714.54130, 0000.00000, 0090.00000

BACKpressure for ejector discharge
2067.84000

PRIMary nozzle discharge conditions.
SPECify states at each time step.
T           MDOT1P      T1PO        P1P
0000.00010, 0018.70000, 0769.70000, 2219.78000
0000.00020, 0018.70000, 0769.70000, 2219.78000
0000.00030, 0018.70000, 0769.70000, 2219.78000
0000.00040, 0018.70000, 0769.70000, 2219.78000
0000.00050, 0018.70000, 0769.70000, 2219.78000
0000.00060, 0021.85000, 0760.60000, 2250.92000
0000.00070, 0021.85000, 0760.60000, 2250.92000
0000.00080, 0021.85000, 0760.60000, 2250.92000
0000.00090, 0021.85000, 0760.60000, 2250.92000
0000.00100, 0021.85000, 0760.60000, 2250.92000
0000.00110, 0021.85000, 0760.60000, 2250.92000
0000.00120, 0021.85000, 0760.60000, 2250.92000
0000.00130, 0021.85000, 0760.60000, 2250.92000
QUIT primary nozzle data input

STOP reading DATA
```

```
***** TEA INPUT *****

Test for step change in primary flow for STVOL ejector design.

 CHECK PRINT LEVEL IS 100

 EJECTOR GEOMETRIC CHARACTERISTICS,
   X0 =    9.36000     Y0 =    1.25000
   X1 =    0.10801     Y1 =    0.10801
   NX1=    12          NY1=     3
   X2 =    0.78000     Y2 =    0.34700
   X3 =    9.36000     Y3 =    1.04100
   X4 =    9.36000     Y4 =    1.87500
   Z1 =    0.90000     NZ =     5

 MIXING LOSS CORRECTION FACTOR
   BETA =      1.05500

 KINETIC ENERGY MIXING COEFFICIENT
   CSIGMA =    0.30000

 FREE-STREAM THERMODYNAMIC PROPERTIES
   STATIC TEMPERATURE  =  542.79999 DEG-RANKINE
   STATIC PRESSURE     = 2067.84009 LB-F/FT3
   SPECIFIC HEAT RATIO =    1.40000
   GAS CONSTANT, AIR   = 1714.54126 FT2/S2-R
   FREESTREAM VELOCITY =    0.00000 FT/S
   ANGLE-OF-ATTACK     =   90.00000 DEGREES

 EJE BACK PRESSURE IS 2067.84009 LBF/FT2

 PRIMARY NOZZLE DATA

   DATA       T        DMPDT       T1PO        P1P
   SET#     (sec)     (lbm/s)     (degR)     (lbf/ft2)
     1     0.00040    18.70000   769.70001  2219.78003
     2     0.00050    18.70000   769.70001  2219.78003
     3     0.00060    21.85000   760.59998  2250.91992
     4     0.00070    21.85000   760.59998  2250.91992
     5     0.00080    21.85000   760.59998  2250.91992

 PROGRAM WILL OPERATE ON      5 DATA SETS
```

APPENDIX D - OUTPUT LISTING FOR CASE 1

```
          ***** SINGLE POINT CALCULATION *****
                   T =  0.00040 sec


FIELD VARIABLE PROFILE:

Station -> Infinity      1P          1S          3           4

AREA        11.70000     0.41998     9.32378     9.74376    17.55000  FT
V            0.00000   769.94739   282.19669   304.57248   164.99725  FT/S
P         2067.84009  2219.78003  1980.71228  1997.96570  2067.84009  LBF/FT2
PO        2067.84009  2799.79346  2067.84009  2097.37158  2097.37158  LBF/FT2
T          542.79999   720.30579   536.16473   553.28766   558.74860  DEG-R
TO         542.79999   769.70001   542.79999   561.01691   561.01691  DEG-R
RHO          0.07149     0.05783     0.06932     0.06776     0.06945  LBM/FT3
MDOT         0.00000    18.70000   182.39970   201.09969   201.09970  LBM/S
   NOTES:
      Nozzle Pressure Ratio is  1.35397  (Choked NPR is  1.89293 )
      Station 3-4 SURGE error is   0.00002361
      Solution obtained in  17 iterations, limit is  50

FINITE VOLUME PROFILE

  Station      Z           B,inner      B,outer       B,jsl
     2   0.18000E+00  0.12857E-02  0.42297E-01  0.10382E-01
     3   0.36000E+00  0.00000E+00  0.67784E-01  0.16039E-01
     4   0.54000E+00  0.00000E+00  0.93272E-01  0.19376E-01
     5   0.72000E+00  0.00000E+00  0.11876E+00  0.21867E-01
     6   0.90000E+00  0.00000E+00  0.14425E+00  0.23816E-01

  Station     Rho          P            Vm           Ve
     1   0.17974E-02  0.22198E+04  0.76995E+03  0.28220E+03
     2   0.20635E-02  0.19575E+04  0.10653E+04  0.27064E+03
     3   0.20895E-02  0.19822E+04  0.73541E+03  0.27064E+03
     4   0.20987E-02  0.19909E+04  0.59600E+03  0.27064E+03
     5   0.21033E-02  0.19953E+04  0.52124E+03  0.27064E+03
     6   0.21061E-02  0.19980E+04  0.47450E+03  0.27064E+03


  Element  D(Rho)/DT    D(P)/DT      D(Vm)/DT     D(Ve)/DT
     1   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
     2   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
     3   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
     4   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
     5   0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
   NOTES:
      Inner jet expansion, Theta1  0.08603 radians
      Outer jet expansion, Theta2  0.14066 radians
      Initial jet with, BO,  0.01681 Ft
      Allowable jet width, Bmax,  0.39000 Ft

PREDICTED THRUST AND PERFORMANCE:

  Total ejector thrust      =   926.57001 Lb
  Isentropic primary thrust =   508.74969 Lb
  Thrust augmentation ratio =     1.82127
```

***** SINGLE POINT CALCULATION *****
T = 0.00050 sec

FIELD VARIABLE PROFILE:

Station ->	Infinity	1P	1S	3	4	
AREA	11.70000	0.41998	9.32378	9.74376	17.55000	FT
V	0.00000	769.94739	282.19650	304.57236	164.98514	FT/S
P	2067.84009	2219.78003	1980.71240	1997.96570	2067.99219	LBF/FT2
PO	2067.84009	2799.79346	2067.84009	2097.37158	2097.37158	LBF/FT2
T	542.79999	720.30579	536.16474	553.28766	558.74890	DEG-R
TO	542.79999	769.70001	542.79999	561.01691	561.01691	DEG-R
RHO	0.07149	0.05783	0.06932	0.06776	0.06945	LBM/FT3
MDOT	0.00000	18.70000	182.39959	201.09961	201.09961	LBM/S

NOTES:
Nozzle Pressure Ratio is 1.35397 (Choked NPR is 1.89293)

FINITE VOLUME PROFILE

Station	Z	B,inner	B,outer	B,jsl
2	0.18000E+00	0.12857E-02	0.42297E-01	0.10382E-01
3	0.36000E+00	0.00000E+00	0.67784E-01	0.16039E-01
4	0.54000E+00	0.00000E+00	0.93272E-01	0.19376E-01
5	0.72000E+00	0.00000E+00	0.11876E+00	0.21867E-01
6	0.90000E+00	0.00000E+00	0.14425E+00	0.23816E-01

Station	Rho	P	Vm	Ve
1	0.17974E-02	0.22198E+04	0.76995E+03	0.28220E+03
2	0.20635E-02	0.19575E+04	0.10653E+04	0.27064E+03
3	0.20895E-02	0.19822E+04	0.73541E+03	0.27064E+03
4	0.20987E-02	0.19909E+04	0.59600E+03	0.27064E+03
5	0.21033E-02	0.19953E+04	0.52124E+03	0.27064E+03
6	0.21061E-02	0.19980E+04	0.47450E+03	0.27064E+03

Element	D(Rho)/DT	D(P)/DT	D(Vm)/DT	D(Ve)/DT
1	0.00000E+00	0.44516E+00	0.71454E-02	-0.18450E+01
2	0.00000E+00	0.22258E+00	0.61080E-02	-0.18450E+01
3	0.42453E-06	0.44516E+00	0.57823E+00	-0.18450E+01
4	-0.42453E-06	0.22258E+00	-0.44430E+00	-0.18450E+01
5	-0.42453E-06	-0.22258E+00	-0.37205E+00	-0.18450E+01

NOTES:
Inner jet expansion, Theta1 0.08603 radians
Outer jet expansion, Theta2 0.14066 radians
Initial jet with, B0, 0.01681 Ft
Allowable jet width, Bmax, 0.39000 Ft

PREDICTED THRUST AND PERFORMANCE:

Total ejector thrust = 926.50159 Lb
Isentropic primary thrust = 508.74969 Lb
Thrust augmentation ratio = 1.82113

***** SINGLE POINT CALCULATION *****
T = 0.00060 sec

FIELD VARIABLE PROFILE:

Station ->	Infinity	1P	1S	3	4	
AREA	11.70000	0.41998	9.32378	9.74376	17.55000	FT
V	0.00000	860.78772	282.19669	303.30927	164.33514	FT/S
P	2067.84009	2250.91992	1980.71228	1998.06897	2067.49927	LBF/FT2
PO	2067.84009	3027.15869	2067.84009	2096.64307	2096.64307	LBF/FT2
T	542.79999	698.86292	536.16473	553.28772	558.70282	DEG-R
TO	542.79999	760.59998	542.79999	560.95300	560.95300	DEG-R
RHO	0.07149	0.06044	0.06932	0.06777	0.06944	LBM/FT3
MDOT	0.00000	21.85001	182.39970	200.27596	200.27597	LBM/S

NOTES:
Nozzle Pressure Ratio is 1.46392 (Choked NPR is 1.89293)

FINITE VOLUME PROFILE

Station	Z	B,inner	B,outer	B,jsl
2	0.18000E+00	0.46881E-04	0.41181E-01	0.11199E-01
3	0.36000E+00	0.00000E+00	0.65551E-01	0.15560E-01
4	0.54000E+00	0.00000E+00	0.89922E-01	0.18624E-01
5	0.72000E+00	0.00000E+00	0.11429E+00	0.20934E-01
6	0.90000E+00	0.00000E+00	0.13866E+00	0.22756E-01

Station	Rho	P	Vm	Ve
1	0.18785E-02	0.22509E+04	0.86079E+03	0.28220E+03
2	0.20719E-02	0.19656E+04	0.10916E+04	0.27064E+03
3	0.20910E-02	0.19836E+04	0.73827E+03	0.27068E+03
4	0.20992E-02	0.19914E+04	0.59681E+03	0.27068E+03
5	0.21036E-02	0.19955E+04	0.52150E+03	0.27068E+03
6	0.21063E-02	0.19981E+04	0.47460E+03	0.27068E+03

Element	D(Rho)/DT	D(P)/DT	D(Vm)/DT	D(Ve)/DT
1	0.83474E-01	0.80936E+05	0.26340E+06	0.18311E+01
2	0.14618E-01	0.14168E+05	0.28578E+05	0.18311E+01
3	0.57034E-02	0.54621E+04	0.80213E+04	0.18311E+01
4	0.23664E-02	0.22534E+04	0.26043E+04	0.18311E+01
5	0.10866E-02	0.10325E+04	0.98203E+03	0.18311E+01

NOTES:
Inner jet expansion, Theta1 0.09286 radians
Outer jet expansion, Theta2 0.13457 radians
Initial jet with, B0, 0.01681 Ft
Allowable jet width, Bmax, 0.39000 Ft

PREDICTED THRUST AND PERFORMANCE:

Total ejector thrust = 919.07166 Lb
Isentropic primary thrust = 659.06592 Lb
Thrust augmentation ratio = 1.39451

```
          ***** SINGLE POINT CALCULATION *****
                    T =  0.00070 sec


FIELD VARIABLE PROFILE:

Station -> Infinity       1P          1S           3            4

AREA      11.70000     0.41998     9.32378      9.74376     17.55000  FT
V          0.00000   860.78772   280.10501    301.62244    163.46561  FT/S
P       2067.84009  2250.91992  1981.97961   1998.23413   2066.87256  LBF/FT2
PO      2067.84009  3027.15869  2067.84009   2095.70337   2095.70337  LBF/FT2
T        542.79999   698.86292   536.26273    553.28790    558.64166  DEG-R
TO       542.79999   760.59998   542.79999    560.86810    560.86810  DEG-R
RHO        0.07149     0.06044     0.06936      0.06777      0.06943  LBM/FT3
MDOT       0.00000    21.85001   181.13047    199.17854    199.17854  LBM/S
    NOTES:
      Nozzle Pressure Ratio is  1.46392  (Choked NPR is  1.89293 )

FINITE VOLUME PROFILE

  Station     Z            B,inner       B,outer        B,jsl
     2    0.18000E+00   0.00000E+00   0.41214E-01   0.11696E-01
     3    0.36000E+00   0.00000E+00   0.65618E-01   0.15927E-01
     4    0.54000E+00   0.00000E+00   0.90023E-01   0.18886E-01
     5    0.72000E+00   0.00000E+00   0.11443E+00   0.21151E-01
     6    0.90000E+00   0.00000E+00   0.13883E+00   0.22978E-01

  Station    Rho            P             Vm            Ve
     1    0.18785E-02   0.22509E+04   0.86079E+03   0.28011E+03
     2    0.20775E-02   0.19712E+04   0.11092E+04   0.26850E+03
     3    0.20937E-02   0.19863E+04   0.74354E+03   0.26858E+03
     4    0.21005E-02   0.19926E+04   0.59852E+03   0.26859E+03
     5    0.21041E-02   0.19960E+04   0.52205E+03   0.26860E+03
     6    0.21064E-02   0.19982E+04   0.47475E+03   0.26860E+03


  Element  D(Rho)/DT     D(P)/DT       D(Vm)/DT      D(Ve)/DT
     1    0.56055E-01   0.55826E+05   0.17555E+06  -0.20917E+05
     2    0.27180E-01   0.26487E+05   0.52730E+05  -0.20917E+05
     3    0.12250E-01   0.11782E+05   0.17126E+05  -0.20917E+05
     4    0.50163E-02   0.47934E+04   0.54920E+04  -0.20917E+05
     5    0.17346E-02   0.16524E+04   0.15618E+04  -0.20917E+05
    NOTES:
      Inner jet expansion, Theta1  0.09330 radians
      Outer jet expansion, Theta2  0.13476 radians
      Initial jet with, B0,  0.01681 Ft
      Allowable jet width, Bmax,  0.39000 Ft

PREDICTED THRUST AND PERFORMANCE:

  Total ejector thrust       =   909.19916 Lb
  Isentropic primary thrust =   659.06592 Lb
  Thrust augmentation ratio =     1.37953
```

***** SINGLE POINT CALCULATION *****
T = 0.00080 sec

FIELD VARIABLE PROFILE:

Station ->	Infinity	1P	1S	3	4	
AREA	11.70000	0.41998	9.32378	9.74376	17.55000	FT
V	0.00000	860.78772	282.21085	303.42273	164.39374	FT/S
P	2067.84009	2250.91992	1980.70361	1998.74744	2068.25391	LBF/FT2
PO	2067.84009	3027.15869	2067.84009	2097.42896	2097.42896	LBF/FT2
T	542.79999	698.86292	536.16406	553.28845	558.70764	DEG-R
TO	542.79999	760.59998	542.79999	560.95941	560.95941	DEG-R
RHO	0.07149	0.06044	0.06932	0.06779	0.06947	LBM/FT3
MDOT	0.00000	21.85001	182.40828	200.41866	200.41867	LBM/S

NOTES:
Nozzle Pressure Ratio is 1.46392 (Choked NPR is 1.89293)

FINITE VOLUME PROFILE

Station	Z	B,inner	B,outer	B,jsl
2	0.18000E+00	0.47418E-04	0.41180E-01	0.11992E-01
3	0.36000E+00	0.00000E+00	0.65550E-01	0.16289E-01
4	0.54000E+00	0.00000E+00	0.89920E-01	0.19109E-01
5	0.72000E+00	0.00000E+00	0.11429E+00	0.21208E-01
6	0.90000E+00	0.00000E+00	0.13866E+00	0.22894E-01

Station	Rho	P	Vm	Ve
1	0.18785E-02	0.22509E+04	0.86079E+03	0.28221E+03
2	0.20811E-02	0.19748E+04	0.11206E+04	0.27057E+03
3	0.20969E-02	0.19894E+04	0.74972E+03	0.27066E+03
4	0.21024E-02	0.19945E+04	0.60126E+03	0.27069E+03
5	0.21051E-02	0.19970E+04	0.52321E+03	0.27069E+03
6	0.21070E-02	0.19987E+04	0.47524E+03	0.27070E+03

Element	D(Rho)/DT	D(P)/DT	D(Vm)/DT	D(Ve)/DT
1	0.36388E-01	0.35501E+05	0.11427E+06	0.21058E+05
2	0.31656E-01	0.30789E+05	0.61846E+05	0.21058E+05
3	0.19465E-01	0.18730E+05	0.27408E+05	0.21058E+05
4	0.10562E-01	0.10093E+05	0.11643E+05	0.21058E+05
5	0.53912E-02	0.51329E+04	0.48831E+04	0.21058E+05

NOTES:
Inner jet expansion, Theta1 0.09286 radians
Outer jet expansion, Theta2 0.13457 radians
Initial jet with, B0, 0.01681 Ft
Allowable jet width, Bmax, 0.39000 Ft

PREDICTED THRUST AND PERFORMANCE:

Total ejector thrust = 920.05444 Lb
Isentropic primary thrust = 659.06592 Lb
Thrust augmentation ratio = 1.39600

***** SOLUTION PROFILE *****

T (m-sec)	DMpDT (lbm/s)	THRUST (lb)	PHI
0.40000	18.70000	926.57001	1.82127
0.50000	18.70000	926.50159	1.82113
0.60000	21.85001	919.07166	1.39451
0.70000	21.85001	909.19916	1.37953
0.80000	21.85001	920.05444	1.39600

REFERENCES

1. Drummond, C.K.: A Control-Volume Method for Analysis of Unsteady Thrust Augmenting Ejector Flows. NASA CR-182203, 1988.
2. Drummond, C.K.: Transient Flow Thrust Prediction for an Ejector Propulsion Concept. NASA TM-102078, 1989.
3. Drummond, C.K.: Preliminary Dynamic Tests of a Flight-Type Ejector. NASA TM-105814, 1992.
4. Drummond, C.K., and Barankiewicz, W.S.: A Modeling Technique for STOVL Ejector and Volume Dynamics. NASA TM-103167, 1990.
5. Drummond, C.K., and Ouzts, P.J.: Real-Time Simulation of an F110/STOVL Turbofan Engine. NASA TM-102409, 1989.

TABLE I. - EJECTOR GEOMETRY FOR STOVL TEST CASE

[Configuration for 12 nozzles; 112-in. wide duct; 3 orifices per nozzle.]

Station	Direction		
	X	Y	Z
	Characteristic dimension, ft.		
0	9.333	1.875	0.900
1	.108	.108	.900
2	.778	.347	-
3	9.333	1.042	2.917
4	9.333	1.875	-

Mixing region

Volume, dV	Area, dA	Scale factors		
		Number of Units		For dV and dA
		n_x	n_y	$N = n_x n_y$
$Wdxdz = z_1$ $Wdx = z_1 A$	Wdx	12	3	36

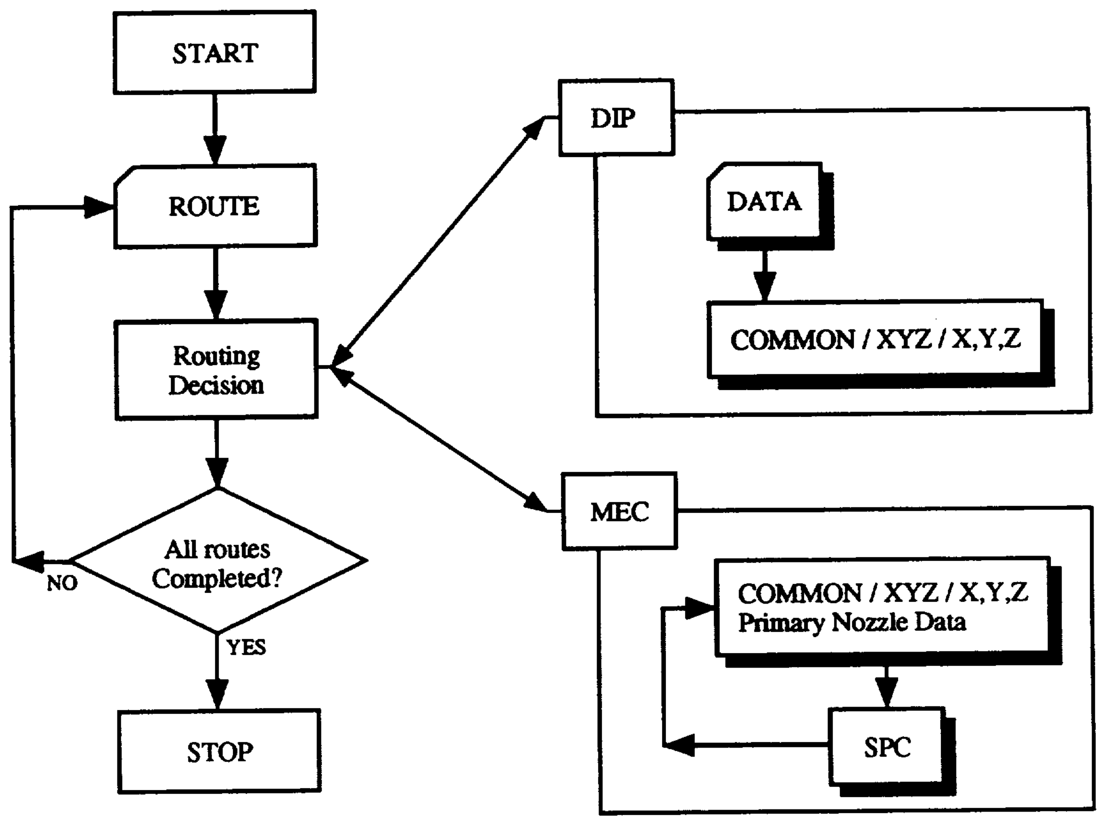


Figure 1. - General program structure.

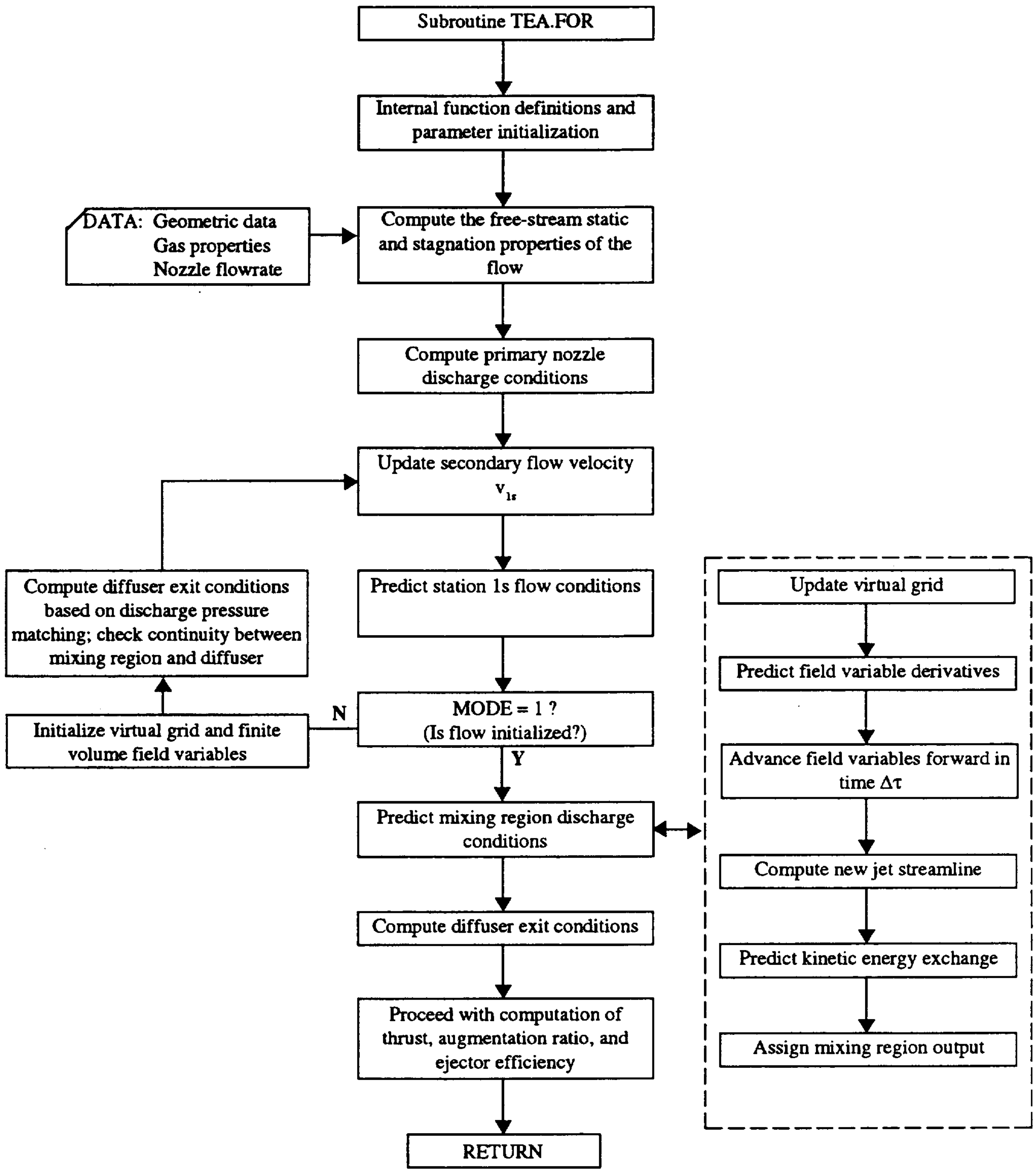


Figure 2 - Outline of the SPC solution procedure.

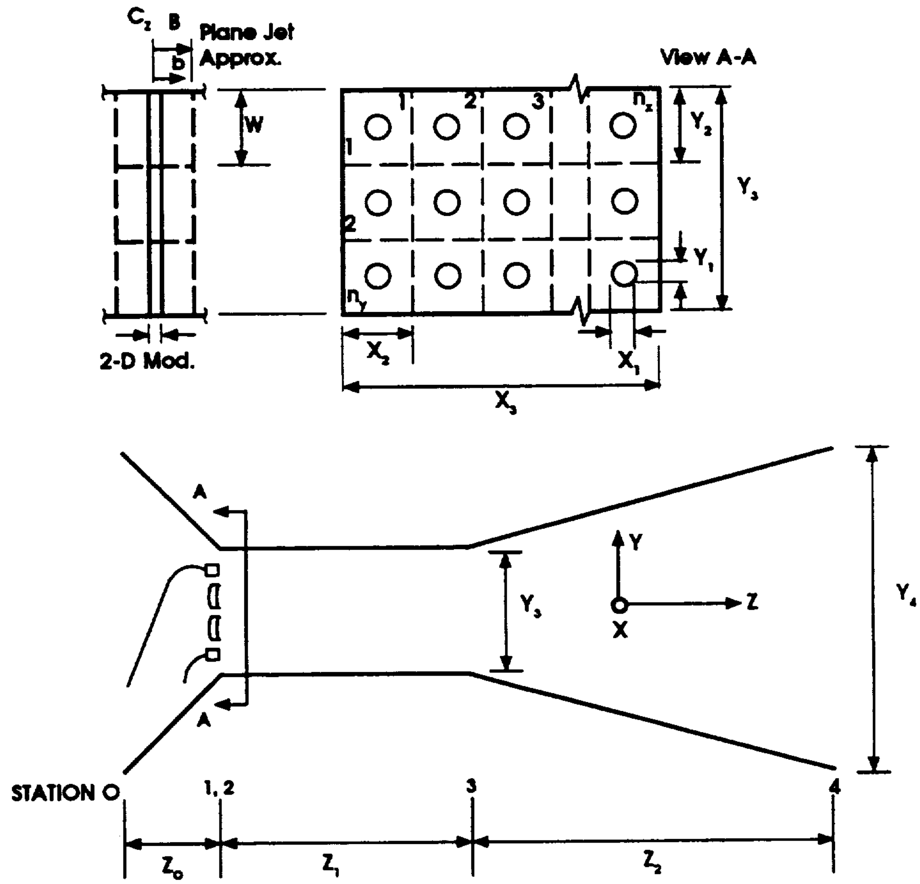


Figure 3. - Geometric ejector approximation.

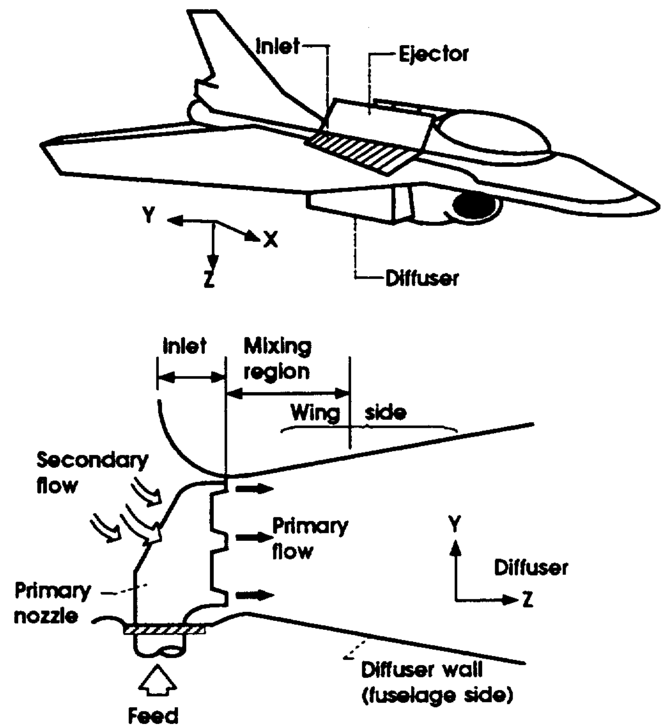


Figure 4. - STOVL ejector application.

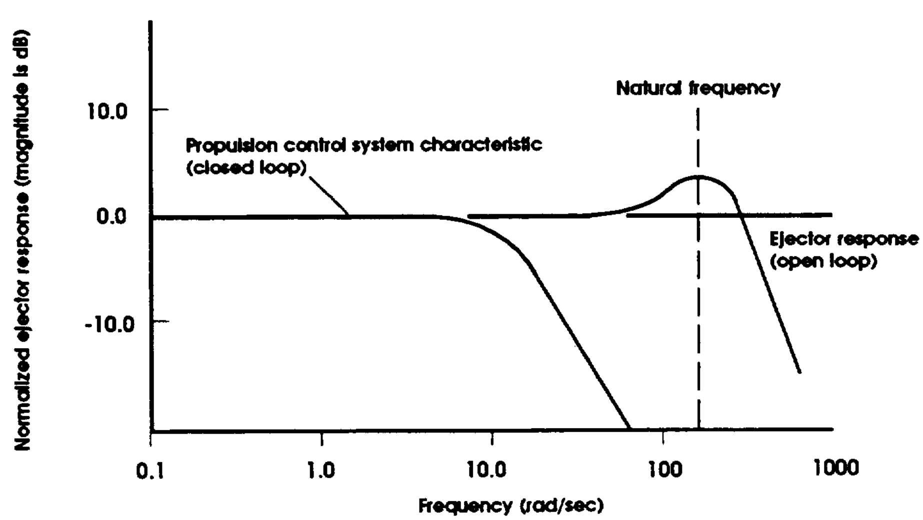
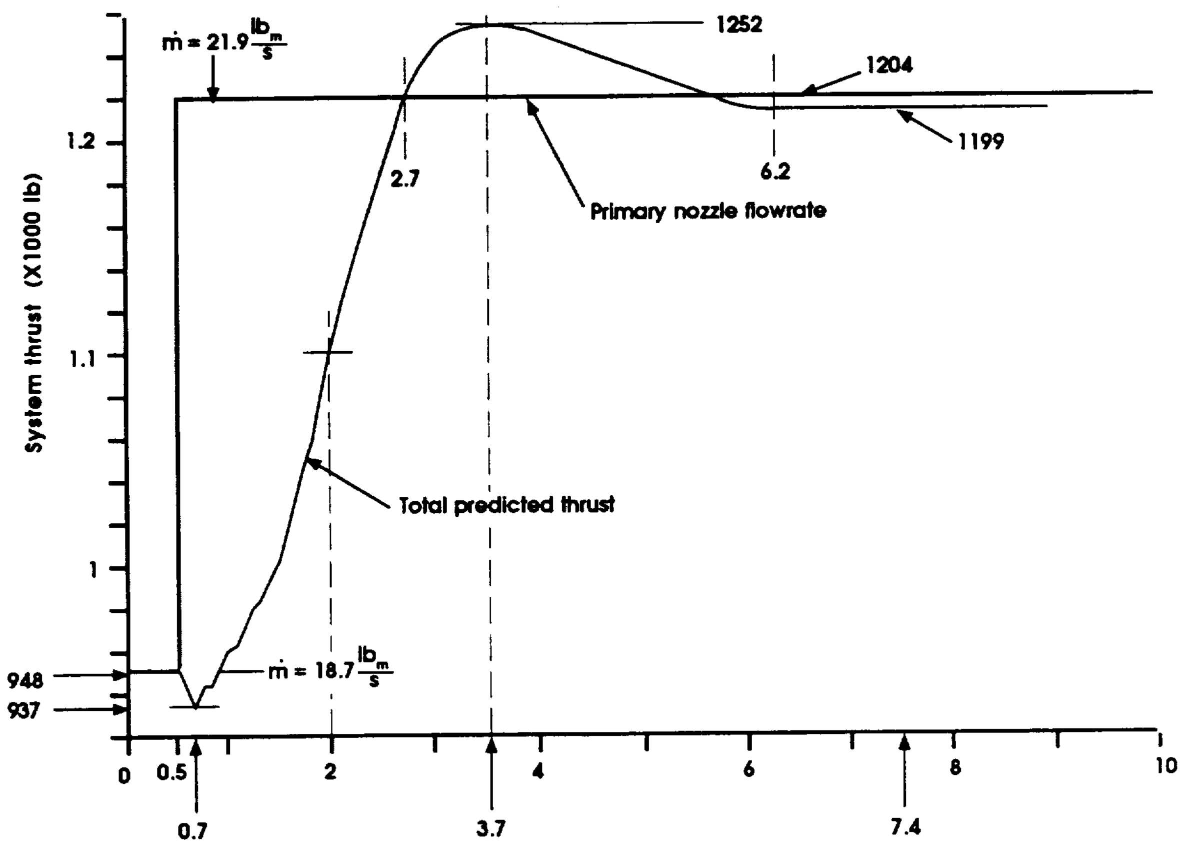


Figure 5. - Quasi-steady response criteria.



Elapsed time (milliseconds)

Figure 6. - Result from transient flow test case.

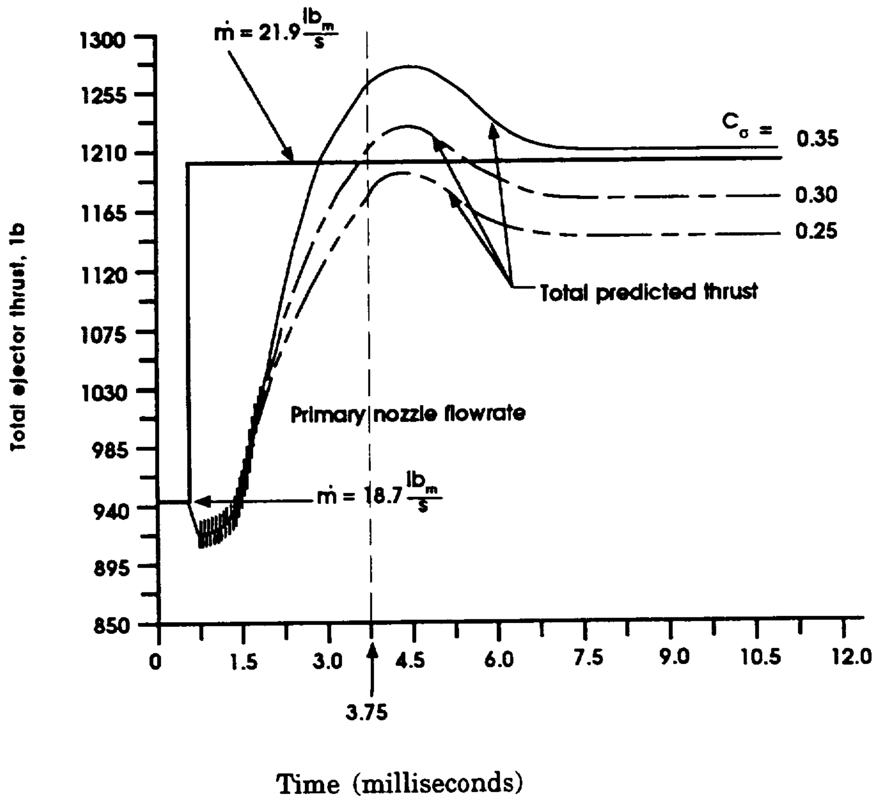


Figure 7. - Effects of CSIGMA on thrust prediction.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1993	Technical Memorandum

4. TITLE AND SUBTITLE

Transient Ejector Analysis (TEA) Code User's Guide

5. FUNDING NUMBERS

WU-505-62-30

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

E-8050

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, D.C. 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM-106310

11. SUPPLEMENTARY NOTES

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12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category 07

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A FORTRAN computer program for the semianalytic prediction of unsteady thrust augmenting ejector performance has been developed, based on a theoretical analysis for ejectors. That analysis blends classic self-similar turbulent jet descriptions with control-volume mixing region elements. Division of the ejector into an inlet, diffuser, and mixing region allowed flexibility in the modelling of the physics for each region. In particular, the inlet and diffuser analyses are simplified by a quasi-steady-analysis, justified by the assumption that pressure is the forcing function in those regions. Only the mixing region is assumed to be dominated by viscous effects. The present work provides an overview of the code structure, a description of the required input and output data file formats, and the results for a test case. Since there are limitations to the code for applications outside the bounds of the test case, the user should consider TEA as a research code (not as a production code), designed specifically as an implementation of the proposed ejector theory. Program error flags are discussed, and some diagnostic routines are presented.

14. SUBJECT TERMS

Ejector; STOVL; Control-volume; Transient flow

15. NUMBER OF PAGES

50

16. PRICE CODE

A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102