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NNEP - THE NAVY NASA ENGINE PROGRAM

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INTRODUCTION

The NASA Lewis Research Center has, for the past several years, had contracts with Pratt & Whitney Aircraft and General Electric to study engines for the Supersonic Cruise Airplane Research or SCAR program. Many novel engine concepts were considered during these contracts, including several that have been broadly termed Variable Cycle Engines or VCE's.

In order to evaluate these new engine concepts and in particular as applied to supersonic aircraft, a computer code capable of calculating performance of these engines throughout the flight envelope was needed. In the past, this "matching" of turbofan and turbojet engines was accomplished at Lewis with either the GENENG I or GENENG II computer codes (refs. 1 and 2). These codes could simulate turbofans with up to 3 spools and 3 streams (including aftfans) and 1 or 2 spool turbojets. It soon became apparent that these two codes were not capable of simulating some of the engine concepts evolving from the SCAR studies.

We therefore needed to develop a new computer code in which an arbitrary engine configuration consisting of selected component combinations could be described at input time. It was also necessary to change engine configuration while running the code to simulate the operation of various VCE concepts, and to optimize the settings of variable components such as nozzle or turbine areas (e.g. to minimize SFC for a given thrust).

Contact with the Naval Air Development Center, Warminster, Pa., revealed that they had a computer code, NEPCOMP (ref. 3), which already contained some of the features desired and whose structure was flexible enough to permit the addition of others. This code lacked optimization capability and the ability to operate with "stacked" maps which would represent variable component performance. However, it already had the capability for processing arbitrary engine configurations. NASA-Lewis therefore contracted with the Naval Air Development Center for the joint development of a revised computer code. The objective of the joint effort was to develop a code capable of: simulating any turbine engine the user could conceive, simulating variable component performance, changing airflow paths while running, and optimizing variable-geometry settings to minimize the specific fuel consumption or maximize the thrust.

An interim version of this new code given the acronym NNEP (Navy NASA Engine Program) became operational in May of 1974 and has been continuously refined since then to include all of the desired capabilities.

NNEP contains almost all of the subroutines and incorporates the philosophy of construction of NEPCOMP as described in reference 3. The improvements incorporated in NNEP relative to NEPCOMP are in the addition of: (1) a performance optimization capability, (2) processing of stacked component maps for VCE operation, (3) multi-configurations (modes) to simulate flowpath switching, (4) a computer generated engine configuration schematic, (5) throttle dependent inlet and boattail drag calculations, and (6) a simpler input data format. This present report will discuss these improvements and provide a summary of the capabilities and limitations of the code in its present form, along with a few examples of its use.

OPTIMIZATION TECHNIQUE

As previously mentioned, one of the primary objectives of the joint Navy/NASA engine code development was to add the capability to optimize the engine performance (e.g. minimize SFC for constant thrust). Two basic approaches to the optimization problem were investigated: (1) optimization inside the loop and (2) optimization outside the loop.

By "outside the loop" we mean that the engine is first matched; then the free variables are changed and the engine rematched. This procedure is continued until the optimization is achieved.

By "inside the loop" we mean that at the same time as the engine is being matched, the free variables are changing. When the match point is finally achieved, the free variables will be at their optimum values. Ideally, inside the loop optimization should require 2/n times as much computer time as outside the loop (where n represents the number of free variables). Both methods of optimization were tried with results as follows.

Outside the Loop Optimization

Five separate methods were tried to evaluate outside the loop optimization. These were:

(1) Hooke-Jeeves pattern search (ref. 4)
(2) A first-order gradient technique (ref. 5)
(3) A first-order gradient technique building second order information (ref. 5)
(4) Davidon-Fletcher-Powell penalty function method (ref. 6)
(5) Powell's Principal Axis method (ref. 7)

The Hooke-Jeeves pattern search failed to find the true optimums. It stopped the search while apparently crossing a ridge. The next three methods all require the calculation of derivatives by finite difference. Noise in these derivatives caused all three methods to fail. The sources of this noise are internal convergence loops on thermodynamic properties, table lookups, and tolerances on the interface errors within which an engine is considered matched. In order to eliminate this noise, extremely tight tolerances on convergence loops and interface errors would be required and computation time would increase significantly.

Of all the methods tested for outside the loop optimization, Powell's Principal Axis method (BOTM) worked the best and is the method presently employed in the NNEP computer code. A discussion of the computational algorithm used in BOTM is given in Appendix A. BOTM is however slow, as probably all outside the loop methods will be. Since NNEP itself takes on the order of 3 to 7 seconds of CPU time on an IBM 360 computer to achieve a converged solution and the engine is continually rematched while optimizing, computation time grows quickly as more free variables are introduced. For the two free variable optimization shown in Appendix B, 84 tries were required to find the optimum and this required approximately 180 seconds of CPU time. Since each try is near the last converged try NNEP is balancing the engine in about 2 seconds per try. As previously mentioned, the relatively large amount of computer time required by outside of the loop methods prompted the search for an inside the loop optimization method.

Inside the Loop Optimization

Having successfully incorporated Powell's Principal Axis method into NNEP, it was now possible to try inside the loop methods and see if they found the optimum which was now known.

Four methods were tried. These were:

(1) CONMIN (ref. 8)
(2) Martensson's method(ref. 9)
(3) FLEXI - the flexible tolerance method (ref. 10)
(4) Hamiltonian/ Lagrangian multiplier method (ref. 11)

CONMIN requires the calculation of gradient information and therefore was subject to the same problem of noise as outside the loop gradient methods. After consuming much computer time without achieving the optimum, the method was abandoned.

Martensson's method combines the Lagrangian multiplier method with the penalty function method. This method requires the guess of a scalar constant C. Test runs showed that for some values of C, equality constraints became satisfied but the free variables remained unchanged, while for other values of C, the free variables changed but the constraints were not satisfied. It was felt that each engine would require the determination of its own best value of C in order to converge. This was deemed to be totally unacceptable and this method was also abandoned.

FLEXI does not require the calculation of derivatives. It generates a surface of both feasible and near- feasible points and proceeds to the optimum by eliminating near-feasible points. The near- feasible points are made more restrictive until, in the limit, only those points satisfying all of the equality and inequality constraints are left. In the test problem no progress towards convergence was observed. Other researchers in optimization theory have noted that FLEXI has great difficulty in satisfying equality constraints and therefore no further testing of the method was tried.

The Hamiltonian/ Lagrangian multiplier method was the last inside the loop method tried. This method attaches a multiplier onto each of the constraint equations essentially doubling the number of variables (each control variable will have an associated multiplier). The method, however, requires the calculation of second partial derivatives which are even noisier than the first partials. Optimization progressed initially towards the known optimum but as the optimum was approached and derivatives became smaller, the noise caused the method to fail and no further progress was achieved. In addition, calculation of the second partials consumed large amounts of computer time. It was therefore decided to also drop this method from consideration.

As a result of the foregoing investigations, Powell's Principal Axis method was adopted for NNEP.

STACKED MAPS

Most of the VCE's evolving from the SCAR studies have to some degree variable geometry components ranging from variable inlet guide vanes to variable stators and rotors in the compressors and turbines. The component maps for these variable geometry components represent the component performance as a function of the settings of the variable features.

Thus, the map of corrected airflow as a function of pressure ratio and corrected speed for a turbine might look like figure 1 where there are three separate maps with stator angle as a fourth parameter. NNEP can interrogate this "stacked" map determining the corrected airflow for any combination of pressure ratio, corrected speed, and stator angle.

DRAWING OF THE ENGINE

Subroutine FIGURE was added to the NEPCOMP code to draw a schematic of the engine in each of its modes (different airflow paths) when the configuration data is read in. This is extremely useful when looking at the code's output since outputs are identified by either flow station number or component number. These can thus be referenced to the engine schematic previously drawn on the output.

As can be seen by the example figures shown on the output in Appendix B, each time a branch occurs out of the main flow, a new column of station numbers and component numbers appears. The first component in this new stream is identical to the one in the main flowstream where the branch took place. The last component is either a nozzle or the same component as the one in the main flowstream where re-entry took place.

INSTALLATION EFFECTS

If desired, inlet and nacelle boattail drag penalties may be estimated for the engine, assuming an isolated nacelle, to indicate installed engine performance. Inlet drag is calculated using combined empirical and theoretical relations in which the inlet capture area is sized at the design Mach number with a specified inlet bleed requirement. At other operating points, the calculated engine demand airflow and capture area are used to estimate spillage. Inlet spillage drag per unit capture area is then assumed to be directly proportional to the spillage fraction and a full-spillage drag coefficient schedule for the specified inlet type. An empirical inlet overboard bleed schedule is also used to offset spillage drag by assuming that part of the excess captured airflow can recover a fraction of its initial momentum.

Aft-end drag is calculated for the isolated nacelle using the mean slope of the boattail section estimated from the maximum nacelle diameter and the nozzle exit area setting, which varies with power level and airflow throughout the flight envelope. An empirical drag coefficient function of boattail slope is calculated at each Mach number and can be scaled to suit desired aft-end characteristics.

Therefore, the installation drag calculations are throttle-dependent, require a minimum of inputs, and can be scaled or tailored to meet expected characteristics for specific inlet types and boattail shapes.

PROGRAM DESCRIPTION

NNEP contains almost all of the subroutines and incorporates the philosophy of construction of NEPCOMP as described in reference 3. This philosophy resulted in a code that was broken into finite blocks so that the user could, if desired, replace individual subroutines with ones of his own choosing. The flow diagram for NNEP is shown in figure 2.

Components

The individual component types are represented as individual subroutines. Engine components fall into two broad catagories in addition to controls used to balance the engine and optimization variables.

Flow components- falling under this classification are

(1) inlets
(2) ducts/burners
(3) compressors
(4) turbines
(5) mixers
(6) heat exchangers
(7) splitters
(8) nozzles

Mechanical components- are not represented by separate subroutines

(1) shafts
(2) loads

There is a limit of a total of 60 components (including all of the flow, mechanical, control and optimization variables) allowed within the code. The maximum number of any one type of flow or mechanical components is 24 and the maximum number of controls + optimization variables is 20.

Subroutine Description

A brief description of the function of each subroutine is given below. Reference to the NNEP flow diagram (fig. 2) indicates the interfacing between the various subroutines.

VCENG -is the main routine. It decides when to write output, read input, balance the engine, or turn control over to BOTM for optimization.

INPRT -is the optimization subroutine and all printing. The user has the option of printing each try at balancing of the engine or only the final converged case.

BOTM -is the optimization subroutine which uses Powell's Principal Axis method to find the optimum. Once BOTM has been called, it takes over as the supervisory routine until an optimum has been found at which time control is returned to VCENG.

CALCFX-is used to evaluate the value of the function being minimized or maximized for BOTM.

NEPCAL-determines the values of the error matrix used to balance the engine, determines the new guesses for the independent variables, calls INPUT when directed to by VCENG, and calls FLOCAL to perform the engine cycle calculations.

INPUT -reads in all of the input data, and writes out the configuration information as determined by CONFIG for the various modes onto scratch units. It also calls the appropriate data back in when modes are switched. At the design point, INPUT calls FIGURE.

FIGURE-when the configuration data is read in at the design point for all of the modes, FIGURE schematically represents the flowpath on the output sheets.

CONFIG-processes the engine configuration for each mode. The flow components are assembled from inlets to nozzles as they would appear in the flow stream. The logic to be followed in calculating performance is set by CONFIG.

DMINV -is the IBM 360 double precision matrix inversion routine used to invert the matrix of partial derivatives used in the balancing of the engine.

FLOCAL-sequentially calls the components in the correct order to do cycle calculations based on the flowpath generated by CONFIG.

INLET -performs inlet calculations.

DBURNR-performs duct,burner, and afterburner calculations.

COMPRS-performs compressor calculations.

TURBIN-performs turbine calculations.

MIXER -performs mixer calculations.

HEATXC-performs heat exchanger calculations.

NOZZLE-performs nozzle calculations.

SPLITR-performs splitter calculations (bypass engines).

THERM -uses built - in cubic spline curve fits for air, stoichiometric combustion products, and water vapor to calculate gas properties such as: temperature, relative pressure, enthalpy, specific heats, and the Universal gas constant.

TREAD -first is called by INPUT to read in all of the maps in tabular form which are to be used by any of the components. Then, it is called by each of the component subroutines to interrogate the tabular data previously read in.

SPLNQ1-is a function used to fit cubic splines through the tabular data being interrogated by TREAD. It is used to caculate interpolated or extrapolated values from the tables.

Computer Code Flow

Returning now to figure 2 we can follow a typical run through the NNEP program.

Design Point

VCENG calls NEPCAL which in turn calls INPUT. INPUT reads all of the maps from TREAD and then reads in the configuration and the cycle data for all of the components in all of the modes. This data is then processed by CONFIG and an engine schematic drawn by FIGURE for each mode. The program returns to NEPCAL which then calls FLOCAL to calculate engine performance. Control then passes back to VCENG which calls INPRT to print out the design case.

Off-Design Point

VCENG calls NEPCAL which calls INPUT. INPUT detects that the point being run is not a design point and the program returns to NEPCAL. NEPCAL calls FLOCAL to calculate cycle performance. FLOCAL checks after the cycle is calculated whether or not the engine is "matched". If not, perturbations are made in each of the control variables to generate an error matrix. NEPCAL then calls DMINV to invert the matrix. NEPCAL then generates new values for the control variables and this process is repeated until a balance is achieved. Control then passes back to VCENG anc INPRT prints the answers.

Optimization

The flowpath followed for a case with optimization is identical to that of an off-design case. After the engine is balanced and control has returned to VCENG, a check is made to see if optimization is desired. If this is the case, then BOTM is called and takes over complete control of the program. BOTM acts as a supervisory routine: perturbing the optimization variables; calling NEPCAL which rebalances the engine;and, predicts new values for the optimization variables. When the engine is both balanced and performance optimized, control is returned to VCENG which calls INPRT to print the answers.

CONFIGURING AN ENGINE

Components are connected together through an indexing system which requires numeric coding of each component and flow station. Each component can have a primary and a secondary upstream flow entering and a primary and secondary downstream flow leaving. The CONFIG subroutine searches through the components from inlets to nozzles and generates the correct sequence of component calculations to be performed. This information is mass stored on scratch file units numbered the same as the mode;i.e. MODE 1 configuration data is stored on Unit 1. When a particular mode is to be run, the information containing the flowpath and configuration data is retrieved from the appropriate Unit and this information is processed by the FLOCAL subroutine.

NNEP uses NAMELIST input as opposed to the fixed field input used in NEPCOMP. A typical input card specifying the type of component and its position in the flow stream is shown in figure 3. As an example of a configuration input card, consider a compressor (assigned component number 4) with a primary upstream flow station 4. The primary downstream flow station number is 5 and secondary downstream (bleed stream) station number is 6. Then, the KONFIG input card for this example would be as follows:

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KONFIG(1,4)='COMP',4,0,5,6,
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KONFIG is a doubly subscripted array of dimension 5 X 60. Each of the 60 possible components has 5 values associated with it. The first value is component type, the second and third are the primary and secondary upstream flow station numbers and the fourth and the fifth are the primary and secondary downstream flow station numbers. Since KONFIG is doubly subscripted and we are using NAMELIST, we must say KONFIG(1,4)= where the 1 lines up the data correctly for the component number 4 (the second number). The zero in the example KONFIG card indicates that there is no secondary upstream flow station for this component.

Names of the components are coded as 'INLT', 'COMP', 'DUCT', 'TURB', 'MIXR', 'HTXC', 'SPLT', 'NOZZ', 'LOAD', 'SHFT', 'CNTL', 'OPTV'. On a UNIVAC 1100 series these would be 4HINLT, 4HCOMP etc. For loads and shafts which are mechanical components, there are no flow station numbers. The KONFIG card for a load would just have the component name but the KONFIG card for a shaft would have all the component numbers connected to the shaft instead of flow station numbers. The KONFIG cards for controls ('CNTL') and optimization variables ('OPTV') are discussed later.

DEFINING CHARACTERISTICS OF COMPONENTS

Each component type has a separate list of inputs required. A typical list of the inputs or specifications is shown in figure 4. SPEC is a doubly subscripted array of dimension 15 X 60. Each component (of which there may be up to 60) has up to 15 required inputs. Representation of a compressor map requires 3 input elements: pressure ratio versus "R", corrected airflow versus "R", and efficiency versus "R" where "R" represents lines drawn on a typical compressor map which roughly parallel the surge line. The introduction of the intermediate variable "R" in the map representation was necessary to circumvent difficulties in reading the maps in regions where two values of corrected flow are possible at a given value of pressure ratio and speed. On each map are constant corrected speed lines and in addition there may be a third dimensional variable if the compressor has variable geometry such as stator angle. Each map is given an arbitrary unique table reference number so that the computer code will know where to look up the map data.

For a compressor at its design point, the elements of the spec array are as follows: (1) represents the value of the "R" line passing through the design point, (2) is the fraction of the total flow entering the compressor which leaves by way of the secondary downstream flowpath (bleed flow), (3) (5) (7) and (9) are scale factors which are internally calculated by the code to make the values at the design point on the map equal the design values for the engine being simulated. They should initially be set to 1.0, (4) is the map reference number of corrected airflow as a function of "R", speed, and stator angle, (6) is the map of efficiency versus "R", and (8) pressure ratio versus "R". (10) is the value of the stator angle setting, (11) represents the fractional horsepower lost when part of the bleed is extracted from the middle stages of the compressor, (12) and (13) are the desired values of efficiency and pressure ratio at the design point on the maps and (14) represents the design point value of corrected speed at the actual design point on the maps. (15) is not used for compressors.

CONTROLS

Once an engine has been configured and the necessary component information supplied, design point calculations may be made to establish appropriate map scale factors. At all conditions throughout the operating envelope of the engine, flow continuity and an energy balance must exist amongst the various components. Those components connected by shafts and gearboxes must rotate in a distinct speed relationship. In order to "match" the engine at any other than design conditions, it is therefore necessary to input to the code those component variables that are free to change in order to achieve equilibrium.

This is accomplished through the use of components known as "CONTROLS". As previously mentioned, a total of 20 CONTROL and OPTIMIZATION components are allowed in an engine. A typical CONTROL is shown in figure 5. In figure 5 a KONFIG card identifies component 30 as a control. There are no station numbers for controls. A new input SPCNTL of dimension 9 X 60 describes this control. This card is read as follows:

Vary SPEC (1st input) of component (2nd input) so that Station Property sub (4th input) at flow station (5th input) has a value of (6th input) within a tolerance of +/- (7th input). The minimum allowable value of SPEC (1st input) is (8th input) and the maximum allowable value is (9th input).

The 3rd input can be 'STAP' for a flow station property, 'DOUT' for an output of a component such as static pressure difference in a mixer, and 'PERF' for a performance property such as thrust. The meaning of the 4th and 5th inputs change as a function of the 3rd input.

For the case shown here, we will vary the "R" value on the maps for compressor 4 to drive the relative difference between the corrected airflow at flow station 10 and the amount of corrected airflow that the component downstream of station 10 will pass, to zero. Since pressure ratio, corrected airflow, and efficiency are all functions of "R" for a compressor, changing "R" will change all three quantities and this will be used to balance the engine.

OPTIMIZATION VARIABLES

The last type of component is an optimization variable. As shown in figure 6, a KONFIG card for these variables uses only the first and fourth positions. Input (1) identifies this component as an optimization variable ('OPTV'). Inputs (2) and (3) are zero and input (4) indicates which component has the free variable. In this example, component 12 has the free variable. The SPEC card uses inputs (2) and (3) to state the minimum and maximum allowable values of the free variable; input (4) identifies which is free to vary which in the example is SPEC(1) of component (12).

SIMULATION OF TYPICAL VCE

In this section of the text, a typical application of NNEP is illustrated with the simulation of a VCE.

Figure 7 shows the configuration schematic used to represent the engine. In MODE 1, the flows are mixed and exited through a single nozzle. In MODE 2, the main and bypass flows have been separated, the mixer has been eliminated, and a second nozzle has been added downstream of the bypass duct.

As can be seen from this figure, components 1, 2, 3, 4, 5, 6, 7, 9, 11, 12, 13, and 14 are common to the two modes. Component 8, the mixer, is present only in MODE 1. Component 10 in MODE 1 and component 25 in MODE 2 are the same nozzle. The area of this nozzle must change when modes are switched as a result of the difference in airflow. This is accomplished by using different component numbers in each mode indicating a "different" nozzle. Hence, the appropriate nozzle area will automatically be used when modes are switched. Nozzle 24 is an additional nozzle necessary for MODE 2.

A typical computer output for this engine is shown in Appendix B. The carriage control has been turned off to compress the output. Input card images appear on the output. The first set of input tells how many modes there are and which one is the design mode. Next appears a table telling which maps have been loaded and how much storage they occupy. This is followed by the KONFIG and SPEC cards for MODE 1, the computer drawn engine schematic for MODE 1, a table of the configuration data and control information for MODE 1 and a summary of the input data.

The KONFIG and SPEC cards for MODE 2, the computer drawing of the schematic for MODE 2, the table of the configuration data and control information for MODE 2 and a summary of the MODE 2 input data follow.

Since there are only two modes, the code is now ready to calculate the design point performance in the design mode (MODE 1). A table of updated INPUTS is printed and then the design point output. The inputs required to calculate installation effects on all the cases have been turned off and therefore installed and uninstalled performance will always be the same.

The next case calculates the performance for MODE 2. Since the only change has been the separation of the flows, the engine is already completely balanced except for the nozzle flow. But, we have two new nozzles which will now be designed to pass the flow coming into them. The engine thus balances without having to iterate. The third case shows the performance at Mach 0.8, 36089 feet (11000 m.) at a turbine inlet temperature of 2600 °R. (1440 K). For the fourth case, we turn on control 29 which varies the TIT so that the thrust is 1400 lbs. (5800 n). For the fifth (last) case, we leave on the control on thrust and vary the two nozzle areas to minimize the specific fuel consumption. Area of a nozzle is DATOUT5 and these have been circled on cases four and five to show how the areas were opened to lower the SFC (the main nozzle increased by 28 percent and the duct nozzle 7 percent) and the SFC has been reduced by over 8 percent.

CONCLUSIONS

The Navy-NASA Engine Program NNEP has proven itself to be a powerful computer code. It can be used to simulate any turbine engine made up of combinations of inlets, ducts/ burners, compressors, turbines, mixers, heat exchangers, splitters, nozzles, shafts, and loads. It can switch modes and uses stacked maps to simulate variable cycle engines with variable geometry. It has the ability to optimize engine performance. The optimization method presently being used, however, has been found to be slow and any future code development work will be directed at speeding up the optimization process or developing a method of predicting optimum performance. Additional work is also anticipated in installation effects modeling.

At the present time, the distribution of NNEP is RESTRICTED TO GOVERNMENT AGENCIES ONLY.

APPENDIX A

BOTM

Outside of the loop optimization is accomplished by a subroutine, "BOTM", adapted from ref. 7. BOTM is considered suitable for the problem at hand because it does not require derivatives to be calculated. It is significantly faster than the better known "one-at-a-time" method because it systematically generates conjugate search directions -- eg., along the principal axes of ellipsoidal response contours. Ref. 7 shows that for the idealized case in which the response contours are actually ellipsoids, the true minimum will be located in no more than N iterations (where N is the dimension of the problem). As each iteration entails N+1 linear searches, the minimum is found after no more than N(N+1) linear searches. Since the contours in some neighborhood of a minimum are approximately ellipsoidal even for a general non-linear problem, BOTM converges very rapidly after reaching this neighborhood. In the early going, even after a poor initial approximation, BOTM is at least as good as alternate non-derivative methods.

A typical iteration of the computational algorithm is described below and illustrated (for ellipsoidal contours) in figure 8.

Let X_o = an N-dimensional vector defining the best current approximation to the minimum.

Subscript r = dimensional index, $1 \leq r \leq N$

Y_r = N linearly independent search directions in the N-dimensional space containing X_o.

λr = scalar step length along Y_r- direction

X_r = current value of X following the r-th linear search along Y_r- direction.

Initially X_o is chosen arbitrarily and the search directions Y_r are taken to be the coordinate directions. A typical iteration then proceeds as follows:

(1) Choose λr to minimize $f\ (X_{r-1} + \lambda_r Y_r)$ for r=1,2,...,N

(2) Replace Y_r by Y_{r+1} for r=1,2,...,N-1

(3) Replace Y_N by $(X_N - X_o)$

(4) Choose λ to minimize $f\ (X_N + \lambda(X_N - X_o))$ and replace X_o by $X_o + \lambda(X_N - X_o)$.

Repeat steps (2) through (4) until the minimum is achieved.

APPENDIX B

SAMPLE COMPUTER RUN

Typical Variable Cycle Engine

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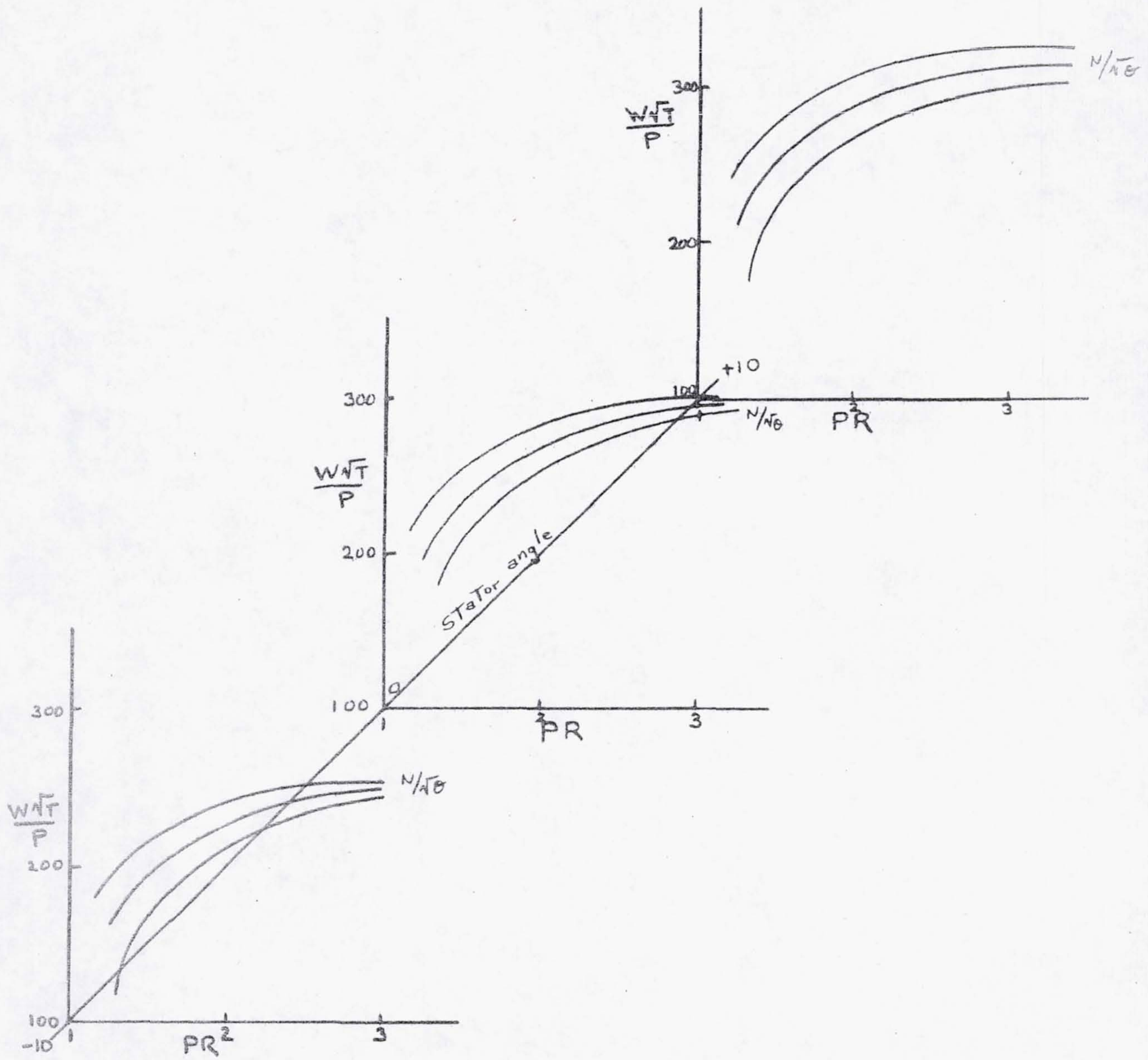


Fig. 1: Example of a "stacked" map

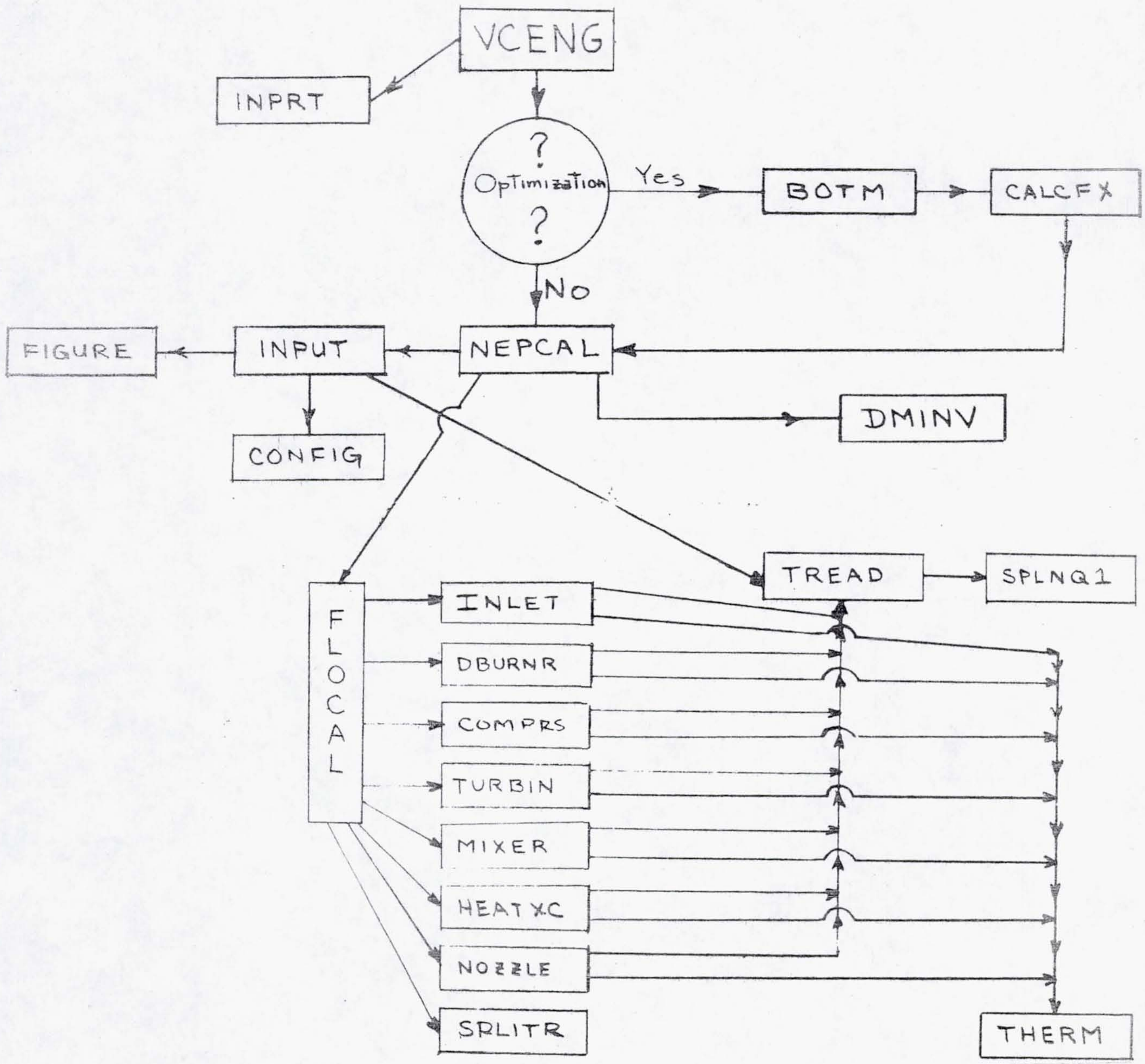
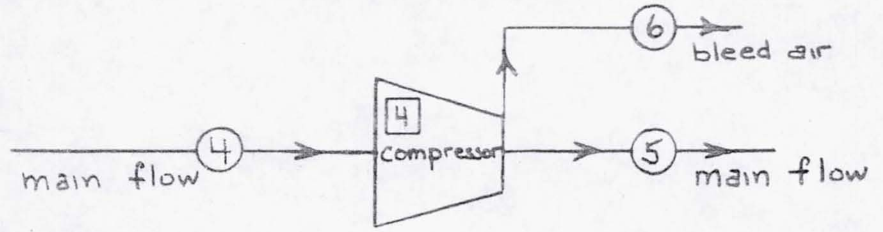


Fig 2 : NNEP Flow diagram



KONFIG (1,4) = 'COMP', 4, 0, 5, 6

component # — Type — Primary upstream — Secondary upstream — Primary downstream — Secondary downstream

$\underbrace{\text{Primary upstream, Secondary upstream, Primary downstream, Secondary downstream}}_{\text{Flow station numbers}}$

Fig. 3 : Define component Type and location in flowsTream

$$\text{SPEC}(1,4) = \underset{(1)}{1.1}, \underset{(2)}{.036}, \underset{(3)}{1}, \underset{(4)}{3707}, \underset{(5)}{1}, \underset{(6)}{3708}, \underset{(7)}{1}, \underset{(8)}{3709}, \underset{(9)}{1}, \underset{(10)}{0}, \underset{(11)}{0},$$

$$\underset{(12)}{0.88}, \underset{(13)}{4.1}, \underset{(14)}{1.0}, \underset{(15)}{0},$$

(1) "R" value on map = 1.1
(2) Bleed flow / Total flow = .036
(3), (5), (7), and (9) scale factors on $N/\sqrt{\theta}$, $W\sqrt{\theta}/\delta$, η, and PR on maps. These are initially set = 1 and are internally computed
(4) map reference number of $W\sqrt{\theta}/\delta$ versus "R" = 3707
(6) map reference number of η versus "R" = 3708
(8) map reference number of PR versus "R" = 3709
(10) 3rd dimensional argument on "stacked maps" = stator angle = 0
(11) fractional horsepower loss due to interstage bleed = 0
(12) Desired adiabatic efficiency η at design point on map = 0.88
(13) Desired pressure ratio PR at design point on map = 4.1
(14) Design point corrected speed $N/\sqrt{\theta}$ = 1.0
(15) not used

Fig 4 : Defining component characteristics (for a compressor)

KONFIG(1,30) = 'CNTL'

SPCNTL(1,30) = 1, 4, 'STAP', 8, 10, 0, .001, 1, 2.2,

Vary SPEC( )
of component ( )
so that station property
number ( )
at flow station ( )
has a value of ( )
and a tolerance of ( ).
The minimum allowable value of the variable is ( )
and maximum value is ( )

Fig. 5: Defining controls

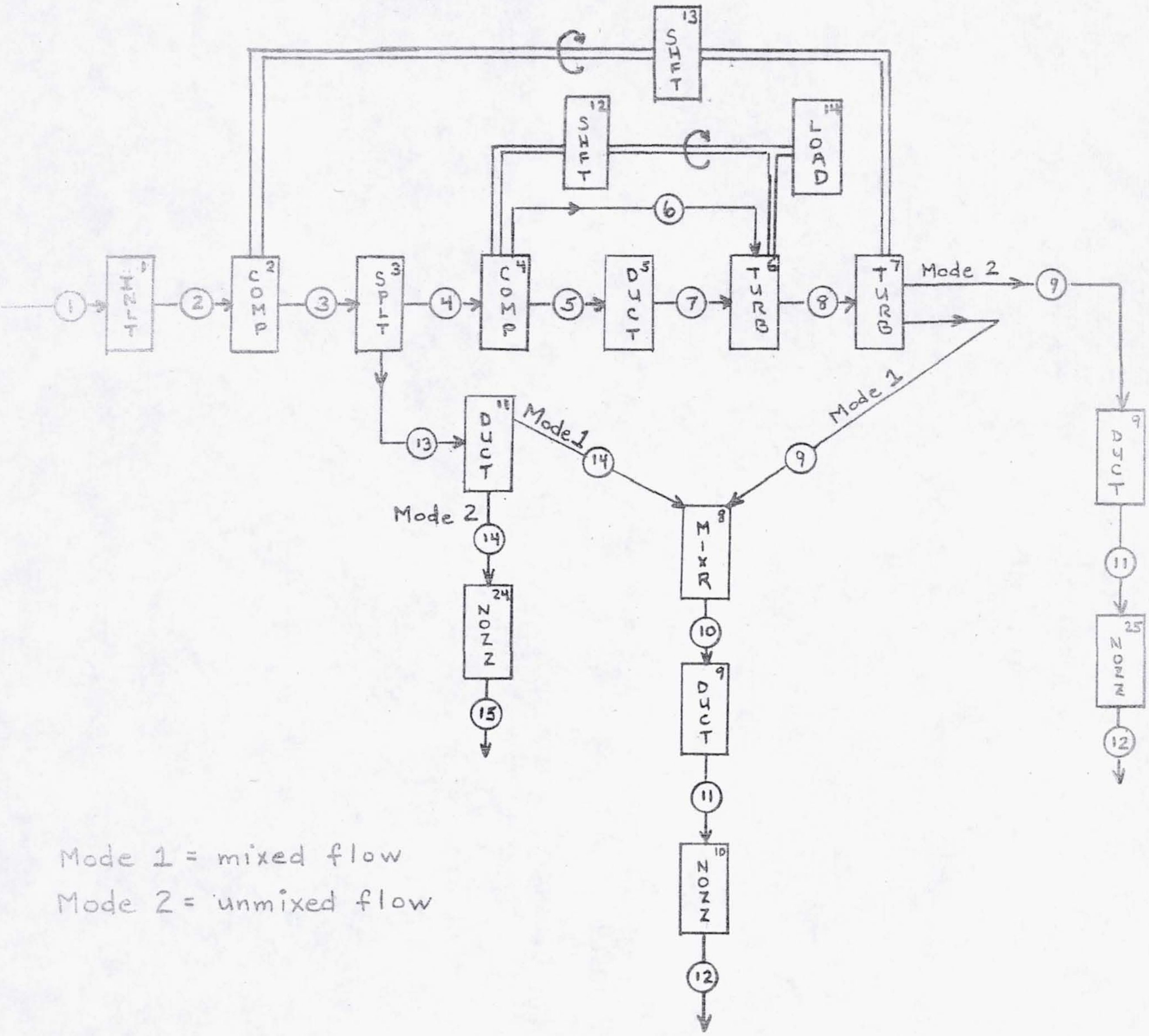
The component number which ha
The free variabl

KONFIG(1,37) = 'OPTV', 0, 0, 12, 0,

SPEC(1,37) = 0, 248, 826, 1, 4*0., .1,

not used
min. allowable value
max. allowable value
which SPEC is free var.
4 slots not used
absolute tolerance to which this variable is to be optimized

Fig 6: Defining optimization variables



Mode 1 = mixed flow

Mode 2 = unmixed flow

Fig. 7: Schematic of mixed/unmixed VCE

1st	iteration:	$x_0 \to x_1$	(λ_1)	x-direction
		$x_1 \to x_2$	(λ_2)	y-direction
		$x_2 \to x_0$	(λ)	first $x_2 - x_0$ direction
2nd	iteration	$x_0 \to x_1$	(λ_1)	y-direction
		$x_1 \to x_2$	(λ_2)	first $x_2 - x_0$ direction
		$x_2 \to x_0$	(λ)	new $x_2 - x_0$ direction

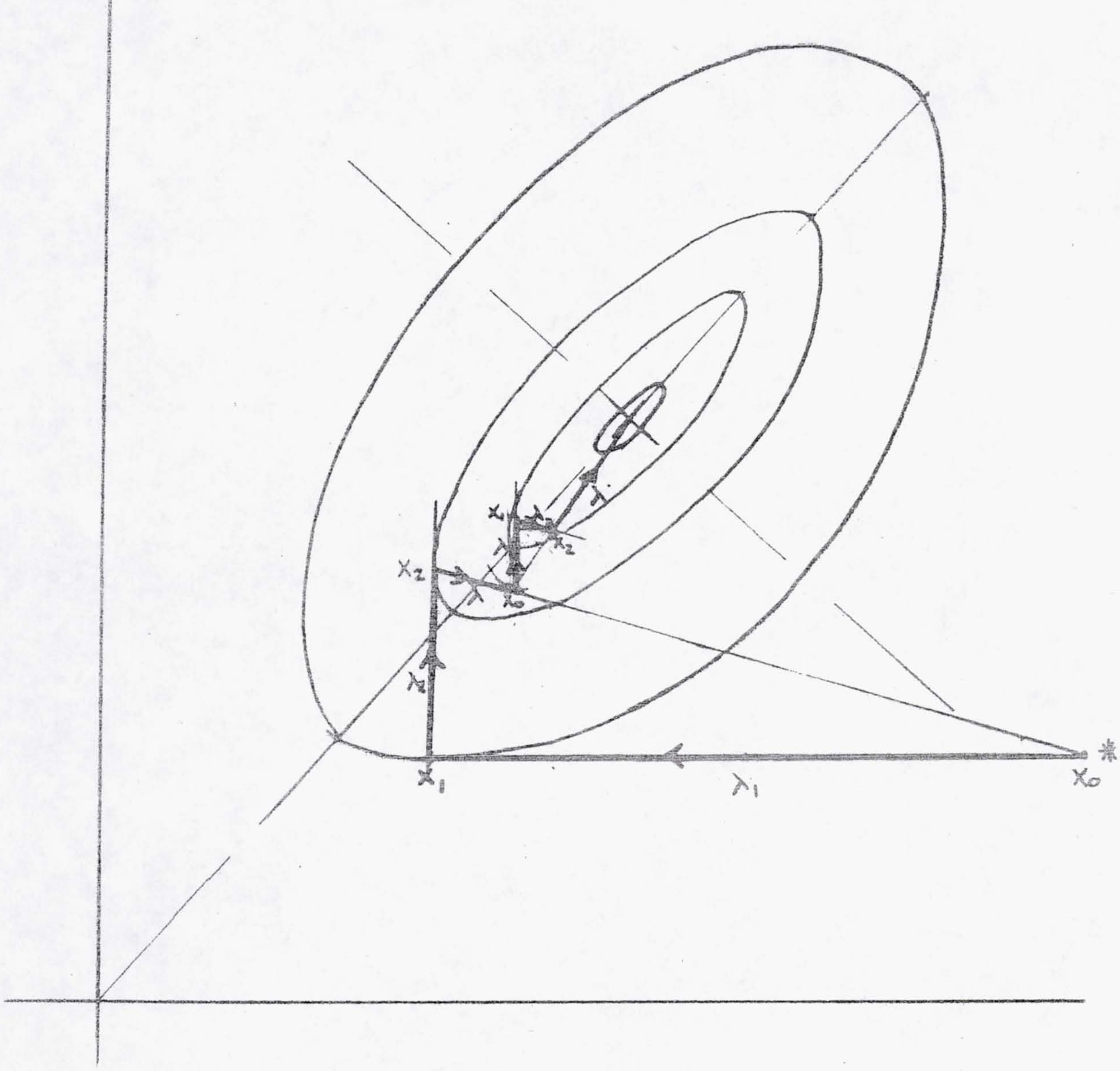


Fig 8: BOTM Iterative Procedure

```
FICTICIOUS ENGINE FOR DEMONSTRATION PURPOSES
&D NMODES=2,MODESN=1,DRAW=T,LONG=F &END
1                                TABLE DATA INPUT SUMMARY 16 TABLES
```

Map Summary

TABLE NUMBER	REFERENCE NUMBER	ARRAY LOCATION
1	3761	1
2	3762	1075
3	3763	2149
4	3704	3223
5	3705	4297
6	3706	5371
7	3707	6445
8	3708	7681
9	3709	8917
10	3801	10153
11	3802	10606
12	3803	11203
13	3804	11656
14	3901	12397
15	3902	12799
16	3903	13213

```
DATA STORAGE ALLOCATION 20000
DATA STORAGE NOT USED    6385
```

Mode 1 inputs

```
&D MODE=1,
KONFIG(1,1)='INLT',1,0,2,0,SPEC(1,1)=100,4*0,.99,
KONFIG(1,2)='COMP',2,0,3,0,SPEC(1,2)=1.8,0,1,3761,1,3762,1,3763,1,0,0,.90,2.0,
1.0,
KONFIG(1,3)='SPLT',3,0,4,13,SPEC(1,3)=.5,
KONFIG(1,4)='COMP',4,0,5,6,SPEC(1,4)=1.1,.036,1,3707,1,3708,1,3709,1,0,0,.88,
4,1,1,
KONFIG(1,5)='DUCT',5,0,7,0,SPEC(1,5)=.05,.3,0,2800,.99,18300,
KONFIG(1,6)='TURB',7,6,8,0,SPEC(1,6)=3.5,1,1,3801,1,3802,1,1,.5,1,.9,5600,1,
KONFIG(1,7)='TURB',8,0,9,0,SPEC(1,7)=2.2,0,1,3903,1,3804,1,1,0,1,.91,5200,1,
KONFIG(1,8)='MIXR',9,14,10,0,SPEC(1,8)=0,0,.3,.8,
KONFIG(1,9)='DUCT',10,0,11,0,SPEC(1,9)=.03,
KONFIG(1,10)='NOZZ',11,0,12,0,SPEC(1,10)=0,.98,0,0,.98,1,0,0,1,
KONFIG(1,11)='DUCT',13,0,14,0,SPEC(1,11)=.03,
KONFIG(1,12)='SHFT',6,4,14,0,SPEC(1,12)=5000,3*1,0,3*1,0,
KONFIG(1,13)='SHFT',7,2,0,0,SPEC(1,13)=8000,1,1,0,0,1,1,0,0,
KONFIG(1,14)='LOAD',SPEC(1,14)=-200,
KONFIG(1,15)='CNTL',SPCNTL(1,15)=1,7,'STAP',9,11,0,1,
KONFIG(1,16)='CNTL',SPCNTL(1,16)=1,6,'STAP',8,8,0,1,
KONFIG(1,17)='CNTL',SPCNTL(1,17)=1,4,'STAP',8,7,0,1,1,2.4,
KONFIG(1,18)='CNTL',SPCNTL(1,18)=1,2,'STAP',8,4,0,1,1,2.2,
KONFIG(1,19)='CNTL',SPCNTL(1,19)=1,1,'STAP',8,2,0,1,
KONFIG(1,20)='CNTL',SPCNTL(1,20)=1,3,'DOUT',8,8,0,1,
KONFIG(1,21)='CNTL',SPCNTL(1,21)=1,12,'DOUT',8,12,0,1,0,5300,
KONFIG(1,22)='CNTL',SPCNTL(1,22)=1,13,'DOUT',8,13,0,1,0,8500,
KONFIG(1,23)='OPTV',0,0,10,0,SPEC(1,23)=0,0,500,1,4*0,.1,
&END
1
```

Engine Schematic for Mode 1

```
     1
<INLT   1>
     2
<COMP   2>
     3
<SPLT   3>        <SPLT   3>
```

```
                     4                  13
<COMP    4>      <COMP    4>      <DUCT   11>
     6               5                  14
<TURB    6>      <DUCT    5>      <MIXR    8>
                     7
                 <TURB    6>
                     8
                 <TURB    7>
                     9
                 <MIXR    8>
                    10
                 <DUCT    9>
                    11
                 <NOZZ   10>
                    12
```

OSHAFT (12) IS CONNECTED TO TURB(6) AND COMP(4) AND LOAD(14) AND
OSHAFT (13) IS CONNECTED TO TURB(7) AND COMP(2) AND
0 THE FOLLOWING REPRESENTS THE CONFIGURATION FOR MODE= 1
FICTICIOUS ENGINE FOR DEMONSTRATION PURPOSES

CONFIGURATION DATA 14 STATIONS 23 COMPONENTS

COMPONENT NUMBER	NKIND	COMPONENT TYPE	UPSTREAM STATIONS		DOWNSTREAM STATIONS	
1	1	INLET	1	0	2	0
2	4	COMPRESR	2	0	3	0
3	7	SPLITTER	3	0	4	13
4	4	COMPRESR	4	0	5	6
5	2	DUCT B	5	0	7	0
6	5	TURBINE	7	6	8	0
7	5	TURBINE	8	0	9	0
8	8	MIXER	9	14	10	0
9	2	DUCT B	10	0	11	0
10	9	NOZZLE	11	0	12	0
11	2	DUCT B	13	0	14	0
12	11	SHAFT	6	4	14	0
13	11	SHAFT	7	2	0	0
14	10	LOAD	0	0	0	0
15	12	CONTROL	11	0	7	0
16	12	CONTROL	8	0	6	0
17	12	CONTROL	7	0	4	0
18	12	CONTROL	4	0	2	0
19	12	CONTROL	2	0	1	0
20	12	CONTROL	8	0	3	0
21	12	CONTROL	12	0	12	0
22	12	CONTROL	13	0	13	0
23	13	OPTVAR	0	0	10	0

CONTROL INFORMATION

15 VARY DATINP 1 OF COMPONENT 7 SO THAT STATP 8 OF FLOW STATION 11 EQUALS 0.00000
16 VARY DATINP 1 OF COMPONENT 6 SO THAT STATP 8 OF FLOW STATION 8 EQUALS 0.00000
17 VARY DATINP 1 OF COMPONENT 4 SO THAT STATP 8 OF FLOW STATION 7 EQUALS 0.00000
18 VARY DATINP 1 OF COMPONENT 2 SO THAT STATP 8 OF FLOW STATION 4 EQUALS 0.00000
19 VARY DATINP 1 OF COMPONENT 1 SO THAT STATP 8 OF FLOW STATION 2 EQUALS 0.00000
20 VARY DATINP 1 OF COMPONENT 3 SO THAT DATOUT 8 OF COMPONENT 8 EQUALS 0.00000

```
21        VARY DATINP  1 OF COMPONENT 12 SO THAT DATOUT 8 OF COMPONENT 12 EQUALS  0.00000
22        VARY DATINP  1 OF COMPONENT 13 SO THAT DATOUT 8 OF COMPONENT 13 EQUALS  0.00000
0CASE IDENTIFICATION    FICTICIOUS ENGINE FOR DEMONSTRATION PURPOSES
```

INPUT DATA

COMPONENT NO.	TYPE	DATINP1	DATINP2	DATINP3	DATINP4	DATINP5	DATINP6	DATINP7	DATINP8	DATINP9
1	INLET	0.10000D 03	0.00000	0.00000	0.00000	0.00000	0.98000D 00	0.00000	0.00000	0.00000
2	COMPRESR	0.18000D 01	0.00000	0.10000D 01	0.37610D 04	0.10000D 01	0.37620D 04	0.10000D 01	0.37630D 04	0.10000D 01
3	SPLITTER	0.50000D 00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	COMPRESR	0.11000D 01	0.36000D-01	0.10000D 01	0.37070D 04	0.10000D 01	0.37080D 04	0.10000D 01	0.37090D 04	0.10000D 01
5	DUCT B	0.50000D-01	0.30000D 00	0.00000	0.28000D 04	0.99000D 00	0.18300D 05	0.00000	0.00000	0.00000
6	TURBINE	0.35000D 01	0.10000D 01	0.10000D 01	0.38010D 04	0.10000D 01	0.38020D 04	0.10000D 01	0.10000D 01	0.50000D 00
7	TURBINE	0.22000D 01	0.00000	0.10000D 01	0.38030D 04	0.10000D 01	0.38040D 04	0.10000D 01	0.10000D 01	0.00000
8	MIXER	0.00000	0.00000	0.30000D 00	0.80000D 00	0.00000	0.00000	0.00000	0.00000	0.00000
9	DUCT B	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
10	NOZZLE	0.00000	0.98000D 00	0.00000	0.00000	0.98000D 00	0.10000D 01	0.00000	0.00000	0.10000D 01
11	DUCT B	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
12	SHAFT	0.50000D 04	0.10000D 01	0.10000D 01	0.10000D 01	0.00000	0.10000D 01	0.10000D 01	0.10000D 01	0.00000
13	SHAFT	0.80000D 04	0.10000D 01	0.10000D 01	0.00000	0.00000	0.10000D 01	0.10000D 01	0.00000	0.00000
14	LOAD	-0.20000D 03	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
15	CONTROL	0.00000	0.00000	0.00000	0.10000D 01	0.00000	0.80000D 01	0.00000	0.00000	0.10000D 01
16	CONTROL	0.00000	0.00000	0.00000	0.10000D 01	0.00000	0.80000D 01	0.00000	0.00000	0.10000D 01
17	CONTROL	0.00000	0.10000D 01	0.24000D 01	0.10000D 01	0.00000	0.80000D 01	0.00000	0.00000	0.10000D 01
18	CONTROL	0.00000	0.10000D 01	0.22000D 01	0.10000D 01	0.00000	0.80000D 01	0.00000	0.00000	0.10000D 01
19	CONTROL	0.00000	0.00000	0.00000	0.10000D 01	0.00000	0.80000D 01	0.00000	0.00000	0.10000D 01
20	CONTROL	0.00000	0.00000	0.00000	0.10000D 01	0.00000	0.00000	0.80000D 01	0.00000	0.10000D 01
21	CONTROL	0.00000	0.00000	0.53000D 04	0.10000D 01	0.00000	0.00000	0.80000D 01	0.00000	0.10000D 01
22	CONTROL	0.00000	0.00000	0.85000D 04	0.10000D 01	0.00000	0.00000	0.80000D 01	0.00000	0.10000D 01
23	OPTVAR	0.00000	0.00000	0.50000D 03	0.10000D 01	0.00000	0.00000	0.00000	0.00000	0.10000D 00

1

Mode 2 inputs

```
&D MODE=2,
KONFIG(1,1)='INLT',1,0,2,0,SPEC(1,1)=100,4*0,.98,
KONFIG(1,2)='COMP',2,0,3,0,SPEC(1,2)=1.8,0,1,3761,1,3762,1,3763,1,0,0,.90,2.0,
1.0,
KONFIG(1,3)='SPLT',3,0,4,13,SPEC(1,3)=.5,
KONFIG(1,4)='COMP',4,0,5,6,SPEC(1,4)=1.1,.036,1,3707,1,3708,1,3709,1,0,0,.88,
4.1,1,
KONFIG(1,5)='DUCT',5,0,7,0,SPEC(1,5)=.05,.3,0,2800,.99,18300,
KONFIG(1,6)='TURB',7,6,8,0,SPEC(1,6)=3.5,1,1,3801,1,3802,1,1,.5,1,.9,5600,1,
KONFIG(1,7)='TURB',8,0,9,0,SPEC(1,7)=2.2,0,1,3803,1,3804,1,1,0,1,.91,5200,1,
KONFIG(1,9)='DUCT',9,0,11,0,SPEC(1,9)=.03,
KONFIG(1,11)='DUCT',13,0,14,0,SPEC(1,11)=.03,
KONFIG(1,12)='SHFT',6,4,14,0,SPEC(1,12)=5000,3*1,0,3*1,0,
KONFIG(1,13)='SHFT',7,2,0,0,SPEC(1,13)=8000,1,1,0,0,1,1,0,0,
KONFIG(1,14)='LOAD',SPEC(1,14)=-200,
KONFIG(1,15)='CNTL',SPCNTL(1,15)=1,7,'STAP',8,11,0,1,
KONFIG(1,16)='CNTL',SPCNTL(1,16)=1,6,'STAP',8,8,0,1,
KONFIG(1,17)='CNTL',SPCNTL(1,17)=1,4,'STAP',8,7,0,1,1,2.4,
KONFIG(1,18)='CNTL',SPCNTL(1,18)=1,2,'STAP',8,4,0,1,1,2.2,
KONFIG(1,19)='CNTL',SPCNTL(1,19)=1,1,'STAP',8,2,0,1,
KONFIG(1,21)='CNTL',SPCNTL(1,21)=1,12,'DOUT',8,12,0,1,0,5300,
KONFIG(1,22)='CNTL',SPCNTL(1,22)=1,13,'DOUT',8,13,0,1,0,8500,
KONFIG(1,24)='NOZZ',14,0,15,0,SPEC(1,24)=0,.985,0,0,.985,1,0,0,1,
KONFIG(1,25)='NOZZ',11,0,12,0,SPEC(1,25)=0,.98,0,0,.98,1,0,0,1,
KONFIG(1,26)='OPTV',0,0,24,0,SPEC(1,26)=0,0,100,1,4*0,.1,
```

```
KONFIG(1,27)='CNTL',SPCNTL(1,27)=1,3,'STAP',8,14,0,1,
KONFIG(1,28)='OPTV',0,0,25,0,SPEC(1,28)=0,0,500,1,4*0,.1,
KONFIG(1,29)='CNTL',SPCNTL(1,29)=4,5,'PERF',6,0,1300,0,0,2800,
&END
1
```

Engine Schematic for Mode 2

```
                                   1
                                <INLT    1>
                                   2
                                <COMP    2>
                                   3
                                <SPLT    3>          <SPLT    3>
                                   4                    13
         <COMP    4>            <COMP    4>          <DUCT   11>
            6                      5                    14
         <TURB    6>            <DUCT    5>          <NOZZ   24>
                                   7                    15
                                <TURB    6>
                                   8
                                <TURB    7>
                                   9
                                <DUCT    9>
                                  11
                                <NOZZ   25>
                                  12
```

```
OSHAFT (12) IS CONNECTED TO TURB( 6) AND COMP( 4) AND LOAD(14) AND
OSHAFT (13) IS CONNECTED TO TURB( 7) AND COMP( 2) AND
0 THE FOLLOWING REPRESENTS THE CONFIGURATION FOR MODE=    2
  FICTICIOUS ENGINE FOR DEMONSTRATION PURPOSES
        CONFIGURATION DATA   15 STATIONS    29 COMPONENTS
```

COMPONENT NUMBER	NKIND	COMPONENT TYPE	UPSTREAM STATIONS		DOWNSTREAM STATIONS	
1	1	INLET	1	0	2	0
2	4	COMPRESR	2	0	3	0
3	7	SPLITTER	3	0	4	13
4	4	COMPRESR	4	0	5	6
5	2	DUCT B	5	0	7	0
6	5	TURBINE	7	6	8	0
7	5	TURBINE	8	0	9	0
9	2	DUCT B	9	0	11	0
11	2	DUCT B	13	0	14	0
12	11	SHAFT	6	4	14	0
13	11	SHAFT	7	2	0	0
14	10	LOAD	0	0	0	0
15	12	CONTROL	11	0	7	0
16	12	CONTROL	8	0	6	0
17	12	CONTROL	7	0	4	0
18	12	CONTROL	4	0	2	0
19	12	CONTROL	2	0	1	0
21	12	CONTROL	12	0	12	0
22	12	CONTROL	13	0	13	0
24	9	NOZZLE	14	0	15	0
25	9	NOZZLE	11	0	12	0
26	13	OPTVAR	0	0	24	0
27	12	CONTROL	14	0	3	0
28	13	OPTVAR	0	0	25	0
29	12	CONTROL	0	0	5	0

CONTROL INFORMATION

```
15        VARY DATINP  1 OF COMPONENT  7 SO THAT STATP   8 OF FLOW STATION 11 EQUALS  0.00000
16        VARY DATINP  1 OF COMPONENT  6 SO THAT STATP   8 OF FLOW STATION  8 EQUALS  0.00000
17        VARY DATINP  1 OF COMPONENT  4 SO THAT STATP   8 OF FLOW STATION  7 EQUALS  0.00000
18        VARY DATINP  1 OF COMPONENT  2 SO THAT STATP   8 OF FLOW STATION  4 EQUALS  0.00000
19        VARY DATINP  1 OF COMPONENT  1 SO THAT STATP   8 OF FLOW STATION  2 EQUALS  0.00000
21        VARY DATINP  1 OF COMPONENT 12 SO THAT DATOUT  8 OF COMPONENT 12 EQUALS  0.00000
22        VARY DATINP  1 OF COMPONENT 13 SO THAT DATOUT  8 OF COMPONENT 13 EQUALS  0.00000
27        VARY DATINP  1 OF COMPONENT  3 SO THAT STATP   8 OF FLOW STATION 14 EQUALS  0.00000
29        VARY DATINP  4 OF COMPONENT  5 SO THAT PERPET 4 EQUALS  0.13000D 04
OCASE IDENTIFICATION     FICTICIOUS ENGINE FOR DEMONSTRATION PURPOSES
```

INPUT DATA

COMPONENT NO.	TYPE	DATINP1	DATINP2	DATINP3	DATINP4	DATINP5	DATINP6	DATINP7	DATINP8	DATINP9
1	INLET	0.10000D 03	0.00000	0.00000	0.00000	0.00000	0.98000D 00	0.00000	0.00000	0.00000
2	COMPRESR	0.18000D 01	0.00000	0.10000D 01	0.37610D 04	0.10000D 01	0.37620D 04	0.10000D 01	0.37630D 04	0.10000D 01
3	SPLITTER	0.50000D 00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	COMPRESR	0.11000D 01	0.36000D-01	0.10000D 01	0.37070D 04	0.10000D 01	0.37080D 04	0.10000D 01	0.37090D 04	0.10000D 01
5	DUCT B	0.50000D-01	0.30000D 00	0.00000	0.28000D 04	0.99000D 00	0.18300D 05	0.00000	0.00000	0.00000
6	TURBINE	0.35000D 01	0.10000D 01	0.10000D 01	0.38010D 04	0.10000D 01	0.38020D 04	0.10000D 01	0.10000D 01	0.50000D 00
7	TURBINE	0.22000D 01	0.00000	0.10000D 01	0.38030D 04	0.10000D 01	0.38040D 04	0.10000D 01	0.10000D 01	0.00000
9	DUCT B	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
11	DUCT B	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
12	SHAFT	0.50000D 04	0.10000D 01	0.10000D 01	0.10000D 01	0.00000	0.10000D 01	0.10000D 01	0.10000D 01	0.00000
13	SHAFT	0.80000D 04	0.10000D 01	0.10000D 01	0.00000	0.00000	0.10000D 01	0.10000D 01	0.00000	0.00000
14	LOAD	-0.20000D 03	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
15	CONTROL	0.00000	0.00000	0.00000	0.10000D 01	0.00000	0.80000D 01	0.00000	0.00000	0.10000D 01
16	CONTROL	0.00000	0.00000	0.00000	0.10000D 01	0.00000	0.80000D 01	0.00000	0.00000	0.10000D 01
17	CONTROL	0.00000	0.10000D 01	0.24000D 01	0.10000D 01	0.00000	0.80000D 01	0.00000	0.00000	0.10000D 01
18	CONTROL	0.00000	0.10000D 01	[illegible]000D 01	0.10000D 01	0.00000	0.80000D 01	0.00000	0.00000	0.10000D 01
19	CONTROL	0.00000	0.00000	0.00000	0.10000D 01	0.00000	0.80000D 01	0.00000	0.00000	0.10000D 01
21	CONTROL	0.00000	0.00000	0.53000D 04	0.10000D 01	0.00000	0.00000	0.80000D 01	0.00000	0.10000D 01
22	CONTROL	0.00000	0.00000	0.85000D 04	0.10000D 01	0.00000	0.00000	0.80000D 01	0.00000	0.10000D 01
24	NOZZLE	0.00000	0.98500D 00	0.00000	0.00000	0.98500D 00	0.10000D 01	0.00000	0.00000	0.10000D 01
25	NOZZLE	0.00000	0.98000D 00	0.00000	0.00000	0.98000D 00	0.10000D 01	0.00000	0.00000	0.10000D 01
26	DRIVAR	0.00000	0.00000	0.10000D 03	0.10000D 01	0.00000	0.00000	0.00000	0.00000	0.10000D 00
27	CONTROL	0.00000	0.00000	0.00000	0.10000D 01	0.00000	0.80000D 01	0.00000	0.00000	0.10000D 01
28	DRIVAR	0.00000	0.00000	0.50000D 03	0.10000D 01	0.00000	0.00000	0.00000	0.00000	0.10000D 00
29	CONTROL	0.00000	0.00000	0.28000D 04	0.40000D 01	0.13000D 04	0.00000	0.00000	0.40000D 01	0.00000

1
THE MAXIMUM COMPONENT NUMBER USED 29 DOES NOT EQUAL 25 THE NUMBER OF COMPONENTS CONFIGURED IN ANY ONE MODE - WARNING ONLY
OMODE 1 NOW BEING USED

Now run the design mode - Mode 1 (mixed flow mode)

UPDATED INPUT DATA TO REFLECT CALCULATED INPUT

COMPONENT NO.	TYPE	DATINP1	DATINP2	DATINP3	DATINP4	DATINP5	DATINP6	DATINP7	DATINP8	DATINP9
1	INLET	0.10000D 03	0.00000	0.14696D 02	0.00000	0.00000	0.98000D 00	0.00000	0.00000	0.00000
2	COMPRESR	0.18000D 01	0.00000	0.80000D 04	0.37610D 04	0.10239D 03	0.37620D 04	0.10462D 01	0.37630D 04	0.53345D 00
3	SPLITTER	0.50000D 00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	COMPRESR	0.11000D 01	0.36000D-01	0.44849D 04	0.37070D 04	0.37219D 02	0.37080D 04	0.89791D 00	0.37090D 04	0.39597D 00

5	DUCT B	0.50000D-01	0.30000D 00	0.00000	0.28000D 04	0.99000D 00	0.18300D 05	0.72336D 02	0.00000	0.00000
6	TURBINE	0.35000D 01	0.10000D 01	0.38428D 00	0.38010D 04	0.12005D 01	0.38020D 04	0.10141D 01	-0.29275D 00	0.50000D 00
7	TURBINE	0.22000D 01	0.00000	0.70676D 00	0.38030D 04	0.63025D 00	0.38040D 04	0.99851D 00	0.28897D 00	0.00000
8	MIXER	0.31914D 03	0.33639D 04	0.30000D 00	0.80000D 00	0.00000	0.00000	0.00000	0.00000	0.00000
9	DUCT B	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
10	NOZZLE	0.22147D 03	0.98000D 00	0.00000	0.00000	0.98000D 00	0.10000D 01	0.00000	0.00000	0.10000D 01
11	DUCT B	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
12	SHAFT	0.50000D 04	0.10000D 01	0.10000D 01	0.10000D 01	0.00000	0.10000D 01	0.10000D 01	0.10000D 01	0.00000
13	SHAFT	0.80000D 04	0.10000D 01	0.10000D 01	0.00000	0.00000	0.10000D 01	0.10000D 01	0.00000	0.00000
14	LOAD	-0.20000D 03	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

0CASE IDENTIFICATION   FICTICIOUS ENGINE FOR DEMONSTRATION PURPOSES

Design Point OutPut

STATION PROPERTY OUTPUT DATA

FLOW STATION	WEIGHT FLOW STATP1	TOTAL PRESSURE STATP2	TOTAL TEMPERATURE STATP3	FUEL/AIR RATIO STATP4	REFERRED FLOW STATP5	MACH NUMBER STATP6	STATIC PRESSURE STATP7	INTERFACE CORRECTED FLOW ERROR STATP8
1	0.10000D 03	0.14696D 02	0.51867D 03	0.00000	0.99998D 02	0.00000	0.00000	-0.00000
2	0.10000D 03	0.14402D 02	0.51867D 03	0.00000	0.10204D 03	0.00000	0.00000	-0.00000
3	0.10000D 03	0.28804D 02	0.64465D 03	0.00000	0.56879D 02	0.00000	0.00000	-0.00000
4	0.66667D 02	0.28804D 02	0.64465D 03	0.00000	0.37919D 02	0.00000	0.00000	-0.00000
5	0.64267D 02	0.11810D 03	0.10014D 04	0.00000	0.11112D 02	0.00000	0.00000	-0.00000
6	0.24000D 01	0.11810D 03	0.10014D 04	0.00000	0.00000	0.00000	0.00000	0.00000
7	0.66179D 02	0.95465D 02	0.28000D 04	0.29754D-01	0.23670D 02	0.00000	0.00000	-0.00000
8	0.68579D 02	0.55123D 02	0.24577D 04	0.28683D-01	0.39799D 02	0.00000	0.00000	-0.00000
9	0.68579D 02	0.40930D 02	0.23102D 04	0.28683D-01	0.51967D 02	0.30000D 00	0.38620D 02	-0.00000
10	0.10191D 03	0.39464D 02	0.18126D 04	0.19122D-01	0.70944D 02	0.00000	0.00000	-0.00000
11	0.10191D 03	0.38280D 02	0.18126D 04	0.19122D-01	0.73139D 02	0.10000D 01	0.20656D 02	-0.00000
12	0.10191D 03	0.38280D 02	0.18126D 04	0.19122D-01	0.73139D 02	0.11959D 01	0.14696D 02	0.00000
13	0.33333D 02	0.28804D 02	0.64465D 03	0.00000	0.18960D 02	0.00000	0.00000	-0.00000
14	0.33333D 02	0.27940D 02	0.64465D 03	0.00000	0.19546D 02	0.70949D-02	0.38620D 02	0.00000

COMPONENT OUTPUT DATA

COMPONENT NO.	TYPE	DATOUT1	DATOUT2	DATOUT3	DATOUT4	DATOUT5	DATOUT6	DATOUT7	DATOUT8	DATOUT9
1	INLET	0.00000	0.00000	0.00000	0.10000D 01	0.10000D 01	0.00000	0.98000D 00	0.10284D 01	0.00000
2	COMPRESR	-0.42821D 04	0.80000D 04	0.00000	0.18000D 01	0.80000D 04	0.10000D 01	0.10239D 03	0.90000D 00	0.20000D 01
3	SPLITTER	0.50000D 00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	COMPRESR	-0.82181D 04	0.50000D 04	0.00000	0.11000D 01	0.44849D 04	0.10000D 01	0.37219D 02	0.88000D 00	0.41000D 01
5	DUCT B	0.14909D 00	0.50000D-01	0.30000D 00	0.29754D-01	0.72336D 02	0.68840D 04	0.30000D 00	0.18300D 05	0.99000D 00
6	TURBINE	0.84181D 04	0.50000D 04	0.10000D 01	0.35000D 01	0.38428D 00	0.56000D 04	0.12005D 01	0.90000D 00	0.17319D 01
7	TURBINE	0.42821D 04	0.80000D 04	0.10000D 01	0.22000D 01	0.70676D 00	0.52000D 04	0.63025D 00	0.91000D 00	0.13468D 01
8	MIXER	0.31914D 03	0.33639D 04	0.10598D 01	0.72347D 00	0.67641D 03	0.88234D 01	0.36645D 03	-0.91992D-16	0.10219D 01
9	DUCT B	0.00000	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.18300D 05	0.00000
10	NOZZLE	0.71481D 04	0.22567D 04	0.26048D 01	0.23027D 04	0.22147D 03	0.98000D 00	0.98000D 00	0.18532D 01	0.26048D 01
11	DUCT B	0.00000	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.18300D 05	0.00000
12	SHAFT	0.00000	0.50000D 04	0.50000D 04	0.50000D 04	0.50000D 04	0.00000	0.00000	0.00000	0.00000
13	SHAFT	0.00000	0.80000D 04	0.80000D 04	0.80000D 04	0.00000	0.00000	0.00000	0.00000	0.00000
14	LOAD	-0.20000D 03	0.50000D 04	-0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

MACH= 0.0000   ALTITUDE= 0.   RECOVERY= 0.9800   0 ITERATIONS   2 PASSES

AIRFLOW (LB/SEC)	100.00	GROSS THRUST	7148.12	FUEL FLOW (LB/HR)	6883.97
NET THRUST	7148.12	TSFC	0.9630	NET THRUST/AIRFLOW	71.4812
TOTAL INLET DRAG	0.00	TOTAL BRAKE SHAFT HP	0.00	BOATTAIL DRAG	0.00
INSTALLED THRUST	7148.12	INSTALLED TSFC	0.9630	SPILLAGE + LIP DRAG	0.00

1

&D MODE=2, &END

OMODE 2 NOW BEING USED
OCASE IDENTIFICATION FICTICIOUS ENGINE FOR DEMONSTRATION PURPOSES

Case 2 - Mode 2 at SLS (Separate flow mode)

STATION PROPERTY OUTPUT DATA

FLOW STATION	WEIGHT FLOW STATP1	TOTAL PRESSURE STATP2	TOTAL TEMPERATURE STATP3	FUEL/AIR RATIO STATP4	REFERRED FLOW STATP5	MACH NUMBER STATP6	STATIC PRESSURE STATP7	INTERFACE CORRECTED FLOW ERROR STATP8
1	0.10000D 03	0.14696D 02	0.51867D 03	0.00000	0.99998D 02	0.00000	0.00000	-0.00000
2	0.10000D 03	0.14402D 02	0.51867D 03	0.00000	0.10204D 03	0.00000	0.00000	0.22467D-16
3	0.10000D 03	0.28804D 02	0.64465D 03	0.00000	0.56879D 02	0.00000	0.00000	-0.00000
4	0.66667D 02	0.28804D 02	0.64465D 03	0.00000	0.37919D 02	0.00000	0.00000	0.24183D-15
5	0.64267D 02	0.11810D 03	0.10014D 04	0.00000	0.11112D 02	0.00000	0.00000	-0.00000
6	0.24000D 01	0.11810D 03	0.10014D 04	0.00000	0.00000	0.00000	0.00000	0.00000
7	0.66179D 02	0.95465D 02	0.28000D 04	0.29754D-01	0.23670D 02	0.00000	0.00000	0.10737D-08
8	0.68579D 02	0.55123D 02	0.24577D 04	0.28683D-01	0.39799D 02	0.00000	0.00000	0.19233D-05
9	0.68579D 02	0.40930D 02	0.23102D 04	0.28683D-01	0.51967D 02	0.00000	0.00000	-0.00000
11	0.68579D 02	0.39702D 02	0.23102D 04	0.28683D-01	0.53574D 02	0.10000D 01	0.21605D 02	-0.00000
12	0.68579D 02	0.39702D 02	0.23102D 04	0.28683D-01	0.53574D 02	0.12254D 01	0.14696D 02	0.00000
13	0.33333D 02	0.28804D 02	0.64465D 03	0.00000	0.18960D 02	0.00000	0.00000	-0.00000
14	0.33333D 02	0.27940D 02	0.64465D 03	0.00000	0.19546D 02	0.10000D 01	0.14759D 02	-0.00000
15	0.33333D 02	0.27940D 02	0.64465D 03	0.00000	0.19546D 02	0.98800D 00	0.14696D 02	0.00000

COMPONENT OUTPUT DATA

COMPONENT NO.	TYPE	DATOUT1	DATOUT2	DATOUT3	DATOUT4	DATOUT5	DATOUT6	DATOUT7	DATOUT8	DATOUT9
1	INLET	0.00000	0.00000	0.00000	0.10000D 01	0.10000D 01	0.00000	0.98000D 00	0.10284D 01	0.00000
2	COMPRESR	-0.42821D 04	0.80000D 04	0.00000	0.18000D 01	0.80000D 04	0.10000D 01	0.10239D 03	0.90000D 00	0.20000D 01
3	SPLITTER	0.50000D 00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	COMPRESR	-0.82181D 04	0.50000D 04	0.00000	0.11000D 01	0.44849D 04	0.10000D 01	0.37219D 02	0.88000D 00	0.41000D 01
5	DUCT B	0.14909D 00	0.50000D-01	0.30000D 00	0.29754D-01	0.72336D 02	0.68840D 04	0.30000D 00	0.18300D 05	0.99000D 00
6	TURBINE	0.84178D 04	0.50000D 04	0.10000D 01	0.35000D 01	0.38428D 00	0.56000D 04	0.12005D 01	0.90000D 00	0.17319D 01
7	TURBINE	0.42820D 04	0.80000D 04	0.10000D 01	0.22000D 01	0.70676D 00	0.52000D 04	0.63025D 00	0.91000D 00	0.13468D 01
9	DUCT B	0.00000	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.18300D 05	0.00000
11	DUCT B	0.00000	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.18300D 05	0.00000
12	SHAFT	-0.30317D 00	0.50000D 04	0.50000D 04	0.50000D 04	0.50000D 04	0.00000	0.00000	-0.36015D-04	0.00000
13	SHAFT	-0.12715D 00	0.80000D 04	0.80000D 04	0.80000D 04	0.00000	0.00000	0.00000	-0.29694D-04	0.00000
14	LOAD	-0.20000D 03	0.50000D 04	-0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
24	NOZZLE	0.11632D 04	0.11227D 04	0.19012D 01	0.11398D 04	0.57835D 02	0.98500D 00	0.98500D 00	0.18931D 01	0.19012D 01
25	NOZZLE	0.55387D 04	0.25985D 04	0.27015D 01	0.26515D 04	0.16334D 03	0.98000D 00	0.98000D 00	0.18376D 01	0.27015D 01

MACH= 0.0000 ALTITUDE= 0. RECOVERY= 0.9800 0 ITERATIONS 1 PASSES

AIRFLOW (LB/SEC)	100.00	GROSS THRUST	6701.89	FUEL FLOW (LB/HR)	6883.97
NET THRUST	6701.89	TSFC	1.0272	NET THRUST/AIRFLOW	67.0189
TOTAL INLET DRAG	0.00	TOTAL BRAKE SHAFT HP	-0.43	BOATTAIL DRAG	0.00
INSTALLED THRUST	6701.89	INSTALLED TSFC	1.0272	SPILLAGE + LIP DRAG	0.00

1
&D MACH=.8,ALTP=36089,ETAR=.96,SPEC(4,5)=2600 &END
OMODE 2 NOW BEING USED
OCASE IDENTIFICATION FICTICIOUS ENGINE FOR DEMONSTRATION PURPOSES

Case 3 - Mode 2 at subsonic cruise - TIT = 2600°R

STATION PROPERTY OUTPUT DATA

FLOW STATION	WEIGHT FLOW STATP1	TOTAL PRESSURE STATP2	TOTAL TEMPERATURE STATP3	FUEL/AIR RATIO STATP4	REFERRED FLOW STATP5	MACH NUMBER STATP6	STATIC PRESSURE STATP7	INTERFACE CORRECTED FLOW ERROR STATP8

1	0.37677D 02	0.32924D 01	0.39019D 03	0.00000	0.14586D 03	0.80000D 00	0.00000	-0.00000
2	0.37680D 02	0.48181D 01	0.44026D 03	0.00000	0.10588D 03	0.00000	0.00000	-0.78833D-04
3	0.37680D 02	0.10160D 02	0.55762D 03	0.00000	0.56511D 02	0.00000	0.00000	-0.00000
4	0.25047D 02	0.10160D 02	0.55762D 03	0.00000	0.37564D 02	0.00000	0.00000	0.65976D-07
5	0.24145D 02	0.42754D 02	0.87337D 03	0.00000	0.10770D 02	0.00000	0.00000	-0.00000
6	0.90168D 00	0.42754D 02	0.87337D 03	0.00000	0.00000	0.00000	0.00000	0.00000
7	0.24818D 02	0.34382D 02	0.26000D 04	0.27878D-01	0.23750D 02	0.00000	0.00000	0.23248D-07
8	0.25720D 02	0.19906D 02	0.22786D 04	0.26874D-01	0.39797D 02	0.00000	0.00000	0.18238D-08
9	0.25720D 02	0.14743D 02	0.21388D 04	0.26874D-01	0.52061D 02	0.00000	0.00000	-0.00000
11	0.25720D 02	0.14301D 02	0.21388D 04	0.26874D-01	0.53671D 02	0.10000D 01	0.77641D 01	-0.23704D-08
12	0.25720D 02	0.14301D 02	0.21388D 04	0.26874D-01	0.53671D 02	0.14465D 01	0.32924D 01	0.00000
13	0.12633D 02	0.10160D 02	0.55762D 03	0.00000	0.18947D 02	0.00000	0.00000	-0.00000
14	0.12633D 02	0.98552D 01	0.55762D 03	0.00000	0.19533D 02	0.10000D 01	0.52046D 01	0.85048D-07
15	0.12633D 02	0.98552D 01	0.55762D 03	0.00000	0.19533D 02	0.12511D 01	0.32924D 01	0.00000

COMPONENT OUTPUT DATA

COMPONENT NO.	TYPE	DATOUT1	DATOUT2	DATOUT3	DATOUT4	DATOUT5	DATOUT6	DATOUT7	DATOUT8	DATOUT9
1	INLET	0.90718D 03	0.77468D 03	0.45895D 03	0.11283D 01	0.15244D 01	0.80000D 00	0.96000D 00	0.87295D 00	0.36089D 05
2	COMPRESR	-0.14995D 04	0.77627D 04	0.00000	0.18191D 01	0.80000D 04	0.10532D 01	0.10239D 03	0.89140D 00	0.21087D 01
3	SPLITTER	0.50438D 00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	COMPRESR	-0.27093D 04	0.46334D 04	0.00000	0.10476D 01	0.44849D 04	0.99639D 00	0.37219D 02	0.88804D 00	0.42081D 01
5	DUCT B	0.15349D 00	0.50000D-01	0.30000D 00	0.27878D-01	0.72336D 02	0.24232D 04	0.28815D 00	0.18300D 05	0.99000D 00
6	TURBINE	0.29093D 04	0.46334D 04	0.10000D 01	0.34839D 01	0.38428D 00	0.53854D 04	0.12005D 01	0.89809D 00	0.17272D 01
7	TURBINE	0.14995D 04	0.77627D 04	0.10000D 01	0.22120D 01	0.70676D 00	0.52403D 04	0.63025D 00	0.90999D 00	0.13502D 01
9	DUCT B	0.00000	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.18300D 05	0.00000
11	DUCT B	0.00000	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.18300D 05	0.00000
12	SHAFT	-0.14728D-02	0.46334D 04	0.46334D 04	0.46334D 04	0.46334D 04	0.00000	0.00000	-0.50625D-06	0.00000
13	SHAFT	0.65845D-04	0.77627D 04	0.77627D 04	0.77627D 04	0.00000	0.00000	0.00000	0.43913D-07	0.00000
14	LOAD	-0.20000D 03	0.46334D 04	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
24	NOZZLE	0.51886D 03	0.13214D 04	0.29933D 01	0.13415D 04	0.57835D 02	0.98500D 00	0.98500D 00	0.18936D 01	0.29933D 01
25	NOZZLE	0.23622D 04	0.29550D 04	0.43435D 01	0.30153D 04	0.16334D 03	0.98000D 00	0.98000D 00	0.18419D 01	0.43435D 01

MACH= 0.8000 ALTITUDE= 36089. RECOVERY= 0.9600 13 ITERATIONS 30 PASSES

AIRFLOW (LB/SEC)	37.68	GROSS THRUST	2881.07	FUEL FLOW (LB/HR)	2423.18
NET THRUST	1973.89	TSFC	1.2276	NET THRUST/AIRFLOW	52.3900
TOTAL INLET DRAG	907.18	TOTAL BRAKE SHAFT HP	-0.00	BOATTAIL DRAG	0.00
INSTALLED THRUST	1973.89	INSTALLED TSFC	1.2276	SPILLAGE + LIP DRAG	0.00

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&D SPEC(9,29)=.1,LABEL=T &END
OMODE     2 NOW BEING USED
          WARNING *** EXIT VELOCITY IS SONIC *COMPONENT  5
          WARNING *** EXIT VELOCITY IS SONIC *COMPONENT  5
          WARNING *** EXIT VELOCITY IS SONIC *COMPONENT  5
          WARNING *** EXIT VELOCITY IS SONIC *COMPONENT  5
          WARNING *** EXIT VELOCITY IS SONIC *COMPONENT  5
          WARNING *** EXIT VELOCITY IS SONIC *COMPONENT  5
          WARNING *** EXIT VELOCITY IS SONIC *COMPONENT  5
          WARNING *** EXIT VELOCITY IS SONIC *COMPONENT  5
          WARNING *** EXIT VELOCITY IS SONIC *COMPONENT  5
OCASE IDENTIFICATION   VARY THE TIT TO MAKE THE THRUST 1300 +/- .1 LBS.
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Case 4 - Throttle back so thrusT = 1300 lbs.

STATION PROPERTY OUTPUT DATA

FLOW STATION	WEIGHT FLOW STATP1	TOTAL PRESSURE STATP2	TOTAL TEMPERATURE STATP3	FUEL/AIR RATIO STATP4	REFERRED FLOW STATP5	MACH NUMBER STATP6	STATIC PRESSURE STATP7	INTERFACE CORRECTED FLOW ERROR STATP8

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] D 03	0.80000D 00	0.00000	-0.00000
	[illegible]	[illegible]	[illegible]	[illegible]	0.91117D 02	0.00000	0.00000	-0.83611D-06
	[illegible]	[illegible]	0.53636D 03	0.00000	0.53646D 02	0.00000	0.00000	-0.00000
4	0.20[illegible]D 02	0.96[illegible]5D 01	0.53636D 03	0.00000	0.34694D 02	0.00000	0.00000	-0.32422D-06
5	0.29219D 02	0.32507D 02	0.79613D 03	0.00000	0.11322D 02	0.00000	0.00000	-0.00000
6	0.75490D 00	0.32507D 02	0.79613D 03	0.00000	0.00000	0.00000	0.00000	0.00000
7	0.20653D 02	0.26277D 02	0.21938D 04	0.21643D-01	0.23754D 02	0.00000	0.00000	-0.18210D-04
8	0.21407D 02	0.15116D 02	0.19129D 04	0.20864D-01	0.39970D 02	0.00000	0.00000	-0.54186D-06
9	0.21407D 02	0.11170D 02	0.17897D 04	0.20864D-01	0.52318D 02	0.00000	0.00000	-0.00000
11	0.21407D 02	0.10835D 02	0.17897D 04	0.20864D-01	0.53936D 02	0.10000D 01	0.58468D 01	-0.25515D-06
12	0.21407D 02	0.10835D 02	0.17897D 04	0.20864D-01	0.53936D 02	0.13157D 01	0.32924D 01	0.00000
13	0.11455D 02	0.90325D 01	0.53636D 03	0.00000	0.18952D 02	0.00000	0.00000	-0.00000
14	0.11455D 02	0.87615D 01	0.53636D 03	0.00000	0.19538D 02	0.10000D 01	0.46268D 01	0.24906D-05
15	0.11455D 02	0.87615D 01	0.53636D 03	0.00000	0.19538D 02	0.11915D 01	0.32924D 01	0.00000

COMPONENT OUTPUT DATA

COMPONENT NO.	TYPE	DATOUT1	DATOUT2	DATOUT3	DATOUT4	DATOUT5	DATOUT6	DATOUT7	DATOUT8	DATOUT9
1	INLET	0.78071D 03	0.77468D 03	0.45895D 03	0.11283D 01	0.15244D 01	0.80000D 00	0.96000D 00	0.87295D 00	0.36089D 05
2	COMPRESR	-0.10563D 04	0.68093D 04	0.00000	0.13027D 01	0.80000D 04	0.92386D 00	0.10239D 03	0.90164D 00	0.18747D 01
3	SPLITTER	0.54627D 00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	COMPRESR	-0.18599D 04	0.42538D 04	0.00000	0.11617D 01	0.44849D 04	0.93270D 00	0.37219D 02	0.90714D 00	0.35989D 01
5	DUCT B	0.14909D 00	0.50000D-01	0.30000D 00	0.21643D-01	0.72336D 02	0.15750D 04	0.30174D 00	0.18300D 05	0.99000D 00
6	TURBINE	0.20599D 04	0.42538D 04	0.10000D 01	0.35224D 01	0.38428D 00	0.53824D 04	0.12005D 01	0.89813D 00	0.17384D 01
7	TURBINE	0.10563D 04	0.68093D 04	0.10000D 01	0.22224D 01	0.70676D 00	0.50169D 04	0.63025D 00	0.91137D 00	0.13532D 01
9	DUCT B	0.00000	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.18300D 05	0.00000
11	DUCT B	0.00000	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.18300D 05	0.00000
12	SHAFT	0.47018D-01	0.42538D 04	0.42538D 04	0.42538D 04	0.42538D 04	0.00000	0.00000	0.22825D-04	0.00000
13	SHAFT	0.20639D-01	0.68093D 04	0.68093D 04	0.68093D 04	0.00000	0.00000	0.00000	0.19539D-04	0.00000
14	LOAD	-0.20000D 03	0.42538D 04	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
24	NOZZLE	0.43947D 03	0.12344D 04	0.26611D 01	0.12532D 04	0.57835D 02	0.98500D 00	0.98500D 00	0.18936D 01	0.26611D 01
25	NOZZLE	0.16413D 04	0.24668D 04	0.32909D 01	0.25171D 04	0.16334D 03	0.98000D 00	0.98000D 00	0.18531D 01	0.32909D 01

NOZZLE AREAS

MACH= 0.8000 ALTITUDE= 36089. RECOVERY= 0.9600 13 ITERATIONS 32 PASSES

AIRFLOW (LB/SEC)	32.42	GROSS THRUST	2080.77	FUEL FLOW (LB/HR)	1575.04
NET THRUST	1300.05	TSFC	1.2115	NET THRUST/AIRFLOW	40.0949
TOTAL INLET DRAG	780.71	TOTAL BRAKE SHAFT HP	0.07	BOATTAIL DRAG	0.00
INSTALLED THRUST	1300.05	INSTALLED TSFC	1.2115	SPILLAGE + LIP DRAG	0.00

```
&D NVOPT=5 &END
OMODE    2 NOW BEING USED
  0.10000D 01  0.00000       0.12115D 01  0.57835D 02  0.16334D 03
  0.99950D 00  0.00000       0.12109D 01  0.58335D 02  0.16334D 03
  0.99904D 00  0.00000       0.12104D 01  0.58835D 02  0.16334D 03
  0.99763D 00  0.00000       0.12086D 01  0.63835D 02  0.16334D 03
  0.99742D 00  0.00000       0.12084D 01  0.62542D 02  0.16334D 03

ITERATION     1              5 FUNCTION VALUES         F = 0.99742495D 00
  0.62542126D 02  0.16333929D 03
  0.99553D 00  0.00000       0.12061D 01  0.62542D 02  0.16384D 03
  0.99359D 00  0.00000       0.12037D 01  0.62542D 02  0.16434D 03
  0.97514D 00  0.00000       0.11814D 01  0.62542D 02  0.16934D 03
  0.95906D 00  0.00000       0.11619D 01  0.62542D 02  0.17434D 03
  0.94543D 00  0.00000       0.11454D 01  0.62542D 02  0.17934D 03
  0.93515D 00  0.00000       0.11329D 01  0.62542D 02  0.18434D 03
  0.92847D 00  0.00000       0.11249D 01  0.62542D 02  0.18934D 03
  0.92413D 00  0.00000       0.11196D 01  0.62542D 02  0.19434D 03
  0.92153D 00  0.00000       0.11165D 01  0.62542D 02  0.19934D 03
```

Optimization History

```
   0.92030D 00  0.00000        0.11150D 01  0.62542D 02  0.20425D 03
   0.92013D 00  0.00000        0.11148D 01  0.62542D 02  0.20642D 03

 ITERATION    1             16 FUNCTION VALUES            F = 0.92013469D 00
    0.62542126D 02  0.20642109D 03
   0.13566D 01  0.35938D 00  0.12081D 01  0.67249D 02  0.24950D 03
   0.92078D 00  0.00000        0.11155D 01  0.63042D 02  0.20642D 03
   0.17690D 01  0.84187D 00  0.11233D 01  0.57542D 02  0.20642D 03
   0.92048D 00  0.00000        0.11152D 01  0.62771D 02  0.20642D 03
   0.92034D 00  0.00000        0.11150D 01  0.62634D 02  0.20642D 03
   0.92027D 00  0.00000        0.11149D 01  0.62555D 02  0.20642D 03
   0.92011D 00  0.00000        0.11147D 01  0.62402D 02  0.20642D 03
   0.92018D 00  0.00000        0.11148D 01  0.62470D 02  0.20642D 03
   0.92012D 00  0.00000        0.11147D 01  0.62422D 02  0.20642D 03
   0.92011D 00  0.00000        0.11147D 01  0.62408D 02  0.20642D 03

 ITERATION    2             26 FUNCTION VALUES            F = 0.92011137D 00
    0.62401901D 02  0.20642109D 03
   0.92010D 00  0.00000        0.11147D 01  0.62402D 02  0.20692D 03
   0.92010D 00  0.00000        0.11147D 01  0.62402D 02  0.20729D 03
   0.92011D 00  0.00000        0.11147D 01  0.62402D 02  0.20701D 03
   0.92012D 00  0.00000        0.11147D 01  0.62402D 02  0.20673D 03
   0.92011D 00  0.00000        0.11147D 01  0.62402D 02  0.20689D 03
   0.92011D 00  0.00000        0.11147D 01  0.62412D 02  0.20695D 03

 ITERATION    2             32 FUNCTION VALUES            F = 0.92009618D 00
    0.62401901D 02  0.20692109D 03
   0.91997D 00  0.00000        0.11146D 01  0.62262D 02  0.20742D 03
   0.93252D 00  0.13041D-01  0.11140D 01  0.61561D 02  0.20992D 03
   0.92003D 00  0.00000        0.11146D 01  [illegible]  0.20724D 03

 ITERATION    2             35 FUNCTION VALUES            F = 0.91997158D 00
    0.62261676D 02  0.20742109D 03
   0.91998D 00  0.00000        0.11146D 01  0.62262D 02  0.20752D 03
   0.91998D 00  0.00000        0.11146D 01  0.62262D 02  0.20747D 03
   0.91999D 00  0.00000        0.11146D 01  0.62262D 02  0.20642D 03
   0.91998D 00  0.00000        0.11146D 01  0.62262D 02  0.20696D 03
   0.91998D 00  0.00000        0.11146D 01  0.62262D 02  0.20722D 03
   0.91998D 00  0.00000        0.11146D 01  0.62262D 02  0.20734D 03
   0.91998D 00  0.00000        0.11146D 01  0.62262D 02  0.20740D 03
   0.91998D 00  0.00000        0.11146D 01  0.62262D 02  0.20744D 03

 ITERATION    3             45 FUNCTION VALUES            F = 0.91997158D 00
    0.62261676D 02  0.20742109D 03
   0.91992D 00  0.00000        0.11145D 01  0.62198D 02  0.20765D 03
   0.91994D 00  0.00000        0.11145D 01  0.62215D 02  0.20759D 03
   0.93379D 00  0.14315D-01  0.11140D 01  0.61557D 02  0.20993D 03
   0.91992D 00  0.00000        0.11145D 01  0.62189D 02  0.20768D 03

 ITERATION    3             47 FUNCTION VALUES            F = 0.91992005D 00
    0.62189499D 02  0.20767845D 03
   0.91986D 00  0.00000        0.11144D 01  0.62117D 02  0.20794D 03
   0.91955D 00  0.00000        0.11141D 01  0.61756D 02  0.20922D 03
   0.99023D 00  0.70937D-01  0.11137D 01  0.61035D 02  0.21180D 03
   0.91974D 00  0.00000        0.11143D 01  0.61932D 02  0.20860D 03
   0.91966D 00  0.00000        0.11142D 01  0.61839D 02  0.20893D 03
   0.91963D 00  0.00000        0.11141D 01  0.61793D 02  0.20909D 03

 ITERATION    3             51 FUNCTION VALUES            F = 0.91955251D 00
    0.61756441D 02  0.2092226[illegible] 03
```

```
0.91960D 00  0.00000      0.11141D 01  0.61756D 02  0.20932D 03
0.91960D 00  0.00000      0.11141D 01  0.61756D 02  0.20927D 03
0.91956D 00  0.00000      0.11141D 01  0.61756D 02  0.20822D 03
0.91958D 00  0.00000      0.11141D 01  0.61756D 02  0.20873D 03
0.91958D 00  0.00000      0.11141D 01  0.61756D 02  0.20899D 03
0.91959D 00  0.00000      0.11141D 01  0.61756D 02  0.20912D 03
0.91959D 00  0.00000      0.11141D 01  0.61756D 02  0.20919D 03
0.91952D 00  0.00000      0.11140D 01  0.61756D 02  0.20923D 03
0.91945D 00  0.00000      0.11139D 01  0.61756D 02  0.20924D 03

ITERATION     4           62 FUNCTION VALUES         F = 0.91944934D 00
  0.61756441D 02   0.20924210D 03
0.91956D 00  0.00000      0.11141D 01  0.61711D 02  0.20940D 03
0.91959D 00  0.00000      0.11141D 01  0.61744D 02  0.20929D 03
0.91963D 00  0.00000      0.11141D 01  0.61802D 02  0.20908D 03
0.91959D 00  0.00000      0.11141D 01  0.61752D 02  0.20926D 03
0.91961D 00  0.00000      0.11141D 01  0.61776D 02  0.20917D 03
0.91953D 00  0.00000      0.11140D 01  0.61764D 02  0.20922D 03
0.91947D 00  0.00000      0.11140D 01  0.61758D 02  0.20924D 03

ITERATION     4           69 FUNCTION VALUES         F = 0.91944934D 00
  0.61756441D 02   0.20924210D 03
0.91960D 00  0.00000      0.11141D 01  0.61756D 02  0.20926D 03
0.91960D 00  0.00000      0.11141D 01  0.61756D 02  0.20934D 03
0.91960D 00  0.00000      0.11141D 01  0.61756D 02  0.20929D 03
0.91956D 00  0.00000      0.11141D 01  0.61756D 02  0.20824D 03
0.91958D 00  0.00000      0.11141D 01  0.61756D 02  0.20876D 03
0.91959D 00  0.00000      0.11141D 01  0.61756D 02  0.20902D 03
0.91959D 00  0.00000      0.11141D 01  0.61756D 02  0.20915D 03
0.91956D 00  0.00000      0.11141D 01  0.61756D 02  0.20922D 03
0.91960D 00  0.00000      0.11141D 01  0.61756D 02  0.20925D 03
0.91948D 00  0.00000      0.11140D 01  0.61756D 02  0.20924D 03

ITERATION     5           79 FUNCTION VALUES         F = 0.91944934D 00
  0.61756441D 02   0.20924210D 03
0.91958D 00  0.00000      0.11141D 01  0.61728D 02  0.20934D 03
0.91959D 00  0.00000      0.11141D 01  0.61743D 02  0.20929D 03
0.91962D 00  0.00000      0.11141D 01  0.61784D 02  0.20914D 03
0.91943D 00  0.00000      0.11139D 01  0.61755D 02  0.20925D 03
0.91959D 00  0.00000      0.11141D 01  0.61746D 02  0.20928D 03

ITERATION     5           84 FUNCTION VALUES         F = 0.91942812D 00
  0.61754536D 02   0.20924890D 03
0.91959D 00  0.00000      0.11141D 01  0.61753D 02  0.20926D 03
0CASE IDENTIFICATION   VARY THE TWO NOZZLE AREAS TO MIN SFC WITH F=1300 LBS
```

Case 5 - Minimum SFC

STATION PROPERTY OUTPUT DATA

FLOW STATION	WEIGHT FLOW STATP1	TOTAL PRESSURE STATP2	TOTAL TEMPERATURE STATP3	FUEL/AIR RATIO STATP4	REFERRED FLOW STATP5	MACH NUMBER STATP6	STATIC PRESSURE STATP7	INTERFACE CORRECTED FLOW ERROR STATP8
1	0.39038D 02	0.32924D 01	0.39019D 03	0.00000	0.15113D 03	0.80000D 00	0.00000	-0.00000
2	0.39038D 02	0.48181D 01	0.44026D 03	0.00000	0.10970D 03	0.00000	0.00000	0.17160D-07
3	0.39038D 02	0.11746D 02	0.58770D 03	0.00000	0.51991D 02	0.00000	0.00000	-0.00000
4	0.23851D 02	0.11746D 02	0.58770D 03	0.00000	0.31765D 02	0.00000	0.00000	-0.82516D-06
5	0.22992D 02	0.34705D 02	0.82413D 03	0.00000	0.12273D 02	0.00000	0.00000	-0.00000
6	0.85864D 00	0.34705D 02	0.82413D 03	0.00000	0.00000	0.00000	0.00000	0.00000
7	0.23395D 02	0.28376D 02	0.19762D 04	0.17498D-01	0.23650D 02	0.00000	0.00000	-0.36553D-06
8	0.24253D 02	0.16224D 02	0.17177D 04	0.16868D-01	0.39979D 02	0.00000	0.00000	0.10797D-07

9	0.24253D 02	0.90307D 01	0.15104D 04	0.16868D-01	0.67352D 02	0.00000	0.00000	-0.00000
11	0.24253D 02	0.87598D 01	0.15104D 04	0.16868D-01	0.69435D 02	0.10000D 01	0.47008D 01	0.38626D-07
12	0.24253D 02	0.87598D 01	0.15104D 04	0.16868D-01	0.69435D 02	0.12017D 01	0.32924D 01	0.00000
13	0.15187D 02	0.11746D 02	0.58770D 03	0.00000	0.20226D 02	0.00000	0.00000	-0.00000
14	0.15187D 02	0.11394D 02	0.58770D 03	0.00000	0.20852D 02	0.10000D 01	0.60174D 01	-0.49385D-07
15	0.15187D 02	0.11394D 02	0.58770D 03	0.00000	0.20852D 02	0.13185D 01	0.32924D 01	0.00000

COMPONENT OUTPUT DATA

COMPONENT NO.	TYPE	DATOUT1	DATOUT2	DATOUT3	DATOUT4	DATOUT5	DATOUT6	DATOUT7	DATOUT8	DATOUT9
1	INLET	0.93996D 03	0.77468D 03	0.45895D 03	0.11283D 01	0.15244D 01	0.80000D 00	0.96000D 00	0.87295D 00	0.36089D 05
2	COMPRESR	-0.19525D 04	0.84864D 04	0.00000	0.12367D 01	0.80000D 04	0.11514D 01	0.10239D 03	0.86546D 00	0.24379D 01
3	SPLITTER	0.63675D 00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4	COMPRESR	-0.19298D 04	0.42418D 04	0.00000	0.12921D 01	0.44849D 04	0.88851D 00	0.37219D 02	0.89480D 00	0.29546D 01
5	DUCT B	0.13933D 00	0.50000D-01	0.30000D 00	0.17498D-01	0.72336D 02	0.14483D 04	0.32890D 00	0.18300D 05	0.99000D 00
6	TURBINE	0.21298D 04	0.42418D 04	0.10000D 01	0.35586D 01	0.38428D 00	0.56550D 04	0.12005D 01	0.90064D 00	0.17490D 01
7	TURBINE	0.19525D 04	0.84864D 04	0.10000D 01	0.37564D 01	0.70676D 00	0.65982D 04	0.63025D 00	0.88690D 00	0.17965D 01
9	DUCT B	0.00000	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.18300D 05	0.00000
11	DUCT B	0.00000	0.30000D-01	0.00000	0.00000	0.00000	0.00000	0.00000	0.18300D 05	0.00000
12	SHAFT	0.37386D-03	0.42418D 04	0.42418D 04	0.42418D 04	0.42418D 04	0.00000	0.00000	0.17553D-06	0.00000
13	SHAFT	0.24854D-02	0.84864D 04	0.84864D 04	0.84864D 04	0.00000	0.00000	0.00000	0.12729D-05	0.00000
14	LOAD	-0.20000D 03	0.42418D 04	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
24	NOZZLE	0.67480D 03	0.14296D 04	0.34605D 01	0.14513D 04	0.61753D 02	0.98500D 00	0.98500D 00	0.18934D 01	0.34606D 01
25	NOZZLE	0.15652D 04	0.20763D 04	0.26606D 01	0.21187D 04	0.20926D 03	0.98000D 00	0.98000D 00	0.18635D 01	0.26606D 01

NOZZLE AREAS

MACH= 0.8000 ALTITUDE= 36089. RECOVERY= 0.9600 1 ITERATIONS 11 PASSES

AIRFLOW (LB/SEC)	39.04	GROSS THRUST	2239.96	FUEL FLOW (LB/HR)	1448.34
NET THRUST	1300.00	TSFC	1.1141	NET THRUST/AIRFLOW	33.3007
TOTAL INLET DRAG	939.96	TOTAL BRAKE SHAFT HP	0.00	BOATTAIL DRAG	0.00
INSTALLED THRUST	1300.00	INSTALLED TSFC	1.1141	SPILLAGE + LIP DRAG	0.00

1

&D ENDIT=1 &END

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15. Supplementary Notes

16. Abstract

The Naval Air Development Center and NASA's Lewis Research Center have jointly developed a computer code capable of simulating almost any conceivable turbine engine. This code uses stacked component maps and multiple flowpaths to simulate variable cycle engines with variable component geometry. It is capable of design and off-design (matching) calculations and can optimize free variables such as nozzle areas to minimize specific fuel consumption. It is a derivative of the Navy code NEPCOMP. NNEP is restricted to U.S. Government Agencies.

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