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Walter C. Merrill  
*Lewis Research Center  
Cleveland, Ohio*

and

Edward C. Beattie and Richard F. LaPrad  
*Pratt & Whitney Aircraft Co.  
United Technologies Corp.  
East Hartford, Connecticut*

and

Stephen M. Rock and Muhammed M. Akhter  
*Systems Control Technology, Inc.  
Palo Alto, California*

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# HYTESS - A HYPOTHETICAL TURBOFAN ENGINE SIMPLIFIED SIMULATION

Walter C. Merrill  
National Aeronautics and Space Administration  
Lewis Research Center  
Cleveland, Ohio 44135

Edward C. Beattie and Richard F. LaPrad  
Pratt & Whitney Aircraft Co.  
United Technologies Corp.  
East Hartford, Connecticut 06108

and

Stephen M. Rock and Muhammad M. Akhter  
Systems Control Technology, Inc.  
Palo Alto, California 94303

## SUMMARY

A hypothetical turbofan engine simplified simulation is presented. The digital program, written in FORTRAN, is self-contained, efficient, realistic, and easily used. This simulation was developed from linearized operating point models but still retains essential nonlinear engine effects. The simulation is representative of a hypothetical, low bypass ratio turbofan engine. Program structure and input and output information are provided. This simulation can be used for engine dynamics and controls analysis.

## INTRODUCTION

This report is a users manual for the hypothetical turbofan engine simplified simulation (HYTESS). This digital simulation exists as FORTRAN source code and was designed for use on the NASA Lewis Research Center's IBM 3033 AP computer running under the TSS/370 operating system. The program is self-contained and was developed to offer those interested in engine dynamics and controls research an efficient, realistic, and easily used engine simulation.

Typically turbine engine simulations incorporate detailed nonlinear descriptions of both steady-state and dynamic engine operation throughout the engine's flight envelope. These detailed nonlinear simulations are very accurate and realistic and, when implemented in a digital computer, require relatively large amounts of computer storage and computer processing time. This makes these detailed simulations difficult and costly to use. HYTESS was developed as an alternative. It is structurally simpler than a full nonlinear engine simulation and therefore has reduced storage and processing requirements. HYTESS retains the essential nonlinear effects inherent in the engine's operation. This is accomplished by modeling the engine using a linear state space formulation, and incorporating the nonlinear characteristics by representing the matrix elements within the linear state space structure as nonlinear functions of various engine variables. The compromise implied in this process is that, although the fidelity of HYTESS is maintained for the variables considered, it is very difficult to identify individual component behavior

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as in a detailed simulation. Also HYTESS is restricted to operation in regions about the normal operating line of the engine. The engine characteristics simulated by HYTESS, although hypothetical, are qualitatively similar to those of realistic advanced turbofan engines. Typical applications for this simulation would include open-loop engine dynamics studies as well as closed-loop controls analysis using a user generated control law.

This report begins with a description of the engine simulated by HYTESS. Next descriptions of the mathematical model and the simulation are given. Finally, some results are given. Flow charts and variable definitions are also included.

## ENGINE DESCRIPTION

The engine simulated by HYTESS is representative of current high technology engines and is shown schematically in figure 1. It is a low bypass ratio, twin-spool, axial-flow turbofan engine, consisting of the following components:

- (1) Low-speed fan driven by a turbine (spool 1)
- (2) High-speed compressor driven by a turbine (spool 2)
- (3) Main burner
- (4) Annular fan duct that surrounds the basic gas generator and discharges air into the mixed flow augmentor
- (5) Variable area nozzle

Variable inlet guide vanes are used ahead of the fan to improve inlet distortion tolerance and fan efficiency. Variable stators in the high compressor improve starting and high Mach number characteristics. Airflow bleed is extracted at the compressor exit to improve starting. The exhaust nozzle variable geometry enables all three nozzle performance parameters (nozzle area, expansion ratio, and boattail drag) to be simultaneously near optimum throughout the operating range. A list of engine inputs and outputs is given in the next section.

### Engine Model

A detailed nonlinear engine model can be written in vector differential equation form

$$\left. \begin{aligned} \dot{X} &= f(X, U, \phi) \\ Y &= g(X, U, \phi) \end{aligned} \right\} \quad (1)$$

where  $X$  is a state vector,  $U$  is the vector of controls,  $Y$  is the output vector, and  $\phi$  is a vector of environmental conditions. Detailed nonlinear engine relations are represented by the functions  $f(\cdot)$  and  $g(\cdot)$ . At a base point, that is a steady-state point on the operating line,

$$\left. \begin{aligned} f(X_b, U_b, \phi_b) &= 0 \\ Y_b &= g(X_b, U_b) \end{aligned} \right\} \quad (2)$$

In HYTESS the state space description of the model of equations (1) and (2) is implemented as

$$\left. \begin{aligned} X_{ss} &= X_b - F^{-1}G(U - U_b) \\ \dot{X} &= F(X - X_{ss}) \\ Y &= Y_b + H(X - X_b) + D(U - U_b) \end{aligned} \right\} \quad (3)$$

The subscript  $b$  is used to denote base points. The subscript  $ss$  is used to denote the steady-state value of  $X$  for a given  $U$ . The matrices  $F$ ,  $F^{-1}G$ ,  $H$ , and  $D$  are the typical system matrices. The states, control inputs, and outputs were chosen to be typical of those variables used in dynamics and controls analysis in modern turbofan engines and consist of the following variables.

States:

- $X_1$  fan speed (N1), rpm
- $X_2$  compressor speed (N2), rpm
- $X_3$  burner exit slow response temperature (TT4PLO), K
- $X_4$  fan turbine inlet slow response temperature (TT45LO), K

Control inputs:

- $U_1$  main burner fuel flow (WFMB), kg/sec
- $U_2$  nozzle jet area (AJ),  $m^2$
- $U_3$  fan guide vane position (FGV), deg
- $U_4$  high compressor variable stator vane angle (SVA), deg
- $U_5$  customer compressor bleed flow (BLC), percent

Engine outputs:

- $Y_1$  fan speed (N1), rpm
- $Y_2$  compressor speed (N2), rpm
- $Y_3$  burner pressure (PT4),  $N/m^2$
- $Y_4$  augmentor pressure (PT6),  $N/m^2$
- $Y_5$  fan turbine inlet temperature (FTIT), K
- $Y_6$  thrust (FNMX), N
- $Y_7$  compressor surge margin (SMHC)

Operating conditions:

- $\phi_1$  engine face pressure (PT2),  $N/m^2$
- $\phi_2$  engine face temperature (TT2), K

The system matrices were determined in the following manner. Linearized system matrices at several base points were found from a representative detailed nonlinear simulation using perturbational techniques. The elements of each of these matrices were regressed upon selected engine variables or elementary

functions of these variables (elements of  $Y$  and  $\phi$ ). As a result nonlinear polynomial functions were found that fit the change in these matrix elements for the full range of engine power through the flight envelope as shown in figure 2. An example of some typical regression polynomials for the system matrices is given in table I. Rewriting equation (3) with a more explicit functional notation yields

$$\left. \begin{aligned} X_{ss} &= X_b(Y, \phi) - [F^{-1}G](Y, \phi)[U - U_b(Y, \phi)] \\ \dot{X} &= F(Y, \phi)[X - X_{ss}] \\ Y &= Y_b(Y, \phi) + H(Y, \phi)[X - X_b(Y, \phi)] + D(Y, \phi)[U - U_b(Y, \phi)] \end{aligned} \right\} \quad (4)$$

### Engine Control Model

The purpose of an engine control is to manipulate thrust according to the pilot's request. In this simulation the control is simply an open-loop schedule between the pilot's request (PLA) as the independent variable and the requested engine controls as the dependent variables.

$$U_r = h(PLA, \phi) \quad (5)$$

The function  $h(\cdot)$  is selected to define the desired steady-state relations between PLA and the engine outputs. These steady-state relations are often called reference point schedules and are simulated in the subroutine RPSCH. The open-loop control law then becomes

$$U = U_r \quad (6)$$

Closed-loop control could be incorporated in the simulation by appropriately modifying the implementation of equation (6) in the subroutine TRANS. For example, immediately following the call to subroutine RPSCH in TRANS, equation (6) is implemented. Closed-loop control could be implemented here simply by including the closed-loop component  $U_{CL}$  as in equation (7).

$$U = U_R + U_{CL} \quad (7)$$

### SIMULATION DESCRIPTION

This section contains a description of the program, input program requirements, output, and execution requirements. Selected test case results are also presented.

## Program Description

HYTESS contains all the subroutines necessary to execute the program. There are no system library routines required. The program was originally developed for execution on a VAX 11-780 but has since been executed on an IBM 3033AP with no changes. The program is written in FORTRAN IV, and it is anticipated that few modifications will be required to execute the program on any system of adequate size that supports FORTRAN IV. The program itself consists of a main program and 27 subroutines and 3 block data routines. (See table II for program hierarchy.) There are a total of seven levels with a maximum of six levels of nested subroutines. For example at level II the subroutine INLET (called by MAIN) calls four subroutines: ALTABL, PRCMB, HFTA, and TFHA. Subsequently, PRCMB, HFTA, and TFHA all call PVAL. Subroutines are listed in the order of their first occurrence in the calling program. Several of the subroutines may be called more than once by the calling routine. No attempt has been made to show multiple calls in table II. In table III a description of the purpose of each subroutine and block data is given.

Basic program flow is shown in figure 3. Essentially, the program initializes, reads input data, calculates a steady-state point, and if required, calculates a user-specified transient. The program accepts as steady state or transient input either of the following two sets of inputs:

### Input set 1 (IS1)

- Altitude (Alt)
- Mach number (MN)
- Power level angle (PLA)

### Input set 2 (IS2)

- Altitude (Alt)
- Mach number (MN)
- Fuel flow (WFMB)
- Nozzle area (AJ)
- Fan guide vane angle (FGV)
- High compressor stator vane angles (SVA)
- Bleed flow (BLC)

Input set 1 would typically be used to simulate open-loop engine response to pilot PLA requests. Input set 2 would be more useful for controls analysis. The program also accepts, as input, program control parameters which define and control steady-state and transient execution of the program. Figure 4 describes the iteration performed to establish a steady-state point. Note that all iterations require the evaluation of both the base point quantities and the system matrices as described in equation (2). The procedures for calculations depend on the particular input set chosen. If IS1 is used the base points are found from the reference point schedules (RPSCHE) directly using the specified PLA. If IS2 is used a "virtual" PLA is first found which corresponds to the specified rotor speed. This virtual PLA is then used by the reference point schedules to determine the base points (note that this is also the procedure used during transient simulation). In both cases the system matrices are determined from the base point values and the engine face conditions.

The model equations then are used to generate estimates of  $X$  and  $Y$ . The low rotor speed estimate ( $N1$  predicted) obtained from the model equations

is then used to begin the steady-state calculation process anew. This iteration on low rotor speed continues until convergence is achieved and a steady-state condition is found.

The program will simulate engine transient operation for time history inputs of PLA or control inputs (WFMB, AJ, FGV, SVA, BLC). Initial conditions for a simulated transient are the steady-state values obtained using the procedure of figure 4. Transient program operation as shown in figure 5 is very similar to the steady-state case. The significant difference is that the iteration through the basic loop is not terminated by a convergence process. Each iteration represents an update of the Euler integration scheme and the iteration continues until the specified final time is reached. Appendix A is a description of important simulation parameters.

### Input Requirements

HYTESS uses the FORTRAN input mode called Namelist to accept values for input parameters. There are three namelists used in subroutine READIN to define input parameters INPUT, INTRAN, and PLOT. Two examples of program input which correspond to IS1 and IS2 are given in tables IV and V, respectively.

#### Namelist INPUT

The namelist INPUT is used to define the steady-state input. All of the variables used to define a steady-state engine condition as well as some option control parameters are contained in namelist INPUT. The variable names, their default values, and descriptions are given in table VI. For example in table IV the namelist INPUT is used to (1) indicate that a transient is required (TRAN = 1); (2) indicate that plotting variables are to be saved (IPLOT = 1); and (3) define the initial conditions for IS1 (SALT = 0.0, SMACH = 0.0, SPLA = 20).

#### Namelist INTRAN

The namelist INTRAN is used to define the input necessary for an engine transient. This namelist is only read if TRAN = 1.0 in the namelist INPUT. All of the parameters entered via this namelist are entered in the following array format

$$\text{ARRAY} = t_1, v_1, t_2, v_2, \dots, t_n, v_n$$

where ARRAY represents the respective variable array and  $t_1, v_1$  is a time/value pair. Up to seven pairs may be entered for each array variable, i.e.,  $n < 7$ . The INTRAN namelist parameters are accepted as either step or ramp inputs. Since the particular array variable is specified at  $n$  discrete time points, the intervals between time points need to be further specified. This is accomplished by defining step and ramp inputs. For a step input the array value in any interval, say  $t_j$  to  $t_{j+1}$ , is equal to the preceding time point array value  $v_j$ . For a ramp input, the array value in any interval lies on a straight line defined by the two points  $t_j, v_j$  and  $t_{j+1}, v_{j+1}$ . Variable names,

default values, and descriptions for the transient input namelist INTRAN are given in table VII. For example in table IV namelist INTRAN is used to define the print interval and the user-specified PLA transient. In this case the PLA input is specified as shown in figure 6.

### Namelist PLOT

The namelist PLOT is used to specify plotted variables. This namelist will only be read if IPLOT = 1 in the namelist INPUT. Namelist PLOT contains an array variable called IPVAR1 which is dimensioned to 30 and therefore can be used to specify up to 30 variables to be plotted. A certain variable is specified for plotting by including its associated integer value (channel number) as defined in appendix A in the variable IPVAR1. For example if 13, 18, and 19 were entered into IPVAR1, then fuel flow (WFMB), fan speed (SNFAN), and compressor speed (SNCOM) would be specified for plotting.

### Program Output

Figure 7 demonstrates a sample of the printout for the test case of table IV. The program first prints the number of iterations required to reach a steady-state point. Next the values of the states, controls, and outputs are printed for the converged steady-state point. This output is controlled by the subroutine STDST8. The main program output is generated by calls to the subroutine PRINT. For both steady-state and transient data subroutine PRINT prints the variables from the common ENGOUT (appendix A) and the variables from common MVCOUT (appendix B). The ENGOUT variables are labeled 'ENGINE RESPONSE VARIABLES' and the MVCOUT variables are labeled 'REFERENCE POINT SCHEDULES.' The routine PRINT uses a 10-column format. Each column corresponds to a time at which routine PRINT was called. The program also creates an unformatted binary data file written on unit 10 for plotting.

### Execution Requirements

HYTESS consists of 1 main program, 3 block data routines, and 27 subroutines. Totally these 31 routines are described by 1952 lines of FORTRAN IV source code including comment statements. The approximate storage requirements for the object modules of HYTESS on the Lewis IBM 370/3033 system are summarized in table VIII. Individual storage requirements for the common blocks in the three block data routines are also given in table IX. A detailed nonlinear simulation would require approximately three times as much storage for a comparable engine.

As an indication of the execution time required by HYTESS a timing study was accomplished for the IS1 test Case of table IV. Results of the timing study are given in table X. These results show that a 10-sec simulated transient required 3.5 sec of CPU time for computation. These results were calculated with a 0.02-sec integration step size. Individual statistics were compiled for 13 of the more important subroutines. Time spent in those subroutines and functions not in this list is accumulated into the totals of the nearest (in terms of hierarchy) calling subroutine in the list. The same

transient simulated on a detailed nonlinear simulation of a comparable engine would take about 20 sec of CPU time.

#### CONCLUDING REMARKS

A hypothetical turbofan engine simplified simulation is presented. The program is suitable for dynamics and control analysis. The simulation is structurally simpler than a detailed performance digital simulation. However, it does retain the essential nonlinearities of the engine and accurately simulates qualitative engine operation. The engine is modeled using a state space structure. Elements within the state matrices are defined by polynomials whose independent variables are functions of engine environment and engine operation. Storage and execution time requirements are significantly less than a detailed nonlinear simulation and are quite reasonable for typical dynamics and control analysis studies.

APPENDIX A

SIMULATION PARAMETERS DEFINED IN ENGOUT

The following is the list of parameters used in the simulation. These parameters are all defined in the COMMON called ENGOUT and are also printed as the hard copy output of the program.

| Channel number | Variable | Units            | Description                                 |
|----------------|----------|------------------|---|
| 1              | T        | sec              | Time  |
| 2              | ALT      | m                | Altitude                                    |
| 3              | SMN      | ---              | Mach number                                 |
| 4              | PLA      | deg              | Power level angle                           |
| 5              | PO       | N/m <sup>2</sup> | Ambient pressure                            |
| 6              | TO       | K                | Ambient temperature                         |
| 7              | DPO      | N/m <sup>2</sup> | Adder to ambient pressure                   |
| 8              | DTO      | K                | Adder to ambient temperature                |
| 9              | PT2      | psia             | Engine face pressure                        |
| 10             | TT2      | K                | Engine face temperature                     |
| 11             | VO       | ---              | Airspeed at the inlet                       |
| 12             | ETARAM   | ---              | Ram efficiency                              |
| 13             | WFMBH    | kg/sec           | Fuel flow                                   |
| 14             | AJCD     | m <sup>2</sup>   | Nozzle area                                 |
| 15             | FGVPOS   | deg              | Fan guide vane angle                        |
| 16             | SVAPOS   | deg              | High compressor stator angle                |
| 17             | BLC      | percent          | Bleed flow                                  |
| 18             | SNFAN    | rpm              | Fan physical speed                          |
| 19             | SNCOM    | rpm              | Compressor physical speed                   |
| 20             | TT4PLO   | K                | Burner exit slow response temperature       |
| 21             | TT45PLO  | K                | Fan turbine inlet slow response temperature |
| 22             | SNFM     | rpm              | Fan physical speed                          |
| 23             | SNCM     | rpm              | Compressor physical speed                   |
| 24             | PT4      | N/m <sup>2</sup> | Burner pressure                             |
| 25             | PT6      | N/m <sup>2</sup> | Augmentor pressure                          |
| 26             | TT45     | K                | Fan turbine inlet                           |
| 27             | FNMX     | N                | Thrust                                      |
| 28             | SMHC     | ---              | Compressor surge margin                     |
| 29             | XTRA1    | ---              | Extra dummy variable                        |
| 30             | XTRA2    | ---              | Extra dummy variable                        |

## APPENDIX B

### SIMULATION PARAMETER DEFINED IN MVCOUT

The following is a list of parameters used in the simulation. These parameters are defined in the COMMON called MVCOUT and are also printed as the hard copy output of the program.

| Position number | Variable name | Units            | Description                                 | Printed |
|-----------------|---------------|------------------|---|---------|
| 1               | PLAEST        | deg              | Estimated PLA                               | N       |
| 2               | TT2EST        | K                | Estimated TT2                               | N       |
| 3               | PT2EST        | N/m <sup>2</sup> | Estimated PT2                               | N       |
| 4               | SMNEST        | ---              | Mach number                                 | N       |
| 5               | Not used      |                  |   |         |
| 6               | SNFEST        | ---              | Normalized estimated fan speed              | N       |
| 7               | SNCEST        | ---              | Normalized estimated compressor speed       | N       |
| 8               | T25EST        | K                | Estimated TT25                              | N       |
| 9-20            | Not Used      |                  |   |         |
| 21              | PLASS         | deg              | Reference point PLA                         | Y       |
| 22              | TT2SS         | K                | Reference point TT2                         | Y       |
| 23              | PT2SS         | N/m <sup>2</sup> | Reference point PT2                         | Y       |
| 24              | SMNSS         | ---              | Mach number                                 | Y       |
| 25              | PMDSS         | Not used         |   |         |
| 26              | SNFSC         | ---              | Normalized reference point fan speed        | Y       |
| 27              | SNCSCH        | ---              | Normalized reference point compressor speed | Y       |
| 28              | T25SCH        | K                | Reference point TT25                        | Y       |
| 29              | FTISCH        | ---              | Normalized reference point FTIT             | Y       |
| 30              | PT4SCH        | ---              | Normalized reference point PT4              | Y       |
| 31              | PT6MSH        | ---              | Normalized reference point PT6              | Y       |
| 32              | TT4PLO        | ---              | Normalized reference point TT45LO           | Y       |
| 33              | TT45LO        | ---              | Normalized reference point TT45LO           | Y       |
| 34              | FNMXSH        | ---              | Normalized reference point thrust margin    | Y       |
| 35              | SMHCSH        | ---              | Normalized reference point stall margin     | Y       |
| 36              | WFMBSH        | kg/sec           | Reference point fuel flow                   | Y       |
| 37              | AJSCH         | m <sup>2</sup>   | Reference point area                        | Y       |
| 38              | FGVSH         | deg              | Reference point FGV                         | Y       |
| 39              | SVAVSH        | deg              | Reference point SVA                         | Y       |
| 40              | BLSCH         | percent          | Reference point bleed                       | Y       |

TABLE I. - TYPICAL REGRESSION POLYNOMIALS FOR THE ELEMENTS  
OF THE SYSTEM MATRICES

| System matrix     | Element | Polynomial <sup>a</sup>   |
|-------------------|---------|---|
| F                 | (1,1)   | $-\frac{0.0968}{\delta} - \frac{0.0019}{\delta^2} PT6^2 - 2.463$  |
| F <sup>-1</sup> G | (4,1)   | $\frac{0.000933}{\delta} PT6 - \frac{0.97 \times 10^{-9}}{\sqrt{\theta}} NI \cdot \frac{PT6^2}{\delta^2} - 0.03606$ |
| H                 | (5,3)   | $0.0311\theta + 0.5486 \times 10^{-4} \frac{TT45}{\theta} - 0.3612$   |
| D                 | (5,1)   | $-0.0354\theta + \frac{31.35\delta}{PT4} + 0.04914$   |

<sup>a</sup> $\delta = P1/14.696$ ;  $\theta = T1/518.67$ .

TABLE II. - HYTESS PROGRAM/SUBROUTINE HIERACHY

| Level |   |                                 |                                   |   |   |                 |        |
|-------|---|---------------------------------|-----------------------------------|---|---|-----------------|--------|
| I     | II  | III                             | IV                                | V   | VI  | VII             |        |
| MAIN  | SETUP<br>READIN<br>INLET  | ALTABL<br>PRCMB<br>HFTA<br>TFHA | PVAL<br>PVAL<br>PVAL              |   |   |                 |        |
|       |   |                                 |                                   |   |   |                 | STDST8 |
|       |   |                                 | EMODEL                            | SNFMPH<br>RPSCH   | UNBAR<br>N2TABL<br>SCURVE<br>SPRINT<br>GVICAL | SCURVE<br>UNBAR | UNBAR  |
|       |   |                                 | FILTER                            | ADD<br>SUB<br>MUL<br>SCA  |   |                 |        |
|       |   | TRANS                           | PRINT<br>PRINT<br>NUTIME<br>INLET | SCALLA<br>SCALLA  |   |                 |        |
|       |   |                                 | RPSCH                             | ALTABL<br>PRCMB<br>HFTA<br>TFHA<br>N2TABL<br>SCURVE<br>SPRINT<br>GVICAL | PVAL<br>PVAL<br>PVAL<br>SCURVE<br>UNBAR       | UNBAR           |        |
|       |   |                                 | EMODEL                            | SNFMAP<br>RPSCH   | UNBAR<br>N2TABL<br>SCURVE<br>SPRINT<br>GVICAL | SCURVE<br>UNBAR | UNBAR  |
|       |   |                                 |                                   | FILTER  | ADD<br>SUB<br>MUL<br>SCA                      |                 |        |
|       | ACTCRV <sup>a</sup><br>ENGPRN <sup>a</sup><br>MVCPRN <sup>a</sup> |                                 |                                   |   |   |                 |        |

<sup>a</sup>Block data.

TABLE III. - SUBROUTINE DESCRIPTION

| Subroutine name | Purpose   |
|-----------------|---|
| ADD             | General matrix addition   |
| ALTABL          | Calculates temperature and pressure corrections at various altitudes          |
| EMODEL          | Calculates appropriate engine model matrices and base points                  |
| FILTER          | Updates state space model equations using Euler integration                   |
| GVICAL          | Calculates fan guide vane (FGV) position                                      |
| HFTA            | Calculates enthalpy as a function of temperature                              |
| INLET           | Solves for engine's inlet conditions  |
| MAIN            | Main program for execution of simulation                                      |
| MUL             | General matrix multiply   |
| NUTIME          | Finds print interval and values of ramp functions                             |
| N2TABL          | Calculates N2 as a function of PLA and TT2 or PLA as a function of N2 and TT2 |
| PRCMB           | Calculates specific heat as a function of temperature                         |
| PRINT           | Formats and prints output of simulation                                       |
| PVAL            | Function that evaluates a given polynomial                                    |
| READIN          | Reads input data  |
| RPSCH           | Calculates steady-state operating points                                      |
| SCA             | Multiplies elements of a matrix by a constant                                 |
| SCALLA          | Converts normalized variables to engineering units                            |
| SCURVE          | Contains data (curves) for steady-state operating points                      |
| SETUP           | Initializes program's named commons   |
| SN1SCH          | Finds N1 as a function of TT2, SMN, and PLA                                   |
| SNFMAP          | Finds PLA as a function of N1, TT2, and SMN                                   |
| SPRINT          | Table lookup routine  |
| STDST8          | Calculates a steady-state point   |
| SUB             | General matrix subtraction  |
| TFHA            | Calculates temperature as function of enthalpy                                |
| TRANS           | Controls transient execution of program                                       |
| UNBAR           | A table lookup routine  |
| Block data      | Purpose   |
| ACTCRV          | High compressor stator name and nozzle area data                              |
| ENGPRN          | Names for engine inputs, outputs, and states                                  |
| MVCPRN          | Initial values for all common blocks  |

TABLE IV. - IS1 EXAMPLE INPUT TEST CASE

```
&INPUT
  TRAN=1., IPLOT=1, SALT=0., SMACH=0.,
  SPLA=20.,
&END
&INTRAN
  PNTBLK=0., 0.1, 10., .1,
  PLABLK=0., 20., 0.1, 20., .5, 83., 10., 83.,
&END
&PLOT
  IPVAR1=1, 4, 22, 23, 24, 25, 26, 27, 28,
&END
```

TABLE V. - IS2 EXAMPLE INPUT TEST CASE

```
&INPUT
  SMACH=0., SALT=0., SPLA=52., TRAN=1.,
  SFGVV=-25., SSVAV=6.0,
&END
&INTRAN
  PNTBLK=0., .1, 10., .1,
  FGVBLK=0.0, -25.0, 0.1, -25.0, .2, -22.5, 10., -22.5,
  SVABLK=0.0, 6.0, 5.0, 6.0, 5.1, 5.4, 10., 5.4,
&END
```

TABLE VI. - DESCRIPTION OF STEADY-STATE NAMELIST INPUT

| Variable name | Default | Description                                  |
|---------------|---------|--|
| TRAN          | 0       | If TRAN=1 then transient run desired         |
| IPLLOT        | 0       | If IPLLOT=1 then plotting desired            |
| SALT          | -999    | Altitude, m                                  |
| SMACH         | ↓       | Mach number                                  |
| SPLA          |         | Power level angle, deg                       |
| STAM          |         | Ambient temperature, K                       |
| SPAM          |         | Ambient pressure, N/m <sup>2</sup>           |
| SDTAM         |         | Adder to ambient temperature, K              |
| SDPAM         |         | Adder to ambient pressure, N/m <sup>2</sup>  |
| SPT2          |         | Engine face total pressure, N/m <sup>2</sup> |
| STT2          |         | Engine face total temperature, K             |
| SWF           |         | Fuel flow, kg/sec                            |
| SAJ           |         | Nozzle jet area, m <sup>2</sup>              |
| SFGVV         |         | Fan guide vane angle, deg                    |
| SSVAV         |         | Compressor stator vane angle, deg            |
| SBLC          |         | Bleed flow, percent                          |

TABLE VII. - DESCRIPTION OF TRANSIENT NAMELIST INTRAN

| Variable array name | Default | Description                             |
|---------------------|---------|---|
| Step input          |         |   |
| PNTBLK              | -999    | Print interval                          |
| Ramp inputs         |         |   |
| PLABLK              | ↓       | PLA ramp input                          |
| ALTBK               |         | Altitude ramp input                     |
| XMNBK               |         | Mach number ramp input                  |
| WFBLK               |         | Fuel flow ramp input                    |
| AJBK                |         | Nozzle area ramp input                  |
| FGVBK               |         | Fan guide vane ramp input               |
| SVABK               |         | Compressor stator vane angle ramp input |
| BLCBK               |         | Bleed flow ramp input                   |

TABLE VIII. - HYTESS OBJECT MODULE STORAGE REQUIREMENTS

| Program name        | Number of lines<br>of source code | Direct module storage<br>requirement (bytes) <sup>a</sup> |
|---------------------|-----------------------------------|---|
| MAIN                | 80                                | 1 288   |
| ALTABL              | 109                               | 2 616   |
| ACTCRV (block data) | 49                                | 1 252   |
| EMODEL              | 281                               | 8 488   |
| ENGPRN (block data) | 38                                | 264   |
| FILTER              | 36                                | 1 228   |
| GVICAL              | 10                                | 496   |
| HFTA                | 16                                | 404   |
| INLET               | 60                                | 2 316   |
| ADD                 | 7                                 | 548   |
| SUB                 | 7                                 | 548   |
| MUL                 | 9                                 | 760   |
| SCA                 | 7                                 | 516   |
| MVCPRN (block data) | 50                                | 3 200   |
| N2TABL              | 50                                | 1 064   |
| NUTIME              | 51                                | 1 588   |
| PRCMB               | 38                                | 904   |
| PRINT               | 87                                | 5 672   |
| PVAL                | 99                                | 1 860   |
| READIN              | 33                                | 948   |
| RPSCH               | 120                               | 3 568   |
| SCURVE              | 267                               | 4 732   |
| SETUP               | 18                                | 176   |
| SNFMAP              | 73                                | 1 544   |
| SNISCH              | 21                                | 960   |
| SPRINT              | 68                                | 2 100   |
| STDST8              | 77                                | 1 884   |
| TFHA                | 16                                | 404   |
| TRANS               | 83                                | 1 632   |
| UNBAR               | 77                                | 1 940   |
| SCALLA              | 15                                | 400   |
| Totals              | 1952                              | 55 300  |

<sup>a</sup>4 Bytes per word.

TABLE IX. - STORAGE REQUIREMENTS FOR BLOCK DATA

| Block data name | Common block | Common block storage requirement <sup>a</sup> | Total block data storage requirement <sup>a</sup> |
|-----------------|--------------|---|---|
| ACTCRV          | ACTCRV       | 1252  | 1252  |
| ENGPRN          | ENGPRN       | 264   | 264   |
| MVCPRN          | MVCPRN       | 320   | 3200  |
|                 | EBLKS        | 1008  |   |
|                 | BASEV        | 64  |   |
|                 | STDV         | 64  |   |
|                 | MVCOUT       | 160   |   |
|                 | MATRIX       | 556   |   |
|                 | ENGOUT       | 120   |   |
|                 | ENCONTR      | 32  |   |
|                 | ESSIN        | 56  |   |
|                 | PTITLE       | 80  |   |
|                 | RAMREC       | 16  |   |
|                 | PLOTV        | 460   |   |
|                 | ENGPRN       | 264   |   |

<sup>a</sup>Storage requirement given in bytes.

TABLE X. - EXECUTION (CPU) TIME RESULTS FOR HYTESS TEST CASE 1

| Group number          | Module name | Accumulated CPU time, msec | Percent of total | Number of entries | Number of exits | CPU time average per call |
|-----------------------|-------------|----------------------------|------------------|-------------------|-----------------|---------------------------|
| 1                     | MAINHYTS    | 4                          | 0.11             | 1                 | 1               | 4.000                     |
| 3                     | READIN      | 6                          | .17              | 1                 | 1               | 6.000                     |
| 4                     | INLET       | 210                        | 5.94             | 501               | 501             | .410                      |
| 5                     | STDST8      | 25                         | .71              | 1                 | 1               | 25.000                    |
| 6                     | PRINT       | 656                        | 18.54            | 101               | 101             | 6.495                     |
| 7                     | TRANS       | 179                        | 5.06             | 1                 | 1               | 179.000                   |
| 8                     | SNFMAP      | 114                        | 3.22             | 502               | 502             | .227                      |
| 9                     | N2TABL      | 202                        | 5.71             | 1004              | 1004            | .201                      |
| 10                    | FILTER      | 377                        | 10.66            | 502               | 502             | .751                      |
| 11                    | SCALLA      | 2                          | .06              | 101               | 101             | .020                      |
| 12                    | RPSCH       | 1264                       | 35.73            | 1003              | 1003            | 1.260                     |
| 13                    | EMODEL      | 499                        | 14.10            | 502               | 502             | .994                      |
| Timed CPU total       |             | 3538                       | 100.00           |                   |                 |                           |
| Overhead <sup>a</sup> |             | 1370                       |                  |                   |                 |                           |
| Job total             |             | 4908                       |                  |                   |                 |                           |

<sup>a</sup>Overhead is the CPU time required to calculate the CPU statistics given in table.



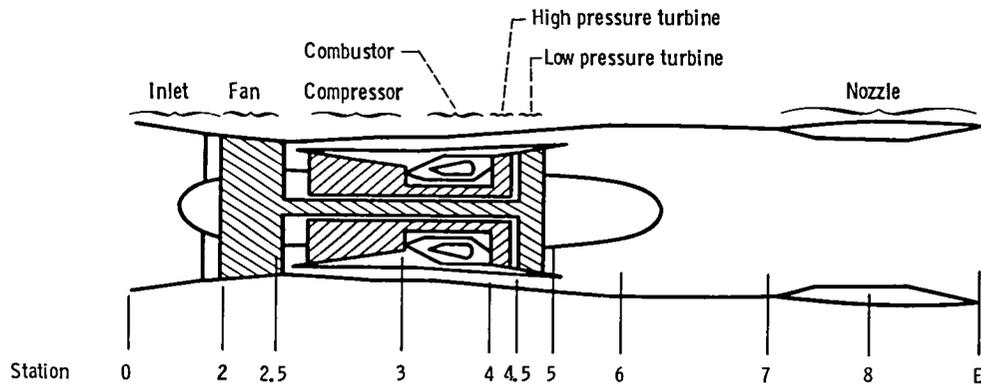


Figure 1. - Schematic representation of a hypothetical turbofan engine.

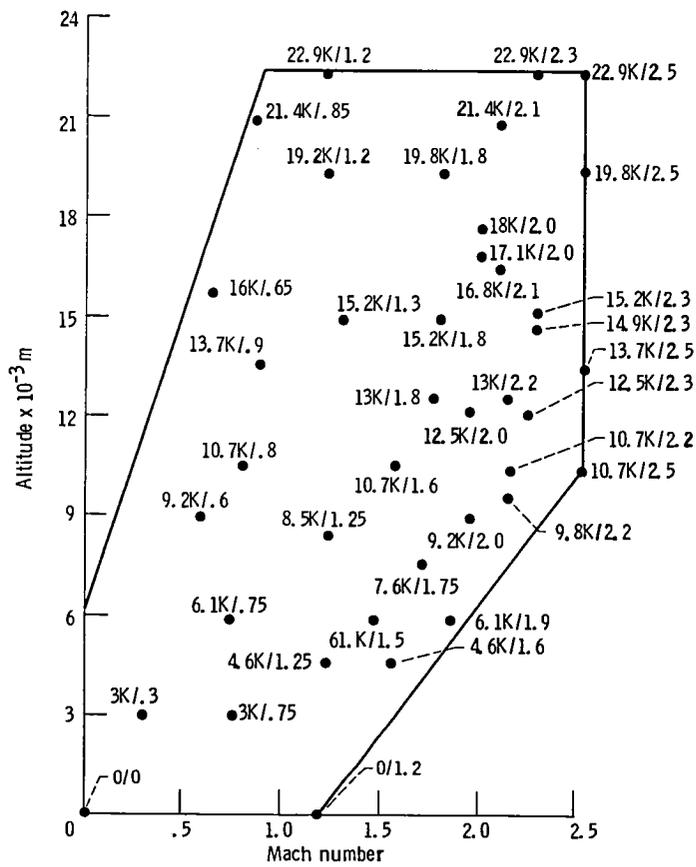


Figure 2. - Engine flight envelope with engine operating points.

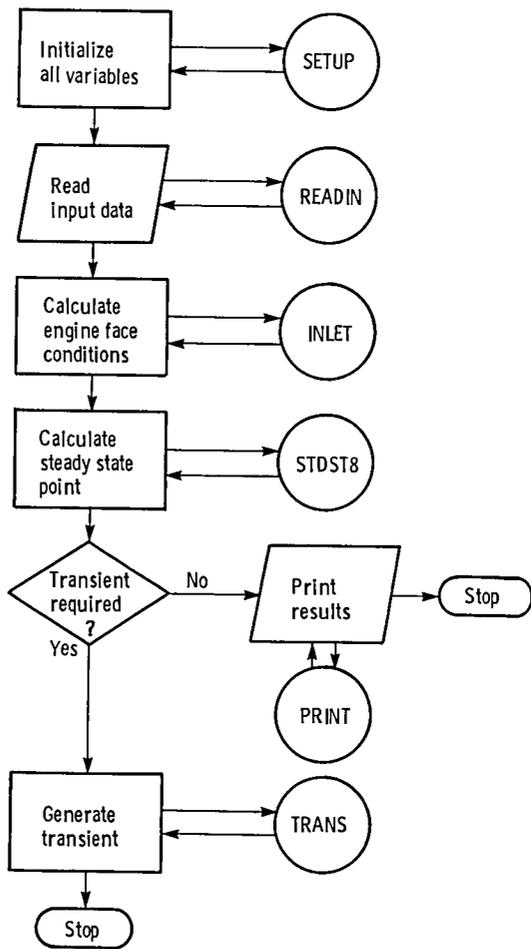


Figure 3. - Basic program flow through MAIN.

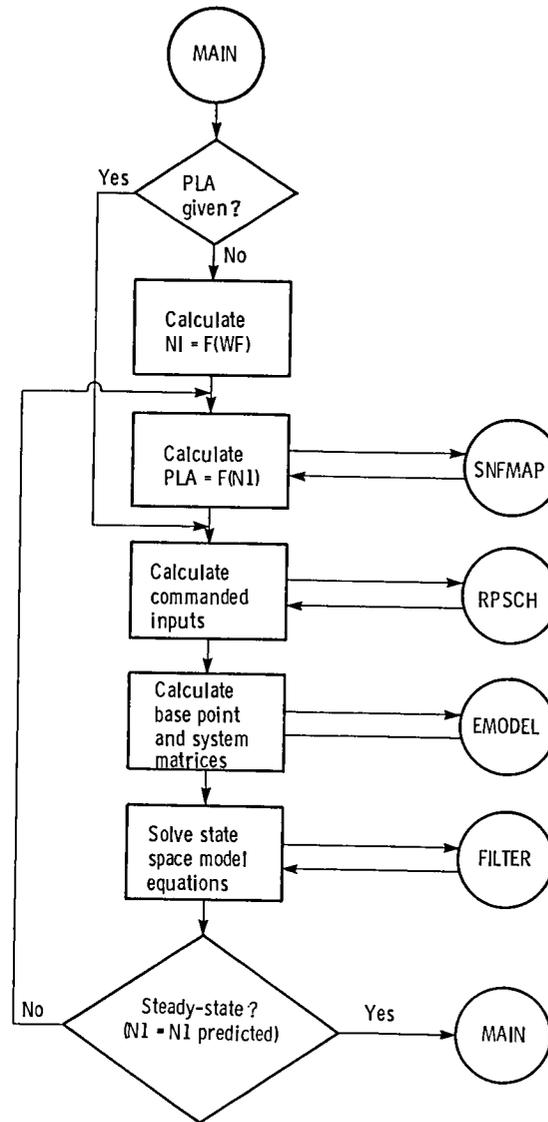


Figure 4. - Basic program flow through STDST.

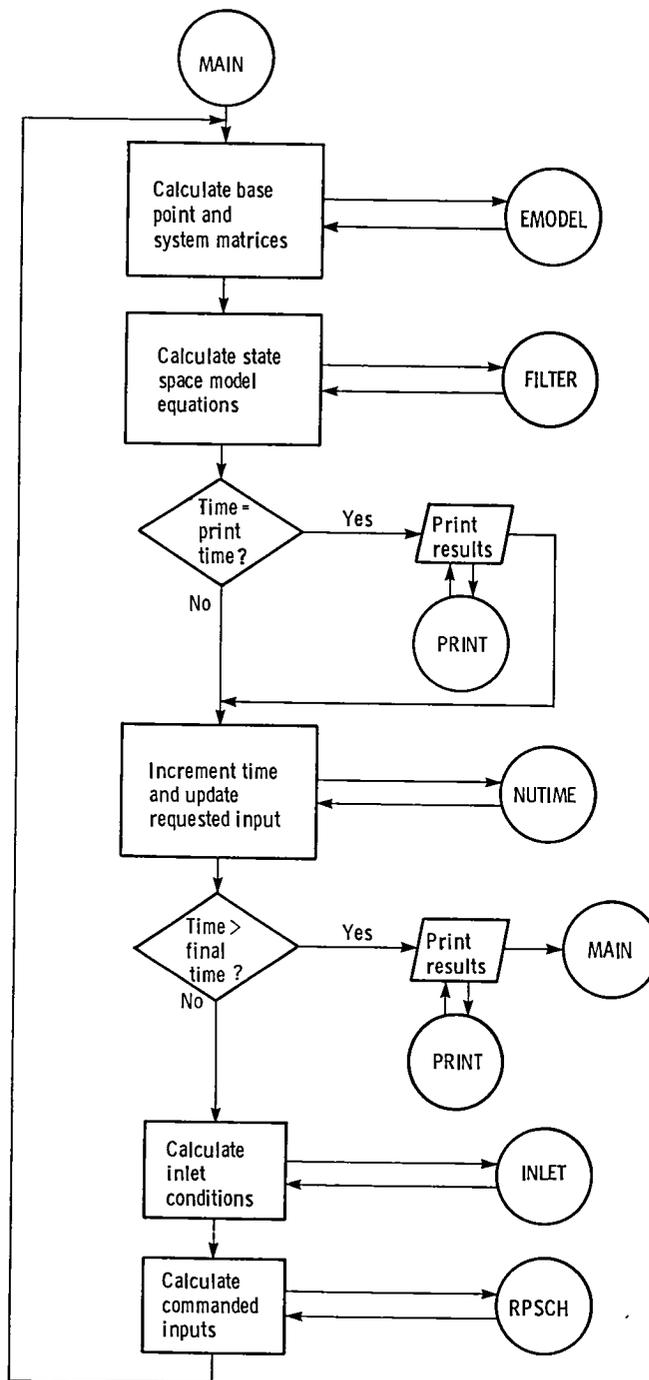


Figure 5. - Basic program flow through TRANS.

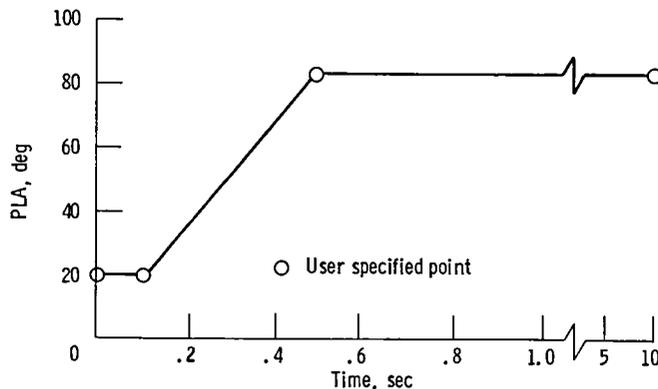


Figure 6. - User specified PLA input transient - ISI example test case. (See table IV.)

SIMPLIFIED ENGINE SIMULATION  
HYPOTHETICAL JET ENGINE

| *** ENGINE RESPONSE VARIABLES *** |             |             |             |             |             |             |             |             |             |             |
|-----------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 1 TIME                            | 0.00000     | 0.10000E 00 | 0.20000     | 0.30000     | 0.40000     | 0.50000     | 0.60000     | 0.70000     | 0.80000     | 0.90000     |
| 2 ALT                             | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     |
| 3 SHN                             | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     |
| 4 PLA                             | 20.000      | 20.000      | 35.750      | 51.500      | 67.250      | 83.000      | 83.000      | 83.000      | 83.000      | 83.000      |
| 5 PO                              | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      |
| 6 TO                              | 518.69      | 518.69      | 518.69      | 518.69      | 518.69      | 518.69      | 518.69      | 518.69      | 518.69      | 518.69      |
| 7 DP8                             | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     |
| 8 DTO                             | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     |
| 9 PT2                             | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      |
| 10 TT2                            | 518.67      | 518.67      | 518.67      | 518.67      | 518.67      | 518.67      | 518.67      | 518.67      | 518.67      | 518.67      |
| 11 VO                             | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     |
| 12 ETARAM                         | 1.0000      | 1.0000      | 1.0000      | 1.0000      | 1.0000      | 1.0000      | 1.0000      | 1.0000      | 1.0000      | 1.0000      |
| 13 WFBMH                          | 1133.1      | 1133.1      | 3247.5      | 5094.6      | 6787.9      | 10588.      | 10588.      | 10588.      | 10588.      | 10588.      |
| 14 AJCD                           | 3.0000      | 3.0000      | 3.0000      | 3.0000      | 3.0000      | 3.0000      | 3.0000      | 3.0000      | 3.0000      | 3.0000      |
| 15 FGVPOS                         | -25.000     | -25.000     | -25.000     | -25.000     | -25.000     | -25.000     | -25.000     | -25.000     | -25.000     | -25.000     |
| 16 SVAPDS                         | -39.033     | -39.033     | -34.975     | -21.942     | -2.9506     | 6.0000      | 6.0000      | 6.0000      | 6.0000      | 6.0000      |
| 17 BLC                            | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     |
| 18 SNFAN                          | 3540.9      | 3540.9      | 3724.9      | 4227.7      | 5125.9      | 6801.7      | 7856.3      | 8573.0      | 9061.6      | 9273.9      |
| 19 SNGOM                          | 8695.4      | 8695.4      | 8977.2      | 9555.6      | 10607.      | 11534.      | 12046.      | 12221.      | 12254.      | 12271.      |
| 20 TT4PLO                         | 93.630      | 93.630      | 104.83      | 131.83      | 169.25      | 196.79      | 203.91      | 206.35      | 207.33      | 207.40      |
| 21 TT4SLO                         | 66.272      | 66.272      | 77.389      | 102.55      | 135.48      | 163.03      | 172.08      | 172.01      | 169.22      | 166.12      |
| 22 SNFAN                          | 3540.9      | 3540.9      | 3724.9      | 4227.7      | 5125.9      | 6801.7      | 7856.3      | 8573.0      | 9061.6      | 9273.9      |
| 23 SNGOM                          | 8695.4      | 8695.4      | 8977.2      | 9555.6      | 10607.      | 11534.      | 12046.      | 12221.      | 12254.      | 12271.      |
| 24 PT4                            | 65.498      | 65.498      | 92.335      | 126.50      | 173.43      | 229.93      | 280.98      | 311.87      | 324.16      | 329.73      |
| 25 PT6                            | 17.571      | 17.571      | 18.462      | 19.751      | 23.779      | 32.409      | 36.080      | 41.742      | 45.717      | 46.422      |
| 26 TT45                           | 565.79      | 565.79      | 1342.4      | 1903.7      | 2158.7      | 2370.9      | 1804.8      | 1629.2      | 1521.4      | 1514.6      |
| 27 FMXK                           | 1363.9      | 1363.9      | 1822.7      | 2420.8      | 4547.6      | 12762.      | 12601.      | 11575.      | 11035.      | 11035.      |
| 28 SMHC                           | 0.68756     | 0.68756     | 0.51764     | 0.45349     | 0.41861     | 0.17661     | 0.21895     | 0.22693     | 0.22756     | 0.21267     |
| *** REFERENCE POINT SCHEDULES *** |             |             |             |             |             |             |             |             |             |             |
| 1 PLASS                           | 20.000      | 20.000      | 35.750      | 51.500      | 67.250      | 83.000      | 83.000      | 83.000      | 83.000      | 83.000      |
| 2 TT255                           | 58.970      | 58.970      | 58.970      | 58.970      | 58.970      | 58.970      | 58.970      | 58.970      | 58.970      | 58.970      |
| 3 PT255                           | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      | 14.696      |
| 4 SMNS5                           | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     |
| 5 PMDS5                           | -999.00     | -999.00     | -999.00     | -999.00     | -999.00     | -999.00     | -999.00     | -999.00     | -999.00     | -999.00     |
| 6 SNFSCH                          | 0.35409     | 0.35409     | 0.49855     | 0.79445     | 0.85966     | 0.93653     | 0.93653     | 0.93653     | 0.93653     | 0.93653     |
| 7 SNCSCH                          | 0.57969     | 0.57969     | 0.67655     | 0.71865     | 0.75987     | 0.82078     | 0.82078     | 0.82078     | 0.82078     | 0.82078     |
| 8 T255GH                          | 162.70      | 162.70      | 162.70      | 162.70      | 162.70      | 162.70      | 162.70      | 162.70      | 162.70      | 162.70      |
| 9 FTISCH                          | 0.35362     | 0.35362     | 0.56496     | 0.66584     | 0.78236     | 0.95261     | 0.95261     | 0.95261     | 0.95261     | 0.95261     |
| 10 PT45CH                         | 0.11909     | 0.11909     | 0.28448     | 0.36931     | 0.46827     | 0.61451     | 0.61451     | 0.61451     | 0.61451     | 0.61451     |
| 11 PT6M5H                         | 0.13516     | 0.13516     | 0.18832     | 0.23672     | 0.29766     | 0.36094     | 0.36094     | 0.36094     | 0.36094     | 0.36094     |
| 12 TT4PLO                         | 0.58519E-01 | 0.58519E-01 | 0.83647E-01 | 0.95640E-01 | 0.10949     | 0.12974     | 0.12974     | 0.12974     | 0.12974     | 0.12974     |
| 13 TT4SLO                         | 0.41420E-01 | 0.41420E-01 | 0.61117E-01 | 0.70518E-01 | 0.81377E-01 | 0.97244E-01 | 0.97244E-01 | 0.97244E-01 | 0.97244E-01 | 0.97244E-01 |
| 14 FMXSH                          | 0.54556E-01 | 0.54556E-01 | 0.27886     | 0.34131     | 0.38377     | 0.43383     | 0.43383     | 0.43383     | 0.43383     | 0.43383     |
| 15 SMHCSH                         | 0.68756     | 0.68756     | 0.67495     | 0.67495     | 0.67495     | 0.20965     | 0.20965     | 0.20965     | 0.20965     | 0.20965     |
| 16 WFBMSH                         | 1133.1      | 1133.1      | 3247.5      | 5094.6      | 6787.9      | 10588.      | 10588.      | 10588.      | 10588.      | 10588.      |
| 17 AJSCH                          | 3.0000      | 3.0000      | 3.0000      | 3.0000      | 3.0000      | 3.0000      | 3.0000      | 3.0000      | 3.0000      | 3.0000      |
| 18 FGV5SH                         | -25.000     | -25.000     | -25.000     | -25.000     | -25.000     | -25.000     | -25.000     | -25.000     | -25.000     | -25.000     |
| 19 SVAVSH                         | -39.033     | -39.033     | -34.975     | -21.942     | -2.9506     | 6.0000      | 6.0000      | 6.0000      | 6.0000      | 6.0000      |
| 20 BLC5H                          | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     | 0.00000     |

Figure 7. - Example output for HYTESS test case.



|   |  |  |  |   |            |
|---|--|--|--|---|------------|
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| 15. Supplementary Notes Walter C. Merrill, NASA Lewis Research Center; Edward C. Beattie and Richard F. LaPrad, Pratt & Whitney Aircraft Co., United Technologies Corp., 400 Main St., East Hartford, Connecticut 06108; Stephen M. Rock and Muhammed M. Akhter, Systems Control Technology, Inc., 1801 Page Mill Road, P.O. Box 10180, Palo Alto, California 94303.  |  |  |  |   |            |
| 16. Abstract<br><br>This report is a users manual for a hypothetical turbofan engine simplified simulation. This digital simulation exists as FORTRAN source code. The program is self-contained and was developed to offer those interested in engine dynamics and controls research an efficient, realistic, and easily used engine simulation. The engine is modeled using a state space formulation. Matrix elements within the linear state space structure are nonlinear functions of various engine variables. |  |  |  |   |            |
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