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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

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

where X is a state vector, U is the vector of controls, Y is the output vector, and Φ 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,

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

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

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

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:

Φ_1	engine face pressure (PT2), N/m^2
Φ_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 Φ). 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

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

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.

$$U_r = h(PLA,\Phi) \tag{5}$$

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

$$U = U_r \tag{6}$$

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).

$$U = U_R + U_{CL} \tag{7}$$

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 (RPSCH) 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

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

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., $n \leq 7$. 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_i to t_{i+1}, is equal to the preceding time point array value v_i. For a ramp input, the array value in any interval lies on a straight line defined by the two points t_i, v_i and t_{i+i}, v_{i+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^2	Ambient pressure
6	TO	K	Ambient temperature
7	DPO	N/m^2	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^2	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^2	Burner pressure
25	PT6	N/m^2	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^2	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^2	Reference point PT2	Y
24	SMNSS	---	Mach number	Y
25	PMDSS	Not used		
26	SNFSCH	---	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 thurst	Y
35	SMHCSH	---	Normalized reference point stall margin	Y
36	WFMBSH	kg/sec	Reference point fuel flow	Y
37	AJSCH	m^2	Reference point area	Y
38	FGVVSH	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[a]
F	(1,1)	$-\frac{0.0968}{\delta} - \frac{0.0019\ PT6^2}{\delta^2} - 2.463$
$F^{-1}G$	(4,1)	$\frac{0.000933\ PT6}{\delta} - \frac{0.97\times10^{-9}\ N1}{\sqrt{\theta}} \cdot \frac{PT6^2}{\delta^2} - 0.03606$
H	(5,3)	$0.0311\theta + 0.5486\times10^{-4}\ \frac{TT45}{\theta} - 0.3612$
D	(5,1)	$-0.0354\theta + \frac{31.35\delta}{PT4} + 0.04914$

[a] δ = P1/14.696; θ = T1/518.67.

TABLE II. - HYTESS PROGRAM/SUBROUTINE HIERACHY

Level						
I	II	III	IV	V	VI	VII
MAIN	SETUP					
	READIN					
	INLET	ALTABL				
		PRCMB	PVAL			
		HFTA	PVAL			
		TFHA	PVAL			
	STDST8	SNFMAP	UNBAR			
		SN1SCH	SCURVE	UNBAR		
		N2TABL	SCURVE	UNBAR		
		RPSCH	N2TABL	SCURVE	UNBAR	
			SCURVE	UNBAR		
			SPRINT			
			GVICAL			
		EMODEL	SNFMPH	UNBAR		
			RPSCH	N2TABL	SCURVE	UNBAR
				SCURVE	UNBAR	
				SPRINT		
				GVICAL		
		FILTER	ADD			
			SUB			
			MUL			
			SCA			
		PRINT	SCALLA			
	TRANS	PRINT	SCALLA			
		NUTIME				
		INLET	ALTABL			
			PRCMB	PVAL		
			HFTA	PVAL		
			TFHA	PVAL		
		RPSCH	N2TABL	SCURVE	UNBAR	
			SCURVE	UNBAR		
			SPRINT			
			GVICAL			
		EMODEL	SNFMAP	UNBAR		
			RPSCH	N2TABL	SCURVE	UNBAR
				SCURVE	UNBAR	
				SPRINT		
				GVICAL		
			FILTER	ADD		
				SUB		
				MUL		
				SCA		
ACTCRV[a]						
ENGPRN[a]						
MVCPRN[a]						

[a] 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
IPLOT	0	If IPLOT=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^2
SDTAM	↓	Adder to ambient temperatuare, K
SDPAM	↓	Adder to ambient pressure, N/m^2
SPT2	↓	Engine face total pressure, N/m^2
STT2	↓	Engine face total temperature, K
SWF	↓	Fuel flow, kg/sec
SAJ	↓	Nozzle jet area, m^2
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	-999	PLA ramp input
ALTBLK	↓	Altitude ramp input
XMNBLK	↓	Mach number ramp input
WFBLK	↓	Fuel flow ramp input
AJBLK	↓	Nozzle area ramp input
FGVBLK	↓	Fan guide vane ramp input
SVABLK	↓	Compressor stator vane angle ramp input
BLCBLK	↓	Bleed flow ramp input

TABLE VIII. - HYTESS OBJECT MODULE STORAGE REQUIREMENTS

Program name	Number of lines of source code	Direct module storage requirement (bytes)[a]
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
SN1SCH	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

[a] 4 Bytes per word.

TABLE IX. - STORAGE REQUIREMENTS FOR BLOCK DATA

Block data name	Common block	Commom block storage requirement[a]	Total block data storage requirement[a]
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	

[a] 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[a]		1370				
Job total		4908				

[a] Overhead is the CPU time required to calculate the CPU statistics given in table.

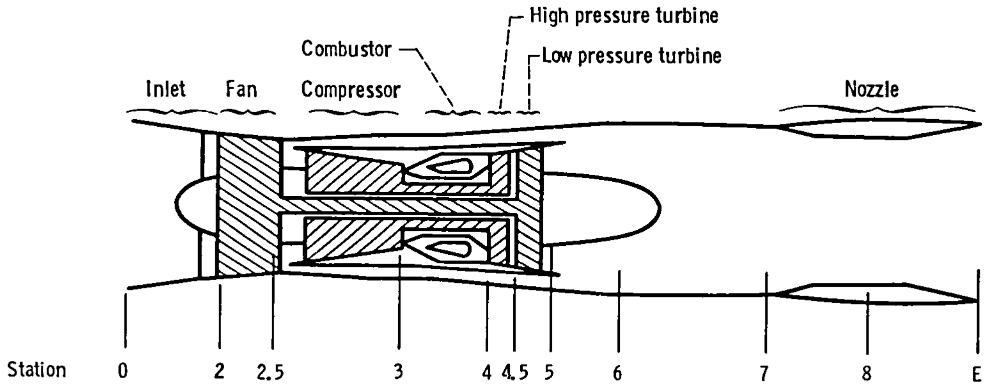

Figure 1. - Schematic representation of a hypothetical turbofan engine.

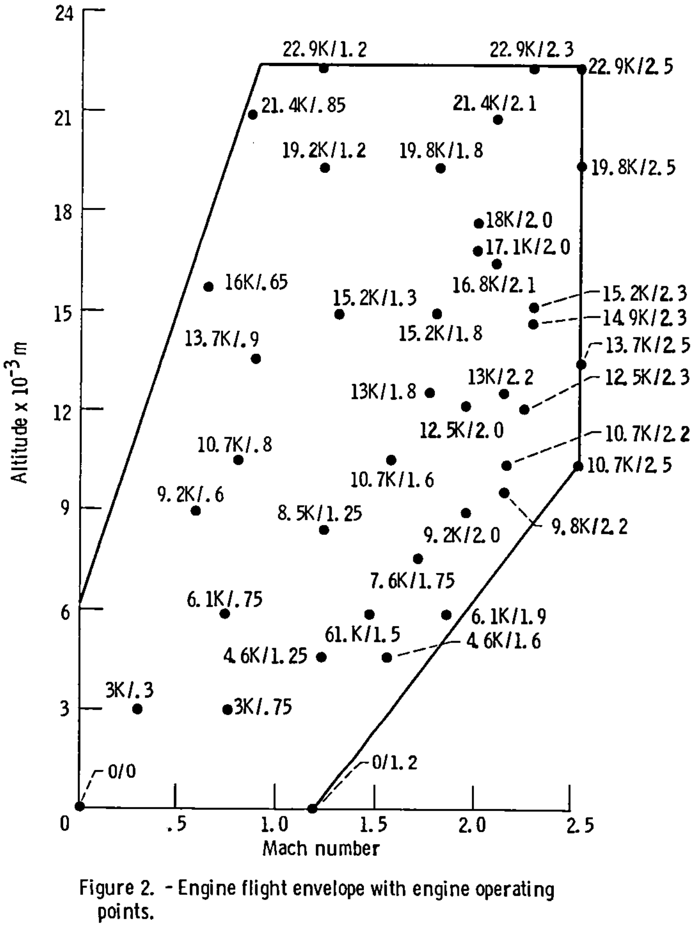

Figure 2. - Engine flight envelope with engine operating points.

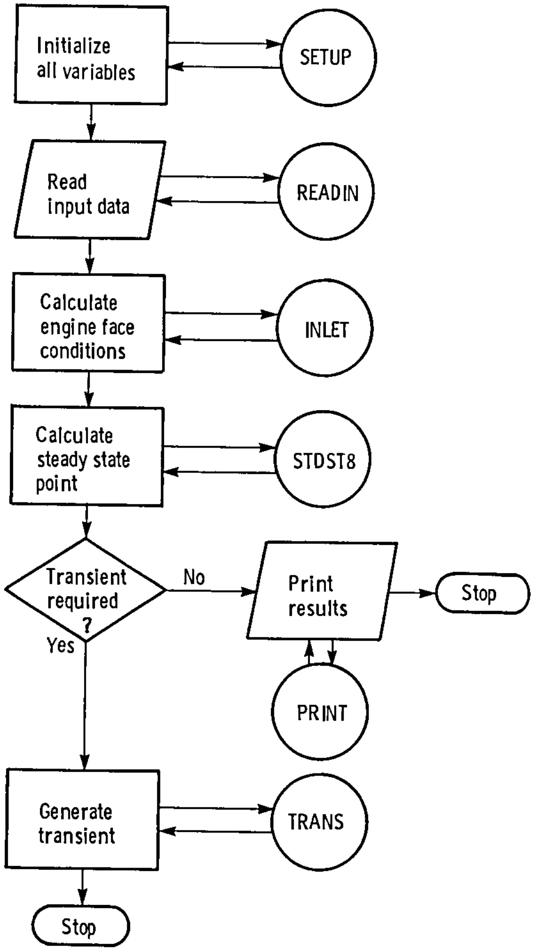

Figure 3. - Basic program flow through MAIN.

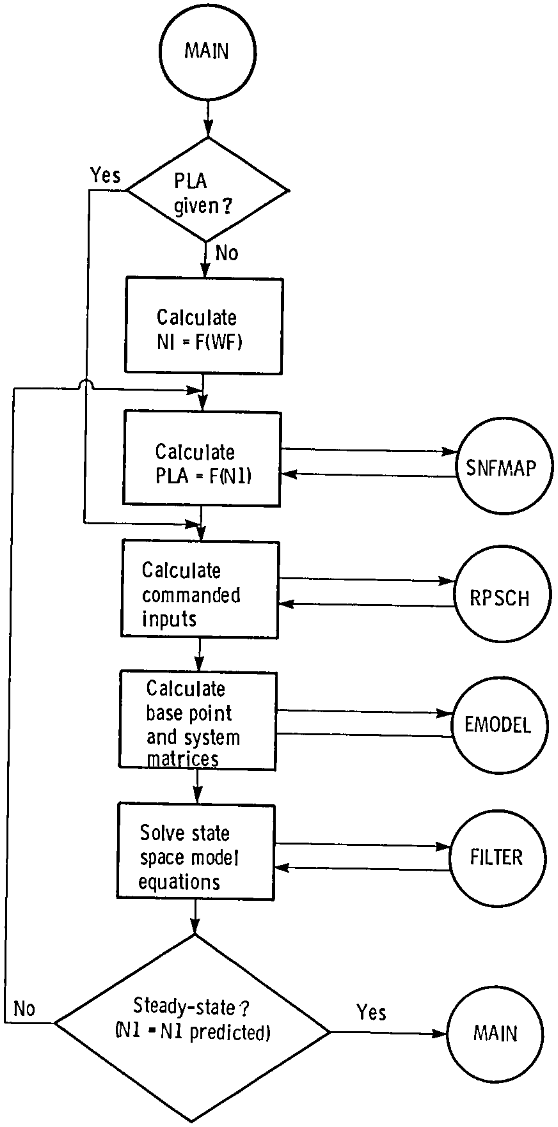

Figure 4. - Basic program flow through STDST.

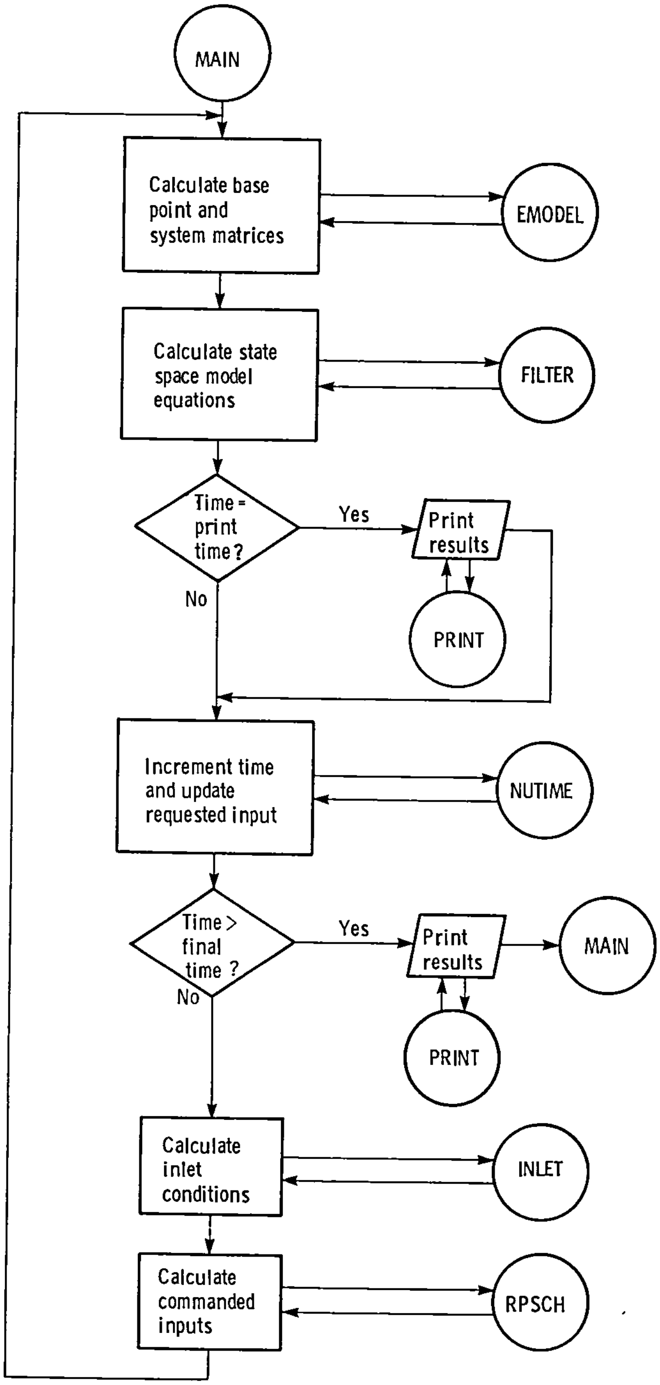

Figure 5. - Basic program flow through TRANS.

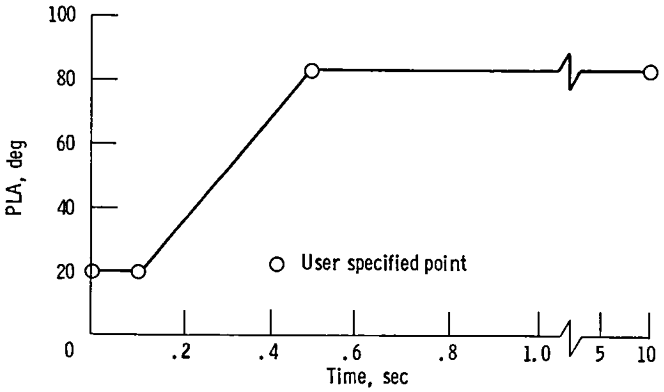

Figure 6. - User specified PLA input transient - ISI example test case. (See table IV.)

```
                                                  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 SMN    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 P0      14.696      14.696      14.696      14.696      14.696      14.696      14.696      14.696      14.696      14.696
  6 T0      518.69      518.69      518.69      518.69      518.69      518.69      518.69      518.69      518.69      518.69
  7 DP0    0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
  8 DT0    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 V0     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 WFMBH   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 SVAPOS -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 SNCOM   8695.4      8695.4      8977.2      9655.6      10607.      11534.      12046.      12221.      12254.      12217.
 20 TT4PLO  93.630      93.630      104.83      131.83      169.25      196.79      203.91      206.35      207.33      207.40
 21 TT45LO  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 SNCOM   8695.4      8695.4      8977.2      9655.6      10607.      11534.      12046.      12221.      12254.      12217.
 24 PT4     65.498      65.498      92.335      126.50      173.43      249.93      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 FNMX    1363.9      1363.9      1822.7      2420.8      4547.6      12762.      12601.      12316.      11575.      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 TT2SS   58.970      58.970      58.970      58.970      58.970      58.970      58.970      58.970      58.970      58.970
  3 PT2SS   14.696      14.696      14.696      14.696      14.696      14.696      14.696      14.696      14.696      14.696
  4 SMNSS  0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
  5 PMDSS  -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     0.69855     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 T25SCH  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 PT4SCH 0.11909     0.11909     0.28448     0.36931     0.46827     0.61451     0.61451     0.61451     0.61451     0.61451
 11 PT6MSH 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 TT45LO 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 FNMXSH 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     0.32503     0.27495     0.24150     0.20965     0.20965     0.20965     0.20965     0.20965
 16 WFMBSH  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 FGVVSH -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 BLCSH  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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16. Abstract

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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