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COMPUTER PROGRAM FOR THE DESIGN AND OFF-DESIGN PERFORMANCE OF TURBOJET AND TURBOFAN ENGINE CYCLES

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COMPUTER PROGRAM FOR THE DESIGN AND OFF-DESIGN PERFORMANCE OF TURBOJET AND TURBOFAN ENGINE CYCLES

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SUMMARY

A rapid computer program for the calculation of the design and the off-design performance of a turbojet or turbofan engine is described. The program is designed to be run in a stand-alone mode or operated within a larger program such as ACSYNT, an aircraft synthesis program for preliminary design, which is in use at Ames Research Center. The computation is based on a simplified one-dimensional gas turbine cycle. Each component in the engine is modeled thermodynamically. The component efficiencies used in the thermodynamic modeling are scaled for the off-design conditions from input design point values using empirical trends which are included in the computer code. The engine cycle program is capable of producing reasonable engine performance prediction with a minimum of computer execute time. The current computer execute (CPU) time on the IBM 360/67 for one Mach number, one altitude, and one power setting is about 0.1 seconds.

The principal assumption used in the calculation is that the compressor is operated along a line of maximum adiabatic efficiency on the compressor map. The fluid properties are computed for the combustion mixture, but dissocation is not included. The procedure included in the program is only for the combustion of JP-4, methane, or hydrogen; however, modifications are possible which would allow the calculation for any hydrogen, carbon, or hydrocarbon. Sample input and output listings are included.

INTRODUCTION

The design of advanced aircraft requires the consideration of many parameter variations in order to arrive at an optimum design for a particular mission or group of missions. These design studies are traditionally done using many large, separate computing programs that consider the various disciplines in a noninteractive sense. However, recent rapid advances in computer technology allow use of the computer to automate the early conceptual design of airborne systems. The desire to use the computer for aircraft conceptual design generates the need for a rapid, accurate means of calculating the performance of the propulsion system. This report is oriented toward satisfying this need.

The most detailed gas turbine cycle analyses for design and off-design performance are GENENG (GENeralized ENGine) (refs. 1 and 2) which was developed from SMOTE (Simulation of Turbofan Engine) (ref. 3) and NNEP (Navy-NASA Engine Program) which was derived from NEPCOMP (refs. 4 and 5, respectively). These programs perform a detailed flow and performance match of the compressor and turbine for each desired operating point. This matching requires the use of detailed compressor and turbine performance maps and a means of matching the compressor and turbine performance at each operating point. These programs run in slightly less than 10 seconds per Mach number, altitude and power setting on an IBM 360/67.

Waters (ref. 6) has published a description of a design or off-design gas turbine cycle analysis. This analysis has an empirically determined effect of compressor speed variation upon off-design compressor pressure ratio, but it does not consider the effect of off-design operation on the various component efficiencies.

Vanco (ref. 7) has published a design-point cycle calculation. This work does not consider the off-design case, nor does it have the built-in capability to size the engines for a particular mission requirement.

The computer code presented in this report can compute the design or off-design performance of a one or two spool turbojet or turbofan engine, with or without afterburning or ductburning. It uses a compressor model which empirically estimates the off-design pressure ratio and adiabatic efficiency of the compressor. The efficiencies of the other engine components are also modeled empirically. The gas properties are approximated using the polynomial approximations suggested by Vanco (ref. 7). The present program uses a model for the off-design fan pressure ratio which eliminates the cycle iterations required for matching the engine. Use of the presented program increase the computational speed by at least a factor of 10 when compared with other programs which use cycle iterations. This computational speed is achieved at the expense of decreased accuracy.

A comparison of the results of the computer program with the performance of existing engines is included.

SYMBOLS

A	flow area (meters^2, feet^2)
BR	bypass ratio
C_p	specific heat at constant pressure (Joules/kg^{o}k, BTU/lbm^{o}R)
dp	derivative of total pressure (Newton/meter^2, lbf/ft^2)
f	fuel air ratio by mass
g	gravitational constant (meters/sec, ft/sec^2)

h	specific total enthalphy (Joules/kg, BTU/lbm)
HVF	fuel lower heating value (Joules/kg, BTU/lbm)
J	conversion factor (1.0 for SI units, 778 ft lbf/BTU)
M	molecular weight
N	rotational speed (RPM)
p	total pressure (Newtons/m^2, lbf/ft^2)
PRCD	compressor design pressure ratio
PRFD	fan design pressure ratio
R	universal gas constant (Joule/kgmol^{o}K, ft lbf/lbmo^{o}R)
RPM	revolutions per minute
s	entropy
SFC	specific fuel consumption
T	total temperature (^{o}K, ^{o}R)
V	velocity (meters/sec, ft/sec)
W	mass flow (kg/sec, lbm/sec)
Δh	incremental enthalpy (Joules/kg, BTU/lbm)
ΔS	incremental entropy
$\Delta\phi$	incremental entropy function
η	efficiency

SUBSCRIPTS:

1	
2	
3	
4	station numbers (see figure 1)
5	
6	
7	

8	
a	initial
A/B	afterburner
air	air
ambient	ambient
b	final
B	burner
comp	compressor
design	design condition
D/B	duct burner
f	fuel
i	isentropic (or ideal)
in	into considered component
nozzle	nozzle
o	free-stream
out	out of considered component
ov	overall
prim	primary
prodûct	products of combustion
pro	propulsive
R	reference
s	static
sec	secondary (duct)
th	thermal
t	turbine

CYCLE DESCRIPTION

A schematic diagram of a general gas turbine engine cycle is shown in Figure 1. The air enters the inlet with a resultant loss in stagnation pressure which is typically a function of flight Mach number. The airflow then enters the fan and/or outer compressor where it may be divided into the primary flow (the flow through the primary gas turbine) and, if the engine is a turbofan, the secondary or bypass flow. The primary airflow is then routed through the inner compressor for additional compression. A small amount of the primary flow is directed around the combustor to provide cooling for the turbines. The remainder of the primary flow enters the combustor where fuel is added and combustion occurs. The combustors are designed for fuel-lean conditions (less fuel than required for stoichemetric burning) in order that the gas temperature entering the turbine does not exceed the structural or material limitations of the turbine. Many studies have been made on methods of cooling these turbines and quite involved techniques are used in modern gas turbine engines. Current cooling technology allows the turbine inlet temperature to go as high as 1389^{o}K to 1778^{o}K (2500^{o}R to 3200^{o}R).

The primary airflow, including the turbine cooling air that was routed around the combustor, enters the inner turbine which is connected to the inner compressor with a shaft along the centerline of the engine. This shaft transfers the energy required to drive the inner compressor from the inner turbine to the inner compressor. The combination of compressor, shaft, and turbine is usually called a spool. The primary gas flow then enters the outer turbine which is connected via a shaft running through the hollow inner turbine shaft to the outer compressor-fan combination. This shaft supplies the energy required to drive the outer compressor-fan combination. The combination of outer compressor-fan, outer turbine and connecting shaft is called the outer spool. The fan may or may not have the same number of stages (rows of blades) as the outer compressor. In a three spool engine, the fan is driven by a separate turbine. Many engines do not have a fan but have an inner and outer compressor (a two spool turbojet). The gas flow leaving the outer turbine enters the afterburner section where additional fuel can be added and burned. The afterburner may or may not be present, depending on the operational requirements of the engine. In general, the afterburner supplies a large amount of additional thrust (about 1.5 times nonafterburning thrust) at the expense of increased specific fuel consumption. The primary gas flow is then expanded through a nozzle to produce thrust. In some engines, the primary and secondary (bypass) gas flows are mixed ahead of the nozzle. These engines are called mixed flow exhaust engines. Other engines have separate nozzles for both the secondary and primary gas streams. Some turbofan engines have combustors located in the bypass duct and are, therefore, called ductburners or ductburning turbofans.

METHOD OF ANALYSIS

The method of analysis used in this study involves the thermodynamic modeling of each component (the compressor, burner, turbine, etc.) of a gas turbine engine. The analysis is applicable to a one or two spool turbojet or turbofan, with or without afterburning or ductburning. The analysis does not involve any cycle iterations. Properties of the combustion gases for use in the thermodynamic modeling are computed using polynomial curve fits of the specific heat, the enthalpy, and the entropy of the combustion gases (ref. 7). These fitted parameters are functions of the fuel-air ratio of the combustion gas and of the gas temperature. The technique is limited to temperatures below the dissociation temperature (about 2200^{o}K or approximately 4000^{o}R). The properties included in the computer code are for JP-4, methane, or hydrogen; however, modifications to include any hydrogen, carbon, or hydrocarbon fuel are possible.

The component efficiencies used in the thermodynamic modeling are scaled for off-design conditions from the input design-point value using empirical trends included in the code.

Principal Assumptions

The principal assumptions in the present analysis are:

1. Each compressor operates along a specified compressor operating line.
2. The bypass ratio is held constant at the design value.
3. The flow through the turbine nozzles is sonic (choked).
4. The combustor, afterburner and duct burner pressure drops are assumed constant at the design (input) value.
5. The thermodynamic properties are calculated using polynomial curve fits (ref. 7) which include the effect of fuel addition, but do not include dissociation.
6. The exhaust nozzles for the primary and secondary flow are assumed to be separate.

A total enthalphy-entropy diagram for a two spool turbofan is presented in Figure 2. Each of the individual engine components are labeled and both the ideal process and the actual process are shown. Diagrams for other types of engines would be similar.

GOVERNING EQUATIONS

Gas Properties

The gas properties have been approximated by the polynomial expressions of reference 7. These properties are functions of gas temperature, fuel to air ratio, and type of fuel. The computer code includes property descriptions for JP-4, hydrogen, or methane.

Using this technique, the specific heat of the gas is expressed by a polynomial equation. Appropriate integrations of this expression yield the enthalpy change and the entropy function. The entropy function is defined as

$$\Delta\phi = \int_{T_1}^{T_2} \frac{C_p}{T}\, dT \qquad (1)$$

The enthalpy change is defined as

$$\Delta h = \int_{T_1}^{T_2} C_p \, dT \tag{2}$$

The importance of the entropy function can be seen from recalling that a general expression for entropy change between two state points is

$$\Delta S = \int_{T_1}^{T_2} C_p \frac{dT}{T} - \int_{1}^{2} \frac{R}{JM} \frac{dp}{p} = \Delta\phi - \int_{1}^{2} \frac{R}{JM} \frac{dp}{p} \tag{3}$$

For an isentropic process this reduces to

$$\Delta\phi = \int_{T_1}^{T_2} C_p \frac{dT}{T} = \int_{P_1}^{P_2} \frac{R}{JM} \frac{dp}{p} \tag{4}$$

When the appropriate integrations are accomplished, equations (1), (2), (3), and (4) produce a property description for the combustion gas. Using this property description, it is possible to compute the properties through the gas turbine from thermodynamic considerations. If the type of fuel is specified, the properties can be expressed in functional form. Using this form, the entropy function becomes

$$\Delta\phi = \Delta\phi \, (T_a, T_b, f) \tag{5}$$

the enthalpy function is

$$\Delta h = \Delta h \, (T_a, T_b, f) \tag{6}$$

and the specific heat is

$$C_p = C_p \, (T_a, T_b, f) \tag{7}$$

where T_a is the initial temperature, T_b is the final temperature and f is the fuel/air ratio for the considered mixture. Equations (5), (6), and (7) are also functions of the particular fuel being used (i.e. kerosene, hydrogen, methane).

Inlet

The function of the inlet is to meter and condition the airflow to conform with the demands of the engine. During this process, there occurs a drop in total pressure of the flow because of losses due to friction as well as possible shock and separation losses. A measure of these losses is the total pressure recovery (the ratio of total pressure out of the inlet to total pressure into the inlet). The total pressure recovery will be used in this report to indicate the efficiency of the inlet.

Standard functional relationships for inlet total pressure recovery have been developed (ref. 8). These usually relate the inlet total pressure recovery to the free stream flight Mach number.

Two of these functional relationships are

the AIA Ram Recovery

$$p_1/p_0 = 1.0 - 0.1\ (M_\infty - 1.0)^{1.5} \qquad M_\infty > 1$$
$$= 1.0 \qquad M_\infty \leq 1 \tag{8}$$

and the Military Spec 5008B

$$p_1/p_0 = 1.0 - 0.075\ (M_\infty - 1.0)^{1.35} \qquad M_\infty > 1$$
$$= 1.0 \qquad M_\infty \leq 1 \tag{9}$$

The AIA Ram Recovery and the Military Spec 5008B Recovery are included in the present program. It is also possible to input any other desired inlet total pressure recovery.

Compressor

Typical mathematical models of compressors involve detailed maps of compressor pressure ratio as a function of compressor corrected weight flow and corrected rotational speed with the compressor adiabatic efficiency as a parameter (refs. 9 and 10). These compressor models are usually empirically determined and are dependent on the particular compressor design. The empirical performance of eight different compressor designs was examined in the article by Robbins and Dugan (ref. 9). The purpose of their study was to obtain a general empirical description of compressor performance for a wide family of axial flow compressors. The present work uses the results of the study by Robbins and Dugan. In addition, the present work utilizes the assumption that the compressor is operated along a line of maximum adiabatic efficiency as the compressor weight flow and speed is varied. It is also assumed that the compressor reference point described by Robbins and Dugan is equal to the compressor design point. This assumption eliminates an iteration and seems to cause no appreciable error. Using these assumptions and the work of Reference 9, it is possible to describe the performance of a family of axial flow compressors using three charts which have been reproduced from Reference 9 as Figures 3, 4, and 5. Figure 3 presents the percent corrected speed as a function of design compressor pressure ratio and percent corrected airflow. The compressor corrected weight flow and design compressor pressure ratio are used to obtain the percent corrected speed using this figure. Figure 4 presents off-design compressor pressure ratio (in percent of design) as a function of design compressor pressure ratio and percent design corrected speed. The input to this figure is design compressor pressure ratio and percent design corrected speed which is obtained from the previous figure. The off-design compressor pressure ratio is obtained from this figure. Figure 5 presents off-design adiabatic efficiency as a function of design compressor pressure ratio and percent design corrected speed. The off-design adiabatic efficiency is obtained from this figure. Each of these charts is curve fit. If the cycle has multiple compressors, the above model is used on each separate compressor.

After the pressure ratio and adiabatic efficiency for each compressor has been obtained, the work required to drive these components can be computed. The ideal compressor exit temperature can be found from

$$\Delta\phi \left(T_{out_i}, T_{in}\right) = \frac{R}{J} \ln \left(\frac{p_{out}}{p_{in}}\right) \tag{10}$$

where T_{out_i} is the ideal exit total temperature for the outer compressor.

The outer compressor work is

$$W_{in}\left(h_{out} - h_{in}\right) = \frac{W_{in}\left(h_{out_i} - h_{in}\right)}{\eta_c} \tag{11}$$

where the compressor adiabatic efficiency is obtained from Figure 7. The inner compressor work is found in a similar manner.

The total mass flow into the engine is the sum of the secondary (bypass) mass flow (W_{sec}) and the primary mass flow (W_{prim})

$$W_{ov} = W_{sec} + W_{prim} \tag{12}$$

and the bypass ratio is defined as

$$BR = W_{sec}/W_{prim} \tag{13}$$

The exit total temperature for the compressor can be found for the inner and outer compressor by using enthalpy obtained in equations (10) and (11), respectively, along with the definition of the incremental enthalpy in equation (6).

Fan

For bypass engines, the fan supercharges the primary flow. For the purpose of the paper, the inner portion of the fan flow which pressurizes the primary mass flow is considered part of the outer compressor. The outer annulus portion of the flow which enters the bypass duct, if the engine is a turbofan, will be denoted as secondary flow and any reference to fan performance will consist only of this outer portion of the fan. The fan and outer compressor are assumed to have the same pressure ratio per stage for both design and off-design operation. The fan off-design pressure ratio can therefore be determined by scaling its value from the outer compressor off-design pressure ratio by using the known values for the design fan and outer compressor pressure ratios.

This scaling results in the equation

$$\left(\frac{p_{out}}{p_{in}}\right)_{fan} = \left(\frac{p_{out}}{p_{in}}\right)_{comp}^{\frac{\ln\,(PRFD)}{\ln\,(PRCD)}} \tag{14}$$

where p is the total pressure at the indicated points, and PRFD and PRCD are the design fan and compressor pressure ratios.

Equation (14) can be used to approximate the fan pressure ratio at off-design conditions from the compressor off-design pressure ratio, which is obtained from the compressor model, and the ratio of design fan pressure ratio to design compressor pressure ratio.

This technique eliminates the need to do cycle iterations to find the fan off-design pressure ratio. However, it is not as accurate as the techniques involving cycle iteration using separate fan maps and, in general, it over-predicts the off-design fan pressure ratio. The cycle iteration approach involves guessing values of the parameter of interest, computing through the cycle, checking the results against some required bounary condition, and then correcting the input parameter if the boundary conditions are not satisfied (refs. 1 to 5).

The bypass ratio, the ratio of secondary airflow through the fan duct to primary airflow through the core gas turbine, is assumed to be constant at the design point value.

The exit fan ideal total temperature can be found using equation (4) for the known fan pressure ratio.

The adiabatic efficiency of the fan is assumed equal to the outer compressor adiabatic efficiency. The fan work can be obtained from an equation similar to equation (11).

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Combustor/Afterburner/Ductburner

The computation for the combustor, afterburner, and ductburner involves a mass and energy balance across each of these components. If the mass balance and energy balance are combined, the following equation for the fuel-air ratio is obtained:

$$f \equiv \frac{W_{f_{in}}}{W_{air_{in}}} = \frac{h_{product} - h_{air}}{(h_f + \eta_B \, HVF) - h_{product}} \qquad (15)$$

The total enthalphy of the products ($h_{products}$) can be computed from the input combustor exit temperature and the fuel-air ratio. The total enthalphy of the fuel is the sum of the sensible enthalphy (h_f) and the chemical enthalphy (HVF) or lower heat value of the fuel. The program operation requires that the combustor design exit temperature be input. The combustor inlet temperature is reduced if the engine is to be operated at reduced power.

The combustor pressure drop is assumed to be constant at the design (input) value.

Typical values for the burner efficiency, η_B, are shown in figure 6 (refs. 11, 12, and 13). The burner efficiency is shown as a function of $p_S \, T_S/V_R$, where p_S is the static pressure at the entrance, T_S is the static temperature at the burner entrance, and V_R is the combustor reference velocity, based on p_S, T_S, and the combustor maximum cross section area. The computer program contains a nondimensional version of this figure which approximates the lower limits of figure 6.

Turbine

The inner turbine usually sets the limit for the maximum combustor exit temperature. The inner turbine nozzles operate at a Mach number of one (choked) and thus limit the mass flow through the engine. For choked flow, it is assumed (ref. 14) that

$$\frac{W\sqrt{T}}{A_p} = \text{constant} \qquad (16)$$

where W is the mass flow into the flow area A at a total temperature T and a total pressure p. In the computer program there are two modes of operation for the inner turbine computer model.

The first mode is the design mode in which the turbine nozzle area required to supply airflow sufficient to produce an input thrust level at a given flight condition is determined.

In this design mode of operation, the inner turbine nozzle flow area is computed for input component efficiencies, design pressure ratios and design combustor exit temperatures. The airflow through the engine is arbitrarily chosen for this mode as the airflow and flow areas scale directly with thrust and, therefore, the computed inner nozzle flow area can be scaled to the required input thrust level.

The inner turbine nozzle area is then fixed for the second mode of operation - the off-design mode - and the combustor exit temperature is computed which satisfies equation (16) for a known inner turbine nozzle flow area, mass flow, and total pressure.

The isentropic turbine work is equal to the work required to drive the attached compressor plus the additional work required to overcome the losses of the turbine. These turbine losses are usually accounted for by using a turbine adiabatic efficiency, η_t, which is empirically determined. Thus, the isentropic work of the turbine is:

$$\begin{array}{c}\text{isentropic}\\ \text{turbine}\\ \text{work}\end{array} = \frac{W_{comp}\left(h_{out} - h_{in}\right)_{comp}}{\eta_t} \qquad (17)$$

The isentropic total temperature out of the turbine can be computed from the ideal turbine enthalphy difference of equation (17) by use of equation (6). The turbine total pressure ratio can be computed from the turbine entry temperature, the isentropic turbine exit temperature and the fuel air ratio by use of equation (4).

In order to complete the calculation, it is necessary to find the turbine adiabatic efficiency. The design point turbine adiabatic efficiency is input by the program user. The off-design turbine adiabatic efficiency can be computed from an approximation suggested by Dugan in reference 9. The approximation can be expressed as:

$$\eta_t = \eta_{t_{design}} \left[1 - \frac{1}{\left(\frac{N_t}{\sqrt{\Delta h}}\right)^2_{design}} \left(\frac{N_t}{\sqrt{\Delta h}} - \left(\frac{N_t}{\sqrt{\Delta h}}\right)_{design} \right)^2 \right] \qquad (18)$$

Where $\eta_{t_{design}}$ is the input design adiabatic turbine efficiency, N_t is the turbine RPM and Δh is the actual total enthalphy difference across the turbine. The turbine RPM, N_t, is equal to the associated compressor RPM. The total enthalphy difference across the turbine Δh can be found using:

$$\Delta h = \frac{W_{comp}}{W_t} \left(h_{out} - h_{in} \right)_{comp} \qquad (19)$$

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Dugan stated that the accuracy of equation (18) for the off-design adiabatic efficiency was "quite good over much of the turbine performance map. Near limiting loadings, however, actual turbine efficiencies are much lower than those calculated."

The outer turbine's performance is computed in a similar manner except the outer turbine flow passages are not sized or assumed choked.

Nozzle

The nozzle calculations utilizes the assumption that the flow is fully expanded to ambient pressure isentropyically. A correction term, the nozzle velocity coefficient, is applied to the computed velocity to account for incomplete expansion as well as other losses. An energy balance across the nozzle for an ideal nozzle gives:

$$h_{in} = h_{out} = h_{out_s} + \frac{V^2_{out}}{2gJ} \tag{20}$$

Using the isentropic fully expanded nozzle assumption equation (4) can be written:

$$\Delta\phi_{nozzle} = \frac{R}{JM} \ln \frac{p_{out}}{p_{in}} \tag{21}$$

Where p_{out}/p_{in} are equal to the reciprocal of the engine nozzle total pressure ratio. The above expression for $\Delta\phi$ can be used to compute the ideal total temperature at the nozzle exit by using equation (5). The ideal nozzle total enthalphy can be computed using equation (6), and the ideal velocity can be computed from equation (20). This velocity is then corrected to the actual jet velocity using an input velocity coefficient which can be a function of the engine nozzle pressure ratio (total pressure at nozzle entrance divided by ambient static pressure).

Specific Thrust

The specific thrust of an engine is defined as the net thrust divided by the total airflow of the engine. The net thrust of the engine can be obtained from a momentum balance across the engine. Recall the nozzles are assumed to be fully expanded ($p_{exit} = p_{ambient}$). It is customary (refs. 8, 10, and 15) to reference the engine thrust to free stream conditions and make the appropriate corrections for any external cowl drag or change in stream momentum ahead of the engine. Therefore, the engine thrust is

$$\begin{aligned} &\text{Gross thrust} = (W_8 V_8 + W_6 V_6)/g \\ &\text{Ram Drag} = W_{ov} \times V_o/g \\ &\text{Net Thrust} = \text{gross thrust} - \text{ram drag} \end{aligned} \tag{22}$$

and the specific thrust using (22) is

$$ST = \frac{\text{net thrust}}{W_o} = \frac{W_8 V_8 + W_6 V_6 - W_o V_o}{W_o g} \tag{23}$$

Specific Fuel Consumption

The specific fuel consumption is defined as the total fuel flow in pounds per hour divided by the net thrust in pounds. This important parameter is a measure of the overall efficiency of the engine. The fuel flow per hour is

$$\text{fuel flow per hour} = \left(W_{f_{prim}} + W_{f_{A/B}} + W_{f_{D/B}}\right) 3600 \tag{24}$$

Using (22) and (24) with the definition of SFC

$$SFC = \frac{\left(W_{f_{prim}} + W_{f_{A/B}} + W_{f_{D/B}}\right) 3600\ g}{\left(W_8 V_8 + W_6 V_6 - W_o V_o\right)} \tag{25}$$

Overall Engine Efficiency

The overall efficiency of the engine is another important parameter of the engine cycle. This efficiency is described quite completely by Shepard (ref. 8). The overall efficiency is defined as the useful power (thrust x velocity) divided by the net energy input per unit time.

$$\eta_{ov} = \frac{(\text{net thrust})(V_o)}{\text{rate of energy in}} \tag{26}$$

The rate of energy into the engine is equal to the fuel flow times the energy stored in the fuel. Using the definition of SFC and considering both the chemical and kinetic energy of the fuel, the rate of energy is

$$\text{rate of energy in} = \frac{SFC(\text{net thrust})(HVF)J + \frac{V_o^2}{2g}}{3600} \tag{27}$$

$$\eta_{ov} = \frac{3600(V_o)}{SFC\left((HVF)J + \frac{V_o^2}{2g}\right)} \tag{28}$$

In many texts, the kinetic energy of the fuel is neglected and thus (28) becomes

$$\eta_{ov} = \frac{3600(V_o)}{(SFC)(HVF)(J)} \tag{29}$$

The overall efficiency, η_{ov}, can be divided into two components; the propulsive efficiency, η_{pro}, and the thermal efficiency η_{th}. The propulsive efficiency is the useful power (thrust times velocity) divided by the rate of kinetic energy production by the exhaust

$$\eta_{pro} = \frac{(\text{net thrust})(V_o)}{\frac{W_8}{2}\left(V_8^2 - V_o^2\right) + \frac{W_6}{2}\left(V_6^2 - V_o^2\right)} \tag{30}$$

The fuel added to the engine has been neglected in (30). The propulsive efficiency is a measure of the losses due to difference in exhaust jet velocity and the free-stream velocity. The thermal efficiency is the energy rate out of the engine which is available for useful work divided by the rate of energy into the engine. This is a measure of the efficiency of the cycle.

Therefore, the thermal efficiency η_{th}, is

$$\eta_{th} = \frac{\frac{W_8}{2}\left(V_8^2 - V_o^2\right) + \left(V_6^2 - V_o^2\right)}{\frac{(SFC)(\text{net thrust})}{3600}\left[(HVF)(J) + V_o^2/2g\right]} \tag{31}$$

and note that by comparing (28), (30), and (31)

$$\eta_{ov} = \eta_{th}\,\eta_{pro} \tag{32}$$

ACCURACY OF THE PROGRAM

The accuracy of the program can be evaluated by comparing the program output for a known engine cycle with the comparable specification (ref. 16). of the known engine. This comparison requires the knowledge of the component efficiencies for the engines which are used in the comparison. Unfortunately, the component efficiencies are not available in the literature for particular engines, however, general trends and typical values are well known (refs. 9, 10, 15, and 17) and could be used for the comparison. Another method of obtaining values for the component efficiencies for a particular engine is to match the sea level static performance of the engine by varying the input component efficiencies within the bounds of known technology. The approach, using this technique, is the fix all known engine cycle parameters and to vary the component efficiencies until the sea level static performance from the cycle analysis is equal to the actual engine specifications. The results using this technique are not unique but experience shows that values for the engine component efficiencies do not vary more than a few percent from design to design if the engines were designed at the same technology level. In the following comparisons, the sea level static 100 percent RPM, thrust and SFC point was matched approximately to the engine specifications (ref. 16) by varying the component efficiencies. These efficiencies were examined to be sure that they were reasonable and consistent. The code then was used to generate all off-design (part throttle) and design points other than the sea level static, 100 percent RPM point. During these calculations, the input design point efficiencies were used, with off-design variations to these parameters computed from curve fits of empirical data contained in the code. Figures 7, 8, and 9 present comparisons for the JT8D, the J-79, and the CF6 engines, respectively. The engine specifications from Reference 16 are represented by the solid lines. Average differences of 5 percent are typical with maximum error of less than 15 percent. The maximum error usually occurs during the after-burning or duct-burning and is probably caused by the assumption of constant combustion efficiency and pressure drop which was made in the code.

RESULTS AND CONCLUSIONS

A method for computing the design and off-design performance of a gas turbine engine is presented and the results are compared with engine specifications for several typical engines. The results indicate average errors in the performance calculation of less than 5 percent with maximum errors of about 15 percent. The maximum errors usually occur when the after-burner is in operation.

A computer code is described which is capable of producing performance calculations for a gas turbine engine at one Mach altitude and power setting in less than 0.1 second on the IBM 360/67 as compared to slightly less than 10 seconds for GENENG.

The increase in computational speed was accomplished by not using detailed compressor and turbine maps and not using any iterations between components in the calculations. The compressor model used in the present report is based on empirical data and required the assumption that the compressor is operated along a line of maximum compressor adiabatic efficiency.

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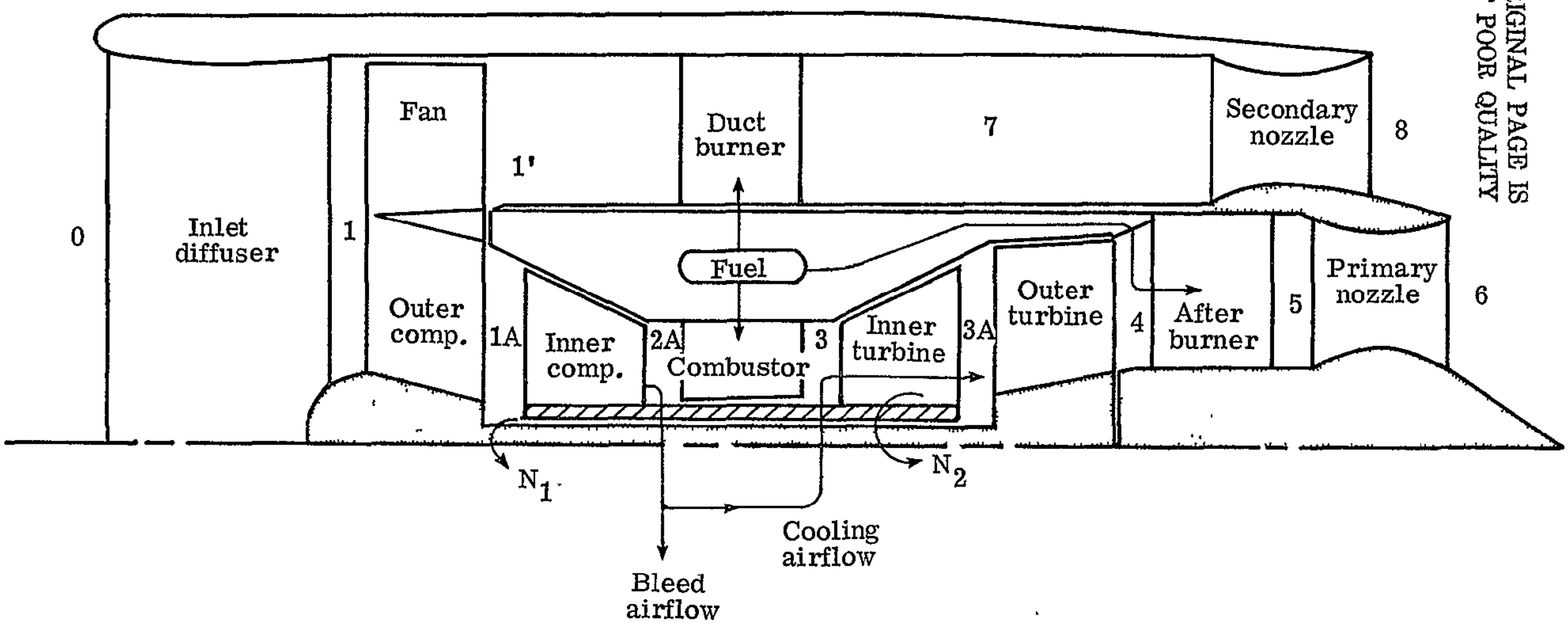

Figure 1.- Engine schematic for a two spool turbofan.

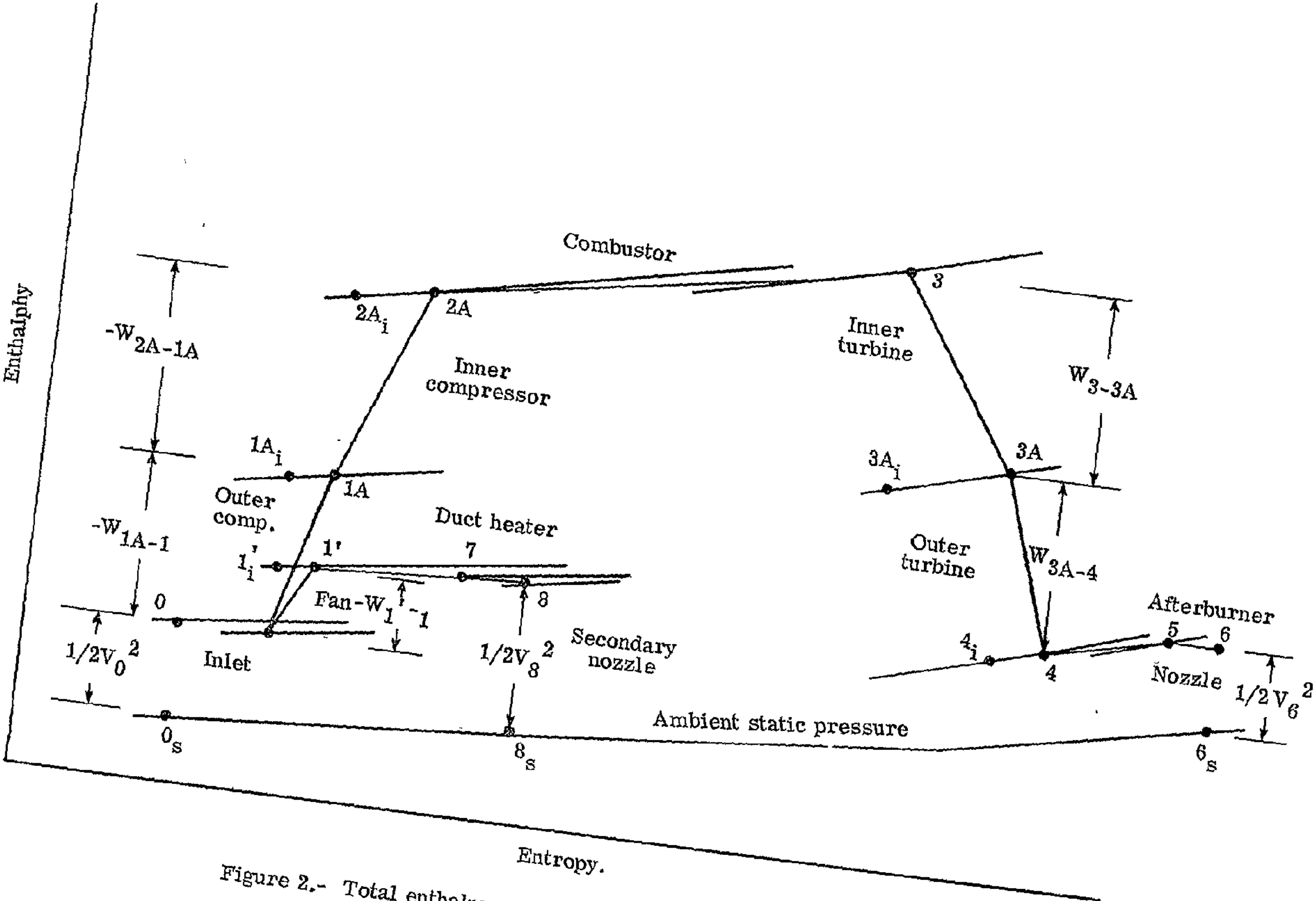

Figure 2.- Total enthalpy entropy diagram for a two spool turbofan.

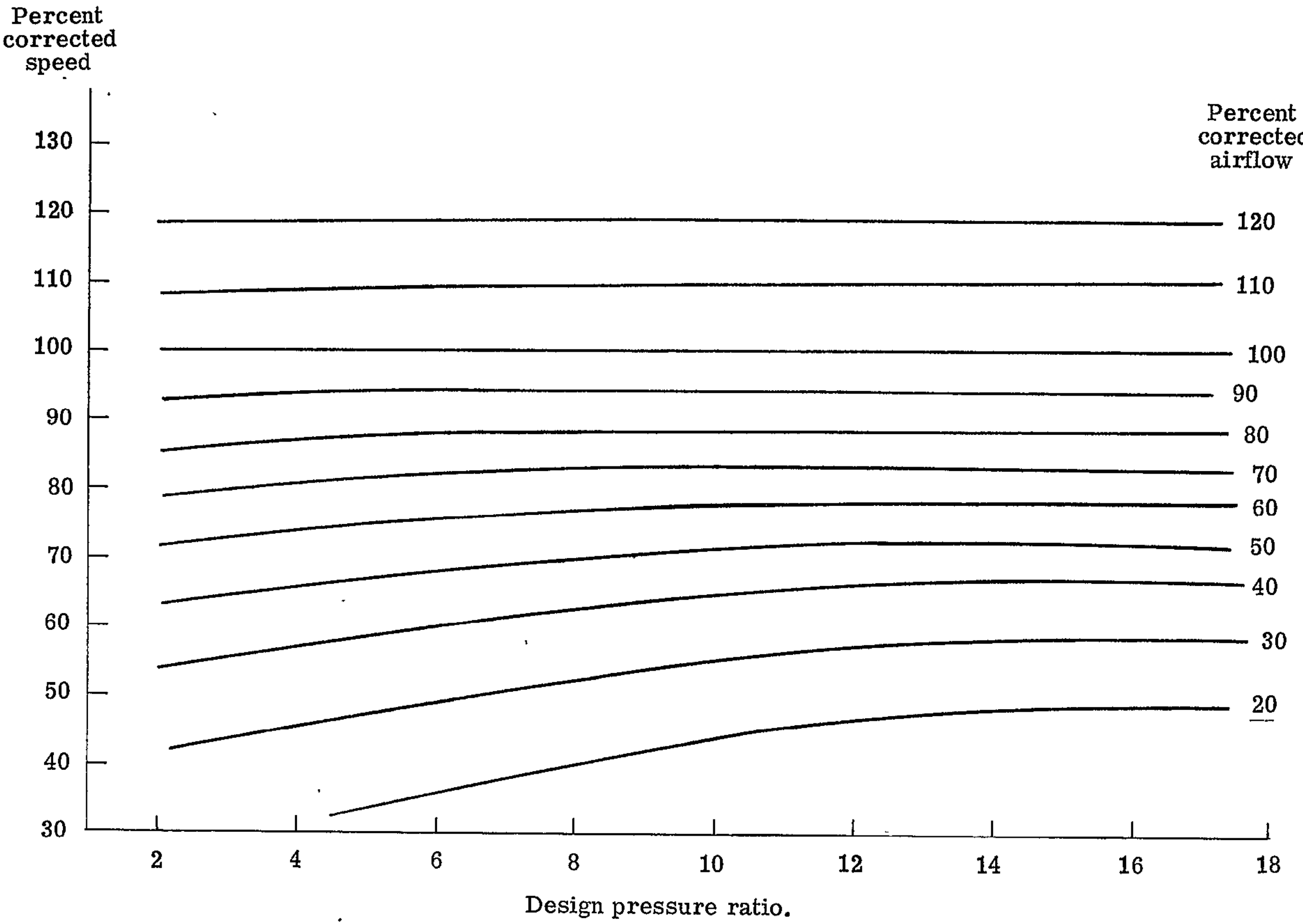

Figure 3.- Compressor model-percent corrected speed variation.

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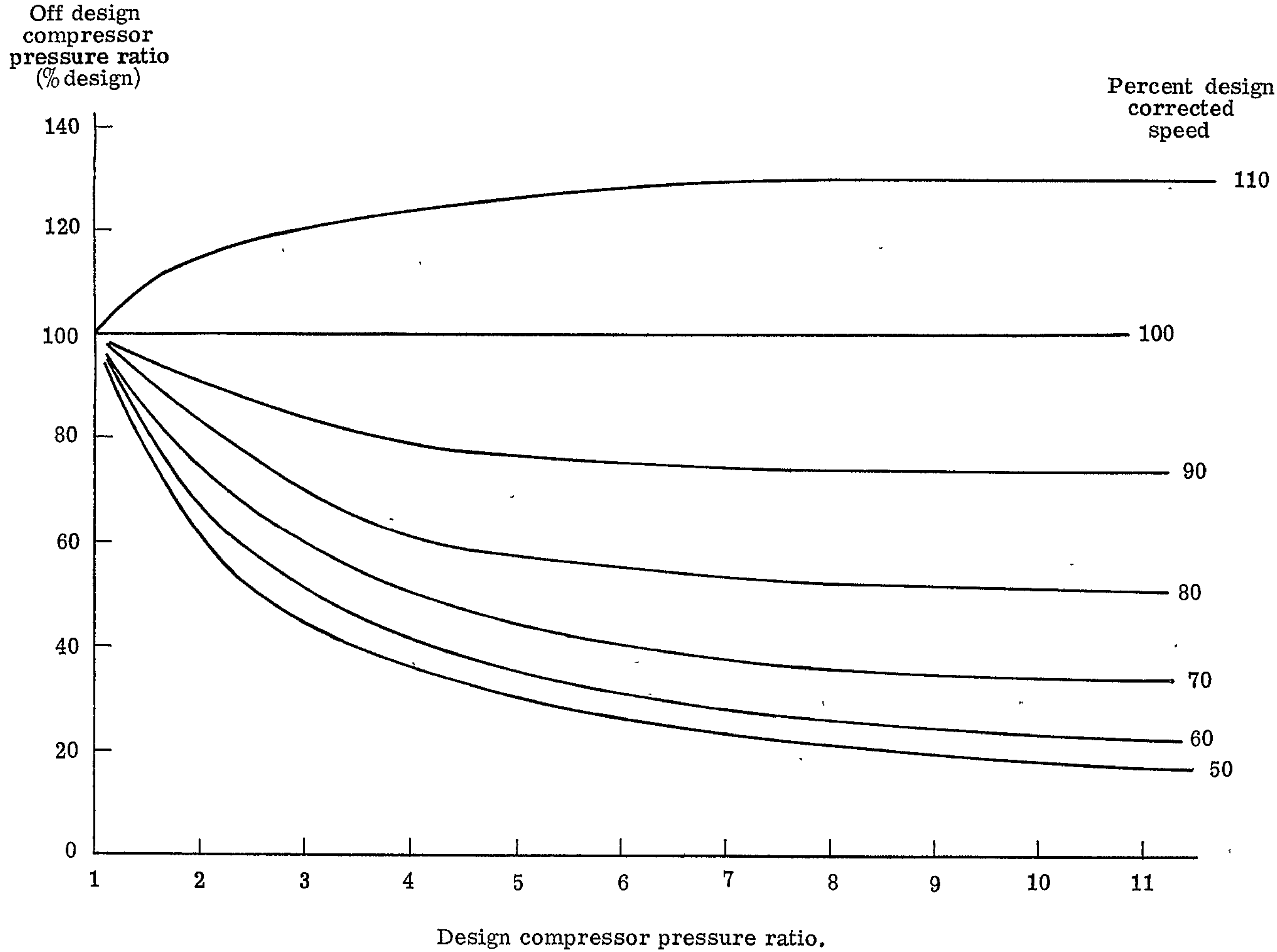

Figure 4.- Compressor model-pressure ratio variation.

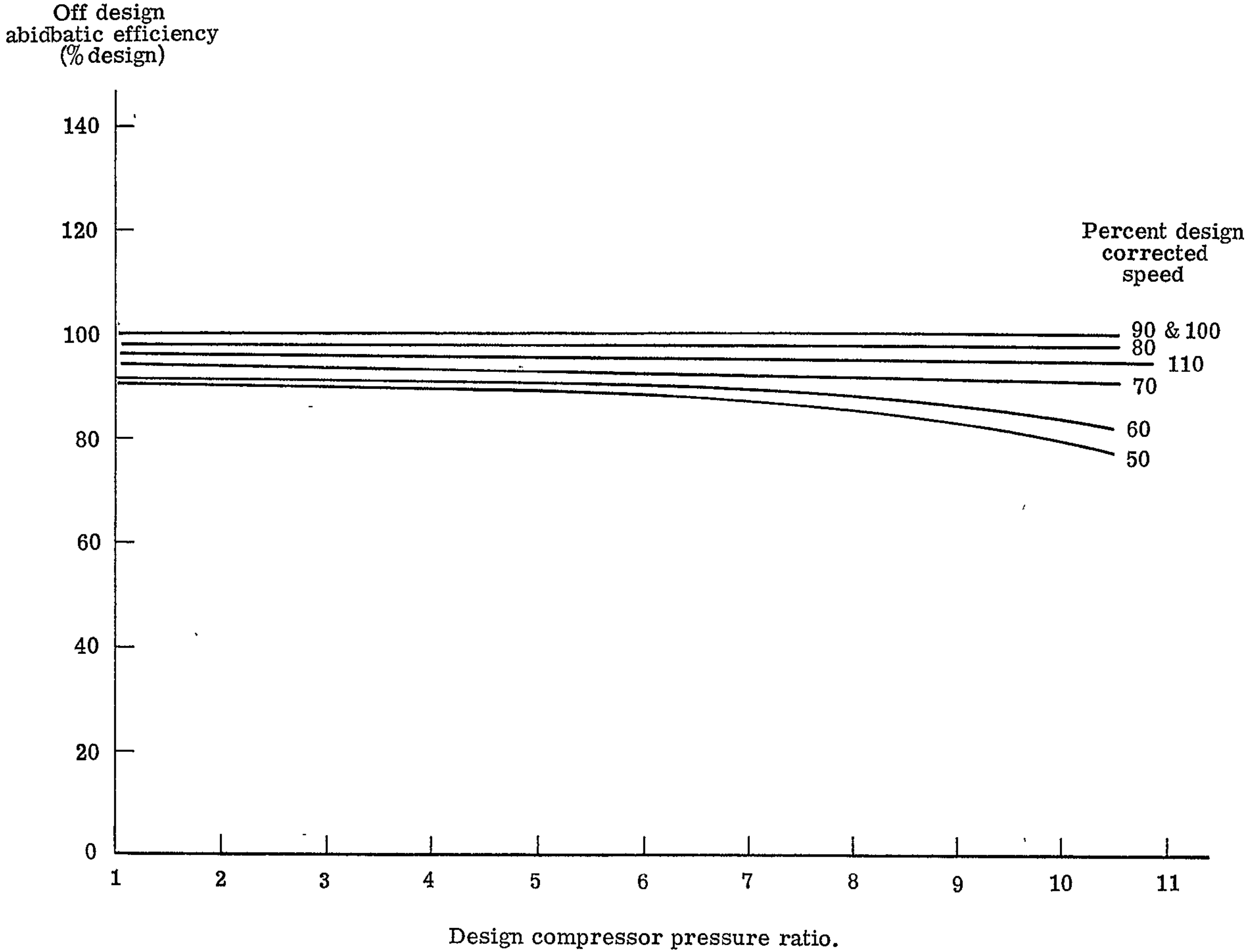

Figure 5.- Compressor model-adiabatic efficiency variation.

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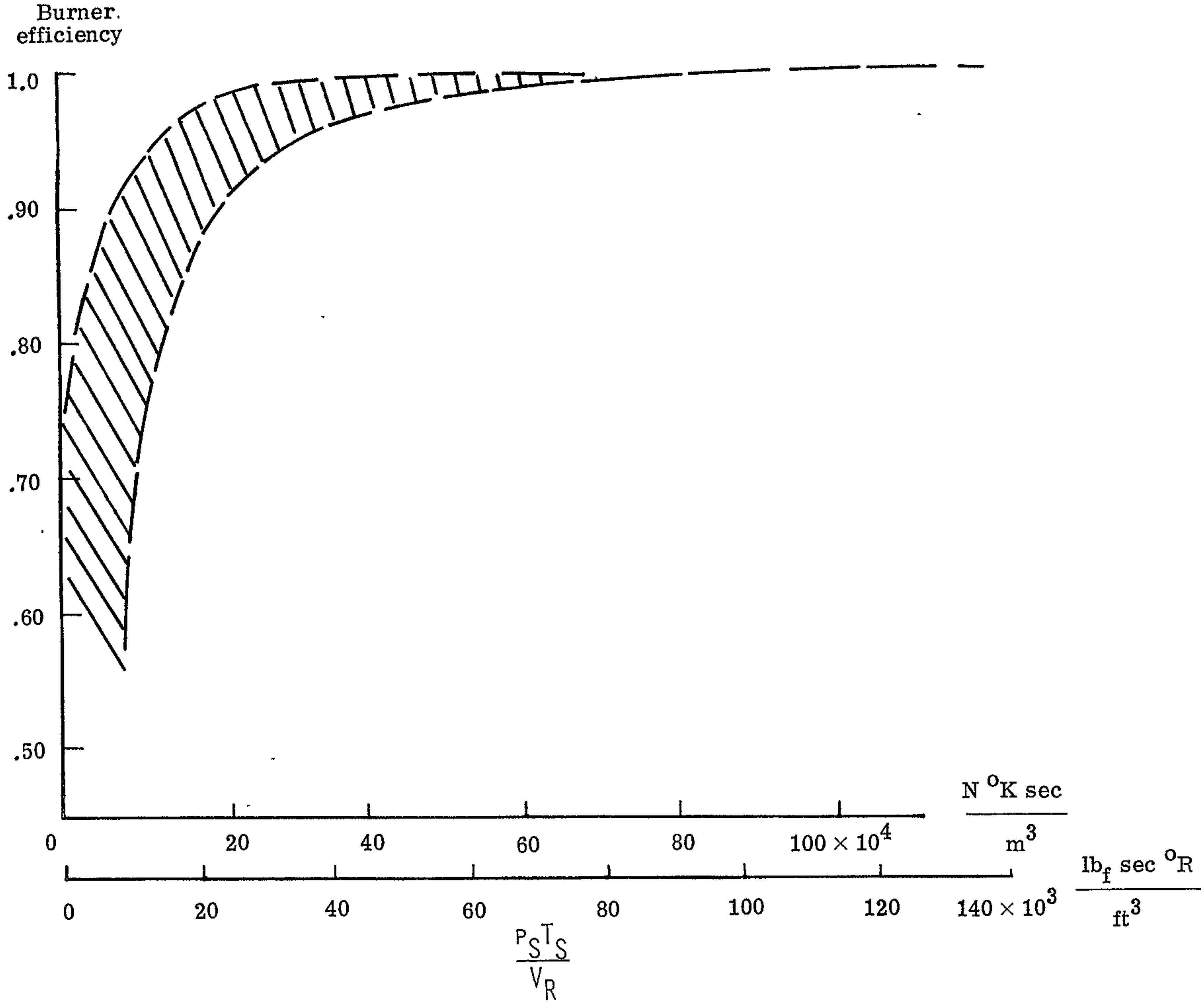

Figure 6.- Combustor efficiency.

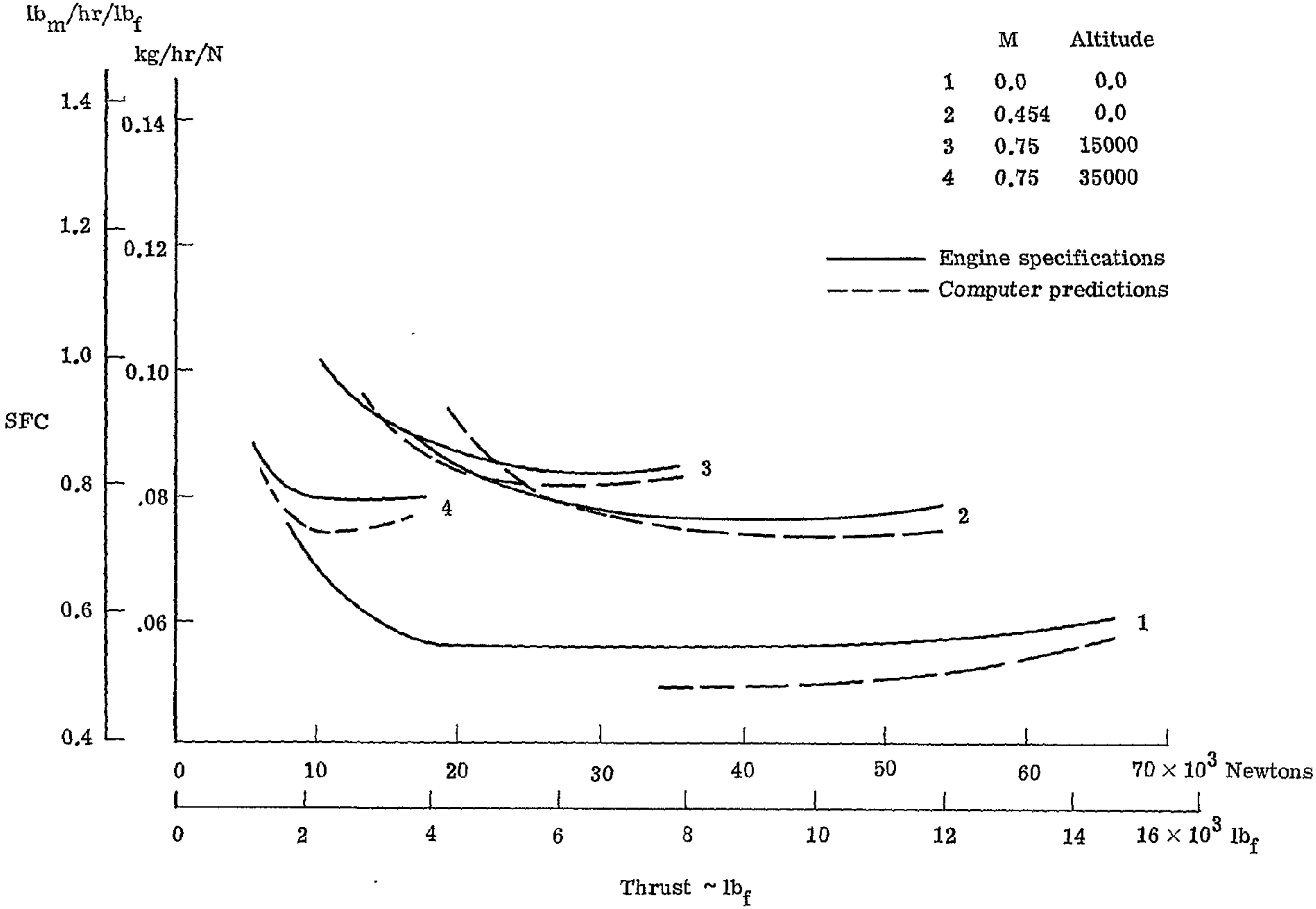

Figure 7.- Thrust versus SFC-P&WJT8D-9.

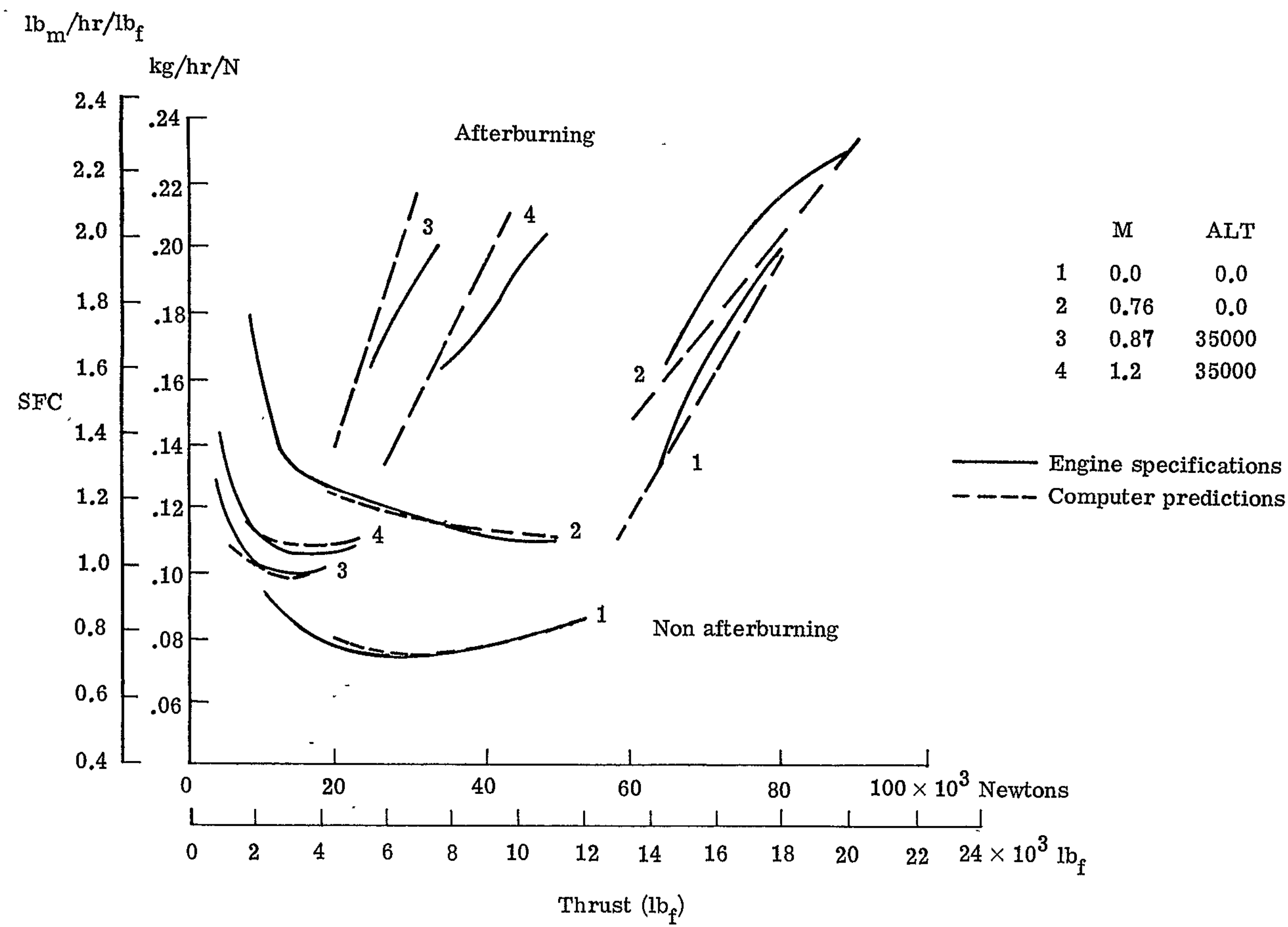

Figure 8.- Thrust versus SFC-GEJ79-17.

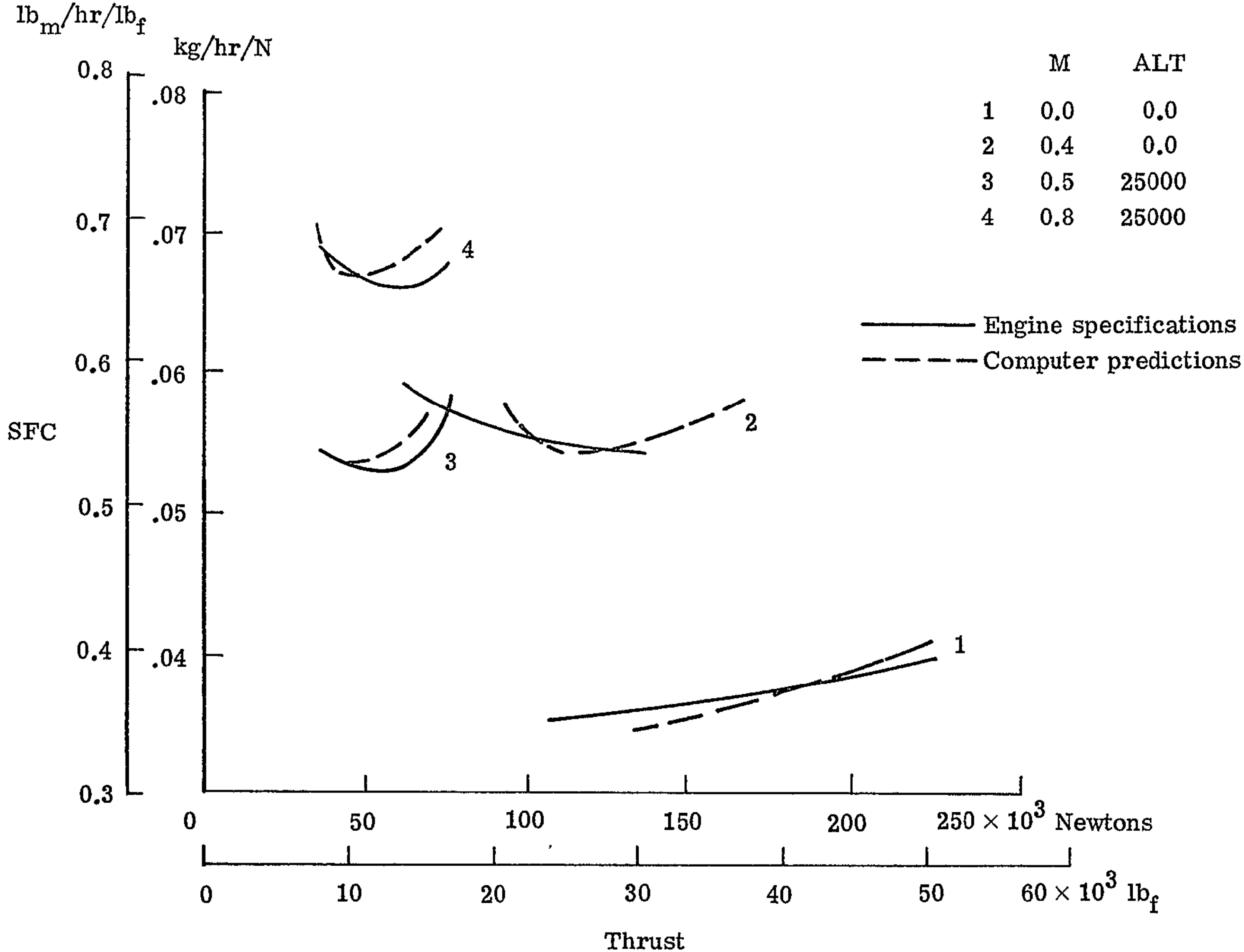

Figure 9.- Thrust versus SFC-GECF6-50D.

APPENDIX A

Program Input

Input to the computer program is achieved via a namelist called LEWIS. The various input variables are described in this appendix. The inputs followed by ** are required for operation of the program. The other inputs have default values incorporated in the code.

INPUT DESCRIPTION:

NOTE: THE '**' INDICATES PARAMETERS THAT HAVE NO DEFAULT VALUE AND THUS MUST BE INPUT VIA NAMELIST 'IENIS'.

FORTRAN NAME		VARIABLE DESCRIPTION	UNITS
R32		COMBUSTOR PRESSURE RATIO	NONE
R54		A/B PRESSURE RATIO (TYP 0.94)	NONE
R54N		A/B PRESSURE RATIO W/O A/B LIT (TYP 0.95)	NONE
ETAC1		COMPRESSOR ADIABATIC EFFICIENCY (TYP 0.82)	NONE
ETAT1		TURBINE ADIABATIC EFFICIENCY (TYP 0.90)	NONE
HVF		FUEL HEATING VALUE (TYP 18600. FOR JP4)	BTU/LB
WCHA1	**	ACCOUNTABLE BLEED TO PRIMARY AIRFLOW	NONE
EAB1		A/B ADIABATIC EFFICIENCY (TYP 0.75)	NONE
EB1		COMBUSTOR ADIABATIC EFFICIENCY (TYP 0.98)	NONE
TR		REFERENCE TEMPERATURE (USUALLY 520. DEG R)	DEG R
ED1		DUCT BURNER ADIABATIC EFFICIENCY (TYP 0.75)	NONE
R711		D/B PRESSURE RATIO W/ D/B LIT (TYP 0.95)	NONE
R711N		D/B PRESSURE RATIO W/O D/B LIT (TYP 0.95)	NONE
ETAF1		FAN ADIABATIC EFFICIENCY (TYP 0.80)	NONE
AM		FLIGHT MACH NO(OVERRODE BY MACH IF PRODR1 USED)	NONE
VC1		NOZZLE VELOCITY COEFFICIENT (TYP 0.98)	NONE
R10A		INLET TOTAL PRESSURE RECOVERY CODE	NONE
		IF R10A = -1.0 AIA RECOVERY USED	
		IF R10A = -2.0 MIL SPEC 5008B USED	
		IF R10A POSITIVE INPUT=TOTAL PRESSURE RECOVERY	
ALTI		FLIGHT ALTITUDE(OVERRODE IF DRIVEN BY PRODR1)	FEET
TOSA		FLIGHT STATIC TEMPERATURE (OVERRODE IF DRIVEN BY PRODR1)	DEG R
POSA		FLIGHT STATIC PRESSURE (OVERRODE BY PRODR1)	IN OF HG
P2P1	**	DESIGN OVERALL COMPRESSOR PRESSURE RATIO	NONE
P11P1	**	DESIGN OUTER COMPRESSOR PRESSURE RATIO	NONE
BA	**	BYPASS RATIO	NONE
T3	**	MAX TURBINE INLET TEMPERATURE	DEG R
T71	**	D/B TEMPERATURE (SET=0.0 IF NO D/B)	DEG R
T7M	**	D/B MAX TEMPERATURE (SET = 0.0 IF NO D/B)	DEG R
T51	**	A/B TEMPERATURE	DEG R
T5M	**	A/B MAX TEMPERATURE	DEG R
KODE	**	=0,TURBOJET ; =2 TURBOFAN	NONE
KT5	**	=0, NO A/B; =-1,A/B NOT LIT; =2,A/B LIT	NONE
KT7	**	=0, NO D/B; =-1,D/B NOT LIT; =2,D/B LIT	NONE
SM1		ENGINE FACE MACH NUMBER (TYP 0.5)	NONE
PWCC		ENGINE CORRECTED MASSFLOW (PERCENT) (TYP 100.)	NONE
DIA1		ENGINE FACE DIAMETER	FEET
HTR	**	ENGINE HUB TO TIP RATIO	NONE
PRFD	**	DESIGN FAN PRESSURE RATIO	NONE
NOZZ		=0, CONVERGENT NOZZLE; =1, C-D NOZZLE ; =2,VC1 USED	NONE
YREN	**	YEAR OF ENGINE CERTIFICATION(60.=1960)	NONE
SCPP		AVERAGE STAGE COMPRESSOR PRESSURE RISE	NONE
IPRINT	**	IF IPRINT=1 DETAILED PROPULSION PRINT , 0 PRINT SUPPRESSED	
KERROR		ERROR CODE CONTROL	
		=0 (DEFAULT) NO PRINT ON ANY ERROR EXCEPT FATAL ERRORS	

```
                 =1, NON FATAL ERRORS PRINTED AT DETAILED SUMMARY
                   FATAL ERRORS PRINTED AS THEY OCCUR
                 =2, NON FATAL AND FATAL ERRORS PRINTED AT TIME OF OCCURANCE
   TWTO          THRUST TO WEIGHT RATIO AT T/O FOR ENGINE SIZING
   TWOAB         THRUST IN LBF PER ENGINE AT MACH AND ALTITUDE SPECIFIED WHEN IPS
                 =-3 IS CALLED FROM THE MISSION PROGRAMS THIS OPTION OVERRIDES THE
                 THRUST COMPUTED FROM THRUST = DRAG AND LETS THE USER SPECIFY THE
                 THRUST OF THE ENGINE AT A GIVEN MACH AND ALTITUDE W/O A/B
                 THE ENGINE WILL BE SIZED TO THRUST=TWOAB AT THE SPECIFIED MACH AND
                 ALTITUDE WHEN IPS = -3 IS CALLED AND TWOAB IS GREATER THEN ZERO.
   TWAB          ENGINE IS SIZED AT THRUST=TWAB PER ENGINE
                 ENGINE SIZED AT SPECIFIED MACH AND ALTITUDE WHEN IPS=-2 IS CALLED
                 FROM MISSION PROGRAM.
                 THIS OPTION OVERRIDES THE THRUST COMPUTED FROM THE THRUST
                 = DRAG AND LETS THE USER SPECIFY THE SIZE OF THE DESIRED ENGINE
                 AT A GIVEN MACH AND ALTITUDE WITH A/B.
                 THE ENGINE WILL BE SIZED TO A GIVEN THRUST = TWAB AT THE SPECIFIED
                 MACH AND ALTITUDE WHEN IPS = -2 IS SET AND TWAB IS GREATER THAN ZERO.
   XMACH ALTD XMACH AND ALTD ARE THE MACH AND ALTITUDE POINTS WHERE A SUMMARY OF
                 THE ENGINE SPECIFICATIONS IS DESIRED. THE INPUT SHOULD LOOK LIKE
                 XMACH=0.0,0.4,0.6,0.8,0.8,0.8,
                 ALTD=0.0,10000.,20000.,30000.,40000.,50000.,
                 WHERE THE PARTICULAR VALUES ARE UP TO THE USER.
                 CURRENTLY 6 VALUES MUST BE USED
   NAB       **  SPECIFIES THE NO OF POINTS IN THE ABOVE XMACH ALTD INPUT WHICH HAVE A
                 A/B AND OR D/B LIT.  POINTS GT NABHAVE THE A/B D/B LIT.POINTS LE NAB
                 DO NOT HAVE THE D/B  A/B LIT.
   AENWT         ACTUAL ENGINE WEIGHT IF ESTIMATE NOT WANTED                LBM
   AENLE         ACTUAL ENGINE LENGTH IF ESTIMATE NOT USED                  FEET
   AENDIA        ACTUAL ENGINE DIAMETER IF ESTIMATE NOT USED                FEET
   NOTE:.IF ANY OF THE ABOVE THREE INPUTS ARE ZERO OR NOT INPUT THE
                 ENGINE SIZE IS ESTIMATED (WEIGHT AND DIMENSIONS ) IN SUBROUTINE
                 ENGWT AND OFEDI FROM A REGRESSION ANALYSIS OF AVAILABLE
                 ENGINES. ONLY IF ALL THREE ARE INPUT AND NOT LE 0 IS THE
                 ENGINE SIZE AND WEIGHT OUTOUT AS THE ABOVE.
```

SAMPLE INPUT VALUES (FOR FIGURES 7,8, AND 9)

	JT8D-9	J79-17	CF6-50D
P2P1	16.9	13.5	30.0
P11P1	4.2	1.0	1.72
BA	1.03	0.0	4.4
T3	2180.	2270.	2930.
KODE	2	0	2
KT5	0	-1	0
KT7	0	0	0
PRED	1.91	1.0	1.56
YREN	68.	63.	70.
HTR	0.35	0.4	0.35
WCWA1	0.02	0.04	0.08
TWOAB	14500.	11870.	43225.
NAB	6	6	6
EB1	0.90	0.98	0.98
IPRINT	1	1	1
XMACH	0.0	0.0	0.0
	0.454	0.76	0.4
	0.75	0.87	0.5
	0.75	1.2	0.8
	0.84	2.0	0.85
	0.84	2.0	0.85
ALTD	0.0	0.0	0.0
	0.0	0.0	0.0
	15000.	35000.	25000.
	35000.	35000.	25000.
	35000.	35000.	35000.
	45000.	55000.	40000.

APPENDIX B

Program Output

1) DETAILED OUTPUT NOMENCLATURE
2) SAMPLE DETAILED OUTPUT (PWJT8D-9)
3) SAMPLE SUMMARY OUTPUT (PWJT8D-9)

DETAILED OUTPUT NOMENCLATURE

DETAILED OUTPUT:

(LISTED AS APPEARS ON DETAILED OUTPUT)

MACH	FLIGHT MACH NUMBER
ALTITUDE	FLIGHT ALTITUDE (FEET)
PWCC	PERCENT DESIGN CORRECTED AIRFLOW
PNTHF	PERCENT DESIGN CORRECTED FAN SPEED
PNTHC	PERCENT DESIGN CORRECTED HIGH PRESS COMPRESSOR SPEED
N THRUST	NET THRUST (LBF)
GR THRUST	GROSS THRUST (LBF)
RAM DRAG	RAM DRAG (LBF)
SFC	SPECIFIC FUEL CONSUMPTION (LBM/HR/LBF)
PROP EFF	PROPULSIVE EFFICIENCY
OVL EFF	OVERALL EFFICIENCY
WTOT	TOTAL MASSFLOW PER ENGINE (LBM/SEC)
WCORR	CORRECTED MASSFLOW PER ENGINE (LBM/SEC)
SPEC THR	SPECIFIC THRUST (LBF/(LBM/SEC))
FUEL FLOW	FUEL FLOW PER ENGINE (LBM/HR)
WCWAPRI	RATIO OF ACCOUNTABLE COOLING MASSFLOW TO TOTAL PRIMARY MASSFLOW
WBLEWPRI	RATIO OF BLEED MASSFLOW TO TOTAL PRIMARY MASSFLOW
POWER	POWER EXTRACTED FROM ENGINE (BTU/SEC) A POSITIVE NUMBER
DES BR	DESIGN BYPASS RATIO (DUCT TO PRIMARY FLOW)
DE OPR	DESIGN OVERALL COMPRESSOR PRESSURE RATIO
DES FPR	DESIGN FAN PRESSURE RATIO
DES TIT	DESIGN COMBUSTOR EXIT TEMPERATURE (DEG R)
ACT BR	ACTUAL BYPASS RATIO (DUCT TO PRIMARY MASSFLOW)
ACT OPR	ACTUAL OVERALL COMPRESSOR PRESSURE RATIO
ACT FPR	ACTUAL FAN PRESSURE RATIO
ACT TIT	ACTUAL COMBUSTOR EXIT TEMPERATURE (DEG R)
R10	INLET TOTAL PRESSURE RATIO
PR	TOTAL PRESSURE RATIO OF COMPONENT
ETC	COMPRESSOR ISENTROPIC EFFICIENCY
PNTH	PERCENT CORRECTED SPEED
ETB	BURNER EFFICIENCY
ETT	TURBINE ISENTROPIC EFFICIENCY
PN	PERCENT SPEED
NPR	PRIMARY NOZZLE PRESSURE RATIO
CV	PRIMARY NOZZLE VELOCITY COEFFICIENT
VJ	JET VELOCITY (FT/SEC)
NPRS	SECONDARY NOZZLE PRESSURE RATIO
CVD	SECONDARY NOZZLE VELOCITY COEFFICIENT

SAMPLE DETAILED OUTPUT

PW JT8D-9

```
                          DRY TURBOFAN ENGINE CYCLE PROGRAM
      MACH       =   0.000 ALTITUDE =      0.0 PWCC       = 100.00 PNTHF      = 100.00 PNTHC       = 100.00
      N THRUST =10528.4 GR THRUST=10528.4 RAM DRAG =      0.0
      SFC        =. .5406 PROP EFF = 0.0000 OVL EFF    = 0.0000
      WTOT       = 228.83 WCORR      = 228.96 SPEC THR = 46.009 FUEL FLOW=  5692.
      WCHARGI =      .020 WBLEED/PRI =  0.000 POWER     =      0.0
      DES BP     =  1.030 DES OPR    = 16.900 DES FPR    =  1.910 DES TIT    =2180.00
      ACT BP     =  1.030 ACT OPR    = 16.900 ACT FPR    =  1.910 ACT TIT    =2180.00

                                                       TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                       PTIN        PTOUT        TTIN        TTOUT
 INLET  R10 = 1.0000                                   2116.2      2116.2       518.7       518.7
 FAN    PR   =  1.910 FTC =  .8500 PNTH=100.000        2116.2      4041.9       518.7       641.9
 LPC    PR   =  4.200 FTC =  .8500 PNTH=100.000        2116.2      8888.0       518.7       823.9
 HPC    PR   =  4.024 FTC =  .8200 PNTH=100.000        8888.0     35763.7       823.9      1288.0
 COMB   PR   =   .940 FTB =  .9800 TITB= 2180.0       35763.7     33617.9      1288.0      2180.0
 HPT    PR   =  2.580 ETT =  .9200 PN   = 100.00      33617.9     13028.9      2180.0      1773.9
 COOL AIR                                             13028.9     13028.9      1773.9      1764.2
 LPT    PR   =  2.850 ETT =  .9200 PN   = 100.06      13028.9      4571.0      1764.2      1388.1
 A/B    PR   =  1.000 FTB =  .7500 TBUR= 1388.1        4571.0      4571.0      1388.1      1388.1
 P NOZZ NPR  =  2.160 CV   =  .9931 VJ   = 1812.3
 D/B    PR   = 1.0000 FTB =  .7500 TBUR=   641.9
 S NOZZ NPRS=  1.910 CVD  =  .9947 VJ   = 1135.7
```

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                    DRY TURBOFAN ENGINE CYCLE PROGRAM
MACH       =  0.000 ALTITUDE =      0.0 PWCC      = 100.00 PNTHF     = 100.00 PNTHC     = 100.00
N THRUST =14500.0 GR THRUST=14500.0 RAM DRAG =      0.0
SFC        =  .5406 PROP EFF = 0.0000 OVL EFF   = 0.0000
WTOT       = 315.16 WCORR     = 315.33 SPEC THR = 46.009 FUEL FLOW=  7839.
PCWAPRT =      .020 WHLEWPRT =  0.000 POWER     =      0.0
DES RR     =  1.030 DES OPR   = 16.900 DES FPR   =  1.910 DES TIT   =2180.00
ACT FR     =  1.030 ACT OPR   = 16.900 ACT FPR   =  1.910 ACT TIT   =2180.00

                                                  TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                    PTIN      PTOUT      TTIN      TTOUT
INLET   RIO = 1.0000                               2116.2     2116.2     518.7     518.7
FAN     PR  =  1.910 ETC =  .8500 PNTH=100.000     2116.2     4041.9     518.7     641.9
LPC     PR  =  4.200 ETC =  .8500 PNTH=100.000     2116.2     8888.0     518.7     823.9
HPC     PR  =  4.024 ETC =  .8200 PNTH=100.000     8888.0    35763.7     823.9    1288.0
COMB    PR  =   .940 ETB =  .9800 TITH= 2180.0    35763.7    33617.9    1288.0    2180.0
HPT     PR  =  2.580 ETT =  .9200 PN   = 100.08   33617.9    13028.9    2180.0    1773.9
COOL AIR                                          13028.9    13028.9    1773.9    1764.2
LPT     PR  =  2.850 ETT =  .9200 PN   = 100.06   13028.9     4571.0    1764.2    1388.1
A/B     PR  =  1.000 ETB =  .7500 TBUR= 1388.1     4571.0     4571.0    1388.1    1389.1
P NOZZ NPR  =  2.160 CV  =  .9931 VJ   = 1812.3
D/B     PR  = 1.0000 ETB =  .7500 TBUR=  641.9
S NOZZ NPRS=  1.910 CVD =  .9947 VJ   = 1135.7
```

```
                 DRY TURBOFAN ENGINE CYCLE PROGRAM
   MACH      =  0.000 ALTITUDE =      0.0 PWCC       =  98.00 PNTHF      =  98.72 PNTHC      =  98.70
   N THRUST =12769.4 GR THRUST=12769.4 RAM DRAG =      0.0
   SFC       =   .5103 PROP EFF = 0.0000 OVL EFF   = 0.0000
   WTOT      = 308.85 WCORR     = 309.02 SPFC THR = 41.344 FUEL FLOW=  6517.
   WCWAPRI =      .020 WBLEWPRI =  0.000 POWER    =       0.0
   DES RR    =  1.030 DES OPR   = 16.900 DES FPR   =  1.910 DES TIT   =2180.00
   ACT RR    =  1.030 ACT OPR   = 15.983 ACT FPR   =  1.886 ACT TIT   =2030.35

                                                  TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                   PTIN      PTOUT      TTIN      TTOUT
INLET  R10 = 1.0000                              2116.2    2116.2     518.7     518.7
FAN    PR  =  1.886 FTC =  .8500 PNTH= 98.720    2116.2    3991.2     518.7     639.3
LPC    PR  =  4.084 FTC =  .8500 PNTH= 98.720    2116.2    8642.3     518.7     816.7
HPC    PR  =  3.914 FTC =  .8200 PNTH= 98.702    8642.3   33824.0     816.7    1266.6
COMB   PR  =   .940 FTB =  .9800 TITB= 2030.4   33824.0   31794.6    1266.6    2030.4
HPT    PR  =  2.696 FTT =  .9198 PN   =  98.27  31794.6   11792.4    2030.4    1631.3
COOL AIR                                        11792.4   11792.4    1631.3    1623.9
LPT    PR  =  3.081 FTT =  .9198 PN   =  98.78  11792.4    3827.0    1623.9    1249.2
A/F    PR  =  1.000 FTB =  .7500 TBUR= 1249.2    3827.0    3827.0    1249.2    1249.2
P NOZZ NPR =  1.808 CV  =  .9953 VJ   = 1527.3
D/B    PR  = 1.0000 FTB =  .7500 TBUR=  639.3
S NOZZ NPRS=  1.886 CVD =  .9948 VJ   = 1123.4
```

```
                     DRY TURBOFAN ENGINE CYCLE PROGRAM
    MACH       =  0.000 ALTITUDE =      0.0 PWCC       =  95.00 PNTHF      =  97.44 PNTHC      =  97.40
    N THRUST =10907.0 GR THRUST=10907.0 RAM DRAG =      0.0
    SFC        =  .4875 PROP EFF = 0.0000 OVL EFF   = 0.0000
    WTOT       = 302.55 WCORR      = 302.72 SPEC THR = 36.050 FUEL FLOW=  5317.
    WCJAPRI =      .020 WFLEWPRI =  0.000 POWER     =       0.0
    DES BR     =  1.030 DES OPR    = 16.900 DES FPR   =  1.910 DES TIT   =2180.00
    ACT BR     =  1.030 ACT OPR    = 15.092 ACT FPR   =  1.862 ACT TIT   =1886.51

                                                    TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                    PTIN       PTOUT       TTIN       TTOUT
 INLET   RIO = 1.0000                              2116.2      2116.2      518.7      518.7
 FAN     PR   =  1.862 ETC =   .8500 PNTH= 97.440  2116.2      3939.6      518.7      636.6
 LPC     PR   =  3.968 ETC =   .8500 PNTH= 97.440  2116.2      8396.5      518.7      809.5
 HPC     PR   =  3.804 ETC =   .8200 PNTH= 97.405  8396.5     31938.5      809.5     1245.0
 COMB    PR   =   .940 ETB =   .9800 TITB= 1886.5 31938.5     30022.2     1245.0     1886.5
 HPT     PR   =  2.829 ETT =   .9194 PN   =  96.55 30022.2     10612.2     1896.5     1494.8
 COOL AIR                                         10612.2     10612.2     1494.8     1489.6
 LPT     PR   =  3.368 ETT =   .9194 PN   =  97.50 10612.2      3150.7     1489.6     1117.0
 A/B     PR   =  1.000 ETB =   .7500 TBUR= 1117.0  3150.7      3150.7     1117.0     1117.0
 P NOZZ  NPR  =  1.489 CV  =   .9974 VJ   = 1200.6
 D/B     PR   = 1.0000 ETB =   .7500 TBUR=  636.6
 S NOZZ  NPRS=  1.862 CVD =   .9950 VJ   = 1110.6
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                    DRY TURBOFAN ENGINE CYCLE PROGRAM
    MACH      =  0.000 ALTITUDE =      0.0 PWCC       =  94.00 PNTHF     =  96.16 PNTHC     =  96.11
    N THRUST = 8693.0 GR THRUST= 8693.0 RAM DRAG =     0.0
    SFC       =  .4871 PROP EFF = 0.0000 OVL EFF   = 0.0000
    WTOT      = 296.25 WCORR     = 296.41 SPEC THR = 29.344 FUEL FLOW=  4234.
    WCWAPRT =     .020 WBLEWPRT =  0.000 POWER     =      0.0
    DES BR    =  1.030 DES OPR   = 16.900 DES FPR   =  1.910 DES TIT   =2180.00
    ACT BR    =  1.030 ACT OPR   = 14.227 ACT FPR   =  1.837 ACT.TIT   =1748.44


                                                      TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                       PTIN       PTOUT      TTIN       TTOUT
INLET   RIO = 1.0000                                  2116.2     2116.2     518.7      518.7
FAN     PR   =  1.837 ETC =  .8500 PNTH= 96.160       2116.2     3887.2     518.7      633.9
LPC     PR   =  3.852 ETC =  .8500 PNTH= 96.160       2116.2     8150.8     518.7      802.0
HPC     PR   =  3.694 ETC =  .8200 PNTH= 96.107       8150.8    30107.0     802.0     1223.0
COMB    PR   =   .940 ETB =  .9800 TITB= 1748.4      30107.0    28300.6    1223.0     1748.4
HPT     PR   =  2.982 ETT =  .9186 PN   =   94.82    28300.6     9489.9    1748.4     1364.5
COOL AIR                                              9489.9     9489.9    1364.5     1361.4
LPT     PR   =  3.731 ETT =  .9186 PN   =   96.22     9489.9     2543.7    1361.4      991.7
A/B     PR   =  1.000 ETB =  .7500 TBUR=    991.7     2543.7     2543.7     991.7      991.7
P NOZZ NPR =  1.202 CV   =  .9992 VJ   =    781.5
D/B     PR   = 1.0000 ETB =  .7500 TBUR=    633.9
S NOZZ NPPS=  1.837 CVD  =  .9951 VJ   = 1097.4
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                    DRY TURBOFAN ENGINE CYCLE PROGRAM
   MACH      =   .454 ALTITUDE =     0.0 PNCC      = 100.00 PNTHF     = 100.00 PNTHC     = 100.00
   N THRUST =11576.9 GG THRUST=17173.7 RAM DRAG = 5596.8
   SFC       =. .7259 PROP EFF =  .4821 OVL EFF   =   .1736
   WTOT      = 355.68 WCORR    = 315.27 SPFC THR = 32.548 FUEL FLOW=  8404.
   WCWAPRI =     .020 WPLEWPRI = .0.000 POWER    =      0.0
   DES BR    =  1.030 DES OPR  = 16.900 DES FPR  =  1.910 DES TIT   =2180.00
   ACT BR    =  1.030 ACT OPR  = 16.900 ACT FPR  =  1.910 ACT TIT   =2180.00


                                                        TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                          PTIN       PTOUT      TTIN       TTOUT
 INLET  RIO = 1.0000                                    2437.4     2437.4      540.0      540.0
 FAN     PR  =  1.910 FTC =  .8500 PNTH=100.000         2437.4     4655.4      540.0      668.1
 LPC     PR  =  4.200 FTC =  .8500 PNTH=100.000         2437.4    10237.1      540.0      857.0
 HPC     PR  =  4.024 FTC =  .8200 PNTH=100.000        10237.1    41192.2      857.0     1337.2
 COMB    PR  =   .940 FTB =  .9800 TITB= 2180.0        41192.2    38720.6     1337.2     2180.0
 HPT     PR  =  2.691 FTT =  .9200 PN   = 101.99       38720.6    14387.8     2180.0     1757.5
 COOL AIR                                              14387.8    14387.8     1757.5     1749.1
 LPT     PR  =  3.029 FTT =  .9200 PN   = 102.10       14387.8     4750.3     1749.1     1356.1
 AZB     PR  =  1.000 FTB =  .7500 TBUR= 1356.1         4750.3     4750.3     1356.1     1356.1
 P NOZZ NPR =  2.245 CV   =  .9926 VJ   = 1829.5
 DZB     PR  = 1.0000 FTB =  .7500 TBUR=  668.1
 S NOZZ NPRS=  2.200 CVD  =  .9929 VJ   = 1264.3
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                         DRY TURBOFAN ENGINE CYCLE PROGRAM
     MACH       =    .454 ALTITUDE =      0.0 PWCC       =  98.00 PNTHF      =  98.72 PNTHC      =  98.70
     N THRUST =10742.1 GF THRUST=16227.0 RAM DRAG = 5484.9
     SFC        =   .7235 PROP EFF =   .4990 OVL.EFF   =   .1742
     WTOT       = 348.57 WCORR     = 308.96 SPEC THR = 30.818 FUEL FLOW=  7772.
     WCWAPPI =      .020 WBLEWPPI =  0.000 POWER     =      0.0
     DES BR     =  1.030 DES OPR   = 16.900 DES FPR   =  1.910 DES TIT   =2180.00
     ACT PR     =  1.030 ACT OPR   = 15.983 ACT FPR   =  1.886 ACT TIT   =2114.68


                                                    TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                      PTIN       PTOUT       TTIN       TTOUT
 INLET   RIO = 1.0000                                2437.4     2437.4      540.0      540.0
 FAN      PR   =  1.886 FTC =   .8500 PNTH= 98.720   2437.4     4597.0      540.0      665.4
 LPC      PR   =  4.084 FTC =   .8500 PNTH= 98.720   2437.4     9954.1      540.0      849.6
 HPC      PR   =  3.914 FTC =   .8200 PNTH= 98.702   9954.1    38958.1      849.6     1315.1
 COMB     PR   =   .940 FTB =   .9800 TITB= 2114.7  38958.1    36620.6     1315.1     2114.7
 HPT      PR   =  2.687 FTT =   .9199 PN   = 100.23  36620.6    13627.7     2114.7     1703.3
 COOL AIR                                           13627.7    13627.7     1703.3     1695.5
 LPT      PR   =  3.064 FTT =   .9198 PN   = 100.79  13627.7     4447.4     1695.5     1308.8
 A/B      PR   =  1.000 FTB =   .7500 TBUR= 1308.8   4447.4     4447.4     1308.8     1308.8
 P NOZZ NPR  =  2.102 CV    =   .9935 VJ   = 1730.8
 D/B      PR   = 1.0000 FTB =   .7500 TBUR=  665.4
 S NOZZ NPRS=  2.172 CVD   =   .9930 VJ   = 1252.8
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                       DRY TURBOFAN ENGINE CYCLE PROGRAM
     MACH      =    .454 ALTITUDE =     0.0 PWCC      =  96.00 PNTHF     =  97.44 PNTHC     =  97.40
     N THRUST = 8839.1 GF THRUST=14212.1 RAM DRAG = 5373.0
     SFC       =. .7178 PROP EFF =  .5526 OVL EFF   =  .1755
     WTOT      = 341.45 WCORR     = 302.66 SPEC THR = 25.887 FUEL FLOW=  6345.
     WCHAPRI =     .020 WBLEWPRI =  0.000 POWER     =      0.0
     DES BR    =  1.030 DES OPR   = 16.900 DES FPR   =  1.910 DES TIT   =2180.00
     ACT BR    =  1.030 ACT OPR   = 15.092 ACT FPR   =  1.862 ACT TIT   =1964.86


                                                       TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                         PTIN       PTOUT       TTIN       TTOUT
 INLET   RIO = 1.0000                                   2437.4     2437.4      540.0      540.0
 FAN      PR  =  1.862 ETC =  .8500 PNTH= 97.440        2437.4     4537.6      540.0      662.6
 LPC      PR  =  3.968 ETC =  .8500 PNTH= 97.440        2437.4     9671.0      540.0      842.0
 HPC      PR  =  3.804 ETC =  .8200 PNTH= 97.405        9671.0    36786.3      842.0     1292.8
 COMB     PR  =   .940 ETB =  .9800 TITB= 1964.9       36786.3    34579.2     1292.8     1964.9
 HPT      PR  =  2.819 ETT =  .9194 PN  =  98.47       34579.2    12266.0     1964.9     1561.0
 COOL AIR                                              12266.0    12266.0     1561.0     1555.4
 LPT      PR  =  3.347 ETT =  .9194 PN  =  99.49       12265.0     3664.7     1555.4     1170.6
 A/B      PR  =  1.000 ETB =  .7500 TBUR= 1170.6        3664.7     3664.7     1170.6     1170.6
 P NOZZ NPR  =  1.732 CV  =  .9958 VJ  = 1427.5
 D/B      PR  = 1.0000 ETB =  .7500 TBUR=  662.5
 S NOZZ NPRS=  2.144 CVD =  .9932 VJ  = 1241.0
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                    DRY TURBOFAN ENGINE CYCLE PROGRAM
    MACH      =    .454 ALTITUDE =      0.0 PWCC      =  94.00 PNTHF      =  96.16 PNTHC      =  96.11
    N THRUST = 6726.9 GR THRUST=11987.9 RAM DRAG = 5261.0
    SFC       =  .7517 PROP EFF =  .6123 OVL EFF   =  .1677
    WTOT      = 334.34 WCORR     = 296.35 SPEC THR = 20.120 FUEL FLOW=  5056.
    WCUAPRT =     .020 WBLPWPRI =  0.000 POWER     =      0.0
    DES PR    =  1.030 DES OPR   = 16.900 DES FPR   =  1.910 DES TIT   =2180.00
    ACT PR    =  1.030 ACT OPR   = 14.227 ACT FPR   =  1.837 ACT TIT   =1821.06

                                                       TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                        PTIN      PTOUT      TTIN      TTOUT
 INLET  RIO = 1.0000                                   2437.4     2437.4     540.0     540.0
 FAN     PR   =  1.837 ETC =  .8500 PNTH= 96.160       2437.4     4477.2     540.0     659.7
 LPC     PR   =  3.852 ETC =  .8500 PNTH= 96.160       2437.4     9388.0     540.0     834.3
 HPC     PR   =  3.694 ETC =  .8200 PNTH= 96.107       9388.0    34676.9     834.3    1270.1
 COMB    PR   =   .940 ETP =  .9800 TITB= 1821.1      34676.9    32596.2    1270.1    1821.1
 HPT     PR   =  2.971 ETT =  .9196 PN   =  96.71     32596.2    10970.8    1821.1    1425.1
 COOL AIR                                             10970.8    10970.8    1425.1    1421.7
 LPT     PR   =  3.705 ETT =  .9186 PN   =  98.18     10970.8     2961.4    1421.7    1039.6
 A/B     PR   =  1.000 ETB =  .7500 TBUR= 1039.6       2961.4     2961.4    1039.6    1039.6
 P NOZZ  NPR  =  1.399 CV  =  .9980 VJ   = 1069.0
 D/B     PR   = 1.0000 ETB =  .7500 TBUR=  659.7
 S NOZZ  NPRS=  2.116 CVD =  .9934 VJ   = 1228.7
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DRY TURBOFAN ENGINE CYCLE PROGRAM

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MACH      =    .454 ALTITUDE =      0.0 PWCC      =   92.00 PNTHF      =  94.88 PNTHC      =  94.81
J THRUST  = 3929.0 GR THRUST= 9078.1 RAM DRAG =  5149.1
SFC       =   .9921 PROP EFF =   .6061 OVL EFF   =   .1271
VTOT      = 327.23 WCORR    =  290.05 SPEC THR =  12.007 FUEL FLOW=  3898.
JCWAPRT =       .020 WBLEWPRT =   0.000 POWER     =      0.0
DES BR    =   1.030 DES OPR  =  16.900 DES FPR   =   1.910 DES TIT   =2180.00
ACT BR    =   1.030 ACT OPR  =  13.387 ACT FPR   =   1.812 ACT TIT   =1683.26
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								TOTAL PRESS(PSFA) AND TEMP(DEG R)			
								PTIN	PTOUT	TTIN	TTOUT
INLET	RIO =	1.0000						2437.4	2437.4	540.0	540.0
FAN	PR =	1.812	ETC =	.8500	PNTH=	94.880		2437.4	4415.8	540.0	656.8
LPC	PR =	3.736	ETC =	.8500	PNTH=	94.880		2437.4	9105.0	540.0	826.4
HPC	PR =	3.584	ETC =	.8200	PNTH=	94.810		9105.0	32629.7	826.4	1247.0
COMB	PR =	.940	ETB =	.9800	TITB=	1683.3		32629.7	30671.9	1247.0	1683.3
HPT	PR =	3.148	ETT =	.9175	PN =	94.95		30671.9	9743.8	1683.3	1295.7
COOL AIR								9743.8	9743.8	1295.7	1294.3
LPT	PR =	4.166	ETT =	.9176	PN =	96.87		9743.8	2338.8	1294.3	915.9
A/B	PR =	1.000	ETE =	.7500	TBUR=	915.9		2338.8	2338.8	915.9	915.9
P NOZZ	NPR =	1.105	CV =	.9999	VJ =	557.2					
D/F	PR =	1.0000	ETE =	.7500	TBUR=	656.8					
S NOZZ	NPRS=	2.057	CVD =	.9936	VJ =	1216.0					

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                          DRY TURBOFAN ENGINE CYCLE PROGRAM
     MACH        =    .750 ALTITUDE =15000.0 PWCC       = 100.00 PNTHF      = 100.00 PNTHC      = 100.00
     N THRUST  = 7849.8 GR THRUST=14222.6 RAM DRAG = 6372.8
     SFC         =   .8175 PROP EFF =   .5969 OVL EFF   =   .2414
     WTOT        = 259.73 WCORR      = 315.33 SPEC THR = 30.340 FUEL FLOW=  6417.
     WCWAPRI =      .020 WFLFWPRI =   0.000 POWER     =       0.0
     DES PR      =  1.030 DES OPR   = 16.900 DES FPR   =   1.910 DES TIT   =2180.00
     ACT PR      =  1.030 ACT OPR   = 16.900 ACT FPR   =   1.910 ACT TIT   =2175.36


                                                        TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                         PTIN       PTOUT       TTIN       TTOUT
  INLET  RID = 1.0000                                    1735.4     1735.4      517.6      517.6
  FAN     PR  =  1.910 ETC =  .8500 PNTH=100.000         1735.4     3314.7      517.6      640.6
  LPC     PR  =  4.200 ETC =  .8500 PNTH=100.000         1735.4     7288.8      517.6      822.2
  HPC     PR  =  4.024 ETC =  .8200 PNTH=100.000         7288.8    29328.7      822.2     1295.5
  COMB    PR  =   .940 ETB =  .9800 TIT8= 2175.4        29328.7    27569.0     1295.5     2175.4
  HPT     PR  =  2.591 ETT =  .9200 PN   =   99.90      27569.0    10682.9     2175.4     1769.9
  COOL AIR                                              10682.9    10682.9     1769.9     1760.3
  LPT     PR  =  2.851 ETT =  .9200 PN   =   99.95      10682.9     3747.0     1760.3     1384.8
  A/B     PR  =  1.000 ETB =  .7500 TBUR= 1384.8         3747.0     3747.0     1384.8     1384.8
  P NOZZ NPR =   3.136 CV  =  .9871 VJ   = 2140.8
  D/B     PR  = 1.0000 ETB =  .7500 TBUR=  640.6
  S NOZZ NPRS=   2.774 CVD =  .9893 VJ   = 1381.2
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                    DRY TURBOFAN ENGINE CYCLE PROGRAM
    MACH       =    .750 ALTITUDE =15000.0 PWCC      =   98.00 PNTHF     =   98.72 PNTHC     =   98.70
    N THRUST = 6655.4 GR THRUST=12900.7 RAM DRAG = 6245.4
    SFC        =  .8015 PROP EFF =   .6426 OVL EFF   =   .2462
    WTOT       = 253.55 WCORR      = 309.03 SPEC THR = 25.249 FUEL FLOW=   5334.
    WCKAPRT =     .020 WBLEDPRT =   0.000 POWER    =      0.0
    DES BR     =  1.030 DES OPR   = 16.900 DES FPR   =   1.910 DES TIT   =2180.00
    ACT BR     =  1.030 ACT OPR   = 15.983 ACT FPR   =   1.886 ACT TIT   =2026.03
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                                                  TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                    PTIN      PTOUT      TTIN      TTOUT
INLET   RIO = 1.0000                               1735.4     1735.4     517.6     517.6
FAN     PR  =  1.886 ETC =  .8500 PNTH= 98.720     1735.4     3273.0     517.6     638.0
LPC     PR  =  4.094 ETC =  .8500 PNTH= 98.720     1735.4     7087.3     517.6     815.1
HPC     PR  =  3.914 ETC =  .8200 PNTH= 98.702     7087.3    27738.1     815.1    1264.2
COMB    PR  =   .940 ETB =  .9800 TITB= 2026.0    27738.1    26073.8    1264.2    2026.0
HPT     PR  =  2.697 ETT =  .9195 PN  =  98.17    26073.8     9668.9    2026.0    1627.6
COOL AIR                                           9668.9     9668.9    1627.6    1620.3
LPT     PR  =  3.082 ETT =  .9198 PN  =  98.68     9668.9     3137.0    1620.3    1246.2
A/B     PR  =  1.000 ETB =  .7500 TBUR= 1246.2     3137.0     3137.0    1246.2    1246.2
P NOZZ NPR  =  2.626 CV  =  .9902 VJ  = 1891.0
D/B     PR  = 1.0000 ETB =  .7500 TBUR=  638.0
S NOZZ NPRS=   2.739 CVD =  .9895 VJ  = 1371.2
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                     DRY TURBOFAN ENGINE CYCLE PROGRAM
    MACH       =    .750 ALTITUDE =15000.0 PWCC       =   96.00 PNTHF      =  97.44 PNTHC      =  97.40
    N THRUST = 5430.0 GR THRUST=11547.9 RAM DRAG = 6117.9
    SFC        =   .8016 PROP EFF =    .6955 OVL EFF    = .2462
    WTOT       = 248.38 WCORR      = 302.72 SPEC THR = 21.862 FUEL FLOW=  4353.
    WCWAPRT =      .020 WBLEWPRT =   0.000 POWER    =       0.0
    DES HP     =  1.030 DES OPR    = 16.900 DES FPR    =  1.910 DES TIT   =2180.00
    ACT HP     =  1.030 ACT OPR    = 15.092 ACT FPR    =  1.862 ACT TIT   =1882.49


                                                           TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                            PTIN      PTOUT       TTIN       TTOUT
 INLET   RIO = 1.0000                                      1735.4    1735.4      517.6       517.6
 FAN      PR   =  1.862 ETC =   .8500 PNTH= 97.440         1735.4    3230.7      517.6       635.3
 LPC      PR   =  3.968 ETC =   .8500 PNTH= 97.440         1735.4    6885.8      517.6       807.8
 HPC      PR   =  3.804 ETC =   .8200 PNTH= 97.405         6885.8   26191.8      807.8      1242.5
 COMB     PR   =   .940 ETB =   .9800 TITB= 1882.5        26191.8   24620.3     1242.5      1882.5
 HPT      PR   =  2.830 ETT =   .9194 PN   =  96.45       24620.3    8701.2     1882.5      1491.5
 COOL AIR                                                  8701.2    8701.2     1491.5      1486.3
 LPT      PR   =  3.369 ETT =   .9194 PN   =  97.40        8701.2    2582.5     1486.3      1114.3
 A/B      PR   =  1.000 ETB =   .7500 TBUR= 1114.3         2582.5    2582.5     1114.3      1114.3
 P NOZZ   NPR  =  2.162 CV  =   .9931 VJ   = 1621.3
 D/B      PR   = 1.0000 ETB =   .7500 TBUR=  635.3
 S NOZZ   NPRS=   2.704 CVD =   .9897 VJ   = 1361.0
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                    DRY TURBOFAN ENGINE CYCLE PROGRAM
   MACH      =    .750 ALTITUDE =15000.0 PWCC      =  94.00 PNTHF     =  96.16 PNTHC     =  96.11
   N THRUST  = 4132.9 GR THRUST=10123.4 RAM DRAG  = 5990.5
   SFC       =   .8386 PROP EFF  =  .7524 OVL EFF   =  .2353
   WTOT      = 243.20 WCORR     = 296.41 SPEC THR  = 16.994 FUEL FLOW=  3466.
   WCWAPRT =    .020 WBLEWPRT  =  0.000 POWER     =     0.0
   DES BR    =  1.030 DES OPR   = 16.900 DES FPR   =  1.910 DES TIT  =2180.00
   ACT BR    =  1.030 ACT OPR   = 14.227 ACT FPR   =  1.837 ACT TIT  =1744.72
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                                                  TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                   PTIN      PTOUT      TTIN      TTOUT
 INLET  RIO = 1.0000                              1735.4    1735.4     517.6     517.6
 FAN    PR  =  1.837 FTC =  .8500 PNTH= 96.160    1735.4    3187.7     517.6     632.5
 LPC    PR  =  3.852 FTC =  .8500 PNTH= 96.160    1735.4    6684.2     517.6     800.4
 HPC    PR  =  3.694 FTC =  .8200 PNTH= 95.107    6684.2   24689.9     800.4    1220.6
 COMB   PR  =   .940 FTB =  .9800 TITB= 1744.7   24689.9   23208.5    1220.6    1744.7
 HPT    PR  =  2.983 FTT =  .9186 PN  =  94.72   23208.5    7780.9    1744.7    1361.5
 COOL AIR                                         7780.9    7780.9    1361.5    1358.3
 LPT    PR  =  3.732 FTT =  .9186 PN  =  96.12    7780.9    2084.9    1358.3     989.3
 A/B    PR  =  1.000 FTB =  .7500 TBUR=  989.3    2084.9    2084.9     989.3     989.3
 P NOZZ NPP =  1.775 CV  =  .9957 VJ  = 1319.4
 D/B    PR  = 1.0000 FTB =  .7500 TBUP=  632.5
 S NOZZ NPRS=  2.568 CVD =  .9900 VJ  = 1350.4
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                      DRY TURBOFAN ENGINE CYCLE PROGRAM
MACH       =    .750 ALTITUDE =15000.0 PJCC      =  92.00 PNTHF     =  94.88 PNTHC     =  94.81
N THRUST = 2661.7 GR THRUST= 8524.7 RAM DRAG = 5863.0
SFC      =. 1.0025 PROP EFF =   .7816 OVL EFF  =   .1968
WTOT     = 238.03 WCORR     = 290.11 SPEC THP = 11.182 FUEL FLOW=  2669.
WCMAPPI =     .020 WHLFMPRI =  0.000 POWER    =      0.0
DES BR   =   1.030 DES OPR   = 16.900 DES FPR  =  1.910 DES TIT  =2180.00
ACT BR   =   1.030 ACT OPR   = 13.387 ACT FPR  =  1.812 ACT TIT  =1612.69

                                                  TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                  PTIN      PTOUT     TTIN      TTOUT
INLET   RIO = 1.0000                              1735.4    1735.4    517.6     517.6
FAN     PR   =  1.812 ETC =  .8500 PNTH= 94.880   1735.4    3144.0    517.6     629.7
LPC     PR   =  3.736 ETC =  .8500 PNTH= 94.880   1735.4    6482.7    517.6     792.8
HPC     PR   =  3.584 ETC =  .8200 PNTH= 94.810   6482.7   23232.3    792.8    1198.3
COMB    PR   =   .940 ETB =  .9800 TITB= 1612.7  23232.3   21838.3   1198.3    1612.7
HPT     PR   =  3.161 ETT =  .9175 PN  =  93.00  21838.3    6909.3   1612.7    1237.7
COOL AIR                                          6909.3    6909.3   1237.7    1236.6
LPT     PR   =  4.200 ETT =  .9176 PN  =  94.84   6909.3    1644.9   1236.6     871.4
A/B     PR   =  1.000 ETB =  .7500 TBUR=  871.4   1644.9    1644.9    871.4     871.4
P NOZZ NPR  =  1.377 CV  =  .9981 VJ  =  955.4
D/F     PR   = 1.0000 ETB =  .7500 TBUR=  629.7
S NOZZ NPRS=  2.631 CVD =  .9902 VJ  = 1339.4
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                    DRY TURBOFAN ENGINE CYCLE PROGRAM
MACH       =    .750 ALTITUDE =15000.0 P/CC      =   90.00 PNTHF     =   93.60 PNTHC      =  93.51
N THRUST =   493.9 GR THRUST= 6229.4 RAM DRAG = 5735.5
SFC        = 3.9583 PROP EFF =   .3219 OVL EFF   =   .0498
WTOT       = 232.85 WCORR      = 283.80 SPEC THR =   2.121 FUEL FLOW=  1955.
WCWAPPI =      .020 WHLEWPRI =   0.000 POWER     =     0.0
DES PR     =  1.030 DES OPR    = 16.900 DES FPR  =   1.910 DES TIT   =2180.00
ACT FR     =  1.030 ACT. OPR   = 12.573 ACT FPR  =   1.786 ACT TIT   =1486.38
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	TOTAL PRESS(PSFA) AND TEMP(DEG R)			
	PTIN	PTOUT	TTIN	TTOUT
INLET R10 = 1.0000	1735.4	1735.4	517.6	517.6
FAN PR = 1.786 ETC = .8500 PNTH= 93.600	1735.4	3099.6	517.6	626.8
LPC PR = 3.619 ETC = .8500 PNTH= 93.600	1735.4	6281.2	517.6	785.0
HPC PR = 3.474 ETC = .8200 PNTH= 93.512	6281.2	21819.0	785.0	1175.6
COMB PR = .940 ETB = .9800 TITB= 1486.4	21819.0	20509.9	1175.6	1486.4
HPT PR = 3.369 ETT = .9161 PN = 91.28	20509.9	6087.6	1486.4	1120.3
COOL AIR	6087.6	6087.6	1120.3	1121.0
LPT PR = 4.821 ETT = .9162 PN = 93.56	6087.6	1262.8	1121.0	760.9
A/B PR = 1.000 ETB = .7500 TBUR= 760.9	1262.8	1262.8	760.9	760.9
P NOZZ NPR = 1.057 CV = 1.0002 VJ = 379.1				
D/B PR = 1.0000 ETB = .7500 TBUR= 626.8				
S NOZZ NPRS= 2.594 CVD = .9904 VJ = 1328.0				

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                      DRY TURBOFAN ENGINE CYCLE PROGRAM
    MACH      =    .750 ALTITUDE =35000.0 PWCC      = 100.00 PNTHF     = 100.00 PNTHC     = 100.00
    N THRUST = 3185.7 GR THRUST= 5852.5 RAM DRAG = 2666.8
    SFC       =. .7343 PROP EFF =   .6047 OVL EFF  =   .2474
    WTOT      = 117.57 WCORR     = 315.53 SPEC THR = 27.095 FUEL FLOW=  2339.
    WCWAFRT =     .020 WBLFWPRT =   0.000 POWER    =      0.0
    DES BR    =  1.030 DES OPR   = 16.900 DES FPR  =  1.910 DES TIT   =2180.00
    ACT BR    =  1.030 ACT OPR   = 16.900 ACT FPR  =  1.910 ACT TIT   =1841.15

                                                      TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                      PTIN      PTOUT     TTIN      TTOUT
 INLET   R10 = 1.0000                                 725.5     725.5     438.6     438.6
 FAN     PR  =   1.910 FTC =   .8500 PNTH=100.000     725.5    1385.9     438.6     543.4
 LPC     PR  =   4.200 FTC =   .8500 PNTH=100.000     725.5    3047.2     438.6     698.9
 HPC     PR  =   4.024 FTC =   .8200 PNTH=100.000    3047.2   12261.5     698.9    1100.1
 COMB    PR  =    .940 FTB =   .9800 TITB= 1841.1   12261.5   11525.8    1100.1    1841.1
 HPT     PR  =   2.611 FTT =   .9200 PN   =  92.10  11525.8    4415.1    1841.1    1483.9
 COOL AIR                                            4415.1    4415.1    1483.9    1476.2
 LPT     PR  =   2.907 FTT =   .9200 PN   =  92.02   4415.1    1518.8    1476.2    1146.4
 A/B     PR  =   1.000 FTB =   .7500 TBUR= 1146.4    1518.8    1518.8    1146.4    1146.4
 P NOZZ NPR =   3.042 CV  =   .9877 VJ   = 1922.2
 D/B     PR  = 1.0000 FTB =   .7500 TBUR=  543.4
 S NOZZ NPRS=   2.775 CVD =   .9893 VJ   = 1271.8
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                    DRY TURBOFAN ENGINE CYCLE PROGRAM
    MACH       =   .750 ALTITUDE =35000.0 PNCC      =  98.00 PNTHF     =  98.72 PNTHC     =  98.70
    N THRUST = 2689.2 GR THRUST= 5302.7 RAM DRAG = 2613.4
    SFC        =  .7223 PROP EFF =   .6514 OVL EFF   =  .2515
    WTOT       = 115.22 WCORR      = 309.22 SPFC THR = 23.339 FUEL FLOW=  1942.
    FCWAPRI =     .020 WBLEWPRI =   0.000 POWER     =      0.0
    DES BR     =  1.030 DES OPR   = 16.900 DES FPR   =  1.910 DES TIT   =2180.00
    ACT BR     =  1.030 ACT OPR   = 15.983 ACT FPR   =  1.886 ACT TIT   =1714.76
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	TOTAL PRESS(PSFA) AND TEMP(DEG R)			
	PTIN	PTOUT	TTIN	TTOUT
INLET RIO = 1.0000	725.5	725.5	438.6	438.6
FAN PR = 1.886 FTC = .8500 PNTH= 98.720	725.5	1368.4	438.6	541.2
LPC PR = 4.034 FTC = .8500 PNTH= 98.720	725.5	2963.0	438.6	692.7
HPC PR = 3.914 FTC = .8200 PNTH= 98.702	2963.0	11596.5	692.7	1081.5
COMB PR = .940 FTB = .9800 TITB= 1714.8	11596.5	10900.7	1081.5	1714.8
HPT PR = 2.729 FTT = .9198 PN = 90.51	10900.7	3993.7	1714.8	1364.0
COOL AIR	3993.7	3993.7	1364.0	1358.3
LPT PR = 3.150 FTT = .9198 PN = 90.84	3993.7	1268.0	1358.3	1030.7
A/B PR = 1.000 FTB = .7500 TBUR= 1030.7	1268.0	1268.0	1030.7	1030.7
P NOZZ NPR = 2.539 CV = .9907 VJ = 1691.6				
D/B PR = 1.0000 FTB = .7500 TBUR= 541.2				
S NOZZ NPRS= 2.740 CVD = .9895 VJ = 1262.6				

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                          DRY TURBOFAN ENGINE CYCLE PROGRAM
     MACH      =    .750 ALTITUDE =35000.0 PWCC      =  96.00 PNTHF     =  97.44 PNTHC     =  97.40
     N THRUST = 2177.4 GR THRUST= 4737.5 RAM DRAG = 2560.1
     SFC       =   .7267 PROP EFF =   .7050 OVL EFF   =  .2500
     WTOT      = 112.87 WCORR     = 302.91 SPEC THR = 19.292 FUEL FLOW=  1592.
     WCWAPRI =      .020 WFLEAPRI =   0.000 POWER     =       0.0
     DES BR    =   1.030 DES OPR  = 16.900 DES FPR   =   1.910 DES TIT   =2180.00
     ACT BR    =   1.030 ACT OPR  = 15.092 ACT FPR   =   1.862 ACT TIT   =1593.27


                                                           TOTAL PRESS(PSFA)  AND TEMP(DEG R)
                                                            PTIN       PTOUT       TTIN       TTOUT
 INLET   R10 = 1.0000                                       725.5      725.5       438.6      438.6
 FAN     PR  =  1.862 FTC =  .8500 PNTH= 97.440             725.5     1350.7       438.6      538.9
 LPC     PR  =  3.968 FTC =  .8500 PNTH= 97.440             725.5     2878.7       438.6      686.5
 HPC     PR  =  3.804 FTC =  .8200 PNTH= 97.405            2878.7    10950.0       686.5     1062.7
 COMB    PR  =   .940 FTB =  .9800 TITB= 1593.3           10950.0    10293.0      1062.7     1593.3
 HPT     PR  =  2.866 FTT =  .9194 PN   =  93.91          10293.0     3591.9      1593.3     1249.5
 COOL AIR                                                  3591.9     3591.9      1249.5     1245.6
 LPT     PR  =  3.451 FTT =  .9194 PN   =  89.66           3591.9     1040.9      1245.6      921.0
 A/B     PR  =  1.000 FTB =  .7500 TBUR=  921.0            1040.9     1040.9       921.0      921.0
 P NOZZ  NPR =  2.085 CV  =  .9936 VJ   = 1441.4
 D/B     PR  = 1.0000 FTB =  .7500 TBUR=  538.9
 S NOZZ  NPRS=  2.705 CVD =  .9897 VJ   = 1253.2
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                      DRY TURBOFAN ENGINE CYCLE PROGRAM
   MACH      =    .750 ALTITUDE =35000.0 PWCC      =  94.00 PNTHF     =  96.16 PNTHC     =  96.11
   N THRUST = 1630.9 GR THRUST= 4137.7 RAM DRAG = 2506.8
   SFC       =  .7705 PROP EFF =  .7604 OVL EFF   =  .2358
   WTOT      = 110.52 WCORR     = 296.60 SPEC THR = 14.757 FUEL FLOW=  1257.
   WCWAPRI =     .020 WELFUPRI =  0.000 POWER     =     0.0
   DES BR    =  1.030 DES OPR   = 16.900 DES FPR   =  1.910 DES TIT   =2180.00
   ACT BR    =  1.030 ACT OPR   = 14.227 ACT FPR   =  1.837 ACT TIT   =1476.67


                                                   TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                   PTIN       PTOUT      TTIN       TTOUT
 INLET  RIO = 1.0000                               725.5      725.5      438.6      438.6
 FAN    PR  =  1.337 ETC =  .8500 PNTH= 96.160     725.5     1332.7      438.6      536.5
 LPC    PR  =  3.852 ETC =  .8500 PNTH= 96.160     725.5     2794.5      438.6      680.1
 HPC    PR  =  3.694 ETC =  .8200 PNTH= 96.107    2794.5    10322.1      680.1     1043.5
 COMB   PR  =   .940 ETB =  .9800 TITB= 1476.7   10322.1     9702.8     1043.5     1476.7
 HPT    PR  =  3.023 ETT =  .9186 PN  =  87.32    9702.8     3210.1     1476.7     1140.4
 COOL AIR                                         3210.1     3210.1     1140.4     1138.2
 LPT    PR  =  3.831 ETT =  .9186 PN  =  88.48    3210.1      837.8     1138.2      817.4
 A/B    PR  =  1.000 ETB =  .7500 TBUR=  817.4     837.8      837.8      817.4      817.4
 P NOZZ NPR =  1.679 CV  =  .9962 VJ  = 1159.1
 D/B    PR. = 1.0000 ETB =  .7500 TBUR=  536.5
 S NOZZ NPRS=  2.669 CVD =  .9899 VJ  = 1243.4
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                         DRY TURBOFAN ENGINE CYCLE PROGRAM
    MACH      =    .750 ALTITUDE =35000.0 PWCC      =   92.00 PNTHF     =   94.88 PNTHC     =   94.81
    N THRUST  =   998.0 GR THRUST=  3451.4 RAM DRAG = 2453.4
    SFC       =   .9654 PROP EFF =   .7713 OVL EFF  =   .1882
    WTOT      = 108.17 WCORR     = 290.29 SPEC THR  =   9.227 FUEL FLOW=    963.
    WCBAPPT =     .020 WBLEWPPT =   0.000 POWER     =     0.0
    DES BR    =   1.030 DES OPR  = 16.900 DES FPR   =   1.910 DES TIT   =2180.00
    ACT BR    =   1.030 ACT OPR  = 13.387 ACT FPR   =   1.812 ACT TIT   =1364.93


                                                    TOTAL PRESS(PSFA)  AND TEMP(DEG R)
                                                    PTIN      PTOUT      TTIN       TTOUT
 INLET   RIO = 1.0000                               725.5     725.5      438.6      438.6
 FAN     PR   =  1.812 ETC =   .8500 PNTH= 94.880   725.5    1314.4      438.6      534.1
 LPC     PR   =  3.736 ETC =   .8500 PNTH= 94.880   725.5    2710.2      438.6      673.6
 HPC     PR   =  3.594 ETC =   .8200 PNTH= 94.810  2710.2    9712.7      673.6     1024.1
 COMB    PR   =   .940 ETB =   .9800 TITH= 1364.9  9712.7    9129.9     1024.1     1364.9
 HPT     PR   =  3.205 ETT =   .9175 PN   =  85.73 9129.9    2848.9     1364.9     1036.6
 COOL AIR                                          2848.9    2848.9     1036.6     1036.1
 LPT     PR   =  4.323 ETT =   .9176 PN   =  87.31 2848.9     659.0     1036.1      719.9
 A/B     PR   =  1.000 ETB =   .7500 TBUR=   719.9  659.0     659.0      719.9      719.9
 P NOZZ NPR  =  1.320 CV  =   .9985 VJ   =  811.3
 D/B,    PR   = 1.0000 ETB =   .7500 TBUR=   534.1
 S. NOZZ NPRS=   2.632 CVD =   .9902 VJ   = 1233.3
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                         DRY TURBOFAN ENGINE CYCLE PROGRAM
     MACH       =    .750 ALTITUDE =35000.0 PUCC       =  90.00 PNTHF      =  93.60 PNTHC      =  93.51
     N THRUST = -123.0 GR THRUST= 2277.1 RAM DRAG = 2400.1
     SFC        =-5.6959 PROP EFF = -.2318 OVL EFF   = -.0319
     WTOT       = 105.82 WCOR2      = 283.98 SPFC THR = -1.163 FUEL FLOW=    701.
     WCUAPRI =     .020 WBLEWPRI =   0.000 POWER     =       0.0
     DES BR     =  1.030 DES OPR   = 16.900 DES FPR   =  1.910 DES TIT   =2180.00
     ACT BR     =  1.030 ACT OPR   = 12.573 ACT FPR   =  1.786 ACT TIT   =1258.02


                                                  TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                  PTIN       PTOUT      TTIN       TTOUT
 INLET  RIO = 1.0000                              725.5      725.5      438.6      438.6
 FAN    PR  =  1.786 ETC =  .8500 PNTH= 93.600    725.5     1295.8      438.6      531.6
 LPC    PR  =  3.619 ETC =  .8500 PNTH= 93.600    725.5     2626.0      438.6      666.9
 HPC    PR  =  3.474 ETC =  .8200 PNTH= 93.512   2626.0     9121.9      666.9     1004.4
 COMB   PR  =   .940 ETB =  .9800 TITB= 1258.0   9121.9     8574.5     1004.4     1258.0
 HPT    PR  =  3.418 ETT =  .9161 PN  =  84.13   8574.5     2508.8     1258.0      938.3
 COOL AIR                                        2508.8     2508.8      938.3      939.3
 LPT    PR  =  4.974 ETT =  .9162 PN  =  86.13   2508.8      504.3      939.3      628.7
 AZB    PR  =  1.000 ETB =  .7500 TBUR=  628.7    504.3      504.3      628.7      628.7
 P NOZZ NPP =  1.010 CV  = 1.0005 VJ  =  146.6
 DZB    PR  = 1.0000 ETB =  .7500 TBUR=  531.6
 S NOZZ NPRS=  2.595 CVD =  .9904 VJ  = 1222.8
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DRY TURBOFAN ENGINE CYCLE PROGRAM

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                    DRY TURBOFAN ENGINE CYCLE PROGRAM
MACH      =   .840 ALTITUDE =35000.0 PUCC      = 100.00 PNTHF     = 100.00 PNTHC     = 100.00
N THRUST = 3398.7 GR THRUST= 6621.9 RAM DRAG = 3223.2
SFC       =  .7680 PROP EFF =  .6320 OVL EFF  =  .2650
WTOT      = 126.88 WCORR     = 315.51 SPFC THP = 26.767 FUEL FLOW=  2610.
WCWAPRI =     .020 WPLFWPRI =  0.000 POWER    =      0.0
DES BR    =  1.030 DES OPR  = 16.900 DES FPR  =  1.910 DES TIT  =2180.00
ACT BR    =  1.030 ACT OPR  = 16.900 ACT FPR  =  1.910 ACT TIT  =1888.95


                                                      TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                       PTIN      PTOUT      TTIN      TTOUT
INLET  RIO = 1.0000                                    793.1      793.1     449.9     449.9
FAN    PR  =  1.910 ETC =  .8500 PNTH=100.000          793.1     1514.7     449.9     557.3
LPC    PR  =  4.200 ETC =  .8500 PNTH=100.000          793.1     3330.8     449.9     716.6
HPC    PR  =  4.024 ETC =  .8200 PNTH=100.000         3330.8    13402.7     716.6    1127.0
COMB   PR  =   .940 ETB =  .9800 TIT5= 1889.0        13402.7    12598.5    1127.0    1889.0
HPT    PR  =  2.606 ETT =  .9200 PN  =   93.26       12598.5     4833.8    1889.0    1524.6
COOL AIR                                              4833.8     4833.8    1524.6    1516.6
LPT    PR  =  2.899 ETT =  .9200 PN  =   93.20        4833.8     1667.6    1516.6    1180.0
A/B    PR  =  1.000 ETB =  .7500 TBUR= 1180.0         1667.6     1667.6    1180.0    1180.0
P NOZZ NPR =  3.340 CV  =  .9959 VJ  = 2015.3
D/B    PR  = 1.0000 ETB =  .7500 TBUR=  557.3
S NOZZ NPRS=  3.033 CVF =  .9977 VJ  = 1332.8
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                    DRY TURBOFAN ENGINE CYCLE PROGRAM
    MACH      =    .840 ALTITUDE =35000.0 P4CC      =   98.00 PNTHF     =   98.72 PNTHC     =  98.70
    N THRUST = 2368.5 GR THRUST= 6027.3 RAM DRAG = 3158.7
    SFC       =   .7557 PROP EFF =   .6775 OVL EFF   =   .2693
    WTOT      = 124.34 WCORR     = 309.20 SPEC THR = 23.070 FUEL FLOW=   2168.
    WCWAPRI =      .020 WPLFWPRI =  0.000 POWER     =        0.0
    DES BR    =  1.030 DES OPR   = 16.900 DES FPR   =   1.910 DES TIT   =2180.00
    ACT BR    =  1.030 ACT OPR   = 15.983 ACT FPR   =   1.886 ACT TIT   =1759.28

                                                  TOTAL PRESS(PSFA)  AND TEMP(DEG R)
                                                  PTIN        PTOUT       TTIN        TTOUT
 INLET  RIO = 1.0000                              793.1       793.1       449.9       449.9
 FAN    PR  =  1.886 ETC =  .8500 PNTH= 98.720    793.1      1495.7       449.9       555.1
 LPC    PR  =  4.084 ETC =  .8500 PNTH= 98.720    793.1      3238.7       449.9       710.3
 HPC    PR  =  3.914 ETC =  .8200 PNTH= 98.702   3238.7     12675.8       710.3      1108.0
 COMB   PR  =   .940 ETB =  .9800 TIT6= 1759.3  12675.8     11915.2      1108.0      1759.3
 HPT    PR  =  2.725 ETT =  .9198 PN  =  91.65  11915.2      4372.8      1759.3      1401.5
 COOL AIR                                        4372.8      4372.8      1401.5      1395.5
 LPT    PR  =  3.140 ETT =  .9198 PN  =  92.00   4372.8      1392.8      1395.5      1061.1
 A/B    PR  =  1.000 ETB =  .7500 TBUR= 1061.1   1392.8      1392.8      1061.1      1061.1
 P NOZZ NPR =  2.789 CV  =  .9892 VJ  = 1787.3
 D/B    PR  = 1.0000 ETB =  .7500 TBUR=  555.1
 S NOZZ NPRS=  2.995 CVD =  .9880 VJ  = 1323.9
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                    DRY TURBOFAN ENGINE CYCLE PROGRAM
   MACH      =   .840 ALTITUDE =35000.0 PWCC      =  96.00 PNTHF     =  97.44 PNTHC     =  97.40
   N THRUST = 2326.1 GR THRUST= 5420.3 RAM DRAG = 3094.3
   SFC       =  .7593 PROP EFF =  .7294 OVL EFF   =  .2680
   WTOT      = 121.80 WCORR    = 302.39 SPEC THR = 19.097 FUEL FLOW=  1766.
   WCNAPRI =     .020 WBLEWPRT =  0.000 POWER    =     0.0
   DES BR    =  1.030 DES OPR  = 16.900 DES FPR  =  1.910 DES TIT  =2180.00
   ACT BR    =  1.030 ACT OPR  = 15.092 ACT FPR  =  1.862 ACT TIT  =1634.64


                                                 TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                  PTIN      PTOUT      TTIN      TTOUT
 INLET   RIO = 1.0000                             793.1     793.1      449.9     449.9
 FAN     PR  =  1.862 ETC =  .8500 PNTH= 97.440   793.1    1476.4      449.9     552.7
 LPC     PR  =  3.968 ETC =  .8500 PNTH= 97.440   793.1    3146.7      449.9     703.9
 HPC     PR  =  3.804 ETC =  .8200 PNTH= 97.405  3146.7   11969.1      703.9    1088.7
 COMB    PR  =   .940 ETB =  .9800 TIT5= 1634.6 11969.1   11251.0     1088.7    1634.6
 HPT     PR  =  2.861 ETT =  .9194 PN  =  90.04 11251.0    3933.1     1634.6    1283.9
 COOL AIR                                        3933.1    3933.1     1283.9    1279.8
 LPT     PR  =  3.439 ETT =  .9194 PN  =  90.81  3933.1    1143.7     1279.8     948.2
 A/B     PR  =  1.000 ETB =  .7500 TBUR=  948.2  1143.7    1143.7      948.2     948.2
 P NOZZ NPR  =  2.290 CV  =  .9923 VJ  = 1542.0
 D/B     PR  = 1.0000 ETB =  .7500 TBUR=  552.7
 S NOZZ NPRS=  2.957 CVD =  .9882 VJ  = 1314.7
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                     DRY TURBOFAN ENGINE CYCLE PROGRAM
MACH       =   .840 ALTITUDE =35000.0 PWCC      =  94.00 PNTHF      =  96.16 PNTHC      =  96.11
N THRUST = 1755.0 GR THRUST= 4784.8 RAM DRAG = 3029.8
SFC        =  .7995 PROP EFF =   .7836 OVL EFF   =   .2545
WTOT       = 119.27 WCORR      = 296.57 SPFC THR = 14.715 FUEL FLOW=  1403.
WCWAPPI =     .020 WBLEWPRI =  0.000 POWER     =      0.0
DES BR     =  1.030 DES OPR   = 16.900 DES FPR   =  1.910 DES TIT   =2180.00
ACT BR     =  1.030 ACT OPR   = 14.227 ACT FPR   =  1.837 ACT TIT   =1515.01

                                                        TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                         PTIN     PTOUT      TTIN      TTOUT
INLET   RID = 1.0000                                     793.1     793.1     449.9     449.9
FAN     PR  =  1.837 ETC =   .8500 PNTH= 96.160          793.1    1456.7     449.9     550.3
LPC     PR  =  3.852 ETC =   .8500 PNTH= 96.160          793.1    3054.6     449.9     697.4
HPC     PR  =  3.694 ETC =   .8200 PNTH= 96.107         3054.6   11282.8     697.4    1069.2
COMB    PR  =   .940 ETB =   .9800 TITB= 1515.0        11282.8   10605.8    1069.2    1515.0
HPT     PR  =  3.017 ETT =   .9186 PN   =  88.42       10605.8    3515.4    1515.0    1171.7
COOL AIR                                                3515.4    3515.4    1171.7    1169.4
LPT     PR  =  3.817 ETT =   .9186 PN   =  89.62        3515.4     921.0    1169.4     841.5
A/B     PR  =  1.000 ETB =   .7500 TBUR=   841.5         921.0     921.0     841.5     841.5
P NOZZ NPR =  1.844 CV   =   .9951 VJ   = 1269.6
D/B     PR  = 1.0000 ETB =   .7500 TBUR=   550.3
S NOZZ NPRS=  2.917 CVD  =   .9884 VJ   = 1305.2
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                    DRY TURBOFAN ENGINE CYCLE PROGRAM
MACH     =    .840 ALTITUDE =35000.0 PWCC      =  92.00 PNTHF     =  94.88 PNTHC     =  94.81
N THRUST = 1116.8 GR THRUST= 4082.2 RAM DRAG = 2965.3
SFC      =  .9639 PROP EFF =  .6079 OVL EFF  =  .2111
WTOT     = 116.73 WCORR    = 290.26 SPEC THR =  9.568 FUEL FLOW=  1076.
FCWAPRT =    .020 WBLEAPRT =  0.000 POWER    =    0.0
DES BR   =  1.030 DES OPR  = 16.900 DES FPR  =  1.910 DES TIT  =2180.00
ACT BR   =  1.030 ACT.OPR  = 13.387 ACT FPR  =  1.812 ACT.TIT  =1400.36

                                                TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                PTIN      PTOUT      TTIN      TTOUT
INLET   RIO = 1.0000                            793.1     793.1      449.9     449.9
FAN     PR  =  1.812 ETC =  .8500 PNTH= 94.880  793.1     1436.8     449.9     547.8
LPC     PR  =  3.736 ETC =  .8500 PNTH= 94.880  793.1     2962.5     449.9     690.7
HPC     PR  =  3.584 ETC =  .8200 PNTH= 94.810  2962.5    10616.7    690.7     1049.3
COMB    PR  =   .940 ETB =  .9800 TITB= 1400.4  10616.7   9979.7     1049.3    1400.4
HPT     PR  =  3.199 ETT =  .9175 PN   =  86.81 9979.7    3120.0     1400.4    1065.1
COOL AIR                                        3120.0    3120.0     1065.1    1064.5
LPT     PR  =  4.305 ETT =  .9176 PN   =  88.43 3120.0    724.7      1064.5    741.2
A/B     PR  =  1.000 ETB =  .7500 TBUR=  741.2  724.7     724.7      741.2     741.2
P NOZZ NPR  =  1.451 CV  =  .9976 VJ   =  946.8
D/B     PR  = 1.0000 ETB =  .7500 TBUR=  547.8
S NOZZ NPRS=   2.877 CVD =  .9887 VJ   = 1295.4
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                    DRY TURBOFAN ENGINE CYCLE PROGRAM
    MACH      =   .840 ALTITUDE =35000.0 PWCC      =  90.00 PNTHF     =  93.60 PNTHC     =  93.51
    N THRUST  =  254.0 GG THRUST= 3154.8 RAM DRAG = 2900.9
    SFC       = 3.0858 PROP EFF  =  .4146 OVL EFF   =  .0659
    WTOT      = 114.19 WCORR     = 283.95 SPEC THR  =  2.224 FUEL FLOW=   784.
    WCWAPRI  =    .020 WBLEWPRT  =  0.000 POWER     =    0.0
    DES BR    =  1.030 DES OPR   = 16.900 DES FPR   =  1.910 DES TIT   =2180.00
    ACT BR    =  1.030 ACT OPR   = 12.573 ACT FPR   =  1.786 ACT TIT   =1290.68
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	TOTAL PRESS(PSFA) AND TEMP(DEG R)			
	PTIN	PTOUT	TTIN	TTOUT
INLET RIO = 1.0000	793.1	793.1	449.9	449.9
FAN PR = 1.786 ETC = .8500 PNTH= 93.600	793.1	1416.5	449.9	545.3
LPC PR = 3.619 ETC = .8500 PNTH= 93.600	793.1	2870.4	449.9	683.9
HPC PR = 3.474 ETC = .8200 PNTH= 93.512	2870.4	9970.8	683.9	1029.2
COMB PR = .940 ETB = .9800 TITB= 1290.7	9970.8	9372.6	1029.2	1290.7
HPT PR = 3.411 ETT = .9161 PN = 85.20	9372.6	2747.7	1290.7	964.1
COOL AIR	2747.7	2747.7	964.1	965.1
LPT PR = 4.953 ETT = .9162 PN = 87.23	2747.7	554.8	965.1	647.2
A/B PR = 1.000 ETB = .7500 TBUR= 647.2	554.8	554.8	647.2	647.2
P NOZZ NPR = 1.111 CV = .9998 VJ = 480.3				
D/B PR = 1.0000 ETB = .7500 TBUR= 545.3				
S NOZZ NPRS= 2.837 CVD = .9889 VJ = 1285.2				

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                    DRY TURBOFAN ENGINE CYCLE PROGRAM
   MACH      =   .840 ALTITUDE =45000.0 PWCC     = 100.00 PNTHF     = 100.00 PNTHC     = 100.00
   N THRUST = 2102.4 GR THRUST= 4100.0 RAM DRAG = 1997.6
   SFC      =  .7630 PROP EFF =  .6324 OVL EFF  =  .2653
   WTOT     =  74.04 WCORR    = 315.52 SPEC THR = 26.598 FUEL FLOW=  1604.
   PCWAPRI =    .020 WFLEWPRT =  0.000 POWER    =     0.0
   DES BR   =  1.030 DES OPR  = 16.900 DES FPR  =  1.910 DES TIT  =2180.00
   ACT BR   =  1.030 ACT OPR  = 16.900 ACT FPR  =  1.910 ACT TIT  =1869.26


                                                     TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                     PTIN      PTOUT     TTIN      TTOUT
INLET  RID = 1.0000                                  491.5     491.5     445.3     445.3
FAN    PR  =  1.910 FTC =  .8500 PNTH=100.000        491.5     938.7     445.3     551.6
LPC    PR  =  4.200 FTC =  .8500 PNTH=100.000        491.5    2064.2     445.3     709.3
HPC    PR  =  4.024 FTC =  .8200 PNTH=100.000       2064.2    8305.9     709.3    1115.9
COMB   PR  =   .940 FTB =  .9800 TITB= 1869.3       8305.9    7807.5    1115.9    1869.3
HPT    PR  =  2.608 FTT =  .9200 PN   =  92.79      7807.5    2993.6    1869.3    1507.8
COOL AIR                                            2993.6    2993.6    1507.8    1500.0
LPT    PR  =  2.902 FTT =  .9200 PN   =  92.71      2993.6    1031.5    1500.0    1166.1
A/B    PR  =  1.000 FTB =  .7500 TBUR= 1166.1       1031.5    1031.5    1166.1    1166.1
P NOZZ NPR =  3.334 CV  =  .9859 VJ   = 2001.9
D/B    PR  = 1.0000 FTB =  .7500 TBUR=  551.6
S NOZZ NPRS=  3.034 CVD =  .9877 VJ   = 1325.9
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                    DRY TURBOFAN ENGINE CYCLE PROGRAM
MACH       =   .840 ALTITUDE =45000.0 PWCC      =  98.00 PNTHF     =  98.72 PNTHC     =  98.70
N THRUST = 1774.0 GR THRUST= 3731.6 RAM DRAG = 1957.6
SFC        =  .7508 PROP EFF =   .6780 OVL EFF   =  .2696
WTOT       =  77.46 WCORR    = 309.21 SPEC THR = 22.901 FUEL FLOW=  1332.
WCWAPRT =      .020 WBLFWPRI =  0.000 POWER     =      0.0
DES BR     =  1.030 DES OPR  = 16.900 DES FPR   =  1.910 DES TIT  =2180.00
ACT BR     =  1.030 ACT OPR  = 15.983 ACT FPR   =  1.886 ACT TIT  =1740.94

                                                  TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                  PTIN      PTOUT      TTIN      TTOUT
INLET   RTO = 1.0000                              491.5     491.5      445.3     445.3
FAN     PR  =  1.886 FTC =  .8500 PNTH= 98.720    491.5     926.9      445.3     549.3
LPC     PR  =  4.084 FTC =  .8500 PNTH= 98.720    491.5    2007.1      445.3     703.1
HPC     PR  =  3.914 FTC =  .8200 PNTH= 98.702   2007.1    7855.4      703.1    1097.1
COMB    PR  =   .940 FTB =  .9800 TITB= 1740.9   7855.4    7384.1     1097.1    1740.9
HPT     PR  =  2.727 FTT =  .9198 PN  =  91.18   7384.1    2708.0     1740.9    1386.1
COOL AIR                                         2708.0    2708.0     1386.1    1380.2
LPT     PR  =  3.144 FTT =  .9198 PN  =  91.53   2708.0     861.4     1380.2    1048.5
A/B     PR  =  1.000 FTB =  .7500 TBUR= 1048.5    861.4     861.4     1048.5    1048.5
P NOZZ NPR  =  2.784 CV  =  .9892 VJ  = 1775.1
D/B     PR  = 1.0000 FTB =  .7500 TBUR=  549.3
S NOZZ NPRS=   2.995 CVD =  .9880 VJ  = 1317.1
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                              DRY TURBOFAN ENGINE CYCLE PROGRAM
     MACH        =    .840 ALTITUDE =45000.0 PWCC        =    96.00 PNTHF      =  97.44 PNTHC       =  97.40
     N THRUST = 1437.9 GF THRUST= 3355.5 RAM DRAG = 1917.7
     SFC         = .7547 PROP EFF =    .7299 OVL EFF     =     .2683
     WTOT        =   75.88 WCORR      = 302.89 SPEC THR = 18.949 FUEL FLOW=   1085.
     WCWAPRT =       .020 WBLEEDPRT =    0.000 POWER      =       0.0
     DES BP      =  1.030 DES OPR    = 16.400 DES FPR    =   1.910 DES TIT    =2180.00
     ACT BP      =  1.030 ACT OPR    = 15.092 ACT FPR    =   1.862 ACT TIT    =1617.60

                                                              TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                              PTIN        PTOUT       TTIN        TTOUT
INLET   RIO  = 1.0000                                         491.5       491.5       445.3       445.3
FAN     PR   =  1.862 FTC =  .8500 PNTH= 97.440               491.5       914.9       445.3       547.0
LPC     PR   =  3.958 FTC =  .8500 PNTH= 97.440               491.5      1950.0       445.3       696.8
HPC     PR   =  3.804 FTC =  .8200 PNTH= 97.405              1950.0      7417.5       696.8      1078.0
COMB    PR   =   .940 FTP =  .9800 TITR= 1617.6              7417.5      6972.4      1078.0      1617.6
HPT     PR   =  2.863 FTT =  .9194 PN   =  89.58             6972.4      2435.7      1617.6      1269.7
COOL AIR                                                     2435.7      2435.7      1269.7      1265.7
LPT     PR   =  3.444 FTT =  .9194 PN   =  90.34             2435.7       707.3      1265.7       937.0
A/B     PR   =  1.000 FTB =  .7500 TBUR=   937.0              707.3       707.3       937.0       937.0
P NOZZ  NPR  =  2.296 CV  =  .9923 VJ   = 1531.0
D/B     PR   = 1.0000 FTB =  .7500 TBUR=   547.0
S NOZZ  NPRS=   2.957 CVD =  .9882 VJ   = 1307.9
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                         DRY TURBOFAN ENGINE CYCLE PROGRAM
     MACH      =    .840 ALTITUDE =45000.0 PWCC      =   94.00 PNTHF      =  96.16 PNTHC    =  96.11
     N THRUST = 1083.9 GR THRUST= 2961.6 RAM DRAG = 1877.7
     SFC       =   .7952 PROP EFF =   .7840 OVL EFF   =   .2546
     WTOT      =   74.30 WCORR     = 296.59 SPEC THR = 14.589 FUEL FLOW=    862.
     WCHARPT =      .020 WBLEWPPT =   0.000 POWER     =     0.0
     DES BR    =   1.030 DES OPR   = 16.900 DES FPR   =   1.910 DES TIT   =2180.00
     ACT BR    =   1.030 ACT OPR   = 14.227 ACT FPR   =   1.837 ACT TIT   =1499.21

                                                        TOTAL PRESS(PSFA)  AND TEMP(DEG R)
                                                        PTIN       PTOUT       TTIN        TTOUT
 INLET   RIO = 1.0000                                   491.5      491.5       445.3       445.3
 FAN     PR   =   1.837 ETC =   .8500 PNTH= 96.160      491.5      902.8       445.3       544.6
 LPC     PR   =   3.852 ETC =   .8500 PNTH= 96.160      491.5     1893.0       445.3       690.3
 HPC     PR   =   3.694 ETC =   .8200 PNTH= 96.107     1893.0     6992.1       690.3      1058.6
 COMB    PR   =    .940 ETB =   .9800 TITB= 1499.2     6992.1     6572.6      1058.6      1499.2
 HPT     PR   =   3.019 ETT =   .9186 PN   =  87.97    6572.6     2176.9      1499.2      1158.8
 COOL  AIR                                             2176.9     2176.9      1158.8      1156.5
 LPT     PR   =   3.823 ETT =   .9186 PN   =  89.15    2176.9      569.4      1156.5       831.6
 AZB     PR   =   1.000 ETB =   .7500 TBUR=  831.6      569.4      569.4       831.6       831.6
 P NOZZ NPR   =   1.940 CV  =   .9951 VJ   = 1259.9
 DZB     PR   =  1.0000 ETB =   .7500 TBUR=  544.6
 S NOZZ NPRS=     2.917 CVD =   .9884 VJ   = 1298.5
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                        DRY TURBOFAN ENGINE CYCLE PROGRAM
    MACH      =    .640 ALTITUDE =45000.0 PWCC      =  92.00 PNTHF     =  94.88 PNTHC     =  94.81
    N THRUST =  688.0 GR THRUST= 2525.8 RAM DRAG = 1837.8
    SFC       =. .9609 PROP EFF =  .8075 OVL EFF   =  .2107
    WTOT      =  72.72 WCORR     = 290.27 SPEC THR =  9.461 FUEL FLOW=   661.
    ICWAPRT =     .020 BLEWPRT =  0.000 POWER     =    0.0
    DES BR    =  1.030 DES OPR   = 16.900 DES FPR   =  1.910 DES TIT   =2180.00
    ACT BR    =  1.030 ACT OPR   = 13.387 ACT FPR   =  1.812 ACT TIT   =1385.76

                                                      TOTAL PRESS(PSFA)  AND TEMP(DEG R)
                                                      PTIN      PTOUT      TTIN      TTOUT
INLET   RIO = 1.0000                                  491.5     491.5      445.3     445.3
FAN     PR  =   1.812 FTC =  .8500 PNTH= 94.880       491.5     890.4      445.3     542.2
LPC     PR  =   3.736 FTC =  .8500 PNTH= 94.880       491.5    1835.9      445.3     683.7
HPC     PR  =   3.584 FTC =  .9200 PNTH= 94.810      1835.9    6579.3      683.7    1039.0
COMB    PR  =    .940 FTF =  .9800 TITB= 1385.8      6579.3    6184.6     1039.0    1385.8
HPT     PR  =   3.201 FTT =  .9175 PN   =  86.37     6184.6    1932.0     1385.8    1053.4
COOL AIR                                             1932.0    1932.0     1053.4    1052.8
LPT     PR  =   4.313 FTT =  .9176 PN   =  87.97     1932.0     448.0     1052.8     732.4
A/B     PR  =   1.000 FTB =  .7500 TBUR=  732.4       448.0     448.0      732.4     732.4
P NOZZ NPR =   1.448 CV  =  .9976 VJ   =  938.2
D/B     PR  =  1.0000 FTB =  .7500 TBUR=  542.2
S NOZZ NPRS=   2.877 CVD =  .9887 VJ   = 1288.7
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                    DSY TURBOFAN ENGINE CYCLE PROGRAM
   MACH       =    .840 ALTITUDE =45000.0 PWCC       =   90.00 PNTHF      =  93.60 PNTHC      =  93.51
   U THRUST =  150.6 GF THRUST= 1948.4 RAM DRAG = 1797.8
   SFC        = 3.1956 PROP EFF =   .4007 OVL EFF   =  .0634
   VTOT       =  71.14 WCORR      = 283.96 SPFC THR =  2.116 FUEL FLOW=    481.
   HCWAPPT =      .020 WBLEWPPT =   0.000 POWER     =      0.0
   DES BR     =  1.030 DES OPR    = 16.900 DES FPR   =  1.910 DES TIT   =2180.00
   ACT BR     =  1.030 ACT OPR    = 12.573 ACT FPR   =  1.786 ACT TIT   =1277.22

                                                    TOTAL PRESS(PSFA) AND TEMP(DEG R)
                                                    PTIN       PTOUT      TTIN       TTOUT
INLET   PI0 = 1.0000                                491.5      491.5      445.3      445.3
FAN     PR  =  1.786 FTC =  .8500 PNTH= 93.600      491.5      877.8      445.3      539.7
LPC     PR  =  3.619 FTC =  .8500 PNTH= 93.600      491.5     1778.8      445.3      676.9
HPC     PR  =  3.474 FTC =  .9200 PNTH= 93.512     1778.8     6179.1      676.9     1019.0
COMB    PR  =   .940 FTB =  .9800 TITB= 1277.2     6179.1     5808.4     1019.0     1277.2
HPT     PR  =  3.414 FTT =  .9161 PN  =  84.76     5808.4     1701.4     1277.2      953.4
COOL AIR                                           1701.4     1701.4      953.4      954.4
LPT     PR  =  4.962 ETT =  .9162 PN  =  86.78     1701.4      342.9      954.4      639.6
A/B     PR  =  1.000 FTP =  .7500 TBUR=  639.6      342.9      342.9      639.6      639.6
P NOZZ NPR  =  1.108 CV  =  .9999 VJ  =  471.5
D/B     PR  = 1.0000 FTB =  .7500 TBUR=  539.7
S NOZZ NPPS=  2.837 CVD =  .9889 VJ  = 1278.5
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SAMPLE SUMMARY OUTPUT

PW JT8D-9

ENGINE SUMMARY

ENGINE DIAMETER = 3.521 FEET
ENGINE LENGTH= 9.563 FEET
ENGINE WEIGHT= 3266.541 POUNDS
PWCC = PERCENT OF ENGINE CORRECTED AIRFLOW
THRUST = ENGINE THRUST (POUNDS PER ENGINE)
SFC = ENGINE SPECIFIC FUEL CONSUMPTION
WTOT = ENGINE TOTAL AIRFLOW (LBS/SEC PER ENGINE)

MACH = 0.000 ALTITUDE = 0.00 FEET

PWCC	THRUST	SFC	WTOT	OVL EFF	PRO EFF
100.000	14500.000	.541	315.156	0.000	0.000
98.000	12769.377	.510	308.853	0.000	0.000
96.000	10906.975	.488	302.550	0.000	0.000
94.000	8693.036	.487	296.247	0.000	0.000

MACH = .454 ALTITUDE = 0.00 FEET

PWCC	THRUST	SFC	WTOT	OVL EFF	PRO EFF
100.000	11576.869	.726	355.682	.174	.482
98.000	10742.130	.723	348.568	.174	.499
96.000	8839.134	.718	341.455	.176	.553
94.000	6726.883	.752	334.341	.168	.612
92.000	3929.025	.992	327.227	.127	.606

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MACH = .750 ALTITUDE = 15000.00 FEET

PWCC	THRUST	SFC	WTOT	OVL EFF	PRO EFF
100.000	7849.772	.817	258.726	.241	.597
98.000	6655.361	.802	253.551	.246	.643
96.000	5430.022	.802	248.377	.246	.695
94.000	4132.940	.839	243.202	.235	.752
92.000	2661.674	1.003	238.028	.197	.782
90.000	493.896	3.958	232.853	.050	.322

MACH = .750 ALTITUDE = 35000.00 FEET

PWCC	THRUST	SFC	WTOT	OVL EFF	PRO EFF

100.000	3183.692	.734	117.574	.247	.605
98.000	2699.225	.722	115.222	.25[illegible]	.651
96.000	2177.448	.727	112.871	.250	.705
94.000	1630.933	.770	110.519	.236	.760
92.000	993.018	.965	108.168	.188	.771
90.000	-123.023	-5.696	105.816	-.032	-.232

MACH = .840 ALTITUDE = 35000.00 FEET

PWCC	THRUST	SFC	WTOT	OVL EFF	PRO EFF
100.000	3398.728	.768	126.880	.255	.632
98.000	2868.527	.756	124.342	.269	.677
96.000	2326.053	.759	121.805	.268	.729
94.000	1755.029	.799	119.267	.255	.784
92.000	1116.944	.964	116.729	.211	.908
90.000	253.952	3.086	114.192	.066	.415

MACH = .840 ALTITUDE = 45000.00 FEET

PWCC	THRUST	SFC	WTOT	OVL EFF	PRO EFF
100.000	2102.396	.763	79.043	.265	.632
98.000	1773.987	.751	77.462	.270	.678
96.000	1437.888	.755	75.881	.268	.730
94.000	1083.944	.795	74.300	.255	.784
92.000	688.000	.961	72.719	.211	.807
90.000	150.555	3.196	71.139	.063	.401

0.00	0.0100.0	14500.0	0.0	7838.8
0.00	0.0 98.0	12769.4	0.0	6516.7
0.00	0.0 96.0	10907.0	0.0	5317.3
0.00	0.0 94.0	8693.0	0.0	4234.1
.45	0.0100.0	17175.3	5598.4	8404.0
.45	0.0 98.0	16228.5	5486.4	7771.8
.45	0.0 96.0	14213.6	5374.5	6345.1
.45	0.0 94.0	11989.4	5262.5	5056.5
.45	0.0 92.0	5079.5	5150.5	3998.1
.75	15000.0100.0	14721.1	6371.3	6416.9
.75	15000.0 98.0	12899.2	6243.9	5334.4
.75	15000.0 96.0	11546.5	6116.5	4352.6
.75	15000.0 94.0	10122.0	5989.0	3465.7
.75	15000.0 92.0	8523.3	5861.6	2668.4
.75	15000.0 90.0	6228.1	5734.2	1955.0
.75	35000.0100.0	5959.4	2664.7	2339.3
.75	35000.0 98.0	5300.7	2611.4	1942.4
.75	35000.0 96.0	4735.6	2558.1	1592.2
.75	35000.0 94.0	4135.9	2504.9	1256.6

.75	35000.0	92.0	3449.6	2451.6	953.5
.75	[illegible]000.0	90.0	2275.2	2398.3	700.7
.84	35000.0	100.0	6619.5	3220.7	2610.3
.84	35000.0	98.0	6024.8	3156.3	2167.7
.84	35000.0	96.0	5418.0	3091.9	1766.1
.84	35000.0	94.0	4782.5	3027.5	1403.1
.94	35000.0	92.0	4079.9	2963.1	1076.4
.84	35000.0	90.0	3152.6	2898.7	783.7
.84	45000.0	100.0	4098.4	1996.0	1604.0
.84	45000.0	98.0	3730.1	1956.1	1332.0
.84	45000.0	96.0	3354.0	1916.1	1085.1
.84	45000.0	94.0	2960.2	1576.2	862.0
.84	45000.0	92.0	2524.3	1836.3	661.1
.84	45000.0	90.0	1946.9	1796.4	481.1

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15 Supplementary Notes

16 Abstract

A rapid computer program for the calculation of the design and the off-design performance of a turbojet or turbofan engine is described. The program is designed to be run in a stand-alone mode or operated within a larger program such as ACSYNT, an aircraft synthesis program for preliminary design which is in use at Ames Research Center. The computation is based on a simplified one-dimensional gas turbine cycle. Each component in the engine is modeled thermodynamically. The component efficiencies used in the thermodynamic modeling are scaled for the off-design conditions from input design point values using empirical trends which are included in the computer code. The engine cycle program is capable of producing reasonable engine performance prediction with a minimum of computer execute time. The current computer execute (CPU) time on the IBM 360/67 for one Mach number, one altitude, and one power setting is about 0.1 seconds.

The principal assumption used in the calculation is that the compressor is operated along a line of maximum adiabatic efficiency on the compressor map. The fluid properties are computed for the combustion mixture, but dissocation is not included. The procedure included in the program is only for the combustion of JP-4, methane, or hydrogen; however, modifications are possible which would allow the calculation for any hydrogen, carbon, or hydrocarbon. Sample input and output listings are included.

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