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OPERATIONAL PROCEDURE FOR COMPUTER PROGRAM FOR DESIGN-POINT CHARACTERISTICS OF A GAS GENERATOR OR A TURBOJET LIFT ENGINE FOR V/STOL APPLICATIONS

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16. Abstract

The computer program described in this report calculates the design-point characteristics of a gas generator or a turbojet lift engine for V/STOL applications. The program computes the dimensions and mass, as well as the thermodynamic performance of the model engine and its components. The program was written in FORTRAN IV language. Provision has been made so that the program accepts input values in either SI Units or U.S. Customary Units. Each engine design-point calculation requires less than 0.5 second of 7094 computer time.

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SUMMARY

The computer program described in this report calculates the design-point characteristics of a gas turbine engine which can be used as a gas generator or a turbojet lift engine. Intended applications are in the field of propulsion for V/STOL aircraft.

The program computes the dimensions and mass, as well as the thermodynamic performance of a model gas turbine engine. Physical and thermodynamic characteristics of the engine components are also given. The report describes the engine model used in making the calculations.

Details on the required input parameters are given, together with a description of the preparation of the input data cards. The option for selecting either a gas generator or a lift engine design is discussed, and methods for running several designs with a single submission of the program deck are illustrated.

The program was written in FORTRAN IV language. Provision has been made so that the program accepts input values in either SI Units or U. S. Customary Units. Each design-point calculation requires less than 0.5 second of 7094 computer time for execution.

INTRODUCTION

The Lewis Research Center is interested in propulsion systems for direct lift in V/STOL aircraft. Both the turbojet lift engine and the lift fan have been considered attractive candidates for these applications. The lift fan category has been broken down into the integral lift fan system in which the drive engine is directly connected to the fan, and the remote-drive lift fan system in which the lift fan is driven by a turbine mounted at the tip of the fan blades (e.g., ref. 1). The latter has been further divided into systems where the tip turbine is driven by the exhaust from a gas turbine engine (gas generator), and systems where the tip turbine is driven by compressed air from an air generator.

As a part of an analytical research effort in the field of direct-lift propulsion systems, a number of electronic digital computer programs have been written to determine the design-point thermodynamic characteristics, geometry, and mass of these systems. Two of these computer programs have already been described and reported in references 2 and 3. The computer program of reference 2 provides a preliminary design and analysis tool for an entire tip-turbine-driven lift fan assembly. This program is useful for the initial sizing of the fan and turbine. It is also adaptable to parametric studies of the effect of changes in the principal design variables of both the fan and turbine on the design-point characteristics of the fan assembly.

Reference 3 describes a computer program which calculates the design-point characteristics of a compressed air generator such as would be used to power a tip-turbine-driven lift fan. The program computes the dimensions and mass, as well as the thermodynamic performance, of a model air generator configuration consisting of a low spool with its air compressor and drive turbine and a high spool which serves as a gas generator for the drive turbine on the low spool. Physical and thermodynamic characteristics of the air generator components are also given.

The present report deals with two other components for V/STOL propulsion systems. A single computer program, described herein, contains an option whereby the design-point characteristics of either a single spool gas generator or a gas turbine lift engine can be calculated. When the gas generator option is used, the size is established by the prescribed gas flow. In the other option, the size of the lift engine is determined from a prescribed jet thrust. The analysis, approach, and procedure are similar to those used in the air generator program described in reference 3.

This report was compiled to furnish the descriptions and instructions necessary for running the computer program for either option indicated in the preceding paragraph. It was assumed that the user of this report is familiar with digital computer programming and is knowledgeable concerning the parameters used in describing gas turbine engines. A complete description of the input parameters is included, together with instructions as to how the input data are preared. A typical computer output page is included, and the meaning of each output parameter is given. The FORTRAN program statements are included for those who wish to know more about the program, or for those who may wish to change it.

APPROACH

Engine Model

The component arrangement and station locations for the gas turbine configuration upon which the development of the computer program is based are shown in figure 1. Aside from the inlet and exhaust sections, the gas generator and jet lift engines are assumed to have the same component arrangements in the analysis used for the computer program. From the inlet, air enters the compressor where it is compressed by a multistage axial-flow unit. The largest part of the high-pressure air upon leaving the compressor enters the combustion chamber where it mixes with the fuel, and the mixture is burned. If the temperature of the gas leaving the combustor is sufficiently high so that the turbine needs to be air cooled, the cooling air may be taken from the compressor discharge. Air may also be bled from the compressor for aircraft control and other purposes. The hot gas from the combustor passes through the turbine which may have one or more stages. The bare (core) engine, then, from the compressor inlet face to the turbine discharge is the same in concept for both the gas generator and the jet lift engine.

Because the engine inlet is so intimately related to the engine installation, and because each inlet will be different for each installation, no attempt was made to define the inlet for either type of engine. In general, it is probable that the inlet for a gas generator would be long enough to accomodate some form of acoustic treatment in order to reduce the noise generated by the compressor. This assumption is probably true whether the gas generator is forward or rearward facing. On the other hand, for a lift engine, minimal length is of extreme importance, and the compressor noise would be masked by the jet noise so that inlet acoustic treatment may not be necessary. Accordingly, the inlet of the lift engine would probably be as short as possible, commensurate with introducing the flow to the compressor with an acceptable maximum flow distortion and energy loss under the most adverse flight conditions.

On the exhaust end, it is somewhat easier to define a minimal hardware requirement for both the gas generator and the lift engine. In the case of the gas generator, a short duct is required to diffuse the turbine flow velocity down to a velocity such as could be used in a gas transfer line between the gas generator and the tip-mounted turbine driving the lift fan. This diffusion should take place with a minimal loss to conserve the pressure energy to drive the fan.

The model of the exhaust duct assumed for the gas generator is shown in figure 2. For simplicity in the weight and length calculation, a fixed duct geometry was assumed that was believed to be representative of actual configurations. The following quantities were defined in terms of the rotor tip diameter at the turbine discharge D_t:

Axial length: $L_d = 0.75\ D_t$

Exit diameter: $D_d = 0.75\ D_t$

Turbine exit hub-tip ratio: $D_h/D_t = 0.75$

The weight of the outer shell plus the inner cone was then approximated by

$$W_d = K_d D_t^2 \tag{1}$$

For representative input values such as a material density of 8300 kilograms per cubic meter (520 lbm/cu ft) and an effective wall thickness of 0.85 millimeter (0.033 in.), it was calculated that $K_d = 23$ ($K_d = 4.7$ for D_t in ft, W_d in lbm).

On the lift engine, the exhaust section takes on the function of a nozzle and speeds up the flow so that the static pressure at the end of the nozzle is ambient or near ambient pressure. The acceleration can be accomplished in a much shorter length than can the diffusion. Again, for simplicity, a representative nozzle configuration was taken such that

$$L_n = 0.25\ D_t$$

$$D_n = 0.80\ D_t$$

No central cone was considered for the nozzle. The weight of the nozzle was estimated as

$$W_n = K_n D_t^2 \tag{2}$$

where $K_n = 5.5$ ($K_n = 1.1$ for D_t in ft, W_n in lbm).

Computer Program

The computer program - ONE SPOOL GAS GENERATOR/LIFT ENGINE - LIFT COMPONENTS - provides a design point configuration for the gas generator model shown in figure 1 or for a lift engine with a similar component arrangement. The gas generator is sized for a prescribed gas flow, while the lift engine is sized to produce a prescribed thrust. The overall thermodynamic performance is described for either engine along with the overall dimensions and total mass. Thermodynamic performance, size, and mass are also calculated for the principal components. The length and mass calculations, exclusive of the inlet and exhaust sections, are based on the lift engine component mass correlations presented in reference 4.

There is a second form of the computer program described in this report - a so-called "cruise" version, which reflects the design changes representative of a continuously operating engine. Continuous operation would be necessary if the gas generator were to be used directly for cruise thrust or to supply the gas for the operation of a cruise fan. Component and overall masses in the "cruise" form of the program are calculated for the bare engine from the cruise engine component mass correlations presented in reference 4 and yield masses that are greater than those for the lift version. Thus, by using the two forms of the program, it is possible to cover the range of gas generator component and overall masses likely to be encountered in realistic designs of gas generators for commercial V/STOL transport applications. In fact, a comparison of calculated masses as contained in the program for two recently developed gas generator engines showed that the real engine mass corresponded to values of calculated mass at around 50 to 60 percent of the difference between the lift and cruise mass determinations. Because there would be no interest in a continuously operating and relatively heavy lift engine, no provision was made in the cruise version of the program to calculate the performance of a turbojet lift engine.

The remainder of the report emphasizes the ONE SPOOL GAS GENERATOR/LIFT ENGINE - LIFT COMPONENTS form of the program. Any significant differences which appear in the cruise form are specifically indicated.

The program was written in FORTRAN IV language for use on an IBM 7094, Model 2, computer. With modifications this program can be used on all machines that have a FORTRAN compiler. The program was developed in U.S. Customary Units, but it will perform the calculations for either SI inputs or U.S. customary inputs. Each pass through the program requires less than 0.5 second on a 7094 computer.

FORTRAN listings for the first form of the computer program (lift engine option, lift engine mass correlation) and the subroutines are shown in figure 3.

INPUT PARAMETERS

This computer program for the design-point characteristics of a gas generator engine or a turbojet lift engine has considerable inherent flexibility. Some idea of the flexibility can be achieved from the fact that no less than 26 independent input parameters may be specified for any one engine design. In addition, values of four program control parameters must be supplied. The function of these four control parameters is discussed in the DATA INPUT CARDS section. In the following paragraphs the significance of each input parameter is discussed. The symbols used in the FORTRAN language of the computer program are also indicated by capital letters. An attempt has been made to use symbols which are descriptive of the property, component, and engine station as indicated in figure 1. The program accepts either SI Units or U.S. Customary Units. Dimensions for the parameters in both systems of units are given in the DATA INPUT CARDS section.

Ambient Conditions and Engine Inlet

The ambient conditions of pressure PO and temperature TO must be specified. Because this is a design-point program for a powerplant that is to be used primarily for lift, it is assumed in this program that the total pressure and temperature at the inlet correspond to ambient static conditons (i.e., the engine is designed for the takeoff condition).

The performance of the engine inlet is described by a single parameter, the total pressure ratio PI2P1 across the inlet. This pressure ratio is very close to one for a short, clean inlet, but it may be considerably less than that if the inlet flow path is tortuous or filled with acoustic absorption devices. The inlet flow is assumed to be adiabatic.

Compressor

Air passes from the inlet into the compressor which has an overall pressure ratio equal to PC2PC1. This compression takes place in SNC stages with the corrected tip speed of the initial stage equal to UTIPCC. The compressor efficiency ETAC, which may be given in either the adiabatic or polytropic form, should reflect the dependence on stage pressure ratio. Relations between corrected tip speed, overall pressure ratio, number of stages, aerodynamic loading, and stage pressure ratio are illustrated in reference 4. The flow path for the compressor, whether constant hub, constant mean, or constant tip, is determined by the value assigned to JCGEOM.

The tip diameter of the compressor is set by the average axial inlet Mach number AMC1, the inlet hub-tip ratio DHDTC1 for the first rotor row, and the airflow rate. Large airflow rates per unit flow area are advantageous for small engine size and weight. Large specific airflows are the result of high axial inlet Mach numbers and low hub-tip ratios. However, the aerodynamics of the velocity diagram generally limits these values to something less than 0.6 and greater than 0.4, respectively. The airflow rate is determined from the gas flow rate in the case of the gas generator or the required jet thrust in the case of the turbojet lift engine. Overall diffusion through the compressor can be regulated by the selection of the axial velocity ratio across the compressor VC2VC1. The reduction of the axial velocity through the compressor compensates for the increase in density of the air so that reasonable blade heights exist at the compressor discharge. The diffusion also provides for a decrease of velocity into the combustor.

Two difference quantities of air bleed from the discharge of the compressor may be specified. One of them is used to cool the turbine and is discussed in the Cooling Airflow section. The other, a so-called "user" bleed (BUSER), is available for aircraft control and other purposes. This user bleed is usually limited to a few percent of the compressor flow, but it may be up to around 15 percent in some applications.

Combustor

Only three input parameters are required to establish the performance and geometry of the combustor. Although the thermodynamic properties of the products of combustion are based on a fuel with a hydrogen-carbon ratio of 2, the program accomodates fuels with different heating values. The heating value HF is one of the independent combustor parameters. For JP fuel, the heating value is 42 800 kilojoules per kilogram (18 400 Btu/lb). Another independent parameter is the combustor efficiency ETAB.

A third input is the combustor pressure loss PB2PB1 expressed as the overall total pressure ratio across the combustor. This value should generally be a function of the combustor length to height ratio (ref. 4). The ratio of combustor length to height and combustor reference velocity are fixed within the program. In the lift version of the program, these values are 2 and approximately 24 meters per second (80 ft/sec), respectively. In the cruise version, the values are 3 and approximately 18 meters per second (60 ft/sec), respectively, reflecting a relaxation in the severity of the combustor design in this latter type of application.

Turbine

The number of stages SNT required for the turbine depends on the compressor pressure ratio and the desired turbine efficiency. However, one or two stages are satisfactory for most gas generator or jet lift engines. The parameter ALPHAT represents the angle of the flow coming outof the turbine stator as measured from the axis of rotation. The turbine loss coefficient AKCT sets the level of loss and, therefore, efficiency in the turbine. A nominal value for the model loss relations in this program is between 0.35 and 0.40 which results in adiabatic efficiencies in the neighborhood of 0.88 to 0.92 over the range of the speed-work parameter encountered in gas generators or lift engines. Increasing the value of AKCT decreases the turbine efficiency.

The turbine performance is predicated for a symmetrical velocity diagram in all stages. Turbine efficiency is determined from this diagram and an analysis of stage efficiency similar to the approach used in references 5 and 6. Each stage uses the same constant mean diameter. The value of the mean diameter relative to the tip diameter at the inlet to the compressor can be set by the parameter DTMDC1, which is the ratio of the turbine mean diameter to the compressor inlet tip diameter. The value of DTMDC1 is usually less than one. A small value of DTMDC1 reduces the engine weight, but it also reduces the efficiency (through the speed-work parameter) and the hub-tip diameter ratio at the turbine discharge. The minimum value of DTMDC1 is that value which yields an acceptable value of turbine outlet hub-tip ratio.

One of the most significant parameters in the performance of the gas generator or jet lift engine is the temperature at the inlet to the turbine stator TT1. Values used for this temperature should reflect allowable blade stress limits and should influence the amount of cooling airflow prescribed.

Cooling Airflow

The cooling airflow for the turbine PCA is expressed as a fraction of the compressor airflow less the amount of user bleed. The cooling air can be expressed independently by setting the parameter PCA equal to the desired fractional value and by setting the engine application parameter KIND = 0.

Two schedules of cooling air with turbine inlet temperature are also built into the program. The first schedule is intended to represent a cooling air requirement for an engine used in a lift application where the time of operation during a cycle would be relatively short:

$$PCA = 0.00011*TT1 - 0.242 \tag{3}$$

The second schedule yields a cooling air requirement typical of continuous operation at the assigned temperature TT1:

$$PCA = 0.00015*TT1 - 0.297 \tag{4}$$

These two schedules are activated by setting KIND = 50 or KIND = 100, respectively.

Discharge Duct or Nozzle

One of the chief differences between the two options, gas generator or turbojet lift engine, is the treatment of the exhaust gases from the turbine. For the gas generator a short duct is assumed between the turbine and the pipe directing the gas to a tip turbine (fig. 2). The velocity of the flow at the discharge of this short duct is established through the duct exit Mach number AMD2. A value of AMD2 = 0.3 represents a reasonable compromise between high frictional pressure drop and small duct diameter. The flow rate out of the gas generator, the principal parameter required in designing the gas generator, is WG. A total pressure ratio across the duct is included to account for any pressure losses associated with a particular discharge duct geometry or design. This ratio is given by PD2PD1.

When the option to design a jet lift engine is used, the emphasis is on the minimum permissible amount of hardware downstream of the turbine. The duct is shortened, and it takes on the dual role of duct and nozzle. Assumptions on the size and weight of this duct nozzle were indicated earlier in the discussion of the engine model.

In place of the gas flow used to size the gas generator, the jet thrust FJS is the sizing parameter for the jet lift engine. The duct pressure ratio PD2PD1 is maintained, but it will generally have a value close to 1.0. A nozzle velocity or thrust coefficient is also included and is designated as CFJ.

DATA INPUT CARDS

The 26 independent parameters and the four program control parameters required as input for both the lift and cruise form of the computer program are entered on five data input cards. An additional card is also required which serves as an identification card. Although these six cards are required for a single engine analysis, other engines can be analyzed in a single submission of the program deck by adding one or more data cards in the manner described in the section Multiple Cases. The program control parameters N and NN direct the multiple case operation as will be explained later. The control parameter UNITS determines the type of units to be used in the input and output. The fourth control parameter OPTION determines whether the lift version of the program is used to design a gas generator or a jet lift engine. This parameter and function are not included in the cruise version of the program.

Single Case

In the discussion which follows, three columns are used to represent the information. The first column is the name of the input variable, or parameter, as it appears on the computer printout sheet (see fig. 4). The second column contains the FORTRAN language symbol for the variable which is used in the computer program and which is referenced in the section INPUT PARAMETERS. The last column contains a description of the variable and the units used in this program.

The first data card sets the flow path for the compressor and selects the cooling air schedule to be used. The second card identifies the gas generator or lift engine. All the remaining data are entered on the last four cards, which use a 8F10.0 format. In general, the arrangement of the parameters on these last four cards is in the ascending order of frequency of change. This arrangement can be used to advantage when several analyses are being run with one program submission (see the section Multiple Cases).

First card. - There are four fixed-point variables used as input parameters in this program, and they appear on the first data card. The format for the first card is 4I5.

COMP FLOW PATH	JCGEOM	Sets the geometry of the compressor. If JCGEOM = 1, the compressor has a constant hub diameter. If JCGEOM = 2, the compressor has a constant mean diameter. If JCGEOM = 3, the compressor is of constant tip design.
ENGINE APPLICATION	KIND	This parameter selects the cooling air schedule used on the turbine. If KIND = 100, the cooling air is scheduled with a turbine inlet temperature to represent continuous operation at the assigned turbine inlet temperature. If KIND = 50, the schedule of cooling aii is that which might be used in a lift application where the time of operation between shutdowns would be relatively short. If KIND = 0, the program user may specify any amount of cooling air PCA as a fraction of the compressor flow less the user bleed.
INPUT CARD INDEX	N	Set equal to 1 for single case.
INPUT CARD INDEX	NN	Set equal to 1 for single case.

Second card. - The content of this card, which uses a 12A6 format, can be used to identify the particular engine case calculated. This identification is printed out on the third line of the computer printout. For example, on the printout shown in figure 4(a), the gas generator was identified as TEST CASE - CUSTOMARY UNITS.

Third card. - Input variables which are seldom changed appear on the third card.

TURB NOZZLE ANGLE	ALPHAT	Outlet flow angle, measured from the axial direction, for the turbine stator, in radians (deg).
DUCT EXIT MACH NO	AMD2	Mach number which sizes the outlet of the gas delivery duct for a gas generator.
PCA	PCA	Turbine cooling air expressed as a fraction of the compressor airflow less the user bleed. PCA is ignored unless KIND = 0 (see first card).
INLET HUB-TIP RATIO	DHDTC1	Ratio of hub diameter to tip diameter at the inlet of the compressor.
TURB LOSS COEF	AKCT	Coefficient which sets the level of losses in the turbine. Nominal value, 0.35 to 0.40.
FUEL HEATING VALUE	HF	Heating value of the fuel, in kilojoules per kilogram (Btu/lb).
INLET RECOVERY	PI2P1	Total-pressure ratio across the inlet ahead of the compressor.
INLET AXIAL MACH NO	AMC1	Compressor inlet Mach number.

Fourth card. - The fourth card contains only five infrequently changed parameters.

AXAIL VELOCITY RATIO	VC2VC1	Outlet axial velocity divided by inlet axial velocity for the compressor.
COMBUSTOR EFFICIENCY	ETAB	Efficiency of combustion.
TURB STRAIGHT VANES	AKUT	Index for vane or no-vane downstream of the turbine. If AKUT = 0, there is no vane. If an impulse straightening vane is desired, set $0 < AKUT < 1.9$. The loss across the

		vane is AKUT times one-half the loss in a turbine stator.
UNITS	UNITS	If UNITS = 0, all quantities are in U.S. Customary Units. If UNITS $\neq$ 0, SI Units are used.
USER BLEED	BUSER	Bleed, expressed as a fraction of compressor flow, from peak cycle pressure for use outside gas generator.

Fifth card. - Input variables which may be changed more or less frequently appear on the fifth card.

COMP EFFICIENCY	ETAC	Compressor efficiency. If a positive value is used, the program treats it as an adiabatic efficiency. If the value is preceded by a minus sign, the efficiency is considered polytropic.
FLARE RATIO (DTM/DC1)	DTMDC1	The turbine is positioned radially by the selection of the ratio of the turbine mean diameter to the compressor diameter at the inlet tip.
CORR TIP SPEED	UTIPCC	The tip speed at the inlet of the compressor, in meters per second (ft/sec), divided by the square root of the ratio compressor inlet total temperature to standard temperature.
AMBIENT PRESSURE	PO	Pressure, in kilonewtons per square meter (lb/sq ft), for design altitude.
AMBIENT TEMP	TO	Temperature, in K (^{o}R), for design temperature situation, independent of pressure altitude.
COMBUSTOR PRES RATIO	PB2PB1	Total-pressure ratio across combustor.
NO. COMP. STAGES	SNC	Number of stages required to produce the overall pressure ratio on the compressor.

DUCT PRES RATIO	PD2PD1	Total-pressure ratio across discharge duct.

Sixth card. - What were estimated to be the most important, and, therefore, most frequently changed variables are read from the sixth card.

GAS FLOW	WG	Flow from gas generator discharge duct, in kilograms per second (lb/sec). Can be omitted when lift engine option is used.
COMP PRES RATIO	PC2PC1	Overall pressure ratio across the compressor.
TURBINE INLET TEMP	TT1	Maximum cycle temperature in the engine, in K (^{o}R).
TURBINE STAGES	SNT	Number of stages on the turbine.
OPTION	OPTION	Value of parameter selects type of engine to be designed. If OPTION = 1, gas generator performance will be calculated; if OPTION = 2, turbojet lift engine performance will be calculated. This option not available in cruise version of program.
JET THRUST	FJS	Jet thrust, in newtons (lb), produced by jet lift engine when that option is used. Not included in cruise version.

Multiple Cases

The six data cards just described are necessary to determine the performance and geometry of a single gas generator. If a single case is to be run for each submission to the electronic computer, then both indexes N and NN on the first data card should be set equal to 1. However, the program is arranged so that several cases may be run per submission. Three methods are available for running multiple cases. In the following paragraphs, each method is described and illustrated with an example.

The simplest method for running multiple cases is exercised when the input variables to be changed are all among the six variables read from the sixth input data card. Then only one additional card is required for each case, and the desired values of the six variables are indicated on each card. The value of the index N on the first data card is set equal to 1, and the value of NN is set equal to the number of cases to be run.

For example, suppose it were required to investigate the effect of size on the characteristics of a gas generator. This could be done by changing the delivered gas flow WG. Suppose that the size range of interest could be covered by values of delivered gas flow of 30, 35, and 40 kilograms per second. The order of data cards required to run these three cases would be as follows:

Card	Partial contents	Card	Partial contents
1	N = 1, NN = 3	5	-------------
2	-------------	6	WG = 30
3	-------------	6	WG = 35
4	-------------	6	WG = 40

The second method is employed when all of the changes of input values are among the 14 variables appearing on the last two data cards. Then the first four data cards need be submitted only once, and they are followed by the appropriate combinations of the fifth and sixth cards. The same number of sixth cards must follow each fifth card. This number is the value given to the index NN. The index N takes on the value of the number of fifth cards to be submitted.

For example, suppose that it were required to examine the effect of size (WG) on gas generators designed for a standard day (i.e., TO = 288) and for a hot day (i.e., TO = 305). The size effect would be studied by running the same three values of WG as in the first example, and for two different ambient temperatures, so that six cases would be required. The order of data cards would be as follows:

Card	Partial contents	Card	Partial contents
1	N = 2, NN = 3	6	WG = 35
2	-------------	6	WG = 40
3	-------------	5	TO = 305
4	-------------	6	WG = 30
5	TO = 288	6	WG = 35
6	WG = 30	6	WG = 40

The third multiple-case method is used when the parameter to be changed appears on the first four data cards. Then a complete set of data cards has to be submitted for each value of this parameter. However, either of the first two methods may be combined with the third method.

Suppose it was desired to investigate the effect of pressure loss in the inlet of the gas generator and that this effect was to be compared for two different ambient temperature designs, but for a single value of delivered gas flow. The effect of the inlet loss could be determined by changing the inlet recovery PI2P1 from a value of 0.99 (assumed to be the value used for the examples under the first two methods) to PI2P1 = 0.95. The required data input cards would be as follows:

Card	Partial contents	Card	Partial contents
1	N = 2, NN = 1	1	N = 2, NN = 1
2	-------------	2	-------------
3	PI2P1 = 0.99	3	PI2P1 = 0.95
4	-------------	4	-------------
5	TO = 288	5	TO = 288
6	WG = 35	6	WG = 35
5	TO = 305	5	TO = 305
6	WG = 35	6	WG = 35

Note that the data from all three examples could have been generated in a single submission by using the following set of data input cards:

Card	Partial contents	Card	Partial contents
1	N = 2, NN = 3	6	WG = 35
2	-------------	6	WG = 40
3	PI2P1 = 0.99	1	N = 2, NN = 1
4	-------------	2	-------------
5	TO = 288	3	PI2P1 = 0.95
6	WG = 30	4	-------------
6	WG = 35	5	TO = 288
6	WG = 40	6	WG = 35
5	TO = 305	5	TO = 305
6	WG = 30	6	WG = 35

COMPUTER PRINTOUT

A typical sheet of computer printout for a single gas generator design is shown in figure 4. Figure 4(a) shows the printout in SI Units, and figure 4(b) gives the corresponding results in U. S. Customary Units. The first line on the page gives the name of the program and indicates whether the masses shown on the sheet correspond to lift or cruise engine technology. The title, data card 2, is printed next.

All the inputs described in the section INPUT PARAMETERS follow. They are divided, somewhat arbitrarily, into primary and secondary inputs.

If a turbine cooling air schedule has been used, the kind of schedule and the amount of cooling air are indicated on the next two lines following the inputs.

The output from the program follows next. The first part of it is divided into two sections. The left-hand section contains parameters which describe the gas at the engine exhaust and parameters which pertain to the overall gas generator. The gas TEMPERATURE (TD) and PRESSURE (PD2) are those which prevail at the duct-nozzle exit. The units are K (^{o}R) and kilonewtons per square meter (lb/sq ft), respectively. The specific POWER (GHP), or specific energy, is computed on the assumption that the gas expands isentropically to ambient pressure from the state at the end of the duct. The units are kilowatts per kilogram per second (hp/(lb/sec)). The SFC, specific fuel consumption (GSFC), is the ratio of the gas generator fuel flow to gas flow in kilograms of fuel per hour divided by kilograms of gas per second ((lb fuel/hr)/(lb gas/sec)).

The DUCT DIAMETER (DUCTD) and STATIC PRES (PDSTAT) at the duct exit are given in meters (ft) and kilonewtons per square meter (lb/sq ft), respectively. Had the lift jet engine option been called for, these quantities would have applied to the nozzle exit.

The remaining output variables in the left-hand section refer to the gas generator in its entirety. The FUEL FLOW (WF) is given in kilograms per hour (lb/hr). The JET THRUST (FJ) in newtons (lb) is computed on the assumption that the gas at the duct exit expands to ambient pressure through a nozzle with the velocity coefficient CFJ. The THRUST SFC (SFC) has the units of kilograms per hour per newton ((lb fuel/hr)/lb thrust). The SPECIFIC THRUST (FJW1) is based on the gas generator inlet airflow, and is expressed in newtons per kilogram per second (lb/(lb/sec)).

The right-hand section of the output lists the lengths and masses of the gas generator components and exhaust duct and the percent of the total gas generator mass for each of the components. As indicated previously, because the size and mass of the inlet are so intimately related to the engine installation, no attempt was made to calculate a representative length or mass for this component. Lengths and masses of the gas generator and its components are in meters (ft) and kilograms (lb), respectively. The length printed in parentheses under the total engine length is the length between the compressor inlet face and the turbine discharge.

The characteristics of the turbine are printed on the next line of output. The data heading, FORTRAN symbol, and description of the parameter follows:

NUMBER OF STAGES	SNT	Number of turbine stages.
ALPHA1 = -BETA2	ALPHAT	Stator flow angle measured from the axis of rotation, in radians (deg). Because the velocity diagram is symmetrical, this angle is equal to the angle of relative flow leaving the rotor.
BETA1 = -ALPHA2	BETA	Relative flow angle entering the rotor and absolute flow angle leaving the rotor, in radians (deg).
VX1 = VX2 (= VO)	VX	Axial velocity through the turbine, in meters per second (ft/sec); also assumed to be the approach velocity to the first-stage stator.
VU1 = -WU2	VU1	Stator tangential velocity component and tangential component of relative velocity out of the rotor, in meters per second (ft/sec).
VU2 = -WU1	VU2	Tangential component of absolute velocity leaving the rotor and tangential component of the relative velocity entering the rotor, in meters per second (ft/sec).
STAGE LAMDA	STLAMT	Stage speed-work parameter, $U_m^2/(\Delta H)$.
MEAN SPEED	UTM	Mean blade speed U_m, in meters per second (ft/sec).
ABS INLET MACH NO.	AMT1	Mach number of the absolute velocity into the first-stage rotor.
REL. INLET MACH NO.	AMT1W	Mach number of relative velocity at the first-stage rotor inlet.

FLOW COEFF.	FLOWT	Ratio of through-flow velocity to mean blade speed.
ABS OUTLET MACH NO.	AMT2	Mach number of absolute velocity at discharge of last-stage rotor.

The remaining output format is virtually self-explanatory. It displays the thermodynamic properties of the working fluid throughout the gas generator, as well as the principal dimensions of the components.

The data are arranged in tabular form with the name of the component appearing in the first column. Parameters such as length (m (ft)), pressure ratio, change in enthalpy (kJ/kg (Btu/lb)), fuel-air ratio of the working fluid, and total efficiency, all of which are applicable to the component as a whole, are printed on the same line as the name of the component. Values of parameters which are different for the inlet and outlet of the component are printed on lines above and below the component name line, respectively. These parameters include working fluid mass flow rate (kg/sec (lb/sec)), total temperature (K (^{o}R)), total pressure normalized by standard sea-level pressure, axial Mach number, axial velocity of the working fluid (m/sec (ft/sec)), hub-tip ratio, and the corresponding tip and hub diameters (m (ft)). The hub diameter is printed within parentheses under the corresponding tip diameter.

The two sets of values for mass flow and temperature appearing at the inlet of the turbine are for the stator and rotor inlet, respectively. The values reflect the contribution of the stator cooling air, which is 0.5 of the total turbine cooling air. The remaining half of the cooling air is added downstream of the turbine.

In the column headed PRESS RATIO, the value of the ratio is determined by dividing the outlet pressure by the inlet pressure. For the turbine, the reciprocal of the pressure ratio, as defined previously, is also printed within parentheses.

The last number on the table, under TIP DIA., is the diameter in meters (ft) of the exit of the exhaust duct. If the jet lift engine option had been used this last number would have been the exhaust diameter of the jet nozzle.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 17, 1972,
501-14.

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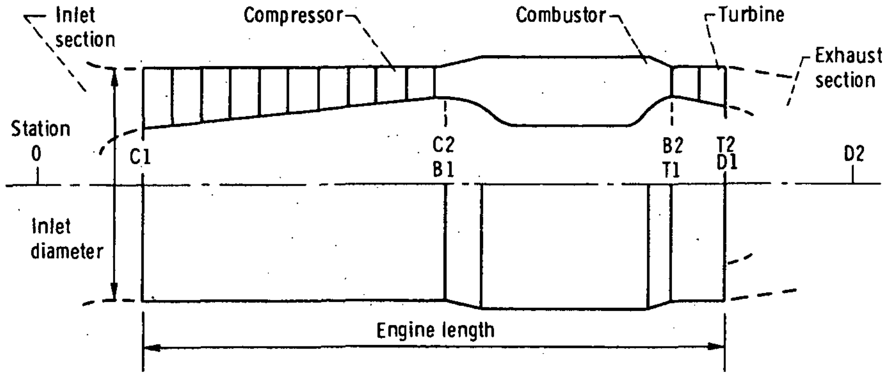

Figure 1. - Schematic of gas generator or lift engine core.

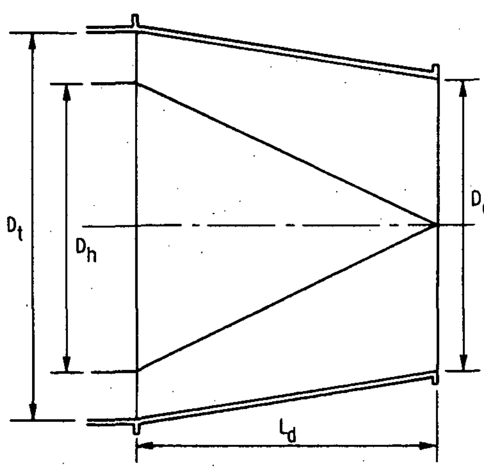

Figure 2. - Exhaust duct model for gas generator.

```
C  PROGRAM 4L     LIFT ENGINE ROTATING COMPONENTS
C     ONE SPOOL GAS GENERATOR/LIFT ENGINE
C
      DIMENSION TITLE(72)
      COMMON /JAN1/ AJ,PIE,G,ZZ,PSTD,TSTD,PSIR,RA,DELO,SQTH1
      DIMENSION UNIA(4), UNIO(6)
      DATA UNIA(1),UNIA(2),UNIA(3),UNIA(4)/6H   CUS,6HTOMARY,6H      ,6H
     1   SI/
      DATA (UNIO(I),I=1,6)/6H      G,6HAS GEN,6HERATOR,6H      ,6H LIFT ,
     16HENGINE/
2     READ (5,58) JCGEOM,KIND,N,NN                                      1
      READ (5,60) (TITLE(I),I=1,12)                                     6
      READ (5,56) ALPHAT,AMD2,PCA,DHDTC1,AKCT,HF,PI2P1,AMC1             13
      READ (5,56) VC2VC1,ETAB,AKUT,UNITS,BUSER,CFJ                      14
      IF (UNITS.EQ.0.) GO TO 4
      ALPHAT=ALPHAT/.01745
      HF=HF/2.326
4     DO 54 J=1,N
      READ (5,56) ETAC,DTMDC1,UTIPCC,PO,TO,PB2PB1,SNC,PD2PD1            21
      IF (UNITS.EQ.0.) GO TO 6
      DIV=.3048
      UTIPCC=UTIPCC/DIV
      PO=PO/.04788
      TO=TO/.5556
6     DO 52 K=1,NN
      READ (5,56) WG,PC2PC1,TT1,SNT,FJS,OPTION                          27
      IF (WG.EQ.0.0) WG=50.
      IF (UNITS.EQ.0.) GO TO 8
      WG=WG/.4536
      TT1=TT1/.5556
8     TC1=TO
      HC1=POLY(TC1,1)                                                   34
      DELO=PO/PSTD
      DELC1=PO*PI2P1/PSTD
      SQTH1=SQRT(TC1/519.)                                              35
      CPC1=POLY(TC1,3)                                                  36
      GAMC1=1./(1.-(RA/(AJ*CPC1)))
      TEM1=GAMC1-1.
      TEM2=TEM1/2.
      TEM4=1.+(TEM2*AMC1*AMC1)
      TEM5=SQRT(GAMC1*G/RA)                                             37
      TEM6=(GAMC1+1.)/(2.*TEM1)
      SWC1=TEM5/ZZ*AMC1/(TEM4**TEM6)*(1.-DHDTC1**2)                     38
      VC1=AMC1*SQRT(GAMC1*G*RA*TC1/TEM4)
C                                                                       39
      CALL COMPRS (TC1,PC2PC1,DELC1,ETAC,HC1,SWC1,TC2,DELC2,DELHC,HC2)
C                                                                       40
      PC1=DELC1*PSTD
      PC2=DELC2*PSTD
      CPC2=POLY(TC2,3)                                                  42
      GAMC2=1./(1.-(RA/(AJ*CPC2)))
      VC2=VC1*VC2VC1
      AMC2=SQRT(VC2*VC2/(GAMC2*G*RA*TC2-(GAMC2-1.)/2.*VC2*VC2))         43
      RHOC2=DELC2*PSTD/(G*RA*TC2)*(1.-VC2**2/(2.*AJ*G*CPC2*TC2))**(1./(G
     1AMC2-1.))                                                         44
      TEM9=G*RHOC2*VC2
      TCOOL=TC2
      HCOOL=POLY(TCOOL,1)                                               45
      W1AC1=SWC1*DELC1/SQTH1
C
C     IF JCGEOM = 1  CONSTANT HUB DIAMETER
C
      IF (JCGEOM.EQ.1) GO TO 10
C
C     IF JCGEOM = 2  CONSTANT MEAN DIAMETER
C
      IF (JCGEOM.EQ.2) GO TO 12
C
C     IF JCGEOM = 3  CONSTANT TIP DIAMETER
```

Figure 3. - FORTRAN listings of gas generator/lift engine computer program.

```
C
      IF (JCGEOM.EQ.3) GO TO 14
10    DHDTC2=1./SQRT(1.+W1AC1/(TEM9*DHDTC1**2))                    56
      DC2DC1=DHDTC1/DHDTC2
      GO TO 16
12    TEM10=((1.+DHDTC1)/2.)**2
      TQ=W1AC1/(4.*TEM9*TEM10)
      DHDTC2=(1.-TQ)/(1.+TQ)
      DC2DC1=(1.+DHDTC1)/(1.+DHDTC2)
      GO TO 16
14    DHDTC2=SQRT(1.-W1AC1/TEM9)                                   61
      DC2DC1=1.
16    DELB2=DELC2*PB2PB1
      DELT1=DELB2
      HT1=POLY(TT1,1)                                              63
      PSIHT1=POLY(TT1,4)                                           64
      HO=HF+1254.
      FB=(HT1-HC2)/(HO-(HC2/ETAB)-PSIHT1)
      FAR=F3/(ETAB*(1.-FB/ETAB))
C
C     HTIG   ENTHALPY OUT OF COMBUSTOR
C     CHRGB  CHARGEABLE BLEED
C   HTIGT  EFFECTIVE ENTHALPY AT ROTOR INLET
C   HN  EFFECTIVE ENTHALPY AT TURBINE EXHAUST AFTER COOLING AIR IS MIXED
C   DELHT    TURBINE ENTHALPY DROP DUE TO WORK REQUIRED BY COMPRESSOR
C            AND PUMPING OF COOLING AIR
C      BUSER = BLEED FLOW(LBS/SEC)/W1
C      IF KIND= 0  PROGRAMMER FURNISHES COOLING BLEED
C      IF KIND = 50   LIFT ENGINE
C      IF KIND = 100    CRUISE ENGINE
C
      INDEX=KIND/50
      IF (INDEX-1) 18,20,22
18    PCA=PCA
      GO TO 24
20    PCA=.000110*TT1-.242
      GO TO 24
22    PCA=.000150*TT1-.297
24    CHRGB=.50
      BETCOL=PCA*(1.-BUSER)
      BETTOT=BETCOL+BUSER
      TEM11=(1.+FAR)*(1.-BETTOT)
      HTIG=HT1+FB*PSIHT1
      DELHB=HTIG-HC2
      UTM=DTMDC1*UTIPCC*SQTH1
      DHPUMP=UTM*UTM/AJ/G
      DELHT=(DELHC+DHPUMP*CHRGB*BETCOL)/(TEM11+(1.-CHRGB)*BETCOL)
      HCOLP=HCOOL+DHPUMP
26    W1=WG/(TEM11+BETCOL)
C
      WT=WG
      WB1=W1*(1.-BETTOT)
      WB2=WB1*(1.+FAR)
      AC1=W1*SQTH1/(DELC1*SWC1)
      DC1=SQRT(4.*AC1/PIE)                                         74
      DTM=DC1*DTMDC1
C
C     ROTOR INLET CONDITIONS
C
      HTIGT=(HTIG*TEM11+(1.-CHRGB)*BETCOL*HCOOL)/(TEM11+(1.-CHRGB)*BETCO
     1L)
      FARR=FAR/(1.+BETCOL*(1.-CHRGB)/(1.-BETTOT))
      FR=ETAB*FARR/(1.+FARR)
      TTR=TT1
28    DELTAT=(HTIGT-POLY(TTR,1)-FR*POLY(TTR,4))/(POLY(TTR,-1)+FR*POLY(TT
     1R,-4))                                                       76   77   78   79
      TTR=TTR+DELTAT
      IF (ABS(DELTAT).LT..1) GO TO 30
      GO TO 28
30    WR=W1*(TEM11+BETCOL*(1.-CHRGB))
```

Figure 3. - Continued.

```
C
      CALL TURBIN (TTR,DELT1,DELHT,AKCT,AKUT,WR,ALPHAT,SNT,FR,1.,DC1,UTM
     1,DTMDC1,TT2,PT2PT1,DELT2,AMT2X,DHDTT2,AMBBT,DT2DC1,ETABT,VX,VU1,VU
     22,BETA,DHDTT1,DT1DC1,AMT1X,AMT1W,AMT1,FLOWT)
C                                                                        85
      PT1PT2=1./PT2PT1
      STLAMT=SNT*AMBBT
      BETAR=BETA*.01745
      AMT2=AMT2X/COS(BETAR)                                              87
      HN=((HTIGT-DELHT)*(TEM11+(1.-CHRGB)*BETCOL)+CHRGB*BETCOL*HCOLP)/(T
     1EM11+BETCOL)
      FAPRIM=FAR/(1.+BETCOL/(1.-BETTOT))
      FPRIME=ETAB*FAPRIM/(1.+FAPRIM)
      TD=TT2
   32 DELT=(HN-(POLY(TD,1)+FPRIME*POLY(TD,4)))/(POLY(TD,-1)+FPRIME*POLY(
     1TD,-4))                                                            89  90  91  92
      TD=TD+DELT
      IF (ABS(DELT).LT..1) GO TO 34
      GO TO 32
C
C     BEGIN DUCT CALCULATIONS
C
   34 CPD=POLY(TD,3)+FPRIME*POLY(TD,6)                                   98  99
      RD=RA+FPRIME*PSIR
      GAMMD=1./(1.-RD/(AJ*CPD))
      WDW1=WG/W1
      PD1=DELT2*PSTD
C
      CALL DUCT2 (PD1,PD2PD1,AMD2,TD,WDW1,SWC1,DELC1,GAMMD,RD,PDSTAT,AD2
     1A1)
C                                                                        100
      PD2=PD1*PD2PD1
      VJ=SQRT(2.*GAMMD/(GAMMD-1.)*G*RD*TD*(1.-(P0/PD2)**((GAMMD-1.)/GAMM
     1D)))*CFJ                                                           102  103
      DELD2=PD2/PSTD
      DUCTD=SQRT(DC1*DC1*AD2A1)
C                                                                        104
      VD2=SQRT(GAMMD*G*RD*TD*AMD2*AMD2/(1.0+(GAMMD-1.0)*AMD2*AMD2/2.0))  105
      FJ=WDW1*W1*VJ/G
      IF (OPTION.LT.1.5) GO TO 36
      DFJ=FJ-FJS
      FJTEST=DFJ/FJS
      IF (ABS(FJTEST).LT..001) GO TO 36
      WG=FJS*G/VJ
      GO TO 26
   36 AMN=SQRT(VJ*VJ/(GAMMD*G*RD*TD-(GAMMD-1.0)/2.*VJ*VJ))              114
      WF=W1*FAR*(1.-BETTOT)*3600.
      SFC=WF/FJ
C
C          GAS AND THRUST SFC'S     GAS POWER
C
      GSFC=WF/WG
      SFCNTH=WF/FJ
      FJW1=WDW1*VJ/G
      PHIX=POLY(TD,2)+FPRIME*POLY(TD,5)                                  115  116
      PHIXI=PHIX-RD/AJ*ALOG(PD2/P0)                                      117
      TXI=TD
   38 DELTX=TXI*(PHIXI-POLY(TXI,2)-FPRIME*POLY(TXI,5))/(POLY(TXI,3)+FPRI
     1ME*POLY(TXI,6))                                                    119  120  121  122
      TXI=TXI+DELTX
      IF (DELTX.GT..1) GO TO 38
      HXI=POLY(TXI,1)+FPRIME*POLY(TXI,4)                                 126  127
      HD=POLY(TD,1)+FPRIME*POLY(TD,4)                                    128  129
      GHP=AJ*(HD-HXI)/550.
C
C          COMPONENT DIAMETERS
C
      DC1T=DC1
      DC1H=DC1*DHDTC1
      DC2T=DC1T*DC2DC1
      DC2H=DC2T*DHDTC2
```

Figure 3. - Continued.

```
      DT1T=DC1T*DT1DC1
      DT1H=DT1T*DHDTT1
      DT2T=DC1T*DT2DC1
      DT2H=DT2T*DHDTT2
C
C
C     LENGTHS - LIFT   ENGINE ROTATING COMPONENTS
C
C
C       COMPRESSOR
C
      CLENDM=0.2+(.234-.218*DHDTC1)*SNC
      COMPL=CLENDM*(DC1H+DC1T)/2.
C
C                COMBUSTOR
C
      WBIN=W1*(1.-BETTOT)
      CORWB1=WBIN*SQRT(TC2/TSTD)/DELC2                                130
      ELOH=2.0
      VREF=80.
      DMAV=(DC2T+DC2H+DT1T+DT1H)/4.
      BURNL=2.2*CORWB1*ELOH*SQRT(TC2)/(DMAV*VREF)/12.
C
C               TURBINE
C                                                                     131
      TSAR=6.45-5.97*DHDTT1
      TRAR=6.1-5.5*DHDTT1
      IF (TRAR.GT.6.) TRAR=6.
      BLDH=DT1T*(1.-DHDTT1)/2.
      SAXCHD=BLDH/TSAR
      RAXCHD=BLDH/TRAR
      TCLR=.40*RAXCHD
      TURBL=SNT*(SAXCHD+RAXCHD+2.*TCLR)+TCLR+SAXCHD
C
C       DUCT
C
      DUCTL=.75*DT2T
      IF (OPTION.GT.1.5) DUCTL=.25*DT2T
C
C       ENGINE
C
      ENGL=COMPL+BURNL+TURBL
      ENGLT=ENGL+DUCTL
      ELOD=ENGL/DC1
      ELODT=ENGLT/DC1
C
C     WEIGHTS -    LIFT ENGINE ROTATING COMPONENTS
C
C
C                COMPRESSOR
C
      ELODRF=.2+.081*SNC
      Q=.5+.5*CLENDM/ELODRF
      COMPW=5.0*(.25*(DC1T+DC1H+DC2T+DC2H))**2.2*SNC**1.2*Q*(UTIPCC*SQTH
     11/1100.)**.3
C
C                COMBUSTOR
C                                                                     136     137     138
      DMBURN=(DC2T+DC2H+DT1T+DT1H)/4.
      BURNW=32.*DMBURN*DMBURN*SQRT(ELOH)
C
C                TURBINE
C                                                                     139
      DMTURB=(DT1T+DT1H+DT2T+DT2H)/4.
      TURBW=.26*SNT*DMTURB**2.5*UTM**0.6
C
C       DUCT
C                                                                     140     141
      DUCTW=4.7*DT2T*DT2T
      IF (OPTION.GT.1.5) DUCTW=1.1*DT2T*DT2T
```

Figure 3. - Continued.

```
C
C       ACCESSORY, STRUCTURE, AND TOTAL
C
      ACCW=.002*(FJ+1.35*WF)
      BENGW=COMPW+BURNW+TURBW+ACCW
      STRW=.10*BENGW
      ENGW=BENGW+DUCTW+STRW
      PCTW=100./ENGW
      COMPWX=COMPW*PCTW
      BURNWX=BURNW*PCTW
      TURBWX=TURBW*PCTW
      DUCTWX=DUCTW*PCTW
      ACCWX=ACCW*PCTW
      STRWX=STRW*PCTW
      AJCGEO=JCGEOM
      AKIND=KIND
      IF (UNITS.EQ.0.) GO TO 40
C
C      WRITE INPUTS IN SI UNITS
C
      WG=.4536*WG
      TT1=.5556*TT1
      PO=.04788*PO
      TO=.5556*TO
C
      UTIPCC=DIV*UTIPCC
      HF=2.326*HF
      ALPHAT=.01745*ALPHAT
C
C      WRITE OUTPUTS IN SI UNITS
C
      TD=.5556*TD
      PD2=.04788*PD2
      GHP=1.644*GHP
      GSFC=GSFC
      DUCTD=DUCTD*.3048
      PDSTAT=PDSTAT*.04788
      WF=.4536*WF
      FJ=4.448*FJ
      SFC=.1020*SFC
      FJW1=9.806*FJW1
C
      WTCON=.4536
      COMPW=WTCON*COMPW
      BURNW=WTCON*BURNW
      TURBW=WTCON*TURBW
      ACCW=WTCON*ACCW
      STRW=WTCON*STRW
      ENGW=WTCON*ENGW
C
      BETA=.01745*BETA
      VX=DIV*VX
      VU1=DIV*VU1
      VU2=DIV*VU2
      UTM=DIV*UTM
C
      ELCON=.3048
      COMPL=ELCON*COMPL
      BURNL=ELCON*BURNL
      TURBL=ELCON*TURBL
      DUCTL=ELCON*DUCTL
      ENGL=ELCON*ENGL
      ENGLT=ELCON*ENGLT
C
      HCON=2.326
      DELHC=HCON*DELHC
      DELHB=HCON*DELHB
      DELHT=HCON*DELHT
C
      W1=WTCON*W1
      WB1=WTCON*WB1
```

Figure 3. - Continued.

```
      WB2=WTCON*WB2
      WR=WTCON*WR
      WT=WTCON*WT
C
      TCON=.5556
      TC1=TCON*TC1
      TC2=TCON*TC2
      TTR=TCON*TTR
C
      VC1=ELCON*VC1
      VC2=ELCON*VC2
      VD2=ELCON*VD2
C
      DC1T=ELCON*DC1T
      DC1H=ELCON*DC1H
      DC2T=ELCON*DC2T
      DC2H=ELCON*DC2H
      DT1T=ELCON*DT1T
      DT1H=ELCON*DT1H
      DT2T=ELCON*DT2T
      DT2H=ELCON*DT2H
C
40    WRITE (6,62)                                                          147
      WRITE (6,60) (TITLE(I),I=1,12)                                        148
      WRITE (6,110)                                                         153
      WRITE (6,72) WG,PO,UTIPCC,ALPHAT                                      154
      WRITE (6,74) TT1,TO,SNC,AKCT                                          155
      WRITE (6,76) PC2PC1,ETAC,DTMDC1                                       156
      WRITE (6,78) SNT,AKIND,AJCGEO,AKUT                                    157
      IU=1
      IF (UNITS.NE.0.0) IU=3
      WRITE (6,80) UNIA(IU),UNIA(IU+1),PI2P1,VC2VC1                         160
      IO=1
      IF (OPTION.GT.1.5) IO=4
      IOE=IO+2
      WRITE (6,82) (UNIO(IP),IP=IO,IOE),AMC1,HF,CFJ                         166
      WRITE (6,84) FJS,DHDTC1,ETAB,PD2PD1                                   171
      WRITE (6,86) BUSER,PB2PB1,AMD2                                        172
      IF (KIND.EQ.0) GO TO 42
      IF (KIND.EQ.50) GO TO 44
      IF (KIND.EQ.100) GO TO 46
42    WRITE (6,64)                                                          182
      WRITE (6,70) PCA                                                      183
      GO TO 48
44    WRITE (6,66)                                                          185
      WRITE (6,70) PCA                                                      186
      GO TO 48
46    WRITE (6,68)                                                          188
      WRITE (6,70) PCA                                                      189
48    WRITE (6,112)                                                         190
      WRITE (6,88)                                                          191
      WRITE (6,90) TD                                                       192
      WRITE (6,92) PD2,COMPL,COMPW,COMPWX                                   193
      WRITE (6,94) GHP,BURNL,BURNW,BURNWX                                   194
      WRITE (6,96) GSFC,TURBL,TURBW,TURBWX                                  195
      WRITE (6,98) DUCTD,DUCTL,DUCTW,DUCTWX                                 196
      WRITE (6,100) PDSTAT,ACCW,ACCWX                                       197
      WRITE (6,102) WF,STRW,STRWX                                           198
      WRITE (6,104) FJ                                                      199
      WRITE (6,106) SFC,ENGLT,ENGW                                          200
      WRITE (6,108) FJW1,ENGL                                               201
      WRITE (6,118)                                                         202
      WRITE (6,116)                                                         203
      WRITE (6,114) SNT,ALPHAT,BETA,VX,VU1,VU2,STLAMT,UTM,AMT1,AMT1W,FLO
     1WT,AMT2                                                               204
      WRITE (6,120)                                                         205
      WRITE (6,136)                                                         206
      WRITE (6,134) W1,TC1,DELC1,AMC1,VC1,DHDTC1,DC1T,DC1H                  207
      WRITE (6,124) PC2PC1,DELHC,ETAC                                       208
      WRITE (6,126) WB1,TC2,DELC2,AMC2,VC2,DHDTC2,DC2T,DC2H                 209
```

Figure 3. - Continued.

```
      WRITE (6,122) PB2PB1,DELHB,FAR,ETAB                                A 422      210
      WRITE (6,132) WB2,TT1,DELT1,AMT1X,VX,DHDTT1,DT1T,WR,TTR,DT1H       A 423      211
      WRITE (6,128) PT2PT1,DELHT,FARR,ETABT                              A 424      212
      WRITE (6,130) PT1PT2,WT,TD,DELT2,AMT2X,VX,DHDTT2,DT2T,DT2H         A 425      213
      AMD2S=AMD2                                                         A 426
      IF (OPTION.LE.1.5) GO TO 50                                        A 427
      AMD2=AMN                                                           A 428
      VD2=VJ                                                             A 429
50    WRITE (6,138) PD2PD1,FAPRIM,WG,TD,DELD2,AMD2,VD2,DUCTD             A 430      217
      AMD2=AMD2S                                                         A 431
52    CONTINUE                                                           A 432
54    CONTINUE                                                           A 433
      GO TO 2                                                            A 434
C                                                                        A 435
56    FORMAT (8F10.0)                                                    A 436
58    FORMAT (4I5)
60    FORMAT (12A6)                                                      A 438
62    FORMAT (1H1,45X,51HONE SPOOL GAS GENERATOR/LIFT ENGINE-LIFT COMPON A 439
     1ENTS)                                                              A 440
64    FORMAT (1X,16H   COOLING BLEED)                                    A 441
66    FORMAT (1X,11HLIFT ENGINE)                                         A 442
68    FORMAT (1X,13HCRUISE ENGINE)                                       A 443
70    FORMAT (1X,9HPCA      =,E12.5)                                     A 444
72    FORMAT (1H0,24H GAS FLOW               ,F8.3,24H   AMBIENT PRESSUR A 445
     1E     ,F8.3,24H  CORR TIP SPEED        ,F8.3,24H  TURB NOZZLE ANGL A 446
     2E     ,F8.3)                                                       A 447
74    FORMAT (25H  TURBINE INLET TEMP     ,F8.3,24H   AMBIENT TEMP       A 448
     1    ,F8.3,24H  NO. COMP. STAGES      ,F8.3,24H  TURB LOSS COEF     A 449
     2    ,F8.3)                                                         A 450
76    FORMAT (25H  COMP PRES RATIO        ,F8.3,32X,24H  COMP EFFICIENCY A 451
     1          ,F8.3,24H  FLARE RATIO(DTM/DC1)  ,F8.3)                  A 452
78    FORMAT (25H  TURBINE STAGES         ,F8.3,24H   ENGINE APPLICATION A 453
     1    ,F8.3,24H  COMP FLOW PATH        ,F8.3,24H  TURB STRAIGHT VANES A 454
     2    ,F8.3)                                                         A 455
80    FORMAT (21H  UNITS              ,2A6,24H   INLET PRES RATIO     ,F A 456
     18.3,24H  AXIAL VELOCITY RATIO  ,F8.3)                              A 457
82    FORMAT (15H  OPTION       ,3A6,24H   INLET AXIAL MACH NO  ,F8.3,23 A 458
     1H  FUEL HEATING VALUE   ,F9.3,24H  NOZZLE COEF            ,F8.3)   A 459
84    FORMAT (25H  JET THRUST             ,F8.3,24H   INLET HUB-TIP RATI A 460
     1O  ,F8.3,24H  COMBUSTOR EFFICIENCY  ,F8.3,24H  DUCT PRES RATIO     A 461
     2   ,F8.3)                                                          A 462
86    FORMAT (33X,24H   USER BLEED          ,F9.4,23H COMBUSTOR PRES RA  A 463
     1TIO  ,F8.3,24H  DUCT EXIT MACH NO     ,F8.3)                       A 464
88    FORMAT (1H0,13X,14HGAS PROPERTIES,57X,6HLENGTH,7X,4HMASS,6X,7HPERC A 465
     1ENT)                                                               A 466
90    FORMAT (20X,11HTEMPERATURE,F11.1)                                  A 467
92    FORMAT (20X,11HPRESSURE   ,F11.1,25X,13HCOMPRESSOR   ,F11.3,2F11.1 A 468
     1)                                                                  A 469
94    FORMAT (20X,11HPOWER      ,F11.1,25X,13HCOMBUSTOR    ,F11.3,2F11.1 A 470
     1)                                                                  A 471
96    FORMAT (20X,11HS F C      ,F11.1,25X,13HTURBINE      ,F11.3,2F11.1 A 472
     1)                                                                  A 473
98    FORMAT (14X,17HDUCT DIAMETER    ,F13.3,23X,13HDUCT/NOZZLE  ,F11.3, A 474
     12F11.1)                                                            A 475
100   FORMAT (14X,17H     STATIC PRES ,F11.1,25X,13HACCESSORIES  ,11X,2F A 476
     111.1)                                                              A 477
102   FORMAT (14X,17HFUEL FLOW        ,F11.1,25X,13HSTRUCTURE    ,11X,2F A 478
     111.1)                                                              A 479
104   FORMAT (14X,17HJET THRUST       ,F11.1)                            A 480
106   FORMAT (14X,17HTHRUST SFC       ,F13.3,27X,9HTOTAL    ,F11.3,F11.1 A 481
     1,6X,5H100.0)                                                       A 482
108   FORMAT (14X,17HSPECIFIC THRUST  ,F11.1,43X,1H(,F5.3,1H))           A 483
110   FORMAT (1H0,9X,14HPRIMARY INPUTS,51X,16HSECONDARY INPUTS)          A 484
112   FORMAT (1H0,57X,6HOUTPUT)                                          A 485
114   FORMAT (1X,7HTURBINE,9X,F3.0,5X,F7.2,2X,F7.2,2X,F7.1,1X,F7.1,F8.1, A 486
     11X,F7.4,1X,F7.1,2X,F7.4,5X,F7.4,3X,F6.3,4X,F6.3//)                 A 487
116   FORMAT (1H0,14X,109HNUMBER OF  ALPHA1=  BETA1=  VX1=VX2   VU1=     A 488
     1VU2=   STAGE     MEAN    ABS.INLET  REL.INLET   FLOW   ABS OUTLET/16 A 489
     2X,109HSTAGES    -BETA2  -ALPHA2   (=VO)     -WU2    -WU1    LAMDA   A 490
     3SPEED    MACH NO.    MACH NO.    COEFF.    MACH NO.  )             A 491
```

Figure 3. - Continued.

```
118   FORMAT (1HO)
120   FORMAT (1HO,22X,5HPRESS,14X,88HFUEL-AIR   TOTAL     MASS      TOTA
     1L     TOTAL    AX. MACH    AXIAL      HUB-TIP    TIP DIA./12X,119H
     2       RATIO      DELTA H     RATIO        EFF.       FLOW       TEMP
     3 PRESS      NUMBER     VELOCITY      RATIO    (HUB DIA.)//)
122   FORMAT (10H COMBUSTOR,8X,F10.4,F9.2,F10.5,F10.5)
124   FORMAT (10H COMPRESS  ,8X,F10.4,F9.2,12X,F8.5)
126   FORMAT (62X,F7.2,3X,F7.1,F10.4,F9.4,F10.1,F10.5,F11.4/120X,2H (,F7
     1.4,2H) )
128   FORMAT (10H TURBINE   ,8X,F10.4,F9.2,F10.5,F10.5)
130   FORMAT (16X,5H    (,F7.4,2H) ,32X,F7.2,3X,F7.1,F10.4,F9.4,F10.1,F1
     10.5,F11.4/120X,2H (,F7.4,2H ))
132   FORMAT (62X,F7.2,3X,F7.1,F10.4,F9.4,F10.1,F10.5,F11.4/62X,F7.2,3X,
     1F7.1,41X,2H (,F7.4,2H) )
134   FORMAT (62X,F7.2,3X,F7.1,F10.4,F9.4,F10.1,F10.5,F11.4/120X,2H (,F7
     1.4,2H) )
136   FORMAT (12H INLET      )
138   FORMAT (12H DUCT/NOZZLE,6X,F10.4,9X,F10.5,15X,F7.2,3X,F7.1/79X,F10
     1.4,F9.4,F10.1,10X,F11.4)
      END
```

```
      BLOCK DATA
      COMMON /JAN1/ AJ,PIE,G,ZZ,PSTD,TSTD,PSIR,RA,DELO,SQTH1
      DATA AJ/777.97/,PIE/3.14159/,G/32.17/,ZZ/.0107663/,PSTD/2116./,TST
     1D/519./,PSIR/1.5785/,RA/53.331/
      END
```

```
      SUBROUTINE COMPRS (T1,P2P1,P1PSO,ETACO,H1,SWC1,T2,P2PSO,DH21,H2)
      COMMON /JAN1/ AJ,PIE,G,ZZ,PSTD,TSTD,PSIR,RA,DELO,SQTH1
C     IF ETACO GT. O ETACO IS TREATED AS AN ADIABATIC EFFICIENCY
C     IF ETACO LT.O ETACO IS TREATED AS A POLYTROPIC EFFICIENCY
      P2PSO=P1PSO*P2P1
      PHI1=POLY(T1,2)
      IF (ETACO) 4,4,2
2     PHI2I=PHI1+ALOG(P2P1)*RA/AJ
      T2I=POLY(PHI2I,8)
      H2I=POLY(T2I,1)
      DH21=(H2I-H1)/ETACO
      H2=H1+DH21
      T2=POLY(H2,7)
      GO TO 6
4     PHI2=PHI1-ALOG(P2P1)/ETACO*RA/AJ
      T2=POLY(PHI2,8)
      H2=POLY(T2,1)
      DH21=H2-H1
6     RETURN
      END
```

```
      SUBROUTINE TURBIN (T4,P4PSO,DH54,AKC,AKU,WC,ALPHAD,EN,F4,FIRST,D1,
     1U,DMTD1,T5,P5P4,P5PSO,VMX5,HTR5,AMBAR,D5D1,ETABAR,VX,VU1,VU2,BETA1
     2,HTR4,D4D1,VMX4,WM4,VM4,VXU)
      COMMON /JAN1/ AJ,PIE,G,ZZ,PSTD,TSTD,PSIR,RA,DELO,SQTH1
      AMBAR=U*U/G/AJ/DH54
      ALPHA=ALPHAD/57.3
C
C     CALCULATE VELOCITY DIAGRAM
```

Figure 3. - Continued.

```
C
      IF (JCGEOM.EQ.3) GO TO 14
10    DHDTC2=1./SQRT(1.+W1AC1/(TEM9*DHDTC1**2))                          56
      DC2DC1=DHDTC1/DHDTC2
      GO TO 16
12    TEM10=((1.+DHDTC1)/2.)**2
      TQ=W1AC1/(4.*TEM9*TEM10)
      DHDTC2=(1.-TQ)/(1.+TQ)
      DC2DC1=(1.+DHDTC1)/(1.+DHDTC2)
      GO TO 16
14    DHDTC2=SQRT(1.-W1AC1/TEM9)                                         61
      DC2DC1=1.
16    DELB2=DELC2*PB2PB1
      DELT1=DELB2
      HT1=POLY(TT1,1)                                                    63
      PSIHT1=POLY(TT1,4)                                                 64
      HO=HF+1254.
      FB=(HT1-HC2)/(HO-(HC2/ETAB)-PSIHT1)
      FAR=FB/(ETAB*(1.-FB/ETAB))
C
C     HTIG   ENTHALPY OUT OF COMBUSTOR
C     CHRGB  CHARGEABLE BLEED
C   HTIGT  EFFECTIVE ENTHALPY AT ROTOR INLET
C   HN  EFFECTIVE ENTHALPY AT TURBINE EXHAUST AFTER COOLING AIR IS MIXED
C   DELHT   TURBINE ENTHALPY DROP DUE TO WORK REQUIRED BY COMPRESSOR
C           AND PUMPING OF COOLING AIR
C      BUSER = BLEED FLOW(LBS/SEC)/W1
C      IF KIND= 0  PROGRAMMER FURNISHES COOLING BLEED
C      IF KIND = 50    LIFT ENGINE
C      IF KIND = 100    CRUISE ENGINE
C
      INDEX=KIND/50
      IF (INDEX-1) 18,20,22
18    PCA=PCA
      GO TO 24
20    PCA=.000110*TT1-.242
      GO TO 24
22    PCA=.000150*TT1-.297
24    CHRGB=.50
      BETCOL=PCA*(1.-BUSER)
      BETTOT=BETCOL+BUSER
      TEM11=(1.+FAR)*(1.-BETTOT)
      HTIG=HT1+FB*PSIHT1
      DELHB=HTIG-HC2
      UTM=DTMDC1*UTIPCC*SQTH1
      DHPUMP=UTM*UTM/AJ/G
      DELHT=(DELHC+DHPUMP*CHRGB*BETCOL)/(TEM11+(1.-CHRGB)*BETCOL)
      HCOLP=HCOOL+DHPUMP
26    W1=WG/(TEM11+BETCOL)
C
      WT=WG
      WB1=W1*(1.-BETTOT)
      WB2=WB1*(1.+FAR)
      AC1=W1*SQTH1/(DELC1*SWC1)
      DC1=SQRT(4.*AC1/PIE)                                               74
      DTM=DC1*DTMDC1
C
C     ROTOR INLET CONDITIONS
C
      HTIGT=(HTIG*TEM11+(1.-CHRGB)*BETCOL*HCOOL)/(TEM11+(1.-CHRGB)*BETCO
     1L)
      FARR=FAR/(1.+BETCOL*(1.-CHRGB)/(1.-BETTOT))
      FR=ETAB*FARR/(1.+FARR)
      TTR=TT1
28    DELTAT=(HTIGT-POLY(TTR,1)-FR*POLY(TTR,4))/(POLY(TTR,-1)+FR*POLY(TT
     1R,-4))                                                             76  77  78  79
      TTR=TTR+DELTAT
      IF (ABS(DELTAT).LT..1) GO TO 30
      GO TO 28
30    WR=W1*(TEM11+BETCOL*(1.-CHRGB))
```

Figure 3. - Continued.

```
      TS4=T4-V4*V4/(2.*G*AJ*CP4)
      VM4=V4/SQRT(GAMMA4*G*R4*TS4)                                          53
      IF (FIRST.EQ.0.) GO TO 14
      VMX4=VX/SQRT(GAMMA4*G*R4*TS4)                                         57
      GF2=0.5*(GAMMA4+1.0)/(GAMMA4-1.0)
      WON=(1.0+(GAMMA4-1.0)*0.5*VM4*VM4)**GF2                               58
      TWO=SQRT(GAMMA4*G/R4)                                                 59
      P4=P4PSO*PSTD
      AF4A1=4.*WC*SQRT(T4)*WON/(P4*TWO*PIE*D1*D1*VMX4)                      60
      RK=4.0*DMTD1*DMTD1
      RK=AF4A1/RK
      HTR4=(1.0-RK)/(1.0+RK)
      D4D1=2.0*DMTD1/(1.0+HTR4)
   14 CP5=POLY(T5,3)+F4*POLY(T5,6)                                          62    63
      P5PSO=P4PSO*P5P4
      GAMMA5=1.0/(1.0-R4/AJ/CP5)
      TS5=T5-V5*V5/(2.*G*AJ*CP5)
      VMX5=VX/SQRT(GAMMA5*G*R4*TS5)                                         64
      WM4=V5/SQRT(GAMMA5*G*R4*TS4)                                          65
      VM5=V5/SQRT(GAMMA5*G*R4*TS5)                                          66
      GF2=0.5*(GAMMA5+1.0)/(GAMMA5-1.0)
      WON=(1.0+(GAMMA5-1.0)*0.5*VM5*VM5)**GF2                               67
      TWO=SQRT(GAMMA5*G/R4)                                                 68
      P5=P5PSO*PSTD
      AF5A1=4.*WC*SQRT(T5)*WON/(P5*TWO*PIE*D1*D1*VMX5)                      69
      RK=4.0*DMTD1*DMTD1
      RK=AF5A1/RK
      HTR5=(1.0-RK)/(1.0+RK)
      D5D1=2.0*DMTD1/(1.0+HTR5)
      RETURN
      END
```

```
      FUNCTION POLY (X,M)
      DIMENSION ICC(8), IORD(8), C(300)
      DATA (ICC(I),I=1,8)/133,146,161,174,187,200,209,226/
      DATA (IORD(I),I=1,8)/4,5,4,4,4,2,6,6/
      DATA (C(I),I=133,242)/100.,107.2616,2.4975E-1,-2.2658E-5,1.96075E-
     18,-3.675E-12,2000.,116.484,.209610,2.554713E-5,-3.338588E-9,1.8843
     2E-13,6000.,100.,1.14506,1.49413E-3,-1.79831E-6,1.39476E-9,-5.8514E
     3-13,1.0156E-16,1400.,1.42938,4.437122E-4,-1.48918E-7,3.4627E-11,-4
     4.513E-15,2.47E-19,6000.,100.,.25232,-5.44152E-5,7.0682E-8,-2.0171E
     5-11,-5.1E-16,1400.,.1861,8.0148E-5,-2.3278E-8,3.41635E-12,-1.989E-
     616,6000.,100.,957.028,-1.397247E-2,2.728088E-4,-7.874997E-8,1.1311
     784E-11,2000.,989.0299,2.421058E-2,1.719862E-4,-2.13151E-8,1.027056
     8E-12,6000.,100.,-.224336,4.84768E-4,-7.184546E-8,-4.315008E-12,3.1
     934744E-15,2000.,-4.089761,5.504657E-3,-2.446699E-6,4.899351E-10,-3
     $.617383E-14,6000.,100.,3.986078E-2,3.562965E-4,-6.512821E-8,2000.,
     $.2063979,1.764343E-4,-1.683137E-8,6000.,100.,-62.685516,-6.9221196
     $E-1,1.9220060E-2,-1.1345611E-5,-9.8360870E-8,2.2458196E-10,-1.4509
     $678E-13,614.,1946.1462,-8.5195086,2.6225174E-2,-2.6543759E-5,1.147
     $9667E-8,-6.4275539E-13,-6.082041E-16,2000.,1.4,415.37102,58.865753
     $,-312.50006,16.528755,-29.769562,5.6792908,53.206712,1.93384,553.8
     $4976,123.43567,-174.32129,22.184326,-104.70823,-43.322374,82.93804
     $9,2.3/
C
C           DATA SOURCE -- HALL AND WEBER, NACA RM E56B27
C
C                                     POLY FUNCTIONS
C              FOR AIR
C     POLY(TEMP,      1) = ENTHALPY          POLY(TEMP,  4) = PSI(ENTHALPY)
C     POLY(TEMP,      2) = ENTROPY           POLY(TEMP,  5) = PSI(ENTROPY)
C     POLY(TEMP,      3) = CP                POLY(TEMP,  6) = PSI(CP)
C     POLY(TEMP,     -1) = CP                POLY(TEMP, -4) = PSI(CP)
C     POLY(TEMP,     -2) = CP/TEMP
C     POLY(ENTHALPY, 7) = TEMP               WHERE PSI IS AN INTERPOLATION
C     POLY(ENTROPY,  8) = TEMP               FACTOR (SEE RM E56B27)
```

Figure 3. - Continued.

```
C
      J=IABS(M)
      K=ICC(J)
      L=IORD(J)+2
2     IF (X-C(K)) 4,6,6
4     K=K-L
      GO TO 2
6     K=K+L
      IF (X-C(K)) 8,8,6
8     IF (M) 14,10,10
10    L=L-1
      POLY=C(K-1)
      DO 12 N=2,L
      KN=K-N
12    POLY=POLY*X+C(KN)
      GO TO 18
14    L=L-2
      POLY=FLOAT(L)*C(K-1)
      DO 16 N=2,L
      KN=K-N
      LN=L-N+1
16    POLY=POLY*X+FLOAT(LN)*C(KN)
18    RETURN
      END
```

```
      FUNCTION VISC (T)
      DIMENSION A(50), V(50)
      DATA (V(J),J=1,50)/73.8,136.0,185.2,227.2,264.7,299.2,331.3,361.4,
     1389.8,417.1,443.5,469.5,495.1,519.7,543.6,567.0,589.8,612.1,633.9,
     2655.3,676.3,697.0,717.3,737.3,757.0,776.5,795.6,814.5,833.2,851.6,
     3869.8,887.8,905.6,923.2,940.6,957.9,974.9,991.8,1008.6,1025.2,1041
     4.6,1058.0,1074.1,1090.2,1106.1,1121.9,1137.5,1153.1,1168.5,1183.8/
      TKELVN=T*5./9.
      A(1)=100.
      DO 2 N=2,50
      A(N)=A(N-1)+100.
2     CONTINUE
      IF (TKELVN.LE.A(1)) GO TO 8
      IF (TKELVN.GE.A(50)) GO TO 10
      K=2
4     IF (TKELVN.LT.A(K)) GO TO 6
      K=K+1
      GO TO 4
6     TOP=A(K)-TKELVN
      DELTT=TOP/100.
      DV=V(K)-V(K-1)
      DIFF=DELTT*DV
      VISM=V(K)-DIFF
      VISC=VISM/14882000.
      GO TO 12
8     VISC=V(1)/14882000.
      WRITE (6,14)                                                     28
      GO TO 12
10    VISC=V(50)/14882000.
      WRITE (6,16)                                                     31
12    RETURN
C
14    FORMAT (32H TKELVN IS LESS THAN 100 DEGREES)
16    FORMAT (36H TKELVN IS GREATER THAN 5000 DEGREES)
      END
```

Figure 3. - Continued.

```
      SUBROUTINE DUCT2 (P1,P2P1,AMD2,TD,WDW1,EQWC1,DELC1,GAMMD,RD,P2STAT
     1,AD2A1)
      COMMON /JAN1/ AJ,PIE,G,ZZ,PSTD,TSTD,PSIR,RA,DELO,SQTH1
      P2=P1*P2P1
      TEM1=1.+(GAMMD-1.)/2.*AMD2**2
      P2STAT=P2/(TEM1)**(GAMMD/(GAMMD-1.))
      SRTDTF=SQRT(TD)/(SQTH1*22.78166)
      TEM2=WDW1*EQWC1*SRTDTF/P2*DELC1*PSTD
      TEM3=AMD2*SQRT(GAMMD*G/RD)
      TEM4=TEM1**((GAMMD+1.)/(2.*(GAMMD-1.)))/TEM3
      AD2A1=TEM2*TEM4*ZZ
      RETURN
      END
```

Figure 3. - Concluded.

ONE SPOOL GAS GENERATOR/LIFT ENGINE-LIFT COMPONENTS

TEST CASE - CUSTOMARY UNITS

PRIMARY INPUTS

SECONDARY INPUTS

GAS FLOW	52.800	AMBIENT PRESSURE	2116.000	CORR TIP SPEED	1300.000	TURB NOZZLE ANGLE	60.000
TURBINE INLET TEMP	2660.000	AMBIENT TEMP	519.000	NO. COMP. STAGES	9.000	TURB LOSS CCEF	0.400
COMP PRES RATIO	8.000			COMP EFFICIENCY	0.880	FLARE RATIO(DTM/CC1)	1.000
TURBINE STAGES	1.000	ENGINE APPLICATION	50.000	COMP FLOW PATH	3.000	TURB STRAIGHT VANES	1.000
UNITS	CUSTOMARY	INLET PRES RATIO	1.000	AXIAL VELOCITY RATIO	0.750		
OPTION	GAS GENERATOR	INLET AXIAL MACH NO	0.600	FUEL HEATING VALUE	18400.000	NOZZLE CCEF	1.000
JET THRUST	-0.	INLET HUB-TIP RATIO	0.480	COMBUSTOR EFFICIENCY	0.985	DUCT PRES RATIO	0.990
		USER BLEED	0.	COMBUSTOR PRES RATIO	0.945	DUCT EXIT MACH NC	0.3C0

LIFT ENGINE
PCA = 0.50600E-01

OUTPUT

GAS PROPERTIES	
TEMPERATURE	2212.0
PRESSURE	7179.6
POWER	255.5
S F C	90.7
DUCT DIAMETER	1.320
STATIC PRES	6773.2
FUEL FLOW	4789.1
JET THRUST	4664.2
THRUST SFC	1.027
SPECIFIC THRUST	90.6

	LENGTH	MASS	PERCENT
COMPRESSOR	1.445	136.4	40.7
COMBUSTOR	0.876	87.5	26.1
TURBINE	0.380	47.1	14.0
DUCT/NOZZLE	1.231	12.7	3.8
ACCESSORIES		22.3	6.6
STRUCTURE		29.3	8.7
TOTAL	3.931 (2.700)	335.2	100.0

	NUMBER OF STAGES	ALPHA1= -BETA2	BETA1= -ALPHA2	VX1=VX2 (=V0)	VU1= -WU2	VU2= -WU1	STAGE LAMDA	MEAN SPEED	ABS.INLET MACH NO.	REL.INLET MACH NO.	FLOW CCEFF.	ABS OUTLET MACH NO.
TURBINE	1.	60.00	24.61	1020.6	1767.4	-467.4	0.5817	1300.0	0.8940	0.4899	0.785	0.512

	PRESS RATIO	DELTA H	FUEL-AIR RATIO	TOTAL EFF.	MASS FLOW	TOTAL TEMP	TOTAL PRESS	AX. MACH NUMBER	AXIAL VELOCITY	HUB-TIP RATIC	TIP DIA. (HUB DIA.)
INLET											
					51.47	519.0	1.0000	0.6000	646.9	0.48000	1.4314 (0.6870)
COMPRESS	8.0000	114.44		0.88000							
					48.87	990.6	8.0000	0.3196	485.2	0.88520	1.4314 (1.2670)
COMBUSTOR	0.9450	503.85	0.02722	0.98500							
					50.20	2660.0	7.5600	0.4471	1020.6	0.81806	1.5746 (1.2881)
					51.50	2622.1					
TURBINE	0.4533 (2.2058)	116.08	0.02652	0.89269							
					52.80	2212.0	3.4273	0.4655	1020.6	0.74432	1.6412 (1.2216)
DUCT/NOZZLE	0.9900		0.02585		52.80	2212.0					
							3.3930	0.3000	663.0		1.3204

01 UNIT05, EOF. REC= 00000 FIL= 00002

(a) U. S. Customary Units.

Figure 4. - Sample computer printout from gas generator/lift engine program.

ONE SPOOL GAS GENERATOR/LIFT ENGINE-LIFT COMPONENTS

TEST CASE - SI UNITS

PRIMARY INPUTS

GAS FLOW	23.950	AMBIENT PRESSURE	101.300
TURBINE INLET TEMP	1478.000	AMBIENT TEMP	288.000
COMP PRES RATIO	8.000		
TURBINE STAGES	1.000	ENGINE APPLICATION	50.000
UNITS	SI	INLET PRES RATIO	1.000
OPTION	GAS GENERATOR	INLET AXIAL MACH NO	0.600
JET THRUST	-0.	INLET HUB-TIP RATIO	0.480
		USER BLEED	0.

SECONDARY INPUTS

CORR TIP SPEED	396.000	TURB NOZZLE ANGLE	1.047
NO. COMP. STAGES	9.000	TURB LOSS CCEF	0.4C0
COMP EFFICIENCY	0.880	FLARE RATIO(DTM/CC1)	1.0C0
COMP FLOW PATH	3.000	TURB STRAIGHT VANES	1.0C0
AXIAL VELOCITY RATIO	0.750		
FUEL HEATING VALUE	42800.000	NOZZLE CCEF	1.000
COMBUSTOR EFFICIENCY	0.985	DUCT PRES RATIO	0.990
COMBUSTOR PRES RATIO	0.945	DUCT EXIT MACH NC	0.3C0

LIFT ENGINE
PCA = 0.50621E-01

OUTPUT

GAS PROPERTIES	
TEMPERATURE	1229.3
PRESSURE	344.1
POWER	420.5
S F C	90.8
DUCT DIAMETER	0.402
STATIC PRES	324.6
FUEL FLOW	2173.8
JET THRUST	20757.2
THRUST SFC	0.105
SPECIFIC THRUST	889.1

	LENGTH	MASS	PERCENT
COMPRESSOR	0.440	61.8	40.7
COMBUSTOR	0.267	39.7	26.1
TURBINE	0.116	21.3	14.0
DUCT/NOZZLE	0.375	12.7	8.8
ACCESSORIES		10.1	6.7
STRUCTURE		13.3	8.7
TOTAL	1.198 (0.823)	151.9	1CC.0

	NUMBER OF STAGES	ALPHA1= -BETA2	BETA1= -ALPHA2	VX1=VX2 (=V0)	VU1= -WU2	VU2= -WU1	STAGE LAMDA	MEAN SPEED	ABS.INLET MACH NO.	REL.INLET MACH NO.	FLOW CCEFF.	ABS OUTLET MACH NC.
TURBINE	1.	1.05	0.43	310.9	538.5	-142.7	0.5810	395.8	0.8935	0.4899	C.786	0.512

	PRESS RATIO	DELTA H	FUEL-AIR RATIO	TOTAL EFF.	MASS FLOW	TOTAL TEMP	TOTAL PRESS	AX. MACH NUMBER	AXIAL VELOCITY	HUB-TIP RATIC	TIP DIA. (HUB DIA.)
INLET											
					23.35	288.0	0.9999	0.6000	197.C	0.48C00	0.4362 (0.2094)
COMPRESS	8.0000	265.86		0.88000							
					22.16	549.7	7.9989	0.3196	147.8	0.88519	0.4362 (0.3861)
COMBUSTOR	0.9450	1172.86	0.02724	0.98500							
					22.77	1478.0	7.5589	0.4468	310.9	0.81793	0.4798
					23.36	1456.9					(0.3925)
TURBINE	0.4538 (2.2034)	269.67	0.02654	0.89264							
					23.95	1229.3	3.4306	0.4653	310.9	0.74428	0.5001 (0.3722)
DUCT/NOZZLE	0.9900		0.02586		23.95	1229.3					
							3.3963	0.3000	202.1		0.4023

(b) SI Units.

Figure 4. - Concluded.

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