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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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.
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.

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 prepared. 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.
APPRAOCH

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 accommodate 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 $D_t$: 

\[ D_t \]
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

\[ W_d = K_d D_t^2 \]  \hspace{1cm} (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

\[ W_n = K_n D_t^2 \]  \hspace{1cm} (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 signifi-
cance of each input parameter is discussed. The symbols used in the FORTRAN lan-
guage 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 $P_O$ and temperature $T_O$ 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 conditions (i.e., the engine is designed for the takeoff con-
dition).

The performance of the engine inlet is described by a single parameter, the total
pressure ratio $P_{I2P1}$ 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 air-
flow 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 accommodates 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 \( ETA \).

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 out of 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:

\[ \text{PCA} = 0.00011 \times \text{TT1} - 0.242 \]  \tag{3} 

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

\[ \text{PCA} = 0.00015 \times \text{TT1} - 0.297 \]  \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 informa-
tion. 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.

<table>
<thead>
<tr>
<th>COMP FLOW PATH</th>
<th>JCGEOM</th>
<th>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.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGINE APPLICATION</td>
<td>KIND</td>
<td>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 air 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.</td>
</tr>
<tr>
<td>INPUT CARD INDEX</td>
<td>N</td>
<td>Set equal to 1 for single case.</td>
</tr>
<tr>
<td>INPUT CARD INDEX</td>
<td>NN</td>
<td>Set equal to 1 for single case.</td>
</tr>
</tbody>
</table>
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** (DHDT DC1): 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**

If UNITS = 0, all quantities are in U.S. Customary Units. If UNITS ≠ 0, SI Units are used.

**USER BLEED**

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 (°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.
**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 (°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:

<table>
<thead>
<tr>
<th>Card</th>
<th>Partial contents</th>
<th>Card</th>
<th>Partial contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N = 1, NN = 3</td>
<td>5</td>
<td>---------------</td>
</tr>
<tr>
<td>2</td>
<td>-----------------</td>
<td>6</td>
<td>WG = 30</td>
</tr>
<tr>
<td>3</td>
<td>-----------------</td>
<td>6</td>
<td>WG = 35</td>
</tr>
<tr>
<td>4</td>
<td>-----------------</td>
<td>6</td>
<td>WG = 40</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Card</th>
<th>Partial contents</th>
<th>Card</th>
<th>Partial contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N = 2, NN = 3</td>
<td>6</td>
<td>WG = 35</td>
</tr>
<tr>
<td>2</td>
<td>-----------------</td>
<td>6</td>
<td>WG = 40</td>
</tr>
<tr>
<td>3</td>
<td>-----------------</td>
<td>5</td>
<td>TO = 305</td>
</tr>
<tr>
<td>4</td>
<td>-----------------</td>
<td>6</td>
<td>WG = 30</td>
</tr>
<tr>
<td>5</td>
<td>TO = 288</td>
<td>6</td>
<td>WG = 35</td>
</tr>
<tr>
<td>6</td>
<td>WG = 30</td>
<td>6</td>
<td>WG = 40</td>
</tr>
</tbody>
</table>
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 $\Pi_2\Pi_1$ from a value of 0.99 (assumed to be the value used for the examples under the first two methods) to $\Pi_2\Pi_1 = 0.95$. The required data input cards would be as follows:

<table>
<thead>
<tr>
<th>Card</th>
<th>Partial contents</th>
<th>Card</th>
<th>Partial contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$N = 2$, $NN = 1$</td>
<td>1</td>
<td>$N = 2$, $NN = 1$</td>
</tr>
<tr>
<td>2</td>
<td>$\Pi_2\Pi_1 = 0.99$</td>
<td>2</td>
<td>$\Pi_2\Pi_1 = 0.95$</td>
</tr>
<tr>
<td>3</td>
<td>TO = 288</td>
<td>3</td>
<td>TO = 288</td>
</tr>
<tr>
<td>4</td>
<td>WG = 35</td>
<td>4</td>
<td>WG = 35</td>
</tr>
<tr>
<td>5</td>
<td>TO = 305</td>
<td>5</td>
<td>TO = 305</td>
</tr>
<tr>
<td>6</td>
<td>WG = 35</td>
<td>6</td>
<td>WG = 35</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Card</th>
<th>Partial contents</th>
<th>Card</th>
<th>Partial contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$N = 2$, $NN = 3$</td>
<td>6</td>
<td>WG = 35</td>
</tr>
<tr>
<td>2</td>
<td>$\Pi_2\Pi_1 = 0.99$</td>
<td>6</td>
<td>WG = 40</td>
</tr>
<tr>
<td>3</td>
<td>TO = 288</td>
<td>1</td>
<td>$N = 2$, $NN = 1$</td>
</tr>
<tr>
<td>4</td>
<td>WG = 30</td>
<td>2</td>
<td>$\Pi_2\Pi_1 = 0.95$</td>
</tr>
<tr>
<td>5</td>
<td>WG = 35</td>
<td>3</td>
<td>TO = 288</td>
</tr>
<tr>
<td>6</td>
<td>WG = 35</td>
<td>4</td>
<td>TO = 305</td>
</tr>
<tr>
<td>5</td>
<td>TO = 305</td>
<td>5</td>
<td>TO = 305</td>
</tr>
<tr>
<td>6</td>
<td>WG = 30</td>
<td>6</td>
<td>WG = 35</td>
</tr>
</tbody>
</table>
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 (°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:

<table>
<thead>
<tr>
<th>NUMBER OF STAGES</th>
<th>SNT</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALPHA1 = -BETA2</td>
<td>ALPHAT</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BETA1 = -ALPHA2</td>
</tr>
<tr>
<td>VX1 = VX2 (= VO)</td>
<td>VX</td>
<td>Axial velocity through the turbine, in meters per second (ft/sec); also assumed to be the approach velocity to the first-stage stator.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VU1 = -WU2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VU2 = -WU1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>STLAMT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UTM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AMT1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AMTIW</td>
</tr>
</tbody>
</table>
FLOW COEFF. FLOWT Ratio of through-flow velocity to mean blade speed.

ABS OUTLET AMT2 Mach number of absolute velocity at discharge of
  MACH NO. 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 (°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.
REFERENCES


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

DIMENSION TITLE(12)
COMMON /JAN1/ AJ,PIE,G,ZZ,PSTD,PSIR,RA,DELO,SOTH1
DIMENSION UNIA(4), UNIO(6)
DATA UNIA(1),UNIA(2),UNIA(3),UNIA(4)/6H CUS,6HTOMARY,6H,6H
DATA UNIO(1),UNIO(2),UNIO(3),UNIO(4),UNIO(5),UNIO(6)/6H GEN,6HERATOR,6H,6H LIFT,
DATA TITLE(1),I=1,6)/6H 1,6H 1,6H 1,6H 1,6H 1,6H 1,6H

READ (5,58) JCGEOM,KIND,N,NN
READ (5,60) (TITLE(U1),U=1,12)
READ (5,56) ALPHAT,AMD2,PCA.DHDTCl,AKCT.HF,PI2P1,AMC1
READ (5,56) VC2VC1,ETAB,AKUT,UNITS,BUSER,CFJ
IF (UNITS.EQ.0.) GO TO 4
ALPHAT=ALPHAT/0.01745
HF=HF/2.326
DO 54 J=1,N
READ (5,56) ETAC.DTMDCl,UTIPCC,P0,T0,PB2PB1,SNC,PD2PD1
IF (UNITS.EQ.0.) GO TO 6
DIV=.3048
UTIPC2=UTIPCC/DIV
TO=TO/5556
6 DO 52 K=1,NN
READ (5,56) WG,PC2PC1,TT1,SNT,FJS,OPTION
IF (WG.EQ.0.0) WG=50.
IF (UNITS.EQ.0.) GO TO 8
WG=WG/.4536
TT1=TT1/.5556
TC1=TO
HC1=POLY(TC1,1)
DEL0=PO/PSTD
DELCl=PO*PI2P1/PSTD
SOTH1=SQR(TC1/519.)
CPC1=POLY(TC1,3)
GAMC1=1./(1.-RA/(AJ*CPC1))
TEM1=GAMC1-1.
TEM2=TEM1/2.
TEM3=1.*(TEM2*AMC1*AMC1)
TEMS=SQR(1.*GAMC1*G/R)
TEMS/=SQR(TC1/TC2)
SWC1=TEMS/(ZC*AMC1**TEM6)*(1.-DHDTC1**2)
VC1=AMC1**SQR(TC1/TC2)**(1./G-1.)
CALL COMPRS (TC1,PC2PC1,DELCl,ETAC,HC1,SWC1,TC2,DELCl2,DELHC,HC2)
PC1=DELCl*PSTD
PC2=DELCl2*PSTD
CPC2=POLY(TC2,3)
GAMC2=1./(1.-RA/(AJ*CPC2))
VC2=VC1*VC2VC1
AMC2=SQR(VC2**2/(GAMC2*G*RA*TC2-1.**2.*VC2**2))
RHOC2=DELCl2*PSTD/(G*RA*TC2)**((1.**2.)*G**2)
LCM2-1.1
TCOOL=TC2
HCool=POLY(TCOOL,1)
WAC1=SWC1*DELCl/SOTH1
IF JCGEOM = 1 CONSTANT HUB DIAMETER
IF (JCGEOM.EQ.1) GO TO 10
IF JCGEOM = 2 CONSTANT MEAN DIAMETER
IF (JCGEOM.EQ.2) GO TO 12
IF JCGEOM = 3 CONSTANT TIP DIAMETER
IF (JCGEOM.EQ.3) GO TO 14

Figure 3. FORTRAN listings of gas generator/lift engine computer program.
C IF (J-GEOM.EQ.3) GO TO 14
10    DHDTC2=1./SQRT(1.+W1AC1/(TEM9*DHDTC1**2)).
11    DC2DC1=DHDTC1/DHDTC2
12    GO TO 16
13    TEM10=((1.+DHDTC1)/2.)*2
14    TQ=W1AC1/(4.*TEM9*TEM10)
15    DHDTC2=(1.-TQ)/(1.+TQ)
16    DC2DC1=(1.+DHDTC1)/1.+DHDTC2)
17    GO TO 16
18    DHDTC2=SQRT(1.-W1AC1/TEM9)
19    DC2DC1=1.
20    DELB2=DEL2C2*PB2PB1
21    DETH1=POLY(TT1,1)
22    PSIHT1=POLY(TT1,4)
23    HD=HF*1254.
24    FB=(HT1-HC2)/(HO-(HC2/ETAB)-PSIHT1)
25    FAR=F3/(ETAB*(1.-FB/ETAB))
26    HTIG-ENTHALPY OUT OF COMBUSTOR
27    CHRGB-CHARGEABLE BLEED
28    HTIGT-EFFECTIVE ENTHALPY AT ROTOR INLET
29    HN-EFFECTIVE ENTHALPY AT TURBINE EXHAUST AFTER COOLING AIR IS MIXED
30    DELT- TURBINE ENTHALPY DROP DUE TO WORK REQUIRED BY COMPRESSOR
31    BUSER = BLEED FLOW(LBS/SEC)/W1
32    IF KIND= 0 PROGRAMMER FURNISHES COOLING BLEED
33    IF KIND = 50 LIFT ENGINE
34    IF KIND = 100 CRUISE ENGINE
35    INDEX=KIND/50
36    IF (INDEX-1) 18,20,22
37    PCA=P1A
38    GO TO 24
39    PCA=0.00100*TT1-.242
40    GO TO 24
41    PCA=0.00150*TT1-.297
42    CHRGB=.50
43    BETCOL=PCA*(1.-BUSER)
44    BETTOT=BETCOL+BUSER
45    TEM11=(1.+FAR)*(1.-BETTOT)
46    HTIG=HTI+FB*PSIHT1
47    DELHB=HTIG-HC2
48    UTM=DTMOCI*UTIPCC*SQTH1
49    DHPUMP=UTM*UTM/AJ/G
50    OELHT=(DELHC+DHPUMP*CHRGB*BETCOL)/(TEM11-M1.-CHRGB)*BETCOL)
51    HCOLP=HCOOL+DHPUMP
52    W1 = WGiMTEM11+BETCOL)
53    HT=WGi
54    WB1=W1*(1.-BETTOT)
55    WB2=WB1*(1.+FAR)
56    AC1=W1*SQTH1/(DEL1*SWC1)
57    DC1=SQRT(4.*AC1/PIE)
58    DTM=DC1*DTMDC1
59    ROTOR INLET CONDITIONS
60    HTIGT=(HTIG*TEM11+(1.-CHRGB)*BETCOL*HCOOL)/(TEM11+(1.-CHRGB)*BETCO)
61    FARR=FAR/(1.+BETCOL*(1.-CHRGB)/(1.-BETTOT))
62    FR=ETAB*FARR/(1.+FARR)
63    TTR=TT1
64    DELT0 = (HTIGT-POLY(TT1,1)-FR*POLY(TT,4))/(POLY(TT,1)+FR*POLY(TT
65    TR+5)
66    TFR=TFR+DELTAT
67    IF (ABS(DELTAT).LT.1) GO TO 30
68    GO TO 28
69    WR=W1*(TEM11+BETCOL*(1.-CHRGB))
CALL TURBIN (TT1,DEL1,DELHT,AKCT,AKUT,WR,ALPHAT,SNT,FR,1.,DC1,UTM)
1,DTMD1,TT2,PT2PT1,DEL1,AMT1,OHDT1,AMBBT,DT2DC1,ETABT,XX,VL1,VU
22,BETA,OHDT1,DT1DC1,AMTI,AMTI,1,FLOWT)
C
PT1PT2=1./PT2PT1
SILAMT=SNT*AMBBT
BETAR=BETA*0.01745
AMT2=AMT2X*COS(BETAR)
HN=((HT1G-DEL1H)*(TEM1+((1.-CHR1GB)*BET1COL)+CHR1GB*BET1COL*HCOLP)/IT
1EM1+BET1COL)
FAPRIM=FAR/U.+BET1TOT)
FPRIME=ETA8*FAPRIM/<1.+FAPR1M)*AMT2*AMT2X/COS(BETAR)
FAPRIM=FAR/U.+BET1TOT)
FPRIME=ETA8*FAPRIM/<1.+FAPRIM)
TD=TT1
DEL1=(HN-((POLY(T0,1)+FPRIME*POLY(T0,4))/((POLY(T0,1)+FPRIME*POLY(T0)
1,4)))/TD,1)*TD,1) IF (ABS(DELT).LT..1) GO TO 34
GO TO 32
C
BEGIN DUCT CALCULATIONS
CPD=POLY(T1D,3)+FPRIME*POLY(T1D,6)
RD=RA+FPRIME*PSIR
GAMMD=1./(1.-RD/(AJ*CPD))
WD1=WD/W1
PD1=DEL1*PD1
CALL DUCT2 (PD1,P02PDIiAM02.TD,H1W1,SWC1,OELC1,GAMMD,RD,PDSTAT,AD1)
PD2=P2P1*PD2PD1
VJ=SQRT(2.*GAMMD/(GAMMD-1.0)*AMD2*AMD2)/(GAMMD-1.0/2.*AMD2*AMD2/2.0))
FJ=HDLH*W1*VJ/G
IF (OPTION.LT.1.5) GO TO 36
DFJ=FJ-FJ
FJTEST=DFJ/FJS
IF (A8S(FJTEST).LT..001) GO TO 36
WG=FJ/G/VJ
GO TO 26
AMN=SQRT((GAMMD*G*RD*TD-(GAMMD-1.0)/2.*GAMMD*G*RD*TD-(GAMMD-1.0)/2.*GAMMD*G*)
FJ=HDLH*VJ/G)
WF=WF/FJ
SFC=WF/FJ
C
SAS AND THRUST SFC'S GAS POWER
GSFC=HF/WG
SFCNTH=WF/FJ
FJW=W1*FAR*(1.-BET1TOT)*3600.
SFC=SFC/3600.
PHIX=POLY(T1D,2)+FPRIME*POLY(T1D,5)
PHIX=POLY(T1D,2)+FPRIME*POLY(T1D,5)
PHIX=PHIX-RA*AMT1/AMT1VJ/G
TXI=TD
DEL1X=(PHIX1-POLY(TXI,2)-FPRIME*POLY(TXI,5))/((POLY(TXI,1)+FPRIME*POLY(TXI,5))
1,5)) TXI=TXI+DEL1X
IF (DEL1X.GT..1) GO TO 38
H1X=POLY(TXI,1)+FPRIME*POLY(TXI,4)
HD=POLY(TXI,1)+FPRIME*POLY(TXI,4)
GHP=AJ*(HD-H1X)/550.
C
COMPONENT DIAMETERS
DC1=JC1
DC1=JC1
DC1=JC1
DC2=JC1
DC2=JC2
DC2=JC2
Figure 3. - Continued.
DT1T=DC1T*DT1DC1
DT1H=DT1T*DHDT1
DT2T=DC1T*DT2DC1
DT2H=DT2T*DHDT2

LENGTHS - LIFT ENGINE ROTATING COMPONENTS

COMPRESSOR
CLENDM=0.2+(0.234-.218*ODHC1)*SNC
COMPL=CLENDM*(DC1H+DC1T)/2.

COMBUSTOR
WBIN=WI*(1.-BETTOT)
CORWB1=WB1N*SQRT(TC2/TSTD)/DELC2
ELOH=2.0
VREF=80.
DMAV=(DC2T+DC2H+DT1T+DT1H)/4.
BURNL=2.2*CORWB1*ELOH*SQRT(TC2)/(DMAV*VREF)/12.

TURBINE
TSAR=6.45-5.97*DHu.T1
TRAR=5.1-5.5*DHDT1
IF (TRAR.GT.6.) TRAR=6.
BLDH=DT1T*(1.-OHDTT1)/2.
SAXCHD=BLDH/TSAR
RAXCHO=BLDH/TRAR
TCLR=.40*RAXCHD
TURBL=SNT*(SAXCHD+RAXCHO+2.*TCLR)+TCLR+SAXCHD

DUCT
DUCTL=.75*DT2T
IF (OPTION.GT.1.5) DUCTL=.25*DT2T

ENGINE
ENGL=COMPL+BURNL+TURBL
ENGLT=ENGL+DUCTL
ELOD=ENGL/DC1
ELODT=ENGLT/DC1

WEIGHTS - LIFT ENGINE ROTATING COMPONENTS

COMPRESSOR
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)

COMBUSTOR
DMBURN=(DC2T+DC2H+DT1T+DT1H)/4.
BURNW=32.*DMBURN*DMBURN*SQRT(ELOH)

TURBINE
DMTURB=(DT1T+DT1H+DT2T+DT2H)/4.
TURBW=.26*SNT*DMTURB**2.5*UTM**0.6

DUCT
DUCTW=4.7*DT2T*DT2T
IF (OPTION.GT.1.5) DUCTW=1.1*DT2T*DT2T

Figure 3. - Continued.
ACCESSORY, STRUCTURE, AND TOTAL

\[ \text{ACCW} = 0.02 *(FJ + 1.35 \times WF) \]

\[ \text{BENGW} = \text{COMPW} + \text{BURNW} + \text{ACCW} \]

\[ \text{STRW} = 1.0 \times \text{BENGW} \]

\[ \text{ENGW} = \text{BENGW} + \text{DUCTW} + \text{STRW} \]

\[ \text{PCTH} = 100. / \text{ENGW} \]

\[ \text{COMPWX} = \text{COMPW} \times \text{PCTW} \]

\[ \text{BURNWX} = \text{BURNW} \times \text{PCTW} \]

\[ \text{TURBWX} = \text{TURBW} \times \text{PCTW} \]

\[ \text{ACCWX} = \text{ACCW} \times \text{PCTW} \]

\[ \text{STRWX} = \text{STRW} \times \text{PCTW} \]

\[ \text{AJCGEO} = \text{JCGEOM} \]

\[ \text{AKIND} = \text{KIND} \]

\[ \text{IF} (\text{UNITS}, \text{EQ.} 0.) \text{ GO TO 40} \]

WRITE INPUTS IN SI UNITS

\[ \text{WG} = 0.4536 \times \text{WG} \]

\[ \text{TT1} = 0.5556 \times \text{TT1} \]

\[ \text{TO} = 0.5556 \times \text{TO} \]

\[ \text{UTIPCC} = \text{DIV} \times \text{UTIPCC} \]

\[ \text{HF} = 2.326 \times \text{HF} \]

\[ \text{ALPHAT} = 0.01745 \times \text{ALPHAT} \]

WRITE OUTPUTS IN SI UNITS

\[ \text{TD} = 0.5556 \times \text{TD} \]

\[ \text{PD2} = 0.4788 \times \text{PD2} \]

\[ \text{GHP} = 1.644 \times \text{GHP} \]

\[ \text{GSFC} = 0.83 \times \text{GSFC} \]

\[ \text{DUCTD} = \text{DUCTD} \times 0.3048 \]

\[ \text{PDSTAT} = \text{PDSTAT} \times 0.04788 \]

\[ \text{WF} = 0.4536 \times \text{WF} \]

\[ \text{FJ} = 4.448 \times \text{FJ} \]

\[ \text{SFC} = 1.020 \times \text{SFC} \]

\[ \text{FJW1} = 0.806 \times \text{FJW1} \]

\[ \text{WTCON} = 0.4536 \]

\[ \text{COMPW} = \text{WTCON} \times \text{COMPW} \]

\[ \text{BURNW} = \text{WTCON} \times \text{BURNW} \]

\[ \text{TURBW} = \text{WTCON} \times \text{TURBW} \]

\[ \text{ACCW} = \text{WTCON} \times \text{ACCW} \]

\[ \text{STRW} = \text{WTCON} \times \text{STRW} \]

\[ \text{ENGW} = \text{WTCON} \times \text{ENGW} \]

\[ \text{BETA} = 0.01745 \times \text{BETA} \]

\[ \text{VX} = DIV \times VX \]

\[ \text{VU1} = DIV \times VU1 \]

\[ \text{VU2} = DIV \times VU2 \]

\[ \text{UTM} = DIV \times UTM \]

\[ \text{ELCON} = 0.3048 \]

\[ \text{COMPL} = \text{ELCON} \times \text{COMPL} \]

\[ \text{BURNL} = \text{ELCON} \times \text{BURNL} \]

\[ \text{TURBL} = \text{ELCON} \times \text{TURBL} \]

\[ \text{DUCTL} = \text{ELCON} \times \text{DUCTL} \]

\[ \text{ENGL} = \text{ELCON} \times \text{ENGL} \]

\[ \text{ENGLT} = \text{ELCON} \times \text{ENGLT} \]

\[ \text{HCON} = 2.326 \]

\[ \text{DELHC} = \text{HCON} \times \text{DELHC} \]

\[ \text{DELHB} = \text{HCON} \times \text{DELHB} \]

\[ \text{DELHT} = \text{HCON} \times \text{DELHT} \]

\[ \text{W1} = \text{WTCON} \times \text{W1} \]

\[ \text{W1} = \text{WTCON} \times \text{W1} \]

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
WRITE (6,62)
WRITE (6,60) TITLE(I),I=1,12
WRITE (6,110)
WRITE (6,72) WG,PO,UTIPCC,ALPHAT
WRITE (6,74) TI,T0,SNC,AKCT
WRITE (6,76) PC2P1,ETAC,DTMOC1
WRITE (6,78) SNT,AKIND,AJCGEO,AKUT

IU=1
IF (UNITS.NE.0.0) IU=3
WRITE (6,80) UNIA(IU),UNIA(IU+1),PI2P1,VC2VC1

10=1
IF (OPTION.GT.1.5) 10=4
IOE=ID+2
WRITE (6,82) (UNIO(IP),IP=IO,IOE),AMC1,HF,CFJ
WRITE (6,84) FJS,DHDTC1,ETAB,P02PD1
WRITE (6,86) BUSER,PB2PB1,AM02

IF (KIND.EQ.O) GO TO 42
IF (KIND.EQ.50) GO TO 44
IF (KIND.EQ.100) GO TO 46
WRITE (6,64)
WRITE (6,70) PCA

WRITE (6,66)
WRITE (6,70) PCA

WRITE (6,68)
WRITE (6,70) PCA

WRITE (6,112)
WRITE (6,88) TD
WRITE (6,92) PD2,COMPL,COMPW,COMPWX
WRITE (6,94) GSPC,TURBL,TURBW,TURBWX
WRITE (6,98) DUCTD,DUCTL,DUCTW,DUCTWX
WRITE (6,100) PDSTAT,ACCH,ACCW
WRITE (6,102) WF,STRW,STRWX
WRITE (6,104) FJ
WRITE (6,106) SFC,ENGLT,ENGW
WRITE (6,108) FJWI,ENGL
WRITE (6,118)
WRITE (6,116)
WRITE (6,114) SNT,ALPHAT,BETA,VX,VU1,VU2,STLAMT,UTM,AMT1,AMT1W,FLO

IWF,AMT2

WRITE (6,120)
WRITE (6,136)
WRITE (6,134) W1,TC1,DELG1,AMC1,VC1,DHDT1,DC1T,DC1H
WRITE (6,124) PC2P1,DELHC,ETAC
WRITE (6,126) WB1,TC2,DELG2,AMC2,VC2,DHDT2,DC2T,DC2H

WRITE (6,124)
WRITE (6,116)

WRITE (6,114) SNT,ALPHAT,BETA,VX,VU1,VU2,STLAMT,UTM,AMT1,AMT1W,FLO

Figure 3. - Continued.
SUBROUTINE COMPRS (T1, P2PI, P1PSO, ETA0, H1, SWC1, T2, P2PSO, DH21, H2)

COMMON /JAN1/ AJ, PIE, G, ZZ, PSTD, TSTD, PSIR, RA, DELO, SQTH1

IF (ETA0 GT. 0) ETA0 IS TREATED AS AN ADIABATIC EFFICIENCY
IF (ETA0 LT. 0) ETA0 IS TREATED AS A POLYTROPIC EFFICIENCY

PHI1 = POLY (T1, 2)

IF (Eta0) 4, 4, 2

PHI2 = PHI1 - ALOG (P2PI) / ETA0 * RA / AJ

T2 = POLY (PHI2, 8)

H2 = H1 + DH21

T2 = POLY (T2, 1)

H2 = POLY (T2, 8)

DH21 = H2 - H1

RETURN

END

SUBROUTINE TURBIN (T4, P4PSO, DH4, AKC, AKU, WC, ALPHAD, EN, F4, FIRST, D1, U, DMTD1, T5, P5PSO, VMX5, HTR5, AMBAR, DSO1, ETABAR, VX, VU1, VU2, BET1A)

COMMON /JAN1/ AJ, PIE, G, ZZ, PSTD, TSTD, PSIR, RA, DELO, SQTH1

AMBAR = U * U / G / AJ / DH4

ALPHA = ALPHAD / 57.3

CALCULATE VELOCITY DIAGRAM

Figure 3. - Continued.
C IF (JCGEOM.EQ.3) GO TO 14

10 DHDTC2=1./SQRT(1.+W1AC1/TEM9*DHDTC1**2))

DC2CL=DHDTC1/DHDTC2

GO TO 16

12 TEM10=1/(1.+DHDTC1)**2

TQ=W1AC1/(4.*TEM9*TEM10)

DHDTC2=(1.-TQ)/(1.+TQ)

DC2CL=(1.+DHDTC1)/(1.+DHDTC2)

GO TO 16

14 DHDTC2=SQRT(1.-W1AC1/TEM9)

DC2CL=1.

16 DELB2=DEL2*PB2PB1

DELT1=DELB2

HTL=POLY(TT1,1)

PSHT1=POLY(TT1,4)

HO=HF=125.

FB=(HT1-HC2)/(HO-(HC2/ETAB)-PSHT1)

FAR=F3/(ETAB+(1.-FB/ETAB))

C HTIG ENTHALPY OUT OF COHBUSTOR

C CHRGB CHARGEABLE BLEED

C HTIGT EFFECTIVE ENTHALPY AT ROTOR INLET

C HN EFFECTIVE ENTHALPY AT TURBINE EXHAUST AFTER COOLING AIR IS MIXED

C DELT 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

INDEX=KIND/50

IF (INDEX=1) 18,20,22

PCA=PCA

GO TO 24

20 PCA=.000100*TT1-.242

GO TO 24

22 PCA=.000150*TT1-.297

24 CHRG8=.50

BETCOL=PCA*(1.-BUSER)

BETTOT=BETCOL+BUSER

TEM11=(1.+FAR)*(1.-BETTOT)

HTIG=HT1+FB*PSHT1

UTM=DTMOCI*UTIPCC*SQTH1

DHPUMP=UTM*UTM/AJ/G

OELHT=(DELHC*DHPUMP*CHRGB*BETCOL)/(TEM11+(1.-CHRGB)*BETCOL)

HCOLP=HCOOL+OELHT

W1=WG/(TEM11+BETCOL)

C ROTOR INLET CONDITIONS

C HTIGT=(HTIG*TEM11+(1.-CHRGB)*BETCOL*HCOL)/(TEM11+(1.-CHRGB)*BETCOIL)

FARR=FAR/(1.+BETCOL*(1.-BETTOT))

FR=ETAB*FARR/(1.+FARR)

TTR=TT1

DELTA=(HTIG-POLY(TTR,1)+FR*POLY(TTR,4))/(POLY(TTR,-1)+FR*POLY(TTR,-4))

1R,=1

TTR=TT+DELTAT

IF (ABS(DELTAT).LT.1) GO TO 30

GO TO 26

30 WR=W1*(1-BETTOT)

Figure 3. - Continued.

29
\[ T_4 = \frac{V_4 \cdot V_4}{2 \cdot G \cdot A_\text{J} \cdot C_\text{P} \_4} \]
\[ V_\text{M} \_4 = \frac{V_4}{\sqrt{G \cdot A_\text{J} \cdot c_\text{P} \_4 \cdot T_4}} \]
\[ \text{IF (FIRST.EQ.0.) GO TO 14} \]
\[ V_\text{M} \_X \_4 = \frac{V_\text{X}}{\sqrt{G \cdot A_\text{J} \cdot c_\text{P} \_4 \cdot T_4}} \]
\[ G_\text{F} \_2 = \frac{0.5 \cdot (G \cdot A_\text{J} \_4 + 1)}{G \cdot A_\text{J} \_4 - 1} \]
\[ W_\text{ON} = (1 + (G \cdot A_\text{J} \_4 - 1) \cdot 0.5 \cdot V_\text{M} \_4 \cdot V_\text{M} \_4)^{G_\text{F} \_2} \]
\[ T_\text{W} \_2 = \sqrt{G \cdot A_\text{J} \cdot c_\text{P} \_4 \cdot T_4} \]
\[ P_4 = P_\text{PSO} \cdot P_\text{STD} \]
\[ A_\text{F} \_4 \_A \_1 = 0.5 \cdot (G \cdot A_\text{J} \_4 + 1) \cdot (G \cdot A_\text{J} \_4 - 1) \cdot W_\text{ON} \cdot P_4 \cdot T_\text{W} \_2 \cdot \pi \cdot D_\text{1} \cdot D_\text{1} \cdot V_\text{M} \_X \_4 \]
\[ R_\text{K} = 4 \cdot D_\text{TD} \_1 \cdot D_\text{TD} \_1 \]
\[ H_\text{T} \_R \_4 = (1 - R_\text{K} \_1 / (1 + R_\text{K})) \]
\[ D_\text{1} \_D \_1 = 2 \cdot D_\text{TD} \_1 \cdot (1 + H_\text{T} \_R \_4) \]
\[ CP_5 = P_\text{LY}(T_\text{5}, 3) + F_4 \cdot P_\text{LY}(T_\text{5}, 6) \]
\[ P_\text{PSO} \_5 = P_\text{PSO} \cdot P_\text{PSO} \_4 \]
\[ G_\text{M} \_5 = 1 + (G \cdot A_\text{J} \_5 - 1) \cdot 0.5 \cdot V_\text{M} \_5 \cdot V_\text{M} \_5 \]
\[ W_\text{ON} \_5 = (1 + (G \cdot A_\text{J} \_5 - 1) \cdot 0.5 \cdot V_\text{M} \_5 \cdot V_\text{M} \_5)^{G_\text{F} \_2} \]
\[ T_\text{W} \_2 = \sqrt{G \cdot A_\text{J} \cdot c_\text{P} \_4 \cdot T_4} \]
\[ P_5 = P_\text{PSO} \_5 \cdot P_\text{STD} \]
\[ A_\text{F} \_5 \_A \_1 = 0.5 \cdot (G \cdot A_\text{J} \_5 + 1) \cdot (G \cdot A_\text{J} \_5 - 1) \cdot W_\text{ON} \_5 \cdot P_5 \cdot T_\text{W} \_2 \cdot \pi \cdot D_\text{1} \cdot D_\text{1} \cdot V_\text{M} \_X \_5 \]
\[ R_\text{K} = 4 \cdot D_\text{TD} \_1 \cdot D_\text{TD} \_1 \]
\[ H_\text{T} \_R \_5 = (1 - R_\text{K} \_1 / (1 + R_\text{K})) \]
\[ D_\text{1} \_D \_1 = 2 \cdot D_\text{TD} \_1 \cdot (1 + H_\text{T} \_R \_5) \]
\[ \text{RETURN} \]

\text{FUNCTION POLY (X,M)}
\text{DIMENSION ICC(I), IORD(B), C(300)}
\text{DATA (ICC(I),1=1,8)/133,146,161,174,187,200,209,226/}
\text{DATA (IORD(I),1 = 1,81/4,5,4,4,4,4,2,6,67 E 4}

\text{DATA SOURCE — HALL AND WEBER, NACA RM E56B27}

\text{POLY FUNCTIONS}
\text{FOR AIR}
\text{POLY(TEMP, 1) = ENTHALPY}
\text{POLY(TEMP, 2) = ENTROPY}
\text{POLY(TEMP, 3) = CP}
\text{POLY(TEMP, -1) = CP}
\text{POLY(TEMP, -2) = CP/TEMP}
\text{POLY(ENTHALPY, 7) = TEM}
\text{POLY(ENTRropy, 8) = TEM}

WHERE PSI IS AN INTERPOLATION
FACTOR (SEE RM E56B27)

\text{Figure 3. - Continued.}
C
J=IABS(M)
K=1CC(J)
L=IORD(J)+2
2 IF (X-C(K)) 4,6,6
4 K=K-L
GO TO 2
6 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
10 KN=K-N
LN=L-N-1
12 POLY=POLY*X+C(KN)
GO TO 10
14 L=L-2
POLY=FLOAT(L)*C(K-1)
DO 16 N=2,L
14 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(I)=100.
DO 2 N=2,50
A(N)=A(N-1)+100.
2 CONTINUE
IF (TKELVN.LE.A(I)) 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
DELT=TOP/100.
DV=V(K)-V(K-1)
DIFF=DELT*DV
VISM=V(K)-DIFF
VISC=VISM/14882000.
GO TO 12
8 VISC=W(V(1)/14882000.
WRITE (6,14)
GO TO 12
10 VISC=W(V(50)/14882000.
WRITE (6,16)
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, WDH1, EQWC1, DELC1, GAMMD, RD, P2STAT, AD2A1)

COMMON /JAN1/ AJ, PIE, G, ZZ, PSTD, TSTD, PSIR, RA, DELO, SQTH1

P2 = P1 * P2P1

TEM1 = 1.0 * (GAMMD - 1.) / 2.0 * AMD2 ** 2

P2STAT = P2 / (TEM1) ** (GAMMD / (GAMMD - 1.))

SRTDF = SQRT(TD) / (SQTH1 * 22.78166)

TEM2 = WDH1 * EQWC1 * SRTDF / P2 * DELC1 * PSTD

TEM3 = AMD2 * SQRT(GAMMD * G / RD)

TEM4 = TEM1 ** ((GAMMD * 1.) / 12.0 * (GAMMD - 1.)) / TEM3

AD2A1 = TEM2 * TEM4 * ZZ

RETURN

END

Figure 3. - Concluded.
### TEST CASE - CUSTOMARY UNITS

<table>
<thead>
<tr>
<th>PRIMARY INPUTS</th>
<th>SECONDARY INPUTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAS FLOW</td>
<td>52,800</td>
</tr>
<tr>
<td>TURBINE INLET TEMP</td>
<td>2600.00</td>
</tr>
<tr>
<td>COMP PRES RATIO</td>
<td>8.000</td>
</tr>
<tr>
<td>TURBINE STAGES</td>
<td>1,000</td>
</tr>
<tr>
<td>UNITS</td>
<td>CUSTOMARY</td>
</tr>
<tr>
<td>OPTION</td>
<td>GAS GENERATOR</td>
</tr>
<tr>
<td>JET THRUST</td>
<td>-0.000</td>
</tr>
<tr>
<td>LIFT ENGINE</td>
<td>PCA = 0.50600E-01</td>
</tr>
</tbody>
</table>

| AMBIENT PRESSURE | 2116.000 |
| CORR TIP SPEED   | 1300.000 |
| TURB NOZZLE ANGLE| 60.000   |
| NO. COMP. STAGES | 9.000    |
| TURB LOST CCEF   | 0.400    |
| COMP EFFICIENCY  | 0.880    |
| FLARE RATIO (1/D) | 0.000  |
| ENGINE APPLICATION| 50.000  |
| COMP FLOW PATH   | 3.000    |
| TURB STRAIGHT VANE | 1.000  |
| INLET PRES RATIO | 1.000    |
| AXIAL VELOCITY RATIO| 0.750  |
| NOZZLE CCEF      | 1.000    |
| INLET AXIAL MACH NO | 0.600 |
| INLET HUB-TIP RATIO | 0.480 |
| USER BLEED       | 0.000    |
| COMBUSTOR EFFICIENCY | 0.985 |
| DUCT PRES RATIO  | 0.990    |
| DUCT EXIT MACH NC| 0.300    |

### 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

### OUTPUT
- COMPRESSOR: 1.449
- COMBUSTOR: 0.876
- TURBINE: 0.380
- DUCT/NOZZLE: 1.231
- ACCESSORIES: 0.236
- STRUCTURE: 0.293
- TOTAL: 3.931
- LENGTH: 335.2
- MASS: 100.0
- PERCENT: 100.0

### NUMBER OF STAGES
- VU1= VX2 = VU2 = STAGE MEAN AX. MACH NO.
- VU1= STAGE MEAN AX. MACH NO.
- VU2= STAGE MEAN AX. MACH NO.
- VU1= STAGE MEAN AX. MACH NO.
- VU2= STAGE MEAN AX. MACH NO.
- VU1= STAGE MEAN AX. MACH NO.
- VU2= STAGE MEAN AX. MACH NO.

### TURBINE
- PRESS RATIO: 51.47
- DELTA H: 519.0
- FUEL-AIR RATIO: 0.6000
- TOTAL EFF.: 646.4
- MASS FLOW: 0.4800
- TOTAL TEMP: 1.4314
- TOTAL PRES: 0.0870
- AX. MACH NUMBER: 0.3196
- AX. MACH VELOCITY: 0.68520
- HUB-TIP RATIO: 0.68520
- TIP DIA.: 1.4314

### INLET
- PRESS RATIO: 8.0000
- DELTA H: 114.44
- FUEL-AIR RATIO: 0.88000
- TOTAL EFF.: 48.87
- MASS FLOW: 990.6
- TOTAL TEMP: 8.0000
- TOTAL PRES: 0.3196
- AX. MACH NUMBER: 485.2
- AX. MACH VELOCITY: 0.88520
- HUB-TIP RATIO: 0.68520
- TIP DIA.: 1.4314

### COMBUSTOR
- PRESS RATIO: 0.9450
- DELTA H: 503.85
- FUEL-AIR RATIO: 0.02722
- TOTAL EFF.: 50.20
- MASS FLOW: 2660.0
- TOTAL TEMP: 7.5600
- TOTAL PRES: 0.4471
- AX. MACH NUMBER: 1020.0
- AX. MACH VELOCITY: 0.81806
- HUB-TIP RATIO: 1.5746
- TIP DIA.: 1.2081

### TURBINE
- PRESS RATIO: 0.4533
- DELTA H: 116.08
- FUEL-AIR RATIO: 0.02652
- TOTAL EFF.: 52.80
- MASS FLOW: 2212.0
- TOTAL TEMP: 3.4273
- TOTAL PRES: 0.4655
- AX. MACH NUMBER: 1020.0
- AX. MACH VELOCITY: 0.74432
- HUB-TIP RATIO: 1.6412
- TIP DIA.: 1.2216

### DUCT/NOZZLE
- PRESS RATIO: 0.9900
- DELTA H: 0.02585
- FUEL-AIR RATIO: 52.80
- TOTAL EFF.: 2212.0
- MASS FLOW: 3.3930
- TOTAL TEMP: 3.0000
- TOTAL PRES: 0.663.0
- AX. MACH NUMBER: 1.3204
- AX. MACH VELOCITY: 1.000

---

*Figure 4. Sample computer printout from gas generator/lift engine program.*
### Test Case - SI Units

<table>
<thead>
<tr>
<th>Primary Inputs</th>
<th>Secondary Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAS FLOW</td>
<td>AMBIENT PRESSURE</td>
</tr>
<tr>
<td>23.95</td>
<td>101.300</td>
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<tr>
<td>TURBINE INLET TEMP</td>
<td>AMBIENT TEMP</td>
</tr>
<tr>
<td>1478.000</td>
<td>NO. COMP. STAGES</td>
</tr>
<tr>
<td>8.000</td>
<td>9.000</td>
</tr>
<tr>
<td>TURBINE STAGES</td>
<td>COMP EFFICIENCY</td>
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<tr>
<td>1.000</td>
<td>0.880</td>
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<td>UNITS</td>
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<td>GAS GENERATORentity</td>
<td>INLET AXIAL MACH NO</td>
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<tr>
<td>JET THRUST</td>
<td>FUEL HEATING VALUE</td>
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<tr>
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<td>COMBUSTOR EFFICIENCY</td>
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<tr>
<td>LIFT ENGINE</td>
<td>COMBUSTOR PRES RATIO</td>
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<tr>
<td>PCA</td>
<td>DUCT EXIT MACH NC</td>
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<td>= 0.50621E-01</td>
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### Output

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<th>Compressor</th>
<th>Mass</th>
<th>Percent</th>
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<tbody>
<tr>
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<td>40.7</td>
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<tr>
<td>Pressure</td>
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<tr>
<td>Power</td>
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<tr>
<td>Duct Diameter</td>
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<tr>
<td>Specific Thrust</td>
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<table>
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<tr>
<th>Number of Stages</th>
<th>Alpha1 - Beta1 - Alpha2 = VX1 = VX2</th>
<th>VU1 = -WU1 - WU2 = VX1 / VX2</th>
<th>Stage</th>
<th>Mean Abs. Inlet</th>
<th>Rel. Inlet</th>
<th>Flow Abs. Outlet</th>
<th>Flow Abs. Outlet</th>
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<td>1229.3</td>
<td>3.4306</td>
<td>0.4653</td>
<td>310.5</td>
<td>0.7442</td>
<td>0.5001</td>
<td>(0.3722)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>23.95</td>
<td>1229.3</td>
<td>3.3963</td>
<td>0.3000</td>
<td>202.1</td>
<td>0.4023</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

(b) SI Units,
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—National Aeronautics and Space Act of 1958

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