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OPERATIONAL PROCEDURE FOR COMPUTER PROGRAM FOR DESIGN-POINT CHARACTERISTICS OF A COMPRESSED-AIR GENERATOR WITH THROUGH-FLOW COMBUSTOR FOR V/STOL APPLICATIONS

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16. Abstract

The computer program described in this report calculates the design-point characteristics of a compressed-air generator for use in V/STOL applications such as systems with 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 which involves a straight through-flow combustor. Physical and thermodynamic characteristics of the air generator components are also given. The program was written in FORTRAN IV language. Provision has been made so that the program will accept input values in either SI units or U.S. customary units. Each air generator design-point calculation requires about 1.5 seconds of 7094 computer time for execution.

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SUMMARY

The computer program described in this report calculates the design-point characteristics of a compressed-air generator for use in V/STOL powerplant applications. These include the remote-drive lift fan system in which the lift fan is driven by a turbine mounted at the tip of the fan blade, and the STOL concepts in which compressed air is supplied to an externally blown flap or augmentor wing.

The program computes the dimensions and mass, as well as the thermodynamic performance of a model air generator configuration which involves a straight through-flow combustor. Physical and thermodynamic characteristics of the air generator components are also given.

The program was written in FORTRAN IV language. Provision has been made so that the program will accept input values in either SI units or U. S. customary units. Each air generator design-point calculation requires about 1. 5 seconds of 7094 computer time for execution.

INTRODUCTION AND APPROACH

As a part of the analytical research effort into the application of lift fans to VTOL aircraft at the Lewis Research Center, several computer programs have been generated for use in this field. These programs are concerned with preliminary design-point evaluation and parametric analysis of both the integral lift fan engine system 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 (see ref. 1). In the remote system, the turbine may be driven either by the exhaust from a turbine engine, or by compressed air from an air generator. There may or may not be a combustor between the air generator and the fan tip turbine.

One of these computer programs has already been described and reported in reference 2. 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 particularly 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.

The computer program for the TWO-SPOOL AIR GENERATOR - STRAIGHT-THRU COMBUSTOR, for which this report is written, determines the design-point characteristics of an air source suitable for use with the tip-turbine-driven lift fan concept such as that of reference 2. Other applications for the air generator include supplying of compressed air for STOL aircraft using the externally blown flap or augmentor wing concepts (ref. 3). The air generator described by this program is a two-spool engine in which the delivered air is taken from the discharge of the low compressor.

A sketch of the component arrangement and station locations for the engine configuration upon which the development of the computer program is based is shown in figure 1. Air enters the engine through an inlet which may be acoustically treated. All the air is compressed by the low-pressure compressor, or fan. The air delivered by the low compressor is split: part of it is collected in a scroll to form the delivered air supply, the ultimate product of the air generator; the remaining air goes through the high-pressure compressor, combustor, and high-pressure turbine. These three components make up the so-called high spool of the air generator, which is, in reality, a gas generator for the low-pressure turbine. This turbine drives the low-pressure compressor, and these two components along with the connecting shaft constitute the low-pressure spool. In the model of figure 1, the exhaust from the low-pressure turbine is ducted through an exhaust system which turns the flow through a right angle to produce vertical thrust.

The inlet and exhaust systems in the model configuration of figure 1 were used for completeness in order to illustrate the effect that these components can have on overall engine length and mass. It is recognized that the inlet and exhaust systems in an actual installation may differ from those shown in the figure. For instance, the design of these systems will depend upon whether or not the air generator is to be used for cruise, whether the exhaust thrust is to be vectored for control purposes, etc.

The computer program provides a design point configuration for the air generator model shown in figure 1, based on the primary input of the required delivered airflow rate. The overall thermodynamic performance, including the core discharge thrust, is described along with the dimensions and total mass. Thermodynamic performance, size, and mass are also calculated for the principal components. The mass calculations are based on the correlations presented in reference 4.

There are two forms of the computer program. The first, PROGRAM 50-L: TWO-SPOOL AIR GENERATOR - STRAIGHT-THRU COMBUSTOR - LIFT COMPONENTS, provides for component masses based on advanced lift engine technology (ref. 4). The second, PROGRAM 50-C: TWO-SPOOL AIR GENERATOR - STRAIGHT-THRU COMBUSTOR - CRUISE COMPONENTS, yields an air generator mass such as would be expected from contemporary cruise engine design. In addition, the reference velocity for the combustor has been reduced from approximately 24 meters per second (80 ft/sec) for the lift engine to 18 meters per second (60 ft/sec) for the cruise engine categories. The resulting mass estimates are expected to represent the range of masses achievable for realistic designs for commercial VTOL transport applications. Actual masses may be affected by the operating cycle employed, the amount of advanced materials used, the design philosophy, and the utilization of anticipated technological developments.

The flow chart in figure 2 presents the FORTRAN statements for PROGRAM 50-L, which uses lift engine technology. The flow chart is complete for the main program except for the write statements, which have been suppressed. Those statements, which differ in PROGRAM 50-C (the cruise version), are marked with a lower case letter to the left of the statement. Corresponding statements for PROGRAM 50-C are given in table I.

This 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 will perform the calculations for either SI inputs or U.S. customary inputs. Each pass through the program requires about 1.5 seconds on a 7094 computer.

This report was compiled to furnish the descriptions and instructions necessary for running the computer program. 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 set of computer output pages is included, and the meaning of each output parameter is given. The flow chart of the FORTRAN statements is included for those who wish to know more about the program, or for those who may wish to change it.

INPUT PARAMETERS

This computer program for the design-point characteristics of an air generator has considerable inherent flexibility. Some idea of the flexibility can be achieved from the fact that no less than 44 independent parameters may be specified for any one air generator design. In addition, values for three program control parameters must be supplied. In the following paragraphs, the significance of each parameter is discussed. The symbol used in the FORTRAN language of the computer program is also indicated by capital letters. An attempt has been made to use a symbol which is descriptive of the property, component, and air generator station as indicated in figure 1. The program will accept either SI units or U. S. customary units. Dimensions for the parameters in both systems of units are given in the section DATA INPUT CARDS.

Ambient Conditions and Air Generator 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 that the total pressure and temperature at the inlet correspond to ambient static conditions (i. e., the air generator is designed for the takeoff condition).

The performance of the air generator inlet is described by a single parameter, the total-pressure "recovery" PI2P1 for the inlet. The inlet flow is assumed to be adiabatic.

Low Compressor

The entire air generator is sized primarily by the quantity of delivered airflow required WL and its pressure. The pressure of the air at the inlet to the delivery duct (station D, fig. 1) is dependent upon the low-compressor pressure ratio PF2PF1 less the pressure loss in the air generator inlet and in the collector scroll. The flow path for the low compressor, whether constant hub, constant mean, or constant tip, is determined by the value assigned to JFGEOM. The number of compressor stages SNF and the corrected tip speed at the compressor inlet UTIPFC should be chosen to be commensurate with the selected pressure ratio (e. g., as is indicated in ref. 4). The value of compressor efficiency ETAF, which may be given in either the adiabatic or polytropic form, should reflect the dependence upon the other low-compressor parameters.

The tip diameter of the compressor is set by the total airflow, average axial inlet Mach number AMF1, and the inlet hub-tip ratio DHDTF1 for the first rotor row. Diffusion through the compressor can be regulated by the selection of the axial velocity ratio across the compressor VF2VF1. The average aspect ratio of the first two stages FANAR affects both the length and mass of the low compressor.

Scroll and Delivery Duct

The scroll diameter, corresponding to the maximum flow area in the scroll, is sized by the scroll Mach number SCROLM. Two diameters are calculated, depending upon whether the two delivery ducts are contiguous or located diametrically opposite around the scroll. The scroll pressure loss is a function of the pressure loss coefficient SCROLK as well as SCROLM.

Although the two delivery ducts are not considered as part of the air generator, the program does calculate the delivery duct inlet diameter, which is dependent upon the duct inlet Mach number AMD.

High Compressor

Most of the parameters required to describe the high compressor are used in the same manner as for the low compressor. The similar parameters are pressure ratio, PC2PC1; flow path, JCGEOM; number of stages, SNC; corrected tip speed, UTIPCC; efficiency, ETAC; and axial velocity ratio, VC2VC1. Two different quantities of air bleed from the discharge of the high compressor may be specified. One of them is used to cool the high turbine and is discussed in the section High Turbine. The other bleed, a so-called "user" bleed, BUSER, is available for aircraft control and other purposes.

Combustor

Only four 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 will accommodate fuels with different heating values. The heating value HF is one of the independent combustor parameters. Another one is the combustor efficiency ETAB.

The combustor reference velocity is fixed within the program so that the resultant flow area, or radial height, of the burner is a dependent variable. Combustor length is determined from this height and the prescribed ratio of combustor length to height ELOH. The overall total-pressure ratio across the combustor PB2PB1 should be a function of the combustor length-height ratio (ref. 4).

High Turbine

The number of stages SNT required for the high turbine will depend on the particular air generator configuration. However, one stage is satisfactory for most air generators. The parameter ALPHAT represents the angle of the flow coming out of the turbine stator as measured from the axis of rotation. The high turbine loss coefficient AKCT sets the level of loss, and therefore, efficiency, in the high turbine. A nominal value is between 0.35 and 0.40.

One of the most significant parameters in the performance of the air generator is the inlet temperature to the high-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 high turbine PCA is expressed as a fraction of the high-compressor inlet 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 yields a cooling air requirement typical of continuous operation at the assigned temperature TT1, while the second 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. These two schedules are activated by setting KIND = 100, or KIND = 50, respectively. Analytical expressions for these schedules as functions of turbine inlet temperature TT1 are given in symbols 20 and 1, respectively, on the second and third pages of figure 2.

Interturbine Duct

If the mean diameters of the high and low turbines (which are both assumed to have constant-mean-diameter flow paths) are different, then a duct is required between the two turbines. The difference in the two turbine mean diameters is accounted for in the program by the low-turbine offset DEMDTM, which is the ratio of the low-turbine mean diameter to the high-turbine mean diameter. The pressure ratio across the duct between the two turbines is the value given the interturbine pressure recovery parameter PE1PT2.

Low Turbine

The parameters SNE and AKCE stand for the number of stages and the loss coefficient, respectively, for the low turbine. Because the air bled from the low compressor reduces the core flow, the low turbine is generally multistage. The loss factor for the low turbine is usually taken equal to that of the high turbine.

The large work extraction from the low turbine reduces the density of the working fluid, and a large flow area is required at the turbine exit. If the low-turbine tip diameter is to be kept small in order to minimize turbine mass and air generator volume, a low exit hub-tip ratio is required to provide the necessary flow area. A low hub-tip ratio leads to a critical turbine design so that some limit should be put upon the exit hub-tip ratio. The value assigned to RE2S sets this limit (generally around 0.55 to 0.6).

The low-turbine outlet vane parameter AKUE makes it possible to select either of two configurations downstream of the last low-turbine rotor. If impulse straightening vanes are desired behind the rotor, set $0 < \mathrm{AKUE} < 1.9$. This value is taken such that the loss across the vanes is then equal to one-half the intermediate-stage stator loss multiplied by AKUE. If AKUE = 2, the program computes the performance of a fully straightening diffusing stator after the rotor. The value of the D-factor for the loading limit of the diffusing stator can be put into the computer by use of the variable DFACT (nominal values are around 0.4).

Core Exhaust System

The exhaust system on the core of the air generator includes both a duct and a nozzle which can deflect the core flow and produce thrust from it. In order to provide some control on the jet noise, the magnitude of the exhaust velocity from the nozzle can be specified through the parameter VX. Provision is also made for a difference in velocity between the nozzle discharge and the axial discharge from the turbine outlet vane. This velocity difference is called DELTAV and is negative when the nozzle velocity is less than the turbine discharge velocity.

Exhaust system losses may be accounted for through the use of (1) a duct pressure loss coefficient AKELBO, which is multiplied by the square of the axial Mach number out of the turbine, and (2) a nozzle discharge velocity coefficient CFJ.

DATA INPUT CARDS

The 44 independent parameters and those program control parameters required as input for the computer program are entered on seven data input cards. An additional card is also required which serves as an identification card. Although these eight cards are required for a single air generator analysis, other air generators 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, while the parameter UNITS determines the type of units to be used in the input and output.

Single Case

In the discussion which follows, three columns will be used to present the information. The first column is the name of the input variable, or parameter, as it appears on the computer printout sheet (see fig. 3). 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 two compressors and selects the cooling air schedule to be used. The second card identifies the air generator. All the remaining data are entered on the last six cards, which use a 8F10.0 format. In general, the arrangement of the parameters on these last six data cards is in ascending order of frequency of change. This arrangement can be used to advantage when several air generator analyses are being run with one program submission (see the section Multiple Cases).

First card. - There are five 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 5I5.

ENGINE APPLICATION	KIND	This parameter selects the cooling air schedule used on the high-pressure 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 inlet flow to the high compressor less the user bleed.
HI COMP FLOW PATH	JCGEOM	Sets the geometry of the high-pressure compressor. If JCGEOM = 1, the compressor has a constant hub diameter. If JCGEOM = 2, the compressor has a constant mean. If JCGEOM = 3, the compressor is of constant tip design.

LOW COMP FLOW PATH	JFGEOM	Same as JCGEOM except for low-pressure compressor or fan.
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 can be used to identify the particular air generator case calculated. This identification is printed out on the third line of the computer printout. For example, on the printout shown in figure 3, the air generator was identified as NOMINAL CASE.

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

INLET RECOVERY	PI2P1	Total-pressure ratio across the inlet ahead of the low compressor.
INLET AXIAL MACH NO.	AMF1	Low-compressor inlet Mach number.
INLET HUB-TIP RATIO	DHDTF1	Ratio of hub diameter to tip diameter at the inlet of the low compressor.
AXIAL VELOCITY RATIO	VF2VF1	Outlet axial velocity divided by inlet axial velocity for the low compressor.
DUCT MACH NUMBER	AMD	Mach number used to size each of two air delivery ducts.
AXIAL VELOCITY RATIO	VC2VC1	Outlet axial velocity divided by inlet axial velocity for the high compressor.
FUEL HEATING VALUE	HF	Heating value of the fuel, in kilojoules per kilogram (Btu/lb).
COMBUSTOR EFFICIENCY	ETAB	Efficiency of combustion.

Fourth card. - Input parameters on this card are concerned primarily with the two turbines.

H T NOZZLE ANGLE	ALPHAT	Outlet flow angle, measured from the axial direction, for the high-turbine stator, in radians (deg).

H T LOSS COEFF	AKCT	Coefficient which sets the level of losses in the high turbine. Nominal value, 0.35 to 0.40.
L T LOSS COEFF	AKCE	Coefficient which sets the level of losses in the low turbine. Nominal value, 0.35 to 0.40.
LOW TURBINE OFFSET	DEMDTM	Ratio of low- to high-turbine mean diameter.
INTERTURB PRESS REC	PE1PT2	Pressure ratio between the inlet of the low turbine and the exit of the high turbine.
L T STRAIGHT VANES	AKUE	Index for type of vane downstream of the last low-turbine rotor. If AKUE = 2, there is a diffusing stator. If $0 < \mathrm{AKUE} < 1.9$, there is an impulse straightening vane, and the loss across the vane is AKUE times one-half the loss in a low-turbine stator.
NOZZLE VEL COEF	CFJ	Ratio of assigned core nozzle discharge velocity to ideal velocity.
COMBUSTOR L/H RATIO	ELOH	Combustor length-to-height ratio. Depends on criticality of the engine length in a particular application and/or the allowable pressure loss.

Fifth card. - The fifth card contains only five parameters.

SCROLL PRES LOSS COEF	SCROLK	Factor multiplying the dynamic head in the scroll to give the total-pressure loss in the collector scroll.
ELBOW/DUCT LOSS COEF	AKELBO	Coefficient which multiplies the dynamic head at the discharge of the low turbine to give the pressure loss in the core exhaust system.

SCROLL MACH NO.	SCROLM	Mach number in the collector scroll. Sizes the scroll and determines the pressure loss.
FAN ASPECT RATIO	FANAR	Average aspect ratio of the first two low-pressure compressor stages.
UNITS	UNITS	If UNITS = 0, all quantities are in U. S. customary units. If UNITS $\neq$ 0, SI units are used.

Sixth card. - The sixth card is the first of two cards which contain input variables that may be changed more or less frequently. It contains eight variables.

AMBIENT PRESSURE	PO	Selection of this pressure, in kilonewtons per square meter (lb/sq ft), makes it possible to design the air generator at different pressure altitudes.
AMBIENT TEMPERATURE	TO	This temperature, in K (^{O}R), permits design for standard or hot day operation.
EFFICIENCY	ETAF	Low-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.
HI COMP EFFICIENCY	ETAC	Same as ETAF except for high compressor.
COMBUSTOR PRES REC	PB2PB1	Total-pressure ratio across combustor.
NOZ-TURBX DELTA V	DELTAV	Nozzle discharge velocity minus axial velocity from low-turbine exit, in meters per second (ft/sec). Permits acceleration or diffusion between the turbine and the nozzle.

L T EXIT H-T RATIO	RE2S	Hub-tip ratio at the discharge of the last low-turbine rotor.
NO. STAGES LOW COMP	SNF	Number of stages required to produce the overall pressure ratio on the low compressor.

Seventh card. - There are six parameters on the seventh card.

NO. STAGES HI COMP	SNC	Number of stages required to produce the overall pressure ratio on the high compressor.
LOW CORR TIP SPEED	UTIPFC	The tip speed at the inlet of the low compressor, in meters per second (ft/sec), divided by the square root of the ratio of compressor inlet total temperature to standard temperature.
HI CORR TIP SPEED	UTIPCC	Same as UTIPFC except for the high compressor.
CORE VELOCITY	VX	Exhaust velocity of the core (nozzle discharge) flow, in meters per second (ft/sec).
PCA	PCA	High-turbine cooling air expressed as a fraction of the high-compressor inlet airflow less the user bleed. PCA is ignored unless KIND = 0 (see first card).
TURB VANE D-FACTOR	DFACT	D-factor value for the diffusing stator downstream of the last low-turbine rotor. Used only when AKUE = 2.

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

DELIVERED AIRFLOW	WL	The delivered airflow of the generator, in kilograms per second (lb/sec).
TURBINE INLET TEMP	TT1	Maximum cycle temperature in the air generator, in K (^{O}R).

LOW COMP PRESSURE RATIO	PF2PF1	Overall pressure ratio on the low compressor.
HIGH COMP PRESS RATIO	PC2PC1	Overall pressure ratio on the high compressor.
HIGH TURBINE STAGES	SNT	Number of stages on the high turbine.
LOW TURBINE STAGES	SNE	Number of stages on the low turbine.
USER BLEED	BUSER	Bleed, expressed as a fraction of high-compressor inlet flow, from peak cycle pressure for use outside air generator.

Multiple Cases

The eight data cards just described are necessary in order to determine the performance and geometry of a single air generator. If a single case is to be run for each submission of the program deck 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 options are available for running multiple cases. In the following paragraphs each option is described and illustrated with an example.

The simplest option for running multiple cases is exercised when the input variables to be changed are all among the seven variables read from the eighth input data card. Then only one additional card is required for each case, and the desired values of the seven 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 an air generator. This could be done by changing the delivered airflow WL. Suppose that the size range of interest could be covered by values of delivered airflow of 40, 50, and 60 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	6	------------
2	------------	7	------------
3	------------	8	WL = 40
4	------------	8	WL = 50
5	------------	8	WL = 60

The second option is employed when all of the changes of input values are in the parameters contained on the last three data cards. Then the first five data cards need be submitted only once, and they are followed by the appropriate combinations of the sixth and seventh cards with the eighth cards. The same number of eighth cards must follow each set of sixth and seventh cards. This number is the value given to the index NN. The index N takes on the value of the number of sets of sixth and seventh cards to be submitted.

For example, suppose that it were required to examine the effect of size (WL) on air generators designed for a standard day (TO = 288) and for a hot day (TO = 305). The size effect would be studied by running the same three values of WL 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	8	WL = 50
2	------------	8	WL = 60
3	------------	6	TO = 305
4	------------	7	------------
5	------------	8	WL = 40
6	TO = 288	8	WL = 50
7	------------	8	WL = 60
8	WL = 40		

The third multiple-case option is used when the parameter to be changed appears on the first five 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 options may be combined with the third option.

Suppose it was desired to investigate the effect of pressure loss in the inlet of the air generator and that this effect was to be compared for two different ambient temperature designs, but for a single value of delivered airflow. 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 options) to PI2P1 = 0.95. The required data input cards would be

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	------------	5	------------
6	TO = 288	6	TO = 288
7	------------	7	------------
8	WL = 50	8	WL = 50
6	TO = 305	6	TO = 305
7	------------	7	------------
8	WL = 50	8	WL = 50

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	8	WL = 50
2	------------	8	WL = 60
3	PI2P1 = 0.99	1	N = 2, NN = 1
4	------------	2	------------
5	------------	3	PI2P1 = 0.95
6	TO = 288	4	------------
7	------------	5	------------
8	WL = 40	6	TO = 288
8	WL = 50	7	------------
8	WL = 60	8	WL = 50
6	TO = 305	6	TO = 305
7	------------	7	------------
8	WL = 40	8	WL = 50

COMPUTER PRINTOUT

A typical set of computer printout sheets for a single air generator design using SI units is shown in figure 3. Two sheets are required to list all the input and output quantities.

First Sheet

The first line of the first sheet is printed by the monitor system on which the program is run. The second line gives the name of the program and indicates whether the masses printed at the bottom of 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 are listed next. They are divided, somewhat arbitrarily, into primary and secondary inputs.

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

The output from the program follows next. For the most part, the first two lines of output pertain to the air generator in its entirety. The quantities are

AIR SFC	ASFC	Fuel flow to the air generator divided by the delivered airflow, in kilograms of fuel per hour divided by kilograms of air per second ((lb fuel/hr)/(lb air/sec)).
INLET DIAM LOW COMP	DF1	Low compressor inlet tip diameter, in meters (ft).
AIR P T	PF2P TF2	Pressure and temperature of the delivered air at the scroll exit, respectively, in kilonewtons per square meter (lb/sq ft) and K (^{o}R).
LEN/DIAM	ELODX	Air generator length, as measured from the low-compressor inlet blade row to the trailing edge of the turbine exit vane, divided by the low-compressor inlet diameter.
	ELOD	Total length of inlet, air generator, and exhaust system divided by the low-compressor inlet diameter.

AIR DUCT (2) DIAMETER	DUCTD	Inlet diameter of one of the two ducts which deliver the compressed air, in meters (ft).
LOW TURB EFF	ETBARE	Efficiency of the low-pressure turbine.
AIRFLOW/ENG M	WAWENG	Delivered air mass flow divided by the air generator mass, in kilograms per second per kilogram ((lb/sec)/lb).
MA/(ME+5M F)	WAWA	Delivered airflow divided by the sum of air generator mass plus the mass of fuel burned in 5 minutes, in kilograms per second per kilogram ((lb/sec)/lb).
MA/(ME+10M F)	WAWAA	Delivered airflow divided by the sum of air generator mass plus the mass of fuel burned in 10 minutes, in kilograms per second per kilogram ((lb/sec)/lb).

The second line of output quantities is

CORE THRUST	VXM	Thrust developed by exhaust products of the air generator, in newtons (lb).
CORR SP L.C. FLOW	SWF1	Low-pressure compressor specific airflow based on the frontal area and corrected to standard sea-level conditions, in kilograms per second - square meter (lb/(sec)(ft^2)).
CORR SP CORE FLOW	SWC1	High-compressor corrected specific airflow based on the high-compressor frontal area, in kilograms per second - square meter (lb/(sec)(ft^2)).
LOW TURB STAT PRES	PE2S	Static pressure at the discharge of the low-turbine outlet vane, in kilonewtons per square meter (lb/ft^2).
CORE EXH AREA RATIO	AXAE2	Ratio of core nozzle discharge area to axial-flow area at the discharge of the last low-turbine rotor.

CORE EXH AREA	AH	Exhaust area for core flow, in square meters (ft^2).
BYPASS RATIO	BPR	Ratio of delivered airflow to core flow.
SPECIFIC ENERGY	AHP	Specific energy of delivered air based on expansion to ambient pressure, in kilowatts per kilogram per second (hp/(lb/sec)).
FUEL FLOW	WFUEL	Air generator fuel consumption, in grams per second (lb/hr).
SCROLL DIAM (1) (2)	SCROD1 SCROD2	Maximum collector scroll diameter in meters (ft), with two ducts contiguous on the scroll periphery and two ducts 180^0 apart on the scroll periphery.

The third and fourth lines of output describe the characteristics of the high-pressure and low-pressure turbines, respectively. In the format which follows, the upper computer variable name is for the high-pressure turbine, while the lower name in each group is for the low-pressure turbine. The quantities are

NUMBER OF STAGES	SNT SNE	Number of turbine stages.
ALPHA1 = - BETA2	ALPHAT ALPHAE	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	BETAH BETAL	Relative flow angle entering the rotor and absolute flow angle leaving the rotor, in radians (deg).
VX1 = VX2 (= VO)	TVX EVX	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	TVU1 EVU1	Stator tangential velocity component and tangential component of relative velocity out of the rotor, in meters per second (ft/sec).

VU2 = -WU1	TVU2 EVU2	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	SLAMT SLAME	Stage speed-work parameter, $U_m^2/(\Delta H)$.
MEAN SPEED	UTM UEM	Mean blade speed, U_m, in meters per second (ft/sec).
ABS. INLET MACH NO.	AMT1 AME1	Mach number of the absolute velocity into the first-stage rotor.
REL. INLET MACH NO.	AMT1W AME1W	Mach number of relative velocity at the first-stage rotor inlet.
FLOW COEFF.	FLOWT	Ratio of through-flow velocity to mean blade speed.
BLADE STRESS	STRESH STRESL	Centrifugal stress at the root of the turbine blade, in kilonewtons per square meter (psi).

Below the four lines of output just described is a table of estimated masses for each of the components as well as the mass of the entire air generator configuration including the inlet and exhaust sections. These masses, in kilograms (lb), correspond to the engine design application indicated at the end of the second line of output. The mass of each component is also expressed as a percent of the total of the configuration.

Second Sheet

The second sheet is virtually self-explanatory. It gives the thermodynamic properties of the working fluid throughout the air 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, in meters (ft); pressure ratio; change in enthalpy, in kilojoules per kilogram (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, in kilograms per second (lb/sec); total temperature, in K (^{O}R); total pressure, normalized by standard sea-level pressure; axial Mach number; axial velocity of the working fluid, in meters per second (ft/sec); hub-tip ratio; and the corresponding tip and hub diameters, in meters (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 high 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 high 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 two turbines and the exhaust section, the reciprocal of the pressure ratio, as defined previously, is also printed within parentheses.

The AX. MACH NUMBER and AXIAL VELOCITY shown under the values for the low-turbine outlet are the values at the discharge of the vane, if any, downstream of the final turbine rotor.

The last number on the table, under TIP DIA., is the diameter in meters (ft) of the exit of the core nozzle exhaust section.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, September 10, 1971,
764-72.

REFERENCES

1. Lieblein, S.: A Review of Lift Fan Propulsion Systems for Civil VTOL Transports. Paper 70-670, AIAA, June 1970.
2. Haller, Henry C.; Lieblein, Seymour; and Auer, Bruce M.: Computer Program for Preliminary Design and Analysis of V/STOL Tip-Turbine Fans. NASA TN D-6161, 1971.
3. Wick, Bradford H.; and Kuhn, Richard E.: Turbofan STOL Research at NASA. Astronautics & Aeronautics, vol. 9, no. 5, May 1971, pp. 32-50.
4. Sagerser, David A.; Lieblein, Seymour; and Krebs, Richard P.: Empirical Expressions for Estimating Length and Weight of Axial-Flow Components of VTOL Powerplants. NASA TM X-2406, 1971.

TABLE I. - STATEMENTS FOR PROGRAM 50-C (CRUISE COMPONENTS)

WHICH DIFFER FROM PROGRAM 50-L (LIFT COMPONENTS)

Identification (see fig. 2)	Statement
a	PROGRAM 50-C AIR GENERATOR WITH STRAIGHT-THRU COMBUSTOR - CRUISE ENGINE COMPONENTS
b	VREF = 60.
c	COMPONENT WEIGHTS - CRUISE ENGINE TECHNOLOGY
d	WNC = 7.8 * DMBAR**2.2 * SNF**1.2 * Q * (UTIPFC*SQTH1/1100.)**.3
e	W2C = 7.8 * DMBAR**2.2 * 2.0**1.2 * (.5+.5*FLODM/.362)*(UTIPFC*SQTH1/1100.)**.3
f	COMPHW = 7.8 *DMBAR**2.2 * SNC**1.2 * Q * (UTIPCC*SQRT(TF2/519.)/1100.)**0.3
g	BURNW = 45. * DMAV * DMAV * SQRT(ELOH)
h	TURBHW = 0.44 * DMBAR**2.5 * UTM**0.6 * SNT
i	TURBLW = 0.44 * DMBAR**2.5 * UEM**0.6 * SNE
j	ACCW = .004 * ((FFAN+VXM)+1.35*WFUEL)
k	ENGWT = COMPLW + COMPHW + BURNW + TURBHW + TURBLW + WSCROL
l	STRW = 0.18 * ENGWT
m	ENGWT = ENGWT + STRW + ACOUSW + ELNOZW + ACCW
n	39 FORMAT (1H1, 30X, 64HTWO SPOOL AIR GENERATOR-STRAIGHT THRU COMBUSTOR - CRUISE COMPONENTS)

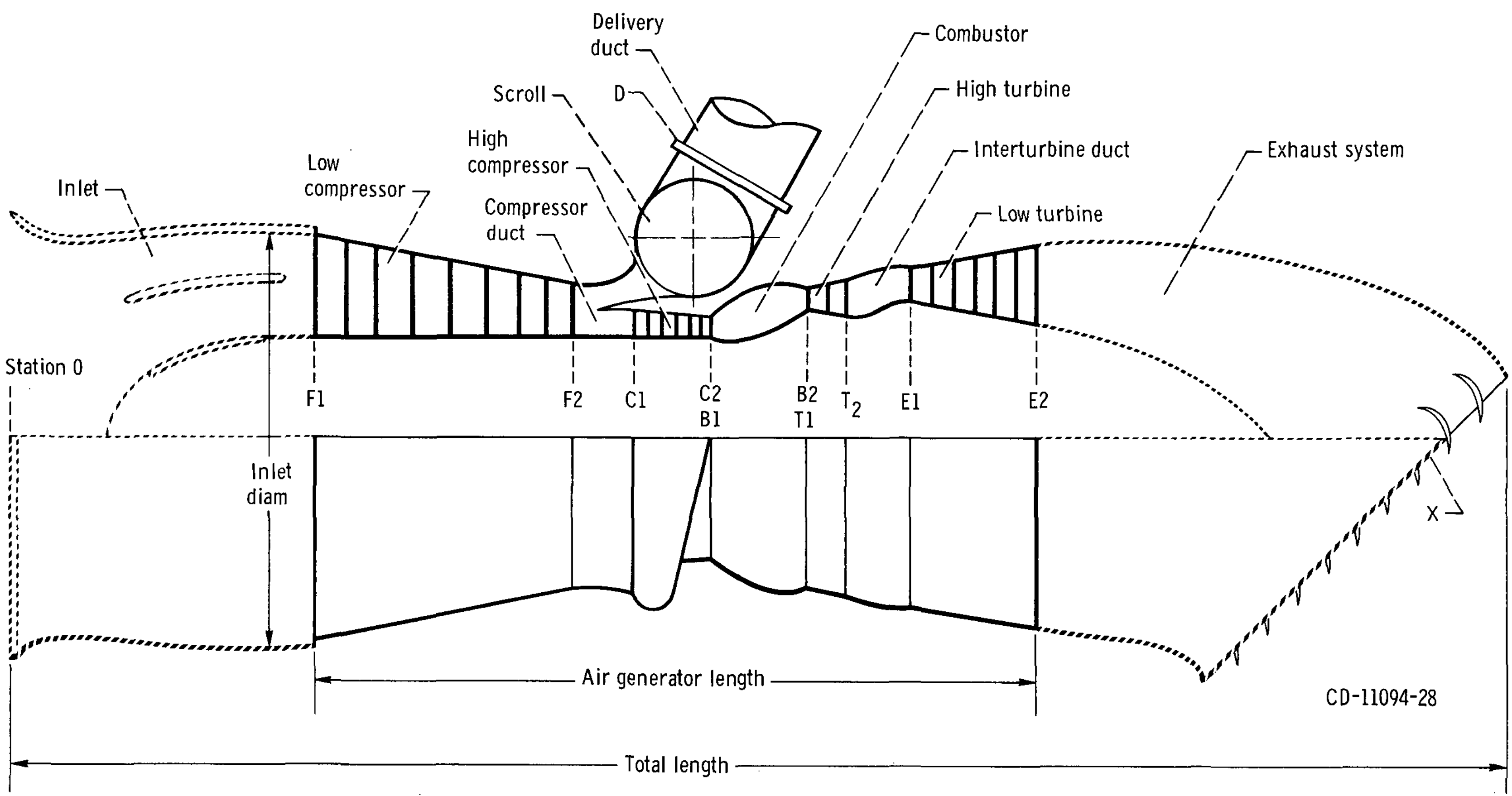

Figure 1. - Schematic drawing of air generator showing station locations.

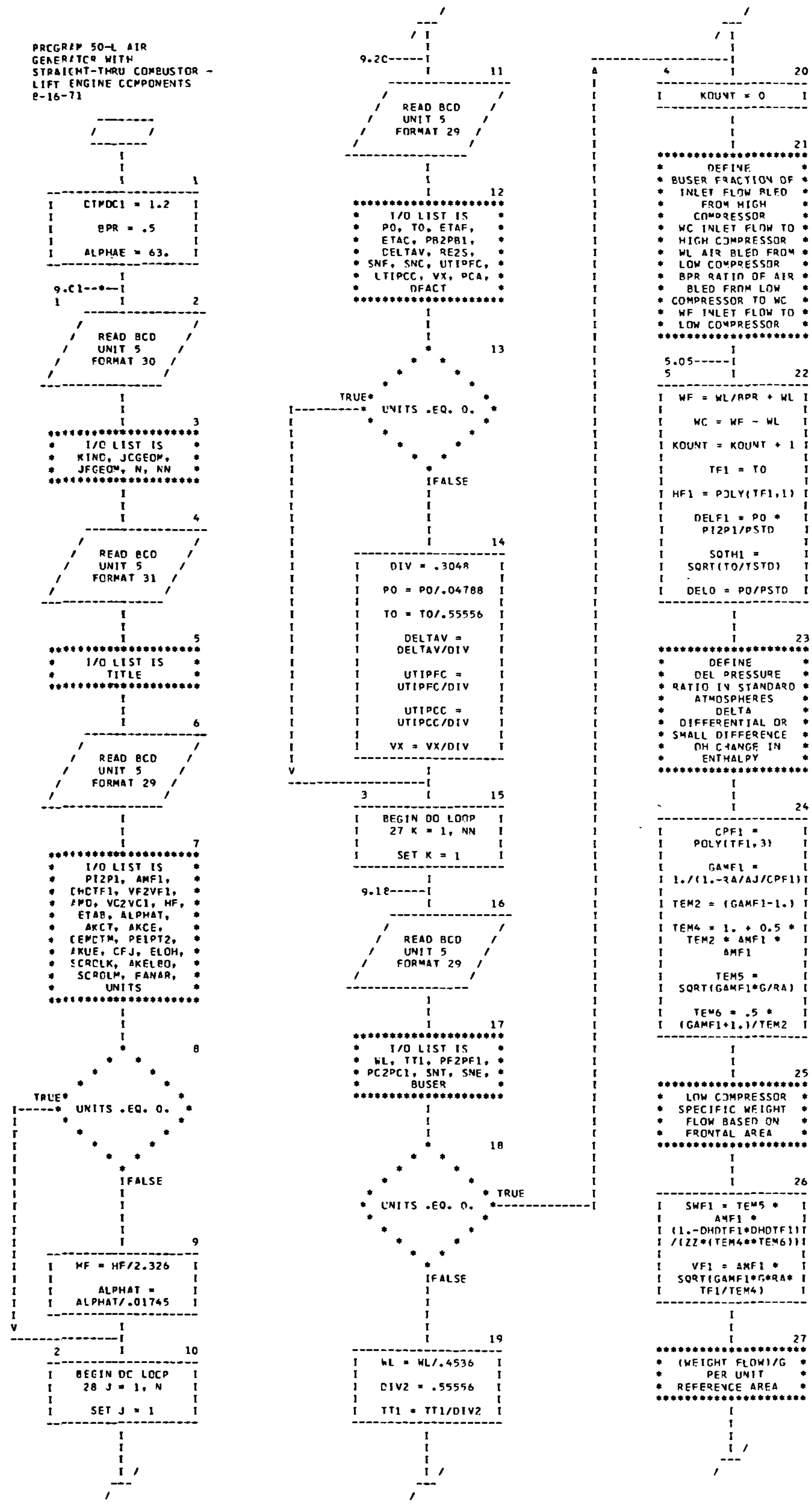

Figure 2. - Flow chart for PROGRAM 50-L.

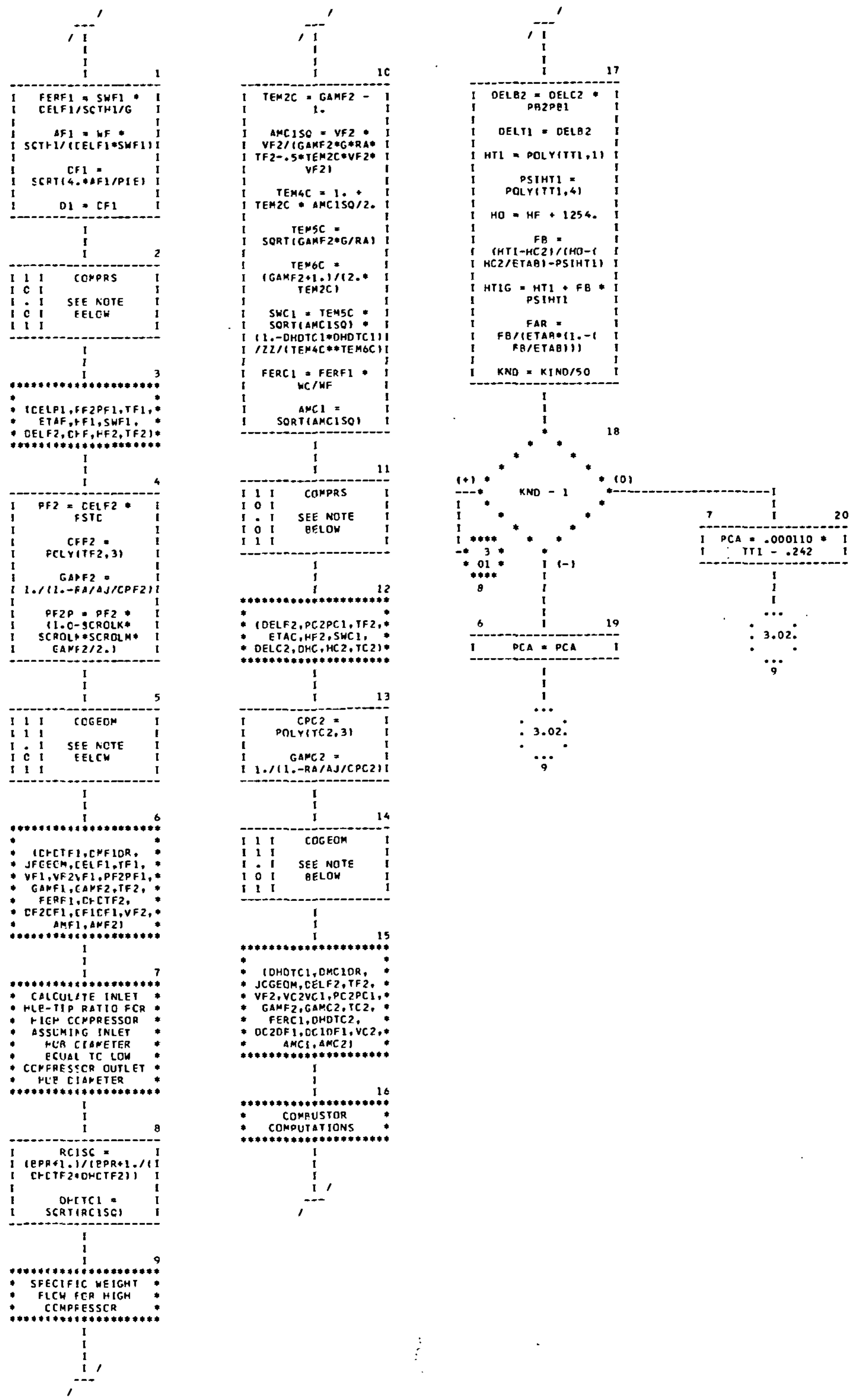

Figure 2. - Continued.

```
   / 8 /
     I
2.18-I
     I                1
----------------------
I FCA = .000150 *    I
I   TT1 - .297       I
----------------------
     I
2.19--*--I
9    I                2
----------------------
I  BETCOL = PCA *    I
I   (1.-BUSER)       I
I                    I
I BETTOT = BETCOL +  I
I   BUSER            I
I                    I
I  HCOL =            I
I  POLY(TC2,1)       I
I                    I
I  WB = WC *         I
I  (1.-BETTOT)       I
----------------------
     I
     I                3
**********************
* HTIG ENTHALPY OUT  *
*  OF COMBUSTOR      *
* CHRGB CHARGEABLE   *
*  BLEED             *
* HTIGT EFFECTIVE    *
*  ENTHALPY AT       *
*  TURBINE INLET     *
*  (ENTHALPY AT      *
*  ROTOR INLET)      *
* HE1 EFFECTIVE      *
*  ENTHALPY AT       *
*  TURBINE EXHAUST   *
*  AFTER COOLING     *
*  AIR IS MIXED      *
* DHT TURBINE        *
* ENTHALPY DROP DUE  *
*  TO WORK REQUIRED  *
*  BY                *
*  COMPRESSOR AND    *
*  PUMPING OF        *
*  COOLING AIR       *
**********************
     I
     I                4
----------------------
I  CHRGB = 0.5       I
I                    I
I TEM16 = (1.+FAR)   I
I  * (1.-BETTOT)     I
----------------------
     I
5.07-I
10   I                5
----------------------
I UTM = UTIPCC *     I
I  DTMDC1 *          I
I  SQRT(TF2/519.)    I
I                    I
I DHPUMP = UTM *     I
I  UTM/AJ/G          I
I                    I
I  DHT =             I
I (DHC+DHPUMP*CHRGB* I
I BETCOL)/(TEM16+(   I
I 1.-CHRGB)*BETCOL)  I
----------------------
     I
     I                6
**********************
*  ROTOR INLET       *
*  CONDITIONS        *
**********************
     I
     I                7
----------------------
I  HTIGT =           I
I (HTIG*(1.+FAR)*(   I
I 1.-BETTOT)+(1.-    I
I CHRGB)*BETCOL*     I
I HCOL)/(TEM16+(1.-  I
I CHRGB)*BETCOL)     I
I                    I
I  FARR =            I
I FAR/(1.+BETCOL*(   I
I 1.-CHRGB)/(1.-     I
I BETTOT))           I
I                    I
I FR = ETAB *        I
I FARR/(1.+FARR)     I
I                    I
I  TTR = TT1         I
----------------------
     I
     I---------------
11   I                8
----------------------
I  DELTAT =          I
I (HTIGT-POLY(TTR,1) I
I -FR*POLY(TTR,4))/( I
I POLY(TTR,-1)+FR*   I
I POLY(TTR,-4))      I
I                    I
I TTR = TTR +        I
I  DELTAT            I
----------------------
     I
     I /
```

```
                 9
   ABS(DELTAT)   * TRUE
     .LT. .1     *----------- A
   IFALSE
```

```
   / 12 /
     I
-----I
     I               10
----------------------
I  WR = WC *         I
I (TEM16+BETCOL*(1.- I
I  CHRGB))           I
I                    I
I  WT =              I
I (TEM16+BETCOL) *   I
I  WC                I
I                    I
I DTMDF1 = DTMDC1 *  I
I  DC1DF1            I
----------------------
     I
     I               11
----------------------
I 1 I  TURBIN        I
I 2 I                I
I . I  SEE NOTE      I
I 0 I  BELOW         I
I 1 I                I
----------------------
     I
     I               12
**********************
*                    *
* (TTR,DELT1,DHT,    *
*  AKCT,0.0,WR,      *
* ALPHAT,SNT,FR,1.,  *
* DF1,UTM,DTMDF1,    *
* DFACT,1.5,.005,    *
* 3.7,TT2,PT2PT1,    *
* DELT2,AMT2X,RT2,   *
* SLAMT,DT2DF1,      *
* ETRART,TVX,TVU1,   *
* TVU2,BETAH,RT1,    *
* DT1DF1,AMT1X,      *
* AMT1W,AMT1,FLOWT,  *
* DELT2S,P2P1VT,TV2, *
*  AMT2)             *
**********************
     I
     I               13
----------------------
I RTAV = 0.5 *       I
I  (RT1+RT2)         I
I                    I
I STRESH = 2. * .7   I
I * .3 * 12./G *     I
I UTM * UTM *        I
I (1.-RTAV)/(1.+     I
I  RTAV)             I
----------------------
     I
     I               14
**********************
*  TOTAL ENTHALPY    *
* AFTER MIXING, HE1  *
**********************
     I
     I               15
----------------------
I HCOLP = HCOL +     I
I  DHPUMP            I
I                    I
I  HE1 =             I
I ((HTIGT-DHT)*(     I
I TEM16+(1.-CHRGB)*  I
I BETCOL)+CHRGB*     I
I BETCOL*HCOLP)/(    I
I TEM16+BETCOL)      I
I                    I
I TE1 = TT1 -        I
I  DHT/.24           I
I                    I
I  FAPRIM =          I
I FAR/(1.+(BETCOL/(  I
I 1.-BETTOT)))       I
I                    I
I FPRIME = ETAB *    I
I FAPRIM/(1.+FAPRIM) I
I                    I
I  TEM17 =           I
I (1.+FAPRIM) *      I
I (1.-BETTOT+BETCOL) I
----------------------
     I
4.01-I
13   I               16
----------------------
I  DELTAT =          I
I (HE1-(POLY(TE1,1)+ I
I FPRIME*POLY(TE1,4) I
I ))/(POLY(TE1,-1)+  I
I FPRIME*POLY(TE1,-  I
I  4))               I
I                    I
I TE1 = TE1 +        I
I  DELTAT            I
----------------------
     I
     I /
```

Figure 2. - Continued.

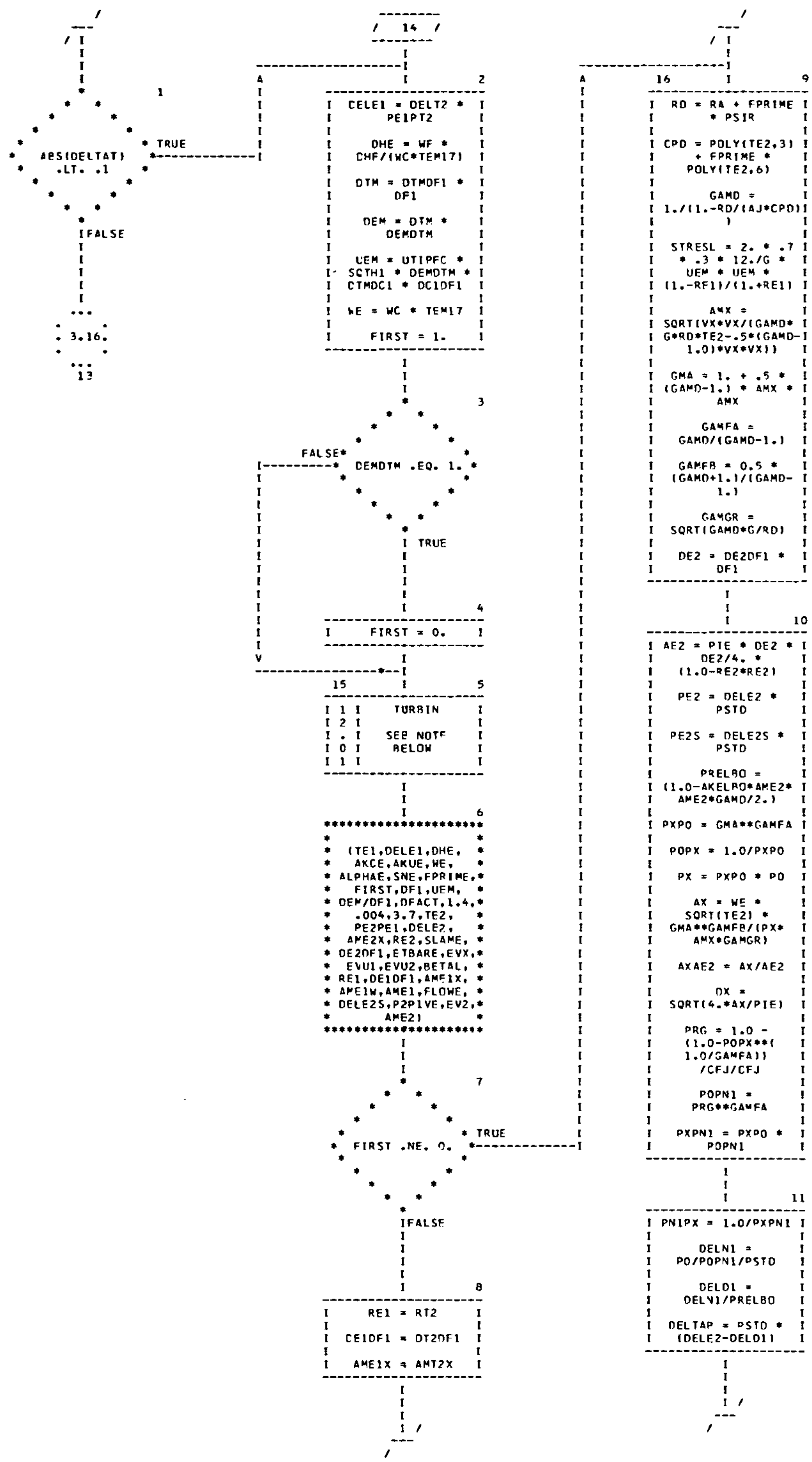

Figure 2. - Continued.

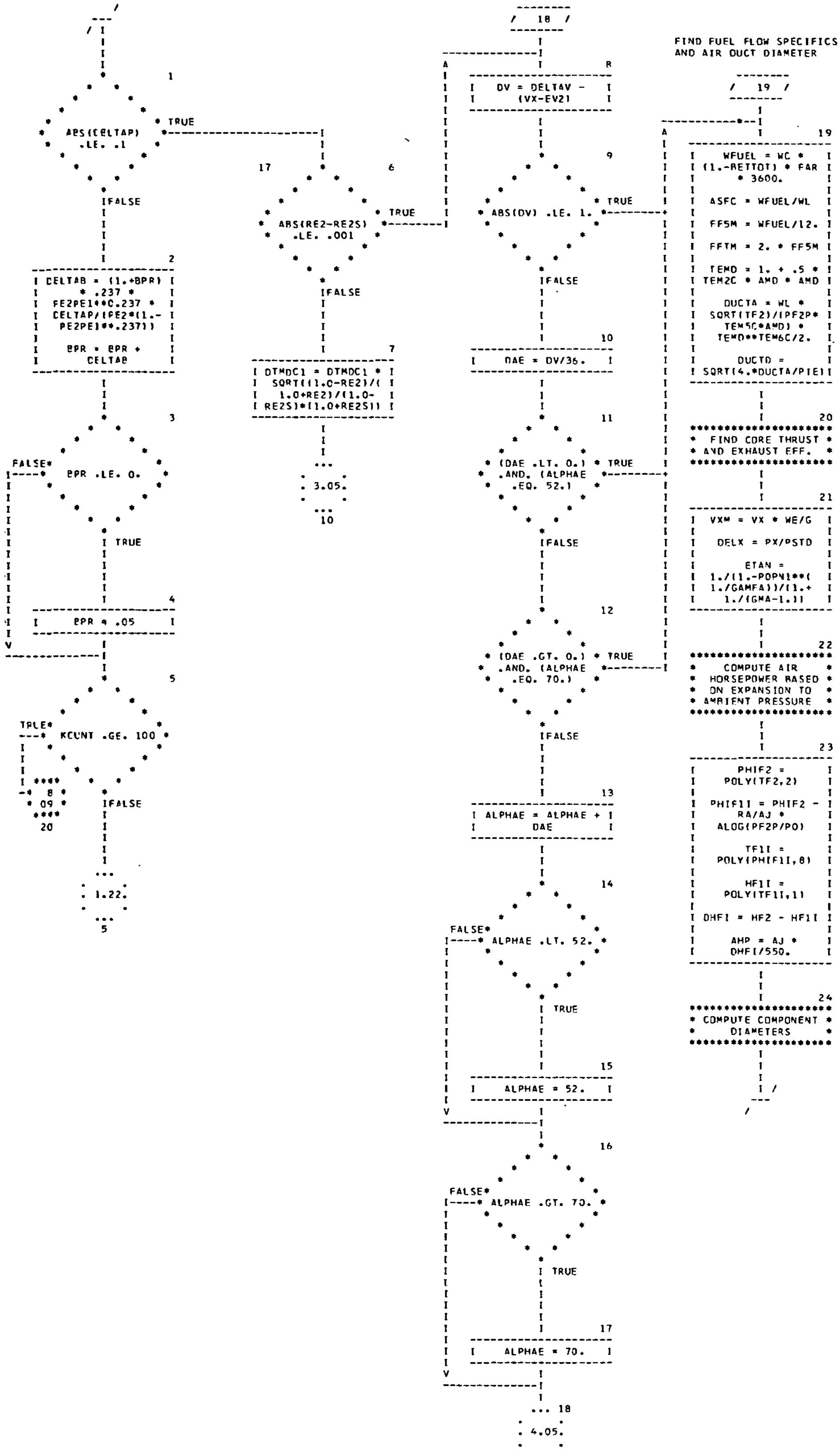

Figure 2. - Continued.

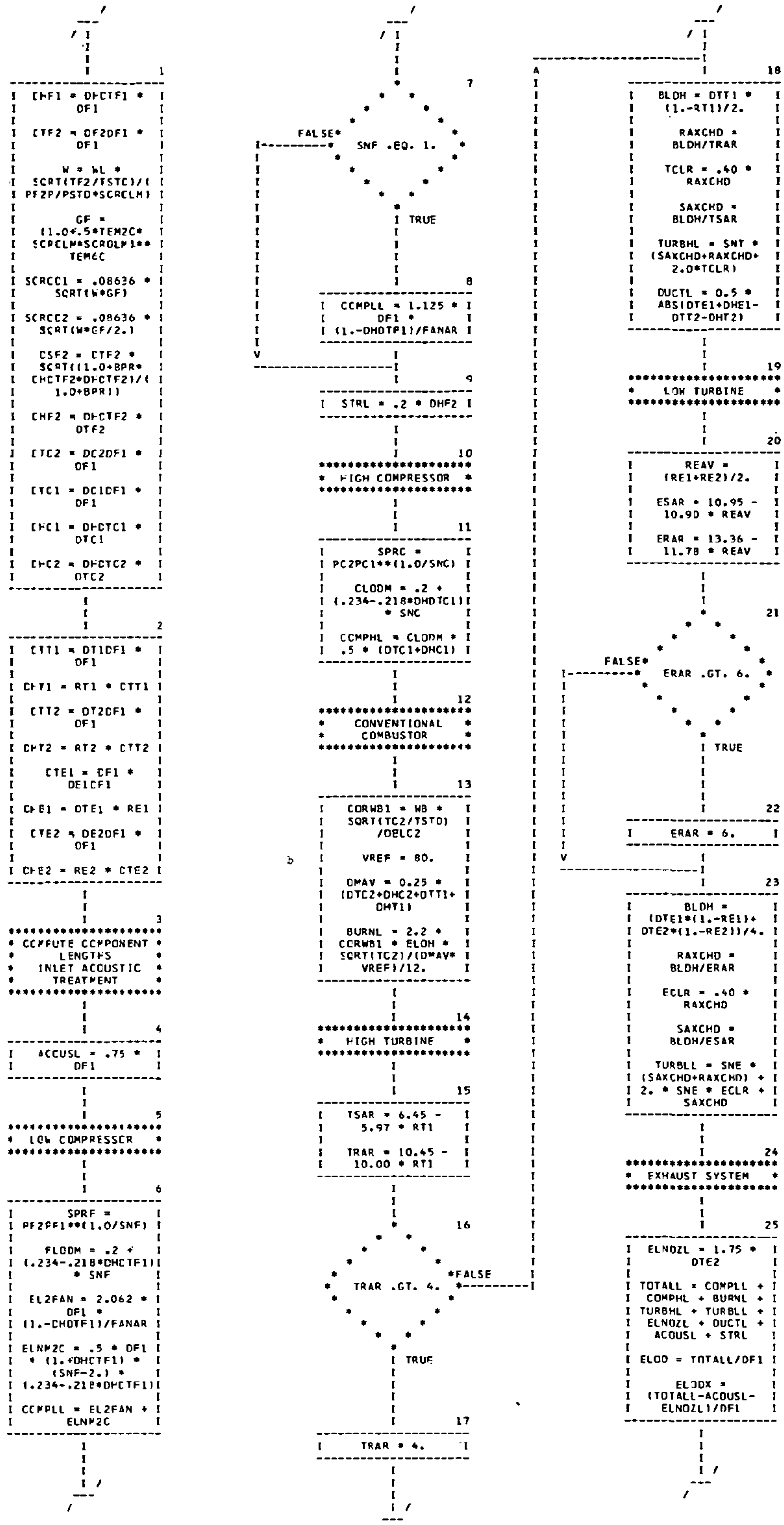

Figure 2. - Continued.

```
 1
c * COMPONENT WEIGHTS *
  *  - LIFT ENGINE    *
  *   TECHNOLOGY      *
  *  INLET ACOUSTIC   *
  *    TREATMENT      *

 2
  RHOW = .55
  RHOR = 1.75
  ACCUSW = PIE *
   CF1 * CF1 *
   (.85*RHOW+.30*
   RHOR)

 3
  * LOW COMPRESSOR *

 4
  ELODRF = 0.2 +
   0.081 * SNF
  C = .5 + .5 *
   FLCOM/ELODRF
  CMBAR = 0.25 *
   (CF1+DHF1+DTF2+
   DHF2)
  W2F = 24. *
   CF1**2.7 *
   (UTIPFC*
   SCTH1/1150.)**
   0.3/SQRT(FANAR)
d WNC = 5.0 *
   CMBAR**2.2 *
   SNF**1.2 * C *
   (UTIPFC*
   SCTH1/1100.)**.3
e W2C = 5.0 *
   CMBAR**2.2 *
   2.0**1.2 *
   (.5+.5*FLCOM/.362)
   *
   (UTIPFC*
   SCTH1/1100.)**0.3
  CCMPLW = W2F +
   WNC - W2C

 5
  SNF .EQ. 1.0
  FALSE -> 7
  TRUE -> 6

 6
  CCMPLW = 12. *
   CF1**2.7 *
   (UTIPFC*
   SCTH1/1150.)**
   .3/SQRT(FANAR)

 7
  CMEAN = .5 *
   (CSF2+DTF2) +
   SCRCCI
  SQT =
   SQRT(TF2/TSTD)
  WPF = WL *
   SQT/(DELF2*SCROLM)
  WSCRCL = .96 *
   CMEAN * SQRT(WPF)

 8
  * HIGH COMPRESSOR *

 9
  ELODRF = 0.2 +
   0.081 * SNC
  C = .5 + 0.5 *
   CLODM/ELODRF
  DMBAR = 0.25 *
   (CTC1+DHC1+DTC2+
   DHC2)
f COMPHW = 5.0 *
   DMBAR**2.2 *
   SNC**1.2 * Q *
   (UTIPCC*SQRT(
   TF2/519.)/1100.)**
   0.3

 10
  * COMBUSTOR -   *
  * CONVENTIONAL  *

 11
g BURNW = 32. *
   DMAV * DMAV *
   SQRT(ELOH)

 12
  * HIGH TURBINE *

 13
  DMBAR =
   (CTT1+DHT1+DTT2+
   DHT2)/4.
h TURBHW = 0.26 *
   DMBAR**2.5 *
   UTM**0.6 * SNT

 14
  * LOW TURBINE *

 15
  DMBAR =
   (DTE1+DHE1+DTE2+
   DHE2)/4.
i TURBLW = 0.26 *
   DMBAR**2.5 *
   UEM**0.6 * SNE

 16
  * EXHAUST SYSTEM *

 17
  ELNOZW = 11. *
   DTE2 * DTE2

 18
  * ACCESSORY WEIGHT *

 19
  EMSQ =
   ((PF2P/PO)**(
   TEM2C/GAMF2)-1.)
   * 2./TEM2C
  EM = SQRT(EMSQ)
  GAMROG =
   SQRT(GAMF2*RA/G)
  FFAN = WL *
   GAMROG *
   (TF2/(1.+TEM2C/2.*
   EMSQ))**.5 * EM
j ACCW = .002 *
   ((FFAN+VXM)+1.35*
   WFUEL)
k ENGWT = COMPLW +
   COMPHW + BURNW +
   TURBHW + TURBLW +
   ACCW + WSCROL
l STRW = .1 * ENGWT
m ENGWT = ENGWT +
   STRW + ACOUSW +
   ELNOZW
  ACOUSX =
   ACOUSW/ENGWT *
   100.
  COMPLX =
   COMPLW/ENGWT *
   100.

 20
  SCROLX =
   WSCROL/ENGWT *
   100.
  COMPHX =
   COMPHW/ENGWT *
   100.
  BURNX =
   BURNW/ENGWT *
   100.
  TURBHX =
   TURBHW/ENGWT *
   100.
  TURBLX =
   TURBLW/ENGWT *
   100.
  ELNOZX =
   ELNOZW/ENGWT *
   100.
  ACCX = ACCW/ENGWT
   * 100.
  STRX = STRW/ENGWT
   * 100.
  XXXX = 100.
  WAWENG = WL/ENGWT
  WAWA =
   WL/(ENGWT+FF5M)
  WAWAA =
   WL/(ENGWT+FFTM)
  AKIND = KIND
  AJCGEO = JCGEOM
  CJFGEO = JFGEOM

 21
  PT1PT2 =
   1./PT2PT1
  PE1PE2 =
   1./PE2PE1
  PN1PO = 1./POPN1
  WB1 = WC *
   (1.-BETTOT)
  WB2 = WC * TEM16
  DHB = HT1G - HC2

 22
  * CHANGE UNITS ON  *
  * INPUT AND OUTPUT *
```

Figure 2. - Continued.

```
                    1
   UNITS .EQ. C.
TRUE --> 8 09 (20)
I FALSE
                    2
WL = .4536 * WL
PO = .04788 * PO
ALPHAT = .01745 * ALPHAT
TT1 = DIV2 * TT1
TO = TO * DIV2
DELTAV = DIV * DELTAV
UTIPCC = DIV * UTIPCC
UTIPFC = DIV * UTIPFC
HF = 2.326 * HF
VX = DIV * VX
PF2P = .04788 * PF2P
DF1 = DIV * DF1
TF2 = DIV2 * TF2
DUCTC = DIV * DUCTC
SCRCD1 = DIV * SCRCD1
VXM = 4.448 * VXM
SWF1 = 4.883 * SWF1
SWC1 = 4.883 * SWC1
                    3
PE2S = .04788 * PE2S
AX = .0929 * AX
AHP = 1.644 * AHP
WFUEL = .126 * WFUEL
SCRCD2 = DIV * SCRCD2
BETAH = .01745 * BETAH
TVX = DIV * TVX
TVU1 = DIV * TVU1
TVU2 = DIV * TVU2
UTM = DIV * UTM
STRESH = 6.895 * STRESH
ALPHAE = .01745 * ALPHAE
BETAL = .01745 * BETAL
EVX = DIV * EVX
EVU1 = DIV * EVU1
EVU2 = DIV * EVU2
UEM = DIV * UEM
```

```
                    4
STRESL = 6.895 * STRESL
WTCON = .4536
ACOUSW = ACOUSW * WTCON
COMPLW = WTCON * COMPLW
WSCROL = WTCON * WSCROL
COMPHW = WTCON * COMPHW
BURNW = WTCON * BURNW
TURBHW = WTCON * TURBHW
TURBLW = WTCON * TURBLW
ACCW = WTCON * ACCW
STRW = WTCON * STRW
ELNOZW = WTCON * ELNOZW
ENGWT = WTCON * ENGWT
ACOUSL = DIV * ACOUSL
WF = .4536 * WF
                    5
VF1 = DIV * VF1
DHF1 = DIV * DHF1
COMPLL = DIV * COMPLL
DHF = 2.326 * DHF
DTF2 = DIV * DTF2
DHF2 = DIV * DHF2
STRL = DIV * STRL
WC = WTCON * WC
VF2 = DIV * VF2
DTC1 = DIV * DTC1
DHC1 = DIV * DHC1
COMPHL = DIV * COMPHL
DHC = 2.326 * DHC
WB = WTCON * WB
TC2 = DIV2 * TC2
VC2 = DIV * VC2
DTC2 = DIV * DTC2
DHC2 = DIV * DHC2
```

```
                    6
BURNL = DIV * BURNL
DHB = 2.326 * DHB
WB2 = WTCON * WB2
DTT1 = DIV * DTT1
WR = WTCON * WR
TTR = DIV2 * TTR
DHT1 = DIV * DHT1
TURBHL = DIV * TURBHL
DHT = 2.326 * DHT
TT2 = DIV2 * TT2
DTT2 = DIV * DTT2
DHT2 = DIV * DHT2
DUCTL = DIV * DUCTL
WT = WTCON * WT
TE1 = DIV2 * TE1
DTE1 = DIV * DTE1
DHE1 = DIV * DHE1
TURBLL = DIV * TURBLL
                    7
DHE = 2.326 * DHE
TE2 = DIV2 * TE2
DTE2 = DIV * DTE2
EV2 = DIV * EV2
DHE2 = DIV * DHE2
ELNOZL = DIV * ELNOZL
DX = DIV * DX
TOTALL = DIV * TOTALL
                    8
* WRITE INPUTS AND OUTPUTS *
5.05--*--
20                  9
/ WRITE BCD UNIT 6 FORMAT 39 /
                    10
/ WRITE BCD UNIT 6 FORMAT 32 /
                    11
* I/O LIST IS TITLE *
                    12
/ WRITE INPUT DATA AND FORMATS /
```

Figure 2. - Continued.

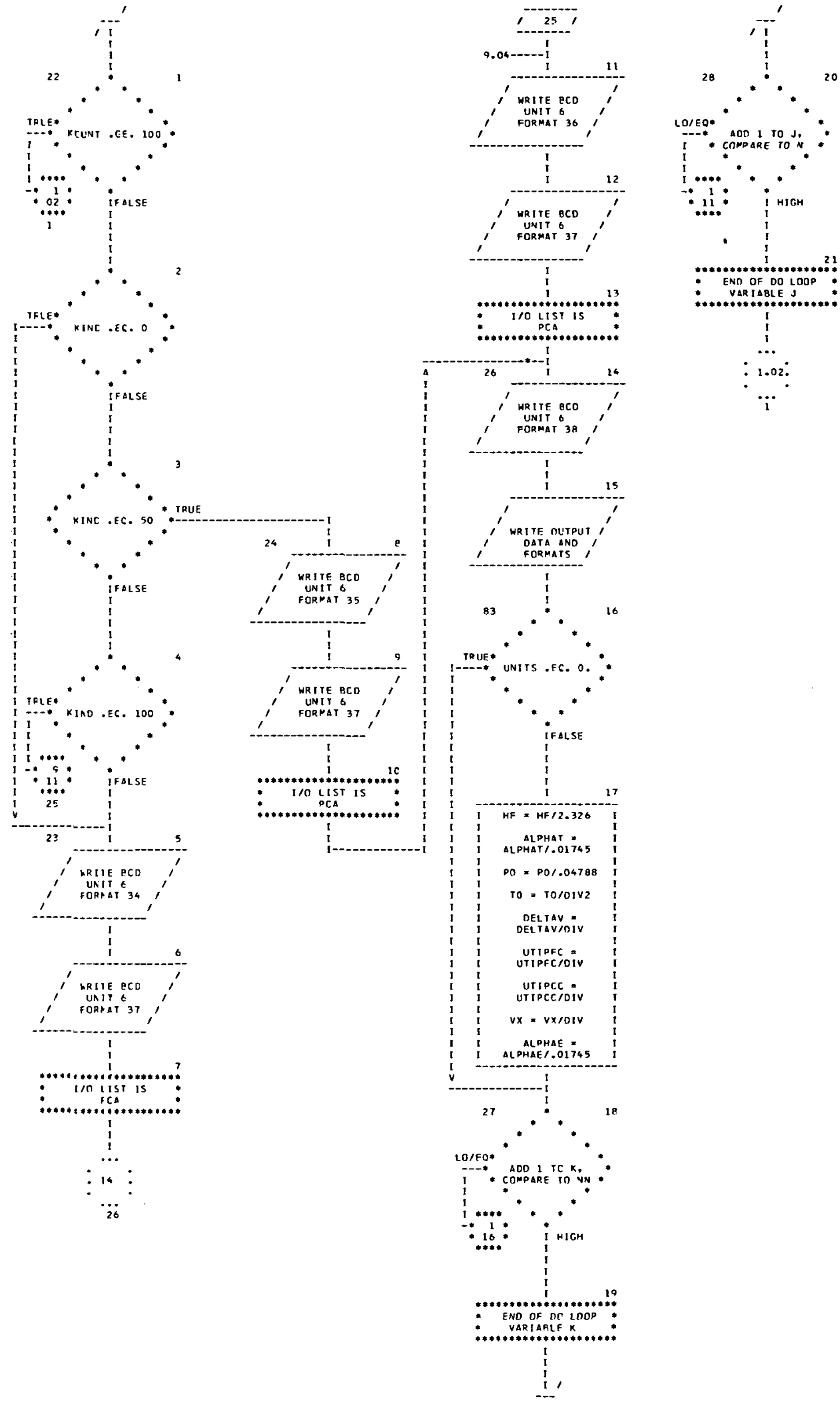

Figure 2. - Continued.

MISCELLANEOUS STATEMENTS

```
      DIMENSION TITLE(12)
      COMMON /JAN1/ AJ,PIE,G,ZZ,PSTD,TSTD,PSIR,RA,DELC,SOTH1
      DATA AJ/777.97/,PIE/3.14159/,G/32.17/,ZZ/.0107663/,PSTD/2116./,TST
     D/519./,PSIR/1.73/,RA/53.331/
   29 FORMAT (8F10.0)
   30 FORMAT (5I5)
   31 FORMAT (12A6)
   32 FORMAT (1H0,50X,12A6)
   33 FORMAT (36X,16HFAN ASPECT RATIO,5X,F8.3,2X,21HSCROLL PRES LOSS COE
     F,F9.3,3X,15HUNITS-CUSTOMARY)
   34 FORMAT (1X,16H     H.T. COOLING)
   35 FORMAT (1X,11HLIFT ENGIAE)
   36 FORMAT (1X,13HCRUISE ENGINE)
   37 FORMAT (1X,9HPCA      =,F6.4)
   38 FORMAT (1H0,63X,6HOUTPUT)
   39 FORMAT (1H1,30X,65HTWO SPOOL AIR GENERATOR-STRAIGHT THRU COMBUSTOR
     -LIFT COMPONENTS   )
   40 FORMAT (1H0,9X,14HPRIMARY INPUTS,51X,16HSECONDARY INPUTS)
   41 FORMAT (1H0,1X,23HDELIVERED AIRFLOW      ,F6.1,5X,21HAMBIENT PRESS
     URE      ,F6.1,4X,20HUSER BLEED          ,F10.3,3X,20HHT NOZZLE ANG
     LE      ,F6.2)
   42 FORMAT (2X,23HTURBINE INLET TEMP      ,F5.0,6X,21HAMBIENT TEMPERATU
     RE  ,F6.1,4X,20HDUCT MACH NUMBER     ,F10.3,3X,20HNOZ-TURBX DELTA V
     1 ,F5.1)
   43 FORMAT (2X,23HLOW COMP PRESSURE RATIO,F8.3,3X,21X,10X,20HHI CORR T
     IP SPEED    ,F8.1,5X,20HHT LOSS COEFF         ,F7.3)
   44 FORMAT (2X,23HHIGH COMP PRESS RATIO  ,F8.3,3X,21HENGINE APPLICATIO
     N    ,F5.0,5X,20HNO. STAGES HI COMP  ,F7.0,6X,20HLT LOSS COEFF
     1 ,F7.3)
   45 FORMAT (2X,23HHIGH TURBINE STAGES    ,F5.0,6X,21HINLET RECOVERY
     1    ,F8.3,2X,20HHI COMP EFFICIENCY  ,F10.3,3X,20HLT EXIT H-T RATIO
     1 ,F7.3)
   46 FORMAT (2X,23HLOW TURBINE STAGES     ,F5.0,6X,21HLOW CORR TIP SPEE
     D    ,F5.0,5X,20HHI COMP FLOW PATH   ,F7.0,6X,20HLOW TURBINE OFFSET
     1 ,F7.3)
   47 FORMAT (36X,21HNO. STAGES LOW COMP  ,F5.0,5X,20HAXIAL VELOCITY RAT
     IO,F10.3,3X,20HINTERTURB PRESS REC ,F7.3)
   48 FORMAT (36X,21HINLET AXIAL MACH NO. ,F8.3,2X,20HFUEL HEATING VALUE
     1 ,F7.0,6X,20HLT STRAIGHT VANES   ,F4.0)
   49 FORMAT (36X,21HINLET HUB-TIP RATIO  ,F8.3,2X,20HCOMBUSTOR EFFICIEN
     CY,F10.3,3X,19HCORE VELOCITY       ,F6.1)
   50 FORMAT (36X,21HEFFICIENCY           ,F8.3,2X,20HCOMBUSTOR PRES REC
     1 ,F10.3,3X,20HNOZZLE VEL COEF      ,F7.3)
   51 FORMAT (36X,21HLOW COMP FLOW PATH   ,F5.0,5X,20HCOMBUSTOR L/H RATI
     O ,F10.3,3X,18HTURB VANE D-FACTOR,F9.3)
   52 FORMAT (36X,21HAXIAL VELOCITY RATIO ,F8.3,2X,20HSCROLL MACH NO.
     1 ,F10.3,3X,20HELBOW/DUCT LOSS COEF,F7.3)
   53 FORMAT (1H0,8H AIR SFC,4X,10HINLET DIAM,7X,3HAIR,6X,8HLEN/DIAM,3X,
     111HAIR DUCT(2),1X,9H LOW TURB,7X,14HAIRFLOW/ENG M ,6X,12HMA/(ME+5M
     1 F),5X,13HMA/(ME+10M F))
   54 FORMAT (14X,8HLOW COMP,4X,1HP,F8.1,5X,F5.3,5X,8HDIAMETER,7X,3HEFF,
     124X,F16.4,F17.4)
   55 FORMAT (F8.1,F13.3,5X,1HT,F8.1,F10.3,F12.3,F13.3,8X,F10.4,F19.4,F1
     17.4)
   56 FORMAT (1H0,2X,4HCORE,7X,7HCORR SP,5X,7HCORR SP,4X,8HLOW TURB,3X,8
     HCORE EXH,3X,8HCORE EXH,4X,6HBYPASS,4X,8HSPECIFIC,4X,4HFUEL,5X,11H
     SCROLL DIAM)
   57 FORMAT (2X,6HTHRUST,5X,9HL.C. FLOW,3X,9HCORE FLOW,2X,9HSTAT PRES,2
     X10HAREA RATIO,4X,4HAREA,6X,5HRATIO,6X,7HENERGY ,4X,4HFLOW,6X,3H(1
     1),F8.3)
   58 FORMAT (F8.1,F12.2,F12.2,F12.1,F11.3,F11.3,F10.3,F11.1,5X,F6.0,5X,
     13H(2),F8.3)
   59 FORMAT (1H0,12X,9HREFERENCE,11X,3HPER)
   60 FORMAT (9X,17H  MASS ESTIMATION,6X,4HCENT//3X,12HACOUST TREAT,5X,F
     16.1,F11.1)
   61 FORMAT (3X,12HLOW COMPRESS,5X,F6.1,F11.1,F13.1,F13.1)
   62 FORMAT (3X,13HHIGH COMPRESS,4X,F6.1,F11.1,F16.1,F13.1)
   63 FORMAT (3X,9HCOMBUSTOR,8X,F6.I,F11.1,F16.1,F13.1)
   64 FORMAT (3X,12HHIGH TURBINE,5X,F6.1,F11.1,F16.1,F13.1)
   65 FORMAT (3X,11HLOW TURBINE,6X,F6.1,F11.1,F16.1,F13.1)
   66 FORMAT (3X,11HACCESSORIES,6X,F6.1,F11.1,F16.1,F11.1)
   67 FORMAT (3X,9HSTRUCTURE,8X,F6.1,F11.1,F16.1,F13.1)
   68 FORMAT (1H0,14X,106HNUMBER OF  ALPHA1=  BETA1=  VX1=VX2   VU1=
     VU2=   STAGE    MEAN   ABS.INLET  REL.INLET   FLOW    BLADE /16X,1
     C9HSTAGES    -BETA2  -ALPHA2   (=VO)    -WU2    -WU1   LAMDA   SPE
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Figure 2. - Continued.

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MISCELLANEOUS STATEMENTS

68     FORMAT (1HO,14X,1C6HNUMBER OF  ALPHA1=  BETA1=  VX1=VX2   VU
       VU2=   STAGE    MEAN   ABS.INLET  REL.INLET   FLOW    BLADE
       C9HSTAGES    -BETA2  -ALPHA2   (=VO)    '-WU2    -WU1   LAMDA   SPE
       ED   MACH NO.   MACH NC.   COEFF.  STRESS     /13H HIGH TURBINE,3X
       ,F3.0,5X,F7.2,2X,F7.2,2X,F7.1,1X,2F8.1,1X,F7.4,1X,F7.1,2X,F7.4,5X,
       F7.4,3X,F6.3,F9.0/12H LOW TURBINE,4X,OPF3.0,5X,OPF7.2,2X,OPF7.2,2X
       ,OPF7.1,1X,OP2F8.1,1X,CPF7.4,1X,OPF7.1,2X,OPF7.4,5X,OPF7.4,3X,OPF6
       .3,OPF9.0)

69     FORMAT (1HO)

70     FORMAT (1HK,22X,5HPRESS,14X,88HFUEL-AIR   TOTAL     MASS      TOTA
       L     TOTAL   AX. MACH   AXIAL     HUB-TIP   TIP DIA./12X,119H LEN
       GTH    RATIO    DELTA H    RATIO       EFF.      FLOW       TEMP
        PRESS     NUMBER   VELCCITY     RATIO   (HUB DIA.)//12H INLET TREAT
       ,F7.3/13X,12X,36X,F7.2,4X,F7.1,F10.4,F9.4,F10.1,F10.4,F11.4/120X,2
       H (,F7.4,2H) )

71     FORMAT (120X,2H (,F7.4,1H))

72     FORMAT (60X,F8.2,F11.1,F10.4,F9.4,F10.1,F10.4,F11.4)

73     FORMAT (1CH  LOW COMP,F9.3,F10.4,F9.2,14X,F6.3)

74     FORMAT (10H COMP DUCT,F9.3)

75     FORMAT (108X,F10.4,F11.4)

76     FORMAT (11H  HIGH COMP,F8.3,F10.4,F9.2,14X,F6.3//60X,F8.2,F11.1,F1
       C.4,F9.4,F10.1,F10.4,F11.4/120X,2H (,F7.4,2H) /11H COMBUSTOR ,F8.3
       ,F10.4,F9.2,F10.5,F10.3//60X,F8.2,F11.1,F10.4,F9.4,F10.1,F10.4,F11
       .4/60X,F8.2,F11.1,41X,2H (,F7.4,2H) /11H  HIGH TURB,F8.3,F10.4,F9.
       2,F10.5,F10.3/20X,2H (,F7.4,2H) /60X,F8.2,F11.1,F10.4,F9.4,F10.1,F
       10.4,F11.4/120X,2H (,F7.4,2H) /11H  TURB DUCT,F8.3,F10.4,F39.2//68
       X,F11.1,F10.4,F9.4,F10.1,F10.4,F11.4/120X,2H (,F7.4,2H) /11H   LOW
        TURB,F8.3,F10.4,F9.2,F10.5,F10.3,F10.2/21X,1H(,F7.4,1H)/61X,F18.1
       ,10X,F9.4,F1C.1,F1C.4,F11.4/79X,F10.4,3X,F6.4,F10.1,12X,2H (,F7.4,
       2H) /11H      ELBOW,F8.3,F10.4/81X,F8.4//11H  CCRE EXH ,8X,F10.4,9
       X,F10.5,F10.3/20X,2H (,F7.4,2H) /60X,F8.2,F11.1,F10.4,F9.4,F10.1,1
       0X,F11.4/11H       TOTAL,F8.3)

77     FORMAT (1H1)

78     FORMAT (3X,11HENG MASS   ,4X,F8.1,F11.1,F16.1,F11.1)

79     FORMAT (3X,12HELBOW+NCZZLE,5X,F6.1,F11.1)

80     FORMAT (1HO)

81     FORMAT (3X,1CHL.C.SCROLL,7X,F6.1,F11.1)

82     FORMAT (36X,16HFAN ASPECT RATIO,5X,F8.3,2X,21HSCROLL PRES LOSS COE
       F,F9.3,3X,11HUNITS- S I )
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Figure 2. - Concluded.

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YOF1731 MARY JANE WINTE                                                         000342
                           TWO SPOOL AIR GENERATOR-STRAIGHT THRU COMBUSTOR-LIFT COMPONENTS

                                                NOMINAL CASE

          PRIMARY INPUTS                                                     SECONDARY INPUTS

DELIVERED AIRFLOW          50.0   AMBIENT PRESSURE      101.3   USER BLEED                0.      HT NOZZLE ANGLE         1.13
TURBINE INLET TEMP       1473.    AMBIENT TEMPERATURE   305.0   DUCT MACH NUMBER          0.300   NOZ-TURBX DELTA V       0.
LOW COMP PRESSURE RATIO    3.804                                HI CORR TIP SPEED       360.0     HT LOSS COEFF           0.400
HIGH COMP PRESS RATIO      3.943  ENGINE APPLICATION     50.    NO. STAGES HI COMP        5.      LT LOSS COEFF           0.400
HIGH TURBINE STAGES        1.     INLET RECOVERY          0.950 HI COMP EFFICIENCY       -0.895   LT EXIT H-T RATIO       0.600
LOW TURBINE STAGES         3.     LOW CORR TIP SPEED    360.    HI COMP FLOW PATH         1.      LOW TURBINE OFFSET      1.100
                                  NO. STAGES LOW COMP     5.    AXIAL VELOCITY RATIO      0.750   INTERTURB PRESS REC     1.000
                                  INLET AXIAL MACH NO.    0.600 FUEL HEATING VALUE    43000.      LT STRAIGHT VANES       2.
                                  INLET HUB-TIP RATIO     0.500 COMBUSTOR EFFICIENCY      0.980   CORE VELOCITY         200.0
                                  EFFICIENCY             -0.895 COMBUSTOR PRES REC        0.914   NOZZLE VEL COEF         0.980
                                  LOW COMP FLOW PATH      1.    COMBUSTOR L/H RATIO       2.000   TURB VANE D-FACTOR      0.400
                                  AXIAL VELOCITY RATIO    0.750 SCROLL MACH NO.           0.300   ELBOW/DUCT LOSS COEF    0.125
                                  FAN ASPECT RATIO        3.000 SCROLL PRES LOSS COEF     0.500   UNITS- S I
LIFT ENGINE
PCA      =0.0497

                                                     OUTPUT

AIR SPC    INLET DIAM       AIR      LEN/DIAM   AIR DUCT(2)  LOW TURB      AIRFLOW/ENG M      MA/(ME+5M F)     MA/(ME+10M F)
            LOW COMP    P   354.6     1.671     DIAMETER      EFF
  43.9       0.842      T   465.3     4.063       0.313       0.884           0.0937             0.0698            0.0556

CORE       CORR SP     CORR SP    LOW TURB   CORE EXH   CORE EXH   BYPASS   SPECIFIC   FUEL    SCROLL DIAM
THRUST    L.C. FLOW   CORE FLOW   STAT PRES  AREA RATIO   AREA      RATIO    ENERGY    FLOW     (1)   0.312
5765.3     152.20       46.98      102.7       1.108      0.348     1.772    141.1     610.     (2)   0.221

              NUMBER OF  ALPHA1=  BETA1=  VX1=VX2   VU1=    VU2=   STAGE    MEAN   ABS.INLET  REL.INLET   FLOW    BLADE
               STAGES    -BETA2  -ALPHA2   (=VC)    -WU2    -WU1   LAMDA   SPEED   MACH NO.   MACH NO.   COEFF.   STRESS
HIGH TURBINE     1.        1.13    0.02    241.3    511.7    -5.1  0.9804  506.7    0.8048     0.3433     0.476  175061.
LOW TURBINE      3.        1.06    0.50    226.3    403.0  -125.0  0.5264  278.0    0.7037     0.3936     0.814   66350.

            REFERENCE          PER
         MASS ESTIMATION       CENT

  ACOUST TREAT       10.8       2.0
  LOW COMPRESS      142.2      26.7
  L.C.SCROLL         14.6       2.7
  HIGH COMPRESS      37.9       7.1
  COMBUSTOR          57.6      10.8
  HIGH TURBINE       49.2       9.2
  LOW TURBINE       130.8      24.5
  ACCESSORIES        12.5       2.3
  STRUCTURE          44.5       8.3
  ELBOW+NOZZLE       33.5       6.3

  ENG MASS          533.6     100.0
```

(a) First sheet.

Figure 3. - Representative printout for PROGRAM 50-L.

	LENGTH	PRESS RATIO	DELTA H	FUEL-AIR RATIO	TOTAL EFF.	MASS FLOW	TOTAL TEMP	TOTAL PRESS	AX. MACH NUMBER	AXIAL VELOCITY	HUB-TIP RATIO	TIP DIA. (HUB DIA.)
INLET TREAT	0.631											
						78.21	305.0	0.9499	0.6000	202.8	0.5000	0.8417 (0.4209)
LOW COMP	0.526	3.8040	162.36		-0.895							
											0.6407	0.6569 (0.4209)
COMP DUCT	0.084											
						28.21	465.3	3.6133	0.3574	152.1	0.8116	0.5185 (0.4209)
HIGH COMP	0.228	3.9430	254.74		-0.895							
						26.81	708.3	14.2472	0.2172	114.1	0.8922	0.4717 (0.4209)
COMBUSTOR	0.194	0.9140	979.00	0.02274	0.980							
						27.42 28.12	1473.0 1455.5	13.0220	0.3432	241.3	0.9075	0.6024 (0.5466)
HIGH TURB	0.063	0.4702 (2.1269)	261.96	0.02217	0.905							
						28.12	1244.8	6.1224	0.3567	241.3	0.8709	0.6141 (0.5349)
TURB DUCT	0.057	1.0000				28.82						
							1237.8	6.1224	0.3445	226.3	0.8625	0.6786 (0.5853)
LOW TURB	0.254	0.1795 (5.5702)	440.55	0.02162	0.884	28.82						
							868.4	1.0991	0.3995 0.3502	226.3 199.8	0.6000	0.7900 (0.4740)
ELBOW	1.382	0.9898										
								1.0879				
CORE EXH		0.9966 (1.0034)		0.02162	0.960							
						28.82	868.4	1.0843	0.3506	200.0		0.6653
TOTAL	3.420											

(b) Second sheet.

Figure 3. - Concluded.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

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