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COMPUTER SIMULATION OF AUXILIARY POWER SYSTEMS.(U)
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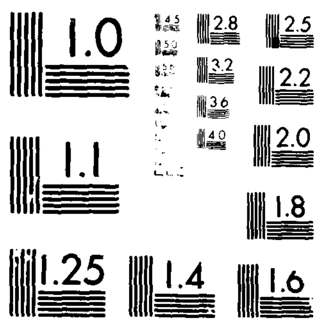

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COMPUTER SIMULATION OF AUXILIARY POWER SYSTEMS

AEROSPACE POWER DIVISION
POWER SYSTEMS BRANCH

March 1980

TECHNICAL REPORT AFAPL-TR-79-2118
Final Report for ~~Period April 1979 - August 1979~~

AIR FORCE AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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This technical report has been reviewed and is approved for publication.

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Chief, Aerospace Power Division

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A digital computer program for the analysis of Auxiliary Power Units (APU's) has been developed. It analyzes the thermodynamics of each component, compressor, combustor, and turbine with regards to basic performance parameters and bleed leakage flows. On the first pass, the code solves for available horsepower from the APU on the basis of input component pressure ratio and efficiencies. On the second pass, the component performance is solved to satisfy the desired design shaft horsepower of the APU. This code is called APUCODE. It is a derivative of SMOTE (Simulation of Turbofan Engine), developed in AFAPL/TBC by Capt John S. McKinney, USAF, AFAPL-TR-67-125.

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FOREWORD

This report describes work conducted within the Air Force Aero Propulsion Laboratory, Power Division, Power Systems Branch (POP-1), Wright-Patterson Air Force Base, Ohio. The work was accomplished under Project 3145, "Aerospace Power," Task 314501, "Dynamic Energy Conversion for Aerospace," Work Units 31450127, "Auxiliary Power Unit Simulation," and 31450142, "Computer Simulation of Auxiliary Power Systems," between July 1974 and November 1979.

This report was submitted by the author, 1Lt Daniel J. Gurecki, in November 1979. Previous project engineers were Capt John G. Grelck, and Richard E. Quigley. Final project engineer is 1Lt Daniel J. Gurecki.

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INTRODUCTION

The typical Auxiliary Power Unit (APU) is a small gas turbine, independent of the main engine, which supplies shaft horsepower and compressed air to start the main engine and run accessories as needed in the aircraft. APU designs are typically single-spool or single-spool with power turbine. The need for high power density in a confined space necessitates use of both axial and centrifugal designs in the compressors and turbines. Presently there exists a need to analyze APU's and aerodynamic torque converter configurations in AFAPL.

This report serves to document the previous modifications to the SMOTE program which have resulted in the APUCODE program. APUCODE simplifies the SMOTE program to analyze the basic single-spool gas generator while incorporating options peculiar to APU's. At present, APUCODE analyses only design-point conditions. In addition, numerous changes have been made to make input and output pages more readable.

This report is a user's manual for design-point APUCODE. It includes complete Fortran listing of the code and sample data cases. The code has been programmed in a straightforward manner for simplicity and ease of modification. Comment cards describe the major subdivisions of the main subroutine, APU, and flowcharts aid the understanding of the program logic.

SECTION II

PROGRAM DESCRIPTION

1. APU IN GENERAL

APU is the main program subroutine in APUCODE. It controls the use of subroutines, sequences the logic of the calculations, and prints the output. The program logic follows the gas path through the APU from inlet to exhaust. Thermodynamic properties of the flow are computed at the inlet or exit of each component. Typical computing stations are shown in Figure 1 and defined in Table 1. Calculations are assumed to be adiabatic. The properties at downstream computing stations are calculated from mass-averaged upstream quantities, and the change in those quantities due to addition or extraction of shaft work and flow.

2. SEQUENCE OF OPERATIONS IN APU

a. Inlet and Compressors

After printing the INPUT page, inlet conditions are computed from 1962 standard atmosphere. Inlet duct pressure loss is used to compute the total pressure at the compressor inlet. Throughout the program, at each computing station, subroutine THERMO provides calculation of gas properties. Work for the low and high pressure compressors is computed from input pressure ratios, efficiencies, and losses. If only one compressor exists, it will be computed as the High Pressure Compressor (HPC).

b. Bleed Flows from the High Pressure Compressor

Bleed flows for turbine cooling and accessory power are subtracted from the HPC inlet flow. The HPC bleed flow can be split into turbine inlet nozzle cooling, High Pressure Turbine (HPT) cooling, and Low Pressure Turbine (LPT) cooling. The remainder is bleed air which is lost from the APU flow and used to power the APU fuel pump, oil pump and other accessories. Each bleed flow is accounted for as a fraction of the HPC inlet flow and listed in the program output. Losses in the bleed ducting are used to arrive at the thermodynamic properties of the bleed flow when it enters the main flow to serve as turbine cooling air.

c. Combustor

The combustor calculates the properties at combustor exit of a mixture of air and standard JP-4 fuel. The combustor exit temperature, T4, must be input. Fuel flow and fuel heating value are optional and will be calculated if not specified. The combustor calculation iterates to a final exit temperature using

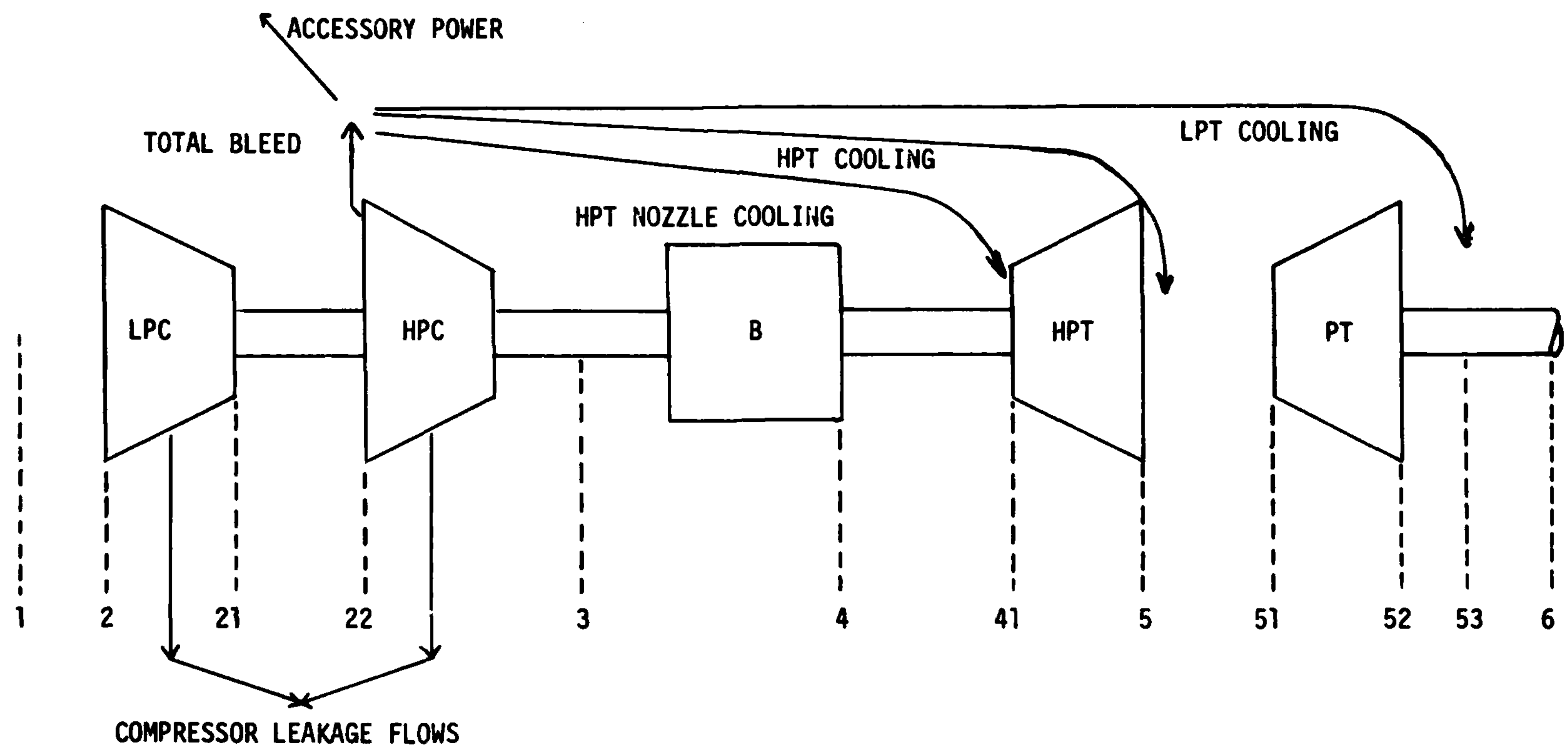


Figure 1 - Computing Station Location

TABLE 1

COMPUTING STATION DESCRIPTION

STATION NUMBER	
1	ambient conditions
2	low pressure compressor inlet
21	low pressure compressor discharge
22	high pressure compressor inlet
3	high pressure compressor discharge/burner inlet
4	main combustor discharge
41	high pressure turbine inlet plus inlet nozzle cooling
5	high pressure turbine discharge before cooling flow has been added
51	low pressure turbine inlet plus HPT cooling
52	low pressure turbine discharge before cooling flow has been added
53	low pressure turbine discharge including LPT cooling
6	exhaust duct exit

the Air Force Quadratic Interpolation Routine (AFQUIR). If the calculation fails to converge, a message is printed to that effect.

d. Turbines

There are three choices for the turbine configuration, see Figure 2: 1) a one-stage turbine, 2) a two-stage turbine, or 3) a one-stage turbine followed by a free turbine. The program makes two passes during each case: the first employs the pressure ratios and efficiencies as input to calculate the shaft work extracted from the APU; the second pass calculates the turbine pressure ratios necessary to provide the design APU shaft horsepower. At the end of the first pass, the output page is printed and control is transferred back to the combustor calculation. With compressors unchanged, the program continues on the second pass, and prints the output for the second pass.

(1) Turbine Overexpansion

If, on the first pass, the last turbine lowers the turbine exit pressure to less than atmospheric, an error is printed indicating overexpansion and the turbine exit pressure is set equal to atmospheric. Then, on the second pass, pressure ratio in the last turbine is recomputed based on expansion to atmospheric turbine exit pressure.

(2) Turbine Cooling

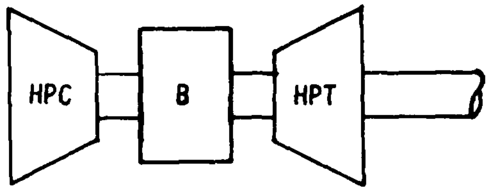
Before output is printed, cooling air modifies the first turbine inlet nozzles and each turbine exit. It is assumed that the cooling air injected into the turbine flow does no useful work, thus cooling air is added to the flow computation after the appropriate turbine exit station. It is then assumed to mix completely with the main flow and thus perform useful work in the downstream turbine.

(3) Exit Velocity

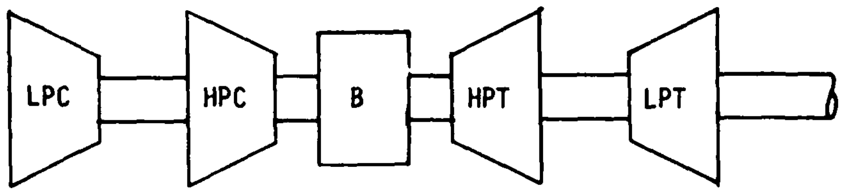
Flow velocity is computed at the last turbine exit based on the change in enthalpy from turbine exit to ambient conditions. Thrust and SFC are computed from this velocity. On the first pass, when turbine overexpansion occurs, this enthalpy change will be negative; hence, the exit velocity calculation will be invalid. This velocity and all values dependent on it will be printed out as "I."

(4) Peculiarities in the Case of One Turbine Followed by a Power Turbine

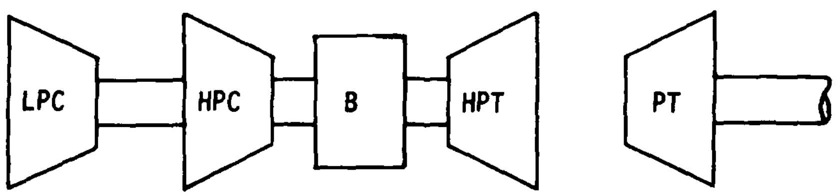
Because the power turbine rotates a shaft separate from the compressor-turbine shaft, the power turbine requires special attention. The power derived from the main turbine must be exactly equal to the power required by the compressors



1 STAGE COMPRESSOR 1 STAGE TURBINE CONFIGURATION



2 STAGE COMPRESSOR 2 STAGE TURBINE CONFIGURATION



2 STAGE COMPRESSOR 1 STAGE TURBINE WITH POWER TURBINE CONFIGURATION

Figure 2 - Possible APU Configurations

and the accessories. Thus, on the first pass, if the input main turbine pressure ratio results in this requirement not being satisfied, the correct pressure ratio of the main turbine is calculated. For this reason, the first pass output pressure ratio for the main turbine may not be that which was input.

Continuing in the first pass, the power turbine work is calculated from the input pressure ratio and printed out. In the second pass, the main turbine is unchanged, and the power turbine pressure ratio is recalculated to provide the design shaft horsepower.

3. QUADRATIC INTERPOLATION ROUTINE

Throughout the program there are many small loops (for example, thermodynamic iterations and table lookup) which require convergence. Trial-and-error methods and linear interpolations can be time-consuming, especially when a tight tolerance is necessary; therefore, a general interpolation routine called AFQUIR was developed.

a. Variables

This routine requires a dummy array dimensioned for nine locations. The other input variables are the independent and the dependent variables, the answer or value which the dependent variable is to converge upon, the number of tries at convergence, the tolerance, and a variable called DIR.

b. The DIR

The DIR is either set or calculated in the calling program. It is an initial guess at the direction and percentage change applied to the first value of the independent variable. If not enough is known to calculate a DIR, an arbitrary value may be set. This should not affect the final result but may increase the number of tries at convergence.

c. The Logic

The DIR, thus, establishes the second value of the independent variable. This value is used in the calling program to determine a corresponding second value of the dependent variable. AFQUIR is called a second time with these two sets of values. A linear interpolation results in a third value of the independent variable. AFQUIR is then called a third time with all three pairs of independent and dependent variables and a quadratic interpolation is made. The values of these three pairs of variables are stored in the dummy array and, henceforth, quadratic interpolations are made using the three sets which give values closest to the answer. Values farthest from the answer are lost.

d. Safeguards

Various safeguards are built into AFQUIR which either return the interpolation method to the initial guess or linear interpolation if the roots of the quadratic become complex. Complex roots are encountered if the quadratic does not intercept the answer, if the value of the independent variable differs radically from previous values, or if two pairs of independent and dependent variables are identical. It is also possible to preload the dummy array and to start directly at the linear or quadratic interpolations if desired.

e. Summary

In summary, AFQUIR is a completely flexible routine which performs quadratic interpolation for quick convergence of general functions. (SMOTE manual, reference no. 1, pages 11 and 12).

4. THERMODYNAMIC PROPERTIES SUBROUTINES

a. THERMO and PROCOM

Two subroutines are used to calculate thermodynamic properties of the flow at each computing station. They are PROCOM, which calculates gas properties for either air or fuel-air mixture, and THERMO, which calls PROCOM and calculates more complex properties. These subroutines are fairly simple and are listed with the rest of the code in Appendix B.

b. Use

The use of PROCOM is straightforward, but THERMO may be used in several ways. If pressure and enthalpy are input, total temperature is calculated. If pressure and temperature are supplied, enthalpy is calculated. Fuel-to-air ratio may also be input and taken into account in the property computations. These options are set by the programmer and are not available as options to the user from the input deck.

SECTION III

INPUT DESCRIPTION

1. GENERAL

Subroutine APU is the main subroutine of APUCODE. Its logic is straightforward and is described at major subdivisions by comment cards. At the beginning of the code listing, the comment cards list brief descriptions of the program variables. The complete set of input variables need not be input for any one case. Variables not input are set equal to their default values as listed in Section III.6. Those parameters which are input override the default values.

2. CARD FORMAT

All of the data cards must start in Column 2 or beyond. To start a data case, punch $INPUT in Columns 2-7 then skip a space and continue by punching the input parameter names, followed by an "equals" sign and the appropriate numerical value. Values can be input up to column 72 inclusively. There is no limit to the number of cards in a data case. Finish the data case by punching a $-sign immediately following the last value in that data case. The program executes the data case and returns to read the next case. The program will use values from the preceding point unless specifically changed in the data case that follows. See example A, Setup of APUCODE Deck, in Appendix A. To terminate a string of data cases, the last data case should be: $INPUT IEND = 1$.

3. TITLE CARD

If specified, a title will be printed at the top of each case. To read a title card, set ITITLE = 1 in the NAMELIST data to which the title applies. The program then reads Columns 1-66 of the first card following that data case as the title. Since the program automatically sets ITITLE = 0 after a title has been read, ITITLE has to be set = 1 <u>only</u> when a new title is desired.

4. ESTIMATES FOR ONE CASE

To compile (CP time) = 7.2 sec.
Input/Output time (IO) = 23 sec.
Line Estimate = 255 lines per case, or 3 computer pages

5. SUBROUTINE DESCRIPTION AND PROGRAMMER OPTIONS

a. ATMOS (<u>ALTP</u>, T1, P1) - Computes temperature and pressure of the 1962 U. S. standard atmosphere up to 90 kilometers.

b. PROCOM (<u>FAR</u>, T1, CS, AKEX, CP, R, PHI, H) - Calculates thermodynamic gas properties for either air, or a fuel-air mixture based on JP-4.

c. THERMO (P, H, T, SOUT, AM, CP, GA, L, FAR, K) - Calculates thermodynamic conditions based on PROCOM. If K=1, P, FAR, and H are input; if K=0, T, FAR, and P are input.

d. COMB (PIN, T4, HIN, ETAB, DPB, POUT, HOUT, SOUT, FAR, HV) - Computes stoichiometric temperature in combustor if heating value for fuel and fuel flow are not input.

e. COMB2 (PIN, T4, HIN, ETAB, DPB, POUT, HOUT, SOUT, FAR, HV) - Similar to COMB. Used when fuel heating value is not input but fuel flow is input.

f. AFQUIR (X, AIND, DEPEND, ANS, AJ, TOL, DIR, ANEW, ICON) - General quadratic interpolation routine. All parameters explained in computer listing, see Appendix B.

NOTE: Parameters which are input to the subroutine are underlined.

6. INPUT DESCRIPTION

The following list describes all possible input parameters and, in parenthesis, their default values if they are omitted:

ALTP - ALTITUDE IN FEET (0.0)
DELTAMB - CHANGE IN AMBIENT TEMPERATURE FROM 1962 ATMOSPHERE (0.0)
DELPAMB - CHANGE IN AMBIENT PRESSURE FROM 1962 PRESSURE (0.0)
DPBLEED - BLEED DUCT PRESSURE LOSS (0.0)
DPB - MAIN COMBUSTOR PRESSURE LOSS (P3-P4)/P3 (0.0)
DPC - INTERCOMPRESSOR PRESSURE LOSS (P22L-P22)/P22L (0.0)
DPD - INLET DUCT PRESSURE LOSS (0.0)
DPT - INTERTURBINE PRESSURE LOSS (P5-P51)/P5 (0.0)
ETALPC - LP COMPRESSOR EFFICIENCY (1.0)
ETAHPC - HP COMPRESSOR EFFICIENCY (1.0)
ETAB - MAIN COMBUSTION EFFICIENCY (1.0)
ETAHPT - HP TURBINE EFFICIENCY (1.0)
ELALPT - LP TURBINE EFFICIENCY (1.0)
ETAM - MECHANICAL EFFICIENCY (1.0)
* HV - MAIN COMBUSTOR FUEL HEATING VALUE AT T4 FOR JP-4
(Optional. If omitted, it is calculated by the combustor calculation.)
HPDS - DESIGN SHAFT POWER (0.0)
HCSL - HPC SEAL LEAKAGE/HPC FLOW (0.0)
IEND - 0 A DATA CASE FOLLOWS
1 THIS IS THE LAST CASE (0)

ITITLE - 0 NO TITLE CARD WILL BE INPUT
1 TITLE CARD FOLLOWS THE DATA CASE (0)

LCSL - LPC SEAL LEAKAGE/LPC FLOW (0.0)

M - NUMBER OF TURBINE STAGES (no default)
= 1, ONE TURBINE APU DESCRIBED BY HPC INPUT
= 2, TWO TURBINE APU
= 4, ONE TURBINE DESCRIBED BY THE HPT INPUT AND ONE POWER TURBINE DESCRIBED BY LPT INPUT

N - NUMBER OF COMPRESSOR STAGES (no default)
= 1, ONE COMPRESSOR STAGE DESCRIBED BY HPC INPUT
= 2, TWO COMPRESSOR STAGES

PRES - A MULTIPLIER ON PRESSURE VALUES FOR OUTPUT (1.0)
= 14.7, PRESSURES ARE IN PSI
= 1.0, PRESSURES ARE IN ATMOSPHERES

* PRHPT - HP TURBINE PRESSURE RATIO (1.0)

* PRLPT - LP TURBINE PRESSURE RATIO (1.0)

PCBLT4 - HP TURBINE INLET NOZZLE COOLING FLOW/HP COMPRESSOR INLET FLOW (0.0)

PCBLHP - HP TURBINE EXIT COOLING FLOW/HP COMPRESSOR INLET FLOW (0.0)

PCBLLP - LP TURBINE EXIT COOLING FLOW/HP COMPRESSOR INLET FLOW (0.0)

PRLPC - LP COMPRESSOR PRESSURE RATIO (1.0)

PRHPC - HP COMPRESSOR PRESSURE RATIO (1.0)

* T4 - COMBUSTOR DISCHARGE TEMPERATURE (DEGREE RANKINE) (must be input, no default)

WAENG - TOTAL ENGINE INLET AIRFLOW (1.0)

WF4DS - DESIGN FUEL FLOW (LB/HR) (if omitted,it will be calculated in combustor calculations)

The program recalculates those parameters preceded by an asterisk. For this reason, they must be input for each case if the user desires to keep them the same for each case.

SECTION IV

OUTPUT DESCRIPTION

1. REGULAR OUTPUT

Output for the three typical APU configurations are presented in Example Cases A, B, and C of the Appendix A. All descriptors on the printed output are designed to be self-explanatory.

a. Two Compressor - One Turbine APU

Example A shows an APU with two compressor stages and one turbine stage. Fuel flow and heating value are input. Pass 1 output shows that using the input parameters, the shaft horsepower obtained exceeds the desired design shaft horsepower. Pass 2 recalculates the pressure ratio of the turbine to satisfy the design shaft horsepower.

b. Two Turbine APU

If two turbine stages had been used, the program would have recomputed both HPT and LPT pressure ratios to obtain the design horsepower by preserving the work-split in the turbines as it was in Pass 1.

c. Example B

Example B illustrates the calculation of fuel heating value when fuel flow is input.

d. Power Turbine APU

Example C exhibits a power turbine configuration with fuel heating value input and fuel flow calculated. The input HPT pressure ratio was deficient so HPT pressure ratio was recalculated on Pass 1. With the input power turbine pressure ratio, overexpansion occurred. Exit velocity and its dependent parameters were computed as being indefinite errors and printed as "I." Pass 2 remedied the problem by recalculating power turbine pressure ratio to achieve design shaft horsepower.

2. DIAGNOSTICS

Input errors will be indicated for each component when parameters are not logical. For compressors and turbines, execution stops when an input pressure ratio is less than 1.0 or an efficiency is greater than 1.0. For the combustor, execution stops when input combustor exit temperature or fuel flow is equal to or less than zero, or when combustor efficiency is greater than 1.0.

a. PROCOM Diagnostics

Subroutine PROCOM generates diagnostics in four cases: 1) when fuel-air ratio is above 0.067623, 2) fuel-air ratio is below zero, 3) the temperature input to PROCOM is below 300°R, or 4) the temperature input to PROCOM is above 4000°R.

b. THERMO Diagnostics

Subroutine THERMO halts execution after 15 iterations, if the value of enthalpy is not within a tolerance of 0.001 percent of the previous enthalpy guess.

c. Combustor Diagnostics

Subroutine COMB and COMB2 both print a message indicating lack of convergence of stoichiometric temperature. This message is a direct result of failure in subroutine AFQUIR. If after 15 iterations the solution to the quadratic equation for stoichiometric temperature has not been found, execution stops.

APPENDIX A
EXAMPLE CASES

INPUT CARDS FOR EXAMPLE CASE A

```
$INPUT ALTP=0., DELTAMB=71., PRES=14.696, WAENG=2.485346, ETAB=.995,
DPC=.01, PRLPC=1.794, PRHPC=6.0, LCSL=0.0, HCSL=.02, ETALPC=.78, DPB=.07,
ETALPT=.870, T4=2559.67, DPT=0.0, M=2, N=2, WF4DS=0., ETAHPC=.746,
HPACC=9.5, PRLPT=9.418, HPDS=200., HV=18400., ITITLE=1, DPIN=.04,
ETAM=.98, ETAHPT=.8, PRHPT=1.5, DPBLEED=.014$
       SAMPLE DATA FOR APU
```

INPUT VALUES

```
ALTITUDE (FT) =  0.
PRESSURE (PSI) = 14.696
DELTA TEMP FROM 1962 ATMOS = 71.00000

BEGIN INDICATOR = 1
END INDICATOR = 0

NO OF COMPRESSOR STAGES = 2
NO OF TURBINE STAGES = 1

FLOW =     2.48535
MECH EFF =    .98000
HPACC EXTRACTED FOR ACCESS = 9.50
DESIGN SHAFT POWER =    165.0000

INLET DUCT PRESS LOSS =  .04
LPC PRESS RATIO = 1.794
LPC EFF =    .78000
LPC SEAL LEAKAGE = 0.0
LPC BLEED, TO BE USED LATER

INTER-COMP PRESS LOSS =  .01
BLEED DUCT PRESS LOSS =   .014

HPC PRESS RATIO = 6.000
HPC EFF =    .74600
HPC SEAL LEAKAGE =  .02

MAIN COMB PRESS LOSS =   .07000
MAIN COMBUSTION EFF =   .99500
DESIGN FUEL FLOW (LB/HR) = 150.00
MAIN COMB FUEL HEATING VALUE AT T4 FOR JP4 = 18400.
COMB DISCHARGE TEMP (DEGREE RANKINE) = 2559.67
HPT INLET NOZ COOLING/HPC INLET FLOW =  0.00000

HPT PRESS RATIO = 1.000
HPT EFF =   .80
TURB COOLING/HPC INLET FLOW =  0.00000

INTER TURB PRESS LOSS (P5-P51)/P5 =  0.00

LPT PRESS RATIO = 9.418
LPT EFF =    .87000
EXHAUST DUCT PRESS LOSS (P53-P1)/P53 = 0.0
LPT COOLING/HPC INLET FLOW =   .01000
```

Example A - 2 Compressor Stages, 1 Turbine Stage

OUTPUT VALUES

STATION	PRESSURE-PSI	TEMP-DEG.F	ENTHALPY	FLOW	COR FLOW	DELTA	THETA	FUEL/AIR	EFF	PRESS RATIO	DEL P
AMBIENT	14.696	130.00	140.93			1.000	1.137				
LP COMP INLET	14.108	130.00	140.93	2.485	2.760	.960	1.137		.78000	1.794	.04000
LP COMP EXIT	25.310	266.94	173.90	2.485	1.708	1.722	1.401				.01000
HP COMP INLET	25.057	266.94	173.90	2.485	1.725	1.705	1.401		.74600	6.000	
HPACOMP EXIT/ BURNER INLET	150.342	890.51	329.82	2.388	.377	10.230	2.603			10.656	
BURNER EXIT	139.818	2100.00	678.40	2.430	.567	9.514	4.935	.01745	.99500		.07000
TURB INLET	139.813	2100.01	678.40	2.430	.567	9.514	4.935	.01745	.87000	9.418	
TURB EXIT	14.846	1169.51	411.03	2.430	4.263	1.010	3.141	.01745			
TURB EXIT PLUS COOLING	14.846	1166.81	410.21	2.455	4.303	1.010	3.136	.01727			
EXHT/STATIC COND	14.696	1166.81	410.21	2.455	4.347	1.000	3.136	.01727			.01009

ALTITUDE (FT) = 0.
SPEED OF SOUND = 1190.44
DELTA TEMP FROM 1962 ATMOS = 71.00
DELTA PRESS FROM 1962 PRESS = 0.00

NO OF COMP STAGES = 2
NO OF TURB STAGES = 1

DESIGN SHAFT HP = 165.0000
SHP EXTRACTED = 254.98212
SHP EXTRACTED, COR FOR SL = 271.875
SHP EXTRACTED, COR FOR MECH EFF = 240.57248
HP EXTRACTED FOR ACCESSORIES = 9.500
HP NEEDED FOR LPC = 115.943
HP NEEDED FOR HPC = 548.26281

CALCULATED FUEL FLOW = 150.0000
FUEL FLOW COEF = 7.09711
MAIN COMB FUEL HEATING VALUE AT T4 FOR JP4 = 18400.0

WORK OF LPC (BTU/LB) = 32.973
LPC SEAL LEAKAGE FLOW FRACTION = 0.00000

WORK OF HPC (BTU/LB) = 155.919
HPC SEAL LEAKAGE FLOW FRACTION = .02000

HPT WORK PERCENT = 0.000
HORSEPOWER OF HPT = 144.22645

LPT WORK PERCENT = 1.000
HORSEPOWER OF LPT = 919.18782

NET THRUST = 17.37298
GROSS THRUST = 17.37298
NET THRUST/ENGINE AIRFLOW = 6.99017
THERMAL EFF = .23504
EXHAUST EXIT VELOCITY = 227.708
ENGINE UNINSTALLED SFC (LB FUEL/HR-HP) = .6235

STATION	PRESSURE-PSI	TEMP-DEG.F	ENTHALPY	FLOW	COR FLOW	DELTA	THETA	FUEL/AIR	EFF	PRESS RATIO	DEL P
AMBIENT	14.696	130.00	140.93			1.000	1.137				
LP COMP INLET	14.108	130.00	140.93	2.485	2.760	.960	1.137		.78000	1.794	.04000
LP COMP EXIT	25.310	266.94	173.90	2.485	1.708	1.722	1.401				.01000
HP COMP INLET	25.057	266.94	173.90	2.485	1.725	1.705	1.401		.74600	6.000	
HPACOMP EXIT/ BURNER INLET	150.342	890.51	329.82	2.388	.377	10.230	2.603			10.656	
BURNER EXIT	139.818	2100.00	678.40	2.430	.567	9.514	4.935	.01745	.99500		.07000
TURB INLET	139.818	2100.01	678.40	2.430	.567	9.514	4.935	.01745	.87000	7.410	
TURB EXIT	18.868	1250.58	433.46	2.430	3.437	1.284	3.297	.01745			
TURB EXIT PLUS COOLING	18.869	1247.10	432.41	2.455	3.468	1.284	3.291	.01727			
EXHT/STATIC COND	14.696	1247.10	432.41	2.455	4.453	1.000	3.291	.01727			.22113

ALTITUDE (FT) = 0.
SPEED OF SOUND = 1190.44
DELTA TEMP FROM 1962 ATMOS = 71.00
DELTA PRESS FROM 1962 PRESS = 0.00

NO OF COMP STAGES = 2
NO OF TURB STAGES = 1

DESIGN SHAFT HP = 165.0000
SHP EXTRACTED = 177.86735
SHP EXTRACTED, COR FOR SL = 189.651
SHP EXTRACTED, COR FOR MECH EFF = 165.00000
HP EXTRACTED FOR ACCESSORIES = 9.500
HP NEEDED FOR LPC = 115.943
HP NEEDED FOR HPC = 548.26281

CALCULATED FUEL FLOW = 150.0000
FUEL FLOW COEF = 7.09711
MAIN COMB FUEL HEATING VALUE AT T4 FOR JP4 = 18400.0

WORK OF LPC (BTU/LB) = 32.973
LPC SEAL LEAKAGE FLOW FRACTION = 0.00000

WORK OF HPC (BTU/LB) = 155.919
HPC SEAL LEAKAGE FLOW FRACTION = .02000

HPT WORK PERCENT = 0.000
HORSEPOWER OF HPT = 144.22645

LPT WORK PERCENT = 1.000
HORSEPOWER OF LPT = 842.07305

NET THRUST = 86.86823
GROSS THRUST = 86.86823
NET THRUST/ENGINE AIRFLOW = 34.95217
THERMAL EFF = .16396
EXHAUST EXIT VELOCITY = 1138.582
ENGINE UNINSTALLED SFC (LB FUEL/HR-HP) = .9091

INPUT VALUES

```
ALTITUDE (FT) =  0.
PRESSURE (PSI) = 14.696
DELTA TEMP FROM 1962 ATMOS = 71.00000

BEGIN INDICATOR = 0
END INDICATOR = 0

NO OF COMPRESSOR STAGES = 2
NO OF TURBINE STAGES = 1

FLOW =     2.48535
MECH EFF =    .98000
HPACC EXTRACTED FOR ACCESS = 9.50
DESIGN SHAFT POWER =    165.0000

INLET DUCT PRESS LOSS =  .04
LPC PRESS RATIO = 1.794
LPC EFF =    .78000
LPC SEAL LEAKAGE = 0.0
LPC BLEED, TO BE USED LATER

INTER-COMP PRESS LOSS =  .01
BLEED DUCT PRESS LOSS =   .014

HPC PRESS RATIO = 6.000
HPC EFF =    .74600
HPC SEAL LEAKAGE =  .02

MAIN COMB PRESS LOSS =    .07000
MAIN COMBUSTION EFF =    .99500
DESIGN FUEL FLOW (LB/HR) = 190.00
MAIN COMB FUEL HEATING VALUE AT T4 FOR JP4 =      0.
COMB DISCHARGE TEMP (DEGREE RANKINE) = 2559.67
HPT INLET NOZ COOLING/HPC INLET FLOW =  0.00000

HPT PRESS RATIO = 1.000
HPT EFF =    .80
TURB COOLING/HPC INLET FLOW =  0.00000

INTER TURB PRESS LOSS (P5-P51)/P5 =  0.00

LPT PRESS RATIO = 9.418
LPT EFF =    .87000
EXHAUST DUCT PRESS LOSS (P53-P1)/P53 = 0.0
LPT COOLING/HPC INLET FLOW =    .01000
```

Example B - 2 Stage Compressor, 1 Stage Turbine
With Fuel Heating Value Calculated

OUTPUT VALUES

STATION	PRESSURE-PSI	TEMP-DEG.F	ENTHALPY	FLOW	COR FLOW	DELTA	THETA	FUEL/AIR	EFF	PRESS RATIO	DEL P
AMBIENT	14.696	130.00	140.93			1.000	1.137				
LP COMP INLET	14.108	130.00	140.93	2.485	2.760	.960	1.137		.78000	1.794	.04000
LP COMP EXIT	25.310	266.94	173.90	2.485	1.708	1.722	1.401				.01000
HP COMP INLET	25.057	266.94	173.90	2.485	1.725	1.705	1.401		.74600	6.000	
HPACOMP EXIT/ BURNER INLET	150.342	890.51	329.82	2.388	.377	10.230	2.603			10.656	
BURNER EXIT	139.818	2201.21	712.87	2.441	.581	9.514	5.130	.02210	.99500		.07000
TURB INLET	139.818	2201.23	712.87	2.441	.581	9.514	5.130	.02210	.87000	9.418	
TURB EXIT	14.846	1244.78	433.99	2.441	4.380	1.010	3.286	.02210			
TURB EXIT PLUS COOLING	14.846	1241.40	432.94	2.466	4.421	1.010	3.280	.02187			
EXHT/STATIC COND	14.696	1241.40	432.94	2.466	4.466	1.000	3.280	.02187			.01009

```
ALTITUDE (FT) =  0.
SPEED OF SOUND = 1190.44
DELTA TEMP FROM 1962 ATMOS = 71.00
DELTA PRESS FROM 1962 PRESS = 0.00

NO OF COMP STAGES = 2
NO OF TURB STAGES = 1

DESIGN SHAFT HP =   165.0000
SHP EXTRACTED =  298.94979
SHP EXTRACTED, COR FOR SL =     318.755
SHP EXTRACTED, COR FOR MECH EFF =  283.66079
HP EXTRACTED FOR ACCESSORIES = 9.500
HP NEEDED FOR LPC = 115.943
HP NEEDED FOR HPC =        548.26281

CALCULATED FUEL FLOW =  190.0000
FUEL FLOW COEF =          8.81705
MAIN COMB FUEL HEATING VALUE AT T4 FOR JP4 =  16829.5

WORK OF LPC (BTU/LB) = 32.973
LPC SEAL LEAKAGE FLOW FRACTION = 0.00000

WORK OF HPC (BTU/LB) = 155.919
HPC SEAL LEAKAGE FLOW FRACTION =    .02000

HPT WORK PERCENT = 0.000
HORSEPOWER OF HPT =        144.22645

LPT WORK PERCENT = 1.000
HORSEPOWER OF LPT =        963.15549

NET THRUST =   17.79274
GROSS THRUST =   17.79274
NET THRUST/ENGINE AIRFLOW =    7.15906
THERMAL EFF =   .23786
EXHAUST EXIT VELOCITY =                    232.159
ENGINE UNINSTALLED SFC (LB FUEL/HR-HP) =    .6698
```

STATION	PRESSURE-PSI	TEMP-DEG.F	ENTHALPY	FLOW	COR FLOW	DELTA	THETA	FUEL/AIR	EFF	PRESS RATIO	DEL P
AMBIENT	14.696	130.00	140.93			1.000	1.137				
LP COMP INLET	14.108	130.00	140.93	2.485	2.760	.960	1.137		.78000	1.794	.04000
LP COMP EXIT	25.310	266.94	173.90	2.485	1.708	1.722	1.401				.01000
HP COMP INLET	25.057	266.94	173.90	2.485	1.725	1.705	1.401		.74600	6.000	
HPACOMP EXIT/ BURNER INLET	150.342	890.51	329.82	2.388	.377	10.230	2.603			10.656	
BURNER EXIT	139.818	2201.21	712.87	2.441	.581	9.514	5.130	.02210	.99500		.07000
TURB INLET	139.818	2201.23	712.87	2.441	.581	9.514	5.130	.02210	.87000	6.614	
TURB EXIT	21.139	1369.28	469.05	2.441	3.187	1.438	3.526	.02210			
TURB EXIT PLUS COOLING	21.139	1364.74	467.64	2.466	3.215	1.438	3.517	.02187			
EXHT/STATIC COND	14.696	1364.74	467.65	2.466	4.625	1.000	3.517	.02187			.30479

ALTITUDE (FT) = 0.
SPEED OF SOUND = 1190.44
DELTA TEMP FROM 1962 ATMOS = 71.00
DELTA PRESS FROM 1962 PRESS = 0.00

NO OF COMP STAGES = 2
NO OF TURB STAGES = 1

DESIGN SHAFT HP = 165.0000
SHP EXTRACTED = 177.86735
SHP EXTRACTED, COR FOR SL = 189.651
SHP EXTRACTED, COR FOR MECH EFF = 165.00000
HP EXTRACTED FOR ACCESSORIES = 9.500
HP NEEDED FOR LPC = 115.943
HP NEEDED FOR HPC = 548.26281

CALCULATED FUEL FLOW = 190.0000
FUEL FLOW COEF = 8.81705
MAIN COMB FUEL HEATING VALUE AT T4 FOR JP4 = 16829.5

WORK OF LPC (BTU/LB) = 32.973
LPC SEAL LEAKAGE FLOW FRACTION = 0.00000

WORK OF HPC (BTU/LB) = 155.919
HPC SEAL LEAKAGE FLOW FRACTION = .02000

HPT WORK PERCENT = 0.000
HORSEPOWER OF HPT = 144.22645

LPT WORK PERCENT = 1.000
HORSEPOWER OF LPT = 842.07305

NET THRUST = 107.69671
GROSS THRUST = 107.69671
NET THRUST/ENGINE AIRFLOW = 43.33268
THERMAL EFF = .14152
EXHAUST EXIT VELOCITY = 1405.220
ENGINE UNINSTALLED SFC (LB FUEL/HR-HP) = 1.1515

THIS PROGRAM WAS DEVELOPED BY COMPONENTS BRANCH TURBINE ENGINE DIVISION
MODIFIED BY POWER DIVISION U.S. AIR FORCE AERO PROPULSION LABORATORY

INPUT VALUES

```
ALTITUDE (FT) =  0.
PRESSURE (PSI) = 14.696
DELTA TEMP FROM 1962 ATMOS =  0.00000

BEGIN INDICATOR = 1
END INDICATOR = 0

NO OF COMPRESSOR STAGES = 1
NO OF TURBINE STAGES = 4

FLOW =     3.86200     .
MECH EFF =    .98000
HPACC EXTRACTED FOR ACCESS = 4.00
DESIGN SHAFT POWER =    230.0000

INLET DUCT PRESS LOSS =   .01
LPC PRESS RATIO = 1.000
LPC EFF =  1.00000
LPC SEAL LEAKAGE = 0.0
LPC BLEED, TO BE USED LATER

INTER-COMP PRESS LOSS = 0.00
BLEED DUCT PRESS LOSS =  0.000

HPC PRESS RATIO = 2.827
HPC EFF =    .79200
HPC SEAL LEAKAGE = 0.00

MAIN COMB PRESS LOSS =    .12300
MAIN COMBUSTION EFF =    .95000
DESIGN FUEL FLOW (LB/HR) =    0.00
MAIN COMB FUEL HEATING VALUE AT T4 FOR JP4 = 18400.
COMB DISCHARGE TEMP (DEGREE RANKINE) = 2260.00
HPT INLET NOZ COOLING/HPC INLET FLOW =  0.00000

HPT PRESS RATIO = 1.540
HPT EFF =    .83
TURB COOLING/HPC INLET FLOW =  0.00000

INTER TURB PRESS LOSS (P5-P51)/P5 =    .02

LPT PRESS RATIO = 1.600
LPT EFF =    .85000
EXHAUST DUCT PRESS LOSS (P53-P1)/P53 = 0.0
LPT COOLING/HPC INLET FLOW =  0.00000
```

Example C - 1 Stage Compressor, 1 Stage Turbine with Power Turbine

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OUTPUT VALUES

LPC NOT USED
PRESSURE RATIO CALCULATED AS NEEDED FOR HPT
ARGUMENT NEGATIVE
ERROR NUMBER 39 DETECTED BY SORT

STATION	PRESSURE-PSI	TEMP-DEG.F	ENTHALPY	FLOW	COR FLOW	DELTA	THETA	FUEL/AIR	EFF	PRESS RATIO	DEL P
AMBIENT	14.696	59.00	123.92			1.000	1.000				
HP COMP INLET	14.549	59.00	123.92	3.862	3.901	.990	1.000		.79200	2.827	
HPACOMP EXIT/ BURNER INLET	41.130	295.00	178.27	3.816	1.634	2.799	1.436			2.827	
BURNER EXIT	36.071	1900.33	595.32	3.916	3.330	2.454	4.357	.02625	.95000		.12300
TURB 1 INLET	36.071	1600.33	596.56	3.916	3.330	2.454	4.357	.02625	.82500	1.564	
TURB 1 EXIT	23.069	1615.46	542.23	3.916	3.330	1.570	4.001	.02625			.02000
TURB 1 EXIT PLUS COOLING	22.608	1615.46	542.23	1.014	5.091	1.538	4.001	.02625			
TURB 2 INLET	22.608	1615.46	542.23	3.916	5.091	1.538	4.001	.02625	.85000	1.600	
TURB 2 EXIT	14.130	1429.37	488.37	3.916	7.772	.961	3.642	.02625			
TURB 2 EXIT PLUS COOLING	14.130	1429.37	486.37	3.916	7.772	.961	3.642	.02625			
EXHT/STATIC COND	14.696	1429.37	488.36	3.916	7.473	1.000	3.642	.02625			-.04007

ALTITUDE (FT) = 0.
SPEED OF SOUND = 1116.99
DELTA TEMP FROM 1962 ATMOS = 0.00
DELTA PRESS FROM 1962 PRESS = 0.00

NO OF COMP STAGES = 1
NO OF TURB STAGES = 4

DESIGN SHAFT HP = 230.0000
SHP EXTRACTED = 298.39499
SHP EXTRACTED, COR FOR SL = 298.395
SHP EXTRACTED, COR FOR MECH EFF = 292.42709
HP EXTRACTED FOR ACCESSORIES = 4.000
HP NEEDED FOR LPC = 0.000
HP NEEDED FOR HPC = 296.99891

CALCULATED FUEL FLOW = 360.5688
FUEL FLOW COEF = 70.37508
MAIN COMB FUEL HEATING VALUE AT T4 FOR JP4 = 18400.0

WORK OF LPC (BTU/LB) = 0.000
LPC SEAL LEAKAGE FLOW FRACTION = 0.00000

WORK OF HPC (BTU/LB) = 54.355
HPC SEAL LEAKAGE FLOW FRACTION = 0.00000

HPT WORK PERCENT = .502
HORSEPOWER OF HPT = 291.25684

LPT WORK PERCENT = .498
HORSEPOWER OF LPT = 298.39499
THIS IS ACTUALLY A POWER TURBINE

NET THRUST = I
GROSS THRUST = I
NET THRUST/ENGINE AIRFLOW = 29 I
THERMAL EFF = .11443
EXHAUST EXIT VELOCITY = I
ENGINE UNINSTALLED SFC (LB FUEL/HR-HP) = 1.2330

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STATION	PRESSURE-PSI	TEMP-DEG.F	ENTHALPY	FLOW	COR FLOW	DELTA	THETA	FUEL/AIR	EFF	PRESS RATIO	DEL P
AMBIENT	14.696	59.00	123.92			1.000	1.000				
HP COMP INLET	14.549	59.00	123.92	3.662	3.901	.990	1.000		.79200	2.827	
HPACOMP EXIT/ BURNER INLET	41.130	285.00	178.27	3.816	1.634	2.799	1.436			2.827	
BURNER EXIT	36.071	1800.33	595.32	3.916	3.330	2.454	4.357	.02625	.95000		.12300
TURB 1 INLET	36.071	1800.33	596.56	3.916	3.330	2.454	4.357	.02625	.82500	1.564	
TURB 1 EXIT	23.069	1615.46	542.23	3.916	3.330	1.570	4.001	.02625			.02000
TURB 1 EXIT PLUS COOLING	22.608	1615.46	542.23	1.014	5.091	1.538	4.001	.02625			
TURB 2 INLET	22.608	1615.46	542.23	3.916	5.091	1.538	4.001	.02625	.85000	1.441	
TURB 2 EXIT	15.691	1469.36	499.86	3.916	7.073	1.068	3.719	.02625			
TURB 2 EXIT PLUS COOLING	15.691	1469.36	499.86	3.916	7.073	1.068	3.719	.02625			
EXHT/STATIC COND	14.696	1469.36	499.86	3.916	7.552	1.000	3.719	.02625			.06340

ALTITUDE (FT) = 0.
SPEED OF SOUND = 1116.99
DELTA TEMP FROM 1962 ATMOS = 0.00
DELTA PRESS FROM 1962 PRESS = 0.00

NO OF COMP STAGES = L
NO OF TURB STAGES = 4

DESIGN SHAFT HP = 230.0000
SHP EXTRACTED = 234.69388
SHP EXTRACTED, COR FOR SL = 234.694
SHP EXTRACTED, COR FOR MECH EFF = 230.00000
HP EXTRACTED FOR ACCESSORIES = 4.000
HP NEEDED FOR LPC = 0.000
HP NEEDED FOR HPC = 296.99891

ALCULATED FUEL FLOW = 360.5688
UEL FLOW COEF = 70.37508
AIN COMB FUEL HEATING VALUE AT T4 FOR JP4 = 18400.0

ORK OF LPC (BTU/LB) = 0.000
PC SEAL LEAKAGE FLOW FRACTION = 0.00000

ORK OF HPC (BTU/LB) = 54.355
PC SEAL LEAKAGE FLOW FRACTION = 0.00000

PT WORK PERCENT = .562
ORSEPOWER OF HPT = 300.99891

PT WORK PERCENT = .438
ORSEPOWER OF LPT = 234.69388
THIS IS ACTUALLY A POWER TURBINE

NET THRUST = 75.77207
GROSS THRUST = 75.77207
NET THRUST/ENGINE AIRFLOW = 19.61990
THERMAL EFF = .09000
EXHAUST EXIT VELOCITY = 622.577
ENGINE UNINSTALLED SFC (LB FUEL/HR-HP) = 1.5677

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THIS PROGRAM WAS DEVELOPED BY COMPONENTS BRANCH TURBINE ENGINE DIVISION
MODIFIED BY POWER DIVISION U.S. AIR FORCE AERO PROPULSION LABORATORY

APPENDIX B
FLOWCHART AND LISTING

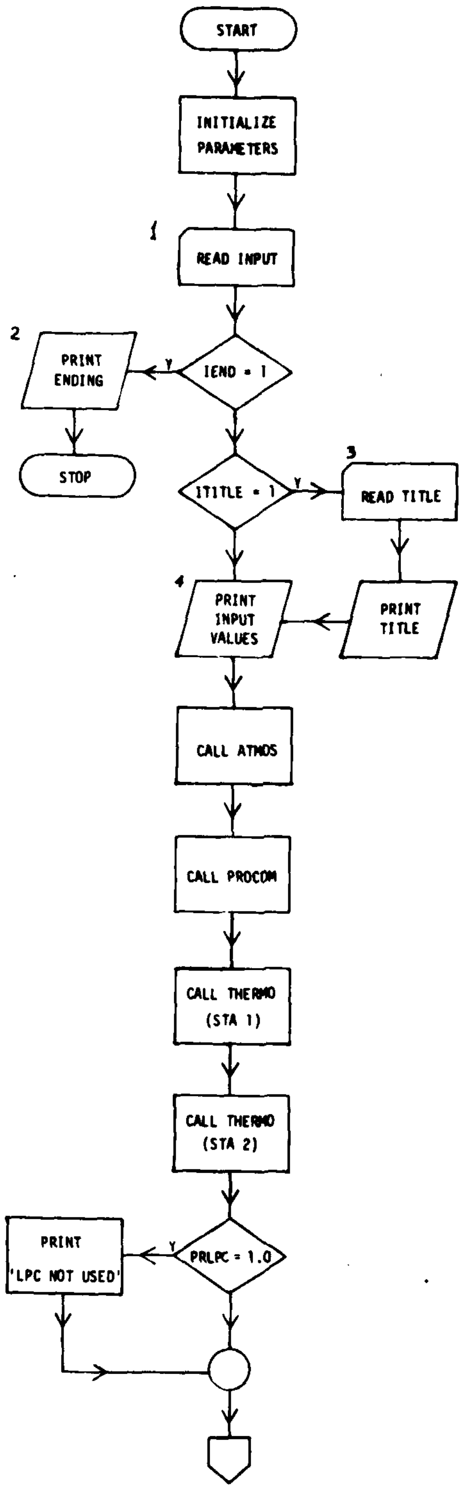

Figure 3 - Flowchart of APU

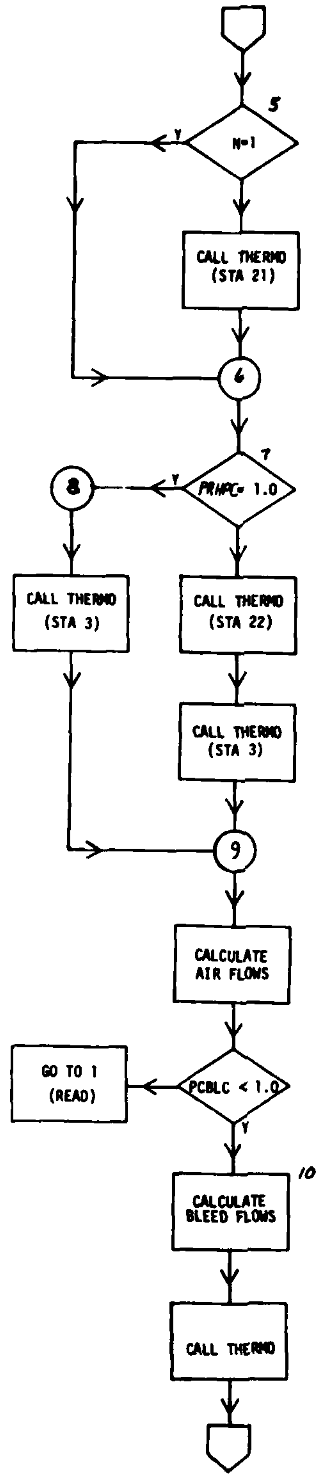

Figure 4 - Flowchart of APU

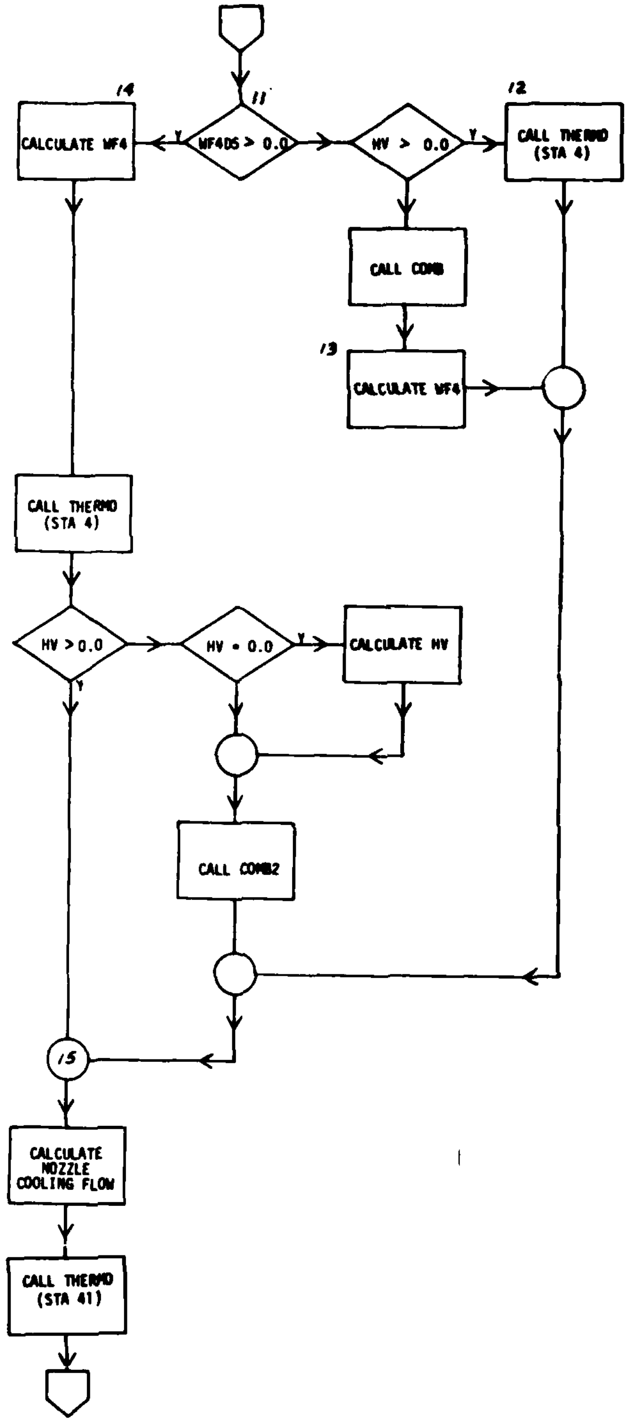

Figure 5 - Flowchart of APU

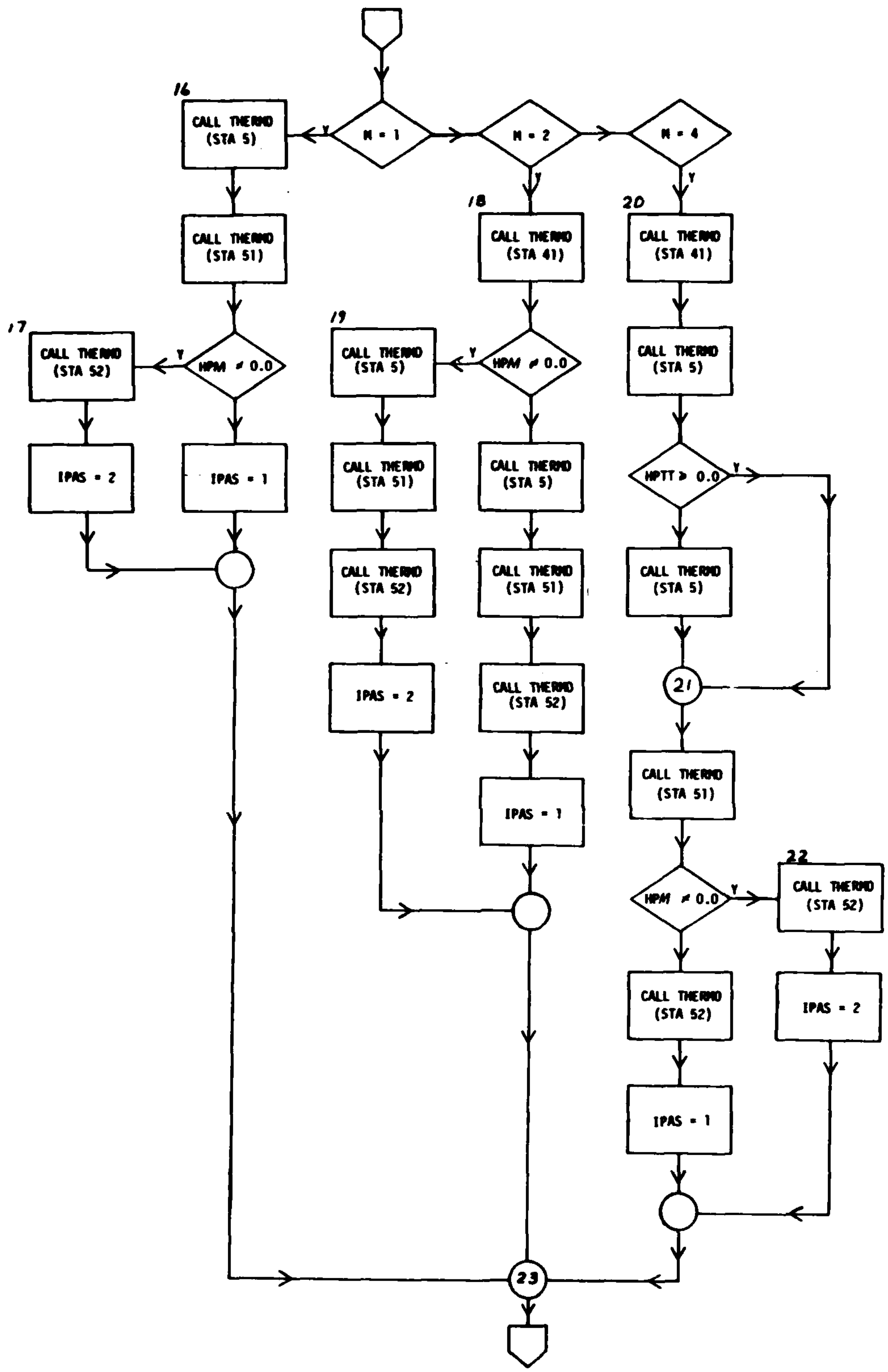

Figure 6 - Flowchart of APU

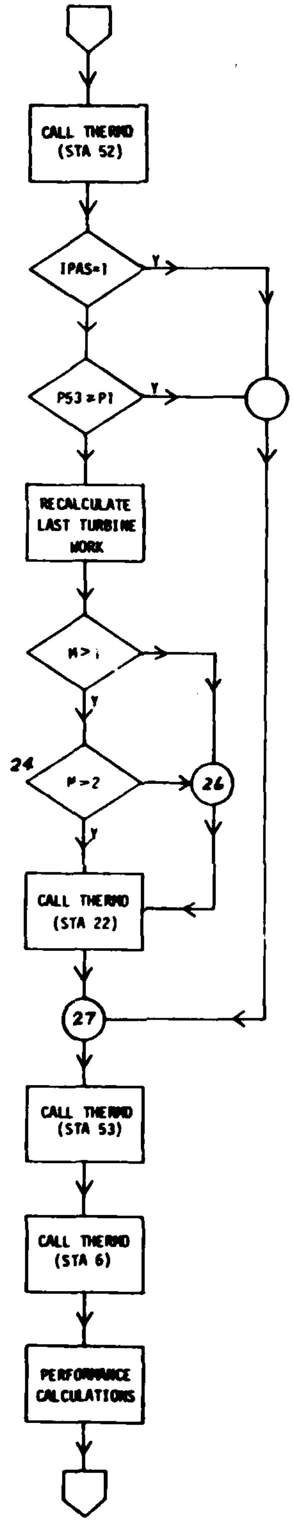

Figure 7 - Flowchart of APU

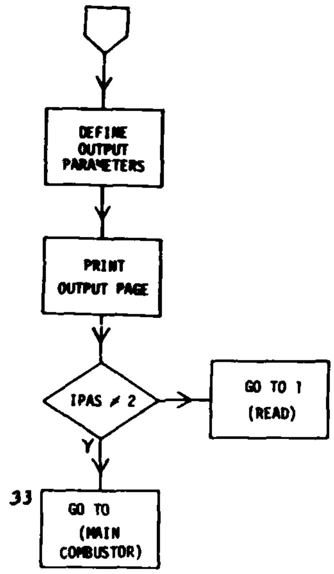

Figure 8 - Flowchart of APU

```
      PROGRAM  APU (INPUT, OUTPUT, TAPE5=INPUT,
     $ TAPE6=OUTPUT)
      COMMON  /PARAM/  ETALPC, ETAHPC, ETAB, ETAHPT,
     $ ETALPT, PRLPC,
     1   PRHPC, DPB, DPT, DPE, DPIN, DPC, HPACC, HPDS,
     $ LCSL, HCSL,
     2   PCBLC, T4, ETAM
      DIMENSION   ANUM (2), AWORD (2), BWORD (2), TITLE
     $ (11)
      REAL        LCSL
      DATA     AWORD / 3HATM, 3HPSI /
      DATA     ANUM / 3H   , 3H 2  /
      DATA     BWORD / 3HLP , 6HHPACC  /
C
      NAMELIST   / INPUT / ALTP, DELPAMB, DELTAMB, PRES,
     $ WAENG, PRHPT,
     1   DPBLEED, DPIN, DPC, PRLPC, PRHPC, LCSL, HCSL,
     $ ETALPC, ETAHPC,
     2   ETAHPT, ETALPT, T4, DPT, M, HV, N, ETAB, WF4DS,
     $ DPB, PCBLT4,
     3   PCBLHP, ETAM, PCBLLP, ITITLE, PRLPT, HPDS, HPACC,
     $ IEND
C
C   STATION 1    - AMBIENT CONDITIONS
C   STATION 2    - LP COMPRESSOR INLET
C   STATION 21   - LP COMPRESSOR DISCHARGE
C   STATION 22   - HP COMPRESSOR INLET
C   STATION 3    - HP COMPRESSOR DISCHARGE/BURNER INLET
C   STATION 4    - MAIN COMBUSTOR DISCHARGE
C   STATION 41   - HP TURBINE INLET
C   STATION 5    - HP TURBINE DISCHARGE BEFORE COOLING FLOW
C     $            HAS BEEN ADDED
C   STATION 51   - LP TURBINE INLET
C   STATION 52   - LP TURBINE DISCHARGE BEFORE COOLING FLOW
C     $            HAS BEEN ADDED
C   STATION 53   - LP TURBINE DISCHARGE INCLUDING COOLING
C     $            FLOW EFFECTS
C   STATION 6    - EXHAUST DUCT EXIT
C   ALTP   - ALTITUDE IN FEET
C   DPBLEED    - BLEED DUCT PRESSURE LOSS
C   BLTOTL     - HP COMPRESSOR TOTAL BLEED (FRACTION OF WA22)
C   BLT4   - HP TURBINE INLET NOZZLE COOLING FLOW (FRACT OF
C     $            BLTOTL)
C   BLHPT   - HP TURBINE DISCHARGE COOLING FLOW (FRACT OF
C     $            BLTOTL)
C   BLLPT   - LP TURBINE DESCHARGE COOLING FLOW (FRACT OF
C     $            BLTOTL)
C   CS    - AMBIENT SPEED OF SOUND (FPS)
C   DELTAMB  - CHANGE IN AMBIENT TEMPERATURE FROM 1962
C     $            ATMOSPHERE
```

```
C  DELPAMB  - CHANGE IN AMBIENT PRESSURE FROM 1962 PRESSURE
C  DPB     - MAIN COMBUSTOR PRESSURE LOSS (P3-P4)/P3
C  DPC     - INTER-COMPRESSOR PRESSURE LOSS (P22L-P22)/P22L
C  DPIN     - INLET DUCT PRESSURE LOSS
C  DPE     - EXHAUST DUCT PRESSURE LOSS (P53-P1)/P53
C  DPT     - INTER-TURBINE PRESSURE LOSS (P5-P51)/P5
C  FAR     - FUEL FLOW/AIRFLOW
C  ETALPC   - LP COMPRESSOR EFFICIENCY
C  ETAHPC    - HP COMPRESSOR EFFICIENCY
C  ETAB    - MAIN COMBUSTION EFFICIENCY
C  ETAHPT   - HP TURBINE EFFICIENCY
C  ETALPT   - LP TURBINE EFFICIENCY
C  ETAM    - MECHANICAL EFFICIENCY
C  ETATHM - THERMAL EFFICIENCY
C  FN/WA   - NET THRUST/TOTAL ENGINE AIRFLOW
C  FG      - GROSS THRUST
C  FN      - NET THRUST
C  HS6     - STATIC ENTHALPY AT EXHAUST EXIT (BTU/LB MASS)
C  HV      - MAIN COMBUSTOR FUEL HEATING VALUE AT T4 FOR JP-
C    $          4
C  HPLPC   - HORSEPOWER NEEDED FOR LP COMPRESSOR
C  HPHPC   - HORSEPOWER NEEDED FOR HP COMPRESSOR
C  HPACC      - HORSEPOWER EXTRACTED FOR ASSESSORIES
C  HPM   - SHP EXTRACTED, CORRECTED FOR MECHANICAL
C    $          EFFICIENCY
C  HPMAMB - SHP EXTRACTED, CORRECTED FOR S.L., STANDARD DAY
C    $          CONDITIONS
C  HPEXT   - SHAFT HORSEPOWER EXTRACTED
C  HPDS    - DESIGN SHAFT POWER
C  HCSL   - HPC SEAL LEAKAGE/HPC FLOW
C  LCSL    -LPC SEAL LEAKAGE/LPC FLOW
C  M       - NUMBER OF TURBINE STAGES
C            = 1, ONE TURBINE APU
C            = 2, TWO TURBINE APU
C            = 4, TWO TURBINE APU, ONE OF WHICH IS A POWER
C    $          TURBINE
C  N       - NUMBER OF COMPRESSOR STAGES
C  PCT     - DESIGN POINT WORK LOAD PERCENTAGE PER TURBINE
C  PRES    - A MULTIPLIER ON PRESSURE VALUES FOR OUTPUT
C  PROA    - OVERALL CORE COMPRESSION RATIO (P3/P2)
C  PRHPT    - HP TURBINE PRESSURE RATIO
C  PRLPT    - LP TURBINE PRESSURE RATIO
C  PCBLA   - ACCESSORY AIR BLEED FLOW EXTRACTED FROM HP
C    $          COMPRESSOR/
C            HPC INLET FLOW
C  PCBLT4 - HP TURBINE INLET NOZZLE COOLING FLOW / HP
C    $          COMPRESSOR
C            INLET FLOW
C  PCBLHP - HP TURBINE EXIT COOLING FLOW / HP COMPRESSOR
C    $          INLET FLOW
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C   PCBLLP - LP TURBINE EXIT COOLING FLOW / HP COMPRESSOR
C      $          INLET FLOW
C   PRLPC    - LP COMPRESSOR PRESSURE RATIO
C   PRHPC     - HP COMPRESSOR PRESSURE RATIO
C   SFCU    - UNINSTALLED SPECIFIC FUEL CONSUMPTION (LB FUEL/
C      $          HR-HP)
C   T4      - COMBUSTOR DISCHARGE TEMPERATURE (DEGREE
C      $          RANKINE)
C   TS6     - STATIC TEMPERATURE AT EXHAUST EXIT (DEGREE F)
C   THG6    - CORE GROSS THRUST PER POUND TOTAL AIRFLOW
C   V6      - EXHAUST EXIT VELOCITY
C   WA22    - AIRFLOW AT HPC INLET/WAENG
C   WAENG   - TOTAL ENGINE INLET AIRFLOW
C   WF      - FUEL FLOW RATE (LB/SEC)
C   WF4DS   - DESIGN FUEL FLOW (LB/HR)
C   WG      - MASS FLOW RATE (INCLUDES FUEL FLOW) (LB/SEC)
C   WLPC    - WORK OF THE LP COMPRESSOR (BTU/LB)
C   WHPC    - WORK OF THE HP COMPRESSOR (BTU/LB)
C
C *** CONSTANTS
        DATA    G, AJ, IEND, IP / 32.174049, 778.26, 0, 1 /
        PRES        = WAENG = PRLPC = PRHPC = ETALPC = ETAHPC
      $ = 1.
        ETAHPT      = ETALPT = ETAM = ETAB = PRHPT = PRLPT =
      $ 1.
        WF4DS       = DELTAMB = DELPAMB = DPIN = DPB = 0.
        DPC         = DPT = DPE = LCSL = HCSL = PCBLC = PCBLT4
      $ = 0.
        PCBLLP      = PCBLHP = HPACC = HPDS = DPBLEED = HV =
      $ 0.
        IPAS        = 0
        IN          = IB = 2
    1   READ (5, INPUT)
        IF (IEND .EQ. 1) WRITE (6,  100)
        IF (IEND .EQ. 1) STOP
        IF  (ITITLE - 1)  2, 3, 3
    2   WRITE (6,  101)
        GO TO 4
    3   READ (5,  102)   (TITLE(I), I=1, 11)
        WRITE (6,  103)   (TITLE(I), I=1, 11)
        WRITE (6,  104)
    4   WRITE (6,  105)  ALTP
        WRITE (6,  106)  PRES
        WRITE (6,  107)  DELTAMB
        WRITE (6,  108)  ITITLE
        WRITE (6,  109)  IEND
        WRITE (6,  110)  N
        WRITE (6,  111)  M
        WRITE (6,  112)  WAENG
```

```
      WRITE (6,  113)  ETAM
      WRITE (6,  114)  HPACC
      WRITE (6,  115)  HPDS
      WRITE (6,  116)  DPIN
      WRITE (6,  117)  PRLPC
      WRITE (6,  118)  ETALPC
      WRITE (6,  119)  LCSL
      WRITE (6,  120)
      WRITE (6,  121)  DPC
      WRITE (6,  122)  DPBLEED
      WRITE (6,  123)  PRHPC
      WRITE (6,  124)  ETAHPC
      WRITE (6,  125)  HCSL
      WRITE (6,  126)  DPB
      WRITE (6,  127)  ETAB
      WRITE (6,  128)  WF4DS
      WRITE (6,  129)  HV
      WRITE (6,  130)  T4
      WRITE (6,  131)  PCBLT4
      WRITE (6,  132)  PRHPT
      WRITE (6,  133)  ETAHPT
      WRITE (6,  134)  PCBLHP
      WRITE (6,  135)  DPT
      WRITE (6,  136)  PRLPT
      WRITE (6,  137)  ETALPT
      WRITE (6,  138)  DPE
      WRITE (6,  139)  PCBLLP
      WRITE (6,  140)
      CALL ATMOS (ALTP, T11, P1)
      T1          = T11 + DELTAMB
      P1          = P1 + DELPAMB
      CALL PROCOM (0.0, T1, CS, X1, X2, X3, X4, X5)
C
C *** BEGINNING OF INLET
      CALL THERMO (P1, H1, T1, S1, AMW1, CP1, GA1, 0, 0.0,
     $ 0)
      H2          = H1
      P2          = P1 * (1.0 - DPIN)
      CALL THERMO (P2, H2, T2, S2, AMW2, CP2, GA2, 0, 0.0,
     $ 1)
      HPM         = 0.0
      IF (PRLPC .EQ. 1.0) GO TO 34
      IF (PRLPC .LT. 1.0 .OR. ETALPC .GT. 1.0) GO TO 35
      IF (PRHPC .LT. 1.0 .OR. ETAHPC .GT. 1.0) GO TO 35
    5 IF (N .EQ. 1) GO TO 5
C
C *** BEGINNING OF LP COMPRESSOR
      P21         = PRLPC * P2
      RATIOA      = (GA2 - 1.) / GA2
      WLPC        = (CP2 * T2 * (((P21 / P2) ** RATIOA) -
     $ 1.)) / ETALPC
```

```
      H21          = WLPC + H2
      CALL THERMO (P21, H21, T21, S21, AMW21, CP21, GA21,
     $ 0, 0.0, 1)
      GO TO 7
    6 P21          = P2
      T21          = T2
      H21          = H2
      WLPC         = 0.0
    7 IF (PRHPC .EQ. 1.0) GO TO 8
C
C *** BEGINNING OF HP COMPRESSOR
      P22          = P21 * (1.0 - DPC)
      H22          = H21
      T22          = T21
      CALL THERMO (P22, H22, T22, S22, AMW22, CP22, GA22,
     $ 0, 0.0, 0)
      P3           = PRHPC * P22
      RATIOB       = (GA22 - 1.) / GA22
      WHPC         = (CP22 * T22 * (((P3 / P22) ** RATIOB) -
     $ 1.)) / ETAHPC
      H3           = WHPC + H22
      CALL THERMO (P3, H3, T3, S3, AMW3, CP3, GA3, 0, 0.0,
     $ 1)
      RATIO3       = (GA3 - 1.0) / GA3
      GO TO 9
    8 P22          = P21
      P3           = P22
      T3           = T21
      H3           = H21
      WHPC         = 0.0
      CALL THERMO (P3, H3, T3, S3, AMW3, CP3, GA3, 0, 0.0,
     $ 0)
    9 PROA         = PRHPC * PRLPC * (1.0 - DPC)
C
C *** AIR FLOWS, FRACTIONS OF WAENG.
      WA2          = 1.0
      WA21         = WA2 * (1.0 - LCSL)
      WA22         = WA21
      WAIRHP       = CP3 * T3 * (((P3 / P1) ** RATIO3) - 1.0)
      BLA          = (HPACC * .7068) / WAIRHP
      PCBLA        = BLA / (WA22 * WAENG)
      PCBLC        = PCBLT4 + PCBLHP + PCBLLP + PCBLA
      WA3          = WA22 * (1.0 - HCSL - PCBLC)
C
      IF ((PCBLC .LT. 1.0)) GO TO 10
      PRINT *, "PERCENTS OF BLEED FLOWS .GT. 1.0--HALT
     $ EXECUTION"
      GO TO 1
   10 BLT4         = PCBLT4 * WA22
```

```
      BLHPT     = PCBLHP * WA22
      BLLPT     = PCBLLP * WA22
      BLP       = P3 * (1.0 - DPBLEED)
      HPLPC     = (WLPC * WA2 * WAENG) / .7068
      HPHPC     = (WHPC * WA22 * WAENG) / .7068
      TB        = T3
      CALL THERMO (BLP, HB, TB, SB, AMWB, CPB, GAB, 0,
     $ 0.0, 0)
C
C *** BEGINNING OF MAIN COMBUSTOR
      IF (WF4DS .LT. 0.0 .OR. T4 .LT. 0.0 .OR.
     $ ETAB.GT.1.0) GO TO 35
   11 IF (WF4DS .GT. 0.0) GO TO 14
      IF (HV .GT. 0.0) GO TO 12
      CALL COMB (P3, T4, H3, ETAB, DP3, P4, H4, S4, FAR4,
     $ HV)
      GO TO 13
   12 P4        = P3 * (1.0 - DPB)
      FAR4      = (.276 * (T4 - T3)) / ((ETAB * HV) -
     $ (.276 * (T4 -
     1   T3)))
      CALL THERMO (P4, H4, T4, S4, AMW4, CP4, GA4, 1,
     $ FAR4, 0)
      FAR4      = (CP4 * (T4 - T3)) / ((ETAB * HV) - (CP4
     $ * (T4 - T3)))
   13 WF4       = FAR4 * WA3
      GO TO 15
   14 WF4       = WF4DS / (WAENG * 3600.)
      FAR4      = WF4 / WA3
      P4        = P3 * (1.0 - DPB)
      CALL THERMO (P4, H4, T4, S4, AMW4, CP4, GA4, 1,
     $ FAR4, 0)
      IF (HV .GT. 0.) GO TO 15
      IF  (HV .EQ. 0.0) HV =  ( (CP4 * (T4 - T3) / FAR4) +
     $ CP4 * (T4 -
     1   T3)) / ETAB
      CALL COMB2 (P3, T4, H3, ETAB, DP3, P4, H4, S4, FAR4,
     $ HV)
   15 WG4       = WA3 + WF4
      P41       = P4
      WG41      = WG4 + BLT4
      FAR41     = WF4 / (WA3 + BLT4)
      H41       = (H4 * WG4 + HB * BLT4) / WG41
      CALL THERMO (P41, H41, T41, S41, AMW41, CP41, GA41,
     $ 1, FAR41, 1)
      IF  (BLT4 .LE. 0.0) T41 = T4
      IF (PRHPT .LT. 1.0 .OR. ETAHPT .GT. 1.0) GO TO 37
      IF (PRLPT .LT. 1.0 .OR. ETALPT .GT. 1.0) GO TO 37
      IF (M .EQ. 1) GO TO 16
      IF (M .EQ. 2) GO TO 18
```

```
      IF (M .EQ. 4) GO TO 20
C
C *** ONE TURBINE APU
   16 P5           = P41
      PRHPT        = P41 / P5
      H5           = H41
      T5           = T41
      FAR5         = FAR41
      CALL THERMO (P5, H5, T5, S5, AMW5, CP5, GA5, 1,
     $ FAR5, 1)
      P51          = P5
      H51          = H5
      T51          = T5
      WG51         = WG41
      FAR51        = FAR41
      CALL THERMO (P51, H51, T51, S51, AMW51, CP51, GA51,
     $ 1, FAR51, 1)
      IF (HPM .NE. 0.0) GO TO 17
      RATIO        = (GA51 - 1.0) / GA51
      TWORK        = ETALPT * CP51 * T51 * (1.0 - ((1.0 /
     $ PRLPT) **
     1   RATIO))
      DHTL         = TWORK
      H52          = H51 - DHTL
      P52          = P51 / PRLPT
      HPLT         = (TWORK * WG51 * WAENG) / .7068
      HPEXT        = HPLT - HPLPC - HPHPC
      HPM          = (HPEXT - HPACC) * ETAM
      PCT1         = 0.0
      PCT2         = 1.0
      IPAS         = 1
      GO TO 23
   17 HPBTU        = ((HPACC + (HPDS / ETAM)) * .7068) /
     $ (WG51 * WAENG)
      DHTL         = HPBTU + (((H3 - H22) * WA22 + (H21 - H2)
     $ * WA2) /
     1   WG51)
      H52          = H51 - DHTL
      P52          = P51 * (1.0 - (DHTL / (ETALPT * CP51 *
     $ T51))) ** (GA51
     1   / (GA51 - 1.0))
      CALL THERMO (P52, H52, T52, S52, AMW52, CP52, GA52,
     $ 1, FAR51, 1)
      TWORK        = DHTL
      HPLT         = (TWORK * WG51 * WAENG) / .7068
      HPEXT        = HPLT - HPLPC - HPHPC
      PCT1         = 0.0
      PCT2         = 1.0
      HPM          = (HPEXT - HPACC) * ETAM
      IPAS         = 2
```

```
      GO TO 23
C
C *** TWO TURBINE APU
   18 CALL THERMO (P41, H41, T41, S41, AMW41, CP41, GA41,
     $ 1, FAR41, 0)
      IF (HPM .NE. 0.0) GO TO 19
      RATIO       = (GA41 - 1.0) / GA41
      THWORK      = ETAHPT * CP41 * T41 * (1.0 - ((1.0 /
     $ PRHPT) **
     1   RATIO))
      DHTH        = THWORK
      H5          = H41 - DHTH
      P5          = P41 / PRHPT
      CALL THERMO (P5, H5, T5, S5, AMW5, CP5, GA5, 1,
     $ FAR41, 1)
      P51         = P5 * (1.0 - DPT)
      WG51        = WG41 + BLHPT
      H51         = (H5 * WG41 + HB * BLHPT) / WG51
      FAR51       = WF4 / (WG51 - WF4)
      CALL THERMO (P51, H51, T51, S51, AMW51, CP51, GA51,
     $ 1, FAR51, 1)
      RATIO       = (GA51 - 1.0) / GA51
      DHTL        = ETALPT * CP51 * T51 * (1.0 - ((1.0 /
     $ PRLPT) **
     1   RATIO))
      H52         = H51 - DHTL
      P52         = P51 / PRLPT
      CALL THERMO (P52, H52, T52, S52, AMW52, CP52, GA52,
     $ 1, FAR51, 1)
      PCT1        = DHTH / (DHTH + DHTL)
      PCT2        = DHTL / (DHTH + DHTL)
      IPAS        = 1
      HPHT        = (THWORK * WG41 * WAENG) / .7068
      HPLT        = (DHTL * WG51 * WAENG) / .7068
      HPEXT       = HPHT - HPHPC + HPLT - HPLPC
      HPM         = (HPEXT - HPACC) * ETAM
      GO TO 23
   19 HPBTU       = ((HPACC + (HPDS / ETAM)) * .7068) /
     $ (WG41 * WAENG)
      DHALL       = HPBTU + ((H3 - H22) * WA22 + (H21 - H2)
     $ * WA2) / WG41
      DWORKHT     = DHALL * (PCT1) * WG41 * WAENG
      FAR5        = FAR41
      DHTH        = DWORKHT / (WG41 * WAENG)
      H5          = H41 - DHTH
      P5          = P41 * (1.0 - (DHTH / (ETAHPT * CP41 *
     $ T41))) ** (GA41
     1   / (GA41 - 1.0))
      CALL THERMO (P5, H5, T5, S5, AMW5, CP5, GA5, 1,
     $ FAR5, 1)
```

```
      PRHPT      = P41 / P5
      P51        = P5 * (1.0 - DPT)
      WG51       = WG41 + BLHPT
      H51        = (H5 * WG41 + HB * BLHPT) / WG51
      FAR51      = WF4 / (WG51 - WF4)
      CALL THERMO (P51, H51, T51, S51, AMW51, CP51, GA51,
     $ 1, FAR51, 1)
      DWORKLT    = DHALL * (PRLPT / (PRHPT * PRLPT)) * WG51
     $ * WAENG
      DHTL       = DWORKLT / (WG51 * WAENG)
      H52        = H51 - DHTL
      P52        = P51 * (1.0 - (DHTL / (ETALPT * CP51 *
     $ T51))) ** (GA51
     1   / (GA51 - 1.0))
      CALL THERMO (P52, H52, T52, S52, AMW52, CP52, GA52,
     $ 1, FAR51, 1)
      PCT1       = DWORKHT / (DWORKHT + DWORKLT)
      PCT2       = DWORKLT / (DWORKHT + DWORKLT)
      HPHT       = DWORKHT / .7068
      HPLT       = DWORKLT / .7068
      HPEXT      = HPHT - HPHPC + HPLT - HPLPC
      HPM        = (HPEXT - HPACC) * ETAM
      IPAS       = 2
      GO TO 23
C
C *** TWO TURBINE APU WITH ONE OF THE TURBINES A POWER
C    $          TURBINE
   20 CALL THERMO (P41, H41, T41, S41, AMW41, CP41, GA41,
     $ 1, FAR41, 0)
      RATIO      = (GA41 - 1.0) / GA41
      THWORK     = ETAHPT * CP41 * T41 * (1.0 - ((1.0 /
     $ PRHPT) **
     1   RATIO))
      DHTH       = THWORK
      H5         = H41 - DHTH
      P5         = P41 / PRHPT
      CALL THERMO (P5, H5, T5, S5, AMW5, CP5, GA5, 1,
     $ FAR41, 1)
      HPHT       = (THWORK * WG41 * WAENG) / .7068
      HPTT       = HPHT - HPACC - HPHPC - HPLPC
      IF (HPTT .GE. 0.0) GO TO 21
      HPBTU      = (HPACC * .7068) / (WG41 * WAENG)
      DHTH       = HPBTU + (((H3 - H22) * WA22 + (H21 - H2)
     $ * WA2) /
     1   WG41)
      H5         = H41 - DHTH
      P5         = P41 * (1.0 - (DHTH / (ETAHPT * CP41 *
     $ T41))) ** (GA41
     1   / (GA41 - 1.0))
      CALL THERMO (P5, H5, T5, S5, AMW5, CP5, GA5, 1,
     $ FAR41, 1)
```

```
      PRHPT      = P41 / P5
      PRINT *, "PRESSURE RATIO CALCULATED AS NEEDED FOR
     $ HPT"
   21 P51        = P5 * (1.0 - DPT)
      WG51       = WG41 + BLHPT
      H51        = (H5 * WG41 + HB * BLHPT) / WG51
      FAR51      = WF4 / (WG51 - WF4)
      CALL THERMO (P51, H51, T51, S51, AMW51, CP51, GA51,
     $ 1, FAR51, 1)
      IF (HPM .NE. 0.0) GO TO 22
      RATIO2     = (GA51 - 1.0) / GA51
      TWORK      = ETALPT * CP51 * T51 * (1.0 - ((1.0 /
     $ PRLPT) **
     1   RATIO2))
      DHTL       = TWORK
      H52        = H51 - DHTL
      P52        = P51 / PRLPT
      CALL THERMO (P52, H52, T52, S52, AMW52, CP52, GA52,
     $ 1, FAR51, 1)
      HPEXT      = (TWORK * WG51 * WAENG) / .7068
      HPLT       = HPEXT
      HPM        = HPEXT * ETAM
      DWORKHT    = DHTH * WG41 * WAENG
      DWORKLT    = DHTL * WG51 * WAENG
      PCT1       = DWORKHT / (DWORKHT + DWORKLT)
      PCT2       = DWORKLT / (DWORKHT + DWORKLT)
      IPAS       = 1
      GO TO 23
   22 DHTL       = ((HPDS / ETAM) * .7068) / (WG51 * WAENG)
      CALL THERMO (P52, H52, T52, S52, AMW52, CP52, GA52,
     $ 1, FAR51, 1)
      P52        = P51 * (1.0 - (DHTL / (ETALPT * CP51 *
     $ T51))) ** (GA51
     1   / (GA51 - 1.0))
      H52        = H51 - DHTL
      TWORK      = DHTL
      HPEXT      = (TWORK * WG51 * WAENG) / .7068
      HPLT       = HPEXT
      DWORKHT    = DHTH * WG41 * WAENG
      DWORKLT    = DHTL * WG51 * WAENG
      PCT1       = DWORKHT / (DWORKHT + DWORKLT)
      PCT2       = DWORKLT / (DWORKHT + DWORKLT)
      HPM        = HPEXT * ETAM
      PRLPT      = P51 / P52
      IPAS       = 2
      GO TO 23
C
C *** LOW PRESSURE TURBINE OR POWER TURBINE EXIT, WITH
C    $          COOLING FLOW,
```

```
C           IF ANY, PLUS STATION 5 CALCULATION.
   23  PRLPT       = P51 / P52
       P52         = P51 / PRLPT
       CALL THERMO (P52, H52, T52, S52, AMW52, CP52, GA52,
     $ 1, FAR51, 1)
       P53         = P52
       IF (IPAS .EQ. 1) GO TO 27
       IF (P53 .GE. P1) GO TO 27
C           ON 2ND PASS WHEN WORK REQUIRED CAUSES
C    $          OVEREXPANSION OF LAST
C              TURBINE, ASSUME THE TURBINE EXPANDS ONLY TO
C    $          ATMOSPHERIC.
       PRINT *, "P53<P1,LPT OVEREXPANDED, SET P53=P1,
     $ RECALC WORK"
       P53         = P52 = P1
       REPRTL      = P51 / P52
       RETIO       = (GA51 - 1.) / GA51
       REWORK      = ETALPT * CP51 * T51 * (1. - ((1. /
     $ REPRTL) ** RETIO))
       PRLPT       = REPRTL
       H52         = H51 - REWORK
       HPRE        = (REWORK * WG51 * WAENG) / .7068
       IF (M .GT. 1) GO TO 24
       HPEXT       = HPRE - HPLPC - HPHPC
       HPM         = (HPEXT - HPACC) * ETAM
       GO TO 26
   24  IF (M .GT. 2) GO TO 25
       HPEXT       = HPHT - HPHPC + HPRE - HPLPC
       HPM         = (HPEXT - HPACC) * ETAM
       PCT2        = HPRE / (HPRE + HPHT)
       GO TO 26
   25  HPEXT       = HPRE
       PCT2        = HPRE / (HPHT + HPRE)
       HPLT        = HPEXT
       HPM         = HPEXT * ETAM
   26  CALL THERMO (P52, H52, T52, S52, AMW52, CP52, GA52,
     $ 1, FAR51, 1)
C              ON 1ST PASS, IF LAST TURBINE NOT
C    $          OVEREXPANDED,
   27  PS6         = P1
C               LAST TURBINE EXIT COOLING CALCULATIONS
       WG53        = WG51 + BLLPT
       H53         = (H52 * WG51 + HB * BLLPT) / WG53
       FAR53       = WF4 / (WG53 - WF4)
       CALL THERMO (P53, H53, T53, S53, AMW53, CP53, GA53,
     $ 1, FAR53, 1)
       RTIO53      = (GA53 - 1.) / GA53
       DPE         = (P53 - PS6) / P53
       TS6         = T53
       CALL THERMO (PS6, HS6, TS6, SS6, AMW6, CP6, GA6, 1,
     $ FAR53, 0)
```

```
      DELNOZ     = H53 * (1. - (P1 / P53) ** RTIO53)
      V6         = SQRT(2 * G * (DELNOZ) * AJ)
      WG6        = WG53
      FAR6       = FAR53
C
C *** PERFORMANCE CALCULATIONS
      THG6       = V6 * WG6 / G
      FNQWA      = THG6 / WA2
      SFCU       = WF4 * WAENG * 3600 / HPM
      FG         = THG6 * WAENG
      FN         = FNQWA * WAENG
      ETATHM     = HPEXT * 550. / (WF4 * WAENG * HV * AJ)
C
C *** DEFINE OUTPUT PARAMETERS
      XWA21      = WA21 * WAENG
      XWA22      = WA22 * WAENG
      XWA3       = WA3 * WAENG
      XWG4       = WG4 * WAENG
      XWG41      = WG41 * WAENG
      XWG51      = WG51 * WAENG
      XWG53      = WG53 * WAENG
      XWG6       = WG6 * WAENG
      XWF4       = WF4 * WAENG * 3600.
      XP1        = P1 * PRES
      XP2        = P2 * PRES
      XP21       = P21 * PRES
      XP22       = P22 * PRES
      XP3        = P3 * PRES
      XP4        = P4 * PRES
      XP41       = P41 * PRES
      XP5        = P5 * PRES
      XP51       = P51 * PRES
      XP52       = P52 * PRES
      XP53       = P53 * PRES
      XPS6       = PS6 * PRES
      CF2        = (WA2 * WAENG * SQRT(T2 / T11)) / (P2 /
     $ P1)
      CF21       = (XWA21 * SQRT(T21 / T11)) / (P21 / P1)
      CF22       = (XWA22 * SQRT(T22 / T11)) / (P22 / P1)
      CF3        = (XWA3 * SQRT(T3 / T11)) / (P3 / P1)
      CF4        = (XWG4 * SQRT(T4 / T11)) / (P4 / P1)
      CF41       = (XWG41 * SQRT(T41 / T11)) / (P41 / P1)
      CF51       = (XWG51 * SQRT(T51 / T11)) / (P51 / P1)
      CF52       = (XWG51 * SQRT(T52 / T11)) / (P52 / P1)
      CF53       = (XWG53 * SQRT(T53 / T11)) / (P53 / P1)
      CF6        = (XWG6 * SQRT(TS6 / T11)) / (PS6 / P1)
      CFF        = XWF4 / ((P4 / P1) * SQRT(T4 / T11))
      HPMAMB     = (HPEXT * SQRT(T1 / 518.67)) / (P1 / 1.0)
      THETA1     = T1 / T11
```

```
      THETA2     = T2 / T11
      THETA3     = T3 / T11
      THETA21    = T21 / T11
      THETA22    = T22 / T11
      THETA4     = T4 / T11
      THETA41    = T41 / T11
      THETA5     = T5 / T11
      THETA51    = T51 / T11
      THETA52    = T52 / T11
      THETA53    = T53 / T11
      THETA6     = TS6 / T11
      DELTA1     = P1 / P1
      DELTA2     = P2 / P1
      DELTA21    = P21 / P1
      DELTA22    = P22 / P1
      DELTA3     = P3 / P1
      DELTA4     = P4 / P1
      DELTA41    = P41 / P1
      DELTA5     = P5 / P1
      DELTA51    = P51 / P1
      DELTA52    = P52 / P1
      DELTA53    = P53 / P1
      DELTA6     = PS6 / P1
      T1         = T1 - 459.67
      T2         = T2 - 459.67
      T21        = T21 - 459.67
      T22        = T22 - 459.67
      TB         = TB - 459.67
      T3         = T3 - 459.67
      T4         = T4 - 459.67
      T41        = T41 - 459.67
      T5         = T5 - 459.67
      T51        = T51 - 459.67
      T52        = T52 - 459.67
      T53        = T53 - 459.67
      TS6        = TS6 - 459.67
C
C *** WRITE OUT THE OUTPUT PAGE
      IF  (PRES .GT. 1.0) IP = 2
      IF (ITITLE .EQ. 0) GO TO 28
      WRITE (6,  141)  AWORD (IP)
      GO TO 29
   28 WRITE (6,  142)  AWORD (IP)
   29 ITITLE     = 0
      WRITE (6,  143)  XP1, T1, H1, DELTA1, THETA1
      IF (PRLPC .LE. 1.0) GO TO 30
      WRITE (6,  144)  XP2, T2, H2, WAENG, CF2, DELTA2,
     $ THETA2, ETALPC,
     1   PRLPC, DPIN
      WRITE (6,  145)  XP21, T21, H21, XWA21, CF21,
     $ DELTA21, THETA21,
```

```
     1    DPC
 30   IF (PRHPC .LE. 1.0) GO TO 31
      WRITE (6,  146)  XP22, T22, H22, XWA22, CF22,
     $ DELTA22, THETA22,
     1    ETAHPC, PRHPC
 31   IF  (PRHPC .LE. 1.0) IB = 1
      WRITE (6,  147)  RWORD (IB), XP3, T3, H3, XWA3, CF3,
     $ DELTA3,
     1    THETA3, PROA
      WRITE (6,  148)  XP4, T4, H4, XW34, CF4, DELTA4,
     $ THETA4, FAR4,
     1    ETAB, DPB
      IF (M .EQ. 1) GO TO 32
      WRITE (6,  149)  XP41, T41, H41, XWG41, CF41,
     $ DELTA41, THETA41,
     1    FAR41, ETAHPT, PRHPT
      WRITE (6,  150)  XP5, T5, H5, XW341, CF41, DELTA5,
     $ THETA5, FAR41,
     1    DPT
      WRITE (6,  151)  XP51, T51, H51, XWG51, CF51,
     $ DELTA51, THETA51,
     1    FAR51
 32   IF  (M .EQ. 1) IN = 1
      WRITE (6,  152)  ANUM (IN), XP51, T51, H51, XWG51,
     $ CF51, DELTA51,
     1    THETA51, FAR51, ETALPT, PRLPT
      WRITE (6,  153)  ANUM (IN), XP52, T52, H52, XWG51,
     $ CF52, DELTA52,
     1    THETA52, FAR51
      WRITE (6,  154)  ANUM (IN), XP53, T53, H53, XWG53,
     $ CF53, DELTA53,
     1    THETA53, FAR53
      WRITE (6,  155)  XPS6, TS6, HS6, XWG6, CF6, DELTA6,
     $ THETA6, FAR6,
     1    DPE
      WRITE (6,  156)  ALTP
      WRITE (6,  157)  CS
      WRITE (6,  158)  DELTAMB
      WRITE (6,  159)  DELPAMB
      WRITE (6,  160)  N
      WRITE (6,  161)  M
      WRITE (6,  162)  HPDS
      WRITE (6,  163)  HPEXT
      WRITE (6,  164)  HPMAMB
      WRITE (6,  165)  HPM
      WRITE (6,  166)  HPACC
      WRITE (6,  167)  HPLPC
      WRITE (6,  168)  HPHPC
      WRITE (6,  169)  XWF4
```

```
      WRITE (6,  170)  CFF
      WRITE (6,  171)  HV
      WRITE (6,  172)  WLPC
      WRITE (6,  173)  LCSL
      WRITE (6,  174)  WHPC
      WRITE (6,  175)  HCSL
      WRITE (6,  176)  PCT1
      WRITE (6,  177)  HPHT
      WRITE (6,  178)  PCT2
      WRITE (6,  179)  HPLT
      IF (M .EQ. 4) WRITE (6,  180)
      WRITE (6,  181)  FN
      WRITE (6,  182)  FG
      WRITE (6,  183)  FNQHA
      WRITE (6,  184)  ETATHM
      WRITE (6,  185)  V6
      WRITE (6,  186)  SFCJ
      IF (IPAS .NE. 2) GO TO 33
      DPE        = 0.0
      PRHPT      = 1.0
      PRLPT      = 1.0
      HV         = 18400.0
      GO TO 1
   33 T1         = T1 + 459.67
      T2         = T2 + 459.67
      T21        = T21 + 459.67
      T22        = T22 + 459.67
      TB         = TB + 459.67
      T3         = T3 + 459.67
      T4         = T4 + 459.67
      GO TO 11
C
C *** ERROR STATEMENTS
   34 WRITE (6,  187)
      GO TO 5
   35 WRITE (6,  188)  PRLPC, PRHPC, ETALPC, ETAHPC
      STOP
   36 WRITE (6,  189)  WF4DS, T4, ETAB
      STOP
   37 WRITE (6,  190)  PRHPT, PRLPT, ETAHPT, ETALPT
      STOP
C

C
  100 FORMAT  (  /  / , 33X, 48HTHIS PROGRAM WAS DEVELOPED
     $ BY COMPONENT
     1S BRANCH , 23HTURBINE ENGINE DIVISION,  / , 34X,
     $ 26HMODIFIED BY PO
     2WER DIVISION, 42H U.S. AIR FORCE AERO PROPULSION
     $ LABORATORY  )
```

```
101  FORMAT  ( 1H1, 20X, 18H***INPUT VALUES***  )
102  FORMAT  ( 11A6 )
103  FORMAT  ( 1H1 / 1H , 40X, 11A5 )
104  FORMAT  ( 1H0, 20X, 18H***INPUT VALUES***  )
105  FORMAT  (  /  / , 5X, 16HALTITUDE (FT) = , F3.0 )
106  FORMAT  ( 5X, 17HPRESSURE (PSI) = , F6.3 )
107  FORMAT  ( 5X, 29HDELTA TEMP FROM 1962 ATMOS = , F8.5
   $ )
108  FORMAT  (  / , 5X, 18HBEGIN INDICATOR = , I1 )
109  FORMAT  ( 5X, 16HEND INDICATOR = , I1 )
110  FORMAT  (  / , 5X, 25HNO OF COMPRESSOR STAGES = , I1
   $ )
111  FORMAT  ( 5X, 23HNO OF TURBINE STAGES = , I1 )
112  FORMAT  (  / , 5X, 7HFLOW = , F10.5 )
113  FORMAT  ( 5X, 11HMECH EFF = , F8.5 )
114  FORMAT  ( 5X, 29HPACC EXTRACTED FOR ACCESS = , F4.2
   $ )
115  FORMAT  ( 5X, 21HDESIGN SHAFT POWER = , F10.4 )
116  FORMAT  (  / , 5X, 24HINLET DUCT PRESS LOSS = , F4.2
   $ )
117  FORMAT  ( 5X, 18HLPC PRESS RATIO = , F5.3 )
118  FORMAT  ( 5X, 10HLPC EFF = , F8.5 )
119  FORMAT  ( 5X, 19HLPC SEAL LEAKAGE = , F3.1 )
120  FORMAT  ( 5X, 27HLPC BLEED, TO BE USED LATER  )
121  FORMAT  (  / , 5X, 24HINTER-COMP PRESS LOSS = , F4.2
   $ )
122  FORMAT  ( 5X, 24HBLEED DUCT PRESS LOSS = , F6.3 )
123  FORMAT  (  / , 5X, 18HHPC PRESS RATIO = , F5.3 )
124  FORMAT  ( 5X, 10HHPC EFF = , F8.5 )
125  FORMAT  ( 5X, 19HHPC SEAL LEAKAGE = , F4.2 )
126  FORMAT  (  / , 5X, 23HMAIN COMB PRESS LOSS = , F8.5
   $ )
127  FORMAT  ( 5X, 22HMAIN COMBUSTION EFF = , F8.5 )
128  FORMAT  ( 5X, 27HDESIGN FUEL FLOW (LB/HR) = , F6.2 )
129  FORMAT  ( 5X, 45HMAIN COMB FUEL HEATING VALUE AT T4
   $ FOR JP4 = ,
   1   F6.0 )
130  FORMAT  ( 5X, 39HCOMB DISCHARGE TEMP (DEGREE
   $ RANKINE) = , F7.2 )
131  FORMAT  ( 5X, 39HHPT INLET NOZ COOLING/HPC INLET
   $ FLOW = , F8.5 )
132  FORMAT  (  / , 5X, 18HHPT PRESS RATIO = , F5.3 )
133  FORMAT  ( 5X, 10HHPT EFF = , F5.2 )
134  FORMAT  ( 5X, 30HTURB COOLING/HPC INLET FLOW = ,
   $ F8.5 )
135  FORMAT  (  / , 5X, 35HINTER TURB PRESS LOSS (P5-P51)
   $ /P5 = , F5.2
   1   )
136  FORMAT  (  / , 5X, 18HLPT PRESS RATIO = , F5.3 )
137  FORMAT  ( 5X, 10HLPT EFF = , F8.5 )
```

```
138  FORMAT  ( 5X, 39HEXHAUST DUCT PRESS LOSS (P53-P1)/
   $ P53 =  , F3.1 )
139  FORMAT  ( 5X, 29HLPT COOLING/HPC INLET FLOW =  , F8.5
   $ )
140  FORMAT  ( 1H1, 52X, 19H***OUTPUT VALUES***   )
141  FORMAT  ( 1H0, 9X, 21HSTATION       PRESSURE-, A3, 2X,
   $ 29HTEMP-DEG.
   1F   ENTHALPY    FLOW, 3X, 42HCOR FLOW   DELTA
   $ THETA   FUEL/AIR
   2  EFF, 2X, 18HPRESS RATIO  DEL P  )
142  FORMAT  ( 1H1, 9X, 21HSTATION       PRESSURE-, A3, 2X,
   $ 29HTEMP-DEG.
   1F   ENTHALPY    FLOW, 3X, 42HCOR FLOW   DELTA
   $ THETA   FUEL/AIR
   2  EFF, 2X, 18HPRESS RATIO  DEL P  )
143  FORMAT  ( 1H , 6X, 9HAMBIENT  , 3X, F8.3, 5X, F8.2,
   $ 3X, F8.2,
   1    21X, F7.3, 2X, F7.3 )
144  FORMAT  ( 1H , 6X, 13HLP COMP INLET, 4X, F8.3, 5X,
   $ F8.2, 3X,
   1    F8.2, 2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 12X,
   $ F7.5, 2X,
   2    F7.3, 2X, F7.5 )
145  FORMAT  ( 1H , 6X, 12HLP COMP EXIT, 5X, F8.3, 5X,
   $ F8.2, 3X, F8.2,
   1    2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 30X, F7.5
   $ )
146  FORMAT  ( 1H , 6X, 13HHP COMP INLET, 4X, F8.3, 5X,
   $ F8.2, 3X,
   1    F8.2, 2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 12X,
   $ F7.5, 2X,
   2    F7.3 )
147  FORMAT  ( 1H , 6X, A3, 10HCOMP EXIT/,  / 1H , 8X,
   $ 12HBURNER INLET
   1, 3X, F8.3, 5X, F8.2, 3X, F8.2, 2X, F7.3, 3X, F7.3,
   $ 2X, F7.3, 2X,
   2F7.3, 21X, F7.3 )
148  FORMAT  ( 1H , 6X, 11HBURNER EXIT, 6X, F8.3, 5X,
   $ F8.2, 3X, F8.2,
   1    2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 2X, F8.5,
   $ 2X, F7.5,
   2    11X, F7.5 )
149  FORMAT  ( 1H , 6X, 12HTURB 1 INLET, 5X, F8.3, 5X,
   $ F8.2, 3X, F8.2,
   1    2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 2X, F8.5,
   $ 2X, F7.5, 2X,
   2    F7.3 )
150  FORMAT  ( 1H , 6X, 11HTURB 1 EXIT, 6X, F8.3, 5X,
   $ F8.2, 3X, F8.2,
   1    2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 2X, F8.5,
   $ 2(X, F7.5 )
```

```
151  FORMAT  ( 1H , 6X, 11HTURB 1 EXIT,  / 1H, 8X,
   $ 12HPLUS COOLING,
   1   3X, F8.3, 5X, F8.2, 3X, F8.2, 2X, F7.3, 3X, F7.3,
   $ 2X, F7.3, 2X,
   2   F7.3, 2X, F8.5 )
152  FORMAT  ( 1H , 6X, 4HTURB, A3, 5HINLET, 5X, F8.3,
   $ 5X, F8.2, 3X,
   1   F8.2, 2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 2X,
   $ F8.5, 2X,
   2   F7.5, 2X, F7.3 )
153  FORMAT  ( 1H , 6X, 4HTURB, A3, 5HEXIT , 5X, F8.3,
   $ 5X, F8.2, 3X,
   1   F8.2, 2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 2X,
   $ F8.5 )
154  FORMAT  ( 1H , 6X, 4HTURB, A3, 4HEXIT,  / 1H , 8X,
   $ 12HPLUS COOLIN
   1G, 3X, F8.3, 5X, F8.2, 3X, F8.2, 2X, F7.3, 3X, F7.3,
   $ 2X, F7.3, 2X,
   2F7.3, 2X, F8.5 )
155  FORMAT  ( 1H , 6X, 17HEXHT/STATIC COND , F8.3, 5X,
   $ F8.2, 3X,
   1   F8.2, 2X, F7.3, 3X, F7.3, 2X, F7.3, 2X, F7.3, 2X,
   $ F8.5, 20X,
   2   F7.5 )
156  FORMAT  (  /  / , 5X, 16HALTITUDE (FT) = , F3.0 )
157  FORMAT  ( 5X, 17HSPEED OF SOUND = , F7.2 )
158  FORMAT  ( 5X, 29HDELTA TEMP FROM 1962 ATMOS = , F5.2
   $ )
159  FORMAT  ( 5X, 30HDELTA PRESS FROM 1962 PRESS = ,
   $ F4.2 )
160  FORMAT  (  / , 5X, 20HNO OF COMP STAGES = , I1 )
161  FORMAT  ( 5X, 20HNO OF TURB STAGES = , I1 )
162  FORMAT  (  / , 5X, 18HDESIGN SHAFT HP = , F10.4 )
163  FORMAT  ( 5X, 16HSHP EXTRACTED = , F10.5 )
164  FORMAT  ( 5X, 28HSHP EXTRACTED, COR FOR SL = , F10.3
   $ )
165  FORMAT  ( 5X, 34HSHP EXTRACTED, COR FOR MECH EFF = ,
   $ F10.5 )
166  FORMAT  ( 5X, 31HHP EXTRACTED FOR ACCESSORIES = ,
   $ F5.3 )
167  FORMAT  ( 5X, 20HHP NEEDED FOR LPC = , F7.3 )
168  FORMAT  ( 5X, 20HHP NEEDED FOR HPC = , F15.5 )
169  FORMAT  (  / , 5X, 23HCALCULATED FUEL FLOW = , F9.4
   $ )
170  FORMAT  ( 5X, 17HFUEL FLOW COEF = , F15.5 )
171  FORMAT  ( 5X, 45HMAIN COMB FUEL HEATING VALUE AT T4
   $ FOR JP4 = ,
   1   F8.1 )
172  FORMAT  (  / , 5X, 23HWORK OF LPC (BTU/LB) = , F6.3
   $ )
```

```
173  FORMAT  ( 5X, 33HLPC SEAL LEAKAGE FLOW FRACTION = ,
   $ F7.5 )
174  FORMAT  (  / , 5X, 23HWORK OF HPC (BTU/LB) = , F7.3
   $ )
175  FORMAT  ( 5X, 33HHPC SEAL LEAKAGE FLOW FRACTION = ,
   $ F8.5 )
176  FORMAT  (  / , 5X, 13HHPT WORK PERCENT = , F5.3 )
177  FORMAT  ( 5X, 20HHORSEPOWER OF HPT = , F15.5 )
178  FORMAT  (  / , 5X, 13HLPT WORK PERCENT = , F5.3 )
179  FORMAT  ( 5X, 20HHORSEPOWER OF LPT = , F15.5 )
180  FORMAT  ( 5X, 32HTHIS IS ACTUALLY A POWER TURBINE  )
181  FORMAT  (  / , 5X, 13HNET THRUST = , F10.5 )
182  FORMAT  ( 5X, 15HGROSS THRUST = , F10.5 )
183  FORMAT  ( 5X, 28HNET THRUST/ENGINE AIRFLOW = , F10.5
   $ )
184  FORMAT  ( 5X, 14HTHERMAL EFF = , F8.5 )
185  FORMAT  ( 5X, 24HEXHAUST EXIT VELOCITY = , 19X, F9.3
   $ )
186  FORMAT  ( 5X, 41HENGINE UNINSTALLED SFC (LB FUEL/HR-
   $ HP) = , F8.4
   1    )
187  FORMAT  ( 1H0, 12HLPC NOT USED  )
188  FORMAT  ( 1H0, 44H*** ERROR IN COMPRESSOR INPUT
   $ PARAMETERS ***,
   1   / , 5X, 8HPRLPC = , F7.3, 4X, 8HPRHPC = , F7.3,
   $ 4X, 9HETALPC =
   2, F9.5, 4X, 9HETAHPC = , F9.5 )
189  FORMAT  ( 1H0, 43H*** ERROR IN COMBUSTOR INPUT
   $ PARAMETERS ***,  /
   1    , 5X, 8HWF4DS = , F6.2, 4X, 5HT4 = , F7.2, 4X,
   $ 7HETAB = , F8.5
   2    )
190  FORMAT  ( 1H0, 41H*** ERROR IN TURBINE INPUT
   $ PARAMETERS ***,  / ,
   1    5X, 8HPRHPT = , F5.3, 4X, 7HPRLPT= , F5.3, 5X,
   $ 9HETAHPT = ,
   2    F5.2, 4X, 9HETALPT = , F5.2 )
C
      END
```

```
      SUBROUTINE  ATMOS (HFT, TM, DELTA)
C    THIS IS A SUBROUTINE TO COMPUTE CERTAIN ELEMENTS OF THE
C     $          1962
C    U.S. STANDARD ATMOSPHERE UP TO 90 KILOMETERS.
C     CALLING SEQUENCE...
C
C    CALL ATMOS (HFT, TM, DELTA)
C         HFT     =   GEOPOTENTIAL ALTITUDE (FEET)
C         TM      =  MOLECULAR SCALE TEMPERATURE (DEGREES
C     $          RANKINE)
C         DELTA =   RATIO OF PRESSURE TO THAT AT SEA LEVEL
C
C    ALL DATA AND FUNDAMENTAL CONSTANTS ARE IN THE METRIC
C     $          SYSTEM AS
C    THESE QUANTITIES ARE DEFINED AS EXACT IN THIS SYSTEM.
C
C    THE RADIUS OF THE EARTH (REFT59) IS THE VALUE
C     $          ASSOCIATED WITH THE
C    1959 ARDC ATMOSPHERE SO THAT PROGRAMS CURRENTLY USING
C     $          THE LIBRARY
C    ROUTINE WILL NOT REQUIRE ALTERATION TO USE THIS
C     $          ROUTINE.
      DIMENSION   ALM (10), DELTAB (10), HB (10), TMB (10)
      DATA      (HB(I), I=1, 10) /  - 5., 0., 11., 20.,
     $ 32., 47., 52.,
     1   61., 79., 88.743 /
      DATA      (TMB(I), I=1, 10) / 320.65, 288.15, 216.65,
     $ 216.65,
     1   228.65, 270.65, 270.65, 252.65, 180.65, 180.65 /
      DATA      (DELTAB(I), I=1, 10) / 1.75363, 1.,
     $ 2.23361E - 01,
     1   5.40328E - 02, 8.56663E - 03, 1.09455E - 03,
     $ 5.82289E - 04,
     2   1.79718E - 04, 1.0241E - 05, 1.5223E - 06 /
      DATA      (ALM(I), I=1, 10) /  - 5.5,  - 6.5, 0., 1.,
     $ 2.8, 0.,
     1   - 2.,  - 4., 0., 0. /
      DATA    REFT59 / 2.0855531E07 /, GZ / 9.80665 /, AMZ
     $ / 28.9644 /,
     1   RSTAR / 8.31432 /, FTTOKM / 3.048E - 04 /
C   CONVERT GEOPOTENTIAL ALTITUDE TO GEOMETRIC ALTITUDE
      ZFT         = HFT * REFT59 / (REFT59 - HFT)
C   CONVERT HFT AND ZFT TO KILOMETERS
      Z           = FTTOKM * ZFT
      H           = FTTOKM * HFT
      IF (H .LT. -5.0 .OR. Z .GT. 90.0) GO TO 6
        DO 1 M     = 1, 10
        IF   (H - HB(M))  2, 3, 1
    1   CONTINUE
```

```
      GO TO 6
    2 M            = M - 1
    3 DELH         = H - HB(M)
      IF (ALM(M) .EQ. 0.0) GO TO 4
      TMK          = TMB(M) + ALM(M) * DELH
C   GRADIENT IS NON ZERO, PAGE 10, EQUATION I.2.10-(3)
      DELTA        = DELTAB(M) * ((TMB(M) / TMK) ** (GZ * AMZ
     $ / (RSTAR *
     1   ALM(M))))
      GO TO 5
    4 TMK          = TMB(M)
C   GRADIENT IS ZERO, PAGE 10, EQUATION I.2.10-(4)
      DELTA        = DELTAB(M) * EXP( - GZ * AMZ * DELH /
     $ (RSTAR *
     1   TMB(M)))
C   CONVERSION TO ENGLISH UNITS
    5 TM           = 1.8 * TMK
    6 RETURN
      END
```

```
      SUBROUTINE  PROCOM (FARX, TEX, CSEX, AKFX, CPEX,
     $ REX, PHI, HEX)
C *** CALCULATES THERMO GAS PROPERTIES, AIR OR JP-4/AIR
C    $          MIXTURE
      COMMON  /WPAFB/  ICOUNT
      IF (FARX .LE. 0.067623) GO TO 1
      FARX       = 0.067623
      WRITE (6,  100)
    1 IF (TEX .GE. 300.) GO TO 2
      TEX        = 300.
      IF (ICOUNT .GT. 1) GO TO 2
      WRITE (6,  101)
    2 IF (TEX .LE. 4000.) GO TO 3
      TEX        = 4000.
      WRITE (6,  102)
    3 IF (FARX .GE. 0.0) GO TO 4
      FARX       = 0.0
      WRITE (6,  103)
C     AIR PATH
    4 CPA        = ((((((1.0115540E - 25 * TEX - 1.4526770E
     $ - 21) * TEX
     1   + 7.6215767E - 18) * TEX - 1.5128259E - 14) * TEX
     $ - 6.7178376E
     2   - 12) * TEX + 6.5519486E - 08) * TEX - 5.1536879E
     $ - 05) * TEX +
     3   2.5020051E - 01
      HEA        = (((((((1.2644425E - 26 * TEX -
     $ 2.0752522E - 22) * TEX
     1   + 1.2702630E - 18) * TEX - 3.0256518E - 15) * TEX
     $ - 1.6794594E
     2   - 12) * TEX + 2.1839825E - 08) * TEX - 2.5768440E
     $ - 05) * TEX +
     3   2.5020051E - 01) * TEX - 1.7558886E + 00
      SEA        =   + 2.5020051E - 01 * ALOG(TEX) +
     $ ((((((1.4450767E -
     1   25 * TEX - 2.4211238E - 22) * TEX + 1.5243153E -
     $ 18) * TEX -
     2   3.7820648E - 15) * TEX - 2.2392799E - 12) * TEX +
     $ 3.2759743E -
     3   08) * TEX - 5.1576879E - 05) * TEX + 4.5432300E -
     $ 02
      IF (FARX .EQ. 0.0) GO TO 5
C     FUEL/AIR PATH
      CPF        = ((((((7.2678710E - 25 * TEX - 1.3335668E
     $ - 20) * TEX
     1   + 1.0212913E - 16) * TEX - 4.2051104E - 13) * TEX
     $ + 9.9686793E
     2   - 10) * TEX - 1.3771901E - 06) * TEX + 1.7258630E
     $ - 03) * TEX +
```

```
      3   7.3816638E - 02
          HEF          = (((((((9.0848388E - 25 * TEX -
      $ 1.9050949E - 21) * TEX
      1   + 1.7021525E - 17) * TEX - 8.4102708E - 14) * TEX
      $ + 2.4921698E
      2   - 10) * TEX - 4.5906332E - 07) * TEX + 6.1293150E
      $ - 04) * TEX +
      3   7.3816638E - 02) * TEX + 3.0581530E + 01
          SEF          =  + 7.3816638E - 02 * ALOG(TEX) +
      $ ((((((1.0382670E -
      1   25 * TEX - 2.2226118E - 21) * TEX + 2.0425826E -
      $ 17) * TEX -
      2   1.0512776E - 13) * TEX + 3.3228928E - 10) * TEX -
      $ 6.8659505E -
      3   07) * TEX + 1.2258630E - 03) * TEX + 6.483398E -
      $ 01
    5     CPEX         = (CPA + FARX * CPF) / (1. + FARX)
          HEX          = (HEA + FARX * HEF) / (1. + FARX)
          PHI          = (SEA + FARX * SEF) / (1. + FARX)
          AMW          = 28.97 - .946186 * FARX
          REX          = 1.986375 / AMW
          AKEX         = CPEX / (CPEX - REX)
          CSEX         = SQRT(AKEX * REX * TEX * 25031.37)
          RETURN
C
  100     FORMAT  ( 1H0, 63HINPUT FUEL-AIR RATIO ABOVE LIMITS,
      $ IT HAS BEEN
      1RESETTO 0.067623, 6H$$$$$$  )
  101     FORMAT  ( 1H0, 35HPROCOM INPUT TEMPERATURE BELOW
      $ 300., 6H$$$$$$
      1    )
  102     FORMAT  ( 1H0, 36HPROCOM INPUT TEMPERATURE ABOVE
      $ 4000., 6H$$$$$$
      1    )
  103     FORMAT  ( 1H0, 38HPROCOM INPUT FUEL-AIR RATIO BELOW
      $ ZERO,
      1    6H$$$$$$  )
C
          END
```

```
      SUBROUTINE  THERMO (PX, HX, TX, SX, AMX, CPT, GA, L,
     $ FAR, K)
C *** THERMODUNAMIC PROPERTIES BASED ON PROCOM
      COMMON  /WPAFB/  ICOUNT
      ICOUNT    = 1
      FX        = 0.
      IF  (L .EQ. 1) FX = FAR
      IF (K .EQ. 1) GO TO 1
      CALL PROCOM (FX, TX, CS, AK, CP, R, PHI, HX)
      GO TO 3
    1 TX        = 4. * HX
        DO 2 I    = 1, 15
        CALL PROCOM (FX, TX, CS, AK, CP, R, PHI, H)
        ICOUNT    = ICOUNT + 1
        DELH      = HX - H
        IF (ABS(DELH) .LE. 0.00001*HX) GO TO 3
    2   TX        = TX + 4. * DELH
      WRITE (6,  100)
    3 SX        = PHI - R * ALOG(PX)
      AMX       = 1.986375 / R
      CPT       = CP
      GA        = AK
      RETURN
C
  100 FORMAT  ( 31HONO CONVERGENCE IN THERMO$$$$$$  )
C
      END
```

```
      SUBROUTINE  COMB (PIN, TOUT, HIN, ETAB, DPB, POUT,
     $ HOUT, SOUT,
     1   FAROUT, HV)
C *** COMPUTES STOICHIOMETRIC TEMPERATURE IN COMBUSTOR - IF
C    $         HEATING
C     VALUE FOR FUEL AND WF4DS ARE NOT INPUT, T4, ETAB,
C    $         DPB ARE INPUT.
      DIMENSION   X (9)
      X(2)        = 0.0
      X(3)        = 0.0
      POUT        = PIN * (1.0 - DPB)
      HV          = (((((( - .4594317E - 19 * TOUT) -
     $ .2034116F - 15) *
     1   TOUT + .2783643E - 11) * TOUT + .2051501E - 07) *
     $ TOUT -
     2   .2453116E - 03) * TOUT - .9433296E - 01) * TOUT +
     $ .1845537F +
     3   05
      CALL THERMO (POUT, HOUTA, TOUT, X1, X2, X3, X4, 0,
     $ 0.0, 0)
      FAROUT      = (HOUTA - HIN) / ((HV * ETAB) - (HOUTA -
     $ HIN))
      FARS        = FAROUT
      CALL THERMO (POUT, HOUT, TOUT, SOUT, Y1, Y2, Y3, 1,
     $ FAROUT, 0)
    1 DELFAR      = (FARS - FAROUT) / FAROUT
      CALL AFQUIP (X, TOUT, DELFAR, 0., 15., .0001, .95,
     $ TNEW, ICON)
      IF  (ICON - 2)  2, 4, 3
    2 TOUT        = TNEW
      HV          = (((((( - .4594317E - 19 * TOUT) -
     $ .2034116F - 15) *
     1   TOUT + .2783643E - 11) * TOUT + .2051501E - 07) *
     $ TOUT -
     2   .2453116E - 03) * TOUT - .9433296E - 01) * TOUT +
     $ .1845537F +
     3   05
      CALL THERMO (POUT, HOUTA, TOUT, X1, X2, X3, X4, 0,
     $ 0.0, 0)
      FAROUT      = (HOUTA - HIN) / ((HV * FTAB) - (HOUTA -
     $ HIN))
      GO TO 1
    3 WRITE (6,   100)
    4 CALL THERMO (POUT, HOUT, TOUT, SOUT, X1, X2, X3, 1,
     $ FAROUT, 0)
      RETURN
C
  100 FORMAT  ( 46H STOICHIOMETRIC TEMP WILL NOT CONVERGE
     $ IN COMB   )
```

```
C
      END
```

```
      SUBROUTINE  COMB2 (PIN, TOUT, HIN, ETAB, DPB, POUT,
     $ HOUT, SOUT,
     1   FAR4, HV)
C *** SIMILAR TO COMB - HEATING VALUE FOR FUEL IS OPTIONAL,
C     USER MUST INPUT T4, ETAB, DPB, WF4DS.
      DIMENSION   X (9)
      X(2)        = 0.0
      X(3)        = 0.0
      POUT        = PIN * (1.0 - DPB)
    1 CALL THERMO (POUT, HOUTA, TOUT, X1, X2, X3, X4, 0,
     $ 0.0, 0)
      FAROUT      = (HOUTA - HIN) / ((HV * ETAB) - (HOUTA -
     $ HIN))
      FARS        = FAROUT
      DELFAR      = (FAR4 - FARS) / FAR4
      DIR         = SQRT(FAR4 / FARS)
      CALL AFQUIR (X, TOUT, DELFAR, 0., 20., .0001, DIR,
     $ TNEW, ICON)
      IF  (ICON - 2)  2, 4, 3
    2 TOUT        = TNEW
      GO TO 1
    3 WRITE (6,  100)
    4 CALL THERMO (POUT, HOUT, TOUT, SOUT, X1, X2, X3, 1,
     $ FAR4, 0)
      RETURN
C
  100 FORMAT  ( 47H STOICHIOMETRIC TEMP WILL NOT CONVERGE
     $ IN COMB2  )
C
      END
```

```
      SUBROUTINE  AFQUIR (X, AIND, DEPEND, ANS, AJ, TOL,
     $ DIR, ANEW,
     1   ICON)
C *** QUADRATIC CONVERGENCE ROUTINE FOR INTERPOLATION
C X(1)=NAME OF ARRAY TO USE
C AIND=INDEPENDANT VARIABLE
C DEPEND= DEPENDANT VARIABLE
C ANS=ANSWER UPON WHICH TO CONVERGE
C AJ=MAX NUMBER OF TRYS
C TOL=PERCENT TOLERANCE FOR CONVERGENCE
C DIR=DIRECTION AND PERCENTAGE FOR FIRST GUESS
C ANEW=CALCULATED VALUE OF NEXT TRY AT INDEPENDANT VARIABLE
C ICON=CONTROL   =1 GO THRU LOOP AGAIN
C                =2 YOU HAVE REACHED THE ANSWER
C                =3 COUNTER HAS HIT LIMITS
C X(2)=COUNTER STORAGE
C X(3)=CHOOSES METHOD OF CONVERGENCE
C X(4)=THIRD DEPEND VAR
C X(5)=THIRD IND VAR
C X(6)=SECOND DEPEND VAR
C X(7)=SECOND IND VAR
C X(8)=FIRST DEPEND VAR
C X(9)=FIRST IND VAR
C X(3) MUST BE ZERO UPON FIRST ENTRY TO ROUTINE
C
      DIMENSION   X (9)
      Y           = 0.
      IF (ANS .EQ. 0) GO TO 1
      DEP         = DEPEND - ANS
      TOLANS      = TOL * ANS
      GO TO 2
    1 DEP         = DEPEND
      TOLANS      = TOL
    2 IF (ABS(DEP) .LE. TOLANS) GO TO 3
      IF  (X(2) - AJ)  6, 6, 5
    3 ANEW        = AIND
      X(2)        = 0.
      ICON        = 2
      RETURN
    4 ANEW        = Y
      X(2)        = X(2) + 1.
      ICON        = 1
      RETURN
    5 ANEW        = Y
      X(2)        = 0.
      ICON        = 3
      RETURN
    6 IF (X(3) .GT. 0) GO TO 10
C *** FIRST GUESS USING DIR
```

```
    7  X(3)        = 1.
       X(8)        = DEP
       X(9)        = AIND
       IF  (AIND)  8, 9, 8
    8  Y           = DIR * AIND
       GO TO 4
    9  Y           = DIR
       GO TO 4
   10  IF  (X(3) - 1.)  11, 11, 12
C *** LINEAR GUESS
   11  X(3)        = 2.
       X(6)        = DEP
       X(7)        = AIND
       IF (X(8) .EQ. X(6) .OR. X(9) .EQ. X(7)) GO TO 7
       A           = (X(9) - X(7)) / (X(8) - X(6))
       Y           = X(9) - A * X(8)
       IF  (ABS(10. * X(9)) - ABS(Y))  7, 7, 4
C *** QUADRATIC GUESS
   12  X(4)        = DEP
       X(5)        = AIND
       IF (X(7) .EQ. X(5) .AND. X(6) .EQ. X(4)) GO TO 7
       IF (X(7) .NE. X(5) .AND. X(6) .NE. X(4)) GO TO 13
       GO TO 11
   13  IF (X(9) .EQ. X(5) .AND. X(8) .EQ. X(4)) GO TO 14
       IF (X(9) .NE. X(5) .AND. X(8) .NE. X(4)) GO TO 15
       X(9)        = X(7)
       X(8)        = X(6)
       GO TO 11
   14  X(9)        = X(7)
       X(8)        = X(6)
       X(3)        = 1.
       IF  (X(9))  8, 9, 8
   15  F           = (X(6) - X(4)) / (X(7) - X(5))
       A           = (X(8) - X(4) - F * (X(9) - X(5))) /
     $ ((X(9) - X(7)) *
     1   (X(9) - X(5)))
       B           = F - A * (X(5) + X(7))
       C           = X(4) + X(5) * (A * X(7) - F)
       IF (A .EQ. 0 .AND. B .EQ. 0) GO TO 5
       IF (A .NE. 0 .AND. B .NE. 0) GO TO 16
       IF (A .NE. C .AND. B .NE. 0) GO TO 18
       Y           =  - C / B
       GO TO 27
   16  IF (C .NE. 0.0) GO TO 17
       Y           = 0.
       GO TO 27
   17  G           =  - C / A
       IF (G .LE. 0.0) GO TO 5
       Y           = SQRT(G)
       YY          =  - SQRT(G)
```

```
      GO TO 22
18    IF (C .NE. 0.0) GO TO 19
      Y           =  - B / A
      YY          = 0.
      GO TO 22
19    D           = 4. * A * C / B ** 2
      IF  (1. - D)  11, 20, 21
20    Y           =  - B / (2. * A)
      GO TO 27
21    E           = SQRT(1. - D)
      Y           = ( - B / (2. * A)) * (1. + E)
      YY          = ( - B / (2. * A)) * (1. - E)
22    J           = 4
        DO 23 I    = 6, 8, 2
        IF (ABS(X(4)) .LE. ABS(X(I))) GO TO 23
        J           = I
23      CONTINUE
      K           = J + 1
      IF ((X(K)-Y)*(X(K)-YY) .LE. 0.0) GO TO 24
      IF (ABS(X(K)-Y) .LE. ABS(X(K)-YY)) GO TO 27
      Y           = YY
      GO TO 27
24    IF (J .GE. 6) GO TO 25
      JJ          = J + 2
      KK          = K + 2
      GO TO 26
25    JJ          = J - 2
      KK          = K - 2
26    SLOPE       = (X(KK) - X(K)) / (X(JJ) - X(J))
      IF (SLOPE*X(J)*(X(K)-Y) .GT. 0.0) GO TO 27
      Y           = YY
27    X(9)        = X(7)
      X(8)        = X(6)
      X(7)        = X(5)
      X(6)        = X(4)
      GO TO 4
      END
```

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