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EXTENDED PARAMETRIC REPRESENTATION OF COMPRESSOR FANS AND TURBINES

Volume II - PART User's Manual

FINAL REPORT

March 1984

By
General Electric Company
Aircraft Engine Business Group
Advanced Technology Programs Dept.
Cincinnati, Ohio 45215

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
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CLEVELAND, OHIO 44135

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Advanced Technology Programs Department
Cincinnati, Ohio 45215

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16. Abstract

A turbine modeing technique has been developed which will anable the user to obtain consistent and rapid off-design performance from design point input. This technique is applicable to both axial and radial flow turbine with flow sizes ranging from about one pound per second to several hundred pounds per second. The axial flow turbines may or may not include variable geometry in the first stage nozzle. A user-specified option will also permit the calculation of design point cooling flow levels and corresponding changes in efficiency for the axial flow turbines. The modeling technique has been incorporated into a time-sharing program in order to facilitate its use. Because this report contains a description of the input output data, values of typical inputs, and example cases, it is suitable as a user's manual. This report is the second of a three volume set. The titles of the three volumes are as follows:

(1) Volume I CMGEN USER's Manual (Parametric Compressor Generator)
(2) Volume II PART USER's Manual (Parametric Turbine)
(3) Volume III MODFAN USER's Manual (Parametric Modulating Flow Fan)

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1.0 INTRODUCTION

The NASA Lewis Research Center employs a general computer program (Reference 1) for calculating the thermodynamic performance of jet propulsion engines. To calculate off-design engine performance, the user must input component maps. These maps define the characteristics of the various components over their full range of operating conditions.

For advanced propulsion systems these characteristics are not generally known. Furthermore, the typical user of the program is not sufficiently knowledgeable and/or cannot afford the time to do an extensive design analysis of the component in question. Instead he usually scales some available map.

The objective of the study is an improved method of representing the turbine component when performing calculations of off-design performance for advanced air-breathing jet engines. This method, which is a computer program called PART, is compatible in both form and format with the cycle program of Reference 1 and the example map representation of Reference 2.

The current program is a follow-on to NASA Contract NAS3-21999. Under the original contract an axial flow turbine model for large flow size machines was developed. Under the current contract, the model was extended to include both small axial flow turbines (i.e., flow sizes down to about 1 pps), and small fixed geometry uncooled radial flow turbines.

Because this report contains a description of the input-output data, values of typical inputs, and sample cases, it is suitable as a user's manual. A brief description of the engineering analysis used to generate the program is given near the end of the report.

The program uses turbine design point data as input to generate off-design values of turbine flow-function and total-to-total efficiency over a range of pressure ratios and speeds specified by the user. A user-specified option will also permit calculating design point cooling flows for the axial flow machines, and the corresponding change in turbine efficiency. The cooling flow subroutine, developed at the Lewis Research Center, is described in Reference 3.

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Table I. Summary of Turbine Design Point Data.

No.	Data Base Name*	No. of Stages	DHQTD**	TFFD**
1	HPT1-1	1	0.0596	14.6
2	HPT1-2	1	0.0705	16.4
3	HPT1-3	1	0.0335	88.5
4	HPT2-4	2	0.0670	17.3
5	HPT2-5	2	0.0787	32.4
6	HPT3-6	3	0.0810	45.5
7	LPT1-1	1	0.0220	45.0
8	LPT1-2	1	0.0425	45.0
9	LPT2-3	2	0.0571	58.5
10	LPT2-4	2	0.065	60.4
11	LPT4-5	4	0.0665	106.0
12	LPT4-6	4	0.0709	134.4
13	LPT6-7	6	0.0814	104.9
14	PT3-1	3	0.0800	210.0
15	AT3-1	3	0.0590	—
16	AT3-2	3	0.0785	—
17	AT3-3	3	0.0635	43.16
18	AT4-4	4	0.0499	38.85
19	VAT1-1	1	0.044	99.0
20	VAT1-2	1	0.060	60.0
21	VAT1-3	1	0.0238	290.0
22	VAT1-4P	1	0.0328	61.8
23	VAT1-4X	1	0.0328	61.8
24	VAT2-5P	2	0.0636	61.8
25	VAT2-5X	2	0.0636	61.8

*HPT - High Pressure Turbine
LPT - Low Pressure Turbine
PT - Power Turbine
AT - Air Turbine Test Rig
VAT - Variable Area Turbine

** Symbols defined in Table III.

Table II. Summary of Variable Geometry Turbines Included on Data Base.

Turbine No.	Designation	No. of Stages	First Stage Nozzle Area Ratios %					
1	VAT1-1	1	50.0	62.5	75.0	87.5	100.0	
2	VAT1-2	1	71.0	86.0	100.0	109.0	120.0	
3	VAT1-3	1	76.0	84.0	92.0	100.0	108.0	116.0
4	VAT1-4P	1	70.0	100.0	130.0			
5	VAT1-4X	1	70.0	100.0	130.0			
6	VAT2-5P	2	70.0	100.0	130.0			
7	VAT2-5X	2		100.0				

The Aircraft Engine Group of the General Electric Company has a turbine data base consisting of 25 turbines having design point turbine flow functions ranging from about 14 to 290. The number of stages for each of these turbines together with the approximate design point values of specific work output divided by inlet total temperature (DHQTD) and flow function (TFFD) are summarized in Table 1. The last sevel turbines shown in the table are variable-geometry turbines. Table II shows the set of first stage nozzle area ratios for each of the seven variable-geometry turbines. Five of these variable-geometry turbines were generated by turbine design and off-design computer programs similar, if not identical, to that described in Reference 4. Two of the turbines shown in Table II were generated from air turbine test carried out by the Lewis Research Center. The results of these tests are given in References 5 to 8. The Table II designation of the NASA test turbines have been given a trailing X. The analytical prediction of the performance of these turbines obtained from Reference 9 has been a trailing P.

All of the turbines in data base discussed above are of the large axial-flow type. In order to obtain data for small axial-flow turbines and radial flow turbines the open literature was used. References 13 thru 17 give the references used for small axial flow turbines. References 18 thru 24 give those for radial turbines.

2.0 PROGRAM STRUCTURE

A flow chart showing the flow of control in the NASA parametric turbine program is shown in Figure 1. After the input has been read and processed, the program carries out a simple pitch line analysis starting with the last stage of the turbine. The analysis starts at the exit of the turbine stage (in order to avoid iteration) and calculates the bucket and nozzle flow angles. This stage geometry is then used to generate the stage flow and loss characteristics using the analytically based correlations developed during the program. Successive stages are then calculated until the first stage is reached. The first stage characteristics are then generated, and the stages stacked for each value of the first stage turbine nozzle area specified. If the turbine is cooled, then the procedure given in Reference 3 is used to calculate both the cooling flow requirements, and the cooled turbine efficiency. Finally, the output is processed to obtain a turbine map representation compatible with the cycle deck of Reference 1.

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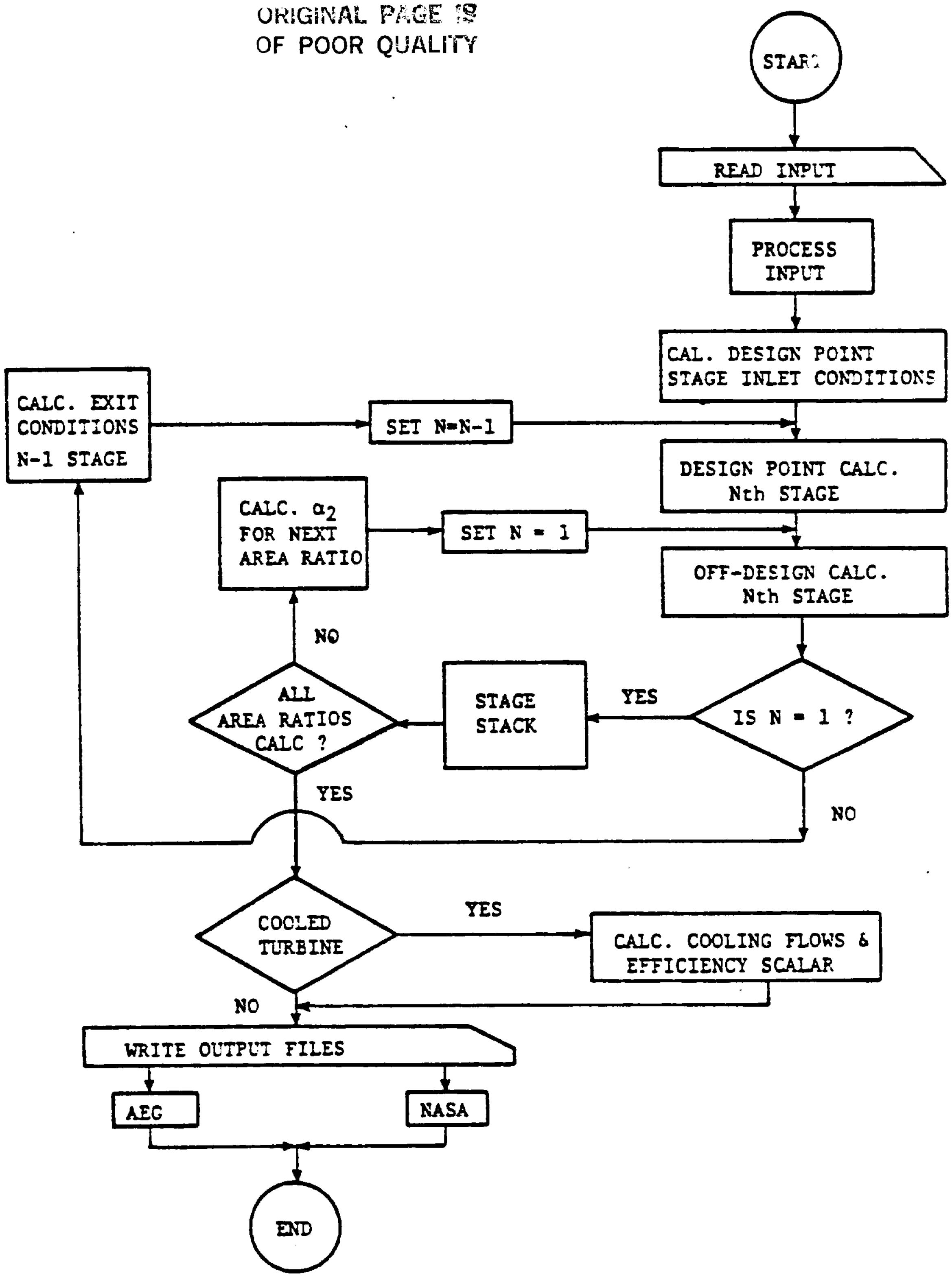

Figure 1. Flow Chart Showing Flow of Control in Parametric Turbine Program.

3.0 PROGRAM INPUTS

All of the PART inputs are of the free-field format (NAMELIST) type, and begin in column two. There is no specified order to the inputs. The program initially lists the contents of the NAMELIST INPUT together with the default settings of all the input variables. The user may then change as many of the inputs as desired. The program then echoes the updated NAMELIST. If none of the inputs are changed, the program will execute the first example case and the user can inspect the output. The input variables together with the default settings for a turbine are summarized in Table III.

The first six input variables in Table III are used to control the number and values of speed, pressure ratio, and nozzle area ratios (transformed into nozzle angle) to be written on the output files. For example, in the input to the first example case shown in Figure 2, all of the corrected speed and pressure ratio arrays are used by the program, but only the first three positions in the area ratio array. Note that speeds and pressure ratios are entered in increasing value, but that area ratios are entered in decreasing value (this is so that the nozzle angles will be written in increasing order on the output file). Speeds less than 10% should not be used. The input to the second example case shown in Figure 3 illustrates the use of the first six variables to limit the size of the output files.

Some of the design point inputs will be calculated internally by the program, if the user inputs the correct value to trigger the calculation. This subset of inputs together with the required settings are summarized in Table IV. An input value equal to or less than zero will trigger all of the calculations with the exception of exit swirl angle, here a value greater than 90 degrees must be input (180 degrees is recommended).

A minimum set of design point input would consist of NSTG and DHQTD. The values of TFFD and XNRTD could be input as 100.0 and the resulting values of TFFD interpreted as percent. The user could then use the settings in Table IV to trigger program calculations of the remaining design point information. The use of the program to calculate the number of stages will frequently result in a single-stage turbine, since the only upper limit on turbine radius is the limiting value of rim speed. This is not usually sufficiently restrictive to require the use of additional stages.

If the user wishes the program to calculate the value of design point cooling flow, and the corresponding decrease in turbine efficiency, the JCOOL switch in the NAMELIST INPUT should be set to 1. The program will then list the contents of the NAMELIST INPUT1 together with the default settings of all the variables. The user may then change as many of the inputs as desired. Since the default settings of the NAMELIST INPUT are for an uncooled turbine, these inputs (namely, TTIN, PTIN) must be changed in order to successfully calculate cooling flows. The input variables for NAMELIST INPUT1 together with their default settings are summarized in Table V. The input to the second example case shown in Figure 3 illustrates the proper format for a cooled three-stage turbine.

Table III. Default Settings for Variables in Namelist "Input."

Variable Name	Units	Default Values (Axial Turbine)	Description
NSPDS	None	15	Number of Speed Lines Desired
APCNC(I)	None	10% to 150%	The Array of Percent Corrected Speeds (Max of 15)
NPR	None	20	Number of Pressure Ratios Desired
APR(I)	None	1.1 to 4.6	The Array of Pressure Ratios (Max of 20)
NAR	None	3	Number of First Stage Nozzle Area Ratios
ARN	None	1.3, 1.0, 0.7	Array of Nozzle Area Ratios (Max of 6)
NSTG	None	1	Number of Turbine Stages (Max of 6)
JCOOL	None	0	Cooling Flow Switch (0=Uncooled; 1=Cooled)
DHQTD	Btu/lbm °R	0.03278	Specific Work Output Divided by Inlet Temperature
ETATTD	None	0.923	Turbine Total-to-Total Efficiency
TFFD	$\frac{lbm\ °R^{1/2}}{sec^* psi}$	62.98	Turbine Inlet Flow Function, i.e., ($TFF = W\sqrt{T_t}/P_t$)
XNRTD	rpm/°R$^{1/2}$	193.52	Turbine Corrected Speed ($XNRT = N/\sqrt{T_t}$)
PSID	None	0.8511	Average Turbine pitch line loading, i.e., $PSID = (DHQT/[2(U/\sqrt{T_t})^2/g_oJ]/NSTG$
ANGSWX	Degrees	15.2	Exit Pitch Line Swirl Angle (Positive When Opposite to Direction of Rotation)
XMZXD	None	0.373	Exit Pitch Line Axial Mach Number
TTIN	°R	518.67	Turbine Inlet Total Temperature
PTIN	psia	14.696	Turbine Inlet Total Pressure
FARGD	None	0.0	Turbine Inlet Fuel-Air Ratio
ETAN	None	.94	Nozzle Efficiency (Ratio of Exit Actual to ideal Kinetic Energy)
R3QR2	None	1.0	Pitch Line Radius Ratio (Rotor Exit to Inlet)
RHQRT3	None	.733	Radius Ratio at Rotor Exit (First Guess)

```
******************PARAMETRIC TURBINE******************

                   P*A*R*T

AXIAL OR RADIAL TURBINE?  1=RADIAL, 0 OR CR=AXIAL
=0

DESCRIPTION OF INPUT VARIABLES IN PART PROGRAM
(NAMELIST INPUT)

UNITS:TTIN=DEG R,PTIN=PSIA,W=PPS,H=BTU/LBM,N=RPM

MAP RANGE(ARRAY VALUES MUST BE IN ASCENDING ORDER)
NSPDS =15     NO OF SPEEDLINES DESIRED(MAX=15)
APCNC         ARRAY OF PERCENT CORRECTED SPEEDS
NPR    =20    NO OF PRESSURE RATIOS DESIRED(MAX=20)
APR           ARRAY OF PRESSURE RATIOS
NAR    =6     NO OF NOZZLE AREA RATIOS(MAX=6)
ARN           ARRAY OF FIRST STAGE NOZZLE AREA RATIOS
NSTG   =6     NO OF TURBINE STAGES(MAX=6)

INTEGER SWITCHES
JCOOL  =0     COOLING FLOW SWITCH(0=UNCOOLED,1=COOLED)

DESIGN POINT VALUES OF:
DHQTD         SPECIFIC WORK OUTPUT DIVIDED BY TTIN
ETATTD        TURBINE TOTAL-TO-TOTAL EFFICIENCY
TFFD          TURBINE INLET FLOW FUNCTION
              (TFF=W*SQRT(TTIN)/PTIN)
XNRTD         TURBINE CORRECTED SPEED(N/SQRT(TTIN))
PSID          AVERAGE TURBINE PITCH LINE LOADING
              PSID=DHQT/(2*(U/SQRT(TTIN)**2/GJ))/NSTG
ANGSWX        EXIT PITCH LINE SWIRL ANGLE(+COUNT-ROT)
XM2XD         EXIT PITCH LINE AXIAL MACH NUMBER
TTIN          TURBINE INLET TOTAL TEMPERATURE
PTIN          TURBINE INLET TOTAL PRESSRUE
FARGD         TURBINE INLET FUEL-AIR RATIO
ETAN          NOZZLE EFF(RATIO ACTUAL TO IDEAL EXIT KE)

GEOMETRY SPECIFICATIONS:
R3OR2         PITCHLINE RAD RATIO(ROTOR EXIT TO INLET)
RHORT3        RADIUS RATIO AT ROTOR EXIT(FIRST GUESS)

 NAMELIST       INPUT
 NSPUS = 15,
 APCNC (I)=
 1        10.0000,       20.0000,        30.0000,        40.0000,
 5        50.0000,       60.0000,        70.0000,        80.0000,
 9        90.0000,      100.0000,       110.0000,       120.0000,
13       130.0000,      140.0000,       150.0000,
 NPR   = 20,
 APR    (I)=
 1         1.1000,        1.2000,         1.4000,         1.6000,
 5         1.7000,        1.8000,         2.0000,         2.2000,
 9         2.4000,        2.6000,         2.8000,         3.0000,
```

Figure 2. Input to First Example Case

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```
13        3.2000,        3.4000,        3.6000,        3.8000,
17        4.0000,        4.2000,        4.4000,        4.6000,
 NAR    =  3,
 ARN    (1)=
 1        1.3000,        1.0000,        0.7000,        0.     ,
 5        0.     ,       0.     ,       1.0000,        1.0000,
 1        1.2490,        1.1440,
 NSTG   =  1,     JCOOL  =  0,
 DHQTD  =      0.032780,      ETATTD=       0.923000,
 TFFD   =     62.980000,      XNRTD  =    193.520000,
 PSID   =      0.851100,      XMZXD  =      0.373000,
 ANGSWX=      15.200000,      TTIN   =    518.669998,
 PTIN   =     14.696000,      FARGD  =      0.       ,
 ETAN   =      0.940000,      R3QR2  =      1.000000,
 RHORT3=       0.733300,
 END NAMELIST        INPUT
ENTER CHANGES TO NAMELIST INPUT
=SINPUTS
 NAMELIST       INPUT
 NSPDS  = 15,
 APCNC  (1)=
 1        10.0000,       20.0000,       30.0000,       40.0000,
 5        50.0000,       60.0000,       70.0000,       80.0000,
 9        90.0000,      100.0000,      110.0000,      120.0000,
13       130.0000,      140.0000,      150.0000,
 NPR    = 20,
 APR     (1)=
 1        1.1000,        1.2000,        1.4000,        1.6000,
 5        1.7000,        1.8000,        2.0000,        2.2000,
 9        2.4000,        2.6000,        2.8000,        3.0000,
13        3.2000,        3.4000,        3.6000,        3.8000,
17        4.0000,        4.2000,        4.4000,        4.6000,
 NAR    =  3,
 ARN    (1)=
 1        1.3000,        1.0000,        0.7000,        0.     ,
 5        0.     ,       0.     ,       1.0000,        1.0000,
 1        1.2490,        1.1440,
 NSTG   =  1,     JCOOL  =  0,
 DHQTD  =      0.032780,      ETATTD=       0.923000,
 TFFD   =     62.980000,      XNRTD  =    193.520000,
 PSID   =      0.851100,      XMZXD  =      0.373000,
 ANGSWX=      15.200000,      TTIN   =    518.669998,
 PTIN   =     14.696000,      FARGD  =      0.       ,
 ETAN   =      0.940000,      R3QR2  =      1.000000,
 RHORT3=       0.733300,
 END NAMELIST        INPUT
NASA OUTPUT ON IFC=15,16  &
```


Figure 2 - (Continued) Input to First Example Case

```
******************PARAMETRIC TURBINE******************

                        P*A*R*T

AXIAL OR RADIAL TURBINE?  1=RADIAL, 0 OR CR=AXIAL
=0

DESCRIPTION OF INPUT VARIABLES IN PART PROGRAM
(NAMELIST INPUT)

UNITS:TTIN=DEG R,PTIN=PSIA,W=PPS,H=BTU/LBM,N=RPM

MAP RANGE(ARRAY VALUES MUST BE IN ASCENDING ORDER)
NSPDS =15     NO OF SPEEDLINES DESIRED(MAX=15)
APCNC         ARRAY OF PERCENT CORRECTED SPEEDS
NPR   =20     NO OF PRESSURE RATIOS DESIRED(MAX=20)
APR           ARRAY OF PRESSURE RATIOS
NAR   =6    . NO OF NOZZLE AREA RATIOS(MAX=6)
ARN           ARRAY OF FIRST STAGE NOZZLE AREA RATIOS
NSTG  =6      NO OF TURBINE STAGES(MAX=6)

INTEGER SWITCHES
JCOOL =0     COOLING FLOW SWITCH(0=UNCOOLED,1=COOLED)

DESIGN POINT VALUES OF:
DHQTD        SPECIFIC WORK OUTPUT DIVIDED BY TTIN
ETATTD       TURBINE TOTAL-TO-TOTAL EFFICIENCY
TFFD         TURBINE INLET FLOW FUNCTION
             (TFF=W*SQRT(TTIN)/PTIN)
XNRTD        TURBINE CORRECTED SPEED(N/SQRT(TTIN))
PSID         AVERAGE TURBINE PITCH LINE LOADING
             PSID=DHQT/(2*(U/SQRT(TTIN)**2/GJ))/NSTG
ANGSWX       EXIT PITCH LINE SWIRL ANGLE(+COUNT-ROT)
XMZXD        EXIT PITCH LINE AXIAL MACH NUMBER
TTIN         TURBINE INLET TOTAL TEMPERATURE
PTIN         TURBINE INLET TOTAL PRESSRUE
FARGD        TURBINE INLET FUEL-AIR RATIO
ETAN         NOZZLE EFF(RATIO ACTUAL TO IDEAL EXIT KE)

GEOMETRY SPECIFICATIONS:
R3QR2        PITCHLINE RAD RATIO(ROTOR EXIT TO INLET)
RHQRT3       RADIUS RATIO AT ROTOR EXIT(FIRST GUESS)

 NAMELIST      INPUT
 NSPDS = 15,
 APCNC (I)=
 1        10.0000,        20.0000,        30.0000,        40.0000,
 5        50.0000,        60.0000,        70.0000,        80.0000,
 9        90.0000,       100.0000,       110.0000,       120.0000,
13       130.0000,       140.0000,       150.0000,
 NPR   = 20,
 APR    (I)=
 1         1.1000,         1.2000,         1.4000,         1.6000,
 5         1.7000,         1.8000,         2.0000,         2.2000,
 9         2.4000,         2.6000,         2.8000,         3.0000,
```


Figure 3. Input to Second Example Case

```
                                                                  3.ØØØØ,
13          3.2ØØØ,          3.4ØØØ,          3.6ØØØ,             4.6ØØØ,
17          4.ØØØØ,          4.2ØØØ,          4.4ØØØ,
 NAR   =  3,
 ARN   (I)=
 1          1.3ØØØ,          1.ØØØØ,          Ø.7ØØØ,             Ø.      ,
 5          Ø.     ,         Ø.     ,         1.ØØØØ,             1.ØØØØ,
 1          1.249Ø,          1.144Ø,
 NSTG  =  1,       JCOOL =  Ø,
 DHQTD =        Ø.Ø3278Ø,         ETATTD=         Ø.923ØØØ,
 TFFD  =       62.98ØØØØ,         XNRTD  =      193.52ØØØØ,
 PSID  =        Ø.8511ØØ,         XMZXD  =        Ø.373ØØØ,
 ANGSWX=       15.2ØØØØØ,         TTIN   =      518.669998,
 PTIN  =       14.696ØØØ,         FARGD  =        Ø.      ,
 ETAN  =        Ø.94ØØØØ,         R3QR2  =        1.ØØØØØØ,
 RHQRT3=        Ø.7333ØØ,
 END NAMELIST        INPUT
ENTER CHANGES TO NAMELIST INPUT
=$INPUT
=NSPDS=6, .
=APCNC=2Ø.,4Ø.,6Ø.,8Ø.,1ØØ.,12Ø.,
=NPR=5,
=APR=2.Ø,2.5,3.Ø,3.5,3.8,
=NAR=1,
=ARN=1.Ø,
=NSTG=3,
=JCOOL=1,
=DHQTD=Ø.Ø635,
=TFFD=58.53,
=XNRTD=4Ø.1Ø,
=PSID=1.5,
=ETATTD=Ø.886,
=ANGSWX=2.9,
=XMZXD=Ø.41,
=TTIN=25ØØ.,
=PTIN=59.8,
=FARGD=Ø.Ø2,
=$

DESCRIPTION OF INPUT VARIABLES IN PART PROGRAM
(NAMELIST INPUT1)

KINDOF=AN ORDERED COMBINATION OF DIGITS REPRESENTING
      THE COOLING CONFIGURATION OF THE TURBINE
TC=TOTAL TEMPERATURE OF THE COOLING FLOW
FARCX=FUEL-AIR RATIO OF THE COOLING FLOW
YEAR=FIRST YEAR OF SERVICE FOR STATOR VANE MATERIAL
YEAR B=FIRST YEAR OF SERVICE FOR ROTOR BLADE MATERIAL
ELIFE=DESIRED LIFE OF TURBINE AIRFOIL

 NAMELIST        INPUT1
 KINDOF=,         11ØØØØ,
 TC     =        5ØØ.ØØØØØØ,       FARCX =          Ø.      .
 YEAR   =      198Ø.,              YEARB =       198Ø.,
 ELIFE  =      Ø.1ØØØØØØE Ø5,
 END NAMELIST         INPUT1
ENTER CHANGES TO NAMELIST INPUT1
=$INPUT1
=KINDOF=864ØØØ,
=TC=7ØØ.,
=$
 NAMELIST       INPUT
 NSPDS =  6,
 APCNC (I)=                                                       8Ø.ØØØØ,
 1          2Ø.ØØØØ,         4Ø.ØØØØ,         6Ø.ØØØØ,
```


Figure 3 - (Continued) Input to Second Example Case

```
 5       100.0000,       120.0000,        70.0000,        80.0000,
 9        90.0000,       100.0000,       110.0000,       120.0000,
13       130.0000,       140.0000,       150.0000,
 NPR   =  5,
 APR    (I)=
 1         2.0000,         2.5000,         3.0000,         3.5000,
 5         3.8000,         1.8000,         2.0000,         2.2000,
 9         2.4000,         2.6000,         2.8000,         3.0000,
13         3.2000,         3.4000,         3.6000,         3.8000,
17         4.0000,         4.2000,         4.4000,         4.6000,
 NAR   =  1,
 ARN   (I)=
 1         1.0000,         1.0000,         0.7000,         0.      ,
 5         0.     ,        0.     ,
 1         1.2490,         1.1440,         1.0000,         1.0000,
 NSTG  =  3,      JCOOL =  1,
 DHQTD =         0.063500,       ETATTD=         0.886000,
 TFFD  =        58.530000,       XNRTD =        40.100000,
 PSID  =  .      1.500000,       XMZXD =         0.410000,
 ANGSWX=         2.900000,       TTIN  =      2500.000000,
 PTIN  =        59.000000,       FARGD =         0.020000,
 ETAN  =         0.940000,       R3QR2 =         1.000000,
 RHQRT3=         0.733300,
 END NAMELIST       INPUT
PCBLED= 0.06470 PCNCH= 0.02001 EFF4=  0.8835 PRN=  3.297
NASA OUTPUT ON IFC=15,16  &
```

Figure 3. - (Continued) <u>Input to Second Example Case</u>

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Table IV. Variable Settings to Trigger Default Calculation of Some Design Point Input.

Variable Name	Setting	Action Taken
NSTG	0.0	Program Calculates Number of Stages (Not Recommended)
ETATTD	0.0	Program Calculates Design Point Efficiency
PSID	0.0	Design Point Loading Set to 0.9
ANGSWX	180.0	Exit Swirl Angle Calculated From Zero Hub Reaction
XMZXD	0.0	Sets Exit Axial Mach Number to 0.5

Table V. Default Settings for Variables in Namelist "Input1"

Variable Name	Units	Default Value	Description
KINDOF	None	86400000	An Ordered Combination of Digits Representing the Cooling Configuration of the Turbine
TC	°R	700.0	Total Temperature of the Cooling Flow
FARCX	None	0.0	Fuel-Air Ratio of the Cooling Flow
Year	---	1980	First Year of Service for Stator Vane Material
YearB	---	1980	First Year of Service for Rotor Blade Material
ELIFE	hrs	10,000	Desired Life of Turbine Airfoil

The integer variable KINDOF represents the cooling configuration of the turbine. Each blade row starting with the first stage stator is assigned an integer value characterizing the type of cooling employed as follows:

0	Uncooled
1	Convection cooling
2	Convection with coating
3	Advanced convection
4	Film with convection (75% trailing edge injection)
5	Film with convection (50% trailing edge injection)
6	Film with convection (25% trailing edge injection)
7	Transpiration with convection (25% trailing edge injection)
8	Full coverage film
9	Transpiration

For example, the 86400000 configuration has the first three blade rows cooled and the remaining five rows uncooled (a four-stage turbine). For a detailed description of the cooling flow calculation and the various cooling flow configurations, the reader should consult Reference 3.

4.0 PROGRAM OUTPUTS

The basic output from the program consists of two tables. These tables show the turbine efficiency and turbine flow function variations for each of the first stage nozzle area ratios, pressure ratios, and percent corrected speeds specified in the input. The input values of area ratio are converted to first stage nozzle angles before being printed out. The output tables for the first example case are shown on pages 22 through 27. The table structure is compatible with NASA cycle deck requirements given in Reference 2 (pages 23 and 24).

The output tables can be visualized as three dimensional, composed of a series of planes with each plane assigned a value of nozzle angle, BETA. Then in each BETA plane, the dependent variable (ordinate axis) is a function of pressure ratio, PR, and corrected speed, rpm. The dependent variables are respectively turbine corrected flow, W, and total-to-total efficiency, ETA.

For example, in the output table on page 30 the forty-five lines of the dependent variable correspond to the fifteen values of corrected speed, where each speed occupies three lines. And the twenty values of the dependent variable in each three line group correspond to the twenty values of pressure ratio.

In addition to these two tables, there is a terminal listing summarizing the results of the cooling flow calculation, if this option was used. The value of the total cooling flow, PCBLED, is printed out together with the cooling flow for the first stage nozzle alone, PCNCH. The new cooled turbine efficiency value, EFF4, is given together with the new value of the total-to-total pressure ratio across the turbine, PRN. An example of this printout is shown on page 13 in the second example case. With the flows, shaft work, and turbine pressure ratio known, the user can calculate the new cooled turbine efficiency, ETATTD, using the bookkeeping procedure compatible with the cycle deck representation to be employed. A cycle deck efficiency scalar could then be used or, if desired, the program could be rerun on the uncooled branch using the new design point efficiency value as an input.

5.0 PROGRAM DIAGNOSTICS

The PART computer program contains error printouts to aid the user in trouble shooting his input. A listing of the error messages and their meanings are given below.

1. LIMITING VALUE OF UTIP=1800.0, CALCULATED VALUE OF UTIP=

This warning message is printed out if the calculated tip speed of a radial turbine exceeds 1800 fps.

2. LIMITING VALUE OF UHUB=1600.0, CALCULATED VALUE OF UHUB=

This warning message is printed out only if the calculated rim speed exceeds the recommended value (this is a disk stress warning).

3. LIMITING VALUE OF ANS=42.0E9, CALCULATED VALUE OF ANS=

This warning message is printed out if the product of the exit annulus area and the rpm squared exceeds the recommended value (this is a centrifugal stress limit on the rotor blading).

4. QUIRE CTR ERROR--(CALLING LINE=,I5,)

There are eight iterations in the program. Seven of the iterations are balanced using the Method of False Position. This method is contained in the subroutine QIREXX. A maximum of 25 passes is allowed for any single iteration to balance. If the iteration does not balance within the specified tolerance, the error message will appear with the number of the offending iteration in the I5 Format field.

Normally, the occurrence of such an error will not cause a problem. However, in the case of QIRE loop number five which calculates the turbine efficiency for the specified input values of pressure ratio and corrected speed, an additional message indicating the convergence error is printed out. This message has the form:

DHQT= ,ERR= ,PQP=

where the blanks contain the current values of specific enthalpy change divided by inlet total temperature, the convergence error in pressure ratio, and the pressure ratio at which the error occurred.

The user should inspect the error to see if the degree of convergence is satisfactory, if not, it may be necessary to restrict the range of input speeds and/or pressure ratios requested. The individual QIRE loops together with the calling routines and type of iteration are as follows:

QIRE LOOP	CALLING ROUTINES	COMMENTS
1	INLETX	Calculates individual stage efficiencies from the input value of overall turbine efficiency (NSTG>1).
2	VELRAT	Obtains the axial velocity ratio across the rotor.
3	CHOKEX	Solves for the value of nozzle Mach number when the rotor chokes.
4	ROTCKX	Solves for exit annulus choke location given the location of rotor choke.
5	PRTEFF	Calculates efficiency for input values of speed and pressure ratio.
6	FSTACK	Solves for the "polytropic" exponent for a multistage turbine.
7	CHOKEX	Solves for the value of the nozzle overexpanded Mach number after nozzle choke and before rotor choke.

There is one iteration in the program balanced by the Newton-Raphson Method. A maximum of 25 passes is allowed for convergence.If an error occurs the program will print out the warning message

ZERO DERIVATIVE IN NEW RAP LNCALL = I 10

The value 1 will appear in the I10 field since this is the first Newton-Raphson loop.

NEWTON-RAPHSON LOOP	CALLING ROUTINE	COMMENTS
1	CHOKEX	Calculates the value of UQAT1 at the speed where both the nozzle and the rotor are choked.

6.0 EXAMPLE CASES

Two example cases are given in order to illustrate the use of the program. The first case utilizes the default settings to generate the output for a single-stage, uncooled, variable-geometry turbine. The second case is a single stage radial turbine.

A complete record of the two terminal sessions including a listing of the output tables is given on the following pages. The program inputs and outputs have been discussed previously in Sections 3.0 and 4.0.

```
*REMOVE CLEARFILES
*OLD /NASAPT/NASAPART
*FRN

Ø058Ø   1Ø/2Ø/83    11.122


******************PARAMETRIC TURBINE******************

                        P*A*R*T

AXIAL OR RADIAL TURBINE?  1=RADIAL, Ø OR CR=AXIAL
=Ø

DESCRIPTION OF INPUT VARIABLES IN PART PROGRAM
(NAMELIST INPUT)

UNITS:TTIN=DEG R,PTIN=PSIA,W=PPS,H=BTU/LBM,N=RPM

MAP RANGE(ARRAY VALUES MUST BE IN ASCENDING ORDER)
NSPDS =15     NO OF SPEEDLINES DESIRED(MAX=15)
APCNC         ARRAY OF PERCENT CORRECTED SPEEDS
NPR   =2Ø     NO OF PRESSURE RATIOS DESIRED(MAX=2Ø)
APR           ARRAY OF PRESSURE RATIOS
NAR   =6      NO OF NOZZLE AREA RATIOS(MAX=6)
ARN           ARRAY OF FIRST STAGE NOZZLE AREA RATIOS
NSTG  =6      NO OF TURBINE STAGES(MAX=6)

INTEGER SWITCHES
JCOOL =Ø     COOLING FLOW SWITCH(Ø=UNCOOLED,1=COOLED)

DESIGN POINT VALUES OF:
DHQTD        SPECIFIC WORK OUTPUT DIVIDED BY TTIN
ETATTD       TURBINE TOTAL-TO-TOTAL EFFICIENCY
TFFD         TURBINE INLET FLOW FUNCTION
             (TFF=W*SQRT(TTIN)/PTIN)
XNRTD        TURBINE CORRECTED SPEED(N/SQRT(TTIN))
PSID         AVERAGE TURBINE PITCH LINE LOADING
             PSID=DHQT/(2*(U/SQRT(TTIN)**2/GJ))/NSTG
ANGSWX       EXIT PITCH LINE SWIRL ANGLE(+COUNT-ROT)
XMZXD        EXIT PITCH LINE AXIAL MACH NUMBER
TTIN         TURBINE INLET TOTAL TEMPERATURE
PTIN         TURBINE INLET TOTAL PRESSURE
FARGD        TURBINE INLET FUEL-AIR RATIO
ETAN         NOZZLE EFF(RATIO ACTUAL TO IDEAL EXIT KE)

GEOMETRY SPECIFICATIONS:
R3QR2        PITCHLINE RAD RATIO(ROTOR EXIT TO INLET)
RHQRT3       RADIUS RATIO AT ROTOR EXIT(FIRST GUESS)

 NAMELIST      INPUT
 NSPDS = 15,
 APCNC (I)=
 1        1Ø.ØØØØ,       2Ø.ØØØØ,       3Ø.ØØØØ,       4Ø.ØØØØ,
 5        5Ø.ØØØØ,       6Ø.ØØØØ,       7Ø.ØØØØ,       8Ø.ØØØØ,
 9        9Ø.ØØØØ,      1ØØ.ØØØØ,      11Ø.ØØØØ,      12Ø.ØØØØ,
13       13Ø.ØØØØ,      14Ø.ØØØØ,      15Ø.ØØØØ,
 NPR   = 2Ø,
 APR    (I)=
 1         1.1ØØØ,        1.2ØØØ,        1.4ØØØ,        1.6ØØØ,
 5         1.7ØØØ,        1.8ØØØ,        2.ØØØØ,        2.2ØØØ,
 9         2.4ØØØ,        2.6ØØØ,        2.8ØØØ,        3.ØØØØ,
```

```
13         3.2000,         3.4000,         3.6000,         3.8000,
17         4.0000,         4.2000,         4.4000,         4.6000,
 NAR    =  3,
 ARN    (I)=
 1         1.3000,         1.0000,         0.7000,         0.    ,
 5         0.    ,         0.    ,
 1         1.2490,         1.1440,         1.0000,         1.0000,
 NSTG   =  1,     JCOOL =  0,
 DHQTD  =        0.032780,       ETATTD=        0.923000,
 TFFD   =       62.980000,       XNRTD  =     193.520000,
 PSID   =        0.851100,       XMZXD  =        0.373000,
 ANGSWX=        15.200000,       TTIN   =     518.669998,
 PTIN   =       14.696000,       FARGD  =        0.      ,
 ETAN   =        0.940000,       R3QR2  =        1.000000,
 RHQRT3=         0.733300,
 END NAMELIST        INPUT
ENTER CHANGES TO NAMELIST INPUT
=$INPUTS
 NAMELIST        INPUT
 NSPDS  = 15,
 APCNC  (I)=
 1        10.0000,        20.0000,        30.0000,        40.0000,
 5        50.0000,        60.0000,        70.0000,        80.0000,
 9        90.0000,       100.0000,       110.0000,       120.0000,
13       130.0000,       140.0000,       150.0000,
 NPR    = 20,
 APR    (I)=
 1         1.1000,         1.2000,         1.4000,         1.6000,
 5         1.7000,         1.8000,         2.0000,         2.2000,
 9         2.4000,         2.6000,         2.8000,         3.0000,
13         3.2000,         3.4000,         3.6000,         3.8000,
17         4.0000,         4.2000,         4.4000,         4.6000,
 NAR    =  3,
 ARN    (I)=
 1         1.3000,         1.0000,         0.7000,         0.    ,
 5         0.    ,         0.    ,
 1         1.2490,         1.1440,         1.0000,         1.0000,
 NSTG   =  1,     JCOOL =  0,
 DHQTD  =        0.032780,       ETATTD=        0.923000,
 TFFD   =       62.980000,       XNRTD  =     193.520000,
 PSID   =        0.851100,       XMZXD  =        0.373000,
 ANGSWX=        15.200000,       TTIN   =     518.669998,
 PTIN   =       14.696000,       FARGD  =        0.      ,
 ETAN   =        0.940000,       R3QR2  =        1.000000,
 RHQRT3=         0.733300,
 END NAMELIST        INPUT
NASA OUTPUT ON IFC=15,16  &
```

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BETA	3	61.	68.	75.				
RPM	15	10.	20.	30.	40.	50.	60.	70.
RPM	15	80.	90.	100.	110.	120.	130.	140.
RPM	15	150.						
PR	20	1.10	1.20	1.40	1.60	1.70	1.80	2.00
PR	20	2.20	2.40	2.60	2.80	3.00	3.20	3.40
PR	20	3.60	3.80	4.00	4.20	4.40	4.60	
EFF	20	0.511	0.405	0.321	0.282	0.269	0.258	0.242
EFF	20	0.231	0.222	0.215	0.209	0.204	0.200	0.196
EFF	20	0.193	0.190	0.188	0.186	0.184	0.182	
EFF	20	0.765	0.655	0.550	0.497	0.479	0.464	0.441
EFF	20	0.424	0.412	0.401	0.393	0.386	0.380	0.375
EFF	20	0.371	0.367	0.363	0.360	0.357	0.354	
EFF	20	0.877	0.801	0.708	0.655	0.637	0.622	0.598
EFF	20	0.580	0.567	0.557	0.546	0.534	0.524	0.515
EFF	20	0.506	0.499	0.493	0.487	0.482	0.476	
EFF	20	0.912	0.879	0.811	0.765	0.748	0.733	0.711
EFF	20	0.691	0.667	0.648	0.632	0.619	0.604	0.591
EFF	20	0.580	0.570	0.561	0.553	0.545	0.538	
EFF	20	0.901	0.914	0.874	0.835	0.820	0.808	0.780
EFF.	20	0.750	0.725	0.705	0.685	0.667	0.652	0.639
EFF	20	0.628	0.617	0.608	0.600	0.592	0.585	
EFF	20	0.860	0.920	0.910	0.878	0.866	0.852	0.818
EFF	20	0.787	0.762	0.739	0.719	0.702	0.687	0.674
EFF	20	0.662	0.652	0.643	0.635	0.628	0.622	
EFF	20	0.799	0.905	0.925	0.902	0.892	0.877	0.841
EFF	20	0.811	0.785	0.762	0.743	0.726	0.712	0.699
EFF	20	0.688	0.678	0.669	0.661	0.654	0.647	
EFF	20	0.718	0.875	0.925	0.912	0.903	0.888	0.853
EFF	20	0.825	0.799	0.778	0.759	0.743	0.728	0.716
EFF	20	0.705	0.695	0.686	0.678	0.670	0.663	
EFF	20	0.622	0.833	0.915	0.911	0.905	0.891	0.859
EFF	20	0.831	0.807	0.786	0.768	0.753	0.739	0.727
EFF	20	0.716	0.706	0.697	0.689	0.681	0.674	
EFF	20	0.507	0.781	0.895	0.903	0.899	0.888	0.858
EFF	20	0.833	0.810	0.790	0.773	0.758	0.744	0.732
EFF	20	0.722	0.712	0.703	0.695	0.687	0.680	
EFF	20	0.385	0.719	0.868	0.888	0.889	0.879	0.853
EFF	20	0.830	0.809	0.790	0.774	0.759	0.746	0.734
EFF	20	0.724	0.714	0.706	0.698	0.690	0.683	
EFF	20	0.253	0.649	0.834	0.868	0.872	0.866	0.845
EFF	20	0.824	0.804	0.786	0.771	0.757	0.745	0.734
EFF	20	0.723	0.714	0.706	0.698	0.691	0.684	
EFF	20	0.106	0.571	0.794	0.844	0.852	0.850	0.833
EFF	20	0.815	0.797	0.780	0.766	0.752	0.741	0.730
EFF	20	0.721	0.712	0.704	0.696	0.689	0.683	
EFF	20	0.0	0.486	0.750	0.816	0.827	0.831	0.819
EFF	20	0.804	0.788	0.772	0.758	0.746	0.735	0.725
EFF	20	0.716	0.707	0.700	0.693	0.686	0.680	
EFF	20	0.0	0.394	0.701	0.784	0.799	0.809	0.802
EFF	20	0.791	0.777	0.762	0.749	0.737	0.727	0.717
EFF	20	0.709	0.701	0.694	0.687	0.681	0.675	
RPM	15	10.	20.	30.	40.	50.	60.	70.
RPM	15	80.	90.	100.	110.	120.	130.	140.
RPM	15	150.						
PR	20	1.10	1.20	1.40	1.60	1.70	1.80	2.00
PR	20	2.20	2.40	2.60	2.80	3.00	3.20	3.40
PR	20	3.60	3.80	4.00	4.20	4.40	4.60	
EFF	20	0.442	0.344	0.269	0.235	0.223	0.214	0.200
EFF	20	0.190	0.183	0.176	0.171	0.167	0.164	0.160
EFF	20	0.158	0.155	0.153	0.151	0.149	0.148	

EFF	20	0.695	0.578	0.474	0.422	0.405	0.390	0.369
EFF	20	0.352	0.340	0.330	0.321	0.314	0.308	0.303
EFF	20	0.299	0.295	0.291	0.288	0.285	0.282	
EFF	20	0.830	0.731	0.626	0.569	0.549	0.533	0.507
EFF	20	0.488	0.474	0.462	0.451	0.443	0.436	0.430
EFF	20	0.424	0.419	0.415	0.411	0.408	0.405	
EFF	20	0.893	0.827	0.736	0.682	0.662	0.646	0.620
EFF	20	0.600	0.585	0.573	0.563	0.554	0.546	0.540
EFF	20	0.534	0.529	0.527	0.524	0.522	0.520	
EFF	20	0.912	0.884	0.814	0.766	0.749	0.733	0.709
EFF	20	0.691	0.676	0.663	0.652	0.646	0.641	0.637
EFF	20	0.633	0.630	0.626	0.623	0.619	0.615	
EFF	20	0.900	0.911	0.866	0.828	0.813	0.800	0.778
EFF	20	0.760	0.745	0.735	0.727	0.721	0.715	0.709
EFF	20	0.702	0.696	0.690	0.685	0.680	0.675	
EFF	20	0.867	0.919	0.900	0.872	0.859	0.849	0.828
EFF	20	0.811	0.799	0.789	0.780	0.772	0.763	0.754
EFF	20	0.746	0.739	0.733	0.727	0.722	0.717	
EFF	20	0.817	0.910	0.918	0.901	0.892	0.884	0.864
EFF	20	0.848	0.836	0.825	0.816	0.804	0.794	0.785
EFF	20	0.776	0.769	0.762	0.756	0.750	0.744	
EFF	20	0.753	0.890	0.925	0.918	0.913	0.906	0.889
EFF	20	0.874	0.861	0.850	0.838	0.826	0.815	0.805
EFF	20	0.796	0.788	0.781	0.775	0.769	0.763	
EFF	20	0.676	0.859	0.922	0.926	0.924	0.919	0.905
EFF	20	0.890	0.877	0.865	0.852	0.839	0.828	0.818
EFF	20	0.809	0.801	0.794	0.787	0.781	0.775	
EFF	20	0.589	0.820	0.912	0.927	0.928	0.925	0.913
EFF	20	0.899	0.886	0.874	0.860	0.847	0.836	0.826
EFF	20	0.817	0.809	0.801	0.794	0.788	0.782	
EFF	20	0.486	0.774	0.895	0.921	0.926	0.925	0.916
EFF	20	0.902	0.889	0.878	0.864	0.851	0.840	0.830
EFF	20	0.821	0.813	0.805	0.798	0.791	0.785	
EFF	20	0.379	0.721	0.873	0.910	0.919	0.921	0.915
EFF	20	0.902	0.889	0.878	0.864	0.852	0.840	0.831
EFF	20	0.822	0.813	0.806	0.799	0.792	0.786	
EFF	20	0.265	0.661	0.845	0.895	0.907	0.912	0.909
EFF	20	0.897	0.886	0.875	0.861	0.849	0.838	0.829
EFF	20	0.820	0.812	0.804	0.797	0.791	0.785	
EFF	20	0.141	0.596	0.813	0.875	0.891	0.900	0.900
EFF	20	0.891	0.880	0.870	0.857	0.845	0.834	0.825
EFF	20	0.816	0.808	0.801	0.794	0.788	0.782	
RPM	15	10.	20.	30.	40.	50.	60.	70.
RPM	15	80.	90.	100.	110.	120.	130.	140.
RPM	15	150.						
PR	20	1.10	1.20	1.40	1.60	1.70	1.80	2.00
PR	20	2.20	2.40	2.60	2.80	3.00	3.20	3.40
PR	20	3.60	3.80	4.00	4.20	4.40	4.60	
EFF	20	0.372	0.287	0.222	0.193	0.184	0.176	0.164
EFF	20	0.156	0.149	0.144	0.140	0.136	0.133	0.131
EFF	20	0.128	0.126	0.125	0.123	0.122	0.120	
EFF	20	0.602	0.491	0.397	0.351	0.335	0.323	0.304
EFF	20	0.290	0.279	0.270	0.263	0.256	0.251	0.247
EFF	20	0.243	0.239	0.236	0.233	0.231	0.228	
EFF	20	0.739	0.634	0.532	0.478	0.460	0.445	0.421
EFF	20	0.403	0.390	0.378	0.369	0.361	0.355	0.349
EFF	20	0.344	0.339	0.335	0.331	0.328	0.325	
EFF	20	0.816	0.732	0.635	0.580	0.561	0.545	0.519
EFF	20	0.500	0.484	0.472	0.461	0.452	0.445	0.438
EFF	20	0.432	0.427	0.423	0.418	0.415	0.411	
EFF	20	0.854	0.796	0.713	0.661	0.642	0.626	0.600
EFF	20	0.580	0.564	0.551	0.540	0.531	0.523	0.516

EFF 20	0.510	0.505	0.500	0.495	0.491	0.488	
EFF 20	0.865	0.837	0.770	0.724	0.706	0.691	0.666
EFF 20	0.647	0.631	0.619	0.608	0.593	0.591	0.584
EFF 20	0.578	0.573	0.568	0.563	0.559	0.555	
EFF 20	0.858	0.859	0.812	0.772	0.756	0.742	0.719
EFF 20	0.702	0.688	0.676	0.666	0.657	0.649	0.643
EFF 20	0.637	0.631	0.626	0.622	0.618	0.614	
EFF 20	0.837	0.868	0.841	0.809	0.795	0.783	0.763
EFF 20	0.747	0.734	0.723	0.714	0.706	0.690	0.692
EFF 20	0.686	0.681	0.677	0.673	0.669	0.666	
EFF 20	0.804	0.866	0.860	0.835	0.824	0.814	0.798
EFF 20	0.784	0.773	0.763	0.754	0.746	0.740	0.734
EFF 20	0.729	0.724	0.720	0.716	0.713	0.710	
EFF 20	0.762	0.856	0.870	0.854	0.846	0.838	0.825
EFF 20	0.813	0.803	0.794	0.787	0.780	0.774	0.769
EFF 20	0.765	0.760	0.757	0.753	0.751	0.748	
EFF 20	0.712	0.839	0.874	0.867	0.860	0.855	0.845
EFF 20	0.836	0.828	0.820	0.814	0.808	0.803	0.798
EFF 20	0.794	0.790	0.789	0.785	0.783	0.780	
EFF 20	0.655	0.816	0.872	0.873	0.870	0.867	0.860
EFF 20	0.853	0.847	0.841	0.835	0.830	0.826	0.822
EFF 20	0.818	0.816	0.813	0.811	0.809	0.807	
EFF 20	0.590	0.788	0.866	0.875	0.875	0.874	0.871
EFF 20	0.866	0.861	0.856	0.852	0.843	0.844	0.841
EFF 20	0.838	0.836	0.834	0.832	0.830	0.828	
EFF 20	0.519	0.755	0.855	0.873	0.875	0.877	0.877
EFF 20	0.875	0.871	0.868	0.865	0.861	0.858	0.856
EFF 20	0.854	0.852	0.850	0.849	0.847	0.841	
EFF 20	0.437	0.718	0.840	0.868	0.873	0.876	0.880
EFF 20	0.880	0.878	0.876	0.874	0.871	0.869	0.867
EFF 20	0.866	0.864	0.863	0.862	0.857	0.851	
EOT							

270 TURBINE FLOW FUNCTION VS. PR, RPM, AND BETA

BETA	3	61.	68.	75.				
RPM	15	10.	20.	30.	40.	50.	60.	70.
RPM	15	80.	90.	100.	110.	120.	130.	140.
RPM	15	150.						
PR	20	1.10	1.20	1.40	1.60	1.70	1.80	2.00
PR	20	2.20	2.40	2.60	2.80	3.00	3.20	3.40
PR	20	3.60	3.80	4.00	4.20	4.40	4.60	
TFF	20	68.255	82.286	83.415	83.415	83.415	83.415	83.415
TFF	20	83.415	83.415	83.415	83.415	83.415	83.415	83.415
TFF	20	83.415	83.415	83.415	83.415	83.415	83.415	
TFF	20	57.320	75.666	81.115	81.115	81.115	81.115	81.115
TFF	20	81.115	81.115	81.115	81.115	81.115	81.115	81.115
TFF	20	81.115	81.115	81.115	81.115	81.115	81.115	
TFF	20	49.673	68.861	79.254	79.254	79.254	79.254	79.254
TFF	20	79.254	79.254	79.254	79.254	79.254	79.254	79.254
TFF	20	79.254	79.254	79.254	79.254	79.254	79.254	
TFF	20	44.944	63.159	77.026	77.742	77.742	77.742	77.742
TFF	20	77.742	77.742	77.742	77.742	77.742	77.742	77.742
TFF	20	77.742	77.742	77.742	77.742	77.742	77.742	
TFF	20	42.231	58.847	74.137	76.517	76.517	76.517	76.517
TFF	20	76.517	76.517	76.517	76.517	76.517	76.517	76.517
TFF	20	76.517	76.517	76.517	76.517	76.517	76.517	
TFF	20	40.912	55.833	71.302	75.480	75.550	75.550	75.550
TFF	20	75.550	75.550	75.550	75.550	75.550	75.550	75.550
TFF	20	75.550	75.550	75.550	75.550	75.550	75.550	
TFF	20	40.566	53.859	68.812	74.095	74.751	74.769	74.769
TFF	20	74.769	74.769	74.769	74.769	74.769	74.769	74.769
TFF	20	74.769	74.769	74.769	74.769	74.769	74.769	
TFF	20	40.864	52.736	66.866	72.650	73.802	74.179	74.192
TFF	20	74.192	74.192	74.192	74.192	74.192	74.192	74.192
TFF	20	74.192	74.192	74.192	74.192	74.192	74.192	
TFF	20	41.638	52.267	65.456	71.369	72.796	73.497	73.780
TFF	20	73.780	73.780	73.780	73.780	73.780	73.780	73.780
TFF	20	73.780	73.780	73.780	73.780	73.780	73.780	
TFF	20	42.717	52.303	64.521	70.363	71.930	72.814	73.490
TFF	20	73.519	73.519	73.519	73.519	73.519	73.519	73.519
TFF	20	73.519	73.519	73.519	73.519	73.519	73.519	
TFF	20	44.132	52.746	64.009	69.668	71.297	72.268	73.205
TFF	20	73.396	73.396	73.396	73.396	73.396	73.396	73.396
TFF	20	73.396	73.396	73.396	73.396	73.396	73.396	
TFF	20	45.774	53.515	63.875	69.282	70.895	71.919	73.005
TFF	20	73.375	73.400	73.400	73.400	73.400	73.400	73.400
TFF	20	73.400	73.400	73.400	73.400	73.400	73.400	
TFF	20	47.558	54.551	64.063	69.184	70.743	71.788	72.943
TFF	20	73.422	73.520	73.520	73.520	73.520	73.520	73.520
TFF	20	73.520	73.520	73.520	73.520	73.520	73.520	
TFF	20	49.830	55.792	64.526	69.345	70.826	71.873	73.037
TFF	20	73.573	73.741	73.746	73.746	73.746	73.746	73.746
TFF	20	73.746	73.746	73.746	73.746	73.746	73.746	
TFF	20	52.868	57.218	65.223	69.734	71.123	72.157	73.287
TFF	20	73.842	74.048	74.070	74.070	74.070	74.070	74.070
TFF	20	74.070	74.070	74.070	74.070	74.070	74.070	
RPM	15	10.	20.	30.	40.	50.	60.	70.
RPM	15	80.	90.	100.	110.	120.	130.	140.
RPM	15	150.						
PR	20	1.10	1.20	1.40	1.60	1.70	1.80	2.00
PR	20	2.20	2.40	2.60	2.80	3.00	3.20	3.40
PR	20	3.60	3.80	4.00	4.20	4.40	4.60	
TFF	20	46.554	59.744	66.417	66.427	66.427	66.427	66.427
TFF	20	66.427	66.427	66.427	66.427	66.427	66.427	66.427
TFF	20	66.427	66.427	66.427	66.427	66.427	66.427	

TFF	20	41.255	55.777	65.717	66.427	66.427	66.427	66.427
TFF	20	66.427	66.427	66.427	66.427	66.427	66.427	66.427
TFF	20	66.427	66.427	66.427	66.427	66.427	66.427	
TFF	20	37.670	52.242	64.290	66.427	66.427	66.427	66.427
TFF	20	66.427	66.427	66.427	66.427	66.427	66.427	66.427
TFF	20	66.427	66.427	66.427	66.427	66.427	66.427	
TFF	20	35.530	49.451	62.558	66.278	66.427	66.427	66.427
TFF	20	66.427	66.427	66.427	66.427	66.427	66.427	66.427
TFF	20	66.427	66.427	66.427	66.427	66.427	66.427	
TFF	20	34.501	47.430	60.852	65.694	66.374	66.427	66.427
TFF	20	66.427	66.427	66.427	66.427	66.427	66.427	66.427
TFF	20	66.427	66.427	66.427	66.427	66.427	66.427	
TFF	20	34.272	46.110	59.337	64.877	66.007	66.415	66.427
TFF	20	66.427	66.427	66.427	66.427	66.427	66.427	66.427
TFF	20	66.427	66.427	66.427	66.427	66.427	66.427	
TFF	20	34.596	45.357	58.072	63.971	65.408	66.160	66.387
TFF	20	66.387	66.387	66.387	66.387	66.387	66.387	66.387
TFF	20	66.387	66.387	66.387	66.387	66.387	66.387	
TFF	20	35.099	44.793	56.747	62.716	64.335	65.320	65.919
TFF	20	65.919	65.919	65.919	65.919	65.919	65.919	65.919
TFF	20	65.919	65.919	65.919	65.919	65.919	65.919	
TFF	20	35.854	44.574	55.687	61.549	63.235	64.365	65.330
TFF	20	65.400	65.400	65.400	65.400	65.400	65.400	65.400
TFF	20	65.400	65.400	65.400	65.400	65.400	65.400	
TFF	20	36.817	44.668	54.935	60.578	62.303	63.470	64.666
TFF	20	64.918	64.918	64.918	64.918	64.918	64.918	64.918
TFF	20	64.918	64.918	64.918	64.918	64.918	64.918	
TFF	20	37.966	45.050	54.503	59.865	61.563	62.744	64.070
TFF	20	64.514	64.535	64.535	64.535	64.535	64.535	64.535
TFF	20	64.535	64.535	64.535	64.535	64.535	64.535	
TFF	20	39.203	45.636	54.319	59.365	61.005	62.172	63.553
TFF	20	64.114	64.217	64.217	64.217	64.217	64.217	64.217
TFF	20	64.217	64.217	64.217	64.217	64.217	64.217	
TFF	20	40.599	46.414	54.379	59.096	60.659	61.793	63.175
TFF	20	63.799	63.996	64.000	64.000	64.000	64.000	64.000
TFF	20	64.000	64.000	64.000	64.000	64.000	64.000	
TFF	20	42.086	47.339	54.635	59.020	60.494	61.583	62.929
TFF	20	63.576	63.834	63.863	63.863	63.863	63.863	63.863
TFF	20	63.863	63.863	63.863	63.863	63.863	63.863	
TFF	20	43.622	48.382	55.057	59.113	60.491	61.527	62.812
TFF	20	63.455	63.739	63.799	63.799	63.799	63.799	63.799
TFF	20	63.799	63.799	63.799	63.799	63.799	63.799	
RPM	15	10.	20.	30.	40.	50.	60.	70.
RPM	15	80.	90.	100.	110.	120.	130.	140.
RPM	15	150.						
PR	20	1.10	1.20	1.40	1.60	1.70	1.80	2.00
PR	20	2.20	2.40	2.60	2.80	3.00	3.20	3.40
PR	20	3.60	3.80	4.00	4.20	4.40	4.60	
TFF	20	31.643	40.636	46.229	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	
TFF	20	28.946	38.494	45.552	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	
TFF	20	27.234	36.733	44.688	46.490	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	
TFF	20	26.354	35.425	43.814	46.317	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	
TFF	20	25.111	34.574	43.034	46.015	46.451	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	46.499

TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	
TFF	20	26.350	34.136	42.408	45.672	46.294	46.497	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	
TFF	20	26.936	34.033	41.960	45.349	46.097	46.441	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	
TFF	20	27.769	34.210	41.689	45.080	45.904	46.344	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	
TFF	20	28.776	34.603	41.580	44.891	45.746	46.243	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	
TFF	20	29.900	35.163	41.615	44.784	45.637	46.162	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	
TFF	20	31.101	35.846	41.770	44.754	45.582	46.109	46.498
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	
TFF	20	32.345	36.617	42.022	44.795	45.579	46.089	46.493
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	
TFF	20	33.607	37.446	42.350	44.895	45.623	46.101	46.491
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	
TFF	20	34.868	38.310	42.732	45.042	45.703	46.138	46.492
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	
TFF	20	36.091	39.187	43.151	45.222	45.811	46.196	46.496
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	46.499
TFF	20	46.499	46.499	46.499	46.499	46.499	46.499	
EOT								

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*REMOVE CLEARFILES
*OLD /NASAPT/NASAPART
*FRN

0Q062   10/20/83    10.202


******************PARAMETRIC TURBINE******************

                       P*A*R*T

AXIAL OR RADIAL TURBINE?  1=RADIAL, 0 OR CR=AXIAL
=1

DESCRIPTION OF INPUT VARIABLES IN PART PROGRAM
(NAMELIST INPUT)

UNITS:TTIN=DEG R,PTIN=PSIA,W=PPS,H=BTU/LBM,N=RPM

MAP RANGE(ARRAY VALUES MUST BE IN ASCENDING ORDER)
NSPDS =15     NO OF SPEEDLINES DESIRED(MAX=15)
APCNC         ARRAY OF PERCENT CORRECTED SPEEDS
NPR   =20     NO OF PRESSURE RATIOS DESIRED(MAX=20)
APR           ARRAY OF PRESSURE RATIOS
NAR   =6      NO OF NOZZLE AREA RATIOS(MAX=6)
ARN           ARRAY OF FIRST STAGE NOZZLE AREA RATIOS
NSTG  =6      NO OF TURBINE STAGES(MAX=6)

INTEGER SWITCHES
JCOOL =0     COOLING FLOW SWITCH(0=UNCOOLED,1=COOLED)

DESIGN POINT VALUES OF:
DHQTD        SPECIFIC WORK OUTPUT DIVIDED BY TTIN
ETATTD       TURBINE TOTAL-TO-TOTAL EFFICIENCY
TFFD         TURBINE INLET FLOW FUNCTION
             (TFF=W*SQRT(TTIN)/PTIN)
XNRTD        TURBINE CORRECTED SPEED(N/SQRT(TTIN))
PSID         AVERAGE TURBINE PITCH LINE LOADING
             PSID=DHQT/(2*(U/SQRT(TTIN)**2/GJ))/NSTG
ANGSWX       EXIT PITCH LINE SWIRL ANGLE(+COUNT-ROT)
XMZXD        EXIT PITCH LINE AXIAL MACH NUMBER
TTIN         TURBINE INLET TOTAL TEMPERATURE
PTIN         TURBINE INLET TOTAL PRESSRUE
FARGD        TURBINE INLET FUEL-AIR RATIO
ETAN         NOZZLE EFF(RATIO ACTUAL TO IDEAL EXIT KE)

GEOMETRY SPECIFICATIONS:
R3QR2        PITCHLINE RAD RATIO(ROTOR EXIT TO INLET)
RHQRT3       RADIUS RATIO AT ROTOR EXIT(FIRST GUESS)

 NAMELIST      INPUT
 NSPDS = 15,
 APCNC (I)=
 1       10.0000,      20.0000,      30.0000,      40.0000,
 5       50.0000,      60.0000,      70.0000,      80.0000,
 9       90.0000,     100.0000,     110.0000,     120.0000,
13      130.0000,     140.0000,     150.0000,
 NPR   = 20,
 APR    (I)=
 1        1.1000,       1.2000,       1.4000,       1.6000,
 5        1.7000,       1.8000,       2.0000,       2.2000,
 9        2.4000,       2.6000,       2.8000,       3.0000,
```

```
13         3.2000,          3.4000,          3.6000,          3.8000,
17         4.0000,          4.2000,          4.4000,          4.6000,
 NAR    =  1,
 ARN    (I)=
 1         1.0000,          0.      ,        0.      ,        0.      ,
 5         0.      ,        0.      ,
 1         0.3300,          1.1440,          1.0000,          1.0000,
 NSTG   =  1,    JCOOL =  0,
 DHOTD  =        0.049330,        ETATTD=        0.868000,
 TFFD   =        0.339500,        XNRTD  =     1718.000000,
 PSID   =        0.487100,        XMZXD  =        0.220000,
 ANGSWX=         0.       ,       TTIN   =      850.000000,
 PTIN   =       37.930000,        FARGD  =        0.       ,
 ETAN   =        0.940000,        R3QR2  =        0.291000,
 RHORT3=         0.200000,
 END NAMELIST        INPUT
ENTER CHANGES TO NAMELIST INPUT
=SINPUTS
 NAMELIST       INPUT
 NSPDS = 15,
 APCNC (I)=
 1        10.0000,         20.0000,         30.0000,         40.0000,
 5        50.0000,         60.0000,         70.0000,         80.0000,
 9        90.0000,        100.0000,        110.0000,        120.0000,
13       130.0000,        140.0000,        150.0000,
 NPR   = 20,
 APR     (I)=
 1         1.1000,          1.2000,          1.4000,          1.6000,
 5         1.7000,          1.8000,          2.0000,          2.2000,
 9         2.4000,          2.6000,          2.8000,          3.0000,
13         3.2000,          3.4000,          3.6000,          3.8000,
17         4.0000,          4.2000,          4.4000,          4.6000,
 NAR    =  1,
 ARN    (I)=
 1         1.0000,          0.      ,        0.      ,        0.      ,
 5         0.      ,        0.      ,
 1         0.3300,          1.1440,          1.0000,          1.0000,
 NSTG   =  1,    JCOOL =  0,
 DHOTD  =        0.049330,        ETATTD=        0.868000,
 TFFD   =        0.339500,        XNRTD  =     1718.000000,
 PSID   =        0.487100,        XMZXD  =        0.220000,
 ANGSWX=         0.       ,       TTIN   =      850.000000,
 PTIN   =       37.930000,        FARGD  =        0.       ,
 ETAN   =        0.940000,        R3QR2  =        0.291000,
 RHORT3=         0.200000,
 END NAMELIST        INPUT
NASA OUTPUT ON IFC=15,16  &
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269 TURBINE EFFICIENCY VS. PR, RPM, AND BETA

BETA	1	50.						
RPM	15	10.	20.	30.	40.	50.	60.	70.
RPM	15	80.	90.	100.	110.	120.	130.	140.
RPM	15	150.						
PR	20	1.10	1.20	1.40	1.60	1.70	1.80	2.00
PR	20	2.20	2.40	2.60	2.80	3.00	3.20	3.40
PR	20	3.60	3.80	4.00	4.20	4.40	4.60	
EFF	20	0.354	0.262	0.197	0.169	0.160	0.152	0.142
EFF	20	0.134	0.128	0.123	0.119	0.116	0.113	0.111
EFF	20	0.109	0.107	0.105	0.104	0.102	0.101	
EFF	20	0.644	0.496	0.380	0.328	0.311	0.298	0.277
EFF	20	0.262	0.251	0.242	0.234	0.228	0.223	0.218
EFF	20	0.214	0.211	0.207	0.205	0.202	0.200	
EFF	20	0.825	0.687	0.545	0.475	0.452	0.433	0.405
EFF	20	0.384	0.368	0.355	0.344	0.335	0.328	0.321
EFF	20	0.315	0.310	0.306	0.302	0.298	0.294	
EFF	20	0.831	0.817	0.684	0.606	0.579	0.557	0.522
EFF	20	0.497	0.477	0.461	0.448	0.437	0.427	0.419
EFF	20	0.412	0.405	0.399	0.394	0.389	0.385	
EFF	20	0.491	0.861	0.790	0.717	0.689	0.666	0.628
EFF	20	0.600	0.577	0.559	0.544	0.531	0.520	0.510
EFF	20	0.502	0.494	0.487	0.481	0.476	0.471	
EFF	20	0.0	0.772	0.853	0.802	0.778	0.756	0.720
EFF	20	0.691	0.667	0.647	0.631	0.617	0.605	0.594
EFF	20	0.585	0.576	0.569	0.562	0.556	0.550	
EFF	20	0.0	0.445	0.860	0.856	0.841	0.824	0.793
EFF	20	0.766	0.744	0.724	0.708	0.693	0.681	0.670
EFF	20	0.660	0.651	0.642	0.635	0.628	0.621	
EFF	20	0.0	0.0	0.786	0.868	0.870	0.864	0.845
EFF	20	0.825	0.806	0.788	0.773	0.759	0.746	0.735
EFF	20	0.724	0.715	0.706	0.699	0.691	0.685	
EFF	20	0.0	0.0	0.591	0.825	0.857	0.870	0.872
EFF	20	0.862	0.850	0.837	0.824	0.811	0.799	0.788
EFF	20	0.778	0.770	0.761	0.754	0.747	0.741	
EFF	20	0.0	0.0	0.121	0.705	0.786	0.829	0.865
EFF	20	0.874	0.873	0.867	0.857	0.848	0.838	0.830
EFF	20	0.821	0.814	0.807	0.800	0.794	0.788	
EFF	20	0.0	0.0	0.0	0.462	0.631	0.725	0.817
EFF	20	0.854	0.870	0.874	0.872	0.868	0.863	0.857
EFF	20	0.851	0.845	0.839	0.834	0.829	0.824	
EFF	20	0.0	0.0	0.0	0.0	0.330	0.522	0.709
EFF	20	0.792	0.833	0.855	0.864	0.868	0.869	0.867
EFF	20	0.865	0.862	0.858	0.855	0.851	0.847	
EFF	20	0.0	0.0	0.0	0.0	0.0	0.122	0.510
EFF	20	0.670	0.753	0.800	0.828	0.843	0.853	0.858
EFF	20	0.860	0.861	0.861	0.860	0.859	0.857	
EFF	20	0.0	0.0	0.0	0.0	0.0	0.0	0.132
EFF	20	0.452	0.607	0.696	0.751	0.786	0.809	0.824
EFF	20	0.834	0.840	0.845	0.848	0.850	0.851	
EFF	20	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EFF	20	0.037	0.353	0.517	0.615	0.681	0.727	0.757
EFF	20	0.779	0.795	0.806	0.815	0.821	0.826	
EOT								

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BETA	1	50.						
RPM	15	10.	20.	30.	40.	50.	60.	70.
RPM	15	80.	90.	100.	110.	120.	130.	140.
RPM	15	150.						
PR	20	1.10	1.20	1.40	1.60	1.70	1.80	2.00
PR	20	2.20	2.40	2.60	2.80	3.00	3.20	3.40
PR	20	3.60	3.80	4.00	4.20	4.40	4.60	
TFF	20	0.217	0.278	0.327	0.339	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	
TFF	20	0.204	0.271	0.324	0.338	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	
TFF	20	0.182	0.259	0.319	0.337	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	
TFF	20	0.147	0.241	0.312	0.335	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	
TFF	20	0.085	0.215	0.302	0.331	0.337	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	
TFF	20	0.026	0.175	0.287	0.325	0.333	0.338	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	
TFF	20	0.030	0.107	0.264	0.314	0.326	0.334	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	
TFF	20	0.035	0.035	0.230	0.299	0.316	0.326	0.337
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	
TFF	20	0.039	0.039	0.176	0.274	0.298	0.314	0.332
TFF	20	0.338	0.339	0.339	0.339	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	
TFF	20	0.043	0.043	0.070	0.234	0.269	0.293	0.321
TFF	20	0.334	0.339	0.339	0.339	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	
TFF	20	0.047	0.047	0.047	0.168	0.223	0.259	0.301
TFF	20	0.323	0.334	0.338	0.339	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	
TFF	20	0.052	0.052	0.052	0.052	0.141	0.201	0.268
TFF	20	0.303	0.322	0.332	0.337	0.339	0.339	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	
TFF	20	0.056	0.056	0.056	0.056	0.056	0.090	0.211
TFF	20	0.268	0.300	0.318	0.329	0.335	0.338	0.339
TFF	20	0.339	0.339	0.339	0.339	0.339	0.339	
TFF	20	0.060	0.060	0.060	0.060	0.060	0.060	0.100
TFF	20	0.204	0.258	0.290	0.310	0.323	0.331	0.335
TFF	20	0.338	0.339	0.339	0.339	0.339	0.339	
TFF	20	0.065	0.065	0.065	0.065	0.065	0.065	0.065
TFF	20	0.076	0.181	0.239	0.274	0.297	0.313	0.323
TFF	20	0.329	0.334	0.337	0.338	0.339	0.339	
EOT								

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7.0 ANALYTICAL BACKGROUND

The following section has been written in order to give the user a general idea of the type of turbine representation used in the program and the approach used in the derivation of the equations. Details of the derivations together with sample calculations may be found in the Monthly Progress Reports (e.g., References 10, 11, and 12).

7.1 TURBINE MAP REPRESENTATION

Typically, cycle deck entry to a turbine map is through corrected speed, N/SQRT(T), and actual energy, DH/T, with turbine flow function, W*SQRT(T)/P, and total-to-total efficiency being output. Total-to-total pressure ratio is sometimes used instead of actual energy as the second map entry.

The discussion of the turbine map representation can be conveniently subdivided into two parts: the flow and the efficiency.

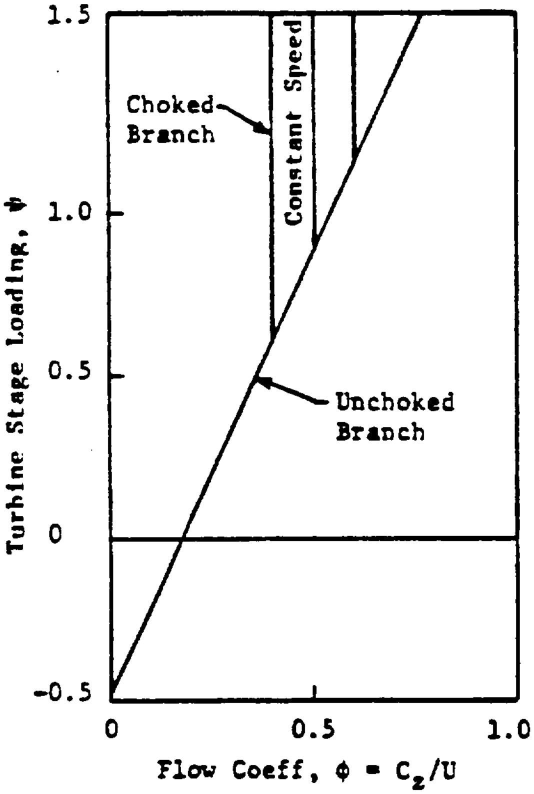
The flow model is illustrated by the three sketches shown in Figure 4. The two curves on the top in the figure are used to generate the flow representation on the bottom. Sketch 4-1 shows the turbine stage characteristic (i.e., a plot of turbine loading against flow coefficient). Sketch 4-2 shows the dependence of the maximum value of the turbine flow function on corrected speed. With the corrected speed and DH/T known, the stage loading can be calculated, and the flow coefficient obtained from Sketch 4-1. Once the flow is choked (i.e., the choked branch of the stage characteristic), the flow coefficient remains constant for that speed. Sketch 4-2 is next used to obtain the maximum value of the turbine flow function at the corrected speed of interest. The value of the turbine flow function is then calculated. The equations used are as follows:

$$U/A_t = (2\pi R/60)\ (N/\sqrt{\gamma R_g g_o T}$$

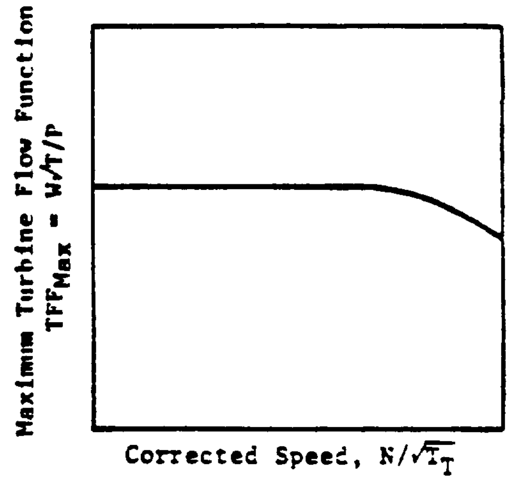
$$\psi = (DH/T)/[2(U/\sqrt{T})^2/g_o J]$$

$$C/A_t = (\phi/\mathrm{Cos}\ \alpha_2)/(U/A_t)$$

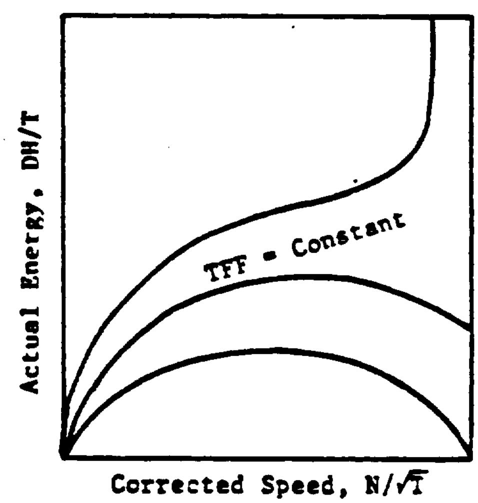
$$TFF = (TFF)_{max} \frac{C/A_t\left(1 - \frac{\gamma-1}{2}\left(\frac{C}{A_t}\right)^2\right)^{\frac{1}{\gamma-1}}}{\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}}}$$



4-1 Stage Characteristic



4-2 Maximum Flow Function



4-3 Flow Function Contours

Figure 4. Turbine Flow Representation.

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where

DH/T = turbine stage specific enthalpy drop divided by inlet total temperature, Btu/lbm R

N/SQRT(T) = corrected speed, RPM/SQRT(R)

R = pitch line radius, ft

C = velocity, ft/sec

A_t = speed of sound at inlet total temperature, ft/sec

TFF = inlet turbine flow function, lbm/sec*SQRT(R)/psia

$Cos(\alpha_2)$ = nozzle exit angle

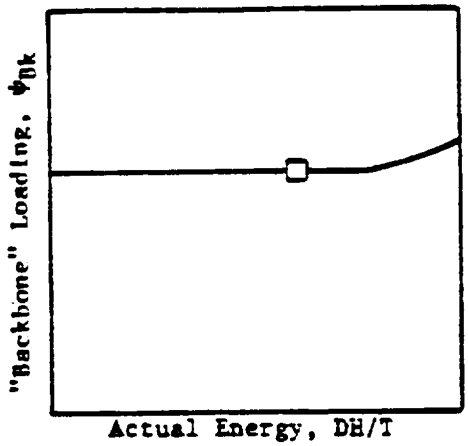
The value of $Cos(\alpha_2)$ is obtained from the design point information as is the value of the pitch line radius.

The efficiency model is illustrated by the five sketches shown in Figure 5. The first three curves in the figure are used to generate the last two sketches. The "backbone" of the turbine map shown in Sketch 5-4 is the locus of the peak efficiency at each value of DH/T. This locus is obtained from Sketch 5-1, which shows turbine pitch line loading along the map "backbone" as a function of DH/T. The "backbone" efficiencies are obtained from Sketch 5-2. This sketch gives the "backbone" loss (defined as the difference between the ideal and actual values of DH/T) as a funciton of DH/T. With the "backbone" loading and efficiencies known at each DH/T, Sketch 5-3 is used to evaluate the "off-backbone" loss and to obtain the efficiency at any value of corrected speed. When the turbine "off-backbone" loss is plotted with the coordinates shown in Sketch 5-3, the resulting curves are nearly linear at any given DH/T. These five curves, three univariate and two bivariate, are sufficient to define the turbine map. Note that as shown on Sketch 5-5, the design point does not generally fall on the "backbone" but is seperated from it by a "stand-off" distance which is calculated from design point information.

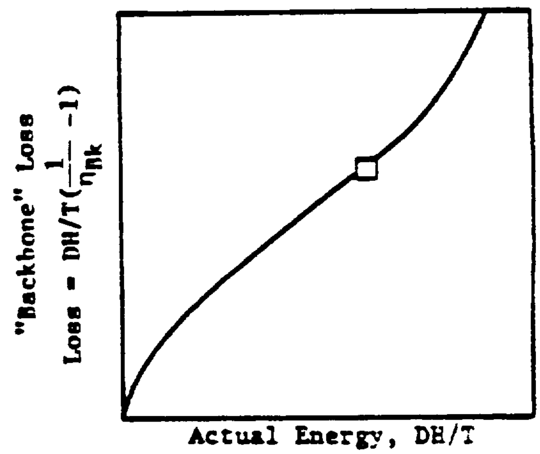
The analytical basis for the five correlating curves is discussed in the following sections.

7.2 TURBINE FLOW MODEL

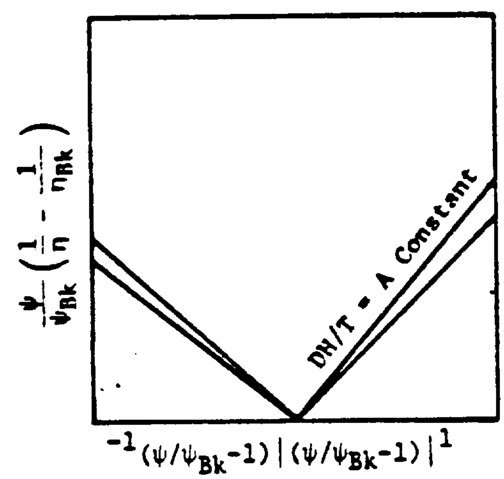
The turbine stage characteristic serves as the basis for modeling the turbine flow. An analytical expression for the stage characteristic of a turbine can be obtained by using the continuity, energy, and angular momentum equations, together with a number of relationships from the pitch line vector diagram. In deriving this equation, it is assumed that the pitch line flow angles at nozzle and bucket exit are invariant, and that the axial velocity ratio across the bucket is constant.



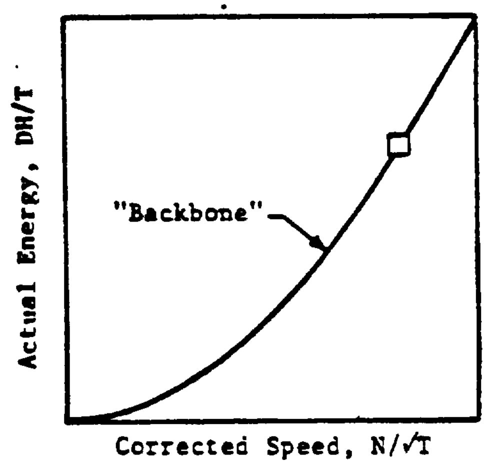
5-1 Backbone Loading



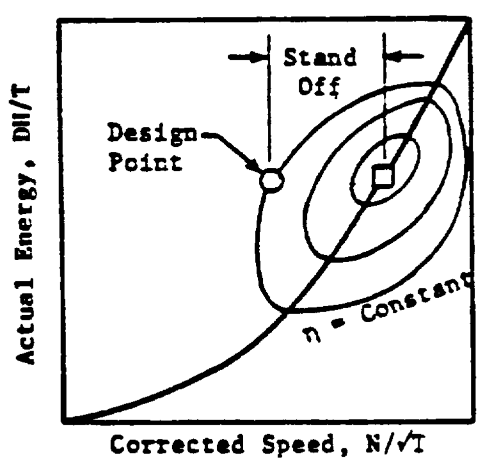
5-2 Backbone Loss



5-3 Loss Function



5-4 Backbone Locus



5-5 Efficiency Contours

Figure 5. Turbine Efficiency Representation.

This later assumption is reasonable for incompressible or low Mach number (M 0.25) flows. It should be emphasized, however, that the final correlations have no such restrictions.

The stage characteristic for a single-stage turbine with the above assumptions can be written in the form

$$\psi = \frac{\phi}{2}\left(\tan\alpha_2 + \frac{C_{z3}}{C_{z2}}\frac{R_3}{R_2}\tan\beta_3\right) - \frac{1}{2}\left(\frac{R_3}{R_2}\right)^2 \qquad (1)$$

where

- ψ = $DH/(2U_2^2/g_0 J)$, Turbine stage Loading
- C_z = Meridional velocity component
- ϕ = C_{z2}/U_2, Flow coefficient
- α_2 = Nozzle exit flow angle
- β_3 = Bucket exit flow angle
- R = Turbine Pitch Line Radius

Selecting a reference point and assuming that

$$\tan\alpha_2 + \frac{C_{z3}}{C_{z2}}\;\frac{R_3}{R_2}\;\tan\beta_3 = \text{a constant},$$

this equation may be written as

$$\frac{\psi}{\psi_R} = \frac{\phi}{\phi_R} + \frac{1}{2\psi_R}\left(\frac{R_3}{R_2}\right)^2\left(\frac{\phi}{\phi_R} - 1\right) \qquad (2)$$

For unchoked flow, the reference point (indicated by the subscript R) was selected at the design point on the turbine map. For choked flow, the reference point was selected at the critical point (subscript CRIT) on the turbine map. The critical point is located at the value of DH/T at the reference speed (e.g., 100%) where nozzle choking first occurs. For a variable-geometry turbine, the angle α_2 is calculated from the input value of nozzle area ratio.

The equation used for the normalized flow coefficient is

$$\frac{\phi}{\phi_R} = \frac{C_z/A_t}{(C_z/A_t)_R}\,\frac{(N/\sqrt{T})_R}{N/\sqrt{T}} = \frac{C/A_t}{(C/A_t)_R}\,\frac{(N/\sqrt{T})_R}{N/\sqrt{T}} \qquad (3)$$

The velocity ratio, C/A_t, for a point at a selected speed is determined by calculating a pseudoarea at which the Mach number is assumed to be unity (i.e., at the maximum turbine flow function for that speed). This pseudoarea is assumed to be constant for that speed. The Mach number (velocity ratio) at any point on the speed line is then calculated from the usual flow function equations. By definition, the pseudoarea varies with speed in direct proportion to the maximum turbine flow function variation with speed. This method of calculating the flow coefficient was found to give better results than that obtained using the first stage nozzle throat area for all speeds. For the case in which the first stage nozzle is choked, the two procedures are identical.

Typically, the calculated and measured values of velocity ratio are within about 6%, with the larger errors occurring at the higher Mach numbers. The predicted value of the normalized flow coefficient intercept (at DH/T=0) are within about 5% of experimentally derived values. These errors combine to yield flow errors on the order of 5% for nominal area maps (i.e., nozzle area ratios equal to 1). Slightly higher values may occur for other stator settings.

A typical comparison between measured and calculated values of the turbine flow function is shown in Figure 6. This figure is for test turbine number 25 in Table 1. The maximum error shown on this figure is about 2.4% and occurs at the lower end of the test data. This type of plot was used in obtaining the error estimates given above.

7.3 TURBINE LOSS MODEL

There are four key steps in the development of the equations governing the turbine off-design loss model. These steps are

1. The development of an equation giving the turbine total-to-total efficiency at a general point in terms of nozzle and bucket efficiencies coupled with a semiempirical loss term due to the departure of the rotor incidence angle from the optimum.

2. The transformation of the semiempirical incidence angle loss law so as to eliminate the explicit occurrence of the incidence angle by introducing the stage loading.

3. The differentiation of the resulting efficiency expression in order to obtain the locus of peak efficiencies. This peak efficiency ridge then becomes the "backbone" of the map.

4. The substitution of the peak efficiency relationships back into the general efficiency equation in order to obtain an expression for the "off-backbone" loss.

The development of the efficiency expression proceeds from the (h,s) diagram for adiabatic flow through a two-dimensional turbine stage as shown in the following sketch.

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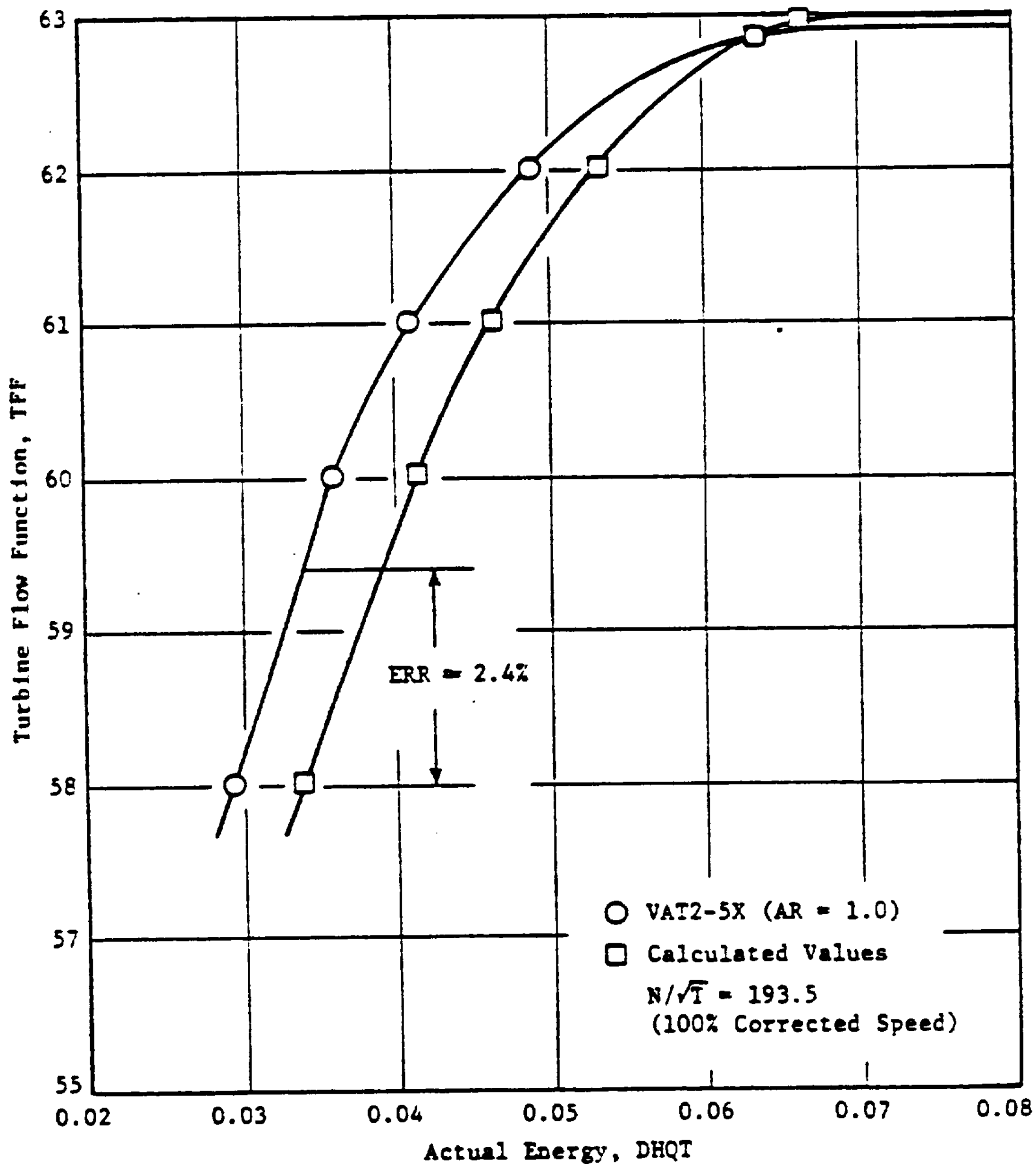
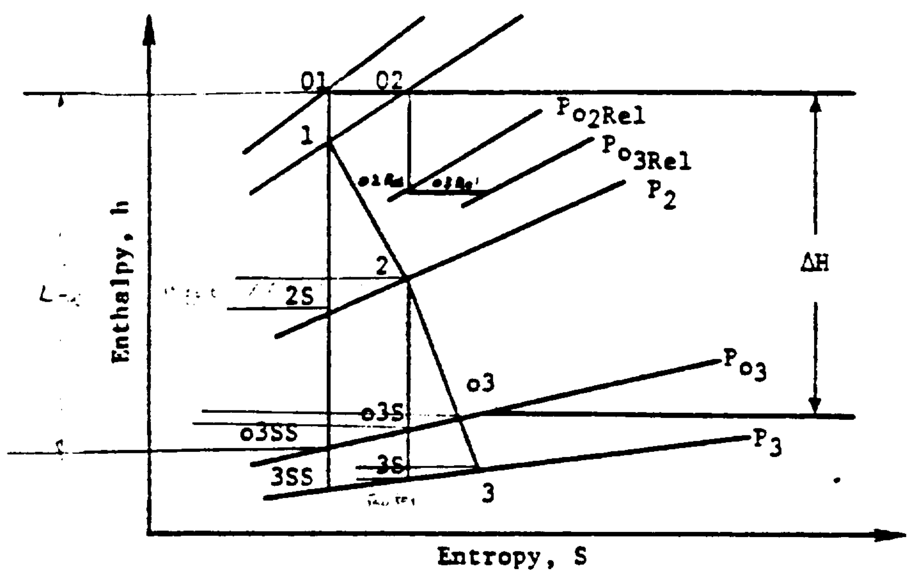


Figure 6. Comparison of Measured and Calculated Values of Inlet Turbine Flow Function.



Enthalpy-Entropy Diagram for a Turbine Stage

Using the station numbers shown in the above sketch, the definition of turbine total-to-total efficiency may be written in the form:

$$\eta_{TT} = \frac{\Delta H}{\Delta H + \frac{T_{o3}}{T_3}(h_3 - h_{3s}) + \frac{T_{o3s}}{T_2}(h_2 - h_{2s})} \tag{4}$$

By definition, the nozzle efficiency is equal to the ratio of the actual nozzle exit kinetic energy to the ideal nozzle exit kinetic energy. A similar definition in terms of relative velocities holds for the bucket efficiency. For off-design calculations at any incidence angle (i), an additional loss term must be included, i.e.,

$$h_3 - h_{3s} = \left(1 - \frac{1}{\eta_B}\right)\frac{W_3^2}{2g_oJ} + \left(1 - \mathrm{Cos}^2(i)\right)\frac{W_2^2}{2g_oJ} \tag{5}$$

where

η_N = nozzle efficiency
η_B = bucket efficiency
W_2 = bucket inlet relative velocity
W_3 = bucket exit relative velocity

The semiempirical incidence angle loss law is based on the assumption that the kinetic energy of the component of velocity normal to the optimum incidence angle is lost. This is a fairly standard assumption (see, for example, Reference 4). Powers other than 2 are frequently used on the cosine.

Before introducing the incidence angle loss term into the efficiency expression, it was transfored into the following expression

$$\left(1-\cos^2(i)\right)\frac{W_2^2}{2gJ} = \frac{U_2^2}{2gJ}\cos^2\beta_{2op}\left(\frac{\phi_2}{\phi_{2op}}-1\right)^2 \qquad (6)$$

The stage characteristic was then used to substitute for flow coefficient in terms of stage loading. The substitution of this results into the expression for efficiency yielded, after simplifying, the following results.

$$\psi\left(\frac{1}{\eta_{TT}}-1\right) = A\left(2\psi+(R_3/R_2)^2\right)^2 + B\left(\psi-\psi_{op}\right)^2 \qquad (7)$$

where

$$A = \frac{1}{4}\,\frac{\left[\frac{T_{03}}{T_3}\left(\frac{1}{\eta_b}-1\right)\left(\frac{C_{z3}}{C_{z2}}\right)^2\frac{1}{\cos^2\beta_3} + \frac{T_{03}}{T_2}\left(\frac{1}{\eta_N}-1\right)\frac{1}{\cos^2\alpha_2}\right]}{\left[\tan\alpha_2+\frac{C_{z3}}{C_{z2}}\frac{R_3}{R_2}\tan\beta_3\right]^2} \qquad (8)$$

$$B = \frac{T_{03}}{T_2}\,\frac{\cos^2\beta_{2op}}{\left(2\psi_{op}+(R_3/R_2)^2\right)^2} \qquad (9)$$

The temperature ratios in Equations 8 and 9 are of order one as is the bucket axial velocity ratio. If these ratios together with the blade row efficiencies and exit flow angles are assumed to remain constant then Equation 7 can be differentiated, and thepeak efficiency point located.

$$\psi_{pk} = \sqrt{\frac{(R_3/R_2)^4A+B\psi_{op}^2}{4A+B}} \qquad (10)$$

$$\frac{1}{\eta_{pk}}-1 = \frac{A\left(2\psi_{pk}+(R_3/R_2)^2\right)^2+B\left(\psi_{pk}-\psi_{op}\right)^2}{\psi_{pk}} \qquad (11)$$

Note that if the nozzle and bucket efficiencies equal unity in Equation (9), then A=0.0. Then there is no loss other than incidence and $\psi_{pk} = \psi_{op}$ as expected.

By substituting Equations 10 and 11 into Equation 7, the following expression for "off-backbone" loss can be obtained.

$$\frac{\psi}{\psi_{pk}}\left(\frac{1}{\eta} - \frac{1}{\eta_{pk}}\right) = \psi_{pk}\ (4A + B)\left(\frac{\psi}{\psi_{pk}} - 1\right)^2 \qquad (12)$$

Equations 10, 11, and 12 give the location of the peak efficiency, the magnitude of the peak efficiency, and the variation in efficiency as we move away from the peak.

These equations represent the stage loss characteristic of a turbine. The design point information is used to obtain the initial values of A and B as well as the values of the blade row efficiencies and metal angles. The loss equations are then applied at incremental values of DHQT starting at zero to obtain the turbine efficiencies. Approximate relationships are used for temperature and velocity ratios to obtain new values of A and B for each DHQT.

Typically, the calculated values of the loss slopes and those obtained from air turbine test data are within about 5% for corrected speeds within plus or minus 20% of the design point value. The values of the "backbone efficiencies" generated by the above equations do not include either Reynold's Number effects or the severe rotor exit losses encountered near exit annulus choke. In order to account for these effects, the loss along the peak efficiency ridge was empirically modified using the results of the NASA air turbine tests. Although relatively good correlation existed between the different test turbines at low values of DHQT, the drop in efficiency in the neighborhood of exit annulus choke was so severe that correlation was difficult. For this reason, variations in efficiency on the order of 5% can be obtained in this region.

A comparison between measured and calculated values of the turbine total-to-total efficiency is shown in Figure 7. This figure is for test turbine number 25 in Table I. The maximum error shown on this figure is about 0.8%. This type of plot was used in obtaining the error estimates given above.

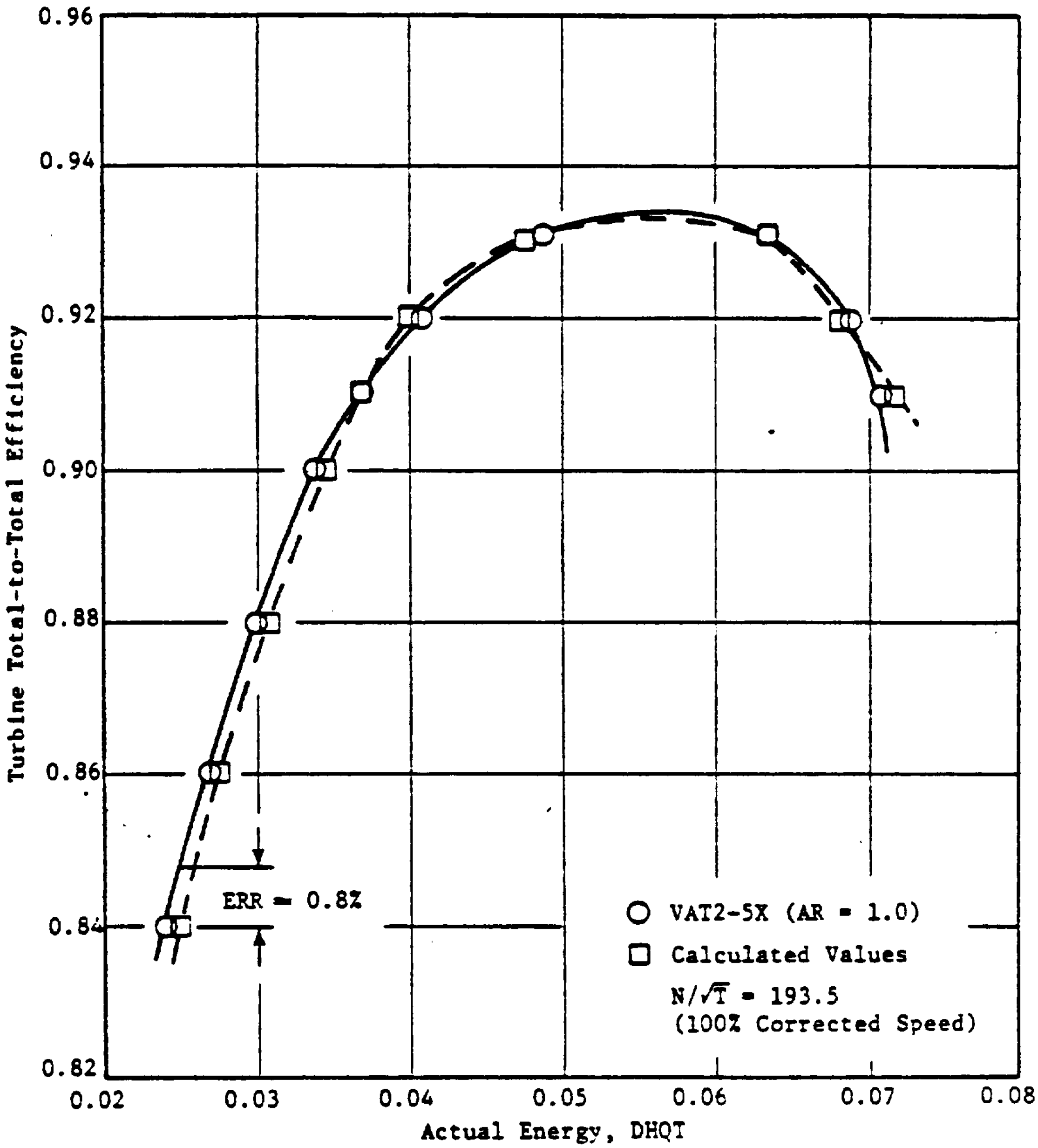


Figure 7. Comparison of Measured and Calculated Values of Total-to-Total Efficiency.

7.4 Comparison of Radial Turbine Test Results and Program Output

A comparison was made between the program output and the "SOLAR" radial turbine described in Reference 20. The key design point parameters are summarized in Table IV. These values are used as the default settings for radial turbines as shown in the second example in Section 6.

The performance map is shown in Figure 8. The exit annulus choke curve forms the physical limit of the map. The portion of the map above this limit line represents a mathematical extension of the map which is necessary for cycle deck iteration purposes. The predicted swirl map is shown in Figure 9. The predicted equivalent weight flows are compared with the test data in Figure 10. The solid lines are the predicted values. In Figure 11 the total-to-static efficiency is compared with the so-called blade to jet speed ratio. This parameter is the ratio of the inlet wheel speed to the velocity calculated by expanding the flow isentropically through the inlet total to exit static pressure ratio. This is the usual manner of presenting radial-turbine efficiency data. The solid lines are the predicted values. The sharp breaks in the lines are due to interpolation. Values of DH/TA at intervals of 0.005 were used to read the map efficiencies and flows from Figure 8. The breaks are due to missing the peak efficiency at a given speed. A smaller interval could not be used due to size limitations on the program.

In general the comparison is quite good, and is probably within the accuracy that the data could be read from the relatively small curve given in Reference 20.

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TABLE VI.

Design Point Data - INFLOW Radial Turbine

	SOLAR (REF.20) Rotor Dia. = 4.75"
NSTG	1
R3CR2	0.291
RHCRT	0.200
R2	2.375-in
T1	850°R
P1	37.9 psia
P1/PS3	2.53
W1	0.433 pps
DHCTD	0.0493
ETATTD	0.868
PSID	0.487
TFFD	0.3395
XNRTD	1718.0
XMZXD	0.22
ANGSWX	0.0
VZ3C2(1)	0.33
ANGβ2	-1.8°

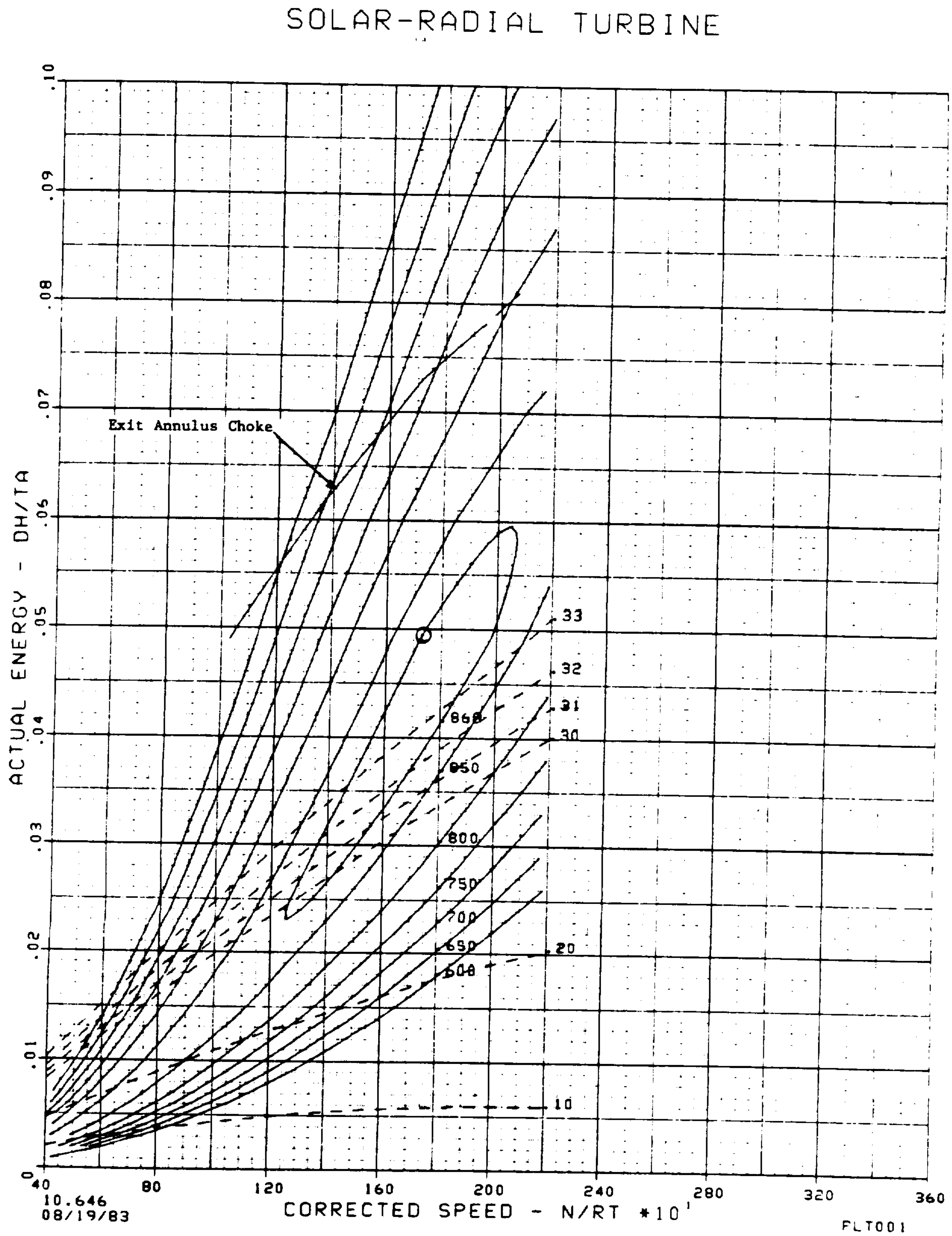

Figure 8. Radial Turbine Performance Map.

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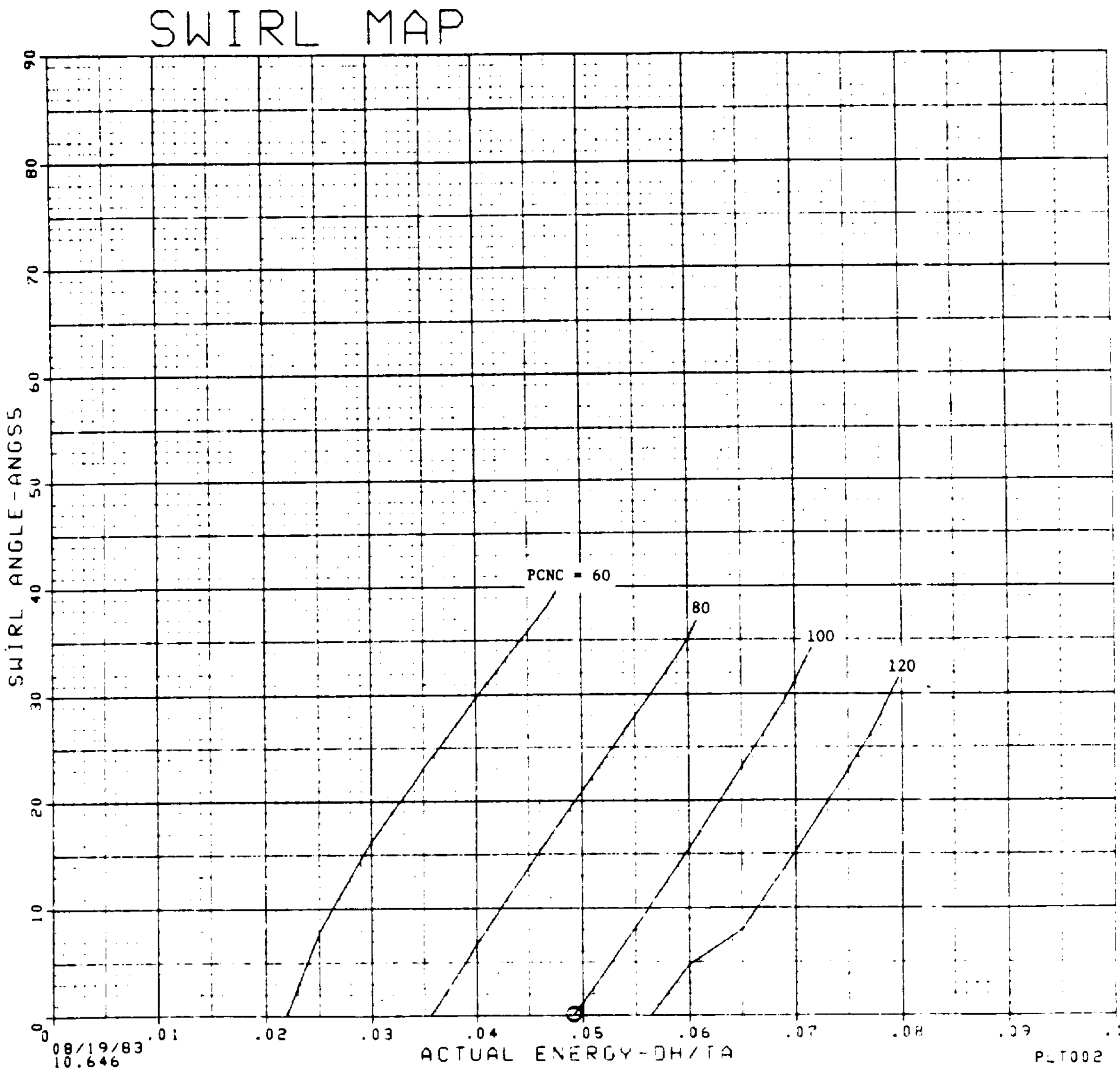
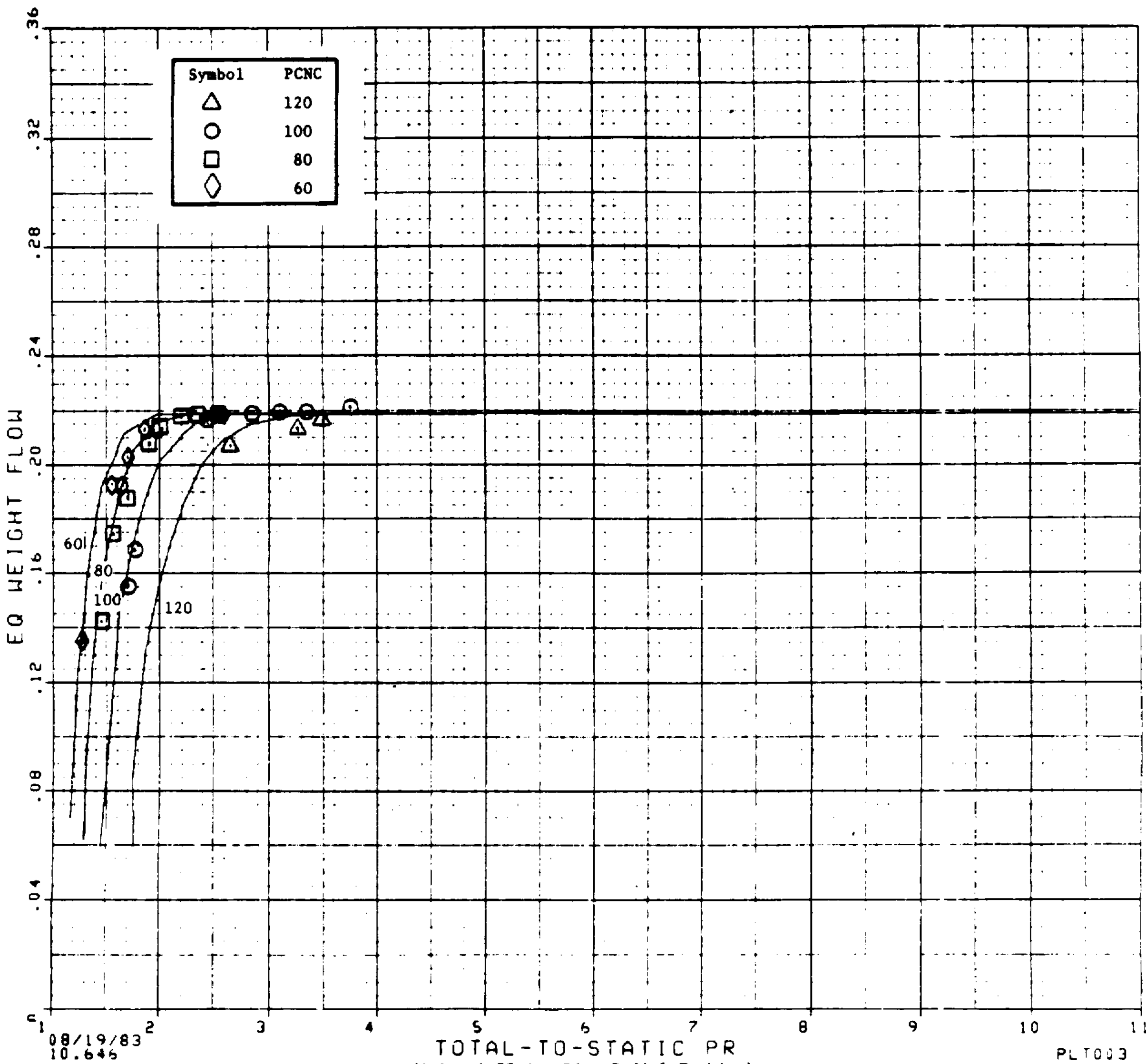


Figure 9. Radial Turbine Swirl Map.



(Solar 4.75-in. Dia. Radial Turbine)

Figure 10. Radial Turbine Flow Comparison.

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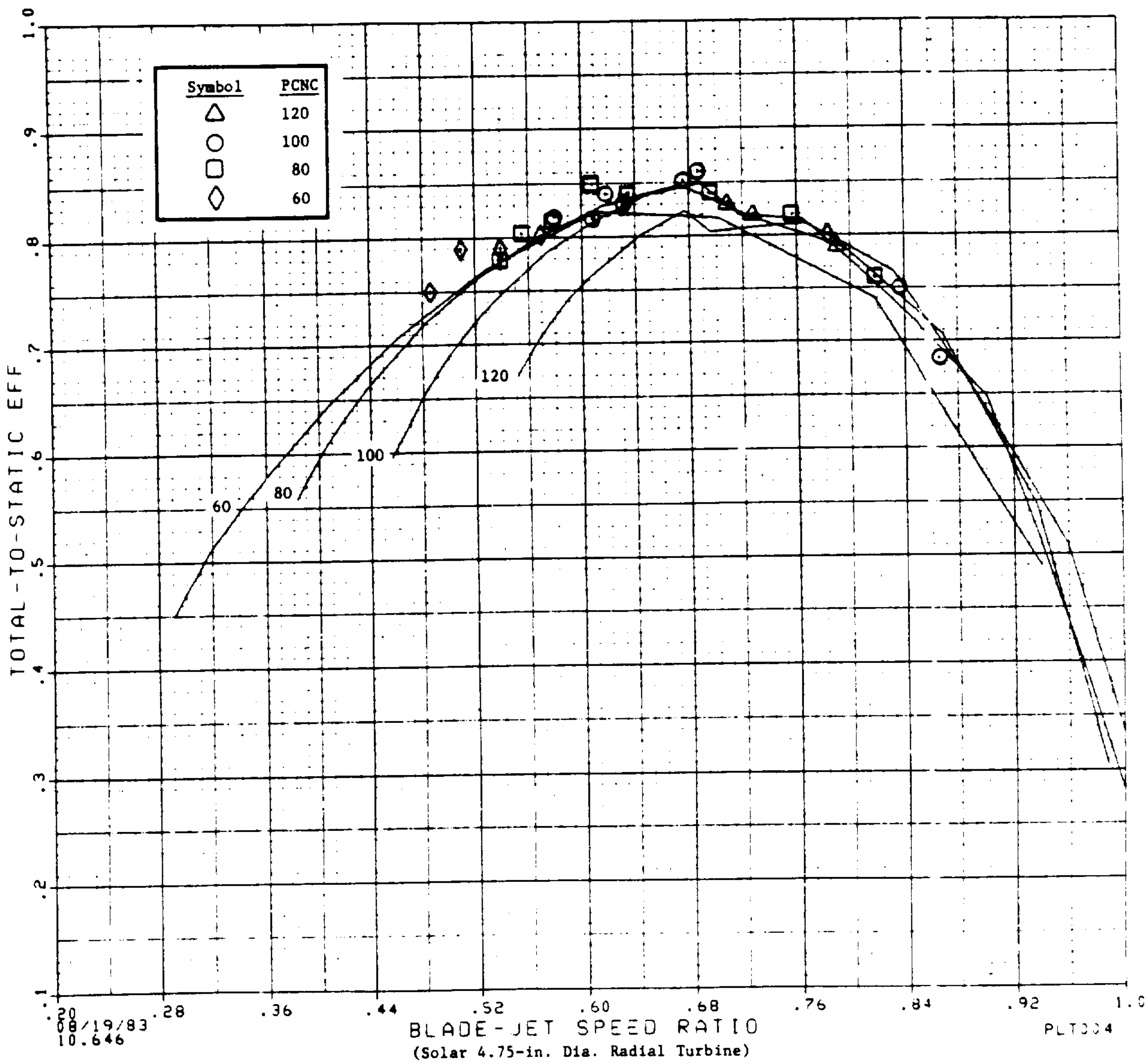

Figure 11. Radial Turbine Efficiency Comparison.

LIST OF SYMBOLS

A, a	Constants
B, b	Constants
C	Velocity, fps
Cp	Constant Pressure Specific Heat, Btu/lbm°R
g_o	Dimensional Constant, 32.17 ft lbm/lbf sec^2
h	Enthalpy, Btu/lbm
i	Incidence Angle ($i = \beta_2 - \beta_{2op}$), degrees
J	Mechanical Equivalent of Heat, 778.16 ft. lbf/Btu
N	Speed, rpm
P	Pressure, psia
R	Radius, ft
Rg	Gas Constant, 53. 35 ft lbf/lbm°R
S	Entropy, Btu/lbm°R
T	Absolute Temperature, °R
U	Wheel Speed, fps
W	Relative Velocity, fps
α	Angle of Absolute Velocity With Axial, degrees
β	Angle of Relative Velocity Vector With Axial, degrees
ΔH	Drop in Total Enthalpy, Btu/lbm
γ	Ratio of Specific Heats
λ	Enthalpy Loss Coefficient
ρ	Fluid Density, lbm/ft^3
θ	Ratio or Total Temperature to Standard Temperature
ψ	Turbine Stage Loading [$\psi = \Delta H/(2U^2/g_o J)$]
ϕ	Flow Coefficient ($\phi = C_z/U$)
η	Efficiency

Subscripts

1	Nozzle Inlet
2	Rotor Inlet
3	Rotor Exit
B	Bucket
d	Design Point Value
N	Nozzle
O	Stagnation
op	Optimum
pk	Peak
TT	Total-to-Total
S	Isentropic
z	Axial

REFERENCES

1. Fishbach, Laurence H., and Caddy, Michael J., "NNEP: The Navy-NASA Engine Program," NASA TM X-71857, 1975.

2. Fishbach, Laurence H., "Konfig and Rekonfig - Two Interactive Pre-Processing Programs to the NAVY/NASA Engine Program (NNEP," NASA TMX-82636, May 1981.

3. Gauntner, James W, "Algorithm for Calculating Turbine Cooling Flow and the Resulting Decrease in Turbine Efficiency," NASA TM81453, Feb., 1980.

4. Flagg, E.E., "Analytical Procedure and Computer Program for Determining the Off-Design Performance of Axial-Flow Turbines," NASA CR-710, March 1966 (GE R67FPD294, August 1967).

5. Whitney, Warren J., Szanca, Edward M., Bider, Bernard, and Monroe, Daniel E., "Cold-Air Investigation of a Turbine for High-Temperature Application. III - Overall Stage Performance," NASA TN D-4389, 1968.

6. Whitney, Warren J., Schum, Harold, and Behning, Frank P., "Cold-Air Investigation of a Turbine for High-Temperature Application. IV - Two-Stage Turbine Performance."

7. Schum, Harold J., Moffitt, Thomas P., and Behning, Frank P, "Effect of Variable Stator Area on Performance of a Single-Stage Turbine Suitable for Air Cooling. III - Turbine Performance With 130-Percent Design Stator Area," NASA TM X-1663, 1968.

8. Schum, Harold J., Scanca, Edward M., and Prust, Herman W., Jr., "Effect of Variable Stator Area on Performance of a Single-Stage Turbine Suitable for Air Cooling. VI - Turbine Performance With 70-Percent Design Stator Area," NASA TM X-1697, 1968.

9. Flagg, E.E., "Analysis of Overall and Internal Performance of Variable Geometry One- and Two-Stage Axial-Flow Turbines," NASA CR-54449 (GE R66 FPD259), 1966.

10. Converse, G.L., "Turbine Modeling Techniques to Generate Off-Design Performance Data for Both Single and Multistage Axial Flow Turbines," November Monthly Progress Report, General Electric, R79AEG598-2, November, 1979.

11. Converse, G.L., "Turbine Modeling Techniques to Generate Off-Design Performance Data for Both Single and Multistage Axial Flow Turbines," December Monthly Progress Report, General Electric, R79AEG598-3, December, 1979.

12. Converse, G.L., "Turbine Modeling Techniques to Generate Off-Design Performance Data for Both Single and Multistage Axial Flow Turbines," February Monthly Progress Report, General Electric, R79AEG598-5, February, 1980.

Small Axial Flow Turbine

13. Schlegel, J.C.; Liu, H.C.; Waterman, W.F., "Reduction of End-Wall Effects in a Small, Low-Aspect-Ratio Turbine by Radial Work Redistribution", Journal of Engineering for Power, Trans. ASME, Series A, January 1976.

14. Stewart, W.L., "A Study of Axial-Flow Turbine Efficiency Characteristics in Terms of Velocity Diagram Parameters, ASME Paper No. 610-WA-37, 1961.

15. Holeski, D.E.; Steward, W.L.; "Study of NASA and NACA Single-Stage Axial Flow Turbine Performance as Related to Reynolds Number and Geometry," Journal of Engineering for Power, Trans ASME, July 1964.

16. Wong, R.Y.; Nusbaum, W.J.; "Air-Performance Evaluation of a 4.0-Inch-Mean-Diameter Single-Stage Turbine at Various Inlet Pressures From 0.14 to 1.88 Atmosphere and Corresponding Reynolds Numbers from 2500 to 50,000", NASA TND-1315,1962.

17. Ohlsson, G.O.; "Low Aspect Ratio Turbines", Journal of Engineering for Power Trans. ASME, Series a, Vol. 86, 1964, pp. 13-17.

Radial Flow Turbines

18. Lane, J.M., "Cooled Radial In-Flow Turbine for Low Specific Speeds and Low Velocity Factors", Paper presented at the Gas Turbine Conference and Products Show, ASME, March 9-12, 1981.

19. Rohlik, H.E.: Kofshey, M.G.: "Recent Radial Turbine Research at the NASA Lewis Research Center", ASME 72-GT-42, 1972.

20. Rogers, Colin, "Efficiency and Performance Characteristics of Radial Turbines", SAE Paper 660754, 1966.

21. Futral, Samuel M.; Wasserbauer, Charles A.; "Off-Design Performance Prediction with Experimental Verification For a Radial-Inflow Turbine: NASA TND-2621, 1965.

22. Rizika, J.W., et.al., "The Design and Performance Analysis of Radial in Flow Turbines", in 2 volumes, NREC Report No. 1067-1, 1067-2, Northern Research and Engineering Corporation, Cambridge, Massachusetts, 1964.

23. Wood, Homer J.: "Current Technology of Radial-Inflow Turbines for Compressible Fluids", Journal of Engineering for Power, Trans. ASME, Series A, Vol. 85, 1963.

24. Knoernschild, E.M.: "The Radial Turbine for Low Specific Speeds and Low Velocity Factors", Journal of Engineering for Power, Trans. ASME, Series A, Vol. 83, 1961.

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