III. AXOD

Turbomachine: Axial Turbine

Analysis: Off-Design

Flow: Spanline

Description:

AXOD computes the flow and efficiency of multistage axial-flow turbines as functions of speed and pressure ratio (i.e., a map). It uses a spanline analysis with simple radial equilibrium. The loss model is made up of blade-row inlet losses, blade row losses, and stage test losses. Coefficients are selected to match the known design-point performance, and the internal model provides the off-design performance.

Program input includes the flowpath diameters and blading angles. For any given speed, performance is computed from low pressure ratio up to limit load. The output includes total and static efficiencies and pressure ratios, both overall and stage actual and corrected performance parameters, and flow velocities and angles at all calculation locations. A map file in NEPP format can be obtained.

This code is sometimes referred to as the Flagg code.

References:

Flagg, E.E.: Analytical Procedure and Computer Program for Determining The Off-Design Performance of Axial Flow Turbines. NASA CR-710, 1967.

Glassman, A.J.: Modeling Improvements and Users Manual for Axial-Flow Turbine Off-Design Performance. NASA CR-195370, 1994.

Files and Location:

axod.f - Fortran source file - subroutines that perform all the calculations

axod.start.c - C source file - main routine that reads command line argument and passes it to *axod.f*

makefile - compiles and links *axod.f* and *axod.start.c* to produce executable *axod*

axod - executable code

These files are located in two places:

1. /aao/nepp/axod - can be executed by any user from any directory on all AAO machines.
2. /mazel/tmdesign/axod - only mazel can execute

Input / Output:
input - unit 05
output - unit 06 - normal output
- unit 07 - map file in NEPP format

Usage:
To run: **axod xxxx** (where xxxx can be any length allowed by system)

where the input file is: *xxxx.axodinp*

and the output file will be: *xxxx.axodout*

and the map file will be: *xxxx.axodplt*

Alternate Version of Code:
There is an alternate version of AXOD that does not require a C compiler. There is one file: /mazel/tmdesign/axod/*axod_exp.f*. The input and output unit numbers are unchanged and the unit 07 map file is written to file *pltfile*.

AXOD Commentary

Program AXOD is advertised as an off-design code, but it can do a design calculation. The reason why I do not particularly recommend it for design is that it has no design-point loss model built in. Loss coefficient values that will provide a known or desired efficiency have to be input. Also, stage work is specified by input values of rotor inlet and exit tangential momentums (i.e., rV_u). This is not a convenient parameter to use because the relationship between the specified inlet and exit values and the more familiar values of blading angles and reaction is not readily apparent. The one advantage of using AXOD for design is that the map can be generated in the same run as the design.

This code is quite fast and quite robust. It takes about one-half second to run a speed line with about 40 points using a 5-sector flow model. Code failure is almost always due to either bad input or an attempt to run at too low a pressure ratio, where there may be no solution at all or possibly a very-low efficiency solution.

There is a missing link in the references between the original GE CR report and the recent update report. About 5 years after development of the original code, GE gave us (gratis) an updated version, which included the design option, the capability to use cooling flow, and a methodology for eliminating (or perhaps just reducing) inaccuracies introduced by the spanline modeling. Since the update was free, we couldn't really ask for documentation.

The angle convention used in AXOD, which is that of GE, is not entirely consistent with the convention used in TURBAN and TD2. There is a sign change for rotor-exit/stator-inlet angles. Remember this when using design-code output numbers as AXOD input.

Hints on Inputs:

TTIN / PTIN / TTINH / PTINH - Use of radially distributed values not warranted.

ALF0H - For HPT, use the default of 0.0. The HPT value doesn't change with off-design operation. For an LPT, however, the inlet flow angle, and consequently incidence loss, will depend on where the HPT is operating. But, in generating an LPT map, there is no equivalent HPT operation for every LPT point. So, just use the value used for the design. Besides, the HPT operating point usually doesn't move around much.

PTPS - This input sets the flow and, consequently, the pressure ratio for the first point on a speed line. Start with the default value (1.1). For some turbines, this may be too low and cause the code to bomb. If this happens, increase PTPS by .1 or .2 and try again.

DELC / DELL / DELA - If you want more points, make the values smaller and vice versa.

SECT - For a free-vortex design, a meanline (i.e., 1 sector) calculation yields results not much different from those of a 5-sector calculation, but with a lot less input required. For non-free-vortex designs, the multiple-sector calculation is required to capture the non-free-vortex effects. The maximum number of sectors is 6, but the use of 5 gives a point at the meanline. The maximum of 6 is tied to the dimension statements. When the code was originally written, core storage was limited.

EXPN / EXPP - Don't mess with these unless you have good reason to and you know what you are doing. These are important parts of the calibrated loss model.

PAF - I haven't really played with this. However, for a free-vortex design, mixing should not make much difference. Of course, if SECT=1, there's nothing to mix. For non-free-vortex, depending on the particular radial distributions, mixing may be necessary to keep the end sectors within reason.

SLI - Go with the default value unless you have detailed loss information for some turbine whose performance you are trying to match.

AACS - The default value extends the speed line all the way to limit load. Lower values end the speed line sooner. Setting DELA=0 ends the speed line at rotor choke.

VCTD - The default value (VCTD=0.0) gives one page of output per point. Using VCTD=1.0 gives several pages per stage per point, and can result in a humungous output file. If you are only interested in overall performance, use VCTD=-1.0, which gives 7 points per page.

PCNH - Use equal values unless you have specific information about endwall region performance in a particular design.

EPR - Use default value. Only affects efficiency beyond blade-row choke.

WTOL / RHOTOL / PRTOL - Default values selected to provide reasonable compromise between accuracy and convergence.

TRLOOP / TRDIAG - Use only to debug problem.

PFIND / DHFIND - Really not of too much use.

IAR - Uses the same correlation curves as was developed for TURBAN, but allows for interpolation between the three curves. Value determines flowpath slope for continuity calculation.

ICYL - Some people/companies define flow angle on the stream surface (tan $\beta=V_u/V_m$) while others define it on a cylindrical surface (tan $\beta=V_u/V_x$). Most people don't have the slightest idea of how the angle they are quoting is defined. The degree of difference depends on the meridional flowpath slope. For a horizontal flowpath, there is no difference. For a 30 deg. flowpath, the angle values will differ by about 2.5-3.5 degrees. To add to the confusion, the angles from TURBAN are stream surface angles, while TD2 provides cylindrical angles. Let the user beware.

ICF - Performance calibration based on default value.

RWG - RWG is cumulative and not incrementally additive. Each value must be equal to or greater than any previous value, including those for previous stages. Note that the 5 J locations are defined in the Input description.

SDEA / SPA and RDEA / RPA - There are two options for specifying blade-row exit geometry, either the angle or the throat opening (total for all passages). With either known, the other can be calculated. Since design codes generally provide the exit angle rather than the throat opening, it is the angle option that is mostly used.

SREC / RREC - The loss model calibration is based on using the default values.

SETA / RETA - The loss model calibration is based on all SETA values equal to each other and all RETA values equal to each other. To reflect the generally higher level of rotor losses, the rotor loss (1. - RETA) was taken as twice the stator loss (1. - SETA). These blade-row efficiencies are set so as to match turbine design-point efficiency.

SCF / RCF - These are set so as to match design-point mass flow rate. Unless there is reason to do otherwise, set them equal to each other.

RTF - Loss model calibration based on default value.

RVU1 / RVU2 - These are for the design option only (see discussion at top of page III-2A). Values are most easily obtained by running one of the other design codes first.

AXOD MAP PLOT OPTIONS (as of 6/12/95)

Map plots were originally available (CR 195370) only with the variables required for the NEPP map files:

Turbine inlet equivalent flow ($w_4 \sqrt{\theta_4}\, \varepsilon / \delta$) vs. Total-to-total pressure ratio ($p_{t,in} / p_{t,ex}$)

and

Thermodynamic total efficiency (η_t) vs. Total-to-total pressure ratio ($p_{t,in} / p_{t,ex}$)

Map plots can now be obtained in terms of alternate variables as specified by a new triply-dimensioned input variable IPLOT. The IPLOT values are defaulted to yield the map files and map plots in terms of the original variables specified above. The options are:

IPLOT(1) - Specifies flow ordinate
- =1 - Turbine inlet equivalent flow ($w_4 \sqrt{\theta_4}\, \varepsilon / \delta_4$) (default)
- =2 - Turbine inlet corrected flow ($w_4 \sqrt{T_4} / p_4$)
- =3 - Turbine inlet flow (w_4)
- =4 - Rotor inlet equivalent flow ($w_{41} \sqrt{\theta_{41}}\, \varepsilon / \delta_4$)
- =5 - Rotor inlet corrected flow ($w_{41} \sqrt{T_{41}} / p_4$)
- =6 - Rotor inlet flow (w_{41})

IPLOT(2) - Specifies efficiency ordinate
- =1 - Thermodynamic total efficiency (η_t) (default)
- =2 - Thermodynamic static efficiency (η_s)
- =3 - Rotor-primary total efficiency ($\eta_{t,rp}$) - Otherwise known as GE efficiency.

IPLOT(3) - Specifies abscissa
- =1 - Total-to-total pressure ratio ($p_{t,in} / p_{t,ex}$) (default)
- =2 - Total-to-static pressure ratio ($p_{t,in} / p_{s,ex}$)
- =3 - Blade - jet speed ratio ($\Sigma U_m / \sqrt{(2\, g\, J\, \Delta h_{id,ts}}$)

A typical input might be: IPLOT=3,2,2,

RECENT MINOR CHANGES (June 1995)

The function for the high pressure-ratio correction to blade-row efficiency was modified to eliminate the discontinuity in slope at the upper limit of pressure ratio. The parabolic function (equation (11) of CR195370) was changed to a cubic function having a zero slope at the upper limit. The value of the correction is not changed to any significant extent, but the kink in the turbine efficiency curve is reduced. This correction resides in subroutine ETAPR.

The output variable RX, which is called stage reaction in the output description, is actually a value based on ideal static enthalpy drops across the rotor and the turbine. A more conventional reaction, defined as ratio of static enthalpy drop across the rotor to total enthalpy drop across the stage, is now also calculated for both the pitch and the root. These were added to the Stage Performance output as REACT P and REACT R. The original RX values are still included.

DESCRIPTION OF INPUT AND OUTPUT

This appendix presents a detailed description of input and output for program AXOD. Included to illustrate the input and output are sample inputs for a single-stage and a multi-stage turbine and sample output for the single-stage turbine.

Input

The input for each case, which is read from unit 05, consists of two title lines and k NAMELIST datasets where k is the number of turbine stages. A case is defined as one speed line for a range of pressure ratios. An input file can include multiple cases. Each of the two title lines, which are printed as page headings on the output, can contain up to 80 characters. One or both of these lines may be left blank, but they must appear as the first two records for each case.

The NAMELIST name is DATAIN. The DATAIN variables, with units and default values, are presented herein as overall input followed by stage input. Overall input is entered only once for a case and need not be repeated for subsequent cases if unchanged. Stage input is entered for each stage, unless otherwise indicated, of the first case but need not be repeated for subsequent cases if unchanged.

Input blade angles must be specified from the axial direction with the following signs:
- Stator exit and rotor inlet - positive in direction of blade speed.
- Rotor exit and stator inlet - positive in direction opposite to blade speed.

Two sample inputs are illustrated. Table IIa presents the input for the single-stage turbine whose performance is shown in figure 1. Table IIb presents the input for the two-stage cooled turbine whose performance is shown in figure 4. There are three cases in each file, one for each speed line. The first case has two title lines; the other cases have only one title line, thus requiring the inclusion of the shown blank lines. Note that very little additional data is required for speed lines beyond the first one.

Overall Input:

TTIN	Inlet total temperature (radially constant), ^{o}R. May be omitted if TTINH is input.
PTIN	Inlet total pressure (radially constant), psi. May be omitted if PTINH is input.
TTINH(I) I=1,SECT	Inlet total temperature radial distribution, ^{o}R. Overrides TTIN.

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PTINH(I) I=1,SECT	Inlet total pressure radial distribution, psi. Overrides PTIN.
ALF0H(I) I=1,SECT	Inlet flow angle radial distribution, deg. (default=SECT*0.0)
WAIR	Inlet water/air ratio (default=0.0). May be omitted if RG and GAMG are input.
FAIR	Inlet fuel/air ratio (default=0.0). May be omitted if RG and GAMG are input.
PTPS	Starting value of first-stator meanline inlet-total to exit-static pressure ratio (default=1.1)
DELC	PTPS increment to initial blade-row choke (default=0.1)
DELL	PTPS increment from initial to last blade-row choke (default=0.1)
DELA	PTPS increment from last blade-row choke to exit-annulus choke (default=0.05) A value of 0.0 terminates the speed line at last-stage rotor choke.
STG	Number of stages, maximum=8.
SECT	Number of radial sectors, maximum=6. (default=1.0)
EXPN	Negative-incidence exponent (default=4.0)
EXPP	Positive-incidence exponent (default=3.0)
RG	Gas constant, ft-lbf/(lbm-^{o}R). Omit for internal computation of RG and GAMG for air.
PAF	Profile (temp & press) averaging switch for next stage inlet (default=0.0) 0.0 - Radially uniform 1.0 - Maintain existing radial profiles 2.0 - Maintain temperature and smooth pressure
SLI	Stage loss-value switch for SREC, SETA, SCF, RREC, RETA, RCF, & RTF (default=1.0) 0.0 - Data to be input for all stages 1.0 - First-stage values used for all stages
AACS	Turbine-exit axial Mach number for termination of speed line (default=1.0)

VCTD	Output switch (default=0.0) -1.0 - Overall performance only 0.0 - Overall performance plus meanline values of key variables 1.0 - Overall performance plus all variable values for all radial sectors
PCNH(I) I=1,SECT	Sector height distribution, fraction of annulus height (default=1.0) (Not cumulative, sum of i values must equal 1.0)
WG	Mass flow rate, lb/sec. Used for design option only (default=0.0) NOTE: A non-zero value triggers the design option.
EPR	Switch for high pressure-ratio correction to blade-row efficiency (default=1.0) 0.0 - Off 1.0 - On
WTOL	Tolerance for mass-flow rate convergence (default=1.e-5)
RHOTOL	Tolerance for density convergence (default=1.e-4)
PRTOL	Tolerance for pressure ratio convergence (default=1.e-6)
TRLOOP	Debug output switch for iteration control variables (default=0.0) 0.0 - Off 1.0 - On
TRDIAG	Debug output switch for flow and state variables (default=0.0) 0.0 - None 1.0 - Station 0 (stator inlet) 2.0 - Station 1 (stator exit) 3.0 - Station 1A (rotor inlet) 4.0 - Station 2 (rotor exit) 5.0 - Station 2A (stage exit) 6.0 - All stations - after each station calculation 7.0 - All stations - after overall performance calculation
PFIND	Selected value of turbine total pressure ratio to be searched for. Omit if not used.
DHFIND	Selected value of turbine specific work to be searched for. Omit if not used.

IAR Switch for axial-chord length (default=0)

- 0 - No slope used for continuity (i.e., axial flow)
- 1 - High aspect-ratio blading
- 2 - Mid aspect-ratio blading
- 3 - Low aspect-ratio blading
- 10 - 20 Fractional values between IAR=1 and IAR=2
- 20 - 30 Fractional values between IAR=2 and IAR=3

ICYL Switch for blading angle definition (default=0)

- 0 - Input blade angles are on a flowpath surface with slope defined by IAR
- 1 - Input blade angles are on a cylindrical surface

ICF Switch for flow coefficient variation (default=0)

- 0 - Flow coefficient varies with blade-row pressure ratio
- 1 - Flow coefficient constant

ENDPLT Switch for writing a map file in NEPP (ref. 10) format (default=0.0)

- 0.0 - No
- 1.0 - Yes

ENDJOB Switch for last case (default=0.0)

- 0.0 - More cases to follow
- 1.0 - Last case

Stage Input: The J subscripts refer to the 5 stage calculation stations, which are stator inlet, stator exit, rotor inlet, rotor exit, and stage exit/next stator inlet. The I subscripts refer to the radius centers of the SECT annular sectors.

STAGE Stage number (not number of stages)

RPM Stage rotative speed, rev/min. Will remain constant for subsequent stages until changed

GAMG(J) J=1,5 Specific heat ratio. Omit if RG is omitted as it is internally computed (for air)

DR(J) J=1,5 Hub diameter, inches

DT(J) J=1,5 Tip diameter, inches

RWG(J) J=1,5	Ratio of station mass-flow rate to turbine inlet mass-flow rate. For the first stage, RWG(1) must equal 1.0. For subsequent stages, RWG(1) must equal RWG(5) of the previous stage.
TWG(J) J=1,5	Temperature of the coolant specified by RWG, ^{o}R. Input only for stations where coolant is added.
PWG(J) J=1,5	Pressure of the coolant specified by RWG, psi. Input only for stations where where coolant is added.
SDIA(I) I=1,SECT	Stator vane inlet angle, deg. Add optimum incidence angle to design angle. Omit for design option.
SDEA(I) I=1,SECT	Stator vane exit angle, deg. Omit if SPA option is used or for design option.
SPA(I) I=1,SECT	Stator throat area per unit height, sq in./in. Omit if SDEA option is used.
SESTH	Ratio of blade height at stator exit to blade height at stator throat. Omit if SDEA option is used.
RDIA(I) I=1,SECT	Rotor blade inlet angle, deg. Add optimum incidence angle to design angle. Omit for design option.
RDEA(I) I=1,SECT	Rotor blade exit angle, deg. Omit if RPA option is used or for design option.
RPA(I) I=1,SECT	Rotor throat area per unit height, sq in./in. Omit if RDEA option is used.
RERTH	Ratio of blade height at rotor exit to blade height at rotor throat. Omit if RDEA option is used.
SREC(I) I=1,SECT	Stator inlet recovery efficiency, decimal. Input only for first stage if SLI=1.0. (default=SECT*1.0)
SETA(I) I=1,SECT	Stator efficiency, decimal. Input only for first stage if SLI=1.0.
SCF(I) I=1,SECT	Stator flow coefficient, decimal. Input only for first stage if SLI=1.0. (default=SECT*1.0)

RREC(I) I=1,SECT	Rotor inlet recovery efficiency, decimal. Input only for first stage if SLI=1.0. (default=SECT*1.0)
RETA(I) I=1,SECT	Rotor efficiency, decimal. Input only for first stage if SLI=1.0.
RCF(I) I=1,SECT	Rotor flow coefficient, decimal. Input only for first stage if SLI=1.0. (default=SECT*1.0)
RTF(I) I=1,SECT	Rotor test factor, decimal. Input only for first stage if SLI=1.0. (default=SECT*1.0)
RVU1(I) I=1,SECT	Design stator-exit angular momemtum (radius * tangential velocity), in.-ft/sec. Input for design option only.
RVU2(I) I=1,SECT	Design rotor-exit angular momemtum (radius * tangential velocity), in.-ft/sec. Input for design option only.
ENDSTG	Switch for last stage (default=0.0) 0.0 - Not last stage 1.0 - Last stage

Output

Three levels of output are available as specified by the input variable VCTD. All levels provide an input echo. The lowest level (VCTD=-1.0) prints only the overall performance. The next level (VCTD=0.0) adds stage meanline variables to the output. The highest level (VCTD=1.0) adds the printout of all variables for all stations and all annular sectors.

Presented in table III is the sample output that corresponds to the sample input of table IIa. This is the highest-level output, but presents computed results for only the first pressure-ratio point on the first speed line. The full output for this case would have about 30 points on each speed line. Shown on the first page of table III is the input echo with the variables all being defined in the Input section. The next page of this table presents the stage and overall performance results that are printed for the mid-level output. Only the overall performance is printed at the lowest level. The last two pages display the detailed interstage performance printed for the highest level in addition to the overall and stage performance. In addition to detailed output presented for the five annular sectors, extrapolated values are printed for the hub and the tip.

The output variables shown in table III are defined in this section. The calculation stations and radial locations are identified as follows:

0 - Stator inlet
1 - Stator exit
1A - Rotor inlet
2 - Rotor exit
2A - Stage exit
P - Pitchline (i.e., meanline)
R - Root
RT - Root
TIP - Tip

The output variables are listed in the order of their first appearance.

TT	Total temperature, ^oR
PT	Total pressure, psi
WG	Mass flow rate, lb/sec
DEL H	Specific work, Btu/lb
WRT/P	Corrected mass flow rate at stage or turbine inlet ($w\sqrt{T}/P$), (lb/sec)(^oR)$^{1/2}$/psi
DH/T	Corrected specific work ($\Delta h_{tt}/T$), Btu/(lb)(^oR)
N/RT	Corrected rotative speed $N/\sqrt{T}$, rpm/$^oR^{1/2}$
ETA TT	Total efficiency
ETA TS	Static efficiency
ETA AT	Rating efficiency
PT0/PS1	Stator inlet-total to exit-static pressure ratio
PT0/PT2	Stage or turbine inlet-total to exit-total pressure ratio
PT0/PS2	Stage or turbine inlet-total to exit-static pressure ratio
PTR1A/PS2	Rotor inlet-relative-total to exit static pressure ratio
TT2/TT0	Stage exit-total to inlet-total temperature ratio
TTR1/TT0	Rotor-inlet-relative-total to stage-inlet-total temperature ratio
PS	Static pressure, psi
TTR	Relative total temperature, ^oR
PTR	Relative total pressure, psi
UP/VI	Ratio of pitchline blade speed to stage isentropic velocity, $U_p/\sqrt{(2gJ\Delta h_{ts,id})}$
UR/VI	Ratio of root blade speed to stage isentropic velocity, $U_r/\sqrt{(2gJ\Delta h_{ts,id})}$
W.F.	Stage or turbine work factor, $gJ\Delta h_{tt}/U^2$
RX	Stage reaction, ratio of rotor-to-stage static enthalpy drops
ALPH(A)	Absolute flow angle, deg
I	Incidence angle, deg
BETA	Relative flow angle, deg
DBETA	Rotor turning angle, deg
M	Absolute Mach number
MR	Relative Mach number

E/TH CR	Stage or turbine equivalent work, $\Delta h_{tt}/\theta$, Btu/lb
N/RTH CR	Stage or turbine equivalent speed, $N/\sqrt{\theta}$, rpm
WRTHCRE/D	Equivalent mass flow rate, $w\sqrt{\theta}\varepsilon/\delta$, lb/sec
RPM	Rotative speed, rev/min
MF	Axial Mach number
PT/T EQ	Turbine equivalent inlet-total to exit-total pressure ratio
PT/S EQ	Turbine equivalent inlet-total to exit-static pressure ratio
PT/PAT2	Turbine inlet-total to exit-axial-total pressure ratio
ETA TTRP	Turbine total efficiency based on first-rotor inlet ideal enthalpy
WNE/60D	Turbine equivalent flow-speed parameter, $wN\varepsilon/60\delta$, (lb)(rev)/sec^2
HP	Turbine power output, horsepower
EQ WG0	Equivalent mass flow rate, $w\sqrt{\theta}\varepsilon/\delta$, lb/sec
TORQUE	Turbine torque, lb-ft
TOR/P	Turbine corrected torque, T/P, ft-in^2
EQ TOR	Turbine equivalent torque, $T\varepsilon/\delta$, lb-ft
U/VIS	Ratio of mean blade speed to turbine isentropic velocity, $U_p/\sqrt{(2gJ\Delta h_{ts,id})}$
DIAM	Diameter, inches
SLOP(E)	Sector geometric flowpath slope
V	Absolute velocity, ft/sec
VU	Absloute velocity tangential component, ft/sec
VZ	Absolute velocity meridional component, ft/sec
TS	Static temperature, ^oR
DENS	Density, lb/ft^3
DEL A	Stator turning angle, deg
ZWI INC	Zweifel incompressible blade loading coefficient
ETA S	Stator efficiency
FTAN/IN	Stator or rotor tangential blade loading per unit height, lb/in
F TAN	Stator or rotor total tangential blade loading, lb
FAX/IN	Stator or rotor axial blade loading per unit height, lb/in
F AX	Stator or rotor total axial blade loading, lb
F DRUM	Axial forces on stator or rotor endwall surfaces, lb
R	Relative velocity, ft/sec
RU	Relative velocity tangential component, ft/sec
U	Blade speed, ft/sec
PSI	Sector work coefficient, $gJ\Delta h_{tt}/2U^2$
ETA R	Rotor efficiency

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TABLE IIa.—SAMPLE INPUT FOR SINGLE-STAGE TURBINE

```
NASA ONE-STAGE TURBINE - TN D-4389
 ˀ0 PERCENT SPEED
 ,ATAIN STAGE=1.,
TTIN=518.7,PTIN=14.696,IAR=2,PTPS=1.25,DELC=.01,DELL=0.1,DELA=0.0,
STG=1.,SECT=5.,PCNH=5*0.2,VCTD=1.,RG=53.35,RPM=4407.4,
GAMG=5*1.4,RWG=5*1.0,EXPN=4.,EXPP=3.,DR=5*22.,DT=5*30.,
SDIA=5*-6.,SDEA=69.6,68.3,67.0,65.8,64.5,
SETA=5*.9628,SREC=5*1.0,SCF=5*.990,
RDIA=45.5,38.0,30.4,21.5,11.5,RDEA=56.35,57.30,58.26,59.19,60.12,
RETA=5*.9256,RTF=5*1.0,RREC=5*1.0,RCF=5*.990,
ENDPLT=1.0,ENDSTG=1. &END

70 PERCENT SPEED
&DATAIN PTPS=1.3,RPM=3085.2,VCTD=-1.,
ENDSTG=1.0 &END

40 PERCENT SPEED
&DATAIN PTPS=1.4,RPM=1763.0,
ENDSTG=1.0,ENDJOB=1. &END
```

TABLE IIb.—SAMPLE INPUT FOR MULTI-STAGE COOLED TURBINE

```
NASA/GE EEE HPT TWO-STAGE COOLED TURBINE
101.6 PERCENT SPEED
 ˀATAIN STAGE=1.,ENDJOB=0.,ENDPLT=1.,
 .IN=1283.,PTIN=50.0,EPR=1.,AACS=.55,
PTPS=1.535,DELC=.001,DELL=.1,DELA=0.1,
STG=2.,SECT=5.,PCNH=5*0.2,VCTD=-1.,
RPM=8416.4,SLI=1.0,IAR=20,ICYL=1,
EXPN=4.,EXPP=3.0,
DR=24.94,25.65,25.60,25.46,25.06,
DT=29.36,28.80,28.82,28.82,29.16,
SDIA=5*-6.,SETA=5*.9530,SREC=5*1.0,SDEA=73.32,73.76,74.2,74.68,75.16,
RDIA=35.0,37.2,37.2,33.6,21.5,RETA=5*.9060,
RDEA=66.3,66.9,66.9,66.3,65.2,RTF=5*1.0,RREC=5*1.0,
RWG=1.0,1.0895,1.105,1.1759,1.1759,TWG=0.0,615.,620.,622.,0.0,
PWG=0.0,50.5,38.6,50.3,0.0,SCF=5*.976,RCF=5*.976,
ENDSTG=0. &END
&DATAIN STAGE=2.,ENDSTG=1.,
DR=25.06,24.58,24.50,24.50,24.50,
DT=29.16,29.96,30.00,30.00,30.00,
RWG=1.1759,4*1.2007,TWG=0.0,640.,3*0.0,PWG=0.0,23.7,3*0.0,
SDIA=10.3,14.3,15.8,12.0,6.1,SDEA=5*69.,
RDIA=23.2,17.8,11.0,0.7,-13.6,RDEA=5*59.8,
&END

76.2 PERCENT SPEED
&DATAIN STAGE=1.0,PTPS=1.590,RPM=6312.3,ENDSTG=0.0 &END
&DATAIN STAGE=2.,VCTD=-1.,ENDSTG=1. &END

ˁ9.3 PERCENT SPEED
 ATAIN STAGE=1.0,PTPS=1.62,RPM=4912.4,ENDSTG=0.0 &END
&DATAIN STAGE=2.,VCTD=-1.,ENDSTG=1.,ENDJOB=1. &END
```

TABLE III.—SAMPLE OUTPUT

```
                     TURBINE COMPUTER PROGRAM
    NASA ONE-STAGE TURBINE - TN D-4389
    100 PERCENT SPEED
*DATAIN
   TTIN=   518.700   PTIN=    14.696  WAIR=        .000 FAIR=        .000
   PTPS=     1.250   DELC=      .010  DELL=        .100 DELA=        .000
    STG=     1.000   SECT=     5.000  EXPN=       4.000 EXPP=       3.000
     RG=    53.350    PAF=      .000   SLI=       1.000 AACS=       1.000
    RPM=  4407.400   VCTD=     1.000 EXPRE=        .000   WG=        .000
 ENDSTG=     1.000 ENDJOB=      .000DHFIND= 10000.000PFIND=   1000.000
    IAR=         2    EPR=     1.000
                      INLET RADIAL PROFILES
 PCNH=     .200      .200      .200      .200      .200      .000
```

```
                          STANDARD OPTION
  STAGE=  1                    AXIAL STATIONS
         STA. 0     STA. 1     STA.1A     STA. 2     STA. 2A
   GAMG=  1.400      1.400      1.400      1.400      1.400        .000
     DR= 22.000     22.000     22.000     22.000     22.000        .000
     DT= 30.000     30.000     30.000     30.000     30.000        .000
    RWG=  1.000      1.000      1.000      1.000      1.000        .000
    TWG=     .0         .0         .0         .0         .0          .0
    PWG=    .00        .00        .00        .00        .00         .00
  SESTH=   .000     RERTH=      .000    RPM=  4407.4

                    STATOR RADIAL DISTRIBUTIONS
   SDIA= -6.000     -6.000     -6.000     -6.000     -6.000        .000
   SDEA= 69.600     68.300     67.000     65.800     64.500        .000
   SREC=  1.000      1.000      1.000      1.000      1.000        .000
   SETA=   .963       .963       .963       .963       .963        .000
    SCF=   .990       .990       .990       .990       .990        .000
    SPA=   .000       .000       .000       .000       .000        .000
   RVU1=     .0         .0         .0         .0         .0          .0

                     ROTOR RADIAL DISTRIBUTIONS
   RDIA= 45.500     38.000     30.400     21.500     11.500        .000
   RDEA= 56.350     57.300     58.260     59.190     60.120        .000
   RREC=  1.000      1.000      1.000      1.000      1.000        .000
   RETA=   .926       .926       .926       .926       .926        .000
    RCF=   .990       .990       .990       .990       .990        .000
    RTF=  1.000      1.000      1.000      1.000      1.000        .000
    RPA=   .000       .000       .000       .000       .000        .000
   RVU2=     .0         .0         .0         .0         .0          .0

 TURBINE LENGTH =    3.51 INCHES
```

TABLE III. ontinued

NASA TURBINE COMPUTER PROGRAM
NASA ONE-STAGE TURBINE - TN D-4389
100 PERCENT SPEED

CASE 1. 1

STAGE PERFORMANCE

	STAGE 1	STAGE 2	STAGE 3	STAGE 4	STAGE 5	STAGE 6	STAGE 7	STAGE 8
TT 0	518.7							
PT 0	14.696							
WG 0	35.341							
DEL H	9.622							
WRT/P	54.769							
DH/T	.01855							
N/RT	193.519							
ETA TT	.91332							
ETA TS	.80057							
ETA AT	.90306							
PT0/PS1	1.250							
PT0/PT2	1.363							
PT0/PS2	1.427							
PTR1A/PS2	1.176							
TT2/TT0	.92268							
TTR1/TT0	.95020							
PS 1	11.752							
TTR 1	492.9							
PTR 1	12.116							
PS 2	10.300							
TT 2	478.6							
PT 2	10.784							
UP/VI	.64452							
UR/VI	.54536							
W.F. P	.96361							
W.F. R	1.34587							
RX P	.35936							
RX R	.15371							
ALPHA 0	.000							
I STATOR	6.000							
BETA 1A	14.244							
I ROTOR	-16.156							
ALPHA 2	-16.164							
DBETA R	96.254							
M 1	.56226							
M1 RT	.65392							
MR 1A	.22667							
MR1A RT	.31222							
MR 2	.46802							
MR2 TIP	.52611							
E/TH CR	9.622							
N/RTH CR	4407.4							
WRTHCRE/D	35.341							
RPM	4407.4							
MF 2A	.24622							

OVERALL PERFORMANCE

W.F. P	.96361	W.F. R	1.34587	DEL H	9.62213	WNE/60D	2596.030	TORQUE	573.185
WRT/P	54.76934	N/RT	193.519	DH/T	.01855	N/RTH CR	4407.367	TOR/P	39.00280
PT0/PT2	1.36282	PT0/PS2	1.42686	PT/PAT2	1.36792	E/TH CR	9.62199	EQ TOR	573.18512
ETA TT	.91332	ETA TS	.80057	ETA TTRP	.91332	HP	481.008	U/VIS	.64452
PT/T EQ	1.36282	PT/S EQ	1.42686	WG 0	35.3410	EQ WG0	35.34124	PT0/PS1	1.25000

TABLE III.—Continued

TURBINE COMPUTER PROGRAM
NASA ONE-STAGE TURBINE - TN D-4389
100 PERCENT SPEED
CASE 1. 1
INTER-STAGE PERFORMANCE

STA 0	STATOR INLET			STAGE 1.			
DIAM 0	22.000	22.908	24.659	26.294	27.832	29.290	30.000
SLOPE 0		.00	.00	.00	.00	.00	
WG 0		7.068	7.068	7.068	7.068	7.068	
TT 0	518.7	518.7	518.7	518.7	518.7	518.7	518.7
PT 0	14.696	14.696	14.696	14.696	14.696	14.696	14.696
ALPHA 0	.000	.000	.000	.000	.000	.000	.000
I STA 0	6.000	6.000	6.000	6.000	6.000	6.000	6.000
V 0	207.230	207.230	207.230	207.230	207.230	207.230	207.230
VU 0	.000	.000	.000	.000	.000	.000	.000
VZ 0	207.230	207.230	207.230	207.230	207.230	207.230	207.230
TS 0	515.1	515.1	515.1	515.1	515.1	515.1	515.1
PS 0	14.345	14.345	14.345	14.345	14.345	14.345	14.345
DENS 0	.07516	.07516	.07516	.07516	.07516	.07516	.07516
M 0	.18626	.18626	.18626	.18626	.18626	.18626	.18626
STA 1	STATOR EXIT						
DIAM 1	22.000	22.800	24.400	26.000	27.600	29.200	30.000
SLOPE 1		.00	.00	.00	.00	.00	
WG 1		5.926	6.501	7.077	7.627	8.210	
TT 1	518.7	518.7	518.7	518.7	518.7	518.7	518.7
ALPHA 1	70.214	69.599	68.299	66.999	65.799	64.499	63.864
DEL A	70.214	69.599	68.299	66.999	65.799	64.499	63.864
V 1	700.727	678.991	641.467	608.791	580.233	554.968	542.943
VU 1	659.358	636.401	596.004	560.390	529.238	500.902	487.427
VZ 1	237.204	236.690	237.192	237.884	237.861	238.929	239.169
TS 1	477.8	480.3	484.5	487.9	490.7	493.1	494.2
PS 1	10.904	11.105	11.456	11.752	12.002	12.216	12.312
DENS 1	.06159	.06240	.06383	.06502	.06602	.06687	.06725
M 1	.65392	.63199	.59452	.56226	.53434	.50984	.49823
ZWI INC	.5953	.6107	.6654	.7194	.7702	.8223	.8368
ETA S	.9628	.9628	.9628	.9628	.9628	.9628	.9628
	STATOR FORCES						
AVG DIA	22.000	22.800	24.400	26.000	27.600	29.200	30.000
FTAN/IN	-151.8	-146.5	-150.5	-154.1	-156.8	-159.8	-155.5
			F TAN	-614.4			
FAX/IN	256.8	241.6	221.1	203.3	188.2	174.5	166.1
			F AX	824.3			
F DRUM	.0						.0

TABLE III.—Concluded

TURBINE COMPUTER PROGRAM
NASA ONE-STAGE TURBINE - TN D-4389
100 PERCENT SPEED

CASE 1. 1
INTER-STAGE PERFORMANCE

STA 1A	ROTOR INLET		STAGE 1				
DIAM 1A	22.000	22.800	24.400	26.000	27.600	29.200	30.000
SLOP 1A		.00	.00	.00	.00	.00	
WG 1A		5.926	6.501	7.077	7.627	8.210	
TTR 1A	487.2	488.3	490.5	492.9	495.4	498.1	499.6
PTR 1A	11.653	11.747	11.933	12.116	12.304	12.507	12.626
BETA 1A	44.888	39.905	28.123	14.244	-.370	-14.241	-20.516
I ROTOR	-5.353	-5.595	-9.877	-16.156	-21.869	-25.741	-26.937
R 1A	334.803	308.547	268.944	245.429	237.866	246.505	255.366
RU 1A	236.278	197.936	126.770	60.387	-1.535	-60.641	-89.500
MR 1A	.31244	.28719	.24926	.22667	.21905	.22646	.23434
U 1A	423.080	438.464	469.234	500.003	530.773	561.542	576.927
STA 2	ROTOR EXIT						
DIAM 2	22.000	22.800	24.400	26.000	27.600	29.200	30.000
SLOPE 2		.00	.00	.00	.00	.00	
WG 2		5.890	6.498	7.077	7.651	8.225	
BETA 2	55.886	56.349	57.299	58.259	59.189	60.119	60.600
DBETA	100.774	96.254	85.422	72.503	58.819	45.878	40.084
R 2	450.717	448.944	474.740	498.547	521.859	545.677	535.821
RU 2	373.157	373.714	399.494	423.982	448.205	473.136	466.817
MR 2	.42345	.42177	.44589	.46802	.48963	.51164	.50238
U 2	423.080	438.464	469.234	500.003	530.773	561.542	576.927
RX	.15622	.20533	.28979	.35936	.41732	.46622	.48781
DEL H	10.299	10.011	9.862	9.674	9.469	9.252	8.695
PSI	.72024	.65188	.56073	.48440	.42075	.36729	.32701
ETA TT	.95901	.93227	.92739	.91760	.90542	.89157	.83787
ETA TS	.85465	.83082	.81942	.80478	.78857	.77143	.72496
ETA AT	.95164	.92510	.91905	.90774	.89388	.87848	.82557
ZWI INC	1.5467	1.4361	1.2212	1.0353	.8764	.7380	.6688
ETA R	.9256	.9256	.9256	.9256	.9256	.9256	.9256
	ROTOR FORCES						
AVG DIA	22.000	22.800	24.400	26.000	27.600	29.200	30.000
FTAN/IN	139.5	130.8	132.9	133.2	132.8	131.8	120.6
			F TAN	528.6			
FAX/IN	40.6	55.6	84.2	112.0	138.5	164.5	175.9
			F AX	443.1			
F DRUM	.0						.0
STA 2A	STAGE EXIT						
DIAM 2A	22.000	22.800	24.400	26.000	27.600	29.200	30.000
SLOP 2A		.00	.00	.00	.00	.00	
WG 2A		5.890	6.498	7.077	7.651	8.225	
PT 2A	10.716	10.716	10.751	10.781	10.809	10.836	10.836
TT 2A	477.0	477.0	477.6	478.4	479.2	480.1	480.1
V 2A	257.666	257.063	265.793	273.071	279.762	285.870	285.150
VU 2A	-49.923	-64.750	-69.740	-76.021	-82.568	-88.407	-110.110
ALPH 2A	-11.172	-14.589	-15.212	-16.164	-17.166	-18.014	-22.715
MF 2A	.23749	.23372	.24090	.24622	.25079	.25490	.24662
VZ 2A	252.783	248.774	256.480	262.276	267.300	271.856	263.033
TS 2A	471.5	471.5	471.7	472.2	472.7	473.3	473.4
PS 2A	10.288	10.290	10.295	10.300	10.304	10.308	10.311
DENS 2A	.05890	.05891	.05891	.05888	.05883	.05878	.05879
M 2A	.24208	.24150	.24964	.25635	.26248	.26804	.26735

BLANK