

TURBN Program

User Guide

January 2016

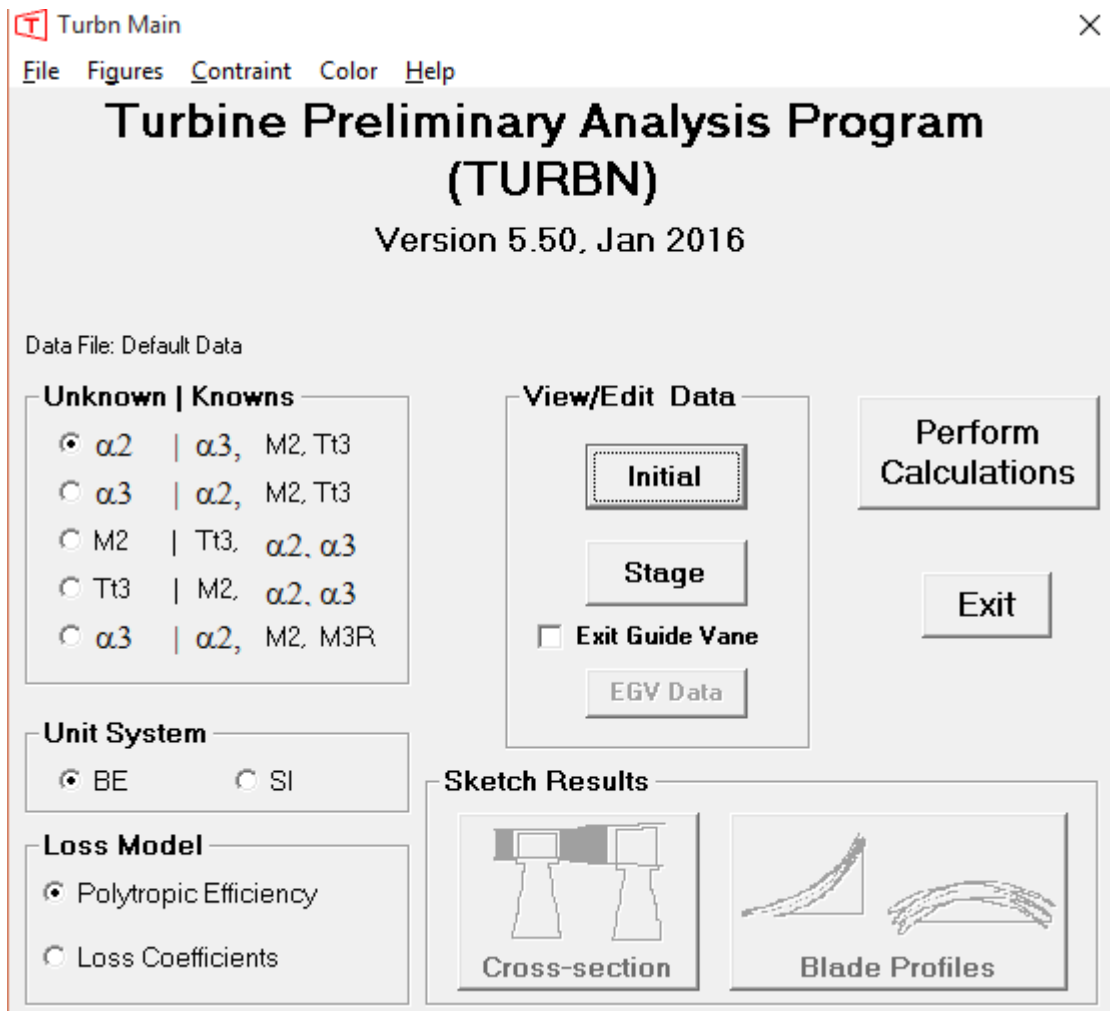
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1. MAIN Window

When the TURBN program is run, the default input data is loaded from within the program and the Main window is displayed as shown below.



The turbine mean-line design program TURBN is based on the equations developed in *Elements of Gas Turbine Propulsion* and *Aircraft Engine Design, Second Edition*. It analyzes a constant mean-line design with free vortex swirl distribution for the following five different cases of unknown and known data:

1. α_2 unknown; α_3, M_2, T_{t3} known.
2. α_3 unknown; α_2, M_2, T_{t3} known.
3. M_2 unknown; $T_{t3}, \alpha_2, \alpha_3$ known..
4. T_{t3} unknown; M_2, α_2, α_3 known.
5. α_3 unknown; α_2, M_2, M_{3R} known.

Each of these designs can be analyzed using the user-selected unit system (English or SI) and loss model (polytropic efficiency or loss coefficients).

This program is designed to be user-friendly and multiple windows are used for program control and data input. TURBN input data files may be saved on disk for later use (the file extension “tbn” is used for these files). Also, saved input data files may be read from disk for current use. Program output is directed to an output window and may be sent to a printer.

It is recommended that a multi-stage turbine design begin with the α_3 unknown; α_2, M_2, M_{3R} known. Starting from the results of this design, each stage can be custom designed using the other unknown and known combinations.

2. VIEW/EDIT DATA Windows

When the **Initial** data button is pressed, the following Initial Data window is displayed:

The 'Initial Data' window contains the following parameters and values:

Number of Stages (10 max)	2	
Mass Flow Rate	100	lbm/s
Rotor Angular Velocity	1200	rad/s
Inlet Total Pressure	300	psia
Inlet Total Temperature	3200	R
Alpha 1 for First Stage	0	deg
Mach 1 for First Stage	0.4	
Ratio of Specific Heats	1.3	
Gas Constant	53.4	ft-lbf/lbm-R
Cp	0.2974	Btu/lbm-R
Mean Radius	10	inches
Mean Rotor Velocity	1000	ft/sec

When the **Stage** data button is pressed, the Stage Data window similar to that shown below is displayed. Data is edited in this window by moving to the desired data cell, double-click on the cell to open an edit window. Make the changes and then press either the Enter key or Tab key and the updated window is displayed. Shown below is a two-stage turbine with α_3 unknown; α_2, M_2, M_{3R} known. The values of α_2 were changed to 65 and M_2 for the second stage changed to 0.8.

Stage Data

	1	2
u3/u2	1.0	1.0
Alpha @ 2	65	65
Mach @ 2	1.05	0.8
Mach @ 3R	0.9	0.6
Stator Z	1.0	1.0
Rotor Z	1.0	1.0
Stator c/h	1.0	1.0
Rotor c/h	1.0	0.7
Stator phi	0.02	0.02
Poly Eff	0.9	0.9

If the **EGV** check box is marked on the Main window, the **EGV** button becomes active. Pressing the **EGV** button opens the EGV Data window.

3. RESULTS Window – Perform Calculations

Pressing the **Perform Calculations** button on the Main window causes the Results window to be opened and the input data and results displayed for the first stage as shown below for the first of a two-stage turbine with α_3 unknown; α_2, M_2, M_{3R} known.

Results

```

TURBN V5.50 - Data File: Default Data
Stage #01   Date - 1/20/2016   Time - 9:48:16 AM
Corr Flow = 12.17 lbm/s  M1 = 0.4000  Tt1 = 3200.0 R   Pt1 = 300.00 psia
Mass Flow = 100.00 lbm/s M2 = 1.0500  AL2 = 65.00    AL1 = 0.00
u3/u2 = 1.0000 phis= 0.020  et = 0.900  Um = 1000 ft/s  rm = 10.00 in
Stator: Z = 1.0000  c/h = 1.0000  Rotor: Z = 1.0000  c/h = 1.0000
Gamma = 1.3000 Gas Const = 53.40ft-lbf/lbm-R  w = 1200 rad/s  M3R = 0.900
Omega = 0.2049      Cp = 0.2974 Btu/lbm-R
    
```

```

RESULT: Tt3/Tt1 = 0.8639  Pt3/Pt1 = 0.4945  DTt = 435.38 R  AN^2=1.145E+10
Reaction Hub = 0.1550  Mean = 0.2640  Tip = 0.3534  Eff = 90.72%
Flow Area 1 = 58.33  Area 2 = 87.16  Area 3 = 106.82 in^2
Coeff. Load = 3.2414  Flow = 1.0989  Vel Rat = 0.3928  RPM = 11,459
Nozzle - # of Vanes = 55  c/s = 1.014
Rotor - # of Blades = 62  c/s = 1.523  M3Rt = 0.9042
    
```

Station	1h	1m	1t	2h	2m	2t	2Rm	3Rm	3h	3m	3t
Prop:											
Tt	R	3200	3200	3200	3200	3200	2951	2951	2765	2765	2765
T	R	3125	3125	3125	2688	2746	2793	2746	2631	2621	2639
Pt	psia	300.0	300.0	300.0	297.1	297.1	209.0	196.7	148.4	148.4	148.4
P	psia	270.7	270.7	270.7	139.6	153.1	164.7	153.1	119.7	117.7	121.3
M		0.400	0.400	0.400	1.127	1.050	0.986	0.705	0.900	0.605	0.582
Vel	ft/s	1057	1057	1057	2761	2600	2463	1746	2182	1464	1411
u	ft/s	1057	1057	1057	1099	1099	1099	1099	1099	1099	1099
v	ft/s	0	0	0	2532	2357	2204	1357	1885	967	885
alpha	deg	0.00	0.00	0.00	66.54	65.00	63.50			41.34	38.84
beta	deg							50.99	59.75		
radius	in	9.54	10.00	10.46	9.31	10.00	10.69	10.00	10.00	9.15	10.00

Print
Stage Nomenclature
Next Stage
Done

If the computer has a default printer, the **Print** button is visible and the user can use it to have the results printed. The **Next Stage** button is active for advancement to the next stage calculations.

The results for the Exit Guide Vane of this two-stage design are shown below.

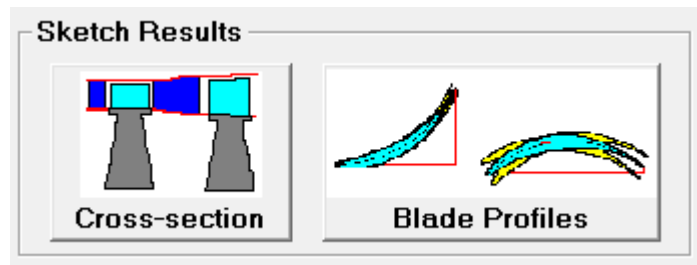
Turbine Exit Guide Vane

Corr Flow = 34.56 lbm/s M1 = 0.3484 Tt1 = 2512.3 R Pt1 = 93.58 psia
Mass Flow = 100.00 lbm/s AL1 = 11.11 Tt2 = 2512.3 R Pt2 = 93.31 psia
Z = 0.900 c/h = 1.000 phis = 0.020 AL2 = 0.00 M2 = 0.500

Flow Area 1 = 189.71 ft² rh1 = 8.49 rm1 = 10.00 rt1 = 11.51 in
Flow Area 2 = 139.79 ft² rh2 = 8.89 rm2 = 10.00 rt2 = 11.11 in

Number of EGV Blades = 6
Solidity (c/s) = 0.250

Pressing the Done button displays the Main window with both Sketch Results buttons active as shown below.



4. SKETCH RESULTS Window

Pressing the **Cross-section** button on the Main window causes the Stage Sketch Data window to be opened and the input data displayed as shown below.

Stage Sketch Data
×

Stage	1	2
Tt2R (R)	2950.6	2600.6
\sqrt{w}/cx	1.2	1.2
hr/\sqrt{w}	1.0	1.0
$\sigma b/r$	0.2	0.2
sp str rim *	4.0	4.0
sp str disk *	2.0	2.0
\sqrt{w}_{dr}/\sqrt{w}_r		
DSF **		
hr (in)		
\sqrt{w}_S ***		

cx = rotor blade axial chord at hub
 * Specific Strength (ksi-ft³/slug) ** Disk Shape Factor *** Wheel Speed at rim (ft/s)

Close
Blade-Disk Structure
Calculate
Sketch

Pressing the **Calculate** button on the Stage Sketch Data window displays the results on an updated window as shown below. If the **Sketch** button is selected before the **Calculate** button, the results are calculated but not displayed

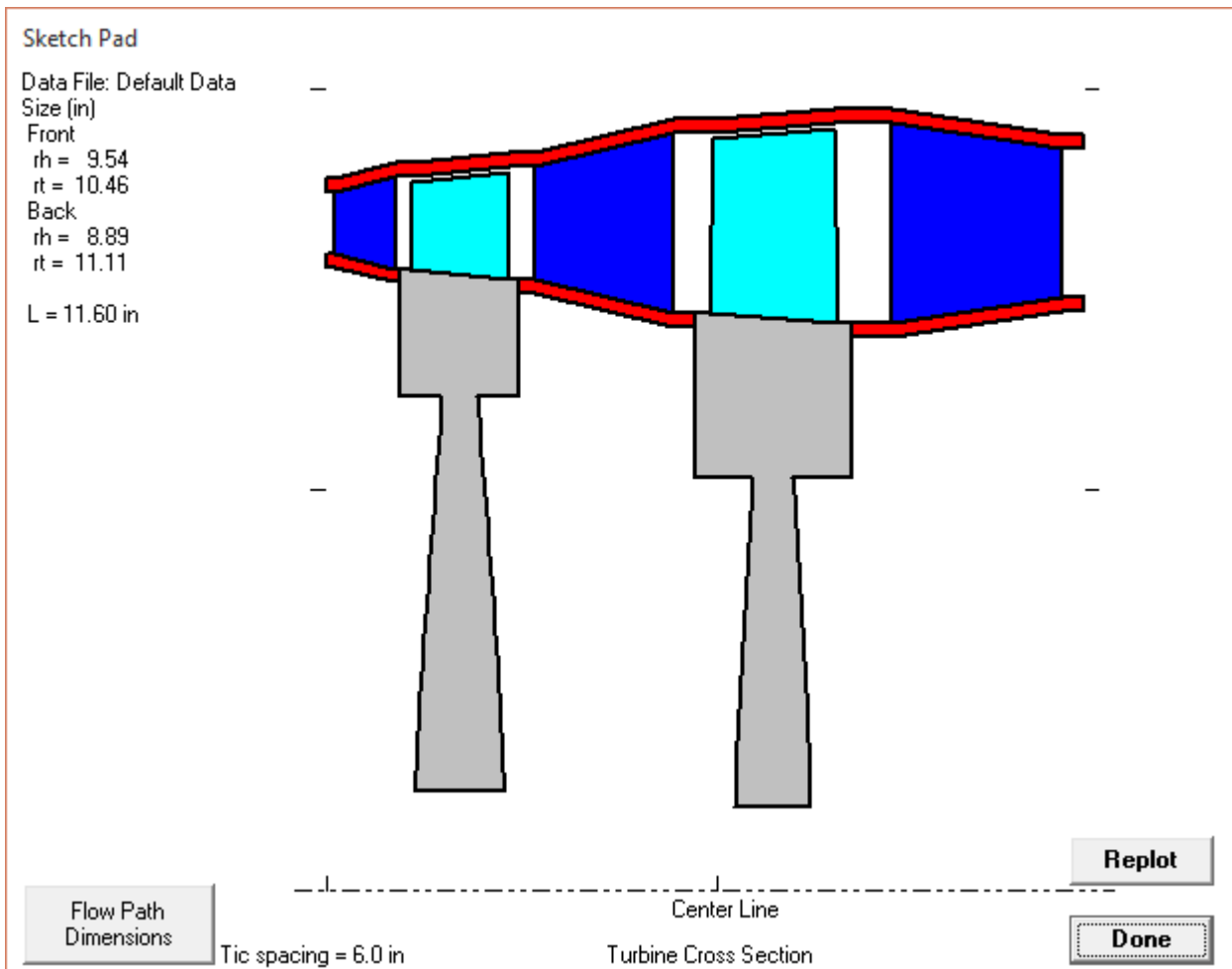
Stage Sketch Data
×

Stage	1	2
Tt2R (R)	2950.6	2600.6
\sqrt{w}/cx	1.2	1.2
hr/\sqrt{w}	1.0	1.0
$\sigma b/r$	0.2	0.2
sp str rim *	4.0	4.0
sp str disk *	2.0	2.0
\sqrt{w}_{dr}/\sqrt{w}_r	0.299	0.256
DSF **	0.950	0.662
hr (in)	1.83	2.39
\sqrt{w}_S ***	739.5	617.6

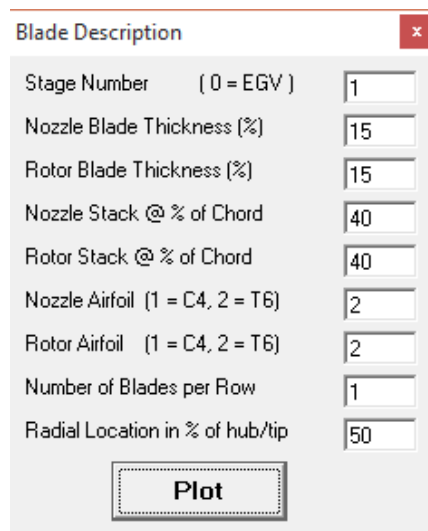
cx = rotor blade axial chord at hub
 * Specific Strength (ksi-ft³/slug) ** Disk Shape Factor *** Wheel Speed at rim (ft/s)

Close
Blade-Disk Structure
Calculate
Sketch

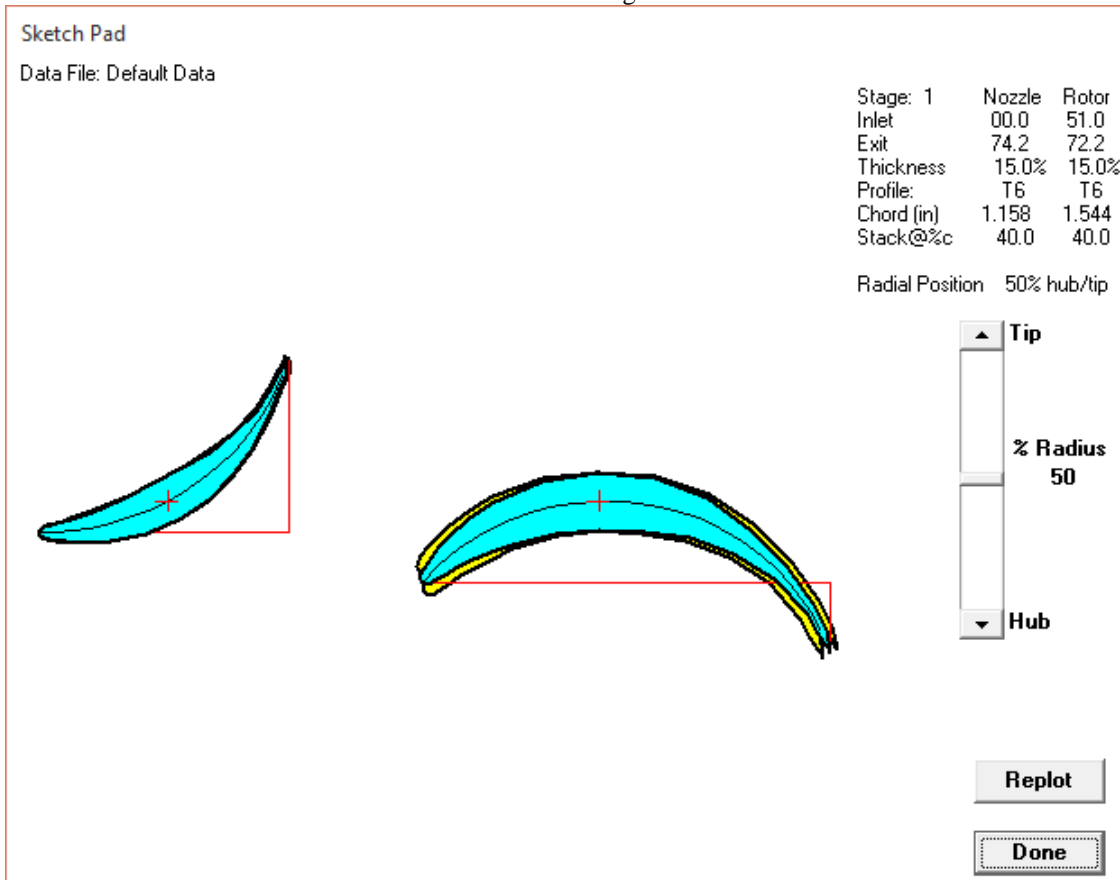
Pressing the **Sketch** button displays the Sketch Pad window with a cross-sectional sketch of the multi-stage axial flow turbine.



Pressing the **Blade Profiles** button on the Main window causes the Blade Description window to be opened and the input data displayed as shown below.



Pressing the **Plot** button for the data above displays the Sketch Pad window with a sketch of the blade shape. The hub and tip blade profiles are shown in yellow and the profile at the radius of interest is shown in light blue. The rotor airfoil is shown on the left and the stator airfoil is shown on the right.



5. Constraint Analysis

Selecting Constraint from the pulldown menu will display the following window where the user can input data to discover limits on radius and rotational speed (ω).

The 1st Stage Constraint Calculations window allows users to input data for constraint analysis. It includes fields for Mean Radius (in), Omega (rad/s), Rim Height, M3R, and various constraints like AN² max, Max Rim Speed, Alpha2 min, and Alpha2 max. The window also features buttons for Calcs, Plot, and Exit.

Mean Radius (in)		Plot	Omega (rad/s)	$\Delta Tt (R)$	Rim Height	M3R
Initial Value	8.00	Min	500	470	1.00 in	
Final Value	12.00	Max	3000			0.8
Steps (max = 100)	100	<input type="checkbox"/> Y Marker: Value	0			

Calcs

Plot

Exit

Constraints

AN ² max	5.000	10 ¹⁰ (in ² -rpm ²)	Alpha2 min	65
Max Rim Speed	1000.0	ft/s	Alpha2 max	70

After calculations are performed, pressing the Plot button displays the results like below.

Constraint Plot

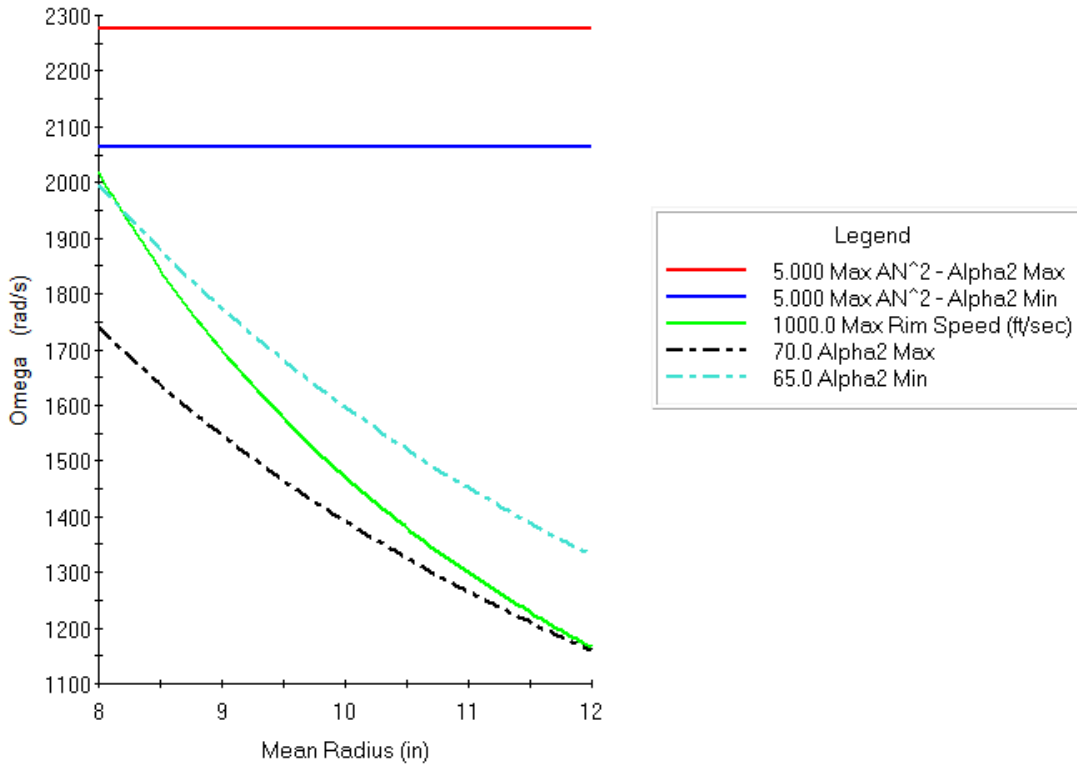
Date: 1/20/2016 10:04:15 AM First Stage Turbine Constraints
Data File: Default Data
Mach 2 = 1.05, Tt Diff = 470.0 R, M3R = 0.800, Rim Height = 1.00 in
mdot = 100.0 lbm/s, Pt1 = 300.0 psia, Tt1 = 3200.0 R



Exit

Print

Right mouse click for plot properties



The plot above shows that the AN² do not limit the rotational speed (ω) but the Rim Speed does. The user would thus choose a combination of ω and r that is below the limit (green line).