Aeolus to TurbAero
Transfer Link

Aeolus Transfer Link

- The Transfer Link automatically converts an ***Aeolus*** meanline model into an initial throughflow model for ***TurbAero/AxTurb*** using experienced-based geometry assumptions

Aeolus *input data Excel file:*

Aeolus_to_AxTurb Transfer Demo for 7-stage Steam Turbine.xls [Compati

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OPERATING CONDITIONS

	Parameter	Units	Value
3	Parameter	Units	Value
4	Title	-	CL55 7-Stage HP Unit
5	Customer	-	
6	Location	-	
7	Fluid	-	STEAM
8	Speed	rpm	5033
9	**Inlet Flange Conditions**		
10	Diameter	inches	10
11	P00	psia	145
12	T00	Deg F	356.1
13	Loss	-	0.030
14	**Exhaust Flange Conditions**		
15	Diameter	inches	20
16	Pexit	psia	6.5
17	Hood Loss	-	0
18	**Number of Turbine Stages**		
19	Stages	-	7
20	**Mechanical Losses**		
21	Gear	%	100
22	Generator	%	100
23	Misc	HP	0
24	Bearing	HP	0
25	**Shaft End Leakage (Override)**		
26	Leakage Flow	lbm/hr	0

NOZZLE & BLADE INPUTS

	Parameter	units	I	J	K	L	M	
3	Parameter	units	6	6	7	7	8	
4	Stage_Number	-	1	1	2	2	3	
5	Component Name	-	inlet nozzle	1st Blade	2nd Nozzle	2nd Blade	3rd Nozzle	3rd E
6	Component Type	-	nozzle	blade	nozzle	blade	nozzle	blad
7	**LE geometry**							
8	Rt.in	inches	13.225	13.275	13.68	13.73	13.9	
9	Rh.in	inches	12.405	12.375	12.78	12.75	12.78	
10	BetaB.in	Degrees	90	29	90	27	90	
11	Rle	inches	0.212	0.012	0.214	0.015	0.258	
12	Wedge_Ang.in	Degrees	42	5	42	12	42	
13	Rshaft.in	inches	6.5	6.5	6.5	6.5	6.5	
14								
15								
16	**TE Geometry**							
17	Rt.out	inches	13.225	13.275	13.68	13.73	13.9	
18	Rh.out	inches	12.405	12.375	12.78	12.75	12.78	
19	BetaG(t)	Degrees	12.31	20.49	13.19	22.29	13.03	
20	BetaG(m)	Degrees	11.87	20.21	12.73	22.02	12.46	
21	BetaG(h)	Degrees	11.46	20.16	12.35	21.80	11.91	
22	R_crv.out	inches	3.4	100	3.4	100	3.4	
23	t_te	inches	0.015	0.012	0.015	0.015	0.015	
24	Wedge_Ang.out	Degrees	6	6	6	6	6	
25	Rshaft.out	inches	6.5	6.125	6.5	6.125	6.5	
26	**Axial Gaps**							
27	Gap	inches	0.160	0.894	0.160	0.732	0.160	
28	**Overall Airfoil Geometry**				0.527			
29	Roughness	inches	0.000063	0.000063	0.000063	0.000063	0.000063	0.0
30	Number of Airfoils	-	72	212	76	194	76	
31	Number Missing Airfoils	-	0	0	0	0	0	

AxTurb *input data file:*

Aeolus_to_AxTurb Transfer Demo for 7-stage Steam Turbine.axt - ...

File Edit Format View Help

```
CL55 7-Stage HP Unit
 3 1 1 5033 6.50 1 1 0.97
0,1,3,1,0,0,0,"Neq=5033"
 1 0 0 0 1 1 0 1
1 28 -14 3 28
 -1 0 -1 0 0 0 0 0 0
 0. 145.00 356.10 90.
 0 0.0000 -12.405 0.0000 -13.225
 1 1.5480 12.4050 1.5480 13.2250
 0 1.7080 -12.3750 1.7080 -13.2750
 2 2.3330 12.3750 2.3330 13.2750
 0 3.2270 -12.78 3.2270 -13.68
 1 4.8090 12.7800 4.8090 13.6800
 0 4.9690 -12.7500 4.9690 -13.7300
 2 5.7560 12.7500 5.7560 13.7300
 0 6.4880 -12.78 6.4880 -13.9
 1 8.0590 12.7800 8.0590 13.9000
 0 8.2190 -12.7500 8.2190 -13.9500
 2 9.0060 12.7500 9.0060 13.9500
 0 9.7980 -12.78 9.7980 -14.23
 1 11.3520 12.7800 11.3520 14.2300
 0 11.5120 -12.7500 11.5120 -14.2800
 2 12.2990 12.7500 12.2990 14.2800
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 2 15.4800 12.7500 15.4800 14.5300
 0 16.0230 -12.78 16.0230 -14.89
 1 17.6100 12.7800 17.6100 14.8900
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 2 18.7300 12.7500 18.7300 14.9400
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 1 20.8350 12.7800 20.8350 15.8400
 0 21.0150 -12.7500 21.0150 -16.2200
 2 22.2550 12.7500 22.2550 16.2200
 1 72 3 49 -1 1
 1.0000 0.4000 0.2000 6.5000 0.0500 12.115 12.3150 0.0150
 12.4050 90.000 11.460 2.0560 0.5770 0.0150 0.2941
 12.8150 90.000 11.870 2.0560 0.5770 0.0150 0.2941
 13.2250 90.000 12.310 2.0560 0.5770 0.0150 0.2941
 2 76 3 4 -1 1
 1.0000 0.5625 0.2813 6.5000 0.0600 12.565 12.6900 0.0150
```

Ln 1, Col 1

Aeolus Turbine Preliminary Design & Analysis

Aeolus is an experienced-based, preliminary design tool coupled with a rigorous performance analysis.

This two-part system can design & analyze flow paths for many types of axial turbines, ranging from small waste heat expanders to large power gen units.

Program Capabilities:

- Any number of stages, impulse or reaction type designs
- Real gas properties, supercritical fluids & wet steam with industry standard databases: NIST RefProp and ASME '97
- Partial admission, Curtis stages, impulse and reaction designs
- Extractions/bleeds/inductions, double-flow stages
- Seal leakages, blade forces and axial thrust loads
- Supersonic expanding nozzles, including drilled (axisymmetric)
- AMDC based loss component analysis, refined by Kacker & Okapuu (Ref. 1) and similar to that in ***TurbAero*** (Refs. 2 & 3).

Aeolus Preliminary Design Tool

The ***Flow Path*** Design tool is a useful complement to ***TurbAero*** in several important areas:

- preliminary sizing & optimization of multi-stage flow paths to establish:
  - flow path radii at hub & tip
  - inlet and exit (gauging) angles for all nozzles & blades
  - airfoil geometry parameters (no. of blades, chord, axial width, max. thickness, trailing edge thickness, clearances
- graphical displays of design parameters to aid the optimization process
- industry standard fluid properties:
  - Steam (ASME '97) and real gases (NIST RefProp)
- Excel based input and output sheets for convenience in entering data, reviewing results and creating output plots

Aeolus for Performance Analysis

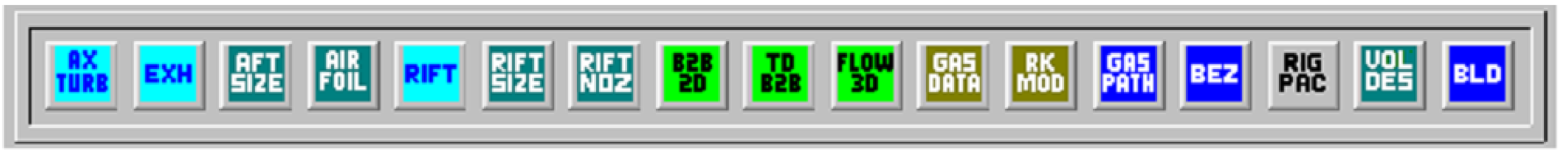
The ***Meanline Performance*** analysis is a useful complement to ***TurbAero*** in several important areas:

- Extended capabilities for steam turbines:
  - supersonic flows (including drilled nozzles)
  - extractions, inductions, double flow stages
  - seal leakages & axial thrust loads
  - converged solutions for a much larger number of stages

  Ref 4 compares results with AxStream™ for a 17-stage steam turbine
- Graphical output and industry standard fluid properties
- Similar loss component analysis as ***TurbAero/AxTurb*** (Ref. 2), allowing for a close comparison of results between ***Aeolus*** and ***AxTurb***.
- Automatic creation of all input data for ***AxTurb***

Overview of **TurbAero** Design System

TurbAero is a software system comprised of 17 different axial & radial turbine aero design and analysis programs (Refs. 2 & 3)



Axial Turbine Programs

AFTSIZE
AXTURB
AIRFOIL
BLADE

⟷

Common Programs

B2B2D/TDB2B
RKMOD
GASDATA
EXHAUST

⟷

Radial Turbine Programs:

RIFTSIZE
RIFT
RIFTNOZ
FLOW3D
GASPATH/BEZIER
RIGPAC
VOLUTE

PerAero TurbineDesigns

TurbAero

AxTurb Description

AxTurb is the throughflow analysis module for ***TurbAero***.

AxTurb Capabilities:

- 2D throughflow analysis for axial turbines based on a streamline curvature approach with full radial equilibrium
- Subsonic to transonic flows including multiple choked rows
- Very good convergence abilities for smaller number of stages (< 10) and subsonic/transonic Mach numbers (< 1.2)
- Real gas properties use Aungier's Modified Redlich-Kwong model
- Program theory & loss models are fully documented (Ref. 2)
- Prediction accuracy has been validated with several test cases (Ref. 2)

PerAero TurbineDesigns

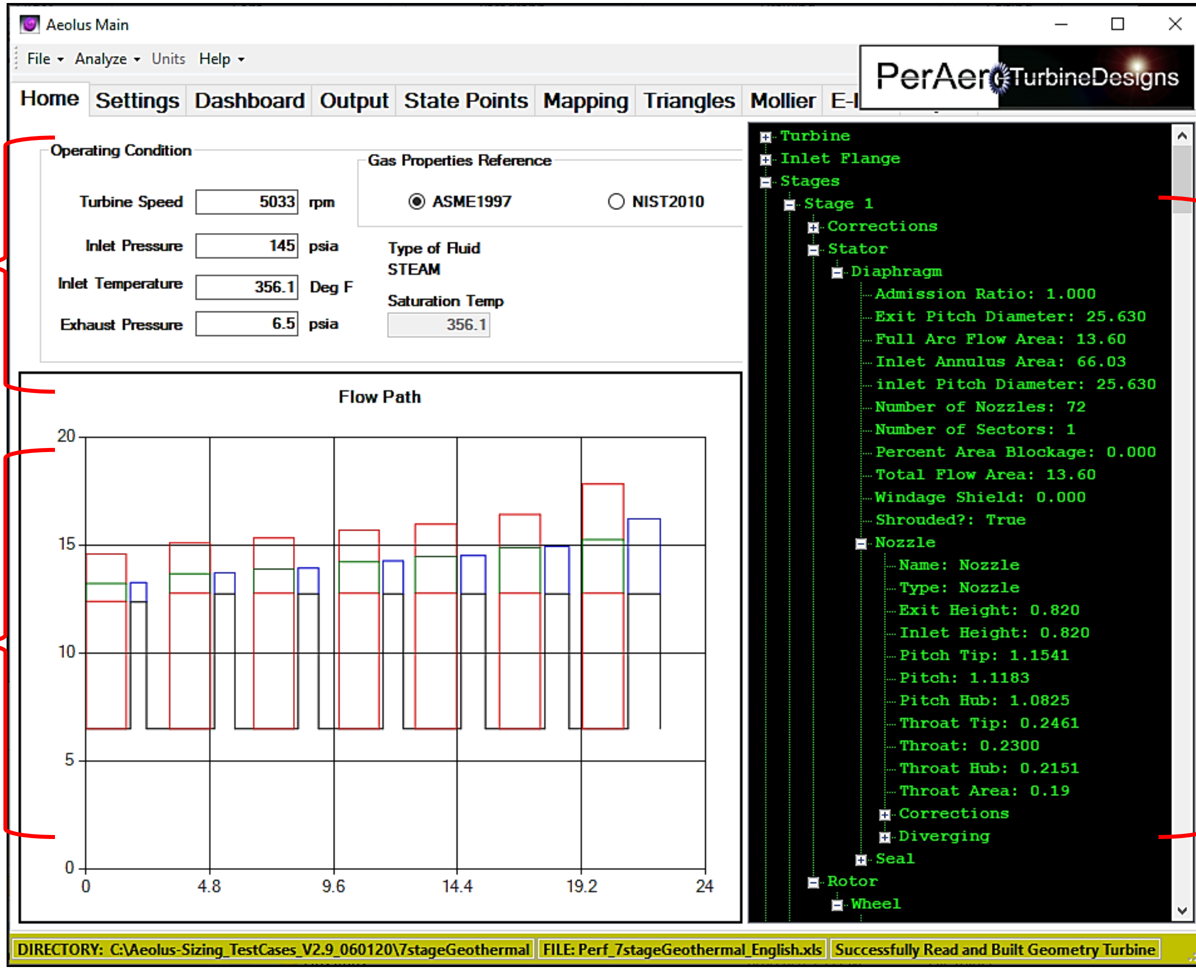
TurbAero

Aeolus to ***AxTurb*** Transfer Demo for a 7-Stage Steam Turbine

Step 1 – Start ***Aeolus*** then read in a turbine input file

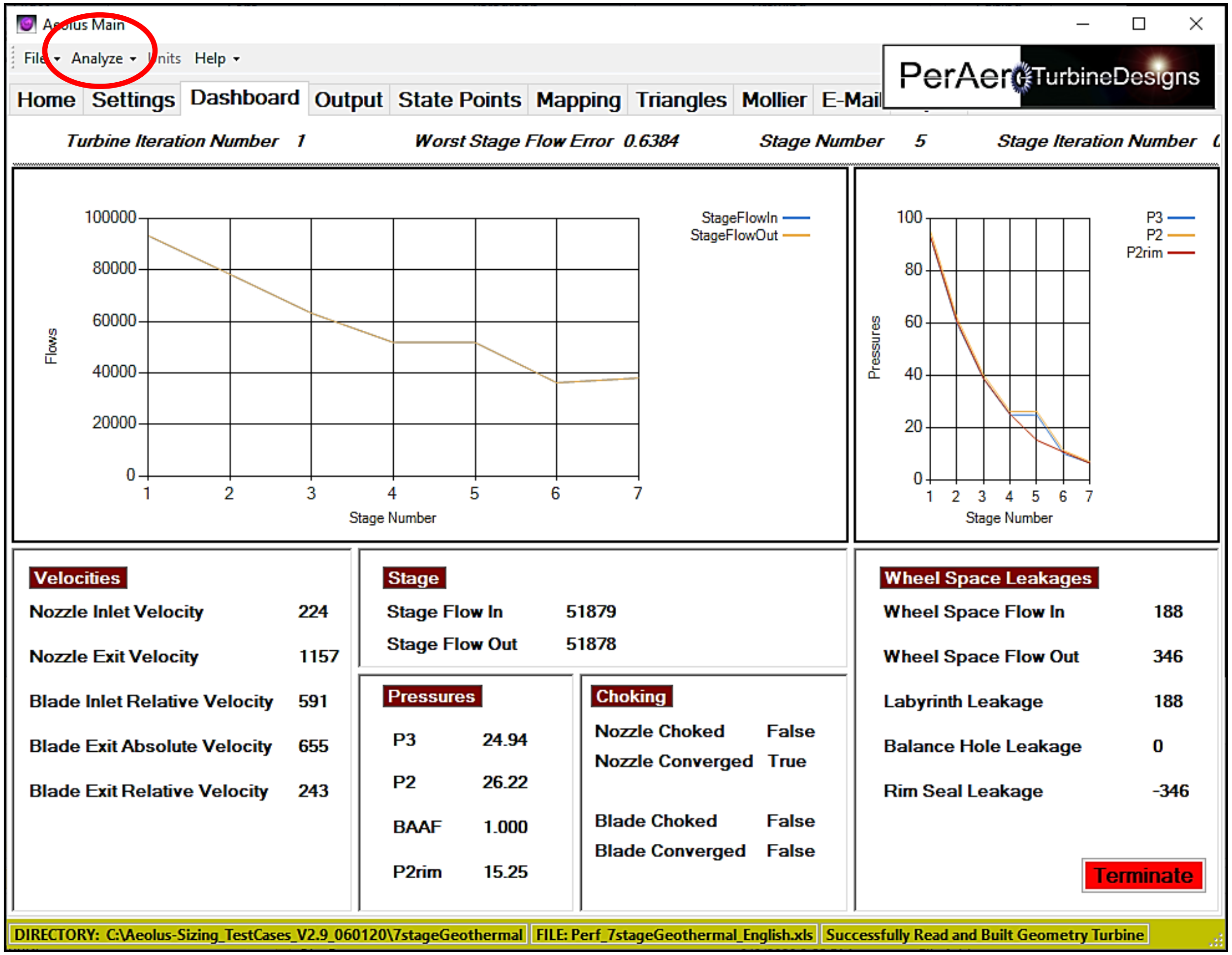
Operating Conditions

Flow Path Model



Input Data Review

Step 2 – Run ***Aeolus*** Meanline Analysis by selecting "Analyze"



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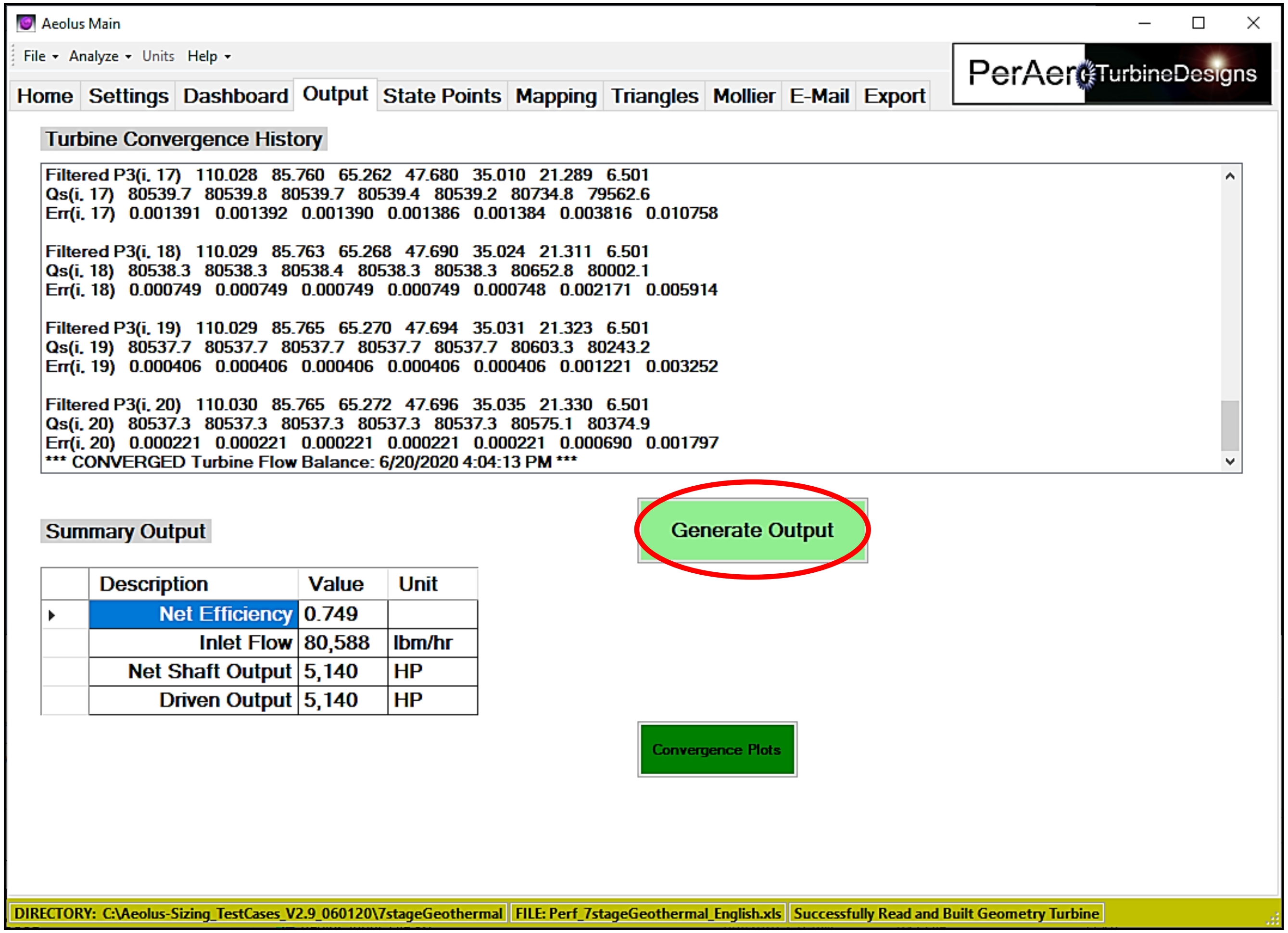
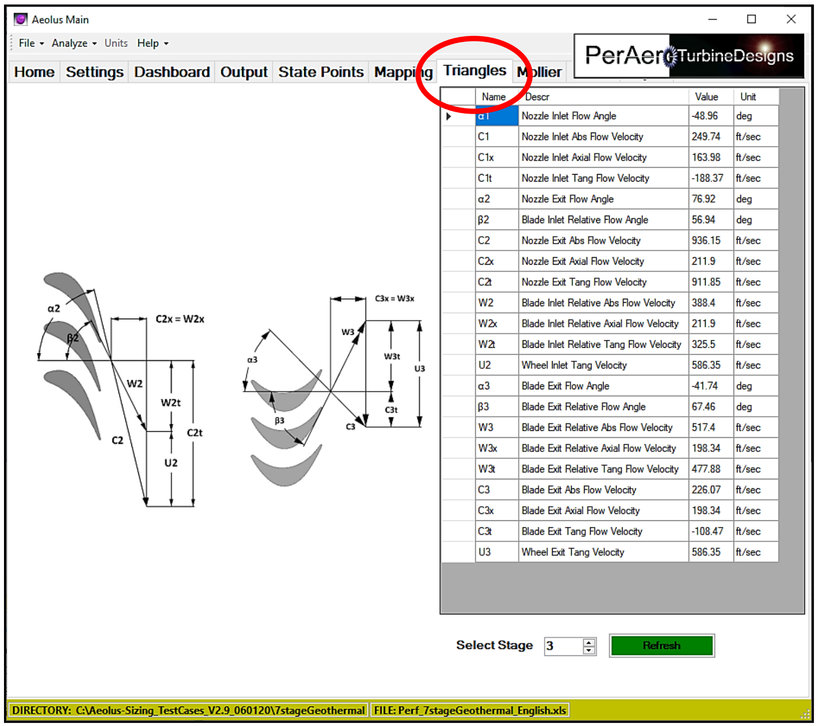
AEOLUS

Step 2 – After reaching convergence, generate the Excel output file



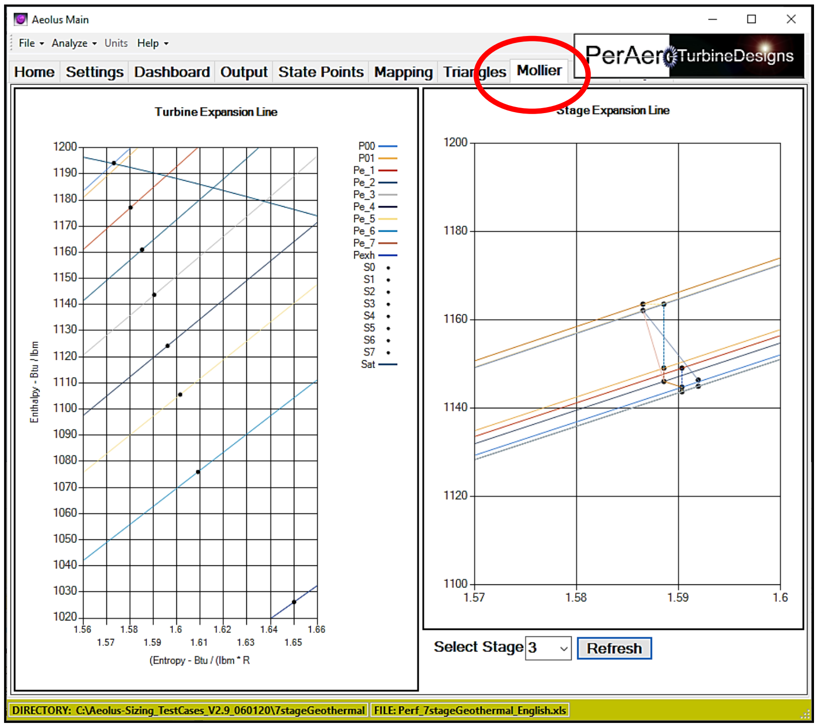
View Graphical Results if Desired (optional)

Stage Velocity Triangles

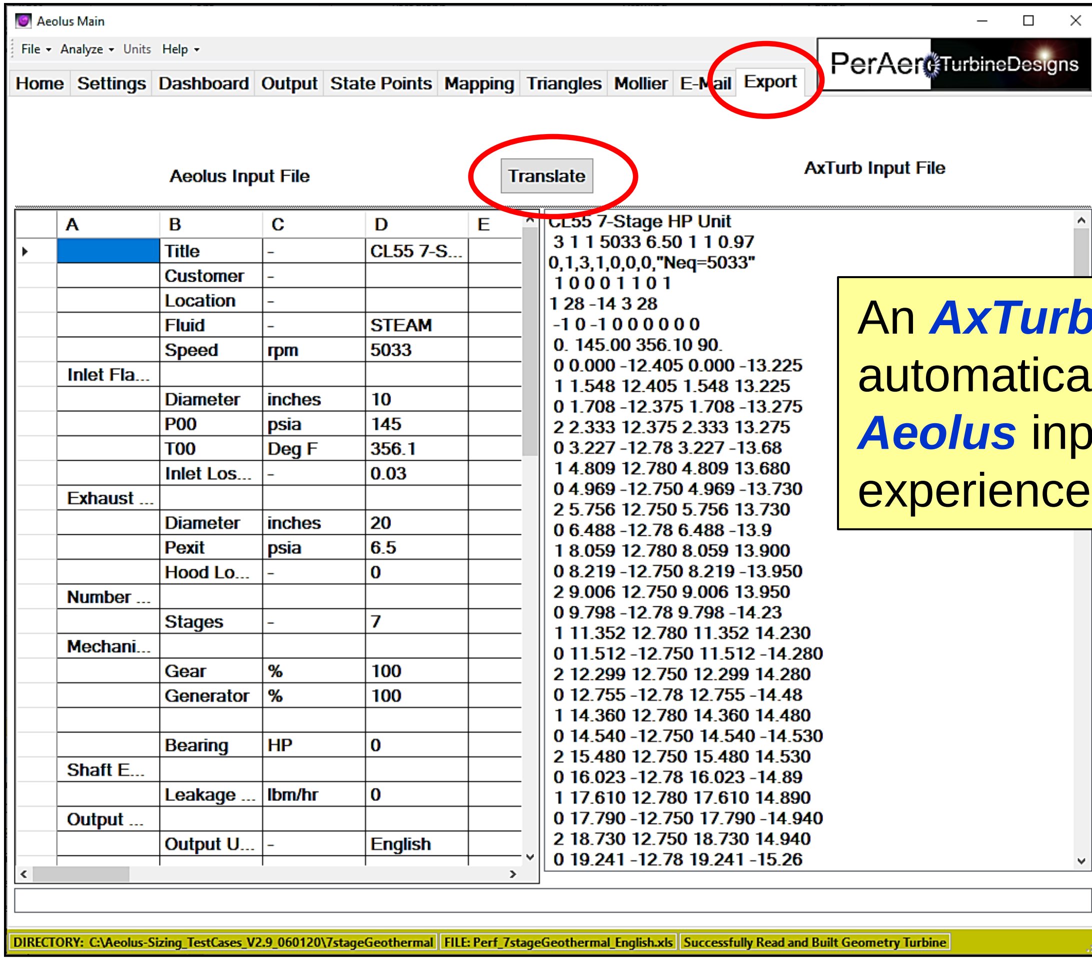


Name	Descr	Value	Unit
α1	Nozzle Inlet Flow Angle	-48.96	deg
C1	Nozzle Inlet Abs Flow Velocity	249.74	ft/sec
C1x	Nozzle Inlet Axial Flow Velocity	163.98	ft/sec
C1t	Nozzle Inlet Tang Flow Velocity	-188.37	ft/sec
α2	Nozzle Exit Flow Angle	76.92	deg
β2	Blade Inlet Relative Flow Angle	56.94	deg
C2	Nozzle Exit Abs Flow Velocity	936.15	ft/sec
C2x	Nozzle Exit Axial Flow Velocity	211.9	ft/sec
C2t	Nozzle Exit Tang Flow Velocity	911.85	ft/sec
W2	Blade Inlet Relative Abs Flow Velocity	388.4	ft/sec
W2x	Blade Inlet Relative Axial Flow Velocity	211.9	ft/sec
W2t	Blade Inlet Relative Tang Flow Velocity	325.5	ft/sec
U2	Wheel Inlet Tang Velocity	586.35	ft/sec
α3	Blade Exit Flow Angle	-41.74	deg
β3	Blade Exit Relative Flow Angle	67.46	deg
W3	Blade Exit Relative Abs Flow Velocity	517.4	ft/sec
W3x	Blade Exit Relative Axial Flow Velocity	198.34	ft/sec
W3t	Blade Exit Relative Tang Flow Velocity	477.88	ft/sec
C3	Blade Exit Abs Flow Velocity	226.07	ft/sec
C3x	Blade Exit Axial Flow Velocity	198.34	ft/sec
C3t	Blade Exit Tang Flow Velocity	-108.47	ft/sec
U3	Wheel Exit Tang Velocity	586.35	ft/sec

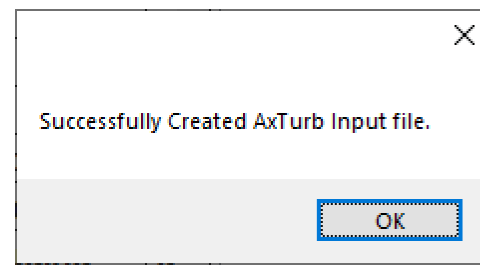
Thermo State Points & Expansion Line



Step 3 – Select ‘Export’ Menu then ‘Translate’



An ***AxTurb*** input file is automatically created from the ***Aeolus*** input data and other experienced-based assumptions



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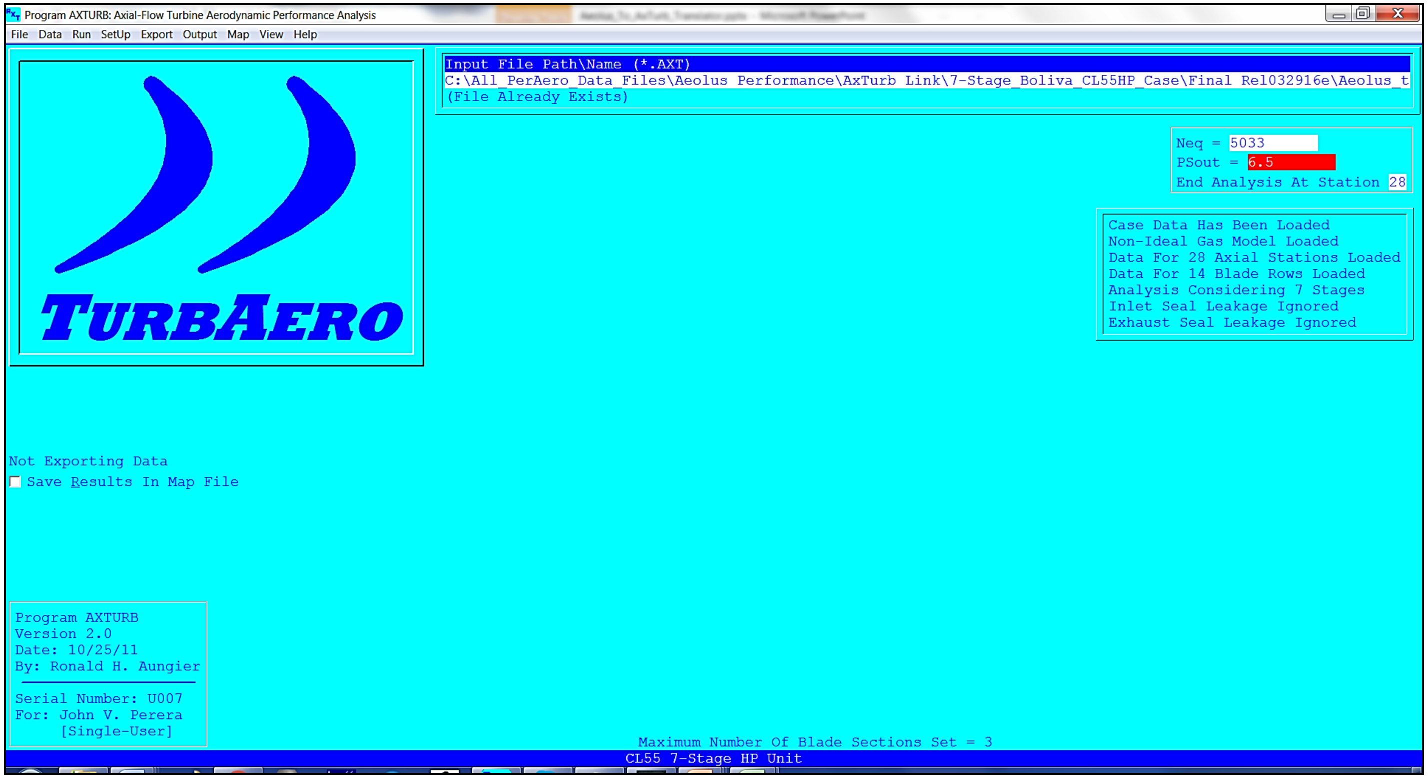
TURBAERO

Step 4 – Start AxTurb Then Read in the New Input File



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TURBAERO

All input data requirements have been transferred from ***Aeolus***

PerAero TurbineDesigns

TurbAero

Step 5 – Run ***AxTurb*** then compare results with ***Aeolus***

Comparison of Overall Performance:

	Aeolus	AxTurb
Efficiency	74.9%	73.0%
Power, HP	5,140	4,891
Flow, lb/hr	80,588	78,680

AxTurb output

Perf_7stageGeothermal_English-axt...

File Edit Format View Help

```
 Inlet Governor Valve Pressure Ratio = 0.97
 Inlet Admission = 100 %
 Inlet Mass Flow = 78679.96 lbm/hr
 Inlet Total Pressure = 140.65 psi
 Inlet Total Enthalpy = 343.81 btu/lbm
 Inlet Total Temperature = 355.15 deg F
 Rotation Speed = 5033 rpm
 Discharge Mass Flow = 78679.96 lbm/hr

PERFORMANCE AT THE LAST STAGE EXIT

 Total Pressure = 7.765 psi
 Static Pressure = 6.501 psi
 Total Enthalpy = 177.39 btu/lbm
 Total Enthalpy Drop = 166.42 btu/lbm
 Total Temperature = 205.61 deg F
 Total Temperature Ratio = 1.226
 Total-To-Total Pressure Ratio = 18.67
 Total-To-Static Pressure Ratio = 22.3
 Total-To-Total Adiabatic Efficiency = 0.7737
 Total-To-Total Polytropic Efficiency = 0.755
 Total-To-Static Adiabatic Efficiency = 0.7298
 Total-To-Static Polytropic Efficiency = 0.7088
 Total Power = 5146.03 Hp
```

Aeolus output

OVERALL TURBINE PERFORMANCE

POWER OUTPUT & LOSSES		
Total Work Done	btu/lbm	162.49
Gross Aero Power	hp	5518.6
Partial Admission Loss	hp	0.0
DiskFriction Loss	hp	15.7
Shroud Friction Loss	hp	0.7
Shaft Output	hp	5,140.4
Bearing Loss	hp	0.0
Net Shaft Output	hp	5,140.4
Output to Driven Equipment	hp	5,140.4
Net Steam Rate	lbm/hp-hr	15.68
Net Axial Thrust	lbf	7,974

TOTAL TO STATIC		
Net Efficiency (Effic_ts)		0.7488
Pressure Ratio (PR_ts)		22.308
Available Energy (DeltaH_is_ts)	btu/lbm	216.76
Velocity Ratio (U/Co_avg_ts)		0.504

TOTAL TO TOTAL		
Net Efficiency (Effic_tt)		0.7778
Pressure Ratio (PR_tt)		20.417
Available Energy (DeltaH_is_tt)	btu/lbm	208.66
Velocity Ratio (U/Co_avg_tt)		0.520

PerAero TurbineDesigns

AEOLUS

TURBAERO

References

1. Kacker, SC, and Okapuu, U, 1981, "A Meanline Prediction Method for Axial Flow Turbine Efficiency," ASME J Eng. for Power, Vol. 103, No. 1.
2. Aungier, R. H., *Turbine Aerodynamics: Axial-Flow and Radial-Inflow Turbine Design and Analysis*, ASME Press, New York, 2006
3. ***TurbAero*** software system developed by Mr. Ron Aungier and now owned by Flexware Inc., https://www.turbo-aero.com/turbaero
4. Perera, J V, "Aeolus and AxStream™ Performance Calculations for a 22 MW Steam Turbine", 2016