Overview

Objectives:

- Increased Range for Electric Powered Vehicles (Air & Ground).
- Hydrocarbon Specific Energy Density is Approximately (50) Times That of the Best Li-Po Batteries.
- Develop a High-Speed/Low-Weight Motor/Generator Set Using Existing AV Generator hardware.

Approach:

- Assume 80kW/270 VDC generator: Est. weight = 65 lbm, Speed Range: 16,000 to 24,000 rpm, 80kw Available Over This Speed Range. Will not "Turn-On" Until 16,000 rpm.
- IC Engine Design Derived From COTS Rotax FR125 Max Engine.

Global Hawk Low-Pressure Turbine-Driven Generator Completes Simulated Altitude Testing

By Plans and Programs Directorate, AFRL/XP / Published December 12, 2006

PHOTO DETAILS / DOWNLOAD HI-RES 1 of 1

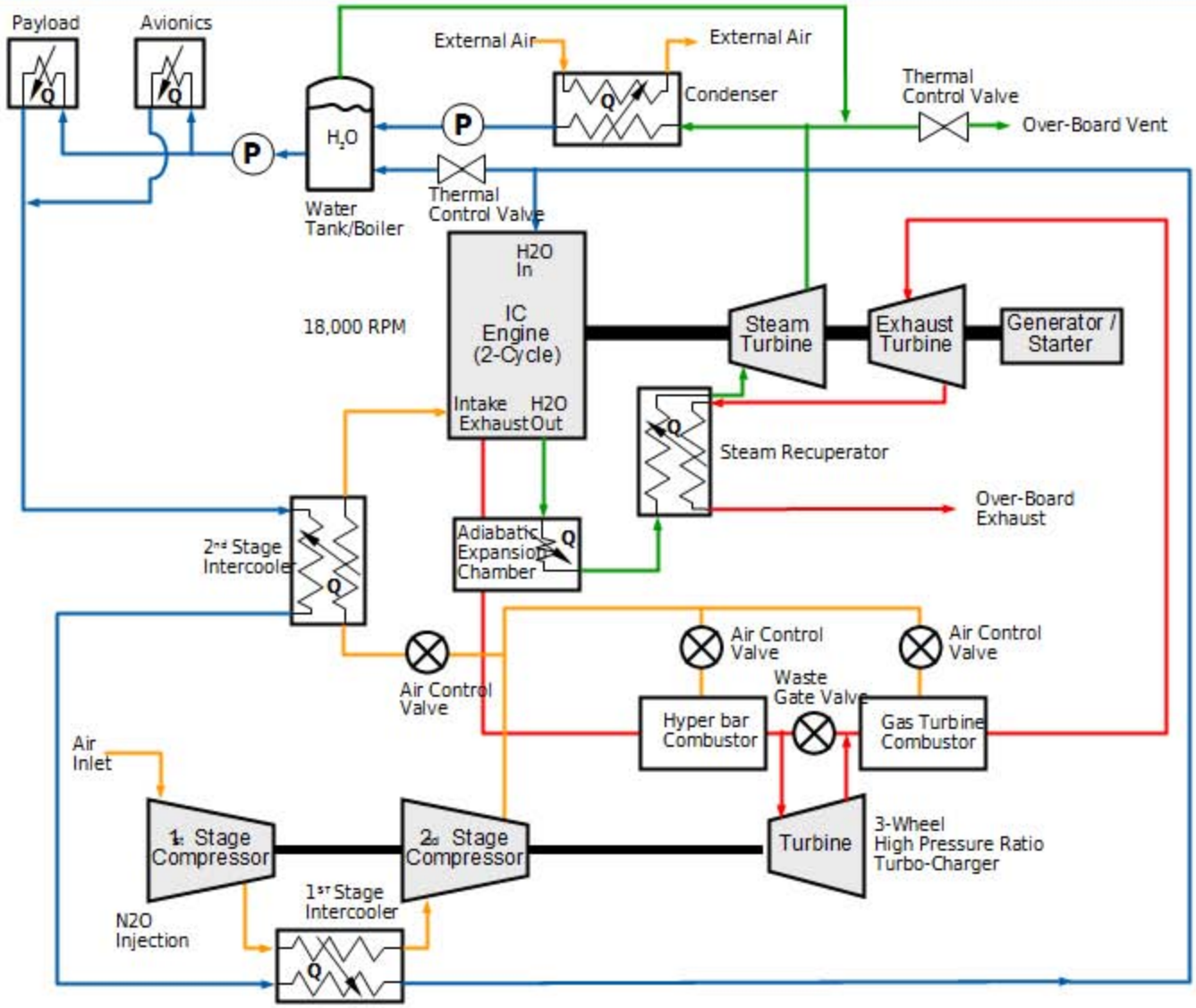
Global Hawk Low-Pressure Turbine-Driven Generator Completes Simulated Altitude Testing

PRINT | E-MAIL

WRIGHT-PATTERSON AIR FORCE BASE, Ohio -- An AFRL team completed demonstration tests simulating altitude operation of a low-pressure (LP) turbine-driven, 270 VDC, 75 kW generator mounted onto an AE3007H engine. The tests accomplished AFRL's goals to develop Global Hawk power upgrades that increase the available payload power over the present RQ-4 Global Hawk baseline by a factor of 3. The tests will also enable the technology's transition to the Global Hawk Systems Group (GHSG) for production development. The AFRL team integrated the LP generator with the engine and received assistance from the laboratory's general contractor, Innovative Power Solutions, as well as from Rolls-Royce Corporation, LibertyWorksTM, and Northrop Grumman. The LP generator utilizes direct drive with the LP shaft of an AE3007H engine as a means to provide an increase in available payload power over the present RQ-4 Global Hawk baseline. The objective of the final test was to verify the LP generator thermal environment and engine performance with LP generator power extraction at Global Hawk mission altitudes.

AFRL developed the Range Altitude Power Innovative Technology (RAPIT) program to coordinate with the GHSG. The RAPIT program's purpose was to develop engine upgrades and electric power enhancements--with funding from the laboratory's Integrated High-Performance Turbine Engine Technology program--for transition to the RQ-4 Global Hawk.

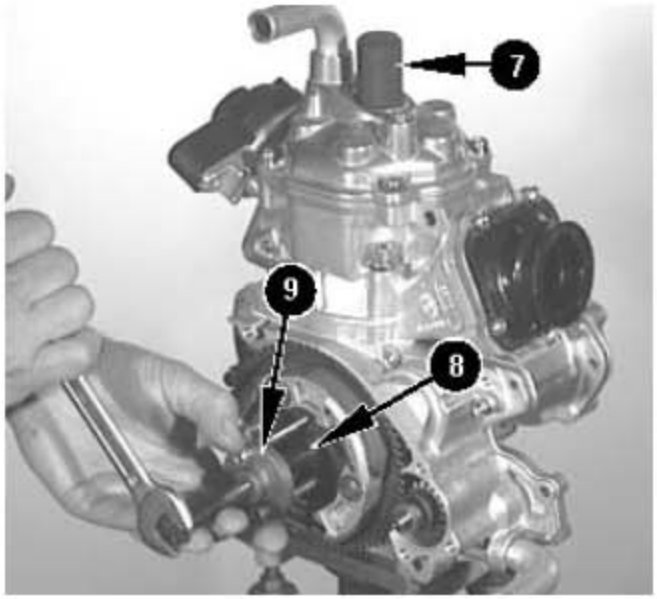
High-Speed Motor/Generator Set Schematic Overview

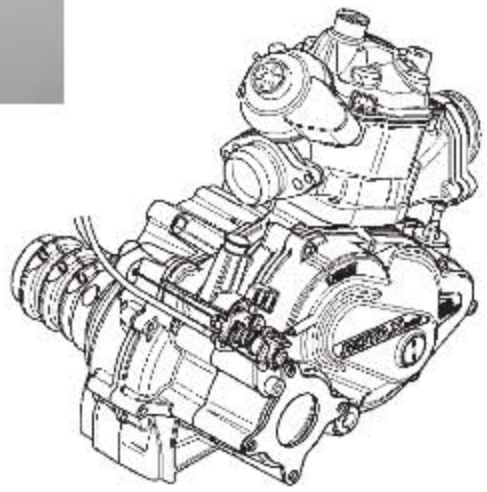


Rotax FR125 Max Modified COTS IC Engine

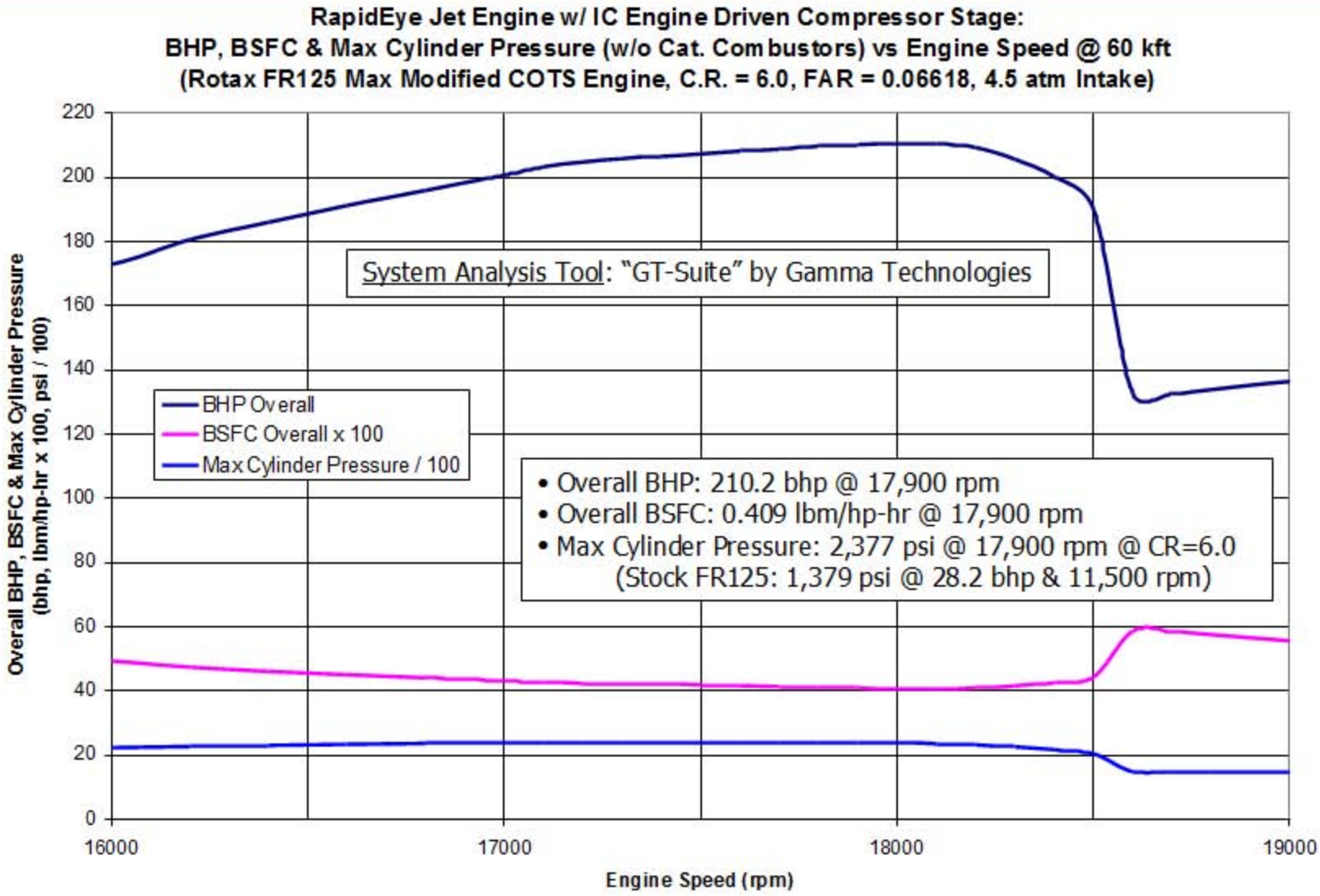
- 210.2 bhp Overall @ 17,900 rpm & Overall BSFC of 0.409 lbm/hr-hp
- 156 bhp @ 17,900 rpm & BSFC of 0.55 lbm/hr-hp IC Engine Only
- 54.2 hp Power Recovery via Combustion Gas Power Recovery Turbine Attached To IC Engine Shaft
- IC Engine Piston, Con Rod & Crankshaft Redesigned for Higher Power Output Level & Speed of Operation
- Adiabatic Expansion Chamber Design Provides Higher Power Recovery Prior to Exhaust Stream Injection into Jet Engine Flow Stream
- 3-Wheel/2-Stage High Pressure Ratio Turbocharger (Pr_max = 8.5 per stage) w/ Gaseous N2O Compressor Injection for Engine Start Sequence
- (2) Part-Time Catalytic Combustors, Pre- and Post-Turbocharger, for Hyper bar and Gas Turbine Operation Modes

Rotax FR125 Max Modified COTS IC Engine

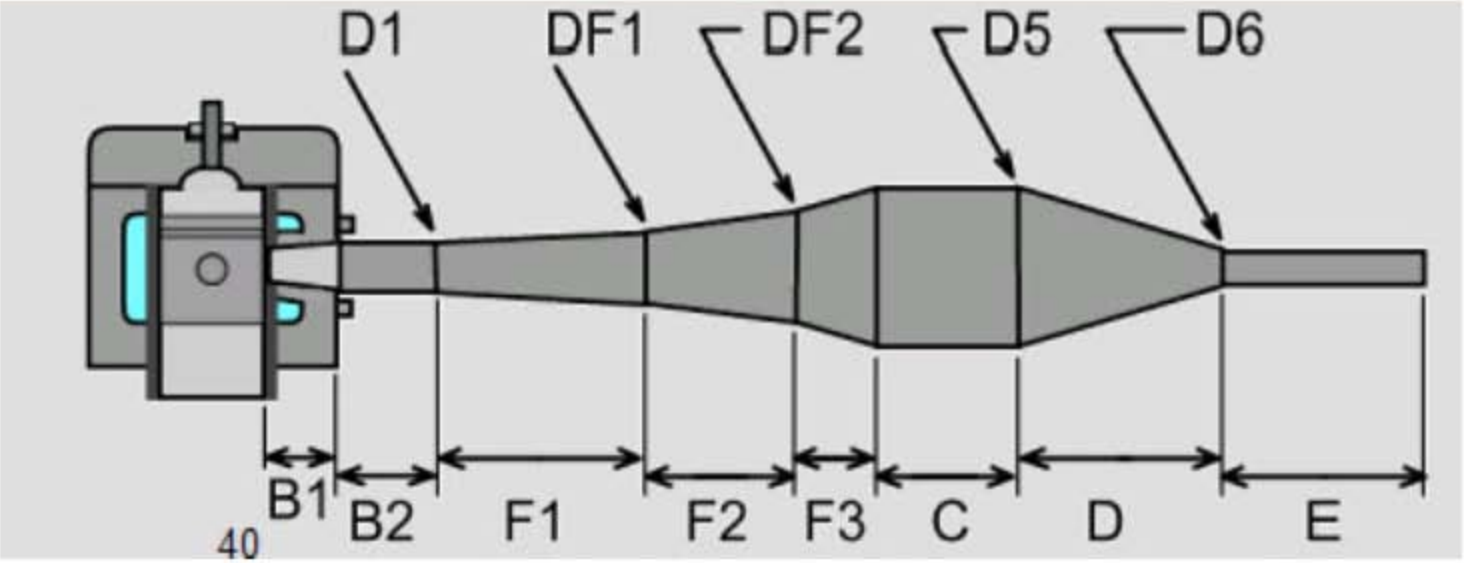




Propulsion System Analysis



3-Stage Adiabatic Expansion Chamber Design

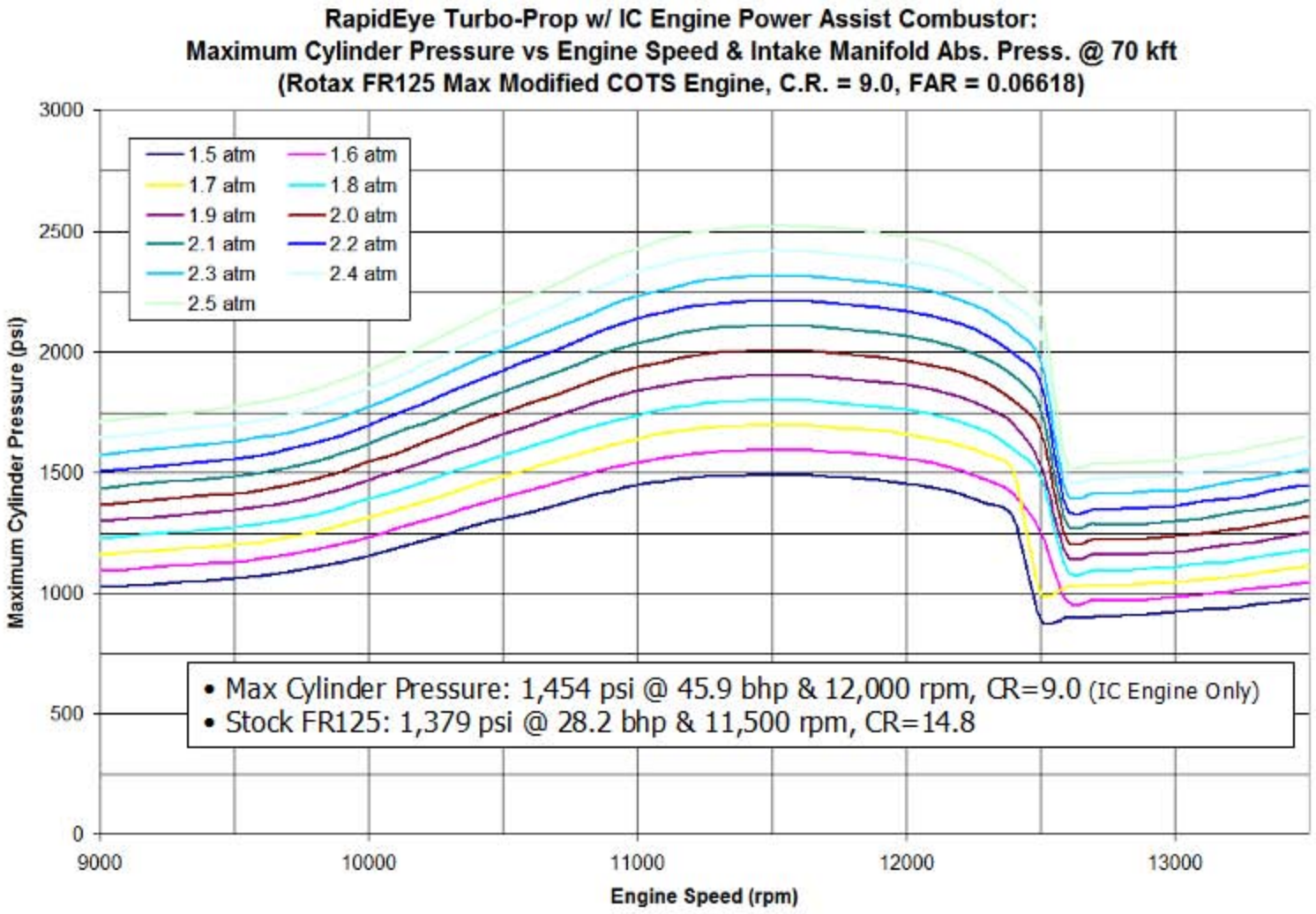


- B1+B2: 31.3 mm
- F1: 200.5 mm
- F2: 138.4 mm
- F3: 104.3 mm
- C: 155.3 mm
- D: 249.2 mm
- E: 224.2 mm
- D1: 36.5 mm
- DF1: 63.5 mm
- DF2: 105.1 mm
- D5: 136.6 mm
- D6: 19.1 mm

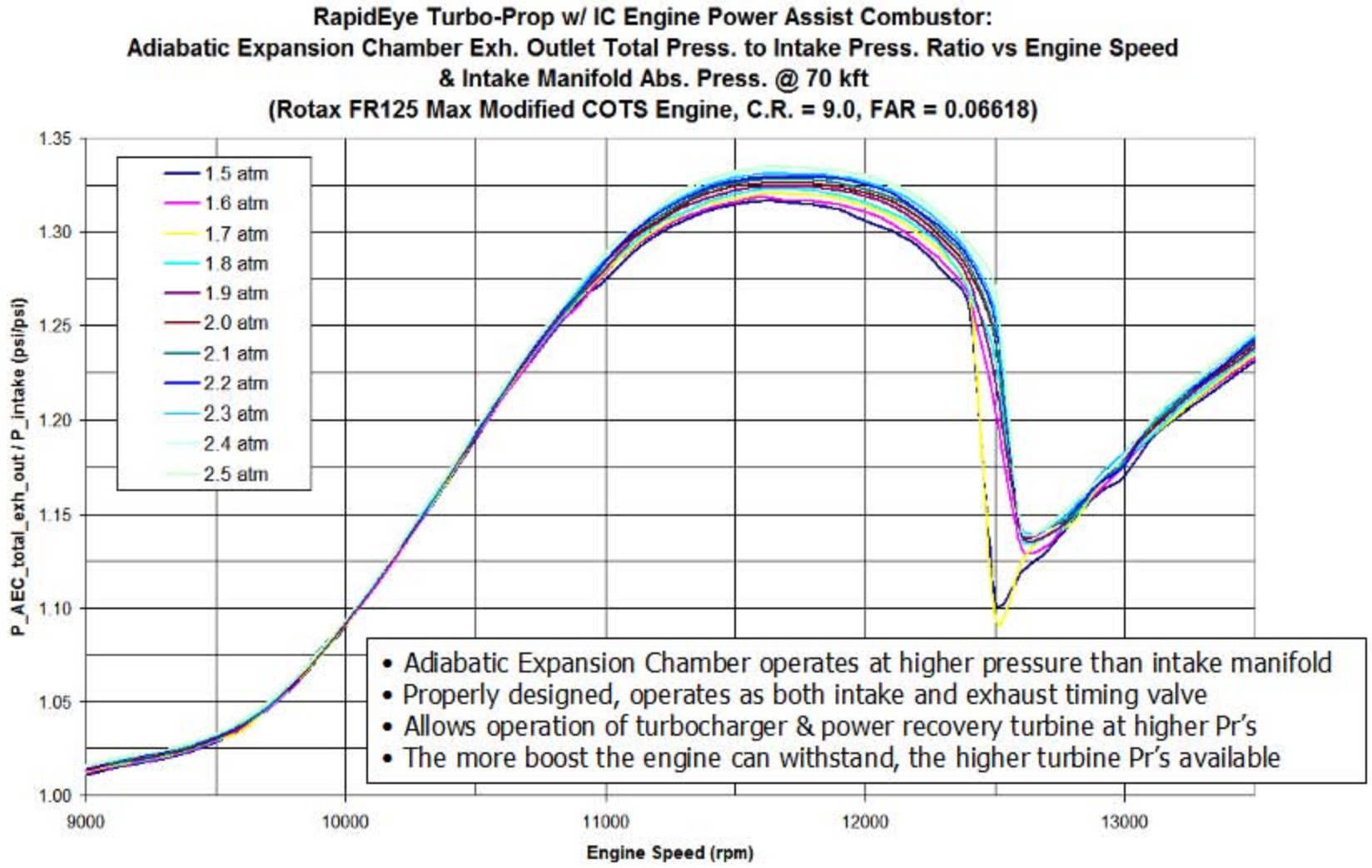
- BHP: 156.0 bhp @ 17,900 rpm
- BSFC: 0.55 lbm/hp-hr @ 17,900 rpm
- Max Cylinder Pressure: 2,377 psi @ 17,900 rpm @ CR=6.0
  (Stock FR125: 1,379 psi @ 28.2 bhp & 11,500 rpm, CR=14.8)

System Analysis Tool: "GT-Suite" by Gamma Technologies

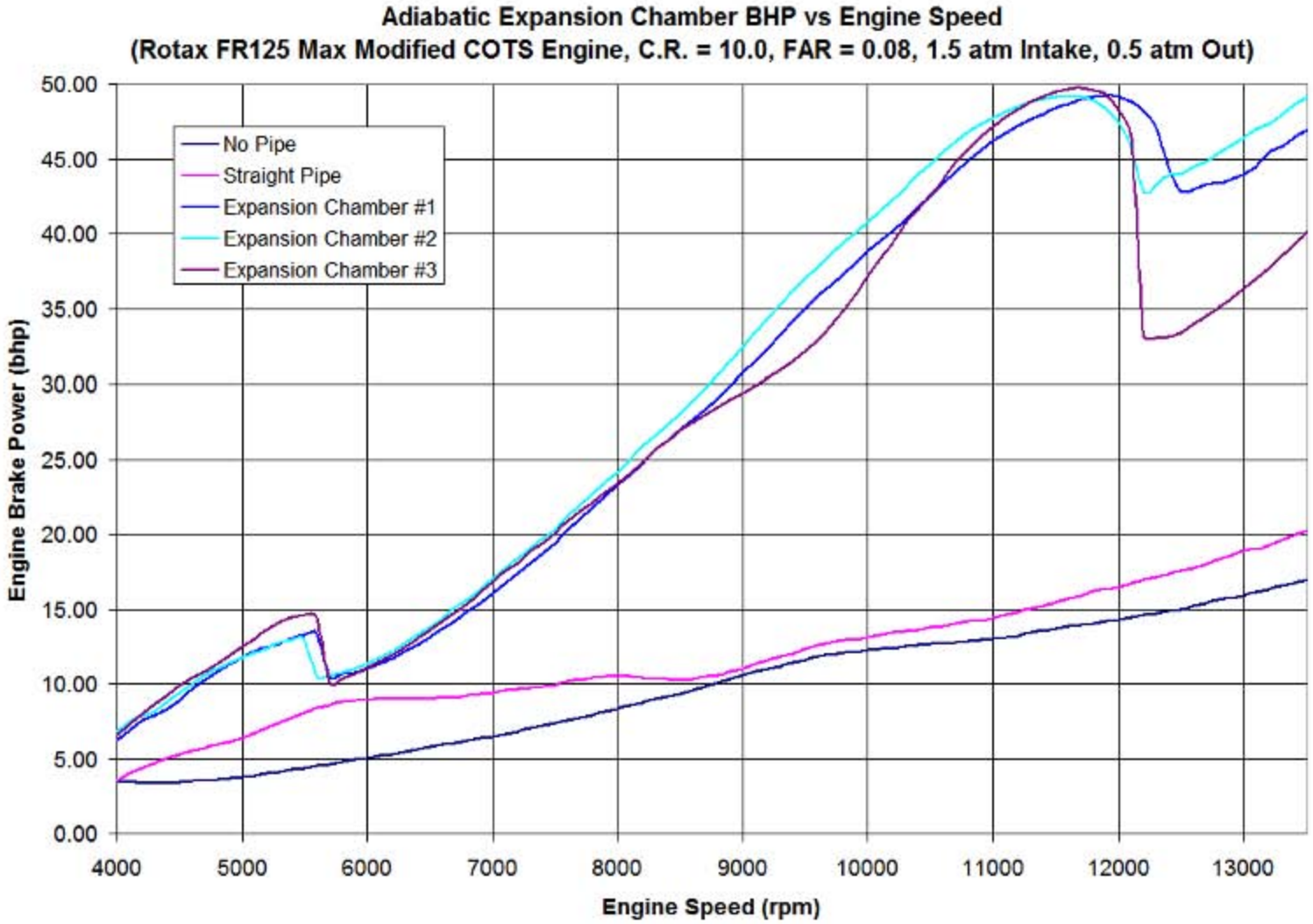
AV Engine Max Cylinder Pressure:



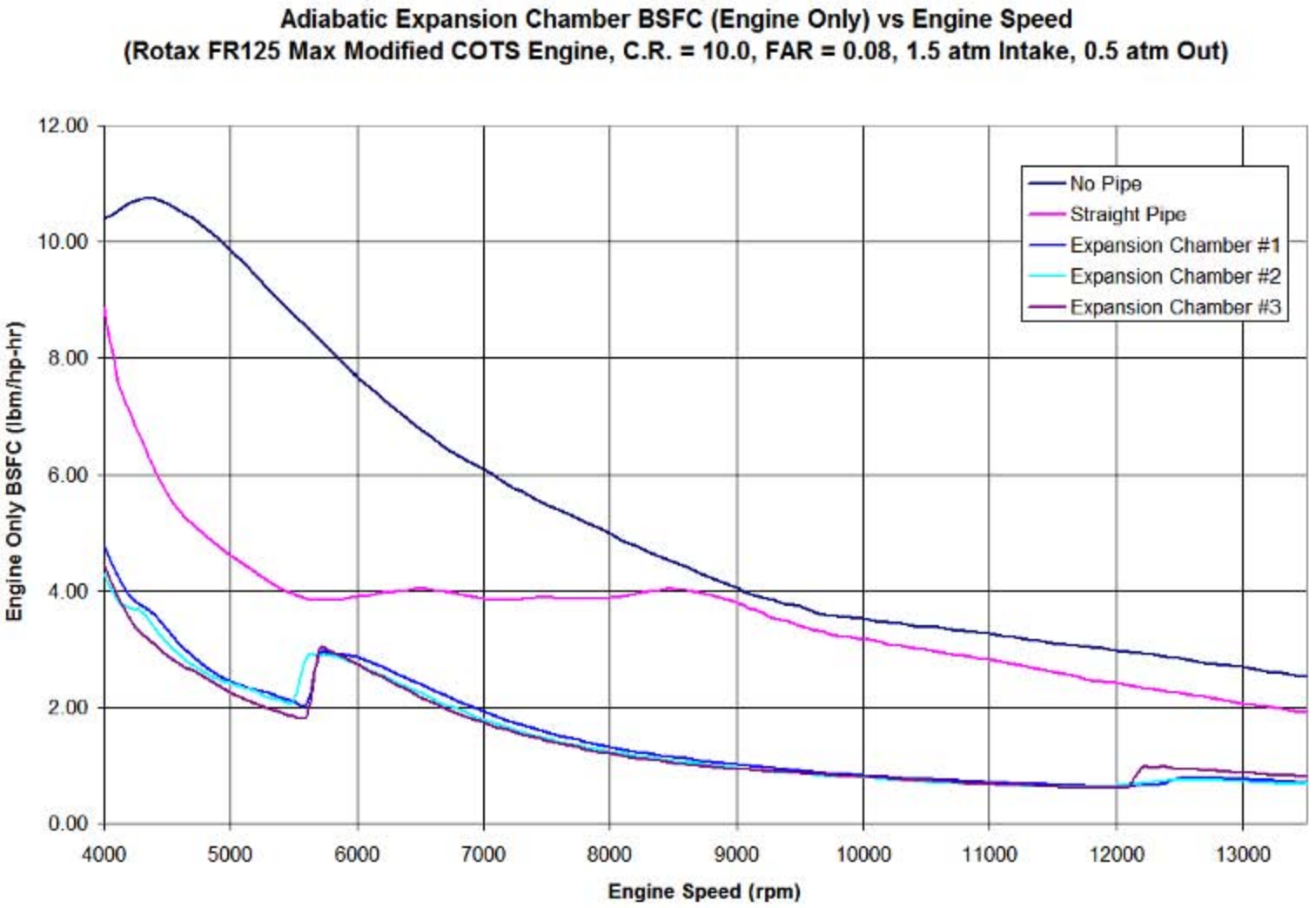
AV Engine Exhaust-to-Intake Pressure Ratio:



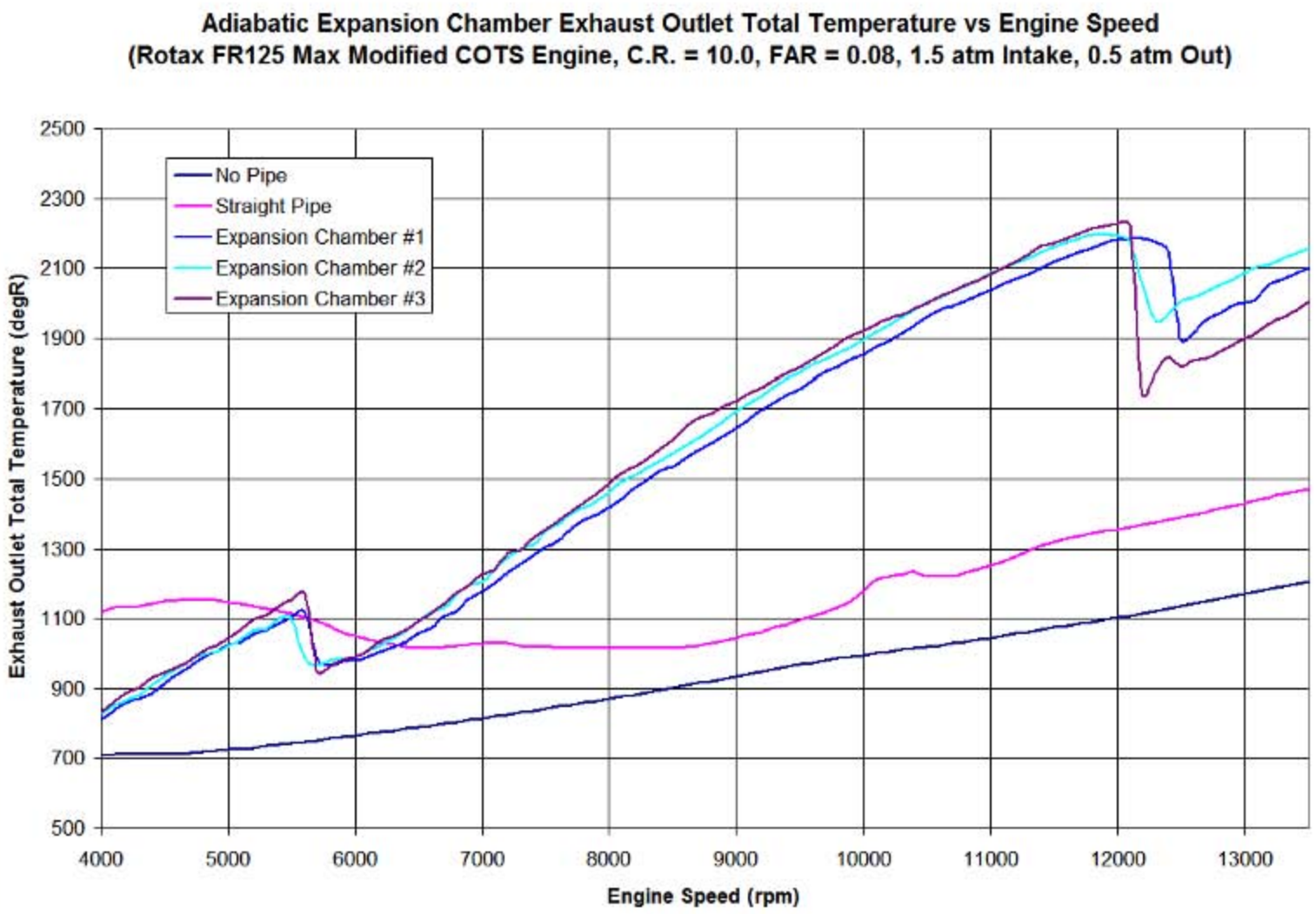
Expansion Chamber BHP Comparison:



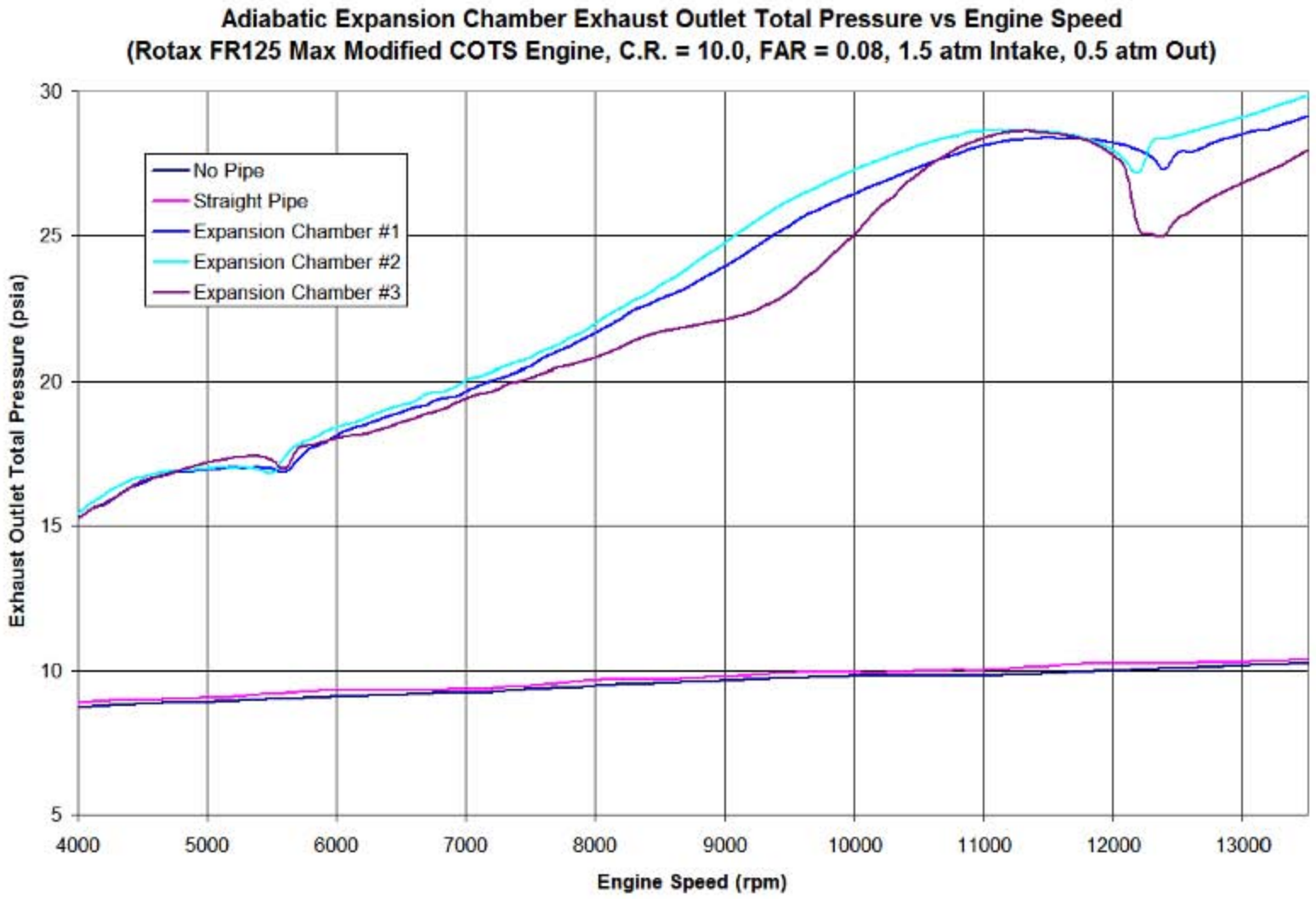
Expansion Chamber BSFC Comparison:



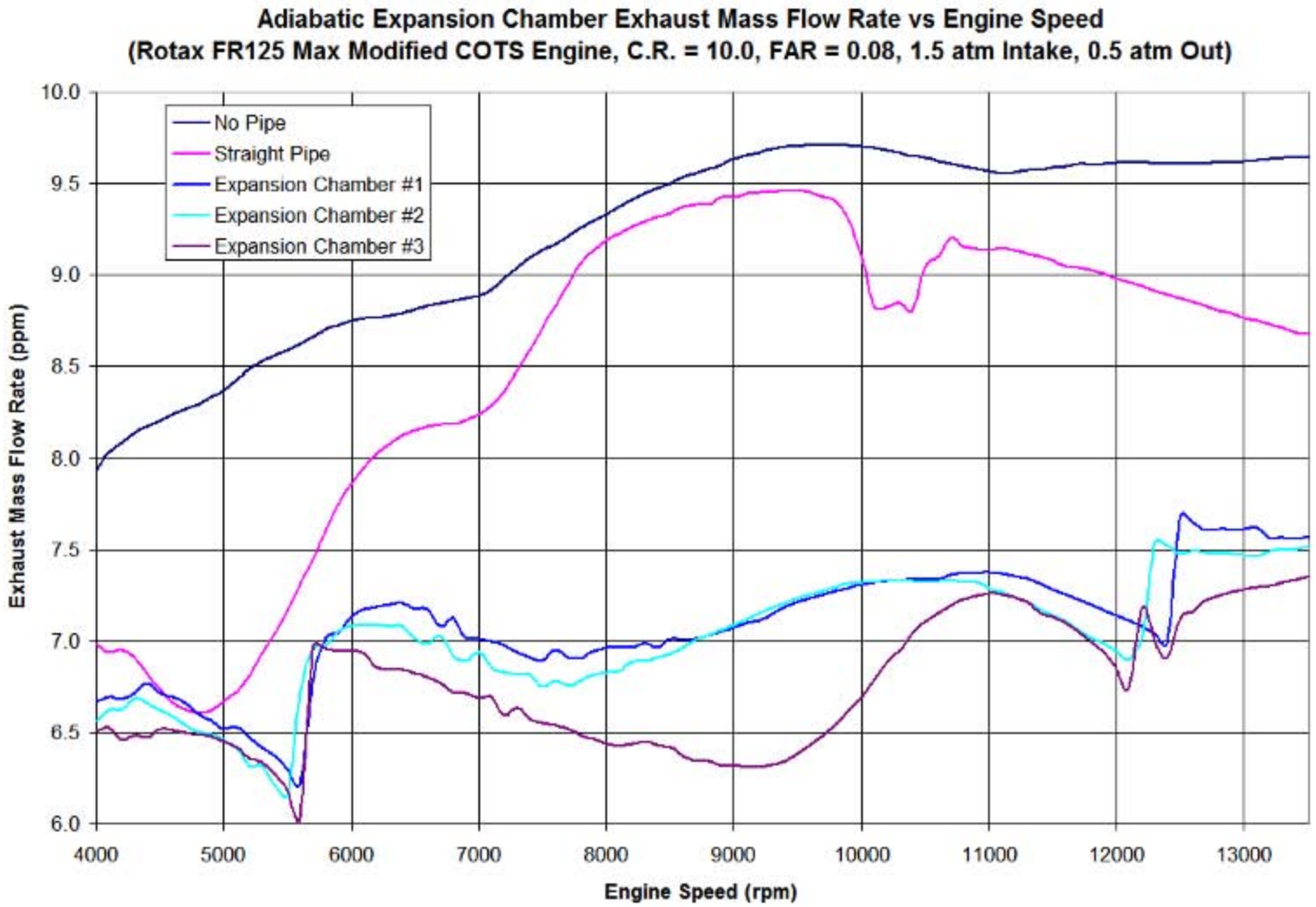
Expansion Chamber Exhaust Outlet T_total Comparison:



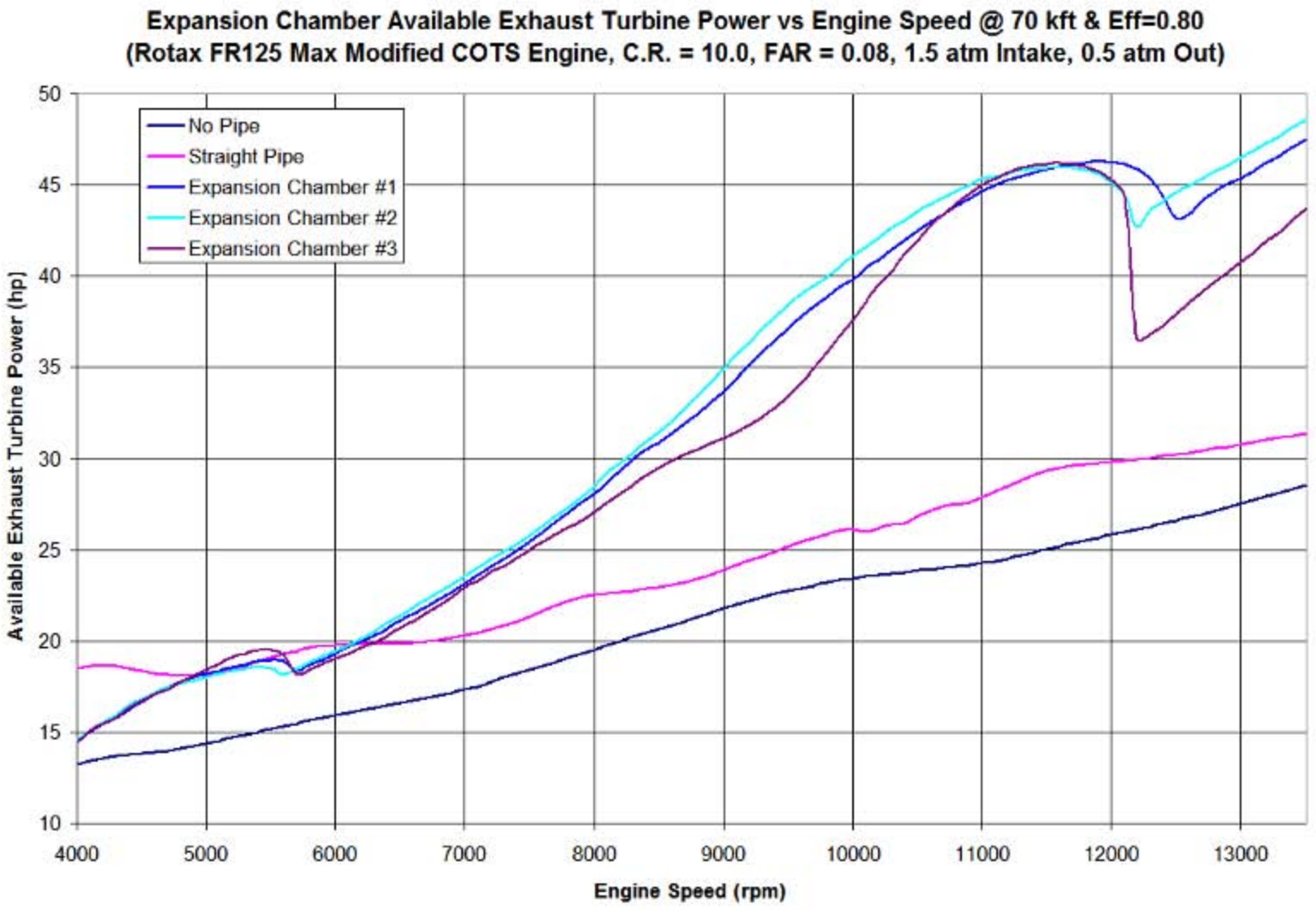
Expansion Chamber Exhaust Outlet P_total Comparison:



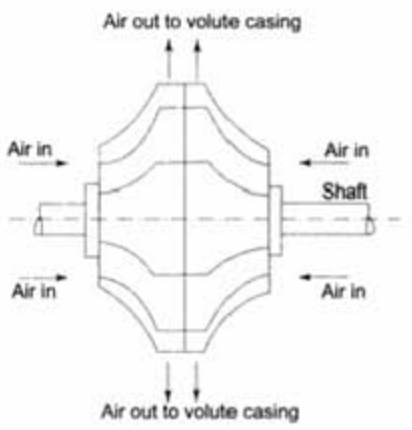
Expansion Chamber Exhaust Outlet Mdot Comparison:

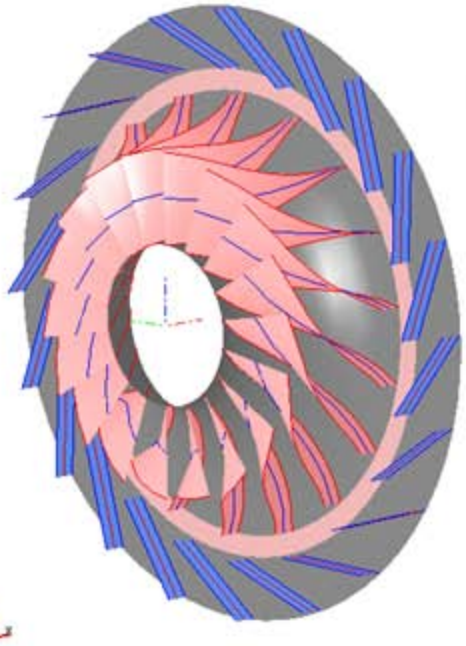


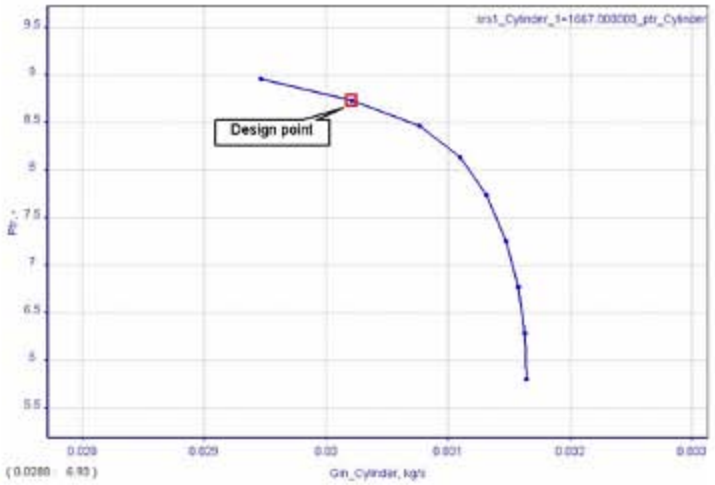
Expansion Chamber Exhaust Turbine Power Comparison:

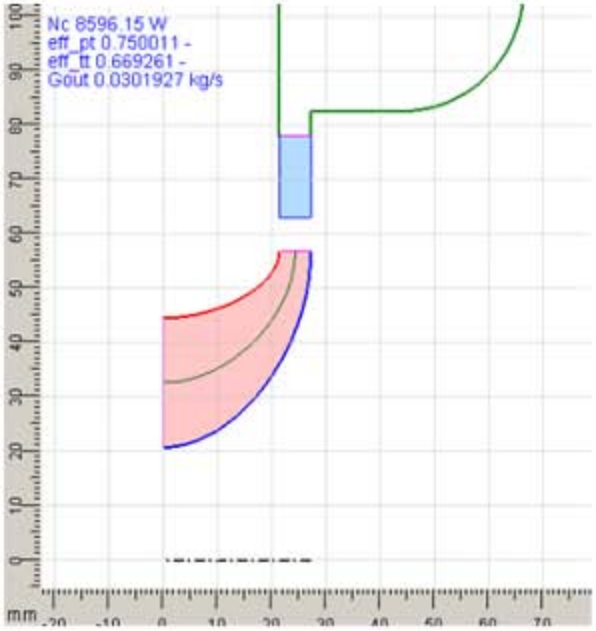


3-Wheel High Pressure Ratio Turbocharger – 1st Stage Double-Sided Compressor (Performance data using AxStream software from SoftInWay Inc.):



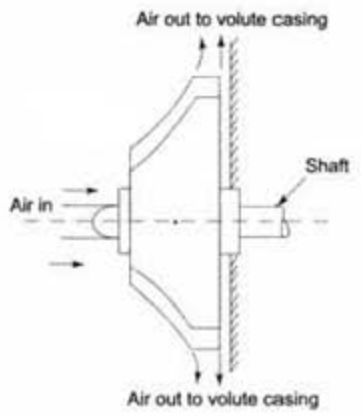


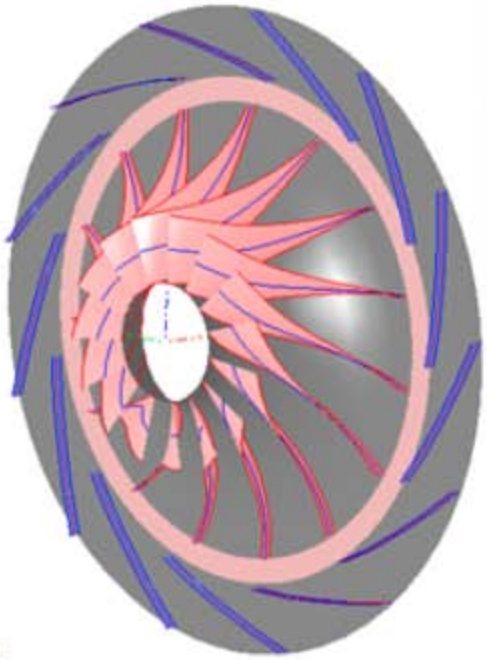


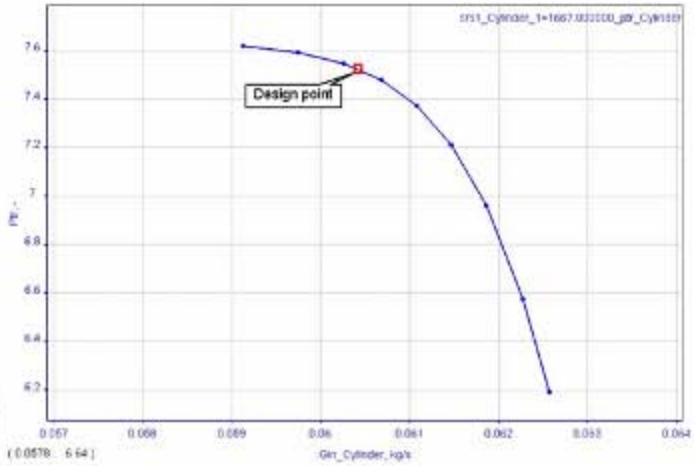


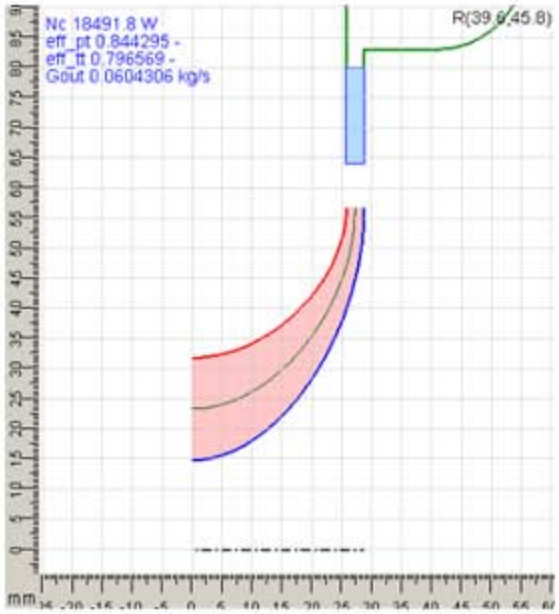
	Property	Unit	Value
Pt_in	total pressure at inlet	Pa	2758.000000
It_in	total enthalpy at inlet	J/kg	222044.725000
Tt_in	total temperature at inlet	°C	-52.100000
Pst_ou	stat. pressure at outlet	Pa	23442.795854
Pt_out	total pressure at outlet	Pa	24119.418576
Gin	mass flow rate at inlet	kg/s	0.030193
	inlet flow angle in abs frame	deg	90.000000
srs1	shaft1 rotational speed	rps	1667.000000
Gv	volume flow rate at outlet	m^3/s	0.182008
Nc	capacity	W	8596.150451
eff_tt	internal total-to-total efficienc	-	0.669261
psr	total-static pressure ratio	-	8.499926
ptr	total-total pressure ratio	-	8.745257

3-Wheel High Pressure Ratio Turbocharger – 2nd Stage Single-Sided Compressor (Performance data using AxStream software from SoftInWay Inc.):



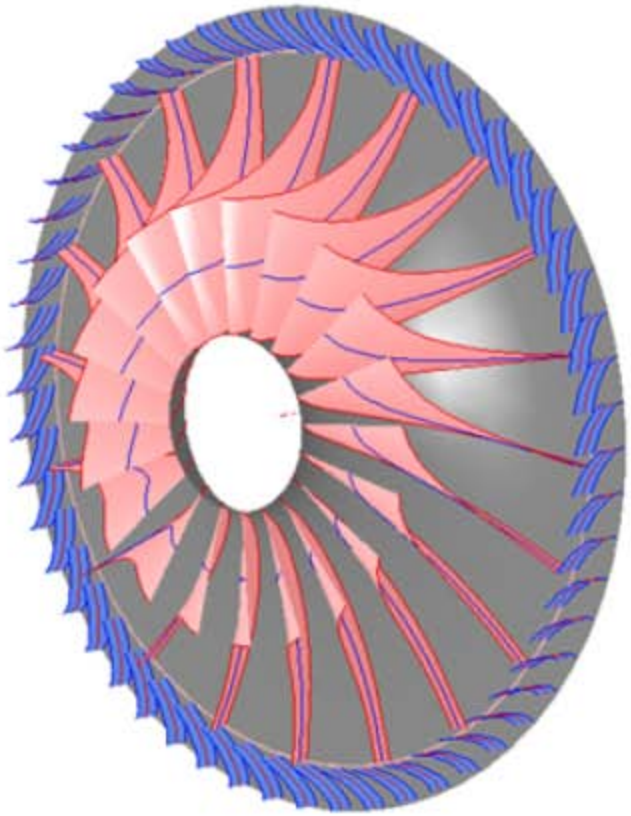




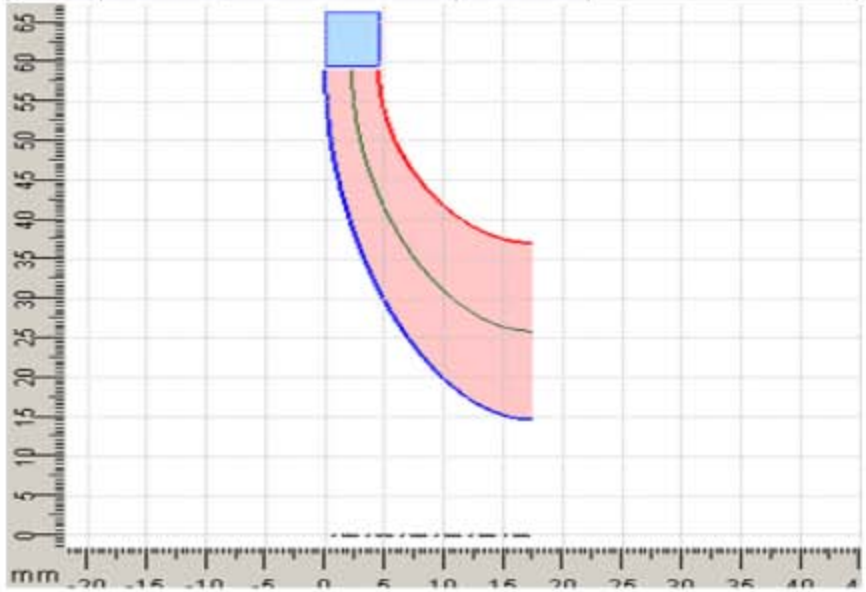


	Property	Unit	Value
Pt_in	total pressure at inlet	Pa	20670.000000
It_in	total enthalpy at inlet	J/kg	312550.175000
Tt_in	total temperature at inlet	°C	38.000000
Pst_o	stat. pressure at outlet	Pa	152979.999723
Pt_out	total pressure at outlet	Pa	155491.087730
Gin	mass flow rate at inlet	kg/s	0.060431
	inlet flow angle in abs fram	deg	90.000000
srs1	shaft1 rotational speed	rps	1667.000000
Gv	volume flow rate at outlet	m^3/s	0.066920
Nc	capacity	W	18491.804370
eff_tt	internal total-to-total efficie	-	0.796569
psr	total-static pressure ratio	-	7.401064
ptr	total-total pressure ratio	-	7.522549

3-Wheel High Pressure Ratio Turbocharger – Turbine (Performance data using AxStream software from SoftInWay Inc.):



	Property	Unit	Value
Pt_in	total pressure at inlet	Pa	198569.000000
It_in	total enthalpy at inlet	J/kg	1548149.169503
Tt_in	total temperature at inlet	°C	1051.999992
Pst_ou	stat. pressure at outlet	Pa	35638.137393
Gin	mass flow rate at inlet	kg/s	0.064568
	inlet flow angle in abs frame	deg	90.000000
srs1	shaft1 rotational speed	rps	1667.000000
UC0	isentropic velocity ratio	-	0.259740
Gv	volume flow rate at outlet	m^3/s	0.486496
Nc	capacity	W	26914.086152
eff_ts	internal total-to-static efficienc	-	0.774089
eff_tt	internal total-to-total efficiency	-	0.806437
psr	total-static pressure ratio	-	5.571812
ptr	total-total pressure ratio	-	5.032628



3-Wheel High Pressure Ratio Turbocharger – 1st Stage Double-Sided Compressor (Performance data using AxStream software from SoftInWay Inc.):

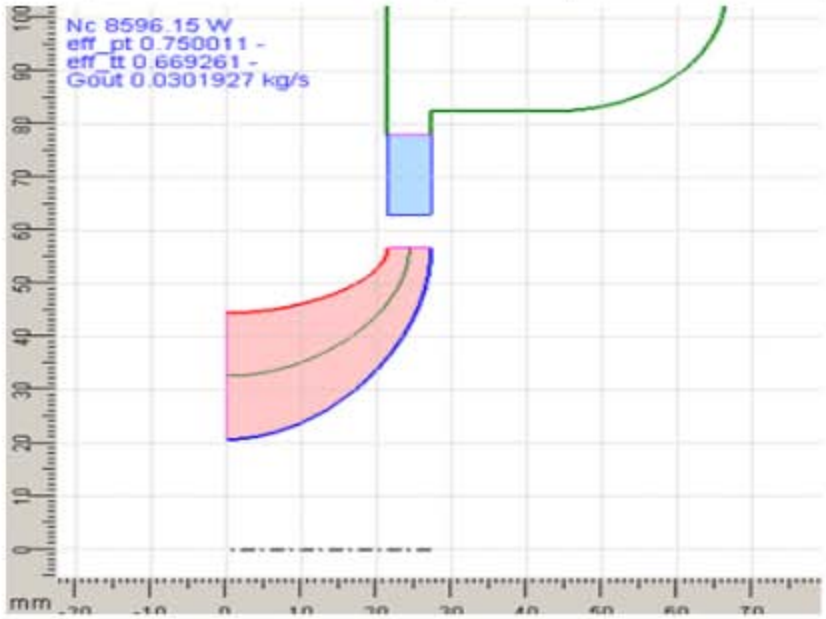
1st Stage final meridional dimensions

Stator			
z	number of nozzles	-	20
l2	airfoil LE meridional length	mm	5.8
D2	channel inlet mean diameter	mm	126
l3	airfoil TE meridional length	mm	5.8
D3	channel outlet mean diameter	mm	156
Rotor			
z	number of blades	-	18
D1t	channel inlet shroud diameter	mm	88.9
D1h	channel inlet hub diameter	mm	41.3
lc2	channel outlet width	mm	5.8
D2	channel outlet mean diameter	mm	113.5
B	axial chord length	mm	27.3

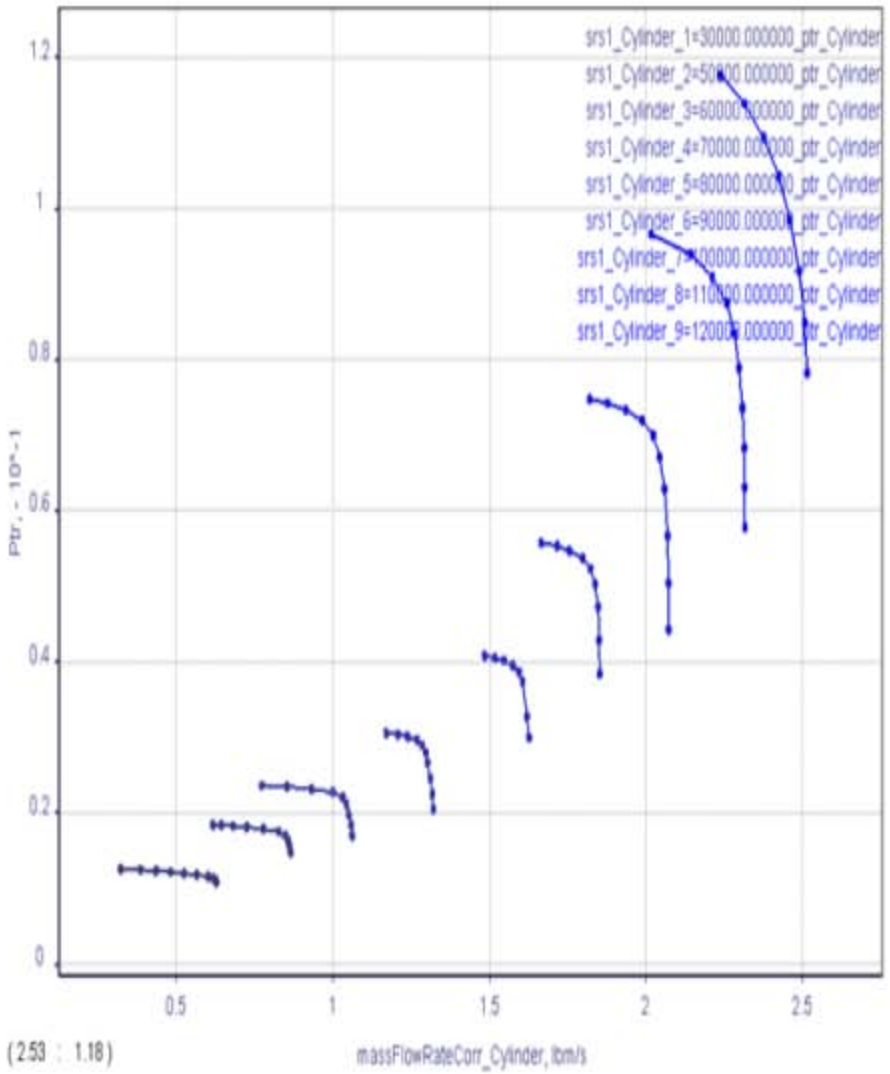
1st Stage angles on mid section (tangential)

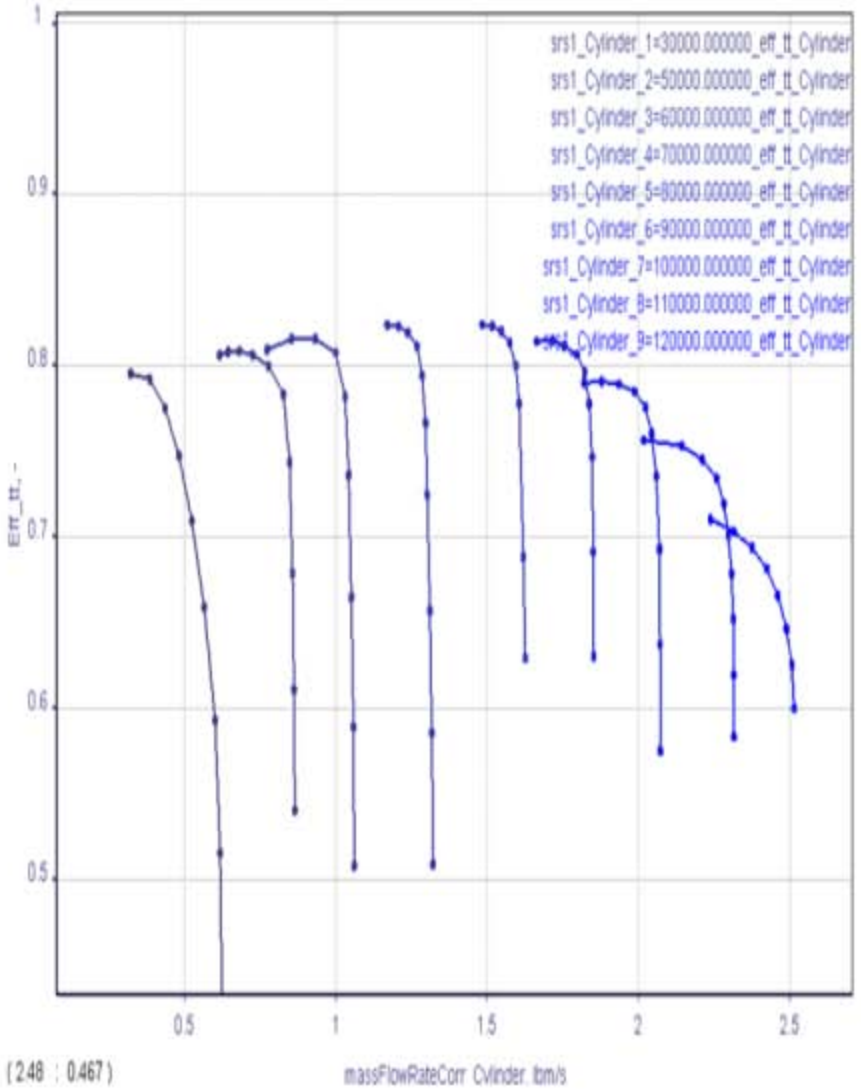
Stator			
A2m	inlet metal angle	deg	22.47
A3m	outlet metal angle	deg	38.36
Rotor			
B1m	inlet metal angle	deg	26.9
B2m	outlet metal angle	deg	65.6

	Property	Unit	Value
Pt_in	total pressure at inlet	Pa	2758.000000
It_in	total enthalpy at inlet	J/kg	222044.725000
Tt_in	total temperature at inlet	°C	-52.100000
Pst_ou	stat. pressure at outlet	Pa	23442.795854
Pt_out	total pressure at outlet	Pa	24119.418576
Gin	mass flow rate at inlet	kg/s	0.030193
	inlet flow angle in abs frame	deg	90.000000
srs1	shaft1 rotational speed	rps	1667.000000
Gv	volume flow rate at outlet	m^3/s	0.182008
Nc	capacity	W	8596.150451
eff_tt	internal total-to-total efficienc	-	0.669261
psr	total-static pressure ratio	-	8.499926
ptr	total-total pressure ratio	-	8.745257

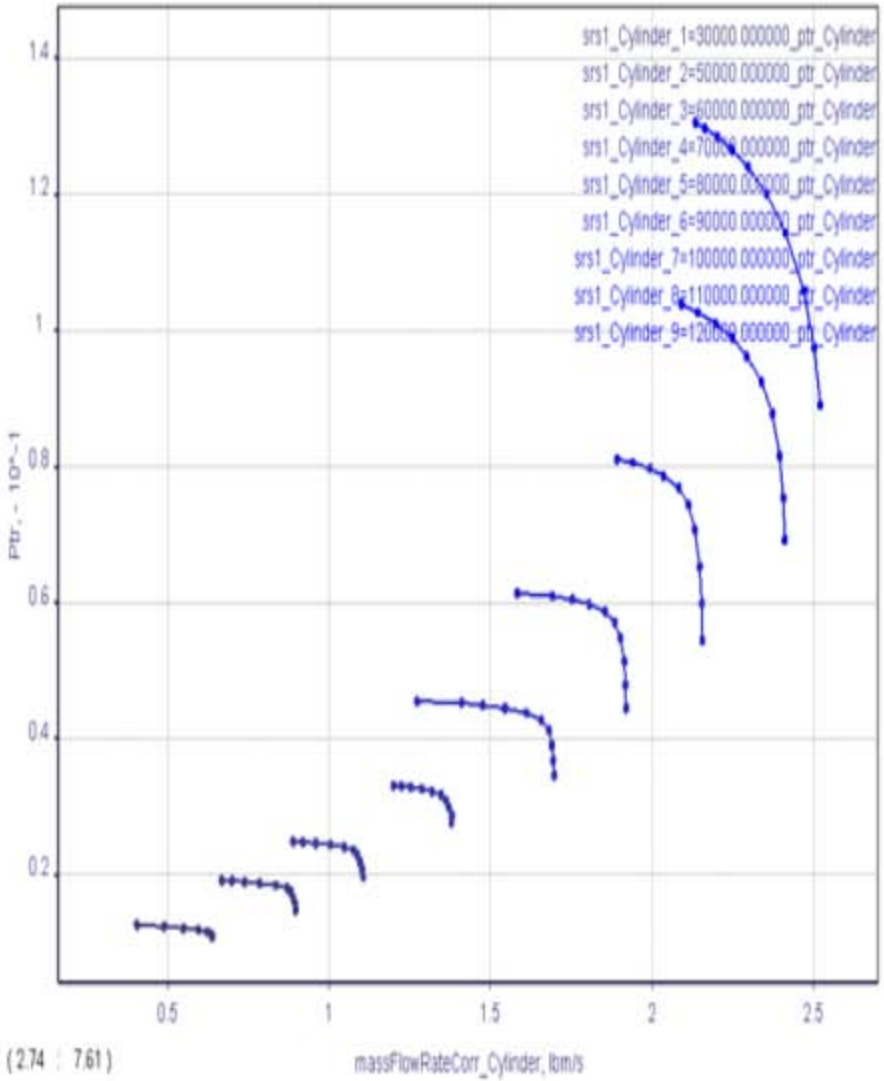


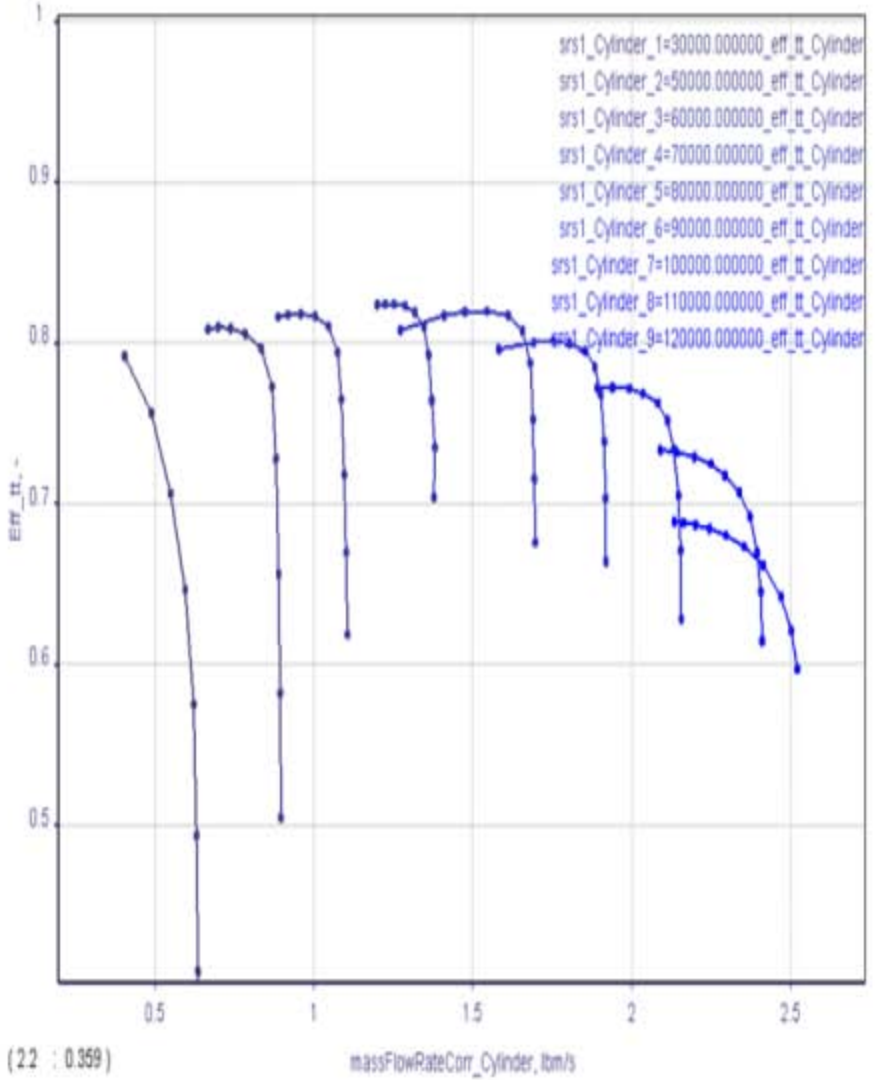
3-Wheel High Pressure Ratio Turbocharger – 1st Stage Double-Sided Compressor Corrected Mass Flow Rate vs. Total Pressure Ratio and Efficiency (tt) @ 0 kft:



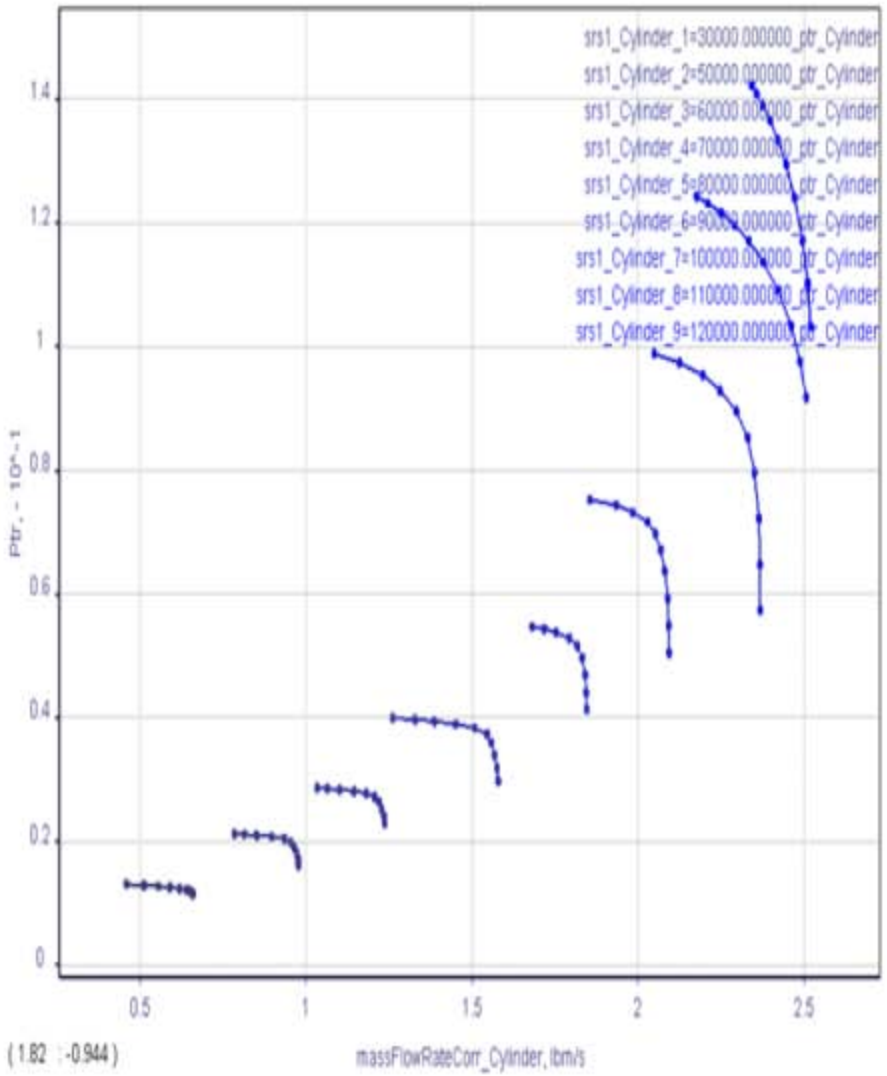


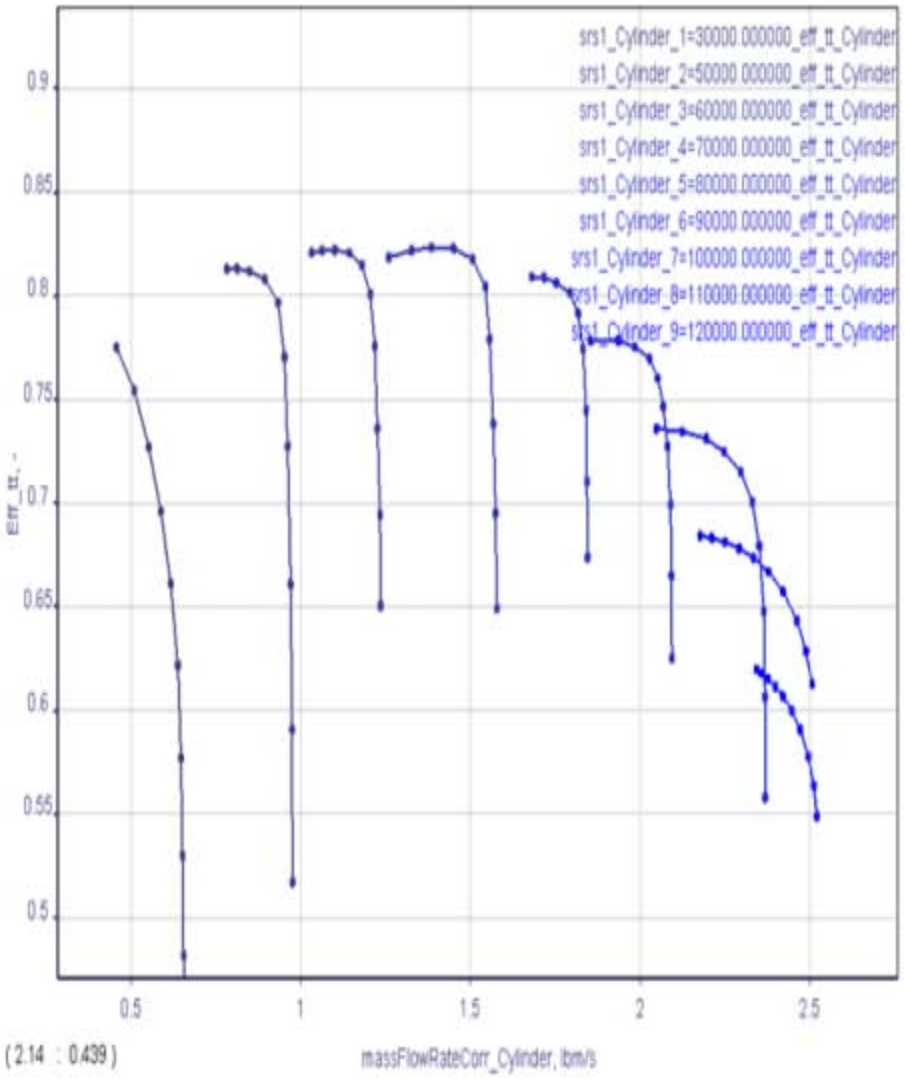
3-Wheel High Pressure Ratio Turbocharger – 1st Stage Double-Sided Compressor Corrected Mass Flow Rate vs. Total Pressure Ratio and Efficiency (tt) @ 10 kft:



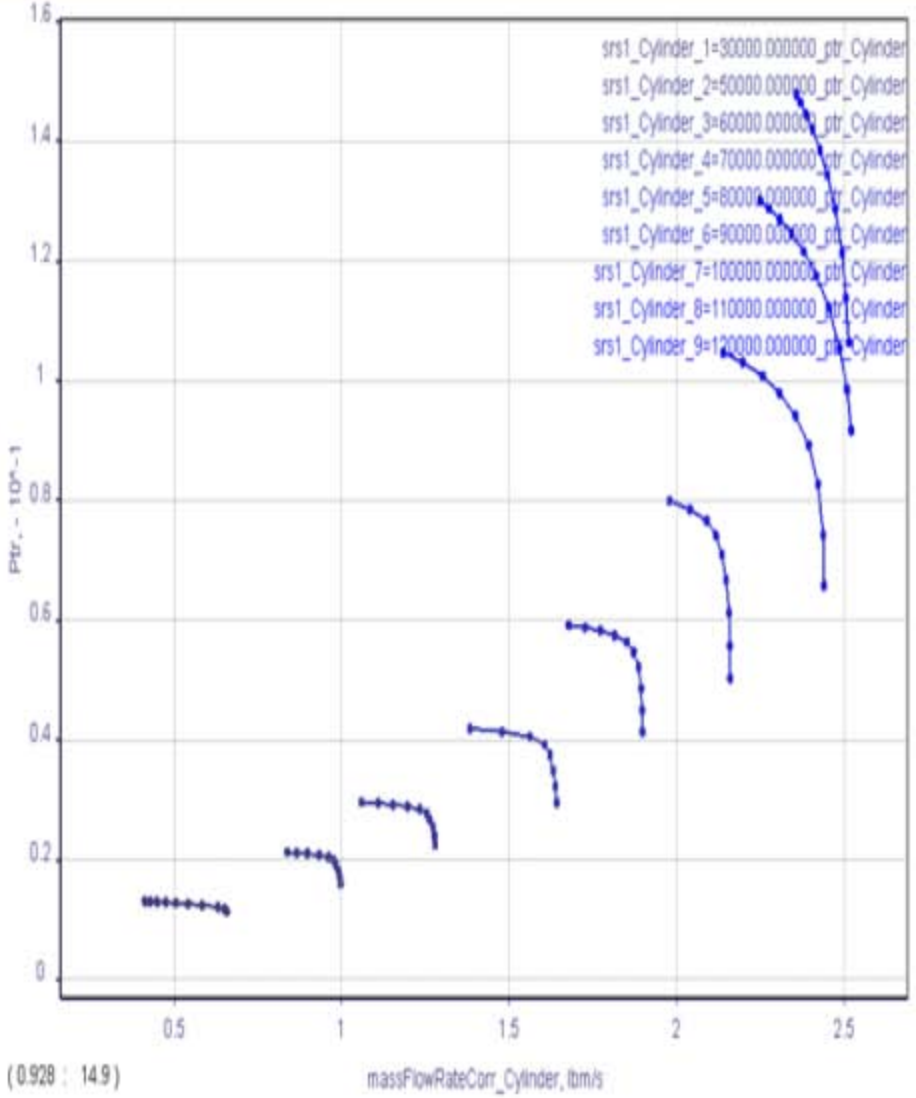


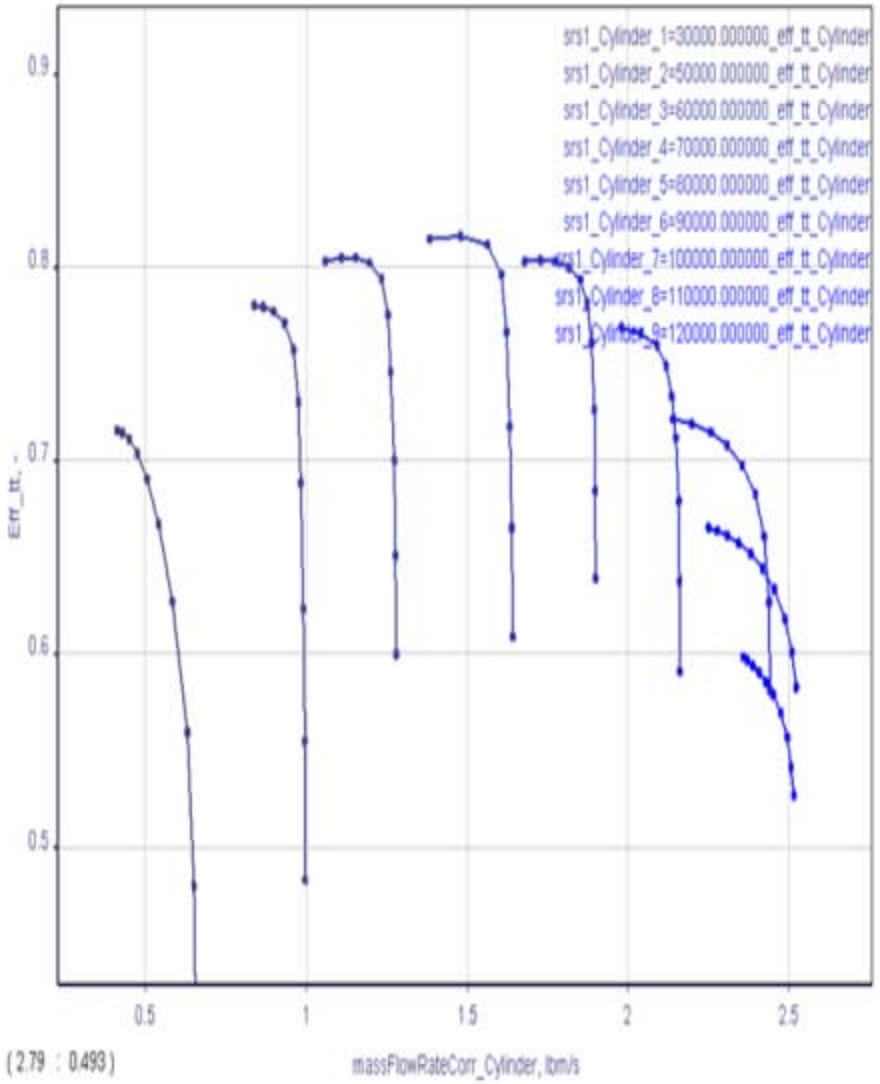
3-Wheel High Pressure Ratio Turbocharger – 1st Stage Double-Sided Compressor Corrected Mass Flow Rate vs. Total Pressure Ratio and Efficiency (tt) @ 30 kft:



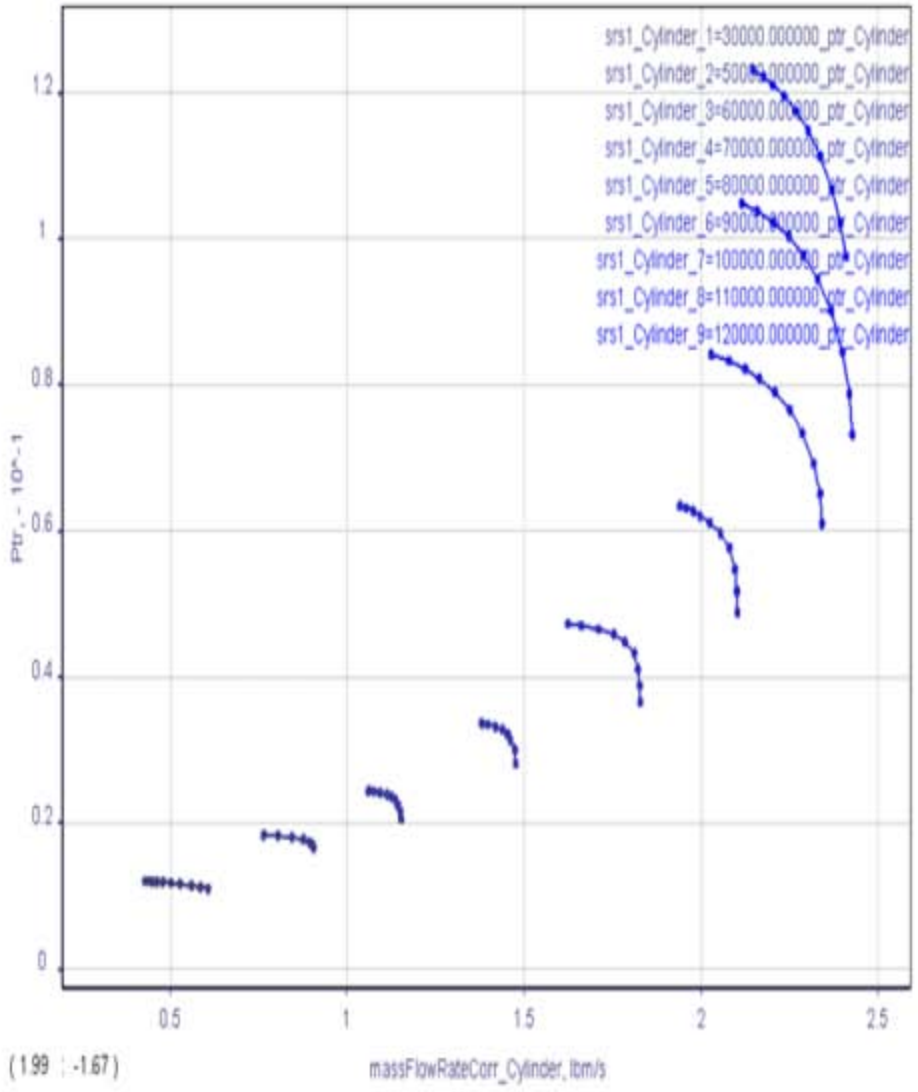


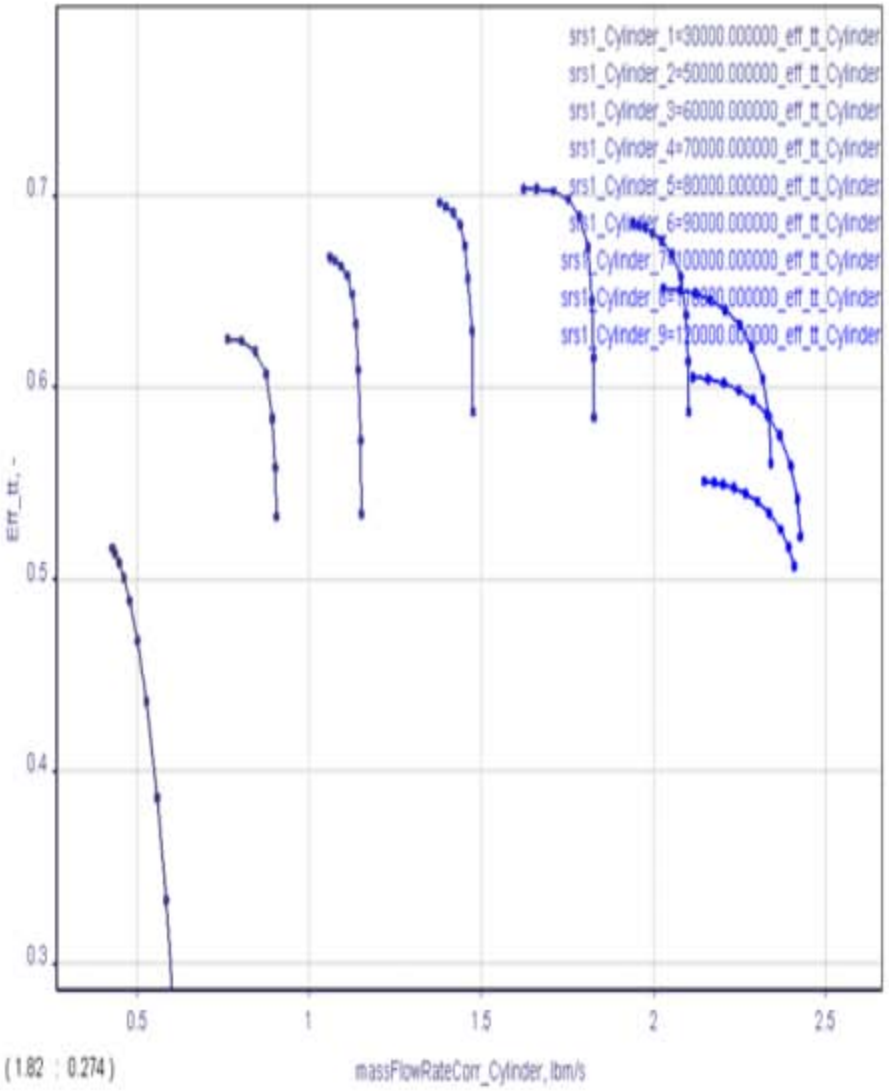
3-Wheel High Pressure Ratio Turbocharger – 1st Stage Double-Sided Compressor Corrected Mass Flow Rate vs. Total Pressure Ratio and Efficiency (tt) @ 50 kft:





3-Wheel High Pressure Ratio Turbocharger – 1st Stage Double-Sided Compressor Corrected Mass Flow Rate vs. Total Pressure Ratio and Efficiency (tt) @ 80 kft:





3-Wheel High Pressure Ratio Turbocharger – 2nd Stage Single-Sided Compressor (Performance data using AxStream software from SoftInWay Inc.):

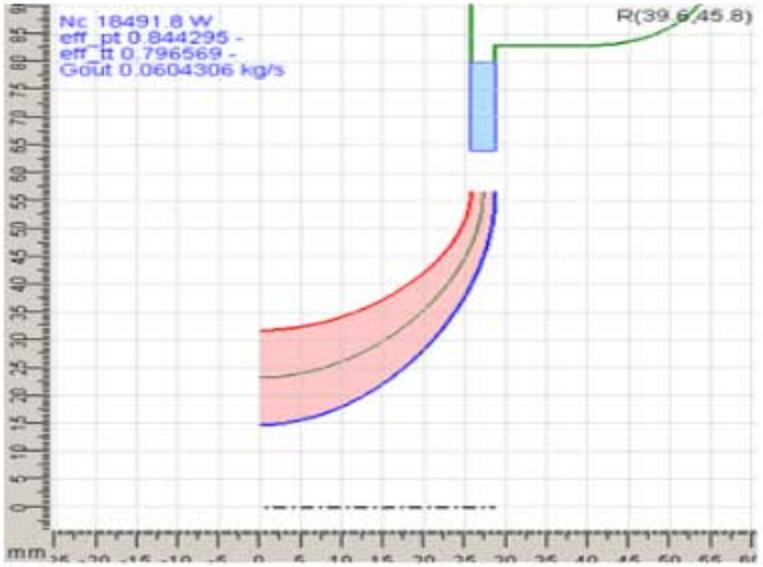
2nd Stage final meridional dimensions

Stator			
z	number of nozzles	-	13
l2	airfoil LE meridional length	mm	3
D2	channel inlet mean diameter	mm	128
l3	airfoil TE meridional length	mm	3
D3	channel outlet mean diameter	mm	160
Rotor			
z	number of blades	-	15
D1t	channel inlet shroud diameter	mm	63.5
D1h	channel inlet hub diameter	mm	29.5
lc2	channel outlet width	mm	3
D2	channel outlet mean diameter	mm	113.5
B	axial chord length	mm	28.74

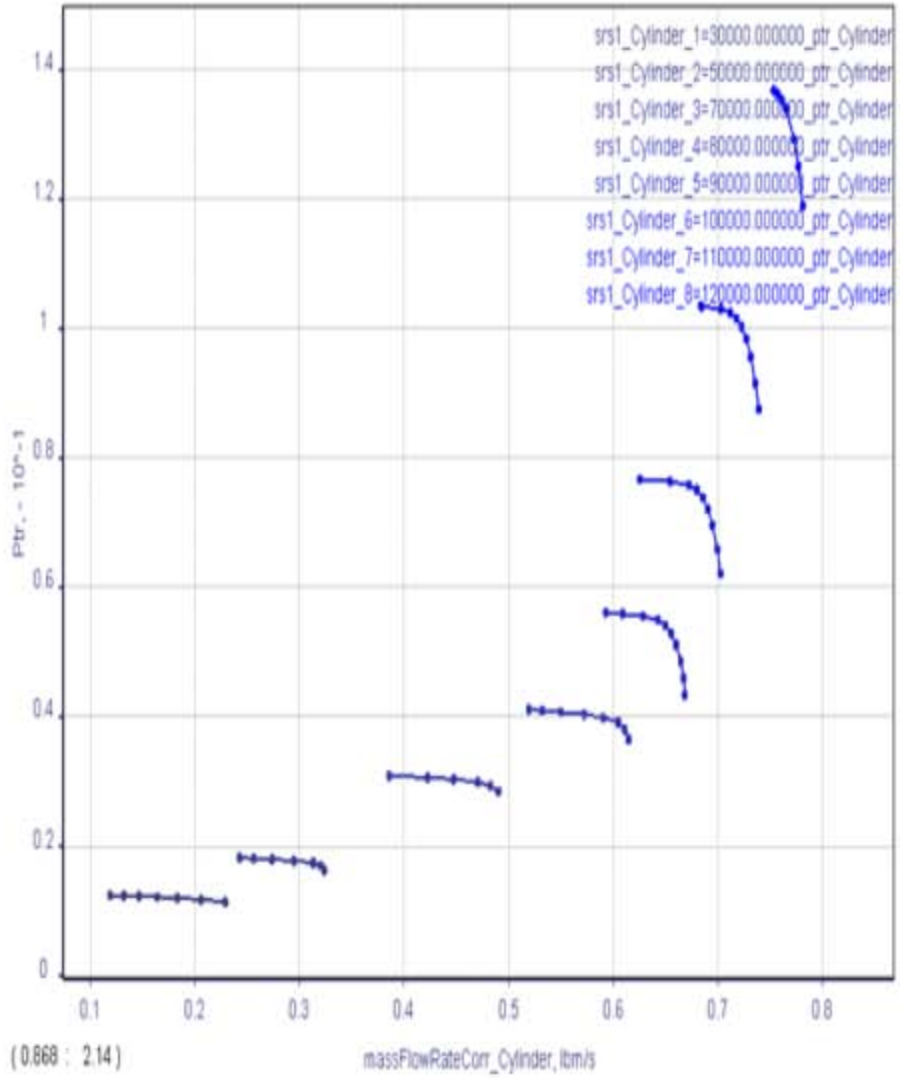
2nd Stage angles on mid section (tangential)

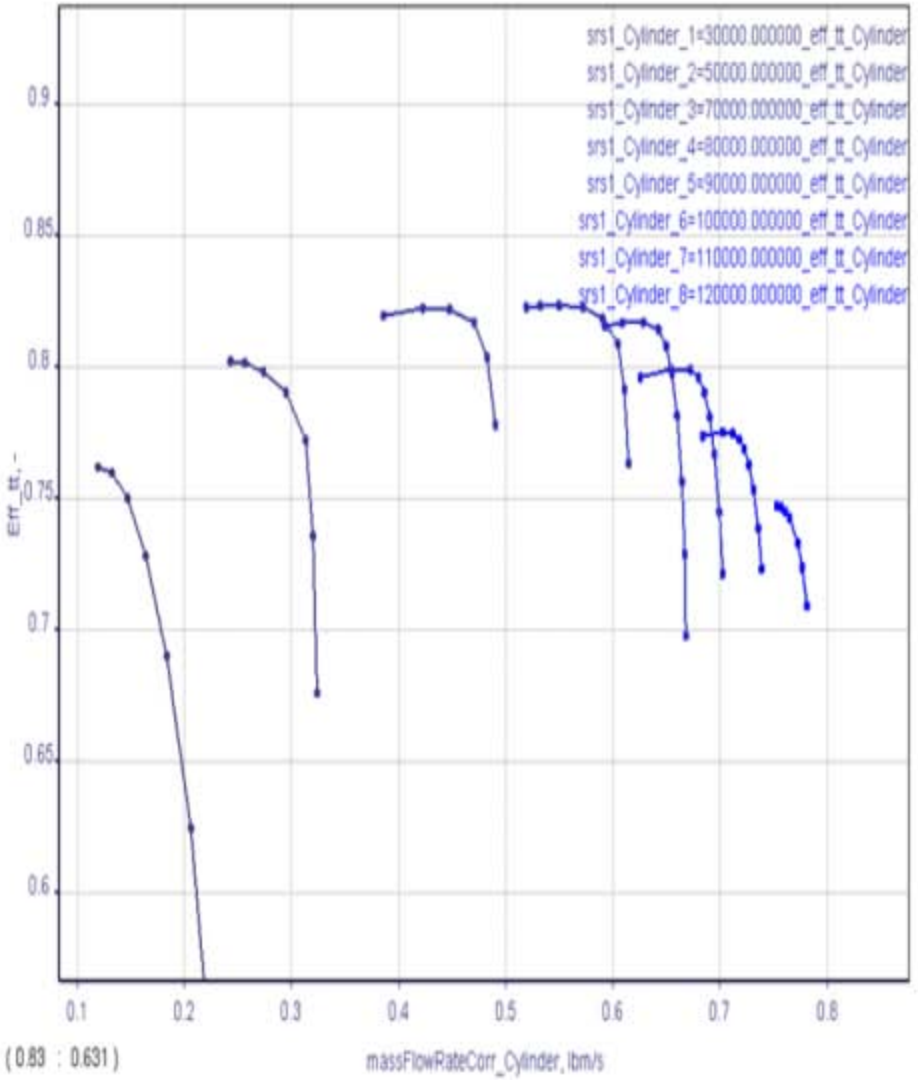
Stator			
A2m	inlet metal angle	deg	12.9328
A3m	outlet metal angle	deg	29.0274
Rotor			
B1m	inlet metal angle	deg	24.6174
B2m	outlet metal angle	deg	68.1695

	Property	Unit	Value
Pt_in	total pressure at inlet	Pa	20670.000000
It_in	total enthalpy at inlet	J/kg	312550.175000
Tt_in	total temperature at inlet	°C	38.000000
Pst_o	stat. pressure at outlet	Pa	152979.999723
Pt_out	total pressure at outlet	Pa	155491.087730
Gin	mass flow rate at inlet	kg/s	0.060431
	inlet flow angle in abs fram	deg	90.000000
srs1	shaft1 rotational speed	rps	1667.000000
Gv	volume flow rate at outlet	m^3/s	0.066920
Nc	capacity	W	18491.804370
eff_tt	internal total-to-total efficier	-	0.796569
psr	total-static pressure ratio	-	7.401064
ptr	total-total pressure ratio	-	7.522549



3-Wheel High Pressure Ratio Turbocharger – 2nd Stage Single-Sided Compressor Corrected Mass Flow Rate vs. Total Pressure Ratio and Efficiency (tt) @ Pin = 2.998 psia & Tin = 560 degR:





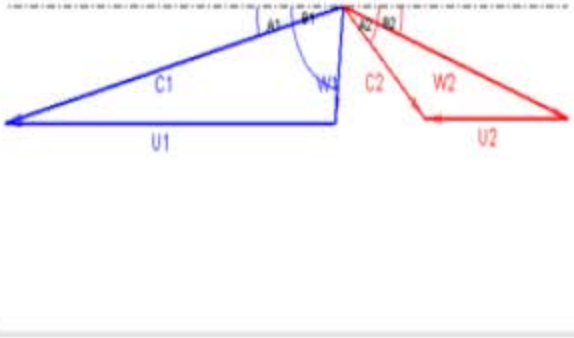
3-Wheel High Pressure Ratio Turbocharger – Turbine (Performance data using AxStream software from SoftInWay Inc.):

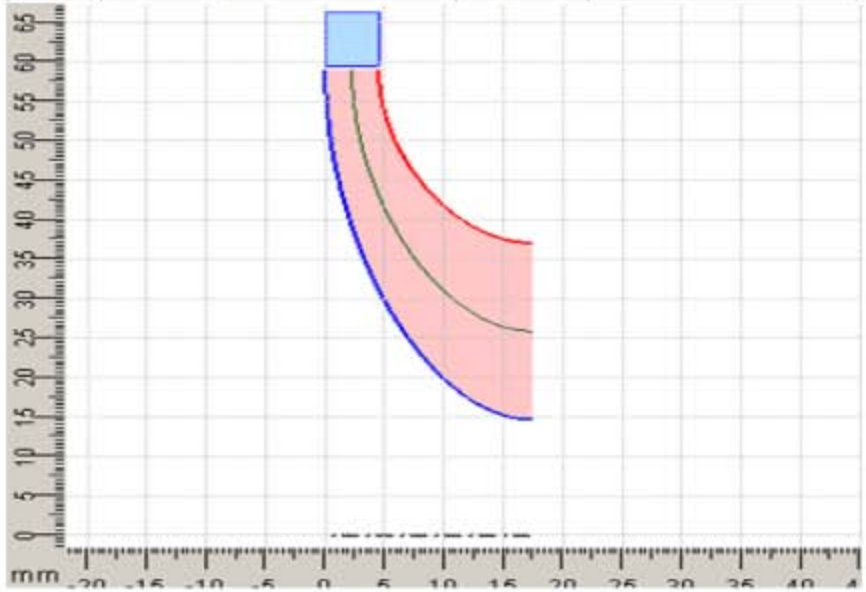
Stator			
z	number of nozzles	-	55
l0	airfoil LE meridional length	mm	4.55
D0	channel inlet mean diameter	mm	132.52
l1	airfoil TE meridional length	mm	4.55
D1	channel outlet mean diameter	mm	119.043

Rotor			
z	number of blades	-	20
lc1	channel inlet width	mm	4.55
D1	channel inlet mean diameter	mm	118.145
D2t	channel outlet shroud diameter	mm	74.1046
D2h	channel outlet hub diameter	mm	29.2881
B	axial chord length	mm	22

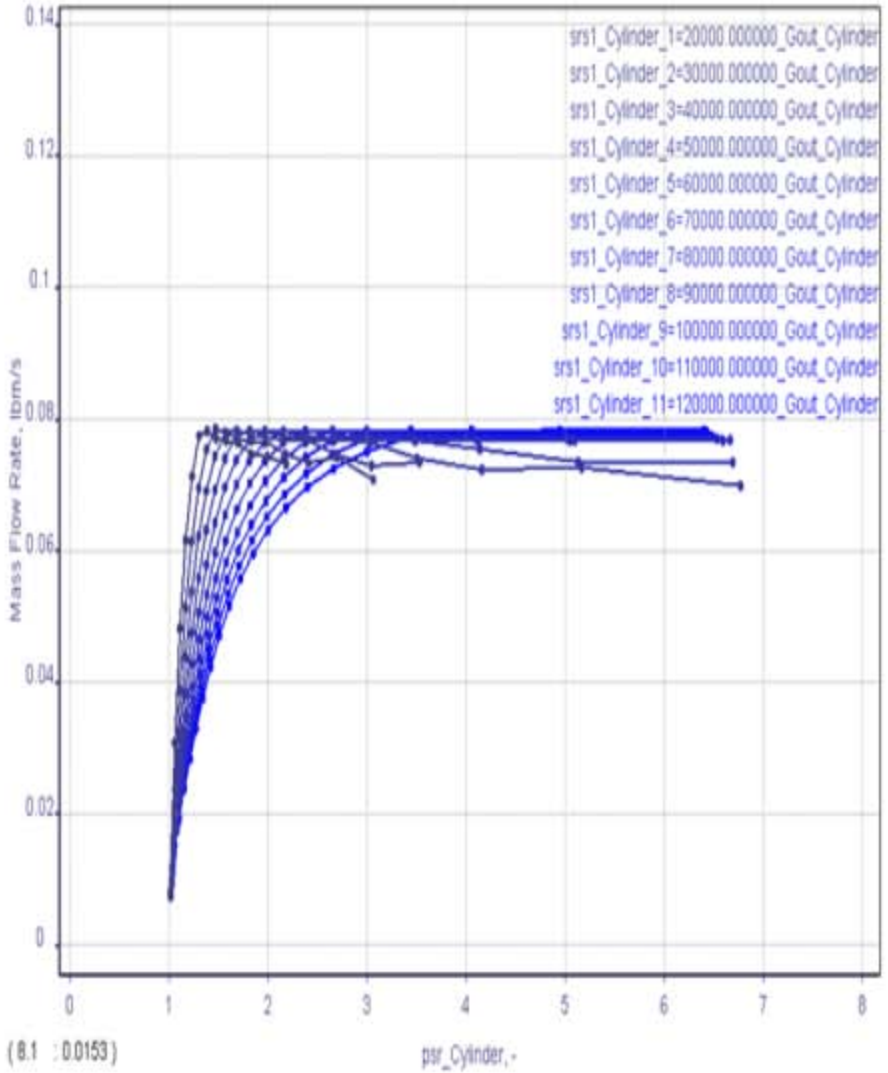
	Property	Unit	Value
Pt_in	total pressure at inlet	Pa	198569.000000
It_in	total enthalpy at inlet	J/kg	1548149.169503
Tt_in	total temperature at inlet	°C	1051.999992
Pst_ou	stat. pressure at outlet	Pa	35638.137393
Gin	mass flow rate at inlet	kg/s	0.064568
	inlet flow angle in abs frame	deg	90.000000
srs1	shaft1 rotational speed	rps	1667.000000
UC0	isentropic velocity ratio	-	0.259740
Gv	volume flow rate at outlet	m^3/s	0.486496
Nc	capacity	W	26914.086152
eff_ts	internal total-to-static efficienc	-	0.774089
eff_tt	internal total-to-total efficiency	-	0.806437
psr	total-static pressure ratio	-	5.571812
ptr	total-total pressure ratio	-	5.032628

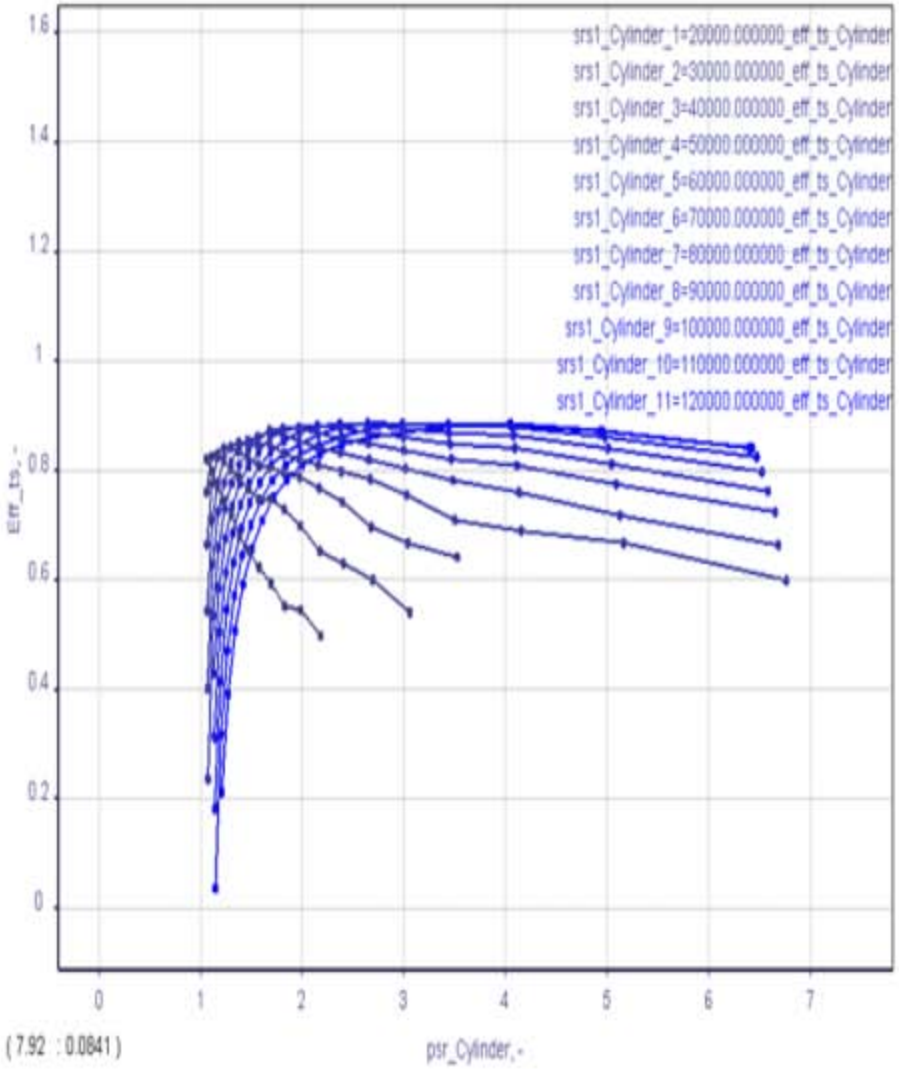
Property	Unit	Value
A1	deg	12.170065
B1	deg	83.710932
C1	m/s	653.292958
W1	m/s	138.557092
c1r	m/s	137.723238
c1u	m/s	638.610378
A2	deg	40.568241
B2	deg	17.295901
C2	m/s	203.723231
W2	m/s	445.641247
c2z	m/s	132.492067
c2u	m/s	-154.754667



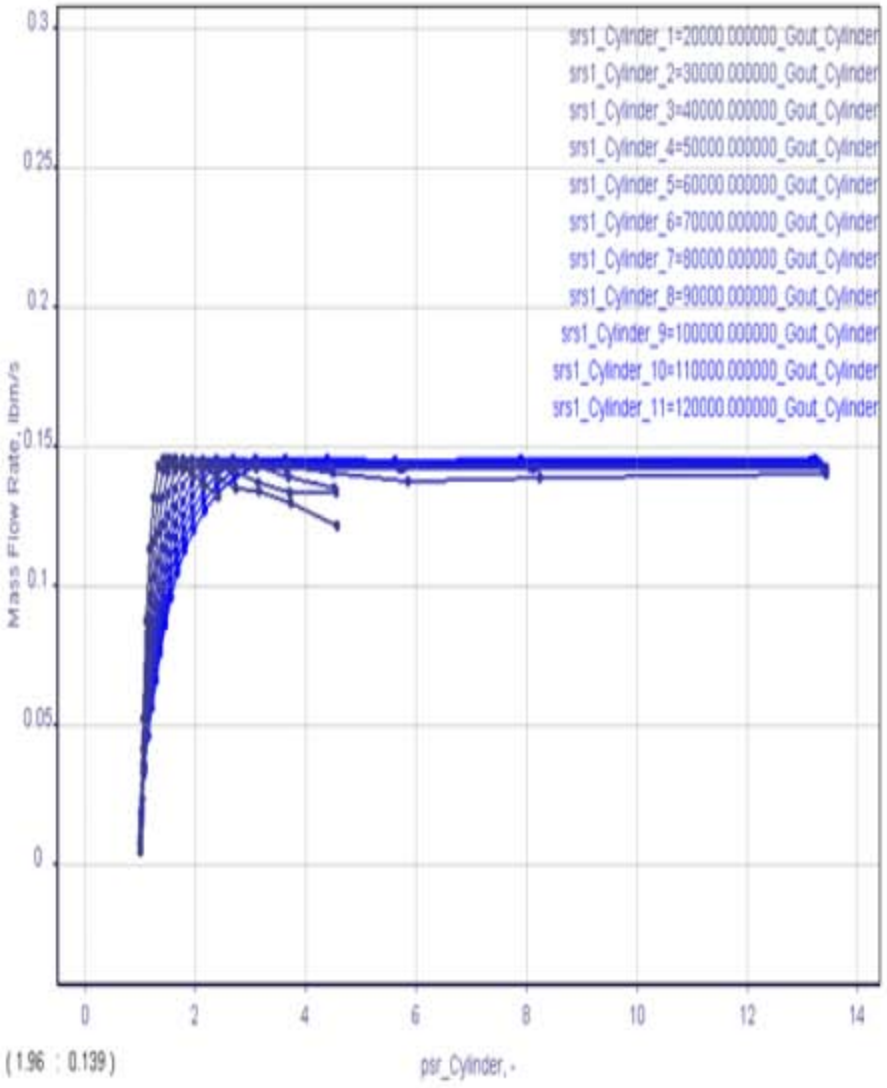


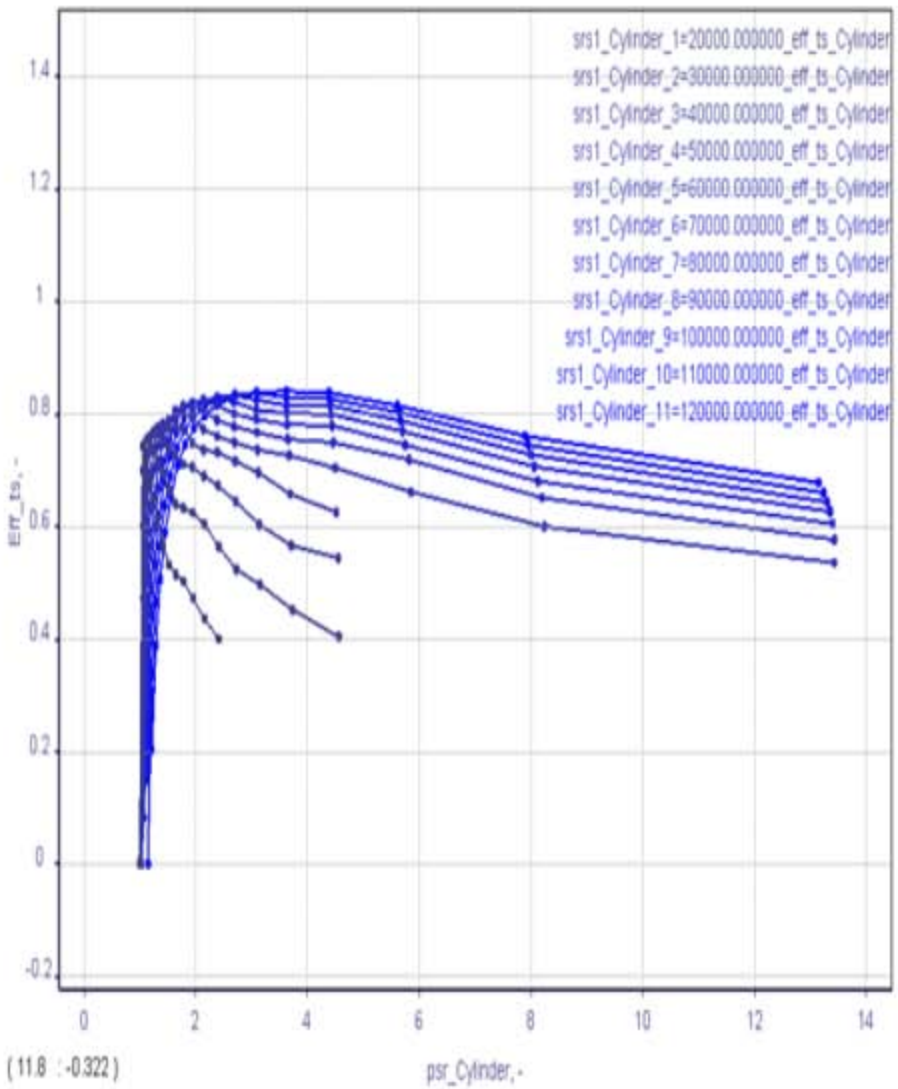
3-Wheel High Pressure Ratio Turbocharger – Turbine Total-to-Static Pressure Ratio vs Mass Flow Rate and Efficiency (ts) @ Pin = 1 bar & Tin = 2385 degR:



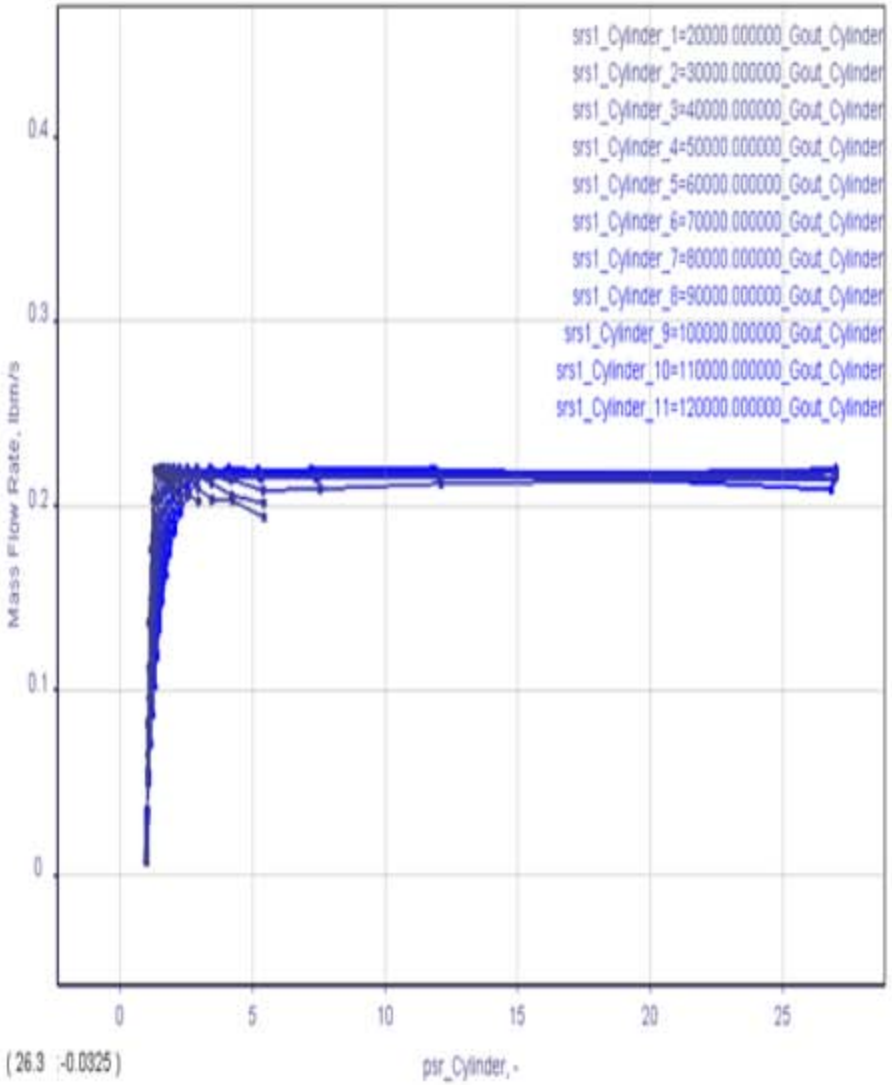


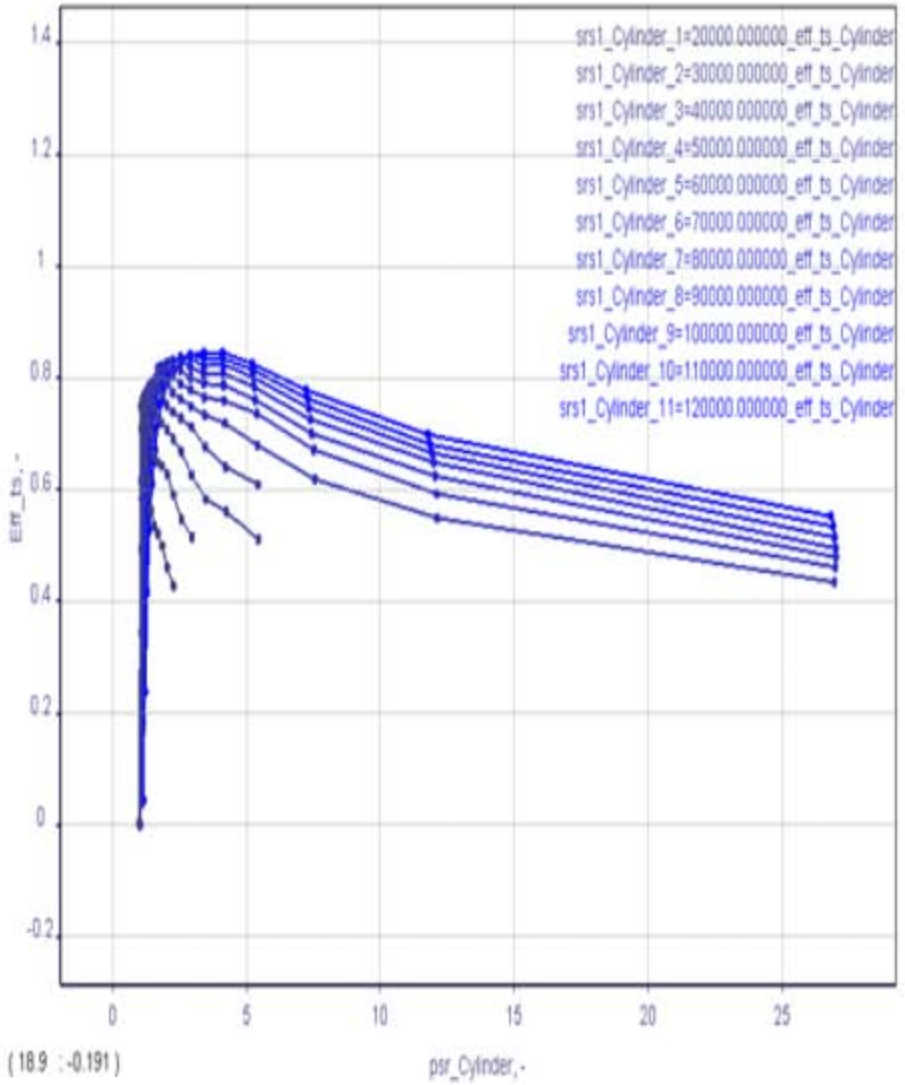
3-Wheel High Pressure Ratio Turbocharger – Turbine Total-to-Static Pressure Ratio vs Mass Flow Rate and Efficiency (ts) @ Pin = 2 bar & Tin = 2385 degR:



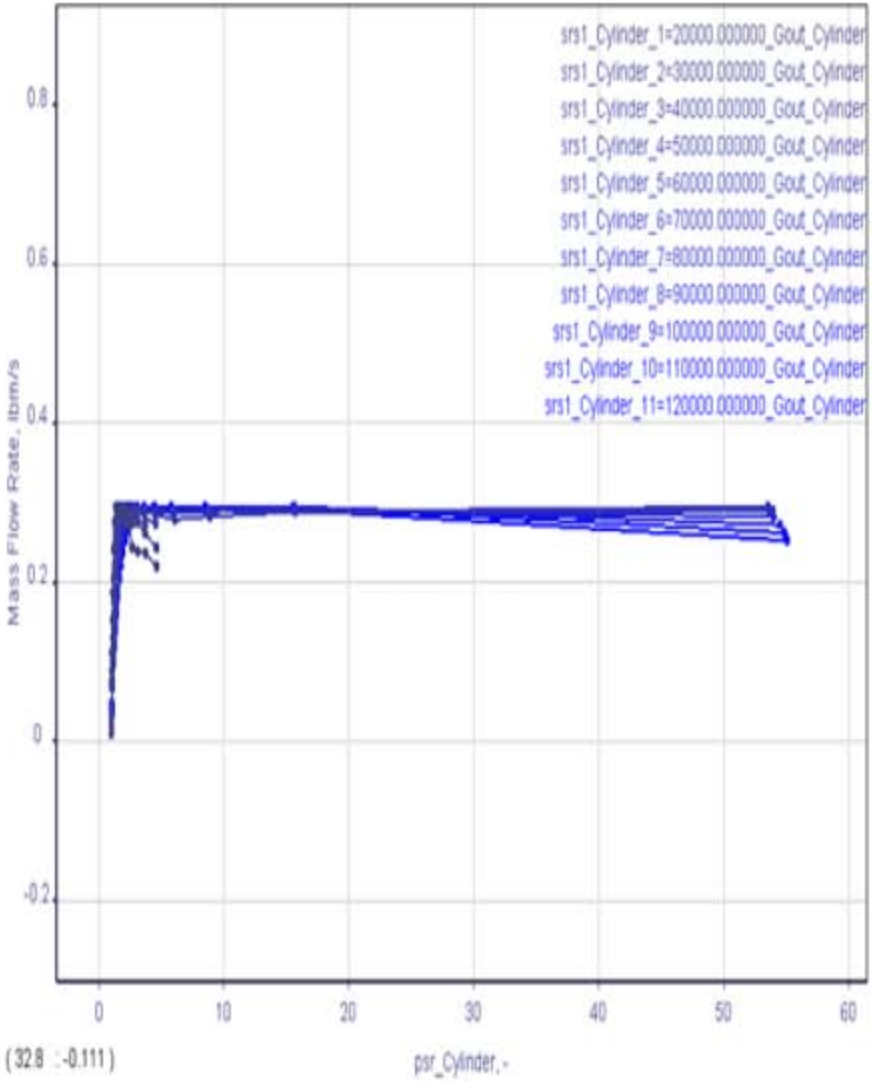


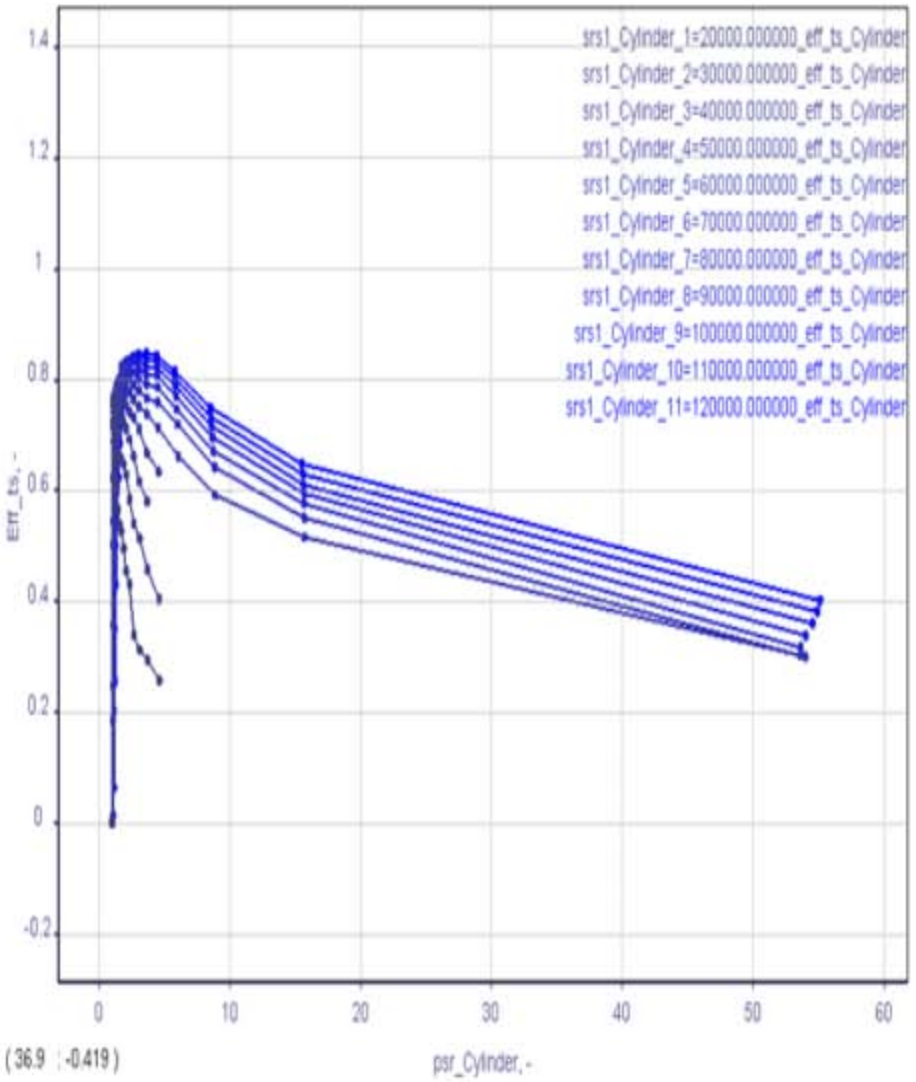
3-Wheel High Pressure Ratio Turbocharger – Turbine Total-to-Static Pressure Ratio vs Mass Flow Rate and Efficiency (ts) @ Pin = 3 bar & Tin = 2385 degR:





3-Wheel High Pressure Ratio Turbocharger – Turbine Total-to-Static Pressure Ratio vs Mass Flow Rate and Efficiency (ts) @ Pin = 4 bar & Tin = 2385 degR:





3-Wheel High Pressure Ratio Turbocharger – Turbine Total-to-Static Pressure Ratio vs Mass Flow Rate and Efficiency (ts) @ Pin = 5 bar & Tin = 2385 degR: