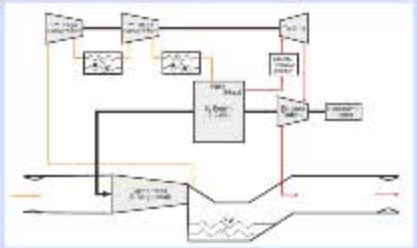
High Altitude Low Cost Configurable Jet Engine Trade Study

STATUS QUO

Current UAV High Altitude Record for Air-Breathing Power Plants is 65,381 feet, Combined with High SFC's and Lower On-Station Persistance

NEW INSIGHTS



Recent Research on Turbocharged Compound 2-Stroke IC Engines at High Altitude Combined with Low Pressure Ratio Jet Propulsion, has Demonstrated High Power Density & Substantial Reductions in SFC's up to 100 kft

TRADE STUDY ACHIEVEMENT

MAIN ACHIEVEMENT:

- Qualitative & Quantitative Assessment of Propulsion Concept and Air Vehicle Configuration Compromises and Performance Benefits
- Major Trades to be Assessed: Adiabatic Expansion Chamber and Port Area Time, 3-Wheel High Pressure Ratio Turbocharger, Primary Shaft-Driven Compressor, Compound Power Recovery Turbine, ICE Compression Ratio, 2-Stream Droplet Heat Exchanger, Thermal Management, Mass Properties, Scaling, & Performance
- Configuration & Performance in Subsonic Airframes & Flow Regimes to be Assessed

HOW IT WORKS:

- Adiabatic Expansion Chamber Operates Choked at High Power Density Level
- Leverages Choked Characteristic to Reduce SFC via Compound Power Recovery Turbine
- Leverages Remaining ICE Exhaust Stream Energy to Increase Jet Pipe Stream Enthalpy
- Low Pressure Ratio Jet Propulsion Provides Lower SFC's at Higher Altitudes with Low Plume Temps

ASSUMPTIONS AND LIMITATIONS:

- ICE Derived From Rotax FR125 Max COTS Engine
- Breadth & Depth of Study Analyses will be Dependent on DARPA Program Schedule & Funding

QUANTITATIVE IMPACT

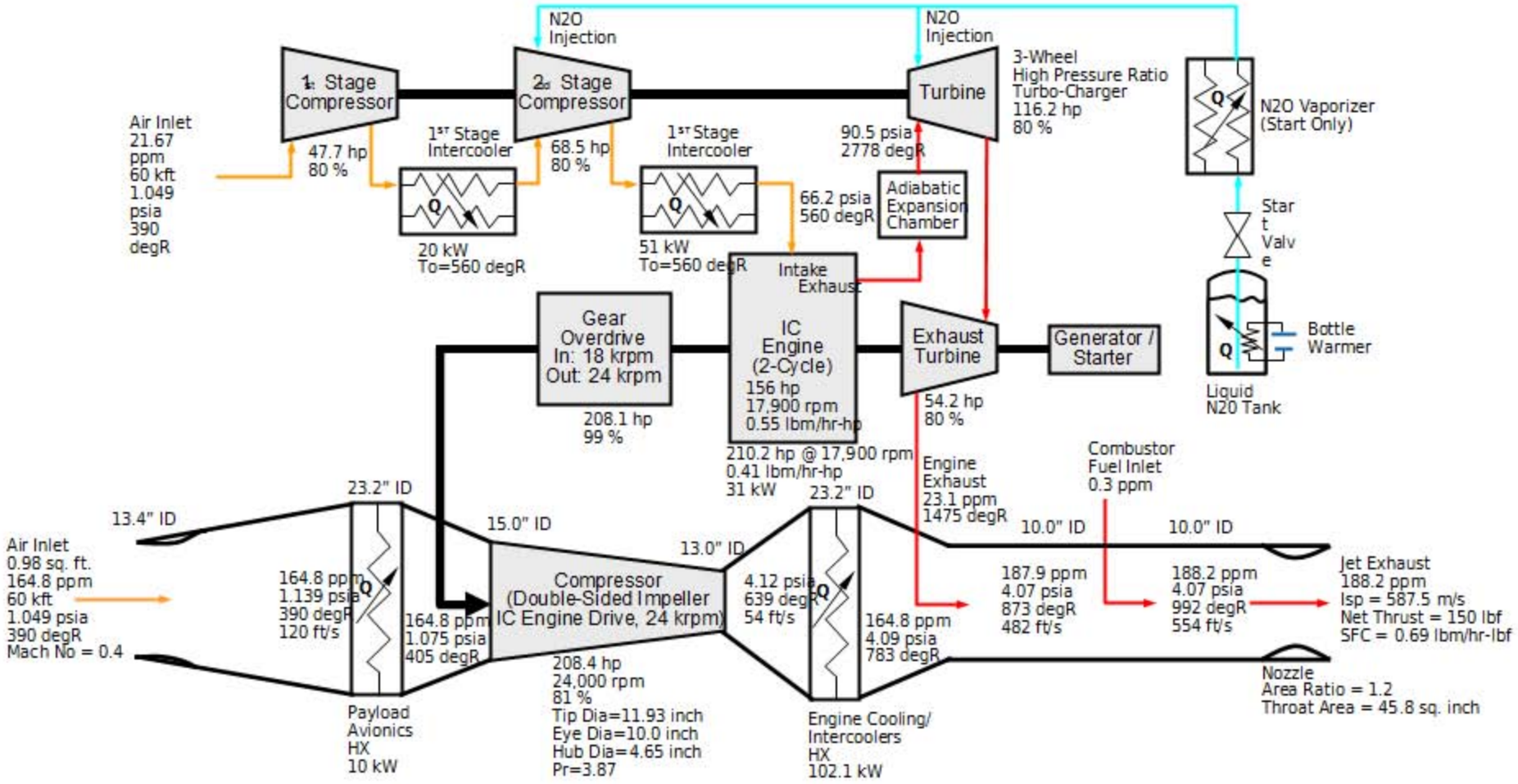
Trade Study Reduces Technical Risks Associated with Airframe Integration of Propulsion Concept while Narrowing the Design & Development Space Toward Optimal Configurations & Technology

END-OF-PHASE GOAL

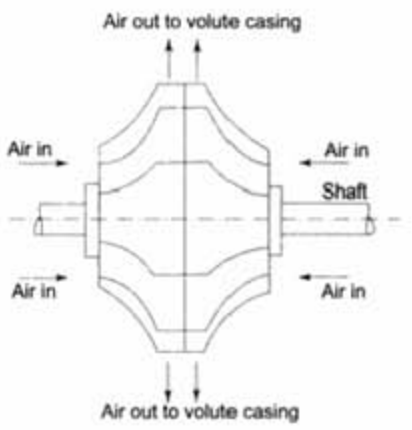
- *Qualitative & Quantitative Description of Relationships Between Major Trade Parameters and Air Vehicle Performance*
- *Parameter Ranges for Optimal Performance & Endurance*
- *Identification of Component Sizing to Maximize Performance and Flight Envelope*

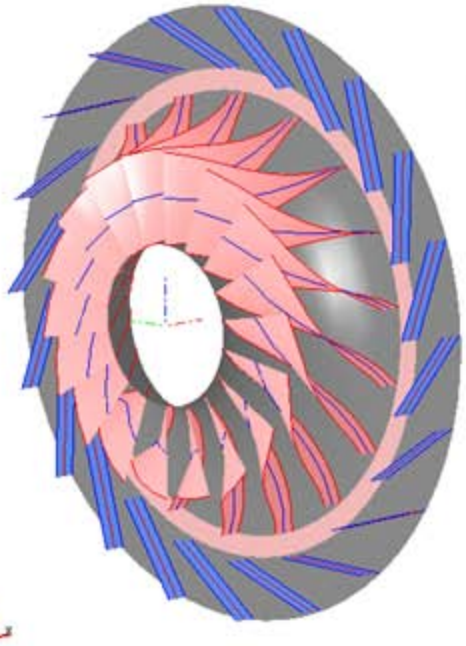
Specific Fuel Consumption of Less Than 0.6 pph/lbf is Attainable at 100 kft and Mach 0.4

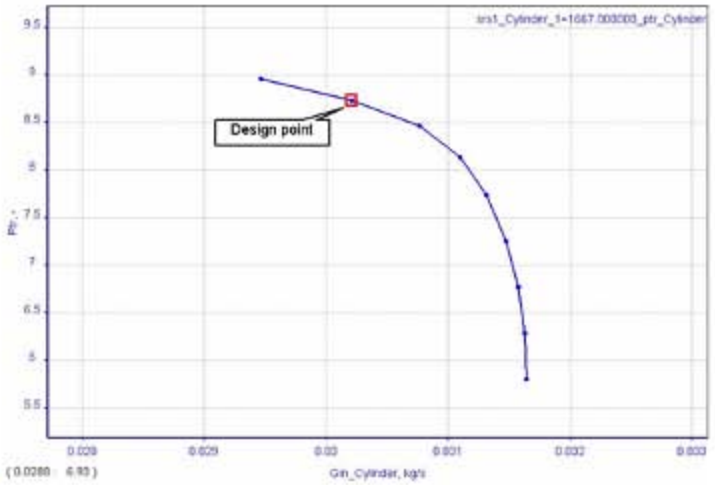
Proposed AV Integrated Propulsion/Thermal Jet Engine System Schematic Overview

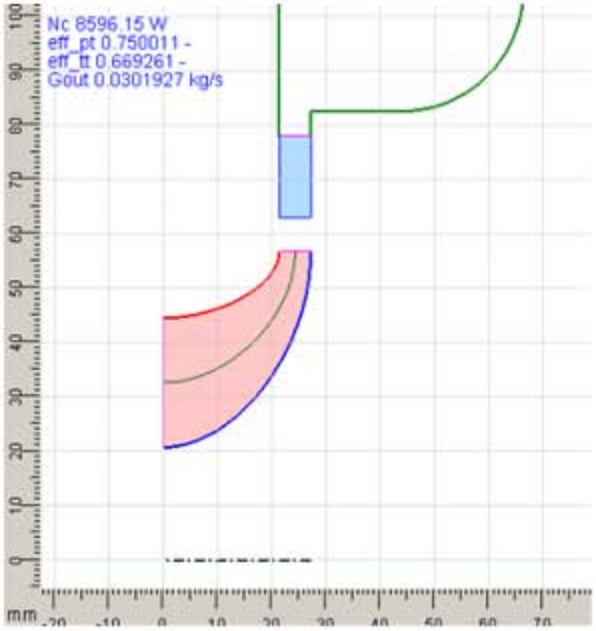


3-Wheel High Pressure Ratio Turbocharger – 1st Stage Double-Sided Compressor (Performance data using AxStream software from SoftInWay Inc.):



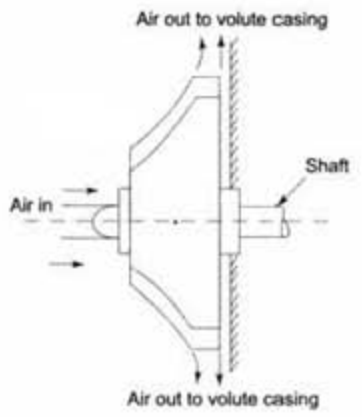


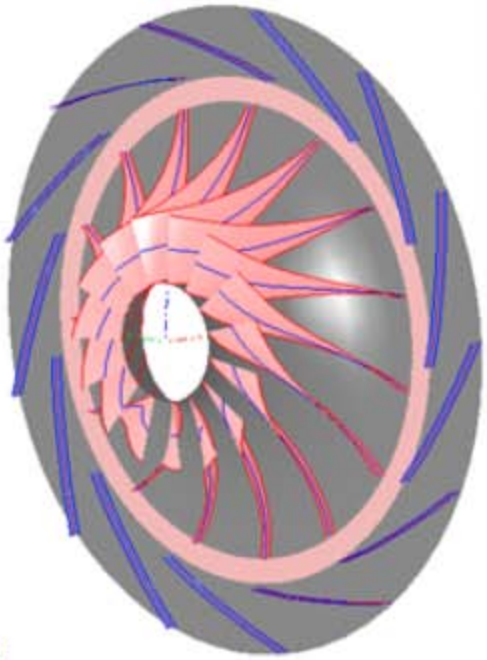


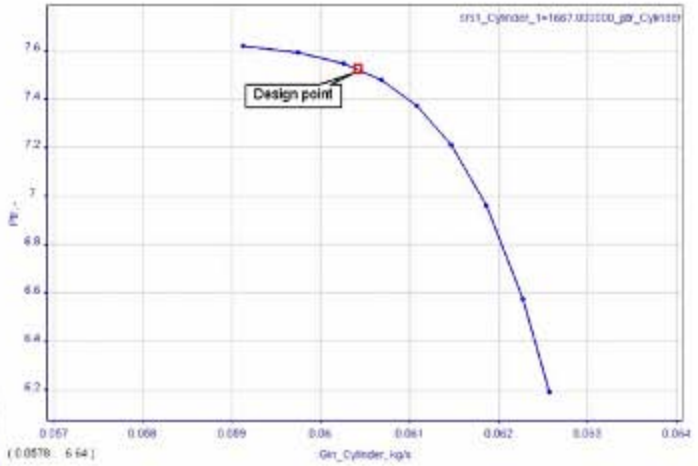


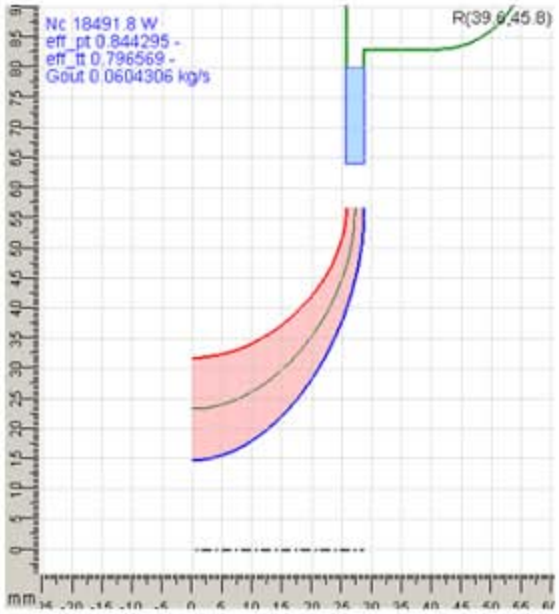
	Property	Unit	Value
Pt_in	total pressure at inlet	Pa	2758.000000
It_in	total enthalpy at inlet	J/kg	222044.725000
Tt_in	total temperature at inlet	°C	-52.100000
Pst_ou	stat. pressure at outlet	Pa	23442.795854
Pt_out	total pressure at outlet	Pa	24119.418576
Gin	mass flow rate at inlet	kg/s	0.030193
	inlet 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.):



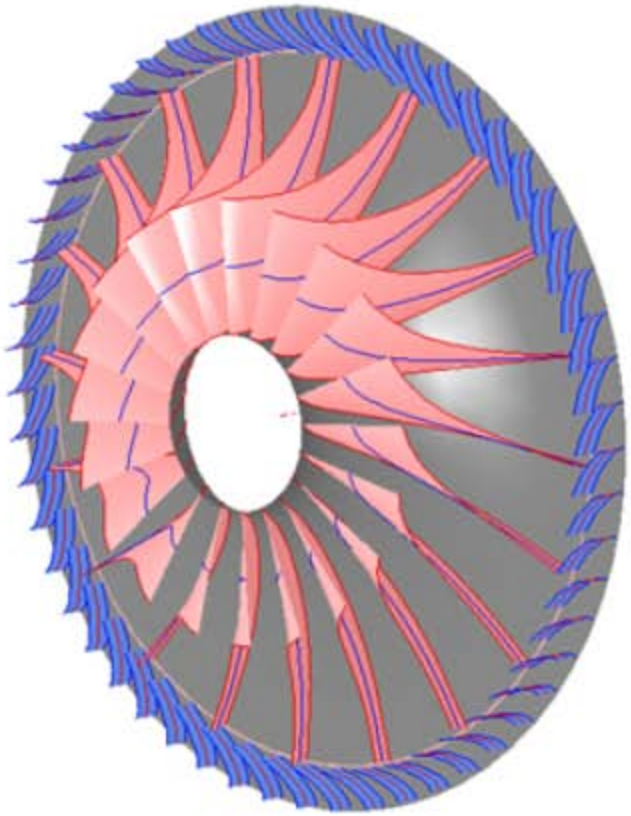




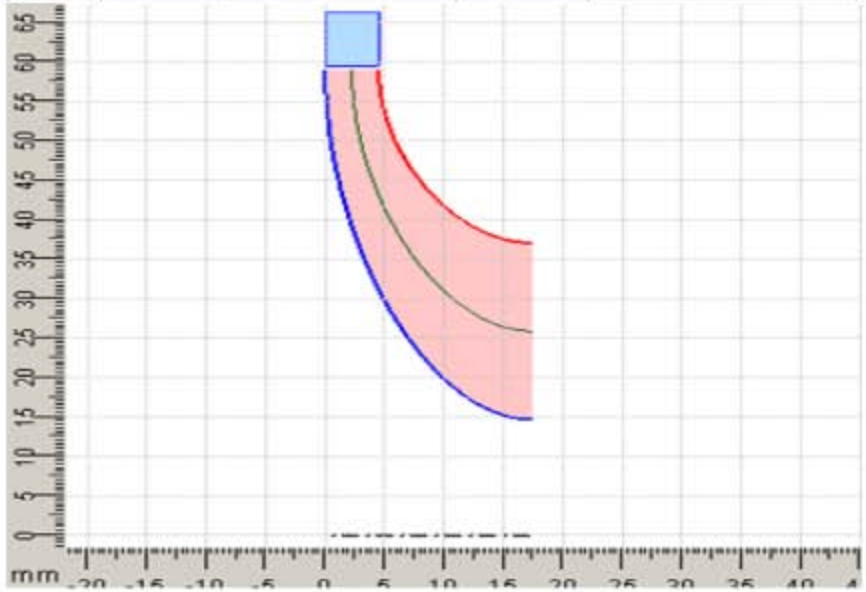


	Property	Unit	Value
Pt_in	total pressure at inlet	Pa	20670.000000
It_in	total enthalpy at inlet	J/kg	312550.175000
Tt_in	total temperature at inlet	°C	38.000000
Pst_o	stat. pressure at outlet	Pa	152979.999723
Pt_out	total pressure at outlet	Pa	155491.087730
Gin	mass flow rate at inlet	kg/s	0.060431
	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.):

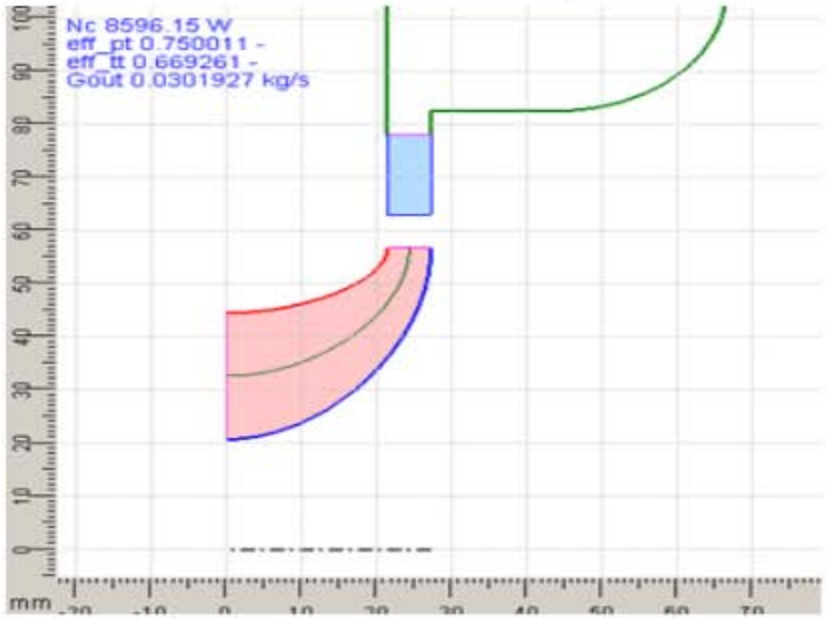
1st Stage final meridional dimensions

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

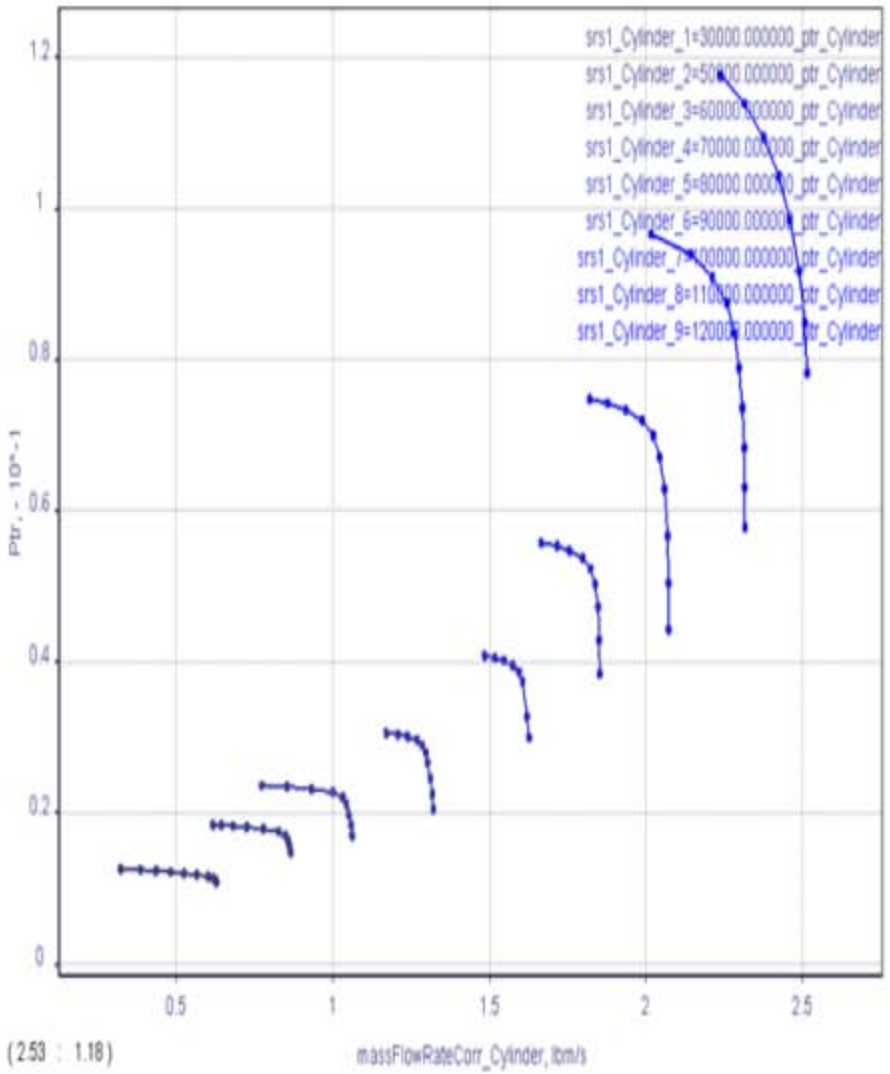
1st Stage angles on mid section (tangential)

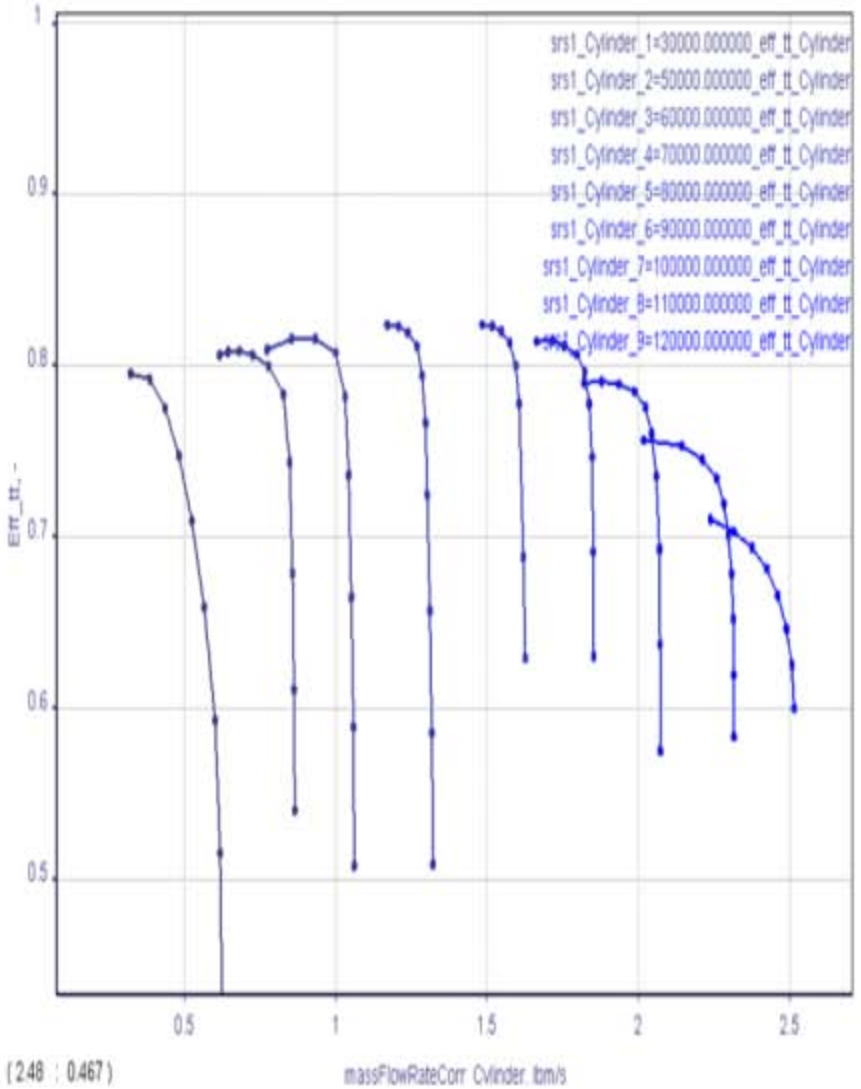
Stator			
A2m	inlet metal angle	deg	22.47
A3m	outlet metal angle	deg	38.36
Rotor			
B1m	inlet metal angle	deg	26.9
B2m	outlet metal angle	deg	65.6

	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

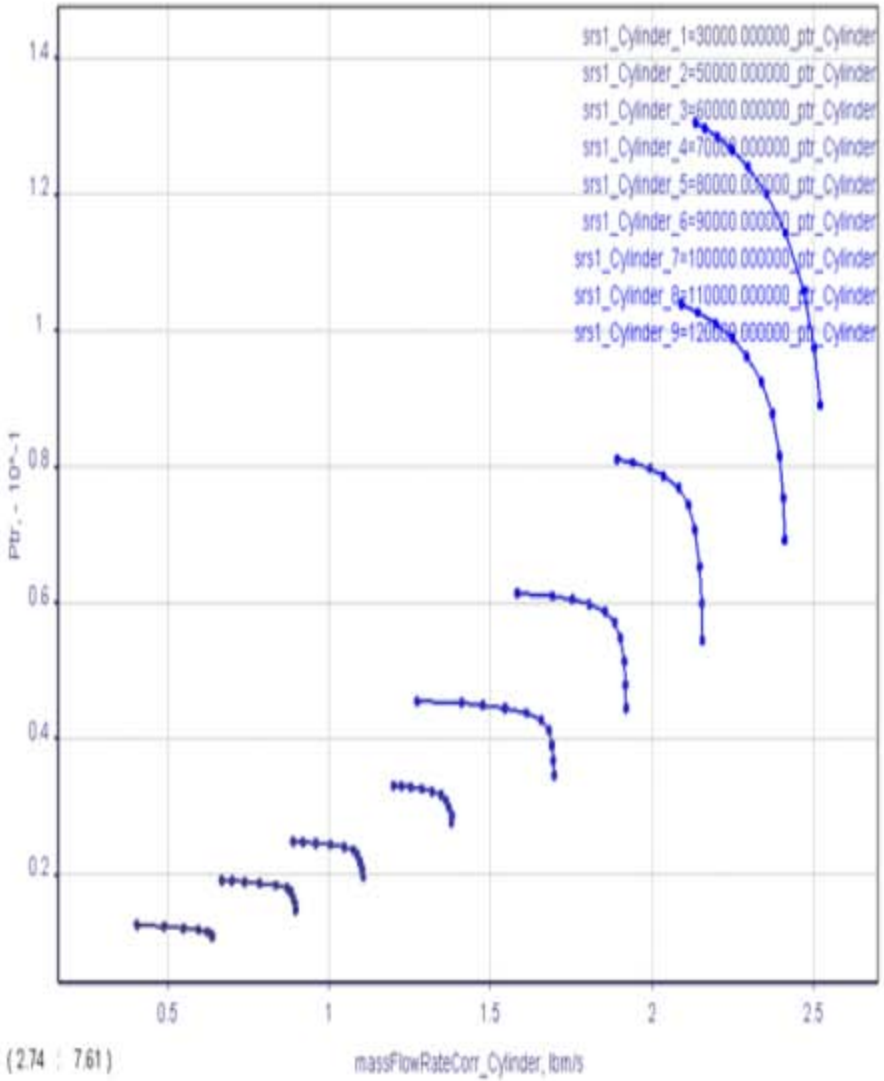


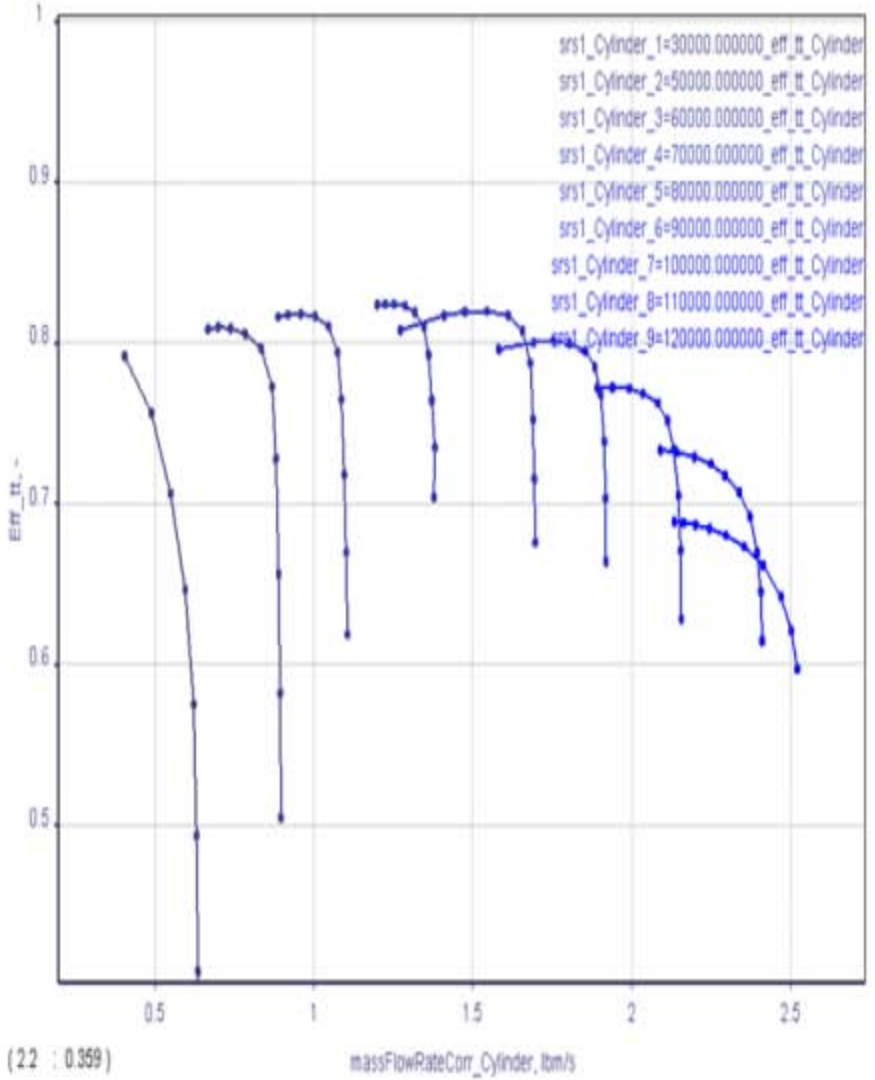
3-Wheel High Pressure Ratio Turbocharger – 1st Stage Double-Sided Compressor Corrected Mass Flow Rate vs. Total Pressure Ratio and Efficiency (tt) @ 0 kft:



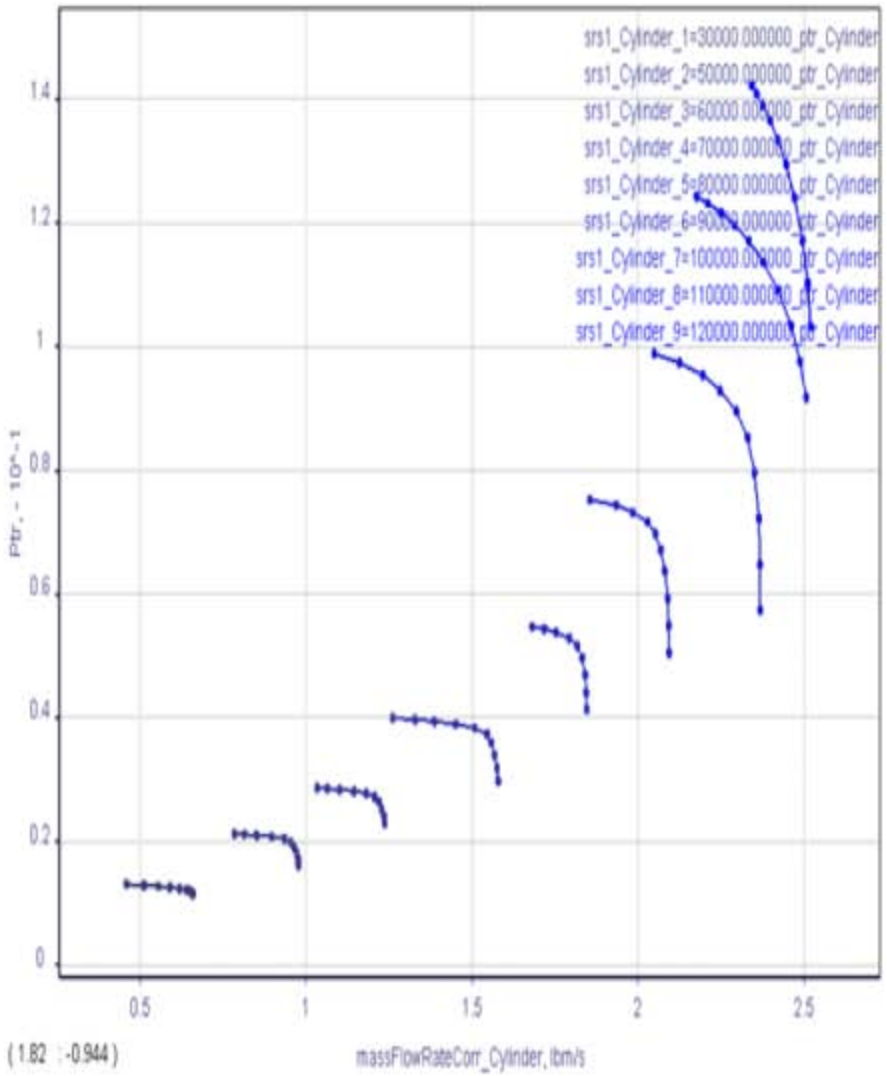


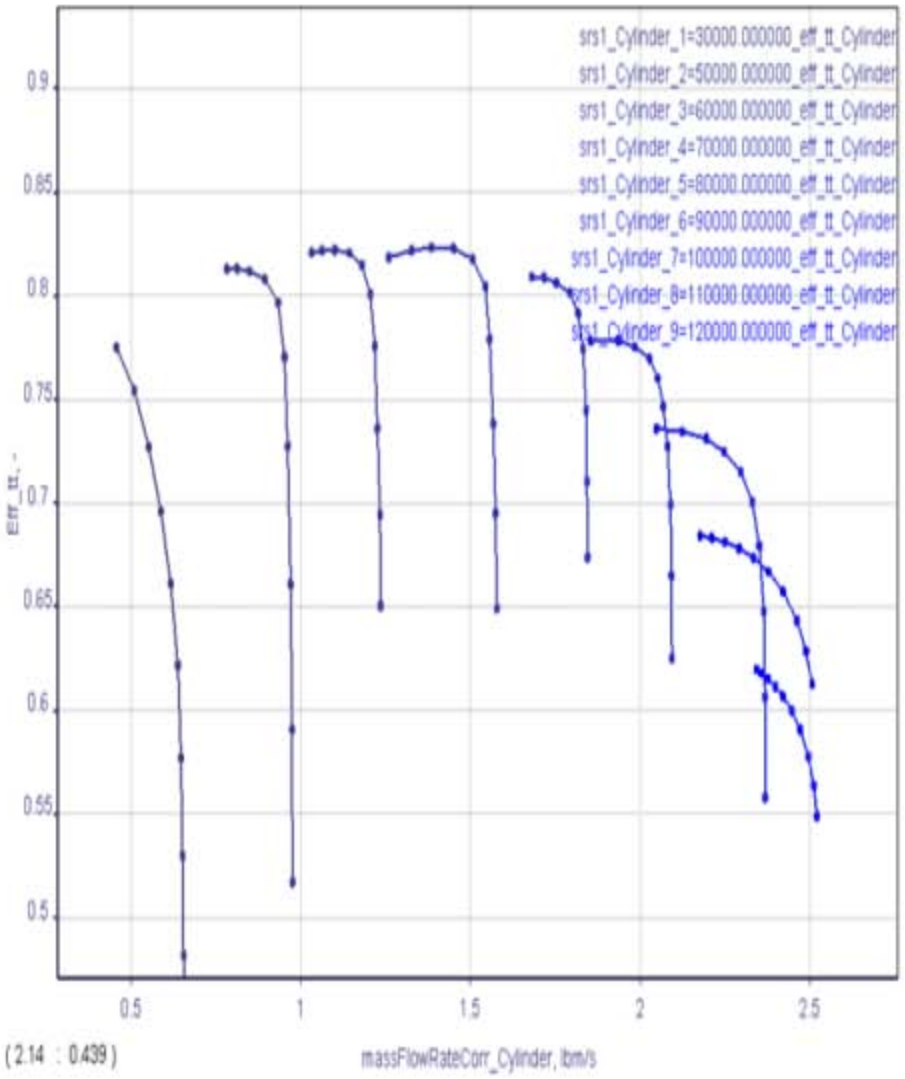
3-Wheel High Pressure Ratio Turbocharger – 1st Stage Double-Sided Compressor Corrected Mass Flow Rate vs. Total Pressure Ratio and Efficiency (tt) @ 10 kft:



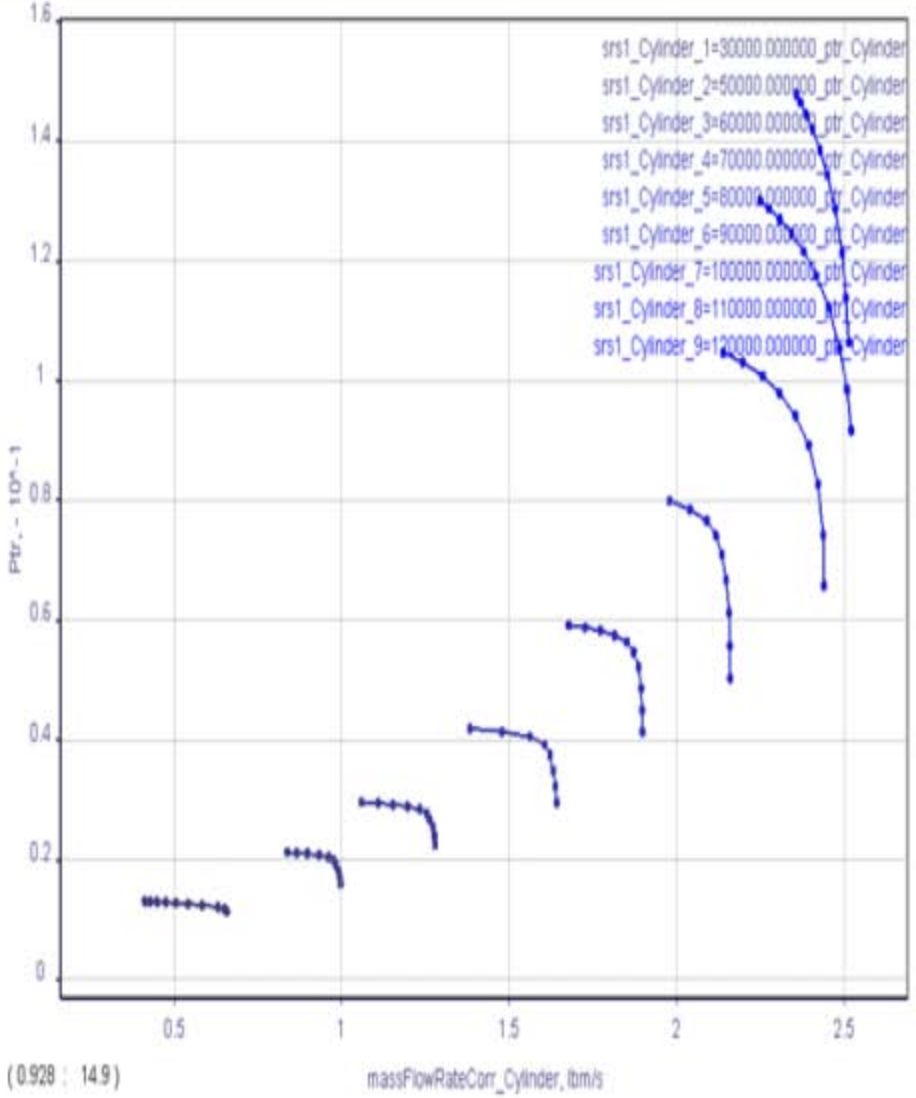


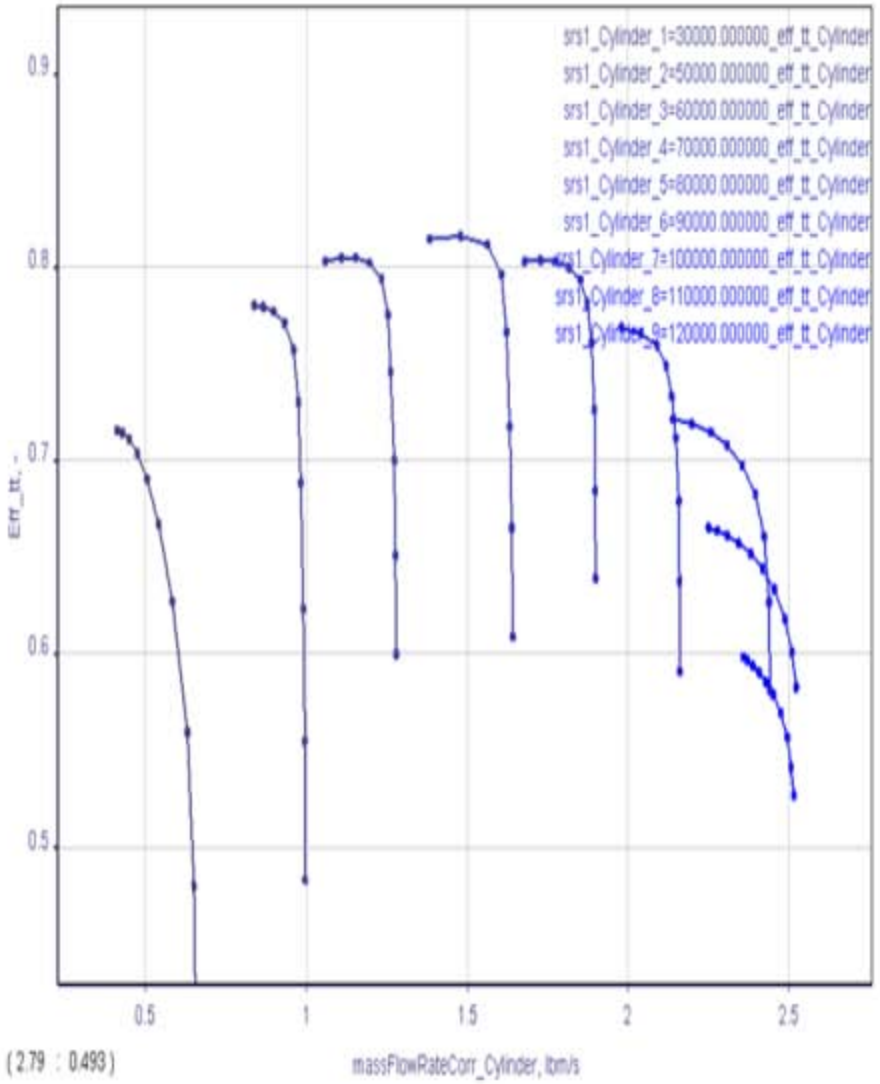
3-Wheel High Pressure Ratio Turbocharger – 1st Stage Double-Sided Compressor Corrected Mass Flow Rate vs. Total Pressure Ratio and Efficiency (tt) @ 30 kft:



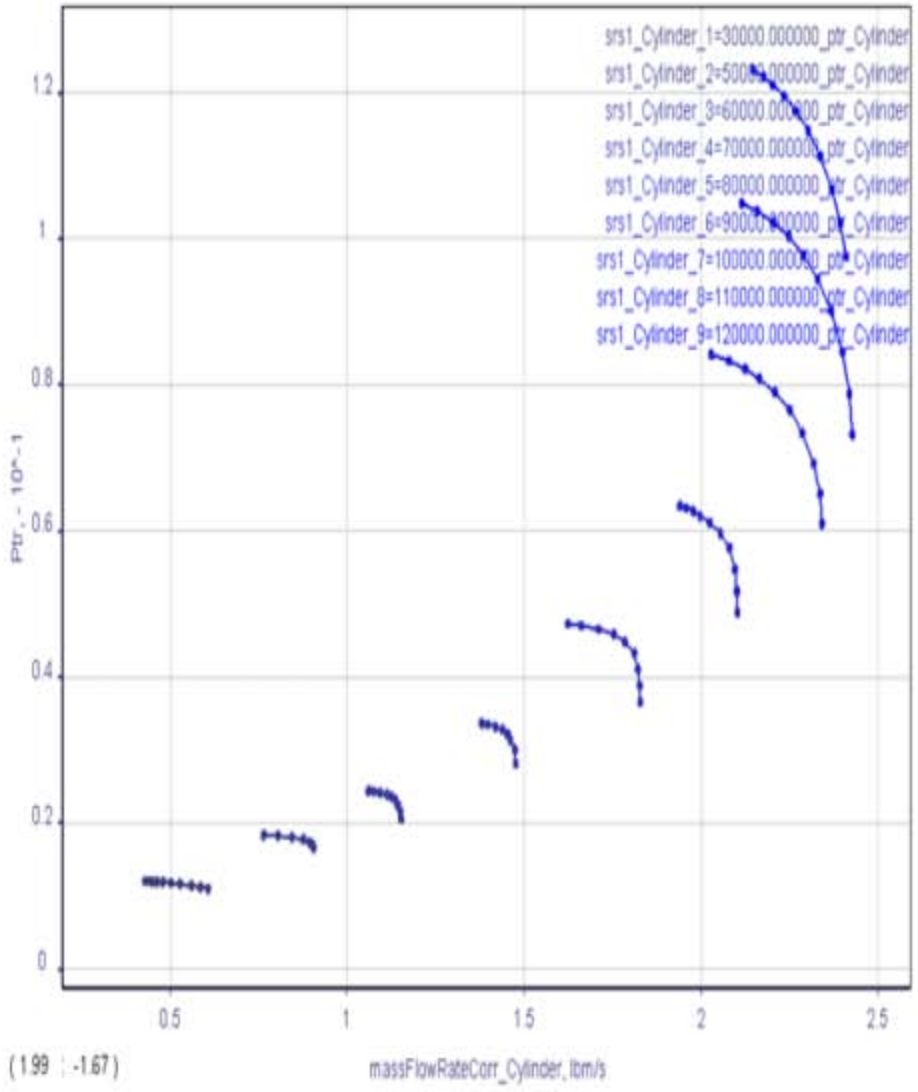


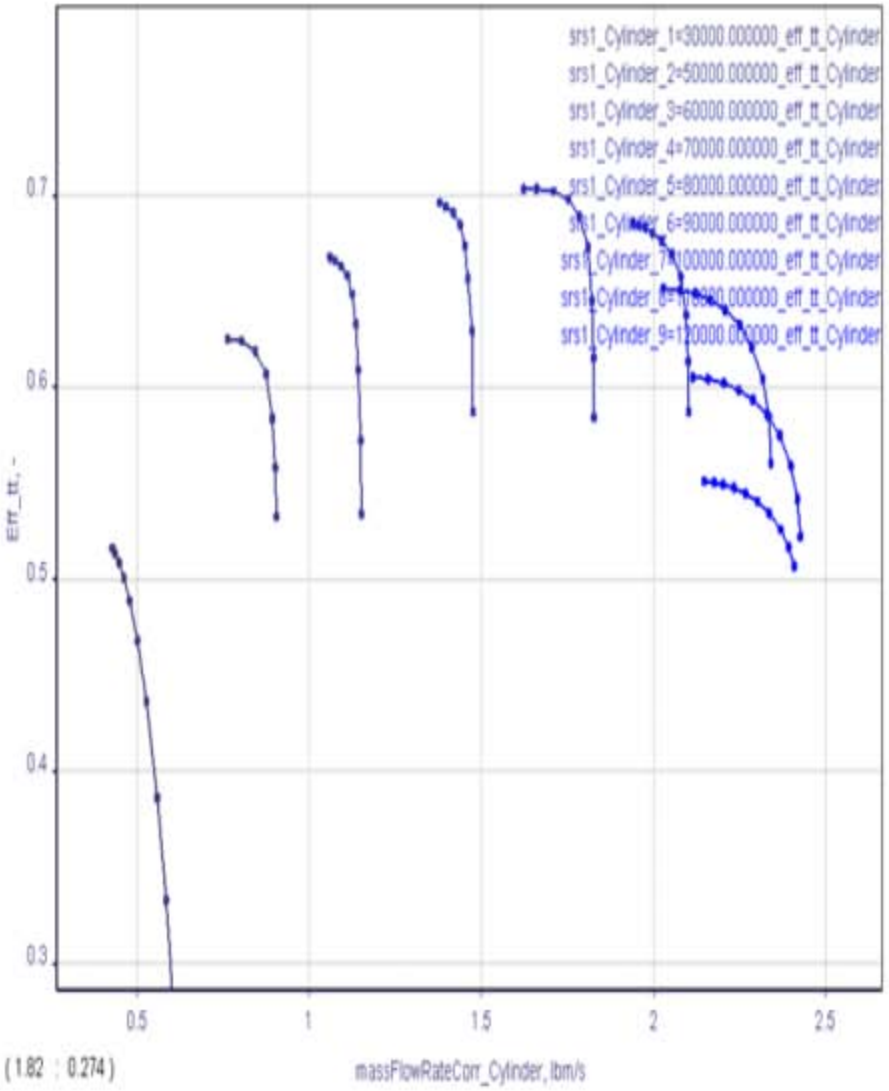
3-Wheel High Pressure Ratio Turbocharger – 1st Stage Double-Sided Compressor Corrected Mass Flow Rate vs. Total Pressure Ratio and Efficiency (tt) @ 50 kft:





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.):

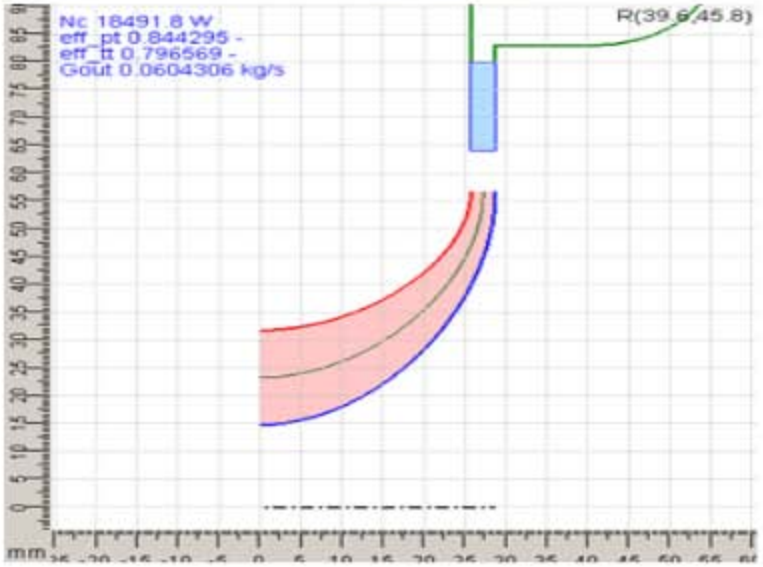
2nd Stage final meridional dimensions

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

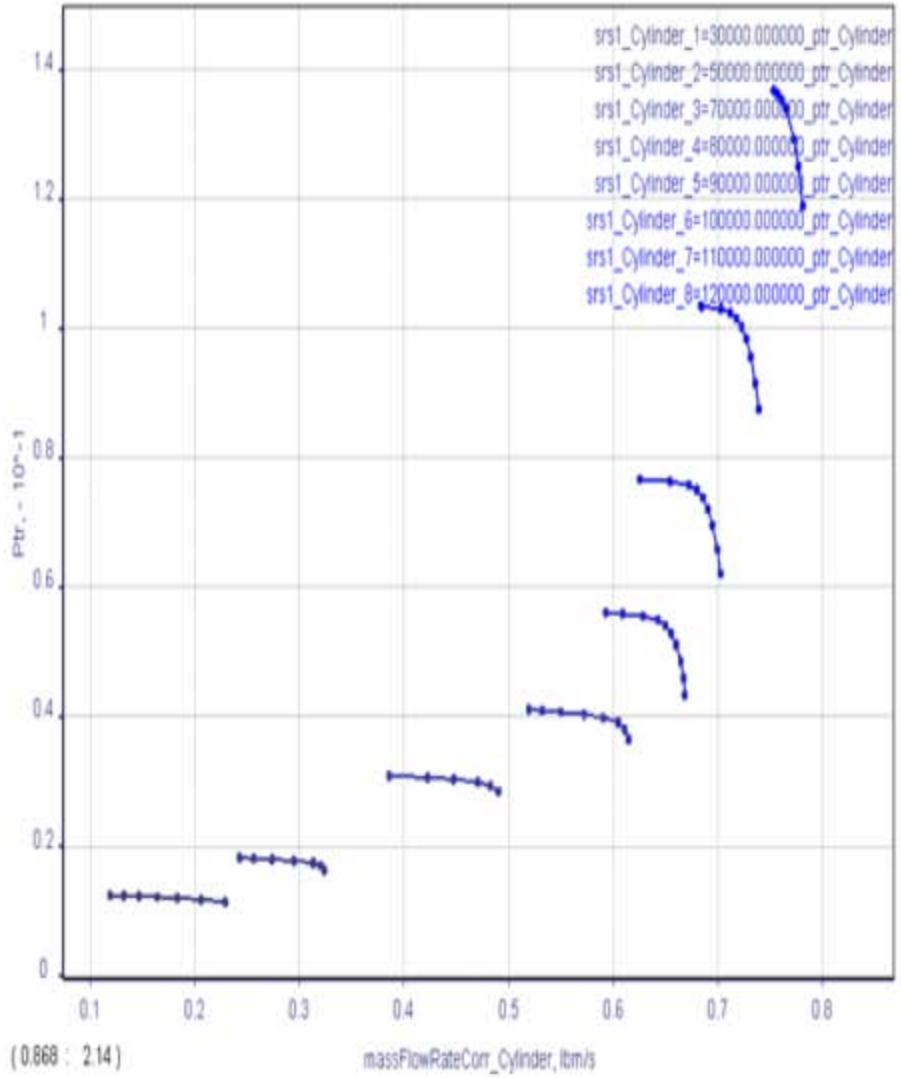
2nd Stage angles on mid section (tangential)

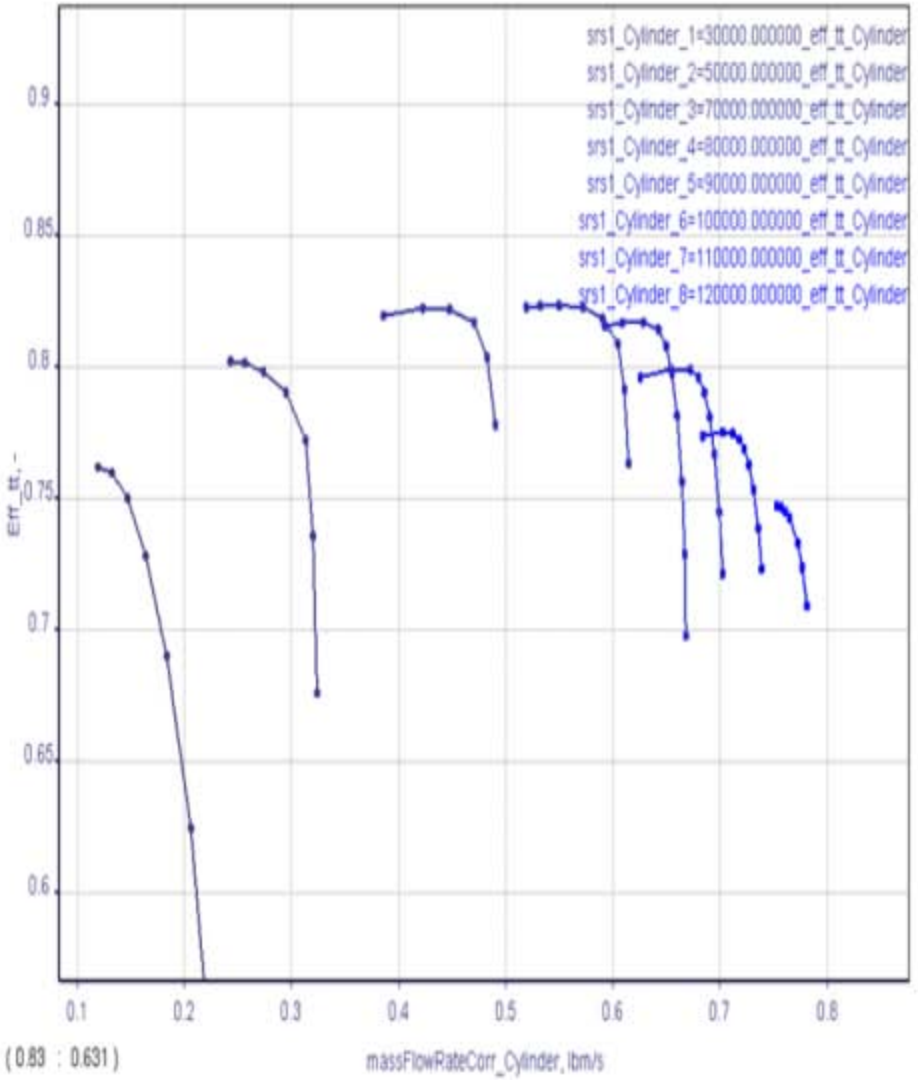
Stator			
A2m	inlet metal angle	deg	12.9328
A3m	outlet metal angle	deg	29.0274
Rotor			
B1m	inlet metal angle	deg	24.6174
B2m	outlet metal angle	deg	68.1695

	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:





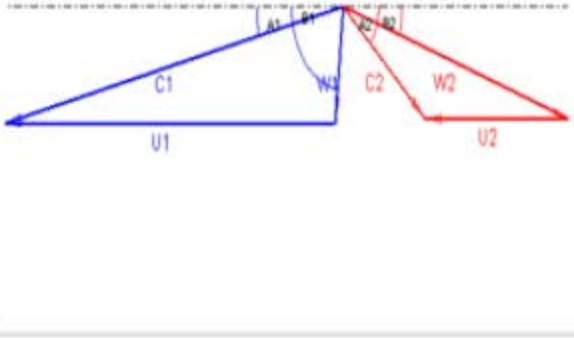
3-Wheel High Pressure Ratio Turbocharger – Turbine (Performance data using AxStream software from SoftInWay Inc.):

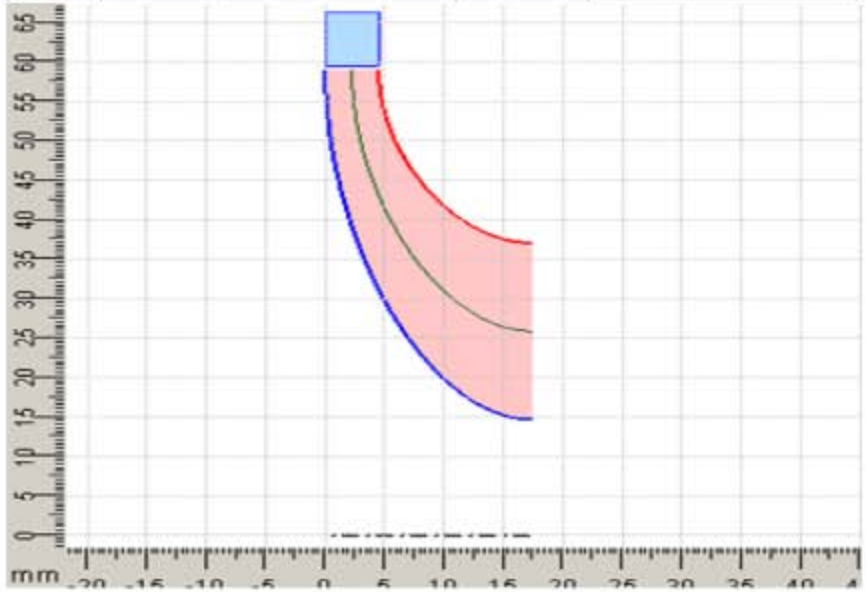
Stator			
z	number of nozzles	-	55
l0	airfoil LE meridional length	mm	4.55
D0	channel inlet mean diameter	mm	132.52
l1	airfoil TE meridional length	mm	4.55
D1	channel outlet mean diameter	mm	119.043

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

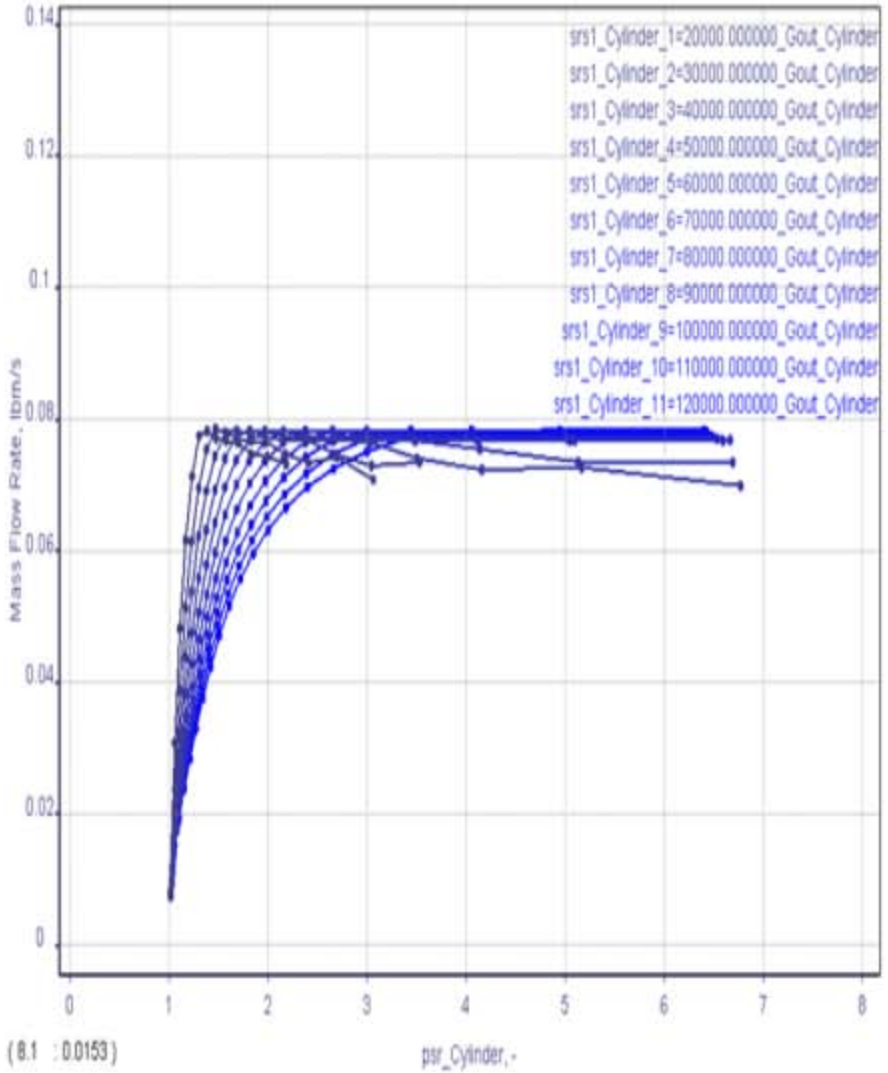
	Property	Unit	Value
Pt_in	total pressure at inlet	Pa	198569.000000
It_in	total enthalpy at inlet	J/kg	1548149.169503
Tt_in	total temperature at inlet	°C	1051.999992
Pst_ou	stat. pressure at outlet	Pa	35638.137393
Gin	mass flow rate at inlet	kg/s	0.064568
	inlet flow angle in abs frame	deg	90.000000
srs1	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

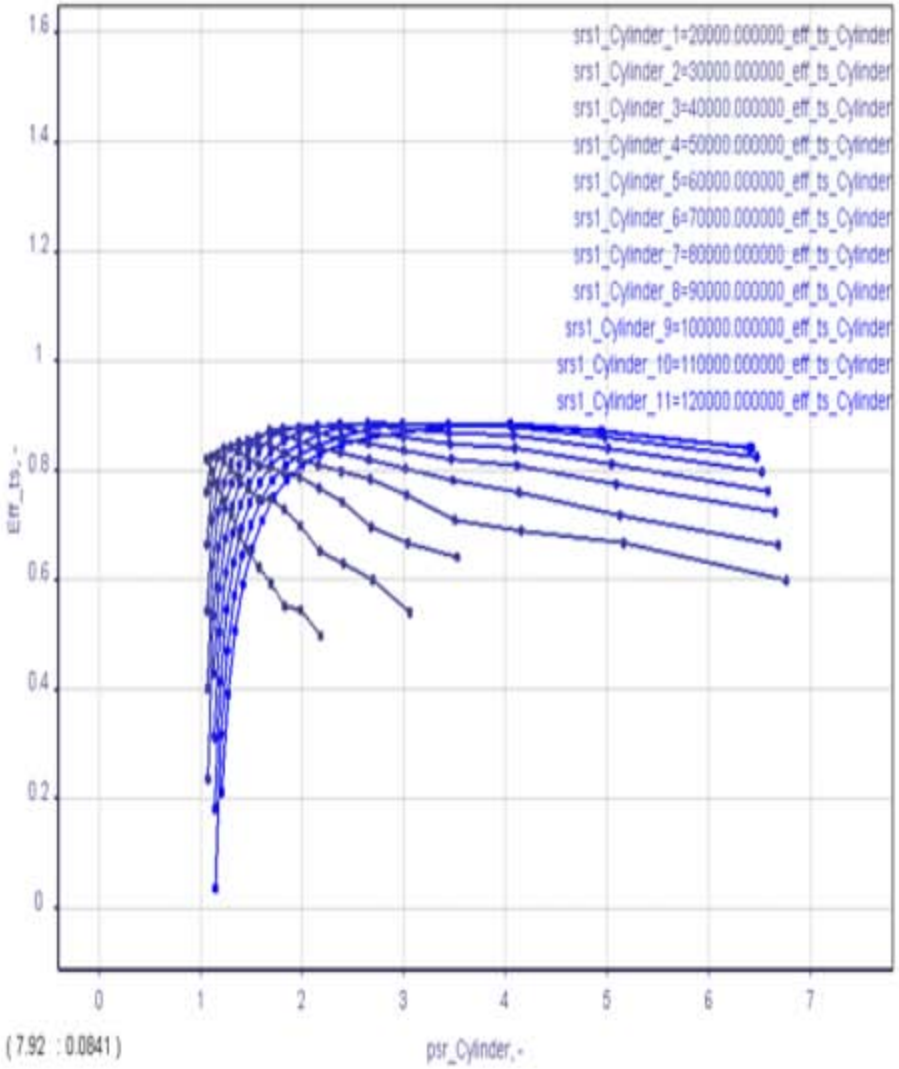
Property	Unit	Value
A1	deg	12.170065
B1	deg	83.710932
C1	m/s	653.292958
W1	m/s	138.557092
c1r	m/s	137.723238
c1u	m/s	638.610378
A2	deg	40.568241
B2	deg	17.295901
C2	m/s	203.723231
W2	m/s	445.641247
c2z	m/s	132.492067
c2u	m/s	-154.754667



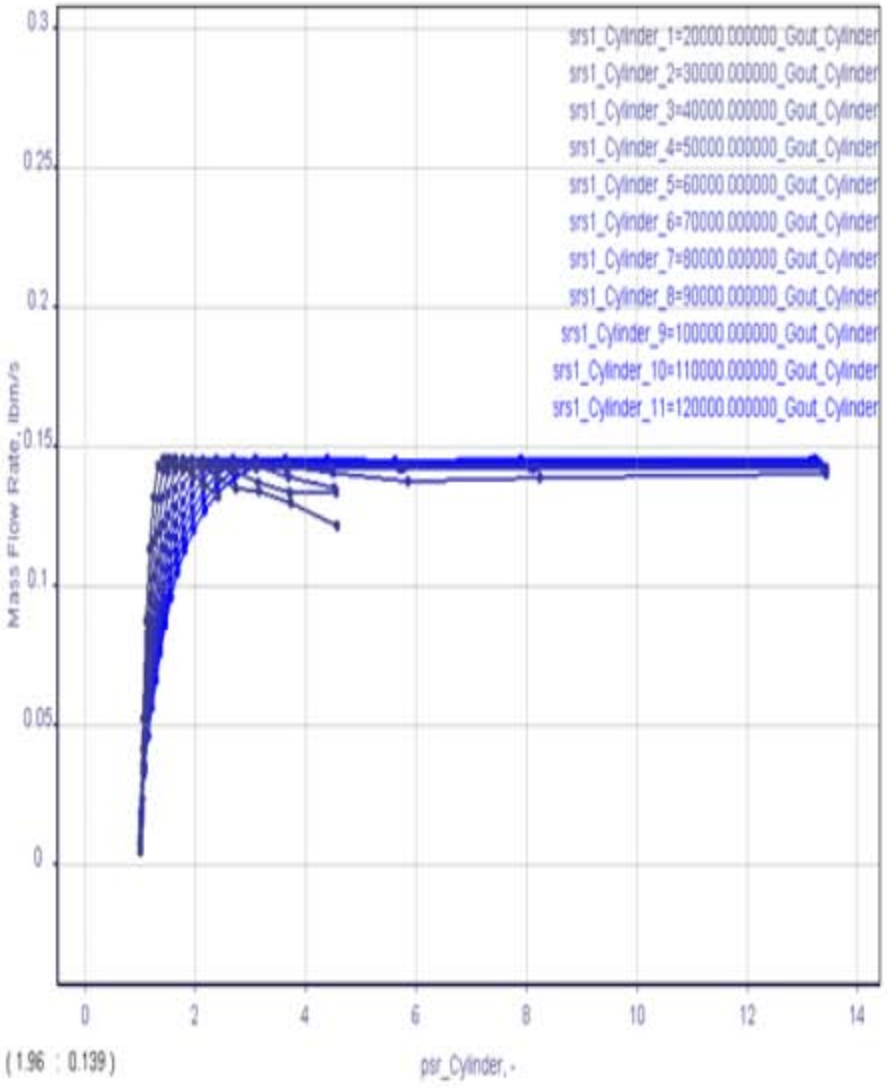


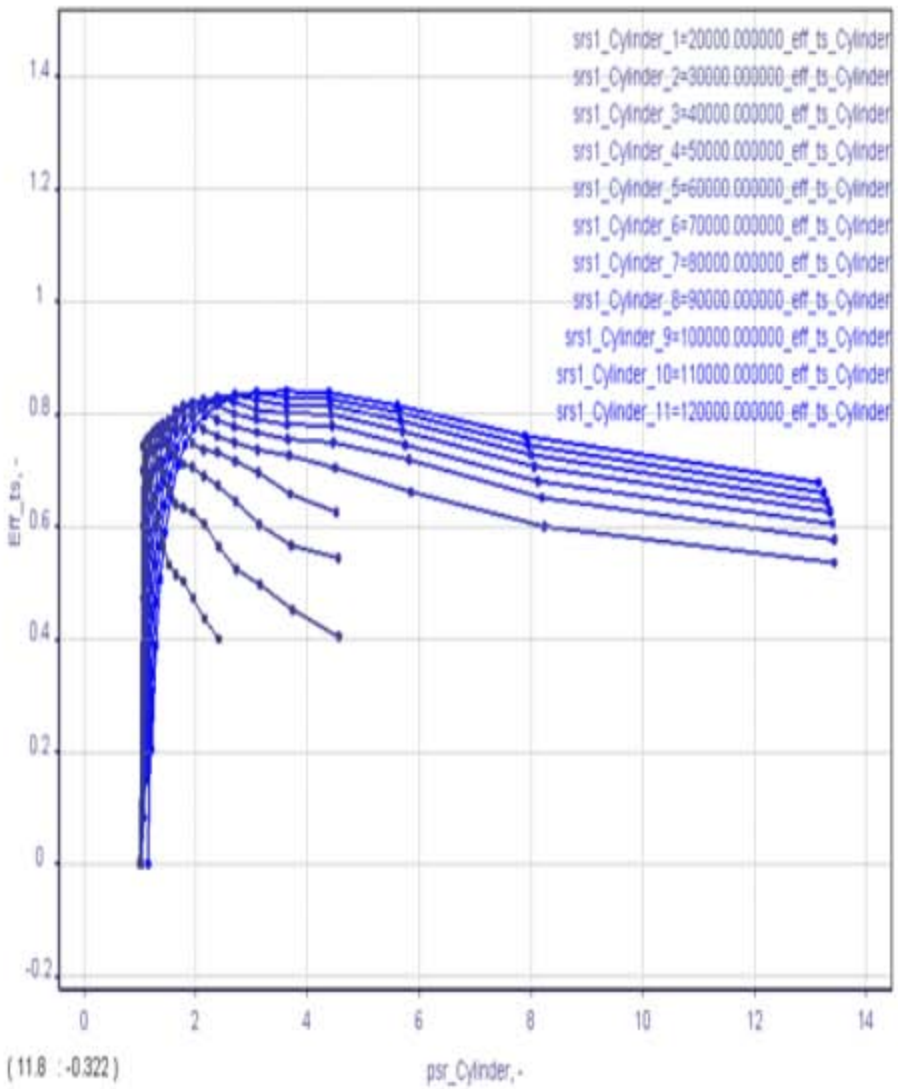
3-Wheel High Pressure Ratio Turbocharger – Turbine Total-to-Static Pressure Ratio vs Mass Flow Rate and Efficiency (ts) @ Pin = 1 bar & Tin = 2385 degR:



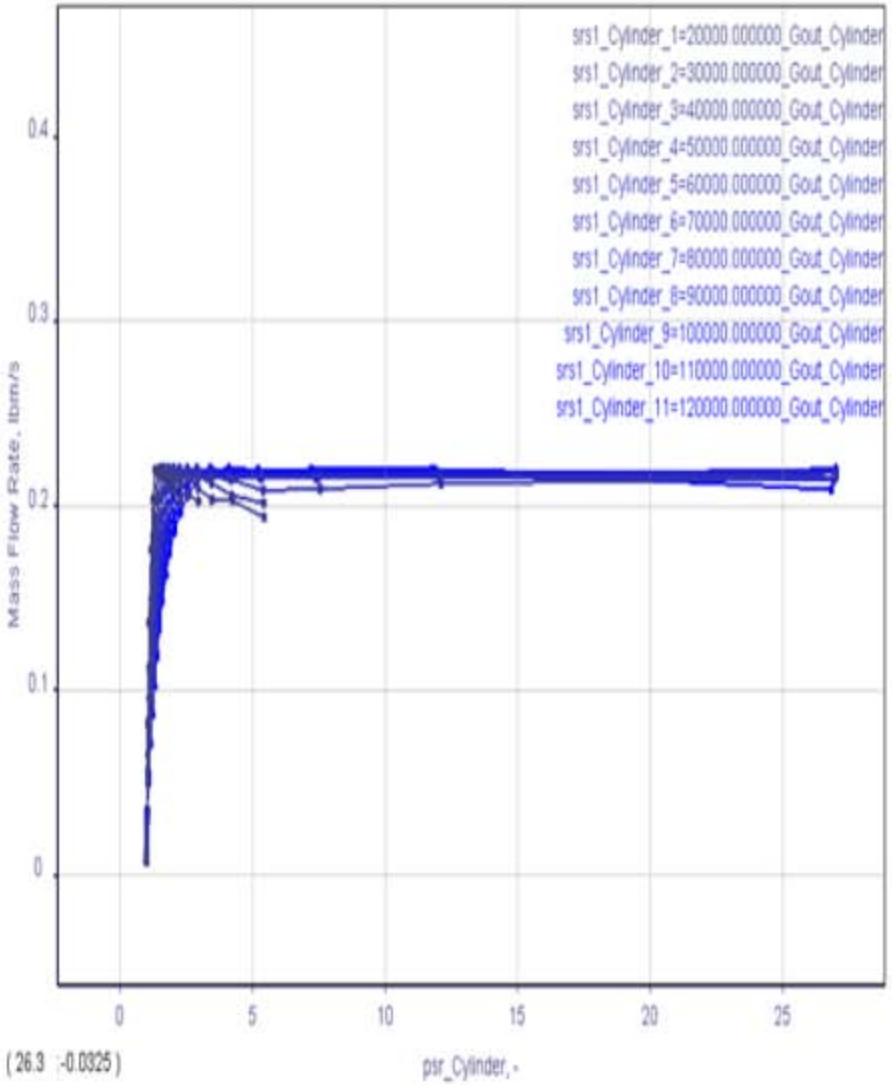


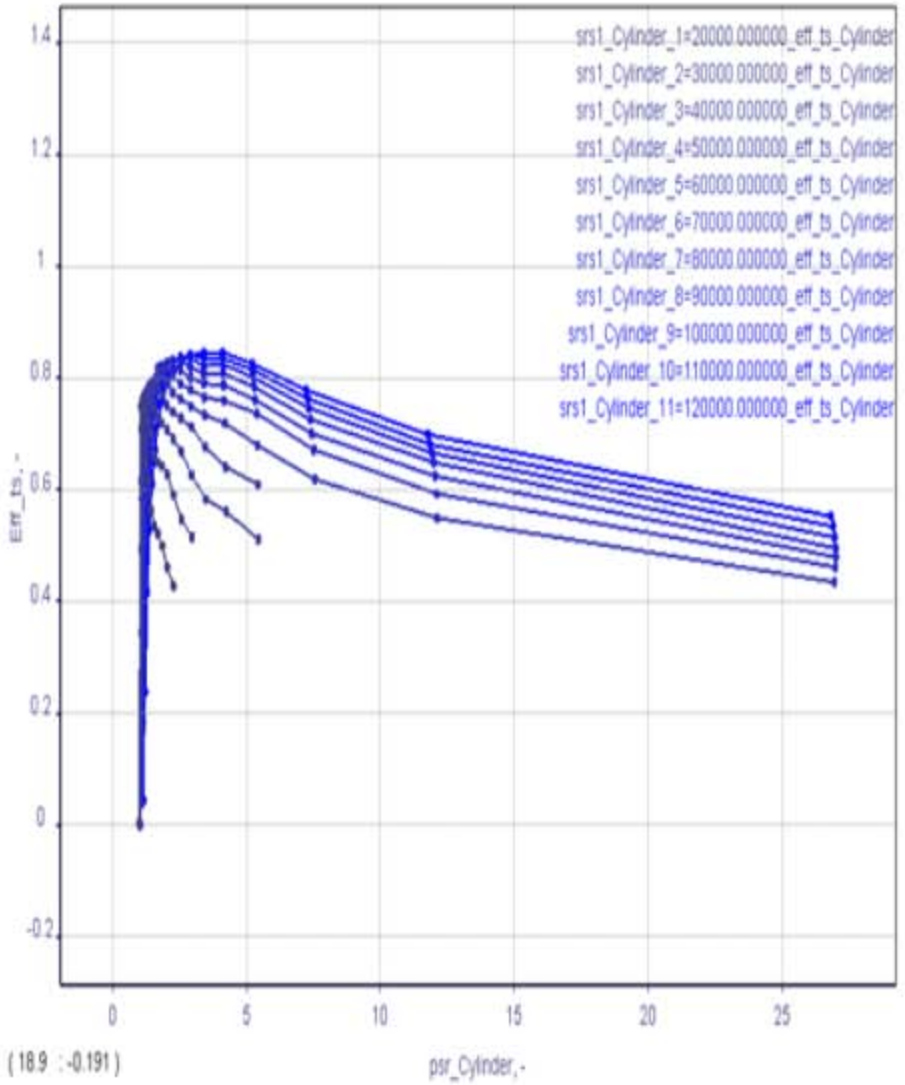
3-Wheel High Pressure Ratio Turbocharger – Turbine Total-to-Static Pressure Ratio vs Mass Flow Rate and Efficiency (ts) @ Pin = 2 bar & Tin = 2385 degR:



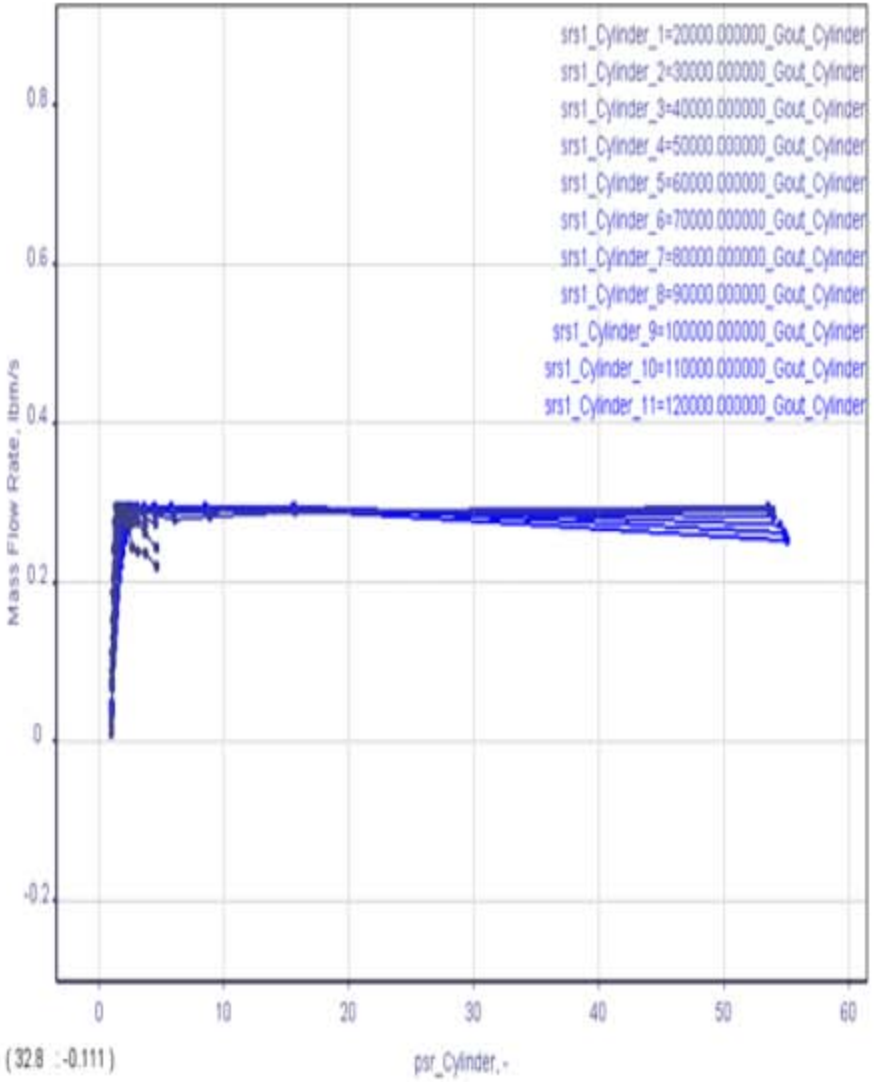


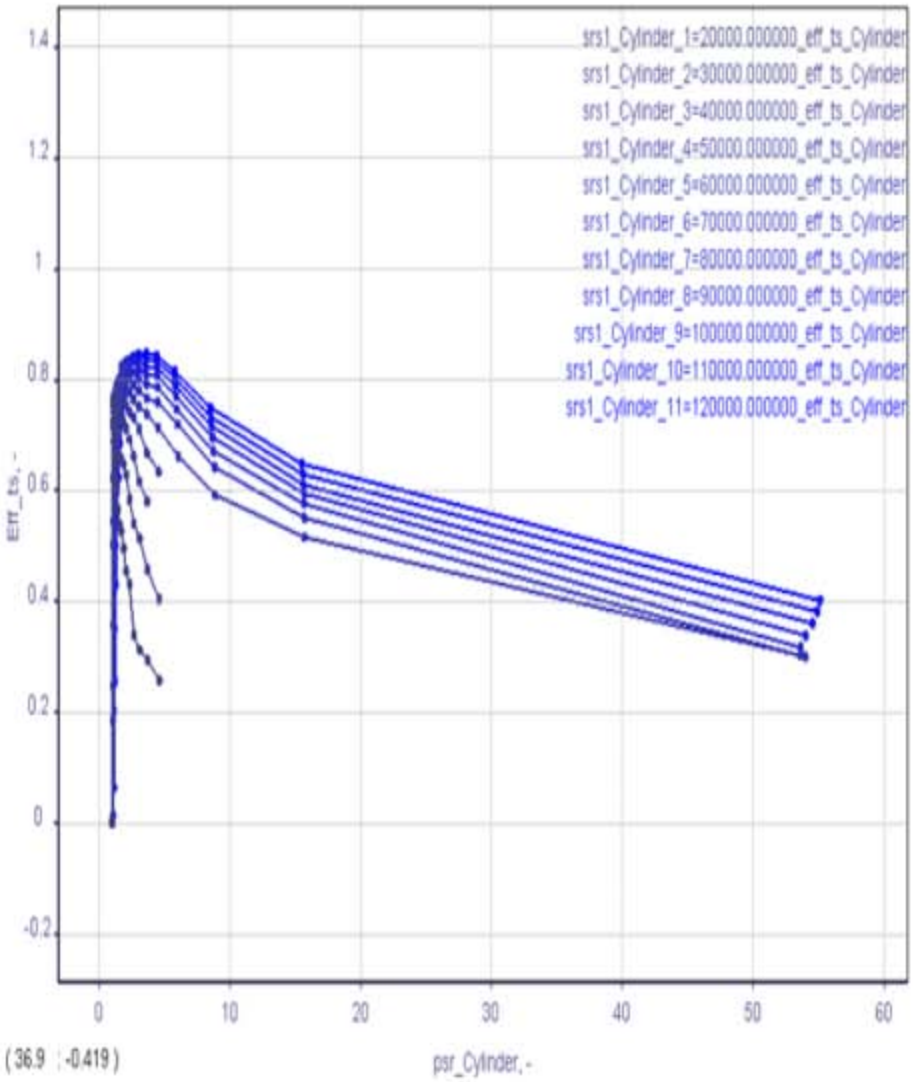
3-Wheel High Pressure Ratio Turbocharger – Turbine Total-to-Static Pressure Ratio vs Mass Flow Rate and Efficiency (ts) @ Pin = 3 bar & Tin = 2385 degR:





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: