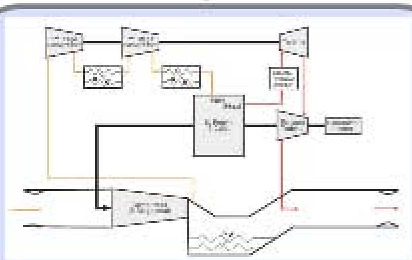
High Altitude Low Cost Configurable Jet Engine Trade Study

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

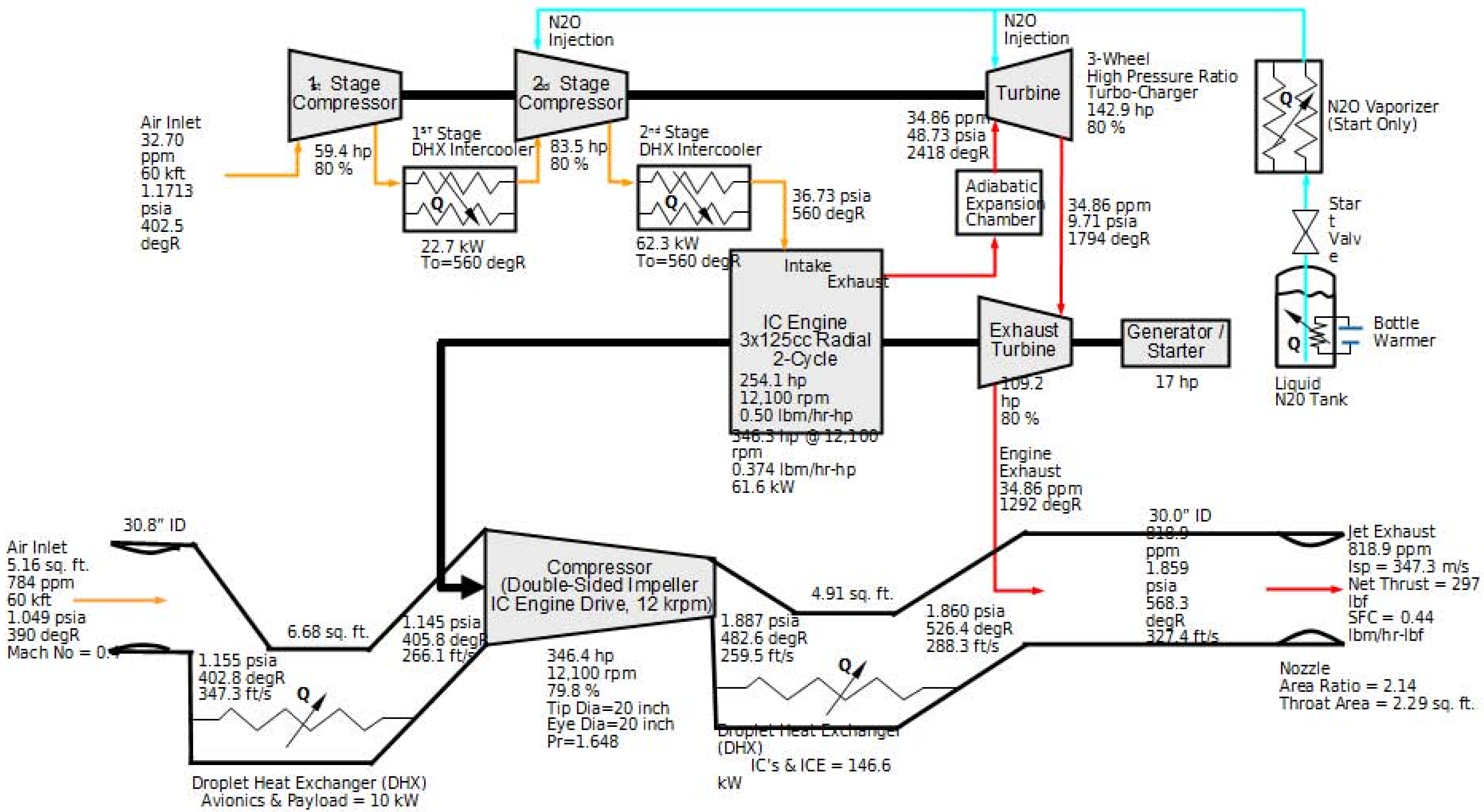
- *Qualitative & Quantitative Description of Relationships Between Major Trade Parameters and Air Vehicle Performance*
- *Parameter Ranges for Optimal Performance & Endurance*
- *Identification of Component Sizing to Maximize Performance and Flight Envelope*

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

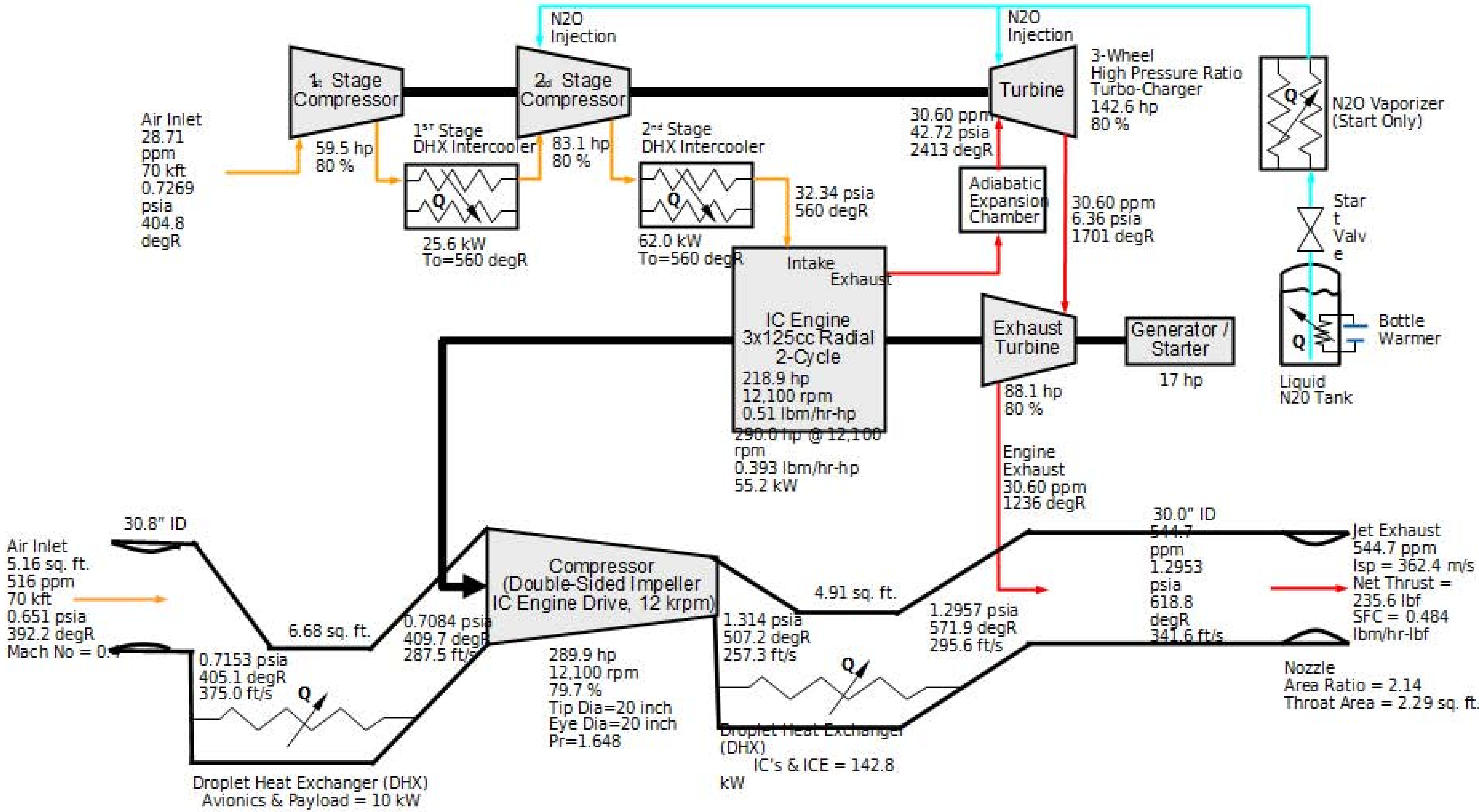
Overview:

- A Low Cost Configurable Jet Engine w/ Integrated Propulsion & Thermal Systems is Proposed for Disposable and/or High Altitude Missions to 100 kft w/ Inherent Low Observable Characteristics
- Mission Configurable and High Altitude Capabilities are Achieved via a Unique Combination of Three Elements:
  - 3-Wheel High Pressure Ratio 2-Stage Turbocharger (Pr_max per stage >10)
  - ICE Shaft-Driven Primary Double-Sided Radial Impeller Compressor (1.25 < Pr < 11.5)
  - 2-Stroke ICE w/ Adiabatic Expansion Chamber & Compound Power Recovery Turbine
- Inherent Low Observable Characteristics are Achieved via Radial Impellers Buried Behind Inline Heat Exchangers and Low Plume Temperatures as a Consequence of High Bypass Operation
- Initial Point Design Yields 150 lbf Net Thrust @ Mach 0.4 & 60 kft w/ SFC of 0.69 lbm/hr-lbf and Propulsion Weight < 150 lbm. Initial Review Shows SFC of 0.5 to 0.6 lbm/hr-lbf is Achievable at Identical Conditions
- Sub-System Components are Cross-Compatible w/ Propeller and Distributed Propulsion Systems, Yielding Flexibility and Lower Overall Development Costs

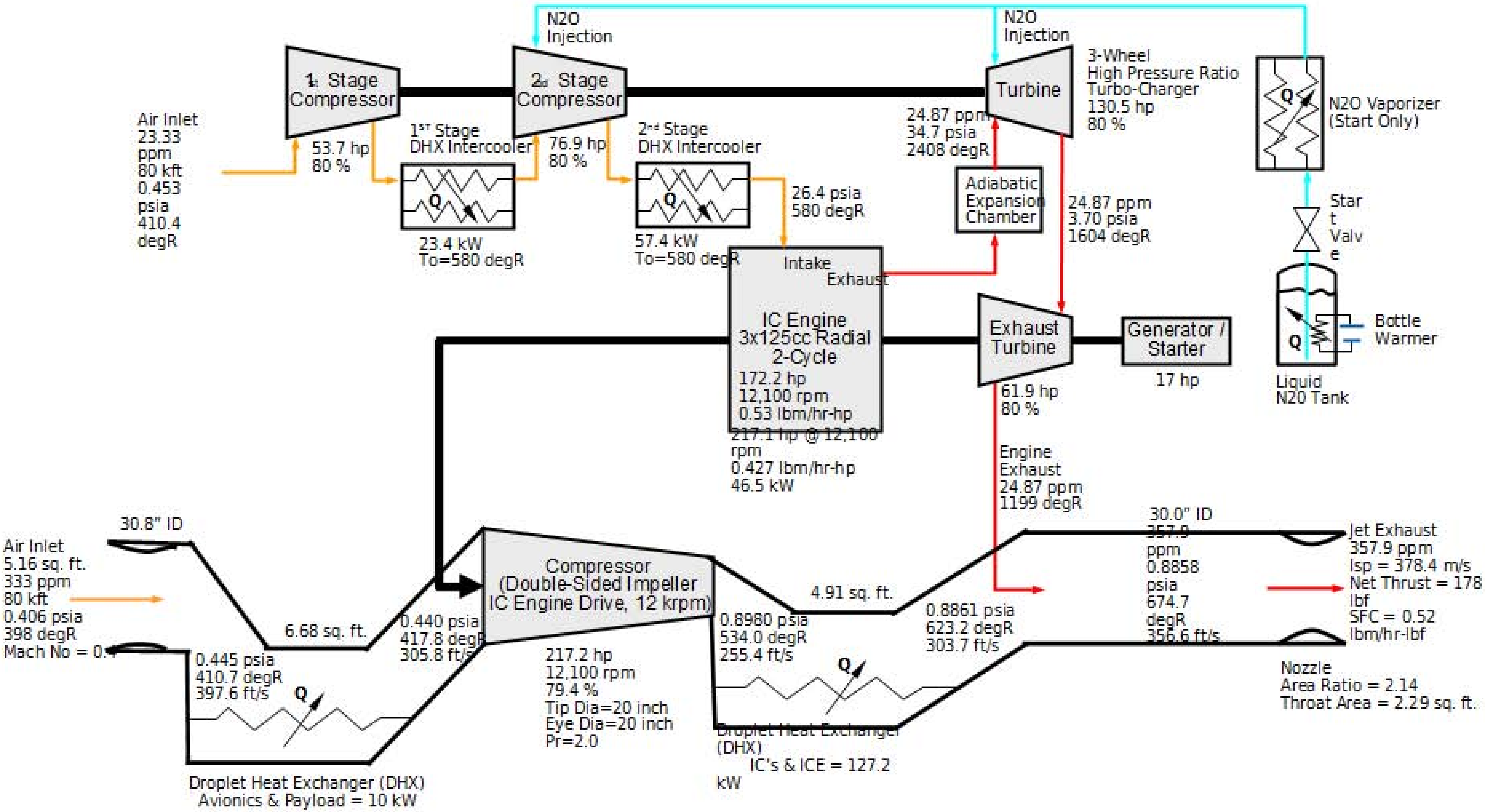
60 Kft & Mach 0.4: Net Thrust = 297 lbf & SFC = 0.44 lbm/hr-lbf



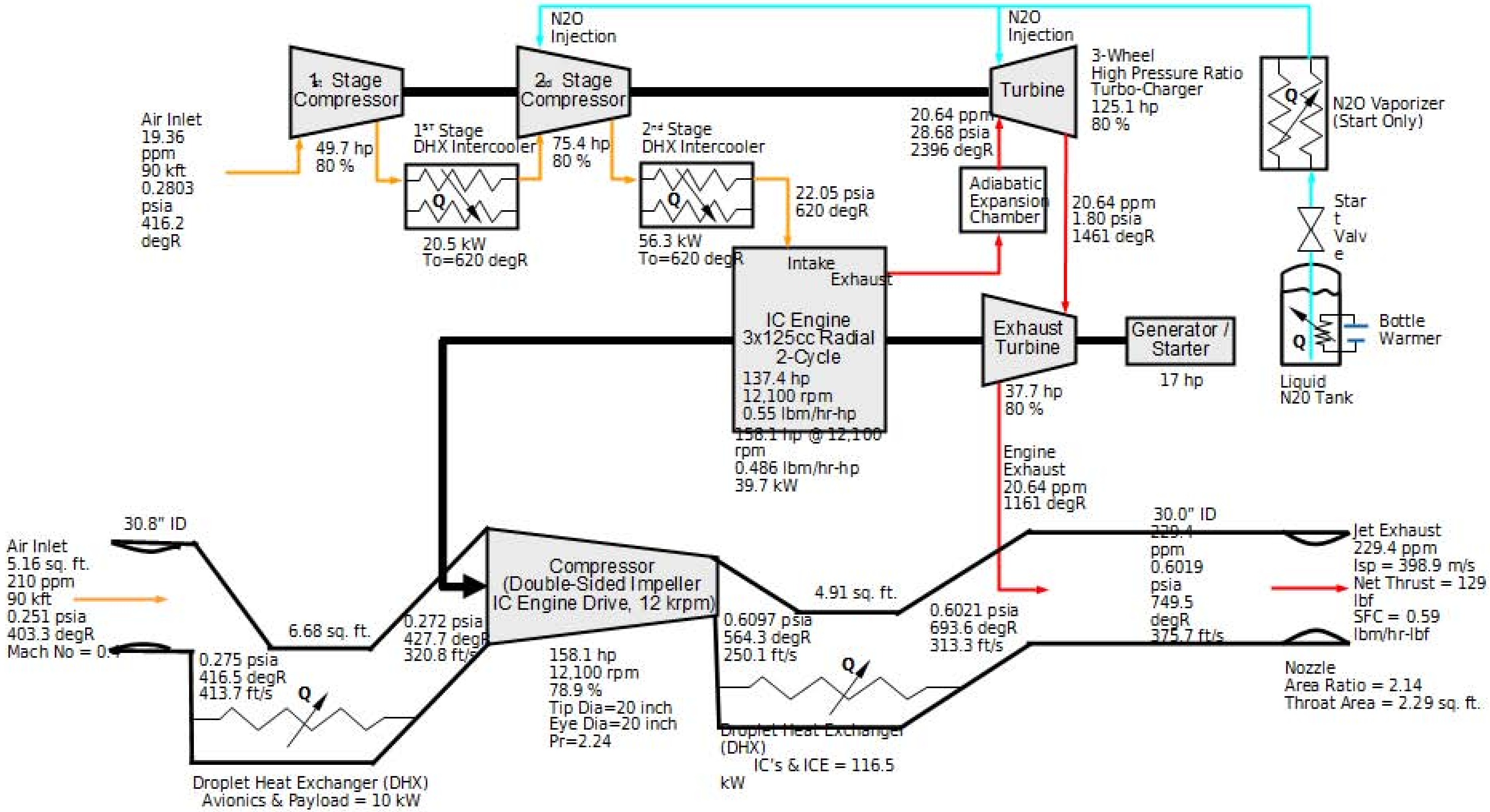
70 Kft & Mach 0.4: Net Thrust = 236 lbf & SFC = 0.48 lbm/hr-lbf



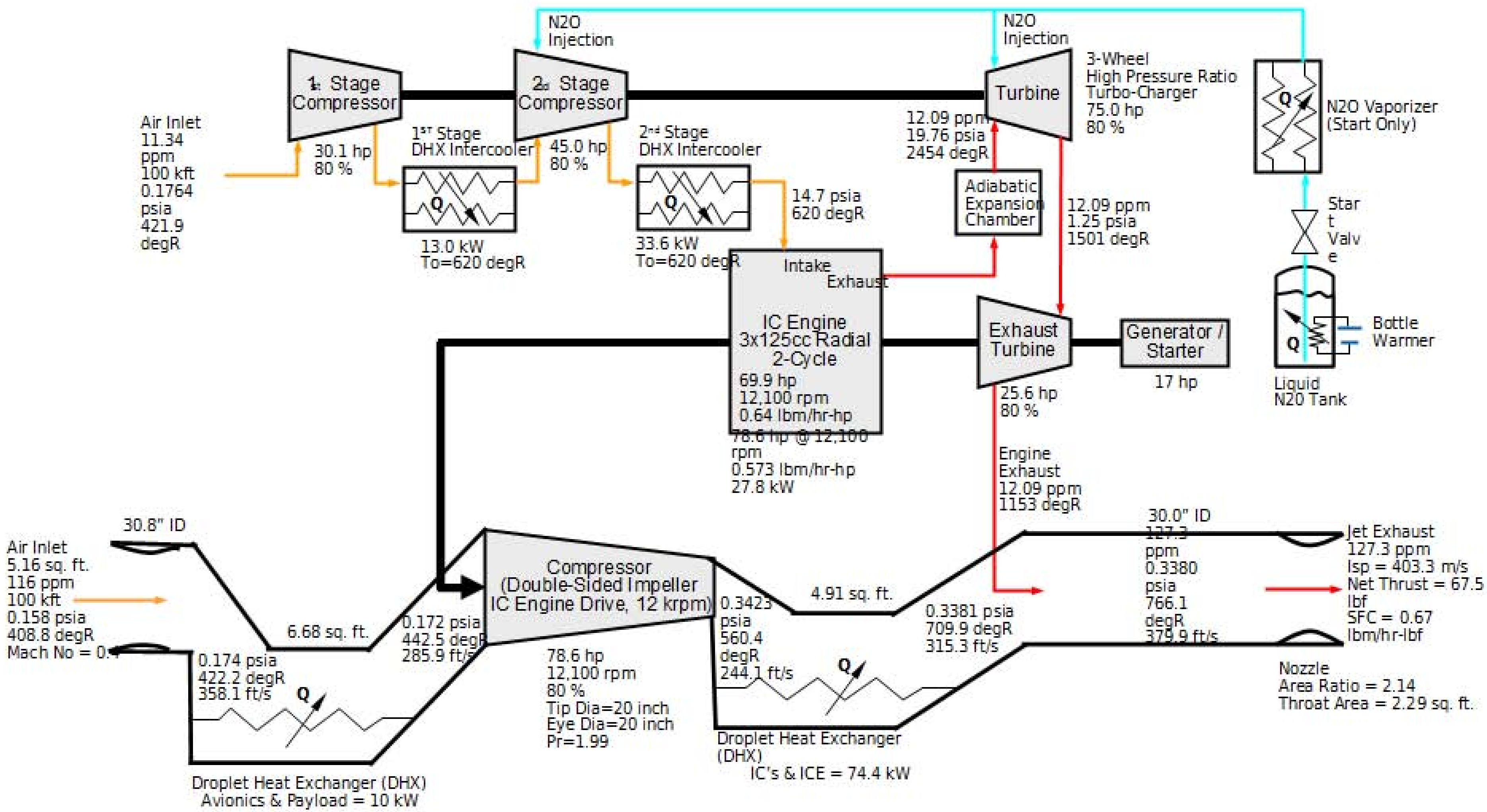
80 Kft & Mach 0.4: Net Thrust = 178 lbf & SFC = 0.52 lbm/hr-lbf



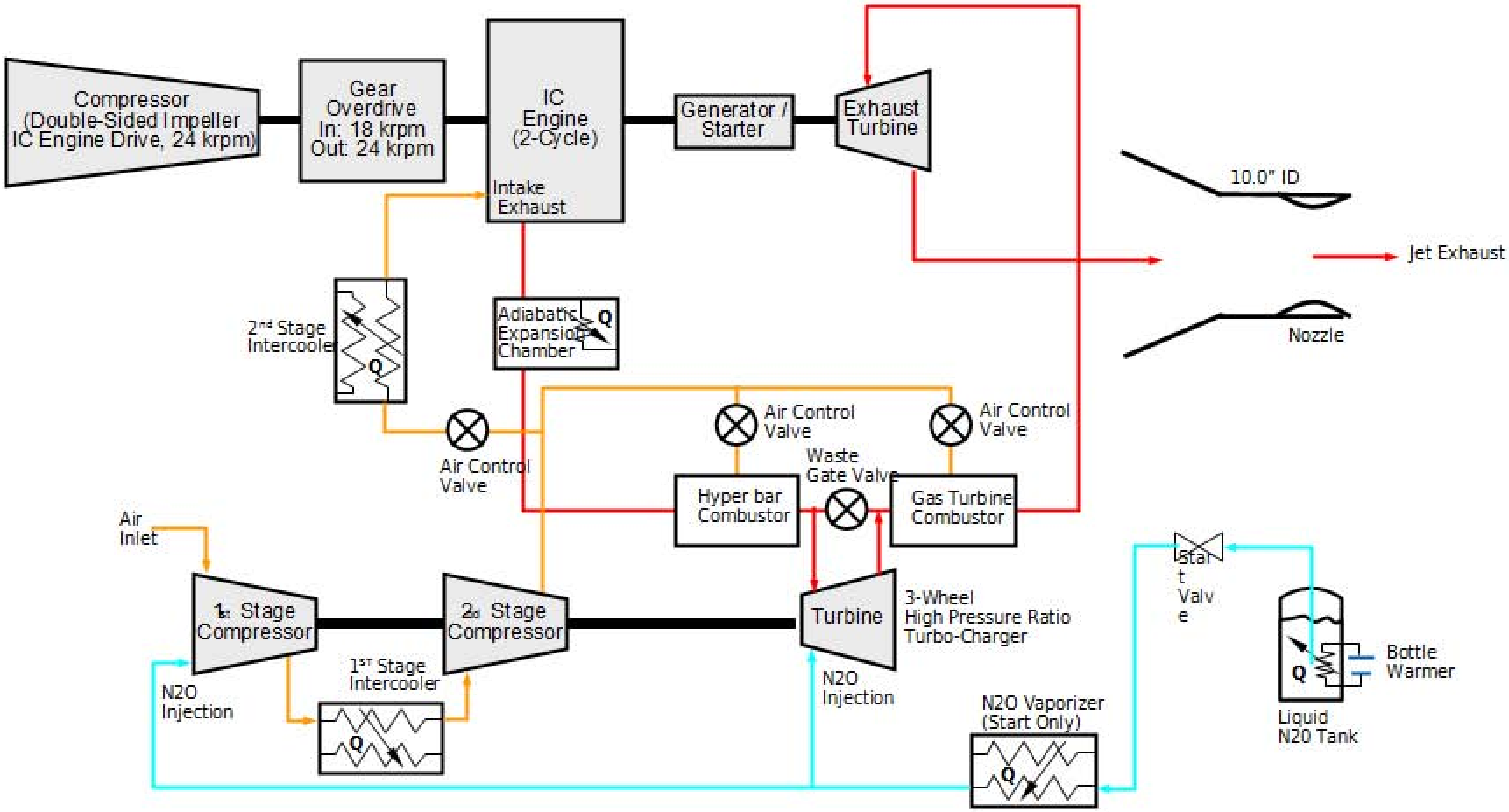
90 Kft & Mach 0.4: Net Thrust = 129 lbf & SFC = 0.59 lbm/hr-lbf



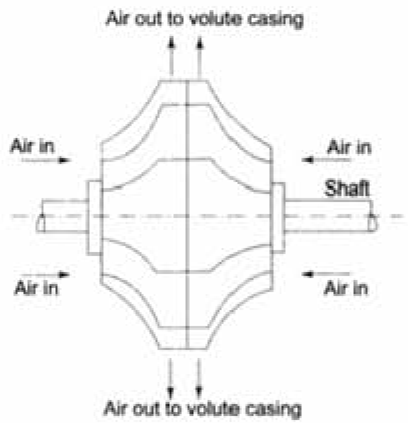
100 Kft & Mach 0.4: Net Thrust = 67.5 lbf & SFC = 0.67 lbm/hr-lbf

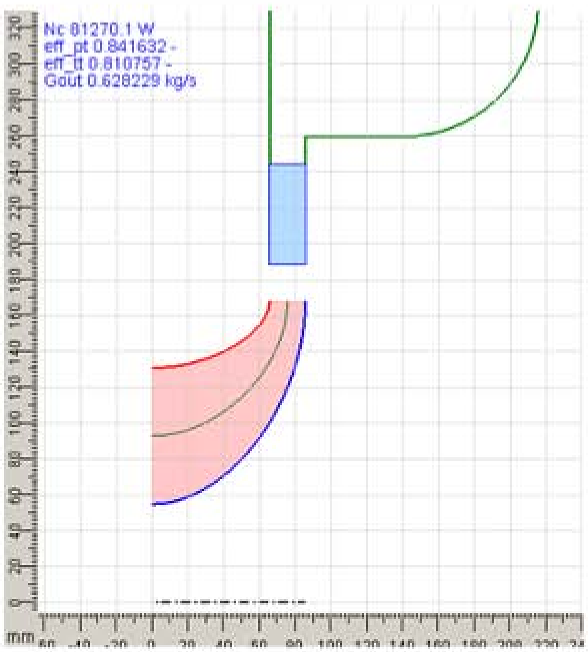


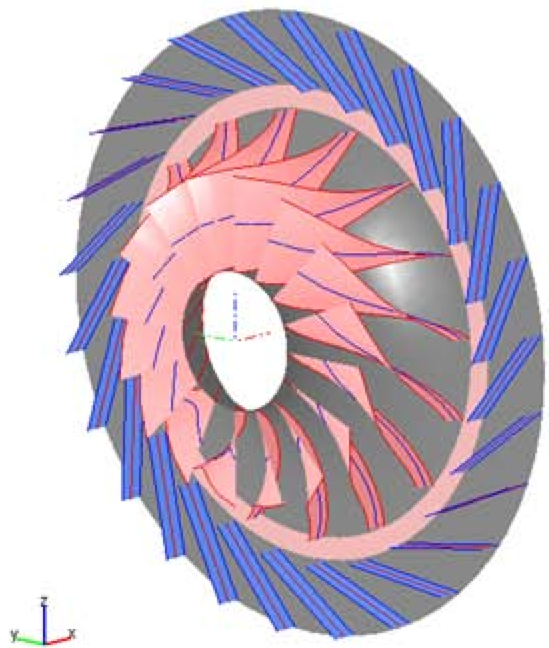
Propulsion System Schematic Overview

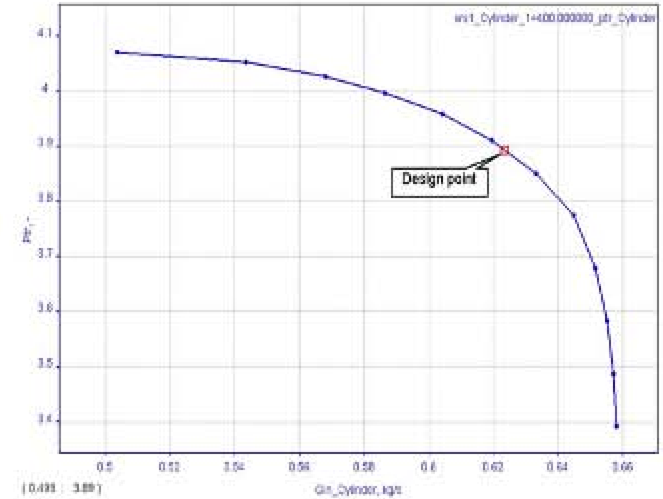


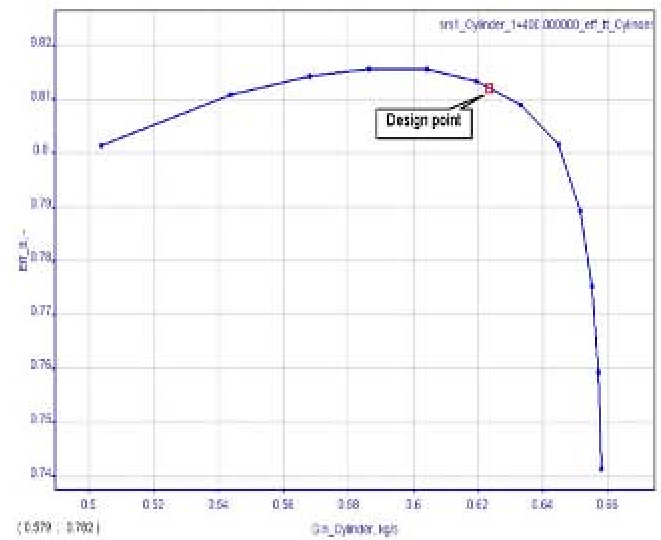
Double-Sided Shaft-Driven Compressor
(Performance data using AxStream software from SoftInWay Inc.):



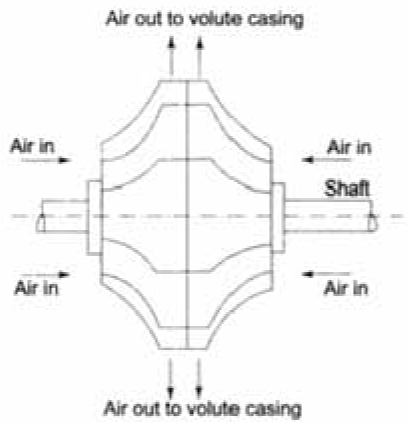


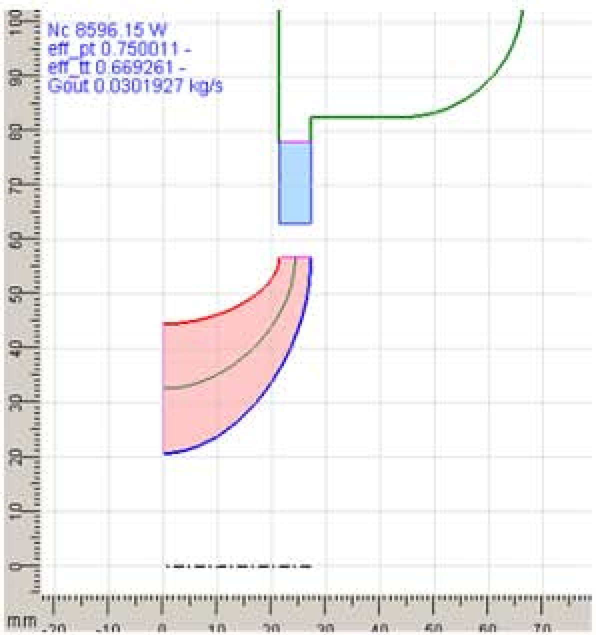


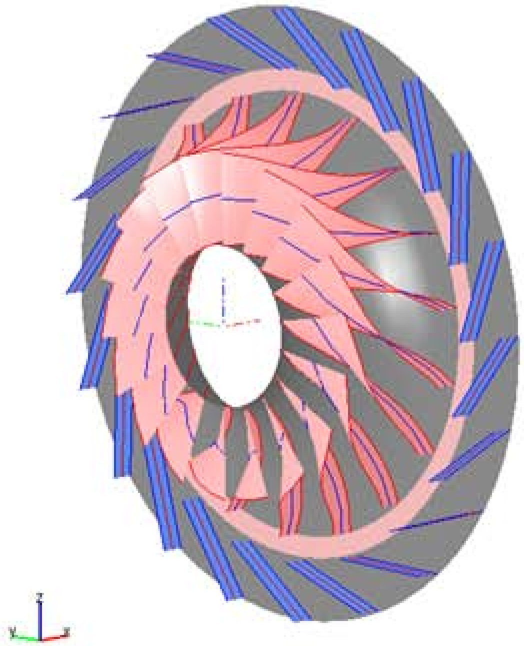


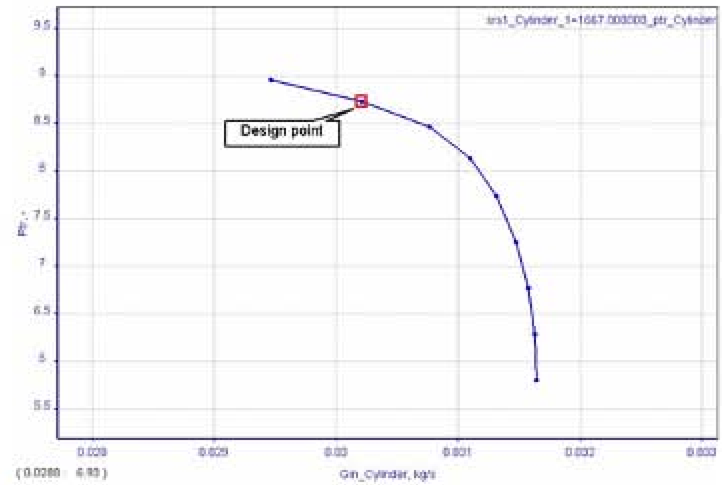


3-Wheel High Pressure Ratio Turbocharger – 1st Stage Double-Sided Compressor (Performance data using AxStream software from SoftInWay Inc.):



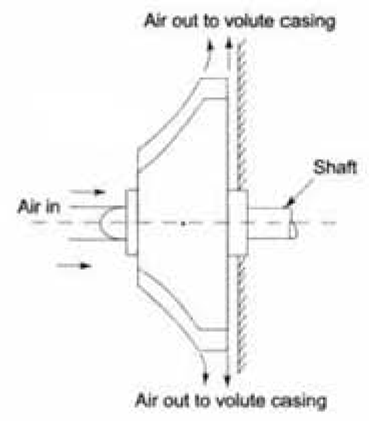


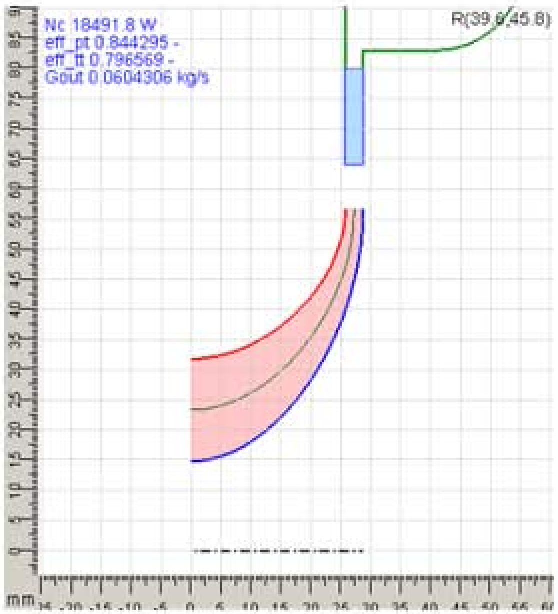


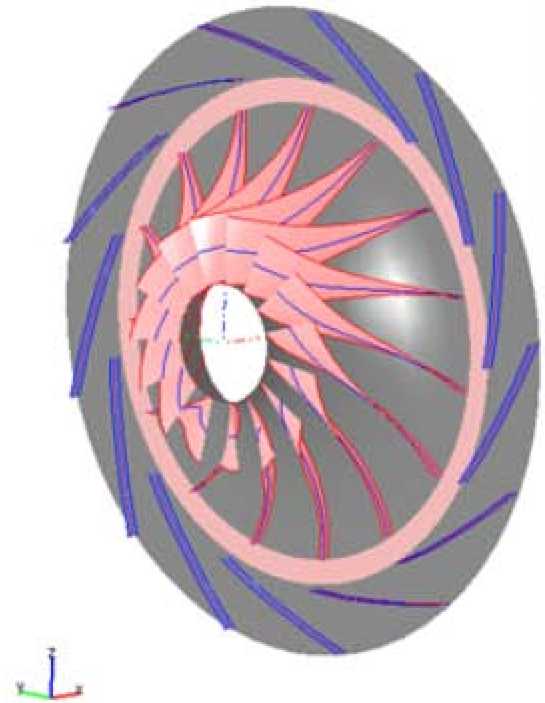


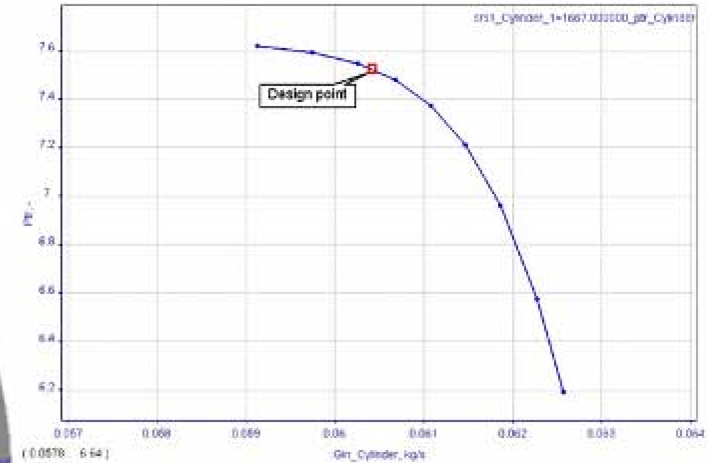
	Property	Unit	Value
Pt_in	total pressure at inlet	Pa	2758.000000
It_in	total enthalpy at inlet	J/kg	222044.725000
Tt_in	total temperature at inlet	°C	-52.100000
Pst_ou	stat. pressure at outlet	Pa	23442.795854
Pt_out	total pressure at outlet	Pa	24119.418576
Gin	mass flow rate at inlet	kg/s	0.030193
	inlet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



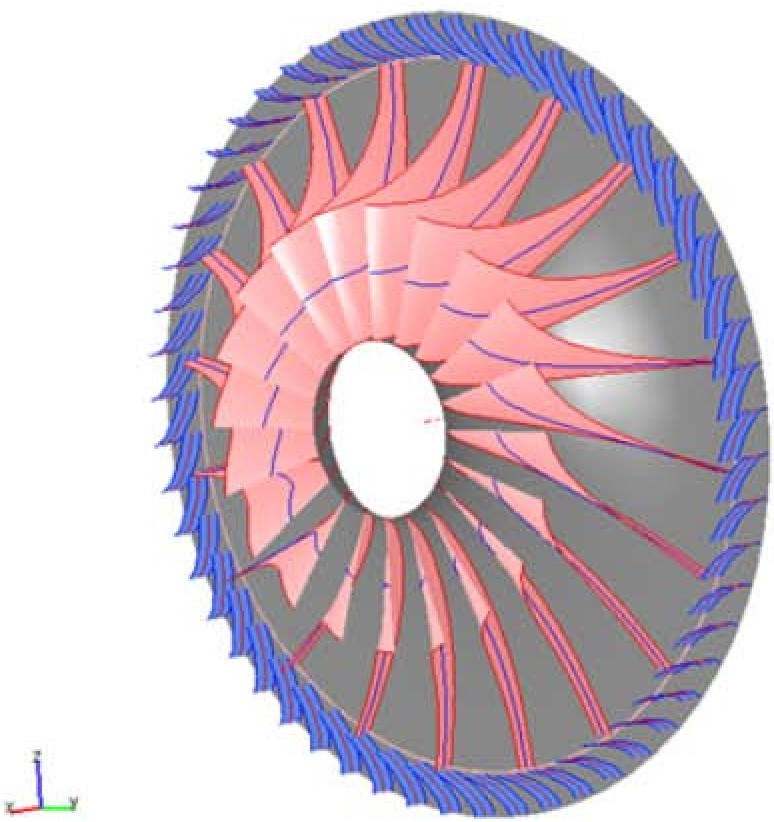




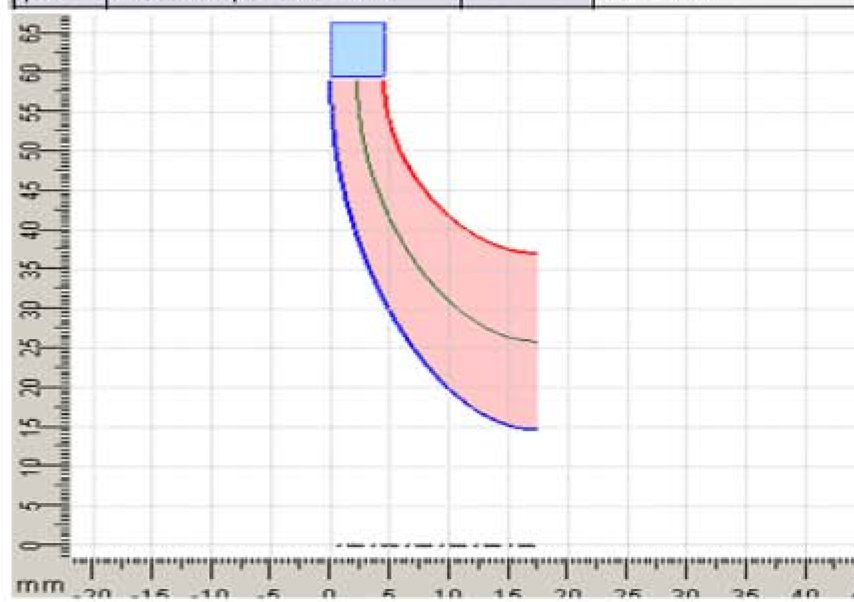


	Property	Unit	Value
Pt_in	total pressure at inlet	Pa	20670.000000
It_in	total enthalpy at inlet	J/kg	312550.175000
Tt_in	total temperature at inlet	°C	38.000000
Pst_o	stat. pressure at outlet	Pa	152979.999723
Pt_out	total pressure at outlet	Pa	155491.087730
Gin	mass flow rate at inlet	kg/s	0.060431
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



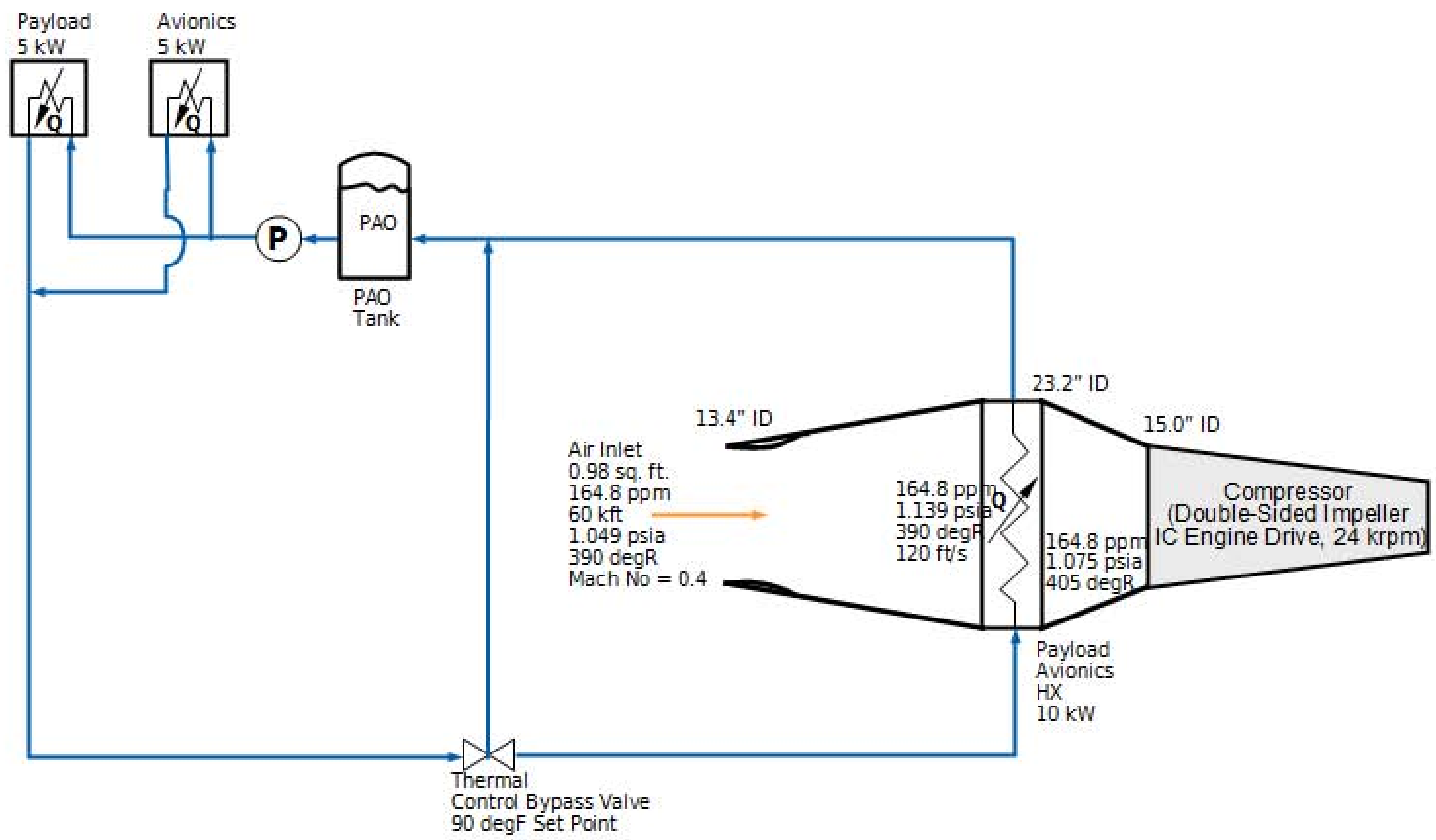
	Property	Unit	Value
Pt_in	total pressure at inlet	Pa	198569.000000
It_in	total enthalpy at inlet	J/kg	1548149.169503
Tt_in	total temperature at inlet	°C	1051.999992
Pst_ou	stat. pressure at outlet	Pa	35638.137393
Gin	mass flow rate at inlet	kg/s	0.064568
	inlet flow angle in abs frame	deg	90.000000
srs1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



Proposed Low Cost Configurable Jet Engine System Overview

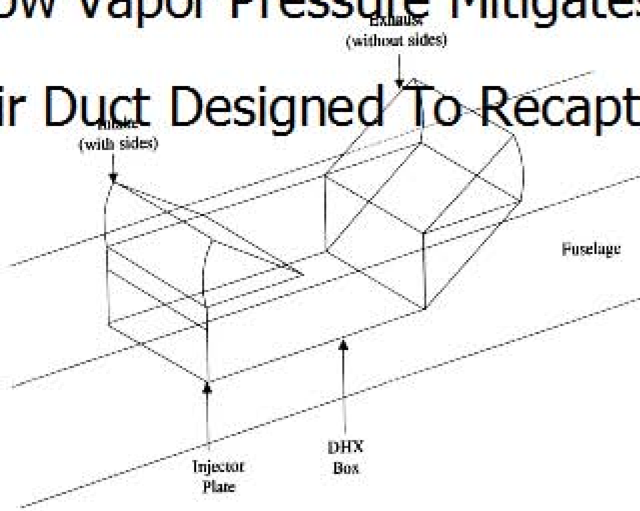
- 150 lbf Net Thrust @ 60 kft & Mach 0.4 w/ SFC of 0.69 lbm/hr-lbf (not optimized). Initial Review Shows 0.5 to 0.6 lbm/hr-lbf Achievable.
- Turbo-Shaft Configuration with IC Engine Driven Compressor Stage
- Double-Sided Radial Impeller Shaft-Driven Compressor, Pr of 3.87 @ 24 krpm
- 3-Wheel/2-Stage 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
- Modified COTS Rotax FR125 Max 125cc Liquid Cooled 2-Stroke Cycle Engine (Stock 28 bhp @ 11,500 RPM, Redline @ 13,500 RPM) Compressor Drive
- Liquid Cooled Adiabatic Expansion Chamber Exhaust System Design for Turbo-Shaft/Turbocharger Operation
- Combustion Gas Power Recovery Turbine Attached To IC Engine Shaft

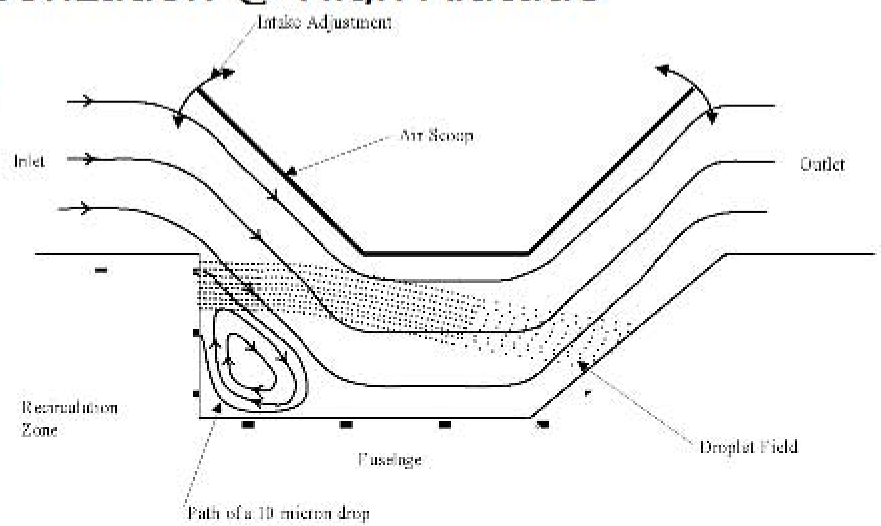
Payload/Avionics Thermal System Schematic Overview



Direct-Contact/"Droplet" Heat Exchanger (DHX) for Avionics & Payload Heat Loads:

- Injects Dow 705 Vacuum Pump Oil Directly into Ducted Air Stream
- Higher Heat Transfer Effectiveness Due to Higher Thermal Contact Area
- Negative Drag Coefficient Due to Heated Air Acceleration
- Low Vapor Pressure Mitigates Vaporization @ High Altitude
- Air Duct Designed To Recapture I

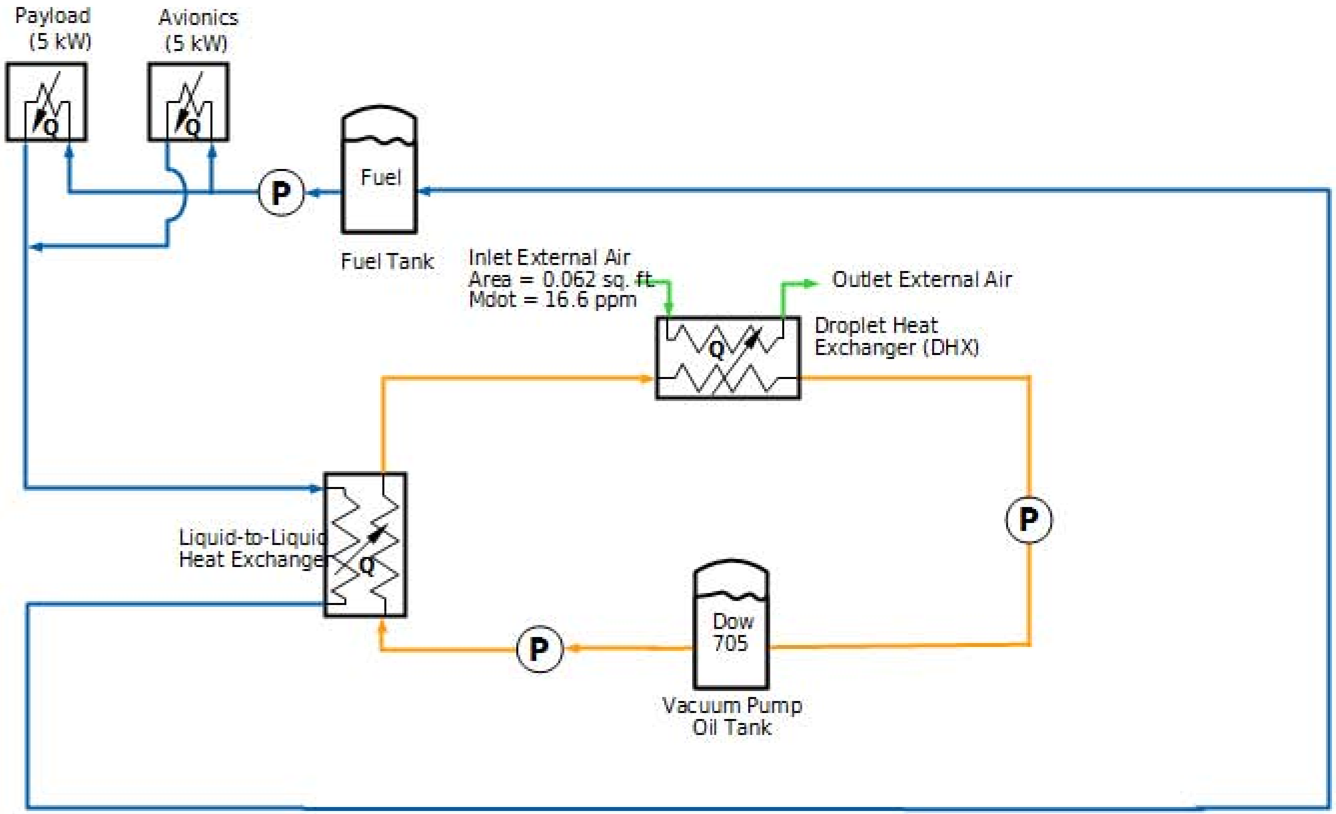




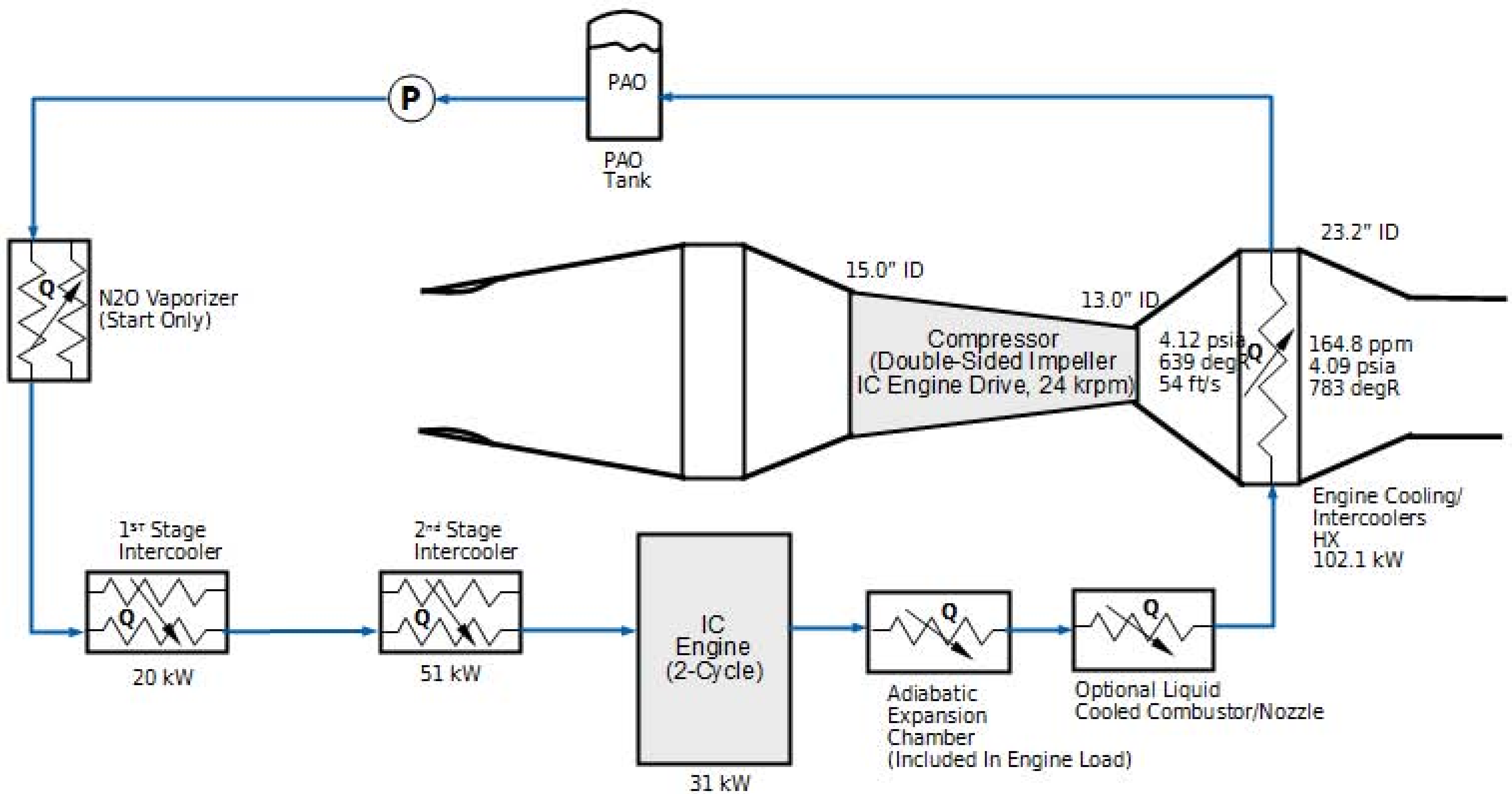
Reference: S.C. Bates, "UAV Droplet Heat Exchanger," SBIR Phase I Final Report, NASA Contract # NAS4-97018, Sept. (1997).

Direct-Contact/"Droplet" Heat Exchanger (DHX)

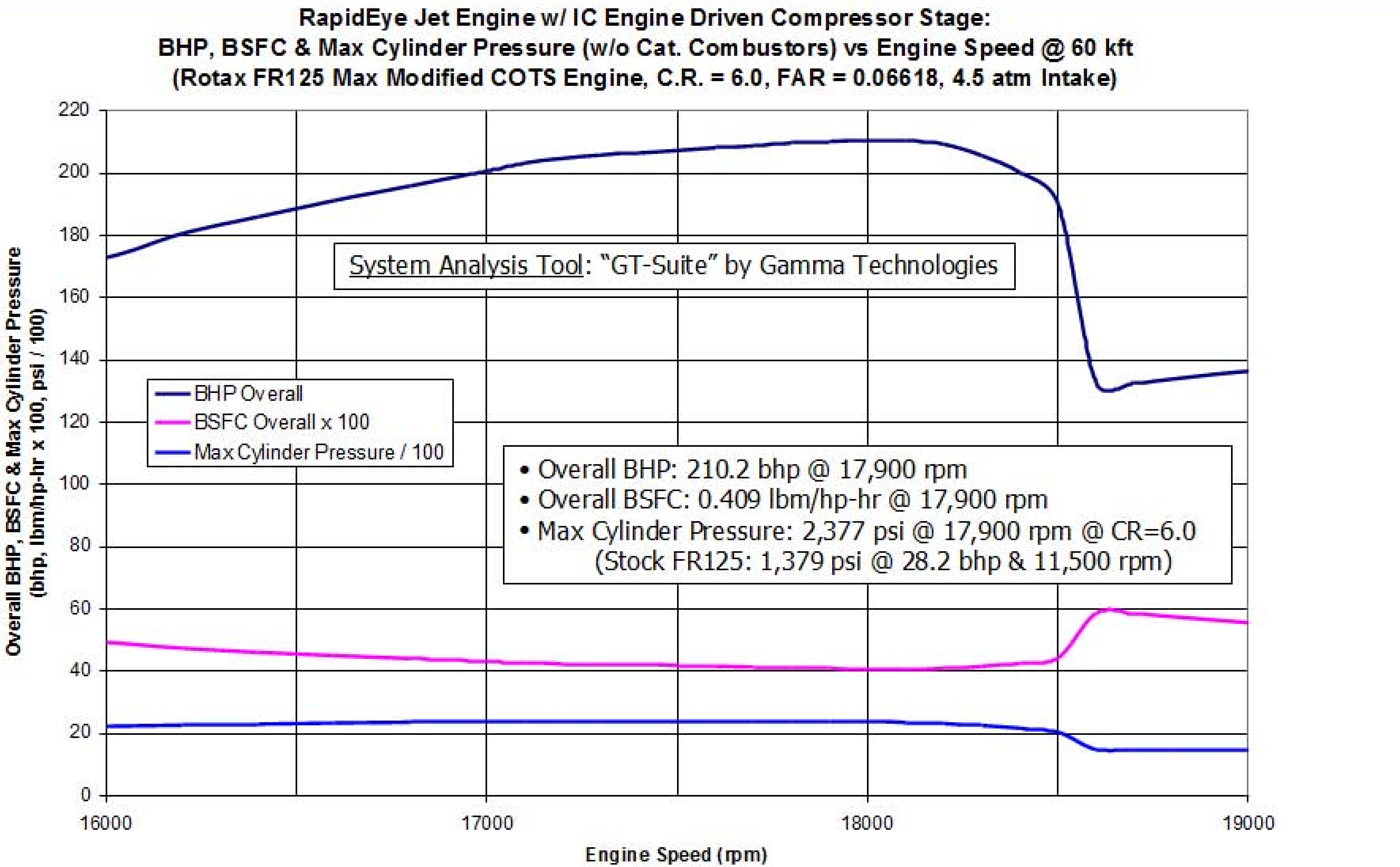
System Schematic Overview:



Propulsion/Thermal System Schematic Overview



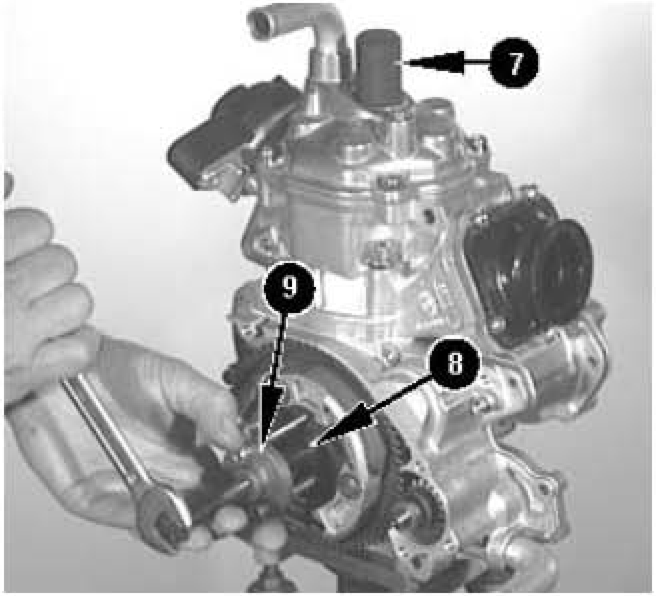
Propulsion System Analysis

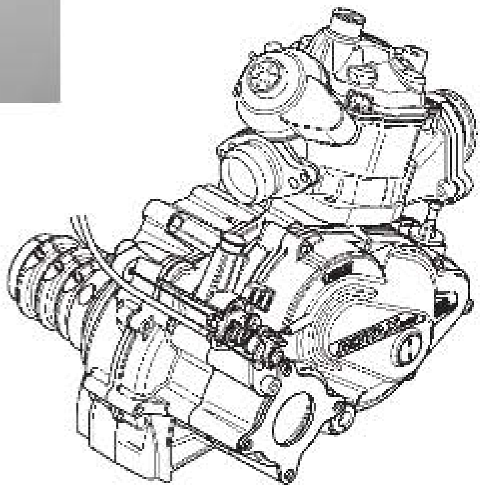


Rotax FR125 Max Modified COTS IC Engine

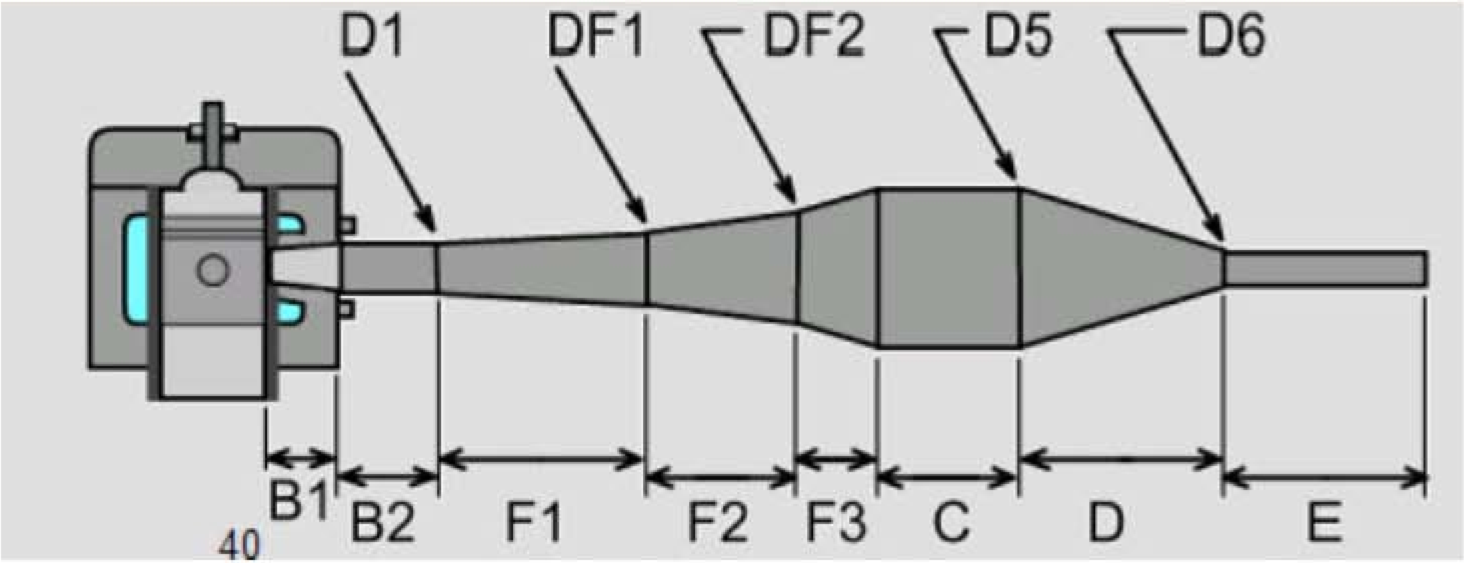
- 210.2 bhp Overall @ 17,900 rpm & Overall BSFC of 0.409 lbm/hr-hp
- 156 bhp @ 17,900 rpm & BSFC of 0.55 lbm/hr-hp IC Engine Only
- 54.2 hp Power Recovery via Combustion Gas Power Recovery Turbine Attached To IC Engine Shaft
- IC Engine Piston, Con Rod & Crankshaft Redesigned for Higher Power Output 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





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