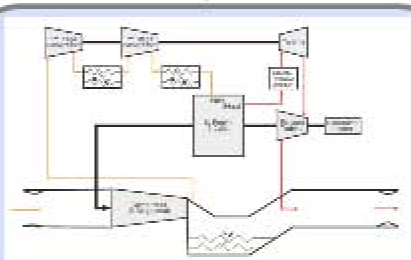
High Altitude Low Cost Configurable Jet Engine Trade Study

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

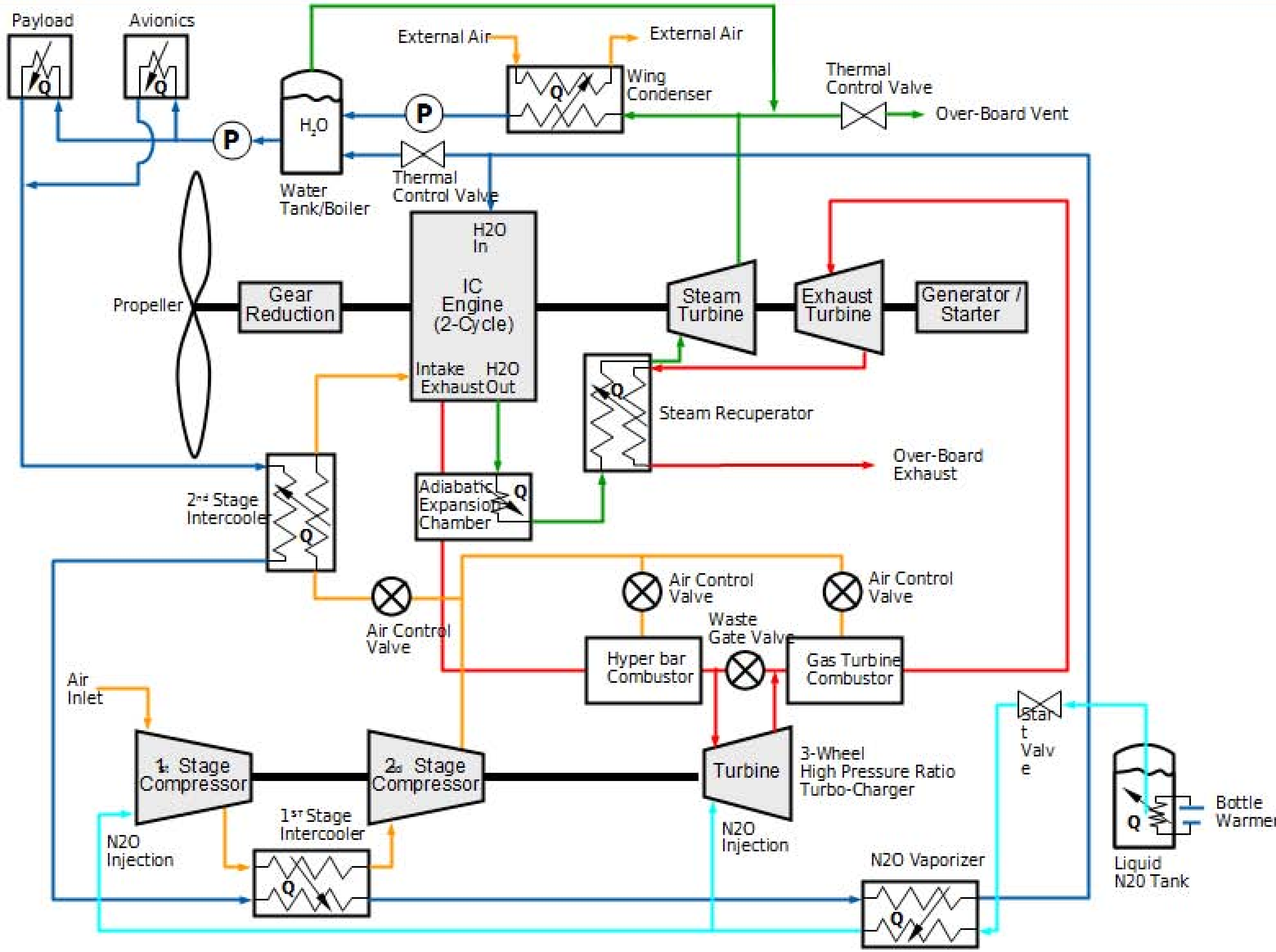
- *Qualitative & Quantitative Description of Relationships Between Major Trade Parameters and Air Vehicle Performance*
- *Parameter Ranges for Optimal Performance & Endurance*
- *Identification of Component Sizing to Maximize Performance and Flight Envelope*

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

Propulsion System Overview

- Turbo-Prop Configuration with IC Engine Power Assist Combustor
- 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 Kart Engine (Stock 28 bhp @ 11,500 RPM, Redline @ 13,500 RPM) Power Assist Combustor
- Liquid Cooled Adiabatic Expansion Chamber Exhaust System Design for Turbo-Prop/Turbocharger Operation and Enthalpy Recovery via Boiling Heat Transfer
- Combustion Gas Power Recovery Turbine Attached To IC Engine Shaft
- Steam Power Recovery Turbine Attached To IC Engine Shaft
- Exhaust Stream Recuperator (Post Combustion Gas Turbine) for Enthalpy Recovery and Improved Overall Brake Specific Fuel Consumption

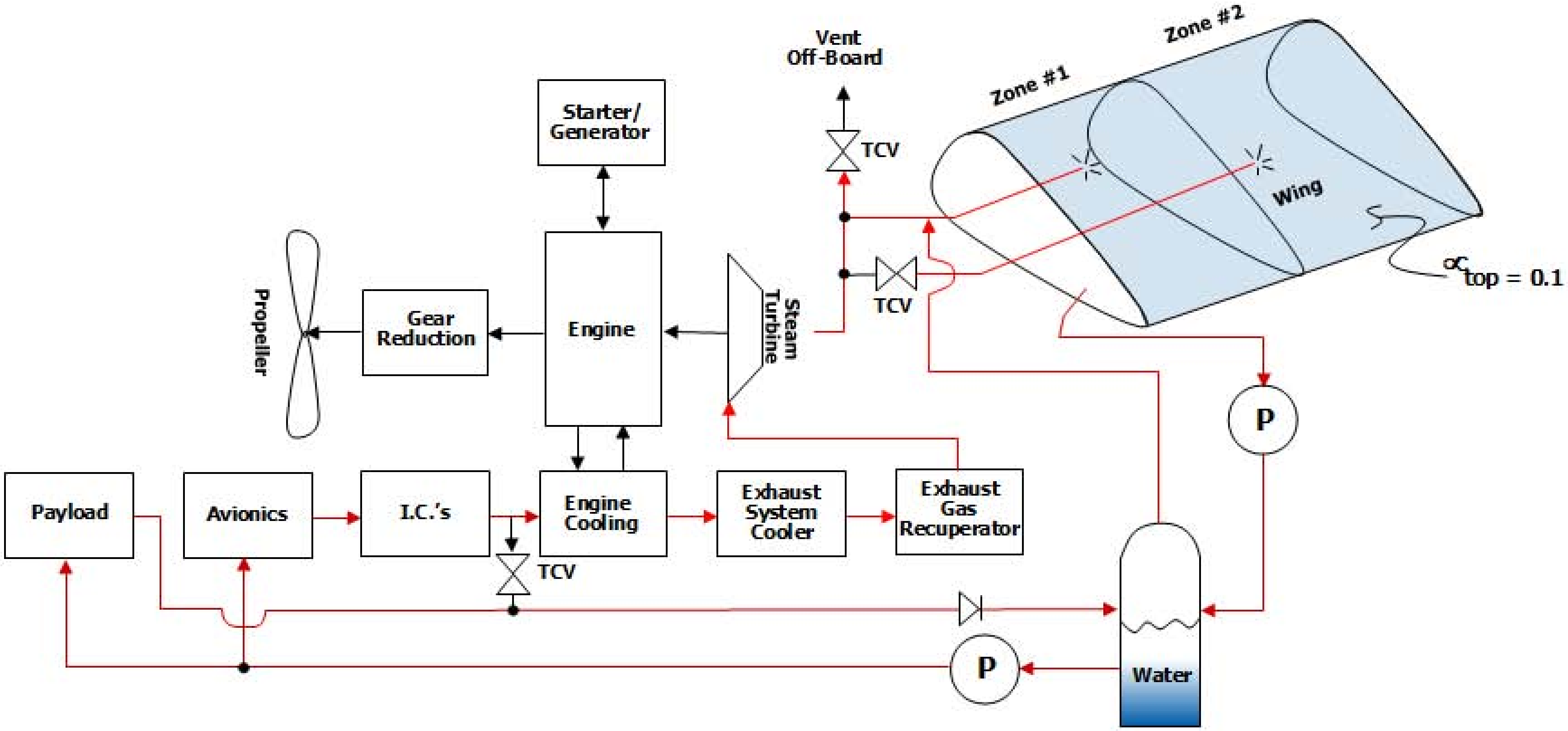
Propulsion System Schematic Overview



Wing Vapor Cycle Thermal Control

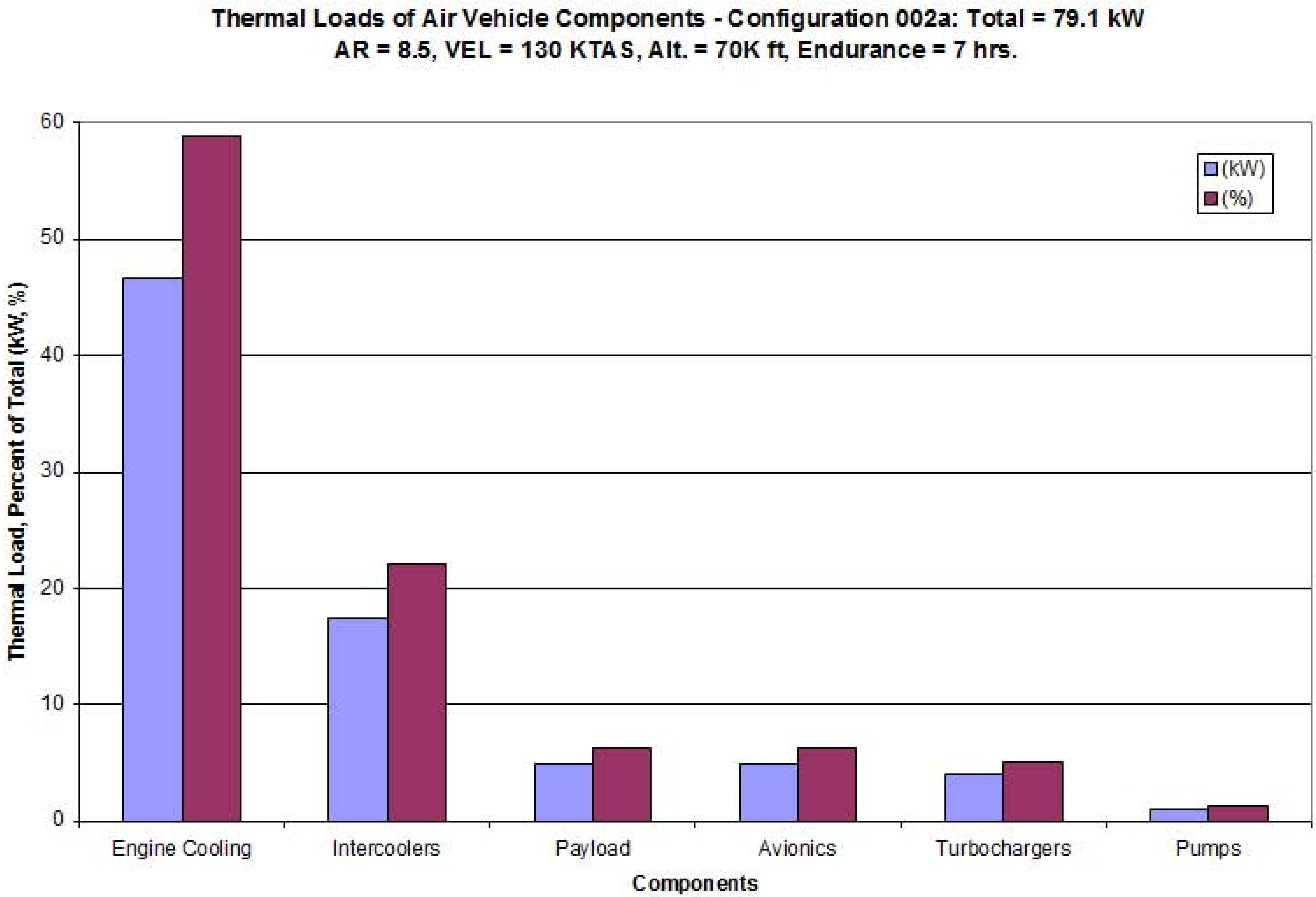
- Water-Vapor Cycle Cooling System, Leveraging Water's High Heat of Vaporization and Depressed Boiling Temperature of 87° F at 0.65 psia Ambient Pressure at 70,000 feet
  - Avionics and Payload are Liquid-Cooled and Supplied w/ 90° F Water Inlet Temperature w/10° F Delta at 10 kW Load
  - IC Engine Intercoolers are Liquid-Cooled and Supplied w/ 100° F Water Inlet Temperature
  - IC Engine and Expansion Chamber Exhaust System are Liquid-Cooled, Employing Boiling Heat Transfer at 250° F and 29.8 psia
  - Exhaust Stream Post Turbocharger and Combustion Gas Turbine Utilize Steam Recuperator
- Power Recovery via Steam Turbine Attached to IC Engine Shaft
- Non-Condensed Steam is Transported via Cloth Hose Span-wise along Wing
- Steam is Condensed on Interior Surfaces of Wings
- High Reflective Surface Coat on Top Wing Surface (alpha = 0.1) Minimizes Solar Load
- Condensed Water Runs Down Wing Span to Collectors w/ Collection Pump Pickup Returning Water to Reservoir/Boiler
- Interior Pressure Controlled Over-Board Valve Vents Excess Steam During Transients in Which Load Exceeds Wing Condenser Capacity

Water Vapor Cycle Thermal Control Schematic

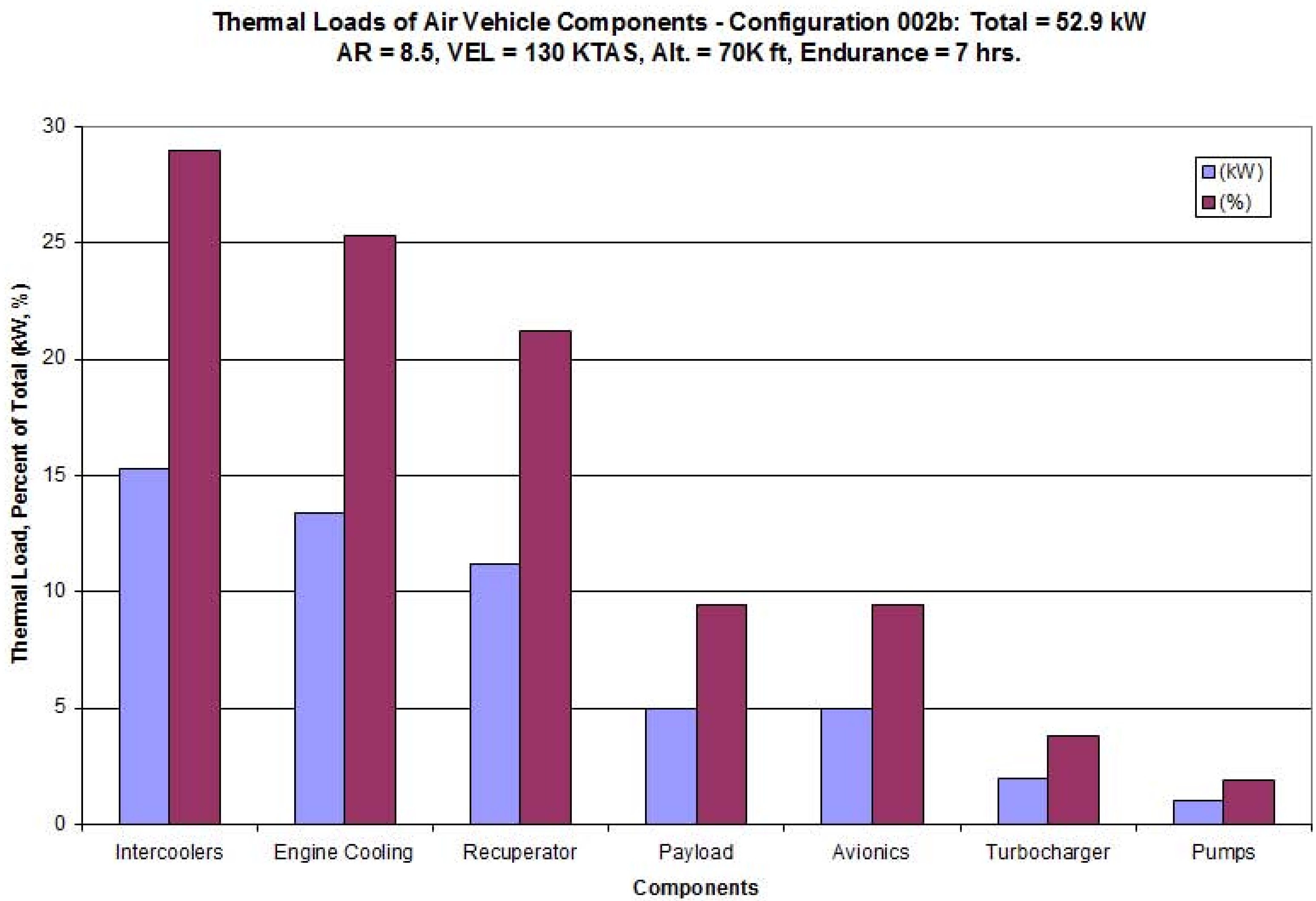


Wing Water Vapor Cycle Cooling Concept

Thermal Breakdown - Configuration_002A



Thermal Breakdown - Configuration_002B



AV Engine Sub-System:

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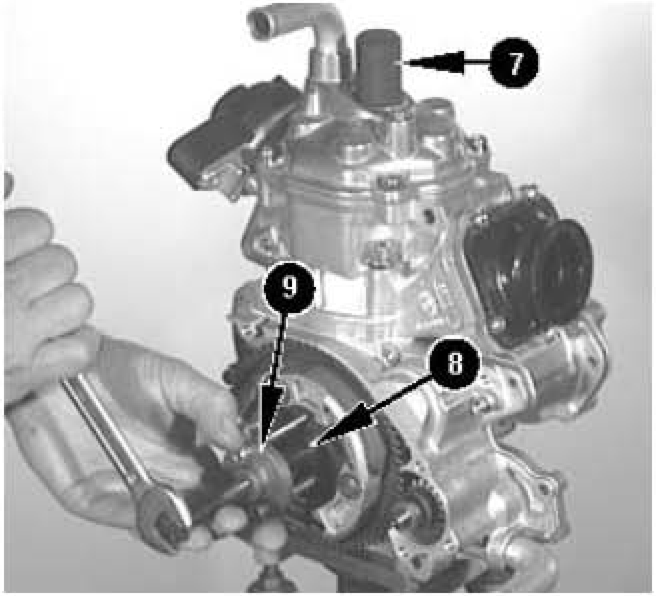
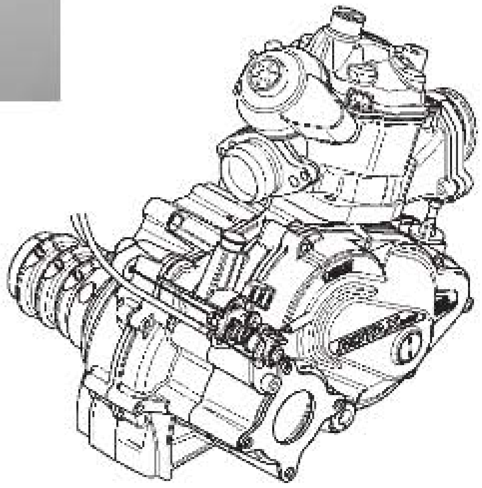
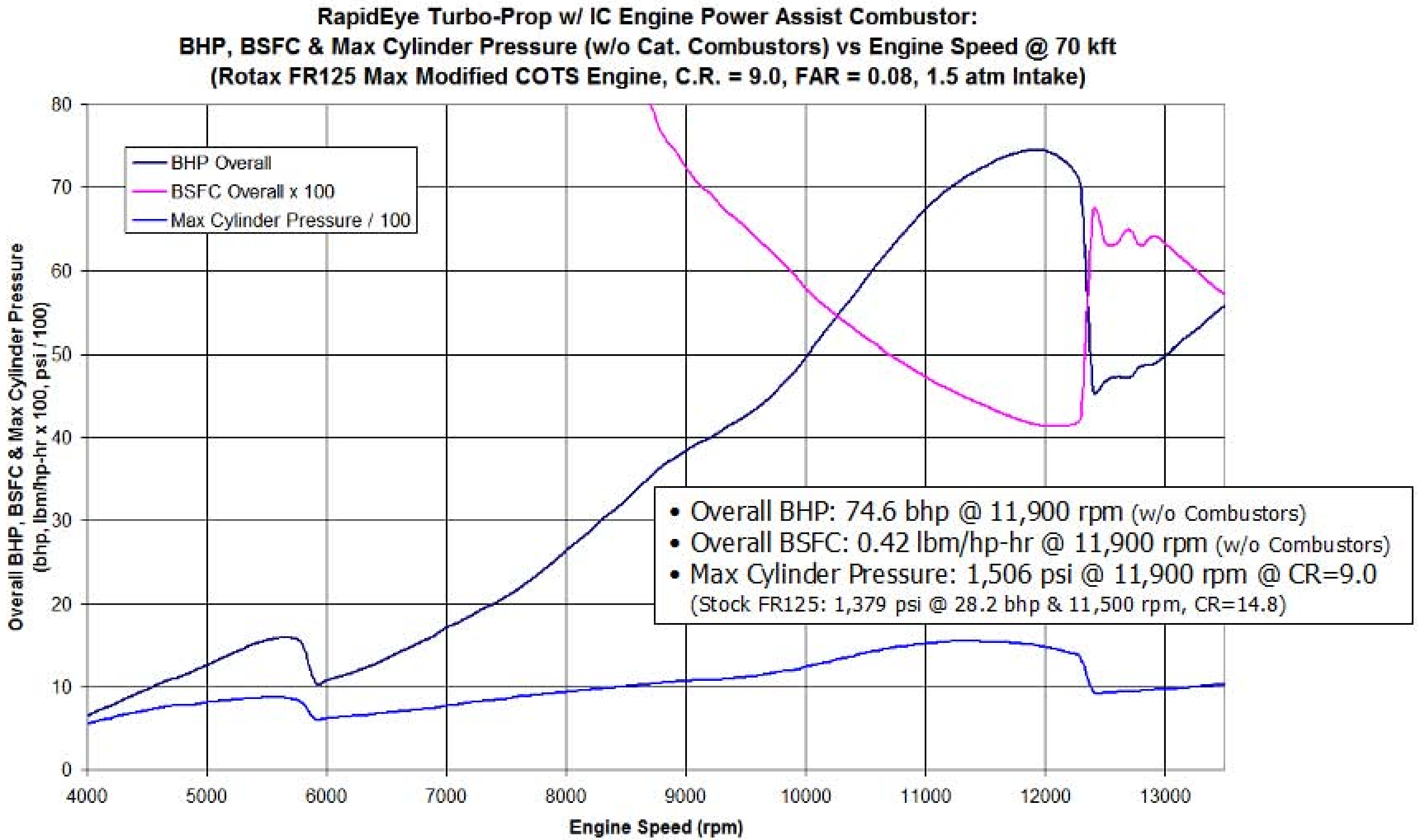


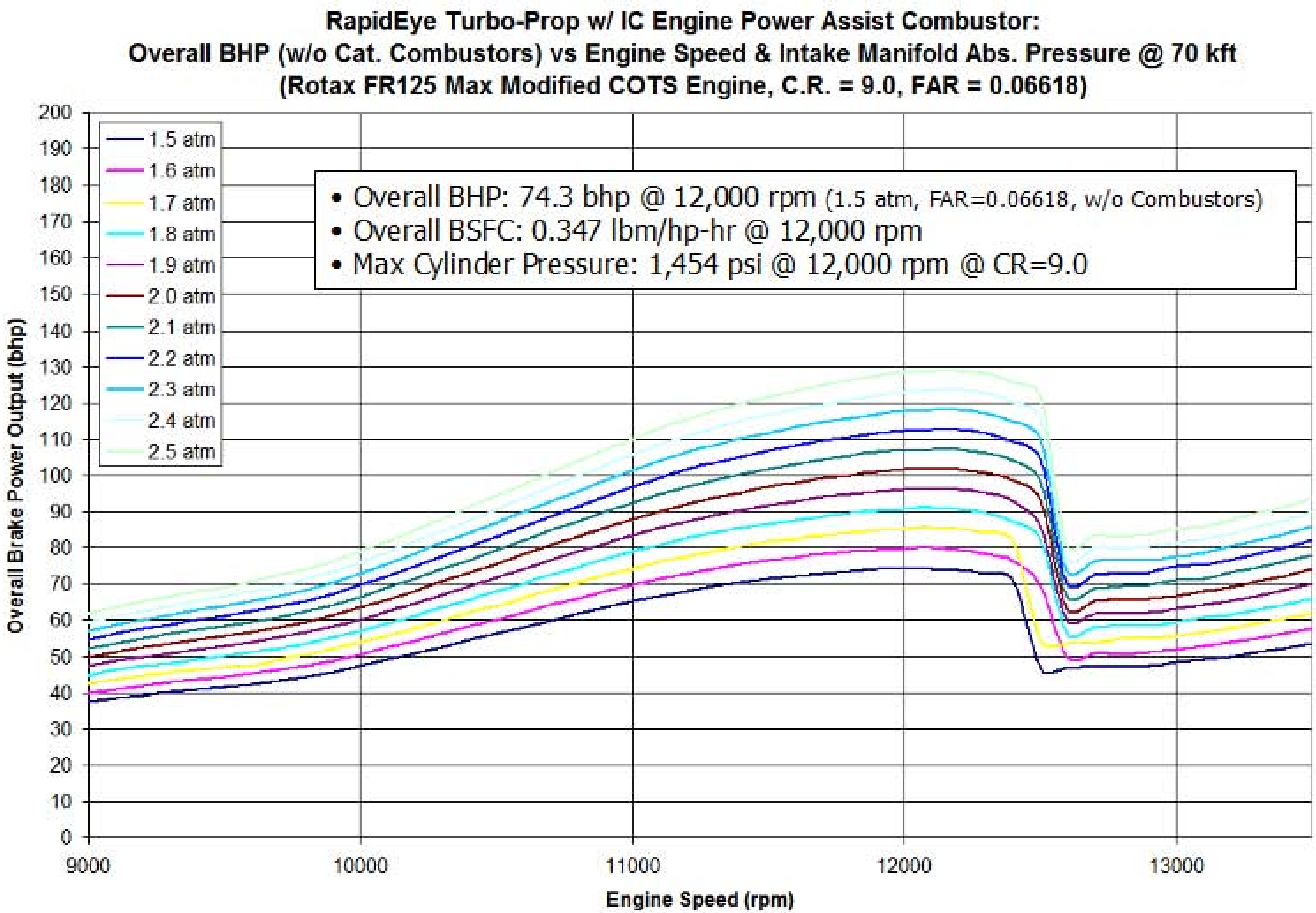


Propulsion System Analysis

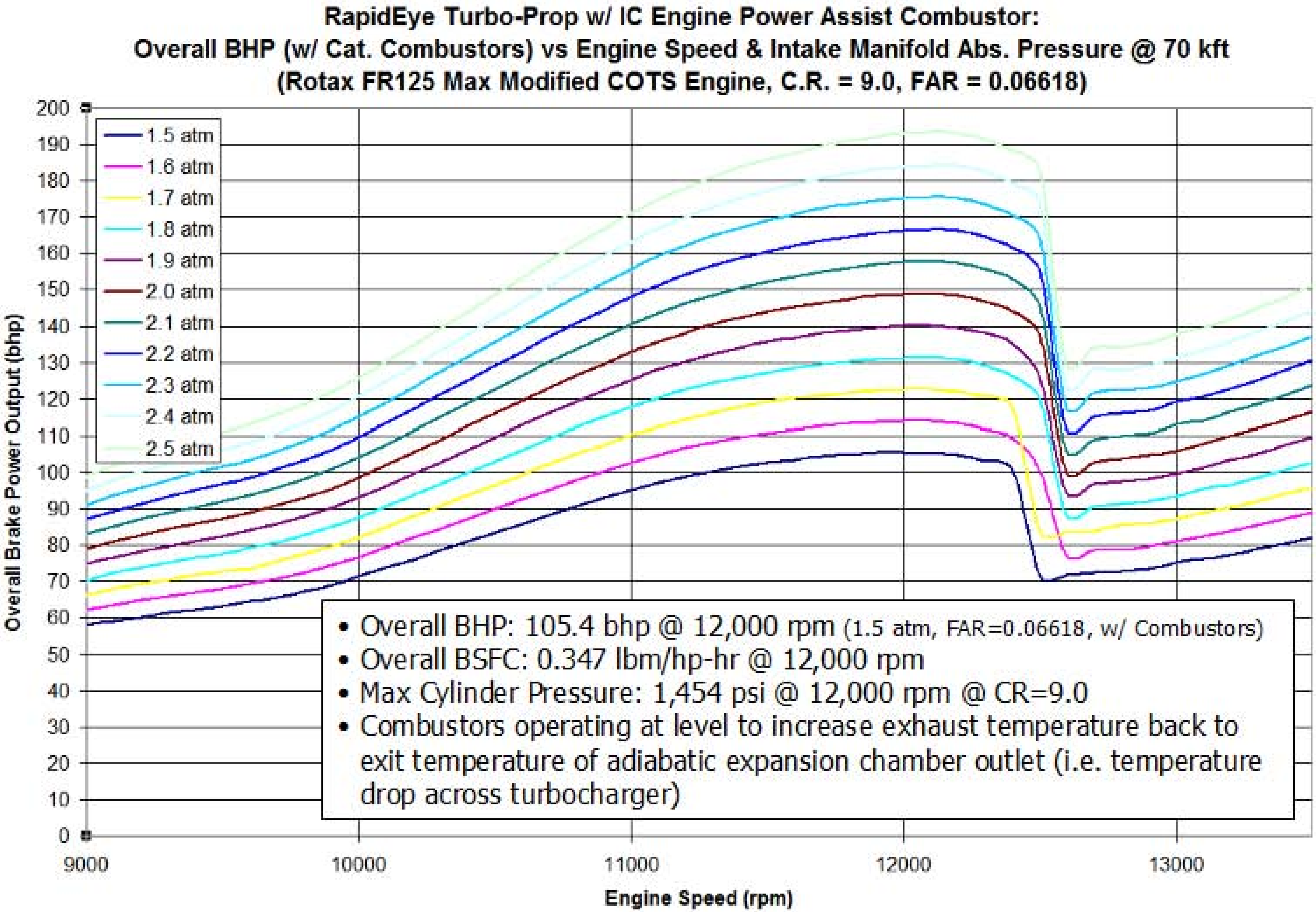


System Analysis Tool: "GT-Suite" by Gamma Technologies

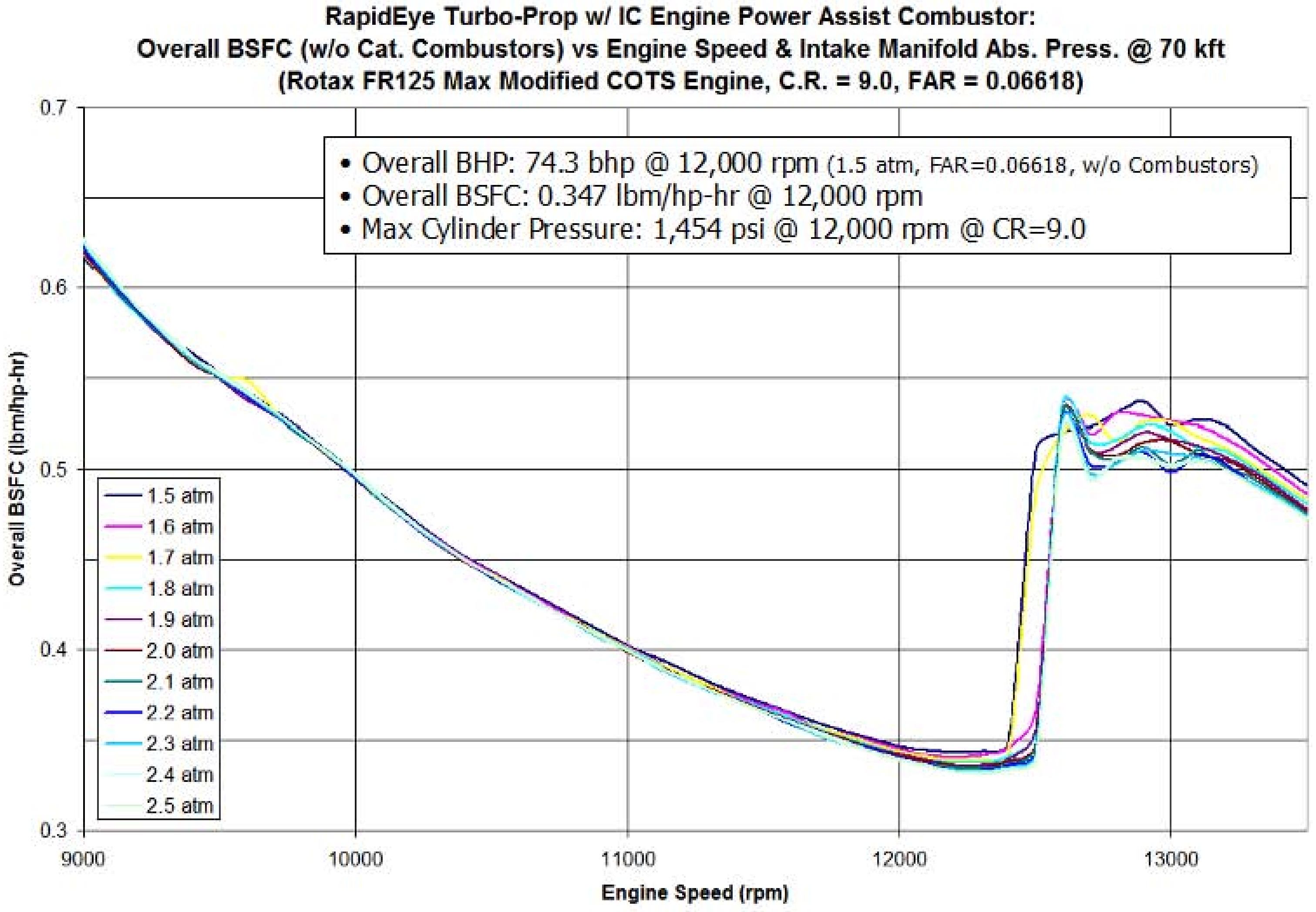
AV Engine Overall BHP w/o Combustors:



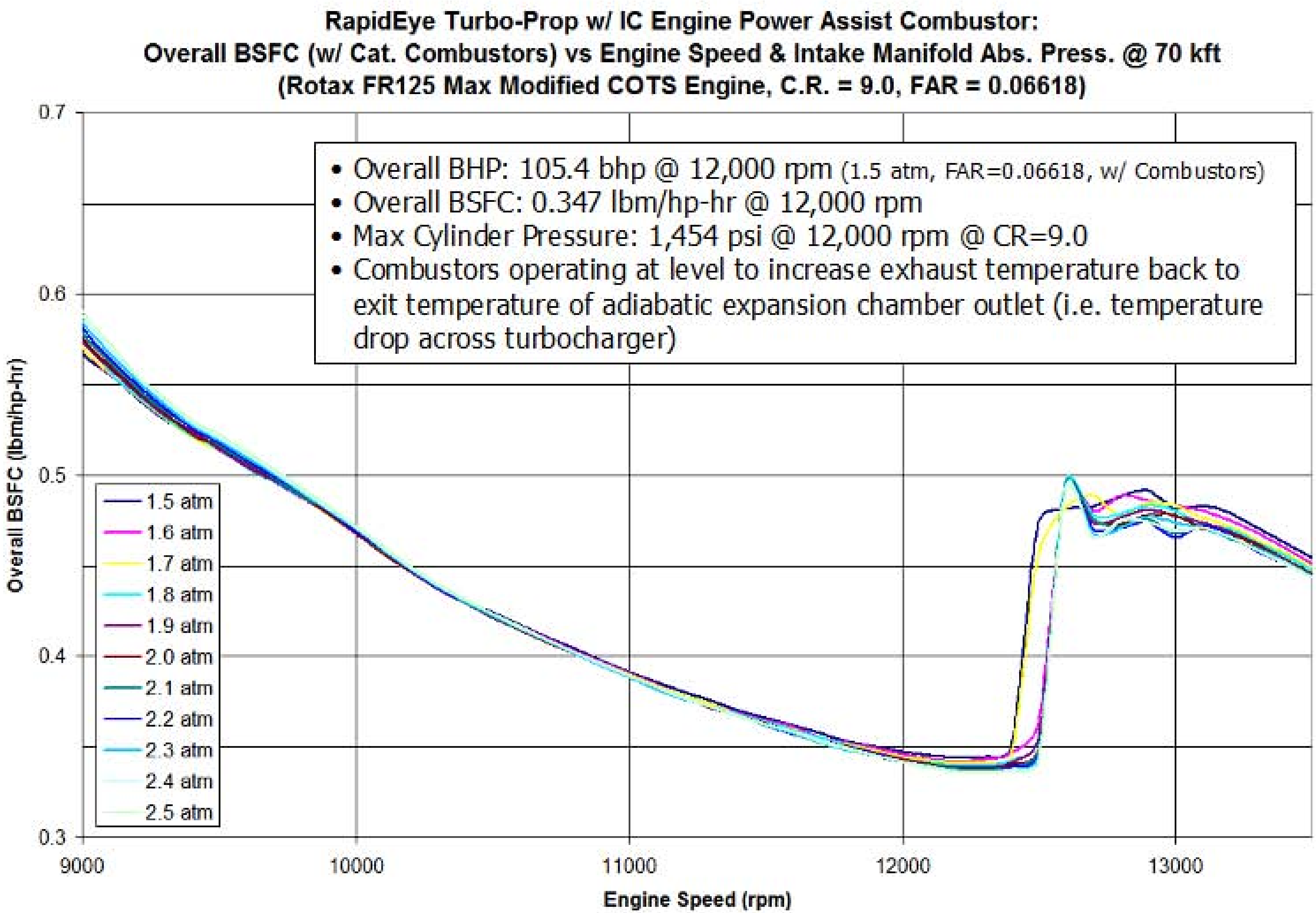
AV Engine Overall BHP w/ Combustors:



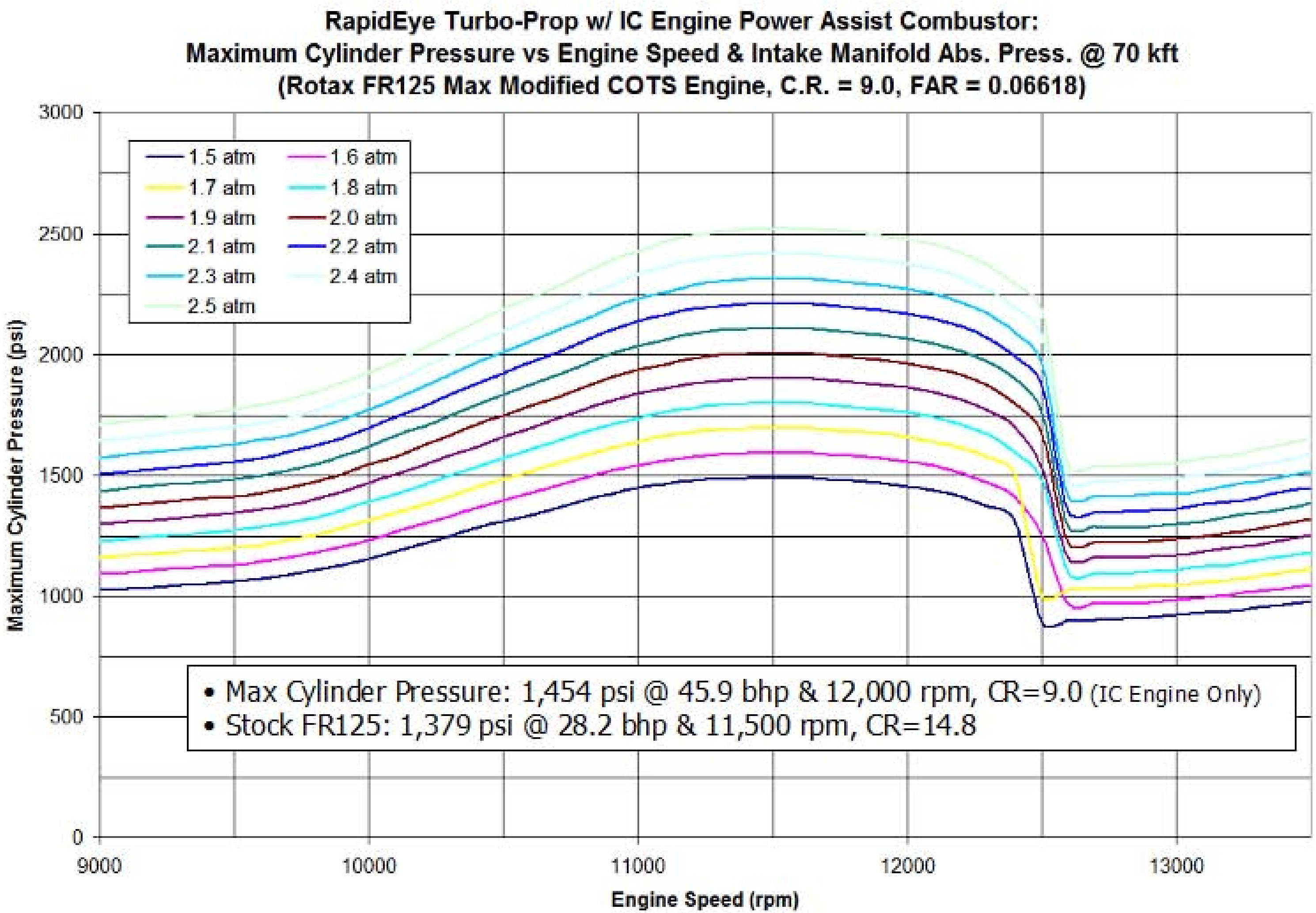
AV Engine Overall BSFC w/o Combustors:



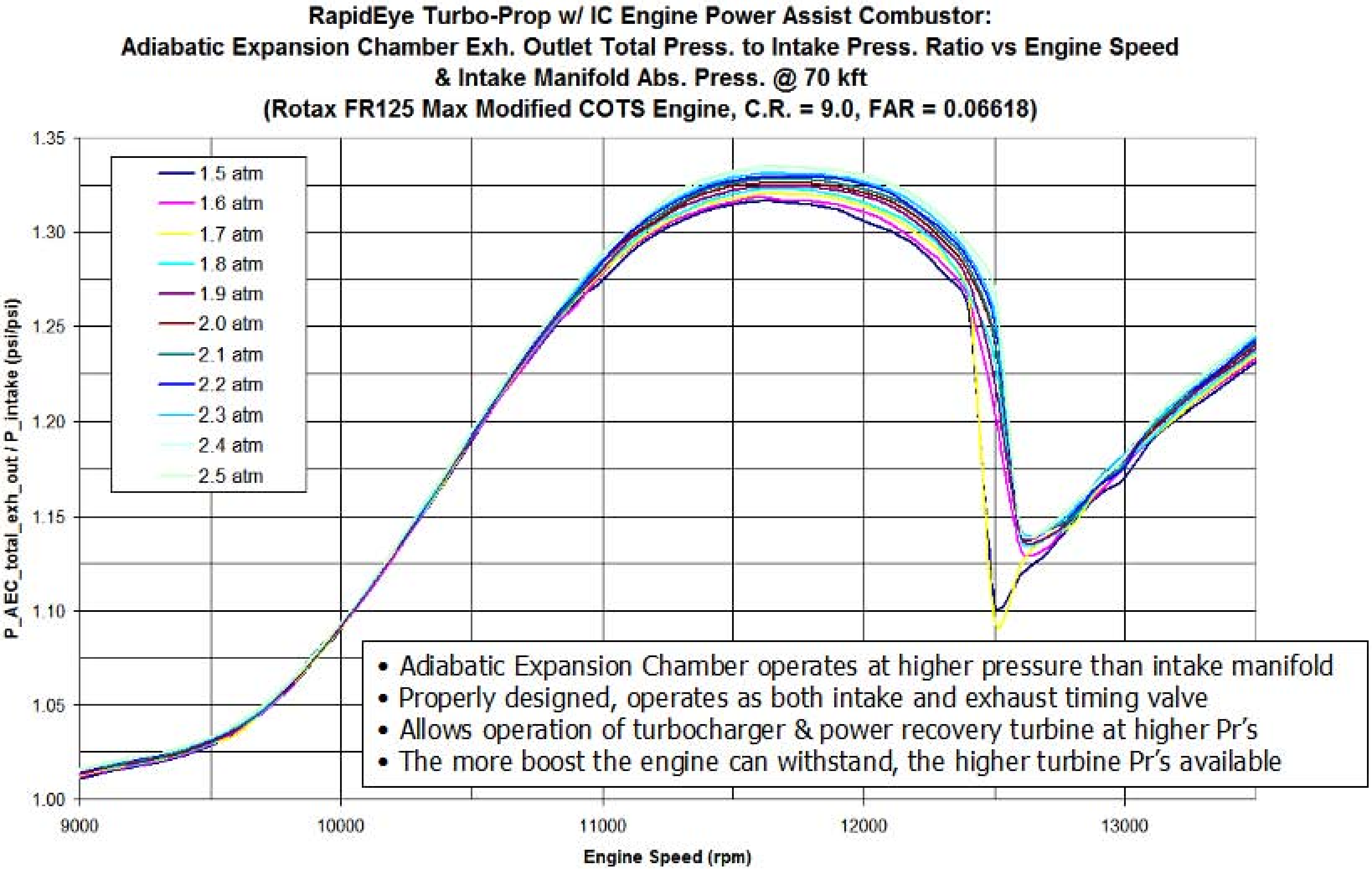
AV Engine Overall BSFC w/ Combustors:



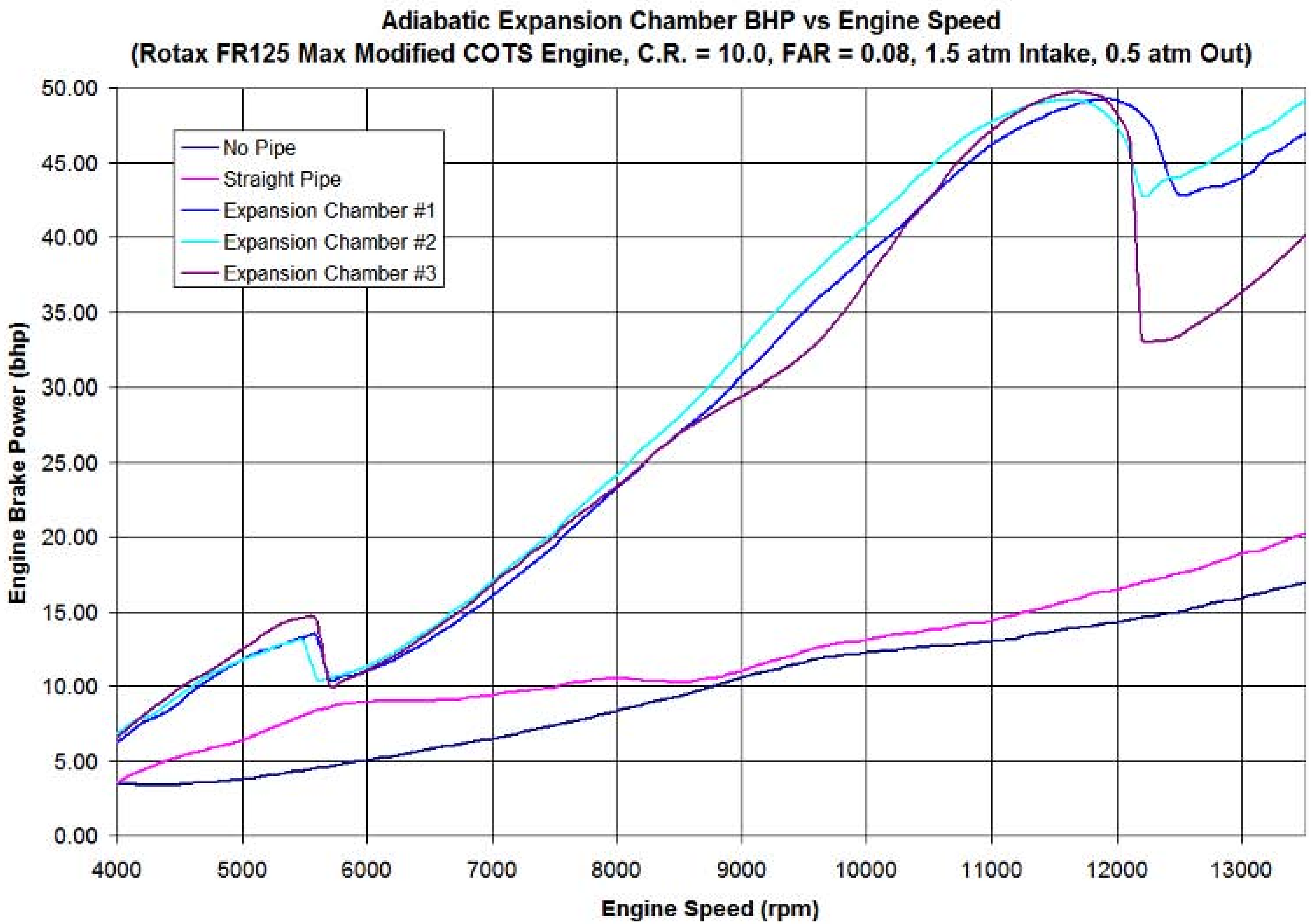
AV Engine Max Cylinder Pressure:



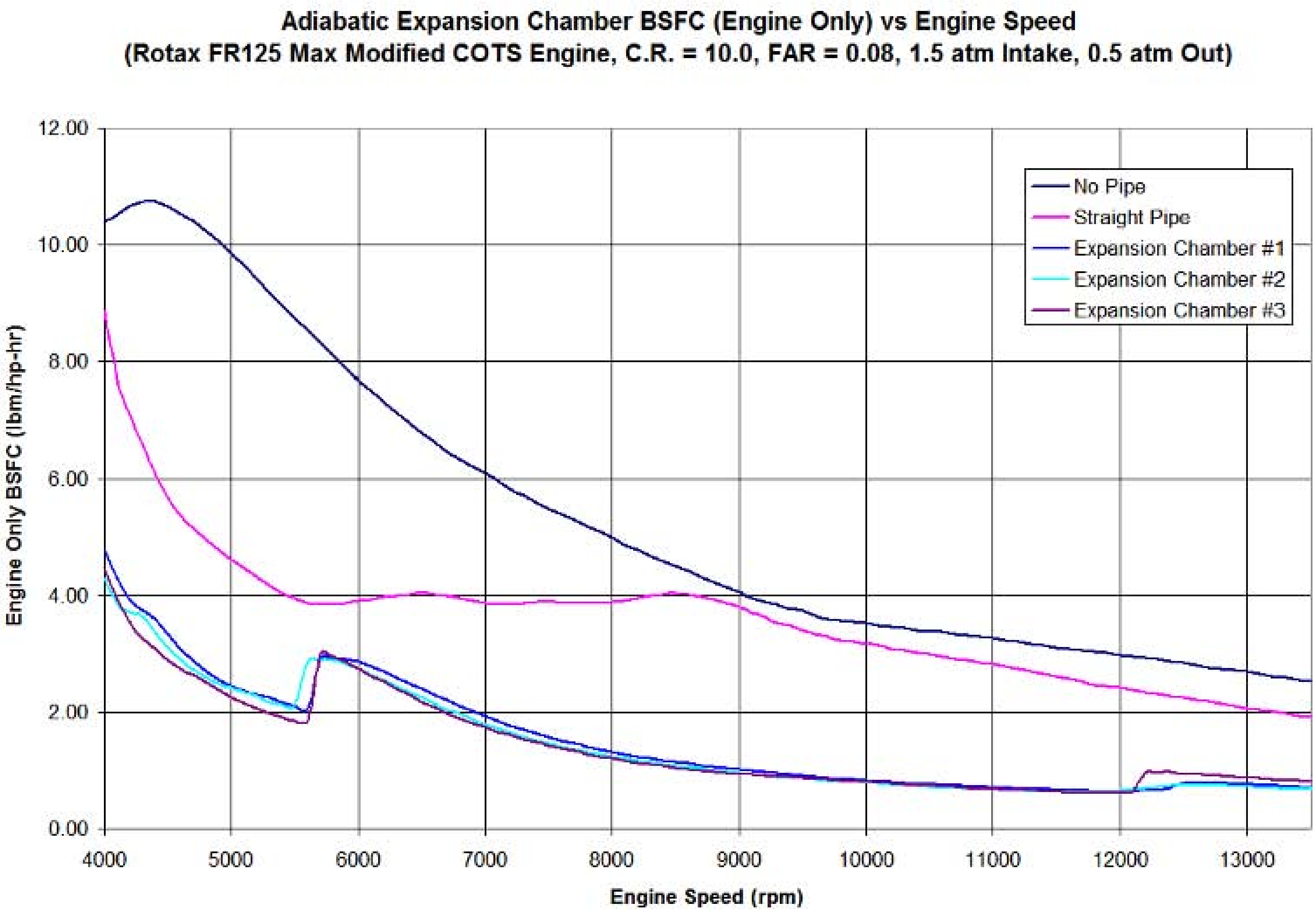
AV Engine Exhaust-to-Intake Pressure Ratio:



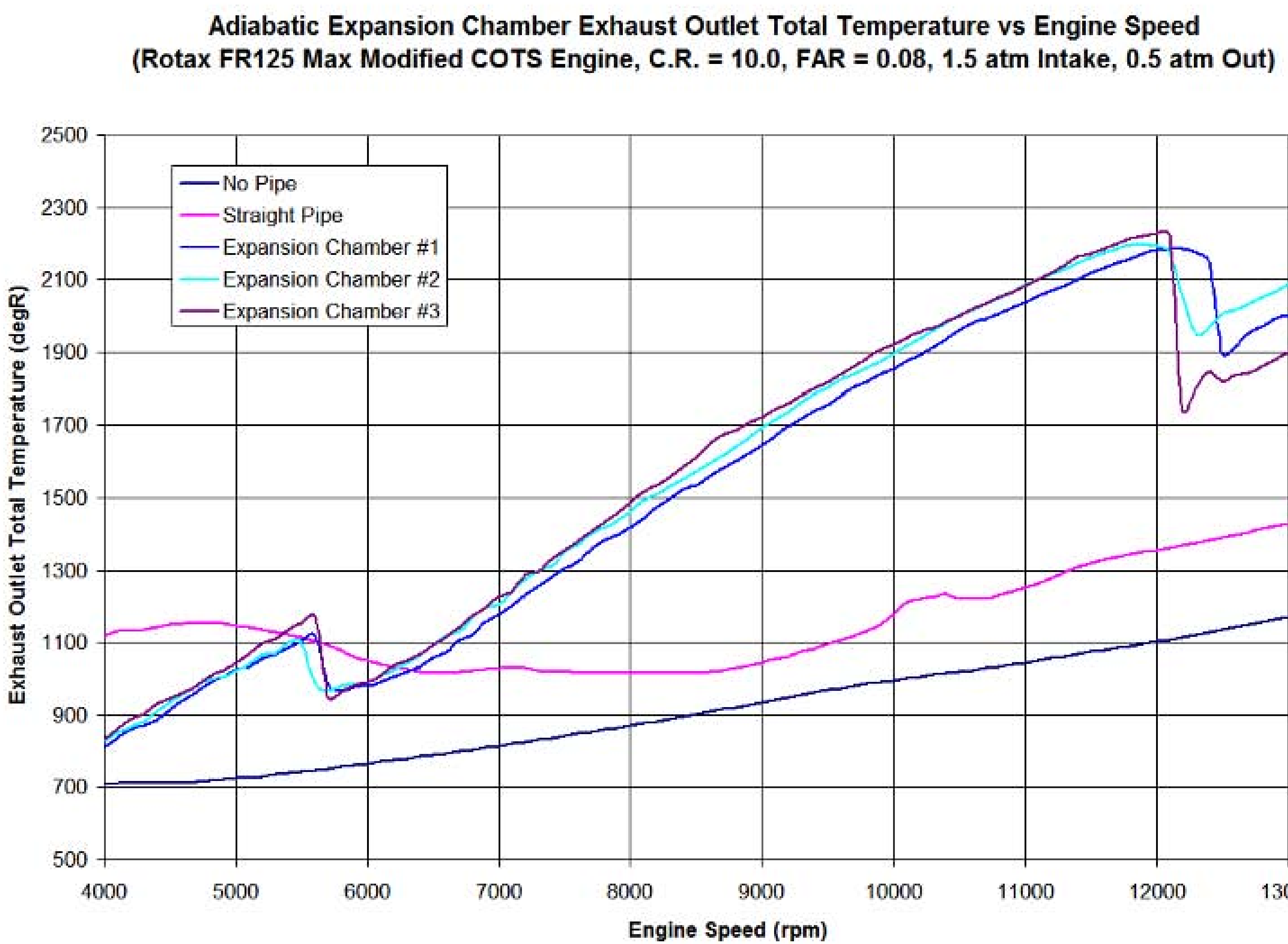
Expansion Chamber BHP Comparison:



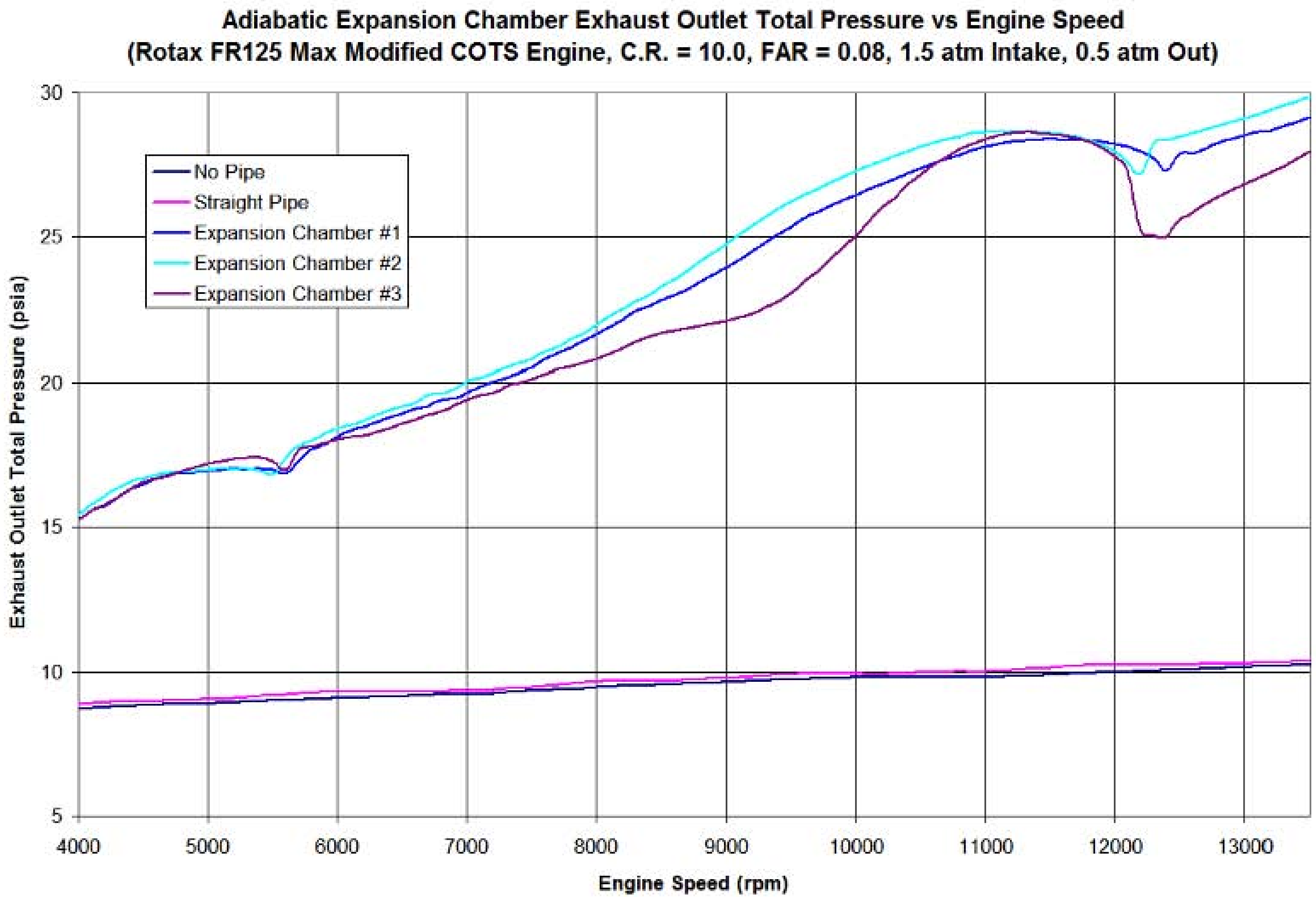
Expansion Chamber BSFC Comparison:



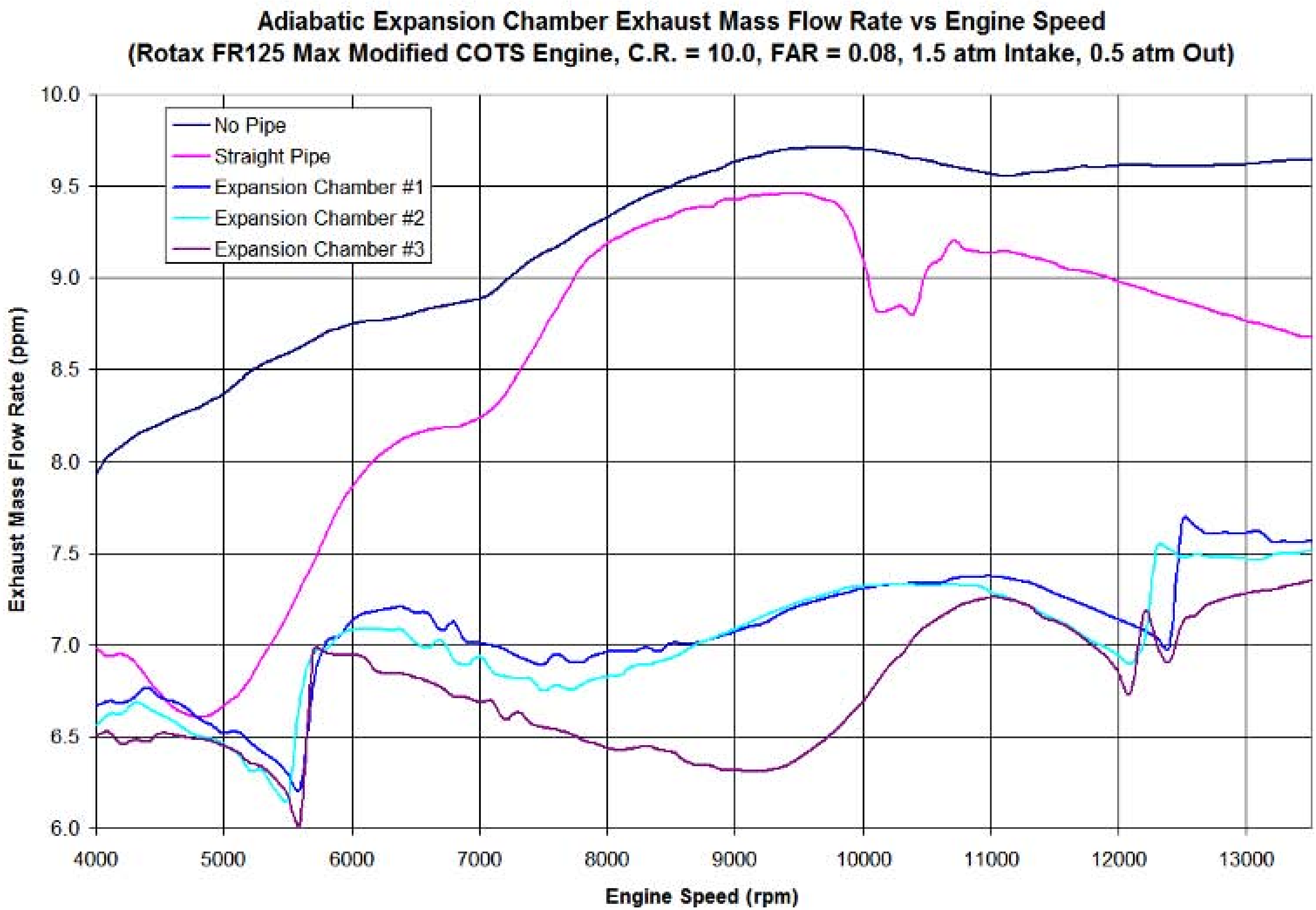
Expansion Chamber Exhaust Outlet T_total Comparison:



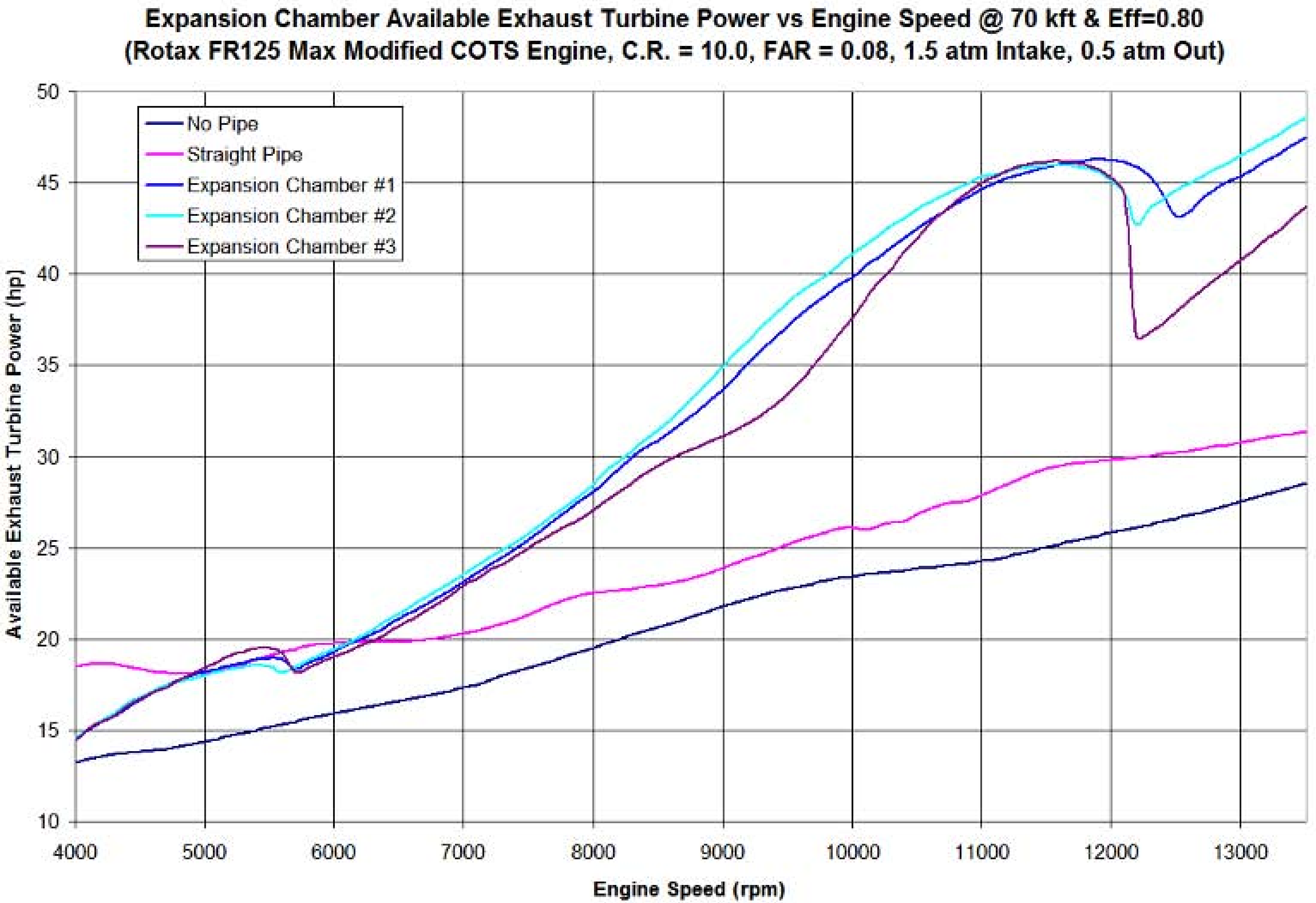
Expansion Chamber Exhaust Outlet P_total Comparison:



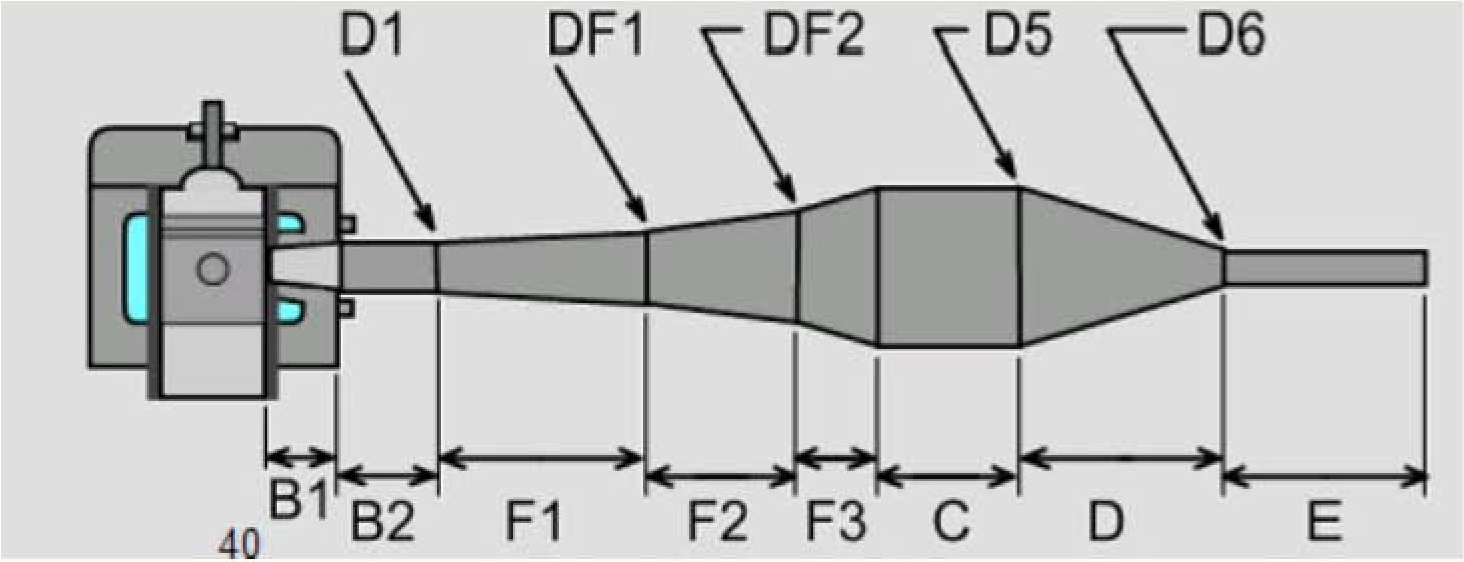
Expansion Chamber Exhaust Outlet Mdot Comparison:



Expansion Chamber Exhaust Turbine Power Comparison:



3-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)

<u>System Analysis Tool</u>: "GT-Suite" by Gamma Technologies