Michigan Technological University

2013 SAE Clean Snowmobile Challenge
Design Presentation

Presented by:

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Presentation Overview

Snowmobile Operator Design Intent

- ✓ Rider-Forward Ergonomics
- ✓ Quiet, Fuel Efficient 4-Stroke

Snowmobile Dealer Perspective

- ✓ Low Maintenance 4-Stroke Option in New Chassis
- ✓ Polaris Product Line Parts Availability
- ✓ Hayes Anti-lock Braking System

Environmental Protection

- ✓ Catalyst Selection for Emissions Reduction
- ✓ Sound Reduction with Exhaust Simulation
- ✓ Performance Electronics ECU
- ✓ Flex-Fuel Implementation
- ✓ Fuel Economy Estimates

Engineering Tests / Proof of Design

- ✓ Over-structure and Engine Mounts (Finite Element Analysis)

Conclusion

Questions/ Additional Information

Snowmobile Operator Design Intent

2013 Polaris Indy SP

- ✓ Rider-Forward Ergonomics
- ✓ Latest Market-Available Chassis
- ✓ Low Initial MSRP

2013 4-Stroke Polaris 875cc Pro-Star

- ✓ RZR Throttle Bodies
- ✓ MTU Designed Intake System
- ✓ Fuel-Efficient Ranger Camshafts and Combustion Characteristics
- ✓ Dependable Wet-Sump Oil System
- ✓ Tolerant to Ethanol Blends
- ✓ 55 HP Power Output

Snowmobile Dealer Perspective

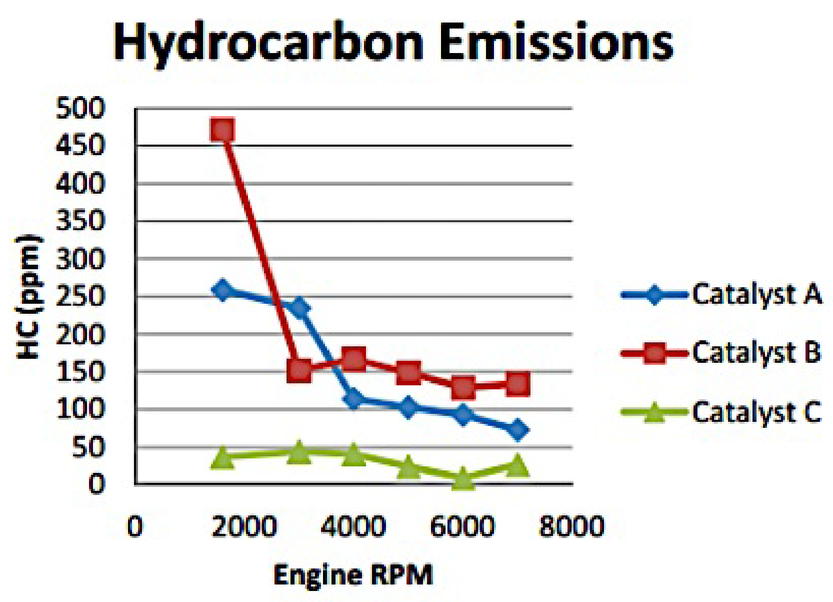
- ✓ Low Maintenance 4-Stroke Option in Pro-Ride Chassis
- ✓ Viable Improvements in Power Output
- ✓ Alternative Fuel Option
- ✓ Hayes Anti-Lock Brake System for Controlled Braking in Extreme Conditions
- ✓ Reasonable MSRP of $12,038.17

Environmental Protection

Catalyst Selection for Emissions Reduction

Catalyst Selection

- ✓ Three Catalysts Compared
- ✓ V-Converter 3-Way Chosen for:
  - ***79%*** Reduction in HC
  - ***23%*** Reduction in CO
  - Slight increase in NOx



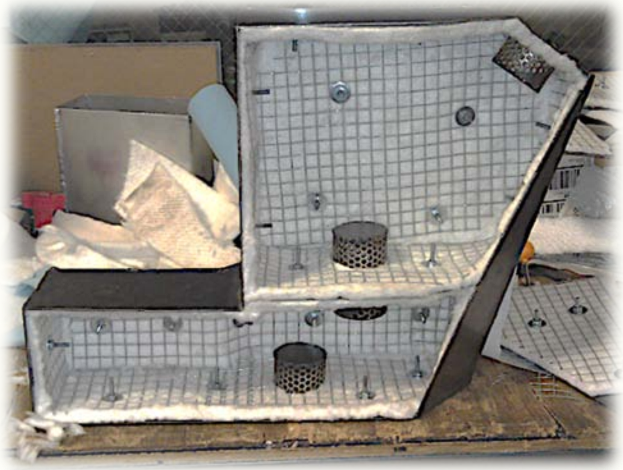
Catalyst Characteristics

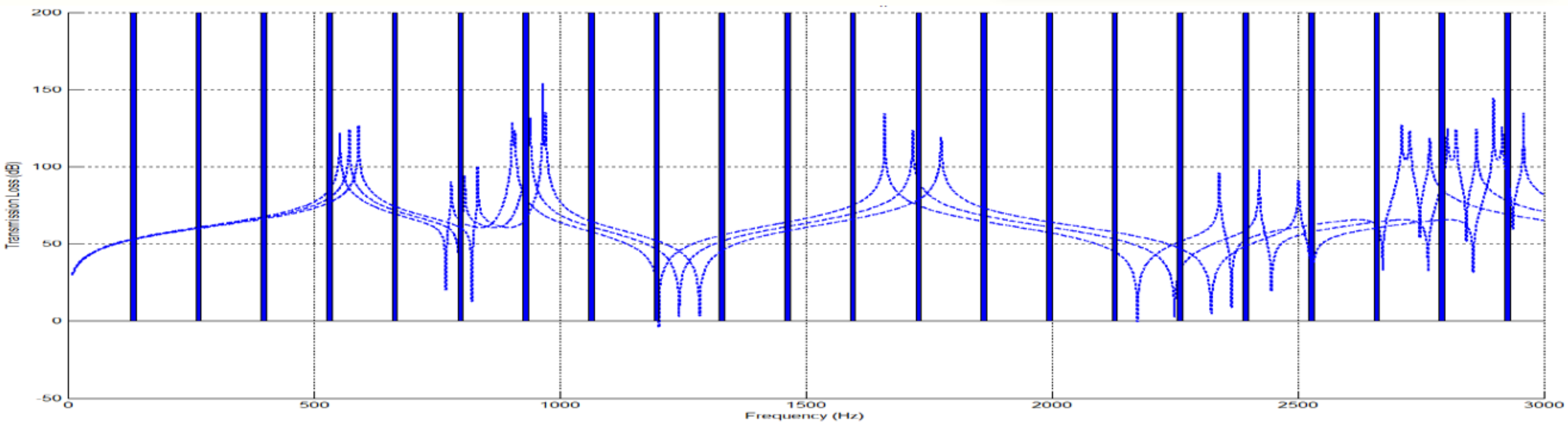
- ✓ 63 C.I. Volume Sized for Pro-Star Engine Application
- ✓ Operates Most Efficient Near Stoichiometric AFR

Environmental Protection

Sound Reduction – Muffler Design Considerations

- Dual Chamber Muffler Analysis
- MATLAB Simulation to select optimum volume for transmission loss
- Packaging Within OEM Plastics



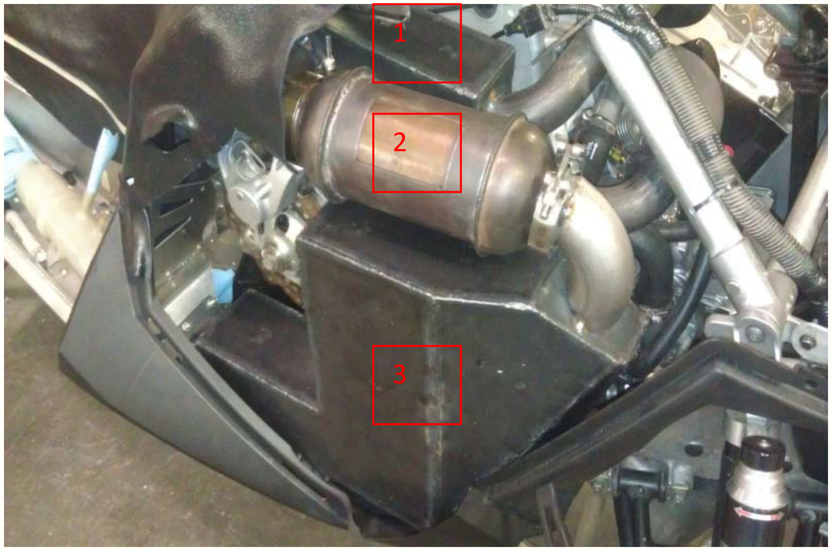


Environmental Protection

Sound Reduction – Final Exhaust Design and Validation

MTU Designed and Fabricated Exhaust System

1. 2 to 1 Collection Chamber
2. V-Converter Catalyst
3. Two-Chamber Muffler



Sound Reduction Verification

- ✓ 74 dB per J192 Standard
- ✓ Intake Noise is Main Focal Point for Improvement

Environmental Protection
Engine and Fuel Management

Performance Electronics PE3

- ✓ Standalone Engine Control Unit (ECU)
- ✓ Precise Fuel and Ignition Control Based on 1250 Load Breakpoints
- ✓ Closed-Loop Fuel Control
  - Stoichiometric AFR Targeted
  - Long Term Factor Feedback
- ✓ 30+ User Defined Fuel and Ignition Trim Tables
- ✓ On-Board Wireless Tuning Capabilities
- ✓ Power output of 55 HP

Environmental Protection

Flex Fuel Implementation

E40 – E85 Ethanol Compensation

- ✓ Siemens Ethanol Content Analyzer
- ✓ Zietronix A/D Converter
- ✓ P.E. Digital 0-5v input
- ✓ MTU Generated Fuel and Ignition Trims
    - Modeled with 33% fuel conversion efficiency at full load
- ✓ Ignition Trims Based on Ethanol Octane Content
- ✓ Control Algorithm for Varying Stoichiometric Air/Fuel Ratios Based on Ethanol and O_2 Sensor Input

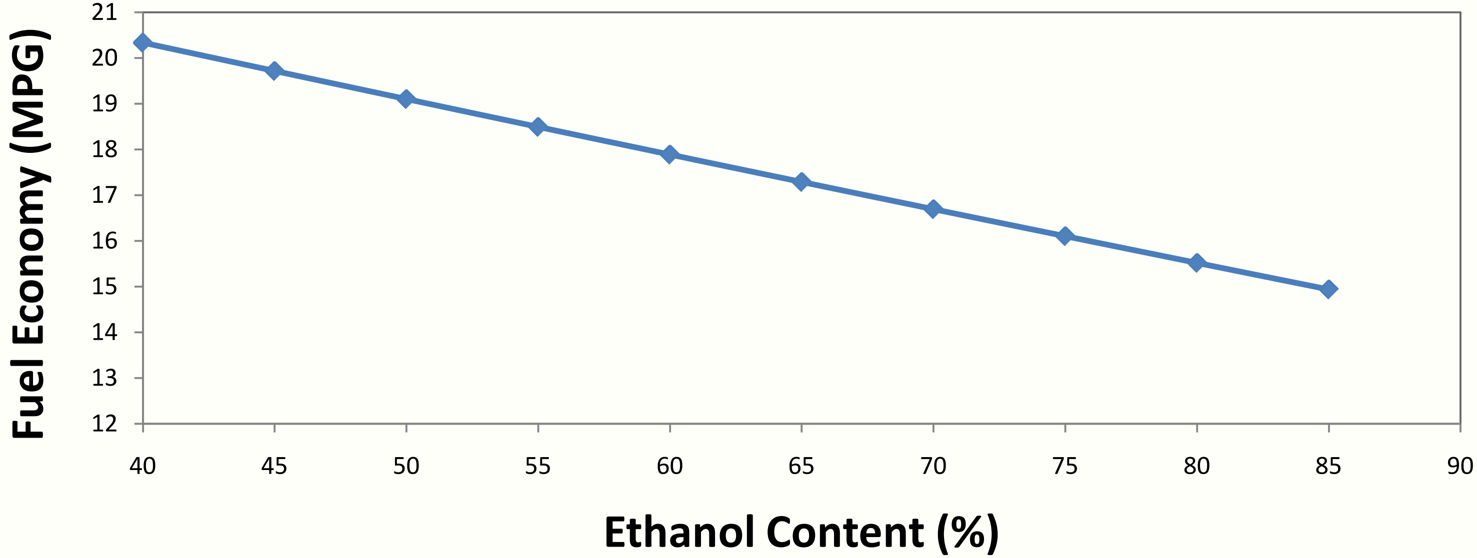
Environmental Protection

Calculated Fuel Economy

Fuel Economy Calculations for 45 mph Derived From:

- ✓ Injector flow rate
- ✓ Varying heating values and densities for E40 – E85
- ✓ Observed Engine Speed and Injector Duty Cycle at Cruising Speed

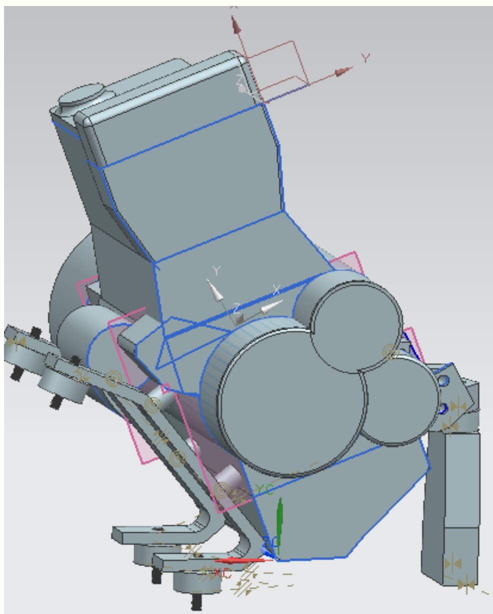
Estimated Fuel Economy: 14.9 – 20.3 mpg

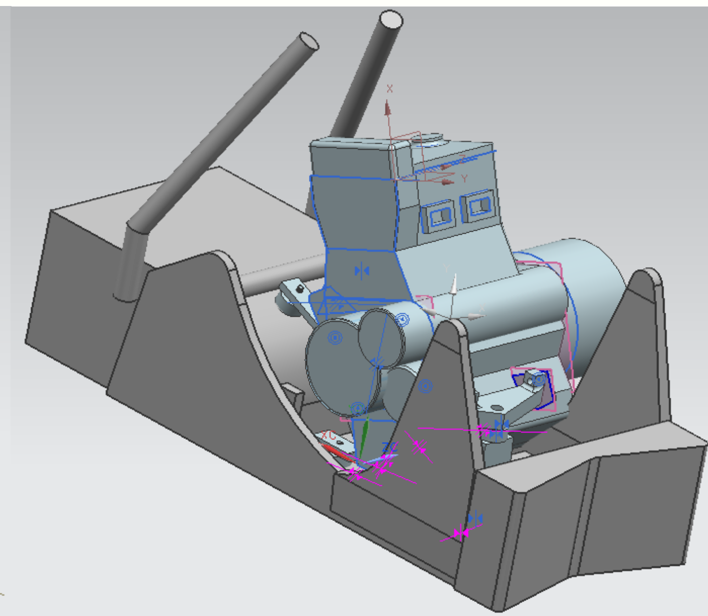


Engineering Tests / Proof of Design

Engine Mounting Design and Verification

- ✓ Engine Securely Cradled at Three mounting Location
- ✓ Torque Stop on PTO Side of Engine

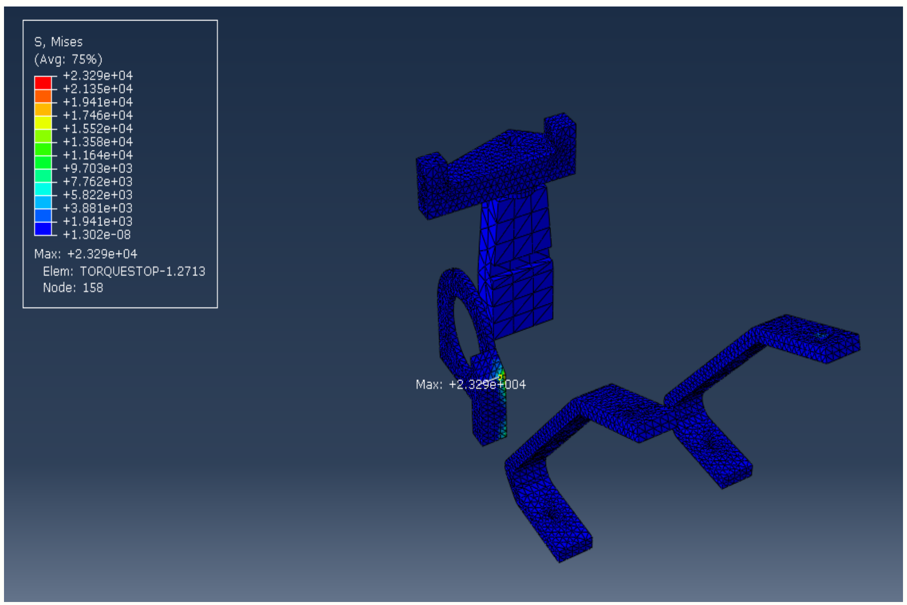


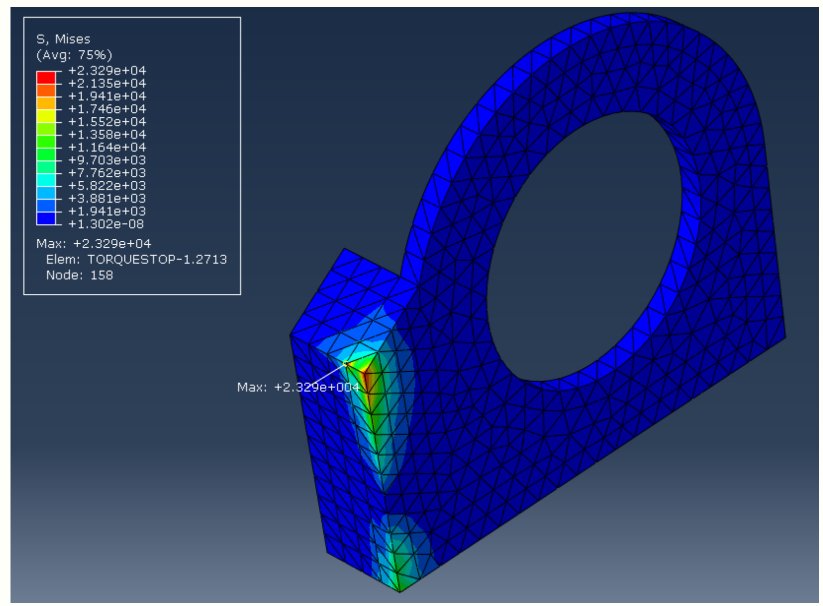


Engineering Tests / Proof of Design

Engine Mounting Design and Verification

- ✓ Maximum Von Mises Stress = 23.29 ksi
- ✓ Yield Strength of Aluminum 6061-T6 = 40 ksi
- ✓ Safety Factor = 1.72
- ✓ 300+ Miles of Field Verification



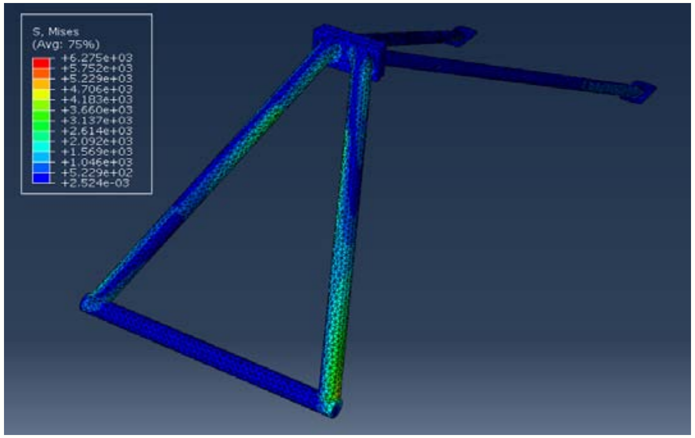


Engineering Tests / Proof of Design

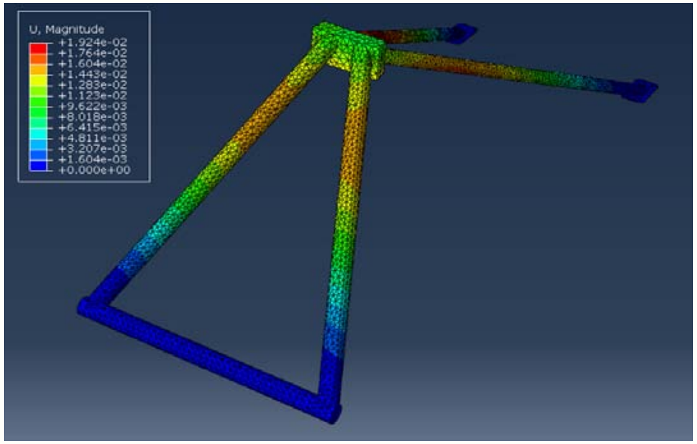
Over-Structure Modification and Verification

Over-Structure Required Modification for Engine Fitment

- ✓ Maximum Von Mises Stress: 6.275 ksi
- ✓ Safety Factor = 6.37
- ✓ Maximum Displacement = 0.019 Inches



Von Mises Contour Plot



Displacement Contour Plot

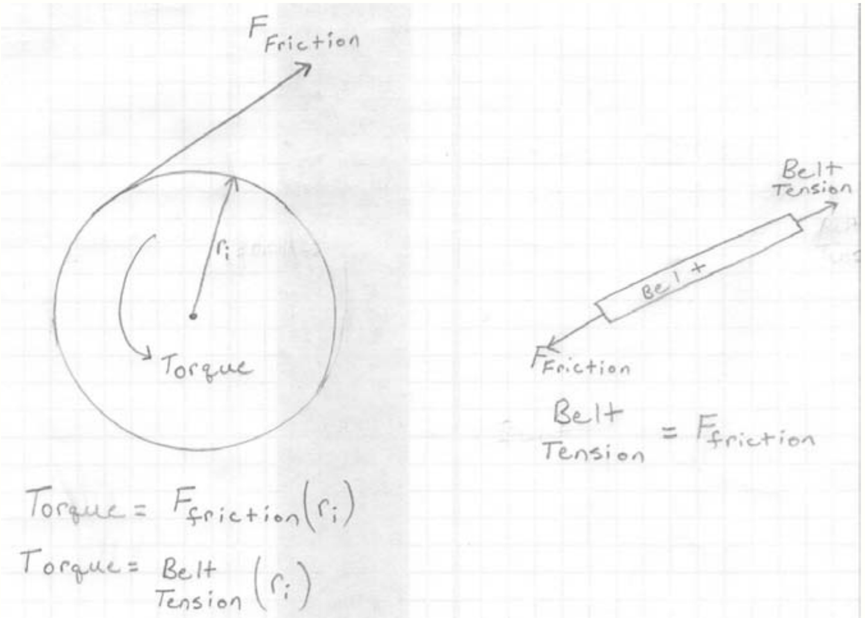
Conclusion

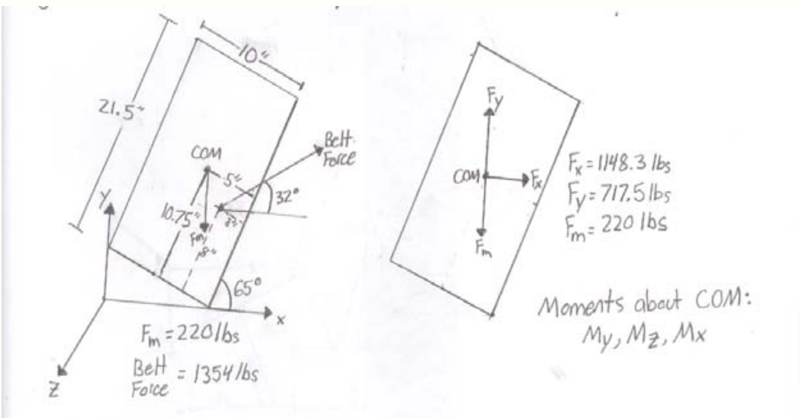
- ✓ Unique Engine and Chassis Configuration
- ✓ Desirable Characteristics for both Consumer and Dealer
- ✓ Environmentally friendly
  - Reduced Emissions Through Catalyst and Engine Calibration
  - Reduced Exhaust Noise Emissions with Dual-Chamber Exhaust System
  - Flex-Fuel Implementation
- ✓ All Chassis Modifications Necessary for Engine Implementation Verified Through FEA and Field Testing

Questions?

Additional Information

Calculating Loads





$$F_{friction} = Belt_{tension} = \frac{Torque}{r_i} = \frac{65}{0.048} = 1354\ lbs$$

$$\text{Impact Loading Factor} = 1 + \sqrt{1 + \frac{v^2}{g} * \delta_{st}}$$

Additional Information

FEA

Loads

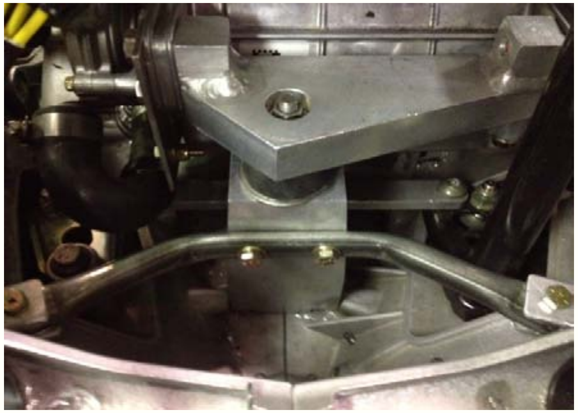
- Belt tension calculated using torque of motor
- Static weight of motor = 110 lbs
- Impact Load due to a “suddenly applied load”

Boundary Conditions

- Fixed at chassis connection for front mount and where rear mounts connect to the isolators

Final Engine Mounting System

Rear Engine Mounts



Front Engine Mount

Torque Stop

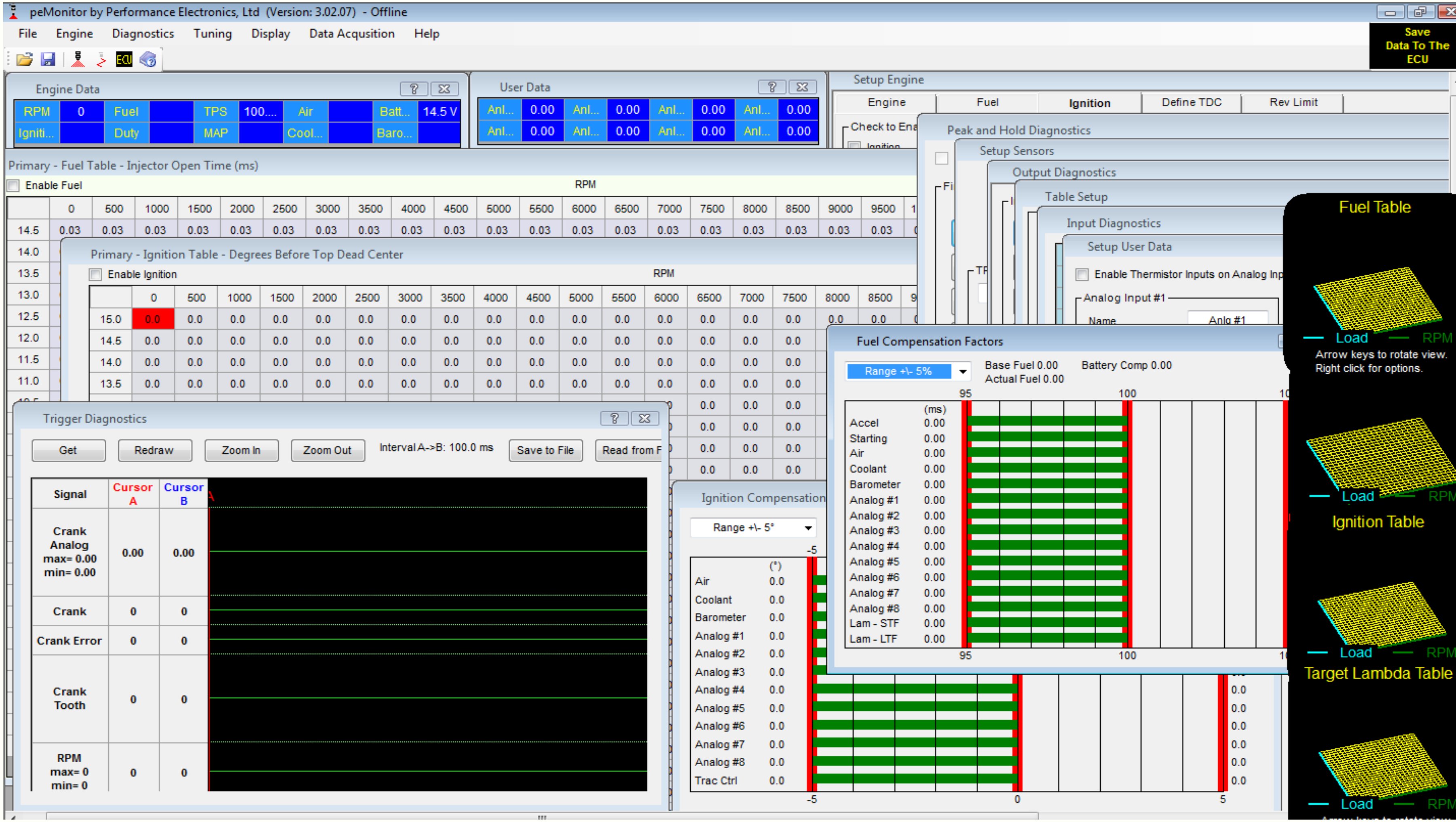
Additional Information

Fuel Economy and Ethanol Trim Verification

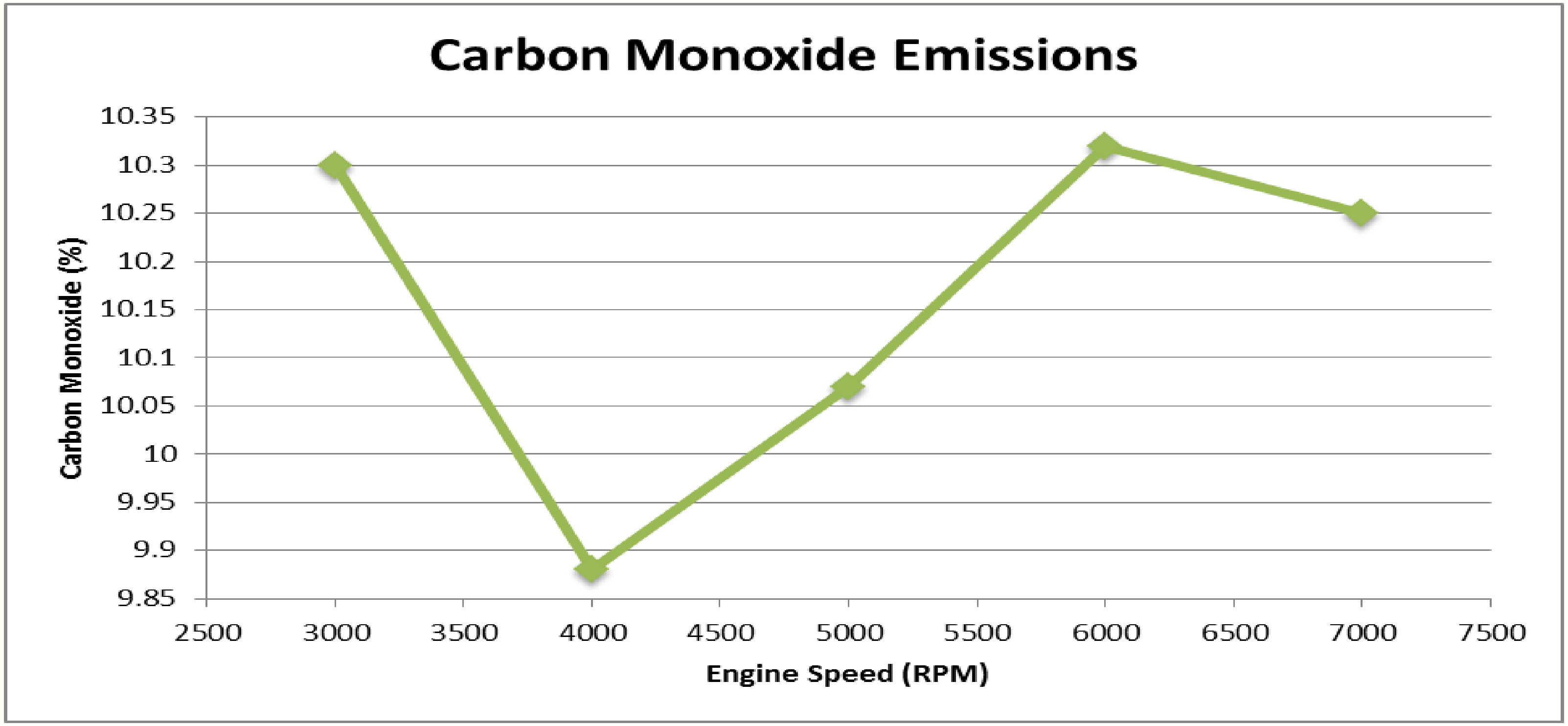
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		Injector Flowrate (cc/min)	100	for 3 bar of pressure			QHV, Gas	47300	kJ/kg								
2		Injector Flowrate (m^3/s)	1.67E-06				QHV, Ethanol	26952	kJ/kg								
3		Density Gasoline (lb/ft^3)	44.9														
4		Density Gas (kg/m^3)	719.298												For 45 mph		
5		Density Ethanol (kg/m^3	789												average speed		
6							Mass		Q,HV		Mass Flow				(.0125 mile/s)		
7		Fuel	Eth	Gas	Density of Fuel (kg/m^3)	Density of Fuel (kg/gal)	Flowrate, Fuel (kg/s)	Power (KW)	Fuel (kJ/kg)	Efficiency	Rate,req'd (kg/s)	Ratio		%change	mi/kg	mi/gal	
8		E40	0.4	0.6	761.1192	2.881149586	0.001271069	45	39,161	0.57095355	0.0020126	1.5834	0.0076	1.5834	6.210832704	17.894338	
9		E45	0.45	0.55	757.6341	2.867957047	0.001265249	45	38,143	0.57095355	0.0020663	1.63311	0.00784	1.63311	6.049474887	17.349634	
10		E50	0.5	0.5	754.149	2.854764508	0.001259429	45	37,126	0.57095355	0.0021229	1.68562	0.00809	1.68562	5.88811707	16.809188	
11		E55	0.55	0.45	750.6639	2.84157197	0.001253609	45	36,109	0.57095355	0.0021827	1.74116	0.00836	1.74116	5.726759253	16.272999	
12		E60	0.6	0.4	747.1788	2.828379431	0.001247789	45	35,091	0.57095355	0.002246	1.8	0.0048	1	5.565401436	15.741067	
13		E65	0.65	0.35	743.6937	2.815186893	0.001241968	45	34,074	0.57095355	0.0023131	1.86243	0.00894	1.86243	5.40404362	15.213393	
14		E70	0.7	0.3	740.2086	2.801994354	0.001236148	45	33,056	0.57095355	0.0023843	1.92879	0.00926	1.92879	5.242685803	14.689976	
15		E75	0.75	0.25	736.7235	2.788801816	0.001230328	45	32,039	0.57095355	0.00246	1.99946	0.0096	1.99946	5.081327986	14.170817	
16		E80	0.8	0.2	733.2384	2.775609277	0.001224508	45	31,022	0.57095355	0.0025407	2.07485	0.00996	2.07485	4.919970169	13.655915	
17		E85	0.85	0.15	729.7533	2.762416738	0.001218688	45	30,004	0.57095355	0.0026268	2.15545	0.01035	2.15545	4.758612352	13.14527	
18																	
19																	
20		E60	Open Time (	Mass Flow Rate (kg/s)	kg fuel injected		open time/s	kg/s			Speed	45	mph				
21			0.0025	0.001247789	3.11947E-06		400	0.00125				0.0125	mile/s				
22												0.00193	kg/s				
23		Fuel efficiency, E60	0.5709535									0.00379	kg/m^3 to kg/gal				

Additional Information

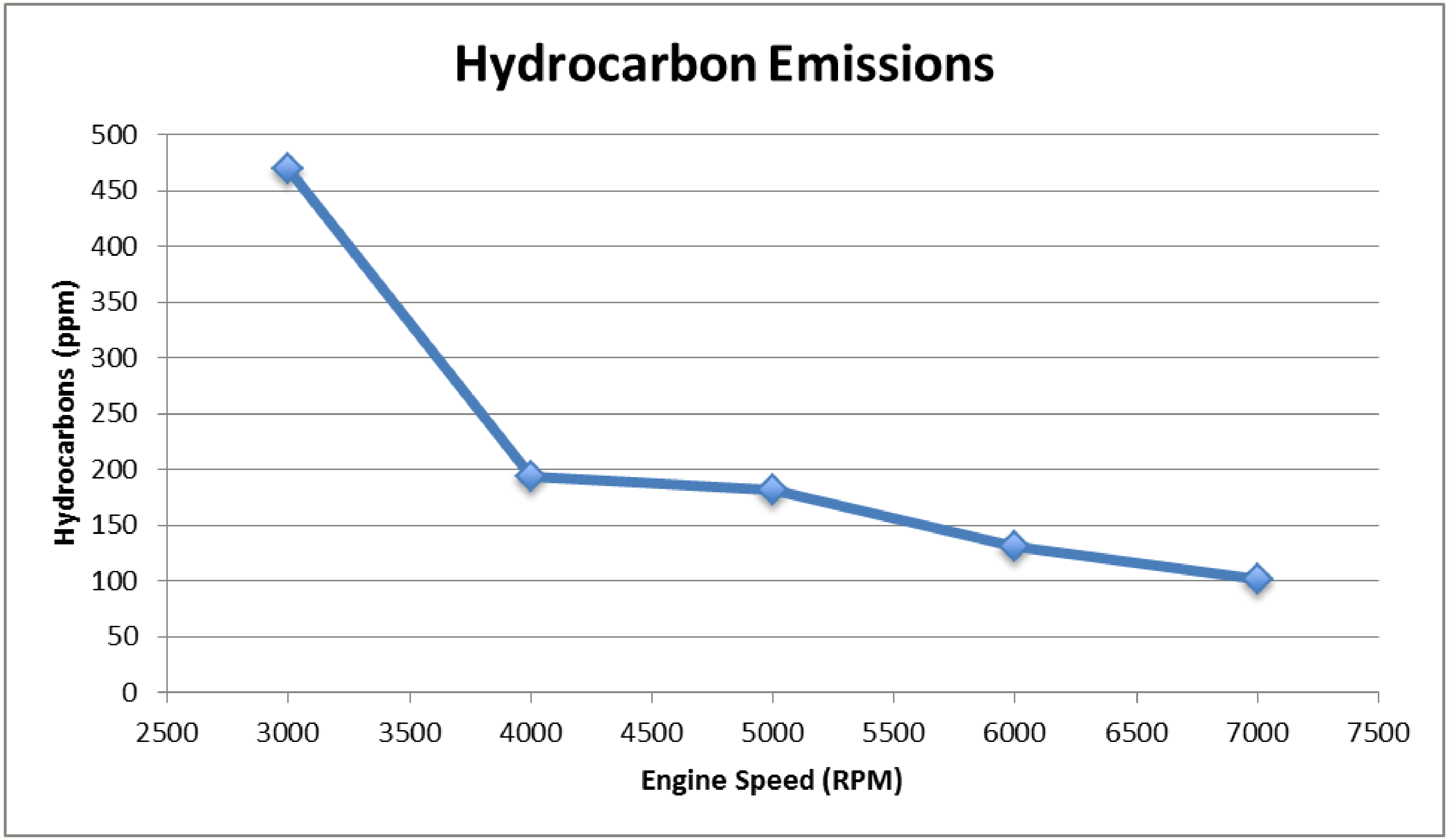
Performance Electronics ECU



Emissions

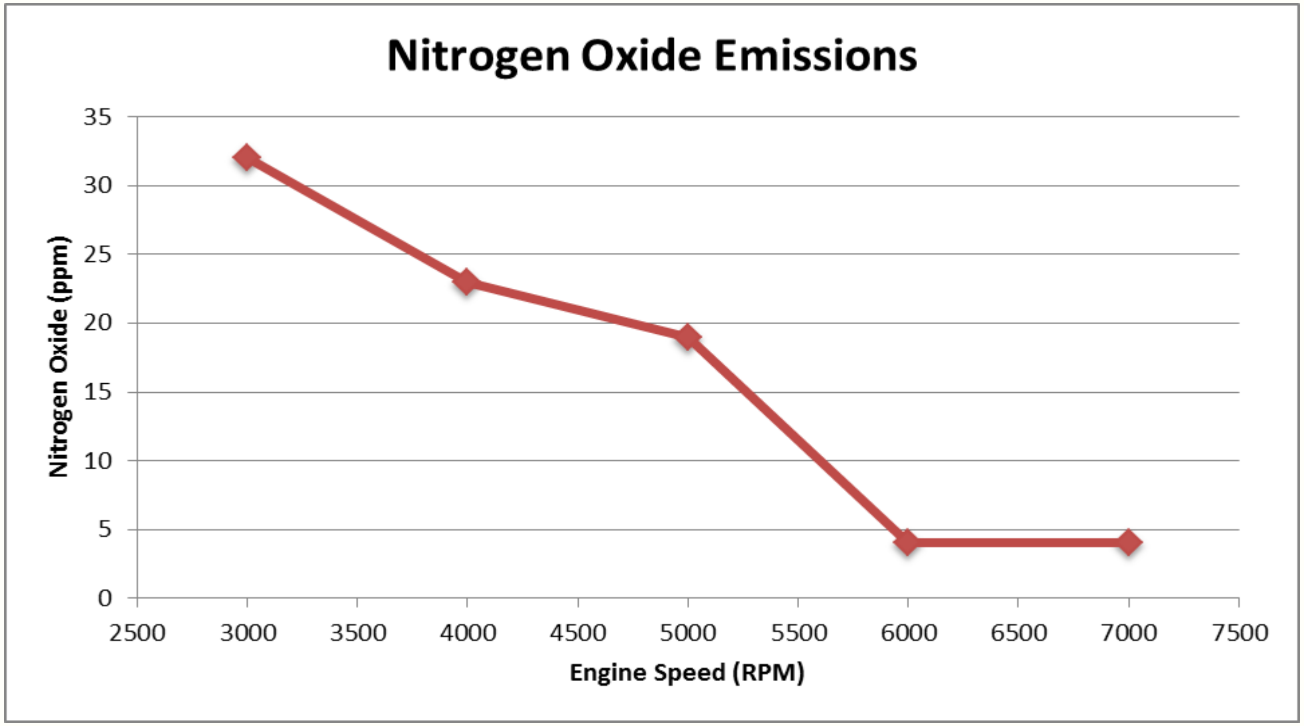

Carbon Monoxide Emissions
10.35
10.3
10.25
10.2
10.15
10.1
10.05
10
9.95
9.9
9.85
Carbon Monoxide (%)
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
Engine Speed (RPM)

Emissions



Hydrocarbon Emissions
Hydrocarbons (ppm)
500
450
400
350
300
250
200
150
100
50
0
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
Engine Speed (RPM)

Emissions



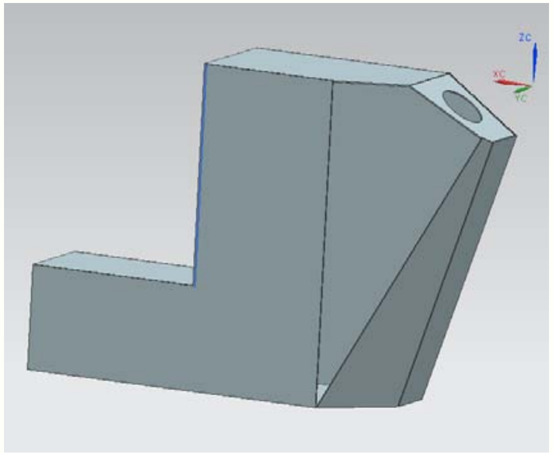
Nitrogen Oxide Emissions
35
30
25
20
15
10
5
0
Nitrogen Oxide (ppm)
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
Engine Speed (RPM)

Collection Box Failure

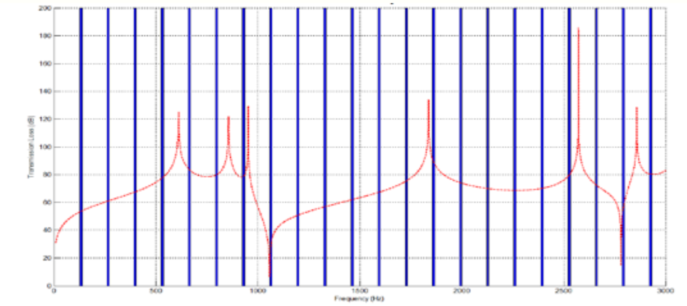
- Collection box failure during validation testing

- Re-designed collection box after failure analysis
  - Features chamfered edges for improved flow characteristics and heat management

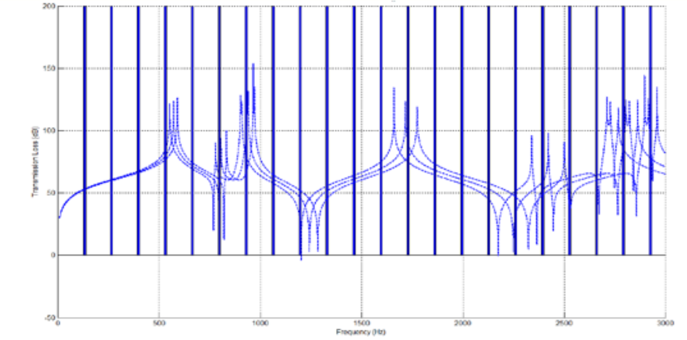
Muffler Design



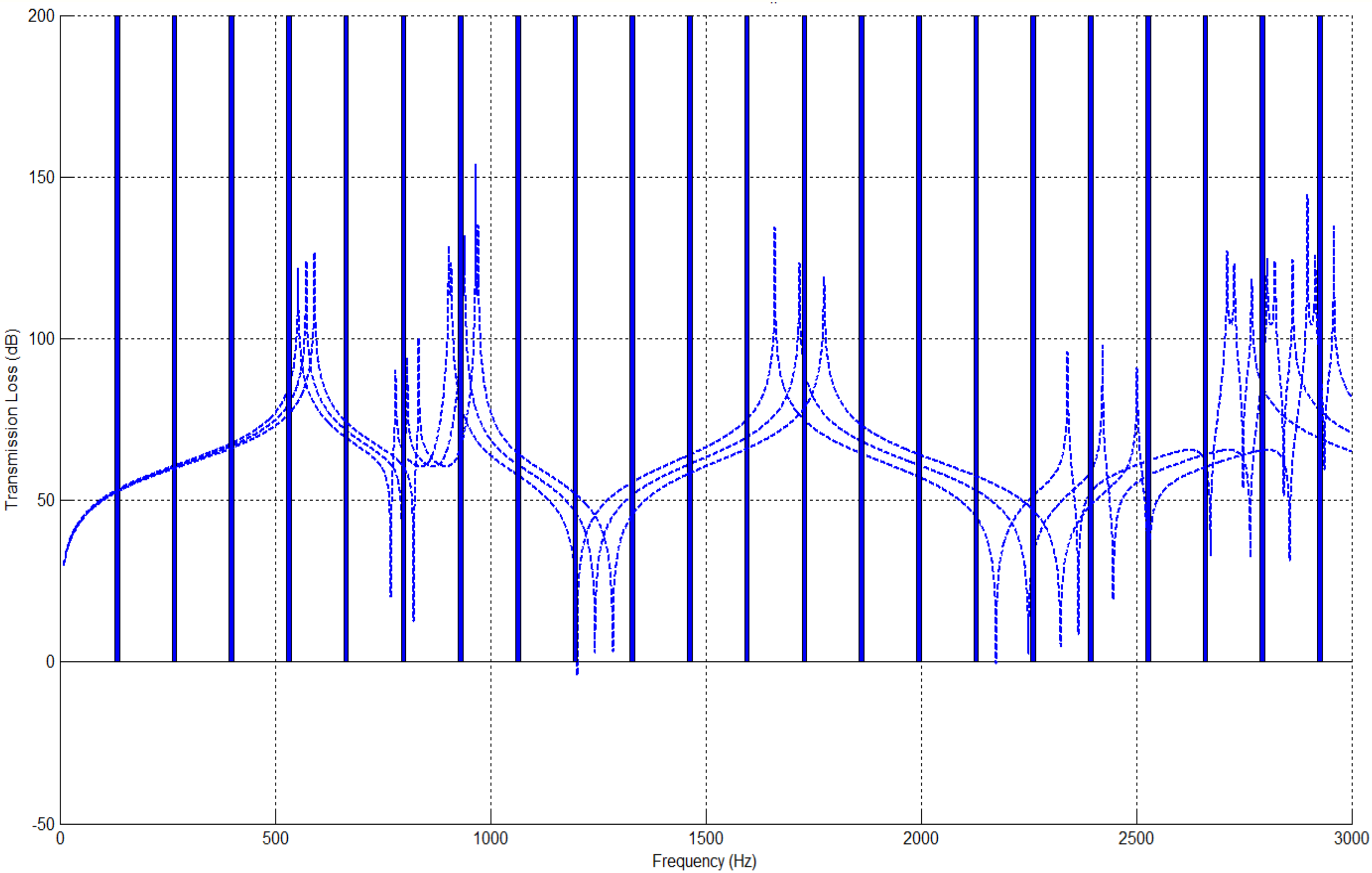
- CAD model of outer shell
  - Designed to be functional yet easy to fabricate/manufacture



- Matlab analysis of single chamber transmission loss
  - Each red spike represents a predicted resonance if aligned with a blue engine frequency line



- Matlab analysis of dual chamber transmission loss
  - Analyzed at 900˚C, 950 ˚C, and 1000 ˚C
  - Muffler simulations were ran for chamber distance of 5, 6, 7, 8, and 9 inches from the top of the muffler



Transmission Loss (dB)
Frequency (Hz)
200
150
100
50
0
-50
0
500
1000
1500
2000
2500
3000