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SAE Snowmobile Team

University of Wisconsin Madison

2009 SAE Clean Snowmobile Challenge

Presented by:

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Brad Hall

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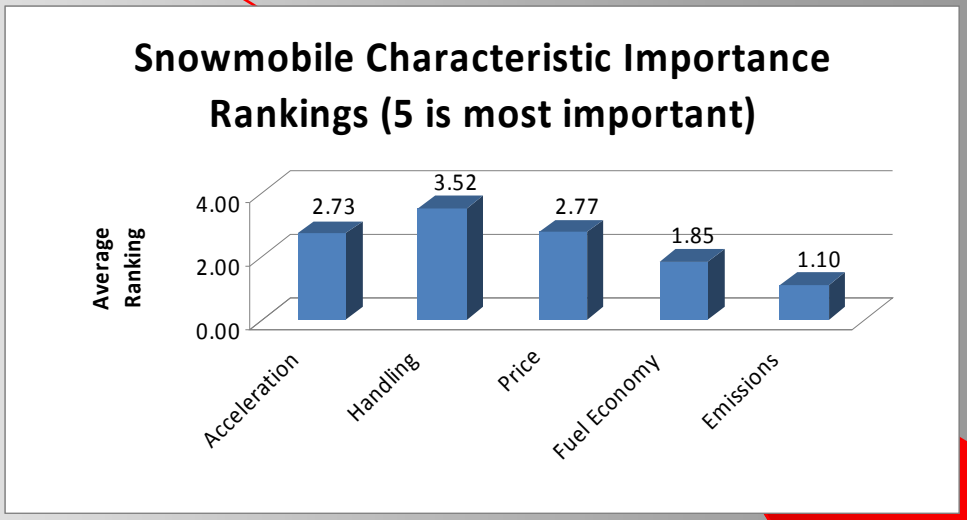
Clean
Quiet
FAST

Design Considerations:

Market Survey

- Survey at Eagle River World Championship Snowmobile Derby
  - Approximately 115 surveys
- Customers Want:
  - Trail Handling
  - Acceleration
- Historical Best Sellers
  - Ski-Doo Rev 600 SDI
  - Polaris 600 XC SP



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Bucky 750 CFS

How it Appeals to Snowmobilers

Reduced Noise
Increased Fuel Economy
Flex Fuel
Improved Acceleration
20+ mpgge
Cruise Control Capable
BAT Compliant
Electric Start
2007 FST LX Chassis
Top of the Line Suspension
105 peak hp operating on E85

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Dealer & Outfitter Perspective

- Sales
  - Cleaner/Quieter Performance Model
  - Less than 4% Increase in Current Turbo Model's MSRP
  - Better Fuel Economy, BAT Compliant
- Maintenance
  - Integrated Catalyst/Muffler – Bolt-in Replacement
  - Plug and Play Flex-Fuel Intake/Fuel System
    - ETC, Grid Heater, Flex Fuel Sensor
- Novice Snowmobiler Operation
  - OEM Controls
- Rider Comfort
  - OEM Seat, Handlebars, Suspension, Reduced Noise

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Engine Selection

- Engine emissions from current snowmobile engines
- Ski-doo SDI system reduces two stroke emissions by 50%[1]
- Stock Polaris FS engine meets 2012 Emissions Certification

Snowmobile Engine Emissions Testing

	HC g/kW-hr	CO g/kW-hr	NO_x g/kW-hr
Two-stroke average (SwRI 2002)	189	517	0.72
Arctic Cat 660 (4s) (SwRI 2002)	6.2	79.9	10.6
Polaris Liberty (4s) (SwRI 2002)	3.2	79.1	7.0
Polaris FS (4s)	9.3	38.6	1.5

1: http://www.ski-doo.com/media/2004_SOTY.pdf

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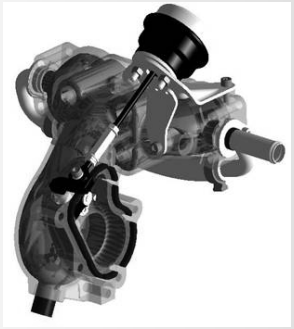
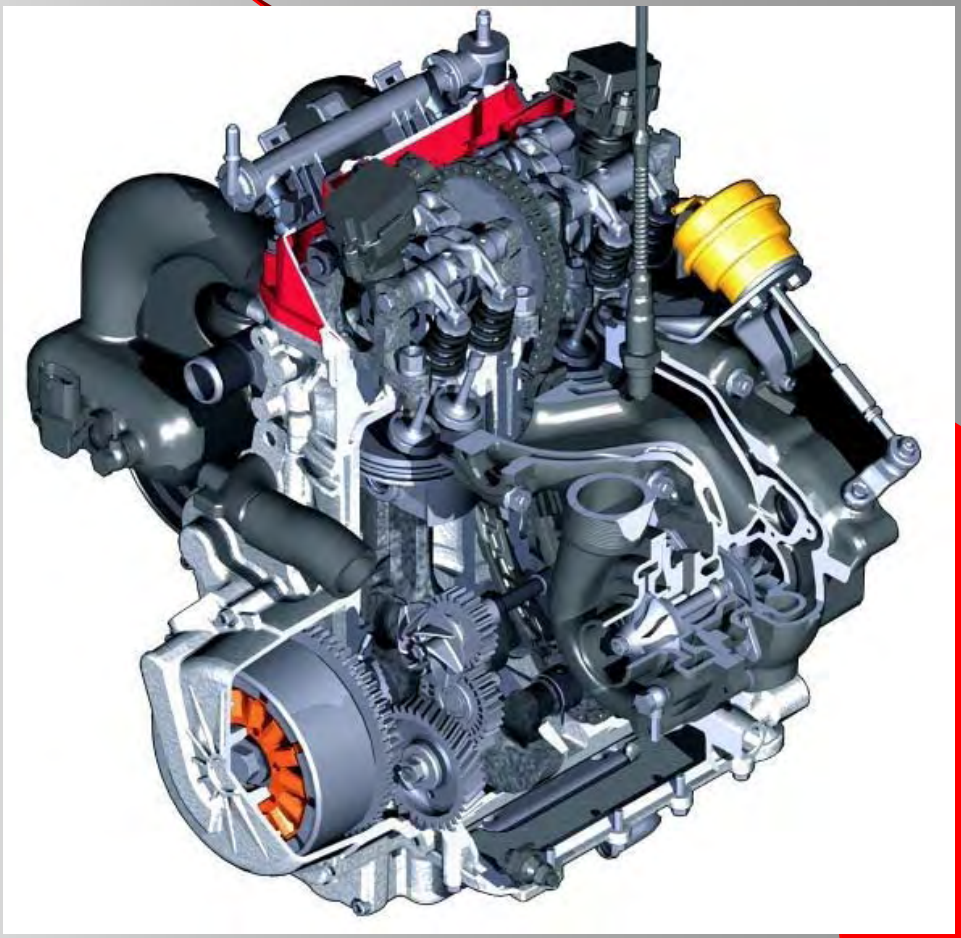
Turbo Charged Weber MPE 750 with Automotive Camshaft





Engine Type	Four Stroke
Cooling	Liquid
Cylinders	2
Displacement	750 cc
Bore x Stroke (mm)	85 x 66
Ignition	Bosch
Exhaust	Single
Fueling	EFI
Compression Ratio	9:1

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Engine Control and Emissions Reduction

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Engine Management

Woodward/Mototron PCM555

Ratings:

- Automotive/Marine Environments
- -40° – 130 °C
- 18 g Shock Load
- Up to 3 Meters Underwater

MATLAB/Simulink Engine Modeling

MotoHawk Automatic Code Generation

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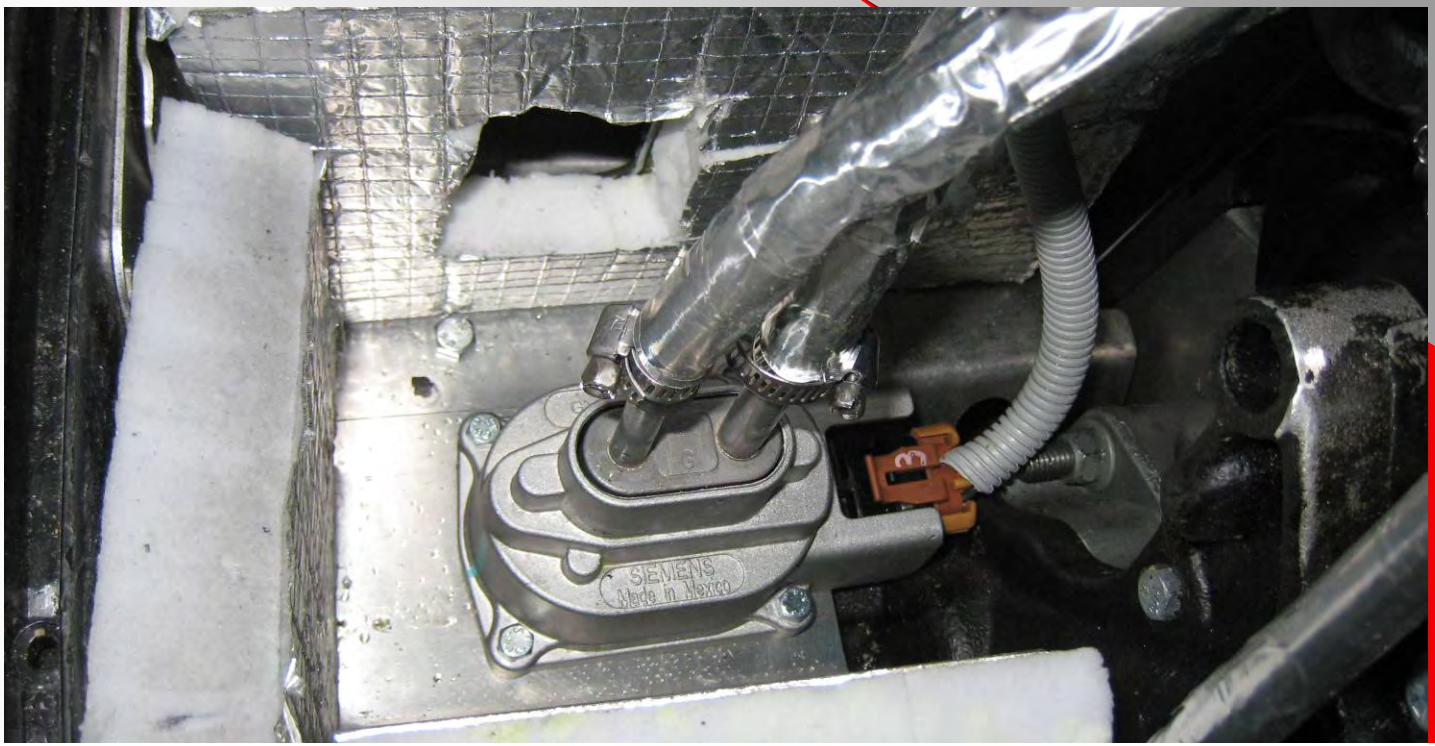
Flex Fuel Sensor



Continental Flex Fuel Sensor

- Reports ETOH Content & Fuel Temperature

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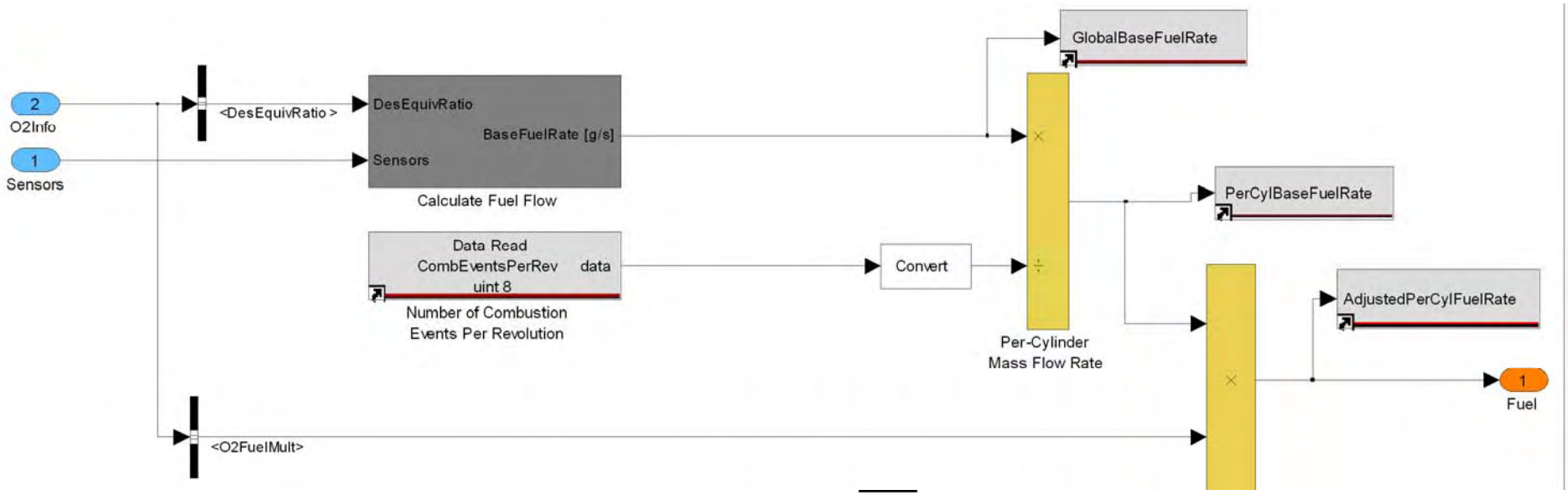
Flex Fuel Control Algorithm



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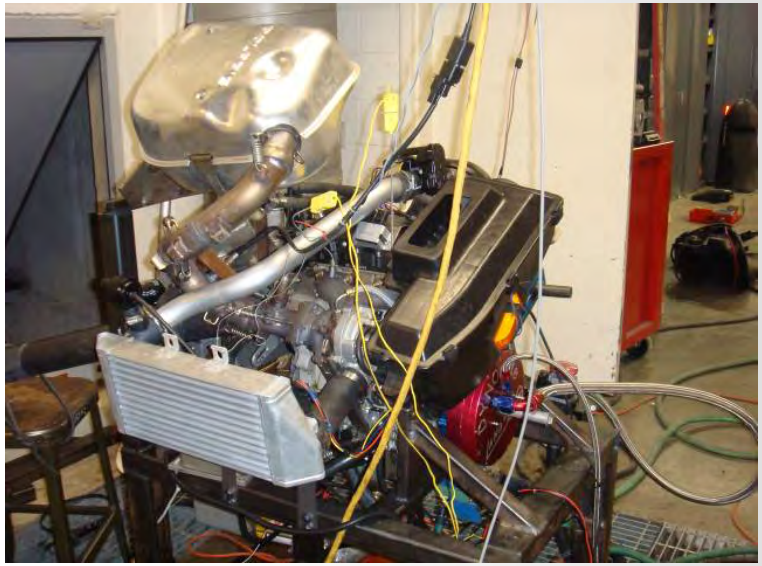
Engine Calibration



- DYNOmite Water-Brake Dyno
- Horiba CO & CO_2 NDIR Analyzer
- Heated wide-band O_2 sensor
- Chemiluminescent NOx Analyzer
- Exhaust Thermocouples

- Calibrated Spark Advancement
- Calibrated Volumetric Efficiency within 1% of Stoichometric
  - 160 cal points
  - Increments: 500 rpm, 0.1 PR
  - Each within ±0.01λ (open-loop)
- Feedback from O_2 Sensor
  - Lean/rich target switching

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Closed-Loop O_2 Feedback Control

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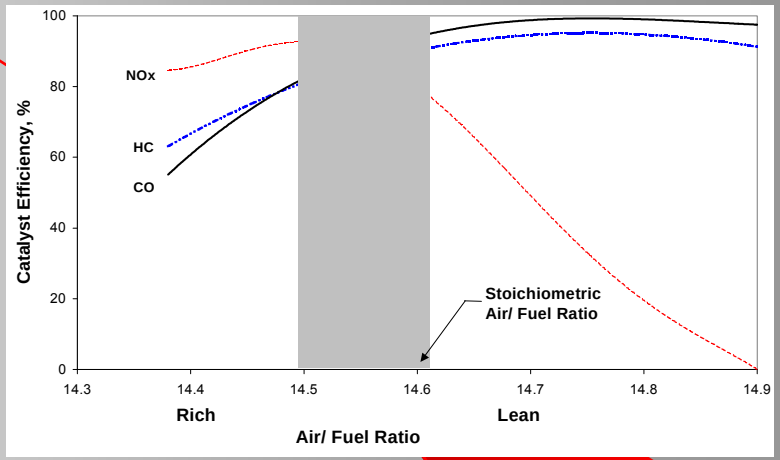
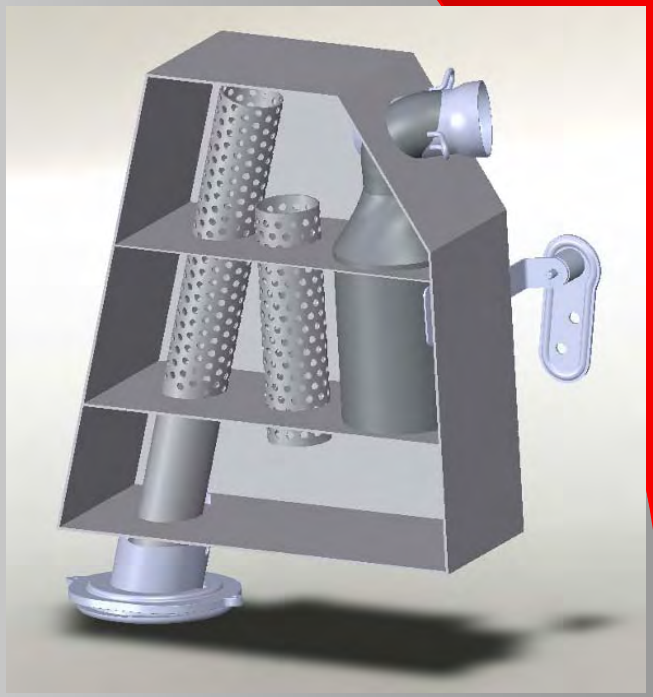
Catalytic Emissions Reduction

Improvements for 2009

- Lean/Rich Switching maximizes three-way catalytic efficiency
- Exhaust system re-designed to minimize weight, engine back-pressure and risk of pre-catalyst leaks



Manufacturer	W.C Heraeus GmbH
Diameter	105mm
Length	140mm
Substrate	SuperFoil® Metal Honeycomb
Density	600 cpsi (cells per square inch)
Loading	Platinum 11.1 g/ft^3 Palladium 55.6 g/ft^3 Rhodium 8.3 g/ft^3



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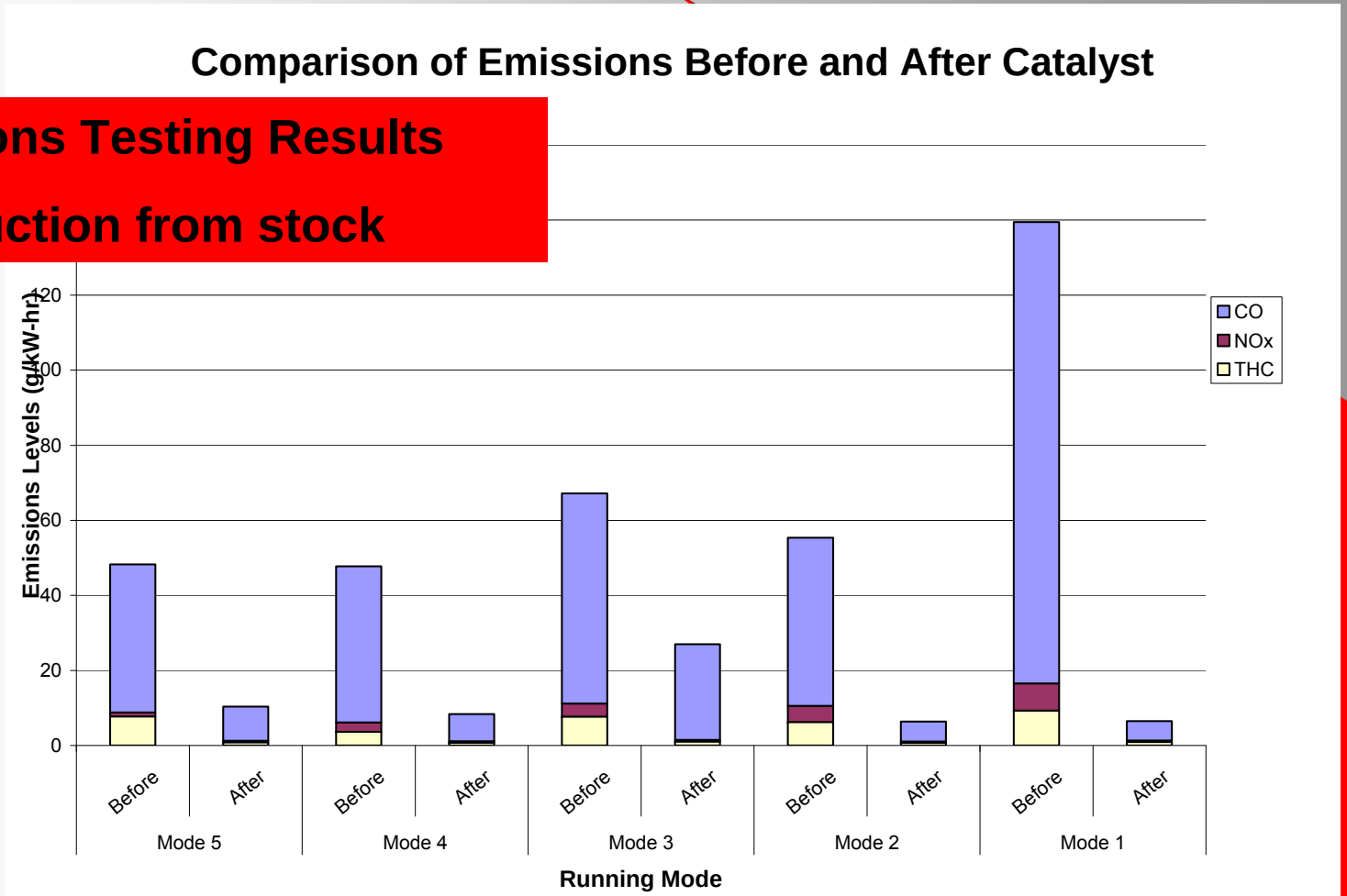
Emissions Results

2009 Emissions Testing Results

96% reduction from stock



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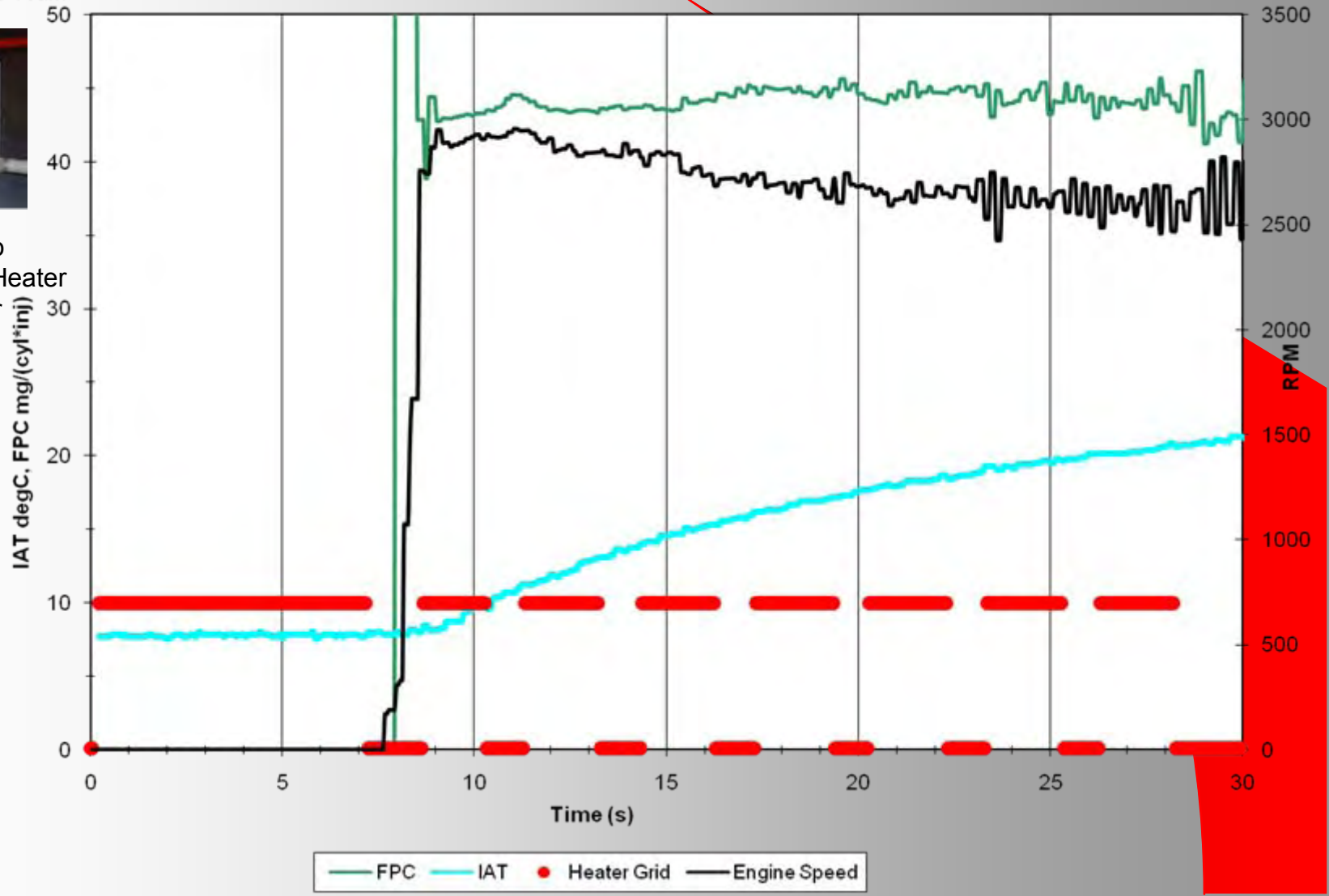
Air Intake Heater aids Cold Start

Phillips and Temro
JD300 Air Intake Heater
1.1 kW grid heater



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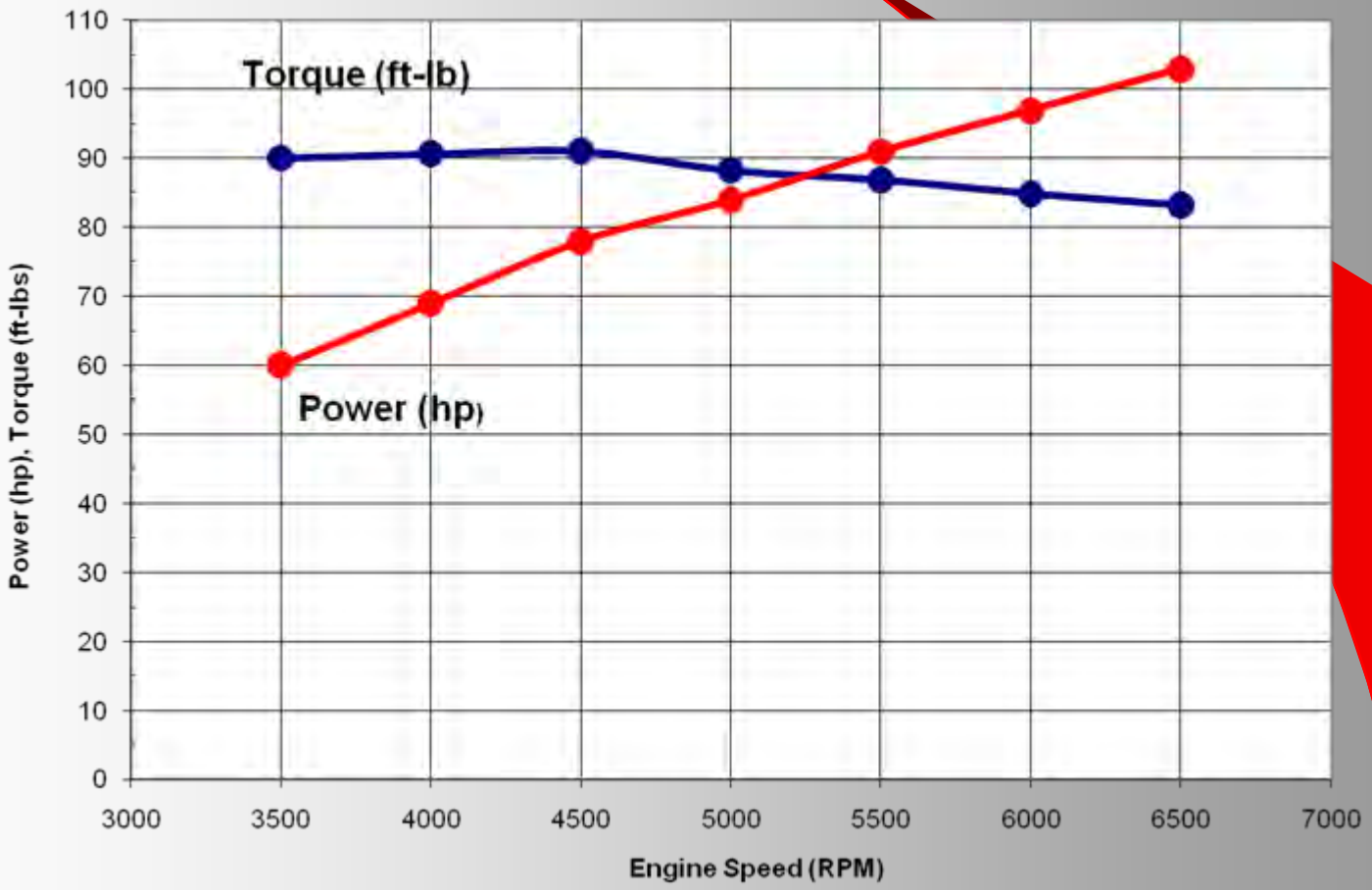
E-85 Power Curve



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Tuning and Performance

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Clutch Tuning

- Goals:
  - Maximize fuel economy
  - Achieve desirable riding characteristics
  - Engine operation within a target rpm range
- Systematic Clutch Adjustments
- Calibration of rev and boost limits

Target
6000 rpm max engine speed
55 mph @ 5000 rpm

Run	Engagement RPM	Max RPM	Max Speed (mph)	Spring Color	Cam Arm Mass (g)
1	4000	6600	15	Black/White	50
2	3900	6600	15	Black/White	52.5
3	3600	6500	35	Orange	60.7
4	3500	6500	50	Orange	72.5
5	3200	6500	55	Orange	76
6	3000	6500	55	Pink	76
7	2200	7000	70	Pink	84
8	2000	6000	90	Pink	90
9	3000	6000	94	Orange	90

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Performance

- Acceleration
  - 150 ft 50 mph
  - 300 ft 60 mph
  - 500 ft 69 mph
- Top Speed
  - 91 mph
- Fuel Economy
  - 20+ mpg gasoline equivalent

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Sound Testing

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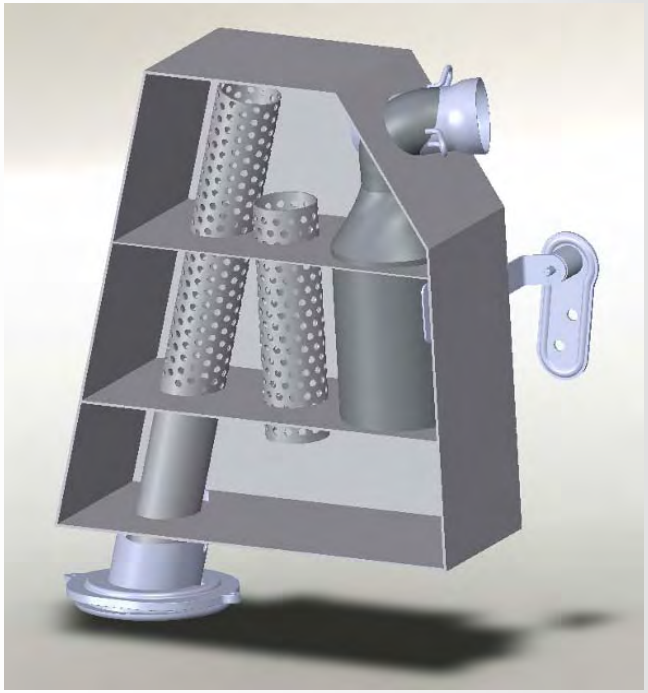
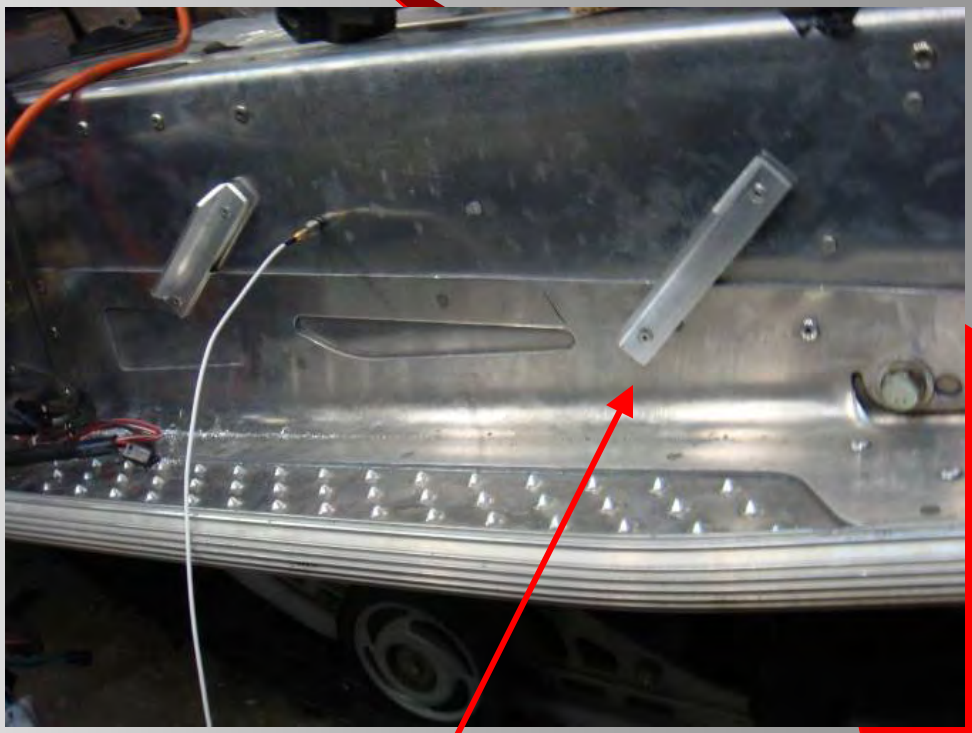
Sound Reduction

Engine

- Three Stage Exhaust System
  - Turbocharger turbine
  - Catalyst
  - Custom-Designed Muffler



Chassis



Tunnel Stiffeners

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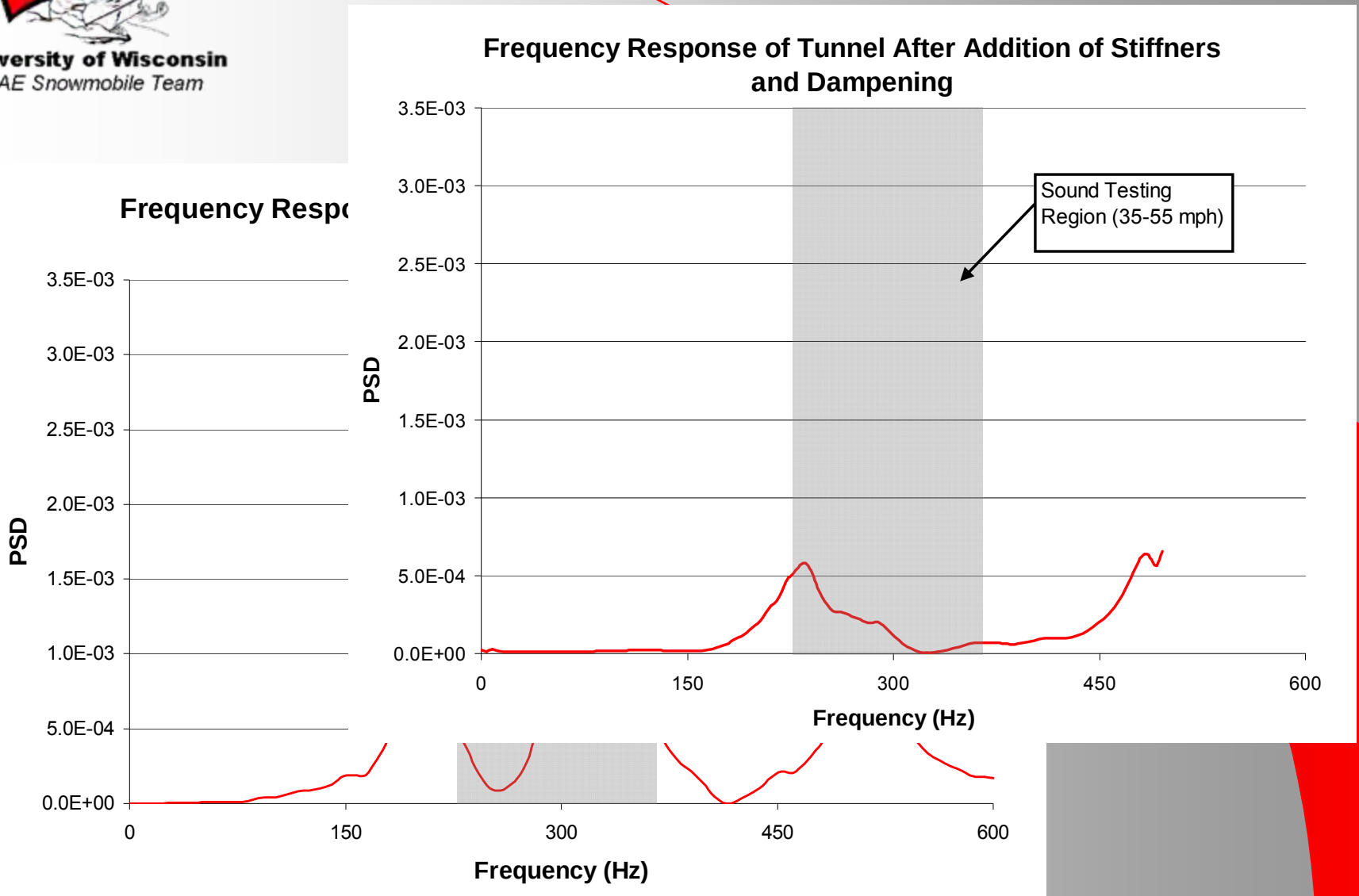
Resonance of Tunnel



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Total Sound Reduction

- Measured sound level of based on pass-by testing - SAE Standard J192

- J192 Limit – 78 dBA maximum
- Stock Muffler – 75 dBA
- Bucky CFS – 73 dBA

- 37% Noise Reduction

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Questions?

Modifications

- Custom exhaust
- Mototron control system
- Electric Throttle Control
- Air intake heater
- Ethanol compatible fuel system
- Fuel oxygenation sensor
- Studded track
- LED headlights and taillights
- Chassis noise reduction
- Lightweight Drive Shaft

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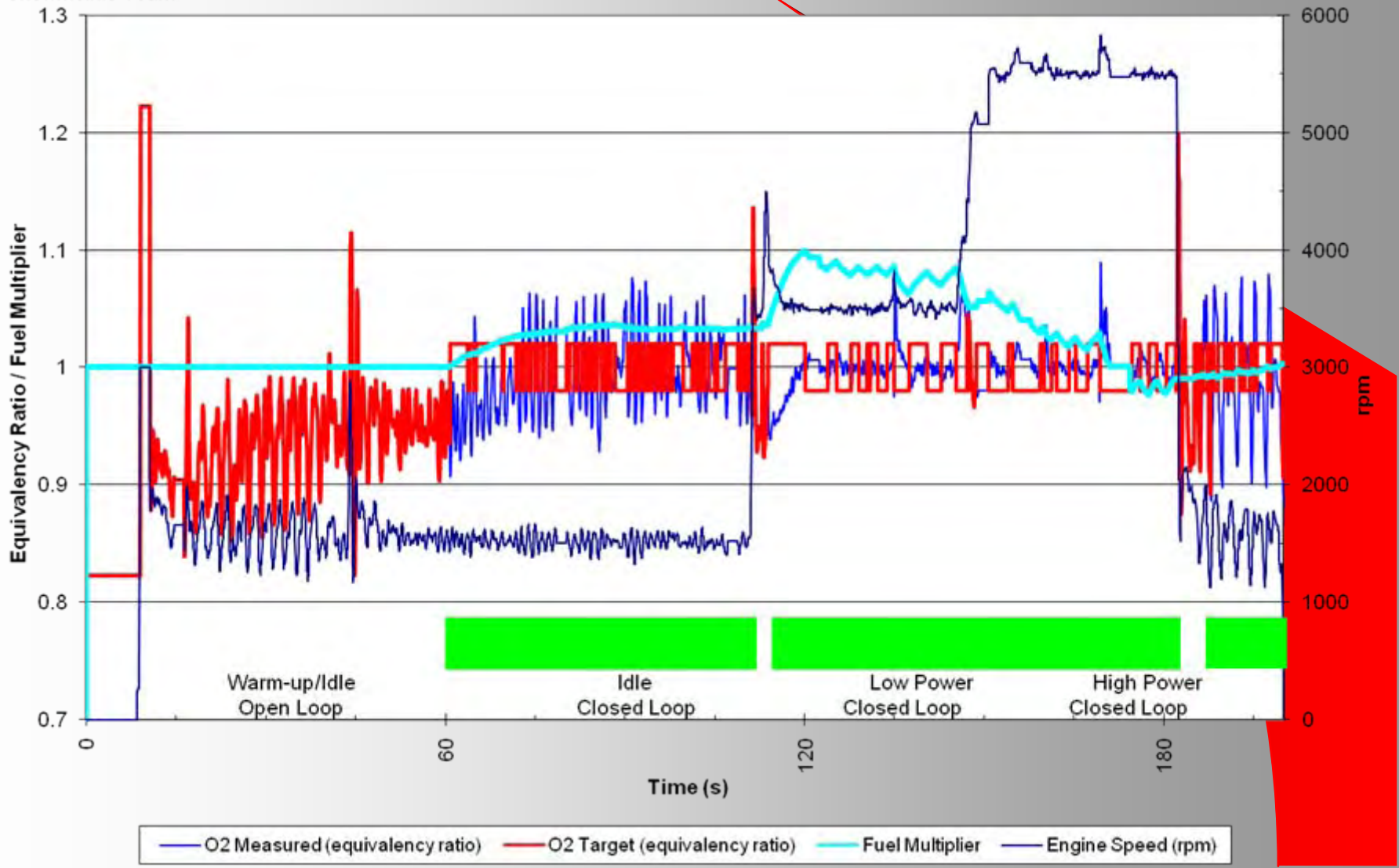
Closed-loop operation after cold start



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Why Not DI2S?

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Emissions Testing Modes

	Engine Speed (rpm)	Torque (N-m)	Power (kW)
Mode 1 (WOT)	5500	105.9	61.0
Mode 2 (85%)	4675	54.0	26.4
Mode 3 (75%)	4125	34.9	15.1
Mode 4 (65%)	3575	20.1	7.5
Mode 5 (idle)	1500	0.0	0.0

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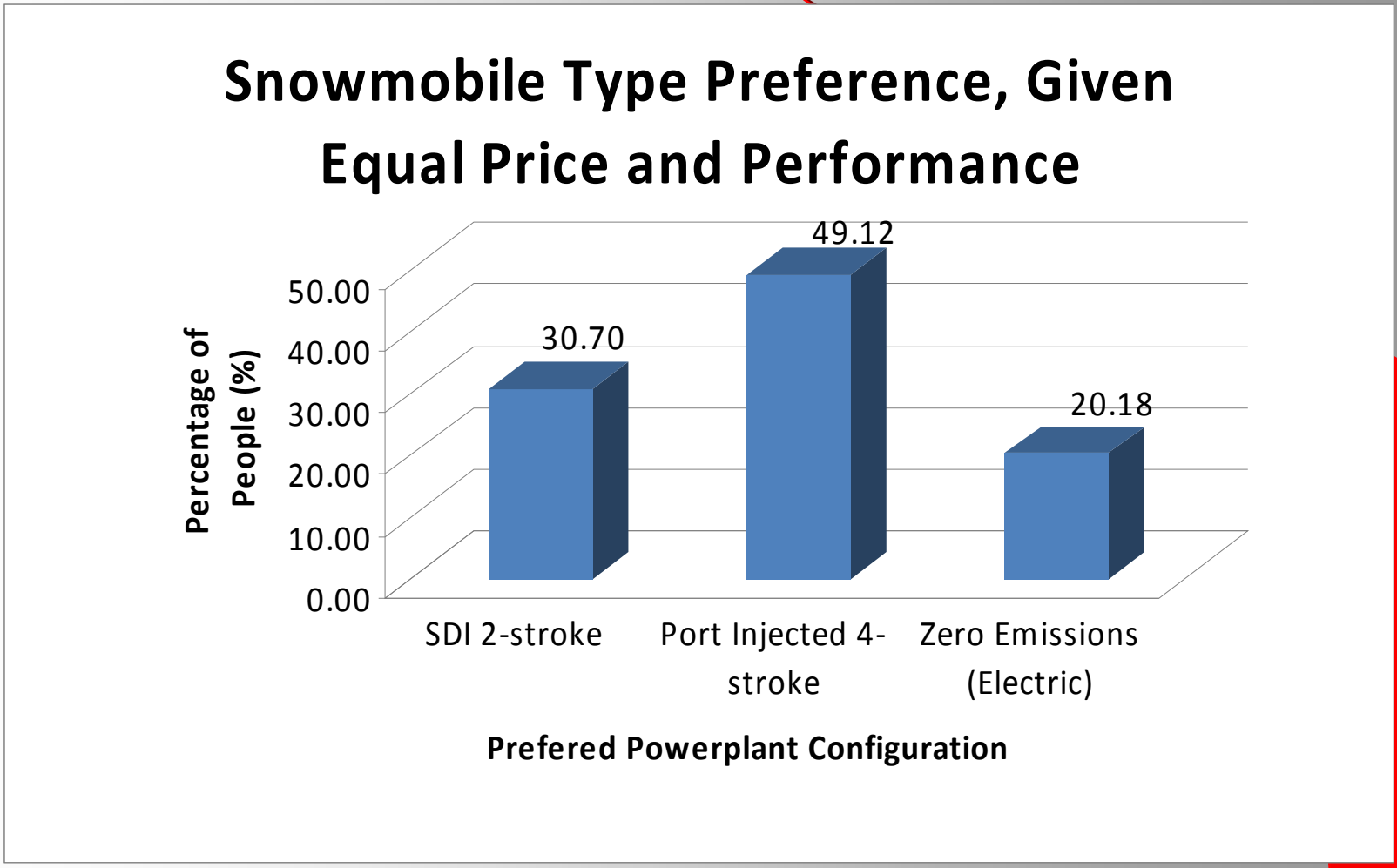
Customer Survey



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Catalyst Specs

Manufacturer	W.C Heraeus GmbH
Diameter	105mm
Length	140mm
Substrate	SuperFoil® Metal Honeycomb
Density	600 cpsi (cells per square inch)
Loading	Platinum 11.1 g/ft^3 Palladium 55.6 g/ft^3 Rhodium 8.3 g/ft^3

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Drive Shaft