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SAE Snowmobile Team

# University of Wisconsin-Madison

## SAE Clean Snowmobile Challenge Design Presentation 2015



**Presenters: Saager Paliwal and Michael Solger**



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# **DESIGN PROCESS AND ENGINE SELECTION**



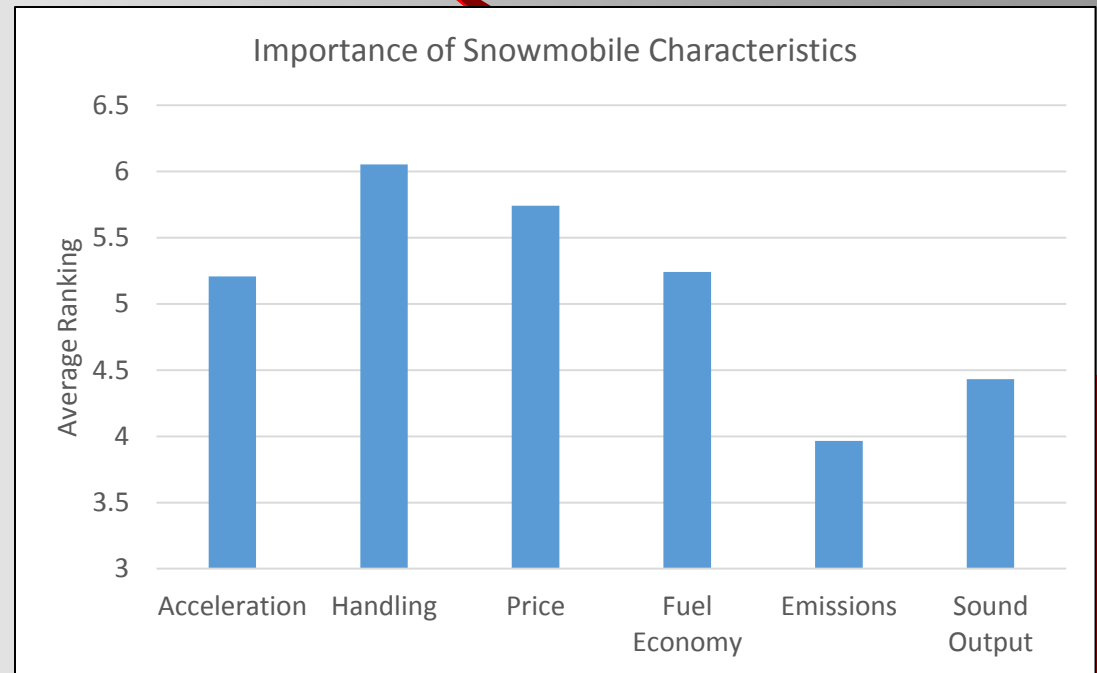
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# Design Considerations:

## Survey of 25 Wisconsin Snowmobile Clubs

- Customers Want:
  - Trail Handling
  - Fuel Economy
- Historical Best Sellers
  - Ski-Doo Rev XP 600 SDI
  - Polaris Rush 600



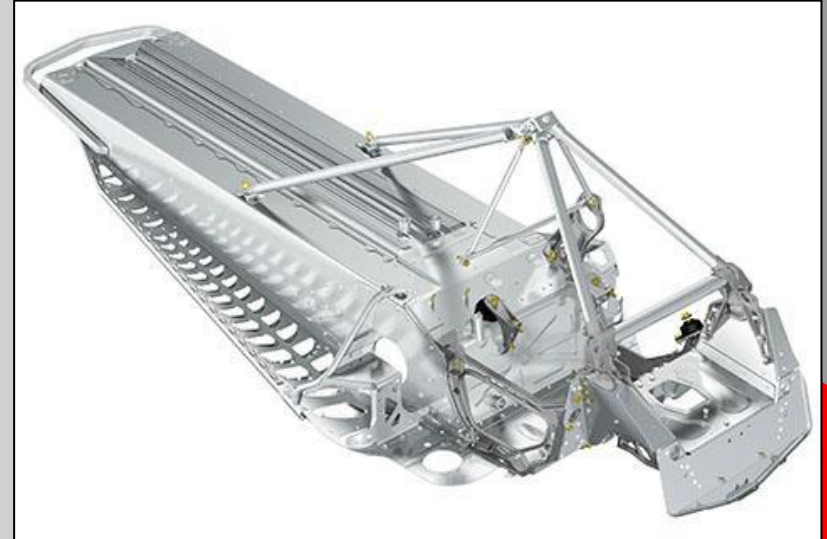


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# Chassis Selection

## 2013 Ski-doo MXZ Sport

- Lightweight
- Rider-forward ergonomics
- SC-5 suspension
- Cost-effective





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# Engine Selection

## Focus Points:

- Fuel Economy
- Engine Out Emissions

Base Snowmobile	Power (kW)	Weight (kg)	Fuel Economy (km/L)	Emissions g/kW-hr)		
				HC	CO	NOx
Ski Doo ACE 600	42	40	12.3	8	90	N/A
Ski Doo ACE 900	67	55	10*	8	90	N/A
Ski Doo 1200 4tec	97	64	7.2	6.2	79.9	N/A
Polaris FST	97	62	7.6	9	116	N/A



# Turbocharged Rotax ACE 600

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Engine Type	Four Stroke
Cooling	Liquid
Cylinders	2
Displacement	600 cc
Bore x Stroke (mm)	74 x 69.7
Ignition	Custom
Exhaust	Custom 2-into-1
Fueling	EFI
Compression Ratio	12:01





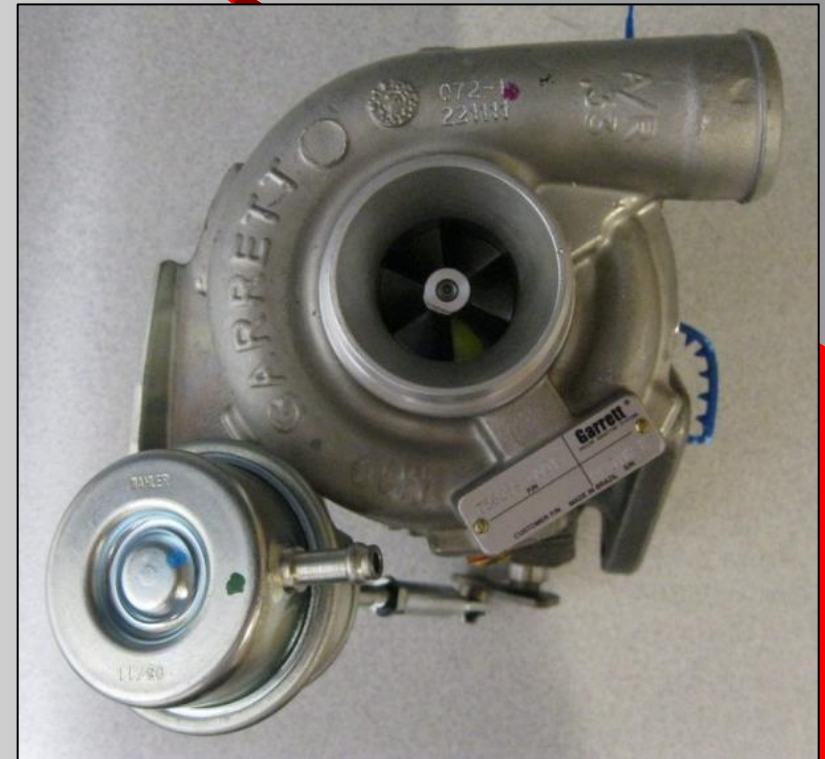


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# Turbocharger Choice

## Garrett GT1241

- 37-90 kW applications
- External wastegate with closed loop electronic boost control
- Benefits:
  - Improved efficiency
  - Increased power when needed





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# Miller Cycle

- Miller cycle operation achieved with late intake valve closing
- Optimized valve timing
- Turbocharger used to compensate for power loss of Miller cycle
- Reduced pumping losses at part load
- Increased Brake Efficiency of 6%

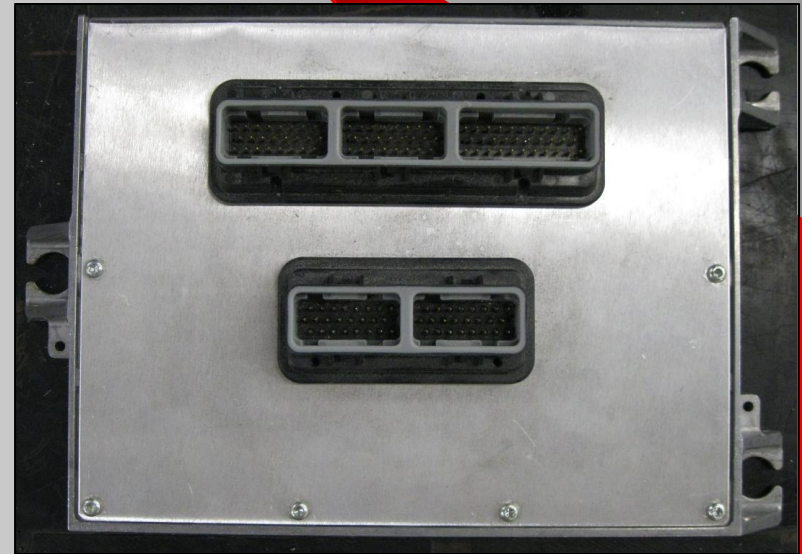




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# Engine Management

- Woodward/Mototron PCM565
  - Automotive/Marine environments
  - -40°– 130 °C
  - 18 g Shock Load
- Up to 3 Meters Underwater
- MATLAB/Simulink engine modeling
- MotoHawk automatic code generation
- Three way switching algorithm





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# Vehicle Calibrations

- Deceleration Fuel Cut and Throttle Curve
- Improved Transient Behavior
  - Increased boost
  - Spark Timing
- Better Handling through New Shocks





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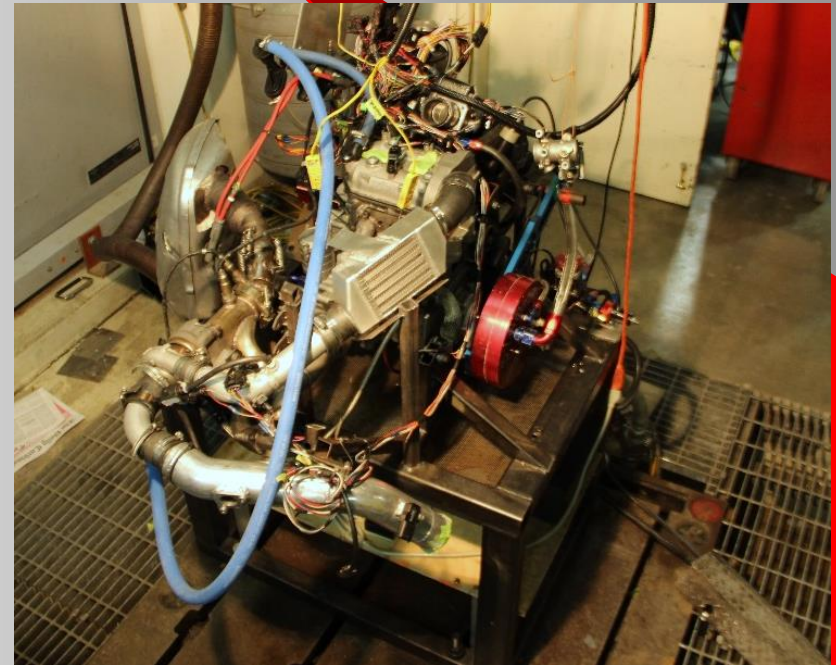
# **ENGINE OPTIMIZATION: ROOT CAUSE ANALYSIS**



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# Engine Calibration

- DYNOMite water brake dyno
- Heated wideband O<sub>2</sub> sensors
- Exhaust thermocouples
- In cylinder pressure transducers
- Calibrated:
  - Spark advance
  - Fuel Injection Quantities
  - Tuned Intake Manifold Geometry
  - Closed loop fueling
  - Throttle control



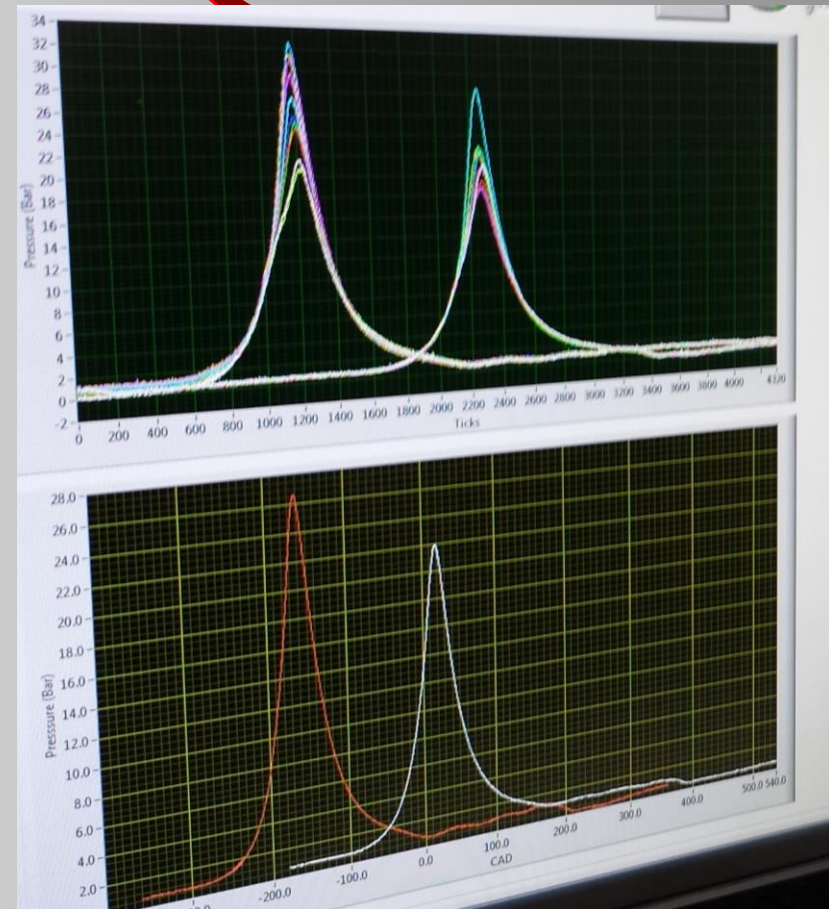
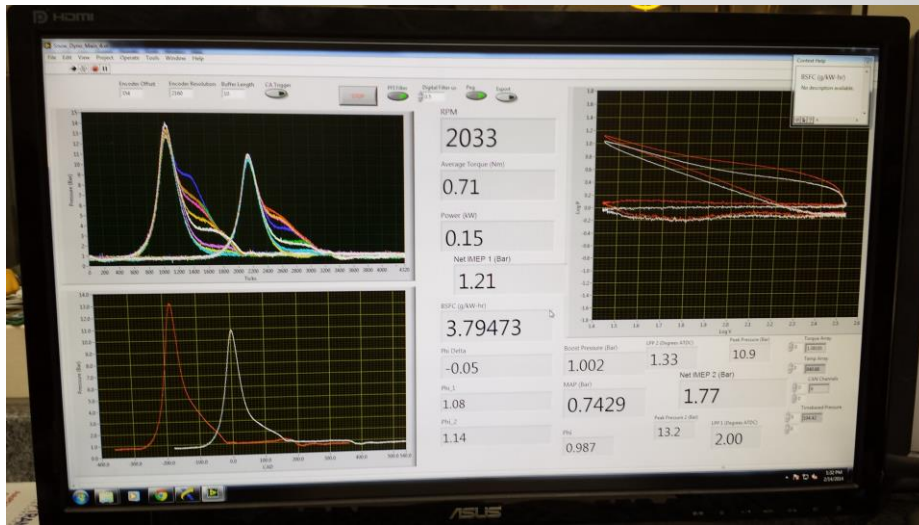




# Cylinder Filling Imbalance

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- Correct cylinder filling imbalance with new intake manifold geometry.
  - Stock manifold designed for N/A
  - 0, 540 firing order “root cause”



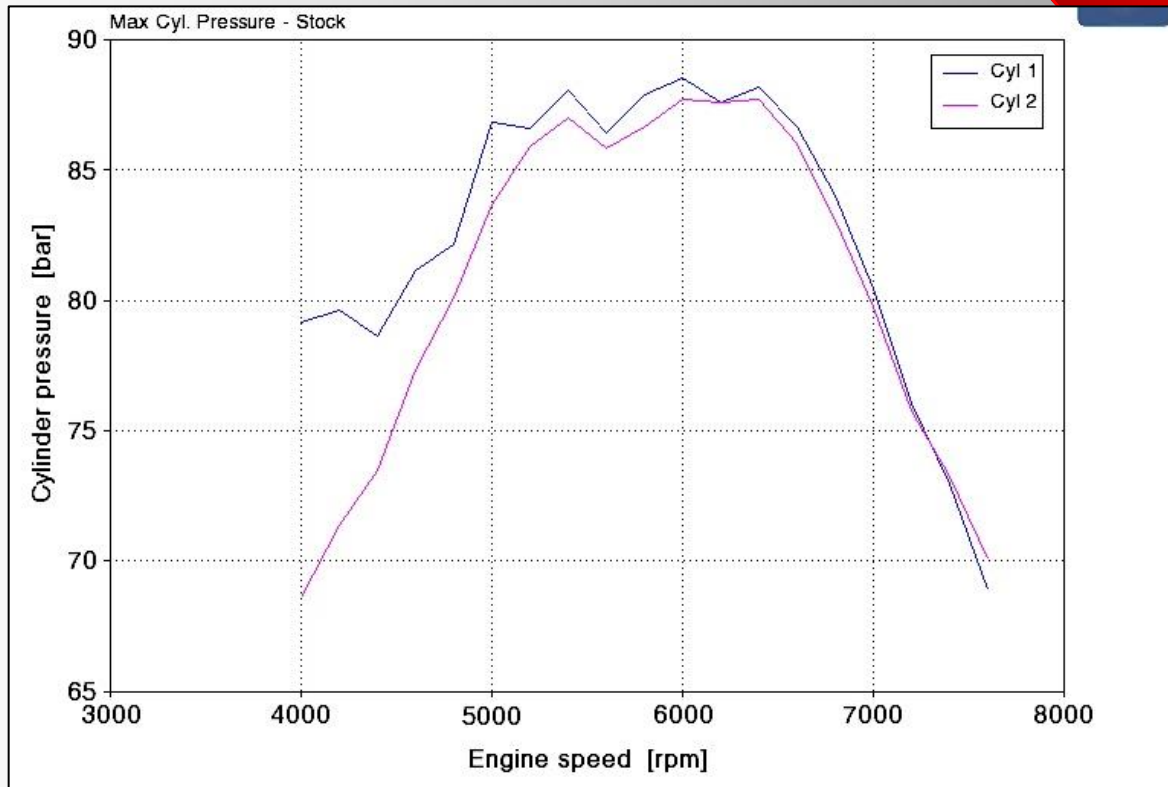


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# Root Cause Analysis

	CA [deg]			
Cylinder	180	360	540	720
1 MAG	Exhaust	Intake	Compression	Expansion
2 PTO	Expansion	Exhaust	Intake	Compression







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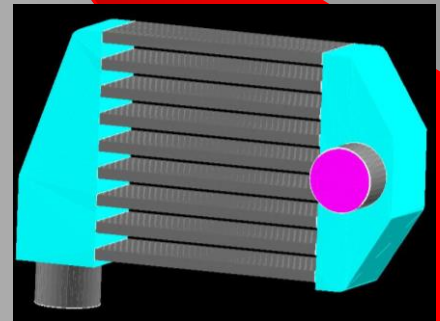
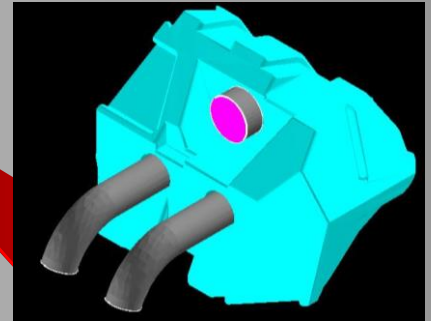
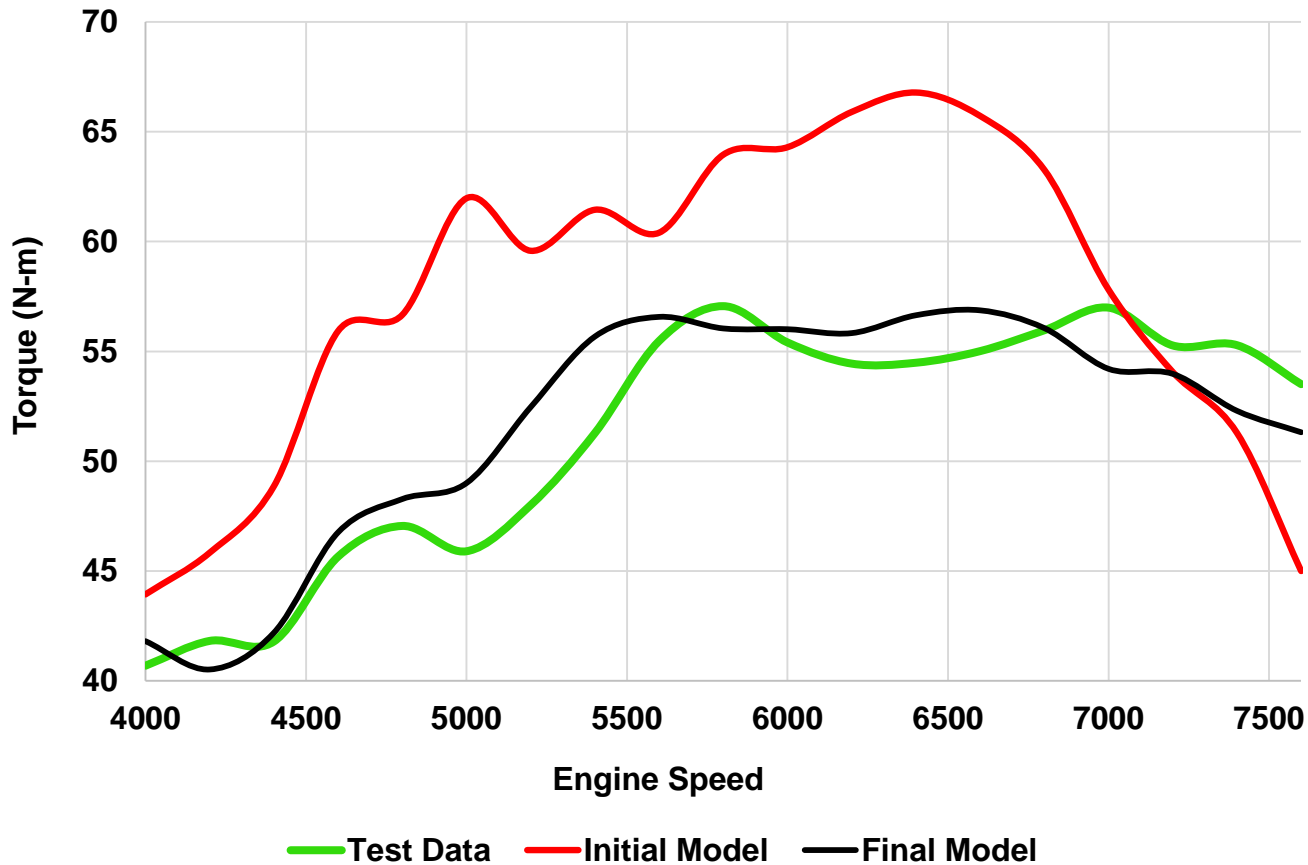
# **ENGINE OPTIMIZATION: MODEL IMPROVEMENTS**



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# Correlation

### Baseline Model Correlation



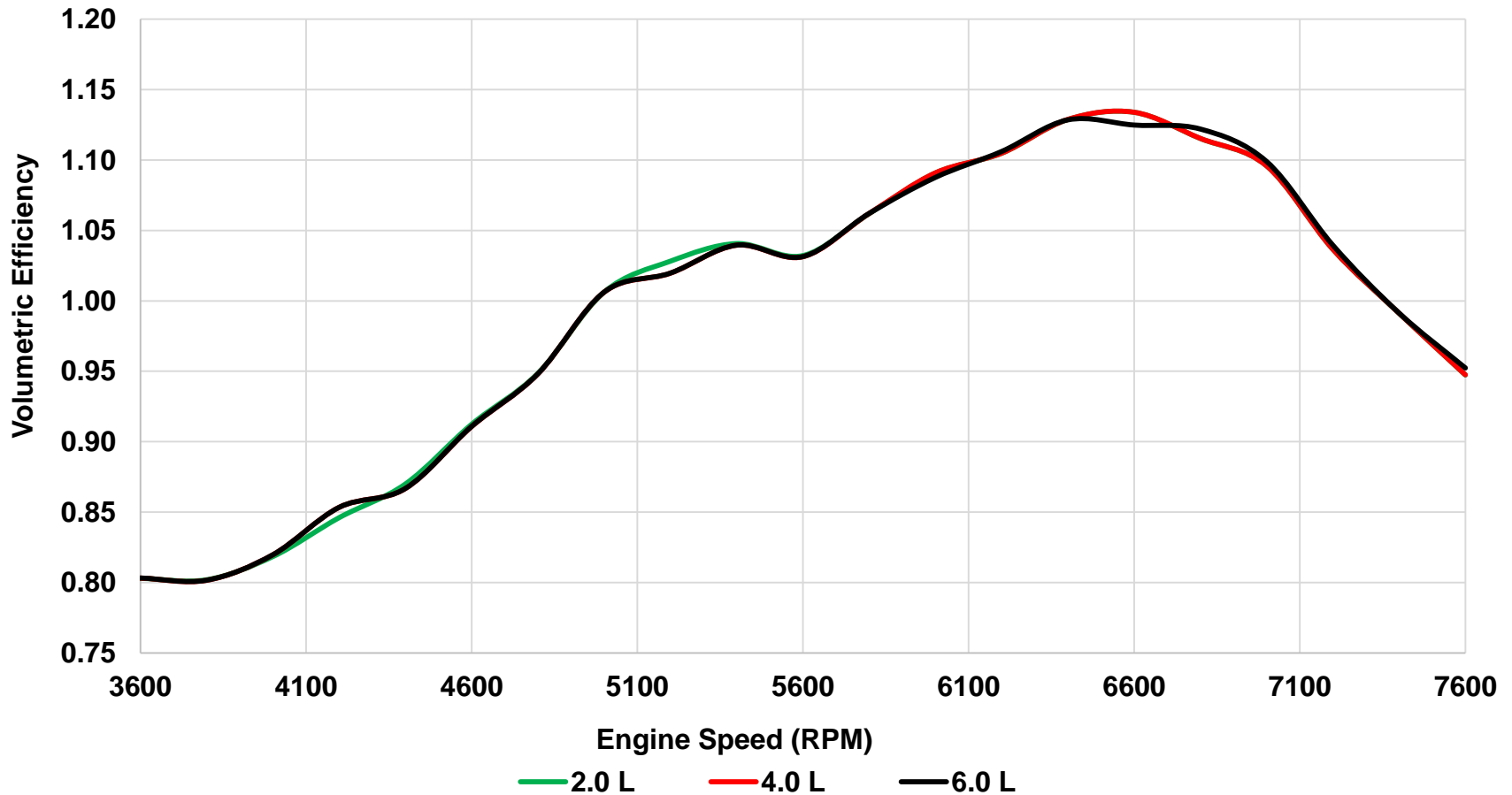


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# Optimization Parameters

## Plenum Volume vs. Volumetric Efficiency



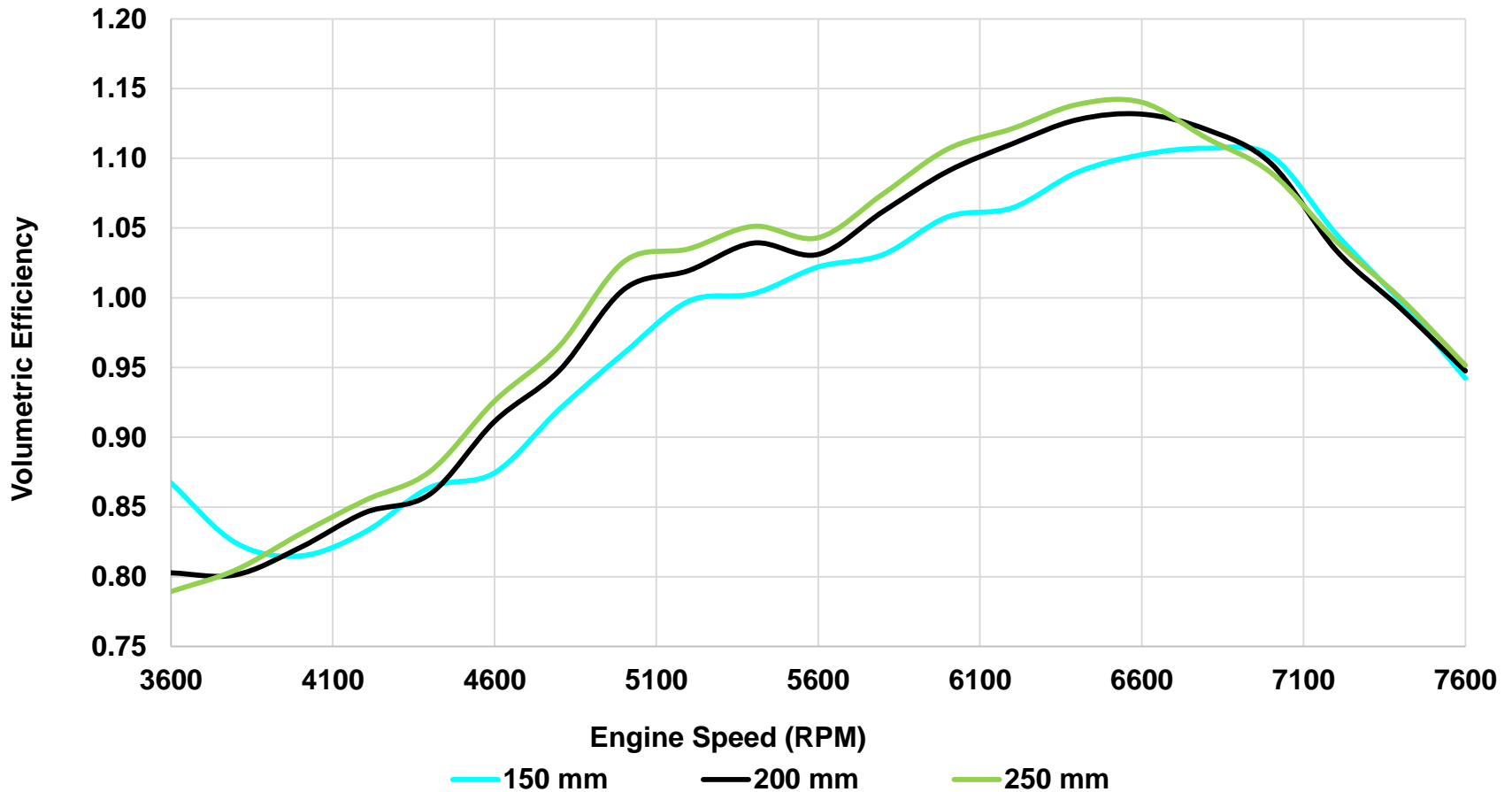


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# Optimization Parameters

## Primary Runner Length vs. Volumetric Efficiency



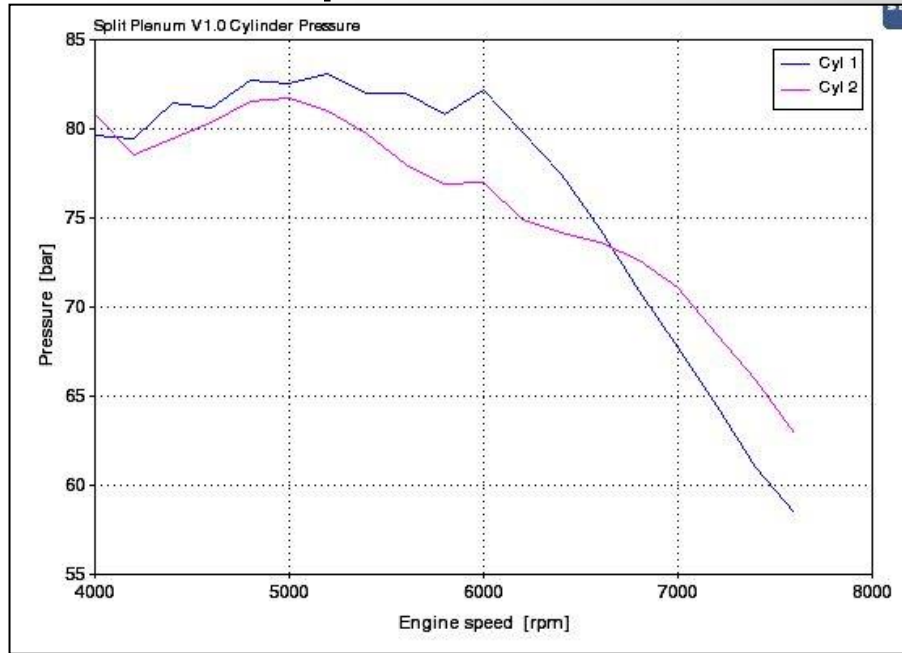


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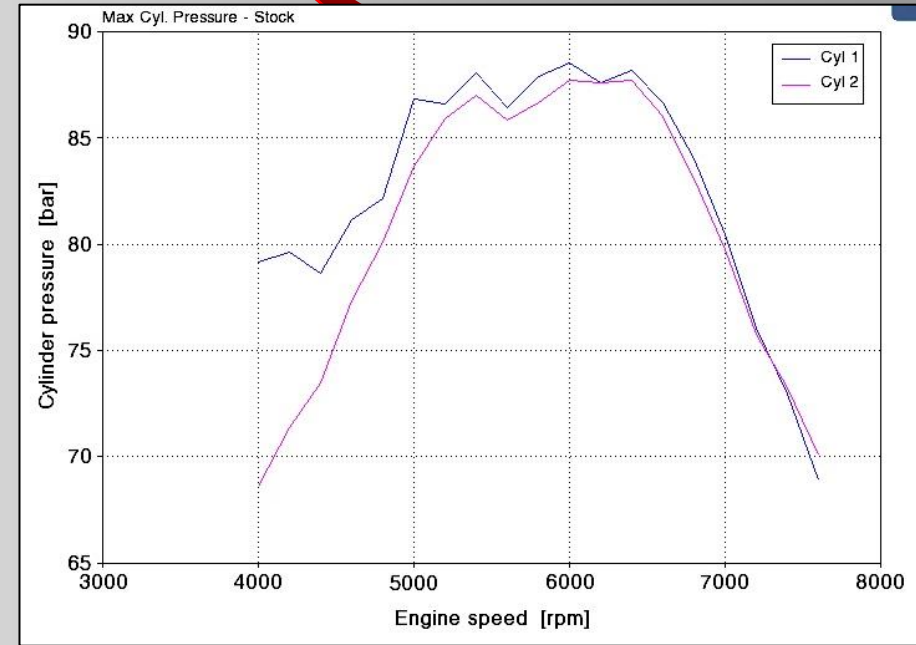
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# Initial Results

## Split Plenum



## Stock

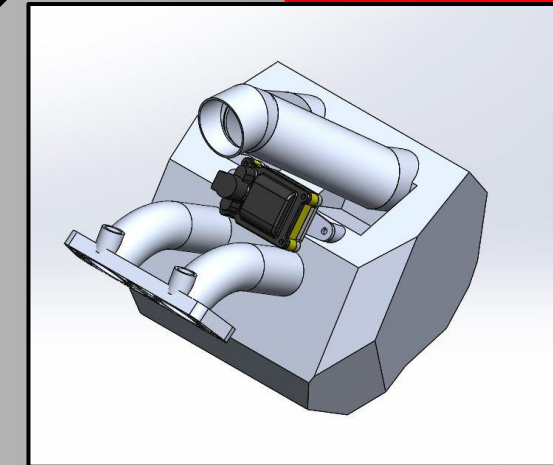
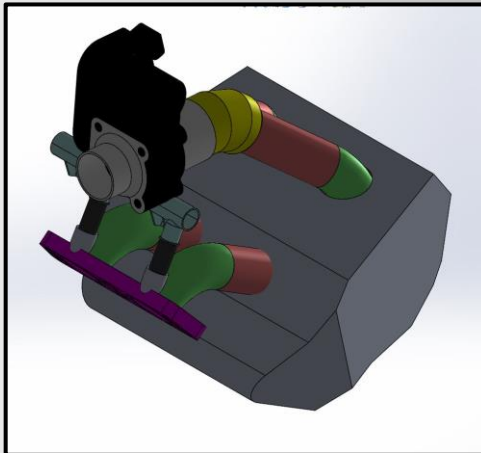
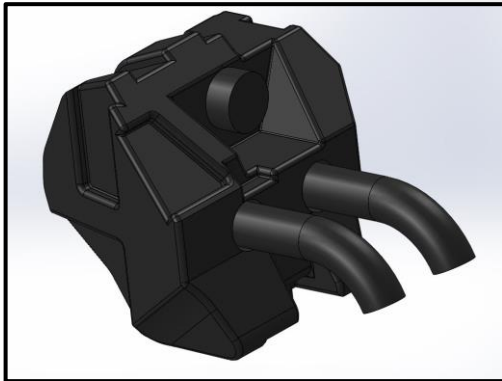
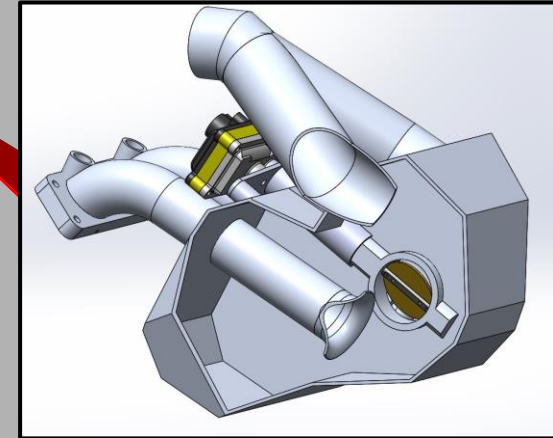
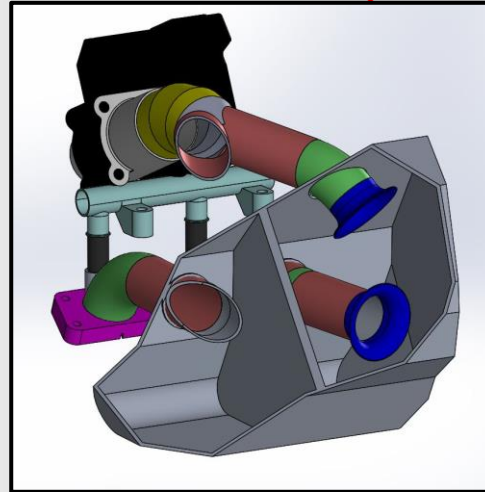
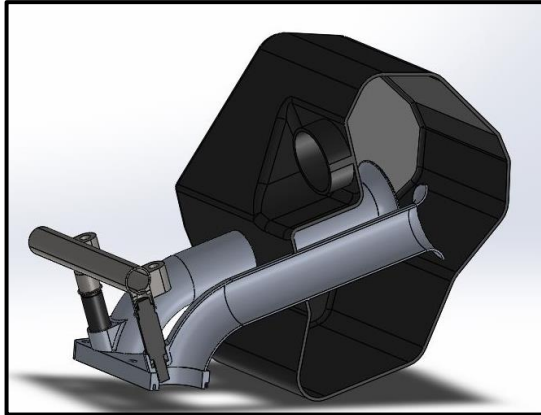


- Balanced until 5000rpm
- VE suffering at higher speeds



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# Manifold Designs



Stock 2013

Split Plenum V1

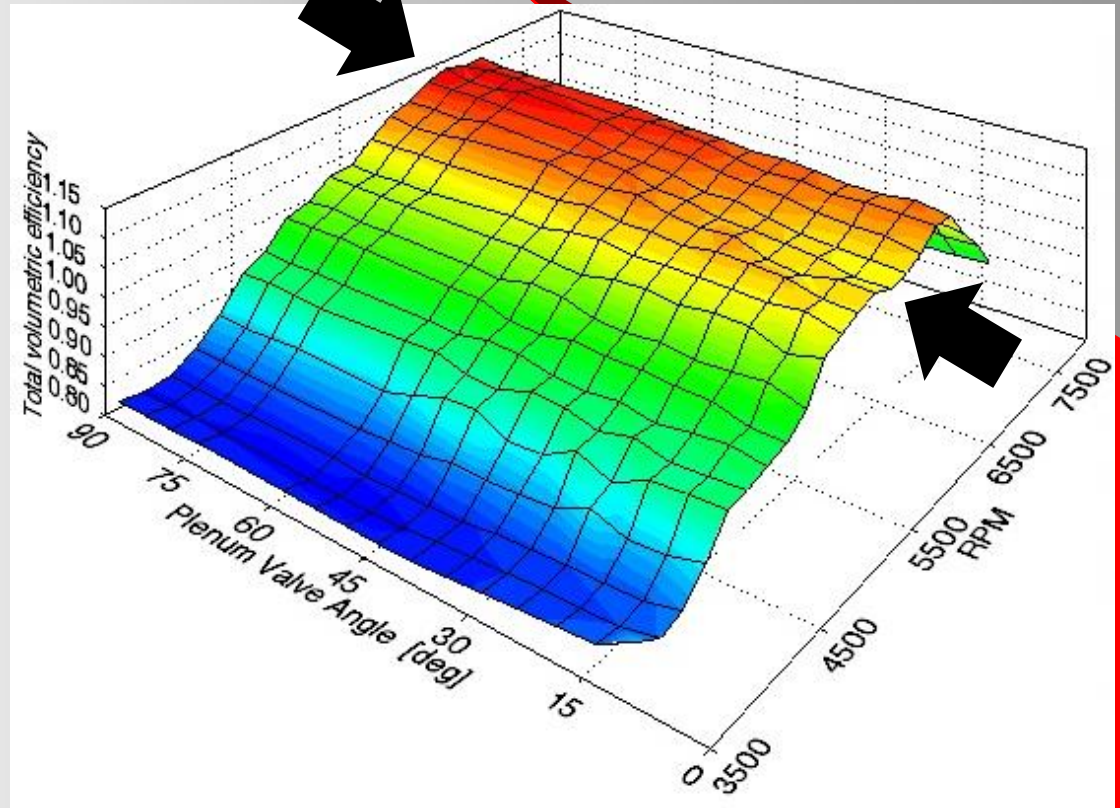
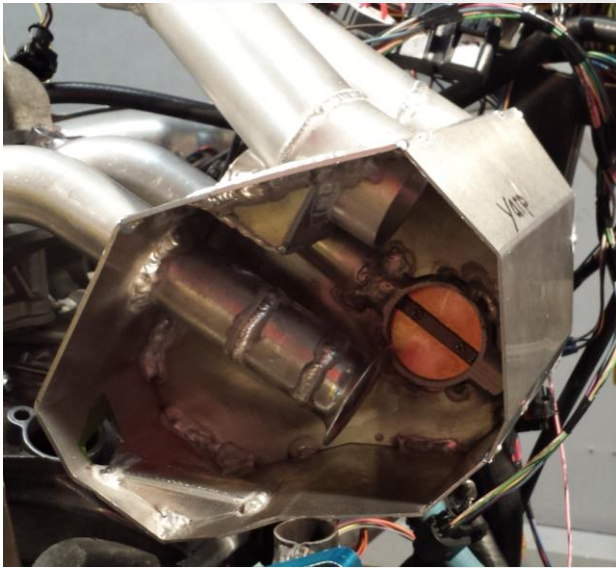
Split VGM





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# Effect of Valve Angle

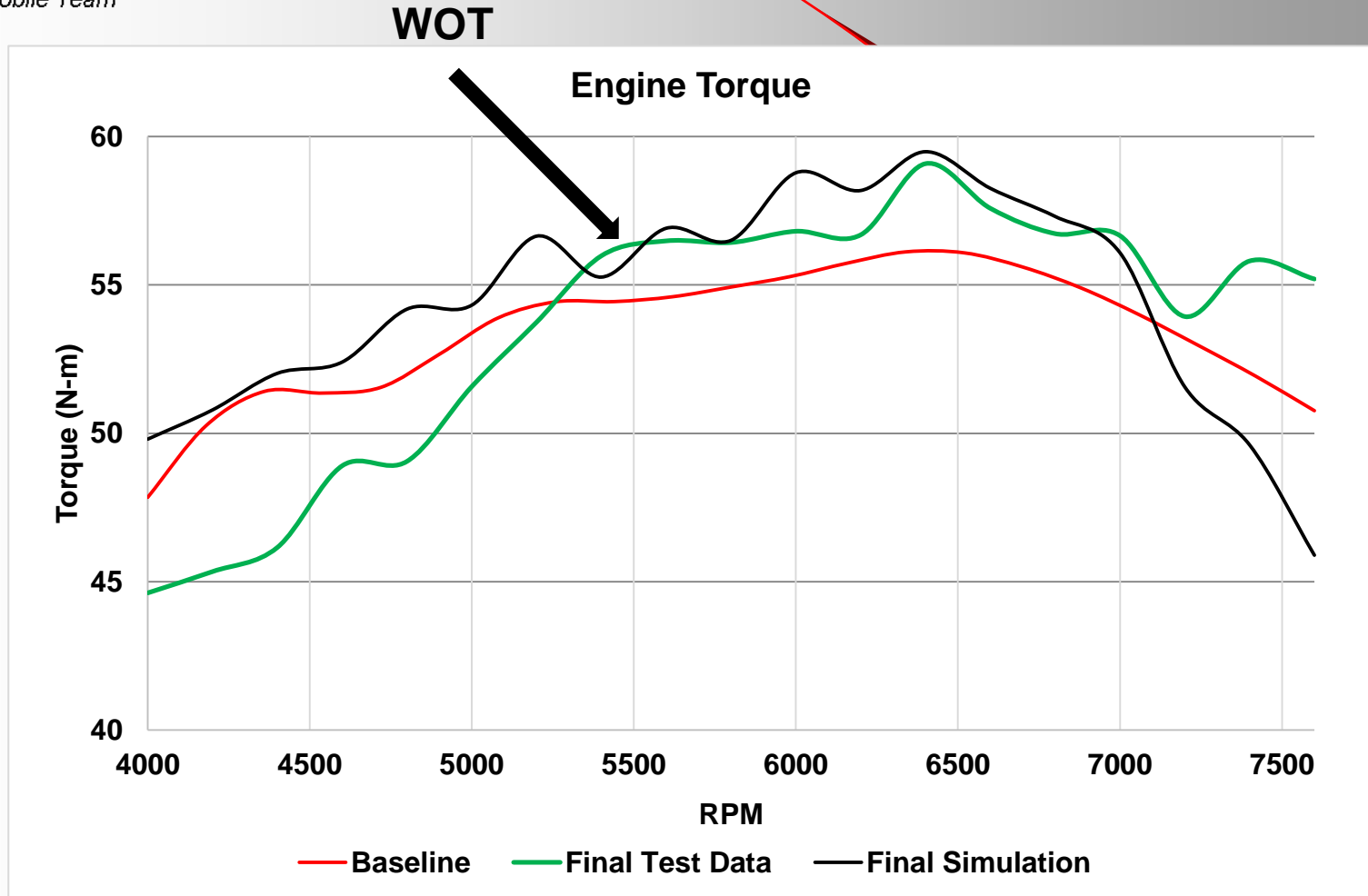




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# Model Validation

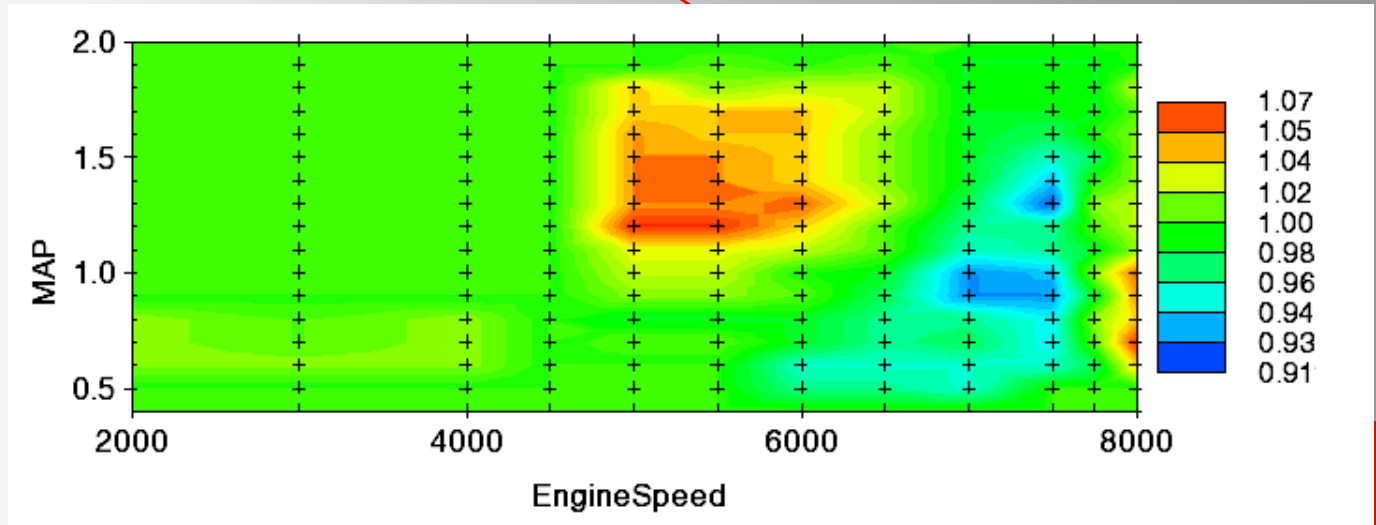




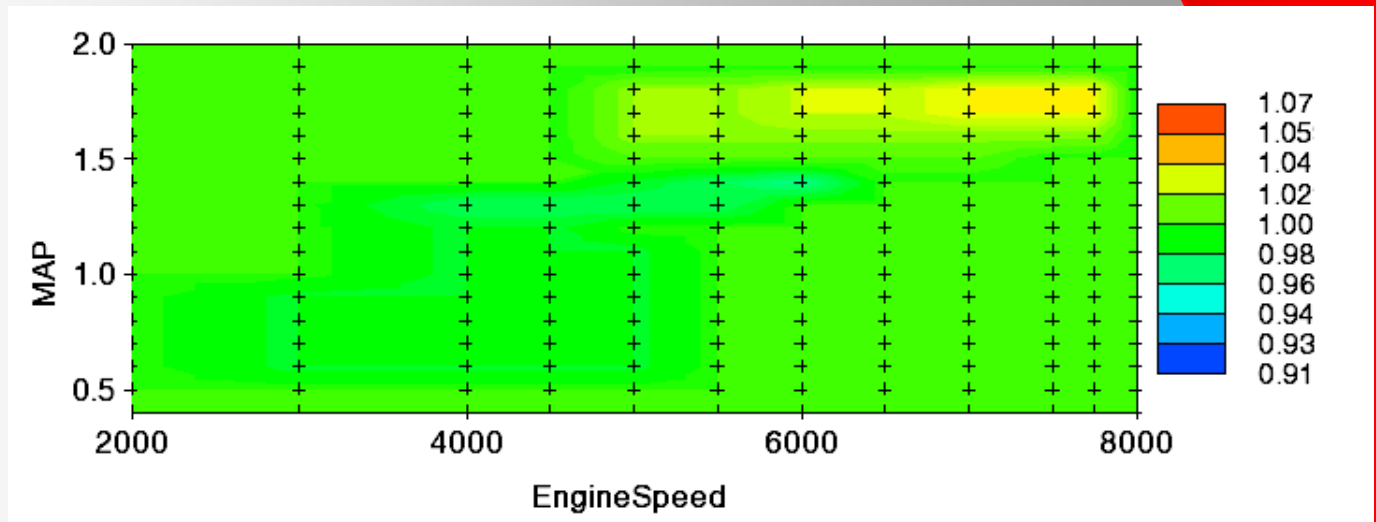
# Cylinder 1 Fuel Injection

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■ 2014



■ 2015





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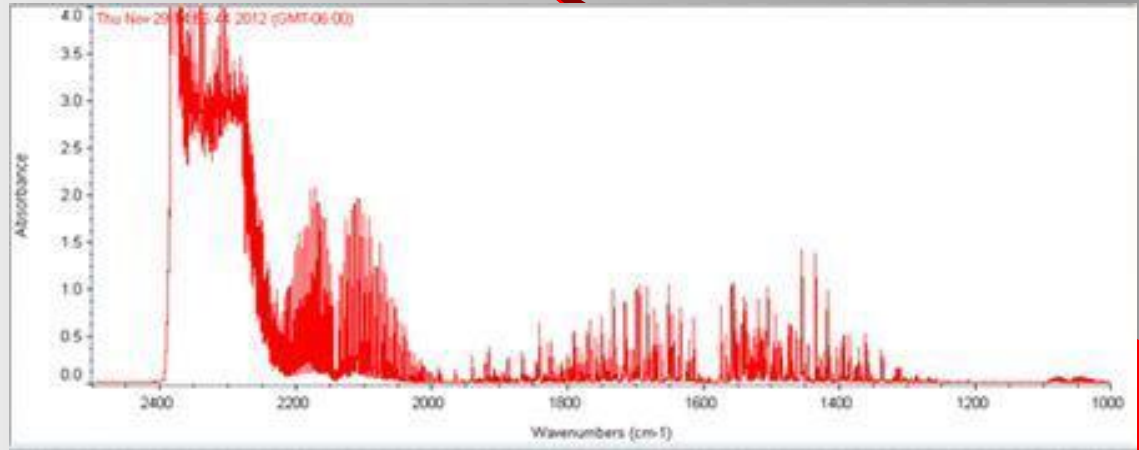
# **EMISSIONS AND NOISE REDUCTION**



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# Engine Emissions



	Bucky Ace Turbo 600	Stock [5]
CO (g/kW-hr)	8.1	90
HC (g/kW-hr)	0.3	8
NOx (g/kW-hr)	1.11	N/A
E-Score	207.04	190



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# Engine Emissions

Wide Band O<sub>2</sub> Sensor



## Three Way Catalyst Specifications

Manufacturer	W. C, Heraeus GmbH
Diameter	70 mm
Length	149 mm
Foil thickness	0.03 mm
Substrate	Emitec SuperFoil® MetalHoneycomb
Density	600 cpsi
Loading	Platinum 11.1 g/ft <sup>3</sup>
	Palladium 55.6 g/ft <sup>3</sup>
	Rhodium 8.3 g/ft <sup>3</sup>





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# Noise Reduction

- LizardSkin Tunnel Liner
- Belt Drive
- Catalyst and Turbocharger
- Sound Attenuation Material
- Modified Muffler - 72 dB



Lizard Skin Tunnel Liner



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# Bucky Ace Turbo 600

- Ultra Quiet
- 20+ mpgge
- Improved Handling
- Electric Start
- BAT Compliant





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# Acknowledgements

- All Sponsors
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  - Ethan Brodsky
  - Glenn Bower



**College of Engineering**  
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**MichiganTech**  
Keweenaw Research Center

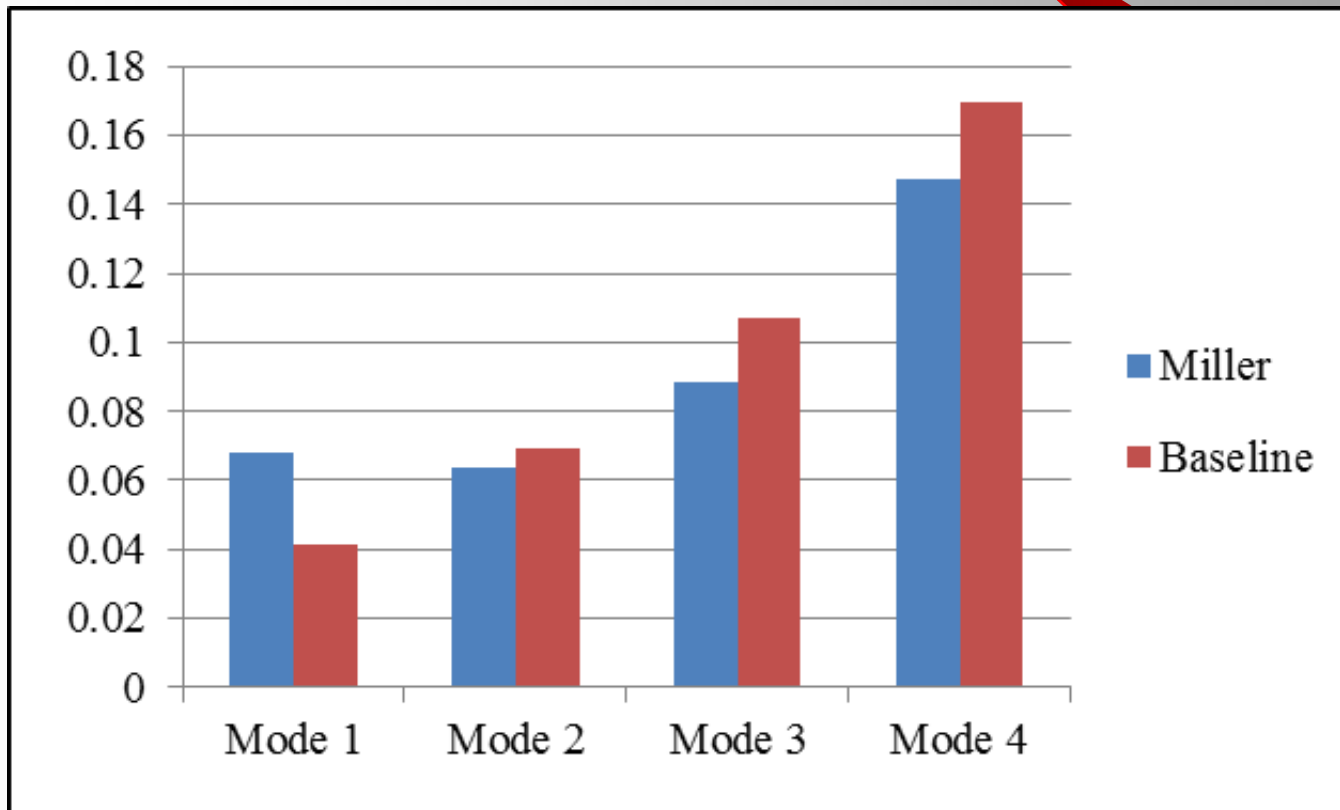




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# Miller Cycle

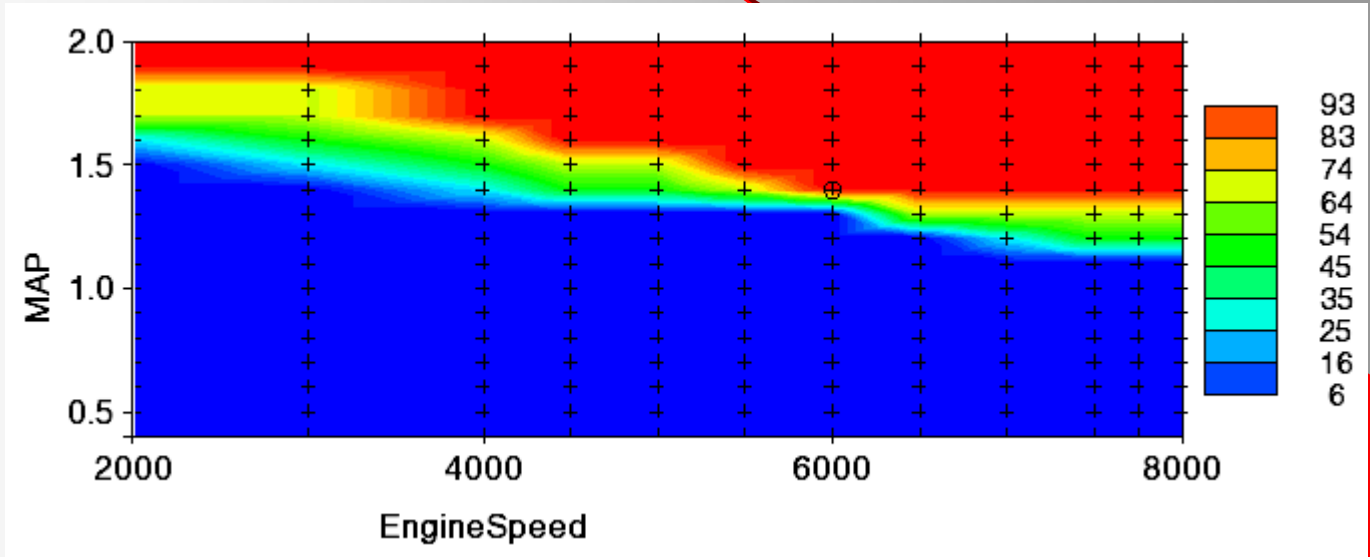
**Fraction of pumping losses:**





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# Model Validation





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# Cylinder Pressure

## Simulated Cylinder Pressure Difference

