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Wisconsin-Rotax ACE 674 (WRACE 674)

SAE Clean Snowmobile Challenge
Design Presentation 2017

University of Wisconsin-Madison

Presenters: Thomas Steffel and Kyle Karnick

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Quiet
FAST

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

Characteristic	Rank
Handling	1
Price	2
Fuel Economy	3
Acceleration	4
Emissions	5
Sound	6

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Engine Selection

Focus Points:

- Fuel Economy
- Engine Out Emissions
- Adequate Power

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

*Manufacturer reported values

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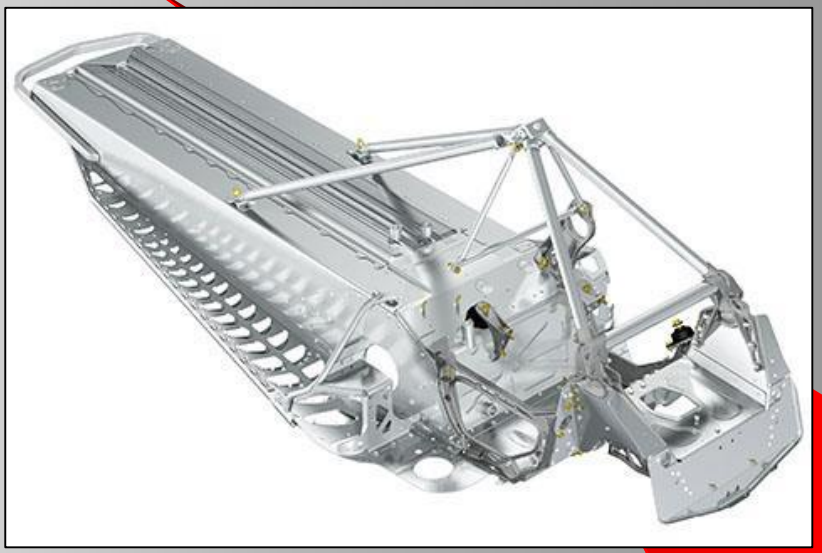
Chassis Selection

2015 Ski-doo MXZ Sport

- Lightweight
- Rider-forward ergonomics
- Cost-effective
- New XS Chassis



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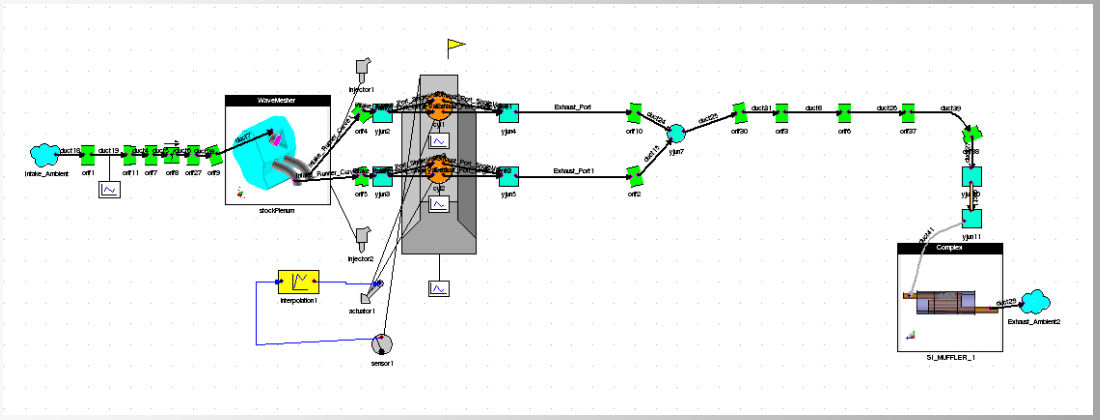
Powertrain Enhancements

- 1-D CFD engine model
- Increase in bore and stroke of engine
- Ported engine head
- Exhaust gas recirculation
- Dual Bank closed loop fuel control



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Dual Bank Closed Loop Control

- Compensates Odd-Fire airflow imbalance
- Increased combustion efficiency
- Maximized emission reduction

- 2x Bosch LSU 4.9 Oxygen Sensor

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Year to Year Improvements

- Installed Pistons Correctly
  - Reversed wristpin offset
- Increased EGR Cooler Effectiveness
  - 9 Tubes to 16 Tubes
- Improved Spark Advance Map
  - Peak Torque 46 -> 55 Nm

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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
- Lean/Rich switching algorithm

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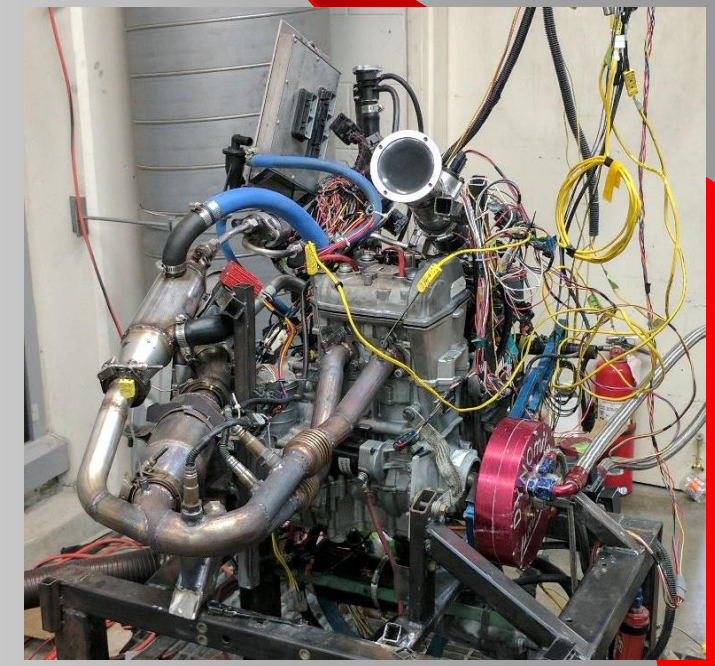
Engine Calibration

- DYNOmite water brake dyno
- Heated wideband O_2 sensors + NO_X sensor
- Exhaust thermocouples
- DYNO Spark Plug pressure transducers
- Calibrated:
  - Spark advance
  - Fuel Injection Quantities
  - EGR flow rates
  - Closed loop fueling
  - Throttle control



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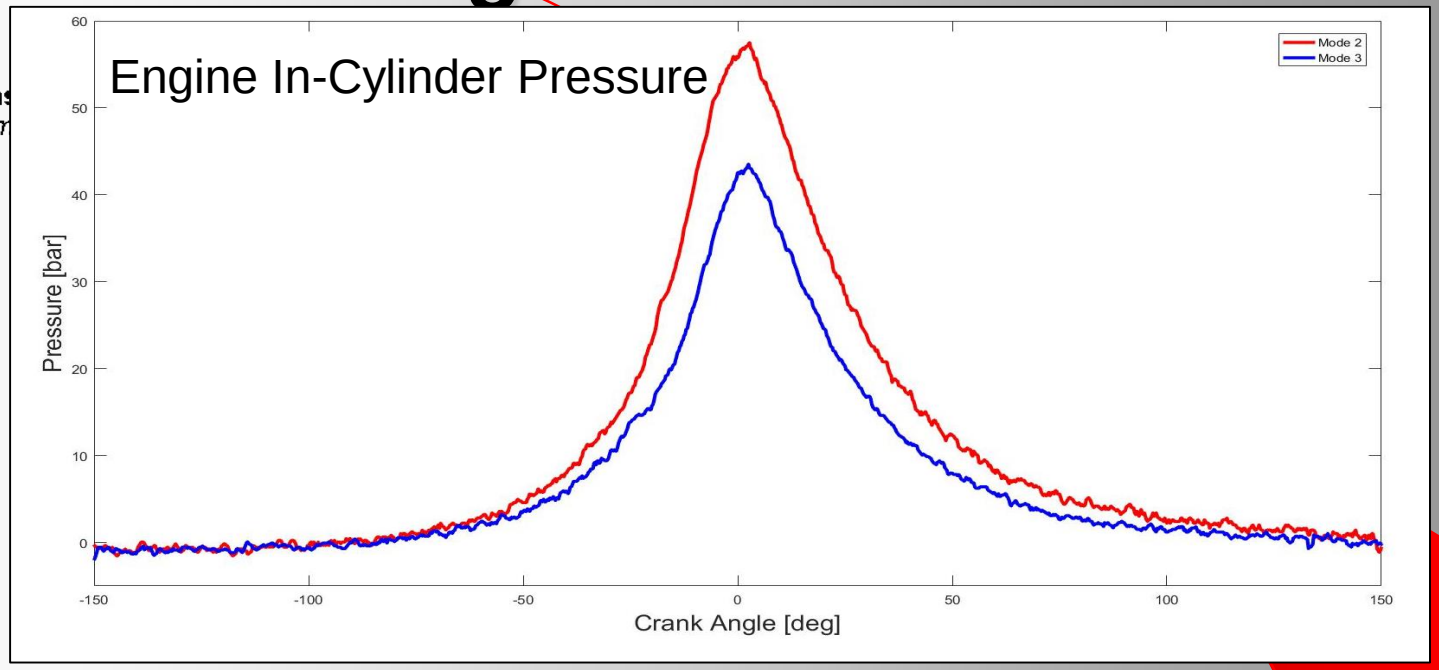
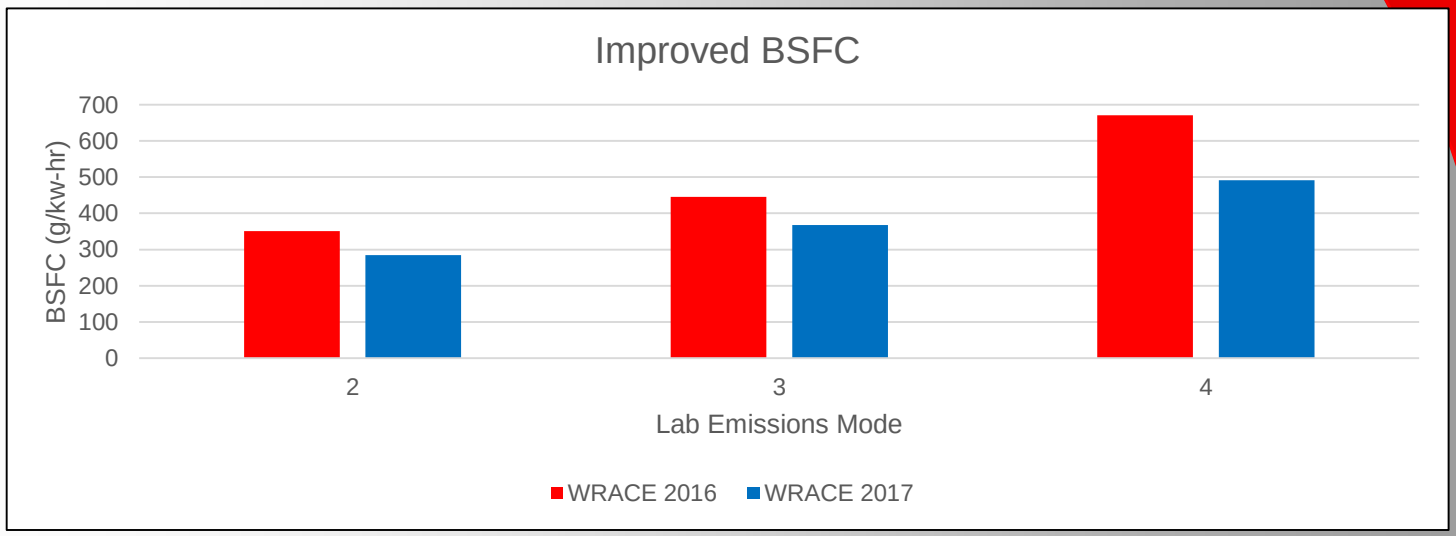
Engine Calibration





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Vehicle Calibrations

- Deceleration fuel cut
- Improved Acceleration
  - Tuned Throttle curve
  - EGR handling
- Improved handling through upgraded shocks

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ENGINE IMPROVEMENTS: BORING AND STROKING

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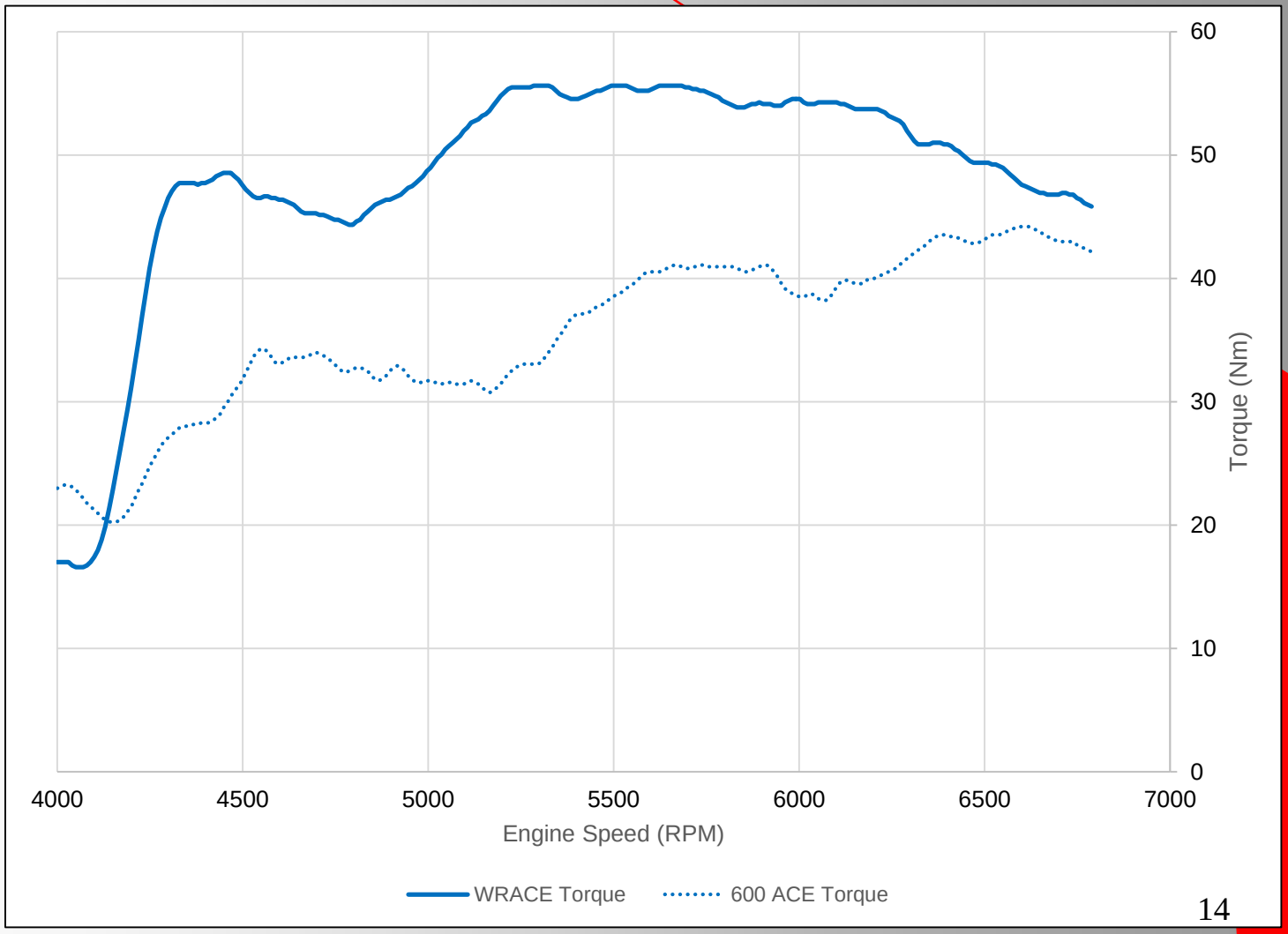
WRACE vs Stock ACE Torque Curve



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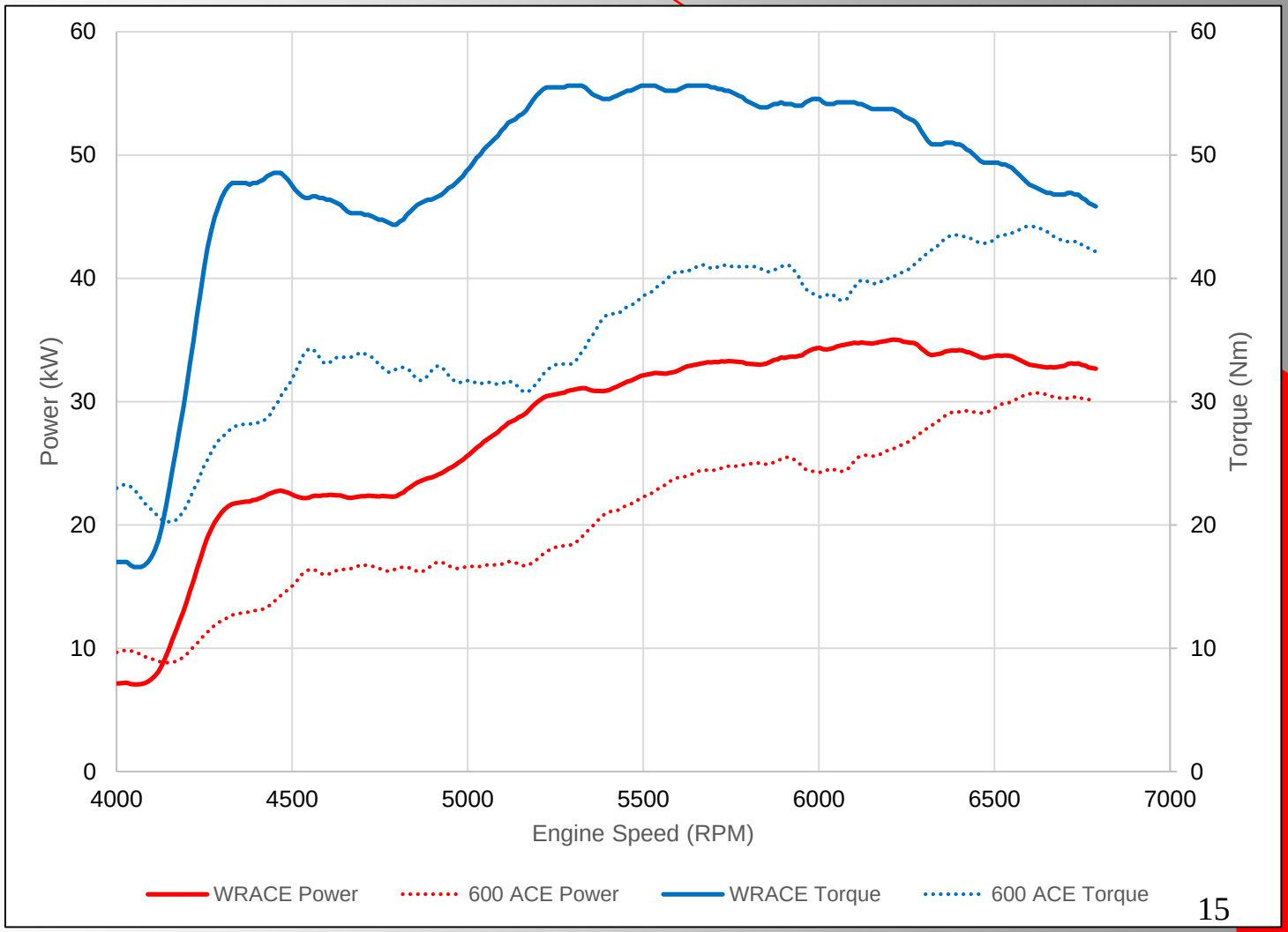
WRACE vs Stock ACE Power and Torque



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Process and Results

3 mm change in crank throw resulting in a stroke of 75.7 mm

↓

Piston size – “square” engine

↓

75 mm piston for Honda CBR954RR

↓

Modified piston dome for valve clearance and chamber geometry

↓

Copper head gasket for desired compression ratio of 12.05 : 1

Stock ACE 600 Piston

Stock Honda Piston

WRACE 674 Piston

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ENGINE IMPROVEMENTS: EXHAUST GAS RECIRCULATION

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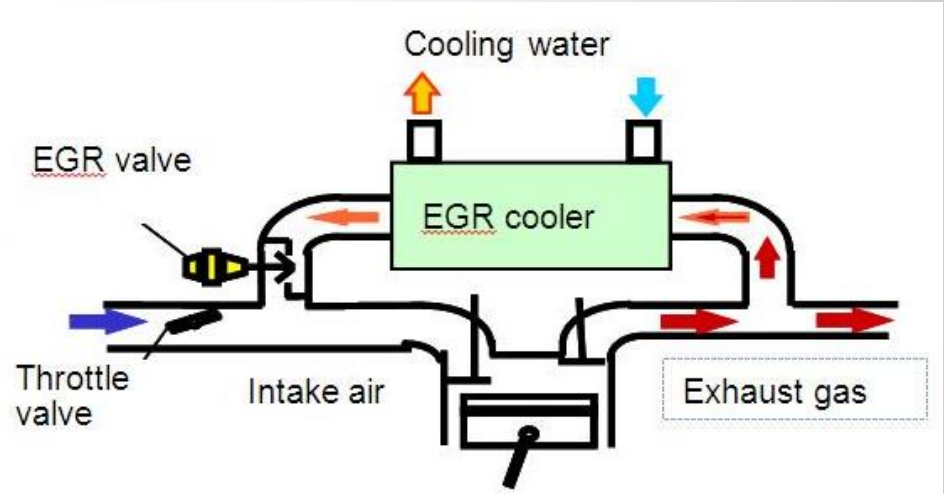
Exhaust Gas Recirculation

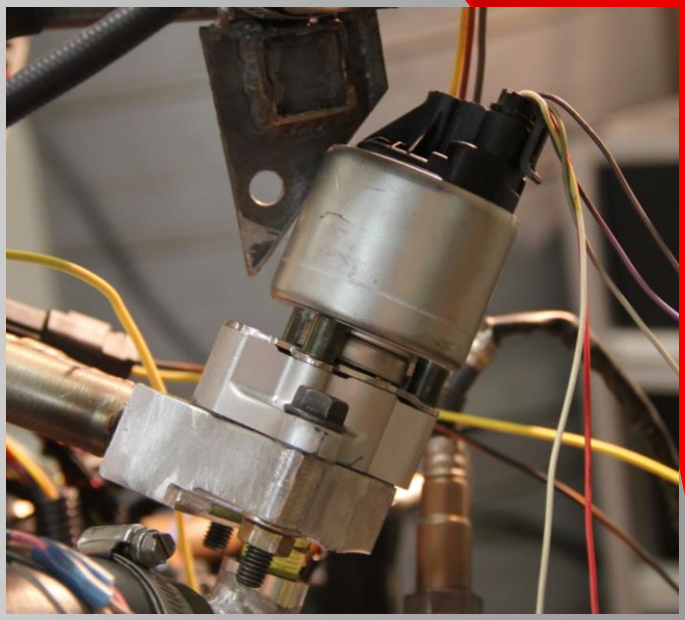
How it Works:

- Fraction of exhaust gas recycled through control valve to intake tubing



Valve Selection:

- Max flowrate measured to be 16.1 kg/hr



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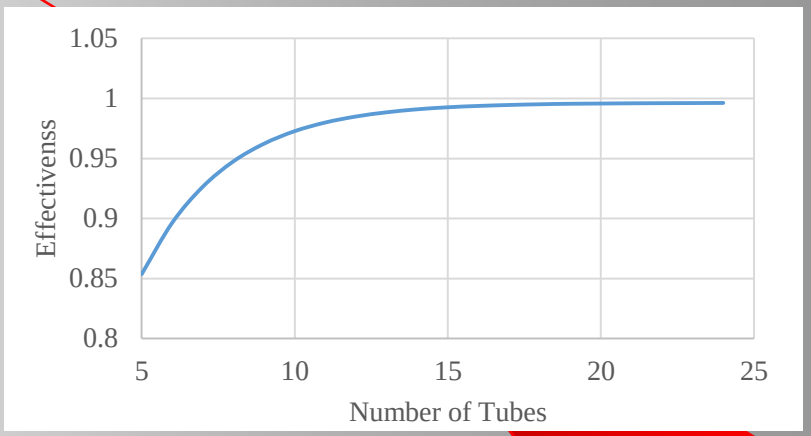
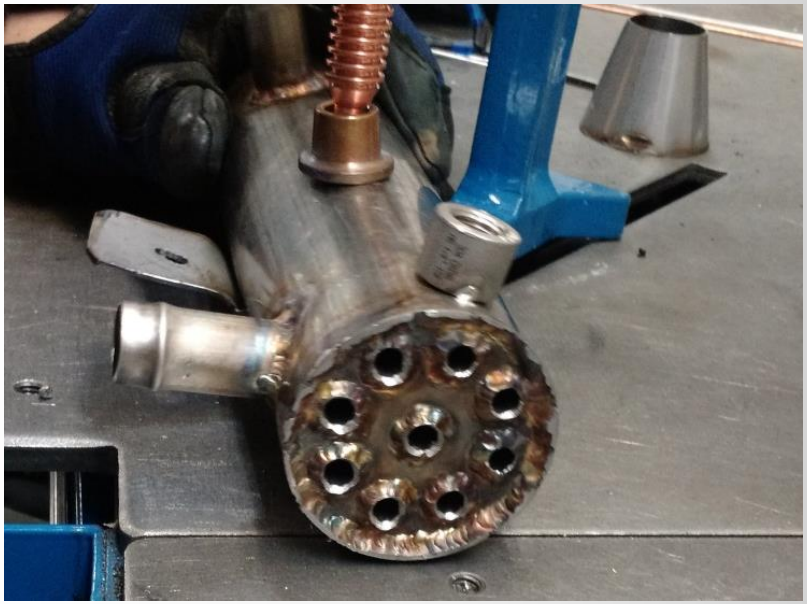
EGR Cooler

- 2nd Iteration
- Improved Heat Removal
- Increased Airflow
- 9 -> 16 Tubes



2016



2017

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EMISSIONS AND NOISE REDUCTION

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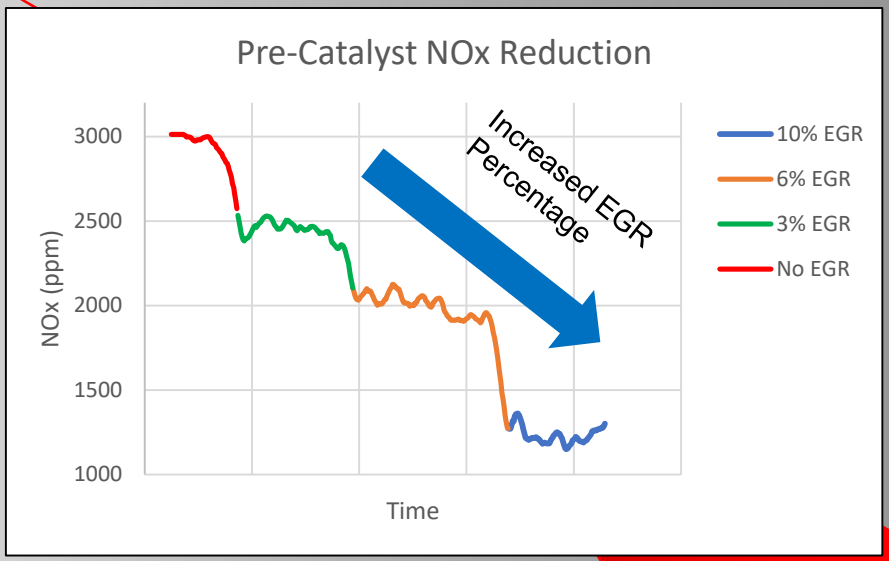
Engine Emissions

Three Way Catalyst Specifications	
Washcoat	W. C, Heraeus GmbH
Substrate	Emitec Metal Honeycomb
Diameter	92 mm
Length	168 mm
Foil thickness	0.03 mm
Density	400 cpsi
Loading	Platinum 24.7 g/ft^3
	Palladium 45.2 g/ft^3
	Rhodium 4.1 g/ft^3



Continental NO_X Sensor

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Emissions Improvements Over Stock

	ACE 600	WRACE 674	% Reduction
CO (g/kW-hr)	90*	12.6	86%
HC (g/kW-hr)	8*	0.228	96%
NO_x (g/kW-hr)	N/A**	1.964	N/A
E-Score	190	205.4	+15.4

*Manufacturer reported values

*Estimated for E-Score

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Noise Reduction

- Soft Rubber Track Material
- Catalyst
- Sound Attenuation Material
- Low RPM clutch engagement

SAE 1161 A-Weighted Slow Response Sound:

66.2 dB ± 1.6 dB

Stock 2015 MXZ Tested: 68.1 dB ± 1.6 dB

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WRACE 674

- 55 N-m torque @ 5300 RPM
- 23 mpgge
- E0 to E85 capable
- Improved Handling
- Ultra Clean
- Ultra Quiet

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Acknowledgements

- All Sponsors
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College of Engineering
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Keweenaw Research Center

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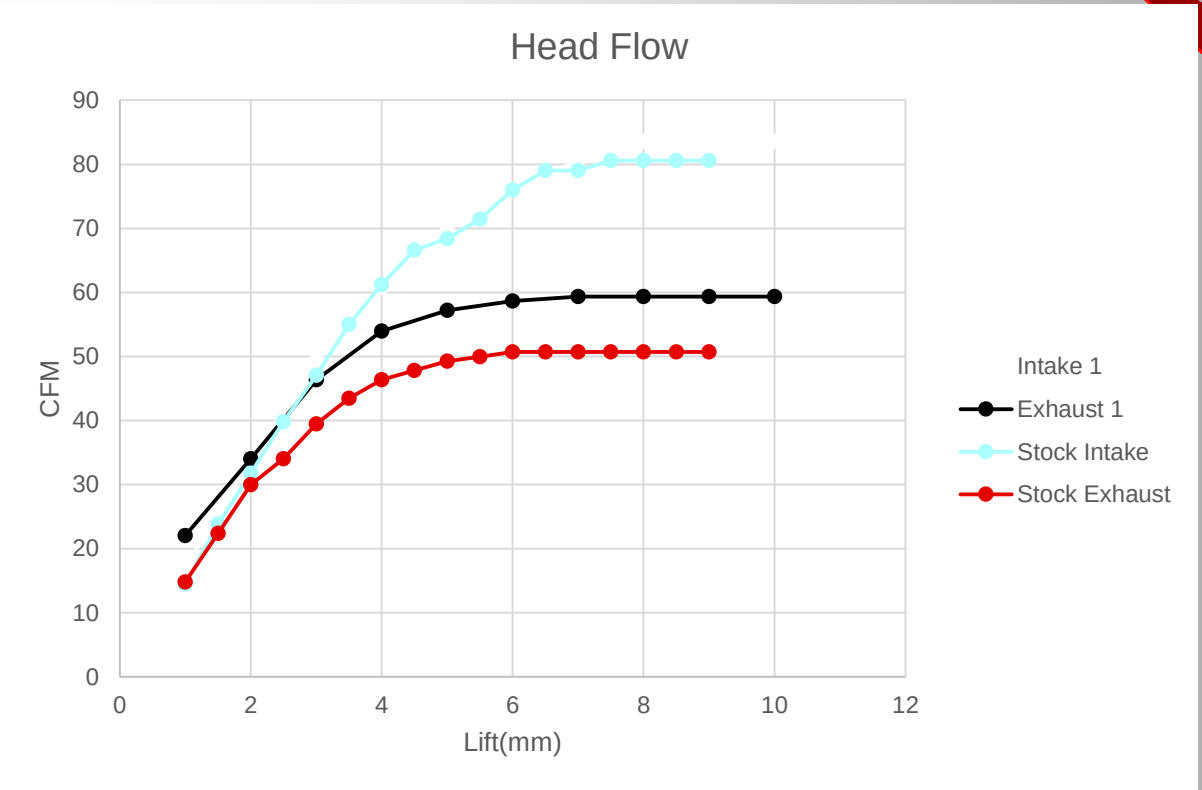
Head Flowbench Data



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Piston Data

	Rotax Stock	Honda Modified
Diameter [mm]	74	75
Wrist Pin Diameter [mm]	17	17
Wrist Pin Location [mm] (relative to compression ring)	28	25.5
Compression Ring to Deck Height [mm]	5.5	5.12
Mass [grams]	254.5	219.36
Bowl Size (cc)	5	5.15
Skirt Length from bottom of Wrist Pin [mm]	9.6	6.4

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Spark Timing Advance 2016-2017

	RPM							
Load (Bar)		3500	4000	4500	5000	5500	6000	6500
	0.6	6	7	5	4	4	7	4
	0.7	6.5	9	6	7	6	7	2
	0.8	6.5	7	4	6	4	3	1
	0.9	4	5	2	3.25	3.5	2	7
	1	1	1	2	2.5	2	2	7.69
	1.1	1	1	1	0.5	5	5	7