University of Wisconsin
SAE Snowmobile Team

Wisconsin-Rotax ACE 674 (WRACE 674)

SAE Clean Snowmobile Challenge
Design Presentation 2016

University of Wisconsin-Madison

Presenters: Saager Paliwal and Kyle Karnick

Clean
Quiet
FAST

University of Wisconsin
SAE Snowmobile Team

DESIGN PROCESS AND ENGINE SELECTION

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

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	% Valued
Handling	1	100%
Price	2	94.9%
Fuel Economy	3	86.6%
Acceleration	4	86.0%
Emissions	5	73.2%
Sound	6	65.5%

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

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
Polaris FST	97	62	7.6	9	116	N/A

*Manufacturer reported values

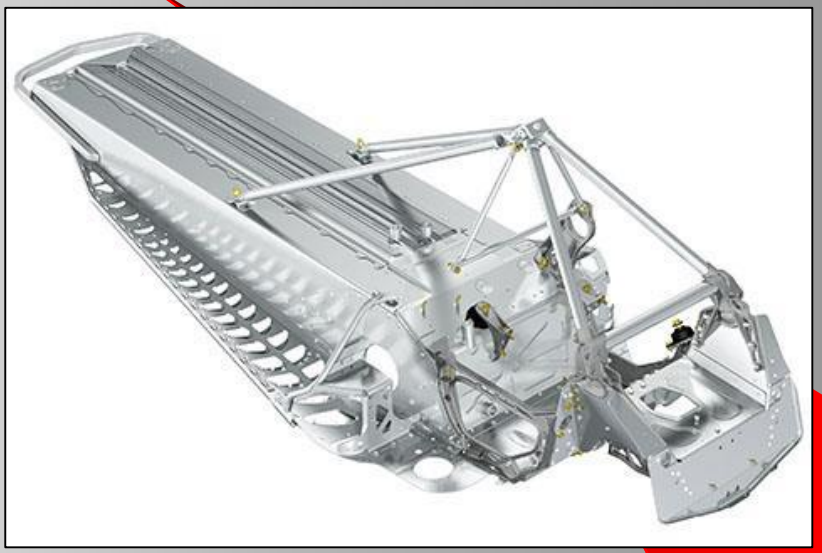
University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Chassis Selection

2013 Ski-doo MXZ Sport

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

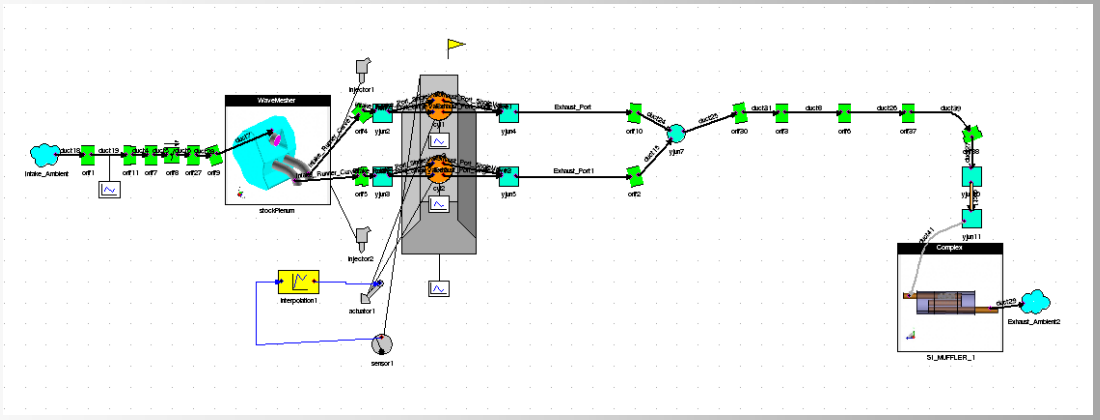


University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Powertrain Enhancements

- 1-D CFD engine model
- Increase in bore and stroke of engine
- Ported engine head
- Exhaust gas recirculation
- Reduced exhaust backpressure
  - 40.4 kPa measured in 2015 resulting in ~2.5 kW pumping loss
  - Reduced to 13.1 kPa recovering ~1.6 kW power.



University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Engine Management

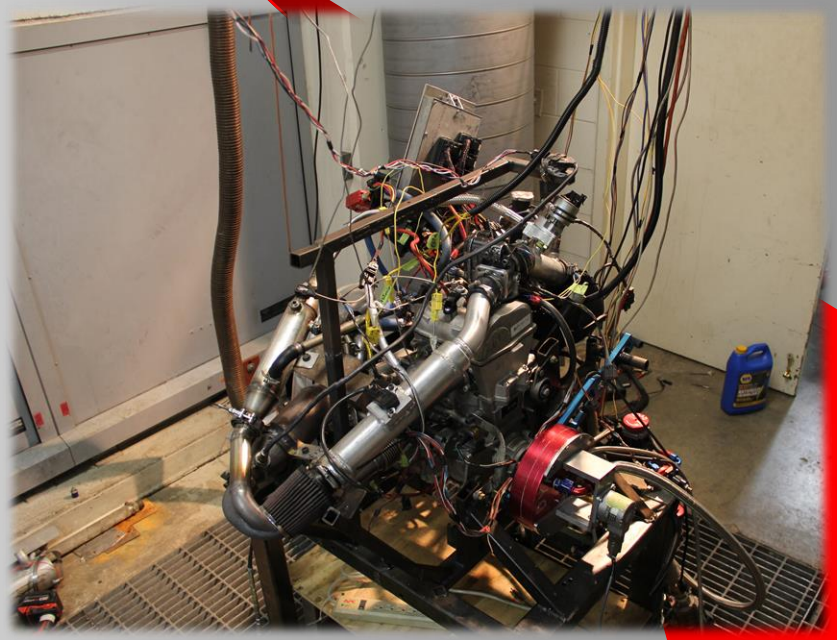
- Woodward/Mototron PCM565
  - Automotive/Marine environments
  - -40°– 130 °C
  - 18 g Shock Load
- Up to 3 Meters Underwater
- MATLAB/Simulink engine modeling
- MotoHawk automatic code generation
- Three way switching algorithm

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

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



University of Wisconsin
SAE Snowmobile Team
Clean
Quiet
FAST

Vehicle Calibrations

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

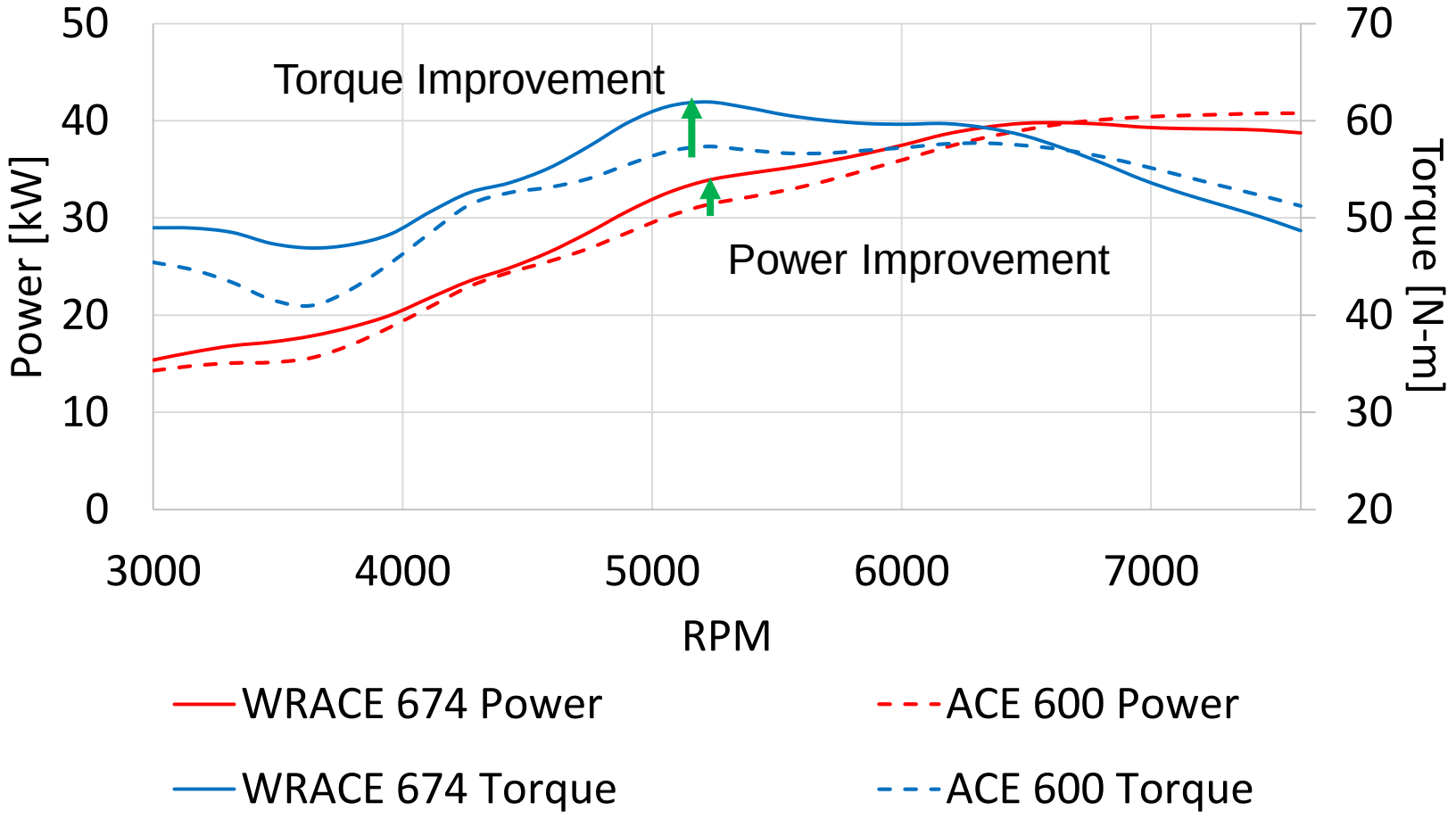
Clean
Quiet
FAST

University of Wisconsin
SAE Snowmobile Team

ENGINE IMPROVEMENTS: BORING AND STROKING

University of Wisconsin
SAE Snowmobile Team
Clean
Quiet
FAST

Boring and Stroking Torque Curve



University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Process and Results

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

↓

Piston size – “square” engine
75 mm and 76 mm bores

↓

75 mm piston for Honda CBR954RR

↓

Modified piston dome for valve clearance and chamber geometry

↓

Copper head gasket for desired compression ratio of 11.82 : 1

Stock ACE 600 Piston

Stock Honda Piston

WRACE 674 Piston

Clean
Quiet
FAST

University of Wisconsin
SAE Snowmobile Team

ENGINE IMPROVEMENTS: EXHAUST GAS RECIRCULATION

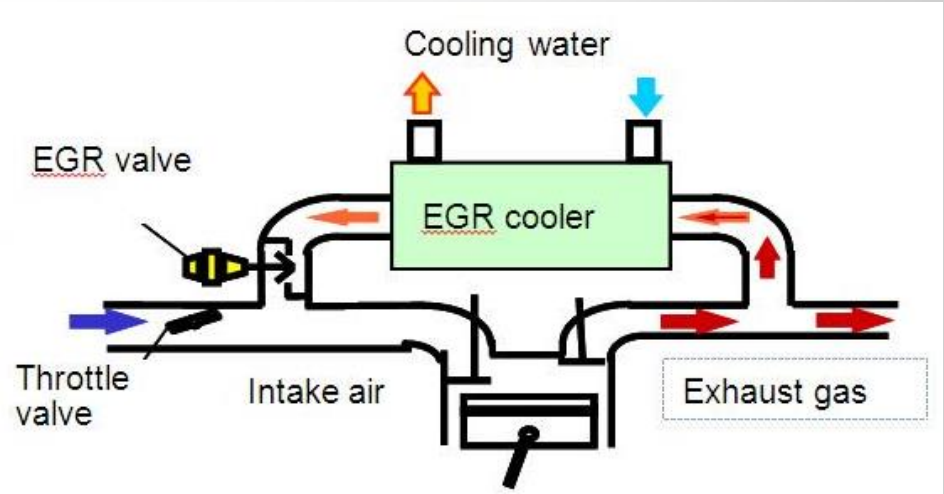
University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Exhaust Gas Recirculation

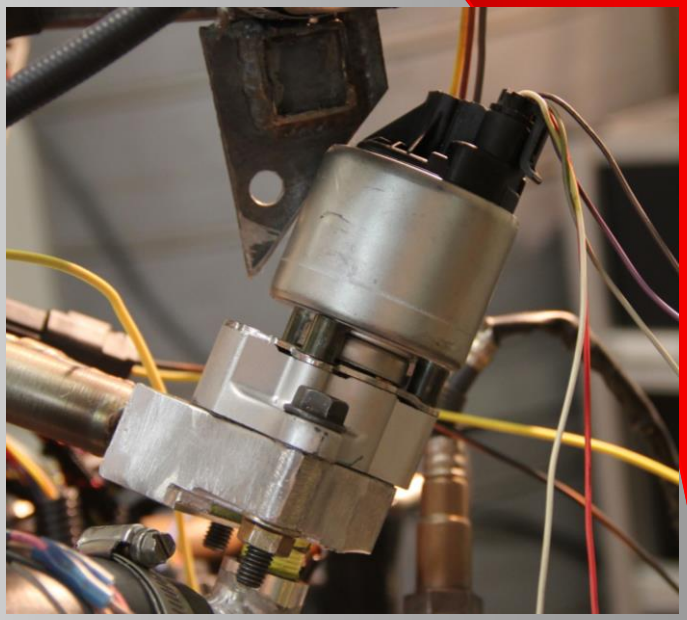
How it Works:

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



Valve Selection:

- Max flowrate measured to be 16.1 kg/hr

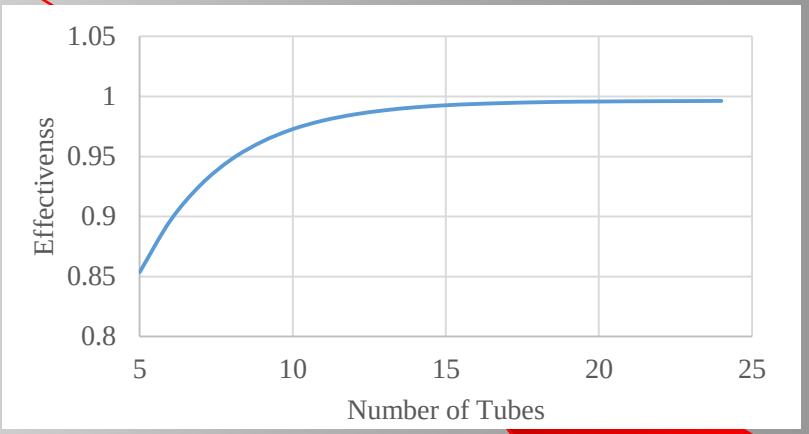


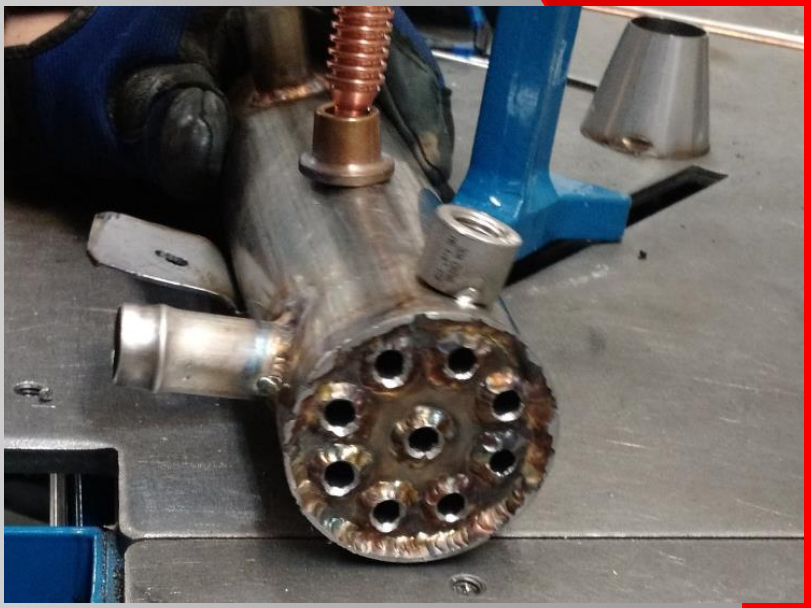
University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

EGR Cooler

- Design Requirements:
  1. Maximum diameter of 64 mm
  2. Maximum length of 204 mm
  3. Cooling capacity of 3 kW
  4. Utilize engine coolant
- Vipertex enhanced surfaces





University of Wisconsin
SAE Snowmobile Team

EMISSIONS AND NOISE REDUCTION

University of Wisconsin
SAE Snowmobile Team
Clean
Quiet
FAST

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 11.1 g/ft^3
	Palladium 55.6 g/ft^3
	Rhodium 8.3 g/ft^3

Mode 3 NO_X Emissions	
0% EGR	2164 ppm
10% EGR	328 ppm

85% Reduction NO_X Reduction with EGR

Continental NO_x Sensor

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Engine Emissions

E-Score Formula:

$$E = \left[1 - \frac{(HC + NOX) - 1.5}{150}\right] * 100 + \left[1 - \frac{CO}{400}\right] * 100 \geq 100$$

	WRACE 674	ACE 600
CO (g/kW-hr)	11.40	90*
HC (g/kW-hr)	0.382	8*
NO_x (g/kW-hr)	0.041	N/A**
E-Score	206.9	190

*Manufacturer reported values

*Estimated for E-Score

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Noise Reduction

- Lizard Skin Tunnel Liner
- Belt Drive
- Catalyst
- Sound Attenuation Material
- Low RPM clutch engagement

SAE 1161 A-Weighted Slow Response Sound:

66.7 dB ± 1.6 dB

Stock 2015 MXZ Tested: 71.1 dB ± 1.6 dB

Lizard Skin Tunnel Liner

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

WRACE 674

- 50 N-m torque @ 5500 RPM
- 20+ mpgge
- E0 to E100 capable
- Improved Handling
- Improvements on BAT compliance

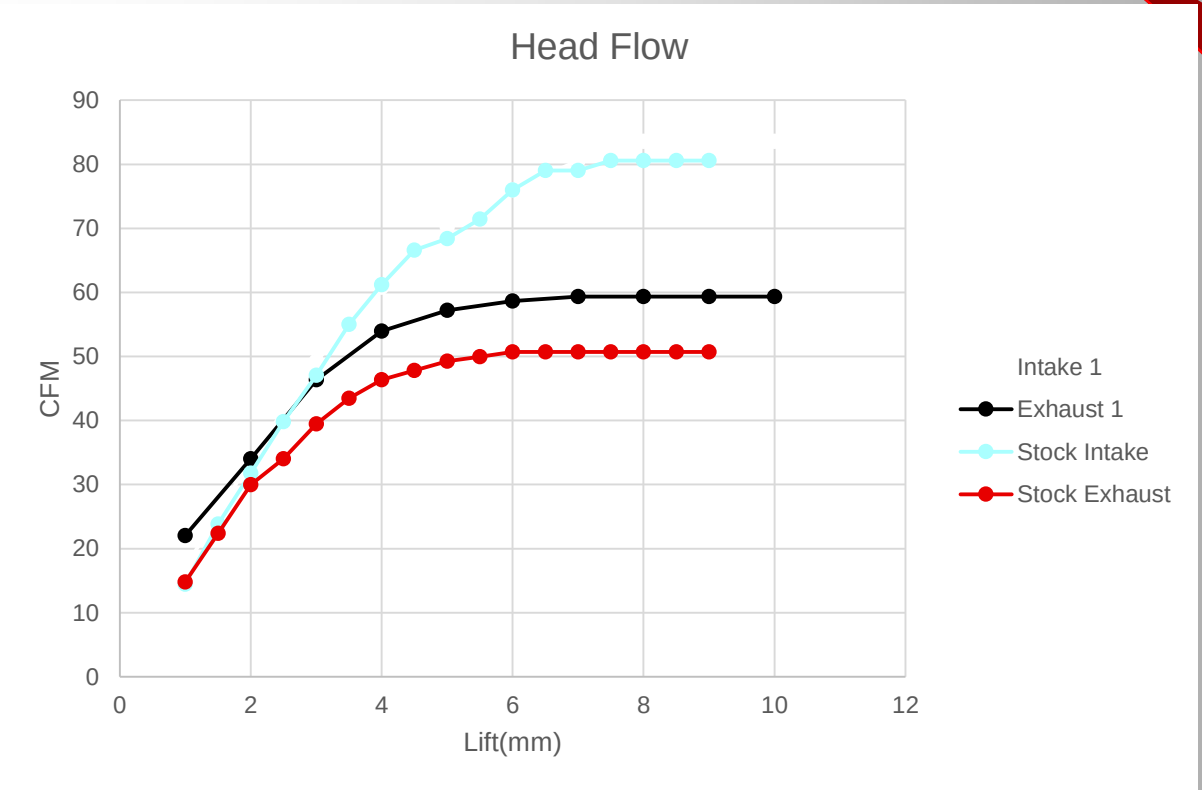
University of Wisconsin
SAE Snowmobile Team

Acknowledgements

- All Sponsors
- Keweenaw Research Center/SAE International
- University of Wisconsin-Madison College of Engineering
- Advisors
  - Ethan Brodsky
  - Glenn Bower

University of Wisconsin
SAE Snowmobile Team
Clean
Quiet
FAST

Head Flowbench Data



University of Wisconsin
SAE Snowmobile Team
Clean
Quiet
FAST

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