Development of an Isobutanol Flexible Fueled Performance Trail Snowmobile for the SAE Clean Snowmobile Challenge

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ABSTRACT

Clean snowmobile technology has been developed and applied to a commercially available two cylinder, four-stroke snowmobile. The goals of this effort included reducing exhaust and noise emissions to levels below the U.S National Parks Service (NPS) Best Available Technology (BAT) standard while increasing vehicle dynamic performance with an increase in peak power over the original equipment version. Further, for maximum rider convenience, this snowmobile can operate using any blend of gasoline, ethanol, and isobutanol fuel. All goals were achieved while keeping the cost affordable. Snowmobiling is a recreational sport; thus the snowmobile must remain fun to drive and cost effective to produce.

The details of this design effort including performance data are discussed in this paper. Specifically, the effort to improve the dynamic performance, fuel efficiency, and emissions of a commercially available two cylinder, four-stroke snowmobile is described. Engine thermal efficiency has been increased through Late Intake Valve Closure (LIVC) valve timing modification for Miller cycle operation, while high load power was increased through the implementation of a turbocharger and variable electronic boost control. An electronic throttle was also implemented in combination with a "performance/economy" mode switch to limit speed and increase fuel efficiency per the rider's demands. Additionally, a new exhaust system featuring a three-way catalytic converter and a simple, lightweight muffler utilizing a passive acoustic valve has been developed to reduce chemical and noise emissions. This snowmobile was modified to run the full range of ethanol and isobutanol-blended fuels using wideband exhaust gas oxygen sensor feedback and student-developed engine controls. Excellent fuel efficiency has been achieved with the lean-burn Miller cycle powertrain in addition to an exhaust emissions improvement of 13 percent from the original equipment version.

INTRODUCTION

Snowmobiles were first introduced into the commercial market emergency and utility usage. The first snowmobile, developed in 1935, was capable of carrying 12 people. The introduction of the snowmobile meant that emergency medical personnel could get to those in need of care even during heavy snowfall. Other early uses included farming and ranching. It was not until the late-1950s that snowmobiles began being used for recreation. However, once recreational snowmobiling began, it grew rapidly. For example, within a decade, dozens of manufacturers were producing snowmobiles. Today, only four primary manufacturers remain with global industry sales of approximately 164,000 snowmobiles annually [1].

Due to the rising environmental concern pertaining to the noise and exhaust emissions of recreational snowmobiling, they have come under increased scrutiny by the federal government. As snowmobiles are used in the winter season, the environmental impacts are greater due to the cold dense air. The cold, dense ambient air will not disperse the exhaust emissions rapidly; this tends to trap the concentrated exhaust leading to locally high concentrations of pollutants. These hazards are especially of concern to ecologically sensitive areas such as Yellowstone national park as well as other national parks where recreational snowmobiling is popular.

Snowmobiling is important to the local and national economy. According to the International Snowmobile Manufacturers Association (ISMA), snowmobiling generates over 29 billion US dollars (USD) of economic activity annually in the world economy. New snowmobile sales directly account for about 1.2 billion USD, while the remainder is accounted for by apparel and accessories, registrations, permits, tourism and spare parts. The snowmobiling industry accounts for over 90,000 fulltime jobs and nearly 2,200 dealerships.

Considering the economic impact of this market, a blanket ban on snowmobiling is not a feasible option. Currently, U. S. national parks are operating under a temporary winter use plan which restricts the number of snowmobiles entering the parks per day. All snowmobiles are required to be Best Available Technology (BAT), which are the cleanest and quietest commercially available snowmobiles. Further, the EPA has issued a three-phase reduction on snowmobile emissions.

The regulations include a 30% reduction in overall emissions by 2006, a 50% reduction overall by 2010, and a 70% reduction overall by 2012. The specific limits are shown in Table 1.

Table 1 Exhaust Emission Standards for Snowmobiles [2]

	Phase In	Emissions (g/kW-hr)		
Model Year	**(% of sales)**	**HC**	**HC+NOx**	**CO**
2006	50	100	-	275
2007-2009	100	100	-	275
2010-2011	100	75	-	275
2012 & later	100	75	90	275
NPS BAT		15		120

This legislation has forced a rapid change upon manufacturers; and they have responded by further developing two-stroke technology and shifting to four-stroke engines in place of the typical two-stroke engines. While the two-stroke engine offers advantages in light weight and peak power output compared to four-stroke engines, the disadvantage is that it emits much higher levels of exhaust pollutants. The four-stroke engine is also quieter, and more fuel efficient when compared with an equivalent two-stroke engine. Nonetheless, the four-stroke engine size and weight disadvantage is a substantial challenge to overcome in a lightweight vehicle.

The Clean Snowmobile Challenge (CSC), which is part of the Collegiate Design Series of the Society of Automotive Engineers (SAE), was created to challenge students to reduce the environmental impact of snowmobiles while retaining the essential performance and cost limitations required to ensure a successful recreational market.

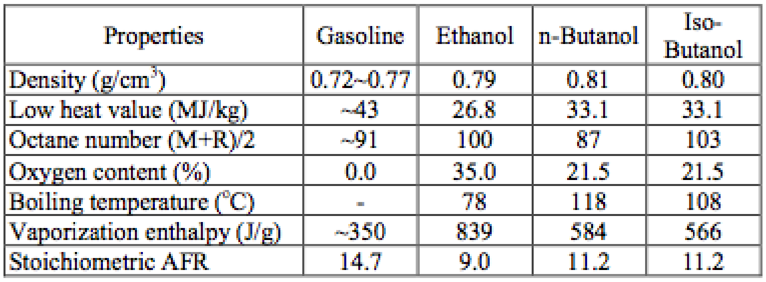
To meet this challenge, Kettering University has chosen to use four-stroke engine technology, reasoning that this technology offers the best long-term potential to meet increasingly stringent exhaust and noise emissions levels.

DESIGN OBJECTIVES

The design objectives included reducing exhaust emissions to levels which are below the BAT standard and increasing the snowmobile's dynamic performance. Minimizing the cost and performance compromises were also major considerations. Snowmobiling is, after all, a recreational sport; thus the snowmobile must remain fun to drive and cost effective.

Competition requirements outline that the snowmobile must be able to run a range of 16-32% isobutanol blended in premium blendstock (90 (R+M)/2, E0) gasoline. Using the values shown in Table 2, it can be calculated that the fuel lower heating value range for IB16-IB32 is the same as that of ethanol blends in the E10-E20 range. The E10-E20 fuel range is available for sale at fuel stations throughout the United States, meaning that the Kettering 2014 Clean Snowmobile, while competing with isobutanol fuel, can run on all commonly available ethanol blends up to a design limit of 85%. Prior art [3, 4, 5] has established that butanol fuels have less material compatibility issues than ethanol fuels. As this powertrain was previously powered by high-blend ethanol fuels, no compatibility issues with butanol fuel have been found.

Table 2 Fuel Properties [3]



Properties	Gasoline	Ethanol	n-Butanol	Iso-Butanol
Density (g/cm^3)	0.72~0.77	0.79	0.81	0.80
Low heat value (MJ/kg)	~43	26.8	33.1	33.1
Octane number (M+R)/2	~91	100	87	103
Oxygen content (%)	0.0	35.0	21.5	21.5
Boiling temperature (°C)	-	78	118	108
Vaporization enthalpy (J/g)	~350	839	584	566
Stoichiometric AFR	14.7	9.0	11.2	11.2

In order to meet these objectives, a commercially available 2014 Ski-Doo MXZ Sport 600 ACE was modified for the 2014 CSC competition.

The base snowmobile was chosen because it is equipped with a four-stroke engine, meets 2012 NPS BAT requirements without modification, and is light weight through the use of the lithe Rev-XP chassis and a 120 inch track length. The team focused on reducing chemical and noise emissions, improving efficiency, and improving performance while maintaining the best-in-class comfort, safety and durability of the vehicle.

The 120” track length was chosen for its efficiency, low mass, and handling characteristics. A 137” track lenth was also tested, however it was found that the test riders preferred the handling of the 120” track better. Though the 137” track was slightly smoother over bumps and offered better traction in deep snow, on the trail the sled had a tendency to understeer in corners while the 120” track test snowmobile did not. The 120” snowmobile was found to be better for trail use due to its ability to navigate corners well and the traction and rough trail capability was not degraded enough compared to the 137” track to compensate for the handling differences. To increase traction, the use of a pre-studded track similar to the OE track was investigated. The development of custom powertrain controls including traction control, however, rendered the extra cost, rotational inertia, and weight of the aftermarket track unnecessary. The OE Camoplast Ripsaw 1” lug 1-ply track weighs only 32 lb, 4 lb lighter than the pre-studded track considered.

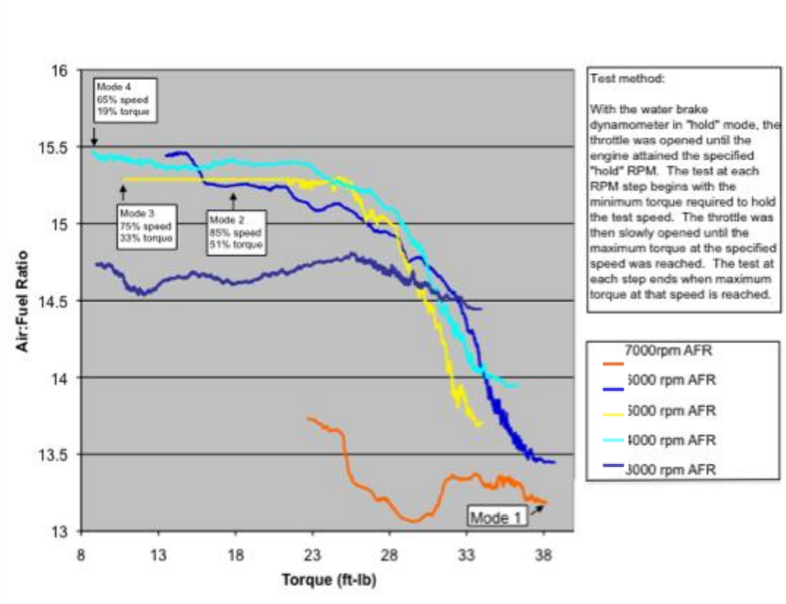
ENGINE SELECTION

The Ski-Doo MXZ Sport comes factory-equipped with a Rotax 600 ACE (Advanced Combustion Efficiency) 600cm^3 four-stroke, 56 horsepower (hp), naturally-aspirated two-cylinder engine. The specifications for this base engine are presented below.

Table 3 Rotax 600 ACE Specifications [6]

Displacement	600 cm3
Configuration	Inline 180 Deg. Two Cylinder
Block Material	Aluminum
Valve Actuation	Dual Over Head Camshaft
Ignition	Coil on Plug
Valves per cylinder	Four
Compression ratio	12:1
Bore x Stroke	74 x 69.7 mm
Intake Valve Open/Close	3 BTDC/37 ABDC
Exhaust Valve Open/Close	44 BBDC/6 ATDC
Engine Control System	Bosch ME17.8.5
Engine Weight	40 kg (88 lb)
Maximum Power	42 kW (56 hp)
Maximum Torque	55 Nm (42 ft*lb)
Maximum Power Speed	7250 rpm

The SAE paper published by Rotax for the development of the 600 ACE engine details several notable characteristics of the powerplant. Of great significance to the Kettering CSC team is the fact that the engine has been designed to run lambda 1.1 and leaner at part load for increased fuel economy. [6] Rotax credits the combustion stability made possible by a hemispherical combustion chamber for the engine’s ability to run lean during much of its operation. Dynamometer testing was performed at Kettering with the unmodified snowmobile to characterize its calibration. The results of the calibration characterization can be seen in Figure 2. With knowledge of the speeds and loads at which the factory sled runs lean and rich of stoichiometric, calibration of the flex-fuel capable engine control unit can be completed more quickly and safely.



Test method:

With the water brake dynamometer in "hold" mode, the throttle was opened until the engine attained the specified "hold" RPM. The test at each RPM step begins with the minimum torque required to hold the test speed. The throttle was then slowly opened until the maximum torque at the specified speed was reached. The test at each step ends when maximum torque at that speed is reached.

Figure 1 Rotax 600 ACE Factory Lean-Burn Calibration

In addition to designing an efficient combustion chamber, Rotax utilized an advanced diamond-like carbon (DLC) coating on the valve tappets to reduce frictional losses in the engine. Other design criteria which decreased the 600 ACE FMEP include minimizing the amount of oil in the cylinder head and reducing pumping losses in the crankcase through the use of a dry sump oil system.

MODIFICATIONS TO IMPROVE EMISSIONS, FUEL EFFICIENCY, AND PERFORMANCE

Starting with the base four-stroke 600 ACE engine, the team worked on the following emissions reductions and fuel economy improvement strategies:

1. Fuel Selection – Ethanol and isobutanol blended fuels were chosen as the fuel to reduce emissions and the propensity for engine knock. Both fuels act as oxygenates to decrease exhaust emissions and feature improved knock resistance and increased latent heat of vaporization to allow improved engine performance over OE.

2. Exhaust Aftertreatment – A three way catalyst has been implemented, as it is the automotive industry standard for predictable chemical emissions reduction from the four-stroke Otto cycle engine. Several decades of development have made the three way catalyst the most durable and available exhaust aftertreatment device.

3. Lean Calibration – To further decrease emissions and improve the fuel efficiency of the snowmobile, an always-lean-burn engine calibration was utilized. Using increased amounts excess air as the charge diluent, engine pumping losses and pre-catalyst NOx emissions were decreased relative to the OE calibration.

4. Turbocharged Miller Cycle Operation - To reduce pumping losses, a late intake valve closing strategy with a custom intake camshaft was implemented in combination with a turbocharger to increase engine power for the performance trail snowmobile.

5. Minimize Weight – In order to improve fuel economy and reduce emissions, the team chose a lightweight snowmobile and made several efforts to maintain low weight with its modifications.

Each of these strategies is discussed below.

Engine simulation and design

Due to limited resources, not all design concepts could be physically tested for conformance to the team's objectives of improved emissions, fuel efficiency, and performance. A 1D engine simulation model, a view of which is seen in Figure 2, was constructed in Ricardo WAVE engine simulation software. The model was created from measurements of the Rotax 600 ACE engine, published specifications, and prior experience correlating models of small engines.

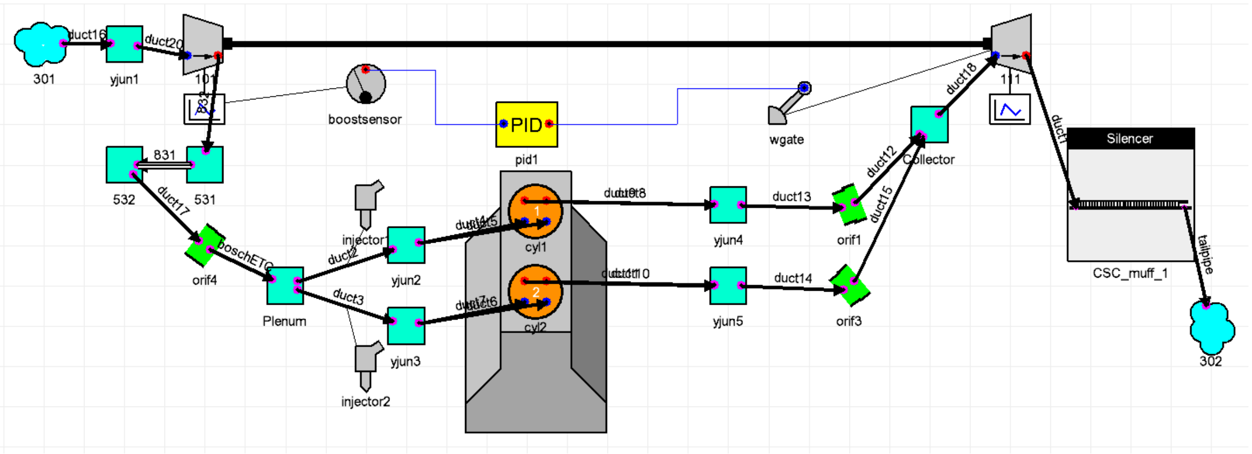


Figure 2 Ricardo WAVE Model of Turbo Miller Cycle 600 ACE

In order to verify the model, baseline dynamometer testing was performed at Kettering using the unmodified snowmobile. A crankshaft water brake engine dynamometer with a servo-controlled load valve was used for all testing. Additionally, data regarding fuel mixture as a function of speed and load was also gathered to aid in calibration of the flex-fuel capable engine control unit.

Through careful modeling of the engine, reasonable correlation to the OE 600 ACE performance was achieved with relatively few iterations of the model.

A design strategy that behaves symbiotically with boosting is LIVC in order to create Miller cycle conditions. Miller cycle operation improves pumping losses from throttling a spark-ignited (SI) engine at part load by decreasing the dynamic compression ratio and amount of retained charge; thus reducing engine output while minimizing the use of the throttle [5]. Further, the relative increase in expansion ratio relative to the decreased compression ratio, allows more of the thermal energy to be captured during the expansion/power stroke of the engine, resulting in improved efficiency. The engine's decreased output can be mitigated through charge boosting to provide the benefits of LIVC at part-load and increased engine output over the original engine at peak load.

In order to estimate the effect of Intake valve timing on engine performance, a parametric sweep was conducted using the boosted model in GT-Power. The results of this study with respect to Brake Specific Fuel Consumption (BSFC) can be seen in Figure 3. These results were then used to determine an appropriate amount of intake camshaft retard for a given intake charge boost pressure.

Based on the simulation results, it was decided that an intake charge boost pressure of 1.6 bar and intake cam timing retarded 20 degrees from the OE engine would provide the best performance to meet the team objectives. Charge air cooling through the use of an intercooler was deemed necessary due to the low-blend alcohol fuel to be used at the CSC 2014 competition.

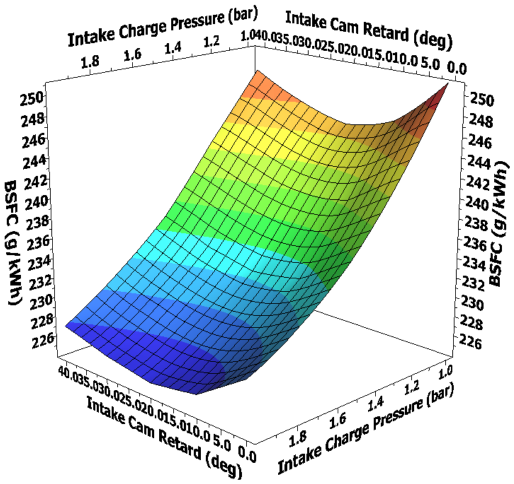


Figure 3 GT-Power DOE--Intake Charge Pressure and Intake Camshaft Retard

COMPRESSOR MATCHING

To increase charge air pressure, both supercharging and turbocharging were considered. Recreational and powersport engines such as the 600 ACE do not feature accessory belt drives; thus making it difficult to implement conventional belt-driven superchargers. Further, engine power would be lost in driving the compressor. Finally, a supercharger provides no attenuation of exhaust noise and often creates additional mid-high frequency noise that would not fit within the team objective of creating a quiet vehicle.

A turbocharger was selected for its ability to capture waste heat energy in the exhaust to drive a compressor. Further, the restriction of the turbocharger turbine housing provides significant attenuation of exhaust noise that helps simplify the design of the vehicle silencer. Two turbochargers were evaluated in a compressor matching exercise for use on the Miller cycle turbo 600 ACE—the Garrett MGT1238Z and the Garrett GT1541V. The MGT1238Z was selected because it operated in a more efficient region of the compressor map at peak boost level throughout the engine speed range used by the Continuously Variable Transmission (CVT)-equipped snowmobile. As can be seen in Figure 4, the red line represents the airflow range of the engine at the desired pressure ratio demonstrates that the compressor operates at efficiencies of 70% or greater. Additionally, the variable geometry turbine of the GT1541V might not withstand sustained operation at peak load that is experienced during in the CSC laboratory emissions test.

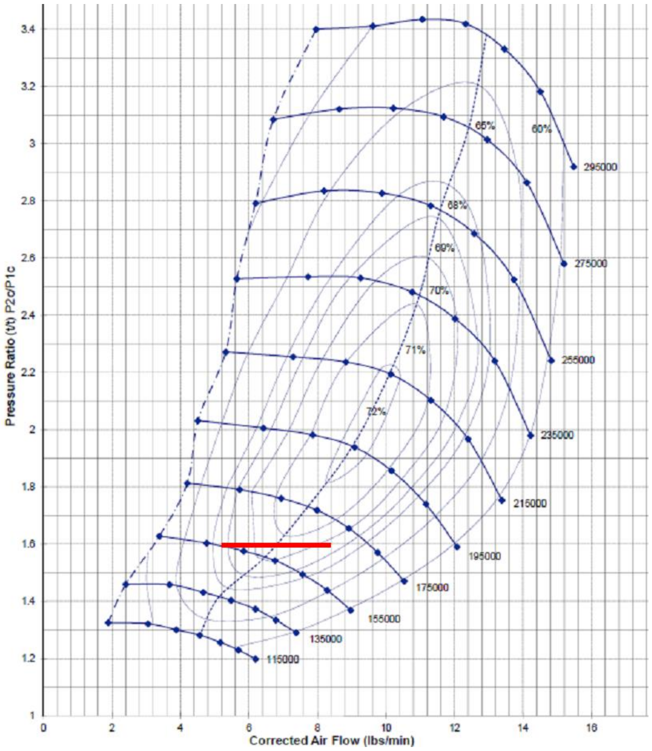


Figure 4 MGT1238Z Compressor Matching

TESTING THE EFFECT OF LIVC AND TURBOCHARGING ON THE ENGINE OUTPUT

The 600 ACE engine was modified for Miller cycle operation with an intake camshaft retarded by 20 degrees from the OEM timing. The LIVC valve lift compared to OEM is shown in Figure 5.

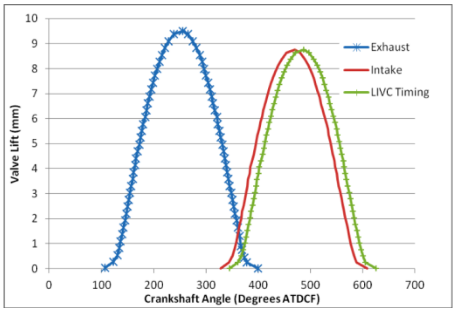


Figure 5 LIVC Valve Timing

To quantify the loss in engine performance attributable to LIVC alone, the baseline naturally aspirated engine was tested with the OEM intake valve timing. The engine was then adjusted to provide LIVC and tested.

A comparison of the results with the OE valve timing and Atkinson (un-boosted Miller) cycle valve timing was then made. The reduction in crank power can be seen in Figure 6 and the reduction in BMEP can be seen in Figure 7. Both tests were performed with the Kettering CSC MotoTron 128 engine controller and mapping while using an E67 ethanol blended fuel. As shown, the greatest reduction in BMEP due to LIVC cam timing occurs at low engine speed, slightly decreasing as the engine speed increases.

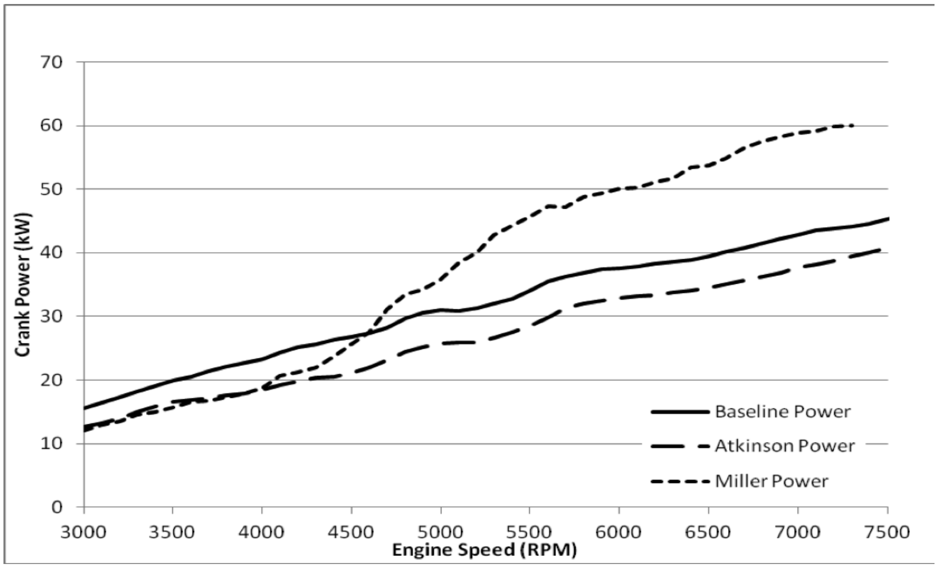


Figure 6 Crank Power

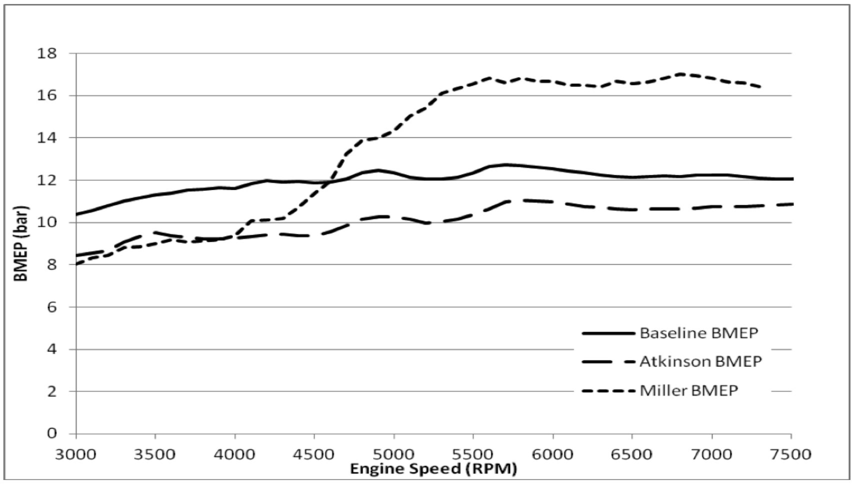


Figure 7 BMEP

ENGINE CONTROLLER SELECTION

The snowmobile was factory equipped by Ski-Doo with a Bosch ME17.8.5 engine control unit (ECU); however there was no way for the team to access and reprogram it. Furthermore, the original system did not provide closed loop fuel control. A new ECU was required.

For the 2014 CSC competition, a Woodward MotoTron ECU provided is used. The 128-pin ECU houses a 32-bit 56 MHz Freescale MPC 565 processor and has the ability to operate in temperatures between -40°C and 105°C. Sealed connectors allow the ECU to remain operable when submerged in up to 10 ft. of water, among other various tough environmental conditions.

Custom speed density engine control code was designed by the student team and flashed to the MotoTron controller. The control code allows for internal control of a Bosch LSU 4.9 wideband oxygen sensor (Bosch CJ125 chip) for use with closed- and adaptive-open-loop fueling algorithms. Extra attention was also given to ignition energy for the ability to ignite the lean charges that the powertrain is designed to run. High-energy IGN-1A Mercury ignition coils were chosen for their 103 mJ of spark energy.

The MotoTron ECU replaces the original Bosch ECU rather than simply running in parallel with it. The stock wiring harness is connected to diagnostic plugs which connect to the original Bosch ECU harness connectors. Wires are soldered to the diagnostic plugs and then routed to the ECU. This allows the original wiring harness to remain intact. The ECU has a multitude of inputs and outputs which enable improved engine performance through the ability to control both the fuel injection and ignition timing. It also has inputs for dual oxygen sensors as well as VR/Hall crank and cam position sensors that allow for greater engine feedback and control. This allows the ECU to monitor the oxygen content of the exhaust gases, reference the reading against a table of desired equivalency ratios, and adjust the air/fuel mixture accordingly. The flex fuel adjustment algorithm uses the wide range exhaust oxygen sensor feedback and adjusts fuel injector pulsewidths by adapting the calibrated stoichiometric value of the fuel mix.

The from-scratch engine controls feature a performance/economy mode switch. The economy mode switch is used to adjust the response of the electronic throttle to the driver thumb accelerator lever. Specifically, the output response is attenuated when the switch is in the economy mode position. This is accomplished by a reduction in maximum throttle opening angle and a reduced target pressure for the electronic boost control. This limits the engine power, while still providing increased power and decreased BSFC at peak load when compared to the normally aspirated (Atkinson cycle) configuration.

AFTERTREATMENT SYSTEM

In addition to the conversion to ethanol blended fuels and altering the engine management accordingly in an effort to decrease emissions, Kettering CSC has implemented a three-way catalytic converter (TWC) to catalyze carbon monoxide (CO), hydrocarbon (HC), and nitrogen oxide (NOx) emissions. The Emitec 600 cell per square inch SuperFoil metallic substrate is 100 mm in diameter and 74.5 mm in length for optimal packaging on the snowmobile. The Heraeus washcoat features a platinum/rhodium (1/0/1) loading for maximum oxygen storage capacity to extend NOx conversion during the Miller cycle turbo 600 ACE engine’s operation.

WEIGHT MINIMIZATION

Chassis modifications were kept to a minimum because the base MXZ Sport utilizes the REV-XP chassis which incorporates an aluminum frame. This makes it a relatively light trail snowmobile with a dry weight of only 206 kg (454 lb).

The 2011 Skidoo Renegade 600 ACE that was previously used had a dry weight of 213 kg (470 lb). When compared to the 2014 MXZ sport, the total weight reduction equates to 7 kg (16 lb).

In the 2008 competition, the forward set of idler wheels in the suspension of the snowmobile had been removed in an attempt to reduce noise. However, it was found that this had only a minimal effect on noise levels and no one was sure if the elimination of the wheels significantly increased drag on the track. To test this, the 2009 snowmobile was dragged behind a vehicle while attached to a load cell at speeds of 16 kph (10 mph) and 24 kph (15 mph). Multiple runs were made and averaged both without and with the forward idler wheels. As is shown in Table 4, when the forward idler wheels were put into the suspension, drag was reduced by 20.6% and 29.2% at 16 kph (10 mph) and 24 kph (15 mph) respectively. Although speeds were not increased beyond these levels because of safety concerns, it seems logical that these drag reductions would increase, or at least remain constant, at higher speeds. Another logical conclusion that can be drawn from the drag testing results is that additional idler wheels would make further reductions in drag.

In accordance with the testing performed, the idler wheels remain in place for this snowmobile so as to not decrease its fuel efficiency.

Table 4 Drag Test Results

	Drag (N/lb_f)			
	16 kph (10 mph)		24 kph (15 mph)	
	With Wheels	Without Wheels	With Wheels	Without Wheels
Trial 1	338 (76)	423 (95)	360 (81)	494 (111)
Trial 2	347 (78)	440 (99)	347 (78)	507 (114)

Average	343 (77)	432 (97)	354 (80)	501 (113)
Delta		89 (20)		147 (33)
Reduction %		20.6%		29.2%

COLD START MODIFICATIONS

One of the trade-offs of using higher blend ethanol fuels is poorer cold startability. Of course, this is of paramount importance for a snowmobile; therefore modifications must be made to allow for cold starting ability. The reason for poorer cold startability is shown in Table 3. The heat required for vaporization of ethanol blended fuels is much higher than that of gasoline. In cold weather starting conditions this presents a problem as ethanol will not vaporize at temperatures below 11°C [6].

In order to compensate for this, the team programmed the ECU to adapt for the cold at startup using fuel enrichment. This is done by injecting a greater volume of fuel into the cylinder during a cold start in order to allow enough gasoline into the cylinder to vaporize and initiate combustion. The cold start enrichment levels were determined through testing.

To ignite rich charges while cranking and lean charges during snowmobile cruising, the coil-on-plug ignition coils receive the maximum possible dwell time allowed by the manufacturer for maximum spark energy. The ignition coils are fired in wasted-spark, once per crank rotation, scheme for fast crank-to start times and decreased emissions.

MECHANICAL NOISE REDUCTIONS

To isolate the sources of mechanical noise, the snowmobile was placed on a stationary warm-up stand and run at different speeds. Sound readings were taken from different points around the snowmobile. The greatest noise levels contributed by mechanical systems were found to be coming from the engine compartment and the track tunnel.

In an effort to reduce mechanical noise, water and heat resistant foam insulation was installed under the hood deadening mat already used in the engine compartment.

The track noise is reduced through the use of a sound deadening coating on the inside of the track tunnel. These noise reducing techniques also contribute to the reduction of the exhaust noise since it is now routed into the tunnel. This will result in lower noise levels experienced by bystanders or in pass-by testing.

RIDER SAFETY

As with any recreational vehicle there are safety hazards to consider. As per competition rules, the unmodified clutch was enclosed with the stock guard made of aluminum and plastic. A leak proof gel cell battery was placed in plastic enclosure to prevent any potential hazards. In an effort to avoid arcing across the battery terminals, the interior of the box was lined with a rubberized, non-conductive material. The stock DESS tether retains its functionality.

COST EFFECTIVENESS

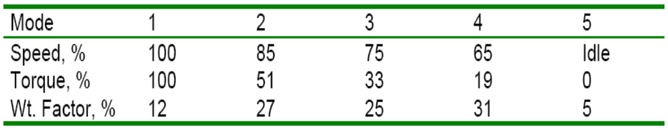
The original Ski-Doo MXZ has a base Manufacturer’s Suggested Retail Price (MSRP) of $7,999. However, added technology and performance enhancements drove this number up. After various fuel system improvements, a more advanced ECU, sound deadening treatment, and exhaust aftertreatment had been added to the snowmobile, the snowmobile cost increased to an estimated base MSRP of just over $9000. With the average base MSRP of a new snowmobile sold in North America in 2009 being $8800, this MSRP is very attractive considering the added value and advanced technology passed on to the customer. The cost of several components, can be expected to decrease with proper sizing for snowmobiles and volume production.

PERFORMANCE RESULTS

In order to assess how the engineering changes to the snowmobile effected the emissions, a baseline test of the emissions was taken on the stock snowmobile.

The emissions were measured while operating the snowmobile on a water-brake emissions dynamometer and using a commercially available direct sampling emissions bench from Horiba. During testing, the snowmobile was operated using 87 octane unleaded gasoline. Testing was conducted using the 5-mode test cycle in accordance with EPA 40 CFR Part 1051 dated November 8, 2002. This cycle and weighting factors is presented below in table 5.

Table 5 Five Mode Emissions Test Protocol



Mode	1	2	3	4	5
Speed, %	100	85	75	65	Idle
Torque, %	100	51	33	19	0
Wt. Factor, %	12	27	25	31	5

Emissions of the turbocharged Miller Cycle 600 ACE, as can be seen in Figure 8, are well below BAT standards and vastly improved over the stock industry-leading clean 600 ACE engine.

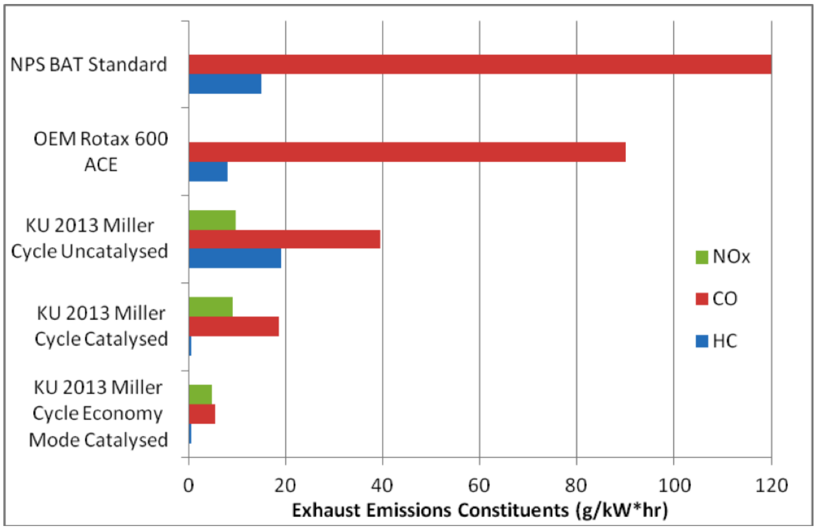


Figure 8 Emissions

CONCLUSIONS

The members of the 2014 Kettering University Clean Snowmobile Challenge team have produced a well-rounded snowmobile which is both clean and still fun to drive. The team has been able to deliver a quieter, cleaner, more efficient snowmobile without compromising the cost, durability, rider safety or performance. Through the use of ethanol blended fuels and add-on technology, the snowmobile has demonstrated much lower emissions than those required in the 2012 Federal regulations.

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- Michigan Corn Growers Association
- Robert Bosch Corporation
- Michigan DOE
- Denso

REFERENCE

1 International Snowmobile Manufacturers Association (ISMA), www.snowmobile.org/pr_snowfacts.asp

2 Recreated from Code of Federal Regulations, 40CFR Part 1051.103

3. Liu, T. et al., “Effect The Feasibility Study of Low-concentration Butanol as Fuel on Motorcycle,” SAE 2013-32-9134

4. S. Soma, et al.,” Investigations of Impact of the Ethanol Content on Exhaust Gases, Fuel Evaporative Emissions, High-temperature Driveability, and Materials for Fuel Supply System Parts of Gasoline Vehicles,” SAE 2005-01-3710

5. E. W. Thomas, “Fluoroelastomer Compatibility with Bioalcohol Fuels,” SAE 2009-01-0994

6. Gumpesberger, M. et al., “The New Rotax ACE 600 Engine for Ski-Doo”, SAE Paper No. 2010-32-0001