University of Idaho's Low Speed Flex Fuel Direct-Injected 797cc Two-Stroke Snowmobile

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ABSTRACT

The University of Idaho's entry into the 2013 SAE Clean Snowmobile Challenge uses a 2009 Ski-Doo XP chassis with a low speed 797 cc direct-injected two-stroke engine modified for flex fuel use on blended ethanol/gasoline fuel. A battery-less direct injection fuel system was used to improve fuel economy and decrease emissions while maintaining a high power-to-weight ratio. Noise was reduced by running the engine at a lower speed, and by strategically placing sound absorbing materials within the engine compartment. A muffler was modified to incorporate a three-way catalyst, which reduced engine emissions without greatly reducing power output or increasing sound output. Pre-competition testing had the snowmobile entering the 2013 SAE CSC competition weighing 263 kg (580 lb) wet, achieving 14.7 l/100km (16 mpg) running on 55% blended ethanol fuel (E55) in mountainous terrain. The snowmobile was tuned to be operable in either a "sport" mode or an "eco" mode with reduced peak power, emissions, and noise. When in eco-mode and using E55 fuel the snowmobile had an EPA five mode emissions test score of 206, and a J192 sound magnitude score of 73.4 dBA under hard pack conditions.

INTRODUCTION

Snowmobiling offers a great opportunity for winter recreation and exploration. Snowmobiles have traditionally been loud, with high levels of toxic exhaust emissions and poor fuel economy. Snowmobiles are often ridden in environmentally sensitive areas such as Yellowstone National Park where the adverse effects of snowmobiles can be substantial. To counter the potentially negative impact of snowmobiles a partnership between industry, conservationists, and the snowmobiling community was created. As part of this partnership, a competition was created for college students to design a cleaner, quieter snowmobile. The Society of Automotive Engineers (SAE), the Environmental Protection Agency (EPA), National Park Service (NPS), and the Department of Energy (DoE) supported the effort and began the Clean Snowmobile Challenge (CSC) in 2000.

The 2013 CSC continued to encourage snowmobile development by mandating use of blended ethanol/gasoline fuel in gasoline engines. The required blend ranged from 40 to 70 percent ethanol by volume (E40-E70) [1]. Ethanol is a renewable fuel that has lower energy content per unit volume than gasoline but maintains a higher effective octane rating. Exhaust emissions from burning blended ethanol fuels differ from those of gasoline, typically with lower total hydrocarbons (HC) and carbon monoxide (CO) quantities but elevated acetaldehydes and formaldehyde emissions [2]. Other challenges associated with blended ethanol fuels are creating flexible engine calibrations, and managing the higher corrosion potential in the fuel system components. This paper outlines the design strategies of the University of Idaho in engineering a solution that meets and exceeds industry standards for regulated emissions, improves efficiency, and maintains performance and reliability.

UICSC SNOWMOBILE DESIGN

Engine Selection

For 2013, the University of Idaho Clean Snowmobile Challenge (UICSC) team chose to use a direct-injected (DI) 797 cc Rotax two- stroke engine mounted in a 2009 Ski-Doo XP Chassis. This selection was based on the better power-to-weight ratio and handling, and reduced cost and complexity of two-stroke engines. The characteristics that make two-stroke engines mechanically simple typically result in lower thermal efficiency, poor part-load operation, and high exhaust emissions compared to four-stroke engines of similar output. Even with these drawbacks, it has been proven that a DI two-stroke powered snowmobile can meet and exceed the demands of the Clean Snowmobile Challenge [3]. UICSC's goal is to design a snowmobile that meets the performance demands of enthusiasts, while simultaneously being clean, quiet, fuel efficient, and generally responsible for use in sensitive areas.

Ergonomics (Human Factors)

An important aspect of snowmobile design that has not been previously addressed by the UICSC team is ergonomics. To improve the comfort of the snowmobile, the team raised the handlebars by implementing a 20.3cm (8in.) riser rather than the stock 11.43cm (4.5in.) riser. The optimal arm position of the upper arm is 60 degrees off centerline of the torso with the forearm parallel to the ground and the angle between the upper arm and forearm between 70 and 90 degrees [4]. Figure 1 demonstrates that the UICSC snowmobile achieves these specifications, based on the average height of a typical person. A variety of handlebar risers exist which could be implemented to achieve these effects for riders of different heights. This position gives the rider the ability to apply the greatest force on the handlebars, increasing the rider's control over the snowmobile, leading to improved handling and lower fatigue to the rider. In addition to decreased fatigue, the raised handlebars increase the rider's ability to control the snowmobile in a standing position. This is important to a rider in mountainous terrain, where typically the rider spends much of their time standing. Raising the handlebars also allows the rider to be in a more stable position with shoulders directly above the hips and knees above ankles. This position increases balance and allows the rider to apply the greatest forces on the handlebars while standing. This also decreases fatigue to the rider because the back is not bent while operating from a standing position.

Figure 1: Rider position on the 2013 UICSC snowmobile (shown at rest, engine off).

Fuel Delivery System

In the 2013 CSC, all gasoline spark ignition engines would be fueled with blended ethanol fuel. Hence a major design goal for the competition was to tune and modify the UICSC DI snowmobile to run on a blended ethanol fuel (E40 –E85) [1]. The challenge rules state E85 ethanol as the upper limit, but nominal E85 dispensed in the state of Michigan during the time of the competition is class 3 E85. Class 3 E85 has an upper limit of 70% ethanol content [5]. Using ethanol as a fuel has some drawbacks, such as increased fuel flow requirements, increased corrosion, shorter shelf life, and greater difficulty cold starting. The E-TEC fuel injectors used in the UICSC DI snowmobile are designed for the Ski-Doo 800R engine rather than the 600 H.O. These injectors allow for the higher flow rates that are necessary to run high ethanol content fuels. The fuel lines and O-rings used are compatible with ethanol blend fuels.

Blended ethanol fuels have a higher heat of vaporization than gasoline and therefore require more energy to vaporize and mix before ignition [6]. Under temperate ambient conditions this is not normally an issue. However, when blended ethanol fuels are used in low temperature environments, such as in a snowmobile application, cold starting becomes more difficult due to poor atomization of the fuel. Use of the E-TEC injectors in a stratified calibration strategy has proven to offer reliable cold starting even while using blended ethanol fuel at temperatures down to -10°C (14°F) [7].

Calibration

A Borghi & Saveri (SRL) eddy current dynamometer, model FE-260-S, was used for all flex-fuel calibration work. A Max Machinery 710 Series Fuel Measurement system allowed fuel flow to be measured. Emissions data were collected with a Horiba MEXA-584L emissions analyzer. An Innovate LM-2 wide band oxygen sensor provided information about the air/fuel ratio (AFR) of the engine. Since the two-stroke cycle allows fresh charge to short circuit out the exhaust, the oxygen value measured in the exhaust does not represent the actual fuel air charge trapped in the cylinder. As a result, the trapped equivalence ratio is unknown during calibration and cannot be used as a calibration objective. The wide band oxygen sensor does provide relative data, which were used to replicate an unburned oxygen concentration. This is useful when fuel injection timing and quantities are changed while engine speed and throttle position remain constant.

An EPA emissions score (E-score) based function was used to optimize engine calibration for the maximum emissions score [1]. The objective function is equation 1 below. In this function, W_m is the mode weight, unburned hydrocarbons (UHC) is in g/hr hexane equivalent, oxides of nitrogen (NO_x) and carbon monoxide (CO) are in g/hr, and P is power measured in kW. When calibrating at a mode point, this function allows the UICSC to compute the points contributing to the total E-score at a single mode. Fuel injection timing and quantity must be calibrated simultaneously due to their strong interaction. Alterations in injection timing have two main effects: mixing time, and short-circuiting control. Earlier injection results in cleaner combustion, but may also result in short-circuiting of fuel. Injection quantity must be altered to control trapped AFR.

$$F(x) = W_m * \frac{\left(\frac{6*UHC+NO_x}{150}+\frac{CO}{400}\right)}{P} \qquad (1)$$

A two-step strategy to minimize the objective function is discussed below, and shown in figures 2 and 3.

Sample data collected during step one is shown in figure 2. Step one is an injection timing sweep. Fuel injection timing is altered while adjusting the injection quantity in order to maintain a constant equivalence ratio, ϕ. Equivalence ratio is the ratio of the stoichiometric AFR to the actual AFR. The injection timing where the objective function is minimized is the optimal injection timing for that equivalence ratio.

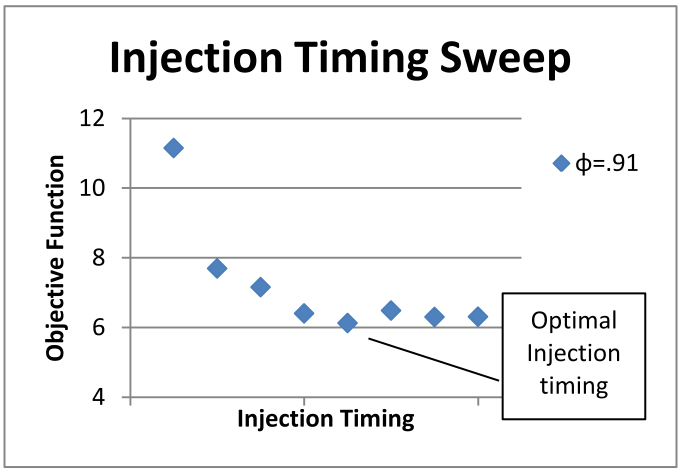

Figure 2: Objective function vs. injection timing at a constant equivalence ratio.

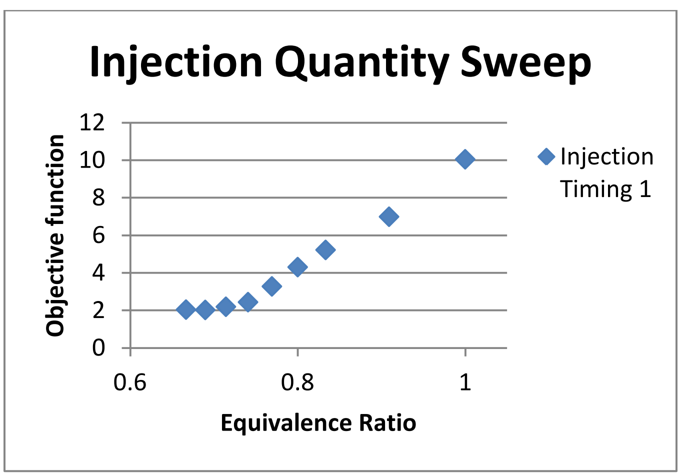

Figure 3: Objective function vs. equivalence ratio at a constant injection timing.

Sample data collected during step two are shown in figure 3. Step two is an injection quantity sweep. While holding the injection timing constant at the optimal value found in step one, the equivalence ratio was altered by adjusting the injection quantity. The equivalence ratio where the objective function is minimized is considered optimal for that operating point. In order to achieve the optimal setting, multiple iterations of injection timing and injection quantity sweeps must be completed for every operating point.

The calibration strategy was employed using the 797cc engine with the same throttle bodies, intake reeds, tuned pipe, and muffler that would be used at the 2013 UICSC design. The base map in the engine management module (EMM) was calibrated using 10% ethanol fuel, with an uncoated catalyst substrate installed in the exhaust stream. This was done to replicate the backpressure caused by the catalyst without risking damage to a catalyst during use of an unrefined EMM map. After the E10 calibration was complete, ethanol compensation calibration was done using a similar strategy as above to find optimal injection timing, quantity, and ignition timing.

Flex Fuel System

For 2013 the UICSC team used a Continental flex fuel sensor and a custom analog circuit to send information about the ethanol content of the fuel to the EMM. The analog circuit converts a frequency signal from the Continental flex fuel sensor into an analog signal that is accepted by the EMM. The CSC has been incorporating flex fuel since 2009. As such it was deemed necessary to create a reliable system that could be used in subsequent years. Figure 4 displays the final circuit design, which is on a compact printed circuit board approximately 4.8 cm x 5 cm x 1.9 cm (1.9 in x 2 in x .75 in). The altered flex fuel signal is connected to an existing input on the EMM, allowing for compensation of injection timing, quantity, and ignition timing.

Figure 4: The UICSC printed flex fuel circuit.

Injection quantity was compensated first. A mathematical compensation was calculated based on the AFR of the fuels and their respective densities. With this theoretical compensation entered into the EMM, engine testing was done to determine if the mixture was rich or lean, then adjustments were made accordingly. Figure 5 shows the theoretical compensation and the calibrated compensation. Increases in fuel quantity were required in part to reduce secondary combustion in the exhaust system.

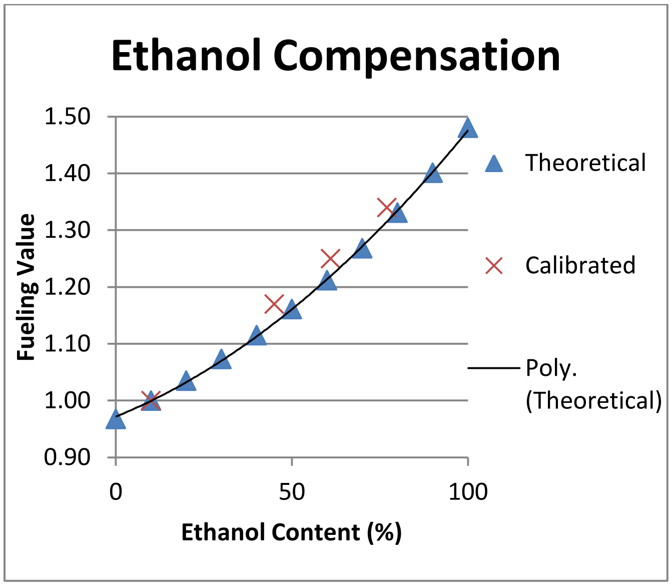

Figure 5: Theoretical and calibrated compensation for blended ethanol fuels.

Injection timing compensation was explored, but was not implemented in 2013 as it did not provide any improvement during testing. Ignition timing was only slightly modified. It is required to retard ignition timing when using 87 octane gasoline as OEM snowmobiles are calibrated for 91 octane. This is done to reduce knock at wide open throttle (WOT). The octane number listed at gas stations is the average of the research octane and motor octane numbers. When using higher ethanol blends it is possible to increase the power output of the engine by increasing the ignition advance. This is due to the high octane rating of ethanol fuels. E85, for example, has an octane rating of 97 (average of research octane and motor octane) [8]. The UICSC team took advantage of this to increase power output. The full potential, however, could not be realized due to the power limit of the competition [1].

Exhaust Emissions

Rule changes for 2013 permitted the University of Idaho CSC team to design the competition snowmobile to operate at two different settings. The aptly named 'eco switch' allows a configuration where exhaust and sound emissions would be lowered (eco-mode) and another setting where performance would be enhanced (sport-mode). Three fuels were used to test the emissions across the range of the competition fuels: 40% ethanol, 55% ethanol, and 70% ethanol. In addition, the presence of a catalyst was also tested. The catalyst coating uses a mixture of palladium and rhodium for HC, CO, and NO_x reduction. This resulted in 12 different configurations to be simulated and calibrated on the dynamometer. For these configurations, a full EPA 5- mode emissions test was run, including a full power curve [1]. Figures 6 and 7 demonstrate the power curves for sport-mode and eco-mode respectively. Peak power in sport-mode is 85 kW (114 hp) at7000 RPM. Peak power in eco-mode is 48 kW (65 hp) at 5750 RPM.

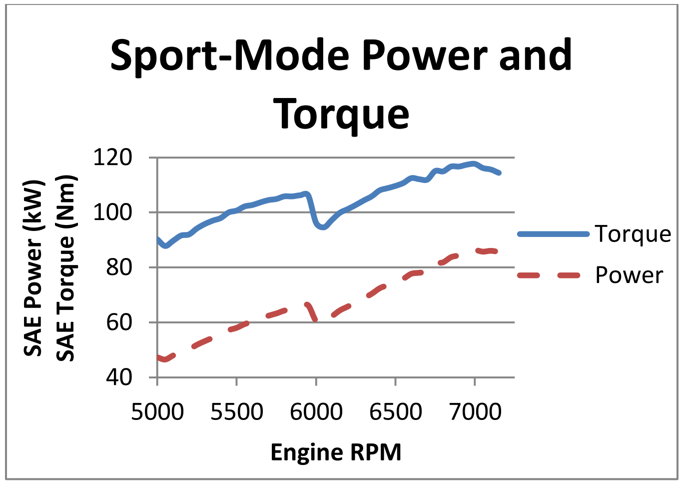

Figure 6: Power sweep for sport-mode (measured horsepower).

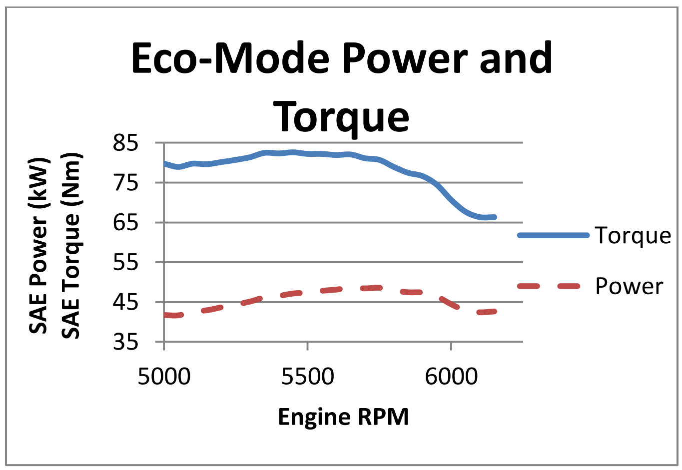

Figure 7: Power sweep for eco-mode (measured horsepower).

As shown in figure 7, the eco-mode power curve is nearly flat after 5500 RPM. This was intentionally created to work with the clutch in a way that would reduce noise output in the J192 pass-by sound test. Peak power data from all 12 configurations are depicted in figure 8. These data are conveyed in SAE power rather than measured power, where SAE power is the product of measured power and a correction factor. This correction factor is based on atmospheric conditions at the place of testing. For the data presented in figure 8, the correction factor was 107%.

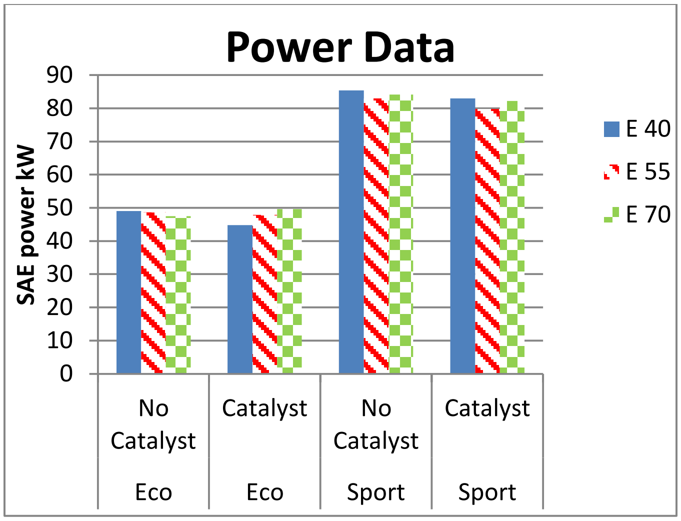

Figure 8: SAE peak power output at two different operating modes.

Peak power output in sport-mode was consistently between 80 kW (107 hp) and 85 kW (114 hp), well below the 96.9 kW (130 hp) limit for the 2013 SAE Clean Snowmobile Competition. As can be seen in figure 8, power was slightly reduced when an active catalyst was introduced. This was due to a slight increase in backpressure caused by expansion of the exhaust gases in the active catalyst region.

EPA 5-mode emissions tests were performed for all twelve configurations based on their respective peak power outputs. The data are shown in three separate charts. Figure 9 displays emissions data for three different fuel blends (E40, E55, and E70), and each chart shows data for the four operating configurations.

When comparing eco-mode to sport-mode without a catalyst, it can be seen that the E-scores are comparable. Since eco-mode operates at slower engine speeds, unburned hydrocarbon emissions are high. This is due to the over-scavenging of the cylinder, where intake charge is expelled into the exhaust. However, carbon monoxide emissions are significantly reduced in eco-mode, since the in-cylinder mixture is much leaner than in sport-mode at mode 1. The rich AFR at mode 1 in the sport-mode leads to poor conversion by the catalyst, because there is not enough oxygen to combust the high levels of HC and CO in the exhaust.

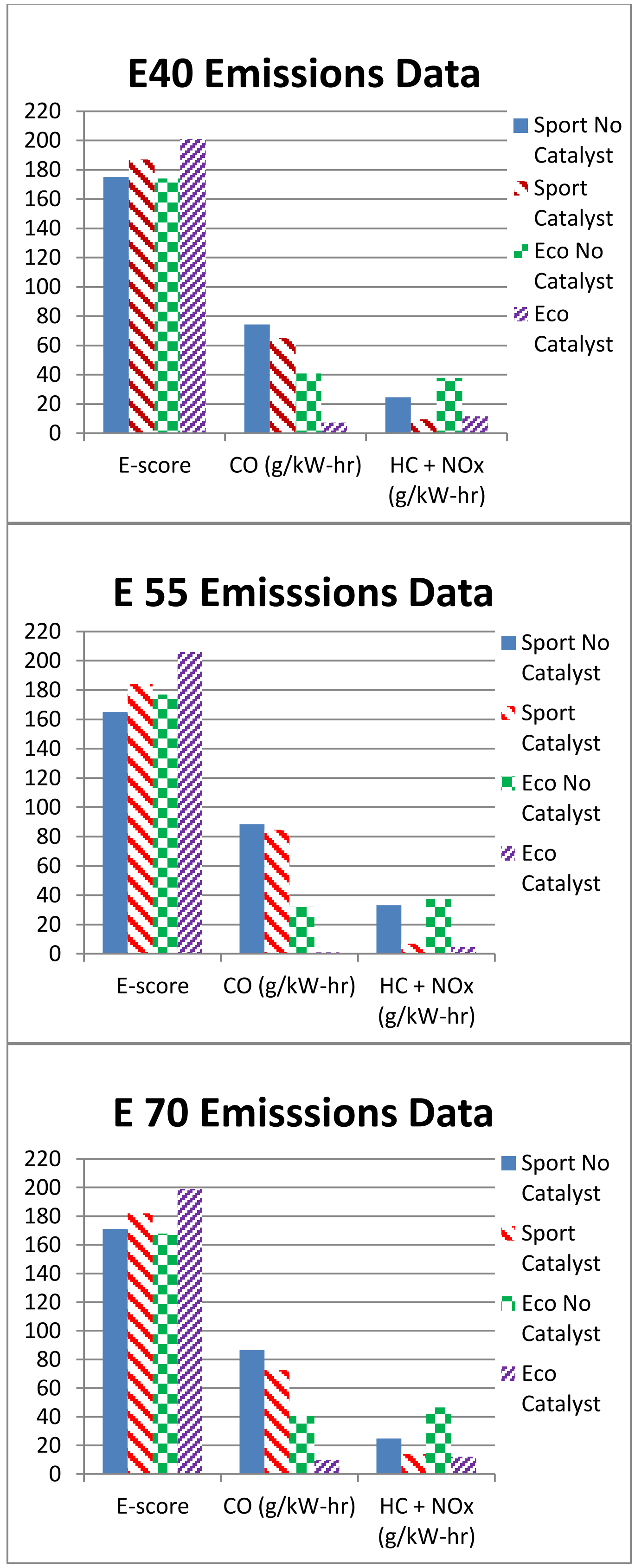

Figure 9: Emissions data for EPA 5 mode tests operating on various ethanol blends.

Mode 1 in the sport-mode setting operates at an equivalence ratio of 1.11; HC is approximately 5800 parts per million (PPM), and CO constitutes about 4.8% of the exhaust stream. These are very high values when compared to the 360 PPM HC and 0.6% CO emitted at mode 2. When a catalyst is used, the 4.5% oxygen in the stream is insufficient to combust all of the HC and CO. As a result HC reduction is minimal, down to 5300 PPM, and CO is increased to 5.7%. This contributes to most of the reduction in E-score for sport-mode. It can be seen in figure 9 that without a catalyst the E-score in eco-mode and sport-mode are very similar. However, the E-score when using a catalyst is much higher in eco-mode compared to sport-mode. Mode 1 in eco-mode is operated at an equivalence ratio of 1, where the three-way catalyst's conversion efficiencies are well-balanced between HC, CO, and NO_x. The other four modes operate lean and at low load. At these low loads very little NO_x is created in-cylinder, and the conversion efficiencies of CO and HC are very good due to high oxygen concentrations in the exhaust stream.

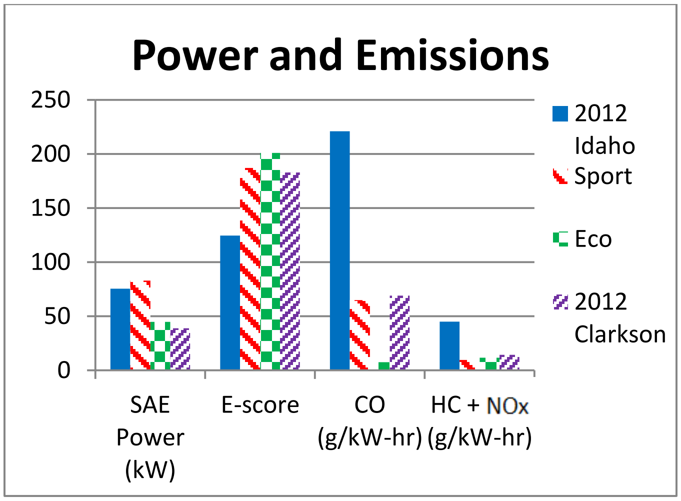

Figure 10: Power and emissions characteristics for different snowmobile configurations.

The 2013 UICSC two-mode vehicle entry is designed to meet or exceed the different specifications that a consumer may desire. Figure 10 shows a comparison of the two modes for 2013, and the results from the 2012 CSC for the UICSC team and the winning team, Clarkson University, which included a four-stroke engine. The sport-mode delivers power up to 85 kW (114 hp), which is more than UI's 2012 entry and far greater than a typical four-stroke. Sport-mode also passes EPA and NPS emissions requirements with EPA requiring an E-score of 100 and NPS requiring an E-score of 170 [1]. In eco-mode, the 2013 UI entry surpasses EPA and NPS emissions, with an E-score exceeding 200, outperforming a competitive four-stroke in both emissions and power, as shown in figure 10 [9].

The UICSC team also wanted to improve the fuel economy and emissions results that would be measured during the in-service emissions event. The snowmobile was ridden over various types of snow conditions at a cruise speed of 48 kph (30 mph). Engine speed and throttle position were collected to find the calibration points corresponding to cruise conditions. The engine was then operated at that point on the dynamometer where fuel and emissions were measured. In the competition configuration, the measured emissions were 1.7 g/km (2.8 g/mi). The emissions in this event are measured as the mass sum of HC, CO, and NO_x emitted over one mile. This value is a vast improvement over the 85 g/km (137g/mi) recorded for the UICSC in the 2012 competition. A large portion of the reduction in emissions can be attributed to the use of a catalytic converter.

Catalyst Aging

In 2012, the UICSC team researched catalyst break-in cycles to get more consistent emission results. A fresh catalyst will convert HC and CO constituents at a much higher efficiency than one that has used on an engine for an extended period of time. While there may be a short-term benefit to running a fresh catalyst, a seasoned catalyst reflects the type of emissions reduction likely over the life of the snowmobile. Therefore, the UICSC team decided to perform an experiment to test different aging techniques that would mimic on-engine aging practices. The results from that experiment showed that aging catalysts on the dynamometer was more effective than other methods, and is therefore further aged. The other methods tested were thermal aging at 760 °C (1400°F) for 24 hours and hydrothermal aging at 760 °C (1400°F) for 24 hours. The hydrothermal aging process involves flowing gaseous water through the substrate while at high temperature, while the thermal process uses static high temperature air. Figure 11 shows the results of the tests. For 2013, the UICSC team used thermal aging prior to engine aging to ensure catalyst aging and reduce the possibility of catalyst failure.

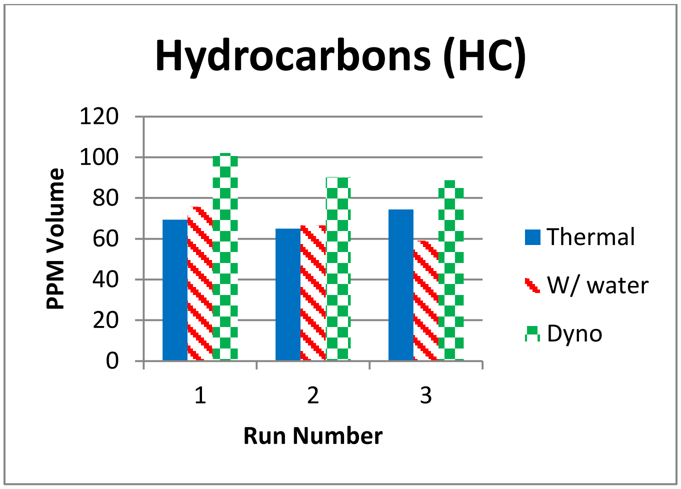

Figure 11: Hydrocarbon emissions after catalyst aging.

Fuel Economy

For 2013, fuel economy was measured during on-snow testing with E-40 to E-70 ethanol blends, the same that could be used in the 2013 competition. Using E-55 fuel, the UICSC snowmobile attained an average fuel economy rating of 14.7 l/100km (16 mpg) over a 101 km (63 miles) endurance run in mountainous terrain. The cruise operating range was identified by recording throttle position and engine RPM while traveling at speeds between 48 kph (30 mph) and 80 kph (50 mph). In this cruise range, the engine was calibrated for minimum brake specific fuel consumption (BSFC) rather than maximum E-score. BSFC is the measured fuel consumption divided by power output. This calibration was accomplished using the same strategy as the emissions calibration, with the objective function being the BSFC, therefore, calibrating for minimum BSFC will a result in improved fuel economy. Fuel economy was also recorded during the in-service emissions simulation. The result was 13.8 l/100 km (17 mpg) on E-55 fuel. This value is very near that of the on-snow tests.

Noise Reduction

In past years, the UICSC team's method for reducing noise emissions involved adding sound deadening material wherever possible. This method, while somewhat successful, added weight to the chassis and did not address the sources of the noise. In 2013 the UICSC design team began by first identifying the contributing sources. The sources explored were mechanical noise, intake noise, and exhaust noise from the engine and drive train. Strategies were then developed to address each area using a variety of techniques to reduce the overall noise emissions. Frequency and overall sound emission measurements were taken for the 2012 UICSC configuration operating in the SAE J192 test and used as baseline. The UICSC team also used a stock 2002 Polaris 700 RMK as a control snowmobile during all of its J192 testing to track changes in environmental conditions, and allow sound measurements from different days and snow conditions to be compared.

Mechanical Noise

For 2013, the UICSC used a strategy of absorption and redirection to reduce mechanical noise emissions during the SAE J192. To identify where in the chassis different sound materials should be placed, a test apparatus was created shown in figure 12 to measure the sound deadening properties of various sound reduction materials. White noise was then directed at the material using a Pioneer 14.0 cm (5.5 in) speaker with a Sony ECM-909A microphone recording the emitted sound. A plastic panel with similar properties to that of the stock Ski-Doo XR body panels was used as a baseline, different sound materials were then attached to the panel and measurements were retaken. Overall dBA measurements of the emitted sound were also taken to gauge the overall effectiveness of each material. While these data are only relative, they allowed the UICSC team to test a large variety of sound absorption materials and decide which materials were best suited for specific locations on the snowmobile.

Figure 12: Sound materials test apparatus

To contain and redirect noise, all hood and side panel vents not necessary for engine compartment cooling were sealed. Vents that could not be eliminated were fitted with directional scoops to reduce direct noise emission and maintain airflow through the engine compartment. During J192 testing the directional vents provided a 1 dBA reduction in the snowmobile's J192 score, along with a noticeable reduction in engine noise directed at the rider. To allow for ample airflow with substantial sound insulation installed, new, larger, Ski-Doo XR panels were fitted. In addition to adding sound insulation room, these panels allowed for the installation of exhaust systems that would have not been possible within the confines of the stock Ski-Doo XR panels.

Intake Noise

In previous years, the UICSC had used a strategy of redirecting intake noise and applying sound materials to the air box to reduce intake noise. In 2013, the UICSC used its analysis of sound materials to select a foam lining that provided a consistent sound intensity reduction across the frequencies typically measured within the engine air intake, along with providing an overall reduction of intake noise as measured in the J192. The UICSC also uses a low density air pre-filter element to further reduce intake noise. The combination of the foam lining in the air box and the air pre-filter element provided a 2.9 dBA reduction in the J192 as measured on the intake side as compared to that of the 2012 UICSC snowmobile, as shown in table 1. Without these changes, the J192 measurements were much louder on the intake side than on the clutch side. With the changes the two sides measured essentially the same.

Table 1: Comparison of SAE J192 Intake side measurements

Configuration	SAE J192 Intake (dBA)
2012 UICSC air box design	78.7
UICSC foam lined air box with pre-filter	75.8
Control Snowmobile	82.1

Exhaust Noise

The UICSC design team decided to take a two-step approach to reducing exhaust noise emissions for 2013. The first step was to reduce the overall maximum operating speed from 8000 RPM to 7000 RPM. The UICSC team also implemented a sport-mode and an eco-mode option. In sport-mode, the engine maximum operating speed is 7000 RPM and while in eco-mode, the engine maximum operating speed is further reduced to 6000 RPM. This was accomplished by interrupting power to the exhaust valve solenoid, preventing the exhaust valves from opening in eco-mode. The reduction in operating speed greatly reduced overall sound level in the SAE J192 with a 2.6 dBA measured reduction from sport-mode to eco-mode. For the second step in exhaust noise reduction, the UICSC team employed the use of an exhaust quarter wave resonator. The purpose of the resonator is to create destructive interference between the sound waves traveling through the pipe and the sound waves from the resonator, effectively reducing the noise of the entire system at the design frequency. The resonator was designed to cancel the second harmonic of the UICSC engine in eco-mode, calculated as 400 Hz. The quarter wave resonator was initially tested on the engine dynamometer as a proof-of-concept, operating at a consistent speed. Sound recording data were then analyzed using a Fast Fourier Transform (FFT), which showed the quarter wave resonator provided approximately a 3 dBA reduction at its design frequency, as shown in figure 13. The quarter wave resonator was then adapted to fit within in the snowmobile chassis as shown in figure 14 where the prototype quarter wave resonator is the curved exhaust tubing just above the muffler. Following the adaption into the snowmobile the quarter wave resonator was then tested on-snow in the J192 test. Table 2 provides a comparison of exhaust side measurements from J192 testing with and without the quarter wave resonator and shows it provided a 2.0 dBA reduction of the exhaust side measurements.

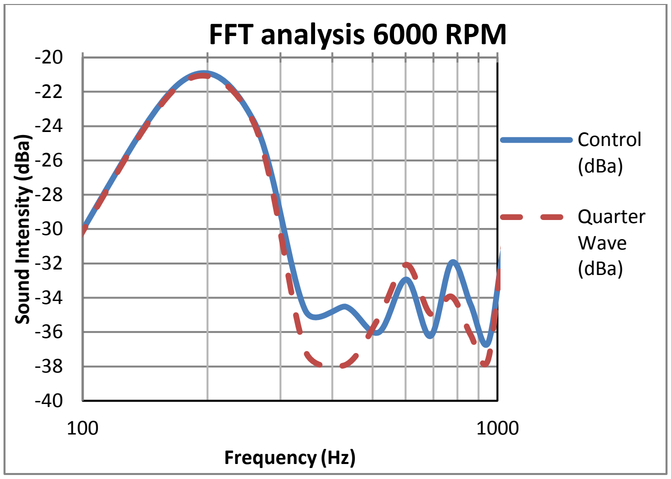

Figure 13: FFT analysis of UICSC engine operating at a constant speed with and without the quarter wave resonator.

Figure 14: Quarter wave resonator in chassis.

Table 2: Comparison of SAE J192 Exhaust side measurements.

Configuration	SAE J192 Exhaust (dBA)
UICSC design with quarter wave resonator	75.5
UICSC design without quarter wave resonator	77.5
Control Snowmobile	80.6

Combined Approach

The combination of the UICSC noise reductions strategies yielded a J192 score of 75.4 dBA in eco-mode and score of 78.0 dBA in sport-mode. Comparing theses scores with 2012 UICSC design, the 2013 UICSC design achieved a 4.3 dBA reduction in eco-mode and a 1.7 dBA reduction in sport-mode.

At previous clean snowmobile challenges, the UICSC's sound pressure meter consistently reads ~2 dBA higher than the Head Acoustic products used at competition. Therefore, both eco-mode with a predicted score of 73.4 dBA and sport-mode with a predicted score of 76.0 dBA are expected to meet EPA standards at competition.

Weight

The UICSC team has always strived to keep their machine light for several reasons. A lighter snowmobile will achieve better fuel economy, improve dynamic performance, and reduce rider fatigue. As snowmobile manufacturers continue to reduce the weight of their machines, the UICSC team needs to follow that trend as well. Pre-competition testing had the snowmobile entering the 2013 SAE CSC competition weighing 263 kg (580 lbs) wet, same as in 2012. The majority of the additional weight added over stock was sound absorbing material, which was used to meet other competition goals. Although this is slightly higher than the production snowmobile, it is still competitive with clean four-stroke snowmobiles. Shown in table 3 is a comparison of measured snowmobile weights at the 2012 CSC competition [9].

Table 3: Comparison of measured snowmobile weights at 2012 CSC competition

University	**Measured Total Weight kg (lbs)**
Idaho 2012	263 (580)
Clarkson 2012	250 (552)
Madison 2012	289 (638)
Michigan Tech 2012	261 (576)

MSRP

The base price for a stock 2013 Ski-Doo MX-Z 600 E-TEC is $10,424. With all modifications included, the Manufacturer's Suggested Retail Price (MSRP) of the 2013 UICSC DI totaled $11,410. Chassis components that add to the MSRP were justified by sound reduction, increased performance, reduced exhaust emissions, and sponsor product awareness. The addition of equipment and components is minimal. This strategy allows the UICSC snowmobile to achieve a low MSRP and reliability on par with a stock snowmobile, while still being competitive with other clean snowmobiles.

SUMMARY/CONCLUSIONS

The University of Idaho has developed a cost-effective dual-mode flex fuel DI two-stroke snowmobile engine capable of running on E40-E70 blended ethanol fuel. The DI two-stroke snowmobile maintains the mechanical simplicity and low weight avid riders enjoy, without sacrificing the clean and quiet characteristics necessary to meet current and upcoming standards. The UICSC design produces 85 kW (114 hp), is lightweight at 263 kg (580 lbs) wet, and achieves a fuel economy of 14.7L/100km (16 mpg) using E-55 fuel. Overall sound production, measured using the SAE standard J192, was reduced from 82.0 dBA to 76.0 dBA in sport-mode. The UICSC design achieves NPS emissions E-scores in both eco- and sport-mode, with eco-mode having an E-score of 206 while operating on E-55. Consumers expect snowmobiles that are clean, quiet, fuel-efficient and fun-to-ride. The 2013 UICSC dual-mode flex-fuel DI two-stroke snowmobile is an economical response to that demand.

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DEFINITIONS/ABBREVIATIONS

AFR	Air Fuel Ratio
BSFC	Brake Specific Fuel Consumption
CO	Carbon Monoxide
CSC	Clean Snowmobile Challenge
DI	Direct Injection
DOE	Department of Energy
EGT	Exhaust Gas Temperature
EMM	Engine Management Module
EPA	Environmental Protection Agency
FFT	Fast Fourier Transform
HC	unburned hydrocarbons
MSRP	Manufacturer's Suggested Retail Price
NO_x	oxides of nitrogen
NPS	National Park Service
PPM	Parts Per Million
RPM	Revolutions Per Minute
SAE	Society of Automotive Engineers
UICSC	University of Idaho Clean Snowmobile Challenge
WOT	Wide Open Throttle