University of Idaho's Direct Injected Two-Stroke Snowmobile Using E2X Fuel

Author, co-author (Do NOT enter this information. It will be pulled from participant tab in MyTechZone)

Affiliation (Do NOT enter this information. It will be pulled from participant tab in MyTechZone)

ABSTRACT

The University of Idaho's entry into the 2011 SAE Clean Snowmobile Challenge was a direct-injection two-stroke powered snowmobile modified to use blended ethanol fuel. The battery-less direct-injection system used to improve fuel economy and decrease emissions maintained near stock power output of the engine at 71 kW (95 hp). Noise from the engine compartment was reduced by custom placement of sound absorbing materials. A muffler was designed that reduced exhaust noise but proved to limit engine performance and was not used. To further reduce exhaust emissions a catalyst was incorporated into the stock muffler. Pre-competition testing had the snowmobile entering the 2011 SAE CSC competition weighing 250 kg (552 lbs) wet, achieving 7.43 km/L (17.5 mpg) running on blended ethanol fuel, with an EPA five mode emissions test score of 177, and a predicted J-192 sound magnitude score of 78 dBA

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. The snowmobile's negative impact and comments by industry and others prompted the snowmobile community as well as conservationists to partner and challenge college students to design a cleaner, quieter snowmobile. Society of Automotive Engineers (SAE), the Environmental Protection Agency (EPA), National Park Service (NPS), and the Department of Energy supported the effort and began the Clean Snowmobile Challenge (CSC) in 2000.

The 2011 CSC continued to encourage snowmobile development by mandating use of blended ethanol/gasoline fuel. The required blend ranged from 20 to 29 percent ethanol per volume (E2X). Ethanol is a renewable fuel that has lower energy content per unit volume than gasoline. Blended ethanol fuels hazardous exhaust emissions also differ from those of gasoline, with lower unburned hydrocarbons (UHC) and carbon monoxide (CO) quantities but elevated acetaldehydes and formaldehyde emissions [1]. The corrosive properties of ethanol also require revised design strategies. This paper outlines the design strategies of the University of Idaho in engineering a solution that meets and exceeds industry standards in reducing regulated emissions, improving efficiency, and maintaining reliability.

UICSC SNOWMOBILE DESIGN

ENGINE SELECTION AND CALIBRATION

For 2011, the University of Idaho Clean Snowmobile Challenge (UICSC) team chose to use a direct injected (DI) 593 cc Rotax two-stroke engine mounted in a 2009 Ski-Doo XP Chassis. This selection was made based on the preferred power-to-weight ratio, better handling, and reduced cost and complexity of two-stroke engines. The characteristics that make two-stroke engines mechanically simple also cause them to have lower thermal efficiency, poor low 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 [2].

A Ski-Doo E-TEC DI system from a stock 2009 Rotax 593cc engine was used with the UICSC custom cylinder head design [3]. In previous years the UICSC team adapted the Evinrude E-TEC DI system to a carbureted snowmobile engine. With the availability of snowmobile engines designed specifically for the E-TEC DI system the team decided to use a newer model engine. The main difference in these two engines is the RAVE exhaust valve. One drawback of the two-stroke engine is that at off-tune points short circuiting of the unburned fresh fuel and air charge can exit out the exhaust. In previous years the 2D RAVE exhaust valve used a two position guillotine blade to help regulate the flow of exhaust by lowering the exhaust port height at off tune points in the operating range. The current model year uses a 3D RAVE valve which has a three position guillotine that also blocks the exhaust transfer ports at low loads to increase volumetric efficiency. Figure1 shows a comparison between the 2D RAVE and 3D RAVE exhaust valves.

Figure 1: Shown are the 2D RAVE (left) and the 3D RAVE (right)

The extra midrange position of the 3D RAVE helps to increase the engines efficiency over a greater RPM range. Shown in Figure 2 is a comparison of brake specific fuel consumption (BSFC) between the 2D RAVE and 3D RAVE valves using E10. The use of the 3D RAVE valves showed an improvement at every mode point, with an average BSFC improvement of 16.6%.

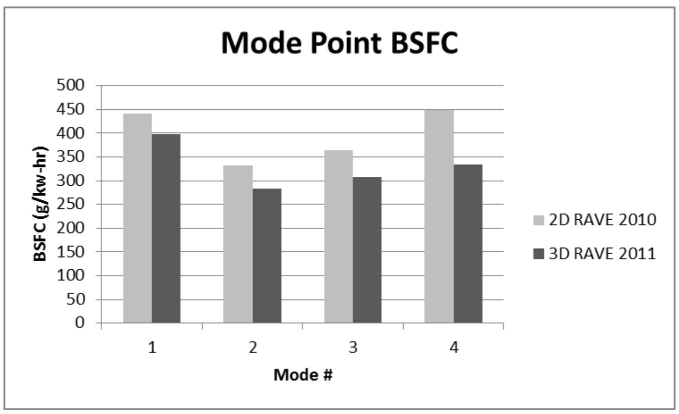

Figure 2: BSFC RAVE Valve Comparison

The DI head design, CNC coding, and manufacturing were all done in 2006, in the University of Idaho Mechanical Engineering Department machine shop. Undergraduate and graduate student mentors designed the two-piece cylinder head and performed all of the machining procedures, aided by the mechanical engineering department's machinist. The machined head installed on the Rotax engine is shown in Figure 3.

Figure 3: Completed UICSC DI head installed on the Rotax 600 H.O. engine.

Inductive Ignition System

For 2011, the UICSC team chose again to use an inductive ignition system. An inductive ignition discharges energy continuously into the fuel-air mixture as opposed to the multiple strike strategy of a capacitive discharge system. This design was chosen due to the added activation energy required for the combustion of ethanol and the added flexibility in engine calibration.

Oil Control and Engine Lubrication

Traditional two-stroke snowmobile engines use a total-loss oiling system. Either the oil is premixed with the fuel or the oil is pumped into the inlet-air stream where it mixes with the incoming fuel. As the fresh air/fuel/oil mixture travels through the crankcase, an oil film is deposited on the surfaces. Any oil that does not attach to a wall is scavenged into the combustion chamber. This system does not require oil filters, oil changes, or a sealed crankcase.

The 2011 UI DI engine uses an electronic total-loss oil injection system from a Ski-Doo E-TEC snowmobile. This system eliminates premixing of oil and fuel and only delivers oil to specific locations. Less oil is required in a DI engine because the oil is not diluted by fuel in the crankcase. With the precision control possible using the electronic pump, oil consumption was reduced by approximately 50% over traditional carbureted two-stroke engines.

Fuel Delivery System

Due to a SAE CSC 2011 rule requiring all spark ignition engines to be fueled with blended ethanol fuel, a major design goal for the 2011 SAE CSC competition was to tune and modify the UICSC DI snowmobile to run on a blended ethanol fuel (E2X) [4]. Taking advantage of the benefits of the fuel, i.e. the lower measured exhaust emissions and greater knock resistance while dealing with the drawbacks such as increased corrosion, increased fuel flow requirements, and difficult cold starting.

Cold start strategy

Blended ethanol fuel has a higher heat of vaporization than gasoline and therefore requires more energy to initiate combustion [5]]. Under ambient conditions this is not normally an issue. However, when blended ethanol fuels are used in reduced temperatures, such as in a snowmobile application, cold start becomes difficult. 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).

Calibration Strategy

Engine calibration for blended ethanol fuel was completed using a Borghi & Saveri Eddy Current dynamometer, Lambda sensor, exhaust gas temperature sensors, precision fuel flow measurements, in-cylinder pressure traces and a Horiba emissions analyzer. Because of excess air in the exhaust stream due to the nature of a DI two-stroke engine, the lambda sensor alone was not adequate for tuning. Once the lean/rich limits were found, the Lambda sensor provided a guide to creating a smooth engine map for operation on E2X fuel. The in-cylinder pressure trace was used to detect detonation while tuning and to monitor heat release rates. Emission tuning was completed using a Horiba five-gas analyzer. The strategy for engine calibration focused on lowering BSFC and improving run quality throughout the map, followed by emission reduction at each of the mode points, without sacrificing run quality.

Engine Emissions

In order to compare the effects of hardware and calibration changes made by the UICSC team a completely stock Ski-Doo E-TEC engine running on E10 was used as a baseline for an EPA 5-mode emissions test. At each of the 5 modes data were collected regarding the exhaust emissions, torque, lambda, throttle position and BSFC. These values are referred to as the “baseline” for the engine. The baseline emission values were found to be very close to the findings of Miers [6]. After the baseline was completed the UICSC cylinder head was installed and a 5-mode emissions test was run without any modifications to the baseline calibration. These values are referred to as “Configuration 1”. Finally, time was spent tuning each mode point in order to further reduce emissions. These values are referred to as “Configuration 2”. Figure 4 shows a comparison of the EPA 5-mode test of the three separate cylinder head and calibration configurations against UICSC’s 2010 competition entry. The 2010 engine configuration consisted of the UICSC cylinder head and older cylinders with a 2D RAVE exhaust valve running on E22. Baseline, Configuration 1, and Configuration 2 use the newer 3D RAVE system running on E10. The significant reduction in emissions from the stock head to the UICSC head is attributed to better combustion chamber geometry and spark plug placement.

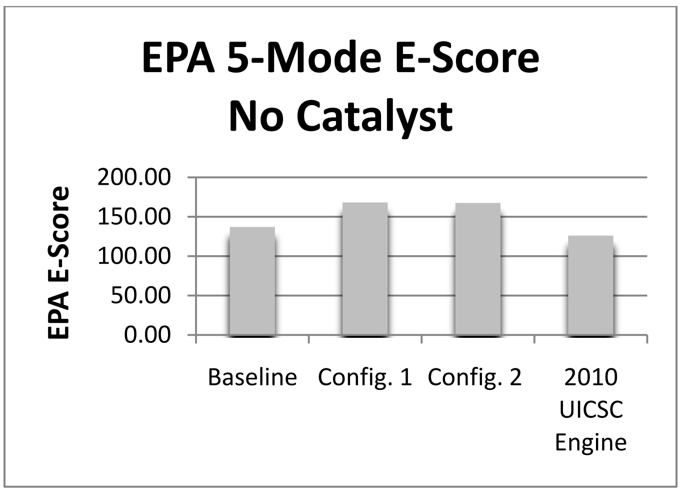

Figure 4 – Comparison of cylinder, cylinder head and calibration effects on emissions using the EPA 5-mode test

Reducing hydrocarbon emissions was the main focus of tuning each of the mode points. Changes in fuel quantity and injection timing were made and the changes in emissions were measured real-time with the Horiba analyzer. The most significant emissions reductions were seen at modes three and four. Both hydrocarbons and NO_x levels were reduced but CO increased. The rise in CO was determined to be acceptable because it was still under the NPS emissions limit of 120 g/kW-hr even though the calibration changes had an over-all negative effect on the final E-score. To reduce the chances of engine failure, safe lambda values and exhaust gas temperatures were monitored at all mode points.

Although the UICSC cylinder head and calibration changes significantly reduced exhaust emissions, a further reduction was required to meet NPS standards of 15 g/kW-hr of HC + NO_x and 120 g/kW-hr of CO. To accomplish this, a catalytic converter was added to the exhaust system. The catalyst was provided by Aristo Catalyst Technologies and was designed with the emissions data gathered from testing the UICSC cylinder head. The catalyst was a cylindrical design 8.9 cm in diameter and 11.4 cm long with 46.5 cells/cm^2 (3.5 in x 4.5 in, 300 cells/in^2). Only a slight change in calibration was needed to account for the added backpressure of the catalyst. The catalyst significantly reduced hydrocarbon as well as NO_x emissions, and brought the UICSC engine’s E-score to a 177. Figure 5 shows an inert and active catalyst comparison of exhaust emissions along with results from UICSC’s 2007 competition entry. The 2007 engine configuration consisted of the UICSC cylinder head, older cylinders with a 2D RAVE exhaust valve, a catalytic converter from Aristo, and ran on E10.

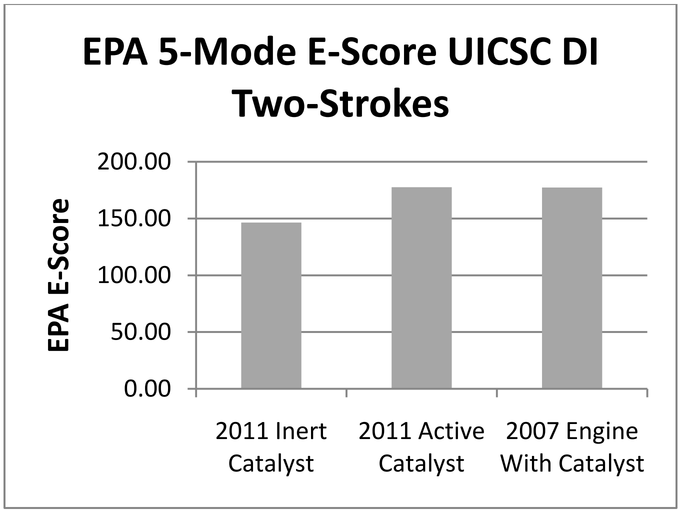

Figure 5 – A 5-mode test comparison of the UICSC 2011 engine and catalysts vs. UICSC's 2007 engine

The weighted emissions, as well as an E-Score comparison, are shown in Figure 6. Although the 2011 engine scored very similarly to the 2007 configuration the composition of the scores is very different. This is due to a different exhaust valve design as well as calibration strategy. The 2011 calibration strategy strictly focused on reducing HC + NO_X as long as CO remained below the NPS of 120 g/kW-hr. This strategy resulted in a score of 177 in the EPA emissions test as well as producing 70% fewer HC emissions, 60% fewer NO_X emissions and producing 10% less CO than required by NPS.

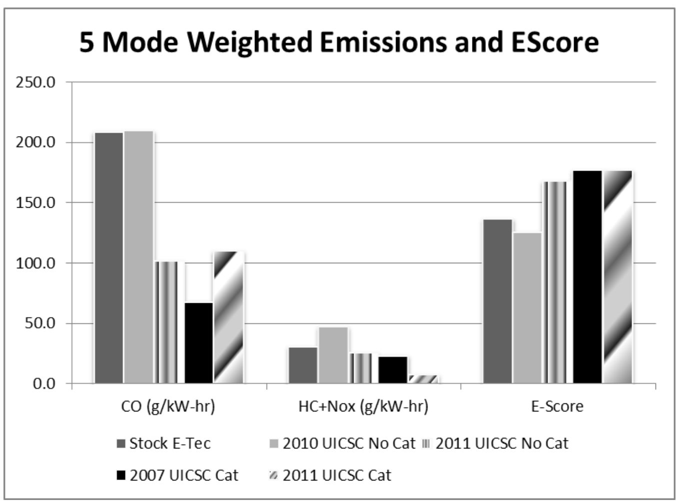

Figure 6 – A 5-Mode weighted emission and E-Score comparison

DRIVETRAIN EFFICIENCY

Seeking to improve upon the fuel economy of its snowmobile the UICSC team decided to research areas to reduce drivetrain losses for 2011. The UICSC chose to test several ideas from the snowmobile industry that are hypothesized to increase drivetrain efficiency. These include:

- A low tension track has less rolling resistance then a high tension track
- Larger rear bogie wheels will create a larger radius for the track to rotate around lowering the angular acceleration and rolling resistance
- More bogie wheels offer better efficiency by avoiding contact with the hyfax
- That a belt drive instead of a chain from the jack shaft to the driver is more efficient

All tests performed were comparative using a Land and Sea track dynamometer stand and the UICSC's 2008 Ski-Doo XP 600 SDI with a constant dynamometer track speed of 1500 rpm and engine speed of 6000 rpm. The experimental set up is shown in Figure 7.

Figure 7: Experimental setup for drivetrain efficiency testing.

Track Tension

The two track tensions were measured by placing a ten pound weight between the rear and middle bogie wheels and measuring the sag of the track from the hyfax to the track. The two different tensions tested were 38 mm of sag for high tension and 51 mm of sag for low tension. The results are plotted as the average torque outputs from the dynamometer for five tests in Figure 8. These results are inconclusive on whether low or high track tension is more efficient.

Rail Bogie Wheels

To test the effects of increased rail bogie wheel numbers, initially a stock quantity of bogie wheels was tested, then eight additional bogie wheels were added along the suspension rail lessening the contact of the hyfax on the track. From the results shown in Figure 8 the effects of additional bogie wheels on the suspension rails proved to be inconclusive.

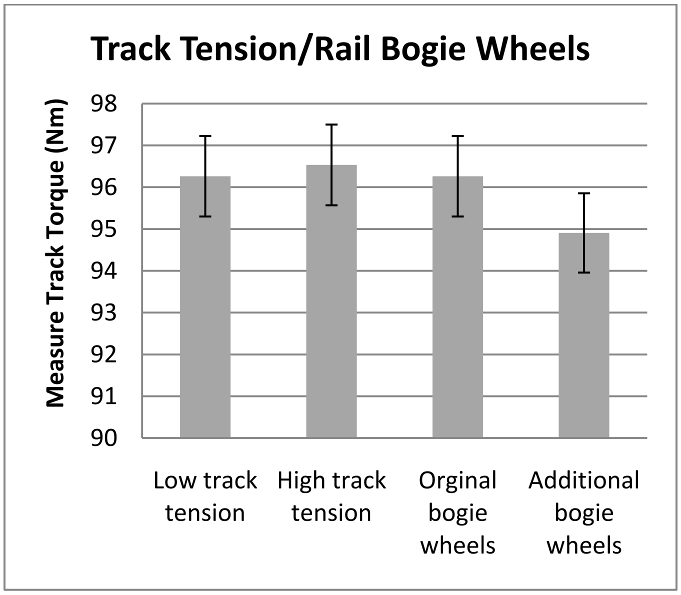

Figure 8: Efficiency testing of track tension and rail bogie wheels

Larger Rear Bogie Wheels

For comparing the effects of larger rear bogie wheels to those of stock dimensions the UICSC choose to compare the factory 178 mm (7 in) diameter bogie wheels on the 2008 Ski-Doo to 254 mm (10 in) diameter Nextech carbon wheels. Correct placement of the larger bogie wheels required offset axle to be designed and built so no other modifications were needed. The tests were performed for 10 repetitions showing no difference between the standard and larger rear bogie wheels. The results are shown in Figure 9.

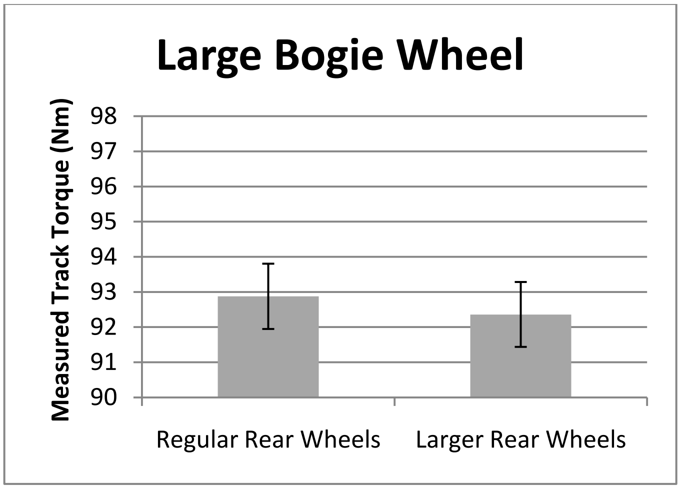

Figure 9: Large Bogie Wheel Test

Belt Drive

To perform a comparison of a belt drive to a chain drive the UICSC built a belt drive to fit the 2008 Ski-Doo XP using components from C3 Motorsports. The tests were performed for 10 repetitions for the chain drive and both a loose and tight belt drive. The results shown in Figure 10 show a 2 ft-lb decrease in torque output with the belt drive and an additional ft-lb loss when belt tension was reduced. This shows that the chain drive is more efficient due to its ability to transfer a greater percentage of engine torque to the track when compared to the belt drive

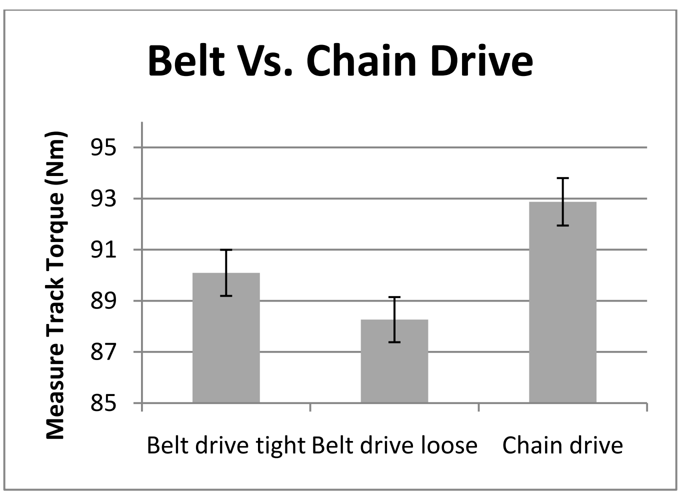

Figure 10: Belt Drive vs. Chain Drive

Overall Drivetrain Results

The results for the drivetrain efficiency testing did not show a clear disadvantage or advantage of any setup except for belt vs. chain final drive. This is because the large variance in each data set makes it difficult to distinguish between a change in performance and testing error. For 2012, the UICSC plans to perform future efficiency testing using an electric motor driving the jackshaft on the snowmobile, which will help eliminate inconsistencies during the test, reducing testing error.

Weight Reductions

Due to a change in the competition rules, the overall weight of the snowmobile is no longer directly awarded points. However, the UICSC team has always strived to keep their machine light for several reasons. First a light snowmobile will achieve better fuel economy. Lower weight also improves dynamic performance, and reduces rider fatigue. Lightweight is also an important aspect of market-ability. As snowmobile manufactures continue to reduce the weight of their machines in response to consumer needs the UICSC team must as well. Pre-competition testing had the snowmobile entering the 2011 SAE CSC competition weighing 250 kg (552 lbs) wet.

Fuel Economy

For the 2011 CSC fuel economy was measured using a Land and Sea track dynamometer. This allowed the UICSC team to accurately control cruise and engine load conditions while completely eliminating track spin and trail variations resulting in a more accurate measure of fuel economy. The 2011 UICSC snowmobile got an average fuel economy rating of 7.43 km/L (17.5 mpg) over a 72.5 km (45 miles) endurance run.

NOISE REDUCTION

For the UICSC snowmobile to be competitive in the noise event, the entire range of human hearing had to be addressed. There are four main sources of noise in snowmobile: 1) mechanical noise emitted from the engine and drive system, 2) track and suspension noise, 3) air intake noise and 4) engine exhaust noise.

One method for reducing sound emission in the past has been to add sound material wherever possible. This was effective in suppressing noise but added unnecessary weight to the chassis. In 2008 a test apparatus was constructed to evaluate sound deadening material effectiveness [7]. It allowed sound deadening material to be selected based on general frequencies to be attenuated. To improve on this, and determine the most effective use of the sound material, coherence and impedance testing have also been implemented.

Coherence testing takes an overall sound sample of the snowmobile and compares it to a local sound sample taken from locations of interest on the chassis. The test determines the percentage of sound at a frequency that contributes to the overall sound pressure level (SPL) of the snowmobile. After testing a variety of materials, the coherence test determines where a material with certain properties should be placed making more efficient use of space and saving weight. Coherence testing not only helps with sound deadening material but it also aides in chassis modifications. Knowing where the bulk of sound energy was emitted from and the difficulty of damping the sound determined priority areas making more effective use of time and sound-damping materials. Equation 1 is the general equation for coherence.

$$\gamma^2(f) = \frac{|G_{xy}(f)|^2}{G_{xx}(f)G_{yy}(f)} \left(0 \le \gamma_{xy}{}^2 \le 1\right) \qquad (1)$$

Mechanical Noise

There are several sources of mechanical noise. These include the clutches, chain drive, and the engine. Mechanical noise emits from the engine compartment through vibrations in the belly pan, panels, and hood as well as from vents in the hood and body panels.

Absorption and redirection were the two methods used to reduce emission of noise through body vibration. By using the test apparatus for sound deadening material properties combined with on-snow J-192 testing, it was found that a material consisting of various density foams and rubber with a reflective heat barrier was the most effective.

To contain and redirect noise, all hood and side panel vents that were not necessary for engine compartment cooling were sealed. Those needed were fitted with thermally activated vents to reduce direct noise emission and maintain airflow through the engine compartment when needed. To allow for ample airflow with substantial sound insulation installed new, larger, stock panels were fitted as well as hood scoops to help force cooling air through the remaining vents. In addition to the added sound insulation room, these panels allowed for the creation of exhaust systems that would not have fit within the stock side panels.

Noise coherence testing was used to select sound-damping materials for the body panels. A material testing box was designed that allowed the UICSC team to determine the best sound deadening material. A piece of plastic with similar properties to that of the stock Ski-Doo XP body panels was used as a baseline. White noise was directed through the material using a 6" speaker and a model spectrum analyzer. An accelerometer was placed on the outside of the plastic panel to determine how much of the noise generated by the speaker was causing the panel to vibrate and add to the overall noise level. The unmodified panel results are shown in Figure 11. The panel vibration accounted for 3.6% of the overall sound sample of white noise at frequencies from 0-3.25 kHz.

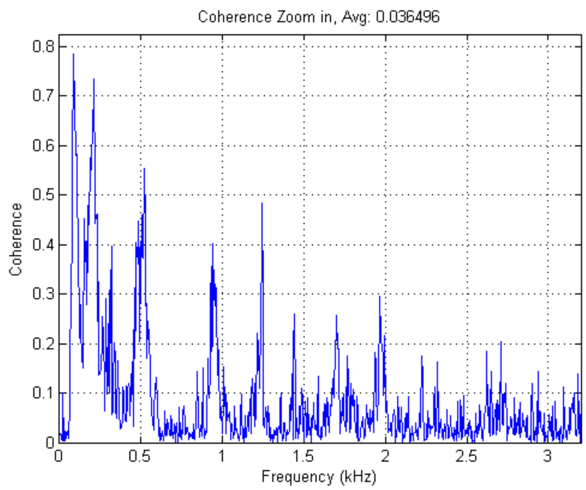

Figure 11: Coherence of un-damped panel subjected to white noise at low frequencies.

A piece of 3-ply sound deadening material from Polymer Technologies was applied to the panel and the experiment was run again. The results are shown in Figure 12. The results show that the damped panel accounted for 1.9% of the overall sound sample which shows a reduction of 47% in panel vibration. The frequencies examined account for the fundamental frequency at 8000 RPM and harmonics of the fundamental frequency.

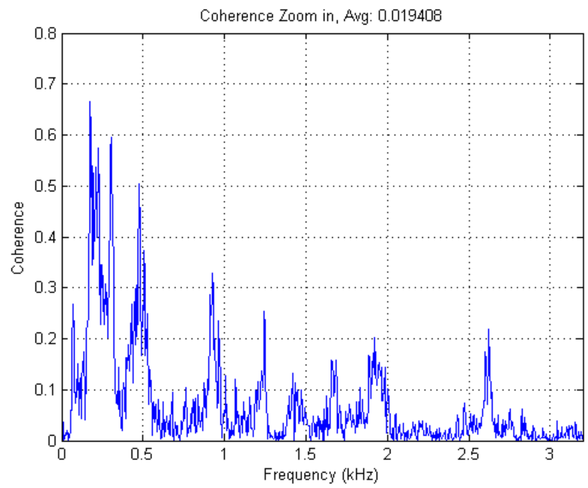

Figure 12: Coherence of damped panel subjected to white noise at low frequencies.

Track and Suspension Noise

Unlike noise in the engine compartment, track and suspension noise cannot be redirected easily. Therefore, the focus of noise reduction will come from absorbing and reducing the overall vibrations through the track and suspension. The UICSC snowmobile uses two different methods to accomplish this reduction. The first method involved the placement of vibration damping material on the tunnel to reduce the vibrations transmitted from the track and suspension. This method has been used successfully in the high performance automotive industry [8]. The second method tested by the UICSC was the addition of suspension dampers in place of the metal bushings between the suspension arms and the tunnel as shown in Figure 13.

Figure 13: Suspension dampers placed on all connections between track suspension and tunnel.

Dampers made of 60A durometer polyurethane were tested using a force inputted to the suspension with a V203 Ling Dynamic Systems shaker creating a 26.7 N (6 lbf) sinusoidal force into the suspension at frequencies of 96 and 384 Hz. These frequencies were calculated to be the approximate rates at which the driver contacts the track lugs at 15 and 60 mph respectively. A force transducer mounted to the shaker measured the inputted force, while an accelerometer placed on the side tunnel measured the reduction in transmitted force. The test layout and results are shown in Figure 14 and Figure 15 respectively.

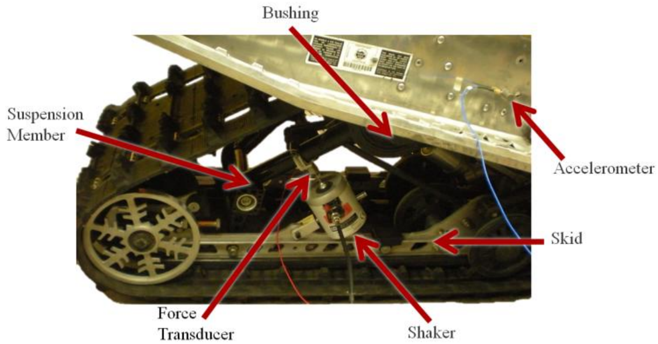

Figure 14: Bushing damper testing layout

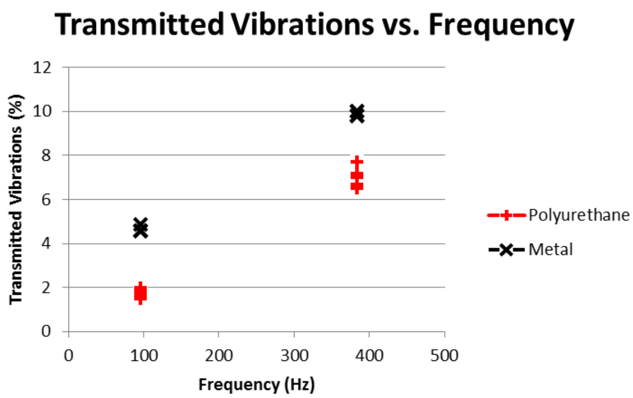

Figure 15: Transmitted vibration percentages through the suspension.

Comparing the results of the metal bushings to the dampers showed a 61.56% reduction at 96 Hz and a 29.04% reduction at 384 Hz for the polyurethane dampers. However at the time of the report the polyurethane bushings had not undergone a J-192 test for their overall effectiveness and had not undergone durability testing to see if they would last for the duration of the competition.

Intake Noise

Previous UICSC intake designs focused on noise reduction through modifying the geometry of the stock intake system. These intake designs failed to produce an overall noise level reduction and significantly restricted airflow to the engine. The 2006 UICSC team lined the air intake box with high density foam to absorb sound while minimizing flow restriction. For 2011, a uni-directional air intake was designed to direct sound through an opening in the hood. This was similar to the UICSC 2008 competition snowmobile which showed that a uni-directional intake greatly reduced the overall intake noise [9].

Exhaust Noise

In previous years, reducing the sound of the exhaust system came through testing of different combinations of tuned pipes, mufflers, and Helmholtz resonators[3]. For 2011, the UICSC design team decided to look into a product that has been used in other branches of the power sports industry.

Hushpower, a division of Flowmaster, Inc., has designed several mufflers for ATVs, motorcycles, and road vehicles. These mufflers use convergent and divergent perforated cones to direct sound while allowing exhaust gas to flow through as shown in Figure 16.

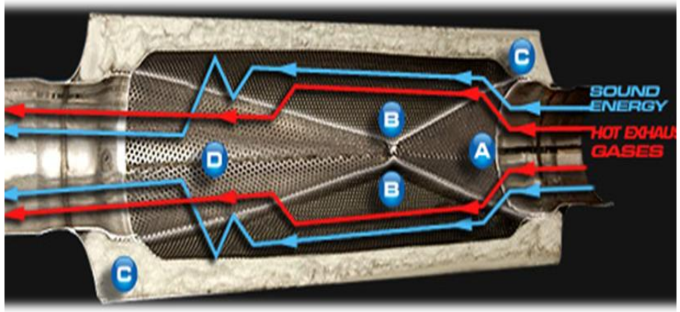

Figure 16: Cutaway view of Hushpower Muffler

Several variations of the Hushpower muffler were donated for sound testing. The Hushpower mufflers were tested against the stock muffler using the SAE procedure J-192. Figure 17 shows two Hushpower mufflers mounted in series to the snowmobile during testing. The same apparatus was configured to test single mufflers, two mufflers in series/parallel, and three mufflers in series.

Figure 17: Two Hushpower mufflers in series mounted on the UICSC snowmobile for sound testing.

Figure 18 below shows the results of the sound testing of the various Hushpower configurations. These test were all performed without body panels. The stock muffler tested in at 85.5 dBA and the closest Hushpower configuration was two in series at 86.5 dBA.

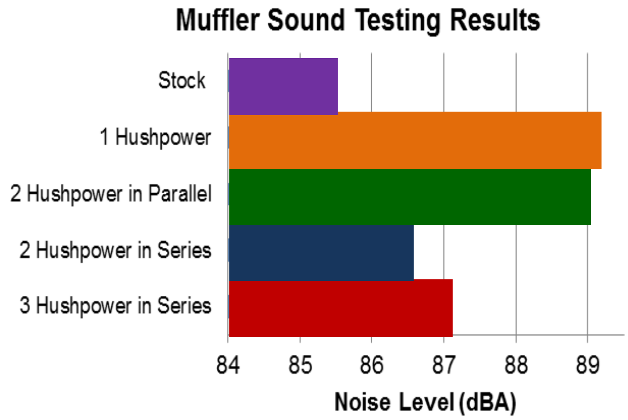

Figure 18: Hushpower muffler configurations vs. stock muffler using J-192 procedures.

The UICSC team decided to construct a muffler using two Hushpower mufflers in series. The testing configuration was crude and hung outside of the snowmobile body and yet was only a decibel louder than stock. With a compact design placed inside the snowmobile the team could achieve lower exhaust noise than stock.

A removable catalyst was also integrated into the exhaust system. The catalyst was placed in one end of a Hushpower shell with flow and sound control material in the rest of the shell. The final design is presented in Figure 19.

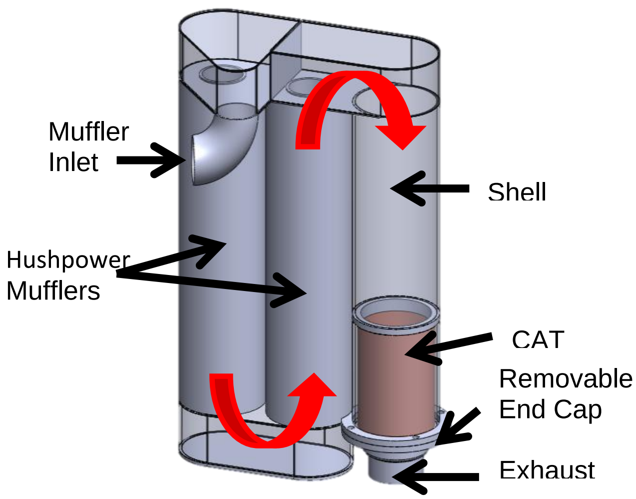

Figure 19: Hushpower and catalyst muffler design.

Changing the muffler on an engine can change the backpressure the engine experiences and affect the performance of the engine. A flow bench was constructed as shown in Figure 20. A flow bench is used for testing the aerodynamic performance of engine components. Its main use is for testing intake and exhaust ports on internal combustion engine heads. The device also tests the air passage qualities of air filters, manifolds, carburetors, and mufflers. The reason for testing a component would be to increase airflow for improved volumetric efficiency and reduced pumping loss. In the case of mufflers the wrong backpressure can cause backfiring, loss of power, and in extreme cases causing the engine to stop completely. With this in mind the stock muffler's backpressure was tested along with the newly constructed muffler. Figure 21 shows the flow testing results.

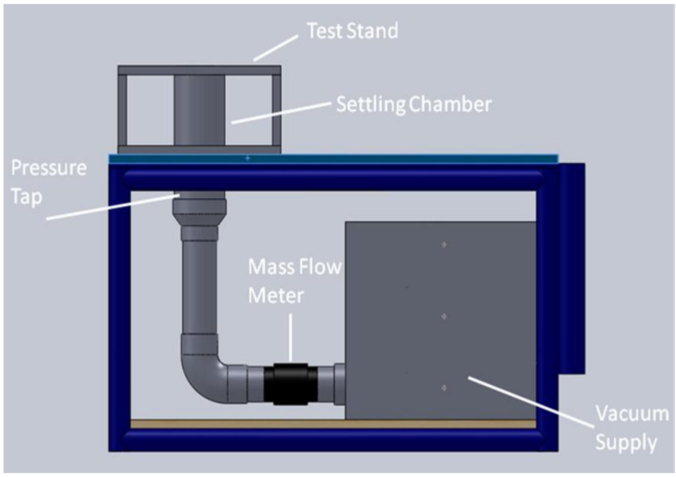

Figure 20: Solid Model of Flow Bench Design

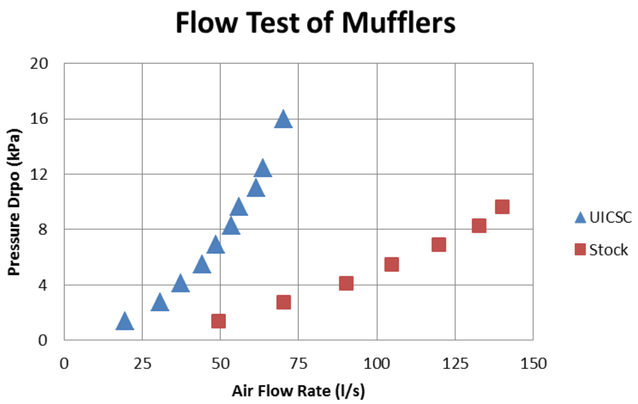

Figure 21: Flow testing results of stock muffler and UICSC muffler.

The UICSC muffler created an increase in backpressure that negatively affected engine performance. With the UICSC muffler the engine produced 40 kW (54 hp), while the 2011 UICSC engine and stock muffler produces 71 kW (95 hp). Therefore, the muffler will not be used for the 2011 Clean Snowmobile Competition until further testing and design can be done to improve the mufflers performance.

Final Approach

No one method adequately reduced noise, so combinations of several methods were implemented in the final sound reduction approach for 2011. Selective sound deadening material, intake lining, and skid dampers were all implemented to reduce noise levels. Implementation of all of these methods yielded an average score of 80 dBA using the SAE J-192 procedure. Previous Clean snowmobile challenges have shown that UICSC's sound pressure meter consistently reads 2 dBA higher than the Head Acoustic products used at competition. Therefore, a score of 78 dBA is expected at competition.

MSRP

With the price of snowmobiles rising every year, cost is fast becoming a primary concern for riders. The base price for a stock 2011 Ski-Doo MX-Z 600 E-TEC is $10,199. With all modifications included, the Manufacturer's Suggested Retail Price (MSRP) of the 2011 UICSC DI, totaled $14,305. This includes the price of donated chassis components totaling $1333. Chassis components that add to the MSRP were justified by weight reduction, increased performance, and sponsor product awareness. The exhaust modifications total $180, which includes a catalyst and heat shielding.

CONCLUSIONS

The University of Idaho has developed a cost-effective DI two-stroke snowmobile engine capable of running on E2X 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 71 kW (95 hp), is lightweight at 250 kg (552 lbs) wet, achieves a fuel economy of 7.4 km/L (17.5 mpg), and meets NPS with an E-Score of 177 producing 7.5 g/kW-hr $HC+NO_X$ and 110 g/kW-hr CO. Overall, sound production measured using the SAE standard J-192 was reduced from 85 dBA to 80 dBA which is expected to pass the competition standard of 78 dBA with the sound measurement equipment used at competition. With future regulations coming for manufacturers, consumers will expect clean and quiet snowmobiles. However, increased fuel economy, a better power-to-weight ratio, and a general enjoyable riding experience are important characteristics that consumers demand. The 2011 UICSC E2X DI two-stroke snowmobile is an economical response to that demand.

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DEFINITIONS/ABBREVIATIONS

SAE Society of Automotive Engineers

CSC Clean Snowmobile Challenge

DI Direct Injection

EPA Environmental Protection Agency

NPS National Park Standards