Development of a Low-Speed Two-Stroke Direct-Injection Snowmobile for Use in the Clean Snowmobile Challenge and National Parks

Final Report

KLK763

N11-03

University of Idaho's Direct-Injected
Two-Stroke Snowmobile Using E-22 Fuel

National Institute for Advanced Transportation Technology

University of Idaho

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July 2011

DISCLAIMER

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle

Development of a Low-Speed Two-Stroke Direct-Injection Snowmobile for Use in the Clean Snowmobile Challenge and National Parks
University of Idaho's Direct-Injected Two-Stroke Snowmobile Using E-22 Fuel

5. Report Date
July 2011

6. Performing Organization Code
KLK763

7. Author(s)

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8. Performing Organization Report No.
N11-03

9. Performing Organization Name and Address

National Institute for Advanced Transportation Technology
University of Idaho
PO Box 440901; 115 Engineering Physics Building
Moscow, ID 83844-0901

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DTRT07-G-0056

12. Sponsoring Agency Name and Address

US Department of Transportation
Research and Special Programs Administration
400 7th Street SW
Washington, DC 20509-0001

13. Type of Report and Period Covered
Final Report: August 2010 – June 2011

14. Sponsoring Agency Code
USDOT/RSPA/DIR-1

15. Supplementary Notes:

16. Abstract

The University of Idaho's entry into the 2011 SAE Clean Snowmobile Challenge (CSC) was a direct-injection (DI) two-stroke powered snowmobile modified to use blended ethanol fuel. The exact composition was unknown prior to the competition. The modulated and battery-less direct-injection system used to decrease exhaust emissions and improve fuel economy maintained near stock power output of the engine. Noise from the engine compartment was reduced by custom placement of sound absorbing materials. A muffler was designed to reduce 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 535 lbs (243 kg) wet, achieving 21.00 mpg (8.93 km/L) running on blended ethanol fuel, with an EPA five mode emissions test score of 177, and a J-192 sound magnitude score of 80 dBA.

17. Key Words

Snowmobiles; recreational vehicles; ethanol

18. Distribution Statement

Unrestricted; Document is available to the public through the National Technical Information Service; Springfield, VT.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	24	…

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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 and 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 (DOE) supported the effort and began the Clean Snowmobile Challenge (CSC) in 2000.

The 2011 Clean Snowmobile Challenge continued to encourage snowmobile development by mandating use of blended ethanol/gasoline fuel. The required blend could range from 20 to 30 percent ethanol per volume, and was not known to the teams before the competition. 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. The design strategies of the University of Idaho (UI) meet and exceed industry standards in reducing harmful emissions, improving efficiency, and maintaining reliability.

UICSC SNOWMOBILE DESIGN

Engine Selection

For 2011, the UICSC team chose to use a direct-injected (DI) 593 cc Rotax two- stroke engine. This selection was made based on the preferred power-to-weight ratio of two-stroke engines and ease of implementation into the existing chassis. The characteristics that make two-stroke engines mechanically simple also cause them to have poor thermal efficiency, poor low load operation, and high exhaust emissions. 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].

The 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. Now with the availability of snowmobile engines designed specifically for E TEC DI systems, 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 the short circuiting of the fresh fuel and air charge can occur. In previous years, the RAVE 1 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 RAVE 2 valve which has a three position guillotine that also blocks the exhaust transfer ports at low loads to increase efficiency. Figure 1 shows a comparison between the RAVE 1 and RAVE 2 exhaust valves.

Figure 1: A comparison between the RAVE 1 (left) and the RAVE 2 (right).

The extra midrange position of the RAVE 2 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 RAVE 1 and RAVE 2 valves. The use of the 3D RAVE valves resulted in an average BSFC improvement of 16.6%.

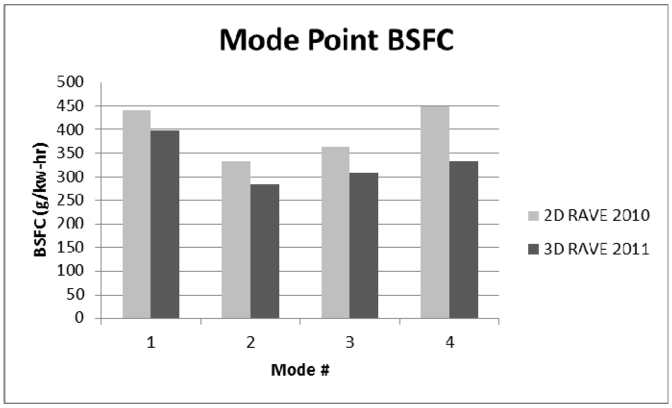

Figure 2: BSFC RAVE Valve Comparison

The DI head design, Computer Numerically Controlled (CNC) coding, and manufacturing were all done in 2006, in the University of Idaho Mechanical Engineering Department machine shop. Undergraduate students and graduate mentors 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 energy requirements for the combustion of ethanol and the added flexibility in engine calibrations it allows for.

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 Skidoo 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 added by the electronic pump, oil consumption was reduced by approximately 50% over traditional carbureted two-stroke engines.

Fuel Delivery System

Due to an 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 an issue. Because of the way fuel is introduced to the combustion chamber, a stratified calibration strategy helps to improve the poor cold start characteristics of blended ethanol fuel.

Calibration Strategy

Engine calibration for blended ethanol fuel was completed using a Borgi Saveri Eddy Current dynamometer, lambda sensor, exhaust gas temperature sensors, 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 was not completely accurate. However, once the lean/rich limits were found, the lambda sensor provided a guide to creating a smooth E2X engine map. The in-cylinder pressure trace was used to detect detonation while tuning. Emission tuning was completed using a Horiba five-gas analyzer. The strategy for testing was focused on BSFC and 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, the stock Skidoo E TEC engine was tested using the EPA 5 mode emissions test. At each of the 5 modes data was collected regarding the exhaust emissions, torque, lambda, throttle position and BSFC. These values are referred to as the baseline for the engine here after. 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. After testing of the UICSC head with an unmodified calibration was completed, time was spent tuning each mode point in order to further reduce emissions. 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 RAVE 1 exhaust valve system while 2011 and Stock E TEC use the newer RAVE 2 system. The significant reduction in emissions from the stock head to the UICSC head is attributed to better combustion chamber geometry and spark plug placement.

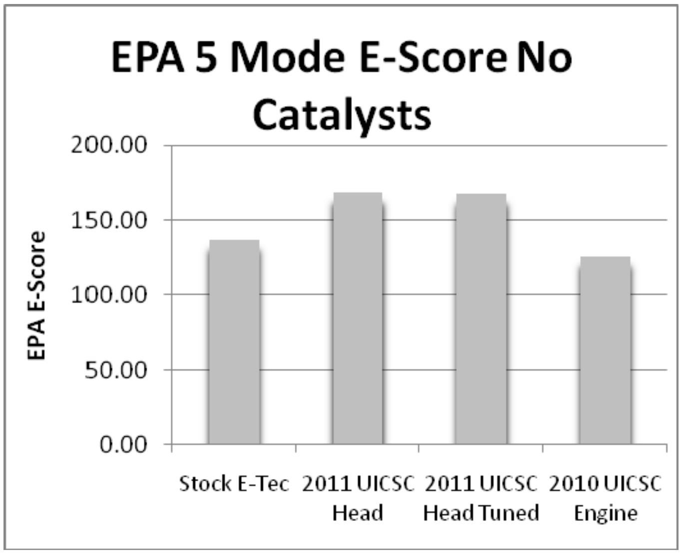

Figure 4: Comparison of cylinder, cylinder head, and calibration effects on emissions using the EPA 5-mode test.

Reducing hydrocarbon emissions was the main focus of tuning at the mode points. Changes in fuel quantity and injection timing were made and effects 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 rose. 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 prevent engine failure, safe lambda values and exhaust gas temperatures were maintained at all mode points.

Although the UICSC cylinder head and calibration changes significantly reduce exhaust emissions, a further reduction was required to meet NPS standards. Hence a catalytic converter was added to the exhaust system. For initial testing, the catalyst was added after the muffler in the emissions collection tube. In order to fit the catalyst in the chassis, it would be moved closer to the muffler in the final design. 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 3.5 inches in diameter and 4.5 inches long with 300 cells per square inch. Only a slight change in calibration was needed to account for the added back pressure of the catalyst. The catalyst significantly reduced hydrocarbon as well as NO_x emissions and brought the UICSC engines' E-score to 177, meeting the NPS standard. Figure 5 below 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 RAVE 1 exhaust valve and a catalytic converter from Aristo.

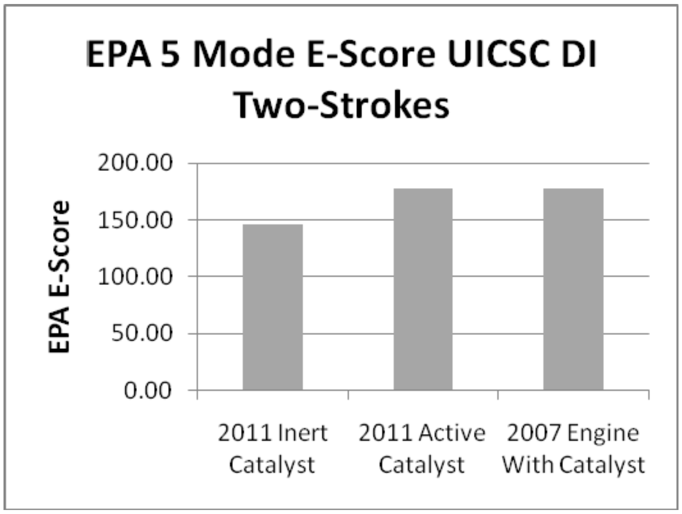

Figure 5: A 5 mode test comparison of the UICSC 2011 engine and catalysts vs. UICSC's 2007 engine.

Although the 2011 engine scored very similarly to the 2007 configuration, the composition of the scores is very different. This is partly due to a different exhaust valve design as well as calibration strategy. Figure 6 below shows a breakdown of the EPA E-score for several DI two-stroke engine configurations. For 2011, UICSC was able to score a 177 in the EPA emissions test as well as meet all of the NPS requirements while still producing near stock power. The weighted emissions, as well as an E-score comparison, are shown in Figure 6.

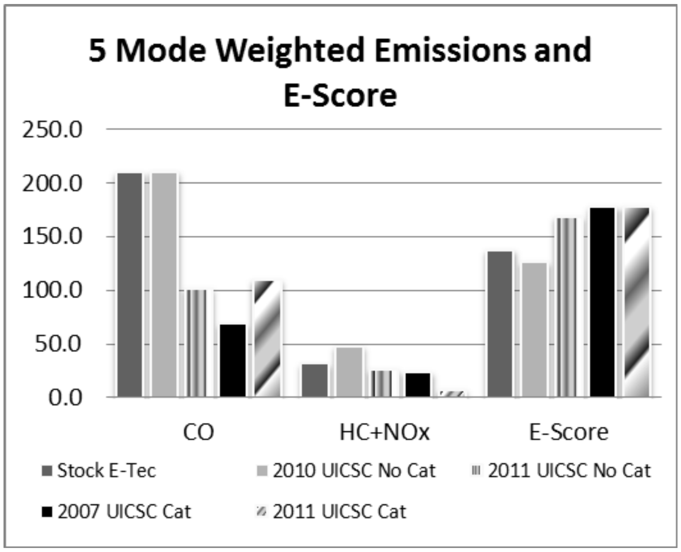

Figure 6: A 5-Mode weighted emission and E-score comparison.

DriveTrain Efficiency

Seeking to improve fuel economy, the team decided to reduce drivetrain losses for 2011. The UICSC chose to test several common theories in the snowmobile industry that increase drivetrain efficiency. These include: that a low tension track has less rolling resistance then a high tension track, that larger rear bogie wheels will create a larger radius for the track to rotate around lowering the angular acceleration and rolling resistance, that more bogie wheels offer better efficiency by avoiding contact with the hyfax and finally, 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 and the UICSC's 2008 Ski Doo XP 600 SDI with a constant 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 measure 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 1.5 inches of sag for high tension and 2 inches of sag for low tension. The results are plotted as the average torque outputs from the dynamometer for five tests in figure one. These results shown provide an inconclusive result 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 configuration 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.

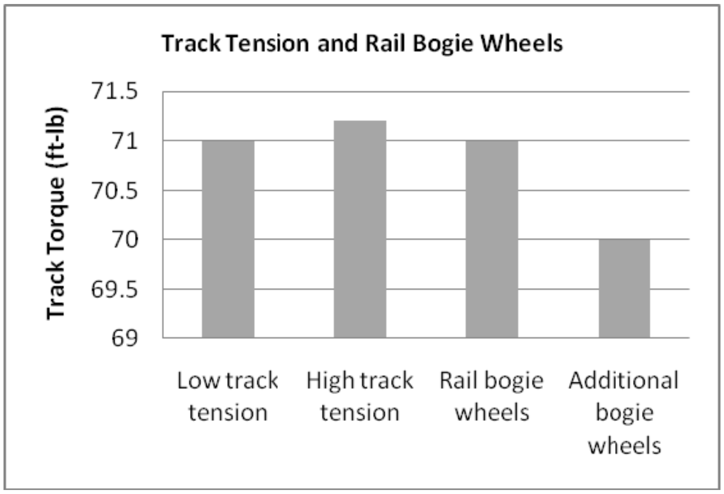

Figure 8: Efficiency testing results.

<u>Larger Rear Bogie Wheels</u>

To compare the effects of larger rear bogie wheels to those stock dimensions, the UICSC chose to compare the factory seven inch diameter bogie wheels on the 2008 Ski Doo to ten inch diameter Nextech carbon wheels. Correct placement of the larger bogie wheels required an offset axle to be designed and built so no other modifications would be needed. After completing the tests the larger rear bogie wheels showed an average gain of 3 ft-lb. However, towards the end of the test the torque sensor started to drift, invalidating the data. The tests were re performed at later date for 10 repetitions showing that on average that were was no difference between the regular and larger rear bogie wheels. The results are shown in Figure 9.

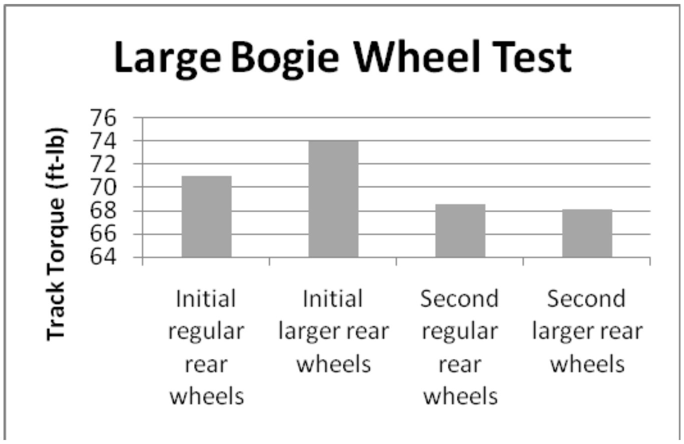

Figure 9: Large bogie wheel test.

<u>Belt Drive</u>

To compare a belt drive to a chain drive, the UICSC built a belt drive to fit the 2008 Skidoo XP using components from a C3 Motorsports belt drive kit. 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.

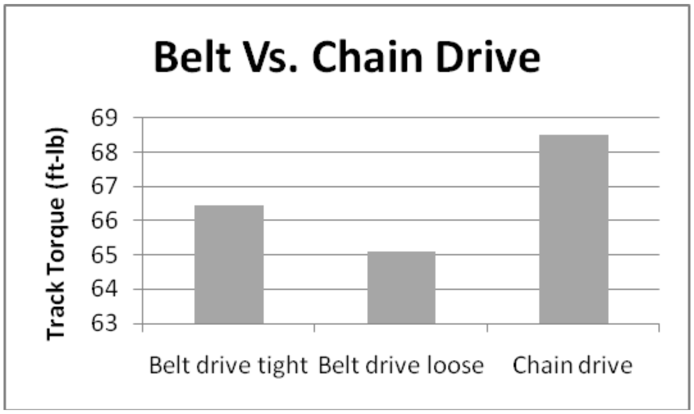

Figure 10: Belt drive vs. chain drive.

Overall Drivetrain Results

The results for the drivetrain efficiency testing did not show a clear disadvantage or advantage of any setup and rendered the data inconclusive. The UICSC plans to perform future efficiency testing in 2012 using an electric motor driving the jackshaft on the snowmobile, which will help eliminate inconsistencies during the test and give a better definition of power used during the tests.

Weight Reductions

Due to a change in the competition rules, the overall weight of the snowmobile is no longer considered for 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 and handle more easily, lessening rider fatigue. Being lightweight is also important for marketability. As snowmobile manufacturers 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 535 lbs (243 kg) wet.

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 a 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.

The method for reducing sound emission in the past has been to add sound material wherever possible. 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 dampening the sound determined priority areas making more effective use of time and resources. Equation 1 is the general equation for coherence.

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

Equation (1)

Mechanical Noise

There are several sources of mechanical noise. These include the clutches, chain drive, and the engine. Mechanical noise can escape 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. Through the previously mentioned material sample testing 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, 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 space, these panels allowed for the creation of exhaust systems that would not have fit within the stock side panels.

Coherence testing was used to choose materials to absorb the mechanical noise. 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 Skidoo 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 plain 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.

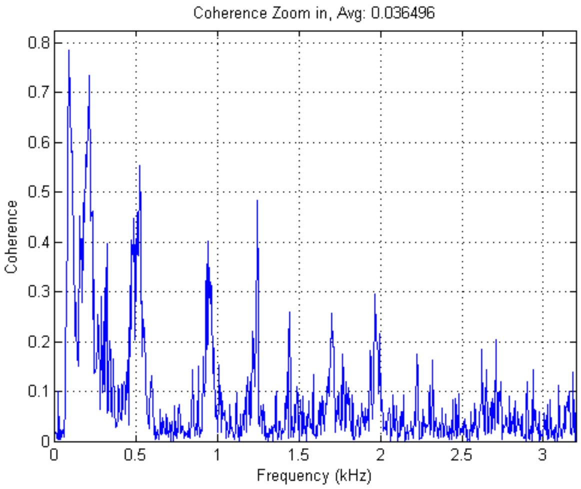

Figure 11: Coherence of un-dampened panel subjected to white noise at low frequencies.

A piece of three-ply sound deadening material from Polymer Technologies was applied to the panel and the experiment was repeated. The results are shown in Figure 12 below. 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 as harmonics of the fundamental frequency.

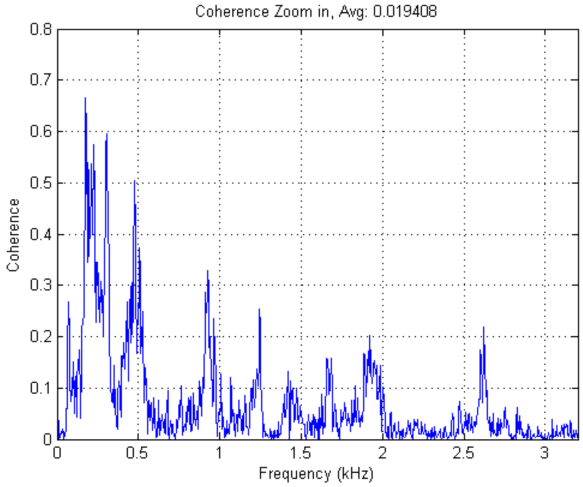

Figure 12: Coherence of damped panel subjected to white noise at low frequencies.

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.

The dampers made of 60A durometer polyurethane were tested using a force inputted to the suspension with a V203 Ling Dynamic Systems shaker creating a 6lb 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.

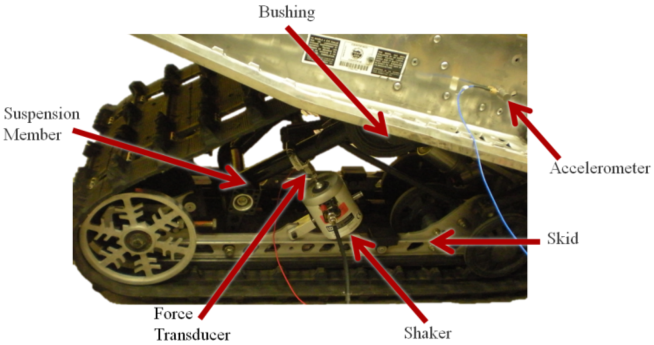

Figure 14: Bushing dampener testing layout.

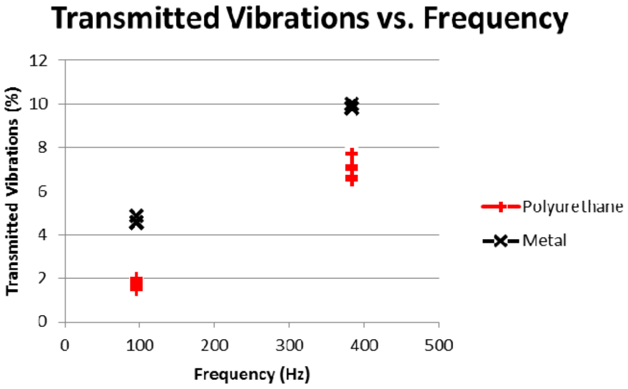

Figure 15: Transmitted vibration percentages through the suspension.

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 were yet to be tested during a J-192 test for their overall effectiveness and had not been durability tested to see if they could 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. In 2006, UICSC 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 parts of the power sports industry.

Hushpower, a division of Flowmaster, Inc., has designed several mufflers for ATVs, motorcycles, and on-road vehicles [10]. These mufflers use two convergent and divergent perforated cones to direct sound while allowing exhaust gas to flow through as shown in Figure 16.

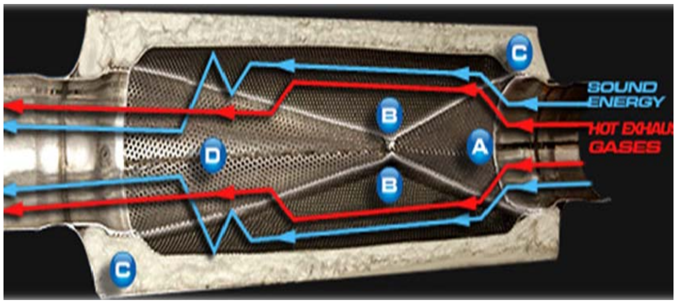

Figure 16: Cutaway view of Hushpower muffler.

Several variations of the Hushpower muffler were donated for sound testing. These mufflers were tested and compared with the stock muffler using the SAE J-192 procedure. Figure 17 shows two Hushpower mufflers mounted to the snowmobile during testing. The same apparatus was used to test a single muffler, 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.

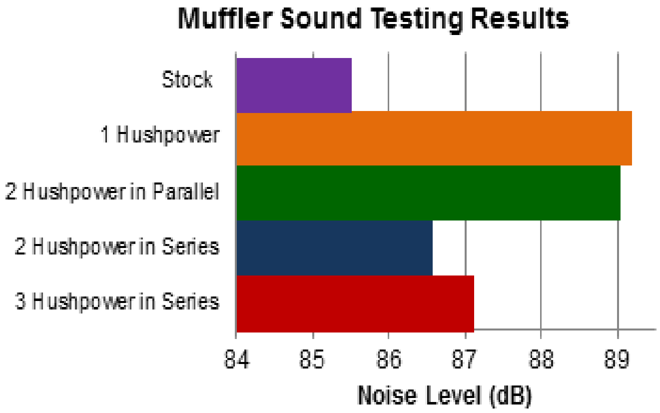

Figure 18: Hushpower muffler configurations vs. stock muffler using J-192 procedures.

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

The UICSC team decided to construct a muffler using two Hushpower mufflers in series. The testing configuration was located outside of the 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.

Furthermore, a removable catalyst was 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.

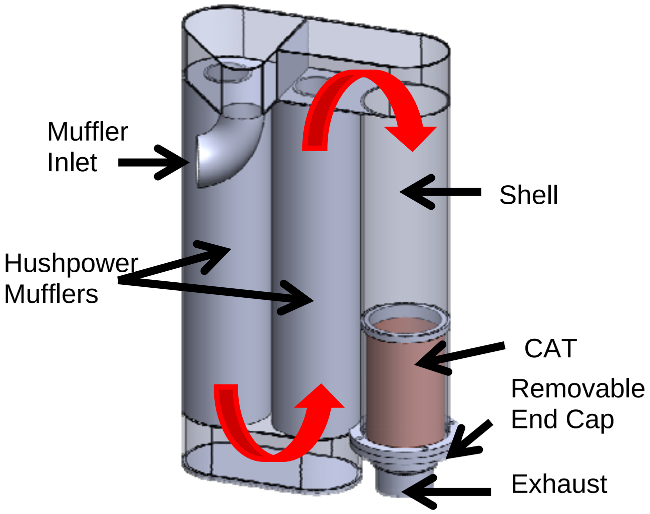

Figure 19: Hushpower and CAT muffler design.

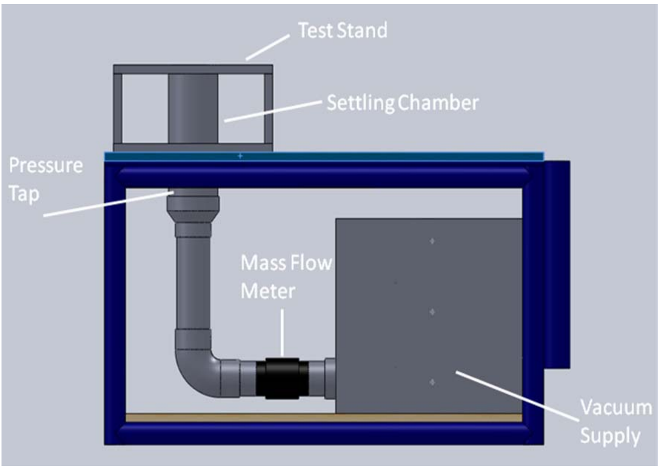

Figure 20: Solid model of flow bench design.

Changing the muffler on an engine can change the backpressure the engine experiences and affect the performance. 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 can also test air passage qualities of air filters, manifolds, carburetors, and mufflers. In the case of mufflers, engines require a certain amount of backpressure to operate at optimal efficiency. The wrong backpressure can cause backfiring, loss of power, and in extreme cases, cause the engine to stop completely. The stock muffler's back pressure was tested along with that of the newly constructed muffler. Figure 21 shows the flow testing results.

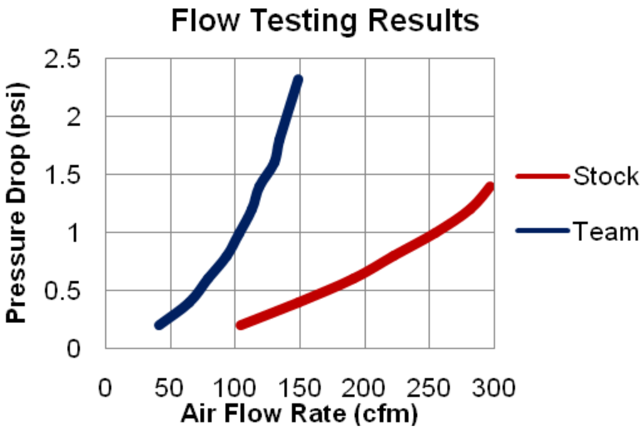

Figure 21: Flow testing results of stock muffler and UICSC muffler.

The UICSC muffler created an increase in back pressure that negatively affected engine performance. Therefore, the muffler was not used for the 2011 CSC and won't be used until further testing and design can be done to improve the 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 dampeners 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. Final testing had the UICSC snowmobile entering the competition at a sound rating of 80 dBA, not quite to competition standards.

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 $10,099. With all modifications included, the Manufacturer's Suggested Retail Price (MSRP) of the 2011 UICSC DI, totaled $11,078. This includes the price of donated chassis components totaling $568. Chassis components that add to the MSRP were justified by weight reduction, increased performance, and sponsor product awareness. The exhaust modifications total $123, which includes a catalyst and heat shielding. The drivetrain modifications totaled $1309.

CONCLUSIONS

The University of Idaho has developed a cost-effective direct-injected 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 105hp (78.3 kW), is lightweight at 507lbs (230 kg) wet without sound deadening material, and achieves a fuel economy of 21 mpg (8.08 km/L). Overall, sound production measured using the SAE standard J-192 was reduced from 85 dBA to 80 dBA, not quite to the competition standard.

The exact composition of the fuel during competition was E22, similar to what is proposed for future on-road vehicles by the EPA. The UI clean snowmobile ran well during competition and required no maintenance, achieving an overall Third Place. It passed the stringent tests for on-road endurance and fuel economy, averaging 17 MPG for 100 trail miles on E22. The snowmobile also passed the sound and lab emissions requirements, and was third in in-service emissions, which are measured on-trail. The team also had the best written paper, achieved Best Ride, and Best Value awards, and was awarded the Most

Sportsmanlike Trophy for stopping to extinguish a fire on a competitor's snowmobile. The snowmobile also achieved points for cold-starting.

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 what the majority of consumers demand. The 2011 UICSC E2x DI two-stroke snowmobile is an economical response to that demand.

REFERENCES

1. Ayyasamy, R., Nagalingam, B., Ganesan, V., Gopalakrishnan, K.V., and Murthy, B. S., "Formation and Control of Aldehydes in Alcohol Fueled Engines," SAE Paper 811220.
2. Society of Automotive Engineers, Inc., SAE Clean Snowmobile Challenge Results 2007.
3. Findlay A., Hanks B., Harker, N., Johnson, J., Tockey, C., and Den Braven, K., "University of Idaho's Clean Snowmobile Design Using a Direct-Injection Two-Stroke Engine," SAE Paper, March 2010.
4. Society of Automotive Engineers, Inc., SAE Clean Snowmobile Challenge 2011 Rules, 2011.
5. Aikawa, K., Sakurai T., and Hayashi A., "Study of Ethanol-Blended Fuel (E85) Effects Under Cold-Start Conditions," SAE Paper 2009-01-0620.
6. Miers, S., Green, C., Meldrum, J., Lundberg, C., Silvis, W., and Pankratz, H., "Measurement of Dry Soot and Particulate Matter from Two-Stroke and Four-Stroke Snowmobiles," SAE Paper 2010-32-0024/201009042, 2010.
7. Dixon, D., Hanks, B., Harker, N., Stock, C., and Den Braven, K., "University of Idaho's Direct-Injected Two-Stroke Snowmobile Using E85 Fuel," SAE CSC Team Report, March 2008.
8. Energy Suspension Inc., CA. Available: http://www.energysuspension.com/
9. Harker, N., Johnson, J., Findlay, A., and Den Braven, K., "University of Idaho's Clean Snowmobile Design Using a Direct-Injected Two-Stroke Engine," SAE Paper 08SETC-0006, Sept. 2008.
10. Hushpower Website. February 2, 2011. http://www.hushpower.com/products/56/ATV.html

DEFINITIONS/ABBREVIATIONS

SAE	Society of Automotive Engineers
CSC	Clean Snowmobile Challenge
DI	Direct Injection
EPA	Environmental Protection Agency
NPS	National Park Service
DOE	Department of Energy
UHC	Unburned Hydrocarbons
CO	Carbon Monoxide
NO_x	Mono Nitrogen Oxides
RPM	Revolutions Per Minute
BSFC	Brake-Specific Fuel Consumption
CNC	Computer Numerically Controlled