University of Maine Clean Snowmobile Challenge Design Report

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ABSTRACT

The 2010-2011 University of Maine Clean Snowmobile Team is entering the 2011 Society of Automotive Engineers Clean Snowmobile Challenge with a 2007 Yamaha Phazer that has been modified for improved exhaust and noise emissions, fuel economy, handling, and aesthetics through the use of a variety of methods. The stock ECU for the 499cc four-stroke Genesis 80FI engine has been replaced by a MicroSquirt system that allows compatibility with a range of ethanol-based fuels and optimization of emissions dependent on air fuel ratio and engine timing. Harmful exhaust gas emissions are further reduced by the addition of a pre-catalytic converter and catalytic converter in the exhaust system. The cowling and the clutch cover have been redesigned for aesthetics and noise control.

INTRODUCTION

The Clean Snowmobile Challenge began in the winter of 2000 in Jackson Hole, Wyoming in response to growing concern in Yellowstone National Park about how snowmobiles were having a negative effect on the environment in the area. The goal was to have universities compete against each other by engineering snowmobiles that could be ridden on groomed trails throughout the park with minimal environmental impact. The event was sponsored by the Society of Automotive Engineers and open to all universities in the United States and Canada. Teams put their snowmobiles to the test in events that included handling, acceleration, and hill climbs. The competition was moved to the Keweenaw Research Center (KRC) in Houghton Michigan in 2003 were it has remained ever since. The 2011 Competition will run from March 7-12 where 15 universities will bring 20 snowmobiles, 5 of which are zero emissions, to compete in events that include the testing of exhaust gas emissions, noise levels, acceleration, handling, and endurance.

The 2011 University of Maine SAE Clean Snowmobile Challenge team brings to competition the 2007 Yamaha Phazer it has inherited from previous University of Maine design teams. The 2011 team's approach to improving noise levels, flex-fuel compatibility, and exhaust emissions are similar to those employed in previous years which have had varying levels of success. The team seeks to eliminate design flaws that limited the Phazer's success in previous competitions, while also improving consumer appeal factors such as performance, handling, aesthetic appeal, and MSRP.

The 2011 University of Maine Clean Snowmobile Competition team seeks to improve upon the placement received in 2008 last time the Yamaha Phazer first went to competition. Table 1 shows how the Phazer performed in each event.

Table 1: 2008 University of Maine competition results.

Event	Score	Place
Static Display	50/50	1 (All Teams Tied)
Noise	231.2/300	3
Emissions	100/300	4
MSRP	27.5/50	5
Penalties/Bonuses	10	5
Cold Start	50/50	PASS (1 of 5 Successful Teams)

Objective Handling	37.6/75	7
Weight	24/100	8
Subjective Handling	1.52/50	9
Acceleration	0/100	10
Design Paper	28.6/100	10
Oral Presentation	8.2/100	10
Fuel Economy	0/200	N/A
Overall	**569/1475**	**9/12**

This year the University of Maine Engine Controls Team has worked on improving the tune on a MicroSquirt ECU allowing for compatibility with a range of ethanol-based fuels. Previous years' teams replaced the stock ECU with a MicroSquirt ECU in order to enable easy modification of key engine software parameters that directly result in the ability to run a snowmobile on ethanol-based fuels, alter power levels at specific engine speeds, and improve emissions as necessary in ways that were not possible with the stock ECU. The addition of a pre-catalytic converter and a catalytic converter to the exhaust system has assisted the MicroSquirt with further reduction in harmful exhaust gas emissions.

To reduce unwanted noise and improve aesthetic appeal the 2011 University of Maine Noise, Vibrations, and Harshness Team has worked on improving the cowling and exhaust design. Knowing that the Phazer passed noise emissions testing in 2008, the redesign of the cowling was driven largely by the need to improve aesthetic appeal. The exhaust has been redesigned largely for the same reason, however with the added goal of making a system that can easily be employed into production. To achieve this goal, the noise vibrations and harshness team has designed the exhaust almost entirely out of parts that are commercially available, relatively inexpensive, yet capable of improving the snowmobile to meet SAE Clean Snowmobile Competition standards.

UMAINE DESIGN

THE BASELINE SLED – The 2007 Yamaha Phazer was chosen for its lightweight design, four-stroke engine, and acceleration and handling characteristics. Sled specifications are given in Table 2.

Table 2: 2007 Yamaha Phazer Manufacturers' Specifications [1]

Engine Type	Four-stroke IC
Cooling Method	Liquid
Intake Design	3-Valve
Fuel Delivery	Fuel Injection, 43mm Throttle Bodies
Cylinders	2
Displacement	499.2 cc
Bore & Stroke / mm	77 X 53.6
Compression Ratio	12.4:1
Maximum Crank Power	80 hp
Dry Weight	474 lbs
Suspension Travel F/R	10"/16.1"
Fuel Tank	8.1 gallons, E10 compatible

EMISSIONS IMPROVEMENTS – The 2011 University of Maine SAE Clean Snowmobile Competition team decided to improve the emissions of the 2007 Phazer by improving on previous years MicroSquirt ECU tune and incorporating a catalytic converter system into the exhaust.

ECU Improvements – In order to achieve a more efficient engine tune, a new ECU had to be chosen to allow change of the engine mapping. Bowling & Grippo's MicroSquirt engine control unit was selected due to its ability to support the Phazer's stock coil-on-plug ignition setup, control timing, fuel air ratios, and its maximum engine speed of 11000 rpm. The MicroSquirt EFI controller also allows for complete tuning of various engine parameters required for attaining lowest emissions. It is a fully-assembled surface mount technology fuel injection controller [6]. Surface mount technology is a method for constructing electronic circuits in which the components are mounted directly onto the surface of printed circuit boards. Printed circuit boards are used to mechanically support and connect electronic components; they are inexpensive and very reliable. Many other aftermarket ECUs are not fully customizable and are significantly more expensive.

A GM Flex-Fuel sensor, model 12570260, has been installed on the snowmobile to provide feedback to the ECU on the ethanol levels of the fuel flowing to the injectors in order to maintain optimal engine performance and emissions. To ensure ethanol compatibility, the fuel pump and fuel lines were replaced with ethanol-resistant items and an adjustable fuel pressure regulator was added. Several of the OEM Yamaha sensors had to be replaced with production automotive sensors compatible with MicroSquirt. Once the correct parameters were set, the tuning process began with the Phazer on a DynoJet chassis dynamometer.

MicroSquirt allows for complete tuning of various engine parameters required for attaining lowest emissions. This is done through the use of MegaTune software which can be used in Windows 9x/Me/XP. When MegaTune is loaded and communicating with the MicroSquirt EFI Controller, the front page shows eight of the more useful gauges for monitoring the engine's performance including engine speed, engine MAP, engine temperature, and air fuel ratio as shown in Figure 1.

Figure 1: MegaTune Front Page View

In order to provide reliable feedback from the engine's operating state, we chose to use a NGK Powerdex AFX wideband oxygen sensor. This directly communicates with the MicroSquirt ECU to ensure that the engine is operating in a safe and efficient range. This can be conveniently monitored in real time by viewing a digital display air fuel ratio mounted on the dashboard. Several of the Yamaha sensors did not provide signal output compatible with the MicroSquirt ECU so they had to be replaced.

Fuel System - Ethanol-blended fuels have been widely used as a way to reduce the rapid depletion of non-renewable fossil fuels by replacing a portion of the fossil fuels with ethanol, a fuel made from corn. The reactive properties of ethanol require replacement of a number of components in the fuel system due to deterioration of certain materials when exposed to ethanol.

To ensure ethanol compatibility, the fuel pump and fuel lines were replaced with ethanol-resistant items and an adjustable fuel pressure regulator was added. This regulator reduces the high pressure from the aftermarket fuel pump to a level safe for the stock injectors and to allow efficient operation. The fuel tank also needed to be modified from the stock 8.1gallon capacity so that the volume would provide adequate range so the team fabricated a new one from fiberglass. A special resin from Dow Chemical's was used to prevent a reaction between the fuel and the composite. A GM Flex-Fuel sensor, model 12570260, has also been installed on the snowmobile to provide feedback to the ECU on the composition of the fuel flowing to the injectors. MicroSquirt is the first aftermarket EFI controller with direct flex-fuel support. As the sensor detects varying compositions of ethanol/gasoline mixtures, MicroSquirt adjusts the spark advance tables and injector pulse widths by linear interpolation maintaining optimal engine performance and emissions.

Emission Testing - Over the past forty years automobile manufacturers have been mandated by the federal government to produce vehicles to more and more stringent emissions regulations. During this same time, small motor and power sports manufacturers have been out of the emissions spotlight. For this reason, these manufacturers have not put forth much effort to reduce the pollution of their machines. In recent years automobile manufacturers have been forced to spend an ever increasing amount of money to research and develop vehicles to meet new regulations while small motor manufacturers have been under limited scrutiny. The automotive industry is looking to put pressure on these small engine and power sports manufacturers to help shift the focus of cleaning up emissions to an area where limited development has occurred. The University of Maine Clean Snowmobile Challenge team feels that within the next five to ten years there will be an enormous push to reduce emissions from small engines, particularly snowmobiles and all terrain vehicles. In order to reduce emissions of the 2007 Yamaha Phazer to automotive standards, the team worked with Random Technologies to obtain two custom catalytic converters specifically for this engines operating regime.

Emission Improvement Results – To a large percentage of snowmobilers, dirty emissions are not a concern. For this reason, manufacturers have not put forth much effort to reduce the pollution of their machines. In order to reduce emission to automotive standards, the team worked with Random Technologies to obtain two custom catalytic converters specifically for this engines operating regime.

University of Maine has found that implementing a cost efficient exhaust system has greatly reduced the emissions of our 2007 Yamaha Phazer. The stock setup was compared to our aftermarket exhaust system using a 5-gas analyzer and specialized software from Automotive Test Solutions (ATS) (Figure 2).

Figure 2 - 5 Gas Analyzer by ATS (Automotive Test Solutions)

The emission testing was executed indoors, using the maximum and minimum ethanol levels (E-29 and E-20 respectively). The Phazer was mounted to a DynoJet chassis dynamometer and monitored closely during wide open throttle testing (Table 3). Hydrocarbon emissions rose steadily until the catalytic converter lit off, resulting in a rapid decrease in emissions.

	Engine Speed (RPM)	Power (HP)	Torque (Ft-lb)
Mode 1 (WOT)	11000	43.4	20.8

Table 3- Engine Operating Parameters for the 2007 Yamaha Phazer during the emissions test

The testing procedure started without catalyst between the motor and the test probe to provide baseline data pertaining to the tune on the ECU.

After fabricating an entirely new exhaust system, we had the ability to interchange our pre-catalyst and catalyst with test pipe sections using custom exhaust clamps. The University of Maine team repeated the emission testing to include emissions data for no catalyst (figure 3), and both catalytic converters together (figure 4).

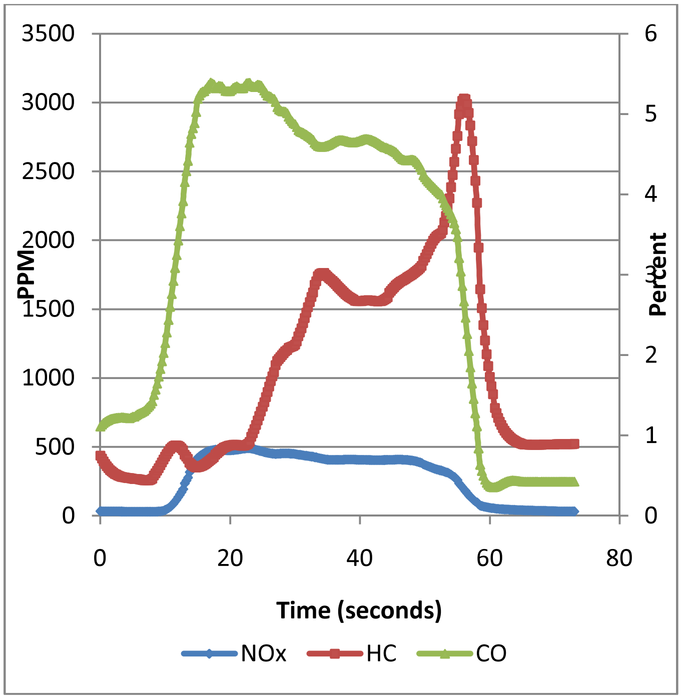

Figure 3 - 2007 Yamaha Phazer emissions testing with stock exhaust

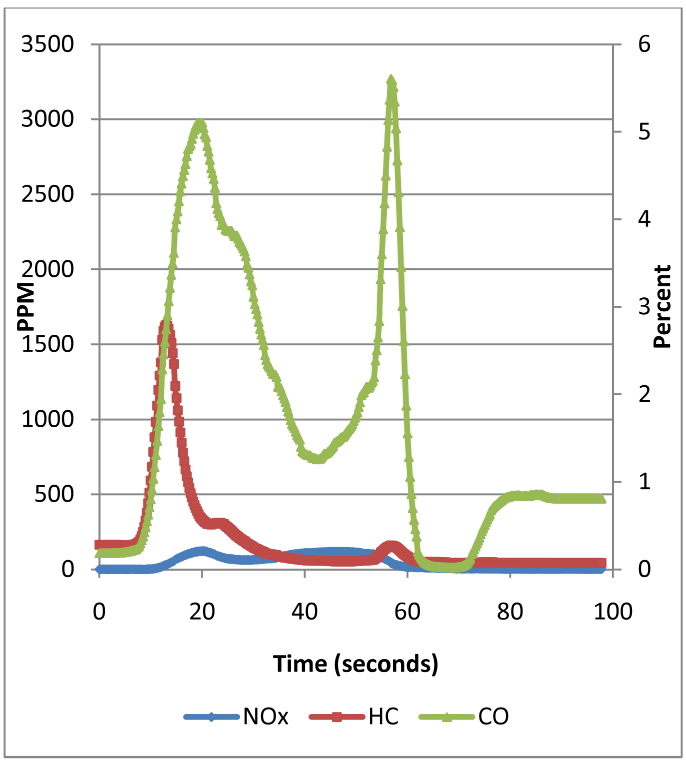

Figure 4 - 2007 Yamaha Phazer emissions testing with pre-catalyst and main catalytic converter

Results show drastic improvement using both catalysts from the engine's base emissions. HC levels dropped from a peak value of around 3000 parts per million (ppm) without any catalyst involved, down to a maximum of around 1600 ppm when both catalytic converters were implemented. During the emissions test involving both catalysts, HC levels reached a low of 54 ppm.

REDUCING NOISE – The 2010-2011 University of Maine SAE Clean Snowmobile team has focused on three methods of reducing the nose emissions of the 2007 Yamaha Phazer. The areas of improvement are the cowling, clutch cover, and exhaust.

For the 2011 SAE Clean Snowmobile Competition the University of Maine team set the goal of firstly reducing factory noise emission to below 72 dB as per requirement of the SAE J-192 noise emissions standard used for judging at competition. Second, the team wanted to reduce the majority of noise emissions by sound proofing the engine bay and avoid altering the stock exhaust configuration in hopes of making the machine more marketable.

The most challenging aspect of reducing the noise of a snowmobile is determining where the most noise is coming from and what noise is most unpleasant. Since rule 9.9.1 of the 2011 SAE Clean Snowmobile Challenge Rules states that part of noise testing is a subjective sound quality assessment at a bystander location the University of Maine Clean Snowmobile Challenge Team decided that reducing engine bay, specifically clutch, noises would be most important because a pleasing exhaust note is to be desired [6]. This reasoning led to the decision of adding most of the sound proofing to the inside of the cowlings and designing the exhaust to primarily reduce emissions. Also, the most annoying frequencies often emitted by an exhaust system are in the 50-200 Hz region which has a reduced effect when measuring sound using a-weighting [2 pg 277].

SAE noise test events are performed using the SAE J-192 Standard. Competition focuses on sound pressure using A-weighted scaling. The theory behind A-weighting is that it closely mimics the hearing threshold of the human ear. The standard A-weighting curve is seen in figure 5. It can be seen that the range of frequencies which are most influential for an A-weighted measurement is 1000-5000 hertz, making it most important to suppress those frequencies during the competition**.**

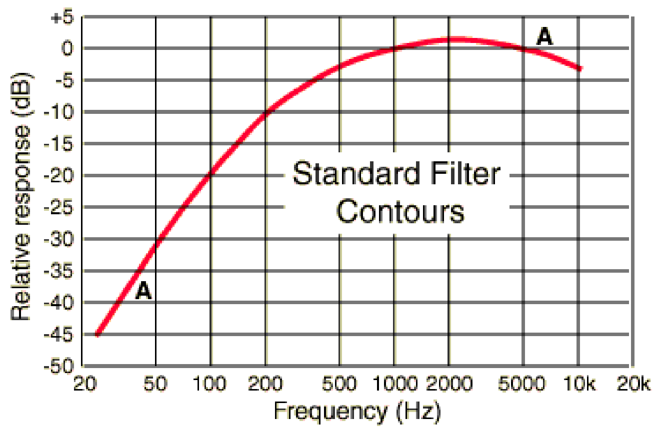

Figure 5: A-weight standard contour filter [4]

<u>Cowlings</u> – The majority of work performed by the noise and vibrations group has been focused on the improved design and fabrication of the clutch side and hood cowlings that were made last year. The decision to remake the clutch side and hood cowlings was driven by the decision to abandon the use of an on board computer system that was part of the dashboard. This resulted in large amounts of unnecessary space in the dash of the snowmobile where sound would have been able to escape from the engine bay.

For construction of the cowling pieces 2 oz fiberglass mesh backed by fiberglass chopped mat was chosen as the predominant construction material. Fiberglass was chosen for its ease of use, ability to conform to nearly any shape, strength to weight ratio, durability, and partial sound reduction qualities. The use of fiberglass ensures that any piece constructed will not react in a way during an accident that could cause harm to the rider or competition spectators.

To fabricate the new clutch side cowling a female mold was fabricated from the old part to ensure proper fitment of the new piece on the Phazer. This was accomplished by preparing the surface of the cowling from 2009 with mold release wax and then covering it in fiberglass as seen in figure 6.

Figure 6: The making of a fiberglass mold from the 2009 clutch side cowling.

Next a plug was created by filling the mold with expanding foam. The plug was then reshaped until it mirrored the opposite side of the Phazer as closely as possible with the idea that a more symmetrical look to the snowmobile would be aesthetically pleasing as seen in figure 7.

Figure 7: The foam plug (left) used to create a mold for new clutch side cowling compared to the opposite side (right).

An exact mirror of the opposite side of the snowmobile was not achievable because of extra room required to fit the primary drive of the clutch. The plug was then covered in body filler, sanded smooth, and covered in fiberglass to create a second female mold which could be used to fabricate the Phazer’s final clutch side cowling piece. The inside of the newly shaped female mold was covered in fiberglass. The new piece was left to harden overnight, and then separated from the mold to obtain the finished clutch side cowling seen in figure 8.

Figure 8: The finished clutch side cowling (prepared for paint).

In order to fabricate the hood of the snowmobile a similar process was used. However, instead of using foam to create a whole new look, the old hood was simply trimmed in strategic areas to result in a tighter fit to the snowmobile and eliminate any unnecessary spaces where sound can escape the engine bay. Fitment of all the cowling pieces can be seen in figure 9.

Figure 9: Improved look and fitment of the new cowling pieces.

The materials to be used on the snowmobile for safety and sound reduction purposes have been tested in a lab setting using the Larson Davis Model 831 sound level meter. Materials were tested by playing sweep tones from 100-16000 Hz using a computer and stereo speaker. Sound was played down a PVC tube at the material being tested and sound data was recorded outside of the tube directly behind the test material. The snowmobile has been tested using SAE J-192 standards. The average A-weighted sound level produced by two passes per side of the snowmobile with the newly constructed cowling was compared to the snowmobile without any cowlings tested using the same method.

<u>Exhaust Modifications</u> – The exhaust on the 2007 Phazer was designed this year with the idea that any modifications that were made to the factory system could be easily put into production. For this reason the University of Mane SAE Clean Snowmobile Challenge Team has added only a pre-catalytic converter and a catalytic converter from Random Technologies and used an unmodified Dyno-

max Walker Quiet-Flow silencer. The result of using parts that involve minimal custom fabrication for fitment opposed to the design of many competing teams is that our design could be implemented into production without a significant addition to cost. An added benefit from using both converters is the reduction in harmful exhaust emissions and the reduction of noise produced by the engine.

A pre-catalytic converter was used this year because its smaller design allows it to be positioned closer to the engines exhaust ports, therefore resulting in a shorter warm up period and improved cold start emissions. In addition the team has elected to use a catalytic converter because it's larger size and ability to further HC, CO, and NO_x emissions through oxidation [5]. The pre-catalytic and catalytic converters were custom manufactured by Random Technologies and are only 3" and 4" in diameter respectively and 9" in length and so that they both fit under the seat of the snowmobile. The mounted catalyst system can be seen in Figure 10.

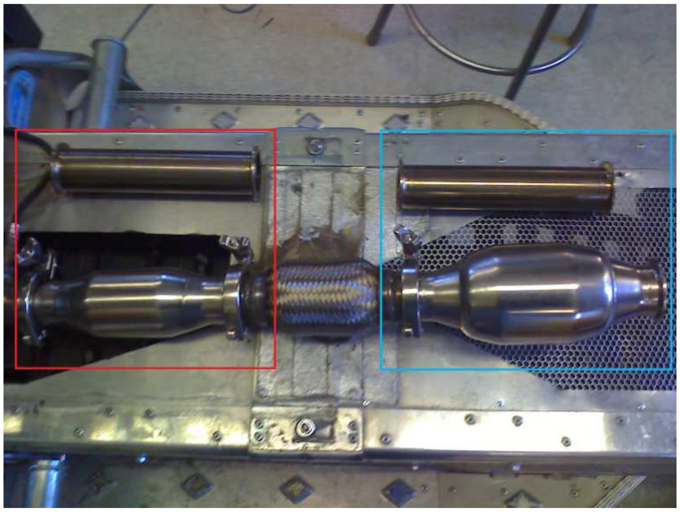

Figure 10: Mounted Pre-catalytic converter (red box), and catalytic converter (teal box) connected by a flex pipe.

An unexpected problem encountered when adding a pre-catalytic converter as well as a converter is that the length of the system would have been deemed too long at competition because of rule 4.2.5 in the 2011 SAE Clean Snowmobile Challenge Rules. To accommodate the added length to the system the exhaust headers were fabricated from scratch saving 16.5 inches.

The new design of the headers also allows for the placement of the O2 sensor 11 inches closer to the engine, and more importantly before the pre-catalytic converter. The new placement of the O2 sensor ensures that it is taking readings from gas that has not been altered by the catalytic converter in any way. The improved header design is seen in figure 11.

Figure 11: Redesigned headers and O2 sensor placement.

For safety, the headers were covered with titanium exhaust wrap from Design Engineering Inc. This will help reduce the amount of heat that builds up in the headers of the exhaust which lie directly under the gas tank. In addition to exhaust wrap, a factory heat shield is in place and the bottom of the gas tank has been lined with heat shield rated for 1750 deg F radiant heat.

Clutch Cover – The clutch cover has been designed to fit closer to the primary and secondary clutch gears than previous year's designs to allow for the fitment of a newly designed cowling that is not as bulky. The clutch cover has been designed to meet and exceed competition safety requirements. It has been constructed of T6061 aluminum and covered in Kevlar belting that meets NHRA requirements.

Originally equipped with a slim band aluminum above the drive belt the factory clutch cover was designed to do little more than protect against belt fragments during a blowout and offered essentially no reduction in clutch noise. To improve both a-weighted and subjective noise testing by reducing the annoying frequencies produced by the snowmobile clutch the 2009 University of Maine Team fabricated a cover that nearly encloses the entire clutch system and padded it with deadening material. The new cover complies with rule 4.4.7 of the 2011 Clean Snowmobile Challenge Rules. Initial ideas were drawn up in Autodesk Inventor and edited until a satisfactory drawing was obtained. The design was measured to fit an inch closer to the primary pulley and four inches closer to the secondary pulley when compared to the clutch cover used in years past. The final drawing of the clutch cover complete with dimensions is seen in figure 12.

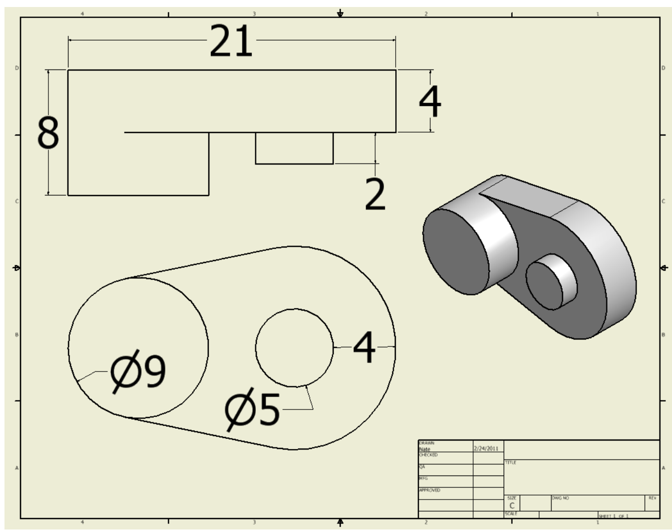

Figure 12: Autodesk Inventor drawing showing dimensions of initial clutch cover design.

After the clutch cover was designed, the team created a cardboard mock up of the clutch cover to make sure it fit properly (figure 13).

Figure 13: Cardboard mock-up of the 2011 clutch cover.

The initial mock up of the desired clutch cover design in cardboard proved to be a worthwhile idea. Clearance Issues were found with the Phazer's frame above the secondary gear and were corrected before construction of the final piece. The finished clutch cover can be seen in figure 14.

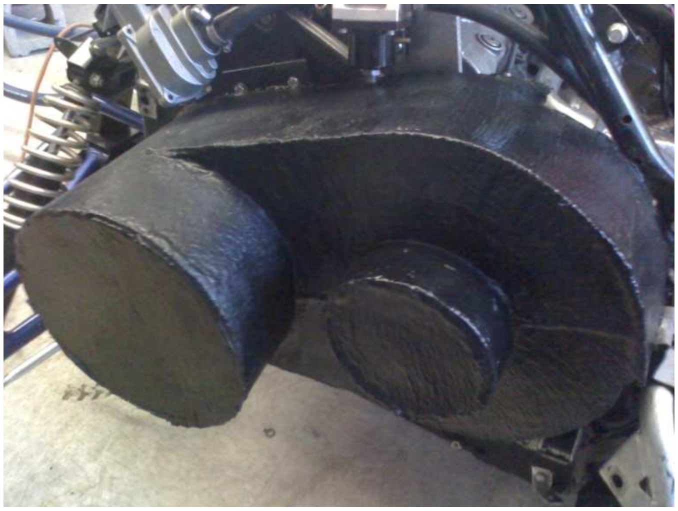

Figure 14: Fabricated 2011 clutch cover.

The final clutch cover piece is constructed of .09" T6061 Aluminum. The inside has been painted with 4 layers of Quiet Car and the outside has been covered in Kevlar belting and another four layers of Quiet Car.

Noise Reduction Results – The noise reduction data on the 2007 Yamaha Phazer has be obtained using a Larson Davis Model 831 Sound level meter that has been generously loaned to the university for as long as it is needed for this yeas competition. The 2011 University of Maine Clean Snowmobile Competition team has measured the operating noise emissions of the snowmobile to an accuracy of .1 dB using the LD 831 SLM.

Results of lab tests of the materials to be used in sound proofing the snowmobile indicate that their performance is well suited for the task of reducing peak A-weighted decibel levels. Lab data in figure 15 shows that the Elemental Designs eDead 80 when used in two layers has the potential to reduce decibel level up to nearly 50 percent and averages a reduction in decibel reading of about 35 percent. The Kevlar belting that was used to coat the clutch cover had the unexpected benefit of reducing noise emissions better than any other material tested as a single layer. The information collected in a lab setting provided information that led the noise and vibrations team to use sound proofing on the cowling and clutch cover in a way that was expected to reduce noise emissions on the snowmobile sufficiently for competition.

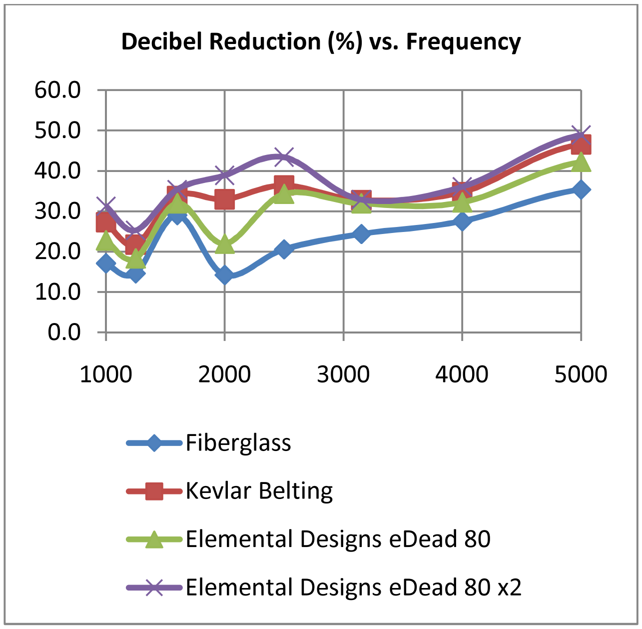

Figure 15: Lab tested noise reduction qualities of sound deadening material used in cowling and clutch cover design.

The results obtained from testing the assembled cowlings on the 2007 Phazer appear in figure 16 and 17. Data form an imperfect test conducted on February 22, 2011 showed that measured reduction in peak noise emissions on an A-weighted curve had not yet met the goal of being less than 72 dB. . It is worth noting however that the data was measured on a snow surface that had a crust capable of supporting a 170lb person, but not capable of supporting the snowmobile. In addition, the factory exhaust was still in use during testing. The crusted snow is likely the reason for the unusually high peak A-weighted measurement in sound pressure level. The data in Figure 16 represents only the effect of the cowlings.

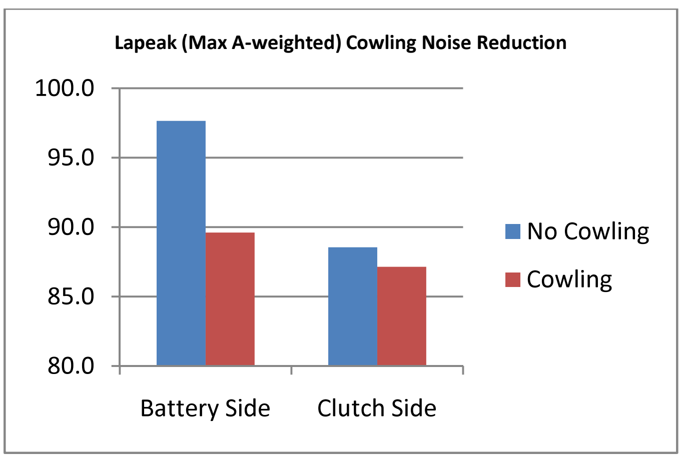

Figure 16: Noise reduction effects of cowling pieces.

From Figure 16 it is evident that the cowling pieces do have a positive effect on the noise emissions of the snowmobile. Unfortunately due to circumstances beyond the control of the snowmobile team the potential full affect the cowling will have on noise has not been measured accurately. Perhaps a better representation of the affect the cowlings have on noise reduction is figure # which shows the average percent reduction in decibels throughout the frequency range most heavily weighted by an A-weighting curve.

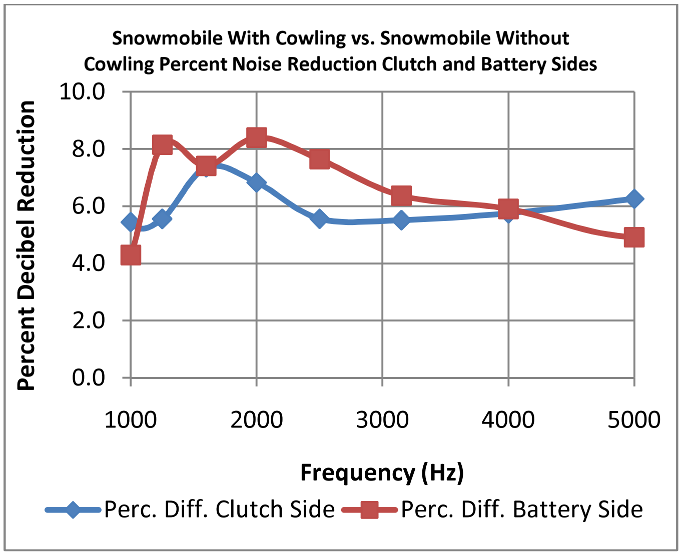

Figure 17: Noise reduction throughout important frequency range of cowling pieces.

$$\% \, Decibel \; Reduction = 100 * \frac{Cowl \; Off - Cowl}{Cowl \; Off} \qquad (1)$$

The data for figure # was calculated using Equation 1. It can be seen that throughout the entire range of frequencies that are most important for competition there is about a 5% reduction in noise.

SUMMARY/CONCLUSIONS

The 2011 University of Maine Clean Snowmobile Competition Team has applied traditional fabrication techniques paired with advanced 3D modeling techniques to improve upon previous year's modifications. The project overall has been a success with the fabrication of a new clutch cover, clutch side cowling, hood, and exhaust system as well as significant improvements in the tune of the engine. This year's aim at improving the snowmobile's marketability has greatly improved with the addition of an exhaust that doesn't need extensive fabrication to create a silencer as many teams have, the additional ability to run a range of flex-fuels, and through in improved look of the new cowlings.

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