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Designing a Clean, Quiet, Fuel Efficient High Performance Four- Stroke Flex Fuel Snowmobile

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ABSTRACT

The University of Wisconsin - Platteville Clean Snowmobile Challenge (CSC) Team has successfully designed and constructed a quiet, efficient, and environmentally friendly snowmobile. The snowmobile is designed for the 2015 Society of Automotive Engineers (SAE) Clean Snowmobile Challenge, held at the Keweenaw Research Center in Houghton, Michigan, March 2nd – 7th 2015. The snowmobile for this year's competition is built on the 2015 Arctic Cat ZR 7000 LXR chassis, which features a 1049cc, three cylinder, 4-stroke engine. The engine control system, which is produced by Performance Electronics (PE), is a stand-alone engine control unit (ECU). The use of this system gives the team complete control over the engine parameters to achieve a decrease in exhaust emissions, as well as an improvement in fuel economy. The exhaust system is also modified to further reduce the emissions by utilizing a pre-burn catalytic system, designed by Tikka Race (TR). Driveline improvements were another significant factor for improving fuel economy. These modifications helped to achieve University of Wisconsin - Platteville's goal in producing a quiet, reliable, and efficient snowmobile.

INTRODUCTION

It is crucial to design snowmobiles that utilize the best available technology. With total 2014's sales increasing by 7 percent, to a total of 157,100 units worldwide, it is clear that snowmobiling is becoming more popular than in previous years [1]. As the sport grows, it is continuously met with pressure from the Environmental Protection Agency (EPA) to lessen these machines' environmental impact. This impact is broken into categories such as: carbon footprint, noise pollution, and fuel efficiency. The most notable of these new regulations was the Yellowstone National Park's ban of snowmobiles in the year 2000.

In an effort to lessen the negative environmental impact caused by the snowmobile industry, SAE teamed up with Teton County Wyoming Commissioner, Bill Paddleford, along with environmental engineer, Lori Fussell, to start working on an innovative solution. Their combined efforts resulted in the first SAE Clean Snowmobile Challenge, in 2000 [2]. The CSC was, and still is, an international collegiate event, aimed at improving on the designs of current snowmobiles with the best available technology. After a year of hard work, teams gather in Houghton, MI to showcase their efforts. The CSC competition standards are more stringent than those currently set by the EPA, the National Parks Service (NPS), and the Department of Energy.

The competition is continuously improved from year to year. In 2014, a notable change was made in fuel selection. The specification of corn-based bio-isobutanol fuel, within the range of 16 to 32 percent, is now used instead of ethanol, and will continue to be used in the 2015 CSC as well. Bio-isobutanol is a renewable additive that can replace petroleum based fossil fuels. A benefit of bio-isobutanol is that it contains approximately 30 percent higher energy content compared to ethanol. According to the bio-fuel company GEVO, "[Bio-isobutanol] has a lower propensity for phase separation in the presence of water and has no stress corrosion cracking compatibility or elastomer incompatibility issues."[5] These characteristics indicate that bio-isobutanol is a superior alternative fuel over ethanol, due to the fact that it is less harsh on fuel systems.

The CSC is grooming the way for future snowmobiles with the implementation of new flex-fuel systems and efficient design strategies. Design objectives are as follows: improving emissions, fuel economy, noise, rider comfort, handling, acceleration, and cold starting abilities. Yellowstone National Park has implemented a new management approach for the 2014-2015 winter season, which allows up to 500 snowmobiles a day into the park [6]. The following paper outlines the University of Wisconsin - Platteville CSC Team's efforts for designing and building such a snowmobile.

DESIGN OBJECTIVES

To be an elite competitor in the 2015 Clean Snowmobile Challenge, the University of Wisconsin - Platteville CSC Team has refined the best 4-stroke technology that the snowmobile industry has to offer. The team's main goal was to improve fuel efficiency. Competitors participate in two different events to gauge fuel economy. The first test consists of a 100 mile (160 km) endurance event. Each team that successfully completes the mileage requirement will be awarded 100 points. Points beyond 100 will be awarded to teams based on their calculated fuel economy. These additional points are awarded relative to the performance of other teams, whom also completed the event. The additional points are calculated by Equation 1 [3]:

$$\text{Team Score} = 100 * \left[\frac{\left(\frac{G_{max}}{G_{team}}\right)^2 - 1}{\left(\frac{G_{max}}{G_{min}}\right)^2 - 1}\right] \quad (\mathbf{1})$$

G is the number of gallons of fuel consumed.

The second measurement of fuel economy is conducted during the in-service emissions event, which is described later. Scores for this event range from 0 to 50, and are based on performance relative to other teams. Points for this event are awarded according to Equation 2 [3]:

$$\text{Team Score} = 50 * \left[\frac{\left(\frac{FE_{max}}{FE_{team}}\right)^2 - 1}{\left(\frac{FE_{max}}{FE_{min}}\right)^2 - 1}\right] \quad (\mathbf{2})$$

FE is the Fuel Economy measured in the event.

The team's second goal was to reduce Hydrocarbon (HC) and Carbon Monoxide (CO) emissions, without increasing the emission of Nitrous Oxides (NO_x). The fuel, chosen by CSC staff, is an unknown blend of bio-isobutanol and gasoline, ranging from 16 to 32 percent bio-isobutanol. Emission testing is performed during two events, the first of which is an in-service emissions test. During this procedure, a test sleigh is coupled behind the snowmobile and exhaust emissions are recorded by the sleigh. This event effectively determines the total gaseous emissions of the snowmobile during a realistic trail ride. Competition organizers operate the snowmobiles on a three mile course (4.8 km), while the test sleigh records grams of HC, CO, CO_2, and NO_x produced. The total weights of emissions are compared between the best and worst competitors to determine a team score, based on a range of 0 to 50 points.

The second emissions event is a lab test performed while the snowmobile is connected to a dynamometer. This is a static test where the engine is operated under predetermined conditions, and emission levels are recorded. The test modes for the lab emissions follow a five-mode test cycle, as published by Southwest Research Institute (SwRI) [4]. For 2015, the emissions will be measured in-between the predetermined modes to give a more accurate representation of emissions produced, rather than methods used in previous years. This year, the transitions between the modes will also be calculated into the final e-score. This will force teams to have clean emissions throughout the map, rather than just in the predetermined modes. Table 1 shows the speeds, loads, and weighting factors for the five-mode test.

Table 1: The five-mode snowmobile test procedure used by the EPA and NPS.

Mode Point	Speed [% of Rated]	Torque [% of Rated]	Weighting [% of total]
1	100	100	12
2	85	51	27
3	75	33	25
4	65	19	31
5	Idle	0	5

From the measured lab emissions, an EPA snowmobile emission number (E) can be calculated. The E-score is determined from the operating points of Table 1 by calculations using Equation 3 [4]. A minimum E-score of 100 is required to meet the corporate 2012 and later snowmobile emission standards. Points in excess of 100 are awarded to teams who beat the minimum EPA requirements. The E-score is calculated as follows.

$$\mathrm{E} = \left[1 - \frac{(HC + NOx) - 15}{150}\right] * 100 + \left[1 - \left(\frac{CO}{400}\right)\right] * 100 \qquad (\mathbf{3})$$

Further requirements state that the average combined HC and NO_x weighted emissions must be less than 90 g/kW-hr, and less than 275 g/kW-hr for CO emissions. As an incentive to meet the stricter National Parks standards, E-scores beating 170 are awarded additional points based on a linear scale. Lastly, soot will be accounted for and must never exceed 100 mg/kW-hr.

Noise emissions were another high priority design objective for the team, as both objective and subjective noise events are conducted during the competition. The objective noise testing procedure follows the SAE J192 recommended practice. During the test, sound pressure created by the snowmobile cannot exceed 78 dB, which is the standard set by the International Snowmobile Manufacturers Association (ISMA). To account for environmental variations, a control snowmobile will be used to adjust the 78 dB pass/fail limit. Teams receive points based on an exponential scale of 0 to 150, which corresponds with the control snowmobile and the best performing machine.

For the subjective noise test, recordings of the snowmobiles, taken during the objective test, are played back and reviewed by a jury of CSC volunteers. The team with the most favorable subjective noise is awarded 150 points, while the least favorable score receives zero points.

Achieving the main goals of economy, emissions, and noise would be a hollow victory if the cost, performance, and comfort of the snowmobile were unreasonably compromised. Although they are not the main focus of the CSC, teams also compete in acceleration, subjective and objective handling, and cold start events. These parameters are used to gauge performance and handling characteristics of the snowmobiles.

In the acceleration event, all snowmobiles must complete a 500 ft. (152 m) course in less than twelve seconds. Based on two attempts, each team’s fastest time is used for scoring of the event. The team with the fastest time is awarded 50 points, while the other teams receive points based on their relative performance.

The handling events are closely related and are used to gauge the snowmobile’s agility and maneuverability. For the objective test, a team member completes individually timed, consecutive laps on a designated course. The team that has the fastest time receives 75 points, while other teams receive points based on their relative performance. During the subjective handling event, professional snowmobile riders drive each vehicle and evaluate ride quality and comfort. The winning team will receive 50 points, with the other teams receiving points based on their relative scores.

A cold start test is also performed during the competition in order to keep design solutions appropriate for the harsh environments which snowmobiles commonly experience. In order to be awarded 50 points for the event, the teams snowmobile needs to start in less than twenty seconds. After starting, machines have two minutes to traverse 100 feet (30.5 m) without stalling.

An oral presentation and static display event are hosted by teams in order to explain their particular design solutions. The presentations explain how the teams met the requirements of the environment, the dealer, as well as the consumer. These events are used to showcase the design process and highlight how teams were able to overcome the challenges presented.

ENGINE SELECTION

The University of Wisconsin - Platteville CSC Team decided to modify a snowmobile that would excel in performance and handling. The efficiency of the modern 4-stroke fuel injected engines compelled the team to investigate ways to make them even cleaner, while still retaining a high level of performance. In previous events, 4-stroke engines have proven to have lower emissions, as well as having higher fuel efficiency. While these engines have established themselves firmly in the competition, the University of Wisconsin - Platteville team has viewed them as lacking the most important quality to the consumers, acceleration and handling.

In an effort to visualize market needs, the team surveyed 150 snowmobile enthusiasts on which characteristics are taken into consideration most while purchasing a new snowmobile. When analyzing the results of the survey, shown in Figure 1, it is apparent that handling and acceleration are the most important factors to consumers when purchasing a new snowmobile. The results of this survey, along with team opinion, proved that a snowmobile must have ample handling and acceleration qualities, while still being environmentally friendly.

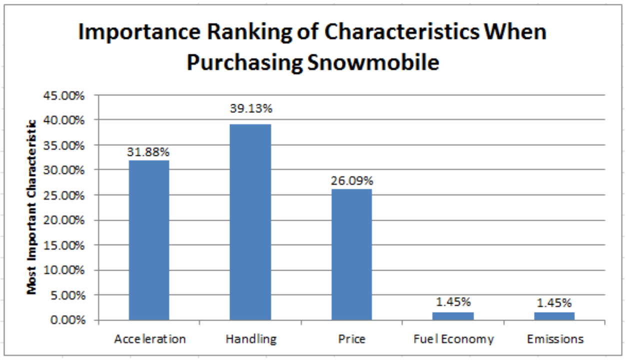

Figure 1: A survey of 150 snowmobile enthusiasts shows that handling and acceleration are the two most important factors when purchasing a snowmobile.

The search led the team toward the ZR 7000, a partnership between Arctic Cat's ProCross chassis and Yamaha's Genesis 130FI, a 1049cc fuel injected, three cylinder, 4-stroke engine, as seen in Figure 2. With the use of electronic fuel injection, precise fuel metering is used to deliver higher fuel efficiency. Dual overhead cams also allow the Genesis 130FI to have a less restricted air flow at higher engine speeds. Furthermore, the Genesis 130FI produces excellent power and torque without the need of a turbocharger.

Figure 2: Yamaha Genesis 130FI Engine.

The Genesis 130FI is equipped with three separate throttle bodies, which allows for near-instant throttle response. The use of fuel injection allowed Yamaha to develop an Engine Braking Reduction System (E.B.R.S), which permits the snowmobile to coast when the throttle is released, performing similar to a 2-stroke snowmobile. Although the Genesis 130FI is new to the ProCross chassis, it has been proven to be reliable and durable in the Yamaha Nytro models. With a 25,000 mile service interval between valve adjustments, the only maintenance required is basic oil changes throughout its lifespan.

The Genesis 130FI has a great balance of power, fuel efficiency, and throttle response which makes it one of the most dominant 4-stroke engines on the market.

Engine Management

The stock Arctic Cat ECU was replaced by the PE3-8400 from Performance Electronics. This ECU works with almost any engine, and allows for the adjustment of fuel and ignition parameters. The team elected to work with this system because it is a stand-alone unit, enabling 100 percent tunability. Parameters were set to compensate for flex-fuel along with other engine operating conditions. The PE has the ability to run a closed loop system to correct the fuel mixture for the desired air to fuel ratio. An example of the PE system is shown in Figure 3.

Figure 3: Performance Electronics PE3 ECU.

Implementing the PE required the use of Delphi HES connectors to connect the PE to the stock wiring harness. The use of these connectors allows the flexibility to easily revert back to a stock ECU for control purposes. The PE also doubles as a data logging system to monitor the engine's parameters while not connected to a computer.

CHASSIS SELECTION

The University of Wisconsin - Platteville CSC Team has selected the Arctic Cat ProCross chassis as a base for the 2015 competition. See Figure 4 for chassis illustration. The ProCross chassis is made up of an inner and outer-formed shell with a boxed support structure. This design utilizes a two-piece tunnel, which saves weight and produces additional strength [7]. The ProCross chassis has large running boards to accommodate a wide variety of riders. The running boards also have an ergonomic design which enables riders to have a more secure grip through profiling that prevents excess snow buildup. For strength, Arctic Cat also implemented a triangular tunnel design that links suspension mounting points, while also reducing weight.

Figure 4: Arctic Cat ProCross Chassis.

BRAKE SYSTEM

To increase stopping efficiency and safety, an aftermarket braking system was installed. The Hayes *Trail Trac 1.0* functions as an Antilock Braking System (ABS). The system uses an electronically controlled single hydraulic cylinder to modulate brake line pressure. The ABS control unit determines when slip is likely to occur, and adjusts brake pressure accordingly. This system results in improved braking performance and vehicle control. In addition to improved deceleration, Continuously Variable Transmission (CVT) disengagement is prevented, which allows for quicker throttle response by keeping the driveline in motion. To validate the brake system modification, the University of Wisconsin - Platteville CSC Team conducted straight line deceleration tests on two different types of surfaces, sugar snow and ice, to compare the stopping distance with and without the ABS activated. It was determined that the Hayes ABS system improved stopping distance by an average of 12 percent. The team's overall opinion was that braking was improved.

DRIVELINE

To increase driveline efficiency, the seven inch diameter stock rear idler wheels were replaced with ten inch aluminum wheels, as seen in Figure 5.

Figure 5: Ten inch wheels with 136 inch track.

The larger diameter wheels reduce the angular acceleration of the track, since it follows a larger radius. By following this enlarged radius, the amount of track deflection is reduced, minimizing the energy consumed to bend the track. Based on the same principle, the team also installed a set of aluminum asphalt drive sprockets and hubs to replace the stock nine tooth drivers. The drivers, manufactured by Proline Performance, are designed to minimize friction with the implementation of plastic rollers on each tooth, and prevent track deformation with the use of a center wheel. To compensate for the larger geometry, a 136 inch track replaced the stock 129 inch track. A survey was conducted which asked participants what features would be preferred in a new snowmobile. The results, shown below in Figure 6, indicate the most desired track size as selected by participants. The 136 inch track was most popular with 56 percent of the vote. This information supported the decision to implement a 136 inch track.

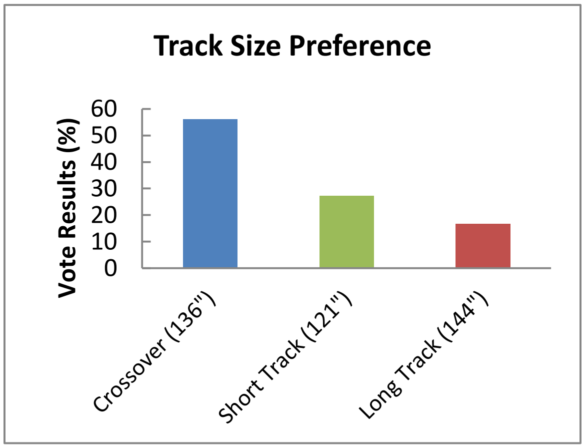

Figure 6: Survey results for track size preference.

In replacement of the conventional chain case, a belt and pulley drive system, designed by C3 Powersports, was tested and utilized. The advantages of the belt drive system include a twelve pound overall weight reduction, and an eight pound decrease in inertia. Another notable advantage is that the belt drive requires no lubrication system, which results in overall maintenance and environmental savings. A 2.5:2 gear ratio was chosen to maintain near stock gear ratios, while allowing for the largest pulley diameters possible in order to decrease the angular acceleration of the belt. In addition, Polaris claims that their belt drive system, comparable to that of C3's, will reduce the required gyroscopic force by 21 percent. This shows that the industry is starting to switch from the traditional chain case system to a more efficient belt drive system. [9]

To prove driveline efficiency, a chassis pull test was conducted to measure rolling resistance through the driveline. For this test, the snowmobile was pulled on a smooth concrete surface by a winch, for a specified distance, while the force required to pull the sled was measured by a digital force gauge. The skis were removed and replaced with wheels so that the effect of the skis would not compromise the driveline data.

Design of Experiment (DOE) is an engineering method that allows the researcher to model a complex process based on a relatively small amount of empirical data.

$$y = 79.5 - 1.1A - 4.75B - 6.87C + 0.28AB - 0.47AC + 1.57BC \qquad \mathbf{(4)}$$

$$y = 79.5 - 4.75B - 6.87C + 1.57BC \qquad \mathbf{(5)}$$

$$uncertainty = \sigma + \left(\frac{\Delta C}{C}\right)\mathrm{C} \qquad \mathbf{(6)}$$

While doing the DOE, the three variables that were taken into consideration were: A: C3 belt drive, B: extra bogie wheels, and C: 10" aluminum idler wheels. Each variable has two settings, as seen in Figure 7 in the Appendix, +1 are the non-stock options, while -1 are the stock options. Each setup was run three times and then averaged. Each trial run had the variance and standard deviation calculated as well to ensure meaningful results. The interactions between the variables were also taken into consideration. For example, AB would be the interaction between the belt drive and the bogie wheels. Using Figure 8, the variable coefficients were calculated and the base equation, Equation 4, was derived. From Equation 4, the variables with the lowest coefficients were neglected, being the variance created was too small to play a significant role in the final value. To confirm these assumptions are valid, an F-Test and T-Test were performed. The F-Test is used to compare the variance, while the T-Test is used for comparing the average values. These probability tests were used to see if the coefficients would fall within a given confidence level. Both tests showed a 95% confidence level, and it was seen that the variables A, AB, and BC can be neglected. The final equation, Equation 5, now gives the setup parameters needed to obtain a desired amount of force needed to move the snowmobile. Using Equation 5 a set up can be found that allows the snowmobile to be pulled with only 68 pounds of force. Using the big wheels, set C to +1, solve for the variable B, the number of bogie wheels. Once solved, B is equivalent to 4.82. A five bogie wheel set up with the big wheels will give allow the sled to be pulled with 68 pounds of force with +/- 1.89 pounds of uncertainty. The uncertainty is calculated using Equation 6.

A second driveline test conducted involved connecting a corded drill to the snowmobiles jackshaft. While using the drill to turn the jackshaft, the amperage draw of the drill was measured using a clamp digital multimeter. By hoisting the chassis off the ground, the free hanging system was analyzed. With this approach, any change in the friction of the driveline would change the amount of power drawn by the drill. A series of measurements was recorded when the track reached steady state conditions. Experimental values for each driveline modification are shown below in Table 2.

Table 2: Driveline tests conducted with an electric drill.

Driveline Drill Test Data		
Type of Drive	Chain Drive	Belt Drive
Average Total Amps	4.376	3.432
Horsepower Lost	0.719	0.564
Efficiency vs. Chain Drive	0%	22%

Using the Equation 7, shown below, the stock driveline absorbed 0.72 horsepower. The C3 PowerSports' belt drive system was tested under the same conditions and the power was reduced to 0.56 horsepower. As shown in Table 2, the C3 PowerSports' belt drive was 22% more efficient than the chain drive, making it a clear choice for the team to implement.

$$\text{Horsepower Lost} = (115\ \text{Volts}) * (\text{Amps}) \left(0.001341 \frac{\text{Hp}}{\text{Watts}}\right) \quad \textbf{(7)}$$

As a final test to prove driveline modifications, the team decided to run a real world driveline test using the throttle position sensor (TPS) to measure throttle position. A Logger Pro handheld data acquisition device was connected to the TPS which monitored the change in voltage. Using a constant test speed of 25 mph, a stock control test was performed. The following variations were tested: C3 belt drive system, 10" aluminum big wheel kit, and DuPont Teflon slides. Results of the tests can be seen in Table 3. The combination of all tested components resulted in a 13% reduction of throttle position required for similar performance, which indicates a higher efficiency. These results were the basis for the University of Wisconsin - Platteville CSC Team's driveline design for the competition snowmobile.

Table 3: Driveline tests at a constant speed measuring throttle position, compared to stock.

Modification	**% Reduction of TPS**
Belt Drive System	9.26
Big Wheels/10 Tooth Drivers	2.12
DuPont Teflon Slides	1.71
All Modifications Combined	**13.1**

SUSPENSION & HANDLING

Skis, carbides, track selection, and the suspension system all have an impact on the handling of a snowmobile. When all of these components are set up correctly, the result is a comfortable riding snowmobile.

The Arctic Cat ZR 7000 LXR is equipped with adjustable front and rear shocks, allowing the suspension to be tuned to the rider's preference. Arctic Cat's FasTrack SLIDE-ACTION rear suspension utilizes a revolutionary design which allows for increased traction through rough terrain. When the back of a conventional coupled rear suspension is compressed, lost motion occurs, which results in a loss of traction. Lost motion is present when the rotation of the pivoting idler arm cannot be transferred to the front of the rear suspension, causing a decrease in ground contact. Since the FasTrack SLIDE-ACTION rear suspension is not coupled in the same fashion a conventional rear suspension, it allows the maximum footprint possible to maintain contact with the ground, resulting in superior handling and traction. This effect is achieved through the use of a floating front torque arm. With this system, the torque arm slides back and forth freely as it straddles the torque sensing link. The action of this system is shown in Figure 8.

Figure 8: Arctic Cat's FasTrack SLIDE-ACTION* r*ear suspension. [8]

To improve trail handling of the snowmobile, the stock skis were replaced with C&A RZ skis. These skis implement the use of V-shaped keels to eliminate darting. A six inch carbide setup was chosen to provide positive steering through corners, and increased handling on ice and aggressive trail riding.

The ProCross chassis allows riders to sit farther toward the front of the snowmobile, which allows for more rider input through corners. This helps riders get the perfect balance of ski pressure and traction, which allows a very predictable ride in every situation. The use of Rox adjustable handle bar risers allows for riders of different heights to set the handle bar height to their preferred position. With the handle bars in the correct position, each rider will be able to get his or her arms parallel to the ground, allowing steering effort to be minimal. The combination of the ProCross chassis and the adjustable risers makes the snowmobile ergonomically comfortable to ride for extended periods of time.

The Camoplast Ice Attak XT track was chosen for the benefits of in-lug studs, which provide added traction with minimal added weight. This track is single-ply, which yields increased flexibility as well.

EMISSIONS

One positive aspect of the Genesis 130FI 4-stroke engine is the reduced gaseous emissions over a typical 2-stroke engine. A 4-stroke engine burns fuel more efficiently, which produces less air pollution while also increasing fuel mileage, without consuming oil.

Tikka Race has supplied a pre-burn catalytic system for the team. In previous years, the University of Wisconsin - Platteville CSC Team has had success with Tikka Race's proprietary and unique solutions. Tikka Race specializes in fitting carbureted and fuel injected 2-stroke and 4-stroke engines with pre-burn catalytic systems.

An overview of the new system has an inlet which leads into a pair of pre-burn catalysts. The pre-burn catalysts converge into the main catalyst chamber, where ignition of the unburnt fuel takes place.

NOISE

Noise reduction is an important factor in the continued allowance of snowmobile usage on today's trail system. Strategies for the University of Wisconsin – Platteville CSC Team's reduction of noise pollution include the implementation of sound dampening material, as well as the development of a post-catalytic muffler. The muffler was developed and improved through identifying the most significant variables implemented in multiple muffler designs.

To select a sound deadening material, a noise sample was taken of the snowmobile at 6000 RPM. This noise sample was played back from a speaker in an enclosed box. The box was covered with various materials and a microphone recorded noise emitted from the box. Figure 9 illustrates the test set up used. The University of Wisconsin - Platteville CSC Team ran four decibel (dB) tests with a hand held Logger Pro system, and from the results selected the quietest material, which was POLYDAMP® Melamine Foam.

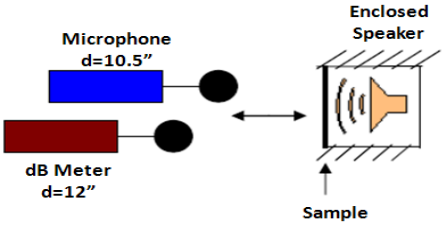

Figure 9: Schematic of the material-sample test configuration.

Having selected the most effective material, additional tests were performed to see how much sound could be mitigated. A set of panels were covered with the POLYDAMP® Melamine Foam and compared to a set of panels that were left untreated. The snowmobile was driven past a decibel meter and a sound recorder at 25 mph at a distance of 50 feet. The resulting frequencies were displayed on a Fast Fourier Transform (FFT) graph, which graphs every frequency picked up by the microphone. By comparing the graphs from each session, there was a noticeable reduction in frequency versus amplitude with each change. The first test of three was run with the stock exhaust can, and without any side panels. The second test was conducted with the catalyst and secondary muffler, again without side panels. The third test was done with the POLYDAMP® Melamine Foam on the side panels, in addition to the catalyst and secondary muffler. Test one was measured to be used as a baseline for the additional tests. Refer to Figures 10, 11, and 12 in the Appendix for the graphical representation of the FFT to visually see the reduction in particular frequencies for the three tests.

Noting the results of this controlled test, the University of Wisconsin - Platteville CSC Team chose to place Polymer Technologies POLYDAMP® Melamine Foam inside the panels because of its high heat tolerance and significant sound reduction.

The new muffler designed for the 2015 competition is a combination of two styles of baffling systems. The first system used resembles a standard motorcycle baffle, consisting of rectangular tubing that has a perforated sheet metal insert. This insert has been packed with fiberglass to absorb excess noise pollution. The exhaust system has three of these baffles. The flow from the initial pair of baffles then continues into the second noise reduction system. This system is designed to split the exhaust flow and divert the high frequency sound before entering the final baffle. To split the exhaust flow, a V shape plate, as shown in Figure 13, diverts the sound waves into the fiberglass packing. The fiberglass packing helps to eliminate the low frequency waves. Sound is also eliminated when the waves reflected from the V plate causes deconstructive interference with the incoming waves. The combination of these different chambers, along with fiberglass packed baffles, is sufficient enough to reduce exhaust noise from a stock sound reading of 80 dB down to a final sound reading of 76 dB.

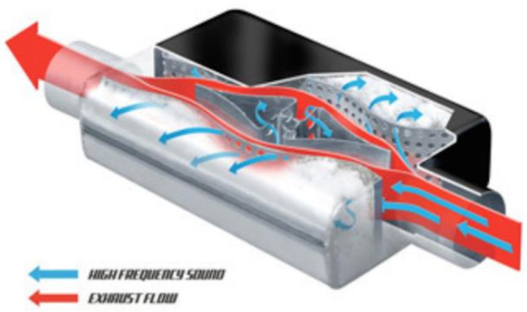

Figure 13: Exhaust flow through V Plate design.

CONCLUSION

Through extensive research and development, the University of Wisconsin - Platteville CSC Team has produced a snowmobile that is performance oriented and environmentally conscious. The aforementioned modifications have created a snowmobile that meets and exceeds the required competition standards. The team was able to deliver a snowmobile consisting of ample power, excellent handling, and improved fuel economy. Furthermore, this snowmobile not only meets the EPA's emissions standards set in 2012, but surpasses them. The team was able to make these improvements with only an estimated added cost of $2,889 over the stock snowmobile for a total of $15,188.

ABBERIVATION

ABS	Antilock Braking System
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CSC	Clean Snowmobile Challenge
CVT	Continuously Variable Transmission
Db	Decibel
DOE	Design of Experiment
E	EPA Emission Number
E.B.R.S	Engine Braking Reduction System
ECU	Engine Control Unit
EPA	Environmental Protection Agency
FFT	Fast Fourier Transform
HC	Hydrocarbon
ISMA	International Snowmobile Manufacturers Association
NO_x	Nitrous Oxide
PE	Performance Electronics
SAE	Society of Automotive Engineers
SwRI	Southwest Research Institute
TPS	Throttle Position Sensor
TR	Tikka Race

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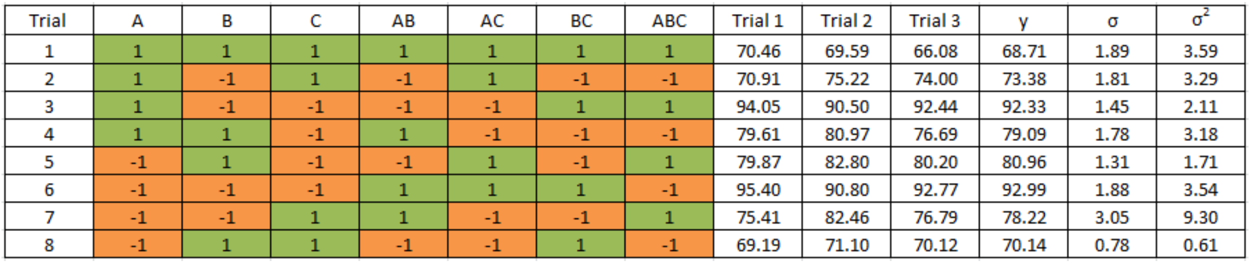
The University of Wisconsin - Platteville CSC Team would like to thank our sponsors: Arctic Cat, Wisconsin Bio-Industry Alliance, University Of Wisconsin - Platteville SUFAC, University of Wisconsin - Platteville SAE - Baja, University of Wisconsin - Platteville SAE - Formula, Millennium Technologies, Fastenal, Goodwin Performance, HMK, FXR, Signs-to-Go, University of Wisconsin - Platteville Mechanical Engineering Department, University of Wisconsin - Platteville Electrical Engineering Department, University of Wisconsin - Platteville Physics Department, Continental Trailers, CVTech-AAB, Association of Wisconsin Snowmobile Clubs, Tikka Race, Proline Performance, HB Performance, and many others who made this project possible.

APPENDIX



Trial	A	B	C	AB	AC	BC	ABC	Trial 1	Trial 2	Trial 3	y	σ	σ^2
1	1	1	1	1	1	1	1	70.46	69.59	66.08	68.71	1.89	3.59
2	1	-1	1	-1	1	-1	-1	70.91	75.22	74.00	73.38	1.81	3.29
3	1	-1	-1	-1	-1	1	1	94.05	90.50	92.44	92.33	1.45	2.11
4	1	1	-1	1	-1	-1	-1	79.61	80.97	76.69	79.09	1.78	3.18
5	-1	1	-1	-1	1	-1	1	79.87	82.80	80.20	80.96	1.31	1.71
6	-1	-1	-1	1	1	1	-1	95.40	90.80	92.77	92.99	1.88	3.54
7	-1	-1	1	1	-1	-1	1	75.41	82.46	76.79	78.22	3.05	9.30
8	-1	1	1	-1	-1	1	-1	69.19	71.10	70.12	70.14	0.78	0.61

Figure 7: Table of DOE trials with trial outcomes in pounds.

	A	B	C	AB	AC	BC	ABC
y average (-)	80.6	84.2	86.3	79.2	79.9	77.9	*78.9*
y average (+)	78.4	74.7	72.6	79.8	79.0	81.0	*80.1*
y(+) - y(-)	-2.2	-9.5	-13.7	0.6	-0.9	3.1	*1.2*
delta/2	-1.10	-4.75	-6.87	0.28	-0.47	1.57	*0.58*

Figure 8: Table used to calculate base equation coefficients.

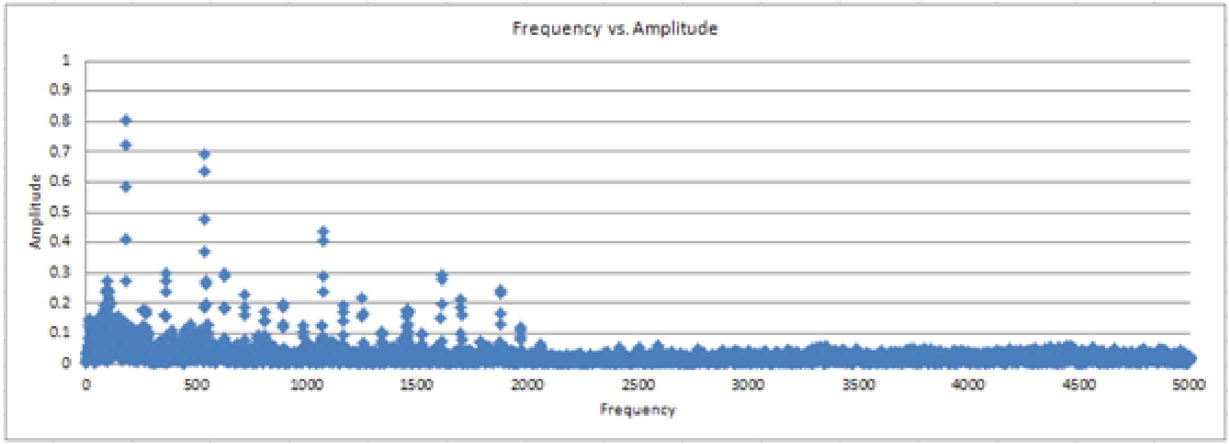


Figure 10: FFT Diagram with no side panels and only catalyst on exhaust.

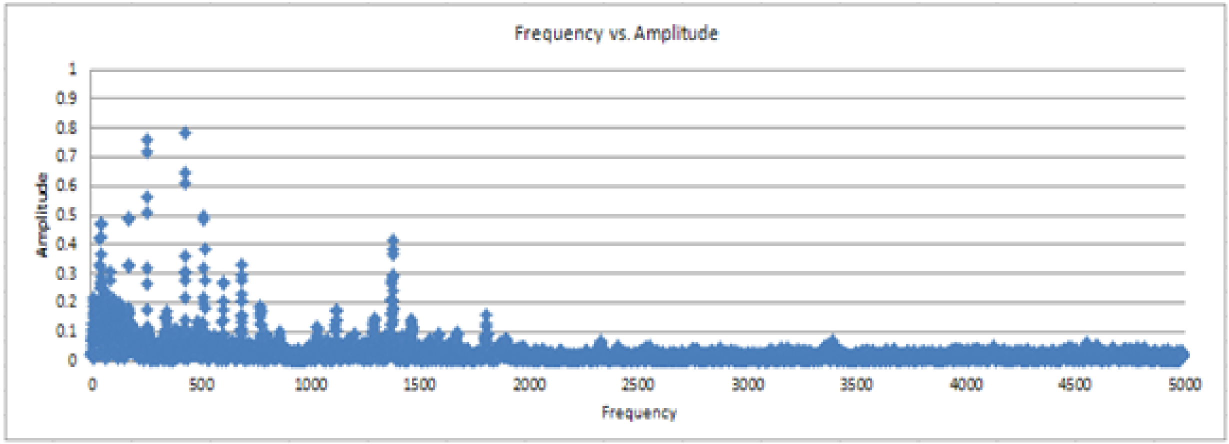


Figure 11: FFT Diagram with no side panels and with catalyst and muffler on exhaust.

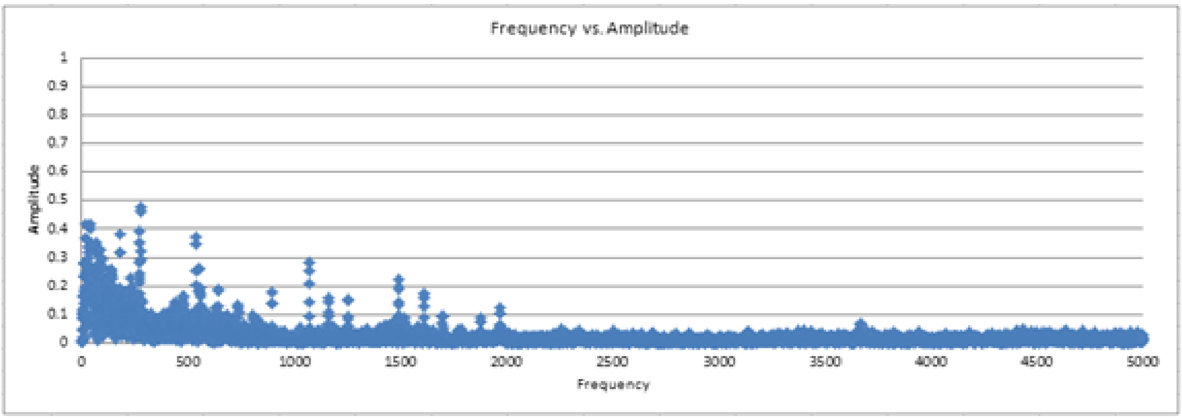


Figure 12: FFT Diagram with side panels and with catalyst and muffler on exhaust.