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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 developed a quiet, efficient, and environmentally friendly snowmobile. The snowmobile is designed to compete in the 2016 Society of Automotive Engineers (SAE) Clean Snowmobile Challenge, held at the Keweenaw Research Center in Houghton, Michigan, March 7th - 12th. The snowmobile for this year's competition is built on the 2016 Arctic Cat ZR 7000 LXR platform, featuring a 1049cc, three cylinder, 4-stroke engine. The UW-Platteville CSC snowmobile features a Power Commander V piggyback engine control unit (ECU). This system gives our team control over the engine parameters to achieve reduced exhaust emissions and improved fuel economy. Additionally, the exhaust system is modified to reduce emissions by utilizing a custom in-house catalytic converter. Driveline improvements, such as a lightweight belt drive and larger idler wheels, are also incorporated to facilitate increased fuel economy. These modifications have aided the UW-Platteville CSC Team to achieve our goal in producing a quiet, efficient, and environmentally friendly snowmobile.

INTRODUCTION

Snowmobile design is ever changing and manufacturers are looking for new technologies to better suit rider and environment needs. With 2015 snowmobile sales increasing by 8 percent in the United States alone, it is clear that snowmobiling is becoming increasingly popular [1]. As the sport grows, it is continuously met with pressure from the Environmental Protection Agency (EPA) to lessen these machines' environmental impact. These concerns are broken into categories including carbon footprint, noise pollution, and fuel efficiency. As a result, environmental regulations have been enacted, including the Yellowstone National Park's ban of snowmobiles in the year 2000.

In an effort to diminish 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 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. For 2016 the CSC will use a blend of 0-85% ethanol as fuel, a change from the bio-isobutanol required in 2015. This fuel is more practical than the bio-isobutanol, as it is readily available with a more developed processing and distribution infrastructure.

The CSC is grooming the way for future snowmobiles with the implementation of new flex-fuel systems and efficient design strategies. Design objectives include improving emissions, fuel economy, noise, rider comfort, handling, acceleration, and cold starting abilities. After the efforts to lessen environmental impact, Yellowstone National Park has implemented a new management approach which began with the 2014-2015 winter season, changing from the fixed maximum number of snowmobiles per day to a more flexible system based on transportation events [5]. According to the National Park Service, "transportation events are defined as one snowcoach or a group of up to 10 snowmobiles, averaging seven seasonally." The following paper outlines the UW-Platteville CSC Team's efforts for designing and building such a snowmobile.

DESIGN OBJECTIVES

To be an elite competitor in the 2016 Clean Snowmobile Challenge, the UW- Platteville CSC Team has refined one of the best 4-stroke platforms the snowmobile industry has to offer. The team's main goal is 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 complete the event. The additional points are calculated by Equation 1 [3]:

Team Score=100*[(GmaxGteam)2-1(GmaxGmin)2-1]   (1)

G is the number of gallons of fuel consumed

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

Team Score=50*[(FEmaxFEteam)2-1(FEmaxFEmin)2-1]   (2)

FE is the Fuel Economy measured in the event.

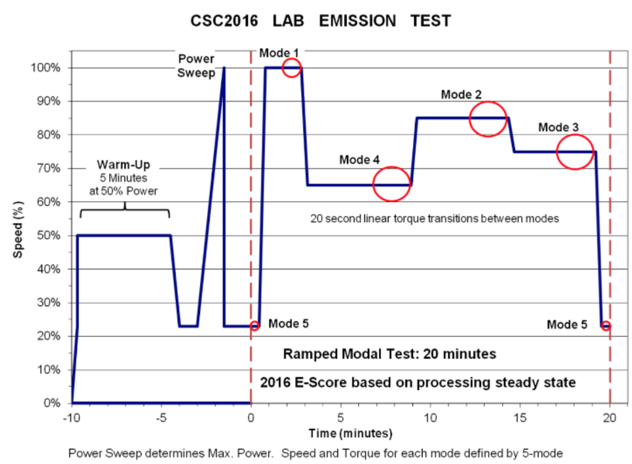
The team's second goal was to reduce Hydrocarbon (HC) and Carbon Monoxide (CO) emissions, without increasing the emission of Nitrous Oxides (NO_x). The fuel, chosen by CSC staff, is an unknown blend of corn-based ethanol and gasoline, having a “bio content” of 0 to 85% ethanol with octane values from 87 to 92. 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 four mile course (6.44 km), while the test sleigh records grams of HC, CO, CO_2, and NO_x produced. Emission test results are compared between the best and worst competitors to determine a score ranging from 0 to 50 points.

The second emissions event is a lab test performed when 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 the ramp modal five-mode test cycle, as published by Southwest Research Institute (SwRI) [4] and adopted by EPA. For the year of 2016, the emissions will be measured in-between the predetermined modes to give a more accurate representation of emissions produced. This year the transitions between the modes will also be counted toward the final e-score. This will force teams to have clean emissions throughout the map, not 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	**Engine Speed [% of Rated]**	**Torque [% of Rated]**	**Weight in [% of total]**
1	100	100	12
2	85	51	27
3	75	33	25
4	65	19	31
5	Idle	0	5

Table 2: Ramp Modal Test



From the lab measured emissions, an EPA snowmobile emission number (E) can be calculated. The E-score is determined from the operating points of Table 1 and by calculations using Equation 3 [4]. A minimum E-score of 175 is required. The E-score is calculated as follows:

E=[1-(HC+NOx)-15150]*100+[1-(CO400)]*100 >=175

(3)

Further requirements state that the average weighted emissions for HC+NO_x 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 175 are awarded additional points based on a linear scale. Lastly, soot will be accounted for and must never exceed 50 mg/kW-hr.

Noise emissions are also a high priority for the team, as both objective and subjective noise events are conducted at the competition. The objective noise test procedure follows the SAE J1161 recommended practice. During the test, sound pressure created by the snowmobile cannot exceed 67dB with ±2dB to account for measurement error and ambient noise, 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 67dB pass/fail limit if necessary. Teams receive points based on an exponential scale of 0 to 150, which corresponds with the control snowmobile and the top performing machine respectively.

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, comfort, and reliability 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 from a standing start. Based on two attempts, each team's fastest time is used for scoring in this 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 stability and maneuverability of the snowmobile. 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. 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 to keep design solutions appropriate for the harsh environments which snowmobiles operate in. In order to be awarded 50 points for the event, the team's snowmobile needs to start in under 20 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 to explain their design solutions. The presentations explain how the teams met the requirements of the environment, the dealer, and the consumer. These events are used to showcase the design process and highlight how teams were able to overcome the challenges presented.

ENGINE SELECTION

In previous competitions, 4-stroke engines have proven to have lower emissions and to be more fuel efficient. The UW- 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 retaining a high level of performance. While these engines have established themselves firmly in the competition, the UW- Platteville CSC Team has viewed them as lacking a good balance of handling, power and drivability.

The search led the team toward the ZR 7000 LXR, 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 1. Electronic fuel injection allows for the fuel to be precisely delivered and burned more efficiently. Dual overhead cams restrict less air flow at higher engine speeds. Furthermore, the Genesis 130FI produces excellent power and torque without the need of a turbocharger.

Figure 1: 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 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

To allow the snowmobile to be fully flex fuel on ethanol up to E-85, the UW-Platteville CSC Team chose to retain the stock ECU and utilize a Power Commander Module to adjust fuel and timing. The unit allows for -100/+250% of fuel adjustment and 20 degrees of timing. This allows the snowmobile to maintain all the stock features while achieving improved fuel efficiency throughout the power curve by "piggybacking" into the stock ECU. The power commander intercepts the signals from the stock ECU and allows the user to modify them. Utilizing this system also ensures that reliability is not compromised. Additionally, Power Commander features integrated auto tune and an android mobile app.

CHASSIS SELECTION

The UW-Platteville CSC Team has selected the Arctic Cat ProCross chassis as a base for the 2016 competition. See Figure 2 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]. This creates an extremely rigid frame with minimal welding to reduce weight. [9]. 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. This is accomplished by profiling that prevents excess snow buildup. For strength, Arctic Cat implemented a triangular tunnel design that links suspension mounting points, while also reducing weight.

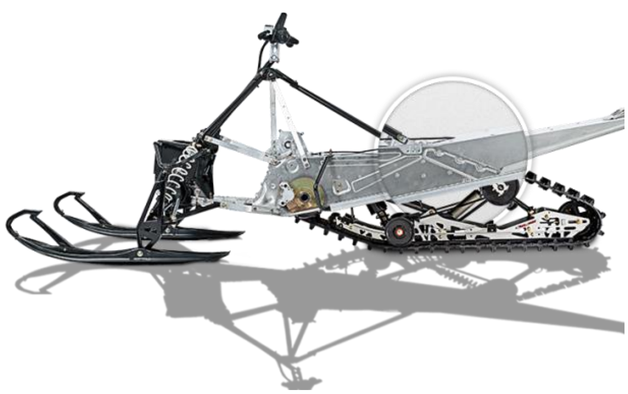


Figure 2: Arctic Cat ProCross Chassis

BRAKE SYSTEM

To increase stopping performance 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, allowing for quicker throttle response by keeping the driveline in motion. To validate the brake system modification, the UW-Platteville CSC Team conducted straight line deceleration tests on two different types of surfaces, sugar snow and ice. These surfaces were tested on stopping distance with and without the ABS system activated. It was determined that the Hayes ABS system improved stopping distance by an average of 12%.

DRIVELINE

To increase driveline efficiency, the seven inch diameter stock rear idler wheels were replaced with ten inch aluminum wheels, as seen in Figure 3.

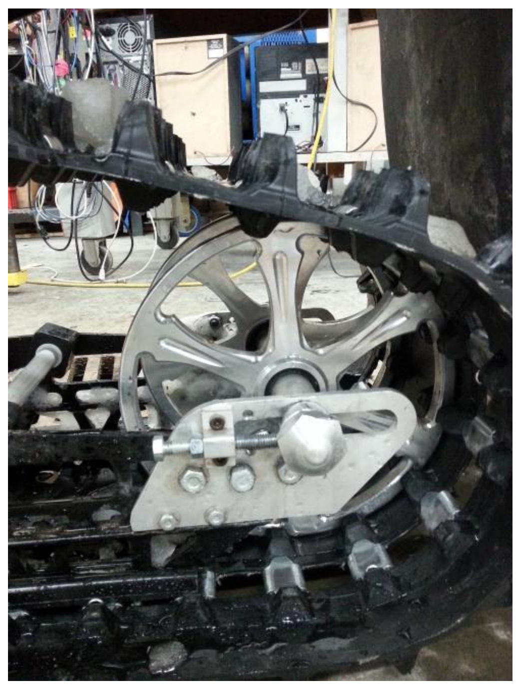


Figure 3: Ten inch idler wheels with 136 inch track

The larger diameter wheels reduce the torque required by minimizing the angular acceleration of the track. By following the enlarged radius, the amount of track deflection is reduced, minimizing the energy wasted bending the track. Based on the same principle, the team also installed a set of aftermarket drive sprockets to replace the stock nine tooth drivers. The drivers, manufactured by Avid Products, are designed to minimize friction with the implementation of extroverts on each tooth. The extroverts allow for looser track tension which increases driveline efficiency. To compensate for the larger geometry, a 136 inch track replaced the stock size of 129 inches. A survey was conducted which asked the general population of snowmobile enthusiasts what features would be preferred in a new snowmobile. The results, shown below in Figure 4, indicate the most desired track size. The 136 inch track was most popular drawing 56% of the vote, which supported the implementation of this change.

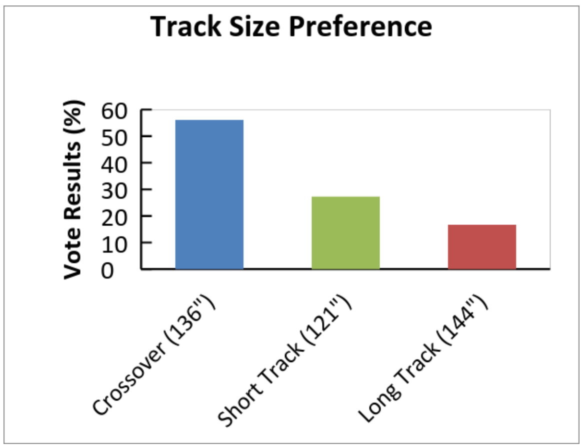


Figure 4: Survey results for track size preference

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 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%. This reflects the industry's transition from the traditional chain case system to a more efficient belt drive system. [8]

This year 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. Upon analyzing the data, shown in Figure 11 in the Appendix, it was found that under stock conditions the force required to maintain motion was 93.0 lbs. The greatest reduction in force from a single modification came with replacing the stock chain and gears with a belt and pulley combination. This modification resulted in a force of 70.1 lbs. required for motion.

Design of Experiment (DOE) is a scientific/engineering approach that allows the researcher to model a complex process based on a "relatively small" amount of empirical data. Using the DOE further proved the team's driveline efficiency.

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

$$y=79.5-4.75B-6.87C+1.57BC$$

$$\text{uncertainty}=+(CC)\ C \quad (5)$$

When doing the DOE, the three variables that were taken into consideration were: A: C3 belt drive, B: extra bogie wheels, and C: 10" idler wheels. Each variable has two settings, as seen in Table 5, +1 represents the non-stock options while -1 represents the stock options. Each setup was run three times and then averaged. Variance and standard deviation were then calculated for each trial. 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 Table 5, the variable coefficients were calculated and the base equation, Equation 4, was derived. From this base equation, the variables with the lowest coefficients were neglected, seeing as they are too small to play a significant role in the final value. To double check whether or not these assumptions are valid, a F-Test and T-Test were run. The F-Test is used to compare the variance, while the T-Test is used for comparing the average values. These statistical tests were used to see if the coefficients would fall within a given confidence level. Both tests had a 95% confidence level, and it was seen that the variables A, AB, and BC can be neglected. The final equation now gives the setup parameters necessary to obtain a desired amount of force needed to move the snowmobile. For example, to find a setup that only takes 68 lbs. of force to move the sled while using the big wheel kit. Set C to +1, for using the big wheels, and solve for B, the number of bogie wheels. Once solved, B is equivalent to 4.82, so 5 bogies will be needed with +/- 1.89 lbs. of uncertainty. The uncertainty can be calculated by using Equation 5. The DOE is a useful tool because not only can it be used to determine the setup needed, but it can also give an uncertainty with its answer.

A second driveline test conducted involved connecting a corded drill to the snowmobile 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 3.

Table 3: 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 below, the stock driveline absorbed 0.72 horsepower as calculated by Equation 6. The C3 belt drive system was tested under the same conditions and the power was reduced to 0.56 horsepower. As shown in Table 3, this system was 22% more efficient than the stock chain drive, making it a clear choice for the team to implement.

$$\text{Horsepower Lost}=(115\ \text{Volts})*(\text{Amps})(0.001341\text{HpWatts}) \quad (6)$$

As a final test to prove the modifications to the driveline, 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 inch big wheel kit, and DuPont Teflon slides. Results of the tests can be seen in Table 4. The combination of all tested components resulted in a 13% reduction of throttle position required for similar results, which indicates a higher efficiency. These results were the basis for the UW-Platteville CSC Team's driveline design for the competition snowmobile.

Table 4: 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 AND HANDLING

Suspension is a crucial part of the set-up of a snowmobile. When the suspension is finely tuned for the rider and the given conditions, handling greatly improves. Along with the suspension set-up many other factors contribute to the handling of the snowmobile including; skis, carbides, and track selection.

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 uses 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 like 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 and straddles the torque sensing link. The action of this system is shown in Figure 5.

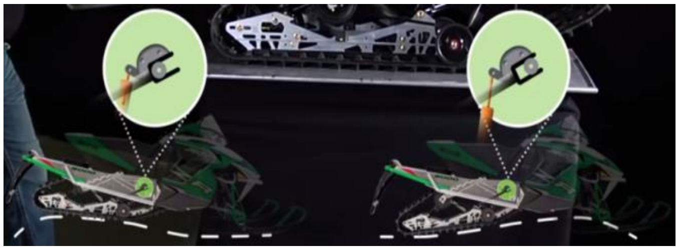


Figure 5: Arctic Cat Slide-Action Rear Suspension [8]

The ProCross chassis allows riders to sit farther forward on the snowmobile and allows for better response to rider input. This helps riders get the perfect balance of ski pressure and traction, which allows for a very predictable ride in every situation. The chassis yields a more ergonomic and comfortable ride for extended periods of time.

The Camso-Camoplast Ice Attak XT track was chosen for the benefits of in-lug studs, which provide added traction with a negligible increase in weight. This track is single-ply, therefore yielding increased flexibility.

Due to rider fatigue the addition of a steering damper helps riders remain comfortable after long rides and inspires confidence on rough, rutted trails. In extreme cases, the damper can prevent the handle bars from being pulled from the riders hands. Additionally, the damper is beneficial to normal trail riding as it isolates the rider from uneven impacts to the skis.

EMISSIONS

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

2016 is the first year that the UW-Platteville CSC Team has chosen to run a universal catalytic converter. MagnaFlow has an effective compact universal catalytic converter that consists of a honeycomb ceramic catalyst and recessed cushioning mat. This catalyst is designed to be more rigid, longer lasting, and provide consistent performance with optimized flow characteristics. The heat needed to ignite this catalyst is significantly lower than previous catalysts that have been used by UW-Platteville CSC Team. A lower starting temperature is achieved by utilizing a smaller volume of catalyst substrate.

NOISE

Noise reduction is an important factor in the continued allowance of snowmobile usage on today's trail system. Strategies for the reduction of noise include the implementation of sound dampening material as well as the development of a post-catalytic muffler.

Shown in the appendix is the stock data we obtained from our Larson Davis Model 831 meter. Refer to Figure 9 for set-up configuration.

To select sound deadening material, a noise sample was taken of the snowmobile at 35 MPH. The UW-Platteville CSC Team ran multiple tests with a hand held Larson Davis Model 831 meter and from the results selected the quietest material.

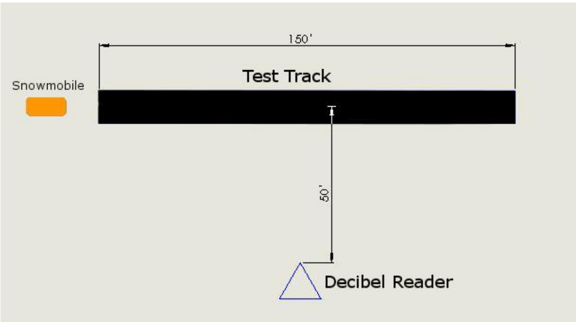


Figure 9: Schematic of J1161 test configuration

Having selected the best materials, additional tests were performed to see how much sound could be mitigated. A set of panels were covered with the sound deadening foam and compared to a set of panels that were left untreated. The snowmobile was driven past the Larson Davis handheld dB meter at 35 mph at a distance of 50 ft. The resulting frequencies were displayed on a Fast Fourier Transform (FFT) graph, which displays every frequency picked up by the microphone. The stock (FFT) graph is shown in Figure 12. 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 system. The second test was conducted with the secondary muffler system (which includes catalyst inside), again without side panels. The third test was done with the POLYDAMP® Melamine Foam on the side panels, in addition to the secondary muffler system. Test one was measured to be used as a baseline for the additional tests, Refer to Figures 12, 13 and 14 respectively 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 UW-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 this year's competition is a combination of a MagnaFlow catalyst and a designated chambers system. This year we are using a, lighter more compact catalyst than in previous years. The catalytic converter is a total of 8 inches long and 2.5 inches in diameter, which allows for much needed space in the engine compartment. The stock envelope was utilized while integrating a MagnaFlow catalyst. The first part of the system consists of a honeycomb ceramic catalyst and recessed cushioning mat as previously mentioned. After flowing through the catalyst, exhaust gases diffuse through perforated tubing and chambered sections, as shown in Figure 10. Hole diameters on the perforated tubing mimic the size of the stock exhaust system. At each end, the perforated tubes are capped, which requires the flow of the exhaust and sound to travel through the holes. As the exhaust transfers from tube to tube, the diameter of the holes decreases. Sequentially, reducing hole diameters causes sound waves to reverberate and possibly cancel. In the final chamber there is a solid tube resonator. The volume of the tube is designed to target specific frequencies of sound waves. Sound waves have a chance of being eliminated when reflected because of deconstructive interference with the transmitted waves. Running an exhaust system that is dimensionally similar to the OEM system allows space to acoustically insulate with fiberglass packing on the exterior. The combination of a catalytic converter, a resonator, distinctive chambers, and external fiberglass are sufficient to reduce exhaust noise.

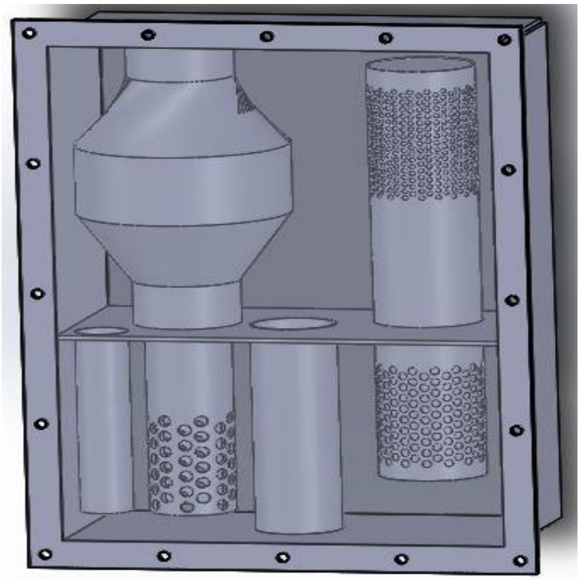


Figure 10: Exhaust System with catalyst (not an image incorporating stock can body)

CONCLUSION

Through extensive research and development, the UW-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 $1,874.60 over the stock snowmobile MSRP for a total of $14,223.60.

ABBREVIATIONS

Antilock Braking System (ABS)

Carbon Monoxide (CO)

Carbon Dioxide (CO_2)

Clean Snowmobile Challenge (CSC)

Continuously Variable Transmission (CVT)

Decibel (dB)

Design of Experiment (DOE)

EPA Emission Number (E)

Engine Braking Reduction System (E.B.R.S)

Engine Control Unit (ECU)

Environmental Protection Agency (EPA)

Fast Fourier Transform (FFT)

Hydrocarbon (HC)

International Snowmobile Manufacturers Association (ISMA)

Nitrous Oxides (NO_x)

National Parks Service (NPS)

Society of Automotive Engineers (SAE)

Southwest Research Institute (SwRI)

Throttle Position Sensor (TPS)

University of Wisconsin (UW)

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The University of Wisconsin - Platteville CSC Team would like to thank our sponsors: 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

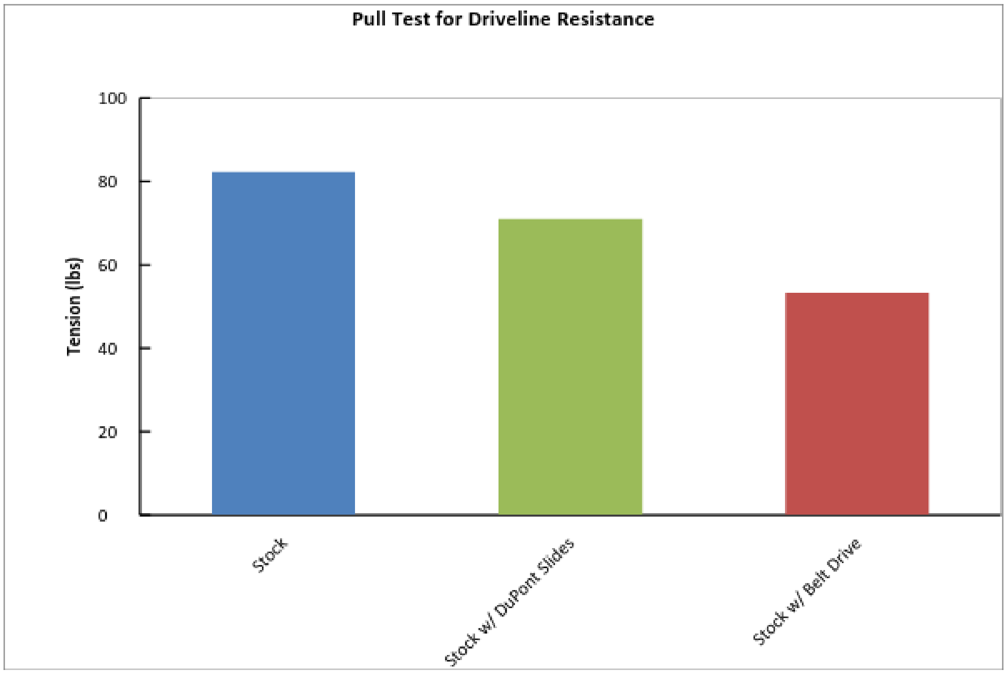

Figure 11: Chassis Pull Test results with multiple setups contrasting with stock setup

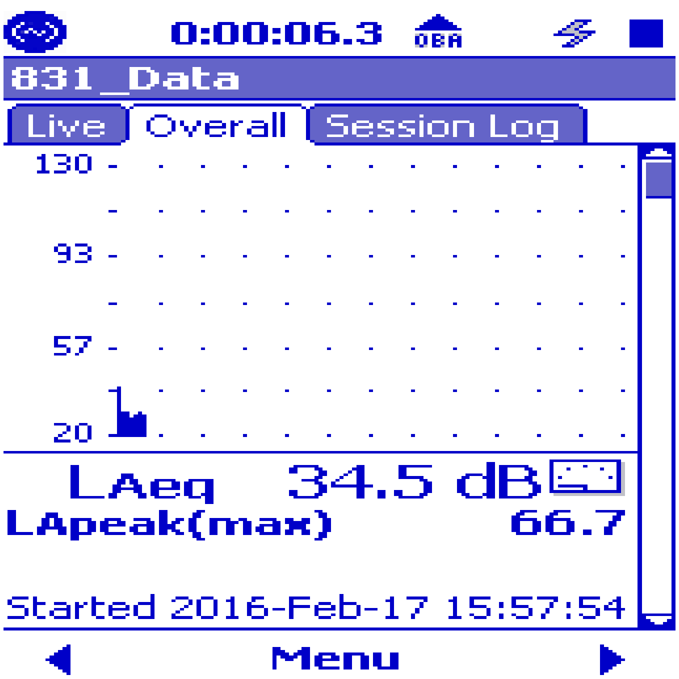

Figure 6: Ambient Noise Data 29° Fahrenheit at 4 P.M.

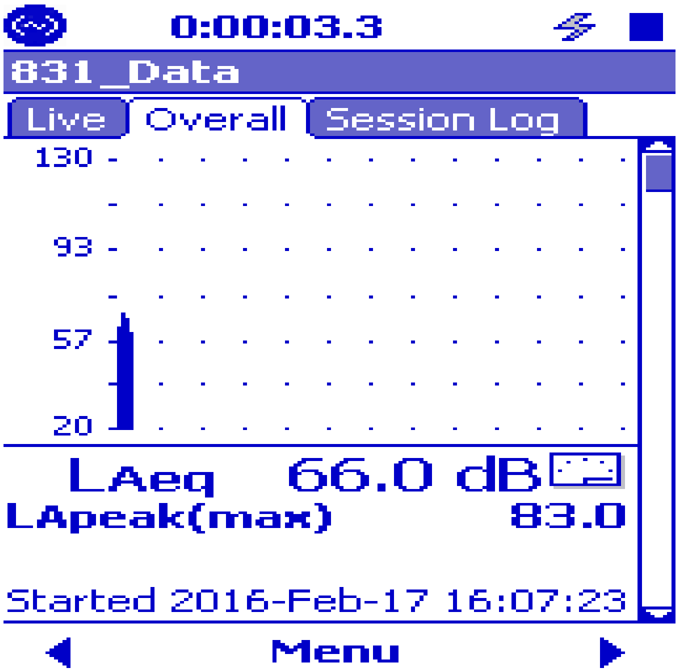

Figure 7: First Stock Run

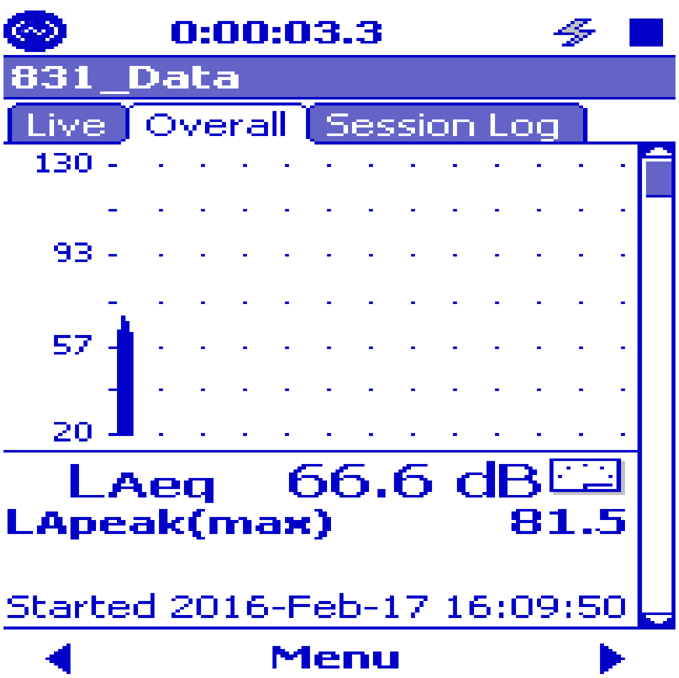

Figure 8: Second Stock Run

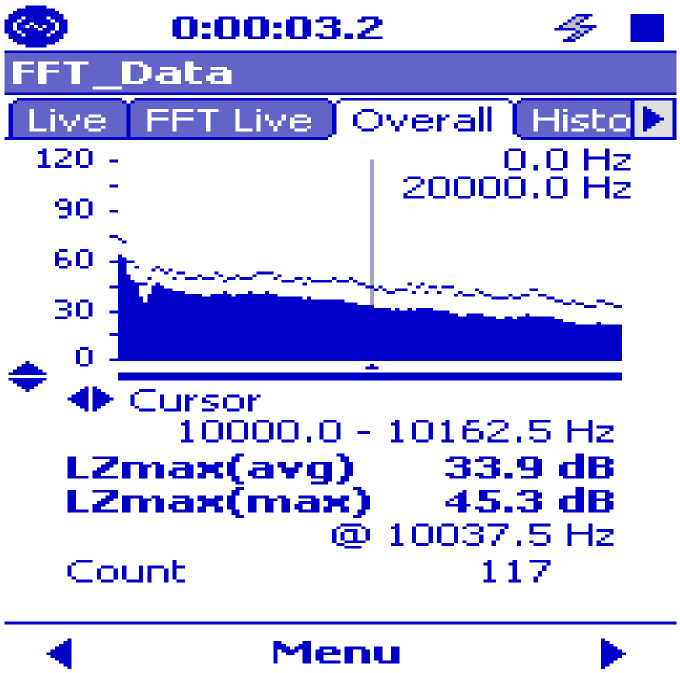

Figure 12: FFT Graph Stock Run

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

Table 5: DOE Driveline Efficiency