2-23-2013

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

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ABSTRACT

The University of Wisconsin-Platteville Clean Snowmobile Team has successfully designed and constructed a quiet, environmentally friendly and efficient snowmobile for the 2013 Society of Automotive Engineers (SAE) Clean Snowmobile Challenge (CSC). This competition is held at the Keweenaw Research Center in Houghton, Michigan, March 4^{th} - 9^{th} 2013. The snowmobile for this year's competition is based on a 2013 Ski-Doo REV-XP chassis which features a direct-injection two-stroke E-TEC engine. In order to achieve operation on a range of fuels from 40 percent to 85 percent ethanol blend, a Microsquirt Engine Control Unit (ECU) serves as a secondary system to the existing E-TEC injection system. This allows for a decrease in exhaust emissions, improved fuel economy and near stock engine power. The muffler system is modified to further reduce the emissions by utilizing a pre-burn catalytic system, customized by Tikka Race, and by adding an additional post-catalyst muffler along with sound absorbing material to reduce the exhaust and engine compartment noise. The efficiency was also increase by improvements added to the driveline. These modifications helped to achieve UW-Platteville's goal in producing a quiet, reliable, and efficient snowmobile.

INTRODUCTION

Today, there are four primary manufacturers of snowmobiles, with total 2012 sales reaching 129,087 units worldwide, and 48,689 of those sales taking place in the U.S [1]. Traditionally, snowmobiles have been plagued with poor fuel economy, high emissions, and high levels of noise pollution.

The environmental impact of these machines has become such a concern that the federal government began limiting snowmobile usage in the national parks in the year 2000. In response to this limitation, the Society of Automotive Engineers, along with the Environmental Protection Agency (EPA), National Parks Service (NPS) and the Department of Energy, created the Clean Snowmobile Challenge. This challenge is an international collegiate design competition with the goal to develop clean, quiet, fuel efficient alternatives to conventional snowmobiles. Competition entries are redesigned versions of original equipment manufacturer (OEM) snowmobiles; and are tested on design strategies, emissions, fuel economy, noise, ride comfort, handling, acceleration, and cold starting abilities. The snowmobiles are expected to self-adjust in order to run efficiently on blends of gasoline and ethanol ranging from E-40 to E-85, be reliable, and be marketable within the current snowmobile industry by maintaining consumer-acceptable levels of performance. Students will showcase their re-designed snowmobiles March 4-9, 2013, at the Keweenaw Research Center in Michigan's Upper Peninsula [2].

Today, U.S. National Parks are operating under a temporary winter use plan, which restricts the number of snowmobiles entering the parks every day. Those wishing to enter park areas are required to have "Best Available Technology", the cleanest and quietest group of commercially available snowmobiles. The EPA has also issued a required reduction on snowmobile emissions, centering around three main categories: hydrocarbons (HC), nitrogen oxides (NOx), and carbon monoxide (CO). Three phases were created to begin emissions regulations.

A summarization of the restrictions is shown in Table 1; highlights of this plan include a 50% reduction of emissions by 2010, and a 70% reduction for 2012 and beyond.

Table 1: Exhaust Emission Standards for Snowmobiles [3]

	Phase In	**Emissions (g/kW-hr)**		
Model Year	**% of sales**	**HC**	**HC+NOx**	**CO**
2007-2009	100	100	-	275
2010-2011	100	75	-	275
2012 & later	100	75	90	200

These restrictions have forced snowmobile manufacturers to explore and rapidly develop new technology. Some companies have shifted their focus to the four-stroke engine, which compared to a two-stroke engine can be made quieter, more efficient and typically emits fewer HCs. Other companies have invested in two-stroke technology, implementing advanced fuel delivery and management systems. These highly sophisticated two-strokes are smaller, lighter, have fewer moving parts, and emit less NO_x compared to equivalent four-stroke engines.

DESIGN OBJECTIVES

To be an elite competitor in the 2013 Clean Snowmobile Challenge, the University of Wisconsin-Platteville Team has re-engineered the best two-stroke technology the snowmobile industry has to offer. The University of Wisconsin-Platteville's main goal is to improve fuel efficiency. Teams will compete in two different events to measure fuel economy. The first will coincide with the 100 mile (160 km) endurance event, where 100 points will be awarded to teams that successfully complete the mileage requirement while maintaining the 45 mph (72 kph) speed requirement. Additional points will be awarded for fuel economy compared to the rest of the field based on Equation 1 [2]:

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

G is the number of gallons of fuel consumed.

Fuel economy is also measured during an in-service emissions event. Scores between 0 and 50 are awarded according to Equation 2 [2].

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

Where FE is the Fuel Economy measured in the event.

The team's second goal was to reduce HC and CO emissions while running ethanol blended fuel. Scoring for this event is based on an exclusive in-service emission test, followed by a five-mode test cycle as published by Southwest Research Institute (SwRI) [2, 3]. Table 2 shows the speeds, loads, and weighing factors for the five-mode test.

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

Table 2: The five-mode snowmobile test procedure used by the EPA and NPS.

An EPA snowmobile emission number (E), is determined by using the results from Table 2 and inputting the recorded emission values into Equation 3 [4]. A minimum E score of 100 is required to meet the corporate 2012 and later snowmobile emission standards. The average weighted emissions for HC+NOx and CO cannot exceed 90 and 200 g/kW-hr respectively. 100 points are awarded to teams achieving the minimum composite score, with additional points given to teams exceeding the minimum composite score, based on relative performance. To meet the harsher NPS standards, a minimum emission number, E, of 170 is required, where HC+NO_x and CO emissions cannot exceed 15 and 120 g/kW-hr respectively [3].

$$E = \left[1 = \frac{(\text{HC} + \text{NOx}) - 15}{150}\right] * 50\text{NO}\left[15\,\frac{\text{CO}}{400}\right] * 100 \quad (\mathbf{3})$$

The in-service emissions event is used to determine the total gaseous emission the snowmobile produces during a trail ride. Unlike the five-mode test, the event is designed to measure total emissions. Competition organizers operate the snowmobiles on a 3 mi (4.83 km) course while an emission measurement trailer collects HC, CO, CO_2, and NO_x produced. Based on total grams of emissions relative to the cleanest and dirtiest competitors, 0 to 50 points are assigned to teams [2].

Noise emissions were also a high priority for the team, as both objective and subjective noise events take place at the competition. The objective noise test procedure follows the SAE J192 recommended practice. During the test, sound pressure created by the sled cannot exceed 78 dB, which is the standard set by the International Snowmobile Manufacturers Association (ISMA). Teams receive 75 points for having a sound pressure less than or equal to 78 dB, and are eligible to receive up to 75 additional points based on how far below the standard they are.

For the subjective noise test, recordings of the snowmobiles taken during the J192 test are played back to a jury of CSC volunteers. 150 points are awarded to the team with the most favorable subjective noise, while the least favorable score receives zero points.

Achieving the three previous goals would be a hollow victory if the cost, performance, or comfort of the snowmobile were unreasonably compromised. Although they are not the main focus of the CSC, teams compete in acceleration, subjective handling, and objective handling events in order to quantify performance and handling characteristics of their snowmobiles. In order to pass the acceleration event, the snowmobiles need to complete the 500 ft (152 m) course in less than 12 seconds. Each team gets two attempts, and the faster time is used for scoring. The fastest team is awarded 50 points, while the other teams receive points based on their relative performance. The first handling event objectively evaluates the agility and maneuverability of each competition snowmobile. A team member completes individually timed consecutive laps on a designated obstacle course. The fastest team receives 75 points. For the subjective handling event, professional snowmobile riders will drive each competition snowmobile through a course designed to evaluate ride quality. 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 at competition. In order to pass the event and receive 50 points, snowmobiles need to start within 20 seconds without the aid of starting fluids and move 100 ft (30.5 m) within the first two minutes.

An oral presentation and static display event are presented by student teams in order to explain their particular solutions and how they meet the needs of the environment, the dealer, and the consumer.

ENGINE SELECTION

The UW-Platteville CSC team decided to modify a snowmobile that would excel in performance and handling. The team searched for engines that had superior power-to-weight ratios. There are many types of snowmobile engines to choose from. There are carbureted 2-stroke, fuel injected 2-stroke, 4-stroke carbureted, or 4-stroke fuel injected engines used in the industry. The simple principles that make a 2-stroke engine function intrigued the UW-Platteville CSC Team to keep investigating ways to improve the current technology. This decision was made in hopes of finding ways to keep 2-stroke engines clean so they may continue to be used in national parks.

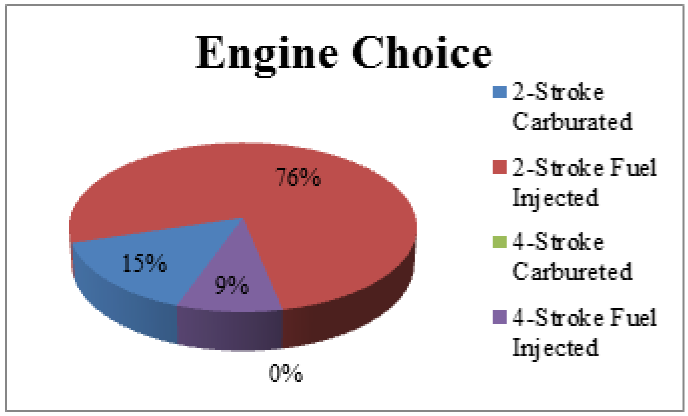

Figure 1: Results from a survey conducted on the HardcoreSledder website showing enthusiasts would prefer a 2-Stroke fuel injected engine as their next snowmobile.

Other than 2007, in which a direct injected 2-stroke proved to be more efficient, the past CSC competitions have proven a 4-stroke engine can be used in snowmobiles to produce a clean, quiet, fuel efficient snowmobile [2007,8,9,10,11,12]. Snowmobile emissions testing, performed by SwRI, also proves this point by stating that commercially available 4-strokes "…emit 98-95 percent less HC, 85 percent less CO, and 90-96 percent less PM" than conventional 2-stroke snowmobile engines [3].

However, the demand for 2-stroke powered snowmobiles is still very high due to their excellent power-to-weight ratio, and new technology continues to emerge.

E-TEC is Ski-Doo's version of a voice-coil injection system that quickly injects fuel directly into the combustion chamber after the exhaust port is closed. This is the key to bringing the emissions of a 2-stroke engine down to 4-stroke levels, according to Snowtech magazine [5]. Ski-Doo expects its high efficiency E-TEC 2-stroke to retain its advantage over 4-stroke competitors such as Yamaha. Ski-Doo also claims a 15 percent increase in fuel mileage with the E-TEC versus the Rotax 600 SDI (Semi-Direct Injected), with a claimed 21 miles per gallon [6]. Table 3 shows the difference in emissions produced and fuel economy between carbureted 2-stroke, electronic fuel injection (EFI) 4-stroke, semi-direct injection 2-stroke, and 2-stroke direct injection snowmobile engines.

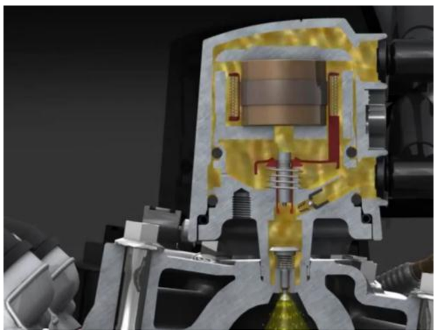

Figure 2: Diagram of stock E-TEC Injector. The body of the injector holds pressurized fuel, and then upon a signal from the ECU the plunger is retracted to allow fuel to enter the cylinder.

Due to the simplistic design of the 2-stroke engine it can typically produce a greater power-to-weight ratio compared to the conventional 4-stroke engine. These higher performance qualities also allow for a torque curve best suited for a continuously variable transmission (CVT). This transmission is standard in the industry as well as a requirement of the competition.

CSC Year Engine Type	CO [g/kW-hr]	UHC [g/kW-hr]	NOx [g/kW-hr]	Fuel Econ. [MPG]
'03 Two-Stroke Carbureted*	319.94	125.50	0.73	8.7
'04 Four-Stroke EFI*	99.84	11.48	23.33	15.3
'05 Two-Stroke SDI*	215.38	63.53	2.39	19.1
’09 Two-Stroke DI**	132	50	-	21
* Indicates snowmobile was control snowmobile ** Information from Ski-Doo backgrounder kit [13]				

Table 3: Emissions and fuel economy of two and four-stroke snowmobiles at CSC [9,10,11,13].

Final Engine Choice

Taking into account the design specifications and potential to vastly improve emissions over production 2-stroke engines, the UW-Platteville CSC team decided to build a clean, quiet, high performance 2-stroke powered snowmobile. The most important aspects of the design are to maintain the engine’s simplicity, low cost, and excellent power-to-weight ratio while reducing emissions and increasing fuel economy.

The UW-Platteville CSC team decided to modify an electronic direct injection, 594 cc, Rotax E-TEC engine. This engine is factory equipped with a tuned exhaust pipe and 3-D Rotax Automatic Variable Exhaust (R.A.V.E.) system. This system controls the exhaust ports to vary exhaust flow based on engine speed, allowing for more efficiency and power at low and mid-ranges [13].

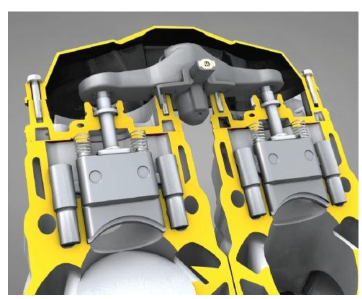

Figure 3: Cross-section of R.A.V.E. system

Engine Type	2-Stroke
Engine Details	Liquid-cooled, eR.A.V.E.
Cylinders	2
Displacement	594.4 cc
Bore x Stroke (mm)	71 x 74
Exhaust	Single
Fueling	Electronic DI

Table 4: Rotax Engine Specifications

CHASSIS SELECTION

The University of Wisconsin-Platteville Clean Snowmobile Team has selected the Rev-XP chassis, as a base for the 2013 competition. In 2008, BRP made rider position more flexible by placing the jackshaft above the tunnel on the Rev-XP chassis. This allows for additional foot clearance in comparison to its predecessor, the Rev chassis (See figure 4). This concept gives the rider better control and comfort, as well as allowing for smoother transitions from sitting to standing. In addition, the chassis is lightweight and is available with the selected engine.

Figure 4: Red outline shows the riding position and layout of a previous Rev chassis. The blue outline shows the current Rev-XP chassis [15].

SYSTEM MODIFICATIONS

Fuel System

In order to meet the ethanol requirements of the competition the stock air-fuel ratios (AFR) must be adjusted. The fuel map on the stock E-TEC engine was unable to provide the extra fuel required. The stock Electronic Control Module (ECM) could not be modified due to security restrictions imposed by Bombardier on the ECM. To compensate for this, the team developed a secondary fuel system to run in addition with the stock system. This system consists of a set of injectors added into the E-TEC cylinders; this operates as a semi-direct injection system. These secondary injectors are controlled by a Microsquirt EFI controller. Secondary injectors and fuel rail can be seen in figure 5.

Figure 5 Photo of UW Platteville's Supplemental Injectors

The MicroSquirt uses inputs from the throttle position sensor (TPS) and engine speed sensor to govern fuel ratios. To adjust for the varying ethanol content, the MicroSquirt controller utilizes a Continental Flex Fuel Sensor to determine the amount of ethanol in the fuel and adjusts accordingly.

Using a DYNOmite dynamometer, tuning was performed measuring exhaust gas temperatures, water temperatures, AFR, and emissions readings. With these parameters, the UW-Platteville CSC Team was able to create a supplemental fuel map for the secondary injection system.

To obtain a stoichiometric (balanced) air-fuel ratio (sAFR) an oxygen sensor was placed in the exhaust pipe. In order to accurately tune the engine for high and low load scenarios, the proper AFR equilibrium needed to be calculated. Burning pure ethanol would reach equilibrium at an AFR of 9:1, while gasoline has an AFR of 14.7:1. To calculate the effective AFR, with a specific mixture of gasoline and ethanol, Equation 4 was used:

$$\text{sAFR} = \left[\left(\begin{matrix}\text{\% of}\\ \text{additive}\end{matrix} * \begin{matrix}\text{sAFR}\\ \text{additive}\end{matrix}\right) + \left(90 - \begin{matrix}\text{\% of}\\ \text{additive}\end{matrix}\right) * \left(\begin{matrix}\text{sAFR}\\ \text{base fuel}\end{matrix}\right)\right]\left(\frac{1}{100}\right) \quad (\mathbf{4})$$

For example, the sAFR for E25 calculated from Equation 4 is 13.22:1. Using this new air fuel ratio for stoichiometric equilibrium, a new baseline AFR at wide open throttle (WOT) can be calculated. The baseline AFR at WOT was found to be 12.5:1. To find the target AFR at WOT for E25, Equation 5 was used:

$$\text{Target AFR} = \frac{\left(\begin{matrix}\text{Target AFR at}\\ \text{WOT on base fuel}\end{matrix}\right) * \left(\begin{matrix}\text{sAFR}\\ \text{of E25}\end{matrix}\right)}{\left(\begin{matrix}\text{sAFR}\\ \text{of base fuel}\end{matrix}\right)} \quad (5)$$

Chassis and Body

The chassis of the 2013 Ski-Doo Rev-XP is solid, lightweight and dependable, providing a strong platform to build the remainder of the snowmobile upon.

This year the team decided to replace the stock Ski-Doo 2-stroke E-TEC panels with a set of 4-TEC panels. The larger 4-TEC panels allow for a thicker layer of sound dampening material, and to accommodate the pre burn catalytic system. A vent was added to the right panel to cool the catalytic system.

Anti-lock Brake System

To help increase stopping efficiency and safety, an aftermarket anti-lock brake system (ABS) was installed. The Hayes *Trail Trac 1.0* is a single hydraulic channel that is an electronically controlled braking system used for snowmobiles. This system provides improved braking performance and vehicle control for a wide range of rider abilities especially for inexperienced riders [19]. To prove the brake system modification, the UW-Platteville CSC team conducted straight line deceleration tests on a two different types of surfaces, including sugar snow and ice, comparing the stopping distance both with and without the ABS activated. It was determined that ABS improved average stopping distance by over 12 percent on both surfaces. Subjective tests were also performed by various team members of differing skill levels who noticed improved handling and control while braking.

Driveline

To increase driveline efficiency, the stock seven inch diameter rear track tensioning wheels were replaced with ten inch diameter billet aluminum rear wheels, as seen in figure 6. The larger diameter wheels reduce the angular acceleration of the track by making a larger radius to change direction. The team also purchased a set of larger; ten tooth drivers to replace the stock eight tooth drivers on the same theory of decreasing angular acceleration. To compensate for the larger diameter wheels and drivers, the team purchased a 128 inch track to replace the stock 121 inch track.

In replacement of the conventional chain case, a belt and pulley drive system from C3 Powersports was tested and utilized. The advantages of the belt drive included a two pound overall reduction in weight, a reduction in rotating mass, and no lubrication required resulting in maintenance and environmental savings. A 1.8:1 ratio was chosen to maintain a near stock gear ratio while allowing for the largest pulley diameters to decrease the angular acceleration of the belt. In addition, Polaris claims that their belt drive system on the new 2013 PRO-RMK'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. [20]

Figure 6: Ten inch wheels with 128 inch track

Last year a chassis pull test was conducted to measure rolling resistance through the driveline. This test can be seen in Figure 6. For this test, the snowmobile was pulled on asphalt by a winch for a specified distance while the force required to pull the sled was measured. The skis were removed and replaced with wheels to reduce kinetic friction as well as reduce noise in the data. By removing the skis, isolation of the drivetrain was maximized. Eight trials were performed to take into account all the possible modifications that could be made to improve efficiency. Upon analyzing the data in Table 5, it was found for stock conditions and setup, the force required to maintain motion was 82 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 53 lbs. required for motion.

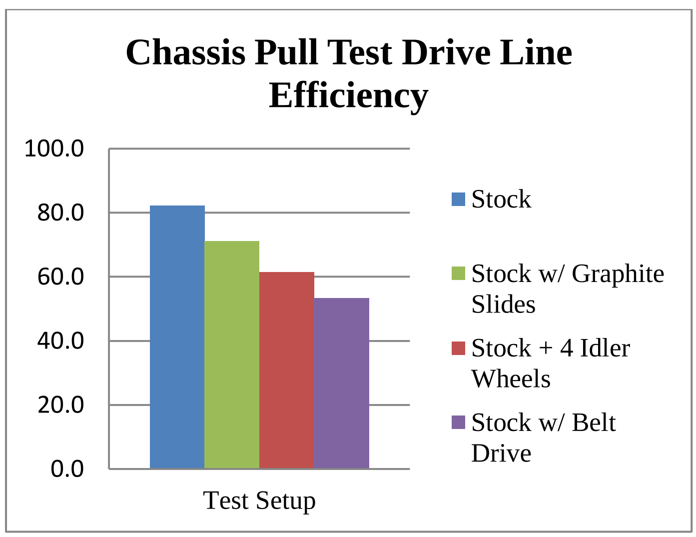

Figure 7: Chassis Pull Test results with multiple setups contrasting with stock setup.

To prove our modifications to the driveline the team decided to run a realistic driveline test in which throttle position was measured at a constant speed of 20mph. A Logger Pro handheld data acquisition device was connected to the TPS for metering the change in voltage. A baseline test was conducted from which all other tests were compared. The following tests were performed: belt drive system, big wheel kit, addition of four idler wheels, and CVTech Powerblock 80 primary clutch. Results of the tests can be seen in table 5. The combination of all these components resulted in a 15.4 percent reduction of throttle position, thus achieving higher efficiency; this combination will be run at competition.

Modification	% Reduction of TPS
Belt Drive System	6.14
Big Wheel Kit	4.93
Extra Idler Wheels	1.39
CVTech Primary Clutch	2.90
All Modifications Combined	**15.36**

Table 5: Driveline tests at a constant speed measuring throttle position, compared to stock.

With the results from the voltage test and the pull test in agreement, the final setup was chosen. It was decided that the stock skid, big wheel kit, four extra idler wheels, graphite slides, belt drive system, and CVTech primary clutch would optimize efficiency.

Suspension/Handling

A key part to the comfort of snowmobiling is the setup and handling of the snowmobile. This includes areas such as front and rear suspensions, skis, and carbides all improving rider control. With an appropriate setup, snowmobiling can be both comfortable and enjoyable.

With the suspension being the center of how the snowmobile rides through the terrain, it is important to ensure the setup of the suspension is appropriate for the rider. Taking this into account, adjustments were made to both the spring rates and the damping coefficients of the suspension. Dual rate springs were added in replacement of the single rate springs. The advantage to the dual spring rate is that as the shock reaches full compression, the spring rate increases, reducing hard bottoming out of the suspension without sacrificing the soft ride in average trail conditions. Shocks on this snowmobile were rebuilt by Hygear Suspension to ensure ride quality.

To improve the trail handling of this snowmobile, the stock skis were removed and replaced with C&A TRX trail skis. This ski offers a rounded keel on the inner and outer edge to eliminate darting. A six inch carbide setup was chosen to provide positive steering through corners and aggressive trail riding without adding increased rider input.

The Camoplast Ice Attak XT was chosen for added traction due to the in-lug studs providing added traction without the added weight and noise of traditional studs and backers. This track is also a single-ply allowing for less rigidity and fully clipped windows to use extravert drivers to minimize ratcheting or slippage.

Emissions

Over the years, many design modifications have been made to improve efficiency and reduce emission output of 2-stroke engines. However, simultaneous introduction of fuel and release of exhaust gases leads to a loss of unburned hydrocarbons (UHC), and ultimately higher emissions output than comparable 4-stroke engines. This problem is perpetuated because 2-stroke engine fuel normally consists of a mixture of gasoline and a petroleum lubricant. The latter material has a higher average molar mass, and is therefore less efficiently oxidized during the combustion process than the less dense gasoline.

A positive aspect of the 2-stroke engine design is that combustion takes place at a lower temperature than a conventional 4-stroke engine. The lower combustion temperature leads to an exhaust gas composition that is relatively low in NO_x emissions, but high in CO and UHC.

The Platteville CSC Team has incorporated the same style catalyst from Tikka Race (TR) that was used in the 2012 competition.

For this, UW-Platteville contacted Tikka Race, a company that specializes in fitting carbureted and fuel injected 2-stroke and 4-stroke engines with pre-burn catalytic systems. TR supplied a custom pre-burn catalytic and muffler system specifically designed for this engine's operating conditions. Three precious metal substrate three-way catalysts are used to reduce emissions.

Since the team had success with the pre-burn catalytic in the previous years, Tikka Race was contacted to help with the emissions on the E-TEC again for the 2013 competition. The test machine that TR used was a 2009 Ski-Doo Renegade E-TEC 600, the same engine the UW-Platteville team is using. TR tested the catalyst and claimed that the hydrocarbon (HC) count dropped from 4500 parts per million (ppm) down to 0-10 ppm during the idle phase of the engine. The Team was also able to achieve these results in their own testing when the hydrocarbon content would fluctuate between 0-100 parts per million beyond the idle state, which is well under the competition regulations.

The exhaust gas first passes through a muffler that preheats the catalytic system by burning unburned HC. From here, the exhaust enters a rhodium catalyst. This facilitates the reduction of the nitrogen oxides to maximize the formation of dinitrogen. The exhaust gas is then passed over a second section of catalyst 1 made of palladium. This part of the catalyst 1 reduces the residual hydrocarbon and carbon monoxide gas after passing through the first section, the rhodium catalyst. In series with catalyst 1, a 100 cells per square inch (CPSI) catalyst (catalyst 3) operates in parallel with a 400 CPSI catalyst (catalyst 2) that further reduce HC, CO, and NOx. Upon engine startup, catalyst 3 lights within the first two minutes. In the following two to four minutes, catalyst 1 and 2 will light. As shown in Table 5, the installation of the pre-burn catalytic after-treatment initially reduced HC emissions by 80 percent.

Emissions (ppm)					
Mode Point	**Speed (RPM)**	**Untreated**	**With TCS Catalyst**		
		HC	**NO_x**	**HC**	**NO_x**
1	**8000**	5000	**530**	1000	70
5	**1500**	4500	58	1	30

Table 6: Emissions data during dynamometer testing.

Optimizing the efficiency of a three-way catalyst requires the entering exhaust gas to oscillate between slightly rich and slightly lean. Since the pre-burn TR catalyst is designed for carbureted engines, it does not depend on the fuel system to create this scenario. As shown in Figure 8, the catalyst itself alternates between a low temperature of 676 °C and a high temperature of 900 °C, creating a slightly rich and slightly lean oscillation pattern [16].

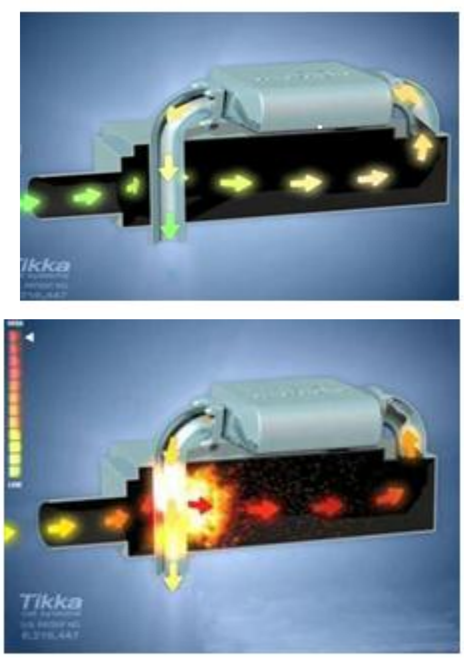

Figure 8: TR catalyst operating at low temperature (top), and high temperature (bottom).

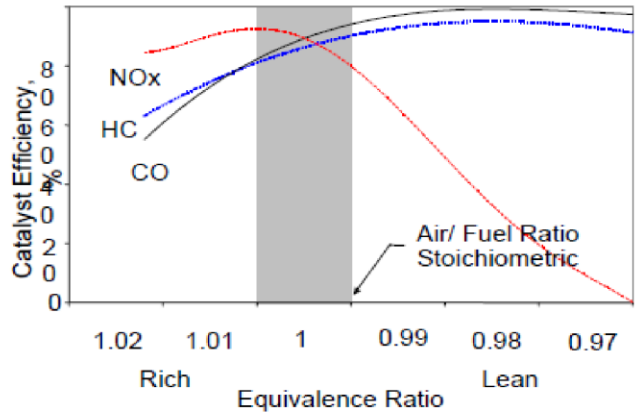

Figure 9: Conversion efficiency of NOx, CO, and HC for a three-way catalytic converter as a function of exhaust gas air/fuel ratio operating on gasoline [17].

NOISE

Once an initial sound clip of the snowmobile at 6000 RPM was recorded on the loudest side of the sled, sound testing was then done in a controlled environment to ensure accuracy of both the equipment and the materials. Each test had a duration of one second at 1000 samples per second. Figure 10 shows a material testing procedure to test different materials.

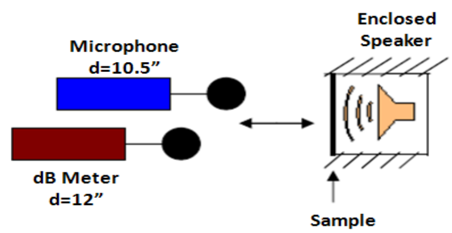

Figure 10: Schematic of the material-sample test configuration

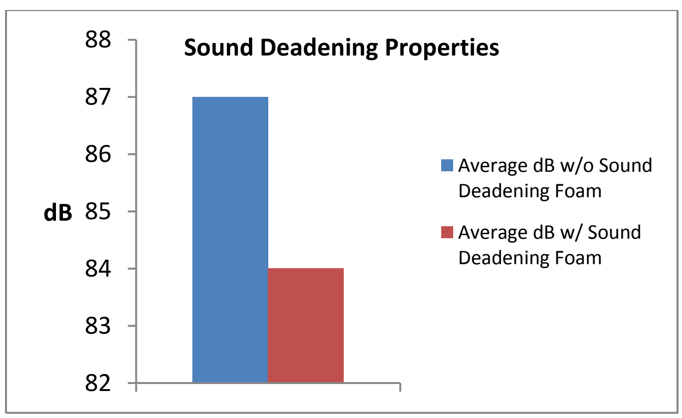

Figure 11: Graph showing sound reduction relative to material

UW-Platteville did four dB tests with the hand held Logger Pro system. The data results are shown in Figure 11.

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

After the material testing was done and the appropriate material was selected another sound test was performed to determine the overall effects done to the snowmobile. The test was conducted by holding a frequency microphone and a decibel meter at 50 feet from the exhaust side of the snowmobile as it would be conducted in competition. After measuring the frequency of the snowmobile, the frequencies were displayed on a Fast Fourier Transform (FFT) graph, which graphs every frequency picked up by the microphone. This test was conducted at 25mph. By comparing the graphs from each session, there was a noticeable reduction in frequency vs. amplitude with each change. Three tests were performed, the first being 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 addition of the side panels with the POLYDAMP®. Refer to figures 12, 13 and 14 for the graphical representation of the FFT to visually see the reduction in particular frequencies for the three tests.

COST ESTIMATE

Advancements in technology currently implemented in the automotive industry are constantly transitioning into the snowmobile and recreational vehicle industry. These advancements have continued to increase the cost of snowmobiles on a yearly basis. The Manufacturer's Suggested Retail Price (MSRP) for a stock 2013 Ski-Doo MXZ® TNT™ E-TEC 600 H.O. is $10,299.00. After the modifications the Wisconsin-Platteville Team made, the estimated MSRP would be raised $4,397.17 to a total of $14,696.17. Justification on the increase in the MSRP is shown in its flex fuel capability, chassis modifications to improve safety, driveline modifications to greatly improve efficiency, and additional components used to reduce emission and noise pollution.

CONCLUSION

Through extensive research and development, the University of Wisconsin-Platteville CSC team has produced a performance oriented and environmentally friendly snowmobile. With the modifications as stated earlier not only did the University of Wisconsin-Platteville CSC team meet the standards, the standards were exceeded. Taking into consideration that not only does a rider want a powerful engine, but a quality snowmobile in all aspects. This snowmobile has a better ride quality, improved fuel mileage, reduced noise pollution, and not only meets the 2012 and beyond EPA's emissions standards but surpasses them. The University of Wisconsin-Platteville team did all this and with only an estimated added cost of $4,397.17 dollars to the stock snowmobile.

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ACKNOWLEDGEMENTS

The University of Wisconsin-Platteville Clean Snowmobile Challenge 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, Edgewater Marine, Nick’s Powersports, Millennium Technologies, Hiperfax, Kohn’s Auto Body, Fastenal, Goodwin Performance, HMK, Signs-to-Go, University of Wisconsin-Platteville Mechanical Engineering Department, University of Wisconsin-Platteville Electrical Engineering Department, University of Wisconsin-Platteville Physics Department, R & R Trailers, CVTech-AAB, Association of Wisconsin Snowmobile Clubs, Tikka Race, Pete Nydahl with Crank & Machining, and many others who made this project possible.

DEFINITIONS / ABREVIATIONS

Air-Fuel Ratio (AFR)

Anti-lock Braking System (ABS)

Bombardier Recreational Products (BRP)

Carbon Monoxide (CO)

Cells per square inch (CPSI)

Clean Snowmobile Challenge (CSC)

Continuously Variable Transmission (CVT)

Decibel (dB)

Engine Control Unit (ECU)

Environmental Protection Agency (EPA)

Fast Fourier Transform (FFT)

Hydrocarbons (HC)

International Snowmobile Manufacturers Association (ISMA)

Manufacturers Suggested Retail Price (MSRP)

National Park Service (NPS)

Nitrogen Oxides (NOx)

Original Equipment Manufacturer (OEM)

Parts per million (ppm)

Rotax Automatic Variable Exhaust System (R.A.V.E.)

Semi-Direct Injection (SDI)

Society of Automotive Engineers (SAE)

Southwest Research Institute (SwRI)

Stoichiometric Air-Fuel Ratio (sAFR)

Throttle Position Sensor (TPS)

Tikka Race (TR)

Unburned hydrocarbons (UHC)

University of Wisconsin-Platteville (UW-Platteville)

Wide Open Throttle (WOT)

APPENDIX

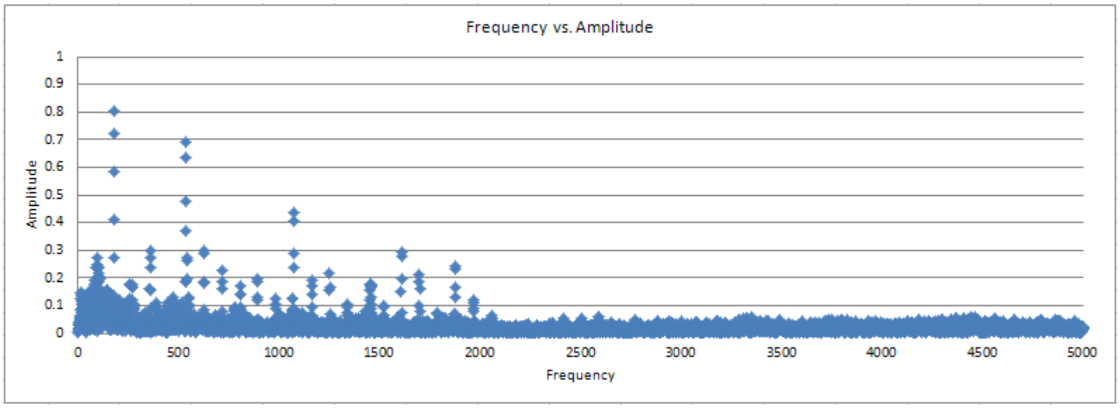

Figure 12: FFT Diagram with no side panels and just the catalyst on exhaust

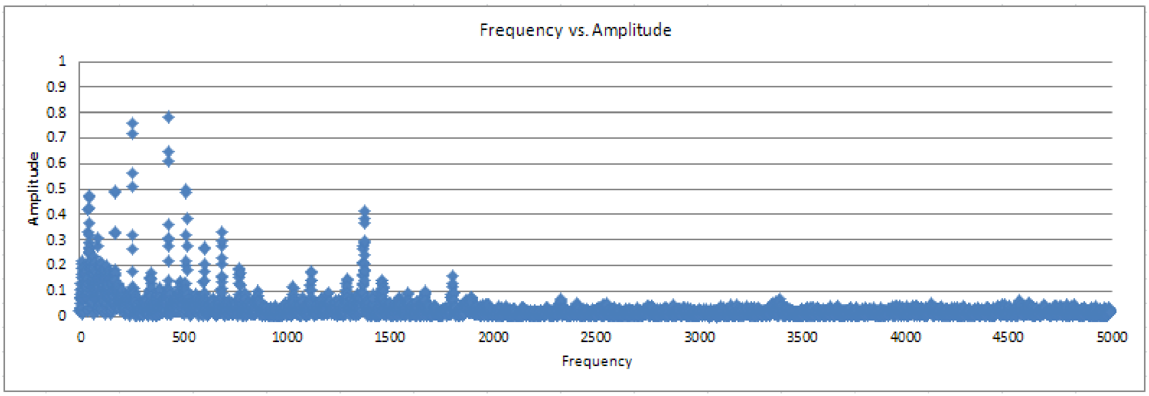

Figure 13: FFT Diagram with no side panels and the catalyst and muffler on exhaust

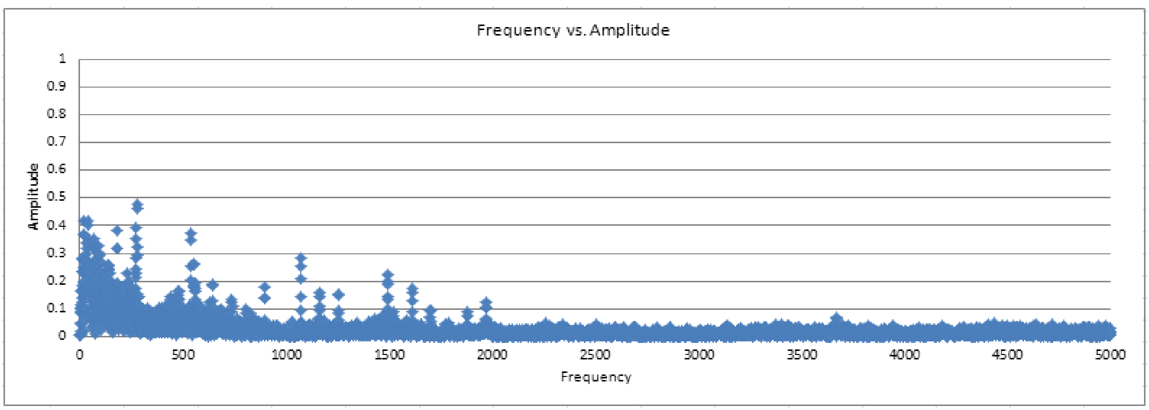

Figure 14: FFT Diagram with side panels and the catalyst and muffler on exhaust