Re-Engineering a 2015 Polaris Indy for the Clean Snowmobile Challenge 2017

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Abstract

Northern Illinois University's Clean Snowmobile team will compete with a re-engineered 2014 Polaris Indy 600 in the 2017 Clean Snowmobile Challenge. The snowmobile will retain its factory equipped two stroke engine. The team has met the competition objectives which are to maintain or increase the snowmobile's performance while improving its exhaust noise and emissions. The stock Polaris engine control unit (ECU) has been augmented with a Power Commander tunable ECU, coupled with a GM Flex Fuel sensor to accommodate a range of ethanol blend fuels. Other improvements were added to the snowmobile in order to improve the exhaust emissions, reduce noise emissions, and improve fuel economy by way of a custom designed muffler and catalytic converter. These modifications were done with user friendliness, cost effectiveness, and clean emissions in mind. The snowmobile was found to be a viable option for recreational riders and performance oriented riders as well.

Introduction

The Northern Illinois Clean Snowmobile Team members have a great passion for the sport. Growing up around snowmobiling and becoming aware of global issues has sparked the team's interest in the area of alternative fuels for use in snowmobiles. The fact that many snowmobiles in use today produce a high amount of chemical pollution has given rise to conversation, debate, and political action in many parts of the world. Often snowmobiling takes place in and around environmentally sensitive areas, such as state and national parks. By reducing the dependency of fossil fuels used in snowmobiles, we can reduce the carbon footprint that snowmobiling creates. This negative impact on the environment has created new objectives for college students [1].

The team began with a 2014 Polaris Indy 600 that met factory specifications. In accordance with competition rules, the first goal of the team was to modify the snowmobile to accommodate the ethanol fuel blend that would be used at competition.

The team has the lofty goal of proving that a traditional two stroke engine is a viable option for this competition. In order to achieve this goal, we focused on fuel system modifications that would maintain the integrity of the engine while also maintaining a snowmobile worthy of the Polaris logo. In order to improve the overall safety of the machine, the team also focused on improving the traction and braking systems. Modifications were also made to the track and skid system in order to improve the fuel economy of the snowmobile. The improvements described herein can be an example for a vast majority of the snowmobiling community. When considering the team's design changes for the competition, consumer appeal was always at the top of the list; the team goal is to implement modifications to the snowmobile that can be a genuine contribution to the snowmobile community at large. By creating a cleaner snowmobile that meets the desires of snowmobile enthusiasts, the sport can have a bright and promising future.

Team Objectives

Reduce Exhaust Emissions

The Northern Illinois University (NIU) team has an objective of lowering the exhaust emissions. A five mode test will be conducted to verify that each snowmobile complies with the Yellow Stone National Park standard. Table 1 clearly identifies each mode and corresponding category.

Table 1: 5- mode emission test cycle

Mode	**1**	**2**	**3**	**4**	**5**
Speed %	**100**	**85**	**75**	**65**	**Idle**
Torque %	**100**	**51**	**33**	**19**	**0**
Wt. Factor, %	**12**	**27**	**25**	**31**	**5**

Test results will show the quantities of CO (carbon monoxide), HC (hydrocarbons), and NOx (nitrogen oxides). HC+NOx are not allowed to be greater than 90 g/KW-hr and CO must be lower than 275 g/Kw-hr [8].

$$E = \left[\frac{(HC+NO_x)-15}{150}\right] * 100 + \left[1 - \left(\frac{CO}{400}\right)\right] * 100 \geq 100 \quad [1]$$

The quantities of each are used in the formula [1] to calculate the team's emission number, where the emission number (E) must exceed 175. The emission number for each team will be used to calculate their final score. The method of reducing the emissions will be with the use of fuel and ignition tuning of the snowmobiles ECU.

Fuel Economy

In addition to the emission test, the fuel economy and endurance of the snowmobile is an important team objective. The team's goal has been to make a system that can use ethanol blended gasoline. This blend ranges from a 0% to 85% mixture. This change in fuel requires a change in fuel mapping, which allows for a change in the fuel economy of the sled. This year the team's approach was to use the stock ECU in conjunction with a Power Commander tunable fuel injection module. A GM Flex Fuel sensor was also added to allow real-time compensation for the range of ethanol blend.

Each team will compete in an endurance event that will require the snowmobile to operate on a groomed trail for 100 miles. Every snowmobile will follow and maintain progress of the assigned trail judge. The trail judge can also disqualify a team from the event if the snowmobile does not maintain the steady pace of up to 45 mph. The teams that complete the endurance event will initially receive 100 points, and then be awarded additional points based on their energy consumption compared to the rest of the field [8]. The fuel economy improvement will be achieved via the engine tuning.

Snowmobile Design

Snowmobile Selection

The NIU Clean Snowmobile team members met and discussed possible candidates that would allow for success in multiple categories; exhaust noise, exhaust emission, power to weight ratio, fuel efficiency and capability of running Isobutanol based fuels. The final decision was made to utilize the twin cylinder, two-stroke 599cc Polaris Indy. This snowmobile is one of many currently on the market that works well on both the trails as well as off trail riding. This model shares many parts with other current Polaris snowmobile models, which allows for a plethora of available parts.

The original engine used the Polaris "Clean Fire" system, as well as variable exhaust valves and a two injector fuel system. The factory settings are designed for either non ethanol or 10% ethanol blend. The motor we are running operates using the standard two cycle combustion cycle. In the case of modern snowmobiles, four-stroke engines are becoming more prominent. A four-stroke engine tends to last longer than a two-stroke and can be more reliable, however they are more expensive to make and maintain. We decided to keep the two-stroke engine that comes with our model snowmobile. Our intentions are to improve upon the current two-stroke engine and prove that it is a viable option for snowmobile manufacturers.

Big Wheel Kit

The NIU Clean Snowmobile team is making a modification to the drivetrain that includes adding a larger rear wheel to the skid. The larger rear wheel is designed to increase the fuel efficiency of the snowmobile by reducing the rolling resistance of the track, therefore losing less power from the engine due to friction.

In order to add this larger rear wheel to the stock snowmobile, some modifications had to be made. The first modification was to add a longer track in order to accommodate the larger rear wheel. Next, and most importantly, was to relocate the rear axle in order to maintain tangency between the bottom of the skid and the rear wheel. The rear axle location also had to be moved backwards (away from the snowmobile) in order to accommodate for the longer track. In order to move the axle location, a bracket was designed to bolt into the factory

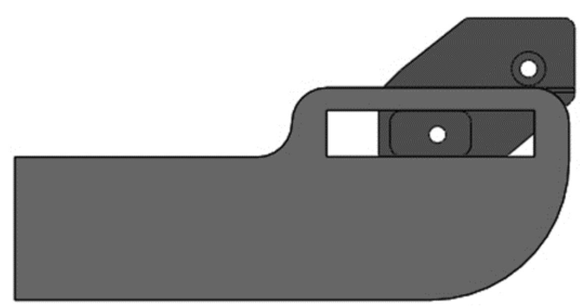

Figure 1.1: Mock Skid (light grey) and Relocation Bracket (dark grey)

axle location on the skid while creating a new location for the axle. This bracket can be seen in dark grey in Figure 1.1. The bracket was designed in such a way that the stock track tensioner remained fully functional in its original location.

Because the stock axle location was moved up and away from the original axle location with the bracket, a twisting moment was created around the stock axle mounting location. The reaction forces in the system can be seen in Figure 1.2. It is pertinent to the structure of the snowmobile and the safety of the rider that this bracket does not impose any significant possibilities of failure during its use. The goal of the design was to prove that the factor of safety is greater than 2.0 for the bracket and the skid.

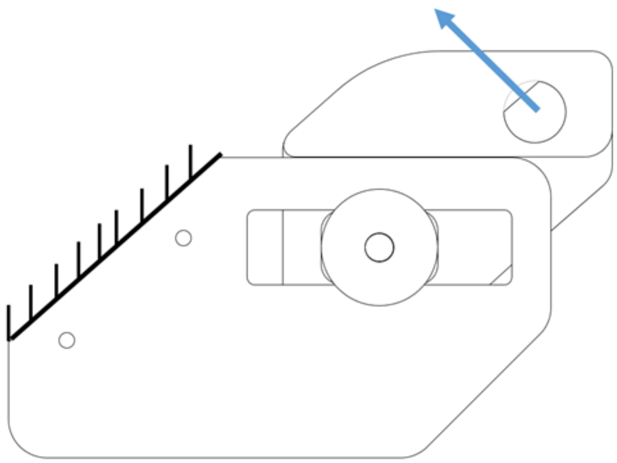

Figure 1.2: Reaction Force on Relocation Bracket

After the bracket was fabricated, the big wheel kit was installed on the 2015 Polaris Indy. In order to reduce possible damage to the wheels, the wheels were powder coated in a thick plastic paint. This ensured that the wheels would maintain their integrity, even with studs installed in the track.

Figure 1.3: Big Wheel Kit on Polaris Indy

Catalytic Converter

For the 2017 CSC Competition, the NIU team embarked on the challenge of incorporating a catalytic converter to the exhaust chain of the snowmobile to reduce emission of harmful gases and unburnt fuel. The team came to the decision to include a three-way catalytic converter designed in collaboration with Emitec and BASF. Ideally, the catalytic converter will intake harmful emissions which will react with the substrate and be expelled as mostly water and carbon dioxide.

The main focus of the design was to provide minimal flow restriction from the expansion chamber into the catalytic while also maximizing flow dispersion through the converter so that the flow would not be overly concentrated within the converter. The secondary design parameters were to make it easy to replace the catalytic converter if need be and to be as light and compact a design as possible so that it could fit within the current body panels of the snowmobile and minimize added weight to the snowmobile.

During research, a consumer product was found that drastically simplified the design process. The current mount is based off of an after-market muffler for the Indy series of snowmobiles called a Trail Can. It was originally intended to improve performance over the stock muffler.

Observing the geometries of the product, it was found that the inlet section of the muffler would be a perfect base from which to fabricate the new mount. The inlet pipe is 2 inches in diameter which then expands to a 4-inch pipe for the original muffler housing and then reduces back down to a 2-inch diameter. Essentially the area that was once the housing for the muffler components became the housing for the catalytic converter. V-Band mounts were added to the bottom of the inlet tubing of the trail can allowing for a simple mounting system for the catalytic converter. The outlet pipe section of the trail-can was then retained to be used as the outlet pipe for the catalytic converter.

This mounting assembly proved to be lightweight and compact while also providing little disturbance in flow through the exhaust path.

Noise Reduction

The noise that is emitted by a snowmobile can be substantial. In order to eliminate the most noise the team decided to add an additional muffler into the exhaust system to help reduce the sound levels. The objective test is a SAE J1161 set by the National Park Service Winter Ruling. Each snowmobile cannot produce more than 67 dB.

In order to achieve that sound profile of 67 dB, a new muffler was designed by the team. The major focus of the design was to keep it as open as possible. The team did not want to risk excess flow restriction by closing off piping like some muffler designs do in an effort to further disperse gases into different section of the muffler however during testing it was decided to close off certain tubes to direct flow.

This muffler design is combination of a typical packed muffler and a modern baffled muffler design. The flow path starts in a triple split flow consisting of three perforated tubes of equal diameter to maximize exhaust dispersion across sound dampening material. The two smaller diameter tubes are blocked at their outlets while the larger diameter tube is blocked at its inlet to force gases through the packing material. Fiberglass sheets were used to wrap the perforated tubing and fiberglass packing was used to fill in the rest of the area around the perforated tubing. This configuration and flow path (indicated by red arrows) can be seen in Figure 1.4.

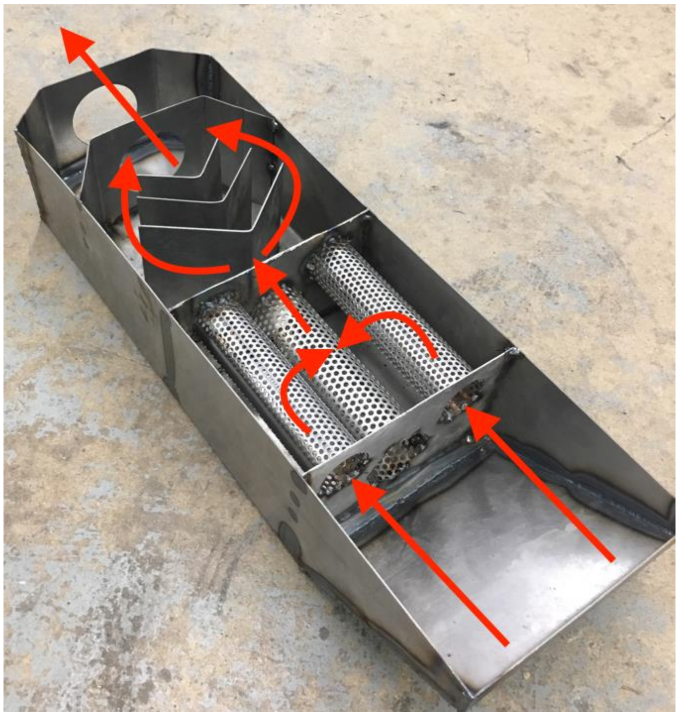

Figure 1.4: Initial Muffler Construction with Flow Path

This exhaust path is followed by a "triple delta" configuration of baffling. This design allows the sound waves to split around the deltas causing areas of substantially lower pressure behind the delta plates. This lower pressure creates a scavenging effect which should significantly reduce the backpressure of the muffler. In similar muffler designs, some have theorized that the Venturi effect may be taking place between the gaps in deltas like this and maybe the root cause of these areas of lower pressure [6].

The final area acts as a resonating chamber to further scatter pressure waves upon exit and to ensure proper exit flow.

Aside from the addition of a new muffler, the team has switched to the Camso Ice Attak XT track which features built in picks in stead of picks mounted in drilled holes within the track. This was a needed modification due to the placement of the picks on the previous track which happen to run along the big wheel kit's path causing unnecessary metal on metal contact. The new track will reduce noise and wheel where compared to the previous track.

Real Time Ethanol Compensation

An important factor in the 2016 SAE Clean Snowmobile Competition is the fuel of choice. Since all teams will be given a fuel mixture that consists of 0% to 85% ethanol, it is pertinent that our snowmobile be ready for the entire range. This was accomplished addition of a Power Commander V piggy-back system to the stock ECU. This setup allows for full modification of engine parameters, including fuel injection and ignition timing.

The addition of a GM flex fuel sensor allowed for monitoring of the ethanol content of the fuel. The GM flex fuel sensor outputs a frequency, which the Power Commander V is not capable of reading as an input. A Zeitronix ethanol content analyzer is used to convert the frequency from the flex fuel sensor and convert it to a 5-volt analog signal.

The Power Commander V was programmed to linearly alter the fuel values based on the 5-volt analog signal from the Zeitronix ethanol content analyzer. The amount of fuel correction depends on the ethanol content determined by the flex fuel sensor. The exact same approach was taken for the ignition correction, which helps to advance timing depending on ethanol content.

Handling Improvements

The factory setup sled performed well in handling, while also offering the rider a great deal of control over the machine in most snow conditions. The areas that the team felt required improvement of the factory setup were that of the skis, carbides, brakes, and the track. The factory skis were replaced with a set of C&A Pro TRX skis. These skis offer improved steering control in loose snow conditions due to the shape. The skis also retained the factory weight. With the new skis Woody's Trailblazer 6in carbides were also added. These carbides provide increased steering control on hard packed and icy conditions.

Testing

Big Wheel Kit Analysis and Results

For this experiment, it was necessary to mount the bracket in a manner similar to its attachment on the snowmobile. To do this, a model of the snowmobile's skid was machined. This also allowed for the mock skid to take the place of the full skid, which is over four feet in length. Since the main focus of this experiment was the rear of the skid, it was not necessary to have the entire skid. Creating the mock skid allowed for a much simpler experimental set up. The mock skid and bracket assembly is seen in Figure 2.1. This assembly not only simulates the make-up of the parts, but also allows the force to be applied in the proper direction by hanging dead weight from the new axle location, as shown in Figure 2.2.

Part of this experiment was to include Finite Element Analysis (FEA) as well as strain analysis on this mock skid to ensure the entire skid-bracket assembly would withstand the maximum force. The possibility existed of increasing strain on the skid with the big wheel modification. Three separate strain gauge rosettes were used for the experiment; one on the bracket and two on the mock skid. Placement of the gages can be seen in Figure 2.1 and Figure 2.3.

Figure 1.1: Experimental Setup for Relocation Bracket

Figure 2.2: Rosette Strain Gauges on Mock Skid

The locations of gage placement were chosen due to their high strain concentrations. It is of note that the highest strain concentrations in this experiment are located at areas such as radii and inside corners. However, these were not practical areas to adhere strain gages due to the interference of the mated parts as well as routing of the wire bundles.

A Finite Element Analysis (FEA) was completed in SolidWorks 2014 to establish a predicted outcome of the experiment. The mock skid and relocation bracket were modeled and assembled in the software. Since the scope of our experiment focused on the relocation bracket and the skid at the local point, it was decided to model only the section of the skid

Figure 2.3: Rosette Strain Gauge on Relocation

that is in close proximity to the original axle mounting location. The force was applied according to the reaction force shown in Figure 1.2. The point strains for rosette gauge 1 and rosette gauge 2 at all simulated forces were recorded in order to have an accurate comparison to the experimental values.

It was determined that the design of the relocation bracket was safe and would withstand the maximum subjectable force of 500lb. Figure 2.4 shows a relatively uniform factor of safety calculated from the FEA, with a minimum factor of safety being 2.7. Also, the maximum stress was calculated at 15.5 ksi, which is well below the yield stress of the 6061 T6 aluminum, which is 42.0 ksi. This data gave confidence to the assumption that the assembly would not reach the yielding stress.

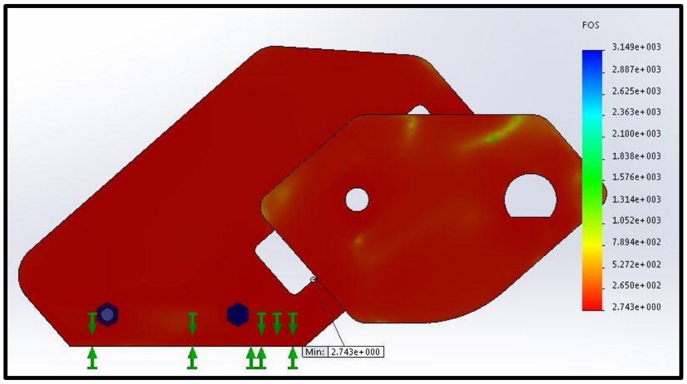

Figure 2.4: FEA Factor of Safety at 500 lbf

After the physical experiment was conducted, the next step was to calculate the first and second principal strain present for rosette gauge 1 and 2. The principal strain was calculated by using the relationships of Mohr's circle. Since the maximum experimental load was 300 lbf, and given that the strain relationship is linear to the force applied, a linear estimate was calculated for the principal strain for each rosette gauge. This linear estimate was then extrapolated to 500 lbf to produce an expected value of strain. These linear estimates are overlaid on the calculated values of the first and second principal strain for rosette gauge 1 and 2 and presented in figure 2.5 and figure 2.6, respectively.

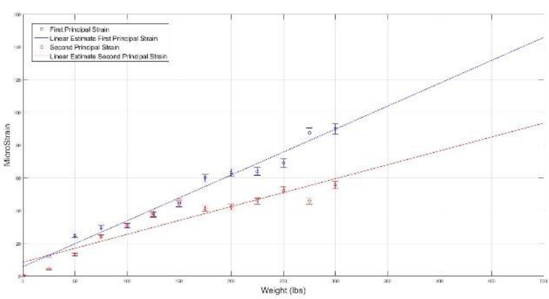

Figure 2.5: Rosette 1 Principal Strains with Linear Estimates

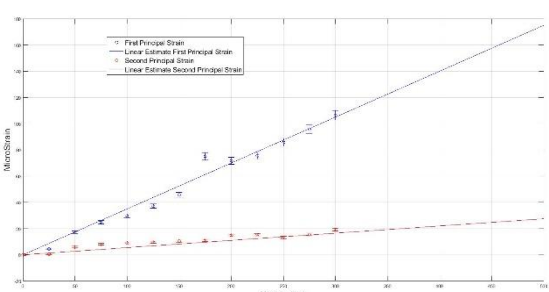

Figure 2.6: Rosette 2 Principal Strains with Linear Estimates

Through this experiment, it was confirmed that the relocation bracket was safe and maintained the desired factor of safety. The experimentally calculated factor of safety was 2.5, while the FEA factor of safety was 2.7. The relocation bracket has been deemed acceptable and provides great value to the big wheel kit as a whole.

Noise Emission Testing and Analysis

Sound is formed from pulses of alternating high and low pressure waves [7]. These waves will vibrate one's eardrum for your brain to interpret. As it goes for most types of machinery, especially snowmobiles, sound is an unpleasant result that should be minimized. This dilemma is one of many arguments for closing snowmobile trails to the public; whether it is environmentalist concern about frightening animals, or land owners displeased with the noise pollution primarily during night hours.

Total sound emissions from the snowmobile are currently measured using SAE J1161 specification [8]. The test calls for the snowmobile to run at 35 mph for 150 feet. The sound emitted from the tail pipe contributes to a majority of the total sound heard and the loudest of the overall sound emitted from the machine. This is caused by the pulsing and expansion of pressure waves from the combustion process.

Sound readings were taken in accordance to the SAE J1161 test. When measured at a distance of 50 feet perpendicular to the test track with the addition of the Glasspack the team was able to get a 9.2% reduction in the sound created by the machine over the factory set up.

Chemical Emissions Collection and Analysis

Chemical emissions were taken from the snowmobile via a Horiba MEXA 584L from a test pipe. The test pipe can be seen in figure 3.1.

Figure 3.1: Emissions Test Pipe

The probe was placed "seven diameters from the point in which the exhaust exits into the atmosphere is to prevent back pulses from reaching the sample probe". [8]

Emissions data was recorded for the stock snowmobile and can be seen in the appendix. The main area of focus was to compare the emissions with the stock exhaust gasoline tune, the stock exhaust ethanol tune and the gasoline tune with catalyst added. The raw data can be found in the appendix, while a summary of results can be seen in figures 9 through 11.

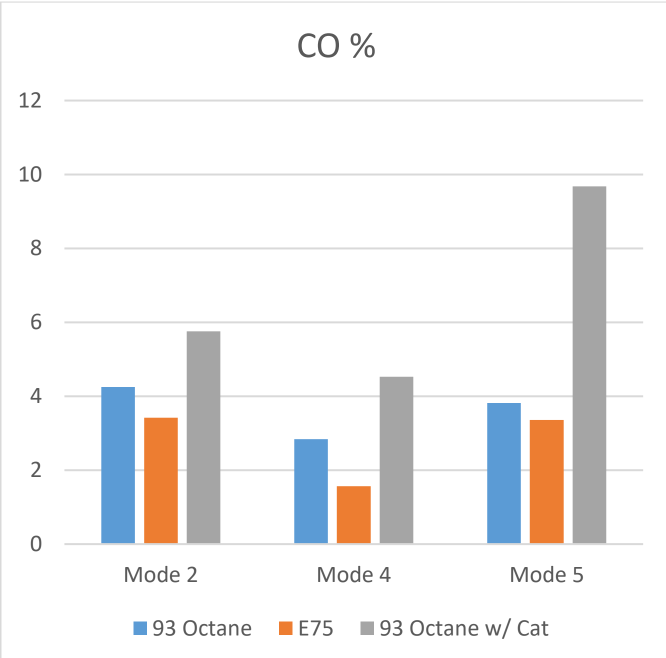

Figure 3.2: CO Emissions

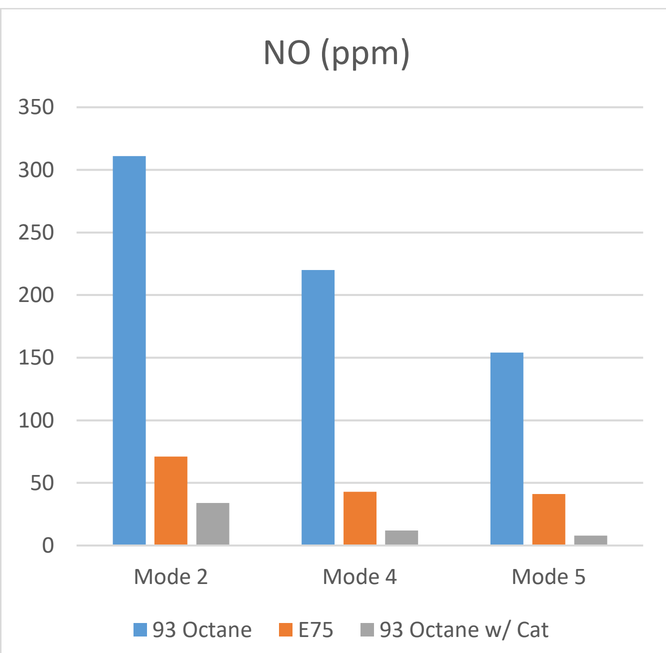

Figure 3.3: NO Emissions

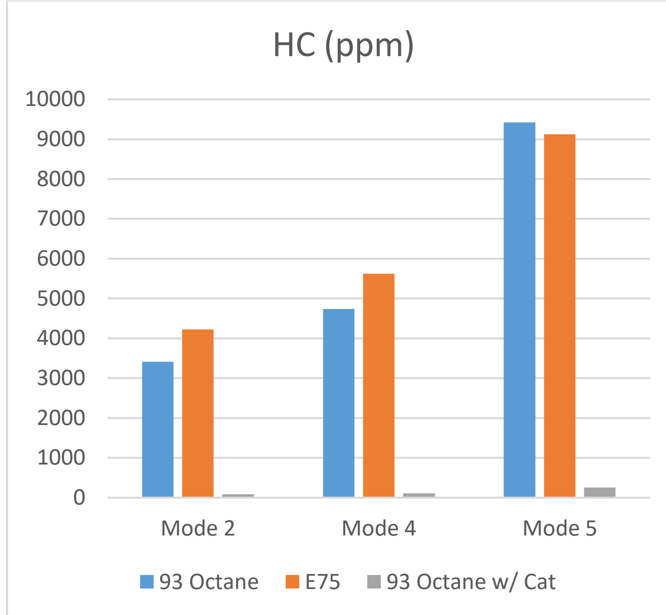

Figure 3.4: HC Emissions

Our data shows that we saw a reduction in NOx and CO. While a reduction in NOx and increase in HC is a natural reaction of ethanol based fuel, it can be shown that the relative reduction achieved by the NIU team is effective for the competition. While other emissions were recorded, the chemicals shown above were the most notable from our experiments.

The figures show that emissions were only recorded in modes 2, 4, and 5. This is the case due to difficulties encountered while operating our snowmobile on the dyno. Given the nature of a two stroke engine, combined with limitations in our equipment, it was not possible for our team to collect reliable data in modes 1 and 3. For that reason, it was excluded from our analysis. It is also of note that our emissions collection was not complete by the time of this paper being submitted. While we are improving our ethanol tune, we will also be taking more emissions data with the hopes of seeing a higher reduction in HC. Final results will be measured at the 2016 Clean Snowmobile Competition.

Consumer Appeal

All of the modifications on NIU's snowmobile can be applied to most current snowmobiles on the market. With rising prices in oil affecting prices at the pump, consumers are looking more toward fuel efficient engines, as well as practical alternative fuels, without having to sacrifice performance. Enthusiasts not only look for these qualities, but also for comfort, maneuverability, and a smooth-riding suspension. Snowmobile design is constantly changing. Innovative ideas are continually being used to increase both fuel efficiency and performance. Snowmobile designers are constantly attempting to maximize all of these factors to make their snowmobile the most attractive to consumers, which is exactly what the Northern Illinois University Clean Snowmobile Team has done.

The Northern Illinois University Clean Snowmobile Team has designed a snowmobile that best fits the qualities that are highly sought after when enthusiasts consider making a purchase. Speed and maneuverability were factors when designing the team sled; however these were not the only considerations. Other factors were the continuing threats of banning snowmobiling of popular snowmobile destinations, such as Yellowstone National Park, due to harmful environmental impacts related to the sport of snowmobiling. With these considerations the team was able to make a snowmobile that is both environmentally friendly, as well as high performance.

The sled was designed to provide a high performance, efficient, and user-friendly alternative to the currently available market of snowmobiles. The consumer would be able to maintain the ride-ability that current sleds offer, while producing less harmful emissions and sound output. The use of pre-existing parts reduces the need for new parts to be designed or manufactured.

Cost Effectiveness

The MSRP for the snowmobile designed by the Northern Illinois University team is $9,542.90. The modified 2014 Indy 600cc snowmobile designed costs $1,143.90 more than a 2016 factory model from Polaris. Many of the parts were sourced direct from the manufacturer or second hand. The design changes that were made would help the consumer see cost savings with certain components. The modifications to the snowmobile are reasonably priced and any consumer can install most of them at home with relative ease. The modifications will also improve the fuel economy, which will save the consumer money at the pump. Therefore, the final price of the NIU's clean snowmobile is a reasonable price for the overall quality of the snowmobile and the benefits it presents to its rider.

SUMMARY/CONCLUSIONS

The SAE Clean Snowmobile Team at Northern Illinois University re-engineered a snowmobile for a quieter sound profile and cleaner exhaust emissions. Throughout the year prior to the competition, the team has designed, tested, and modified a snowmobile to the best of our capabilities with the resources at hand. It is a cost efficient snowmobile that keeps customer appeal, rider safety, and practicality in mind.

The average consumer in today's economy desires fuel efficiency and lower emissions in their motor driven vehicles, and this machine is no exception.

With the incorporation of a catalytic converter the team has presented a snowmobile that can be operated on a clean and renewable fuel with substantially lower chemical emissions than the snowmobiles on the trails today. By incorporating a well designed muffler system, the team has been able to keep the snowmobile well within the limits of acceptability for trail use.

The NIU Clean Snowmobile team holds a firm belief that humans are made better by spending time outdoors and that striving to experience nature whenever possible is a goal that every person should try their best to achieve. It is the team's hope that their innovations in this field as well as other team's contributions throughout the course of this competition are able to keep this motorsport alive for generations to come. In an era where some may question the fate of internal combustion vehicles, the team aspires to help keep these vehicles relevant as the modern landscape of snowmobiles continues to evolve.

References

1. American Lung Association. "Clean Fuels." Clean Air Choice. Accessed October 13, 2013. http://www.cleanairchoice.org/fuels/.
2. Duret, Pierre. New Generation of Two-stroke Engines for the Future. N.p.: Technip Editions, 1993.
3. International Snowmobile Manufactures Association. Accessed September 22, 2013. http://www.snowmobile.org/.
4. Lydecker, Ryck. "Alcohol & Boat Engines, is there another way?" BoatU.S. Last modified December 2011. Accessed February 16, 2014. http://www.boatus.com/magazine/2011/december/affairs.asp.
5. Smith, Phillip H. Scientific Design of Exhaust & Intake Systems. N.p. : Bentley Publishers. 1971. Reprinted in 2006.
6. Flugger, Ray T. Muffler with Intermediate Sound-attenuating Partition and Method. Ray T. Flugger, assignee. Patent US5444197 A. 22 Aug. 1995. Print

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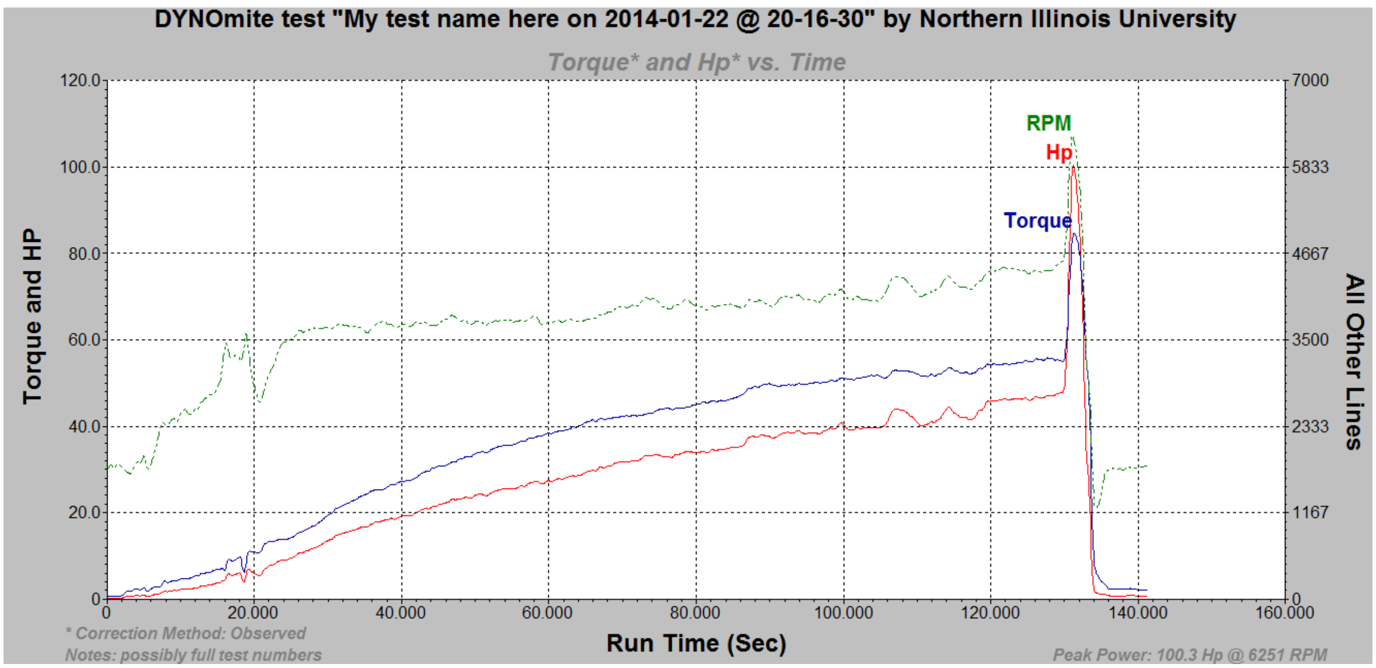
APPENDIX



Dyno Test for max power