Re-Engineering a 2007 Yamaha Phazer for The Clean Snowmobile Challenge 2009

Northern Illinois University

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Abstract

A 2007 Yamaha Phazer has been chosen to be re-engineered to compete in the Clean Snowmobile Challenge 2009. The objectives of the competition were to modify a snowmobile to increase its performance while lowering it's exhaust and noise emissions. Each snowmobile will be tested and analyzed against the EPA 2012 emission standards. The design will also take rider comfort, cost effectiveness, and costumer appeal into consideration. The stock Yamaha engine management computer was replaced with a custom tuned unit in order to accommodate the rules for the 2009 competition. The exhaust system was modified by adding a catalytic converter and a turbo for increased performance and efficiency. All modifications were done to accompany the requirements to run on ethanol blended fuel, or "flex-fuel".

Introduction

Snowmobiles have been creating winter recreation opportunities for many decades. More recently the increase in snowmobiling activities has raised many issues. The combustion of fossil fuels by snowmobile engines raises environmental concerns in terms of air and noise pollution. Often snowmobiling takes place in and around environmentally sensitive areas, such as state and national parks. This negative impact on the environment has created new objectives for college students [1].

The SAE (Society of Automotive Engineers) Clean Snowmobile Challenge 2009 is an engineering design competition aimed to test the capabilities of college students from different universities around the world. The competition challenges the students to modify an existing snowmobile to compete against one another.

The snowmobile will be tested for improved exhaust emissions and reduction of noise as well as events that will challenge the snowmobile in a variety of customs. The events will take place over a period of six days; testing fuel economy, marketability, and overall performance of the snowmobile [2].

Team History

The SAE Clean Snowmobile Team at Northern Illinois University is currently in its second year. The program started in the hands of four mechanical engineering students as a senior design project. The initial idea was to convert a snowmobile engine to run on E85, lowering its emissions. It then turned into the footing for the NIU SAE Clean Snowmobile team. At our inaugural competition last year, the team performed quite well for their rookie competition. The team placed sixth overall with individual results of:

Objective Handling: 2nd
Cost Analysis: 3rd
Fuel Economy: 4th
Acceleration: 4th

The team is now one of multiple SAE affiliated teams at NIU. It is completely organized and managed by the students with the assistance of an advisor and the College of Engineering and Engineering Technology. All funds for this project have been raised by the team from local donors, commercial sponsors, and the College.

Team Objectives

Reduce Exhaust Emissions

The Team's primary objective is to lower the exhaust emissions. A five mode test will be conducted to verify that each snowmobile complies with the 2012 EPA standards. Table 1 clearly identifies each mode and corresponding categories.

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

Table 1: 5- mode emission test cycle

The test results will show the quantities of CO (carbon monoxide), HC (hydrocarbons), and NOx (nitrogen oxides). HC+NOx can not be greater than 90 g/Kw-hr and CO must be lower than 275 g/Kw-hr [2]. The quantities of each are used in formula to calculate the team's emission number, where the emission number (E) must exceed 100. The emission number for each team will be used to calculate their final score. Below is the engine emission formula.

$$E = \left[1 - \frac{(HC + NOx) - 10}{150}\right] \times 100 + \left[1 - \left(\frac{CO}{400}\right)\right] \times 100 \geq 100$$

Figure 1: Engine Emission Formula

Fuel Economy

In addition to the emission test, the fuel economy and endurance of the snowmobile is an important team objective. 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 set pace of 30 mph to 45 mph. The teams that complete the endurance event will initially receive 100 points, and then be awarded addition points for their energy consumption compared to the rest of the field [2].

Noise Reduction

The noise emitted from a snowmobile can be substantial at times. This objective for the team was to reduce or eliminate as much noise from the snowmobile as possible. There will be two types of tests that are performed; objective and subjective noise tests. The objective test is a SAE procedure J192 sound pressure test set by that the International Snowmobile Manufacturers Association. Each snowmobile cannot produce to an excessive degree of 78dBA [2]. Passing this test will present an opportunity for the subjective noise test. During the process of the subjective noise test, the recording of the snowmobile will be played to a blind jury, who will then evaluate the most favorable snowmobiles for noise control.

Performance Characteristics

On top of producing a snowmobile that is cleaner for the environment, teams are challenged with the objective of maintaining or improving its performance characteristics. These characteristics range from its power to control and handling. There are two events that will help expose the differences in performance between each team's snowmobile. Those events are the acceleration and the control and handling event. The acceleration event will test each snowmobile from a standing stop to the maximum speed it can reach in 500 feet. The teams will take the best time of two runs, and the elapsed time must be no more than 12 seconds [2]. Also, all snowmobiles will compete in a timed control and handling event. This event will assess the maneuverability of each snowmobile by having them complete two individual laps on a slalom style course. The best lap time will be recorded.

Furthermore, there are other objectives including cost effectiveness, cold start, rider comfort, the design paper, and design presentation that each team will be judged on. Each objective is equally important to the design of a snowmobile, especially the conversion to E85 for the Clean Snowmobile Challenge 2009.

Conversion to Ethanol Blended Fuel

The Clean Snowmobile Challenge brings a different and new engineering objective each year. This year's challenge is to convert a snowmobile engine to run on "Flex-Fuel", or an ethanol blended fuel.

Background Information on E85

E85 has been growing in popularity in the past few years, and is becoming more readily available in many areas. Since E85 is relatively new to the public, there are many myths that can cause confusion. E85 is a mixture of 85% ethanol and 15% gasoline. This alcohol fuel blend has the highest oxygen content of any publicly available fuel, and the reason it burns cleaner than regular octane gasoline [3]. Also, E85 contains 80% less gum forming compounds than unleaded gasoline. It reduces the carbon buildup in the engine which can hurt performance and exhaust emissions.

There are many benefits when using E85 that out-weigh the benefits of unleaded gasoline. The largest benefit is that it is considerably better for the environment. As E85 is burned, it emits tailpipe emissions that contain far less climate altering greenhouse gases. It also has a much higher octane rating than unleaded gasoline, usually 100 to 105 octane. The fuel allows advanced timing for increase in performance. Adjusting for higher compression will lead to greater efficiency and lower emissions. Since E85 is a renewable resource, it will reduce the dependency for oil from other countries as well.

Flex-Fuel Conversion in Snowmobiles

To comprehend the requirements for the conversion to flex-fuel, there must be an understanding of the conversion to E85. The conversion to E85 itself is not very complicated. Since E85 is lower in energy content when compared to gasoline, it requires approximately 30% more fuel to produce the same air to fuel ratio [3]. The fuel system must have the capabilities to supply this added fuel. This requires a fuel pump that produces a higher pressure and larger volume. Also, for fuel injected operations, the injectors will require modifications (i.e. longer pulse width).

Any alcohol based fuel is much harder on a fuel system than unleaded gasoline, especially the fuel tank, fuel lines, and seals. All of the fuel feed delivery lines and many other components in the fuel system were replaced with E85 compatible products. The stock fuel pump was retained as it was capable of producing adequate pressure, but a boost referenced fuel regulator was added.

There are aftermarket E85 conversion kits available that can be wired into many vehicle fuel systems. Conversion kits of this nature are pre-programmed to increase the pulse width of each fuel injector. Alternatively, they do not allow for adjustments that should be made to run an engine efficiently on flex-fuel. Given this information, an alcohol sensor integrated with a programmable ECU is needed for all modifications to the fuel delivery system.

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-weight ratio, fuel efficiency, and ability with ethanol based fuels. The final decision was made on the 499cc Yamaha Phazer. The snowmobile is one of the lightest on the market today, and has the smallest length track offered, allowing it to maintain its slim unique nature.

The Phazer engine is a parallel twin, odd fire, four-stroke motor with Electronic Fuel Injection. Being a four-stroke with a high compression ratio of 12.5:1, it will allow for easy conversion to ethanol fuel [1]. As stated briefly before, ethanol based fuel requires a higher compression ratio to provide sufficient ignition to the higher octane ratings of the ethanol. Since the engine operates with the Electronic Fuel Injection (EFI), a MegaSquirt ECU was used in order to adjust fuel curves, timing, and make decisions based on the output of an inline alcohol sensor. Being able to adjust the fuel curve is a crucial requirement, since CSC 2009 will require teams to operate their snowmobiles on different types of mystery ethanol blends.

This engine has a baseline of 81 horsepower and can reach in excess of 12,000 revolutions per minute. However, the level will be reduced by as much as 34% due to the E85 fuel and increased resistance from a quieter exhaust system [3]. We compensated this loss of power by adding a turbo charger. The turbo charger will increase the pressure of the intake air by approximately 10psi (often referred to as “pounds of boost”).

Ethanol based fuels pose challenges for cold weather starting as the vapor pressure is too low to provided sufficient surface area for combustion. To remedy this, the fuel curves in the MegaSquirt were adjusted to add extra enrichment when the engine (water) temperature was low [3].

Engine and ECU Modifications

New rules for the CSC 2009 have forced teams to run a more advanced Engine Control Unit (ECU). In previous years the ethanol fuel at the CSC competition was winter blend E85, or E70, throughout the entire competition. For the CSC 2009 competition teams will not know the ethanol content of the fuel, only that it will range anywhere from E10 to E85 winter blend at any point in the competition. This requirement is a realistic expectation for any snowmobile that would be labeled “flex fuel,” but it does add considerable requirements to the engine.

The Engine Control Unit (ECU) must do the following: recognize the alcohol content of the fuel, increase the amount of fuel to the engine appropriately, advance the timing appropriately, and limit the amount of pressure coming from the turbo. It was determined the stock ECU would no longer be a practical solution given that the stock ECU was never designed to perform any of the previously mentioned tasks. In its place a MegaSquirt II ECU was chosen.

The MegaSquirt II is an open source ECU that is widely available and customizable to virtually all applications. Given its sub $400 price point and highly customizable nature, it was considered to be the top choice for the NIU team. The MegaSquirt II is capable of reading a frequency based alcohol sensor and adjusting the injector pulse width and ignition timing according to the alcohol content of the fuel. Once the fuel and timing curves have been determined for E85 and E10, the ECU interpolates along a linear curve to run the appropriate fuel and timing values for any fuel in between.

The MegaSquirt II has also been modified to output this alcohol signal to a boost controller which will allow the turbocharger boost pressure to vary according to the alcohol content. This was an important consideration because the NIU Clean Snowmobile team still has the stock compression ratio of 12.5:1. With this compression ratio it would be difficult to increase cylinder pressures without engine detonation. Now the ECU will allow higher turbo charger boost when running E85, but limit pressures when running on E10. This is accomplished by installing a boost controller that will control the amount of vacuum applied to the turbo chargers variable vane actuator.

Alcohol Sensor

The Megasquirt ECU has an auxiliary input for a fuel composition sensor. This allows the ECU to correct fuel and timing maps based on the percentage of ethanol in the fuel being consumed. For our snowmobile, we used a stock GM fuel composition sensors found on many of their production vehicles with the GM part number being 12570260.

The sensor its self is very simple, it is placed in line with the fuel feed line and outputs a signal varying from 50 to 150Hz, with 50 Hz representing fuel with 0% ethanol content and 150Hz representing fuel with 100% ethanol content. The sensor also outputs a pulse width used to tell the temperature of the fuel going into the engine. The range of pulse widths is from 1 to 5 milliseconds, with 1 millisecond representing -40degrees C and 5 milliseconds representing 125degrees C. This allows the tuner to scale the fuel and ignition tables accordingly to any combination of ethanol and gasoline. When the ethanol content is raised, the injector output time is lengthened in milliseconds as well as advancing the ignition timing to take advantage of the higher octane rating in ethanol.

Figure 2: Picture of alcohol sensor

Addition of Turbocharger

The Team decided to adapt a turbocharger to fit the 499cc Yamaha Phazer 4 stroke engine. As previously stated, in stock form the motor produces 81hp at 11,570rpm. The low performance specifications would have had the negative effect of placing high in select events. A turbocharger is the ideal way of increasing power while maintaining the equal or better engine efficiency.

Choosing the correct turbo for a specific application can be quite difficult and time consuming. Essentially you need to know the amount of air your engine requires as well as how much more air is required to force in based on your desired boost pressure, in our case 10psi. After all this information is calculated, you can then select a turbo based off the compressor map attached in Appendix A.

In order to plot a compressor map, the points from the calculated data were used. The most important data is the flow at 12000rpm, which is red line, the flow at 9500rpm, which is max torque, and flow at 5000rpm for our initial desired boost. The desired boost for this calculation was also 10psi for our application which nets us a pressure ratio (PR) of 1.68. From there we find the flow rates to correspond to 61 cfm, 119cfm and 145cfm respectively to the previously stated rpms, at a (PR) of 1.68. After plotting these points on the compressor maps available from Aerocharger we selected their 53000 90 series, since it was a perfect match for the 499cc Phazer.

The peak horsepower was then needed to choose the height of the compressor and turbine vanes. Since we were transforming our Phazer from 80hp to 130hp, the later number was used since that would be the output with the turbo. The height was decided to be .200in on both compressor and turbine vanes to match the turbo for our specified output. All of our plotted points ended up in the 76% efficiency range on the compressor map, giving us an optimum setup that will be very efficient.

There is negligible power loss associated with running a turbo since it uses exhaust gases to drive the impeller that pressurizes the air entering the motor. Turbochargers convert exhaust pressure and heat energy into mechanical energy to pressurize the intake mixture. It is similar to a supercharger only there is no parasitic loss that is associated with belt driven superchargers. The stock Yamaha motor has high compression which prevents us from running excessive boost, since detonation would most likely occur. The Team opted not to lower the compression since it would negatively impact our engines efficiency and fuel economy, particularly while running on lower alcohol content and lower boost. Below is the Aerocharger Turbo used in the 2009 challenge.

Figure 3: View of the Aerocharger Turbo

The decision was made to use a turbocharger from Aerocharger, a company through Hi Performance LLC. Their turbochargers have several advantages over traditional automotive units. They have a self contained oiling system, which allows for a simple and clean installation. This means the routing of oil feed and return lines from the oil system to the turbo are not required. Another concern of ours was the amount of oil "blow by" that exists in conventional turbochargers. This oil enters the engine thus increasing the exhaust emissions when burnt. With Aerochargers self contained oil system, there are very small amounts of oil leakage, which will help reduce particulate emission.

The Aerocharger turbochargers also have minimal internal friction on the impellers and shafts. This low friction is due to theuse ceramic ball bearings on both the compressor and turbine shafts, and an internal oil mist (rather than an oil bath) on rotation components. In addition to the ball bearings, Aerocharger uses variable vane technology in their turbos. The variable vanes technology allows the internal vanes to be operated from an external actuator that senses vacuum from the intake manifold. The actuator is simply a diaphragm that senses manifold vacuum and then translates this linearly through a rod to the variable vanes. There is virtually no turbo lag since the vanes allow the turbine shaft to start rotating earlier and with less exhaust flow than non variable vane units. Once the compressor reaches the desired boost level, the vanes will maintain a constant angle and the compressor's output level will reach a peak value. Figure 4 is a cut away section view of the Aerocharger Turbo.

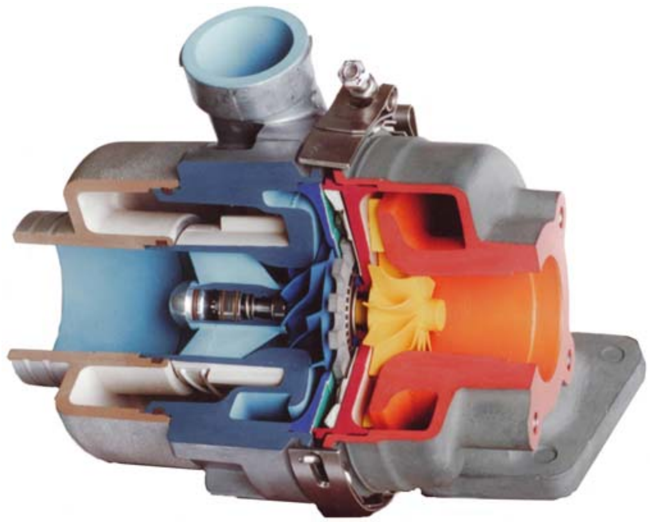

Figure 4: Section View of the Aerocharger Turbo

The first step to designing the turbo kit is to find a desirable mounting location. The turbocharger should not be in close relation to the gas tank, but not so far away as to lose efficiency. The decision was made to mount it on the outside frame adjacent to the engine. All of the header tubing is wrapped with Kevlar header wrap so the maximum amount of heat will remain in the exhaust, which allows for more heat to be transferred to the turbo. The expanding exhaust gas spins the turbo, and the higher temperature exhaust expands the air more, thus creating a more efficient turbo. The exhaust wrap will also reduce the amount of heat that is given off by the exhaust, which allows us to route it closer to objects that should not be exposed to high temperatures.

Exhaust Design

The addition of a turbocharger to the Team's snowmobile created problems for the exhaust system. Issues with the exhaust designs include accommodation of a turbocharger in to the exhaust system and fitting a catalytic converter and mufflers within the remaining space. All of these considerations must be taken in to account while maximizing efficiency and minimizing harmful emissions and noise.

As stated previously, the placement of the turbocharger itself was not that complicated. Given the base body of the sled, the most convenient option was right side of the snowmobile, aligned with the exhaust manifold. This design left enough clearance in the rest of the engine compartment and utilized the available space efficiently by creating direct pathways for the piping, from the turbo to the rest of the exhaust and from the turbo to the intake box. Each exhaust manifold runner was created with equal length and mandrel bent to maximize flow and efficiency. The equal length runners allow for a better exhaust scavenging, and even exhaust flow. This is so there are no high pressure and low pressure waves. This design provides the most efficient flow with the least pressure drop to spin the turbocharger. The turbo manifolds were made from ¼" mild steel flanges and 16 gauge - 1.5" mild steel tubing. For the turbo downpipe, 16 gauge - 2" mild steel tubing was chosen.

The other issue involved the fitment of the catalytic converter and the muffler. The exhaust system after the downpipe consists of a catalyst, fiberglass packed muffler, and a chambered muffler. The catalyst was donated from Aristo Catalyst Technologies. It is a 3.38 inch diameter x 3.5 inch foil length three-way honeycomb catalyst designed for four-stroke engines. It can be referenced as an Advanced TWC Pd/Rh catalyst, but due to proprietary information, the exact chemical composition of the catalyst cannot be disclosed. The catalyst contains a 2" to 3.38" conical reducer to connect the downpipe to the catalyst.

Figure 5: Side and Front profile of Catalyst

The addition of the turbocharger makes the exhaust gas hotter than naturally aspirated motors, and could burn the catalytic converter, rendering it useless. After careful consideration and reviewing of testing results from last year, the decision was made to modify the 2008 design and place the catalytic converter before both of the mufflers. Placing the high flow catalytic converter before the muffler maintains the efficiency of the catalytic converter while maximizing the exhaust efficiency.

After the catalyst we made a reducer from 4" to 2.5" which enters a 12" long fiberglass packed muffler with 2.5" straight throat perforated tube, surrounded by fiberglass packing. The overall case diameter is 4'. Following in series with the first muffler is an additional custom muffler. The muffler is a simplified design that helps reflect the sound waves off each-other, canceling many of the waves out, and reducing the noise initially emitted [7]. It is a multiple chamber design that uses the absorption method of having multiple holes in a directional pipe, or diffuser tube, and wrapping the pipes with long strands of fiber-glass. The absorption method is used to eliminate different types of frequency waves [8]. A more in depth look into noise cancellation can be found in *Noise Emission Testing and Analysis.*

Air Intake Box

Air boxes, which were originally used to help keep dirt and other substances out of the throttle body, have had a much larger role since the 1970's. That role is to reduce noise coming from the intake of the engine after the U.S. government has recently published the 2012 noise standards for snowmobiles [10].

Due to the implementation of the turbo, the stock air box from the Yamaha Phazer is not going to be used. After the decision was made on the location of the turbo, it was decided to place the air box in an open area behind the radiator. This area is large enough to put a sufficient size air box to optimize the airflow into the turbo without significantly reducing the radiator flow. The outside of the air box is constructed out of sheet aluminum alloy 3003. This material was chosen over plastic due to being an easier material to work. 3003 aluminum alloy is well suited for the air box design because of its strength, formability, corrosion resistance, as well as having the ability to yield without deformation or cracking.

The air box internal structure consists of baffling to help reduce the noise output from the intake of the engine. The noise coming from the intake is caused from the intake stroke of the motor. When air is brought into the engine, it emits a low pressure pulse which causes a loud roar.

Since aluminum is far from being a perfect sound absorber, an additional step taken to help reduce the level of sound from the air box is having the air box interior lined with skinned polyether-based polyurethane foam. The natural skin that forms on the foam when it is processed helps to resist dust, dirt, and water. The other reason this material makes a good liner for the air box is its ability to absorb sound. The inside walls of the air box are lined with foam which is 0.5" thick having a noise reduction coefficient of 0.3. The baffles along with the areas around intake air entrance are lined with 1" thick foam having a noise reduction coefficient of 0.75. The noise reduction coefficient ranges from 0 for no ability to absorb sound, to 1 for the best sound absorbing material possible. The air entering the intake box will be coming through bell-mouthed horns. Both the top and bottom of the air box are held on with draw latches, making the interior of the air box accessible from both ends for any needed adjustments or repair [4].

Belt Drive

The NIU Clean Snowmobile Team wanted to concentrate on the noise and weight aspect of snowmobiling this year. A decision was made to try to incorporate a belt drive system in place of the chain case. By replacing the chain case with the belt drive, there is an elimination of metal on metal contact, thus eliminating much of the drive and jack shaft noise that is usually created by the chain case. Two gears were manufactured from 6061-T6 aircraft grade aluminum. The choice of material came from its high ultimate tensile strength mechanical properties, and it is light weight when compared to other types of steel.

Due to the unavailability of a dedicated gear analysis software package at NIU, the two gears were analyzed using ANSYS Workbench 11.0. ANSYS was utilized in order to investigate the actual need for the gear analysis software by modeling the gears as static structural members. This method included modeling the peak load conditions expected on each gear at a maximum operating condition. To achieve this model, the maximum forces expected on each tooth are calculated based on the expected maximum torque at that condition. To apply the maximum torque to the gear, it is assumed that half of the gear teeth will be in contact with the belt at all times. Then this maximum torque is converted to a force which is distributed equally across each tooth, by component forces, comprising of half of the gear.

To model this condition for an instance of possible failure it is then assumed that the shaft supporting the gear is in a situation where it acts as a fixed support. Thus, the gear is in an operating condition where the belt is creating a tension due to this maximum torque while it is not allowed to rotate. With the gear locked into position and force components acting on half of the gear teeth, a simulation is executed to model the deformation, and Von-Mises stress and strain on the gear. It should be noted that it is apparent that stress and strain at the fixed support, or shaft, is in a situation where values may exceed the actual expected values. With this known, the area of interest of these models is more so the area around each gear tooth, to examine for possible failure of the gear teeth. Based on the results of these model, it will be determined if it may be necessary to acquire a gear analysis package. See below in Appendix A.

First analyzing the large gear, we expect there to be 120hp and the gear will experience up to 4440 RPM. From this we can calculate the torque, and based on the radius of the gear we know the total tension force due to the belt. This force is then equally divided by half of the 56 teeth on the gear. This will determine that a force of 27.037 pound force is acting on each tooth. The force on each tooth is then divided into components with respect to the angle that belt tension will make contact with the side surface of the tooth.

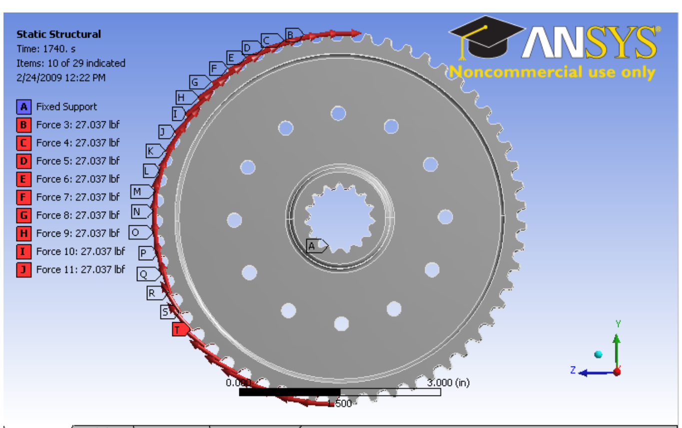

Figure 6: Forces Applied to Large Gear

Analyzing the smaller gear under the same conditions and simulation, the force in this case is distributed across only 12 of the teeth. This is due to a higher expected rotational speed of 10,000 RPM. The force exerted on each tooth of the small gear is 5.252 pound force. It can be noted that the areas of interest near the gear teeth in this case, do start to experience some measured strain and stress values. These forces representing the belt on the gears teeth are illustrated above in Figure 7

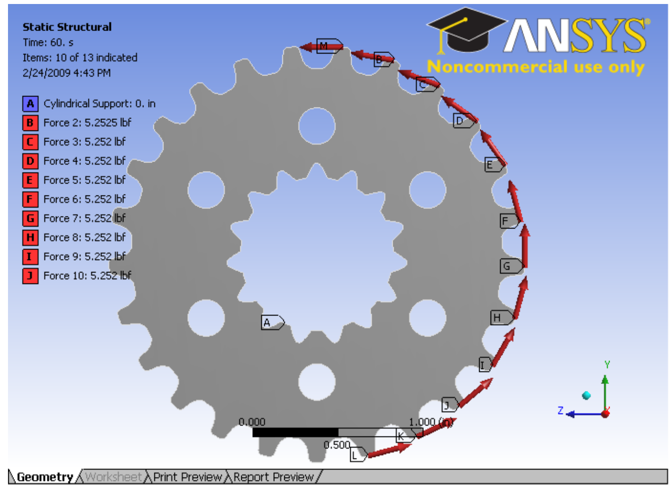

Figure 7. Forces Applied to Small Gear

Through the implementation of ANSYS we were able to see that our gear designs seem to be more than sufficient for maximum operating condition, as seen below in Appendix A. Through these results we can conclude that we do not require a gear analysis software package at this time, although it will be highly considered for future designs. With the confidence in the gear design we can move our focus to the other components surrounding our gears such as the belts and shafts.

Throttle Body Inlet

For the 2009 snowmobile, we needed to design an throttle inlet to replace the stock airbox and connect the throttle bodies to the turbocharger system. The stock airbox had two individual intake runners. Since we installed an intercooler which only had one outlet, we needed a manifold to divert the air towards two different throttle bodies. Using SolidWorks, we designed a inlet which suited our needs. This inlet was then rapid prototyped using ABS plastic.

Before finalizing the design, we chose to analyze the part using Cosmos, which is SolidWorks FEA package. A 50psi pressure was placed inside the inlet which is a 5.5 factor of safety on the 9psi boost pressure. The results were within the specifications of the material, however we still chose to wrap the throttle inlet in fiberglass to increase its strength.

Additionally, we did flow analysis using FloWizard (Release: 3.1.8) to find the high and low pressure areas within the inlet. After calculating the volume flow rate leaving the intercooler, we inserted that flow rate to the intake side of the part and viewed the resulting flow and pressure levels.

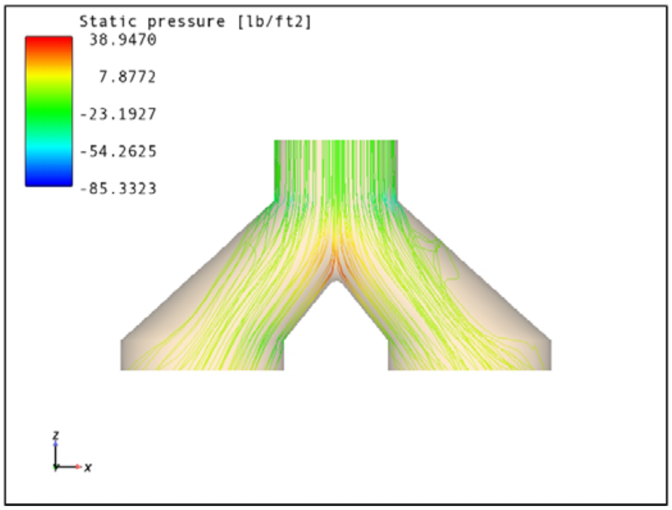

Figure 8: Flow Analysis through Throttle Body Inlet

Insulation of Hood and Body

Using sound reducing insulation on the hood and body of the snowmobile surrounding the engine was found to be an effective way to reduce noise emissions from the engine. Sound insulation effectively dampens noise vibrations reducing the magnitude of the sound waves emitted. Since the sound insulation is directly attached to the belly pan and the hood of the snowmobile, the insulation will also dampen mechanical vibrations in these areas.

Suspension

This year, the team chose to utilize a front A-arm suspension kit from Timbersled Products. The Barkbuster Front-end Kit had be chosen both for its light weight design, and to improve the Yamaha Phazer's control and handling characteristics. The kit is constructed from 4130 chrome molly steel, which will save almost 9 lbs. from the stock front A-arms. The addition of the kit will allow for a more controllable steering snowmobile by allowing the rider to steer 20% sharper than the stock kit [5]. The team has also chosen to replace the stock shocks with Fox Floats.

Testing

Dynamometer Runs

In order to accommodate for the requirements of CSC 2009, much of the preparation time has been spent on the team's Land and Sea Snowmobile Dynamometer. The dynamometer allows simulation of a real world environment by placing variable loads on the engine while simultaneously monitoring the internal and external diagnostics of the snowmobile. The team is able to monitor rpm, horsepower, torque, exhaust gas temp, air intake flow, air/fuel ratio and much more.

The dynamometer equipment is a real asset due to the team's challenge of integrating the MegaSquirt II with the Yamaha Phazer. Since the team has replaced the stock ECU, The MegaSquirt ECU needed to be completely programmed from scratch. Currently the team has run the complete diagnostics of the engine while running on E10. The diagnostics provided is the snowmobile running with stock exhaust and the MegaSquirt II. Provided in Appendix A are the Power vs. Torque curves for the snowmobile running at idle, 50% max RPM/ 50% Load, and a run to estimate max horsepower. Each graph contains the real time exhaust gas temperature curves for both cylinders, torque, rpm, and horsepower. Due to time constraints, the team does not have data for the multiple ethanol blends, and the integration of the turbo. Before the competition, there are plans to test a variety of ethanol blended fuel and compare the results with our baseline information.

Exhaust Emission Testing and Analysis

Emissions of a snowmobile are quite high in reference to a typical automobile driven on the road. Due to this, emissions of snowmobiles have been under a lot of scrutiny. For cleaner air and to better our environment, snowmobile emissions have been regulated by the government in recent years. When the team modified the snowmobile to have better emissions, the use of ethanol blended fuel was incorporated and a catalytic converter was installed to reduce CO and HC. Flex-fuel can provide a great reduction in exhaust emissions compared with regular unleaded gasoline. The primary reason for this reduction is that ethanol contains large amounts of oxygen. The oxygen content assists the burning process, allowing a cleaner and more complete burn of the fuel. 100% combustion of the fuel charge will give the greatest efficiency, but getting as close as possible is the first step to reducing exhaust emissions of the engine.

Ethanol's low carbon content compared to regular gasoline greatly reduces hydro-carbon emissions in comparison to unleaded gasoline, as well as reduced carbon monoxide (CO) and nitrogen oxide (NOx) compounds. As previously mentioned, to reduce tail pipe emissions a catalytic converter was installed into the exhaust system. A catalytic converter is composed of a metal housing which contains a honeycomb of maximum surface area coated with platinum and rhodium. This material catalyses a reduction reaction with the unburned hydrocarbons, carbon monoxide and nitrogen oxides to form nitrogen, carbon dioxide and water vapor.

The NIU Clean Snowmobile Team recently acquired access to a 5 gas exhaust analyzer. During the dynamometer runs, members of the team were able to measure the exhaust gas content of the snowmobile. This content is the engine running with the MegaSquirt ECU and the stock exhaust. Exhaust readings were taken while the snowmobile was running at idle, and due to the previously stated time constraints, sampling had only been done under these conditions running E10, but the team plans to analyze the exhaust content of each ethanol blend and compare it to the baseline exhaust readings.

	O2 (%)	**CO (%)**	**CO2 (%)**	**HC PPM**	**(NO+NO2) PPM**
Idle	1.3	1.7	13.5	198	110
Mid-Throttle	0.3	5.9	11.6	161	178

Table 2: Exhaust Content - Stock Exhaust no Catalyst with MegaSquirt ECU

Noise Emission Testing and Analysis

Sound is formed from pulses of alternating high and low pressure waves [7]. These waves will vibrate your 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 emission from the snowmobile is currently measured using SAE J192 specification [2]. The test calls for the snowmobile to accelerate at full throttle for 150 feet with the measurement taken at 50 feet perpendicular to the lane. The sound emitted from the tail pipe contributes to a majority of the total sound heard. This is caused by the pulsing and expansion of pressure waves from the combustion process.

To combat this, the Team is using a two tiered approach. The first stage consists of an absorption type muffler, more commonly known as a glass-pack, which utilizes fiberglass packing around a perforated tube. This design of muffler reduces a wide range of frequencies and thus quiets the entire rpm range of the snowmobile. The second stage will be a custom built muffler tuned to attenuate the specific frequencies created during a 45 mile per hour cruise and full throttle acceleration. The dominate frequencies will be attenuated utilizing a combination of wave disturbance, cancelation from reflection and the Helmholtz principle of a tuned cavity.

Test data corresponding to cruising and full throttle rpm was not available prior to design paper deadlines, and thus specifics relating to the muffler design were not finalized. Sound and Frequency readings were taken at mid-throttle from 50 ft. away, and the team did find that the stock exhaust did not meet the SAE J192 specification. Frequency spectrum analyses were performed on the snowmobile at idle with the stock muffler and with open pipes, also at idle. The large band pass at 80 Hz of the stock muffler is unnecessary, and shows how much room for improvement there is. Below are the analysis graphs. Attached in Appendix A is the sound recording analysis graphs.

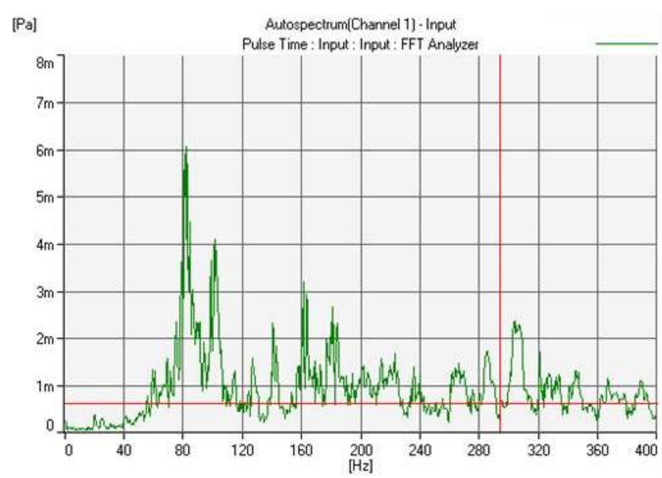

Figure 9. Spectrum analysis with stock muffler at idle.

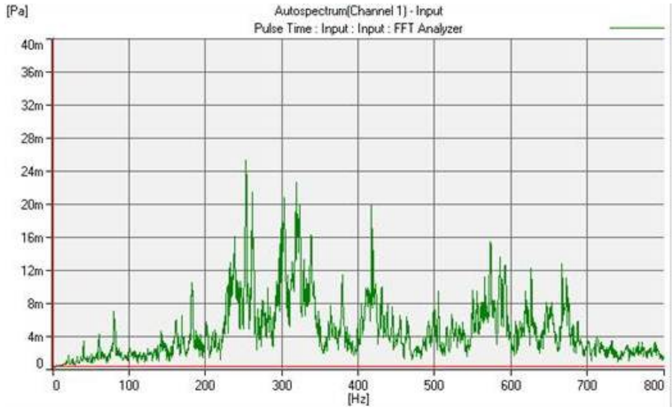

Figure 10. Spectrum analysis without muffler at idle.

Consumer Appeal

With the rising prices in oil affecting prices at the pump consumers are looking more toward fuel efficient engines, or practical alternative fuels, without having to sacrifice performance. Enthusiasts not only look for these qualities, but they also look for qualities such as comfort, maneuverability, as well as the suspension of the snowmobile. 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 these qualities that are 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, 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.

Safety of the Rider

When designing the sled, the safety of the operator was another important consideration of the team. Shields were implemented around moving parts in order to protect the rider from the possibility of parts breaking and possible injury, while still considering ease of access to the engine as well as the design and look of the snowmobile. Carbide studs have been installed on the track to improve traction when driving on ice so the snowmobile does not lose control, and also for improved braking performance. Carbide skegs were also implemented in the skis in order to improve handling of the snowmobile on harder surfaces such as ice.

Cost Effectiveness

The NIU clean snowmobile is not too far off from what consumers might purchase a new snowmobile for on today's market. The MSRP for this snowmobile is around $9,986.00, but has many more benefits compared to your average snowmobile. The NIU snowmobile acquired most of its cost from the HI-Performance Aerocharger Turbo that was installed for added performance. Another costly benefit to this snowmobile were the modifications made to enhance the sled's ability to run with reduced emissions, and the capability to burn any fuel from E10 to E85 without the consumer having to change anything. The end price of the NIU sled is a very reasonable price for the overall quality of the snowmobile and the benefits it presents to its rider.

Conclusion

Recreation Roundtable conducted a recent study on people who spent time outdoors. The results showed that these people lead "happier, healthier, and more productive lives [9]." They also were better citizens and neighbors in their community. As snowmobiling increasingly becomes more popular in future years, the effort for improved, dependable, and environmentally friendly vehicles will take manufacturers to a new level. SAE takes an additional step by challenging engineering students to perform many of these efforts.

The SAE Clean Snowmobile Team at Northern Illinois University re-engineered a snowmobile for better exhaust and noise emissions. Throughout the weeks prior to the competition, the team has designed, tested, and modified a snowmobile to the best capabilities possible. It is a cost efficient snowmobile proven to have costumer appeal, rider safety, and practicality while passing the 2012 EPA emission standards.

Acknowledgements

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L & L Floorcovering, Inc
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Loves Park Motorsports
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C & A Pro Skis
PowerMadd
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Dr. Song
Dr. Sciammarella

References

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[2] The SAE Clean Snowmobile Challenge 2008 Rules, Society of Automotive Engineers.

[3] American Lung Association: Clean Air Choice http://www.cleanairchoice.org/outdoor/E85Benefits.asp

[4] McMaster Carr http://www.mcmaster.com/#sound-absorbing-foam/=qvgcz

[5] Timbersled Mountain Performance http://www.timbersled.com/Index.htm

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[8] Shabana, A.A. Theory of Vibration: An Introduction. Springer Verlag. 1996.

[9] International Snowmobile Manufacturers Association Website: http://www.snowmobile.org/

[10] Resonant Airboxes: Theory and Applications. http://motorcycleinfo.calsci.com/Airboxes.html

Appendix A

Turbo

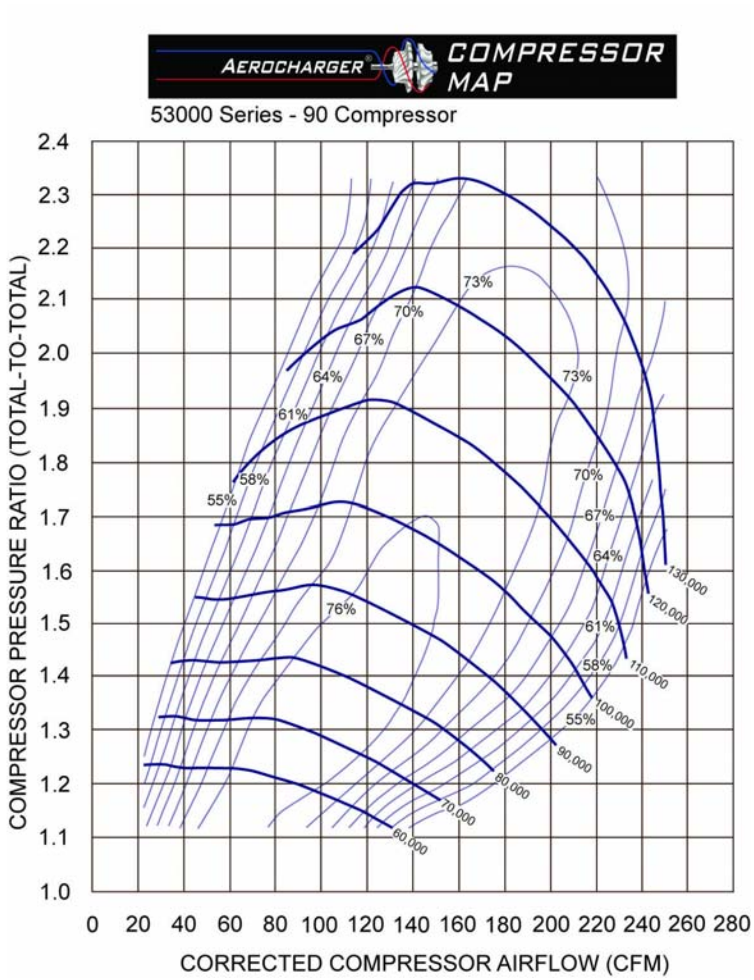

Figure 11: Compressor Map for the Team's Turbocharger

Belt Drive

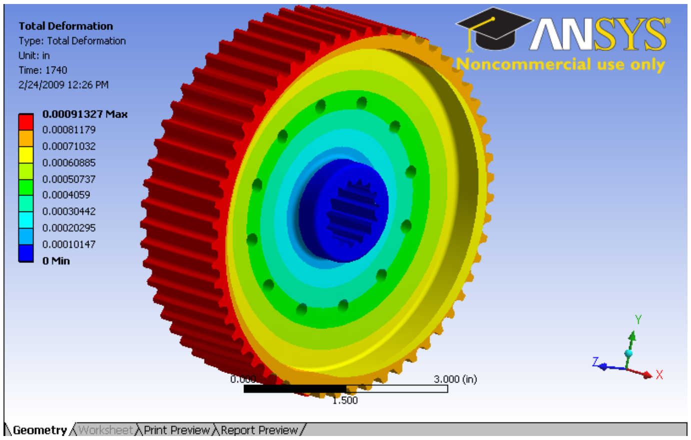

Figure 12: Total Deformation on Large Gear

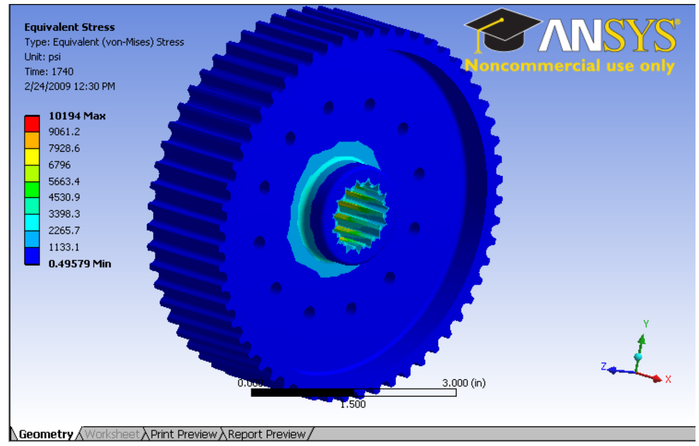

Figure 13: V*on-Mises Stress on Small Gear*

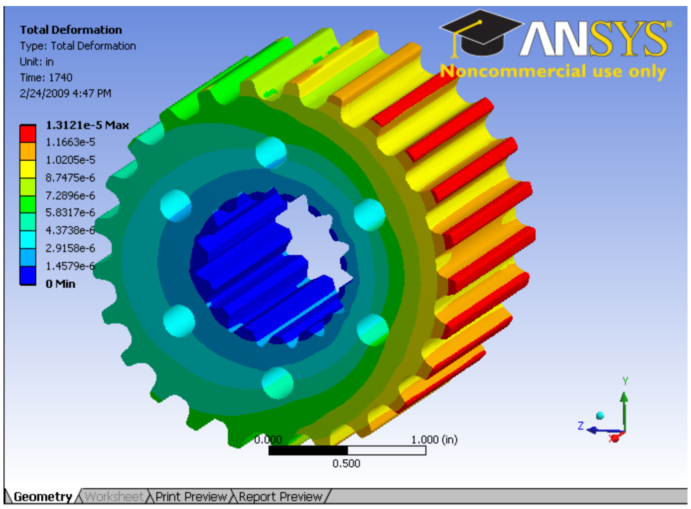

Figure 14: Total Deformation on Small Gear

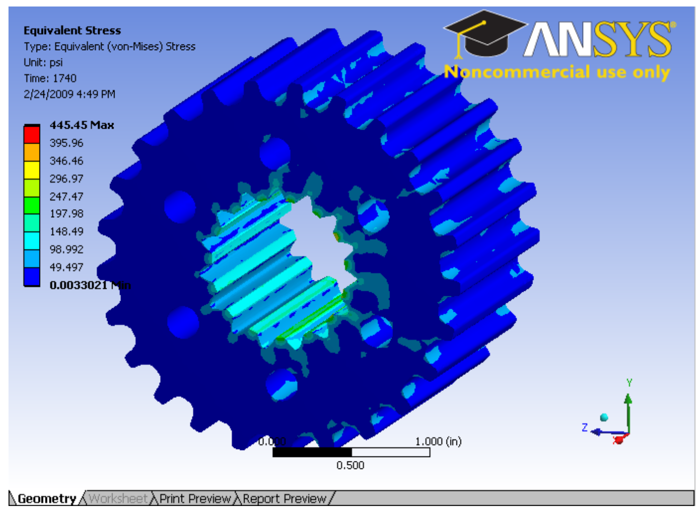

Figure15: V*on-Mises Stress on Small Gear*

Noise Emission Testing

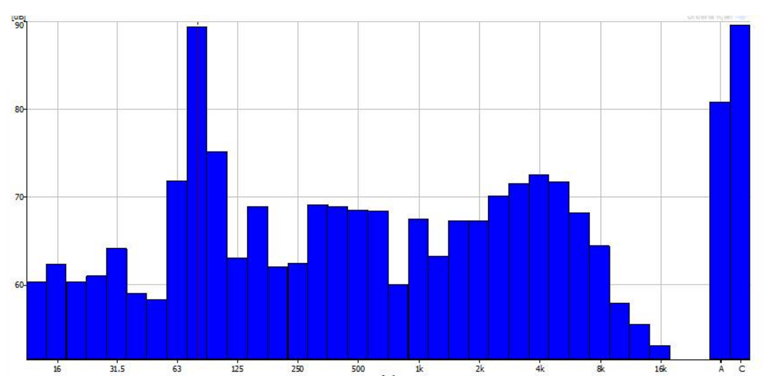

Figure 16: dB Level at Mid Throttle from 50ft. Away Axis)

Figure 17: dB (Vertical Axis) vs. Hz (Horizontal at 70-90 Hz, dB levels reached almost 90 dB.

Dynamometer Runs

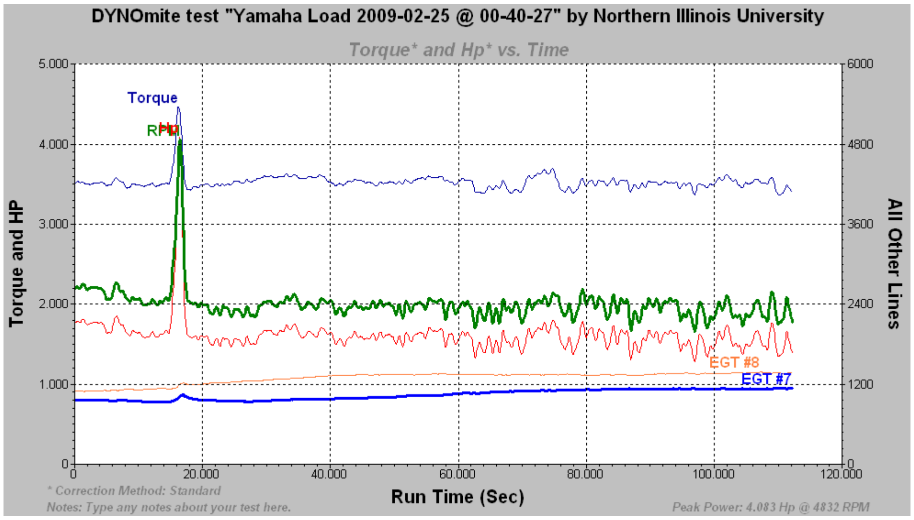

Figure 18: Snowmobile at Idle & No Load

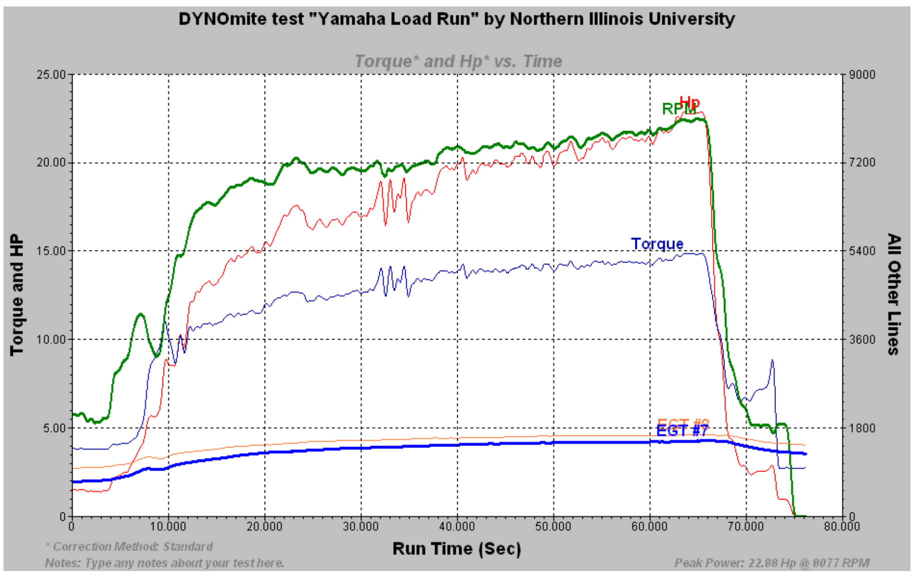

Figure 19: 50% max RPM & 50% Load

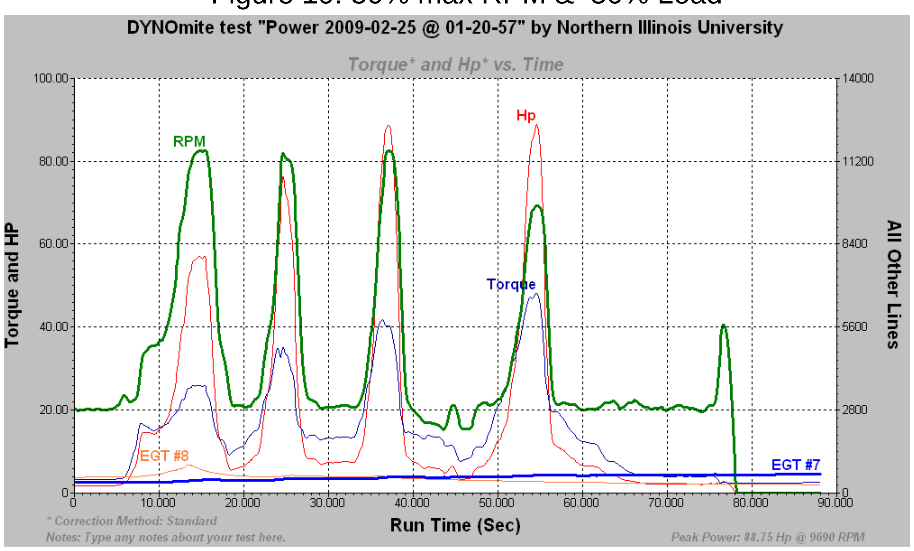

Figure 20: Multiple Attempts to reach Max. Horsepower