Clarkson University Clean Snowmobile 2006

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ABSTRACT

Clarkson University's goal for this year's entry into the 2006 SAE Clean Snowmobile Challenge™ is to design a system that would meet the competition objective of developing a snowmobile that is acceptable for use in environmentally sensitive areas such as national and state parks. Part of this objective is to maintain or improve the stock characteristics of appearance, performance, handling, and comfort. Clarkson's design strategy for meeting SAE's objective is a three-phase approach. The first phase is the design of a system to reduce emissions and sound from the exhaust and noise pollution from the engine compartment and suspension/ drive mechanisms. The second phase will examine how to further reduce exhaust gas emissions through improved engine management and fuel delivery. The third phase will focus on improvements to the front and rear suspensions as well as ergodynamics to improve handling and rider comfort. Subsequent phases will be implemented when in-house and independent testing verifies that system modifications are safe, reliable, and meet performance standards. To maintain the stock appearance of the snowmobile, all component modifications will fit within the existing space constraints and utilize existing mounting points. This approach will result in lower manufacturing costs, end user implementation cost, and ease of implementation by the average snowmobile manufacturer, retailer, owner, and outfitter.

INTRODUCTION

With strict rules being implemented in today's snowmobiling industry and concerns over the impact snowmobiles have on the environment, it is more important than ever to develop cleaner, quieter and more efficient snowmobiles. The impact on the nation's economy is far too great to just outright ban the riding of snowmobiles, yet many environmentalist groups feel it is necessary to due to the potential impacts snowmobiles have on the environment.

It has been shown that snowmobiles contribute a large sum of money into the stream of commerce across the northern part of North America. According to the International Snowmobile Manufactures Association, snowmobile riders in the United States and Canada spend over $27 billion on the sport annually. With the average snowmobile enthusiast spending around $4,000 (USD) on costs associated with riding, such as equipment, vacations, clothing, accessories, and fuel. [1] A recent study performed by students at SUNY Potsdam in cooperation with the New York State Snowmobile Association estimated that snowmobiling contributes approximately $476.2 million dollars to the economy in New York State alone. Also, in 2003 the State of New York surveyed snowmobilers in New York and calculated the economic impact of snowmobiling had increased to $875 million annually; this was an increase of 84% in 5 years. [2]

From this data it is clear that many communities are economically dependent on snowmobiling. With that in mind, there is a need to develop technology that promotes an environmentally friendly snowmobile with reduced sound characteristics, as well as a lower level of pollutants in the exhaust. The new EPA regulations announced in October of 2004 called for a more stringent three-phase reduction in snowmobile emissions. By 2006, emission levels must be reduced to 70 percent of the levels permitted in 2002. By 2010, emissions must be reduced to half of the present day accepted levels, and by 2012 emissions can amount to only 30 percent of the present levels. With nearly 203,000 new snowmobiles being sold in 2002 the EPA is striving to reduce the amount of pollutants emitted into the air and water. [3]

The SAE Clean Snowmobile Challenge™ (CSC) is a collegiate design competition intended to offer undergraduate college students from across the United States and Canada the opportunity to reengineer an existing snowmobile with an aim towards environmental issues. Several of the main design aspects focus on reducing the levels of exhaust gas emissions and the sound produced, while at the same, maintaining or improving the original performance of the stock machine. [4]

DESIGN OBJECTIVES

The main objectives for Clarkson's 2006 entry into the Clean Snowmobile Challenge™ are to develop a system to reduce fuel and sound emissions from a stock snowmobile (first phase design strategy). The foremost goals carried over for this year's team were to make the overall design easily reproducible in large quantities and able to be easily installed on a stock snowmobile are the foremost goals carried over for this year's team. The philosophy for Clarkson University's Winter Knights again for 2006 CSC entry is "Not Just Engineering…Engineering With a Purpose"! Rather than developing a solution that would require snowmobile manufactures to redesign production lines and make vast changes in order to implement the technology, Clarkson's 2006 CSC design approach is geared to appeal to the environmentally conscience snowmobile enthusiast and snowmobile outfitters. In other words, design an after-market upgrade that can be easily installed by the average outfitter to make a stock snowmobile suitable to operate in environmentally sensitive areas such as national and state parks. An important aspect of the design was to cater to the snowmobile enthusiast who is looking to reduce emissions and sound levels in a cost effective way. If implemented, the entire system could be purchased as an aftermarket upgrade from a retailer and could be installed easily in one weekend. Additionally, in keeping with the ease of installation, the entire system must fit within the stock configuration such that modifications to the hood and other vital components would not be necessary. Not only is this attractive to consumers for its ease of implementation, but it also allows the option of retaining the stock appearance of the snowmobile. Design challenges presented while using the Arctic Cat T660 Turbo included limited space under the hood, use of the tunnel as a result of the new exhaust route, additional noise and heat as a result of running a turbocharger, as well as shielding heat away from the vital motor components, gas tank, wiring, seat, and body panels due to the increase in exhaust gas temperatures from the catalytic converter.

SOUND SUPRESSION

MUFFLER

The goal of the 2006 muffler system design was to further reduce noise emissions produced by a turbocharged engine over the system from the 2005 CSC noise level of 105 dBA. Designing a muffler system for a turbocharged engine is significantly different than a system for a naturally aspirated engine in the sense that turbochargers tend to absorb some of the exhaust pulsations, which in turn emits a higher frequency pulsation. There are several traditional ways to reduce sound produced by exhaust systems. These include; fiberglass packed (straight through absorption) mufflers, resonance chambers, baffle type mufflers, and restricted flow mufflers. [5] One of the crucial design parameters in a high performance engine that needs to be monitored is back pressure. The relationship of which is generally the larger the backpressure, the larger the performance loss. A turbocharged engine, in general, should have no more than 2 lbs of backpressure, whereas a naturally aspirated engine can have up to 3 or 4lbs safely. (Excessive backpressure in a turbocharged engine can diminish the gains from a turbocharger, as well as risk internal engine damage.) For these reasons, a restricted flow muffler was ruled out as a design option.

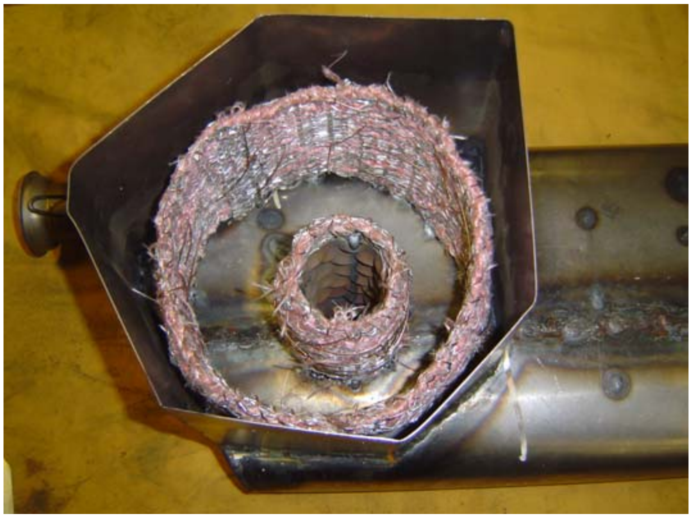
A second factor included in turbocharged systems is the volume of air flow that passes through the waste gate. Because this gas has not passed through the turbine, its firing frequency is that of a naturally aspirated engine, not of a turbocharged engine. One solution for this problem includes re-routing the flow from the waste gate into a separate muffler system that is designed for lower frequency pressure waves. This system could include a resonance chamber as well as the baffle type muffler that is used in the main muffler system. However, routing the exhaust gas away from the waste gate is not practical for this application. The turbocharger would have to be replaced in order for it to accept a remote waste gate system. For this application it would be impractical and not within the competition modification guidelines to replace the turbocharger at a high cost.

Keeping the stock turbocharger and waste gate assembly makes it more economically feasible to sell an after-market upgrade that could reduce the noise levels of the snowmobile (not to mention the reduction in skill requirements for kit installation). In most cases, an exhaust system with a turbocharger is easier to design. For a naturally aspirated engine, tuned headers should be developed to maximize the efficiency of the engine. For a turbocharged engine, the only major factor is the restriction that the exhaust imposes. The flow exiting the turbocharger tends to be very turbulent; therefore it would be detrimental for a rough restriction immediately after it exits. A smooth pipe is the best way to handle the flow until it becomes less turbulent. [6] Designing a muffler of the largest possible volume for the space available is a good starting point. A larger volume muffler, in most cases, allows the pressure pulsations entering the muffler cancel out and/or become smoother. While a muffler with a minimal volume can be effective, it is easier to muffle a large range of conditions with the larger volume.

This year's exhaust system design improved upon the dual in-line muffler system that was developed for the 2004 and 2005 CSC. Since the past two year's exhausts were very heavy, and the rear muffler impeded the use of track studs, a single dual stage muffler was installed. Stock, the Arctic Cat T660 comes with a single stage muffler located on the non-pto side of the engine, in front of the battery, and cradled by the A-arm belly pan housing. Taking the space that the original exhaust used as well as the stock battery space, a dual stage system was installed. After the pipe containing the catalytic converters, the exhaust goes into an automotive style canister which has tuned resonance chambers. Since this engine is not run at one specific temperature and rpm, a perfectly tuned resonance chamber is not feasible. With this in mind, two chambers were built, with noise cancellation and baffling in mind.

Figure 1: Cut-away view of muffler.

Referring to Figure 1, the exhaust travels through the canister to the most rearward chamber, where it is constrained by the first baffle plate, then into the next chamber a 'solid' area, where the gasses pass into the front baffle chamber via a pipe from the 'solid' chamber. From the front baffled chamber, the gasses are released into a larger expansion chamber, then to the side canister. The side canister is a fiberglass packed design, however, contrary to conventional packing techniques; this design was not strictly straight through style absorption. A series of three semi-concentric canisters were made out of expanded metal sheeting which were packed with a wound fiberglass packing material.



Picture 1: Cut-away view of 'concentric' canisters.

Alternating which wall the cans were welded to determined the 's' pattern the gasses would have to travel through to get to the exit pipe. (see Figure 2)

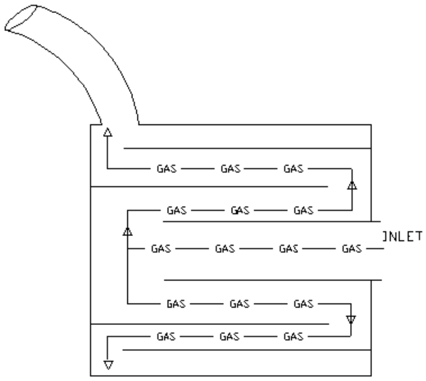
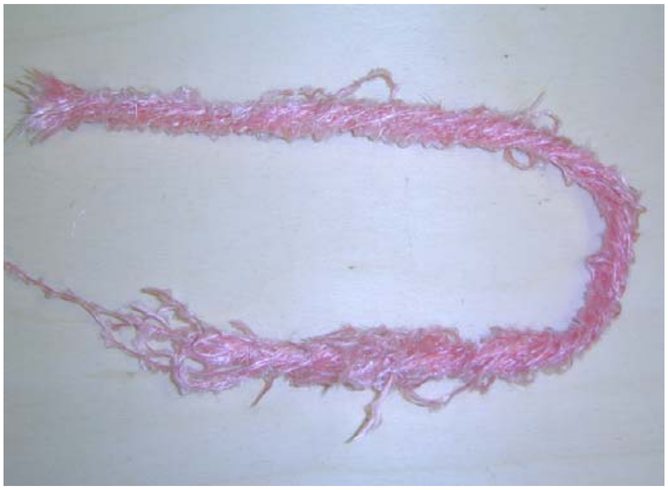


Figure 2: shows a cutaway cad drawing of the 's' pattern.

The fiberglass packing that was used was found to have been manufactured in long strands (possibly continuous, then cut for handling), which was wound laterally in 20-30 foot lengths to prevent blowout. (see Picture 2) These lengths were then enclosed in the expanded metal canisters shown in Picture 1.



Picture 2. Picture of spun fiberglass packing.

The fiberglass packing is effective in absorbing high-frequency noise, which is the reason it is used primarily in two stroke end silencers (as their port design and relatively high RPMs produce high frequencies). The turbocharger tends to absorb some of the lower frequencies and as the gasses pass through and expels higher frequency noise. With this in consideration, the primary exhaust canister was designed for lower frequencies, the second canister for higher frequencies.

The goal of the exhaust exit was to absorb sound and direct the exhaust to a position that will aid in dampening the noise. Conventionally, snowmobile exhaust exits down through the belly pan, where it reflects off the snow. After the second muffler stage, the exhaust is directed down through the tunnel directly onto the track. The rubber further breaks down exhaust pulsations and thus deaden more the exhaust noise. In the design process the only possible problem foreseen in this arrangement is that of track failure due to the rubber breaking down due to heat exposure, however, this proved not to be a problem due to the snow and air that are constantly cooling the track.

The material chosen for all components of the muffler system (with exception to the core of the catalytic converter) is mild steel. The availability, durability, ease of welding, and cost were the main reasons that steel was used. Due to the service life of the snowmobile, stainless steel would be an expensive investment for this application. However, it would make an excellent material for the mass production of an aftermarket system.

If mass-produced, this system could be added to an existing snowmobile or integrated into a manufactured snowmobile. The only modification to the stock snowmobile to integrate this system would be to cut a hole in the tunnel to run the exhaust outlet tube and relocation of the battery to the back. A paper template could assist the user to easily layout and cut the hole in the tunnel.

Several different muffler and silencer designs were developed and tested. However, the herein described muffler/silencer combination produced the quietest arrangement at the exit of the muffler. It should be noted that the design of muffler systems is not an exact science, and most formulas are produced from experimental data.

HEAT SHIELDING

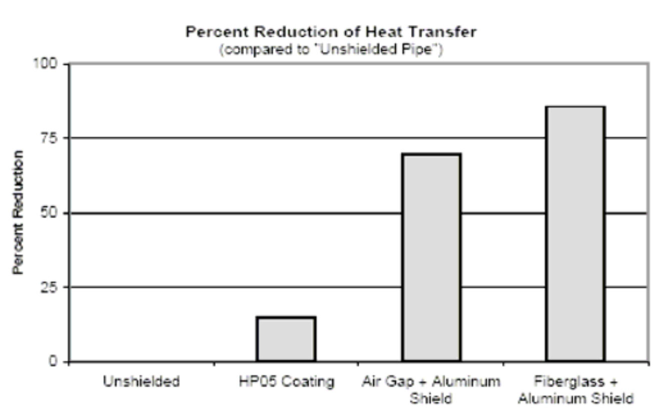
Under-hood temperatures are a concern when dealing with the exhaust system. To protect under-hood engine components from excessive temperatures, a composite heat shielding was installed on the muffler system. One of the emission control elements in the redesigned exhaust system was a catalytic converter. This component of the system is one of the most important parts to consider for heat retention as well as the area closest to the fuel tank. Monitoring the temperature of under-hood components during dynamometer testing did not show a significant increase in surface temperatures with the modified exhaust system as compared to testing with the stock configuration (approximately a 10 to 15 degree increase was measured with the modified exhaust system).

The catalytic converter is one of the primary sources of high exhaust temperatures (+800^{o}F), a fiberglass-based header wrapping material was chosen.

By isolating the heat produced by the catalytic converter from the engine, it allows the engine to run at a cooler temperature and thus maintain better horsepower and emissions outputs. The header wrap also helps to keep the high exhaust temperatures inside the exhaust system. In doing this, the exhaust gases exit the snowmobile faster and help keep the engine performing more efficiently.

The stock exhaust system made use of an aluminum shroud around the exhaust tubing and muffler that was packed with insulation between the shroud and the pipes. Because of the intricate bends of the exhaust tubing and the muffler the header wrap used to encase the catalytic converter was continued throughout the entire exhaust system. To provide an air gap between the header wrapping and the tubing, Vance and Hines fiberglass baffle packing was fitted around the pipes before wrapping them. The fiberglass baffle packing acts as an insulator and, combined with the air gap and fiberglass header wrap, reduce temperatures in the engine bay significantly.

A heat shield cover was also placed between the tunnel and the seat/gas tank, preventing the high temperatures of the exiting exhaust from potentially melting the gas tank or spontaneously igniting the gasoline. During the selection process for heat shielding, a simple heat transfer model was used to compare several common types of heat shielding. In each case, the heat transfer from the muffler to the surrounding components was estimated using a remote heat gun and compared to the unshielded muffler. A comparison of the different types of heat shielding is shown in Graph 1.



(Graph 1: Estimated Percent Reduction of heat transfer for heat shielding options.)

SOUND DAMPENING

The noise dampening effects desired were accomplished in two ways. The primary method was to run a two stage muffler exhaust of which both were located under the hood. These mufflers have been mentioned in detail in earlier sections of this report. The muffler design successfully reduced exhaust noise from the engine; however, it did not address engine noise caused by mechanical operation of the engine components or the turbocharger. To address this, a second method was selected to improve the sound dampening of the engine noise. The final selection based on cost, availability and ease of installation was to use a product manufactured by Cascade Audio Engineering out of Oregon called Echo Eliminator. A track skirt was also implemented to reduce the noise caused by the rotating track and suspension components. [7]

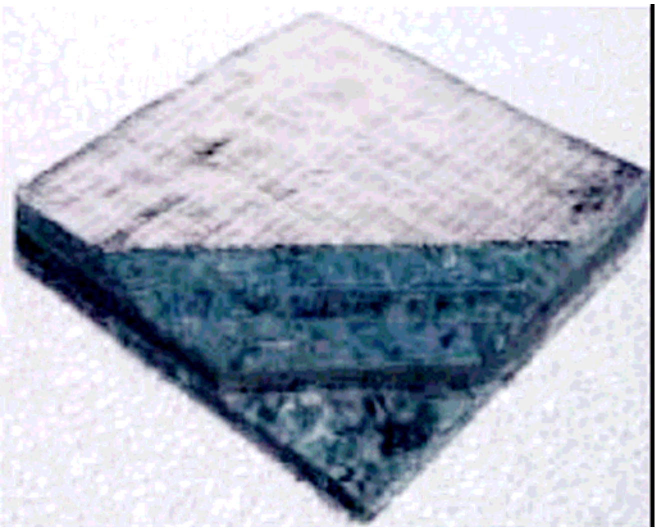


Figure 3: Sample of Echo Eliminator product.

The product selected was bonded acoustical cotton composite with a foil face. This product was selected due to the fact that is waterproof and will not burn at temperatures up to 500 degrees Fahrenheit. Both of these qualities were necessary to ensure safety for this application. The material was applied to the inside of the hood as well as necessary areas in the belly-pan using a high temperature adhesive. Another major source of noise was centered on the intake manifold and the ‘clicking’ produced by the fuel injectors. To dampen as much of the sound in this area, aluminum plates were made that enclosed the intake manifold and injector area. A thin sound dampening material was applied on the inside of these plates to help with sound absorption. The material chosen to line the plates was the Dynamat product that is detailed later in the Air Box section of this document.

EMISSION CONTROL

Results of the emissions testing for the 2004 CSC entry showed a significant increase in carbon monoxide concentration; specifically under Mode 1 testing. Review of the emission test results, it is presumed that one or a combination of the following factors contributed to the increase in carbon monoxide concentration: the catalytic converter was not designed correctly for the specific application; and/or due to insufficient air flow over the air-to-air cooler caused a significant increase in intake air temperatures resulting in a rich air-to-fuel ratio during combustion; and/or due to increased exhaust temperature the oxygen sensor failed. With the exception of testing of the oxygen sensor the exact cause of the increase in carbon monoxide concentration cannot be precisely determined. Testing of the oxygen sensor indicated that the sensor likely functioned correctly during testing. To address the increase in carbon monoxide concentrations, two catalytic converts were considered for the 2005 CSC entry. The first option was to incorporate an air injection system with the 2004 catalytic converter or a new three-way catalytic converter more specific to the intended application. The emission results from the 2004 CSC entry as well as the dynamometer results were provided to Corning Incorporated in Corning, New York (Corning) for review and assistance in selecting of a catalytic converter that would be applicable for application. Emissions testing for both a three-way catalytic converter with and without air injection were completed. Preliminary emissions results showed a marked decrease in unburned hydrocarbons, carbon monoxide, and NO_x using air injection prior to the catalytic converter. Based on the preliminary emissions test results, a three-way catalytic converter with air injection was selected as the primary exhaust treatment. Corning developed the catalytic converter. The design, catalyst, and testing results for this prototype catalytic converter are proprietary to Corning and the catalyst manufacture, therefore specifics cannot be provided in this report. Emission and dynamometer testing results of Clarkson’s 2005 CSC entry will be provided to Corning for analysis of the catalytic converter’s performance.

CATALYTIC CONVERTER

Carbon monoxide, nitrous oxides, and hydrocarbons from unburned fuel are the three main harmful emissions of an internal combustion engine. The effectiveness of a catalytic converter is measured in how fast it can produce these chemical reactions with the gas mixture of toxins. It was also important that the size of the catalytic converter was kept very small for space constraints, yet large enough for the T660 engine. A correctly sized catalytic converter will keep the performance as high as possible while effectively reducing emissions.

Figure 4: Catalytic converter and exhaust down tube.

The flow of gas through the catalytic converter is another critical detail of the exhaust design. In order to produce the reactions inside the catalytic converter, the exhaust gas must flow through potentially a restrictive setup and will therefore possibly create backpressure that is not present within the stock exhaust system. One of the greatest shortcomings of catalytic converters comes in that they only begin to work well at extremely high temperatures. Therefore the catalytic converter had to be placed close to the engine. The high temperature gas from the engine then flows into the catalytic converter where the chemical reactions occur and the emissions are reduced. Keeping the catalytic converter in close proximity to the engine induced many restraints in terms of space and it required the surrounding components to be adequately shielded from heat.

TRACK SKIRT

In order to effectively reduce the amount of sound pollution created as a by-product of the snowmobile's movement across the snow, the implementation of a track skirt to "wrap" around the rear of the snowmobile was chosen. The basis for using a durable rubber was so that the enclosure would "flex" with the movement of the rear suspension and therefore not hinder the quality of the ride. We selected EPDM (ethylene propylene diene monomer) as the rubber to encase the track. EPDM was chosen over others because of its ability to handle a varying degree of temperatures, with an optimal operating temperature range of -40º to +225ºF. Aside from that, EPDM was also chosen because of its resistance against damage from tearing, impact, and abrasion; with a Shore-A durometer rating of 60, it would withstand repeated use. The frame of the track skirt was designed so that it would also withstand any impact from debris or from the trail. The use of 1" x ¼" angle iron to make the frame of the enclosure along with mounts that bolt onto the rear skid in three locations helped to make the design much stronger, preventing any bending or torquing of the frame. Certain bends within the frame were incorporated so that when the rear suspension was collapsed entirely, the track skirt would not make contact with either the ground or the snowmobile.

AIR SILENCER

Two air silencer modification choices were evaluated. The stock air silencer was positioned nearby the catalytic converter which caused material rupture concerns for the stock plastic air silencer. The air silencer was either to remain in its stock location and be constructed of heat tolerant materials or would be repositioned above the intake manifold to avoid potential heat issues. Due to restriction of airflow, additional cost of piping components, difficulty of installation, and modification of stock appearance the air silencer design chosen would remain in the stock location be of identical interior dimensions and be constructed of metal.

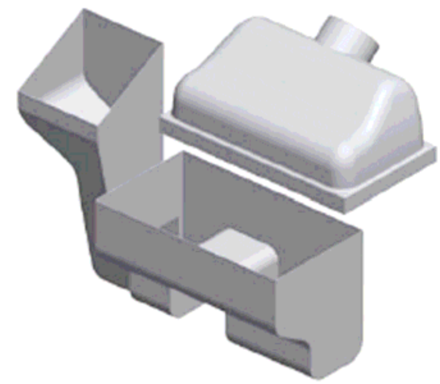


Figure 5: Aluminum air silencer.

Steel and Aluminum, two readily available inexpensive metals, were compared for the air silencer application. Thermal conductivity and melting point were major factors for selecting an optimal material. Intake temperatures should be minimized to maximize engine efficiency. The lower the reactant temperatures entering an engine the larger the temperature differential between the intake and exhaust gases, therefore more expansion work will be generated for the same unit volume reactants. Since aluminum has a higher thermal conductivity than does steel, it would transfer heat from the catalytic converter to the intake air more readily but more importantly it would dissipate the heat to the surroundings prior to heat transfer to the intake air. Therefore, the resulting intake air from an aluminum air silencer would be colder than the air from a steel silencer. Although steel exceeds aluminum's melting point dramatically, the temperatures outside the fiberglass wrapped catalytic converted are far below the melting points of either metal. Aluminum, rather than steel was selected for its heat transfer characteristics as well as its aesthetic shiny appearance.

The air flowing into the air silencer is a substantial source of snowmobile noise. Therefore the inside of the air intake was lined with Dynomat. The rubber vibration damping material, styrenebutyadine, is manufactured by Dynamic Control of North America, Incorporated and reduces intake noise by approximately four percent considering the application's intake temperature. [8] Dynomat also maintains a smooth silencer inner surface for high air flow velocity.

The air box was cut, folded and TIG welded at all seams to ensure an air and watertight box. The stock filter element was reused to reduce implementation cost. Following the theme of aftermarket upgrade kits, the aluminum air box was designed to use the existing mounting points.

BATTERY BOX

In order to meet safety requirements, a battery box was constructed to enclose the battery and protect terminals form accidental discharge in event of accidents. Due to space limitations for the enlarged muffler, the battery box was relocated to the seat's storage compartment. The battery box was fabricated of 14 gauge 6061-T6 Aluminum. Rubber terminal covers were used and aerosol rubberized undercoating was applied to all surfaces of the battery box to inhibit electrical conduction.

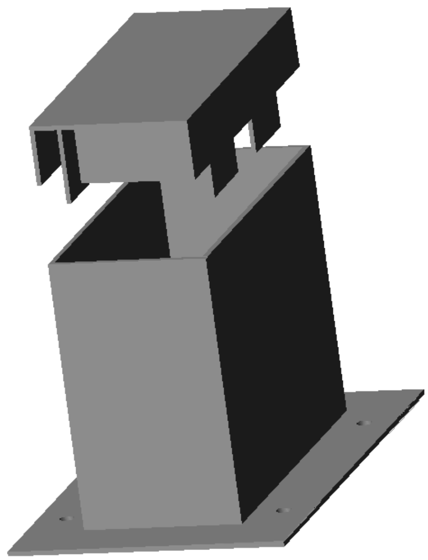


Figure 6: Rubberized battery box

COOLANT RESERVOIR

The stock plastic coolant overflow reservoir required modification to accommodate exhaust piping heat dissipation. Since the muffler outlet exits to the front of the tunnel, the piping passes near the coolant reservoir. To prevent the plastic container from melting when exposed to high exhaust temperatures an aluminum tank was designed and fabricated of 20-gauge aluminum. The reservoir holds the same volume of fluid as the stock reservoir.

CLUTCH GUARD

A redesigned clutch guard was created to increase rider safety. The top of the clutch guard was lined with Kevlar strapping to prevent injury due to clutch or belt failure. Also, the new clutch guard was lined with Dynamat sheeting to reduce noise from the drive system.

TEST RESULTS

HORSEPOWER TESTING DATA

With the newly designed primary muffler and catalytic converter exhaust system, the snowmobile was able to achieve a level of performance near to that of the stock machine. A DynoMite dynamometer produced by Land and Sea, Inc. was used to analyze the performance of the engine.

Two primary mufflers, each with different noise dampening characteristics, were developed and then tested on the dynamometer to determine the best muffler for both power and noise. Sound level measurements were recorded during dynamometer testing to evaluate the mufflers. As can be seen in Graph 2a, the stock snowmobile showed a peak power of 117 hp at 7200 RPM. The stock torque was calculated as 98 ft-lb at 5500 RPM. With the addition of the reengineered primary and the newly designed secondary exhaust system, the peak power was found to be 103 hp at 7300 RPM and the peak torque was 78 ft-lb at 6500 RPM (Graph 2b). This shows that only a minor loss in power was shown after the addition of the new exhaust system. The design of the selected muffler is explained in the exhaust section of this document.

To ensure consistency in engine cooling during testing, a cooling system replicating the one used during the competition was used based on design specifications from SAE. Additionally, a secondary cooling system was designed to supply 3100 cfm of air across the air-to-air intercooler during dynamometer testing. This airflow rate across the air-to-air intercooler is approximately equivalent to the airflow that would be achieved when driving the snowmobile at a speed of 75 to 80 mph.

During dynamometer testing, air intake temperatures were monitored using an EGT temperature probe installed downstream from the air-to-air cooler. Intake air temperatures ranged from approximately 70 degrees F (at idle) to approximately 150 degrees F (100% under 100% load) when using the supplemental air-cooling system. Intake air temperatures at idle with no load were above 150 degrees F when the supplemental air cooling system was not used. Intake air temperatures were not obtained under full power and full load when not using the supplemental air-cooling system to prevent damage to the engine.

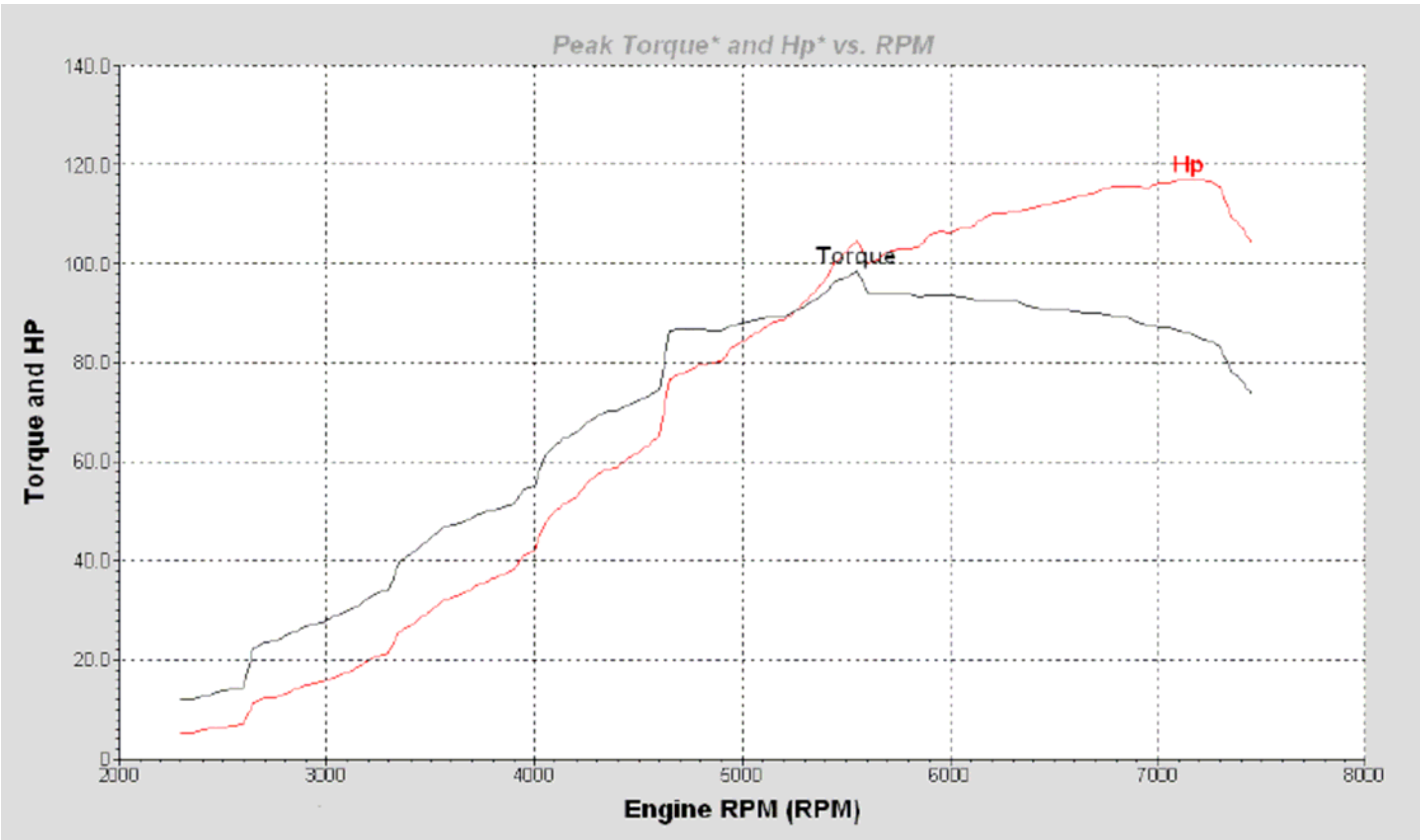
Another problem encountered with the 2005 Clarkson University CSC snowmobile involved excessive backpressure caused by the catalytic converter and muffler designs. This backpressure is believed to be the largest contributing factor in the reduction of 35 horsepower observed during testing as compared to rated 110 horsepower of the stock snowmobile.

This year's focus was to reduce this backpressure therefore helping to maintain the stock horsepower. The prototype catalytic converter developed by Corning, Inc. was developed as a high-flow converter and performed very well. The final designs of the muffler also were developed to keep backpressure minimal while maximizing the drop in sound levels. The selected muffler (discussed above) with the catalytic converter resulted in net increase in backpressure less than 0.5 psig which is comparable to the stock exhaust system.

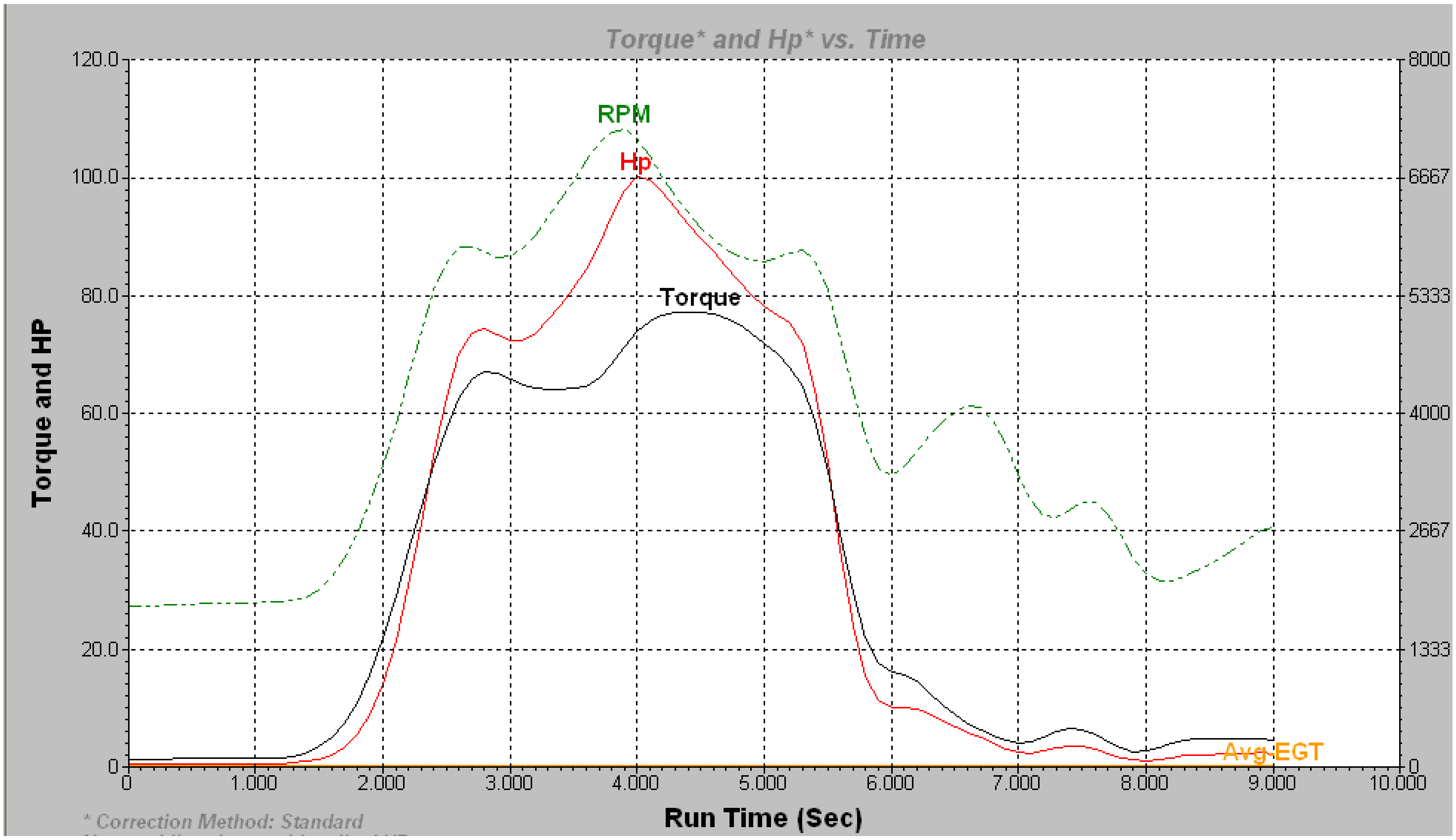
EMISSION TESTING DATA

One of the primary components incorporated in the proposed aftermarket upgrade design was a catalytic converter. As discussed, the catalytic converter is a prototype design produced by Corning Inc. The catalytic converter was selected as the main component for emission reduction. Additionally, a secondary air injection system was developed to incorporate oxygen into the exhaust stream just before entering the catalytic converter. The addition of oxygen to the exhaust gas directly before the catalytic converter helps the converter to burn off more unburned hydrocarbons. Emission testing was completed in general accordance with the EPA five mode emissions testing procedure. Emissions data was collected using a five-gas analyzer during dynamometer runs. During the emissions testing, the head gasket failed preventing completion of the testing.

The results displayed in Table 2 below compare emissions at idle with and without air injection. Further testing will be completed for the remaining testing modes.



Graph 2a: Dynamometer run #1 with stock exhaust system.



Graph 2b: Dynamometer run #2 with modified exhaust system.

Gas	Units	Idle w/out Air	Idle w/ Air
HC	PPM	230	12
CO	%	4.5	0.05
NOx	PPM	>100	20

Table 2: Emissions using a five gas analyzer

The addition of the catalytic converter alone improved the emissions of the engine drastically, however, to further improve the exhaust gas characteristics, the air injection was used. The results of the air injection brought the emission levels to nearly zero.

ACCELERATION AND HANDLING

Power and handling are two of the major characteristics of snowmobiles that entice consumers to purchase a machine. Although the intended demographic for Clarkson's aftermarket exhaust and sound dampening upgrade is directed towards environmentally conscientious consumers, it was still important to provide a high performance product. As mentioned, the horsepower of the new exhaust system was found to be nearly the same as the stock engine. While testing the modified snowmobile for the event, the performance characteristics showed no noticeable change from the stock machine. Acceleration testing was completed during a St. Lawrence County Snowmobile Association event held at Cranberry Lake, New York. Radar was used to measure the speed of the snowmobile accelerations from rest over a 1,000-feet interval.

Clarkson's 2006 CSC entry consistently ran the radar run at approximately 83 mph (corrected for the cosine angle of the radar to the path of the snowmobile).

Excessive track spin was noted at takeoff and when the turbocharger spooled. Track spin can be decreased with the use of studs. Track studs were implemented because that is what our test rider feedback provided us with. Out of all of our riders 97% of them claimed that they had studs on their current snowmobile that they own.

The front suspension was upgraded to a more competitive shock that can be rebuilt. While this was not a necessary addition to make the snowmobile worthy of National and State parks, it did improve the handling response and trail riding capabilities of the snowmobile. We felt it was needed due to the increase in the curb-weight of the sled.

Slight under steering was observed with the stock skis and suspension causing the front end of the sled to slide to the outside when cornering on both hard-packed and soft snow conditions. To correct for the under steering, Clarkson installed performance shocks and skis on the 2006 CSC entry. These simple modifications resulted in minor over steering causing the backend of the sled to slide to the outside when cornering. The installation of track studs would significantly reduce backend sliding in cornering resulting from over steering.

NOISE

Sound testing was performed to determine the level of sound pressure waves emitted from the snowmobile. The snowmobile was run on an open track and sound measurements were retrieved using a standard decibel meter at a distance of 50 feet on both the right and left sides of the machine. The data was sampled at 35 mph, 45 mph, and 50 mph with the stock components in place as well as various muffler designs to determine the best setup.

Test Speed	35 mph	45 mph	50 mph
Avg. Stock	0.178	0.399	0.564
Avg. Modified	0.038	0.044	0.068
% Reduction	78.65 %	88.97 %	87.94 %

Table 3: Average sound data recorded in Pa.

The sound data was collected in decibels and converted to Pascal of sound pressure that is a more widely accepted unit of measure for sound. As the data shows, the sound levels were reduced significantly in terms of pressure.

FUEL ECONOMY

The 2006 Clarkson University Clean Snowmobile Challenge™ team chose not to modify or alter the stock fuel delivery or engine management systems. Clarkson's 2004 CSC entry had a fuel economy of 15.8 mpg. In the 2005 CSC entry we achieved a mpg rate of 17.3; we did improve our rate by 1.5 miles per gallon. The 2005 fuel economy wasn't far from the base-rated mpg of 18 mpg even with the increase in curb-weight. The decrease in fuel economy was a result of increases in curb-weight and exhaust backpressure from stock configuration. Clarkson's 2006 CSC entry is comparable in weight; however, the increase in backpressure has been corrected to that similar to the stock exhaust system. Based on the fuel consumption results from the 2005 CSC, the 2006 CSC entry should show an increase in fuel economy comparable to that of the stock rating of 18 mpg. Due to the increase in weight it is unlikely that fuel economy will increase above the stock rating.

MARKETING/ENDURANCE SURVEY

To test both the reliability and the available market for our improvements, the snowmobile was taken to Cranberry Lake located in the heart of the Adirondack Mountains in New York. The weekend chosen had an ample amount of snow to test the snowmobile on both the lake and trail atmosphere. We wanted to ensure the durability of our improvements in an environment that any other production snowmobile would incur. Both the team members and avid snowmobilers tested the snowmobile rigorously for six straight hours.

At the conclusion of the day, more than 20 riders had put the Clarkson snowmobile through obstacles and terrain that is seen on trails throughout the country. After each rider returned, the test riders found our modifications to be both trail friendly and safe. We had each rider fill out a survey that noted ten different characteristics of the sled. The majority of our riders noted they mainly in the Adirondacks and Tug Hill region of the state. The average test rider was 25 years old, but we did also have a few that did not note their age. 73% of the test riders surveyed said they would purchase a system identical to the one we designed if the government imposed stricter laws that regulated sound and emissions even more than they are today. The only downside that people noted was the turbo lag in our motor and that we did not have a studded track. 87% of the surveyed riders noted that our improvements met the expectations of a clean and quite snowmobile. Again, the weight and handling of a bulky four-stroke was on top of the list of why this was not the ideal snowmobile to own. Although not everyone rode the snowmobile, we talked with many groups of riders who were concerned with the noise. They were more than impressed with the sound improvements we made. More than one person had asked us if the snowmobile was actually on and running on all 3 cylinders. As you can see from chart below, riders were most impressed with our noise level improvements. Areas where riders were most displeased such as weight are aspects that are very hard to improve on due to the stock weight of the four-stroke engine and chassis that is needed to house it.

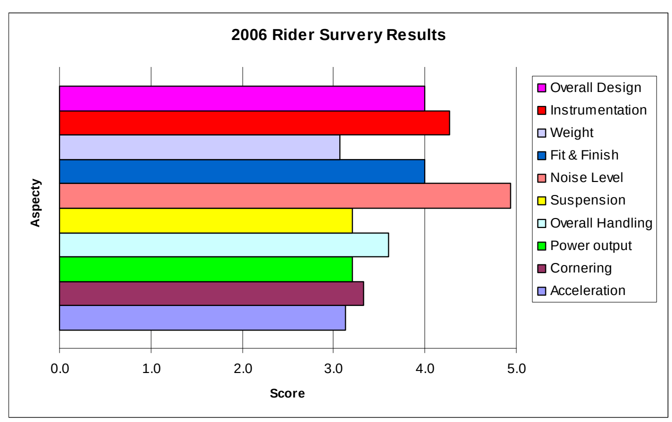


Table 4: Average rating of marketing/endurance survey.

RELIABILITY OF DESIGN MODIFICATION

The 2006 Clarkson CSC design made no modifications to the vital engine components or other major mechanical parts; therefore the final design of the aftermarket upgrade for the T660 Turbo was very reliable. Nearly eighty hours of dynamometer testing was completed on the modified snowmobile as an initial evaluation for reliability. Over 150 miles of trail and lake riding were completed to subject the modified snowmobile to real world riding conditions. During the dynamometer and field testing no malfunctions or breakdowns occurred.

CONCLUSION

The new system implemented to lower the emission and decrease sound levels from a stock snowmobile is very effective at both, while still maintaining, and in some aspects, improving upon the stock performance

characteristics. As was expressed in the opinions of consumers, this year's Clarkson University CSC design is a very cost-effective solution to the problems posed in the SAE Clean Snowmobile Challenge™. The estimated cost of the aftermarket upgrade to the Arctic Cat T660 Turbo was calculated to be $288

ACKNOWLEDGMENTS

The Clarkson Winter Knights would like to thank everyone who has made this year's team possible. Without the support and knowledge we were given, we would not have been able to be as successful as we have been this year. Much of our support has come from Clarkson's Student Projects in Engineering Excellence and Design (SPEED) Director Fredrick Stone P.E. Both his knowledge and wisdom of engineering were vital to our success. We would also like to thank all those who have sponsored the 2005 Clarkson Clean Snowmobile team.

Alcoa, Corning, Incorporated, General Electric Company, Kodak, Procter & Gamble, D&D Racing, Northeastern Sign, SUNY Canton

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