Clarkson University Clean Snowmobile 2005

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ABSTRACT

Clarkson University's goal for this year's entry into the 2005 SAE Clean Snowmobile Challenge™ was 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 while maintaining, or improving, the stock characteristics of appearance, performance, handling and comfort. Clarkson's design strategy for meeting SAE's objective is a three-phased approach. The first phase is the design of a system to reduce emissions and sound from the exhaust and noise emission from the engine compartment. 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 ergo dynamics 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 design approach will result in lower manufacturing costs, end user implementation cost, and ease of implementation by the average snowmobile manufacturer, retailer, owner, and outfitter.

Clarkson's 2005 entry builds off from the strengths and improves on the weaknesses of the 2004 entry. Clarkson's 2004 entry began the implementation of the first phase of the design strategy. Results from the 2004 testing showed a significant decrease in exhaust gas emissions, with the exception of carbon monoxide. Additionally, the 2004 design showed a marked decrease in the sound emissions both from the exhaust system and engine compartment. The modifications include a completely redesigned exhaust system including a catalytic converter and a linear combination of a primary and secondary muffler.

INTRODUCTION

With strict rules being put into place for 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 due to the potential impacts snowmobiles have on the environment. A prime example of this is currently being played out in Yellowstone National Park. Snowmobiling in the park was nearly banned in December of 2003, when U.S. District Judge Emmet Sullivan in Washington, D.C., reinstated a Clinton administration plan to ban snowmobiles. Environmental groups who claimed snowmobiling harassed the wildlife, and endangered the health of park workers supported this ban. Shortly after the ban, U.S. District Judge Clarence Brimmer in Wyoming, realizing the economic harm this would create for communities that depend on snowmobile tourism, blocked the restrictions. Brimmer instead called for limited use of the park for snowmobile recreation, creating a less economically devastating situation for local economies. [1]

It has been shown that snowmobiles contribute a large sum of money into the stream of commerce across the nation. According to the International Snowmobile Manufacturers Association, snowmobile riders in the United States and Canada spend over $10 billion on the sport each year. With the average snowmobile enthusiast spending around $4,000 on costs associated with riding, such as equipment, vacations, clothing, and accessories. [2] 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. [3]

From this it seems clear that many communities have a great economic dependency on snowmobiling; not to mention the large portion of jobs that are backed by the snowmobile industry. 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. [4]

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 time, maintaining or improving the original performance of the stock machine. [5]

DESIGN OBJECTIVES

The main objectives for Clarkson's 2005 entry into the Clean Snowmobile Challenge™ are to develop a system to reduce the emissions and sound emitted from a stock snowmobile (first phase design strategy). Making 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 2005 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 2005 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 easily be installed by the average outfitter to make a stock snowmobile suitable to operate in environmentally sensitive areas such as national and state parks.

With value being and ever-present concern, it was important that the exhaust design be catered to the snowmobile enthusiast looking to reduce emissions and sound levels in a cost efficient way. If implemented, the entire system can be purchased as an aftermarket upgrade from a retailer and could be installed easily in one weekend. Additionally, in keeping with an easy 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 in using the Arctic Cat T660 Turbo included space under the hood, track clearance within 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 2005 muffler system design was to further reduce the level of sound coming out of a turbocharged engine over the system from the 2004 CSC noise level of 108 dBA. Designing a muffler system for a turbocharged engine is significantly different than a system for a naturally aspirated engine. Turbochargers tend to absorb the flow pulsations from the engines exhaust; however they in turn emit a higher frequency pulsation. Most naturally aspirated engines tend to produce a lower frequency noise, and therefore require a different type of exhaust system to be effective.

There are several traditional ways to deaden sound produced by exhaust systems these include; fiberglass packed (straight through absorption) mufflers, resonance chambers, baffle type mufflers, and restricted flow mufflers. [6] In designing a muffler for a system with a turbocharger, the amount of backpressure produced by the exhaust system is related to the performance of the turbocharger and in turn the engine. By decreasing the pressure drop across the turbocharger (increasing backpressure) the performance of the turbocharger decreases. Therefore it is best to design a system that has the lowest possible restriction.

A second factor included in turbocharged systems is the volume of 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. A possibility of dealing with this 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 not be in the spirit of the competition to replace the turbocharger at a high cost.

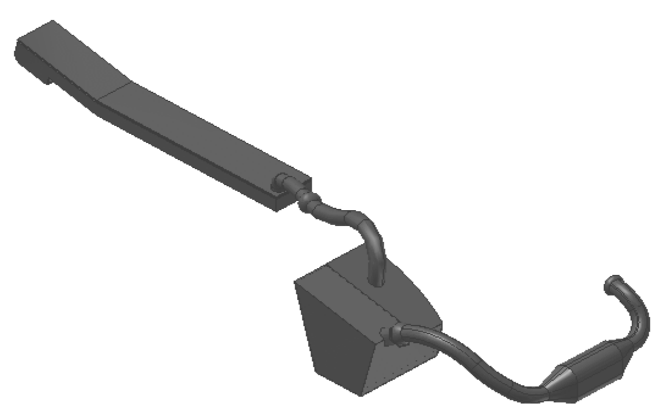


Figure 1: Assembled muffler system.

By keeping the stock turbocharger and waste gate assembly it would make it more economically feasible to sell an after-market upgrade that could reduce the noise levels of the snowmobile (not to mention ease and skill requirements of 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 a good way to handle the flow until it becomes less turbulent. [7]

Designing a muffler of the largest possible volume for the space available is a good way to begin. A larger volume muffler, in most cases, allows the pressure pulsations entering the muffler a better chance of canceling out or becoming smoother. While a muffler with a minimal volume can be effective, it is easier to muffle a range of conditions with the larger volume.

This year's exhaust system design replicated and improved upon the dual in-line muffler system that was developed for the 2004 CSC. The primary muffler, as a single system, incorporates absorption and baffle type silencers in an expansion chamber. A restriction type silencer was ruled out due to the detrimental effects of adding backpressure to an exhaust system with a turbocharger. A resonance chamber was ruled out due to the frequency of the pulsations coming out downstream of the turbocharger. The frequency is too high for a resonance chamber to be effective. Incorporating a resonance chamber design for the pulsations emanating from the waste gate might be a good idea for some applications; however for this application (due to the high speed of the engine) there would most likely be little change in the exhaust noise level considering the remainder of the system.

Figure 2: Cut-away view of primary muffler. Notice perforated inlet tube and perforated bottom plate.

When the exhaust enters the primary muffler there are two routes that it can take. The entrance pipe is perforated to allow part of the flow to disperse into the open volume of the muffler. The rest of the flow is directed to the end of the entrance pipe and is directed 90 degrees toward the inside of the muffler. In order for the combined flows to exit the muffler they must pass through a perforated plate at the bottom of the muffler and pass into the exit pipe.

The theory behind this muffler is to mix the pulsations as much as possible by creating the longest path for the flow to travel in the volume given before exiting. This design incorporates elements of an expansion box silencer, a baffle type silencer, and to some extent a resonator.

The goal of the rear silencer is to absorb sound and direct the exhaust to a position that will aid in dampening the noise. This was accomplished through sound absorptive material and baffling techniques. Since sound waves travel in straight lines and much faster than the velocity of the gas in the exhaust, muffler packing was used to absorb them. The design incorporates baffles that encase fiberglass muffler packing. The baffles are perforated to allow the sound waves to enter.

The goal of the rear silencer is to absorb sound and direct the exhaust to a position that will aid in dampening the noise, while not creating backpressure that would take away from the performance of the turbocharged engine. This was accomplished through sound absorbing material and baffling design. Since sound waves travel in straight lines at a velocity much greater than the gases in the exhaust, muffler packing was used to absorb them. The design incorporates five fiberglass packed baffles. Four of the baffles extend from the side of the muffler along the length of the muffler. The fifth baffle is shaped like a diamond and is located in the center of the other four. The material chosen for the baffle wall was a fine steel mesh. The mesh allows the sound waves to enter and be deadened without creating excessive restriction whereas perforated steel baffles tend to reflect more of the sound waves elsewhere. As a final measure, the exit of the secondary muffler was routed under the tunnel and directed toward the front of the rubber track. The rubber serves to break up even more of the exhaust pulsations and thus deaden more of the exhaust noise. The final results yielded a rear silencer that was very quiet but still reasonably free flowing.

Several different muffler and silencer designs where 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.

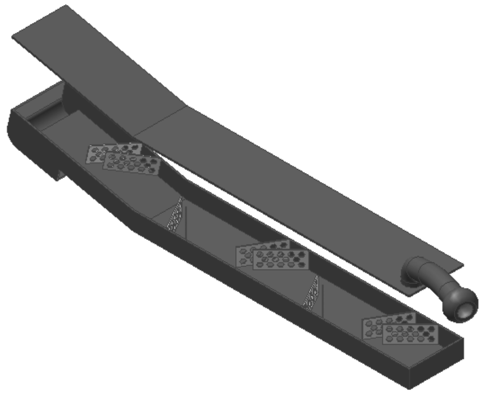


Figure 4: Cut-away view of secondary muffler.

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.

Tightly packed fiberglass packing was chosen to fill each of the baffles in the rear silencer. The two issues encountered by using standard packing are melting and blowout; however the design of the baffles takes these problems into consideration. The packing should be able to withstand the temperatures produced in the secondary exhaust as it is the farthest element from the engine and is self-cooled by the snow debris from the track. The tight steel mesh will adequately hold the packing in so as blow out is limited. While tightly packed fiberglass would deaden the sound to a lesser extent than a looser packed material, the service life, however, would undoubtedly be much shorter.

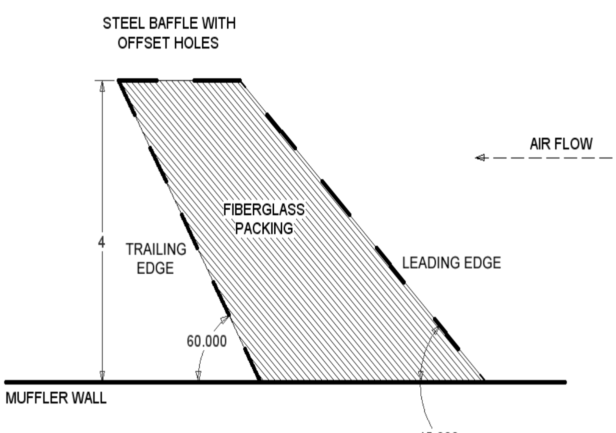


Figure 3: Secondary muffler baffle design.

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 cutting a hole in the tunnel to run the secondary exhaust inlet tube. A template permits the user to easily layout and cut the location for the secondary muffler.

HEAT SHIELDING

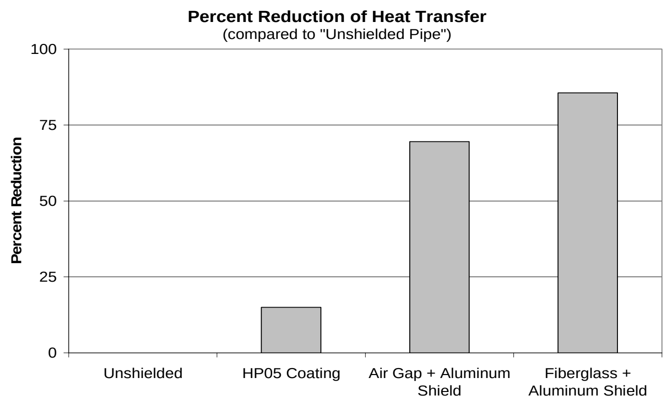
Under-hood temperatures are a concern when dealing with the exhaust system. To protect under-hood engine components from excessive temperatures a composite heat shielding was installed on the muffler system. One of the emission control elements in the redesigned exhaust system was a catalytic converter. This part of the system is one of the most important parts to consider for heat retention along with the area closest to the fuel tank. Modeling of the proposed exhaust system was completed to identify the type/characteristics of the materials necessary to adequately protect the operator and areas under the hood that would require heat shielding. Monitoring 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 measures with the modified exhaust system).

As the catalytic converter is one of the primary sources of extreme exhaust temperatures, a fiberglass-based header wrapping material was chosen. The wrap used on the catalytic converter was implemented to isolate the extreme heat produced at higher RPMs. 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 numbers. 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 mufflers it was decided that the header wrap used to encase the catalytic converter would be 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, should 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 secondary exhaust system from potentially melting the gas tank or igniting the gasoline. The secondary exhaust pipe was designed with an air gap between the exhaust and the tunnel. This gap allows for air to flow between the tunnel and pipe and provides another means of minimizing the heat transferred to the tunnel.

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 primary 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.

All the exhaust piping, the catalytic converter, and the muffler were shielded. This was a precaution taken to prevent vital under-hood components, various hoses, and wires from being damaged by the high temperatures. Due to the tight space allowances between the exhaust system routing and the fuel tank, temperatures needed to be reduced significantly. Shielding this whole area seemed to be the most efficient and cost-effective way to achieve safe temperatures.

SOUND DAMPING

The noise dampening effects desired were accomplished in two ways. The primary method was to run a dual in-line muffler exhaust setup in which a primary muffler was located under the hood and a secondary muffler was located under the tunnel. 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 implementation was to use a product manufactured by Cascade Audio Engineering out of Oregon called Echo Eliminator. [8]

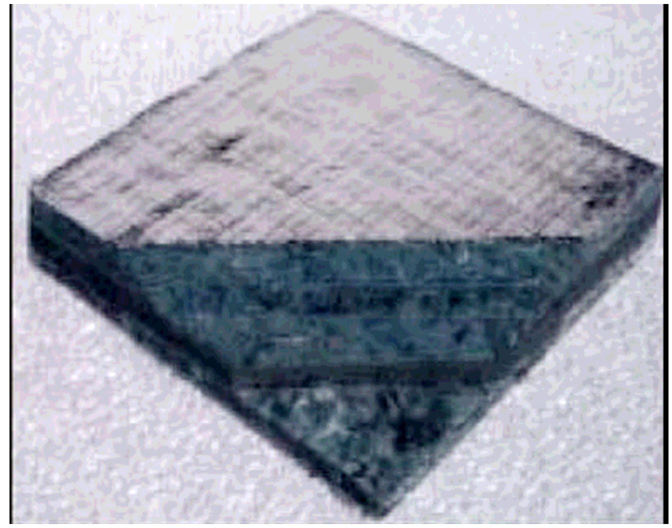


Figure 5: Sample of Echo Eliminator product.

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 developed that enclose 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.

CATYLATIC 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.

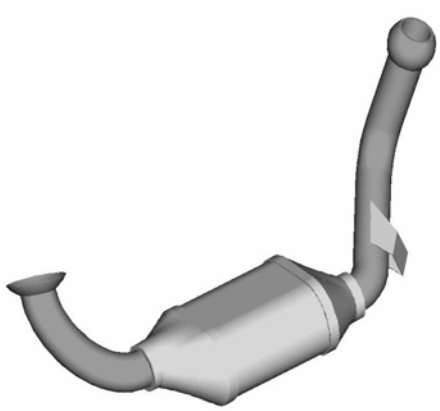


Figure 6: Catalytic converter and exhaust down tube.

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.

CONSTRAINTS

Two stock components required replacement due to their close proximity to the modified exhaust system. These were the air silencer and coolant reservoir. Both these stock components were made of plastic and subject to potential heat damage. With the exception of these two components heat shielding (as discussed above) provides adequate protection against heat damage to other stock components. Monitoring of other stock 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 measures with the modified exhaust system).

AIR SILENCER

Two options were considered to a modified air silencer. The first option was relocated this component to a location above the intake manifold. This location would require rerouting of the intake air to the turbocharger and modification to the hood. This option was not selected due to the increase in implementation cost, decease in the ease of installation, and the modification of the stock appearance of the snowmobile. The section option, which was selected, was the replacement of the air silencer with the same dimensions and volumetric flow made out of a more heat resistant material..

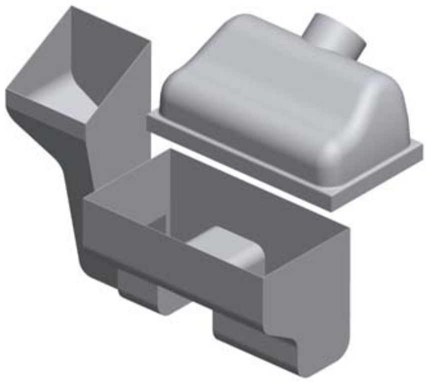


Figure 7: Remodeled air box retaining stock dimensions.

Four criteria were used in selecting the material for the new air silencer. First, the chosen material must be able to dissipate heat at a significantly high rate as well as withstand high radiant heat temperatures. Second the material had to be readily available or easily purchased to keep the application cost to a minimum. Third, since the replacement air box was going to be modeled directly from the stock component, the material need to be malleable to easily conform to the curvature of the stock air silencer. The final consideration was noise properties. The air box is one of the major engine noise dampening elements so the material must be able to absorb sound waves or be made to absorb sound waves using a sound dampening material.

The two materials considered based on these stipulations were 16-gauge steel and 20-gauge aluminum. Material properties for steel and aluminum are summarized below:

Material	Steel	Aluminum
Melting Point[°C] [9]	2730	660
Specific Heat [J/(kg*K)] [9]	500	900
Density [kg/m^3] [9]	7850	2700
Thermal Conductivity [J/(s*m*L)] [9]	~46	210

Table 1: Material Properties for Steel and Aluminum.

Although steel has a much higher melting point then aluminum, it weighs more and transfers heat at a slower rate, thus 20-gauge aluminum was selected for this application.

To maintain the same volume as the stock component, the new air box was made to have the same dimensions and shape therefore giving it the same volumetric flow rate. 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 in the aluminum air box to again reduce implementation cost. In keeping with the theme of an aftermarket upgrade, the aluminum air box was designed to utilize the existing mounting points.

Aluminum is not a very good sound absorbing material; so to improve on the sound dampening qualities of the modified air box an aftermarket material was applied to the interior. The material chosen was a styrene-butyadine-rubber vibration damper made by Dynamic Control of North America, Incorporated. The Dynamat material used was selected for its ability to easily conform to the curves of the air box and its sound dampening qualities. According to manufacturer's specifications the material will dampen vibrations within the air silencer by approximately four percent for the operating temperature range. [10]

BATTERY BOX

In order to meet safety requirements, a battery box was constructed to enclose the battery in case of emergency. Due to space limitations, a commercially available plastic battery box would not fit into the location allotted for the battery. The battery box was fabricated out of standard 16-gauge steel and coated with rubber insulation. As with every other component, the battery box fits into the stock location and uses the stock mounting point.

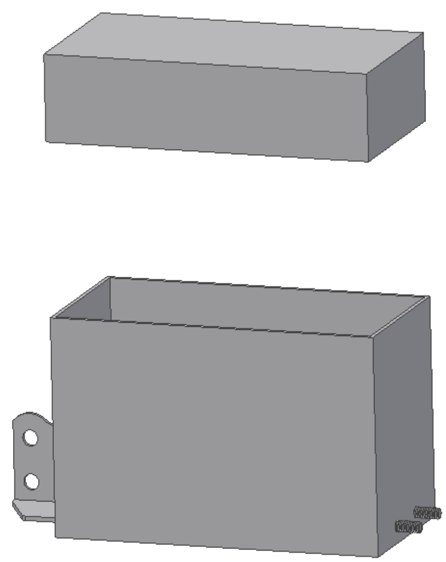


Figure 8: Rubberized battery box.

COOLANT RESERVOIR

A second stock component that required modification was the plastic coolant overflow reservoir. With the secondary muffler mounted under the chassis, the connecting tube between the primary and secondary mufflers ran near the coolant reservoir. To ensure that the plastic would not melt, a new coolant reservoir very similar to the stock element was designed and fabricated to fit in the stock location. Again, standard 20-gauge aluminum was used. It was designed to retain the same volume as the stock overflow reservoir while still being able to withstand higher temperatures.

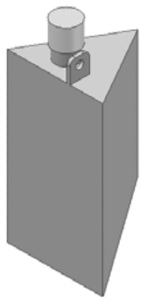


Figure 9: New coolant reservoir.

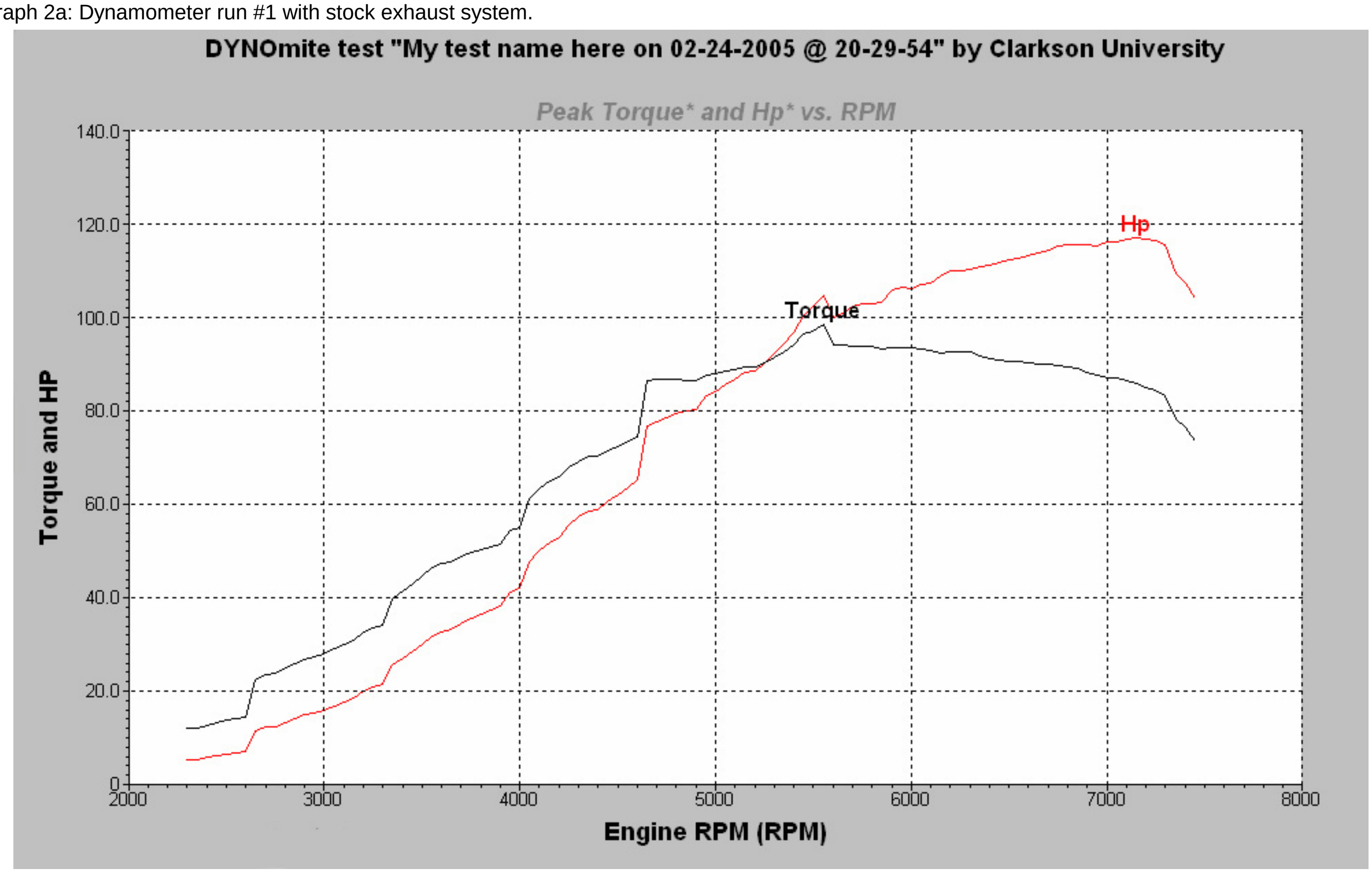
CLUTCH GUARD

A redesigned clutch guard was developed to ensure a much safer operation. Although the stock guard would suffice for an average rider, it was important that an improved design be implemented for two reasons. First, improved safety elements are always important when working with a modified machine. Therefore, the top of the clutch guard was lined with Kevlar strapping to ensure safety in the event of a belt or clutch failure. Also, the new clutch guard was lined with the same Dynamat material as the air box in an attempt to reduce noise from the drive system.

TEST RESULTS

HORSEPOWER TESTING DATA

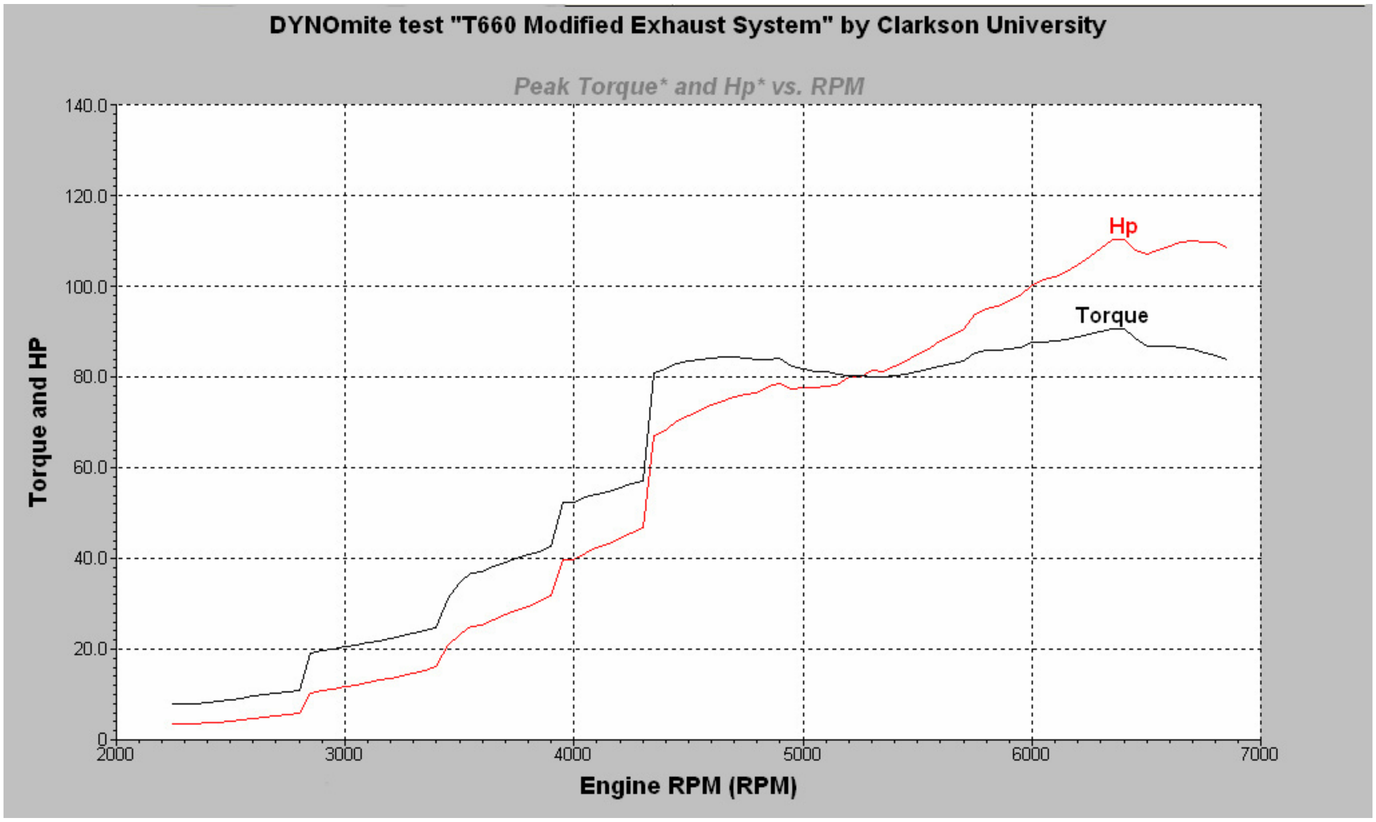
Graph 2a: Dynamometer run #1 with stock exhaust system.



With the newly designed dual 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 power of the engine.

Three separate primary mufflers and three separate secondary mufflers, each with different noise dampening characteristics, were developed and the nine different primary/secondary muffler combinations were then tested on the dynamometer to determine the best combination for both power and noise. Sound level measurements were record during dynamometer testing to evaluate the muffler combinations.

Based on the dynamometer testing results for the nine muffler configurations, to evaluate the configuration that most closely match stock performance characteristics. 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 115 hp at 7300 RPM and the peak torque was 92 ft-lb at 6500 RPM (Graph 2b). This shows that only a very minor loss in power was shown after the addition of the new exhaust system. The primary and secondary muffler design combination selected is described in the Muffler section of this report.



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

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 cooler during dynamometer testing. This airflow rate across the air-to-air heat cooler 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 and EGT probe installed upstream 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 2004 Clarkson University CSC snowmobile involved excessive backpressure caused by the catalytic converted 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 while maintaining the stock horsepower. The prototype catalytic converted developed by Corning, Inc. was developed as a high-flow converter and performed very well. The final designs of the primary and secondary mufflers also were developed to keep backpressure minimal while maximizing the drop in sound levels. The selected muffler combination (discussed above) with the catalytic converter resulted in net increase in backpressure less than 0.5 psig as compared 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 Incorporated. 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. By adding oxygen, any fuel remaining in the exhaust was ignited due to the intense heat of the catalytic converter core. Emission testing was completed in general accordance with the EPA five mode emissions testing procedure. Emission 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.

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

Table 2: Emissions using a five gas analyzer

The addition of the catalytic converter 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-foot run. Clarkson's 2005 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. Modifications to the track to include installation of studs is not permitted in the competition

The secondary muffler posed an additional problem with space. Because the secondary muffler was installed under the tunnel, both of the rear arm-coupler blocks had to be modified to limit the sled from hitting the bump stops and bottoming out. They were moved forward to limit the extension of the rear arm on the suspension. This was done for safety reasons to ensure that the track would not hit the muffler under the tunnel under any riding condition and to prevent damage to the track. The front suspension was also 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.

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 2005 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 combinations of the primary and secondary muffler designs to determine the best pairing.

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 pressures.

FUEL ECONOMY

The 2005 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 that is lower than the rated base of 18 mpg. The decrease in fuel economy was a result of increases in curb-weight and exhaust backpressure from stock configuration. Clarkson's 2005 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 2004 CSC, the 2005 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.

Due to limited outdoor testing conditions, no formal fuel economy testing was completed for this year's entry.

RIDER COMFORT

The newest event in the Clean Snowmobile Challenge™ is the "shock input test" to evaluate rider comfort on the modified snowmobile in accordance with the International Standards Organization (ISO) standard

2631-1, Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration. Due to budgetary constraints formal testing was not completed. Subjective evaluation of rider comfort was completed during field demonstration as outlined below in the Marketing/Endurance Survey.

MARKETING SURVEY

As a means of testing the marketability of the final design, the snowmobile was taken to Cranberry Lake located in the Adirondack Mountains of New York on a typical weekend in February. The purpose of this trip was to perform a survey of the design's marketability and to test the endurance and the durability of the final snowmobile in practical riding conditions. Cranberry Lake is a state owned lake at which many riders come together. Several avid snowmobile riders were given the opportunity to test run the Clarkson University snowmobile. After each test, the rider was asked what he or she thought of the snowmobile in several different categories ranging from noise, to overall design.

The market demographic sampled at Cranberry Lake ranged from 18-66 years of age and various levels of rider ability. Many of the testers described themselves as aggressive riders and really put the Clarkson snowmobile to the test on the groomed trails and lakes of northeastern New York. The demographics included snowmobile riders that categorized themselves, ranging from novice to expert trail riders and competitive drag and snow-cross racers.

Category	Average Score
Acceleration	4
Power Output	5
Cornering	4
Overall Handling	3
Suspension	4
Noise level	5
Fit & Finish	4
Weight	3
Instrumentation	5
Overall Design	5

Table 4: Average rating of marketability survey.

Eighty-five percent of the test demographic had positive comments towards the innovative designs and the construction of the different engineered parts on the snowmobile, and nearly every rider was quick to comment on the low sound levels after the test runs. The survey incorporated ten aspects of the snowmobile design and was rated on a scale of 0 to 5, with a 5 being the best.

The majority of the riders rated the performance, handling and appearance well above average in most categories. The two categories that were ranked average were overall handling and weight. No categories were rated below average (a score of 3).

The suspension category was used as a measure of rider comfort as an alternative to the shock input test. Survey results show that the majority of the riders surveyed rated Clarkson's 2005 CSC entry above average for suspension responsiveness and rider comfort (a score of 4).

Ninety-five percent of the riders surveyed indicated that they would, if required by regulation, purchase Clarkson's 2005 exhaust system and noise reduction upgrade to maintain the ability to ride snowmobile trails in environmentally sensitive areas. Several respondents comment that maintaining the stock appearance of the snowmobile was one of the key factors in their consideration of purchasing the aftermarket upgrade.

RELIABILITY OF DESIGN MODIFICATION

The 2005 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 emissions 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 entire system as an aftermarket upgrade to the Arctic Cat T660 Turbo was calculated to be $288.

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Corning, Incorporated
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