# CSC Snowmobile Conversion Kit Concept

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## ABSTRACT

The University of Maine Snowmobile Team has modified a 2003 Arctic Cat for the 2006 Clean Snowmobile Challenge. The Arctic Cat is a 4 stroke sled with a 660cc engine. These sleds have lower noise, vibration, and have better emissions and fuel economy then 2 stroke sleds. With this in mind the 4 stroke sled was chosen to be the “ideal” base sled for the Conversion Kit concept that our group will feature this year. The idea is to purchase a kit off the shelf, making it possible to transform any 4 stroke sled into a quieter, lower emission producing snowmobile.

## INTRODUCTION

In Maine, there are 13,000 miles of snowmobile trails. Over 100,000 people used these trails last winter alone. Some just for the day and others come for weeks. Some of these trails are being threatened because of the environmental impacts left by snowmobiles. In order to slow this trend, the sleds need to leave less of a mark. This year for competition, the University of Maine is hoping to show that with a few simple modifications, any sled can be a quieter, cleaner machine.

This year the University of Maine Snowmobile Team created the idea of making a Snowmobile Conversion Kit (SCK). Ideally the SCK would be sold as a “do it yourself kit” in order to make any 4 stroke sled into a better performing and cleaner running snowmobile. To accomplish this University of Maine Snowmobile Team was divided into three smaller groups. The first was the Cowling group which had the task of making a custom cover for the snowmobile engine. This needed proper engine ventilation and aesthetic appeal. The second group was Noise, Vibration and Harshness. While 4 stroke sleds have made a major reduction in each of these areas, we decided to push this even further. Much of the noise control was needed around the clutch, the engine compartment and the track. The third group was Emissions group. This group had the task of finding a way to reduce emissions beyond the recently approved 2012 emissions standards. These standards were for CO not to exceed 275 g/kW-hr and $HC+NO_X$ not to exceed 90 g/kW-hr. The standards still leave much room for reduction of emissions to create a more environmentally safe snowmobile, which our team hopes to exploit.

The following paper discusses how the University of Maine Clean Snowmobile Team has developed the idea of the Conversion Kit.

## MODIFICATIONS

### COWLING

Approach

The cowling performs multiple functions on a modern snowmobile. It is not only there to improve the looks of the sled, but it protects the engine bay from the outside elements, provides directed cooling for the engine bay, and finally helps with noise abatement. A stock hood on a modern sled is in itself a decent engineering undertaking due to all these considerations.

That said, the cowling that came stock on our Arctic Cat 4 Stroke sled no longer fits due to the modifications that have taken place under the hood. The relocation of the muffler specifically causes much concern, as the hood would be resting on the muffler. Obviously, due to the extreme heat that comes from the muffler, this is a poor design. Other considerations are taken too, such as the fact that the gages are attached to the hood, making it harder to run tests with the hood up.

With these items in mind, the University of Maine team in the past has created custom hoods for our Arctic Cat sled. Every year has produced a functional hood, though each year has had its shares of flaws. The first attempt was not the cleanest looking hood as far as styling goes, though it did provide adequate clearance of most internal parts. The second attempt was much more traditionally styled. However, this hood did not have enough clearance and as a result the insulation was burned near the hood scoops and other localized spots on the hood. This hood also had problems with fitting, that with any luck can be rectified this year.

Our approach was to take the previous years attempt and improve upon it. They had a very solid start and simply lacked the time to see it through. Our plan was to make sure the overall look stayed traditional and clean, while improving upon the clearance and fit issues.

While doing this, we also underwent some thought processes on improving the composite material choices and lay-up. Previous years basically consisted of laying down more and more fiberglass and filler material with basically an eyeball method. If it looks good, it must be good. This has worked but resulted in a hood that is heavier then it needed to be. Our thoughts were to use lighter weight materials where physically and cost efficiently possible, i.e. carbon fiber, and make sure that it was used as sparingly as possible.

One other drastic change from years past is the resin infusion process. Previous attempts have been made with hand lay-up, pre-pregging the fiberglass and laying it into a waxed mold. This year a vacuum capable mold was made to enable a Vacuum Assisted Resin Transfer Molding (VARTM) process to be used. The result of this is a much more reasonable fiber/volume fraction and a much higher quality part over all.

Of course, all this work would have been for nothing if the sound abatement was not up to par. We worked closely with the Noise/Vibration/Harshness (NVH) team to decide what could be done to improve on sound quality while still keeping airflow adequate to cool the motor.

## Design Overview

The first week or so of the project were spent simply examining the previous years attempt at making a hood. The major design flaw noticed was that where the hood went over the muffler hung too low and would cause it to burn. Another deficiency noticed was that there was no windshield for the cowling. Beyond that there were some fit and finish problems but it was an overall solidly designed hood. We felt we were best served saving time by using the existing plug that was made the previous year and modifying it to fit our needs. A Solid Works drawing of the hood from this existing plug can be seen in figure 1.

Figure 1: Solid Works model

The rest of the time we spent prior to construction was used researching various materials that were applicable to our new cowling. The major materials discussed were carbon fiber and fiberglass. Originally, we were leaning towards fiberglass due to the lower cost and in hopes of keeping the hood cost effective. Carbon fibers superior stiffness and reduced weight compared to fiberglass cause it to be a superior material for this application, a stiffness driven part. Cost being a factor though, it was close to a tossup for a while. However, a timely donation from a company making an innovative type of carbon fiber in Greenville, Maine, caused our thinking to skew in the carbon fiber direction.

## Implementation

The first step in the process of making a new hood was to make a plug able to produce a quality mold capable of using a VARTM process. Knowing that the previous years plug, an item produced via plywood, foam and Bondo filler, produced a viable part, we figured a few simple modifications could cause it to produce another viable part with a few of the kinks worked out.

The first step was to increase the hood height above the muffler. We accomplished this by taking the existing flat spot above the muffler and blending in some 1” foam panels. These were then Bondo-ed into place to create a smooth rise. While doing this, we decided we would rather have a ram-air style air inlet atop the hood instead of the NACA style ducts used previously. This was again made out of foam and then Bondo-ed into place.

While these created the necessary clearances for the muffler, we were still left with the process of making a windshield fit the hood. A little experimentation resulted in the discovery that if we took the flat spot where the light was mounted previously and round it out, we could place the original headlight and windshield onto the hood, improving looks tremendously and making the overall hood more functional. This process can be seen in figure 2.

Figure 2: Windshield plug modification

Concurrently with making these change we placed the plug onto a piece of shower board and filled the gaps down to the board with foam and Bondo so that when the mold is made there will be a flange circling the perimeter of it. This can be seen in figure 3.


Figure 3: Plug preparation

This will enable us to do two things. The added length will enable a prototype cowling to be produced too tall and from there capable of being cut down and custom fitted to the sled, instead of relying on measurements taken to force the part to be made to size initially. Once this is done for the first part it can be placed back in the mold and traced so that future parts do not have excess material and time wasted in fabrication. The second advantage of the flange will be to enable a vacuum bag to be sealed around the perimeter of the mold. This enables a VARTM process to be used in the fabrication of the cowling.

Once the plug is finished it is sanded and painted to a smooth finish (this can be seen in Figure 4). From there a number of layers of release agent are applied to ensure the mold will separate it from the plug. Hand lay-up of a thinner layer of fiberglass and separate thicker layers of fiberglass give the mold a smooth inside shape while still having a stiff shell so that it is less likely to be damaged while being used.


Figure 4: Finished plug

Upon release of the mold, any necessary smoothing of the interior was done. It was waxed and a prototype cowling was produced using some cheaper fiberglass. The VARTM process used was SCRIMP (SEEMAN Composite Resin Infusion Molding Process). It basically consists of pulling a vacuum onto the part and putting a flow media fabric over the fabric to be infused and introducing resin to one side and letting the resin flow across to the vacuum port on the far side. It worked well for the prototype. A day was spent fitting it to the sled and mocking up a hinge system, a part that wasn't on the previous hood but was discovered to be an adaptable part once the hood was on. See figure 4.


Figure 5: Prototype hood

Once the prototype was discovered to be successful, a carbon fiber part was made. It was fitted to the snowmobile and everything was attached to it, from the windshield and headlight to the sound deadening material on the inside.

Results

The end result of our endeavors is a functional hood that combines relatively clean looks with improved functionality over previous years. Overall weight is reduced while the cowling itself is at least as functionally rigid as the older hoods. In addition, usability of the hood has improved due to the implementation of the stock style hinge.

The other result of our work is a mold that is sturdy and well made enough that it can continue to be used for years to come. Just because we used one fiber style and layup does not mean that it is the optimal setup. Future years could have new hoods made that both increase rigidity while reducing weight. This cowling will remain to be useful as long as nothing fundamentally changes in the engine bay.

Conclusion

In conclusion, it appears we have met our goals for this project. The cowling has much better fit and finish qualities now. It has reduced weight, improved cooling and good NVH qualities. Last of all, we now have a mold that can be used year after year as long as the clearances remain the same to continue working in reducing weight and increasing rigidity.

## NOISE, VIBRATION, HARSHNESS

Approach

The Noise, Vibration and Harshness Group decided to approach the problem of a noisy stock snowmobile by identifying the major sources of noise and vibration. Initial sound testing revealed that there were three major sources of harsh noise: Engine compartment, Clutch, and Track/Suspension. Each source had a characteristic noise signature that differed by frequency, amplitude, and nature. Therefore, each source must be reduced by implementing different techniques.

An initial sound test was done using the SAE J192 standard. This is the same test set-up that is used at competition. These test runs were used as the baseline data. Once modifications were made, subsequent tests could be performed to see if the changes reduced the noise.

## Design Overview

### Engine Compartment

Major noise sources in the engine compartment include the motor and the exhaust system. This snowmobile is stock equipped with a 4 stroke 660 cc normally aspirated motor. Since this motor is already very quiet, the only necessary modification to the engine compartment is insulation of the cowling. The insulation used is Acoustical Surfaces Echo Eliminator Composite. This insulation is a four layer cotton composite consisting of a foil front face on a low density cotton sandwiching a high density cotton layer and was chosen for its superior noise absorption at all audible frequencies.

The cowling was redesigned from the previous year to make room for the new sound absorbent material, and to implement the use of a single scoop as a replacement of the previous scoops that emitted too much noise. In an effort to reduce noise emission out of the cowl, the cowling has a single scoop that is coated with QuietCoat sound absorbing material and baffled.

### Clutch

From the preliminary sound test runs, the clutch side of the side of snowmobile was significantly louder than the opposite side. It was decided that this problem was serious enough to dictate a redesign of the clutch cover and compartment to introduce high performance sound deadening material directly around the clutch assembly. To insulate the clutch compartment it will be completely sealed off by the clutch cover and a combination of sound absorbing materials. To manage heat buildup around the clutches we will add a blower to the engine compartment to provide flow through the sealed compartment.

### Track/Suspension

During our initial sound testing, a metallic clanking was heard whenever the snowmobile was in motion. Upon further investigation, it was determined that this sound was caused by the main suspension rebounding against a track crosspiece. This metal on metal contact added harshness to the overall noise generated by the snowmobile. To eliminate this noise, we designed and installed a bumper system made of a motor mount material from Acoustic Surfaces (Solid Works model can be seen in figure 6). This high durometer material was used because of its ability to resist the high forces applied to it when squeezed between the suspension bar and crosspiece.

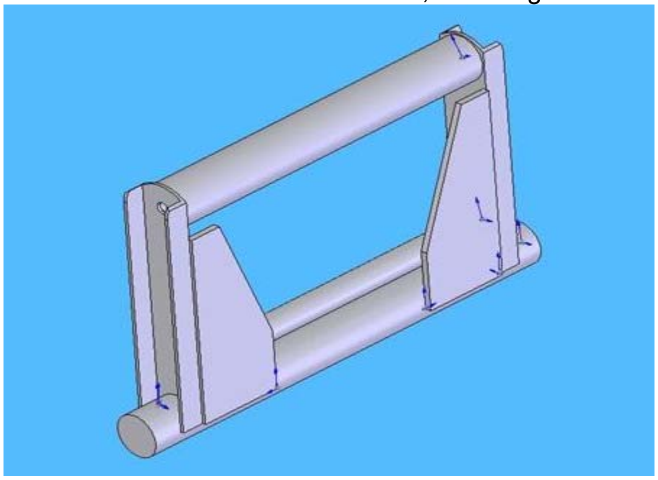

Figure 6: Rebound assembly modification

The other main source of track noise was the track itself rubbing on the runners. To alleviate this noise problem we have added a total of eight new wheels to the suspension geometry. This will decrease the noise and power-loss associated with track friction and also decreases the wear on the runners.

## Implementation

### Engine Compartment

The single hood scoop was riveted to the cowling and then coated with QuietCoat. The main insulation was cut using cardboard templates and adhered to cowling.

### Clutch Compartment

The compartment was lined with mass loaded vinyl to help create a seal and insulated with the cotton Echo Eliminator. A centrifugal blower was mounted in line with the hood scoop and ducted directly into the front of the clutch compartment (see figure 7). The clutch cover was redesigned to fit onto the sealed compartment and facilitate easy removal.

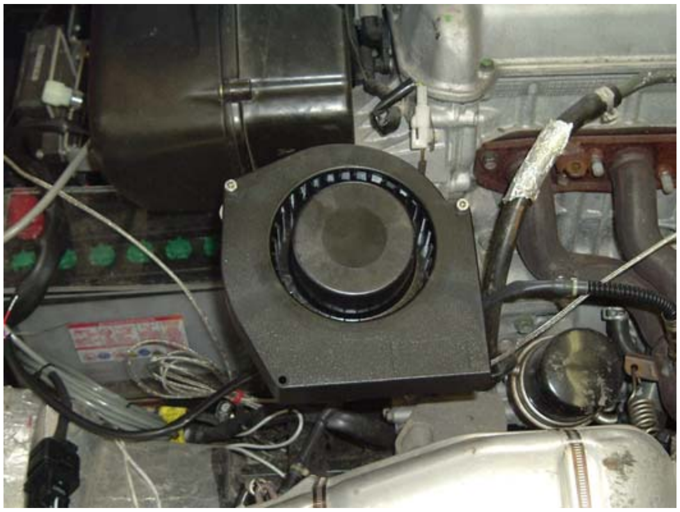
Figure 7: Blower assembly

### Track/Suspension

To create the rebound assembly, a steel plate was cut to fit on the existing rebound arm and steel risers were welded to it to achieve the required distance off of the rebound arm. The motor mount material was cut to size using a band saw and attached to the steel plate using two-part epoxy. To prevent the edges from separating from the plate, a steel gutter was welded to the top and bottom of the assembly (see figure 8).


Figure 8: Rebound assembly

The eight idler wheels were added as two sets of four wheels, one in the very front of the runners towards the engine, and one set in the rear. Two of the four wheels on each set were pressed onto a shaft located between the runners spaced with tubing and hard plastic washers at contact points. Then one wheel is placed on a shaft on either side outside of the runners. The wheels are spaced from the runners using the same plastic tubing. The whole assembly is held together with a bolt from the outside through the outer shaft, into the threaded center shaft (see figure 9).

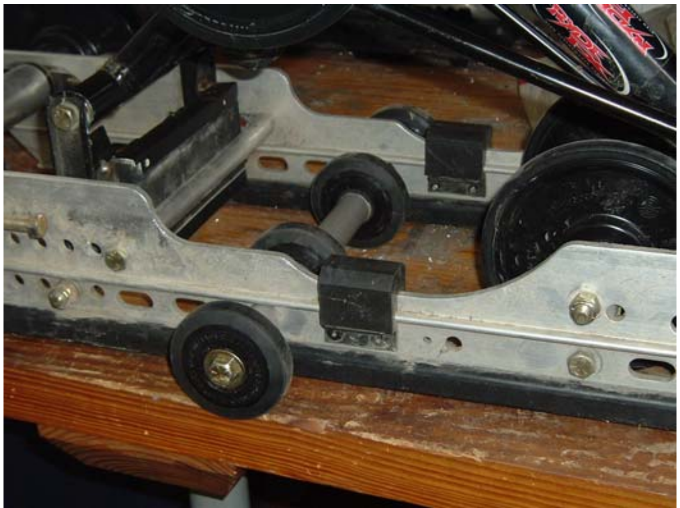
Figure 9: Idler wheel assembly

### Results

The initial sound test was run on damp grass and the ambient temperature was 50°F. There were 4 passes made by the snowmobile. The average of these passes was found to be 77.8 dB. After all the modifications were made, another sound test was performed. This sound test was done on packed snow covered with fresh powder and the ambient temperature was 20°F. There were 6 passed made by the snowmobile. The average of these passes was found to be 68.75 dB. That is a reduction of 9.05 dB. To account for the difference in conditions, a 3 dB correction factor was used. This makes the overall reduction roughly 6 dB.

### Conclusions

It was the goal of this project to take a stock four stroke snowmobile and through several modifications make the sled quieter, cleaner, and more attractive. The Noise, Vibration and Harshness Group decreased the emitted sound by approximately 6 dB by applying a relatively few number of specific solutions. Though the modifications were tailored to this snowmobile, they can be implemented on virtually any stock four stroke snowmobile. This very significant reduction in noise pollution will allow the snowmobile to be used in noise sensitive areas and will improve rider comfort and lessen environmental impact on any trail in the nation.

## MICROCONTROLER / EMISSIONS

### Approach

The Emissions group of the University of Maine sled team decided to continue along a similar path as previous University of Maine emission teams. During the first year in the CSC competition in 2004 the emissions team decided to add a catalytic converter to the 4 stroke 660cc Arctic Cat engine that they were using. Last year the emissions team decided after a serious of tests to leave the catalytic converter intact and try to improve the sled through a micro-controller unit. This first micro-controller unit only took a single reading from the sled. This was used through a large circuit, also known as a piggyback to control the Air Inlet Temperature (AIT). This was altered inside the piggyback depending on various readings to change the AIT that the sled ECU was reading. This in turn controlled the Air to Fuel ratio

(A/F). When the A/F ratio is running at a rich mixture the amount of CO, and HC are reduced. When the mixture is running at a lean mixture the amount of $NO_X$ emissions are reduced. With only one input to determine the sleds conditions it is hard to determine what a good A/F ratio would be.

This year we took the piggyback a step further. We went ahead and added second input to the piggyback in hopes to control the A/F ratio better at idle conditions, which was the worst performance we had last year, and the rest of the throttling range.

## Design Overview

### Catalytic Converter

The use of a catalyst on exhaust emissions is well established. The catalyst facilitates chemical reactions that convert oxides of nitrogen, carbon monoxide and unburned hydrocarbons to less detrimental gases such as carbon dioxide and water.

The catalyst increases the rate of a chemical reaction while not going through any changes itself. This often means that reactions requiring heat can occur at lower temperatures. In order for a reaction to occur, reactants must pass through energy barriers to produce the products. A catalyst lowers the amount of energy needed for a chemical reaction to occur by creating intermediate products which are subsequently broken down. Although the initial and final enthalpy of the reactants and products are not changed, a catalyst lowers the energy required to cause the reaction. The more catalyst surface area exposed to the reactants, the more effective it is. A catalytic converter is a piece of hardware installed on the exhaust of a vehicle to expose a catalyst surface to the exhaust gases, allowing the chemical reaction to occur. Use of catalytic converters has been employed in the auto industry to lower exhaust emissions with this type of chemical reaction. When automotive emissions were first recognized as a problem in the late 1960's and early 70's, two-way catalysts were employed. These first generation catalysts used platinum (Pt) and palladium (Pl) in a ratio of 2.5:1 or 5:1 in the catalyst material. These were strictly oxidation catalysts that burned the unburned hydrocarbons and converted carbon monoxide into water and carbon dioxide. The oxidation reactions are shown mathematically in figure 10.

$$C_yH_n+\left(1+\frac{n}{4}\right)O_2\longrightarrow yCO_2+\left(\frac{n}{2}\right)H_2O$$

$$CO+\left(\frac{1}{2}\right)O_2\longrightarrow CO_2$$

Figure 10: Equation for the oxidation reactions of catalyst

Since these catalysts used only the oxidation reaction to reduce hydrocarbon emissions, nitrogen oxide emissions (NOX) were controlled by use of EGR, exhaust gas recirculation. EGR is a method of reintroducing exhaust gases into the engine to dilute the combustion gases and lower the peak flame temperature, thereby lowering the amount of $NO_X$ formed. EGR led to a reduction in engine performance due to combustion gases mixing with fresh charge coming into the engine. EGR is not completely negative though, as it also causes a reduction in pumping losses in an engine, which usually increases fuel economy and is therefore still used in modern engines. In order to fully reduce $NO_X$ emissions without dependence on EGR, companies allowed for a reduction reaction to occur in the catalytic converter in second generation catalysts. This new catalyst, a three-way catalyst, uses an oxidation reaction that reduced hydrocarbon and carbon monoxide emissions and also uses a reduction reaction to reduce $NO_X$ to Nitrogen. The reduction equations for $NO_X$ are shown mathematically in figure 11.

$$NO(orNO_2)+CO\longrightarrow\left(\frac{1}{2}\right)N_2+CO_2$$

$$NO(orNO_2)+H_2\longrightarrow\left(\frac{1}{2}\right)N_2+H_2O$$

$$\left(2+\frac{n}{2}\right)NO(orNO_2)+C_yH_n$$

$$\longrightarrow\left(1+\frac{n}{4}\right)N_2+yCO_2+\left(\frac{n}{2}\right)H_2O$$

Figure 11: Equation for the reduction reactions of $NO_X$ to Nitrogen

In early systems, the catalysts were impregnated on a ceramic beaded structure due to the abundant supply of beads used in other industrial applications. Unfortunately, these beaded catalysts significantly restricted the flow of exhaust gases and decreased engine performance. To increase exhaust flow within catalytic converters and increase engine performance, a honeycomb style catalyst was developed for second generation catalysts, allowing good catalyst reaction with a large amount of surface area. Rhodium (Rh) was the first metal used as the reduction catalyst in second generation systems, but it was found that at higher temperatures it could combine with oxygen and volatilize. It was then replaced with rubidium (Ru) in third generation catalysts. In these systems, the oxidation reaction takes place downstream from the reduction reaction in the catalytic converter. This allows $NO_X$ to be reduced first, producing excess oxygen. That way, the downstream catalyst causes a reduction reaction where the unburned hydrocarbons and carbon monoxide are burned into carbon dioxide and water using the excess oxygen. While rubidium (Ru) is used in the reduction catalyst, platinum (Pt) and palladium (Pd) were used as an oxidation catalyst. The following illustration notes the flow of exhaust gases and their reduction and oxidation phases within the catalytic converter used in second and third generation catalysts.

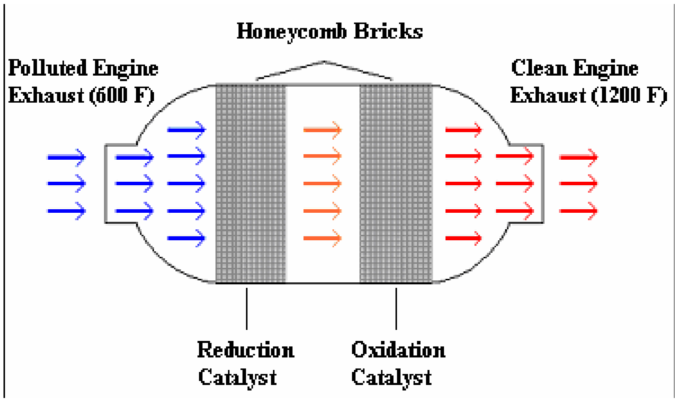

Figure 12: Schematic of Catalytic Converter

Fourth generation catalysts were aided with the development of tighter control over air fuel ratio mixtures. In order to ensure that the proper air to fuel ratio is maintained, an oxygen sensor is placed in the exhaust upstream of the catalysts. Since the oxygen sensor regulated the “dirtiness” of the exhaust emissions before the catalytic converter, a narrower band of operation could be used so that palladium (Pd) replaced platinum (Pt) and rubidium (Ru). This allowed for a cheaper metal substrate that could be coupled closer to the engine allowing it to reach higher temperature quicker, yielding a longer catalyst life. The engine currently used in Arctic Cat snowmobiles uses an exhaust oxygen sensor to control the air fuel ratio. This allows for modern fourth generation three-way catalysts to be added to the exhaust with no modifications, while potentially realizing significant reduction in emissions. Optimal mixture for catalytic converter – In order to ensure that the proper air to fuel ratio is maintained, an oxygen sensor is installed in the exhaust, upstream of the catalysts. When implementing a catalyst on a system that does not have one initially, there must be a balance in the design. The catalyst must fit in the space available in the snowmobile, yet it must have enough surface area to react with all the exhaust gases. If the catalyst is too large it will not get hot enough to light off and therefore will not reduce emissions. Also, the use of the oxygen sensor will be detrimental in determining the optimal air/fuel ratio to be used in lighting off the catalytic converter, thus reducing emissions. Three way catalysts must operate in this balanced manner. High reduction of $NO_X$ requires an oxygen lean environment, while the oxidation of CO and hydrocarbons requires oxygen. In order to properly function and not emit an abundance of harmful pollutants, the engine must operate near the stoichiometric air to fuel ratio, around 14.7:1. Figure 13 shows an operating window for engine operation.

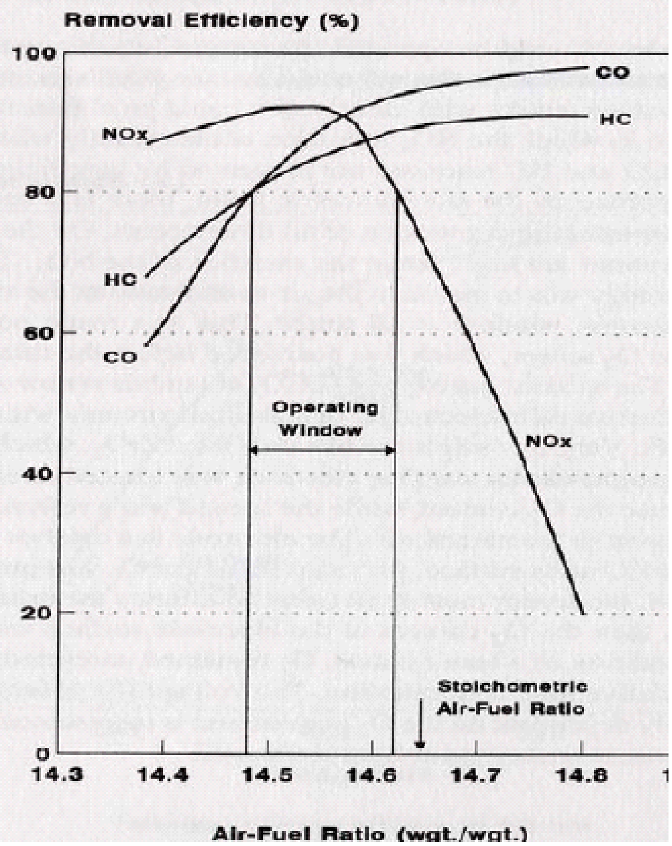

Figure 13: Emissions gas removal as a function of fuel ratio

In the graph above, the percent of emissions gases removed is plotted as a function of the air-fuel ratio. It shows the ideal mixture for maximum emissions reduction of all three gases is approximately 14.6:1. In order to fully reduce emissions with a catalytic converter, the air/fuel ratio must be controlled so that HC, CO and $NO_X$ emissions are reduced. Testing of our catalytic converter with the use of an ECU-micro-controlled piggyback and oxygen sensor would allow the optimal air/fuel ratio to successfully light off the catalyst and reduce emissions.

## Design of ECU Piggyback

One way to control the emissions from the engine is to control the A/F mixture injected into the engine for combustion. The control of the A/F mixture can be accomplished through the use of a “piggyback” electronics system with the help of analyzers such as a wide-band O2 sensor, throttle position sensor, dynamometer, and exhaust gas analyzer. This system will change information going into the Engine Control Unit or ECU. The main purpose of the ECU is to determine the pulse width of the fuel injectors. Pulse width is defined as how long the injectors stay on. The pulse width is determined by sensors which act as inputs to the ECU. The ECU looks at the incoming signals, then through programming logic and data tables determines the appropriate pulse width for the situation. Figure 14 shows a block diagram with the inputs and outputs from the ECU.

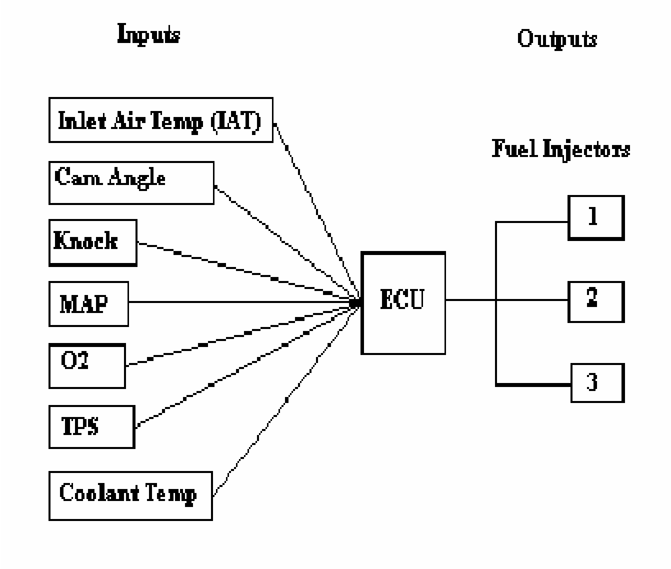

Figure 14: ECU input/output block diagram

Since HC and $NO_X$ are the more important exhaust emissions to reduce, control of the air/fuel ratio via the upstream oxygen sensor must be considered. Since a high reduction in $NO_X$ requires an oxygen lean environment (more fuel, richer air/fuel ratio) and the oxidation of CO and HC requires oxygen (less fuel, leaner air/fuel ratio), finding the optimal air/fuel ratio with the oxygen sensor is needed. However, since Figure 13 does not consider the temperature effects of a catalyst, more consideration needs to be taken when trying to control the A/F ratio with an oxygen sensor. If the catalyst does not reach a high enough temperature, less emissions will be burned off. Therefore, lighting off the catalyst is important to lowering all exhaust emissions such as $NO_X$, CO and HC.
In order to produce high exhaust temperatures, a richer mixture must be used to light off the catalyst. This can be done in one way via the air inlet temperature sensor. Different temperatures yield different preset mixtures from the ECU. By developing a piggyback device that can control the resistance signal, and coupled with the AIT sensor, we are able to control the ECU and effectively change the AFR.

To further aid our goal of reducing emission the throttle position sensor was taped into on the sled and used as another input the to the piggyback to isolate problems we where having at idle conditions. Figure 15 is a hardware diagram of our piggyback for the snowmobile. It is wired in series with the AIT sensor and uses a basic stamp micro-controller and digital potentiometer to control the various resistances.

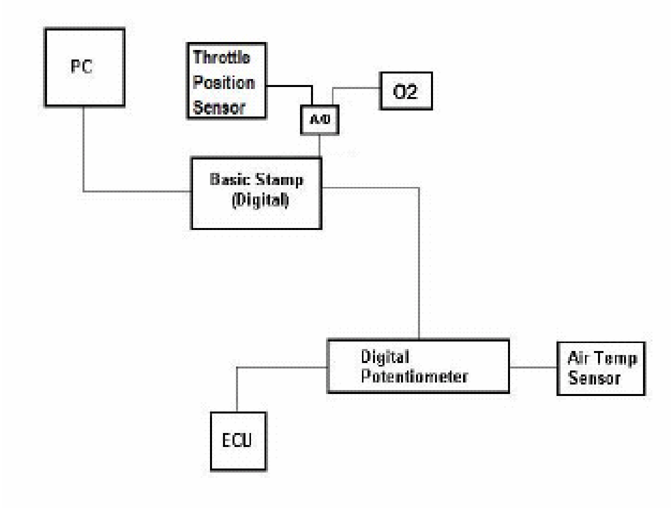

Figure 15: Hardware diagram for digital potentiometer piggyback

Each component is defined below in more detail.

- PC – A computer used to program the basic stamp
- Basic Stamp – A micro-controller
- A/D – Analog to digital converter
- Digital Potentiometer – Changes the resistance
- ECU – Main computer which operates the snowmobile
- Air Temp Sensor – Measures inlet air temperature on the snowmobile
- Throttle position sensor – Measures the position of the throttle
- O2 Sensor – Measures the amount of oxygen in the exhaust system

The basic stamp is a micro-controller developed by Parallax, model BS2P24IC. It can easily be programmed using a form of the BASIC programming language, called PBasic. After the program is written, the micro-controller connects to a computer through a serial cable, and the program uploads into the basic stamps electronically-erasable-programmable-read-only memory (EEPROM). Our design allows different programs to be uploaded onto the microprocessor while the unit is still mounted to the snowmobile. This feature is critical for tuning when adjustments must be made to the logic of the program.

One input to the micro-controller thus far is a Bosch LSU4.2 wide-band O2 sensor. This sensor is mounted before the catalytic converter in the exhaust system to monitor the AFR. The second sensor that was added this year is the throttle position sensor. The micro-controller uses a program based on the relationship between the O2 sensor, the throttle position sensor and the AIT sensor and chooses the best resistance for the current situation.

Once the ECU injects fuel into the cylinders based on the resistance from the AIT sensor, the ECU needs to know if the A/F mixture is too rich or too lean for the operating conditions. This determination of rich/lean mixture is determined by an oxygen sensor is placed in the exhaust stream to measure the amount of O2 in the mixture after combustion. The O2 sensor is calibrated for O2 concentration vs. voltage. The voltage signal is sent back to the ECU as feedback to tell the ECU if the mixture has too much O2 in it or too little, hence if the A/F ratio is too lean or too rich. If the mixture is too rich, the ECU will adjust the injector voltage pulse width so that the mixture is leaner, and vice versa. In order to tune the engine through mixture adjustment with the O2 sensor, there are two types of O2 sensors to choose from based on voltage output. A narrow band O2 sensor uses a 0-1 V range of output, and a wide-band O2 sensor uses a 0-5 V range of outputs. This range of voltage is calibrated for voltage vs. A/F ratio, based on voltage and O2 content in the exhaust stream. Because of the greater range of voltage, a wide-band O2 sensor allows for more fine adjustment of the AFR. This range adjustment can be seen in the O2 sensor comparison in Figure 16.

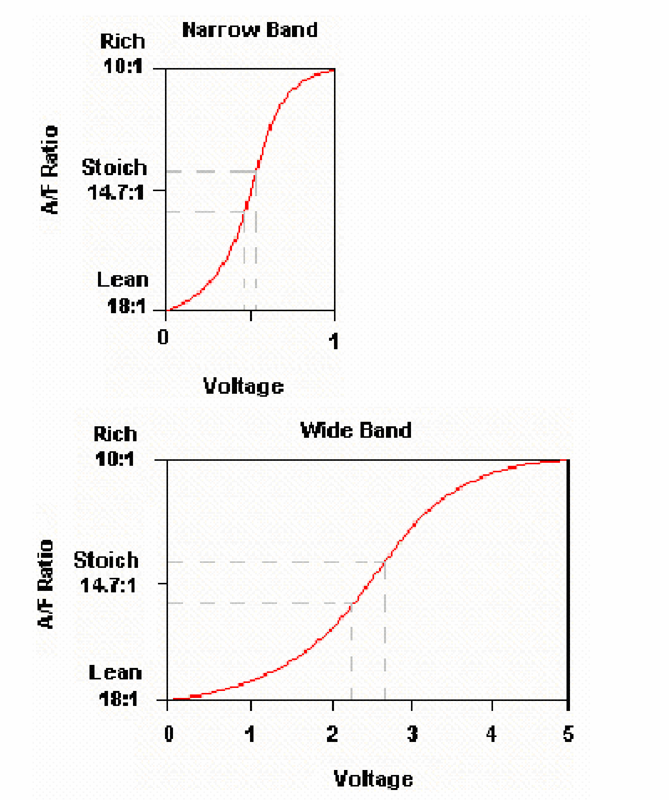

Figure 16: Comparison of narrow and wide band O2 sensor output

Once incorporating the Bosch wide-band oxygen sensor into the design of the piggyback, several computer programs were written to control the air/fuel mixture. Originally, the program called for a variation in A/F ratio throughout the range of voltages supplied by the wide-band O2 sensor. A variation in exhaust gas composition either increased or decreased the resistance on the fly. This type of program worked but due to the complexity in processing for the Basic Stamp, was too complex for our application. After developing several programs, a very simple one worked effectively. This program makes decisions based on the voltage output from the wide-band oxygen sensor in a more defined step pattern. This program gives a firm resistance to a voltage range, rather than allowing the program to vary resistance completely. The output from the oxygen sensor ranges from 0-5 volts, while the micro-controller uses a digital step signal from 0-4095 steps. For example, since stoichiometric air/fuel ratio is approximately 2.35 Volts, this would yield a digital signal step of 1743. In the program, this would yield a resistance of 7.5 kΩ to be sent to the ECU for injector pulse width timing, thus, allowing a richer air/fuel mixture.

## Implementation

The Arctic Cat four-stroke engine exhaust emissions were tested using a similar method as in the SAE CSC competition emissions testing. Instead of using the exact percentages of wide open throttle as supplied by SAE CSC Rules (idle, 65%, 75%, 85% and 100%), the micro-controller piggyback for the ECU was tested using an engine speed schedule of idle speed, 3000, 4000, 5000 and 6000 rpm. To control the load on the snowmobile engine, a DYNO-mite dynamometer was used. With this machine we were able to hold the sled at the set RPMs, while holding the sled at the desired throttle range was unavailable to us. Each RPM interval consisted of a 30 second sampling of exhaust emissions for HC, CO, NO$_X$, CO2 and O2.

The engine coolant temperature was maintained using a small Chrysler radiator and water pump from a supplementary engine testing cart, where all testing were done at a coolant temperature of 180°F. Using an EMS Model 5100 Five-gas analyzer; emissions samples were taken out of the muffler of the snowmobile by a large probe. During testing a rubber tube was connected to the sleds exhaust to control venting of emissions. This tube was lashed on by piper fasteners and the probe was placed inside the tube also tied around the sled exhaust by pipe fasteners. Testing was completed with at least three dynamometer runs for each program alteration and compared to last years results.

## Catalytic converter

In order to recognize the gains in using the catalytic converter, tests were conducted on the stock exhaust system and the exhaust system with the catalytic converter. The procedures for taking the data for these two systems are described in the above Implementation Section of this report. The results for the tests can be seen below in the Results Section of the report.

## 2005 Piggyback Controller

In order to test the piggyback controller from last year the same testing protocol that was applied previously was used here. This process has been previously mentioned at the beginning of the Implementation Section. The Piggyback controller that was used during competition last year was reattached to the sled. The program that we had from last year's competition was downloaded onto the micro-controller before running the piggyback. The results were then recorded and compared to the results in last years report and data files. These can be seen in the Results section.

2006 Piggyback Controller

Several changes were made to the input and program of the piggyback compared to last years model. These could be compared to last years results using this new piggyback but only using the program from last years competition. This program would not take into consideration the additional input from the Throttle Position Sensor (TPS). With this in mind we ran the program on our new stamp. Once we were able to confirm the results from last year were compatible on this new stamp we proceeded to run tests with a new program in order to better control the sleds emissions using the TPS. This involved changing the time steps that the ECU was sampling the TPS, as well as the resistance created to increase or decrease the A/F ratio. The results from this can be seen below in the Results section.

## Results

To determine the best potential areas to lower emissions with the 2006 piggyback unit the two previous years' methods for emissions reductions had to be tested in comparison. These included the addition of catalytic converter on the sled, and then a micro-controller piggyback last year. While the Five gas analyzer gave us readings for several gases the only ones which concerned us were the HC, CO, and $NO_X$ emissions. These test results can be seen below in Figures 17, 18, and 19 for the full throttle range. The methods for taking this data can be found at the beginning of the Implementation section. Each throttle range was held for 30 second intervals.

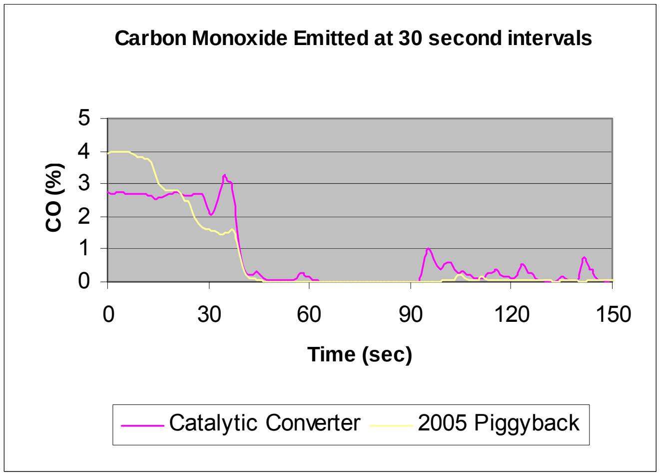

Figure 17: Carbon Monoxide Emissions Data (CO)

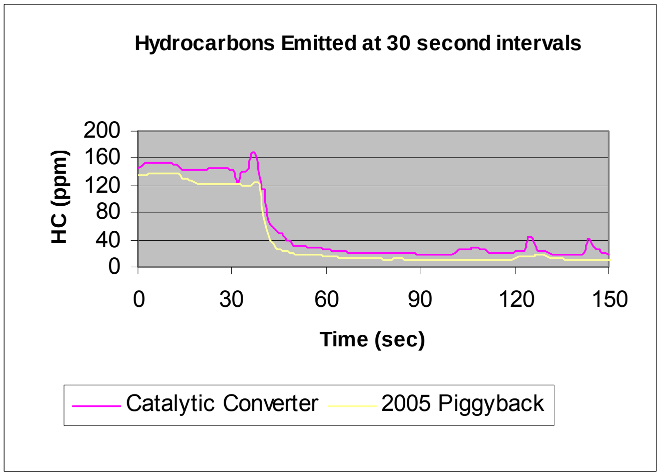

Figure 18: Hydrocarbons Emission Data (HC)

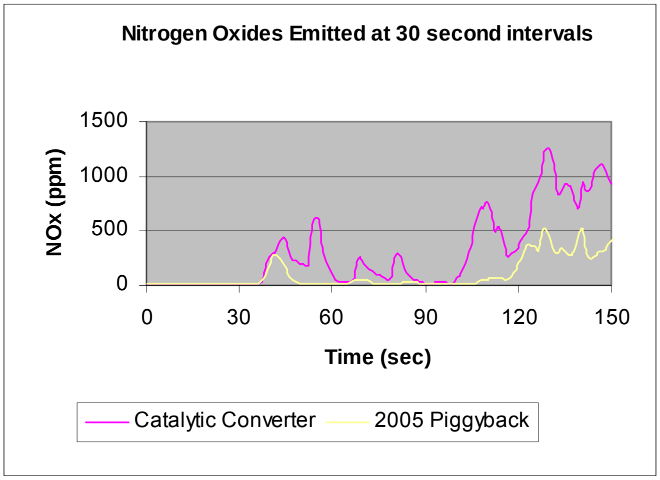

Figure 19: Nitrogen Oxides Emission Data ($NO_X$)

From the figures and running various tests through the full throttle range we were able to determine the best areas to improve emissions. The $NO_X$ emissions seemed to get larger between 5000 and 6000 RPMs. Other then this area the $NO_X$ emissions were well maintained within the rest of the throttle range. The CO and the HC emissions were exactly the opposite. These emissions seemed to get large at idle and low RPMs while they reduced with a higher the throttle position was. This occurs because of the difference in the A/F ratio. With the ratio being to oxygen lean the $NO_X$ emissions will decrease. However having the A/F ratio oxygen rich will allow for the HC and CO emissions to reduce.

With additional tests it became clear that adjusting the $NO_X$, HC and CO emissions at a higher throttle position such as 5000 or 6000 RPMs was possible but much harder to control. Taking this into consideration we decided controlling the idle conditions would be more beneficial to our team's emissions reductions. This position of the throttle range contained the highest readings of HC and CO, while it contained the lowest readings of $NO_X$.

A simple program was developed using the Basic Stamp programming language for our 2006 piggyback. This allowed the TPS to control the sled during certain voltage readings. Once the voltage readings exceeded a arbitrary number we let the wide-band O2 sensor control the A/F ratio for the remainder of the throttle position. This provided the largest emissions changes from the idle range and the 30 second test range at 3000 RPM or 65% throttle position. These emission results can be seen in comparison on Figures 20, 21 and 22.

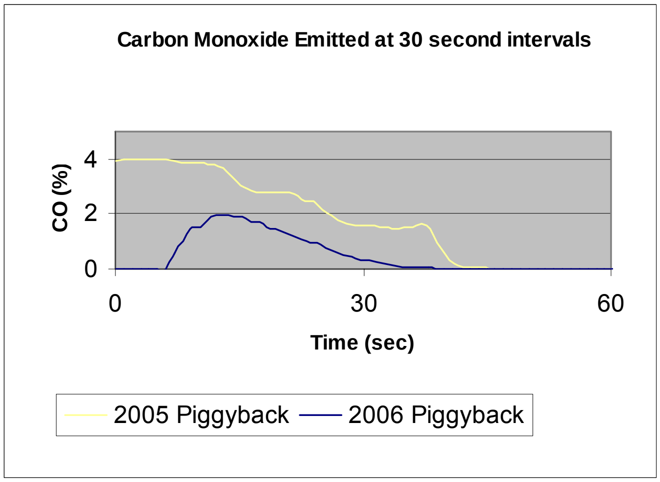

Figure 20: 2006 CO Emissions Data

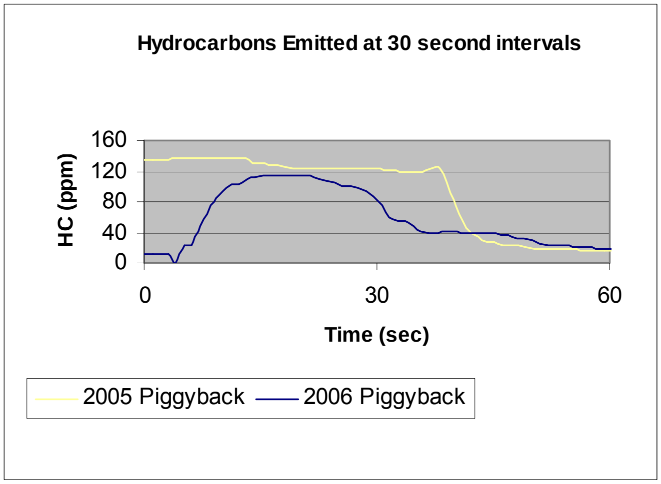

Figure 21: 2006 HC Emissions Data

The emissions results for the HC and CO have been greatly reduced at idle conditions. The $NO_X$ did have a slight spike in them but on average they were also lower at idle conditions. Once the sled moved past its idle condition into 3000 RPM some fluctuations happened on the HC and $NO_X$ emissions. This is attributed to the program switching from using the TPS input to the wide-band O2 input. The program seems to give the best results when it takes a reading and adjusts every 3 seconds. If the program samples faster then this there tends to be more sporadic behavior, because the ECU chooses to adjust what it sees more frequently. This can lead to higher emissions and lower fuel economy.

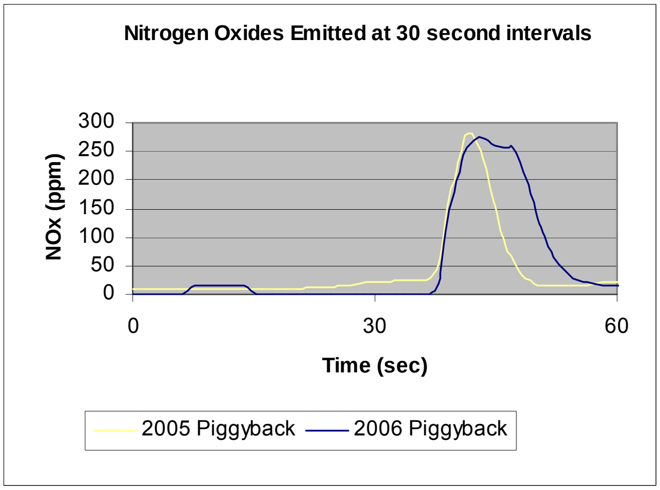

Figure 22: 2006 $NO_X$ Emissions Data

The easiest way to show the overall emission reductions from the 2005 to the 2006 piggyback would be to observe Figure 23 below. This shows that we were very success in our goal to reduce the emissions at idle.

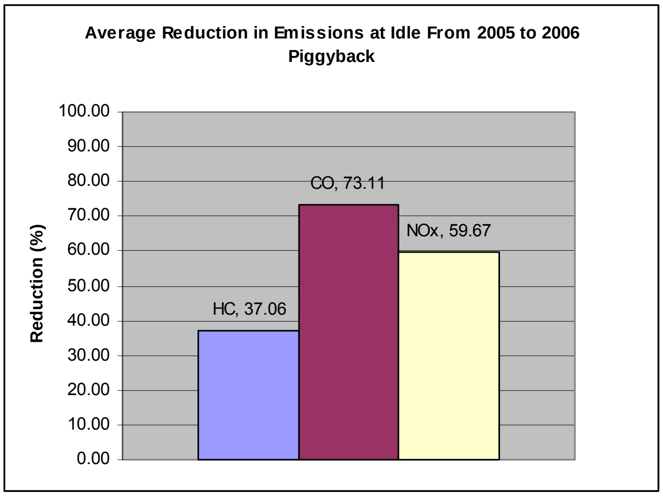

Figure 23: Percent Emission Reductions

The HC were reduced by 37.06% the CO by 73.11% and the $NO_X$ by 59.67%. With the 2006 piggyback all emissions at the idle position run under the 2012 emission standards. The emissions reductions are even higher when in comparison to the stock sled, which can be seen in Figure 24.

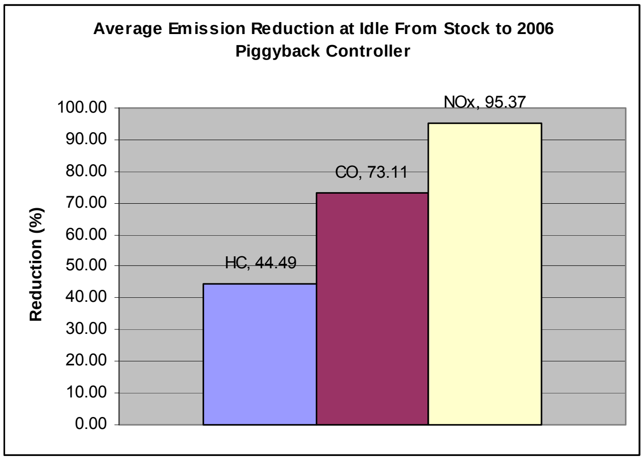

Figure 24: Percent Emission Reductions from Stock Sled

<u>Conclusions</u>

The 2006 Piggyback control unit success achieved the goals of reducing the emissions of the 2003 Arctic Cat 4 stroke snowmobile. Although it was not able to provide significant reductions that exceeded the 2005 piggyback, for the full throttle range, it did greatly reduce the emissions that were being produced during the sled idling. These were the highest emissions of the sled during the competition last year. With the proper inputs this piggyback would make for a quality addition to any stock sled in order to consistently with lower emissions, making it an excellent addition to a Snowmobile Conversion Kit.

## CONCLUSION

Because of the well integrated progress achieved by each of the groups that comprise this year's University of Maine Snowmobile team our Arctic Cat now runs cleaner, quieter, and looks better then ever before. Problems encountered in previous years were analyzed and overcome to provide this year's team with a sled that not only better meets the criteria of success for the competition, but is also more reliable.  All of the improvements done to the sled can easily be applied to any stock fuel injected sled.

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## DEFINITIONS, ACRONYMS, ABBREVIATIONS

**VARTUM:** Vacuum assisted resin transfer molding

**SCRIMP:** SEEMAN composite resin infusion molding process

**NVH:** Noise, vibration and harshness

**A/F:** Air to Fuel ratio

**ECU:**  Engine or Electric Control Unit

**AIT:** Air Inlet Temperature

**EGR:** Exhaust Gas Recirculation

**Microcontroller:** A device that consists of a basic stamp or processor. This is programmed by a PC to hold a program and run through commands using a simple programming language.

**Piggyback:** A device used to override or supplement the Electronic Control Unit of an engine. This changes the readings that the ECU is reading on order to control one or more desired outputs of the sled.

**Wide-band O2 Sensor:** Produces a voltage ranging from 0-5 Volts, as opposed to a 0-1 Voltage output that is the default oxygen sensor on the sled. This provides a more accurate reading of the A/F ratio allowing for more precise control.

## REFERENCES

1. Maine Snowmobile Association http://www.mesnow.com/
2. Acoustical Surfaces, Inc. http://www.acousticalsurfaces.com
3. SAE Website http://students.sae.org/competitions/snow
4. SAE J192