The Clean Snowmobile Approach

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ABSTRACT

The University of Maine's approach to creating a cleaner burning, noise friendly recreational snowmobile has been to use a few after market modifiable parts as well as fabricating custom components. Existing aftermarket components include: catalytic converter, noise-damping insulation, heavy rubber brush applied insulation, centrifugal fans, and radiators. The University manufactured parts include: a carbon fiber hood, piggyback (or microcontroller), a belly pan vent system, and a centrifugal variable transmission venting system. With all these elements on a 4-stroke snowmobile, the results are a quieter, cleaner-burning, more reliable, well-performing snowmobile for the outdoor enthusiast rider.

INTRODUCTION

The University of Maine clean snowmobile team has been competing in the SAE clean snowmobile challenge for a total of six years. In the initial years, the team made leaps in bounds from year to year while experimenting with noise control and reducing emission gases. The greatest advancement for the team occurred in 2002 when, with the aid of a reliable sponsor, the University of Maine purchased a new 4-stroke arctic cat snowmobile. With the newly implemented machine in place, the team finally had a chance to place well at the competition held every year in Houghton, Michigan, which they set forth to do.

The first year with the 4-stroke machine, the University placed third, the next fourth, and last year (after a poor snow year in Maine which prevented adequate testing) fifth. Making note of the steady decline, this year's University of Maine Clean snowmobile team moved forward with the same 4-stroke arctic cat to improve the execution of previous ideas and to continue to generate new ideas to develop an efficient, environmentally friendly, and user-friendly snowmobile.

To begin, it should be noted that not everything on the snowmobile from previous years needed to be re-evaluated and rebuilt. The parts that this years' team left in place from last year includes noise-dampening components and the in-house manufactured cowling. A brief overview of each component on the team's current sled will be discussed here to help the reader better understand where this year's project began, what it's new challenges were, and what improvements were made.

NOISE AND VIBRATION REDUCTION

Cowling

With snowmobiles being primarily a recreational vehicle, noise reduction is typically not high on the priority list; however, with a greater population and rural growth, noise pertaining to recreational motorized equipment on public and private property has become a growing concern. The engine compartment on a stock snowmobile is lightly outfitted with a thin fiberglass or plastic shell and is well ventilated to cool the engine and clutch, but has minimal sound dampening material.

For the University of Maine's Arctic Cat snowmobile, the first place to start cutting the noise was with the cowling. There needed to be ample room for noise damping under the cowl and for accommodating changes made by the team to and around the engine. It was decided that a new, stronger, carbon fiber cowling with nominal ventilation would be constructed using vacuum sealing techniques to yield the highest fiber to volume fraction as possible. Starting with a previously made fiberglass mold from 2005, the 2006 team focused on modifications to increase the height at the nose of the cowl where the muffler was relocated, and creating a single air inlet with an applied baffle. Finally a ¾" layer of acoustical non-flammable cotton was added to the underside of the cowling as the most important feature to limit noise. The new cowling was aesthetically pleasing and performed admirably in the 2006 competitions, and the 2007 team has added no new modifications to the cowling.

Track Suspension

The track itself is very well exposed to the environment, and therefore contributes significantly to noise and vibration. To address the noise and vibration stemming from the track and tunnel, in 2006 a couple of different ideas were applied. First, it was observed that the track's main suspension bumped a track cross-brace, creating significant noise. By applying a piece of high quality rubber between these two components, this issue was immediately resolved.

The second issue created by the track was noise due to friction of the track against the runners (sliders). The solution was to add ten bogie style wheels to the track, which decreased the friction of the track on the runners (sliders). Finally, it was found that the snowmobile was louder while moving away from an observer than while riding past, due mainly to a large opening at the back of the snowmobile. By adding an oversized rubber mud flap, the large opening is now blocked, creating a noise barrier.

Results

Last year's pre-competition testing of the snowmobile yielded promising results. The test conditions were on hard packed snow with a small amount of powder over it, at a temperature of 20°F. In the six passes made, the average decibel reduction was 6.05 dB from the stock run, which had a value of 77.8 dB. A 10 dB reduction is approximately a half noise reduction to the human ear; therefore the noise reduction had been cut a considerably in comparison to stock settings. These improvements were verified in the 2006 SAE competition, when U.M. placed second, receiving 283 of a possible 300 pts in the noise category. The 2007 team has been mindful that any new components or modifications should not negatively impact previous years' improvements.

EMMISIONS

The reduction of emission gases on the University of Maine snowmobile was maximized using two different parts: a catalytic converter and a piggyback. Both of these innovations were added during previous years, with varying degrees of success. The 2007 team's goal was to fine-tune these components and improve their overall efficiency.

Catalytic converter

Introduced to automobile engines in the late 60's to early 70's, the catalytic converter takes in engine emission gases and breaks them down into their organic structure. These simple gases, which are naturally occurring, can be obtained from the emission gases using an oxidation and oxidation-reduction process by means of a catalyst that is directly in line with the engine exhaust system. Emissions from an internal combustion engine will produce HC (hydrocarbon), CO (Carbon Monoxide), NO_x (Nitrogen Oxide), and O_2 (Oxygen). Passing through the catalyst, the gases then go through a chemical reaction, forcing the gases to become H_2O (water), CO_2 (Carbon dioxide, used by plants for photosynthesis), O_2 (Oxygen), and N_2 (Nitrogen). *Figure1* below shows this reaction taking place.

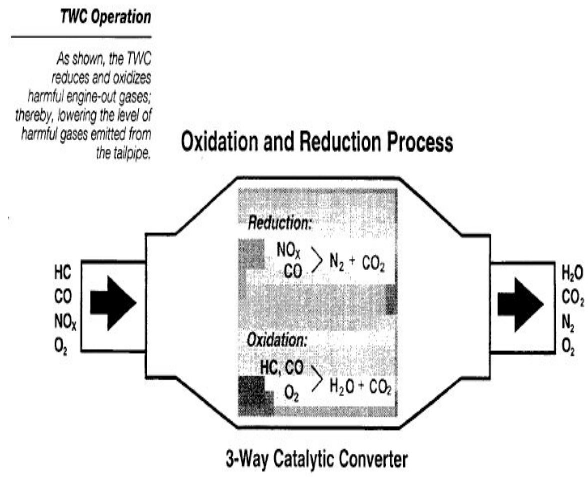

Figure 1: Catalytic Convert0er reaction process

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To better understand this process, shown in *Figure 2* is the chemical equation showing the break down of the hydrocarbons and nitrogen oxides.

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

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

$$NO(\text{or } No_2) + CO \rightarrow \left(\frac{1}{2}\right)N_2 + CO_2$$

$$NO(\text{or } No_2) + H_2 \rightarrow \left(\frac{1}{2}\right)N_2 + H_2O$$

$$2 + \left(\frac{n}{2}\right)NO(\text{or } NO_2) + C_yH_n \rightarrow \left(1 + \frac{n}{4}\right)N_2 + yCO_2 + \left(\frac{n}{2}\right)H_2O$$

Figure 2.) Oxidation reaction of Catalyst

While appearing to be an ideal solution to the emissions dilemma, the Catalytic converter has one draw back in that this process will only take place while the converter itself is extremely hot (approximately 600°F); in general, the hotter the catalytic converter, the better the chemical reaction. (See figure 3).

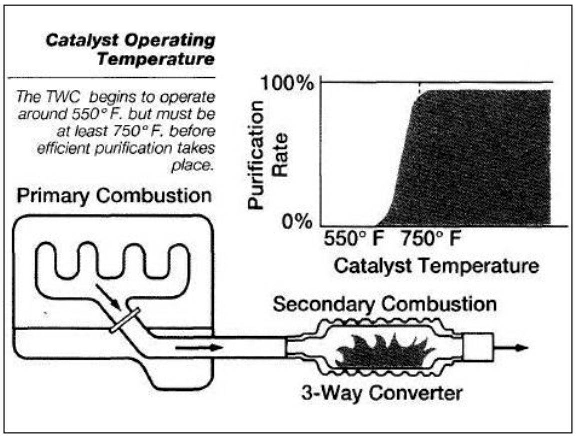

Figure 3: Catalytic converter operating temperature and purification
Source: © Toyota Motor Sales, U.S.A., Inc. All Rights Reserved, "Emissions Sub-systems: Catalytic Converter."
http://www.autoshop101.com/forms/h64.pdf

As a means of making the catalytic converter hotter, while attempting to keep the engine running at its optimal temperature, previous U.M. teams found it necessary to implement what is referred to as a piggyback.

ECU Controller

As a result of installing a catalytic converter, the University of Maine now had to engineer a way to raise the temperature of the converter without the aid of a hotter exhaust gas temperature at the engine. The best way to make the converter run hotter was to force more fuel through the engine, and burn the excess in the catalytic converter, creating the secondary combustion. Adding more fuel to the ratio was the task of the Engine Control Unit (ECU), which now needed to be controlled

Pricing out after market adjustable ECU's, it was found that a stand-alone fuel management system would prove to be a very pricey way to simply add extra fuel to an engine. As an alternative to an entirely new engine computer, the U.M. teams decided to simply alter one signal going to the ECU, therefore "tricking" the computer into thinking the Air Inlet Temperature (AIT) is greater than or less than what it actually is, forcing the computer to adjust the air/fuel ratio.

Given that signals to an ECU are simply interpreted resistances through a wire, the best way to change a resistance is through the use of a potentiometer. The piggyback unit is an in-house made microcontroller that can take in signals from other engine aspects and regulate the potentiometer accordingly. Previous years' teams used just one signal from the engine's O_2 sensor to regulate the AIT. The basic layout is shown best through Figure 4.

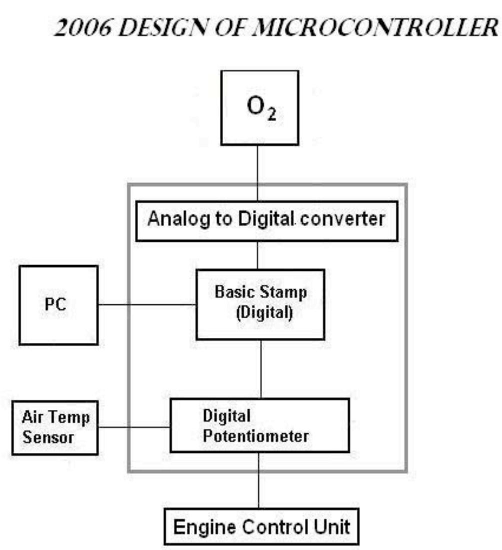

Figure 4: Simple layout of microcontroller

Emissions results

Adding the aftermarket catalytic converter to the snowmobile proved to be a convenient way to reduce emissions given its simple bolt on application. This particular Arctic Cat 4-stroke engine with the catalytic converter alone created a large reduction in emissions. With the addition of the piggyback, the emissions once again were reduced. The reduction in emissions can be seen graphically in Figure 5.

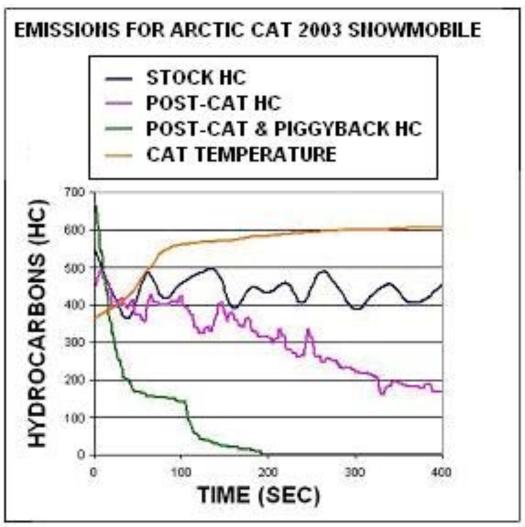

Figure 5 : **Emissions with stock, catalytic converter, and piggyback unit**

Although the data now was sound, the previous years' designs were not without fault. The 2006 team encountered occasional erratic idle speeds and wiring inconsistencies that were directly related to the running of the piggyback system. With these problems, emissions control was at best poor and adversely affected the dependability of the snowmobile. As will be explained later in the report, the 2007 team has eliminated these reliability issues.

The backpressure caused by the catalytic converter was an even greater problem. The increase in backpressure has caused the engine to run at much higher temperatures, to the point of engine failure. While the catalytic converter works efficiently while hot, a new situation has been created in respect to engine cooling. A major challenge for the 2007 team has been to improve engine cooling so that the potential advantages of the piggyback and the catalytic converter can be fully appreciated.

2007 IMPROVEMENTS TO RELIABLITY, DURABILITY, AND EMMISSIONS

OVERVIEW

The largest problem the Arctic Cat has encountered in previous years competitions, has been its reliability. Some small oversights of previous years' teams have, unfortunately, caused major reliability and durability issues ranging from inaccurate dynamometer readings to unstable engine signals and even a warped engine head. The major focus of this year's team was to assess the status of the snowmobile and to make necessary adjustments to the snowmobile to overcome these issues.

THE ENGINE COOLING CHALLENGE

A major issue that the snowmobile faced was a severe overheating problem. After taking into account the following factors, understanding the problem was fairly straightforward:

- The new cowling was heavily insulated and lightly vented
- An aftermarket Catalytic converter was added

- All engine compartment holes were insulated

Keeping the engine in a small, insulated enclosure with minimal cooling and venting, as well as adding in an extra hot catalytic converter, significantly raised the temperature at which the engine ran. The 2007 team strategy was to improve convection cooling by adding vents and cooling fans and by adding a heat exchanger in the form of a second radiator, all while maintaining a low noise emission.

Convection cooling

Keeping noise at a bare minimum meant that the Arctic Cat chassis had to be buttoned to isolate any engine noise. To allow improved airflow through the compartment, the 2007 U.M. team has created what has been termed by the team as the Belly Pan Vent (BPV). This is located on the underside of the engine compartment, directly in front of the track. By venting all engine heat here, any noise will be absorbed either by the rubber track, and/or the snow on which the machine is being driven. Figure 6 below best shows the BPV.

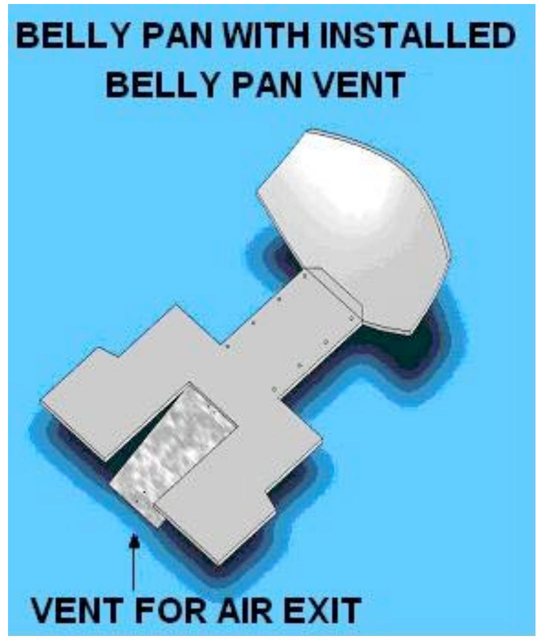

Figure 6: Belly Pan Vent (BPV) made for exhausting engine compartment.

Given that hot air has a tendency to rise, the air now had to be forcibly pulled around the engine and exhausted through the BPV. This was obtained by placing a fan at the base of the engine compartment to push the air through the BPV. The fan placement is as shown in Figure 7.

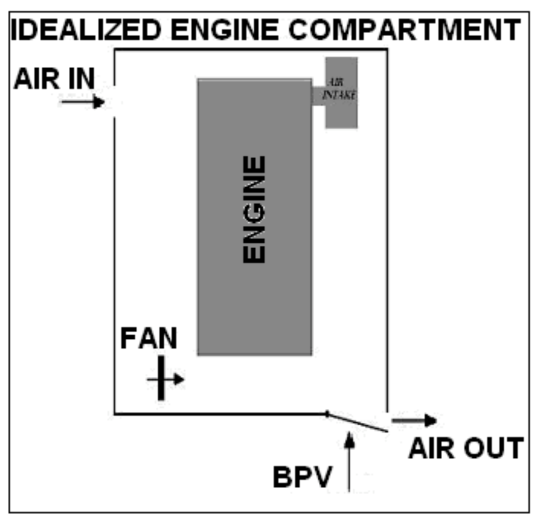

Figure 7: Convection cooling concept with shown approximate placement of fan.

As well as creating the BPV, another concern lay in the vicinity of the Constantly Variable Transmission (CVT). With strict rules applying to the containment of a CVT, this meant that a fair share of heat would be trapped in the clutch compartment. To solve this problem, a direct vent to the track's tunnel was created, where, once again, the track's rubber mixed with snow would allow noise vibrations to be kept at a minimum, while still allowing the engine compartment to exhaust otherwise trapped hot air. To best vent this section, a centrifugal electrical fan was attached on the trackside of the tunnel to pull the air from the CVT area. A shroud was created over the top of this hot air vent to direct the air and to protect the fan from the winter environment. Figure 8 shows the configuration using a solid works model.

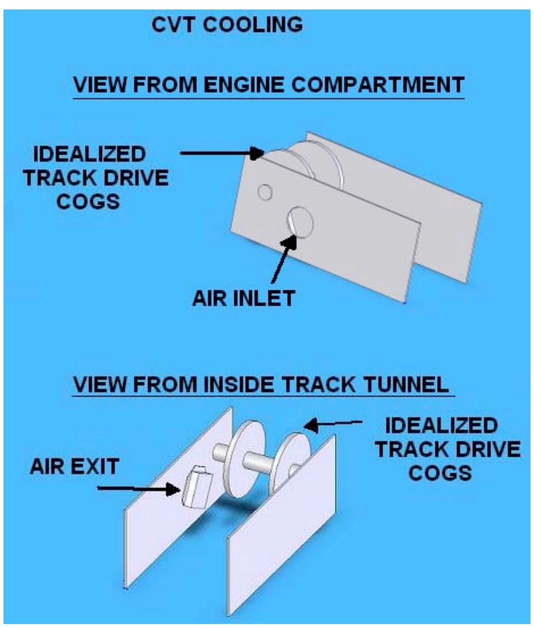

Figure 8: Venting for CVT in track tunnel (left) and from inside engine compartment (right).

The new BPV and clutch venting system will be most effective when the snowmobile is running at speed, but will be much less effective while the machine is simply idling. To further ensure adequate cooling, the team decided to add an additional heat exchanger.

Additional heat exchanger

With the weather insufficient to test our fan convection concept, and understanding that the engine temperature needed to be dropped by 40° F to resolve the overheating issue, a more innovative action was taken. A traditional motorcycle radiator was added to the rear of the snowmobile above the rear bumper. By placing the radiator outside of the engine compartment, it is possible to cool the engine fluid quickly, while eliminating the need to create additional venting to the engine compartment that would allow for the escape of noise pollutants. To best model the system, the equations below were used with the experimental data to obtain the maximum cooling of the radiator.

$$\dot{q} = \frac{m_w C_{pw}\left(T_{fw} - T_{iw}\right)}{\Delta t}$$

(Eq 1)

$$\dot{q} = \dot{m}_c C_{pc}\left(T_{fc} - T_{ic}\right)$$

(Eq 2)

The experiment to find the heat dissipation through the additional radiator was performed with the use of water. Through the use of these simple equations, approximate heat dissipation was found to be ample for our cooling situation.

WIRING IMPROVEMENTS

During the last year, the snowmobile's power system was behaving erratically, causing the engine to have an unstable idle position and therefore giving inconsistent results. It was discovered this year that the primary cause of this was a stock ground bolt placed at the base of the engine. Once this bolt was retightened with a touch of loc-tite©, most of the problems were solved, but a few electrical issues still remained.

Inspecting the electrical system that had been modified over the past three years, the team decided it was necessary to rewire a fair share of the snowmobile to prevent future electrical inconsistencies. A new dedicated wiring harness was run through the engine compartment, eliminating random splices and miss-matched color-coding. In addition, quick disconnect plugs were built into the sled in order to make more parts easily removable and to allow for quick adjustments. Two of the disconnect plugs are dedicated specifically to allow for a quick change to go from stock ECU, to ECU with piggyback, or vise-versa.

PIGGYBACK IMPROVEMENTS

The 2007 emission control system has improved upon existing years ideas only in regards to a new piggyback unit**.** Finding that emissions were not regulated well enough at idle with just one engine sensor, the U.M. team has built a new piggyback which takes signals from the O_2 sensor (like before), and from the Throttle Position Sensor (TPS) to attempt to lower emissions even further. Figure 09 shows how the new system works with the addition of the TPS.

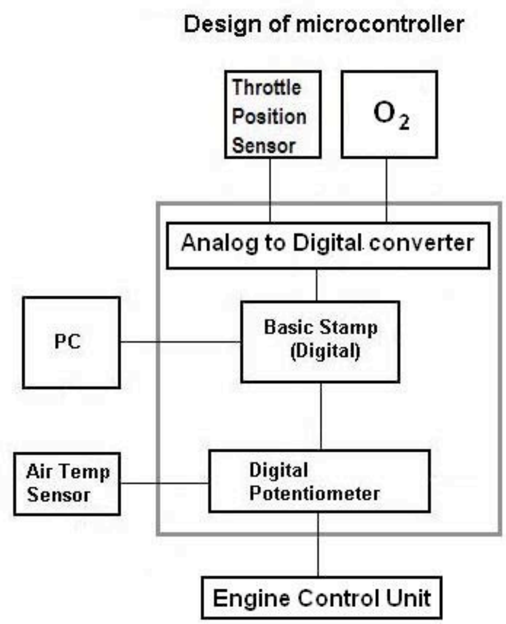

Figure 9: Simple layout of a microcontroller

The TPS was used as another reliable signal to adjust the air/fuel ratio, given that it is already used by the ECU to adjust the air/fuel quantity. With the TPS sending a signal to the basic stamp, just like the O2, this allows the team more flexibility in being able to adjust the AIT while under different operating conditions.

2007 IMPROVEMENTS RESULTS

With the addition of the BPV, the venting fans, and the secondary radiator, the performance of the snowmobile has improved significantly. The snowmobile that was passed off to the 2007 team with a catalytic converter already applied ran at temperatures as high as 220°F both while idling and at operating speed (45 mph). After the 2007 modifications, however, the sled can maintain a respectable operating temperature around 180°F at speeds above 15mph, which is very near the stock temperature of 170°F. When driven at typical speeds of 45 mph, the engine temperature while being tested has not exceeded 185°F. While the team has found a solution for cooling at speed, it still appears that the Arctic Cat with its modifications has reached its hottest temperatures of 195°F while moving at slow speeds of 15 mph or less.

After the thorough attention to rewiring, many of the inconsistent idle rpm's and engine sensor readings have been eliminated to allow for a new found reliability. Last year many times the snowmobile would not even start, let alone run for any length of time without inconsistencies. This year's team has managed to find the root of theses problems well enough to produce predictable behavior.

With the 2007 piggyback unit in place, the snowmobile will produce results just as good as the 2006, with emissions improving a minimal amount due to steady AIT signals. A quick comparison between the 2006 vs 2007 piggyback is shown in Figure 10 through the aid of effect on emissions.

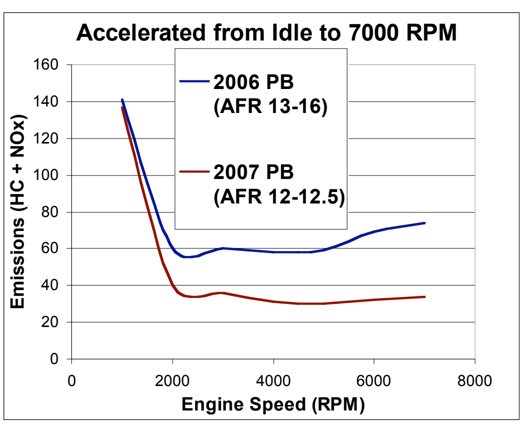

Figure 10: 2006 piggyback unit vs the 2007 piggyback unit

The main focus of the new piggyback unit was to improve emissions while at idle, but primarily while warming up. However, after testing the unit during a warm up period, the piggyback has no effect on emissions, therefore leaving us to conclude that the Arctic Cat ECU has a separate warm up program which does not take AIT into account.

CONCLUSION

The modifications to the Arctic Cat snowmobile have successfully made it a quieter, cleaner running, more reliable and better performing snowmobile.

NOISE AND VIBRATION

With its fabricated cowling, added insulation, and improved heat vents, the U.M. snowmobile is much quieter than any equivalent stock machine, with a decrease in noise of six decimals. The Artic Cat is now more acceptable for use within noise sensitive areas. In addition, this snowmobile with its modifications also tailors well to rider comfort, in the sense that it allows a rider to almost glide through a trail without noise detection. The U.M. approach has lead to a noise solution not only for this particular snowmobile, but for many other snowmobiles alike. Noise absorbing pieces were purchased through the use of the internet, and, with the exception of the cowling, can be fit to many other snowmobile applications to create a whole new riding experience.

EMISSIONS

The greatest attribute to the snowmobile is the significantly lowered emissions. The catalytic converter has given it an extensive edge to emission control by converting hydrocarbons (HC), carbon monoxide (CO), and nitrous oxide (NO_{x}) into environmentally friendly gasses such as Carbon dioxide (CO_2), Nitrogen (N_2) , water (H_2O), and Oxygen (O_2). On average, emissions of hydrocarbons are reduced by 93%, while NO_x is reduced by approximately 80%. Introducing a catalytic converter is perhaps the single best way to improve the emissions on any snowmobile, especially when combined with additional accommodation to offset the heat gain on the engine.

The piggyback add on is the next best step in emissions control after adding a catalytic converter. Because of its ability to manipulate the stock ECU, the piggyback when added to an engine with a catalytic converter can reduce hydrocarbon emissions from a stock 200 ppm, down to an almost undetectable emission of 34 ppm. Although building a microcontroller turns out to be a time consuming process, it is a beneficial compliment to an engine with emission controls. More importantly, though, this innovation's success offers manufacturer research and development teams who are serious about reducing emissions an important area for exploration.

RELIABILITY

With the aid of new wiring, the many replaced sensors corresponding to the ECU, and the attention to engine cooling, reliability of the Arctic Cat has improved significantly. A major problem overlooked for many years was the over heating of the engine. Thanks to the use of an additional radiator and increased ventilation via small electrical fans in the engine compartment, the snowmobile now runs at acceptable temperatures between 160°F to 185°F for standard operating conditions. These temperatures compare well to the characteristic traits of a stock 4-stroke Arctic Cat during normal operating conditions.

Snowmobile manufacturers are significantly limited in ways to improve engine emissions past the current stock levels in a cost effective manner, since adding a catalytic converter also requires modifying the sensors that control the fuel mix and forces manufactures to create additional heat dissipating setups for the engine. The U.M. 2007 team has shown that these innovations can be accomplished without impacting reliability, although they may result initially in an increased price to consumers of hundreds of dollars. While this would be regrettable, the ultimate contribution such reductions would make to the environment would justify the additional costs. The U.M. team has shown, however, that noise pollution levels can be significantly and economically managed through improvements to tracks and to cowlings. With much quieter and cleaner machines, environmentalists' opposition to snowmobiles may wane, allowing new territories to be opened to riding, and this too may help to offset consumer disappointment with higher prices. Finally, as newer fuels are developed and are commercially used, it is possible that emissions could be further reduced. These innovations reduce the environmental impact of snowmobiling while keeping the sport fun.

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REFERENCES

1.) © Toyota Motor Sales, U.S.A., Inc. All Rights Reserved, "Emissions Sub-systems: Catalytic Converter." Retrieved October 2006 from http://www.autoshop101.com/forms/h64.pdf.

2.) Fortier, G. and Mernard, M. "CSC Snowmobile Conversion Kit Concept." 2005-2006 University of Maine CSC Team competition report. University of Maine.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

BPV – BELLY PAN VENT

CVT – CONSTANT VARIABLE TRANSMISSION

PIGGYBACK-MICROCONTROLLER

ECU-ENGINE CONTROL UNIT

AIT- AIR INLET TEMPERATURE

TPS –THROTTLE POSITION SENSOR

O_2 – OXYGEN

CO-CARBON MONOXIDE

NO_X-NITROGENOXIDE

N_2-NITROGEN

H_2O-WATER

HC-HYDROCARBON

H_2-HYDROGEN