SUNY University at Buffalo
UB Approach to a Diesel Powered Snowmobile

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ABSTRACT

The ever increasing concern over the environmental impact of snowmobiles on the environment has been discussed amongst those in government and those who participate in the sport. Due to the increasing popularity of snowmobiling, snowmobile manufacturers have had to rethink their designs. Today's manufacturers are producing snowmobiles that are more environmentally friendly and still acceptable by those who participate in the sport. One design that is not currently in production is a diesel powered snowmobile. The SUNY University at Buffalo (UB) Clean Snowmobile Challenge (CSC) has decided to try this design and utilize a Daihatsu three cylinder diesel engine in a Polaris ProX chassis. The implementation of the diesel engine, along with an exhaust after treatment system and engine output multiplication system, can be a viable solution to the design problem posed by Clean Snowmobile Challenge. Implementing this design into a stock chassis results in a snowmobile that is both environmentally friendly and still fun to ride.

INTRODUCTION

Due to the increasing regulations on exhaust and noise emissions on modern snowmobiles, there is an ever-growing need for further development of new technologies that assist in making snowmobiles cleaner and quieter. The Clean Snowmobile Challenge is a collegiate design competition for student members of the Society of Automotive Engineers (SAE). "The intent of the competition is to develop a snowmobile that is acceptable for use in environmentally sensitive areas. The modified snowmobiles are expected to be quiet, emit significantly less unburned hydrocarbons, carbon monoxide and particulate matter than conventional snowmobiles, without significantly increasing oxides of nitrogen emissions. The modified snowmobiles are also expected to be cost effective. The intent of the competition is to design a touring snowmobile that will primarily be ridden on groomed snowmobile trails. The use of unreliable and expensive solutions is strongly discouraged" [1]. Guidelines for the 2008 SAE Clean Snowmobile Competition state that this year's entries into the competition must surpass the 2012 emissions standards just as the manufacturers must do. Additionally, entries must pass the current Snowmobile Industry noise test minus two decibels.

PROBLEMS WITH TODAY'S SNOWMOBILES

The predominant use of hydrogen and carbon based fuels in snowmobiles leads to hazardous emissions from the combustion process. Hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxides (NO_x) are the most harmful of the exhaust molecules and must be minimized. In order to create a solution to the emissions problem, the cause of the formation of the particles must first be understood.

Hydrocarbons are formed by five modes: incomplete combustion, flame quenching, crevice volume, absorption of fuel vapor, and high equivalence ratio. Incomplete combustion normally occurs during the expansion stroke, when the cylinder pressure drops, causing the unburned gas temperature to drop. This temperature drop causes a decrease in the burn rate. Flame quenching can be attributed to the relatively cold walls of the cylinder. The cooler walls form a boundary layer where the flame cannot penetrate, hence leaving some unburned HC molecules. Crevice volumes, such as the area between the piston and cylinder wall, can once again trap hydrocarbons in a region where the flame cannot enter. The mode of absorption of fuel vapor into the thin oil layer occurs during the compression stroke. Once the pressure gets to a certain level, the fuel vapor can be absorbed into the oil layer. Upon expansion, the fuel vapors containing unburned HC are emitted from the oil layer and exit out through the exhaust. Hydrocarbons are also known to be sensitive to the equivalence ratio, φ. When φ is greater than one, the fuel is rich and consequently HC emissions are high, conversely when φ is less than one, the fuel is lean and the HC emissions drop down.

Carbon monoxide formation is mainly a function of the equivalence ratio. Similar to hydrocarbon formation, CO emissions will increase with a rich fuel mixture, and decrease with a lean fuel mixture [2].

The CO is formed when there is not enough oxygen present to form CO_2. Therefore, poor mixing and incomplete combustion also play a factor in increasing CO emissions [2]. Normally, the formation of oxides of nitrogen is caused mostly by high temperatures and large oxygen concentrations in the combustion chamber. The high temperatures cause the nitrogen to dissociate, and NO/NO_2 forms if there is oxygen present [3]. Equivalence ratio affects both oxygen content and temperature. Maximum temperature occurs at an equivalence ratio of 1.1, but oxygen concentration decreases as equivalence ratio rises, and is too low at $\varphi=1.1$. The maximum amount of NO_x emissions has been empirically found to be at approximately $\varphi=0.9$ [2].

The new emissions problem faced by our team for the 2008 CSC is particulate matter (PM). PM is created by the incomplete combustion of diesel fuel combined with high sulfur content in the fuel. In the last year the United States has come a long way in diesel emissions technology. New Environmental Protection Agency laws have been passed to decrease diesel engine emissions. Also the creation of UltraLow Sulfur Diesel (ULSD) and mandating use of ULSD has helped to advance emissions technology. The new 2007 standards set by the EPA for diesel engines has created havoc in the diesel engine design, thus increasing the advancement of exhaust treatments and active emissions systems. All of these advancements have lead the way to the UB CSC team using diesel in 2008.

UB SOLUTION

For the 2008 CSC the UB team has decided to step outside the box and power the snowmobile with a three cylinder diesel engine. Due to the recent advances in diesel performance and exhaust treatment, the diesel engine can be considered a clean and quiet engine. The other goal for this year is to set up a snowmobile in which we can build and develop over the next few years to create a team timeline, where project sleds are used for two or more years. The 2008 goal concentrations are as follows:

-Implementation of Engine Output Speed Multiplier to allow for proper CVT Operation
-Reduce Engine Emissions
-Reduce Engine Noise
-Maintain Performance
-Increase Reliability
-Improve Fuel Economy
-Rider Safety and Comfort

PERFORMANCE

ENGINE OPTIONS

Selecting a motor for the CSC is one of the most important aspects in the design of an environmentally conscious snowmobile. First, the engine must be within specifications set forward by competition rules. This consists of engine types and displacement sizes. We must choose from the selection of rotary, two stroke, four stroke gasoline engines or diesel engines. The displacement of these engines is mandated with maximum limits. With these options in mind, the team must pick an engine which is suitable for designing an innovative snowmobile to revolutionize the snowmobiles of the future.

The UB CSC team has wanted to do a diesel powered snowmobile for some time. With the recent technological advances in exhaust treatment we are now able to implement a diesel engine into the 2008 CSC. After deciding on a diesel power plant we had to concern our selves with size, weight, power, and availability.

ENGINE SELECTION

The 2008 UB CSC team looked at several diesel engines with a displacement size that would adhere to the rules. The end decision was to go with a Briggs and Stratton, Vanguard three cylinder diesel manufactured by Daihatsu. The engine is a 952 cubic centimeter (cc) inline three cylinder direct injected four stroke diesel engine. This engine is implemented in commercial lawn mowers and personnel lifts. Knowing that the motor is implemented in commercial lawn mowers and debuting in the 2007 6x6 Argo vehicles says how durable the Daihatsu engine is.

The diesel is a 32 horsepower turbo charged engine with 58 ft-lb of torque. The lower engine output creates a power shortage compared to current snowmobiles but as discussed before this sled is only in the implementation stage. Due to the new technology available there is a lot more that can be done to improve the power of the engine. The engine is relatively small and fits in the bulk head of the chassis with a half inch to spare on either side. Figure 1 shows the Daihatsu engine’s dimensions complete with a fan for the radiator which was not utilized in our design. To maintain the engine temperature inside of an enclosed hood we utilized the stock snowmobile heat exchangers located under the tunnel

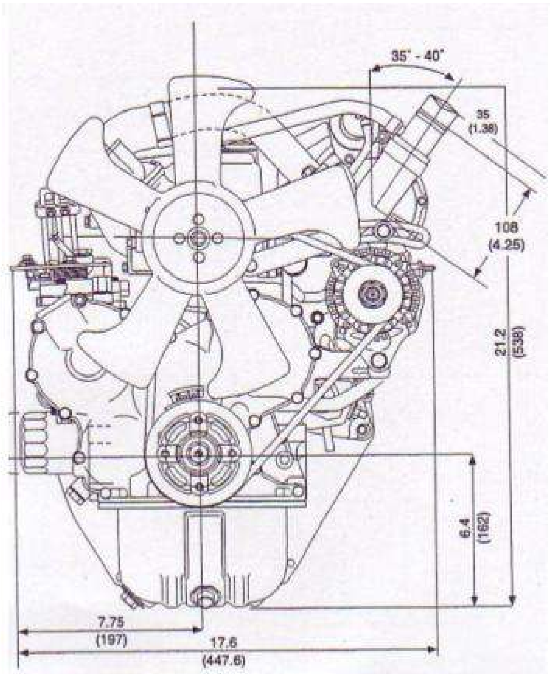

Figure 1: Daihatsu Diesel Engine

The diesel can also be mounted in a variety of different positions provided by the 15 degree running angle and 25 degree intermittent running angle. The ability to mount the engine in a variety of different positions gives us the ability to utilize the limited space in the chassis and create a more central center of gravity. Due to the diesel's low center of gravity and the angle of mounting we were able to keep the sleds center of gravity as low as possible.

One of the major factors in running a diesel engine in any vehicle is that diesels are 3040 percent more efficient than other internal combustion engines. Keeping this in mind our team is hoping for drastically increased fuel economy over two and four stroke snowmobiles. The only real set back to using a diesel engine is the emission of particulate matter (PM). .

FUEL SYSTEM

The fuel system on the Daihatsu diesel is relatively simple due to being mechanically injected. The four parts to the fuel system are the injector pump, fuel filter/water separator, injectors, and the fuel tank all of which are connected via fuel lines. Due to the injector pump's ability to pick fuel up from fifteen inches below its inlet a feeder pump was not necessary. Some unique features to the Daihatsu engine are the steel fuel lines that supply the injectors after the injector pump, and the fuel filter/water separator which has a built in water level warning light and fuel priming pump for when the system is run dry. Since diesels are much more efficient than two and four stroke engines we decided to reuse a redesigned fuel tank that holds six and a half gallons of fuel which makes the tank lighter and the overall sled lighter. Reference Appendix A for a fuel system diagram.

INTAKE DESIGN

OVERVIEW

The 2007 intake design proved to be inadequate in suppressing outputted noise from the turbocharger. The redesign, shown in Figure 2, calls for a box system to replace the current cone filter design. Along with the change in filter type, the filter location also moved from the engine compartment a location on the steering hoop. The heat-transfer system (inter-cooler) from last year was also removed.

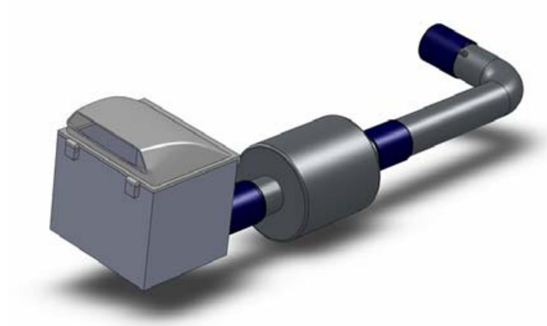

Figure 2: Complete Intake, solid model

EXPANDER

The purpose of the expander is to help in aiding to eliminate the lower based frequencies outputted by the diesel engine intake. Figure 3 below shows the solid model of the expander.

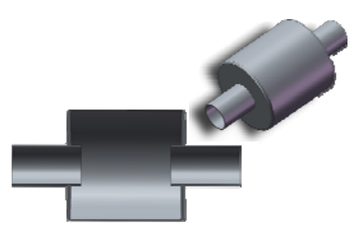

Figure 3: Expander Solid Model

$$TL = 10\log\left[\cos^2\left(\frac{\pi f}{2f_n}\right) + \frac{1}{4}\left(\frac{S}{S_c} + \frac{S_c}{S}\right)^2 \sin^2\left(\frac{\pi f}{2f_n}\right)\right]$$

The expander is modeled on the above equation where *S* is the diameter of the expander S_c is the diameter of the air input and output tubes. *f* is the frequency lost and f_n is the natural frequency of air at room temperature. The characteristic profile of this equation is best shown in figure 3 located on the right. As you can see from the characteristic equation you can see a potential loss of 18 dB at 1 kHz.

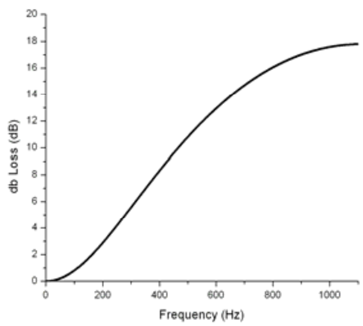

Figure 4: Graph showing amplitude vs. Frequency

RESONATOR

The resonator is based on the principles of the Helmholtz theory. The characteristic equation below shows the transmission loss over the frequency range. Where z_H is the acoustic impedance of the resonator chamber.

$$TL = 10\log_{10}\left|1 + \frac{S_n}{2S_p}\left(\frac{1}{Z_H}\right)\right|,$$

Figure 5.a below is an equation bases on the original output of the diesel engine at 3200 rpm's.

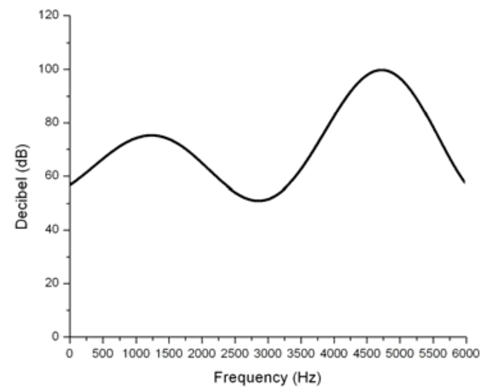

Figure 5.a Char. Curve 3200rpm (Before)

Figure 5.b is the same equation as the one displayed in figure 5.a but the equation of the expander and the resonator are applied to the equation to show the given result.

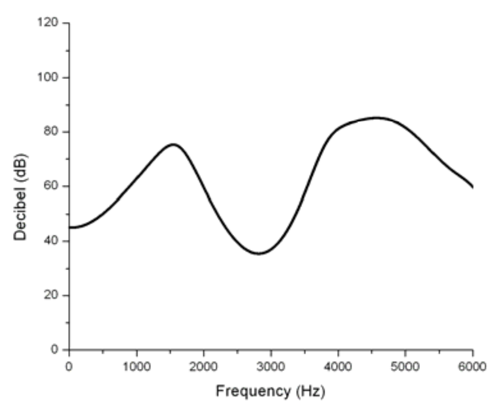

Figure 1.b Char. Curve 3200rpm (After)

RESULTS

The end result from the addition of the expander and the resonator is an estimated total loss of ~11dBA. This loss is significant enough to help in suppressing the noise output from the intake. It also will not resist air current like the previous setup and is significantly lighter as well.

ELECTRICAL SYSTEM

The main power distribution circuit is powered by a 12 V battery and supplies power to the starter, chassis harness, and engine wiring harness. The battery will be located beneath the seat on the tunnel of the snowmobile. This location was chosen because it frees up valuable space inside of the engine compartment, and also helps with weight distribution. A plastic sealed battery box made from Lexan was built to provide a sturdy, nonconductive and hazard containing structure. Monitoring of the engine's vitals will be performed by an EGT system. This system will monitor intake pressure, coolant temperature, and both pre and post Cat/PM exhaust temperature. Reference Appendix B for the wiring diagram.

ENGINE MOUNTS

New engine mounts had to be designed and manufactured to implement the Briggs & Stratton diesel engine into the Polaris ProX chassis bulkhead. Due to the significant weight of the engine the mounts were designed to be in compression under the load of the engine. The lateral stiffness of the mounts had to be robust enough to not deflect when the clutch engages but also isolate the engine vibrations. The Briggs & Stratton engine has a counterbalanced crank shaft and flywheel which allows for use of stiffer engine mounts to isolate vibration.

After contacting Briggs & Stratton engineers it was determined that the engine can be run at up to 15 degrees rearward tilt over long durations and not adversely effect the power output of the engine. Taking this into account the engine mounts were designed to allow a 10 degree rearward tilt to keep the engine center of mass as low as possible in the chassis and minimize the hood modifications due to engine height. Several current commercial applications utilizing this engine were evaluated to design the optimal engine mount. Taking these factors into account along with the stock engine mount locations the front and rear engine mounts were designed.

Front Mount:

The front engine mount is designed to attach the front left and right stock engine mounts to the shock tower cross member located in the front of the bulkhead. The U channel base eliminates off axis engine torsion. The mount is manufactured from .25 inch 6061 aluminum plate, and is the most rigid of the three engine mounts.

Figure 6: Front Engine Mount

Rear Mount:

The rear of the engine is supported using two mounts supporting opposite sides of the engine. The first mount is located on the serpentine belt side of the engine and is configured in an "S" shape. This design was chosen to avoid interference with the steering column and utilize the stock engine mount holes on the ProX chassis. Both rear mounts are manufactured from .25 inch 6061 aluminum plate. The second mount is located on the flywheel side of the engine and connects the upper bulkhead to the stock engine mount plate.

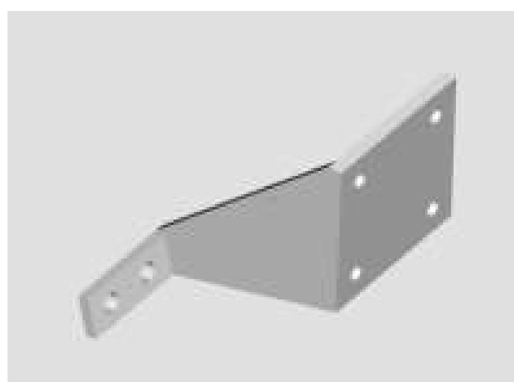

Figure 7: Rear Engine Mount (Serpentine Belt)

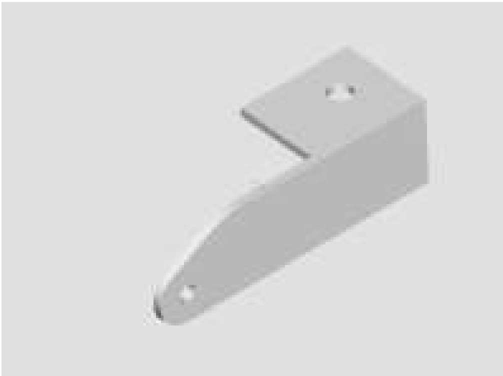

Figure 8: Rear Engine Mount (Flywheel)

ENGINE OUTPUT SPEED MULTIPLIER

OVERVIEW

The CVT has a proven track record of working well with spark ignition (SI) two and four stroke engines because of their higher rates of revolution. But as shown from Buffalo's 2007 CSC entry, deficiencies arise when attempts have been made to connect it to a compression ignition (CI) engine. These deficiencies occur because of the extreme difference in revolution rates between the SI and CI engines. In most cases, the CI angular velocity is barely half that of the SI engine. A way to rectify this difference in revolution is by installing a speed multiplier between the engine's crankshaft and the primary clutch. This multiplier would allow the CI engine to operate normally, but make the output speed seen by the primary clutch comparable to that of an SI engine.

SOLUTION

Numerous solutions to this problem were considered, including both belt and chain driven systems. The chosen solution though, was a synchronous belt system. This type of system requires no tensioner like chain and V-Belt systems, and also shows little if any necessary center to center take up over its life time [4]. A comparison between the three types of systems may be seen in Figure 9.

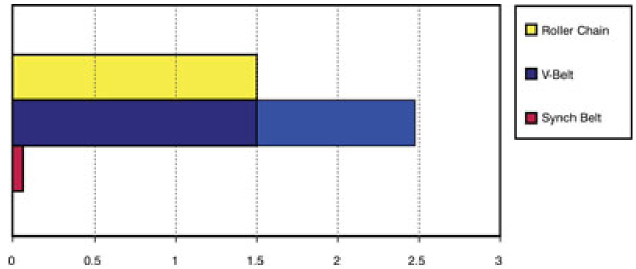

Figure 9: Necessary center to center take-up (in) over life of three different systems.

SYSTEM

The basic system will consist of a large diameter pulley attached to the crankshaft via a keyed adapter. A belt will then transmit the power from this pulley vertically to another, smaller pulley. This smaller pulley will be attached to a keyed shaft with a tapered end to accept the primary clutch. The shaft is pressed into a double row, deep groove ball bearing and then slid into a box and attached with a c-clip. The box is then mounted on a bracket with four bolts and then attached to the chassis. An illustration of this system can be seen below in Figures 10a and 10b.

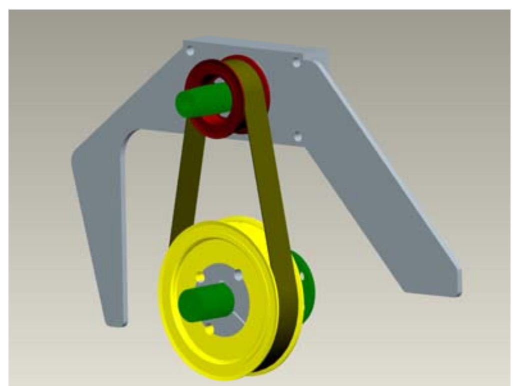

Figure 10a: Isometric view of engine output speed multiplier minus hardware

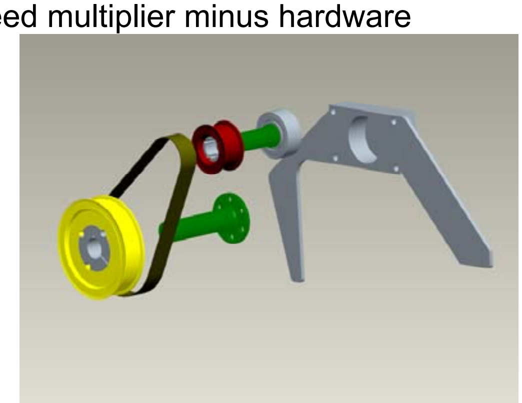

Figure 10b: Exploded view of engine output speed multiplier minus hardware

CHASSIS SELECTION

The chassis that the CSC team is using for the 2007 competition is a 2003 ProX chassis that was used in the 2003 and 2004 competition. The original use of the chassis was for racing mogul racing circuits were the sleds would go over very large mogul bumps at high rates of speed. Knowing this information we can determine that this chassis will be able to handle our competition goals without breaking down. Since the chassis is built for racing it is also optimized for weight savings and is one of the lightest chassis produced in 2003, therefore it is a good chassis to use as weight is being judged in the 2007 CSC. This chassis allows for many adjustments in both ride quality and handling which makes it an ideal chassis for this competition because we can fine tune the sled to perform to our needs.

SUSPENSION

The front suspension used this year will be a pair of FOX FLOAT Airshox. They eliminate the need for standard shock springs by using an internal floating piston coupled with high-pressure nitrogen gas. There is also a weight savings of about 6 lbs. due to the lack of an external spring. FLOAT Airshox also have a great amount of adjustability via a miniature air pump that changes the internal pressure of the shock. This allows for adjustability from race to trail conditions as well as rider weight in a matter of minutes. The rear suspension is from a 2003 Polaris ProX 440 race snowmobile. This suspension utilizes a pair of Walker Evans Racing shocks with remote reservoirs. These shocks also offer easy adjustability for different conditions and rider weights. The shock bodies are made of lightweight anodized aluminum and contain specially stabilized synthetic shock oil for consistent operation even in extreme cold weather. The frame of the suspension is a heavy duty version of the Polaris EDGE suspension. This suspension allows for a ride that can handle deep bumps without easily bottoming out [5].

SKIS

A pair of SlyDog Trail Skis has been implemented in our design. These composite skis are lightweight and offer a great amount of durability and prolonged wear. The patented design on the bottom of the ski allows for reduced darting and improved cornering [6]. A cross section of this ski can be seen in Figure 11.

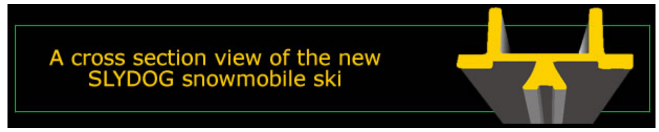

Figure 11: SlyDog Ski Cross Section

EXHAUST SYSTEM

Emissions

The exhaust system is designed to be an integral part of noise and combustion emission control. The exhaust system is designed to assist the snowmobile in meeting the 2012 EPA emissions standards. Diesel engines are substantial emitters of particulate matter and nitrogen oxides (NOx), but only small emitters of carbon monoxide (CO) and volatile organic compounds (VOCs). Gasoline engines are the greatest emitters of CO and substantial emitters of VOCs and NOx, but only modest emitters of particulate matter (PM). In order to decrease the amount of NOx, CO, VOCs and PM we implemented an oxidizing catalyst, PMfilter, deoxidizing catalyst (DOC) hybrid into our exhaust system.

Catalyst/PMFilter DOC Hybrid

The main criteria for catalyst selection were a PM filter and Catalyst in one package and the minimization of exhaust backpressure. The Catalyst/PMFilter DOC Hybrid works by first oxidizing the CO and HC. The next step in the process is the oxidation of Nitric Oxide (NO) into Nitrogen Oxide (NO2). After the NO is split apart the PMFilter uses the NO2 to react with the PM to continually reduce it, the filter also traps the PM in a fleece where it is actively burnt at 200^{o}C. Figure 12 shows roughly how our system works [7].

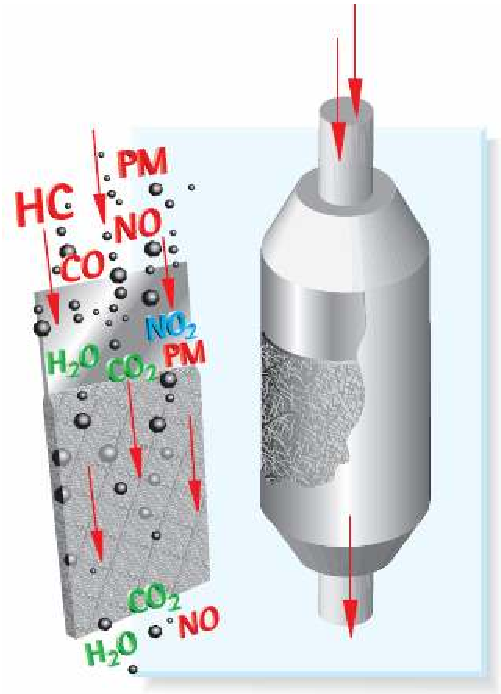

Figure 12: Cat/PM illustration

Muffler

The main criteria for muffler selection were size constraint, noise attenuation, and the minimization of backpressure. The Aero Exhaust 194 Stealth was selected because it fits all of those criteria. The 194 Stealth is constructed of 304 stainless steel for corrosion resistance. There is an internal continuous perforated pipe that exposes the exhaust to a high temperature ceramic sound absorbent material. The high temperature ceramic sound absorbent material is rated up to 3000ºF which makes it more durable (resistant to breakdown) than fiberglass. A cross section of the muffler can be seen in Figure 13.

Specifications

Part: S194

Weight: 7.5 lbs

Material: 304 Stainless Steel

Finish: Bright Polished

Body: 14"x9"x4"

OAL: 20"

I/O: 2" Single x 2" Single

Figure 13: Cross section view of muffler.

HOOD

A new hood was necessary because the stock Polaris hood proved to be inadequate in a few areas. The change from a two stroke engine to a Diesel meant a significant change in necessary clearances, so this issue had to be addressed. Also, the stock hood did not provide adequate noise reduction; this can be attributed to the thin plastic material and multiple hood vents. The new hood was designed to provide adequate space for the new engine and also to keep weight and noise to a minimum.

To create this new hood a plug had to be made to create a fiberglass rendition of our design. The top of the stock hood was removed, leaving only the base and gauge pod. A wire frame was then constructed according to the necessary clearances. The wire frame was then reinforced and strips of fiberglass matting were laid over it, this combination provided the shell of the new hood. On the left side of the hood, a forward facing port had to be constructed for multiplier clearance. This port was constructed with a wire frame and fiberglass matting in the same manner as the top of the hood. These fiberglass sections were then smoothed out with body filler to create a nice finish. The outline of the new hood, also known as a plug, was then sent to a fiberglass shop to have a mold made.

The new hood was then made from this mold using fiberglass enhanced with a material called PDP, a noise reducing material. Fiberglass was chosen for its light weight; saving us nearly 5 pounds when compared to the stock hood. PDP is a constrained layer damping foil for laminating into fiberglass panels to improve sound transmission loss and absorb structural acoustic energy [8]. It interacts with the structure of the composite material to dampen sound waves.

NOISE REDUCTION APPROACH

The reduction of noise was a large concern for the UB team this year. To tackle this challenge, a number of cutting edge materials from American Acoustical Products were used.

A vinyl based matting called VE was used to reduce resonating frequencies coming from areas within the snowmobile. VE is used to lower noise heard from a resonating structure, which is perfect for the underside of a snowmobile tunnel. Noise from the moving track and rear suspension components are trapped in this cavity and resonate. With the use of VE on the interior of the tunnel, this will help to absorb unwanted frequencies and reduce audible noise.

To further reduce noise, acoustic melamine was added to the underside of the hood. The particular melamine we used is called Hushcloth Melamine and was chosen for its light weight, excellent sound absorption, and high heat resistance. The high heat resistance is particularly important because the lack of hood vents leads to extremely high under hood temperatures; and even if the melamine's maximum temperature is reached, it will char rather than burn. Other types of sound absorbing foams are much more flammable and would create a fire hazard. While other materials have higher sound absorption coefficients (figure 14), the Hushcloth Melamine is the best foam for fire resistance and absorbs sound better than other fire resistant materials, like fiberglass. It also works the best in the 1 kHz to 4 kHz range, which is the most common weighted frequency in the dBA scale with our engine setup.

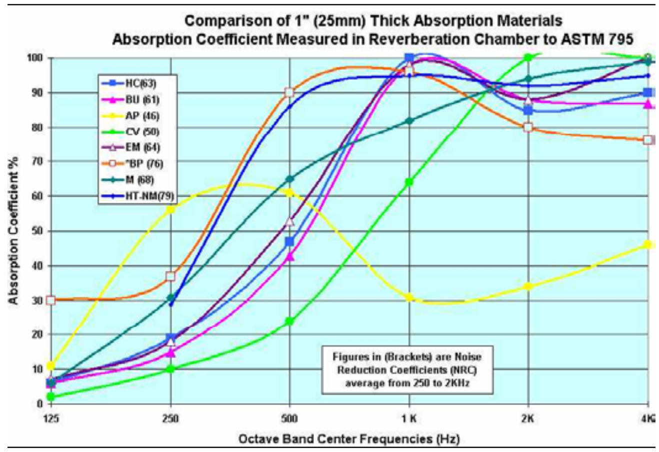

Figure 14: Sound transmission through various commercially available sound absorbing materials. Melamine foam (M) (dark green) is used in the snowmobile hood.

Millennium Metal is an aluminum honeycomb that is used to absorb low frequency noises, and its performance increases when used in conjunction with Hushcloth Melamine.

Due to a diesel engine's fuel knock, close fitting millennium metal shields were used to attenuate the fuel knock sound. Using millennium metal attenuates the sounds coming from the engine which allows the Hushcloth Melamine to attenuate the rest of the noise. American Acoustical has been working with diesel busses with this technology and has proven a ten decibel decrease in engine noise by using the close fitting shields [10]. Results of this work may be seen in Figure 15.

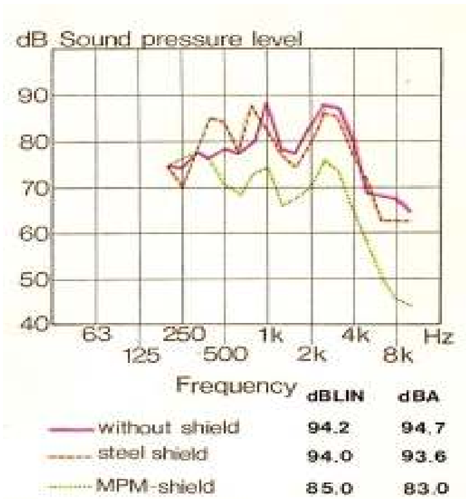

Figure 15: American Acoustical test results for diesel busses with various forms of shielding

Due to the success of American Acoustical's work with these shields, we have chosen to implement a similar design.

TRACK SELECTION

The track on a snowmobile is one of the main contributors to noise emissions, for this reason we have looked to our supplier for what they have considered to be a quiet track. Through talking to our supplier Camoplast we have decided to use their one and a quarter inch Ripsaw track. This track has been tested by Camoplast to be their quietest track when predrilled with 144 stud holes [9]. The Ripsaw track features crescent shaped lugs which improve hard pack snow handling and acceleration. The deeper lug design allows for better deep snow performance.

STUDS

For 2008 the UB CSC team has opted to run studs in the track. Due to the under powered engine we have opted to run studs to improve upon our acceleration. To keep the noise emissions minimal we opted to use 48 Woody's Gold Digger 1.325 inch studs with square aluminum backers to reduce weight. The studs utilize the predrilled pattern and are installed on every other bar on the track.

CONCLUSION

The UB CSC Team has fulfilled the potential of a truly innovative design. The use of a CI engine in a CSC entry was once thought to not be worth the trouble, but with the addition of the engine output multiplier, this design can now show what it is truly capable of. It now has the capability to be a clean, quiet and efficient alternative to a traditional SI powered snowmobile.

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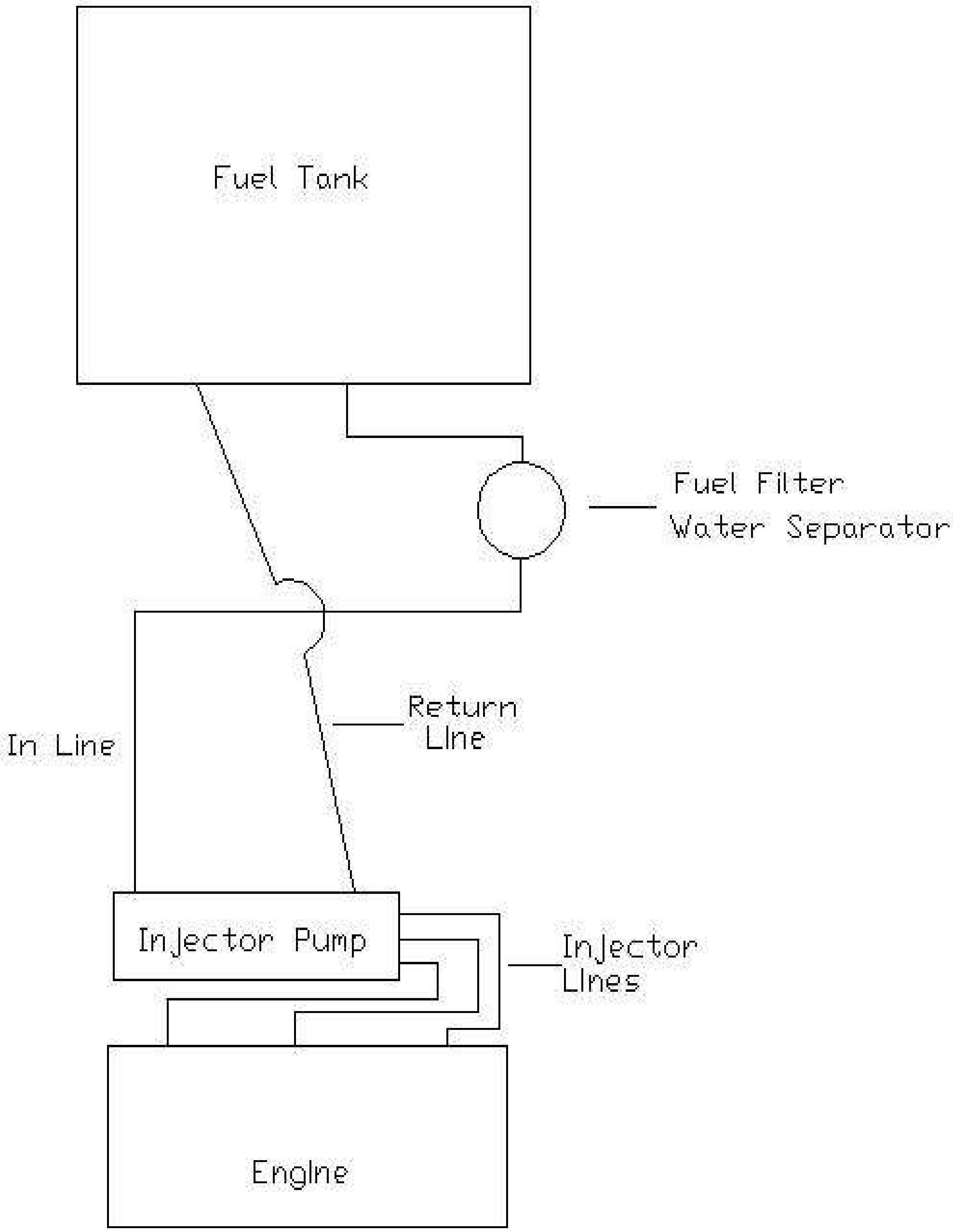
APPENDIX A: Fuel System Schematic



APPENDIX B: Wiring Diagram