The University at Buffalo Approach to a Diesel Powered Snowmobile

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ABSTRACT

The increasing impact of snowmobiles on the environment has become a concern of government officials, environmentalists, and even those who ride snowmobiles themselves. Due to the popularity of snowmobiling, snowmobile manufacturers have had to rethink their designs. In the years since this issue has been raised, snowmobile manufacturers have began to design and produce snowmobiles that emit fewer harmful emissions, are quiet, and more efficient while maintaining the excitement that snowmobile riders call for. The University at Buffalo (UB) Clean Snowmobile team has decided to implement a concept that does not exist currently in the snowmobile market. For the 2009 Clean Snowmobile Challenge the University at Buffalo snowmobile will be powered by a Daihatsu three cylinder diesel engine in a Polaris IQ chassis. By tuning this engine to run cleaner, and with the addition of an exhaust after treatment system, this design can be a viable solution to the problem posed by the Clean Snowmobile Challenge.

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 2009 SAE Clean Snowmobile Competition state that this year's entries into the competition must exceed 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 (NOx) 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 2009 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 made significant progress in diesel emissions technology. New legislative measures brought by the Environmental Protection Agency have been ratified to restrict diesel engine emissions on new vehicles. Also, the creation of Ultra Low 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 2009.

UB SOLUTION

For the 2009 CSC the UB team has decided to 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 2009 goals are as follows:

- Reduce engine emissions
- Reduce engine noise
- Increase vehicle speed
- Decrease vehicle weight
- Enhance rider comfort

CHASSIS SELECTION

For the 2009 Clean Snowmobile competition the University at Buffalo has chosen a 2005 Polaris Fusion as a base snowmobile. This is a modern chassis that uses A-Arm front suspension as well as rider forward position while reducing overall weight. This chassis was ultimately selected based around the size limitations of our diesel engine. Even with the relatively larger engine compartment on the Polaris Fusion chassis, significant modification and relocation to engine systems was required. The oil filter was relocated remotely through the use of a custom adapter. The oil pan was also cut down ¾” to allow clearance for steering linkages. A single v-belt accessory drive was replaced by a custom multi belt design to avoid interference with the side of the bulkhead.

The chassis was upgraded this year due to a rule which involved the structural integrity of using snowmobile chassis from years 2003 and older. This rule stems from teams using the same chassis over and over with different engines and parts making it weak from adding additionally mounting locations year after year. We would like to thank Hudon’s Sled and Salvage for donating a chassis for this year’s competition.

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 2009 CSC. After deciding on a diesel power plant we had to concern ourselves with size, weight, power, and availability.

ENGINE SELECTION

The 2009 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, three cylinder diesel manufactured by Daihatsu. The engine is a 953 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 this design utilizes the stock snowmobile heat exchangers located under the tunnel and a small radiator in the front of the belly pan.

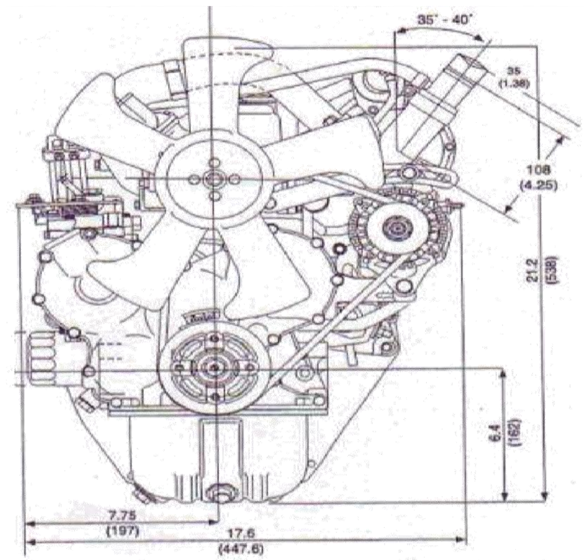


Figure 1: Daihatsu Diesel Engine

The engine can 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 this way gives us the ability to utilize the limited space in the chassis. Due to the low center of gravity of this engine and the angle of mounting we were able to keep the sleds center of gravity as low as possible.

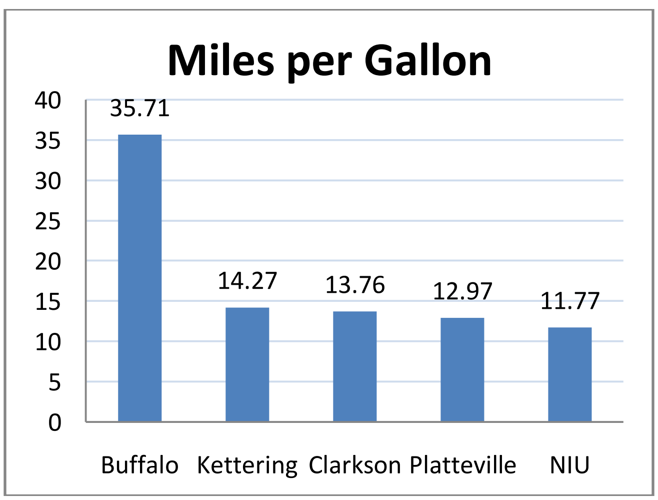
One of the major factors in running a diesel engine in any vehicle is that diesels are 30-40 percent more efficient than other internal combustion engines. Keeping this in mind our team is hoping for drastically increased fuel economy over two and four stroke snowmobiles. The only real set back to using a diesel engine is the emission of particulate matter.

FUEL SYSTEM

The fuel system on the Daihatsu diesel is relatively simple because it is 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. A schematic of the fuel system can be seen in Appendix A. Some unique features of 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.

The fuel pump internal to the stock Polaris Fusion fuel tank was removed and replaced with a custom plug. This unit was designed to accept hose barb fittings on both the inside and outside of the tank. These fuel lines serve as fuel pickup and fuel return feeding between the engine and the fuel tank. Additionally, the engine's injector pump has the ability to pull fuel from up to twenty-four inches below its inlet and because of this a fuel lift pump is not necessary.

Since diesels are typically 30 – 40 percent more efficient than two and four stroke engines we will be able to traverse more miles than other CSC teams on a gallon of fuel. Unfortunately we were unable to find a race fuel tank for this chassis and instead will be running the stock 12 gallon fuel tank. This will add a significant amount of unneeded weight to our snowmobile because 5 gallons of fuel would be sufficient to complete the 100 mile endurance test at the Clean Snowmobile Challenge. During a test run of our snowmobile at speeds between 40 and 50 miles per hour the diesel engine was achieving an average of 35.71 miles per gallon of B10 fuel. The graph pictured below shows the top four fuel mileage numbers from CSC 2008 compared to our diesel snowmobile.



COOLING SYSTEM

The cooling system was an initial concern for this year's design due to the catastrophic failure and overheating of last year's engine. Upon first inspection we noticed additional heat exchangers as well as a front mounted radiator on the Fusion's chassis. The stock cooling system is shown in Appendix D. The Polaris Fusion stock cooling system will suffice the cooling curves for the diesel engine also shown in Appendix D. This cooling system has shown to exceed the necessary heat rejection of the turbo diesel engine. Using the stock cooling system saves weight and allows for easy fitment to the diesel engine. Additionally the largest of the heat exchangers has excellent placement on the underside of the tunnel and is therefore exposed to cool ambient air and snow. This also allows the hood to remain sealed which decreases the amount of noise escaping. Only 2 coolant hoses had to be rerouted to make this system pipe up to the new engine; we are using a filler neck and overflow bottle for this design. Using a filler neck and overflow bottle allows us room to put the filler at the very top of the engine and thus avoid air bubbles which could potentially lock up the system.

INTAKE DESIGN

OVERVIEW

The 2008 intake design proved to be inadequate in suppressing outputted noise from the turbocharger. The 2009 design, shown in Figure 2, uses an expander system along with a K&N cone filter. Along with the change in intake design, the filter location also moved from the engine compartment a location on the stock snowmobile console. This allows the intake to pull in cool ambient air instead the hot air under the hood.

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.

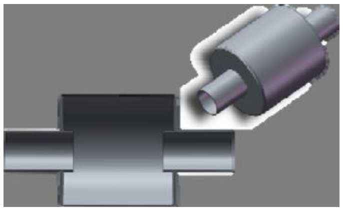


Figure 3: Expander Solid Model

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

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 4. As you can see from the characteristic equation you can see a potential loss of 18 dB at 1 kHz.

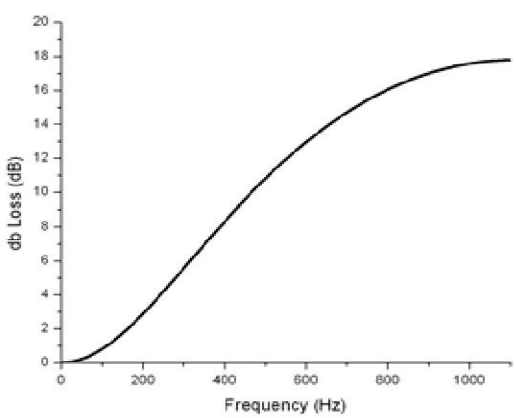


Figure 4: Graph showing amplitude vs. Frequency

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. Below is an equation bases on the original output of the diesel engine at 3200 rpm's:

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

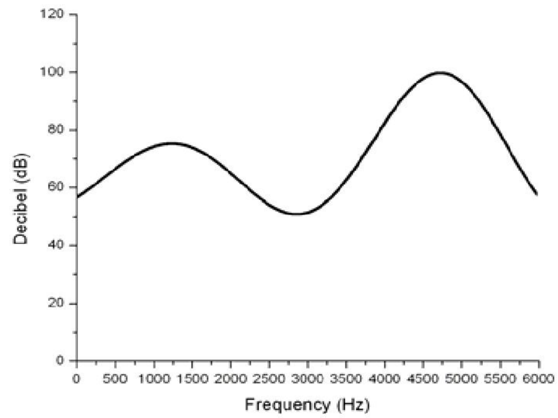


Figure 5.a Char. Curve 3200rpm (Before)

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.

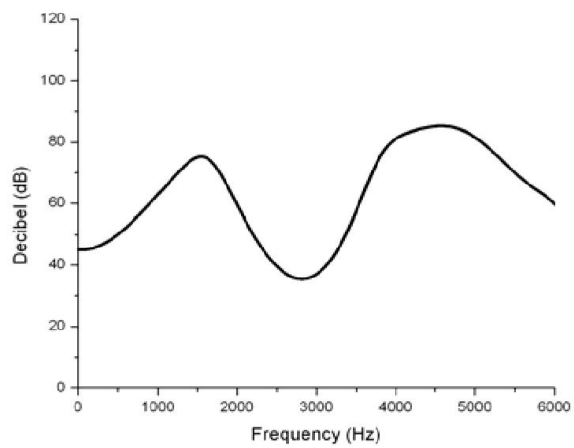


Figure 5.b Char. Curve 3200rpm (After)

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 restrict air flow like the previous setup and is significantly lighter as well.

ELECTRICAL SYSTEM

The Power supplied for engine startup will be a 12V, sealed gel cell X Static 800 battery supplied by Batcap. This battery is very unique in that it supplies 800 cold cranking amps but weights only 14 pounds. This battery has replaced the 34 pound 580cca battery that has been used in the past. In addition to being 20 pounds lighter the new battery is also about 1/3 of the size. The battery is able to achieve 800cca and maintain its small size and weight because it is 70% capacitor and 30% battery. This gives it the unique massive cold cranking amps when needed for starting the engine without using nearly any battery power. This was an obvious choice for replacing the large and bulky battery that had failed us in the 2007 CSC competition. This battery has been used for the past 8 months without a single recharge.

The battery will be housed in a non conductive, lexan battery box under the seat of the Fusion. This allows for a clean look but most of all a distributed weight and more room under the cowl of the snowmobile. The tunnel of the Polaris Fusion also has inset grooves that rigidize the tunnel and also allow for the wiring to be run to the engine and components under the seat. While the glove box in the seat was used to house the battery, the storage compartments in the console house the rest of the electrical components. The left side storage compartment holds the distribution block as well as a normally closed relay (which the solenoid runs through). This relay is hooked up to a push button on/off kill switch as well as a tether kill switch and cuts power to the solenoid, shutting down the engine in case of an emergency. The right side storage compartment houses the snowmobiles relay, preheat timer, and a fuse panel which leads to all of the 12v sources on the snowmobile. This is a new addition to the wiring this year, as past snowmobile designs have all housed the electrical systems under the hood. This allows for an ease of understanding the wiring as well as makes it easy for the user to change a fuse.

Another addition to this year's snowmobile was a speedometer, due to a rule update for CSC2009. Because the stock engine and components were not utilized, the stock speedometer was not a viable option. The team decided to employ an Autometer 5" GPS speedometer. This speedometer uses GPS signal to measure real-time speed, top speed, and average speed. The GPS speedometer was chosen because it has virtually no delay, shows no loss of signal, and is completely waterproof. Additionally, it measures speed from a GPS signal instead of by mechanical means or off the drive shaft like conventional snowmobiles. This means the speedometer returns the actual vehicle speed instead of track speed. This speedometer ensures that we will receive the correct speed at all times regardless of track slippage. Ultimately, this speedometer aids in the testing phase of our snowmobile, making sure it will meet speed requirements for CSC2009.

In addition to a speedometer we will also be utilizing additional gauges and lights to monitor all systems of the snowmobile. A coolant gauge and light will be used to prevent overheating (as it was our catastrophic failure in 2008). Monitoring of the engines other vitals will be performed by an EGT system. This system will monitor intake pressure, and both pre and post Cat/PM exhaust temperature. Additionally, lights are mounted on the snowmobile to alert the rider of water/fuel mixture, coolant overheat, oil pressure, and a charge light to insure the alternator is working correctly.

Reference Appendix B for engine wiring diagram.

ENGINE MOUNTS

New engine mounts had to be designed and manufactured to implement the Briggs & Stratton diesel engine into the Polaris IQ 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. Figure 6 shows the load/deflection relationship for the vibration mounts employed in our design. The curve for the isolators used in this design is labeled "DD" in the figure.

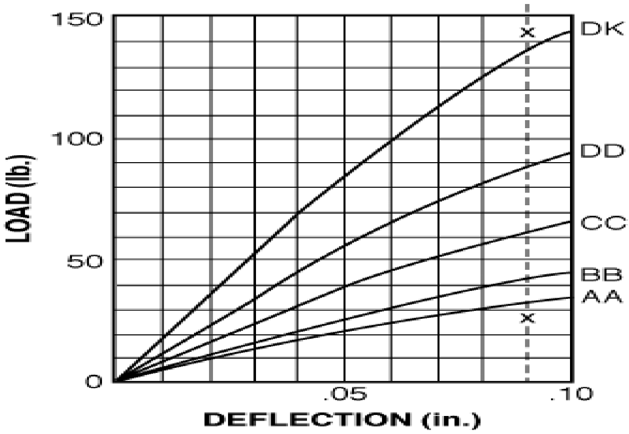


Figure 6 – Load vs deflection for mount isolators

The Briggs & Stratton engine has a counterbalanced crank shaft and flywheel which allows for use of stiffer engine mounts to isolate vibration.

Front Mount

The front engine mount attaches to the snowmobile chassis between the front shock towers. This area was utilized instead of the stock motor mount positions because it allowed the increased weight of the diesel engine to be supported with less concentration of stress. The shock tower support of the stock chassis was reinforced with 14 gauge steel to maintain rigidity in the front suspension. The wide footprint of the front mount is designed to restrict off axis engine torsion that would result in clutch misalignment. The mount is manufactured from 1/4 inch 5052 aluminum plate

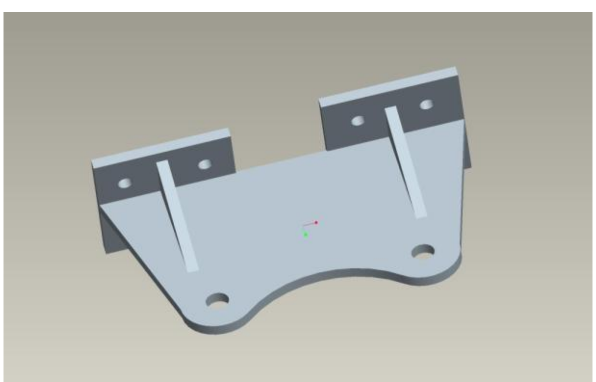


Figure 7-Front Engine Mount

Rear Mounts

The rear of the engine is supported using two mounts supporting opposite sides of the engine. Because of the space constraints in the rear of the engine compartment the mounts were designed to be very compact and were manufactured from 1080 steel to provide the needed strength. The rear mounts use smaller vibration dampers that provide the same deflection vs. load characteristics as the front vibration isolators.

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 8 shows roughly how our system works [7].

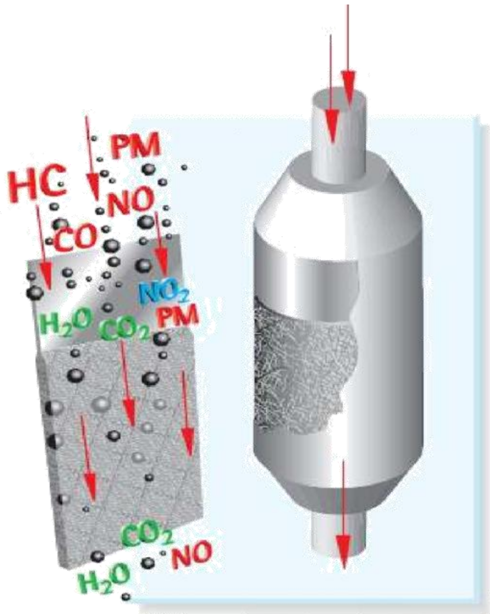


Figure 8: Cat/PM illustration

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 and as a result has excellent 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 9.

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 9: Cross section view of muffler.

The diesel engine used in the 2009 design has been shown to emit very few harmful emissions based on data from the 2007 CSC. Shown in Figure 10 is the 2007 CSC emissions testing results of UB compared to the E85 average emissions

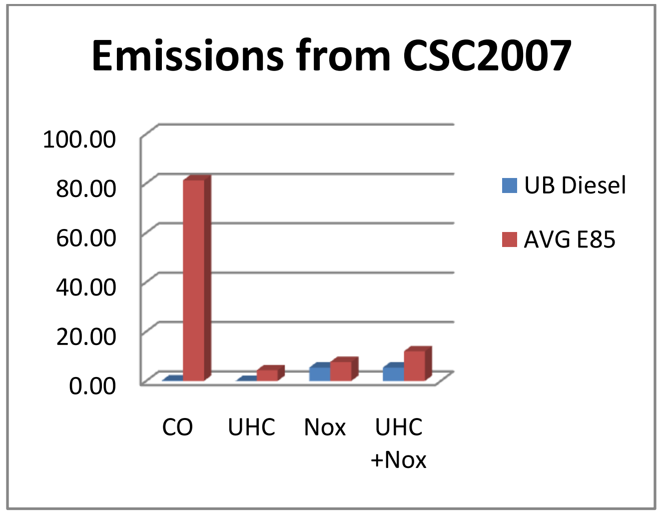


Figure 10: UB Diesel emissions vs. Ethanol emissions in 2007 CSC

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.

Chassis Noise Reduction

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.

Engine Noise Reduction

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. In the event that 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 (see appendix B), 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.

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 Fig 11.

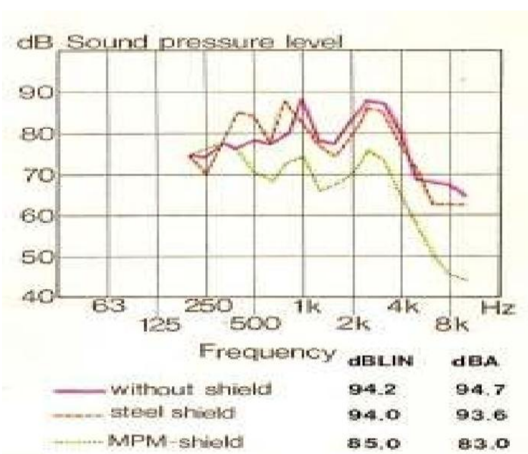


Figure 11: American Acoustical test results for diesel busses with various forms of shielding

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

HOOD

The 2009 UB snowmobile will not employ a custom fiberglass hood like those used in previous designs. This is because the engine sits low enough in this chassis that a custom made hood will not be necessary. Because the fiberglass hoods we typically use are superior for noise reduction we are trying to add as much to our stock hood as possible to eliminate sound from the engine. First, we have sealed all hood vents with bondo and fiberglass. Next, we have coated the inside of the hood in a layer of dynamat to eliminate high pitched frequencies. Next, the hood will be lined with 1" thick melamine foam from American Acoustical Products. Another change will also be made this year from previous years and that is a hinged hood design. This will allow for quicker adjustments during testing and for the speedometer to be mounted in the hood as it is in conventional snowmobiles.

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 stock from a 2005 Polaris Fusion. This suspension utilizes a Fox Zero Pro rear shock and a Ride FX coil shock. These rear 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 rear suspension also incorporates a stiff set of springs to assist in "rebounding" the suspension on rough trails.

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. After speaking to Camoplast we have decided to use a 1 ¼ inch Cobra track. In Camoplast's testing this track has been shown to be the quietest when predrilled with 144 stud holes [9]. The Cobra track features cupped lugs which improve hard pack snow handling and acceleration. The deeper lug design allows for better deep snow performance. In addition to improved sound, the Cobra track has a 3 pound lighter rotating mass than the Ripsaw track used on our 2008 CSC entry.

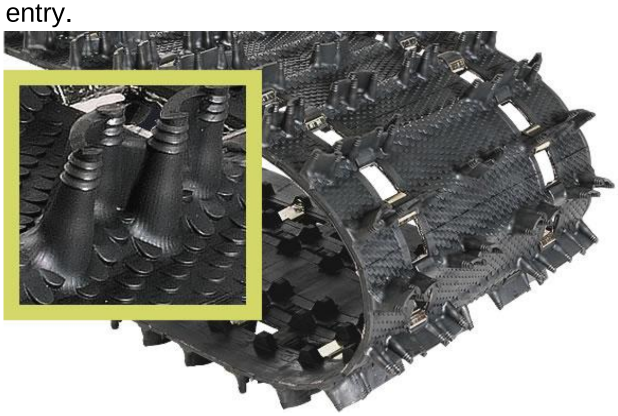


Figure 12: Camoplast Cobra track

SKIS

C&A Pro trail skis have been used in our 2009 CSC 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 because of the big footprint it makes when cutting through the snow. More responsive steering is imperative in this design since the diesel engine adds a significant amount of weight to the front of the snowmobile. Additionally a pair of Woody's carbides will be used to give the snowmobile good traction in unfavorable conditions.

CONCLUSION

The UB CSC Team has fulfilled the potential of a truly innovative design. The use of a compression ignition engine in a CSC entry was once thought to not be worth the trouble, but the University at Buffalo 2009 snowmobile has shown that a diesel snowmobile is a feasible option. It now has the capability to be a clean, quiet and efficient alternative to a traditional spark ignition powered snowmobile.

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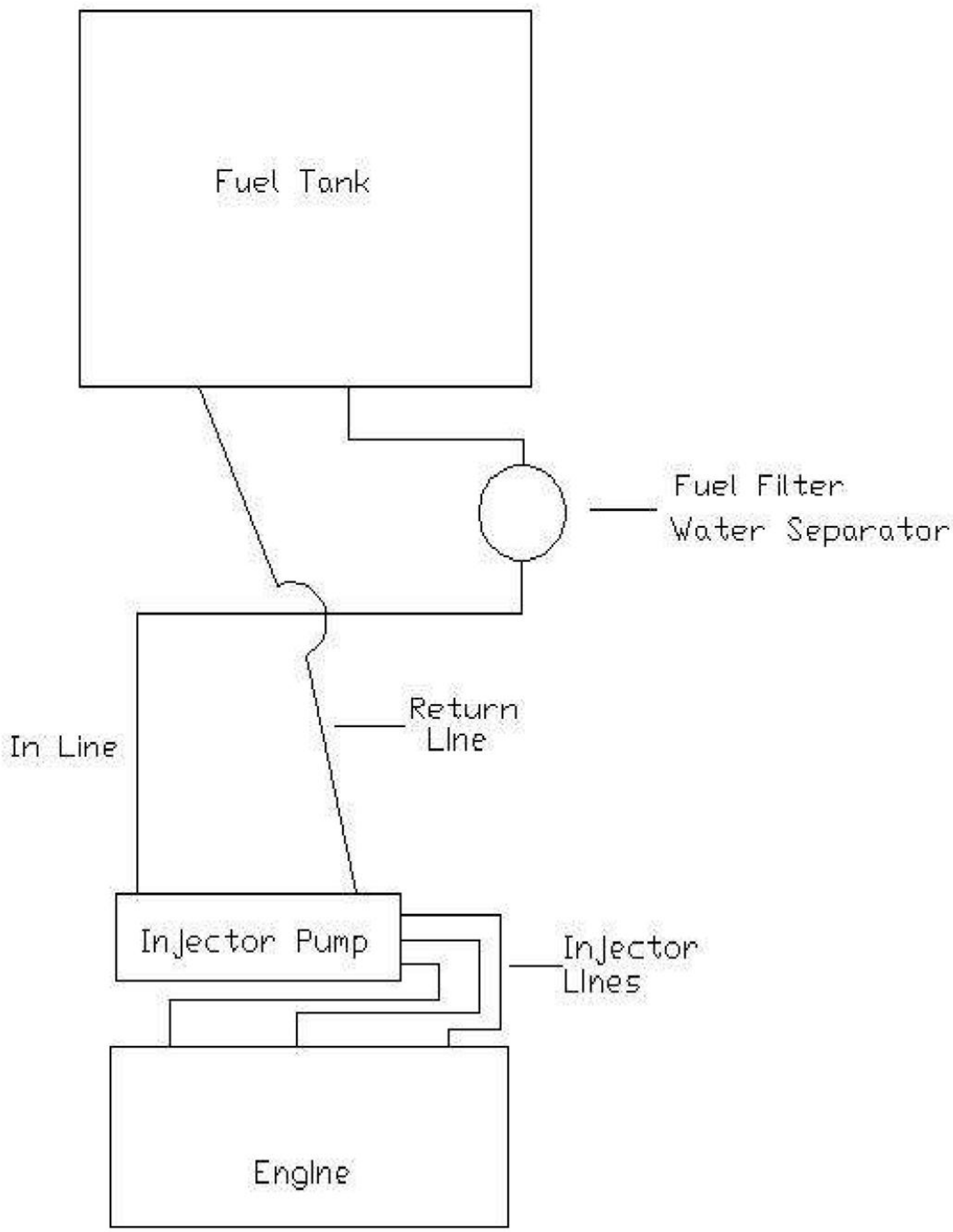
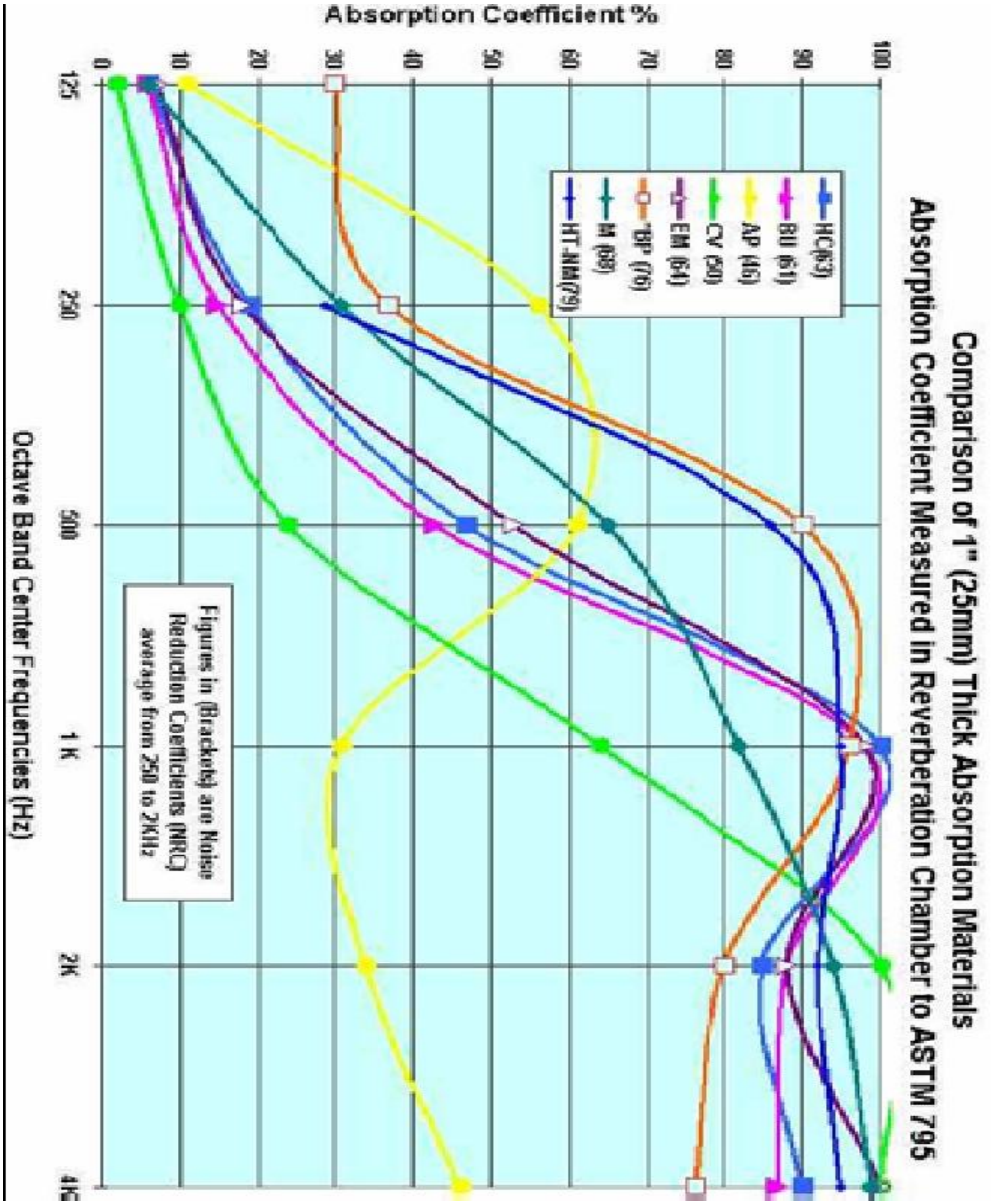
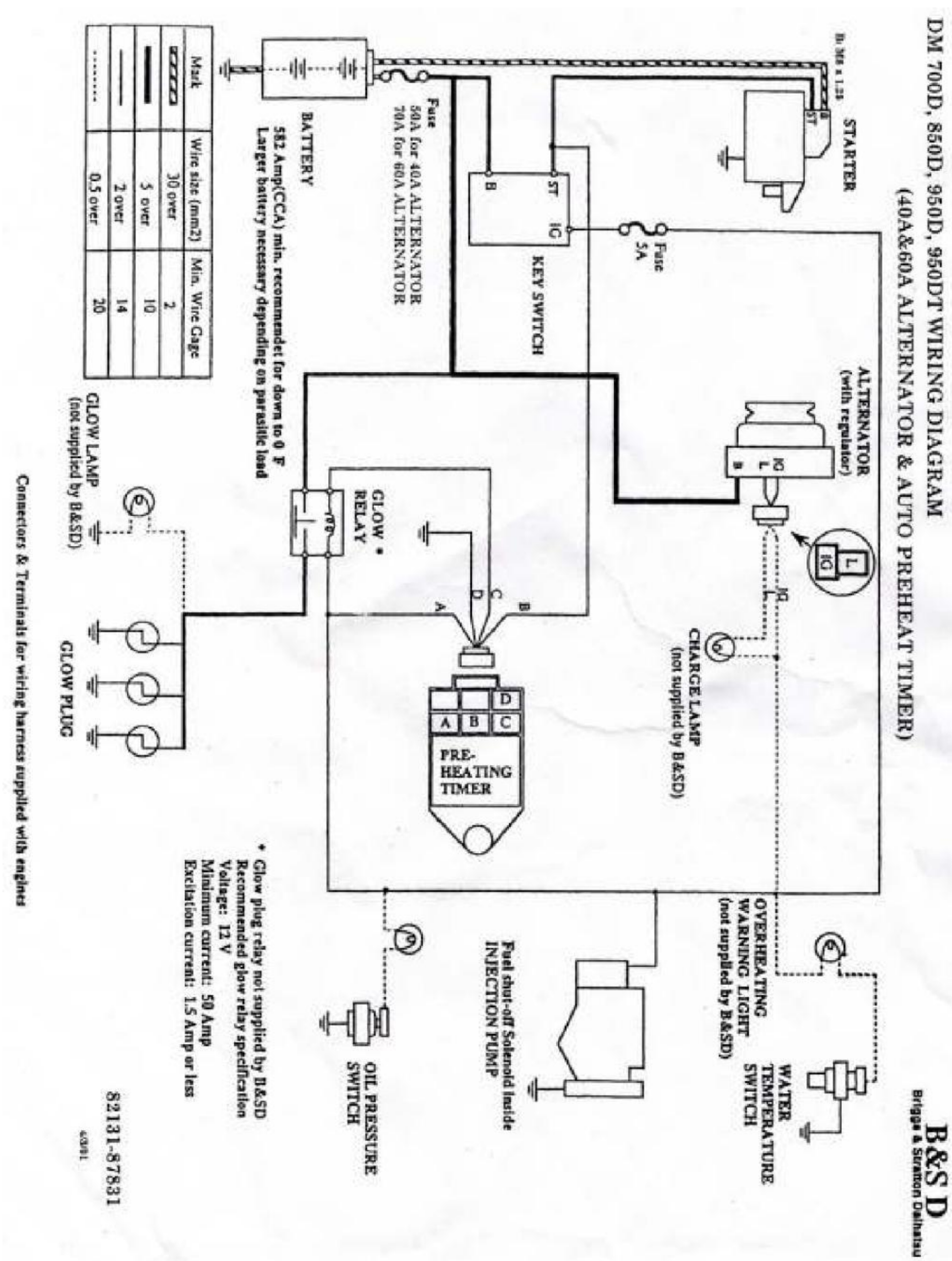
APPENDIX A: Fuel System Schematic



Appendix B: Sound transmission through various commercially available sound absorbing materials **(melamine shown in dark green)**



Appendix C: Engine wiring diagram



Appendix D: Cooling System