École de technologie supérieur (ÉTS)

Direct Injected Two-Stroke Snowmobile

Clean Snowmobile Challenge 2011 Design Report

ABSTRACT

Team QUIETS is very proud to take part in the 2011 Clean Snowmobile Challenge hosted by Michigan Tech. Our 2009 MXZ TNT modified with a new and improved high pressure direct injection system will take place in the competition. The 2 cylinder 2-stroke engine is equipped with a new injection module, a quieter and efficient exhaust system capable of reducing sound emission by 55% compared to the original exhaust system. QUIETS started in January 2003. It was founded to enable a handful of dynamic and motivated students to challenge and surpass their technical knowledge in an environmentally oriented approach. We are trying to make the sport of snowmobile riding more eco friendly, a challenge in line with modern day reality. The club is a great example of what a group of 20 people with common goals can accomplish.

INTRODUCTION

Participating at the 2011 clean snowmobile challenge is not only a way for us to contribute in the research for a more environmentally friendly propulsion system, but also to allow us to experience the competition between different teams which we will likely face after the completions of our studies. This competition also gives us the chance to represent our school. We are a motivated team with interest towards the preservation and protection of our environment. Our ultimate goal is to change the criticizing image given by the consumers towards 2 stroke engines and bring them back in style with better fuel economy, less emissions in a quieter environment. Our objectives for this year's competition include reducing the noise level of the snowmobile to 65 dB, lower than an electric snowmobile and design a functional high pressure with direct injection system. But one of our major and most important goal is to create a new generation of students to pass over our knowledge acquired over the years and prepare them to take over the club once we leave, keeping the club alive and at its highest potential. We will achieve our goals with determination. Our team grew a lot this year and because of the addition of new members, more projects were realized with success. It is with these tools that we will succeed and win this year's competition.

BODY

Snowmobile choice

The team opted for a 2009 MXZ TNT snowmobile from BRP powered by an E-tech 2 stroke engine for the 2011 clean snowmobile challenge competition. This sled was chosen because of it lightweight chassis, excellent handling and the perfect solution to accommodate our revised and improved HPDI system.

Electronic control module

The engine calibration and small tuning was made possible with the help of our MotoTron ECM powered by a Motorolla MPC 555 40MHz micro processor. This electronic control module (ECM) enables us to fully customize and modify with precision engine specs and mapping. The high amount of input and output ports allowed us to add different sensor and actuator to the system and fully monitor the engine. The Mototron control module possessed the best qualities required to operate in the environment in which it will be exposed during various types of snowmobile riding conditions. Operating temperature for this hermetically sealed ECM may vary between -40°C and 105°C making it suitable for cold weather and high engine temperature exposure. The sealed connector make it operable submerged under water at a depth of up to 10 feet.

High pressure fuel pump

For the 2011 competition, we decided to upgrade our electrical powered high pressure pump to a mechanical system driven directly to our engine crank shaft. This system allows us to get a better energetic efficiency for the required work load of the pump. Our high pressure pump provides us up to 200 bar of pressure, more than enough to feed our injection system. Operating temperatures for this pump can vary between -40°C to 120°C and when not in use, -40°C to 70°C. The pump may withstand vibrations up to 60 g's making it very suitable for a snowmobile. The choice for this pump was ideal not only for its advantages, but also for its geometry. This pump is the only model which requires axial movement. The lack of room around the engine bay played at our advantage to favorite this system since the addition of a cam would require too much room. The crack shaft provides the rotation engagement needed to run the pump with the help of gears and belt system. This assembly required the use of the old previously used starter pull to respect the dimensions of the frame reinforcements of the snowmobile.

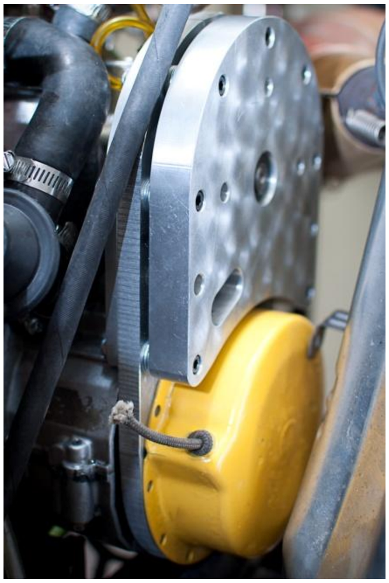


Figure 1 Crank Cover for high pressure fuel pump system

Oil pump

Two solutions were considered to achieve proper lubrication of our crank shaft bearings and RAVE system, a mechanically driven oil pump and an electrical oil pump. The mechanical oil pump, being dependent to the engine RPM prevented us from regulating the desired flow. On the other hand, an electrical oil pump system is completely independent and allowed us to have a greater range of customizable parameters.

Injection module

The injector response was too slow for the high pressure. High pressure injectors are low resistance so we use peak and hold driver to activate them. The coil resistance from the high pressure injector which is used in the snowmobile is 1,5ohms. When the ECU asks for gas, the current is going to 16A (peak) for $800\mu s$ then, is held to 4,7A (hold). This concept minimizes injection ''on'' time.

Injection system

The fuel rail requires lots of amelioration since the quantity of fuel administrated in each injector was not enough. Theses faults in the firsts high pressure injection lines were due to an excess of turbulence as well as to a restricted channel diameter. The new generation of the fuel rail will be very finely inspected with the help of simulated mathematics and digital fluid mechanics (CFD). The support for the original injectors possessed an angle to minimize its distance with the spark plugs and also to allow the use of stratified injection. Unfortunately, this angle interfered with the ideal injection for an HPDI system.

Fuel Rail

The new conception for the fuel rail had as a main objective to establish an inside diameter which would result in a fuel speed that would lean towards 0 m/s. This objective would allow us to get a true pressure reading as well as enabling us to maintain as much as possible the maximum pressure in the accumulator in order to get a greater pressure difference between it and the combustion chamber. Greater pressure difference results in a better fuel particle spray which leads to a better combustion.

The figures bellow demonstrates the speed of the fluid in the fuel rail as the right injector is in use. The speed legend was shrunk since no speed differences were observed. The maximum speed, found with the help of Solidworks, is about 20 m/s. It is represented in the 3 mm canal, the injector representation. It is the vertical section bellow the horizontal disk which also includes the diameter restriction up to 0.5 mm. The conclusion is that the speed in the fuel rail will be 0 m/s.

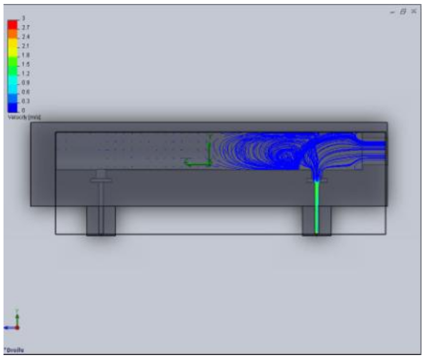


Figure 2 : Front vu representation of the right injector fuel speed.

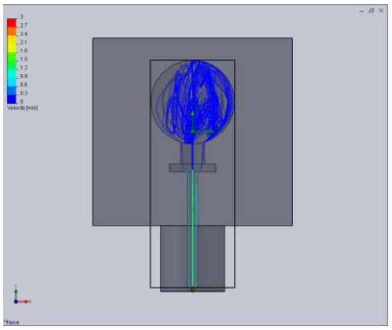


Figure 3 :
Right vu of the right injector fuel speed

It is possible to observe with the following figure that the pressure in the fuel rail assembly remains constant. It is the most important aspect since it allows a constant injection speed with reference to the Bernouilli law.

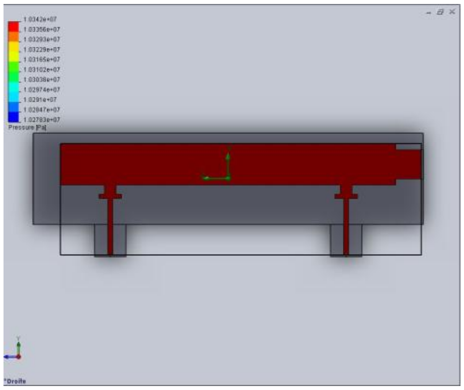


Figure 4 :
Graphic representation of the pressure inside the accumulator

Now, the evaluation for the left injector will represent the same aspects as the right one. Here are the results represented in the figures bellow:

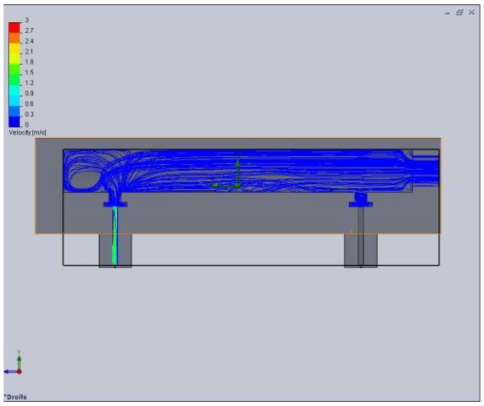


Figure 5 :
Front vu representation of the speed in the left injector

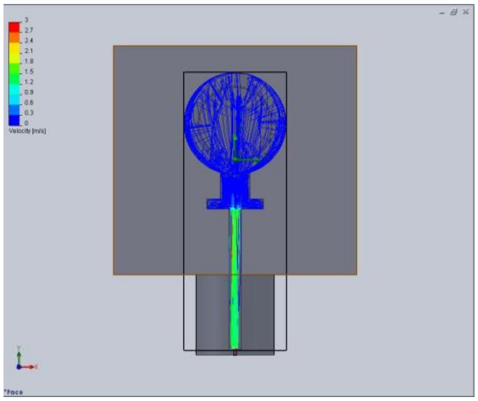


Figure 6 :
Left vu representation of the speed in the left injector

A speed of 1.5 m/s is created in the injectors. Another important aspect which was not previously discussed in the right injector section is the fuel vacuum due to the injector. The effects are the induction of a certain speed at the entrance of the injector and a vacuum all around the hole. The fuel is therefore pulled to the left side needing to be replaced by a lower speed. The liquid which was not sucked in has to be replaced by the following fuel. The effects of this phenomenon are a vacuum loop. The bigger the loop, the lower the losses will be. The comparison is possible between this loop and the right injector. Therefore, this enlargement of the section diameter, which was not present in the first generation fuel rail, will greatly help to the circulation of the fluid. This amelioration would have not been possible without any finished element analysis.

Injector Support

The relocation of the injectors allowed an optimization of the combustion in the combustion chamber. The important modifications were due to the fact that the automobile injectors and the E-TEC injection system did not work in similar ways. On top of that, our first generation did not really take in count for those differences. The E-TEC system injects perpendicular to the cylinder head while the automotive injectors inject with an angle offset. An angle is therefore included in the cylinder head to allow the right projection of the fuel cone with the E-TEC system. The main reason for this is that since we require a minimal distance between the injectors and the spark plugs, the fuel cone therefore needs an angle to allow the injection to occur in a stratified mode.

Technical evaluation of the injectors

The image bellow represents a face vu of the injectors and allowed us to evaluate the cone angle. As seen in the figure, the cone as an opening of 48°. This opening was evaluated with the help of the AutoCAD software.

Figure 7 :
Evaluation of the open cone

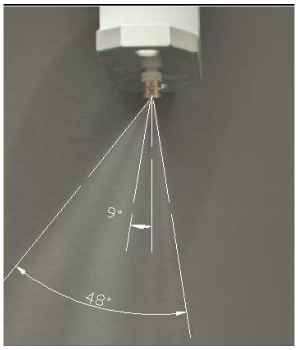


Figure 8 :
Inclined cone

Figure # 8 demonstrates very well the inclining angle of the cone. It allowed a conclusion that offset inclination was of 9°. This measure was also made possible with the help of AutoCAD. The only thing left was to see was the E-TEC system cone angle at the cylinder head lever. This measure was taken with a CMM which gave us the resulting offset angle of 9° as seen in the following figure:

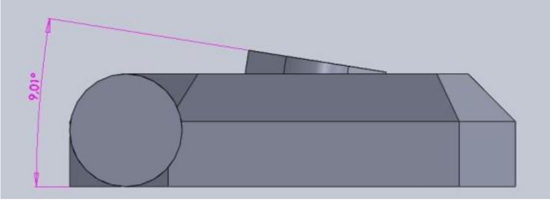


Figure 9 : Inclining angle for the face support of the E-TEC system

It is then possible to conclude that the offset angle which is made by the fuel spray of the E-TEC is also 9° compared to the vertical axe. It also possible to state that the angle of injection made by the injectors, the angle produced by the support assembly and the E-TEC injectors are the same. The conservation of the angle assures use to keep an optimal conception of the combustion chamber since the chamber is directly made to accommodate the E-TEC injectors.

The biggest problem was discovered after many tests last year. As seen in the next figure, the support for the injectors is at the same level as the initial surface for the E-TEC injectors. This means that the injectors will really send the cone at a initial 9° angle. On the other hand, as discussed in the previous section, le fuel cone created by the automotive injectors also had a 9° angle offset. This results in an injection angle of 18° with reference to the vertical axis. The figure 10 shows the inclination of the fuel cone of 33° based on its location on the cylinder head.

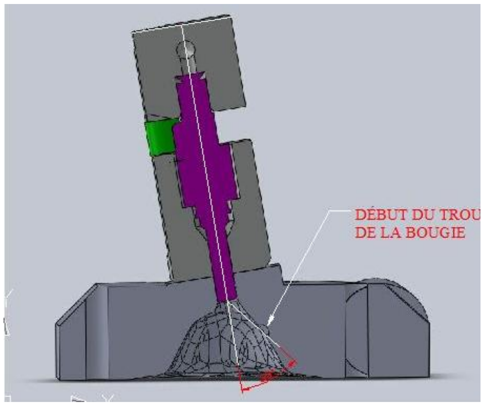


Figure 10:
Problématique reliée à cette 1ière génération

The consequences to having the 18° angle is that the delivered fuel hit directly the spark plug, right where the spark occurs and not ahead. Instead of having an ignition, the spark is flooded by the fuel since the air fuel ratio is rich and not optimal for a good combustion. This height augmentation leads to the contact of the fuel cone and the combustion chamber walls before reaching the spark plug and prevents a complete combustion the of the fuel.

Following the problematic issues discussed in the previous paragraph, the injector supports were reanalyzed from in and out to allow us to optimize the combustion in the chamber. Following the angle analysis, the principal recommendation is to maintain the original angle of 9°from the E-TEC injectors to assure that the combustion chamber is as efficient as possible.

First of all, following the evaluation of the automotive injectors which possessed an injection angle of 9°, it is now possible to design the support which will be parallel to the vertical axis. Another important point was to assure that the new injector supports are able to be fixed to the E-TEC injector anchors which are perpendicular to the 9° surface.

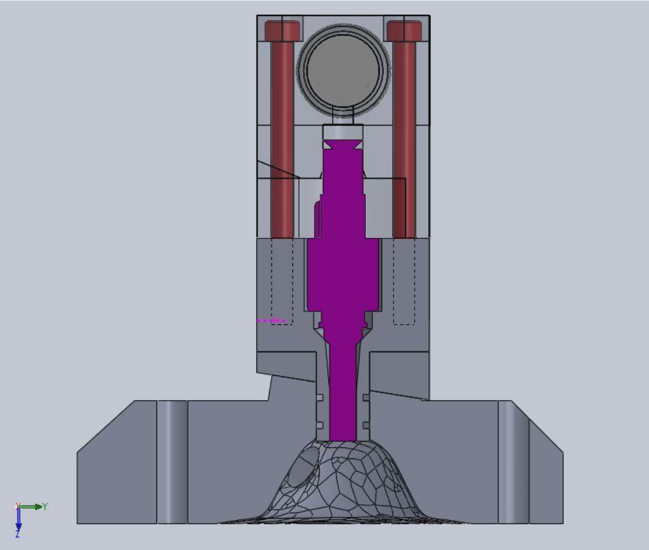


Figure 11:
Vue de coupe de la perpendicularité de l'injecteur

It is possible to observe in the figure above that the injectors are now vertical to the cylinder head and are supported by a single piece. This not only contributes to the elimination of the assembly process, but also helps respect the geometric tolerance attributed. First of all, a two-piece assembly, the base and the injector support, were very favorable. The degree of complexity for the machining of the parts was diminished therefore allowing not only lower geometric tolerances but also an easier final assembly process which made unseen mistakes during the original conception easily fixable.

Cold Start

Many correction maps were made to allow the optimal usage of the engine. Maps versus outside temperature, cooling liquid temperature and exhaust temperature were made. Thoses maps increase the quality of the fuel injection during the thermodynamics cycle and also improve the cold starting of the snowmobile at low temperatures.

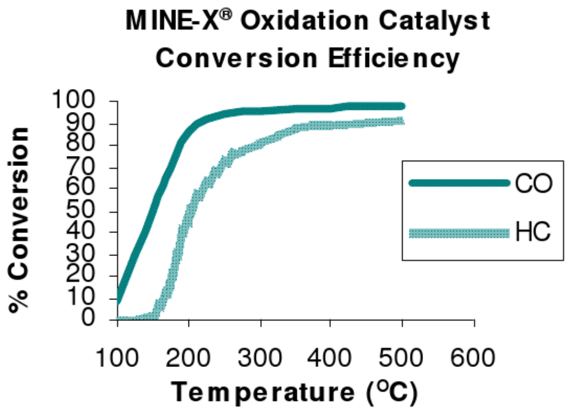
Emissions

Table # 1 Catalyst Specifications

Manufacturer	DCL International Inc.
Diameter	6.00 inches
Length	10.37 inches
Weight	5.5 Ib
Brazed Substrates	304LN austenitic and Fecralloy® ferritic stainless steel Honeycomb

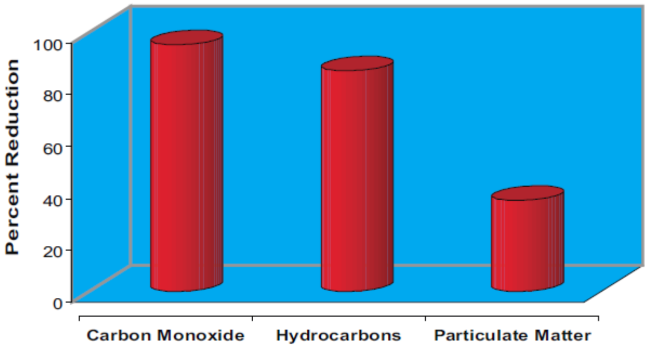
Our research toward the reduction and elimination of exhaust emissions leaded us to the conclusion that a catalyst had to be inserted. Our original choices for the catalyst varied between a DCL diesel catalyst and an Emitec gas engine catalyst. Both products had the potential to withstand oil and other organic particles that could result in the clogging of the entire exhaust. Since Emitec could deliver the desire product on time, we had no choice but to opt for the DCL diesel oxidation catalyst. The oxidation system would allow us to eliminate most of the undesired emissions such as COs (Carbon monoxide) and HCs (Hydro Carbons). Unfortunately, no significant changes were brought regarding the amount of NO_x (Nitrogen Oxides) particles treated by the oxidation catalyst.

Graphic # 1



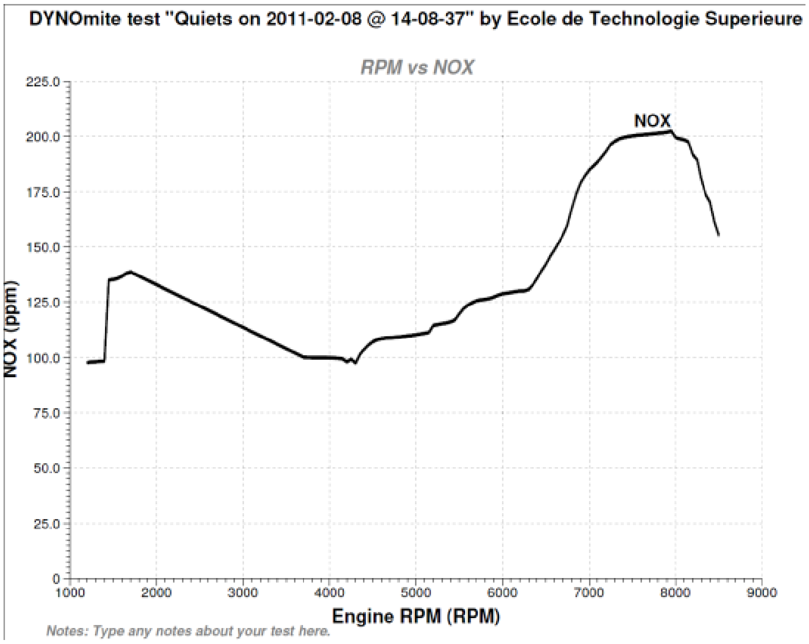
The theoretical performance of the catalyst suggest the removal of 90% of the CO particles at a temperature of 500° F and the removal of 70% of the HC particles at a temperature of 572° F.

Graphic # 2   Emission reduction percentage



The integration of the catalyst to our exhaust system was accomplished by the modifying the low frequency muffler shell. We designed new compartment chambers to accommodate the catalyst. The new 2 compartment design includes one resonating chamber and one larger muffler stuffs with high temperature resistant mineral wool with absorbent properties. By doing so, we were able to acquire both sound reduction and emission reductions properties to the low frequency muffler shell. The data provided above is only theoretical and was estimated with the help specifications provided by the manufacturer.

Graphic # 3   ppm of NOx vs RPM



The following graph represents the NOx ppm of the SDI snowmobile with no catalyst or any filtering device.

Exhaust design

This year, the design of the exhaust was focused on reducing sound emissions in the 0-5000 Hz range. This range covers most of the frequencies produced by an average rider. Here is the overall design of the team's 2011 muffler:

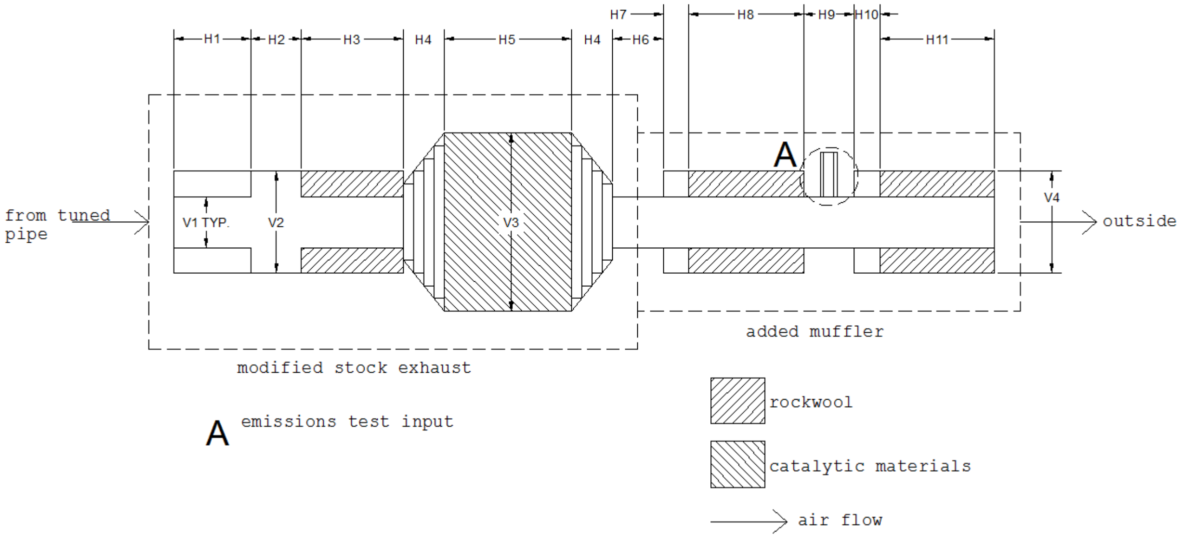
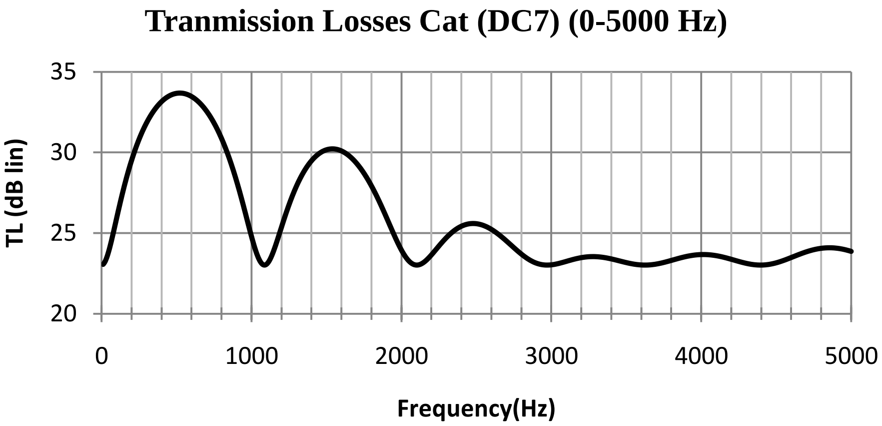


Figure 12 Exhaust system

This year, the stock exhaust was modified. Doing so guaranties us an easy swap in case of catalytic converter failure. A catalytic converter was added inside the exhaust as shown in the next figure:

Figure 13 Catalyst implantation

The stock exhaust is designed with four chambers working together to reduce noise emissions. In order to fit the catalytic converter, two of those chambers had to be removed. One chamber was modified to target low frequency sounds. Although the stock muffler is now completely out on default parameters, the new design is optimal considering the constraints with are in place. The catalytic converter by itself is considered sound reducing because of its shape. The transmission losses of the catalytic converter were simulated on Matlab using the quadric-polar method. The results are shown in the next figure:



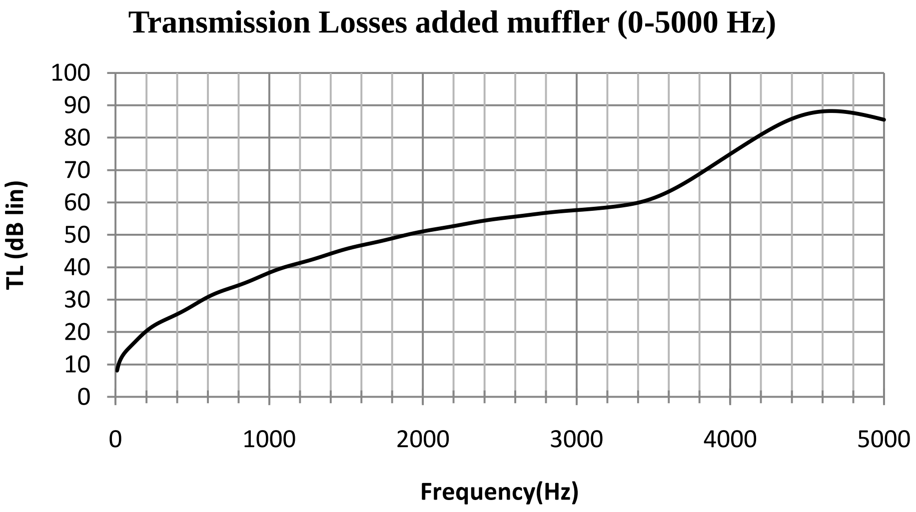
Graphic # 4 Transmission losses Cat

A model is still developed in order to evaluate the overall transmission losses of the new stock muffler assembly. A secondary muffler was then added to further reduce sound emission on the engine's exhaust. The baseline was set by last year's muffler's performances. We wanted to shorten the overall length of last year's muffler and raise its performances if possible. This was achieved by first building a Matlab model of the added muffler. Five variables were then used to find the optimal solution. As shown in Table #2 the lengths H7 to H11 were used to select the optimal solution. Over 5000 solutions were simulated in Matlab through a loop. The simulation that offered the best sound reducing properties in the 0-5000 Hz range was:

Table 2 Sound reductions

H7 (% of H8)	H10 (% of H11)	H8 (m)	H11 (m)	H9 (m)
5%	**5%**	**0.35**	**0.35**	**0.0508**

The transmission losses of the secondary muffler are:



Since the model of the newly designed stock muffler with the catalytic converter is not yet finished, the overall theoretical transmission losses of the entire system are still to be determined.

SUMMARY/CONCLUSIONS

This year's design and systems are the results of 2 years of projects and studies. We are extremely proud of what we've accomplished. The experience acquired in the fields of direct injected two stroke fuel systems, engine management, exhaust design, emissions reductions, suspension and more will be put to the test at this year's competition. We hope to obtain good results in the majority of the events we will compete in. Many small steps go a long way, if you keep walking.

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DEFINITIONS/ABBREVIATIONS

CFD	Conception of finite design
CO	Carbon monoxide
dB	Decibel
ECM	Electronic control module
ETS	École de technologie supérieur
HC	Hydro carbons
HPDI	High pressure direct injection
NO	Nitrogen oxide
PPM	Particle per millions