A NEW GENERATION OF DESIGN AND DEVELOPMENT

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ABSTRACT

Team QUIETS is very proud to take part in the 2008 Clean Snowmobile Challenge hosted by Michigan Tech University. The team is bringing a brand new snowmobile this year! A MXZ REV Blizzard, 2-stroke 600cc SDI from BRP fuelled by an 85% blend of ethanol and gasoline (E85). The engine has been fitted with a haltech system that allows a full engine calibration. Since the team is counting only new members this year, we are most impatient to see the dynamic of the competition and the other team's modifications. We are eager to see how our snowmobile will perform throughout the multiples challenges. In the present technical paper, you will see which modifications we have made and the different reasons that motivate us to make our changes.

INTRODUCTION

Since the creation of the snowmobile in 1960 by J-Armand Bombardier in Québec, Canada, the product knew a quick popularity throughout the country and North America. With an annual average snowmobile sale in Canada of more than 57 000 units in the last twelve years, this winter sport as an important economic impact. In Canada only, it's a business that generates over $6 billions annually. This situation is proportionally the same in the province of Québec. About 800 000 persons practice snowmobiling throughout the province each year. It's also an appreciated activity by tourists that generates a direct economic profit of around 752 M$.

However, all this circulation involve significant consequences. Since december 1st 2004, the court of Québec ordered a judgement prohibiting the snowmobiles on approximately thirty-eight kilometers (km) in the Mont-Tremblant area on the linear parc of "Le Petit Train du Nord". Also there is an another 120 km near the region of Lachute. This legislation came from complaints of owners, living a few hundred meters away from the path. They considered unacceptable the noises emitted by the snowmobiles.[1] This new rule had huge consequences on the snowmobile tourism industry and several jobs were put in danger.

To resolve this situation and to assure the survival of the region winter tourism, new technological solutions must be proposed and used. Those solutions must be both enthusiastic, give the same good performances while being environmentally friendly.

Since 1998, to help improve and find innovative ideas for the snowmobile world, the Society of Automotive Engineers organizes each year the Clean Snowmobile Challenge (CSC). This competition is opened to colleges and universities in North America. The goal is to modify an existing standard snowmobile and make it more ecological, mainly by reducing it's fuel consumption, the levels of pollutants and the noise emitted by the sled. The students must also keep good performances to keep a certain appeal to consumers. This year, the CSC will be held for the 5rd year in a row in Michigan's Keweenaw Peninsula from March 10th to 15th. To represent the province of Québec, QUIETS from the "École de Technologie Supérieure" in Montreal will be participating for its fifth year at the challenge.

Bear in mind that the team members do not receive any credits for this project, has they are considered a none-lucrative company. To realize their achievements, each member worked on building sponsorships by developing a technological partnership with the different companies.

The following paper describes in details the modifications made to the sled and there specific reasons. The first section describes how the team was able to keep a maximum performance while making important changes. Secondly, the emissions section explains the technologies used to reduce harmful exhaust pollutants. The third section is about the drive train changes and the last section is about the noise reduction and the different systems used

to achieve our goals. Finally, a small analysis concerning the overall costs of our modifications. In the end, the sled proposed by team QUIETS is economical, reliable, performant, environmentally friendly and is a good contender in the 2008 CSC.

PERFORMANCE

By talking with snowmobilers, we found the characteristics we were going to focus and work on the snowmobile. Most of the people interviewed were convinced that power, torque, addling and acceleration of the machine are the most important things to keep in the new model. The competition intends on developing a snowmobile that will reflect the need of an environmental vehicle balanced with the pleasure demands of the consumers. First of all, we had to analyze which technologies were offered in terms of power, light weight and low noise and pollutants emissions.

- Two stroke engine
- Four stroke engine
- Two stroke semi-direct injection engine (SDI)
- Two stroke direct injection engine
- Diesel compression technology

The 2-stroke engine is the best engine based on power to weight ratio. It has a good acceleration and powerful torque. However, the biggest problem with this type of engine is certainly its high level of pollution. The snowmobile emissions test clearly shows that the 2-stroke engine pollutes more than the 4-stroke.

Table. 1 Combustion gas chemical composition [2]

	grams/HP-Hour			
Engine	HC	CO	NOx	MP
2 stroke	111	298	0.86	2,7
4 stroke	1.40	28.33	0.245	N/A

Engine choice

However, by taking into account only two of the following criteria: power and reliability, there were only two engines which became more apparent then the others; the 2 stroke engine and 4 stroke the engine. To make a more accurate decision, we compared the characteristics of these two engines:

4-stroke:

- Reliable
- Low power/weight Ratio
- Clean Emissions
- Less fuel consumption
- Harder maintenance
- Present in snowmobiles since 1960
- Quiet
- More advanced technology

2-stroke:

- Less reliable
- High power/weight ratio
- Not very clean emissions
- High fuel consumption
- Easy maintenance
- Present in snowmobiles since 1960
- Noisy
- Simple technology

Again, the 2-stroke engine is more favourable since it's the most seined engine on the market. However, this engine does not satisfy the competition's criteria. To support this choice, here is a study [3] that shows the advantages of 2-stroke DI compared with a 4-stroke engine (another possible alternative). This comparison is made with two similar engine operating in the same conditions.

The 2-stroke engine with direct injection is 30 % lighter, 30 % less expensive, 30 to 40 % less cumbersome and up to 50% more powerful than the 4-stroke engine.

Thus this type of engine offers the following advantages:

- It respects the levels of antipollution regulation at the same cost price as the 4-stroke, even less...
- It becomes more suited than a 4-stroke engine to accept tighter levels of anti-pollution (4-stroke is penalized by its NOx and CO emissions).
- It emits less visible smoke.

Its fuel consumption is 10 to 20 % smaller than the 4-stroke with of the same carburetor capacity.

Each engine has advantages and disadvantages. We can base our choice on several different criteria like the pollutant's emissions, the average fuel consumption, the noise level of the engine and even its reliability or its performances. We needed to take a logical decision as to which engine would represent best today's snowmobile market and the snowmobile owner's choice. We prefer this orientation rather than to invent a new engine or to use another form of energy to move this machine that would not be marketable. Thus, we discovered in our research that the most popular snowmobiles sold these last years were the 2-stroke 500 cc.[4] There was no longer a choice to be made. As we continued our research, we found a survey showing the aspects considered by snowmobile buyers when purchasing a sled. Here is an overview of those results:

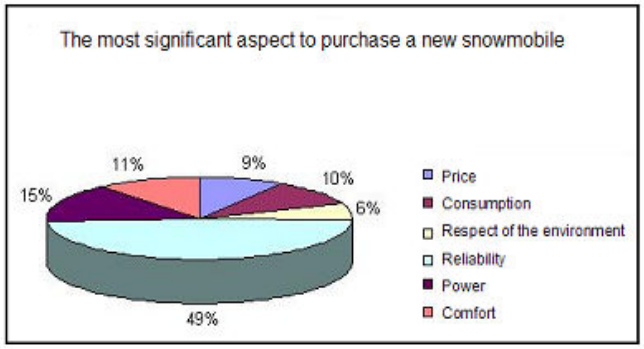


Figure 1 Criteria that guide the consumer's choice for a snowmobile

Our final choice

Finally, to meet all the criteria that will be used to evaluate the sleds during the CSC, that is, consumption, the pollutant emissions, the noise and the performances and to respect our own pre-established criteria, we decided to use a Rotax 2-stroke 600 cc SDI HO from Bombardier.

Figure 2 Rotax 600cc SDI two stroke engine

However, this is a bold choice of engine. Several studies prove that it is the worst enemy of the environment. Isn't this a true challenge? While making it cleaner? To be able to obtain results known as ecological and in the light of the data showed above.

Table 2 Engine description

Engine type	Two stroke
Cooling	Liquid
Cylinders	2
Displacement	600 cc
Hp (hp)	122
Torque (N - m)	95.5

Fuel

For this year's the clean snowmobile challenge requires us to run with a mixture of ethanol and gasoline. The E85, winter blend fuel will be used. This fuel was intended to replace the petrol fuels that we all use. This cleaner fuel will help reduce the quantity of pollutants emitted into the atmosphere.

Several preceded were developed to produce ethanol. One of the primary methods was from corn. However, we know this method brings some question in the province of Quebec. For an other example Brazil produces ethanol from sugar cane. The main problem of these methods is the use of agricultural land for the production of fuel, thus reducing the use of the lands to feed the population. The next manufacturing methods would be from biomass, a process that consumes less energy so gives an life cycle energy balance more efficient. Also the Japanese have been working on a new process still under development with the help of seaweeds.

Theoretically ethanol produces around 60% less polluting fumes then gasoline petroleum-based when burning. Such fuel is therefore a good alternative to petroleum derivative. However, in order to have combustion as closely as possible to perfection and profit of this emission reduction we must approach the perfect parameters of combustion on our engine.

Plus, ethanol as a higher octane leaded indices than ordinary gas and it produces less vapour emanations then regular gas at low temperature because of is low flash point that is approximately of 286.15 K for ethanol versus 230 K for gasoline. Also, ethanol does not relieve as much energy than regular gasoline because of is lowers heat of combustion, the calorific value of E85 is 22790 KJ / L against 31800 KJ / L for regular petrol. To keep the same aspect of the engine we would need to inject about 40 % more fuel in the engine.

Table 3 Compression ratio

	Ordinary fuel	E85
Compression ratio	8 à 12	14
Octane	87	105

Engine

For this year engine modifications we have decided to keep them as basic as possible because of our new team and member, and our first participation at the competition. So we have established a 2 year engine modification plan. So for this year, we decided to do only what was necessary for the competition and push in bigger modifications next year.

Our engine is a Rotax 600 HO SDI cc two-stroke engine, manufactured to run on regular 87 octane gasoline. Several modifications had to be done in order to be able to run the engine with ethanol. Knowing that the new fuel has a compression ratio higher than regular gasoline and has a lower calorific value we had made some changes to the engine in order to optimize the fuel combustion.

The team has made choices on the power developed by the engine. Initially the engine developed about 120 hp. We have decided to reduce this to around 90 hp to reduce the amount of fuel consumed and the amount of pollutant but without compromising the power and acceleration of this engine.

To be able to modify our compression ratio we have made some major changes in the engine head. In order to have a perfect combustion chamber concept, we decided to do business with a company, which specializes in 2 stroke engines. The company made us an analysis of our engine on a computer software: Two-Stroke Racing. All this analysis as been made with ethanol characteristics to assure it’s perfect combustion. At the end the program

issues a report with all essentials information for the proper combustion of ethanol. The combustion chamber had changed from the initial geometry to optimize combustion as well as increasing the compression ratio of the engine.

Figure 3 Engine head insert

Ignition

Knowing that ethanol as a higher flashing point, we knew that the engine would have some problems to start during the cold start event. To remedy to this problem installed two spark plugs per cylinder in order to have absolute control of the lighting in cold weather. Initially, during cold weather the two spark plugs were supposed to function independently. But we fund out that our engine computer wasn't capable of doing that kind of functions. So for this year the spark plugs will operate in a sequence lightning, giving us twice the fire. Weaved provided our schematic ignition module in Appendix A.

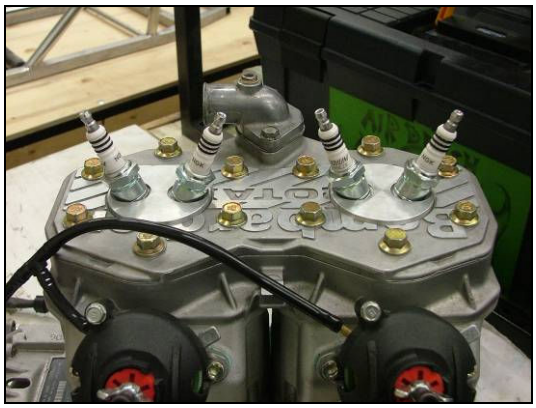


Figure 4 Spark plugs

Injection

To have a perfect combustion of ethanol and a complete control of the engine, there is not only the compression ratio that is important in an engine that works with injectors. To be able to do an all new injection and ignition mapping we used a brand new ECU, a Haltech E6X model. However this computer is manufactured to be use on 4-stroke engine. That's why we add to do several arrangements to be able to make this computer accordance with the engine.

Figure 5 Engine computer

In order to operate the computer on our two-stroke engine, we have made correlations between two-stroke engines and four-stroke engines. These types of correlations were the type of injection that is on 360° for 2 stroke engines and 720 ° for 4-stroke engine. We needed to combine injectors so that our

injection will be done from the injector # 1 and # 3 on the computer.

Before implant those maps for the E85 in the computer, we made a theoretical analysis of the changes needed for the injection mapping. These analyses permitted us to see that we needed to increase the injection time of approximately 40% in order to obtain equivalent power than the original engine. In an other meaning, our digital design of our engine on the two stroke racing program has been designed to have a capacity of approximately 90 hp enabling us to reduce the amount of fuel injected into the engine. This power reduction permits us to keep the original injectors helping us to keep a low cost and still keeping good performance. In order to start from a solid base value of the injector's opening time and ensure excellent results, we have simulated the original engine on the BRP computer. On which we simulated engine temperature, outdoor air, barometric pressure and the speed of rotation of the crank shaft. This enabled us to get the original mapping of our snowmobile and all correction values for temperature and barometric pressure. With these values, we only had to increase the values to respect the theory of ethanol injection.

Unfortunately, our new computer has no ignition module. It was therefore necessary for the team to design an electric module that could meet the criteria, such as 2 spark plugs per cylinder that may operate independently (for next year modifications), resist to extreme cold, vibrations and water. The electric team has developed a module that can meet all these criteria, in addition to being relatively aesthetics. See Appendix A for schematic design.

Figure 6 Ignition module

EMISSIONS

In a perspective to improve the efficiency of the two strokes engine and reduce the bad effect of the combustion, small things on the original conception needed to be changed. For this year the major modifications to reduce the quantity of pollutant emissions is the use of an SDI engine, E85 fuel, to choose the best oil and having a optimized combustion chamber to assure a perfect combustion of ethanol. While having in mind the theories of combustion engine by choosing the best richness and the good ignition advance. Unfortunately we don't have any emission control system, so we have no result of our changes, so we hope that what we did on paper comes out good.

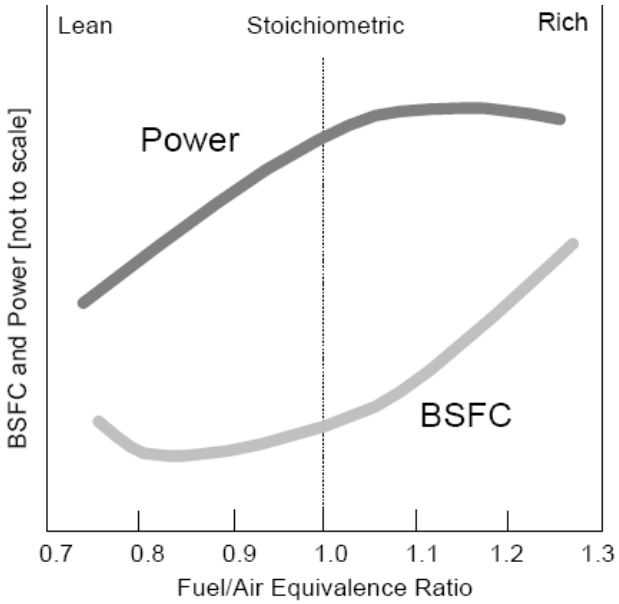


Figure 7 Effect of ignition advance on the pollutants [2]

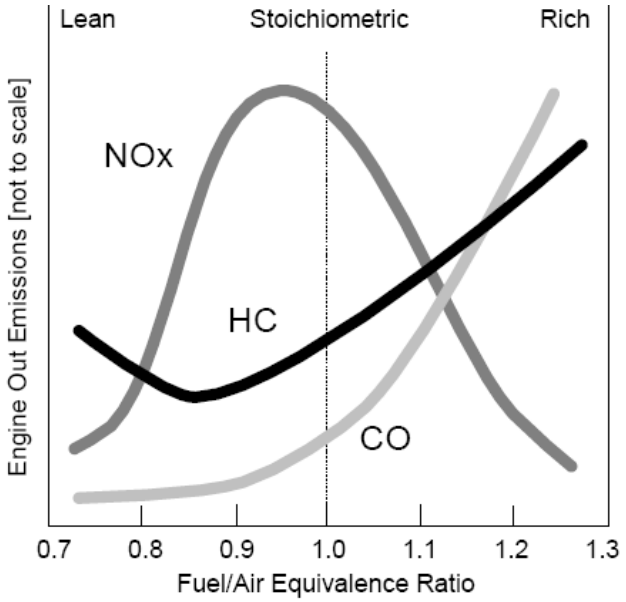


Figure 8 Effect of richness on the pollutants [2]

Oil

When ethanol is used as fuel in a two stroke engine, it obligates us to find the perfect oil to mix. So we have done a lot of research about the different type of oil. We found out that the perfect oil that mix good with alcohol was castor oil. After a big research on which company makes that kind of oil we find out that the only one is Klotz oil. By talking with technical advisors, they help us in finding the best oil for our project. Our choice stopped on Super Technoplate KL-100 that has to be pre-mix. For sure this type of mixture is not the last technologies available in oil and fuel mixture. It will assure us the quantity of oil put in our engine to have good cold start lubrication.

POWER TRAIN

Clutch

For this year, we decided to improve the performance of our power train system to minimise the energy loss in the mechanical parts. Several concepts have been analyzed and studied. We analyzed systems of weight and came for our original clutch CV tech, in order to make it much more efficient on compact field. One of the other options was to change the system completely with another model. The last option was to find the new hydraulic system created by an Quebec inventor. This clutch actuated by the action of rotation makes it compress air and oil in the cylinders and allows and infinity's of adjustments. By pure chance in October we met the inventor in the "Salon des sports motorisés de Québec". After discussing he agreed to participate in the project and to give us his invention for the competition.

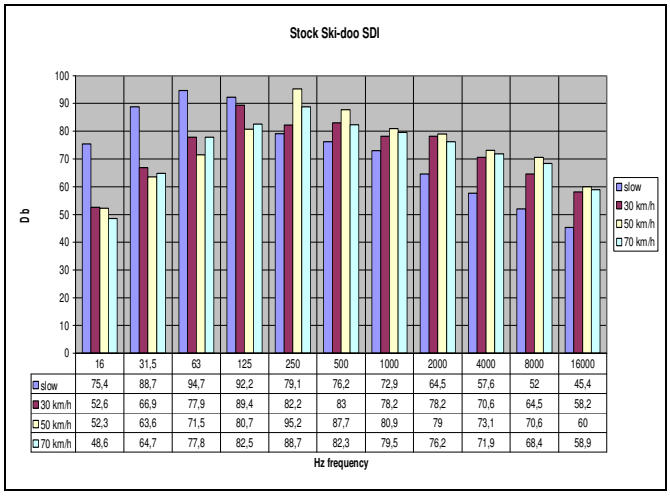
Figure 9 New Inventuim clutch

So this year, we are coming with a brand new hydraulic clutch by Inventium. It enables us to monitor in a very precise tuning off the

equipment. Centrifugal force creates a pressure within the piston making it move in the outside direction. This movement is prevented by a nitrogen pressure in the interior of the clutch. Once the centrifugal force is greater than the nitrogen pressure, the pulleys closes on the belt and consequently making the track rotation. We can add the amount of oil and air pressure in order to increase or decrease the pressure required to close the pulleys. This system comes and minimizes the mechanical losses do to the clutches.

NOISE REDUCTION

The noise produced by the snowmobiles is one of their major drawbacks. It can bother the people living near the trails and can be potentially harmful for the snowmobilers themselves. That is why the noise reduction is one of the main goal of the CSC. We can achieve this goal using many different methods. We have used two separate systems to ensure that our modified sled would be quieter than the original version. We fabricated a totally new exhaust system that as a good reduction of noise without restricting the exhaust gas. We have insulated the motor compartment with new sound damping materials. We also made some changes in the rear suspension system to reduce noise and our new clutch also help reduce noise by having less mechanical moving parts.



	16	31,5	63	125	250	500	1000	2000	4000	8000	16000
slow	75,4	88,7	94,7	92,2	79,1	76,2	72,9	64,5	57,6	52	45,4
30 km/h	52,6	66,9	77,9	89,4	82,2	83	78,2	78,2	70,6	64,5	58,2
50 km/h	52,3	63,6	71,5	80,7	95,2	87,7	80,9	79	73,1	70,6	60
70 km/h	48,6	64,7	77,8	82,5	88,7	82,3	79,5	76,2	71,9	68,4	58,9

Figure 10 Larson-Davis stock Ski-doo SDI sound test

As we can see, some of the sleds could not get in the park due to their high sound levels (higher than 81,9). We can also get our objective to beat an 80,25 dB(A) level at 50 feet with our combined modifications. Here are the first data we collected on a stock sled, a Ski-doo SDI 2005 MXZ Rev from Bombardier. All measurements are also made 50 feet away from the passing sled.

Exhaust

We can see that the exhaust system of the snowmobile can help reduce the noise a lot. In our approach to keep maximum engine performance, we decided to use dissipative silencers. They create less pressure drop, which ensure a great exhaust gas flow.

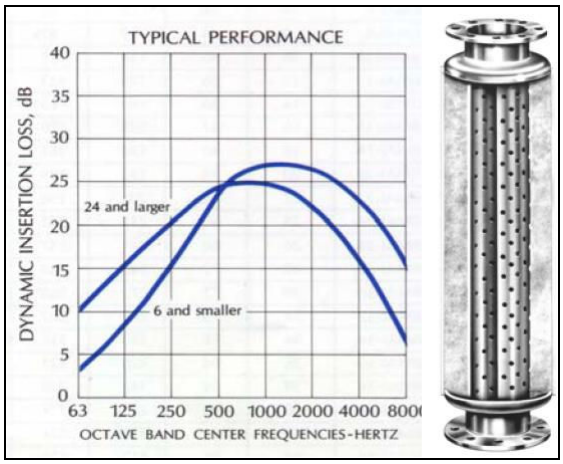


Figure 11 Sound reduction of a dissipative silencer

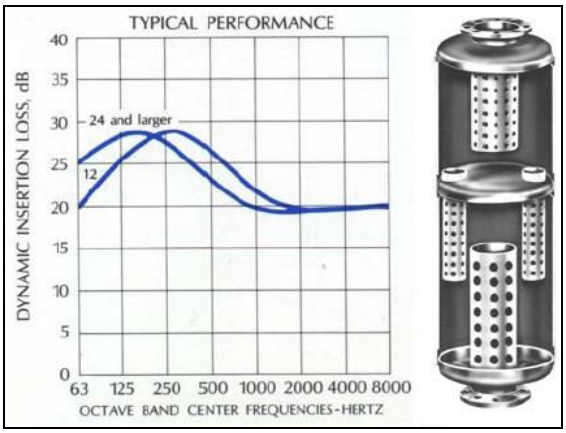


Figure 12 Sound reduction of a reactive silencer

However the reactive silencer is much more effective at our working frequencies. It creates a lot of pressure drop in the exhaust gas, which brings a big loss of power and performance.

Several exhaust tests have been made out to find the ideal compromise between power and noise. Prototypes we made from cardboard helping us achieving very interesting data on the properties of different materials. We've made tests with foam insulation and cork. Indeed, the tests were done on very high decibel intensity to check on the efficiency of the materials. Below are the data of different test

Table 4 Sound test on different materials

Test	Noise intensity (dB)
Air	120 et +
Foam (gray)	120
Foam (white	100
Cork	100

The tests we have attempted on the cork made us curious tp know more about it. Knowing that the ignition temperature of the cork is fairly high, we were wondering what kind of result this material could give us. So we built a prototype muffler from cardboard and have installed it on the snowmobile and made several tests at low and high engine speed. These tests were very convincing. We have obtained noise reduction of about 20%. In addition the prototype made circles with the exhaust fumes, making it very esthetical.

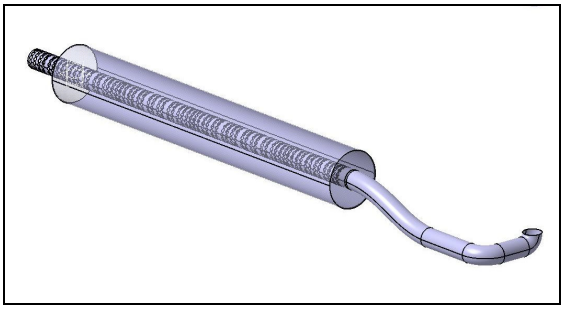


Figure 13 Basic schematic of our modified exhaust system

However, a lack of time made us do only a standard exhaust made from noise reduction foam. Foams used are high absorptions acoustic foam [6].
Plus, this year by talking with are sponsors, some gave us a known system that helps a lot in reducing muffler noise for 2 stroke engines. The system is to put a by pass on the tune-pipe at 90° and bring it directly to the muffler. The tune-pipe is also cap to prevent the engine gas to pass that way. It obligates the gas to pass by the 1.5in pipe at 90°. This system keeps the back pressure needed for the engine and creates a static pressure at the end of the tune-pipe absorbing the noise.

Track

The upgrade that we've done to the track is basic, simple and it has a low cost. By talking with our track sponsor, Camoplast, they have given us a silent track and gave us some good ideas for modification of the track. So for this year, we are coming with a Camoplast Polaris commercially available track modified with holes to create a snow cloud around the rear suspension helping to reduce noise.

Figure 14 New Camoplast track

Also to keep the noise down we have made some small wheels for the rear suspension system. These wheels prevent vibration. The

original wheels made of plastic were not very solid and vibrated a lot on le sled. Also with our now bearing sponsor that we found, we knew firmly that the bearings will help reduce noise. After a good research they got us electrical motor bearing that as incredible friction properties with an special high precision grease [6].

Figure 15 New wheels and bearings

Soundproofing

In addition to the sound coming from the exhaust system and rear suspension, a lot of noise comes from the motor itself, the different vibrations and the rotating parts, mainly the pulley and chain transmission. In order to reduce the sound emissions from the motor compartment, we have decided to insulate it completely.

Figure 16 View of the front panel and foam

To start off, we closed all the openings on both side panels and around the chassis. We applied a sound-absorbing barrier inside all the panels surrounding the motor and under the hood. The two foams used are from Silent source. The white one is Hushfoam FireFlex Anechoic wedge HFX-3 and the other one is Wispermat 2 with surface treatment of aluminized polyester [6]. Each foams has different characteristics and helps in reducing different sound intensity.

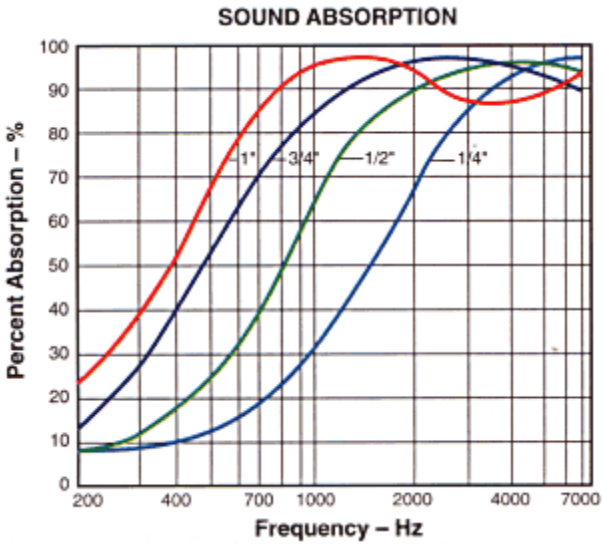


Figure 17 Sound absorption for the Wispermat foam [6]

The different densities of foam absorb a wider range of frequencies and help reduce the overall noise. The top foam is also covered with a thin sheet of aluminum to protect the material from heat radiation.

The following chart shows the effectiveness level of sound absorption in comparison with the frequency of the noise. In a snowmobile, the sound frequencies vary generally between 50 and 400 Hz. The foam absorber shows good efficiency in this range of frequencies but lacks stopping the lower frequency noises. With the addition of the rubber section, which adds mass to the barrier, we should get improved results at lower frequencies.

However, we could not install the sound absorber everywhere because it caused interference with some major component and

we were not able close the panels. This was the case with the intake chamber and in the left side panel and the clutch cover.
Now that the cab is mostly closed and that there is not much air circulation, we could, have over-heating problems. For the motor, which is liquid-cooled, it's not that critical. On the other hand, it can cause problem on the electrical components.

Also we put on a product that helps noise reduction, Proform truck Bed protectiove coating and Proform Proguard Rubherized gravlguard. This product is known for is good noise absorption. We have put this product in the engine area and on the track area.

Finishing touches

To finalize the soundproofing, we used self-adhesive rubber strips to seal the junctions between the different panels. This way, we minimize the sound leaks where we have gaps and improve our sound insulation.

COST

The overall cost modification of our sled is fairly low. In other way, all materials and components can be found in any industrial distributors. The following table shows the different modifications we did with the different price values. These values are taken directly from the technology implementation cost assessment sheet of the CSC 2005.

Subsystem	Subtotal
Engine	$ 1 500,00
Exhaust	$ 200,00
Electronics	$ 100,00
Noise Treatment	$ 300,00
Sled modifications	$ 200,00
Technology Implementation Total Cost	$ 2 300,00

Table 5 Total cost of the modifications

CONCLUSION

With this year's design, considering the different systems used on the sled, the way to progress with the two-stroke engine technology is coming to a good point. Working with, new E85 ethanol and a near perfect combustion chamber, rear suspension vibration reduction, improved exhaust systems and making a good sound insulation, all the major requirements were achieved to have a truly clean snowmobile. Although, major changes were made on the engine and the look of the snowmobile, to keeping good performances and an edgy design that appeal to the snowmobilers. Team QUIETS already await next year's competition in order to develop new and advanced systems.

ACKNOWLEDGMENTS

We would like to thank everyone who helped us bring this project to reality; The Ecole de Technologie Superieure, the Students Association and all of our sponsors for their financial support; BRP centre de Formation, Évasion Hors-Piste, Fédération des clubs motoneigistes du Québec, NSK, Camoplast, Choko, Usinage RT, Prodam, Nova Bus Industries Jack, ADM Sport, ADMDQ, Motoneige.ca and CIMA+ for their technical assistance and their generous gifts. You helped us prove that the snowmobile industry can be clean and environmentally friendly.

We would also like to thanks the Clean Snowmobile Challenge organization and Michigan Tech for hosting the event and bringing all the teams together to find new and innovative solutions to boost the overall image and reputation of snowmobiling.

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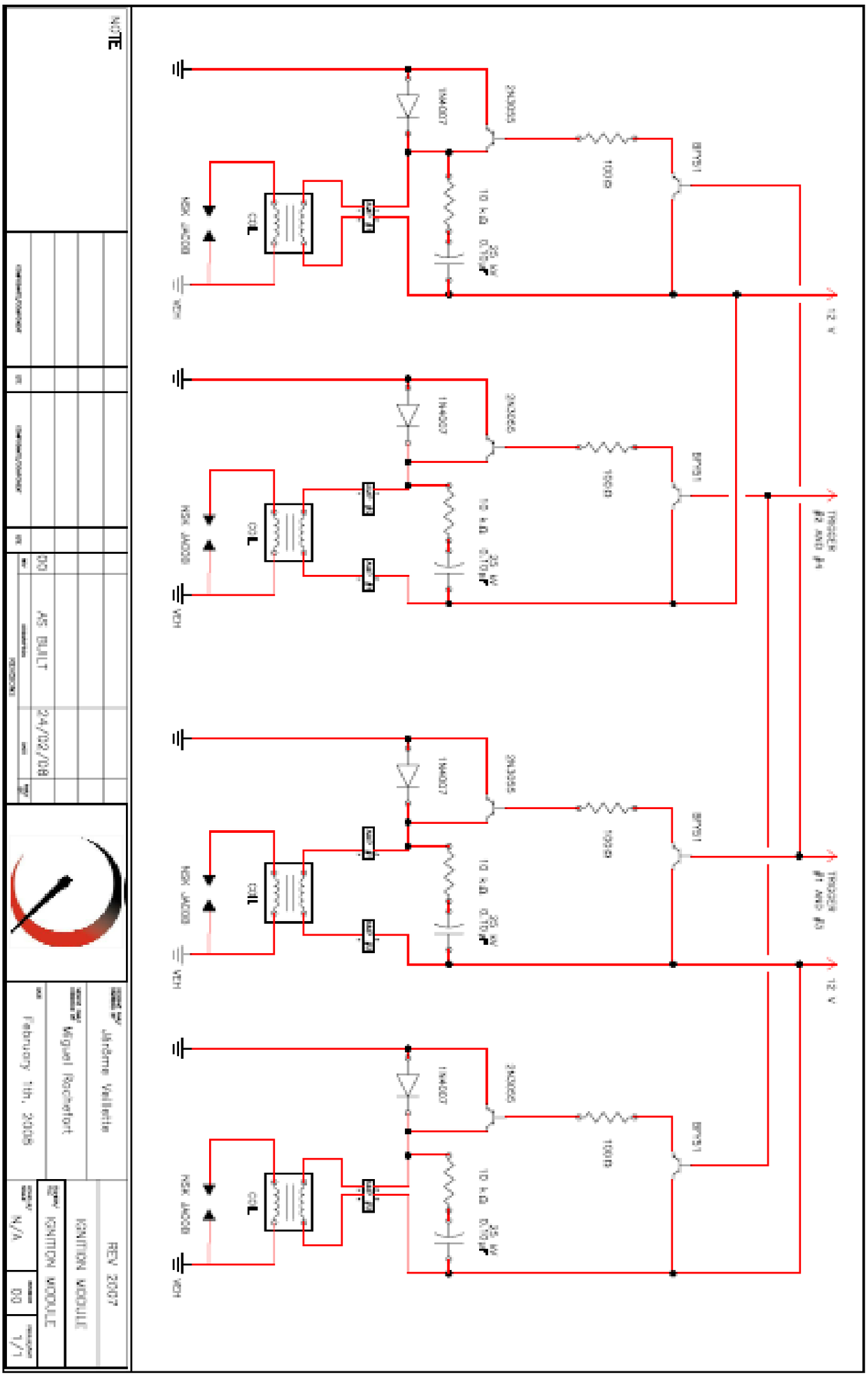
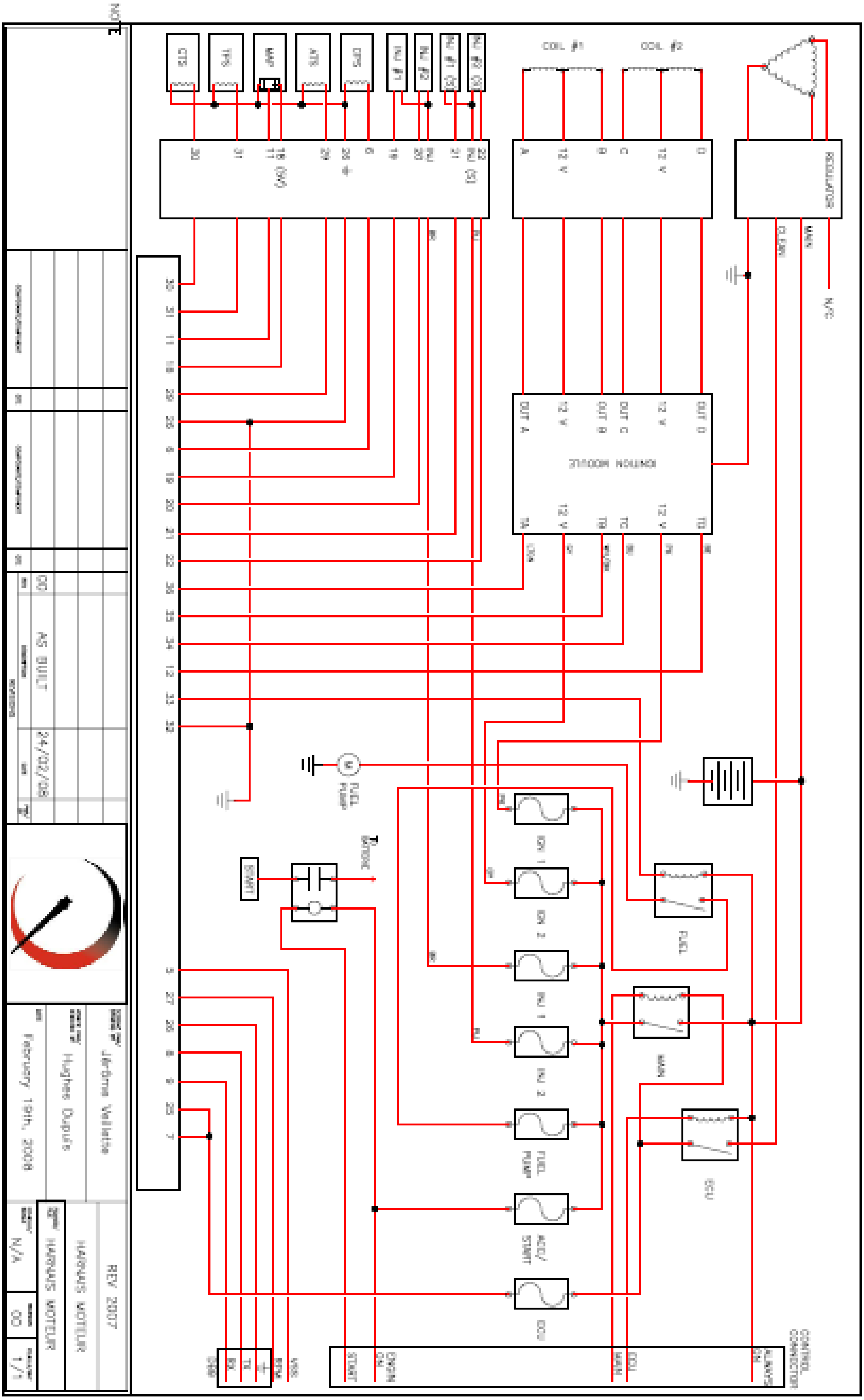
APPENDIX A

Electric wiring

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Jérôme Vallette
Hughes Dupuis
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HARNAIS MOTEUR
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