École de technologie supérieure (ÉTS)

Semi-Direct Injected Two-Stroke Snowmobile

Clean Snow Mobile Challenge 2009 Design Report

Abstract

Team Quiets is very proud to take part in the 2009 Clean Snowmobile Challenge hosted by Michigan Tech University. The team is bringing a brand new sled this year. A 2009 TNT, Semi-Direct Injection, 2 strokes 600cc from BRP. The engine is fuelled by E10 up to E85 as per the CSC 2009 rules. The engine has been fitted with a Mototron controller that allows a full engine calibration. Also an all new changed squish velocity and compression ratio combustion chamber allows better flex fuel capabilities. Since the team has learned a lot on the competition last year, we are eager of seeing how well our sled competes against other teams this year. In the present technical paper, you will see the modifications we have made and the different reasons that motivated our decisions.

Introduction

Since the creation of the snowmobile in 1960 by J-Armand Bombardier in Québec, Canada, this product has known a great popularity throughout the country and North America. With an annual average sale of more than 57 000 snowmobiles in Canada, for the past twelve years, this winter sport has an important economic impact. In Canada only, it's a business that generates over $6 billion annually. This situation is proportionally the same in the province of Québec. Each year about 800 000 people practice snowmobiling throughout the province. It's also an appreciated activity by tourists that generates a direct economic profit of around 752 M$.

However, this circulation involves significant consequences. Since december 1st 2004, the court of Québec ordered a judgement prohibiting the use of 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 that has been prohibited. This legislation originated 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 endangered.

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 give the same good performances while being environmentally friendly.

Since 1998, the Society of Automotive Engineers help improve and find innovative ideas for the snowmobile world by hosting 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 ensure good performances to keep a certain appeal for consumers. For this year, the CSC 2009 will be held in Michigan's Keweenaw Peninsula from March 16th to March 21st. Representing the province of Québec, QUIETS, from the "École de Technologie Supérieure" in Montréal will be participating for its sixth year at the challenge.

Participating to the project as volunteers, the team members do not receive any credits for this project. To realize their achievements, each

member worked on building sponsorships by developing a technological partnership with different companies.

The following paper describes in details the modifications made to the sled and their specific reasons. The first section describes how the team was able to keep a maximum performance while making important changes in order to reduce fuel consumption and pollutant emissions. The second section treats of the noise reduction and the different systems used to achieve our goals. Finally, we have included a small analysis summarizing the overall modifications costs. In the end, the sled proposed by team QUIETS is economical, reliable, powerful, environmentally friendly and is a good contender in the 2009 CSC.

ETS - CSC SNOWMOBILE DESIGN

CHASSIS SELECTION – Quiets ETS team selected a 2009 BRP Ski-Doo XP TNT chassis. This chassis offers lightweight, excellent handling and good modification opportunities, while reflecting the newest technology available on the market.

ENGINE SELECTION – In the past years Quiets ETS team worked on two strokes engines and has acquired a lot of knowledge and experience with this kind of technology. Knowing 4 strokes engine proved there capability of being use in snowmobile while giving good power, fuel efficiency, clean exhaust emission and quiet riding, two-stroke engines are still in demand and sales are still high in the snowmobile industry. We believe it is still important to keep works a head on this kind of technology.

Table 1 Combustion gas chemical composition [3]

	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

The latest technologies used in Two-stroke engines have better fuel efficiency, and can also be compared to today's 4-strokes engines. Semi-direct and direct injection systems are making the two-strokes engine a good alternative. Past researches have proven that changing injection technology provides better fuel efficiency and low emissions [2].

Tableau 1 Combustion gas chemical composition[4]

	grams/HP/Hour			
Engine	HC	CO	NOx	MP
2 stroke	111	296	1	2,7
2stroke DI	22	90	3	0,6

INJECTION SELECTION – The Quiets team had started their work on a direct injection two-stroke engine, knowing his good overall efficiency. Unfortunately, last January a conceptual problem made the team choose another type of fuel injection system. This made the team go back to semi-direct injection system. Knowing, it is not the best technology available on the market, the team as still decided to bring this type of technology at the CSC 2009. Semi-direct injection has proven its good reliability over the past year, and last year's research proven that the modifications made for E85 were, simple with a stock engine. For the 2009 CSC, team Quiets is bringing an all new two-strokes modified engine, capable of running on a range of 10 to 85% of ethanol/ fuel mixture.

Modifications

FUEL CONSUMPTION & EMISSION CONTROL – Working with a two-stroke engine, the new flex fuel rule at the CSC 2009 obligates an all new gas burning combustion chamber. Last year's research made the team determined that new combustion chamber geometry had to be done to be able to use a maximum of fuel efficacy with E85. This year's range of 10 to 85% of ethanol made the new combustion chambers design more complicated. To assure good fuel optimisation' the engine combustion chamber has been analysed in the Two-Stroke Engine (TSR) program with E15 fuel. The new higher octane level fuel obligates the use of a better air-fuel mixture to ensure good fuel

consumption. In order to use this octane level, the squish band geometry has changed to give a higher velocity, 36 m/s to 40 m/s. Last year's calculations, with E85, provided us with a 46 m/s velocity. Unfortunately this velocity is too high to be able to run with E10, and could have probably caused the engine to auto-detonate. For this reason the velocity of 40 m/s and a compression ratio of 6.4 (141lbs) compare to 6.3 (138 lbs) on the stock engine has been determined. These modifications were made to provide good air-fuel mixture while having the smallest squish band volume, to minimise the quantity of on burn fuel. Here is a quick look of the program geometry results.

Table 2 combustion chamber geometry

Geometry\Fuels	E15
Bore	72 mm
One Squish. Dia.	49.88 mm
Squish. Radius	None blending radius. Sharp corner
Dome height	20.26 mm
Dome radius	25.907mm
Cone angle	None (Hemispherical)
Squish height	1.36 mm
Clearance	1 mm
Compression ratio	6.4 (141 lbs)

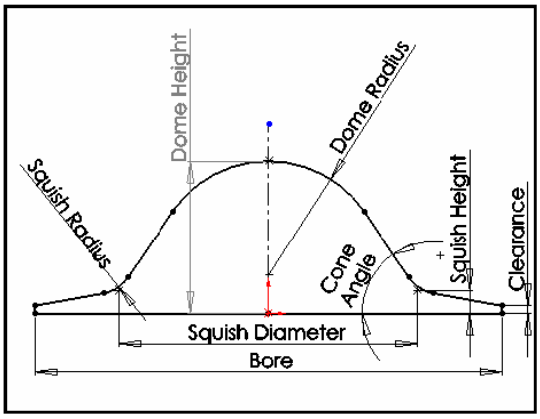

Figure 1 Combustion chamber geometry

IGNITION – Quiets team wanted the best flex fuel engine possible without having a variable compression ratio engine. The two-Stroke Racing program provided us with the best fuel velocity in the squish band area for E85 that would results in the best atomisation of ethanol mixture. Like described in the last section this velocity is too high to be use with E10. Using this velocity would bring the fuel to auto-detonate before the top dead center. In order to correct that calibration problem team Quiets used two sparkplugs on the engine. This modification supplies more activation energy to start the chemical reaction that is needed with E85 compare to E10. This helps the engine to optimise the fuel consumption when E85 is used. Figure 2 shows a photograph of the two sparkplugs engine.

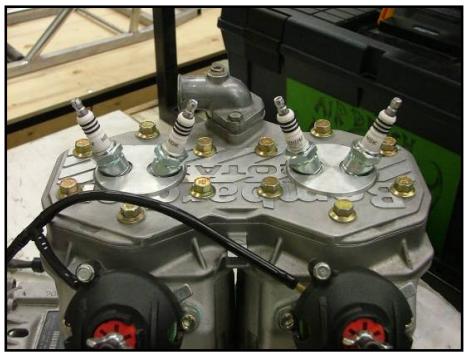

Figure 2 two sparkplugs photograph

CALIBRATION - To ensure good fuel consumption efficiency our engine has been calibrated on a water brake dynamometer. Our Mototron controller helped us injecting the exact quantity of fuel in the engine to ensure a stoichiometric combustion. Figure 3 Air/Fuel ration effect on gas emissions gives a good example of the effect of the Air/Fuel ratio on the exhaust gas emissions.

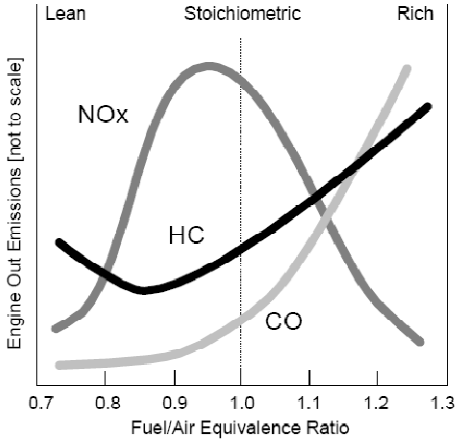

Figure 3 Air/Fuel ration effect on gas emissions [3]

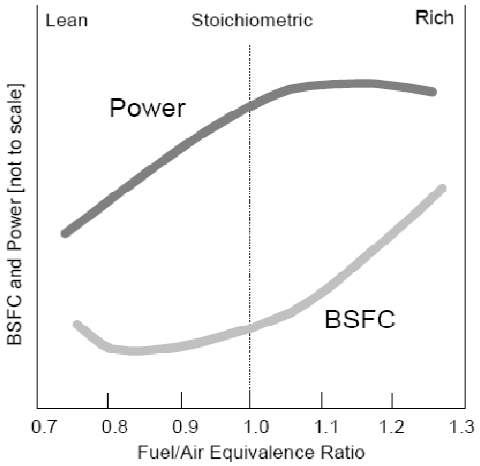

Figure 4 Effect of ignition advance on the pollutants [3]

Also, the engine that Quiets team use is equipped with 2D RAVE valve (Rotax Adjustable Variable Exhaust), which modifies the exhaust ports. This technology allows good two-stroke engine calibration, by closing opening exhaust ports. This allows higher torque in low RPM range while allowing higher power readings at high RPM when open- [2].

It is important to keep in mind that, ethanol as a higher octane leaded level than ordinary fuel. It also produces less vapour emanations than regular gas at low temperature because of its low flash point (Approximately 286.15 K for ethanol versus 230 K for gasoline). Ethanol does not releases as much energy as regular gasoline because of its lower heat of combustion, the calorific value of E85 is 22790 KJ / L versus 31800 KJ / L for regular petroleum fuels. To keep the same power out of the engine we would need to inject about 40 % more fuel in the engine.

OIL – Normal lubricant oil system on a two-stroke engine are total-loss oil system compare to recalculated oil system in four-stroke engines. Oil is normally mixed in the fuel tank or mixed in the inlet-air stream like the olds carburetor and SDI technologies. Rotax newest technology, on the direct injection engine (E-TEC), uses an electronic total-loss oil injection system. This system was adapted on our modified SDI engine. This system eliminates premixing and lubricates specific parts of the engines by oil injectors. On DI engines this technology reduces up to 50% the oil consumption [9] . Using this technology on our SDI engine will bring the same reduction of oil consumption.

Plus, when ethanol is used as fuel in a two-stroke engine, it obligates us to find the perfect oil/fuel mix. We have done some research on the different types of oil. We found out that the perfect oil that mixes well with alcohol is castor oil. Other oils had tendency to separate with alcohol. After an elaborate research on which company makes that kind of oil, we found out that the only one is a company named Klotz oil. By talking with technical advisors, they helped us find the best oil for our project. Our choice was stopped on Super Techniplate KL-100 [7].

EMISSION - At the time of writing this paper, the possibility of putting a catalyst in the tune-pipe is being analyzed. Knowing that this technology needs high temperature to ensure good results, team Quiets is trying to figure out a way of fitting the catalyst inside the tune-pipe without changing the pipe tuning. This catalyst position has been chosen to use the high temperature that occurs by proximity of the exhaust ports.

NOISE REDUCTION - To reduce the noise of our snowmobile; we had to determine where the noise was coming from. Before starting our modifications, a noise analyst was made on our new sled. This helped us locate all the most important noise emission, and find the best way to reduce them. First of all, we divided our sled in parts and tried to find how the sound waves where being propagated. Figure 5 shows our results of this analyst.

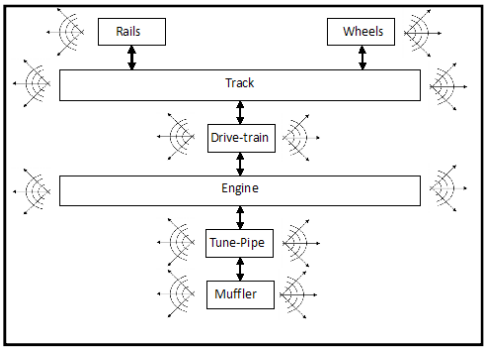

Figure 5 Schematic diagram of noise transmission

The big arrows represent force transmission, and the others represent acoustic dispersion of the parts. Two kind of noise transportation have been found, air and solid transmission. With this schematic analyzes we were capable of pointing

out exactly where the sound was coming from. In fact, we found out that the noise came from the engine parts, rear suspension, all parts of the drive train (Chains, belts, gears, etc) and the frame. All of these noise emissions have their own type of transmission and every transmission kind has its own way to be reduced. As a result our modifications plan has been made to be able of reducing these entire noises sources. With time as a big factor, to be able of doing a good analyst of our modifications we would have had to do sound analysis every time a modification was made, to evaluate its efficiency. To have a working sled at the clean snowmobile challenge we had to do some concession. Our choice was to do one test at initial condition and one last test once the modifications are finish. Unfortunately this can't give us each modification results. The first test was as competition SAE-192 noise event [8]. This test determined that our sled initial energy was 72 dB(A). The results summary in dB(lin) are presented in Table 3.

Table 3 SAE-192 results for stock sled

Frequency	125	250	500	1k	2k
dB(lin)	64.9	66.7	66.7	59.5	59.9

By analyzing Figure 5 we divided our modification plan by noise sources: chassis, engine, rear suspension and the drive train.

Chassis - The major problem of the chassis was it being sound reflecting. To prevent this we covered the frame with a high strength resistive material on the outside working as a sound barrier and a damping material for the inner-side tunnel working as an absorber. These modifications were made to reduce the natural frequency of the frame and absorb noise caused by snow and ice hitting the inside tunnel. Also, frame reinforcing parts were installed on the foot rest.

Engine - Secondly, in order of reducing engine sound emission, two parts were determined as important: exhaust and intake. Are first goal was to reduce exhaust noise. An exhaust is used to absorb noise. But in a two-stroke engine the exhaust has one more property; help built a backpressure, which is essential to the engine tuning. Therefore, if we want to modify the exhaust of our 2 stroke-engine it is important that the back pressure is not disturbed. By analyzing the tune-pipe, we found out that it can easily be modified to become a Helmholtz resonator by adding a small pipe at its end. Figure 6 represents a basic schematic drawing of the modification of the tune-pipe.

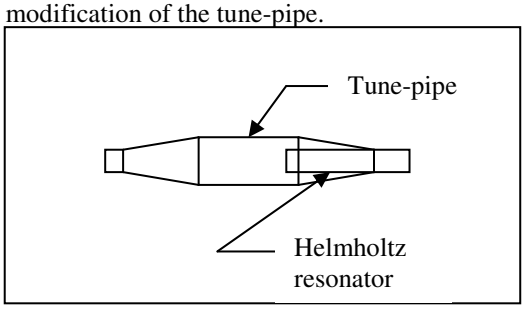

Figure 6 Schematic tune-pipe Helmholtz resonator

Also, to help the stock muffler of reducing sound emission from the exhaust gas, Quiets team added a sound absorbing active muffler. This muffler is placed below the foot rest, where there is enough room to place the new muffler. While analysing the stock muffler, team Quiets found out that BRP was using a mix of expansion chamber with Helmholtz resonators. If we take a look at the theoretical effects of an expansion chamber and a resonator, we would find out that it has a very good sound absorbing capability. Figure 7 and Figure 8 represents a theoretical graphic of an expansion chamber and resonator.

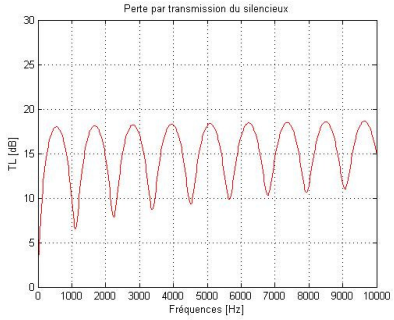

Figure 7 Empty expansion chamber

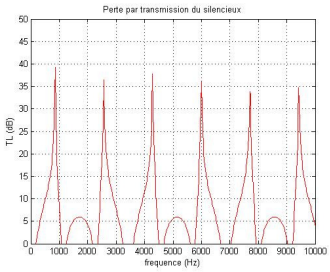

Figure 8 Helmholtz resonator

For this year, team Quiets is bringing an all modified exhaust pipe for two-stroke engine. The first part of the modification is the addition of the resonator in the tune-pipe. This pipe was calculated to break the frequency of 100 Hz, which correspond to the frequency of the engine

at a speed of 70 km/h. Also, a new muffler has been added at the end of the stock muffler. This muffler has the characteristics shown on **Erreur ! Source du renvoi introuvable.**.

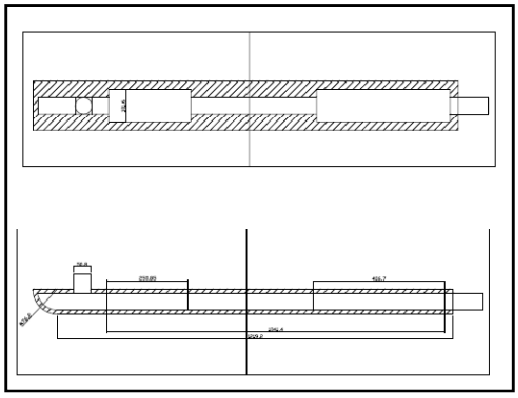

Figure 9 Drawing of the new added muffler

The first part of the muffler is a resonator that helps brake the frequency of 100Hz also. After, the combination of two empty expansion chambers has been used to assure the best sound absorbing characteristics. Also, the muffler is placed in a carbon casing, working as a second layer sound absorbing. Between the inside muffler and the outside carbon casing, an absorbing foam has been used [6]. This sound absorbing foam was used last year as sound absorbing in the snowmobile engine compartment and has proven its good efficiency. This foam resist up to a 1250 °C temperature, thus preventing it to ignite. Figure 10represents the sound absorbing of the muffler simulated on MatLab numerical calculation program.

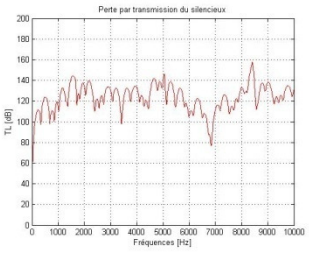

Figure 10 MatLab analyst of the new muffler

Rear suspension – Rear suspension modifications were made in sponsorships with Camoplast. This sponsorship helped us in finding the best modifications to do on the rear suspension. Past research, proved to Camoplast that the biggest noise source in the rear suspension was the reinforced fiber in the tracks. These fibers were hit each time they pass on a rear suspension wheel. To prevent that, without taking out the fiber in the tracks, the solution was to remove the rear wheels. But this could bring to a weld of the track on the rails. To prevent that Quiets team placed two bolts on each front skis, that creates snow dust to work as lubricants on the rear rails. Also, this snow dust should help in absorbing the noise. To choose the correct track, Camoplast, made a test on 2 similar tracks, the Cobra 1¼'', and the same track with the profiles but cut to 1''. Figure 11 represents the results of these tests. These results permitted us to determine that the Cobra 1¼'' is the track use for the CSC 2009 challenge.

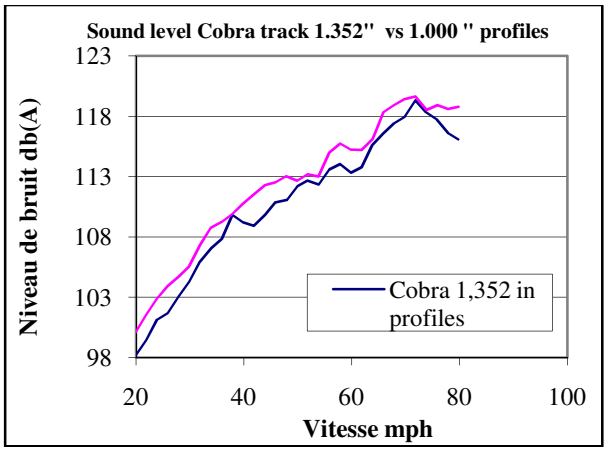

Figure 11 Cobra Track sound level testing 1" vs 1.352" profiles

Soundproofing - In addition to the sound coming from the exhaust system and the rear suspension, a lot of noise comes from the motor itself, the various vibrations and the rotating parts, but 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 12 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 sound-absorbing foam and a sound barrier inside all the panels surrounding the motor and under the hood. The two materials used where Silent Source Hushfoam FireFlex Anechoic wedge HFX-3 and Blachford BaryMat. Each of those foam, have different characteristics and helps in reducing different sound intensity.

The effectiveness level of sound absorption in a snowmobile, vary generally between 15 and 133 Hz for the engine compartment (corresponds to the engine rotation speeds). The foam we chose is efficient in this range of frequencies [6]. The addition of the rubber BaryMat material as mass to soundproofing modifications, we should get improved results at lower frequencies.

At the time of writing this paper the final sound test is not done yet. Consequently, the final results of our modifications will be done at the CSC 2009.

Cost

The overall cost modification of our sled is fairly low. In other words, all materials and components can be found from any industrial distributors. The following table shows a summary of this 2009 CSC Quiets team MSRP.

Subsystem	Subtotal
Engine	$ 1 500,00
Exhaust	$ 408,00
Electronics	$ 1550,00
Noise Treatment	$ 596,50
Sled modifications	$ 285,00
Technology Implementation	
Total Cost	$ 4 339,00

Table 4 Total cost of the modifications

Conclusion

With this year's design, considering the various systems used on the sled, the results with the two-stroke engine technology are coming to a good point. Working with, a new flex fuel 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 keep good performances and an edgy appealing design to 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 bringing this project to reality; The Ecole de Technologie Superieure, the Students Association and all of our sponsors for their financial support; transport Québec, BRP centre de Formation, BRP Racing, Hgrégoire, Fédération des clubs motoneigistes du Québec, Centre ville Volkswagen, NSK, Camoplast, Klim, Usinage RT, Nova Bus, Industries Jack, ADM Sport, ADMDQ, Motoneige.ca, Blachford, Exide technologies and Simplex, 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.

REFERENCE

1. Radio-Canada
http://radio-canada.ca/regions/Montreal/nouvelles/200412/02/004-JUGEMENTMOTONEIGE.shtml

2. Design and Simulation of Two-Stroke Engines, Gordon P. Blair, 1996

3. EPA
http://www.epa.gov/otaq/regs/nonroad/2002/r02022.pdf

4. United States Environmental Protection Agency, September 2002
www.epa.gov/otaj/regs/nonroad/2002/f02040.pdf

5. Econologie.com
http://www.econologie.com/articles.php?lng=&pg=717

6. Silent source
http://www.silentsource.com/afoams-hushfoam.html

7. Klotz
http://www.klotzlube.com/

8. 2009 Clean Snowmobile Challenge Rules

9. http://www.ski-doo.com/brphtml/skidooenginetech/fr/Index.htm