2005

Development of Clean Snowmobile Technology for the 2005 SAE Clean Snowmobile Challenge

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ABSTRACT

Kettering University's Clean Snowmobile Challenge student design team has developed a new robust and innovative snowmobile for the 2005 competition. This snowmobile dramatically reduces exhaust and noise emissions and improves fuel economy compared with a conventional snowmobile. Kettering University has utilized a modified snowmobile in-line four cylinder, four-stroke, engine. The team added an electronically-controlled fuel-injection system with oxygen sensor feedback to this engine. This engine has been installed into a 2003 Yamaha RX-1 snowmobile chassis. Exhaust emissions have been further minimized through the use of a customized catalytic converter and an electronically controlled closed-loop fuel injection system. A newly designed and tuned exhaust as well as several chassis treatments have aided in minimizing noise emissions.

INTRODUCTION

In recent years, the environmental hazards of snowmobiles have come under scrutiny by the federal government. The rising concern pertains to the noise and emissions that snowmobiles emit on the surrounding environment.

The EPA has issued a three phase reduction on snowmobile emissions. The regulations include a 30% reduction in emissions by 2006, a 50% reduction by 2010, and a 70% reduction by 2012.

In November 2000, a Record of Decision (ROD) was signed to phase out snowmobile usage in Yellowstone National Park, Grand Tenton National Park, and John D. Rockerfeller, Jr. Memorial Parkway. In January 2001, a rule to implement the decision of gradually phasing out recreational snowmobiles in favor of multi-passenger snow coaches by the winter season of 2003-2004 was signed. The mass transit snow coaches were to be managed by the National Park Service (NPS). [1]

However, on February 10, 2004, United States Court Judge Brimmer issued an order to temporarily restrain the enforcement of the 2001 snow coach rule. In response to the order, park superintendents issued emergency rules for the remainder of the 2003-2004 season. Snowmobiles were allowed to be commercially guided with group sizes being restricted to ten snowmobiles (in addition to the tour guide). However, under the emergency rules, increased daily limits were issued for both Best Available Technology (BAT) sleds and outfitter sleds, including those with 2-stroke engines. [2]

On November 4, 2004, the NPS approved a Finding of No Significant Impact (FONSI) for the Temporary Winter Use Plans and Environmental Assessment for Winter Use in Yellowstone National Park, Grand Teton National Park, and John D. Rockefeller, Jr. Memorial Parkway. The plan will be in effect for three winters allowing 720 commercially guided snowmobiles per day in Yellowstone and 140 snowmobiles into Grand Teton National Park and John D. Rockefeller, Jr. Memorial Parkway. With a few minor exceptions, all snowmobiles are required to meet the NPS BAT requirements of less than 15 g/kW-hr of hydrocarbons, less than 120 g/kW-hr of carbon monoxide and sound emissions of less than 73 dBA. [1]

Aside from the recreational aspect of snowmobiling, snowmobiling contributes substantially to the nation's economy. According to the International Snowmobile Manufacturers Association (ISMA), the economic impact of snowmobiling is about $26 billion annually in the United States and Canada. This includes expenditures on equipment, clothing, accessories, snowmobiling vacations, etc. [3]

In addition, over 85,000 fulltime jobs are generated by the snowmobile industry in North America alone. Employment ranges from manufacturing and dealerships to tourism related businesses. The nation cannot afford to simply end the use of snowmobiles; however, we must also not continue to allow the adverse environmental consequences of existing snowmobile usage. [3]

The Clean Snowmobile Challenge (CSC) is part of the collegiate design series created by the Society of Automotive Engineers (SAE). The competition was created to challenge students to reduce the impact of snowmobiles in environmentally sensitive areas.

Students are allowed to build and test new concepts to meet environmental concerns while maintaining the performance and costs of current production sleds.

DESIGN OBJECTIVES

Kettering University's 2005 team chose to continue to develop and improve upon the previous years' design. Due to the lack of time and testing on the 2004 CSC snowmobile entry, the team felt that this design had not achieved its full potential. The objectives are to produce a snowmobile that will meet the stringent EPA regulations of reduced emissions and noise as well as maintain cost and performance. Areas of focus addressed by the 2005 team included:

- Performance Improvements
- Closed-loop Fuel Injection
- Noise Reduction
- Emissions Reduction
- Reliability
- Maintain Stock Durability
- Safety and Comfort

PEFORMANCE MODIFICATIONS

The team worked to ensure that the many modifications to the RX-1 sled did not negatively impact the stock performance of the sled by a significant amount. The newly revised sled still has approximately 130 horsepower (97 kW), but it now obtains more than 20 mpg (11.7l/100km). This performance is achieved even while overall noise and emissions have been reduced.

CHASSIS – The chassis choice for the 2005 competition is a 2003 Yamaha RX-1. The team chose to utilize this sled based on its large front and rear suspension travel. Further, this sled was designed to accommodate a four-stroke engine leading to a larger engine compartment size and easier exhaust routing. Finally, the team liked the overall aesthetics of the sled.

ENGINE SELECTION - Due to the limited amount of space under the RX-1 hood and the robust and high performance of the stock RX-1 engine, a modified stock RX-1 engine was utilized. In addition to having a plentiful amount of torque and 145 horsepower (108 kW), the carbureted four stroke engine also has reduced overall emission levels compared with a typical two-stroke engine.

Engine Displacement Modifications - Upon choosing the RX-1 engine, some modifications had to be made in order to meet competition requirements making it cleaner and quieter. Because the stock RX-1 engine had a displacement of 998cc, the first modification was to reduce the overall displacement to meet the 960cc maximum limit imposed by the competition organizers. This was accomplished by having the engine sleeved and custom pistons manufactured. This allowed changes in valve relief, wrist pin diameter and compression ratio with the least amount of modifications.

After all modifications were complete, the modified engine has specifications that are outlined in Table 1.

Table 1. Engine specifications

Displacement:	57.7 in^3 (945cc)
Configuration:	Inline 4 cylinder
Block material:	Aluminum
Cam system:	Dual Overhead
Ignition:	Coil on plug
Valves per cylinder:	Five
Compression ratio:	**11.2:1**
Weight:	144 lbs (65 kg)
Bore:	2.8 in (71 mm)
Stroke:	2.3 in (58 mm)
Aspiration:	Natural
Engine Control System:	Electronically controlled fuel injection.

FUEL INJECTION – The stock carburetor fuel delivery system was inadequate in reducing engine emissions and in providing optimum mixture control for exhaust after treatment. For precise fuel control, a closed-loop fuel injection system had to be developed and integrated into the RX-1 intake system. A similar engine used by Yamaha in a motorcycle (R1) currently implements a fuel injection system. Based on the physical similarities of the engines, the R1 throttle body was chosen for the fuel injection system. This swap eliminated the need to mate separate injectors and a regulator into a fuel rail, increasing reliability and minimizing cost. Since the throttle body system came equipped with a throttle position sensor (TPS) and manifold absolute pressure sensor (MAP) no additional sensors were required by the engine controller for the intake.

When adding the R1 throttle body to the RX-1 engine, the intake had to be redesigned to take into account the dimensional difference between the RX-1 intake ports and the R1 motorcycle throttle body. This was accomplished by milling out a custom flange that bolts onto the engine. Silicon hose was utilized to make the transition between the engine's oval ports the throttle body's round ports. The small steel tubes attached to the intake ports are for the MAP sensor. The customized intake and MAP tubes can be seen in Figure 1.

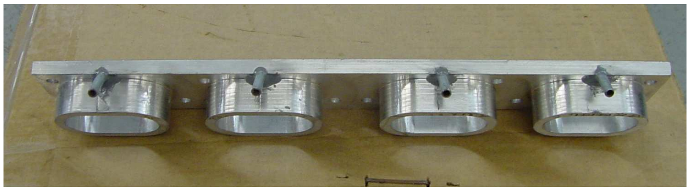

Figure 1. Customized intake flange

ENGINE CONTROL UNIT (ECU) - The stock ECU on the RX-1 engine has been replaced with a Motec M4 ECU. This ECU has the capability of operating in closed loop air-fuel ratio control under all engine speed and loading conditions. This provides a major benefit in controlling air-fuel mixtures, leading to a lowering of engine-out emissions and providing the tight control required by the catalytic converter system. However, there is a major drawback to utilizing the M4 due to the lengthy engine calibration development process. This is a one-time cost and would not play a significant part in production costs; however, it has consumed much of the teams' effort this year in terms of obtaining the ignition and fuel tables.

The calibration for the ECU was accomplished through extensive engine dynamometer testing. This testing was conducted utilizing a water brake dynamometer to simulate the engine speed and loads present in the snowmobile. The experimental setup can be seen in Figure 2. Using this setup, spark timing and fuel injection maps were developed for the engine. Engine manifold absolute pressure (MAP) and engine speed were used as the independent variables to predict spark timing and fuel injector pulse width. This control scheme was chosen because of the inadequacy of the other available schemes, such as throttle position versus engine speed, in accommodating changes to the intake and exhaust systems. Because development was proceeding at a rapid pace, the intake and exhaust manifolds were not completed before calibrating the engine. If the throttle position were used in place of the MAP, the tables would be very inaccurate once the engine was fitted with the new intake and exhaust manifolds. That is, at the same engine speed and throttle position; the engine would consume a radically different amount of air and produce a different level of exhaust. Using the engine MAP helps to compensate for this as the MAP, too, will change in response to different manifold configurations; thus compensating somewhat for these differences. The ECU allowed for all of the stock engine sensors to be utilized; however the team still had to add a wide-band O_2 sensor, two Cam Position sensors and an Intake Air Temperature sensor.

Two Cam Position sensors were used to tell the ECU the position of the engine in its cycle, thus controlling the spark timing of the engine. One sensor was used to provide a reference to a power or pumping revolution for the engine, while the second sensor was used to provide crankshaft position. This sensor was used in place of a more traditional crankshaft sensor due to a poor choice of suitable mounting locations on the crankshaft. By measuring on the camshaft, the team had to compensate for the fact that the camshaft rotates at half the speed of the crankshaft. This was accomplished by setting the pulse count in the ECU to a value that was half of what was actually present. This would lead the ECU to find a speed that is twice the actual speed of the camshaft, which is the actual speed of the crankshaft. Hall-Effect sensors (ATS 635LSB-FP) were used for this application with one being installed to the cylinder head cover in front of each cam chain sprocket. The Hall-Effect sensor on the intake side detects four bolt heads on the intake sprocket which gives the ECU a Reference signal (crankshaft position) while the sensor on the exhaust side detects one bolt head on the exhaust sprocket giving the ECU a Sync input.

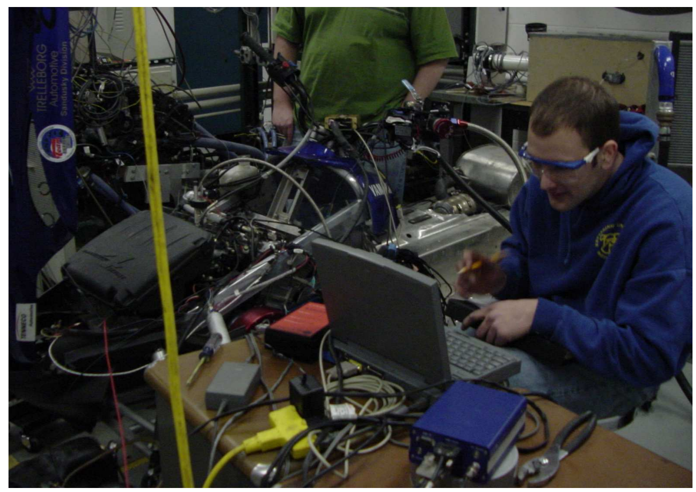

Figure 2. Dynamometer setup for ECU programming

POWER – The original power rating for the RX-1 is specified at 145 horsepower (108 kW). Although the reduction in displacement tends to decrease the power, the addition of fuel injection system tends to increase the power; thus the original power levels are potentially achievable. To date, the team has only measured 130 hp or 99 kW.

SUSPENSION – Extra wheel kits were added to the rear suspension system in order to reduce the rolling friction of the track and to help alleviate track slap and its associated noise. Small wheel kits where mounted in key areas where large wheels would not fit. By adding wheel kits to the bend of the rear suspension rail, slide wear is reduced. In 2005, the number of rear wheels on the suspension was increased from three to four to help reduce friction and bind, allowing for easier track transition at the rear of the suspension.

The remainder of the suspension system was unmodified aside from adding adjustable transfer rods. This helped to maintain the desirable ride associated with that of the original sled. Adjustable transfer rods provide increased adjustment over the stock rods to increase or decrease transfer easily. These transfer rods can be easily adjusted by hand and include reference lines for equal adjustments. They also stay in place and will not freeze.

EMISSIONS

The emission reduction strategy was to utilize the modified four-stroke engine in conjunction with an electronically controlled fuel injection system to minimize the engine out emissions. Exhaust after treatment was added in the form of a three-way catalytic converter to further reduce the engine-out emissions.

INITIAL TESTING – In order to establish target emissions, the team tested the emissions produced by the carbureted stock RX-1 and the 2005 fuel injected set up. Testing was performed by running the complete 5-mode emission test cycle that is currently under consideration by the EPA and discussed in SAE paper number 982017. [9] The exhaust probe was inserted into the tailpipe and emissions were measured using a Horiba Mexa-7100 Exhaust Gas Analyzer. The 5-modes were based off from 100% speed being 10,000rpm and 100% torque being 60ft-lbs. Table 2 depicts the average results from the 5-modes of testing of the preliminary 2005 set up.

Table 2. Average results from 5-mode emissions testing.

Speed (rpm)	Torque (ft-lb)	CO High (%)	CO2 (%)	THC (ppm)	NOx (ppm)
Idle	0	0.00	14.6	206.97	6.25
6500	12	0.29	14.8	146.4	58.1
7500	21	0.08	14.9	81.1	83.1
8500	31	0.12	14.9	94.4	135.3
10000	60	0.18	14.8	191.98	831.1

According to the baseline emission results that were obtained from this testing, the stock RX-1, with no after-treatment and a carbureted fuel system was only cleaner in carbon dioxide (CO_2) than the of the preliminary 2005 RX-1 set-up. However, the preliminary 2005 exhaust after treatment system was significantly cleaner than the stock RX-1 in total hydrocarbons (THC), carbon monoxide (CO) and nitrous oxides (NO_x). Table 3 displays the numerical results and Figure 3 compares the averaged emission results of the stock RX-1 and the preliminary 2005 exhaust after treatment setup.

Table 3. Baseline emissions results.

Sled	Speed (rpm)	CO High (%)	CO2 (%)	O2 (%)	THC (ppm)	NOx (ppm)
Stock RX1	Idle	3.4	12.2	1.1	5551.8	72.9
	6500	5.7	11.3	0.52	4130.3	77.7
	7500	6.3	10.9	0.45	4650.4	88.74
Preliminary '05 Design	Idle	0.00	14.6	0.41	206.97	6.25
	6500	0.29	14.8	0.01	146.4	58.1
	7500	0.08	14.9	0.03	81.1	83.1

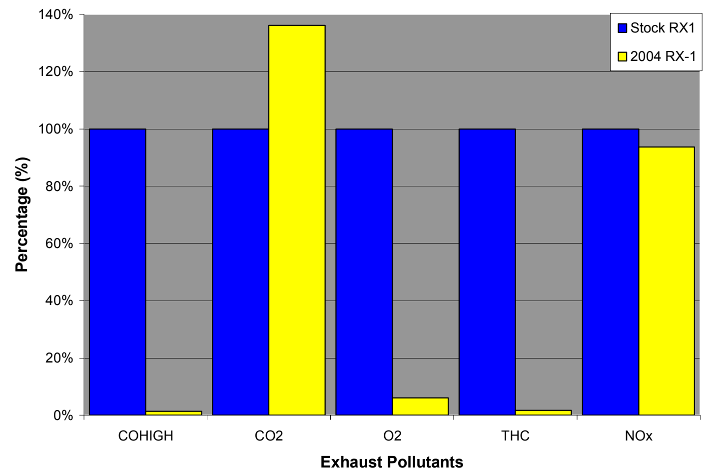

Figure 3. Baseline emission comparison between the Stock Rx-1 and the modified RX-1

Based on these results, new catalysts with modified precious metal loadings were designed to reduce the overall CO_2 level and to help further reduce the NO_X levels. At the time of this writing, the new catalytic converter was not yet completed and installed.

CATALYTIC CONVERTER SELECTION - In order to reduce the amount of CO, HC and NO_x from the exhaust stream, two three-way catalytic converters were implemented into the exhaust system. Although the ideal placement for the converter would have been next to the engine in the headers, packaging restrictions made the most practical location underneath the tunnel.

The basic function of the catalyst is to promote the oxidation of CO and HC to CO_2 and H_2O and the reduction of NO/NO_2 to N_2.[5] In order to accomplish this, the converter substrate is coated with precious metals that act as catalysts for promoting the above reactions. The precious metals that were used in this converter design were rhodium (Rh), and platinum (Pt).

Each precious metal works differently on catalyzing exhaust pollutants. Rhodium is used as a reducing agent and has been shown to be an excellent NO_x reduction catalyst. Platinum can be used as an oxidizing agent for carbon monoxide. It is know to be an oxidative cleavage, meaning that it breaks down hydrocarbons and oxidizes them to CO_2. Based on the accumulated emissions results obtained by the team, the 2005 metallic substrates were loaded 1:0:1 with the ratios being Rhodium:Palladium:Platinum and the ceramic substrates were loaded to 5.5:0:1.

To obtain optimal reductions in emissions, a metallic substrate was placed in series with a ceramic substrate. See Figure 4 for the converter set up. The metallic substrate was placed in front of the ceramic substrate because more surface area is exposed to the exhaust stream than a ceramic substrate of the same size since a fiber mat or wire mesh is not needed for support of the substrate. Also, the metallic heating properties enable the substrate to heat up quicker allowing for quicker light-off timing.

Figure 4. Catalytic Converter design.

In order to help keep converter costs to a minimum, a ceramic substrate was used for the second substrate instead of two metallic substrates. According to the quote received from Tenneco Automotive, the ceramic substrate was $20 less than that of a metallic substrate.

Based on emissions results collected during the team's testing, the substrates were loaded to maximize emission reductions. Therefore, each of the metallic substrates had a volume of 0.21 L with 200 cells per square inch (cpsi) and consisted of the following loadings: Rh - 0.50 and Pt- 0.50. Each ceramic substrate had a volume of 0.25L with 400 cpsi with the following loadings: Pt – 0.60 and Rh – 0.11.

NOISE

According to Tenneco Automotive's Exhaust System Acoustics manual, noise is defined as unwanted sound; sound being an airborne wave-phenomenon that gives rise to the sensation of hearing.[5] Snowmobiles have a tendency to emit noise through several different sources. Some of those sources may include exhaust, intake, track, engine, etc. Because reduction in the overall noise was one of the teams' objectives, the sources of noise had to be determined in addition to tuning an exhaust muffler.

INITIAL TESTING - Since no initial targets were provided, the team wanted to obtain baseline data on the stock RX-1. In addition to exhaust noise testing, additional testing was done to determine which components were contributing to the overall noise and to establish frequencies for a muffler design.

With the assistance of *Brűel & Kjaer* (*B & K*) equipment and Tenneco Automotive's test track, equipment and facility, pass-by testing and acoustic engine sweeps were performed. Calibrations were performed using a B & K pure tone acoustical calibrator set to calibrate at 94dB–1000Hz.

<u>Pass-By Testing</u> - Pass-by noise is a combination of all the noise sources present as the vehicle passes the microphone. Noise sources may include engine air-induction noise, exhaust system shell-radiated noise, track noise, exhaust flow noise, aerodynamic flow noise and exhaust pulsations. [5]

Currently, Yamaha Motor Corporation uses test specifications SAE J1161 and SAE J192 (1985, NPS modified) for pass by testing and is able to meet the 78 dBA ±2 dBA noise requirement. However, Kettering University decided to simulate the competition set up as much as resources would allow by using the combination of test specifications SAE J2104 and ISO 4872. Because the basic length of a snowmobile is between 1 meter and 4 meters, the 10 meter radius hemisphere was used. See Figure 5 for specification set-up. However, due to a lack of equipment, the set up that was actually used consisted of two *B & K* 4190 microphones (instead of four) located 1.5 meters up, 10m away from the center of the hemisphere. The two microphones that were to be 7.1 meters high per the test specification had to be eliminated due to equipment issues as well. Figures 5 and 6 depict the actual track set up that was used.

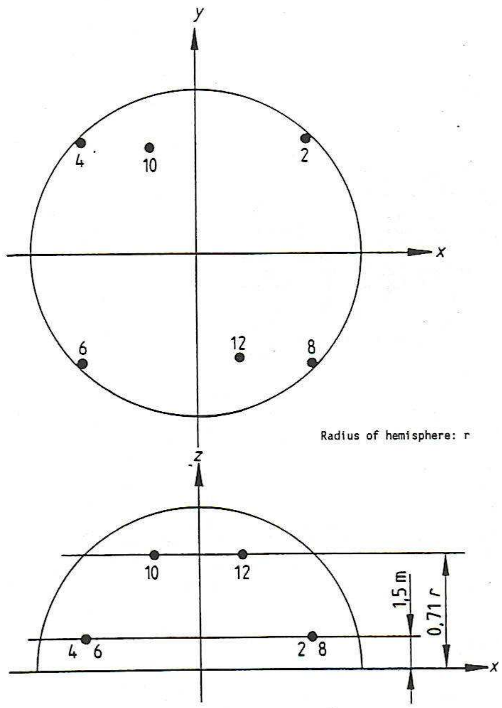

Figure 5. SAE J1161 microphone locations.

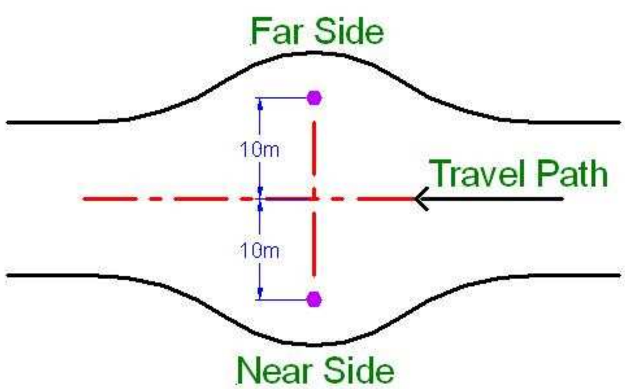

Figure 6. Microphone location for KU tests.

Since the noise event will be at constant speeds between 35mph (56 kph) and 55 mph (89 kph), three speeds were evaluated during the teams' pass-by testing. Two runs at 35mph, 45mph and 55mph were obtained on the stock RX-1. The actual test consisted of entering and exiting the hemisphere at the desired constant speed. An actual test run can be seen in Figure 7. Noise measurements were recorded on a 16-channel, Sony PC216A digital DAT recorder in slow response mode.

Figure 7. Pass by run on the RX1

In order to determine the amount of noise the exhaust was contributing to the RX-1, a Basic Auxiliary Muffler (BAM) was placed on the exhaust as shown in Figure 8. The BAM acts as an extremely large volume to cancel out noise leaving all non-exhaust noise to be measured. Two runs at 35 mph (56 kph), 45 mph (72 kph) and 55 mph (89 kph) were performed with the BAM as well.

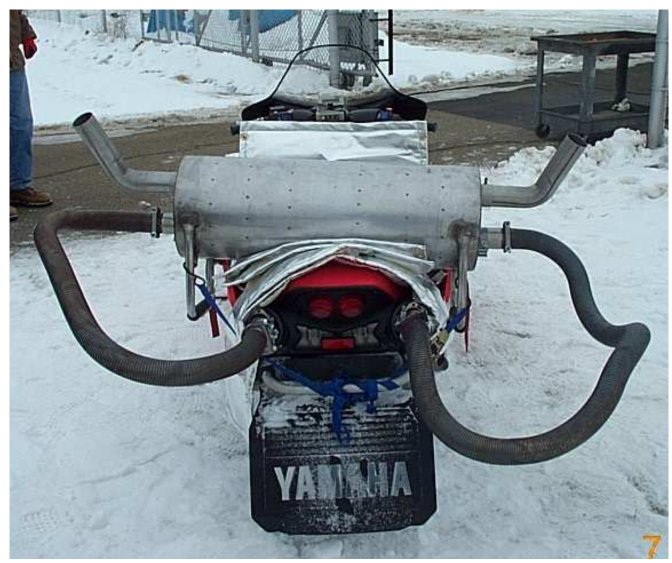

Figure 8. Basic Auxiliary Muffler attachment.

Acoustic Engine Sweeps - For order tracking purposes, engine sweeps were run on the RX-1 both with and with out the BAM. Because the RX-1 engine is an inline 4 cylinder engine, the dominant orders are the second and fourth orders. By placing the BAM on the exhaust and running the acoustic engine sweep, the airborne exhaust noise was greatly reduced if not totally eliminated. The dominant orders were then recorded and the remaining noise was left to originate from the engine, track, intake and anything else that is non-exhaust related. See Figures 8 and 9 for the test set up.

Figure 9. Acoustic engine sweep test

INITIAL RESULTS - Based on both the pass-by testing and the engine sweeps, it was evident that although the exhaust was a factor in some of the overall noise, there were other sources of noise as well. All analyses were performed on the *LMS Road Runner* spectrum analyzer through the Time Data Acquisition module.

Pass By Results - Two different plots were made from the pass by data. First, an A-weighted Sound Pressure Level (SPL) versus Frequency plot was obtained for each microphone. Secondly, an A-weighted SPL versus Time plot was acquired to determine the overall sound. In order to quantify sounds and acoustic levels in a manner that is consistent with human hearing, an A-weighted frequency spectrum was used. A-weighting forces a microphone to “hear” sound with approximately the same sensitivity as human hearing. [5]

The SPL versus Frequency plots indicated that some of the overall exhaust noise may be induced by the induction system due to the spikes around 150Hz - 200Hz and 300Hz. These plots also revealed that exhaust tuning needed to be done in the mid range frequencies. A sample plot can be viewed in Figure 10.

The SPL versus Time plots did not show a significant reduction in overall noise on the RX-1 when comparing the results between the BAM and the stock muffler. Figure 11 contains a sample of the SPL versus Time plot. See Table 4 for the results of overall pass by noise.

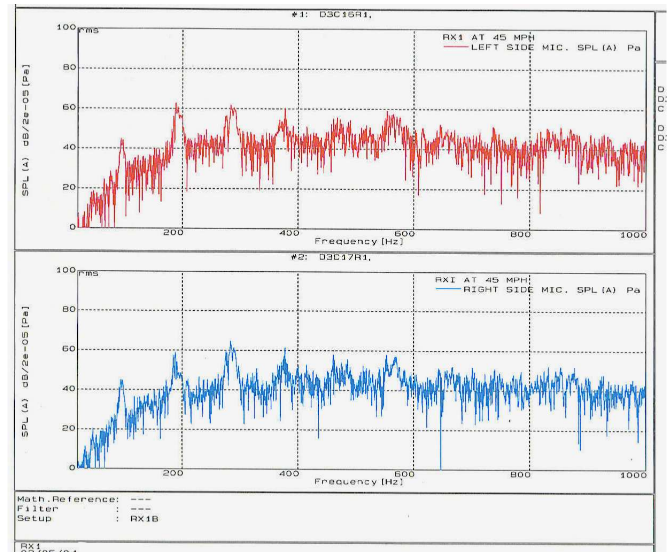

Figure 10. Sample SPL Frequency spectrum plot from noise testing.

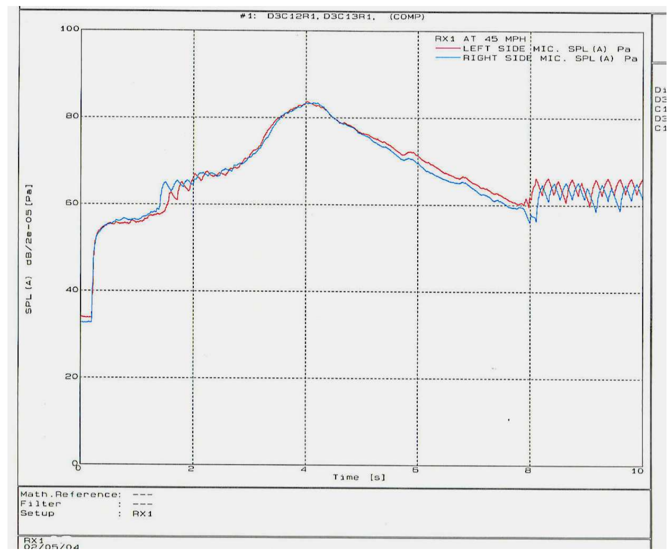

Figure 11. Sample SPL Time plot from noise testing.

Table 4. Peak dBA results of pass by testing.

Sled	Speed (mph)	Peak dBA
Stock RX1	35	81
	45	83
	55	87
RX1 with BAM	35	80
	45	82
	55	85

Engine Sweep - Engine sweep results indicated that there was a significant amount of second order noise as well as some fourth order noise. However, when comparing the results between with and without the BAM, there was an approximate 5dBA difference. This implied that there was room for improvements on the exhaust system, although there was still a significant amount of non-exhaust noise.

MUFFLER - Test results indicated that a muffler needed to be tuned for mid-range frequencies with as much volume as possible. Two muffler designs were able to meet the criteria: a tri-flow muffler and a glass pack muffler. The most difficult task in designing the muffler was to find the largest cross section and length that would fit under the seat and in the contours of the chassis.

The largest muffler that was able to meet the packaging constraints of the RX-1 was a 7.25" x 12" (184mm x 305mm) oval cross section, 11.5 inches (292mm) long. Utilizing these dimensions, a volume of 855.6 in^3 (14.0L) was obtained compared to the approximate volume of 660.2 in^3 (10.8L) found in the stock muffler. By slightly lowering the frame protecting bars under the tunnel in the rear of the sled, making a support bracket and rotating the muffler within the chassis, the new cross section was able to be packaged with no major issues.

Design - For optimal acoustic purposes and simplicity of design, a single inlet and outlet design was used. Instead of directing the noise straight up and out of the muffler heads on both sides of the sled, the single tailpipe was re-routed to exit between the track and snow flap. This was done in an effort to use some of the sound absorbing capabilities of the snow, further reducing the emitted noise. Packaging constraints limited the inlet and outlet tubes to protrude through the muffler shell instead of through the muffler heads.

Tri-Flow Design - With shell inlets and outlets, the tri-flow design was a more challenging option. A tri-flow muffler directs exhaust flow from the inlet through a perforated tuning tube and into a turn-around chamber, through a perforated return tube and into a second turn-around chamber, back through another perforated tuning tube and exits the outlet tube. Figure 12 illustrates this design. The longer the tuning tubes or "tri-flow" area, the more effective the muffler is. For the RX1 application, curved bushings were used to direct exhaust flow from the inlet into the first tuning tube and from the second tuning tube to the outlet. The tri-flow region of the muffler is packed with 25.6oz (725g) of fiberglass roving to help absorb noise.

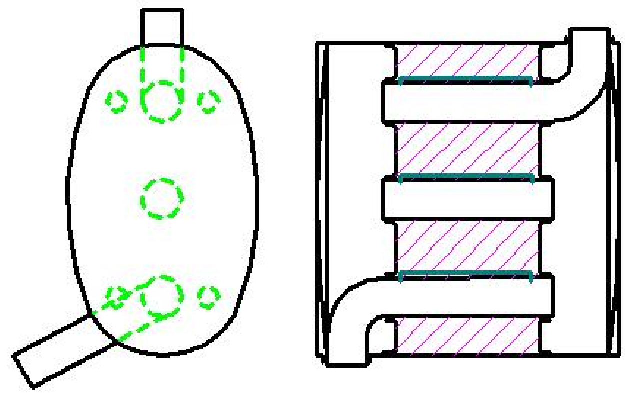

Figure 12. Tri-flow muffler design

Glass Pack Design - Using the same cross-section and length as the tri-flow muffler, a glass pack design was also made. In this system a perforated tube was connected from the inlet pipe to the outlet pipe while the remainder of the volume was packed with 60oz (1700g) of fiberglass roving. The glass pack design is more open and less restrictive on the exhaust flow than the tri-flow and therefore not as much back pressure is created. See Figure 13 for design details. The glass pack design is more optimal when tuning for mid-range to higher frequencies.

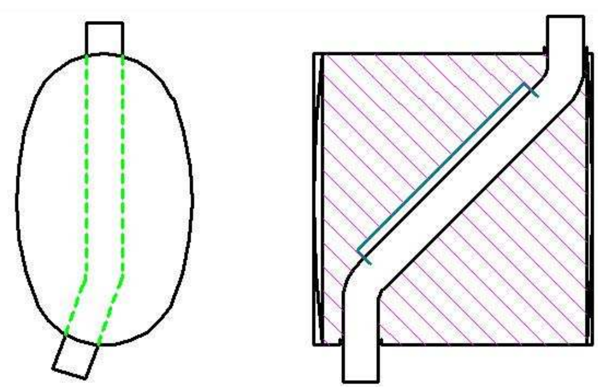

Figure 13. Glass pack muffler design.

MUFFLER TESTING – Because both mufflers are designed to reduce noise in the mid-range frequencies, additional muffler testing had to be done in order to determine which muffler would best suit the needs of the RX1 exhaust system. Transmission loss testing and cold flow testing was performed on the stock muffler, tri-flow muffler and glass pack muffler to help determine the most effective design.

Transmission Loss – Transmission loss is the ratio of sound power incident on a muffler to the sound power transmitted by the muffler. [5] This type of test is ideal when trying to nondestructively check muffler tuning frequencies, measure loss of absorption materials during durability and to easily compare different silencers.

The set up for transmission loss can be seen in Figure 14. Two microphones are located in both in front of the muffler and after the muffler. Noise is emitted by a noise generator through an amplifier and recorded by the microphones.

Figure 14. Transmission loss bench

Results of the transmission loss testing indicated that the glass pack design was the most effective design. Both the glass pack and tri-flow mufflers were more effective than the stock muffler in the mid-range frequencies. See Figure 15 for the transmission loss results.

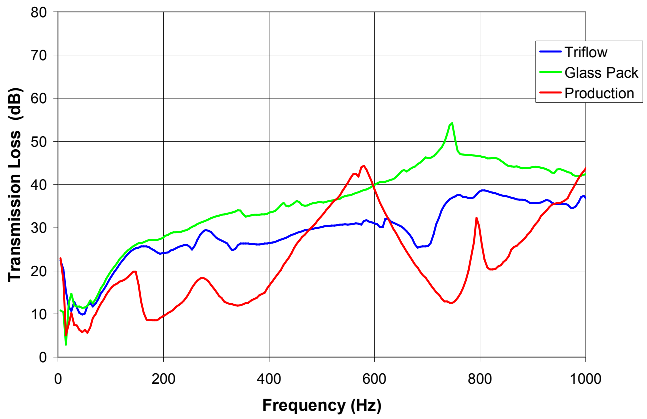

Figure 15. Transmission loss results

Cold Flow Testing – Cold flow testing is used to help determine the amount of backpressure that is created by the muffler. As air is forced to flow through the muffler, a standardized flow rate and corrected back pressure are calculated. The flow rate is measured in scfm and the pressure is measured in inches of mercury.

According to the cold flow results, the glass pack muffler design was about 1.7 times less restrictive than the tri-flow muffler. Figure 16 shows the cold flow results.

Muffler Selection - After reviewing the transmission loss and cold flow results from 2005 noise testing, the team decided to implement the glass pack muffler for the 2005 competition. Although the glass pack was not as low in back pressure as the stock muffler, the combination in overall noise reduction and back pressure was the most efficient solution to implement.

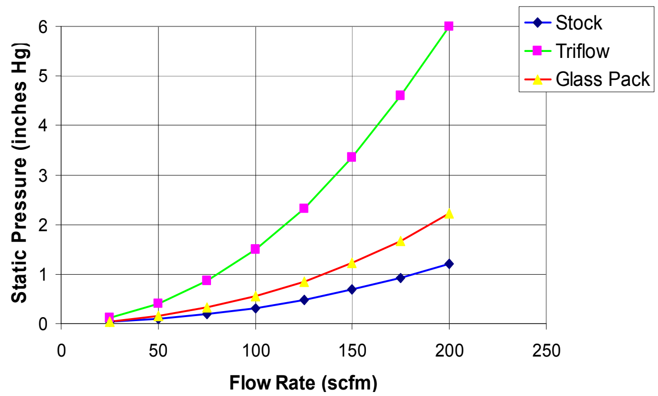

Figure 16. Muffler cold flow results

2005 MUFFLER NOISE RESULTS – Upon the completion of the customized 2005 glass pack muffler design, the Kettering University team performed additional pass by testing to ensure that the new muffler would be quieter than the stock muffler. Based on the additional pass by runs, Kettering was able to reduce the overall noise level of the stock sled at 35 mph, 45 mph and 55 mph. Figure 17 compares the stock RX-1 exhaust to the 2005 customized exhaust design.

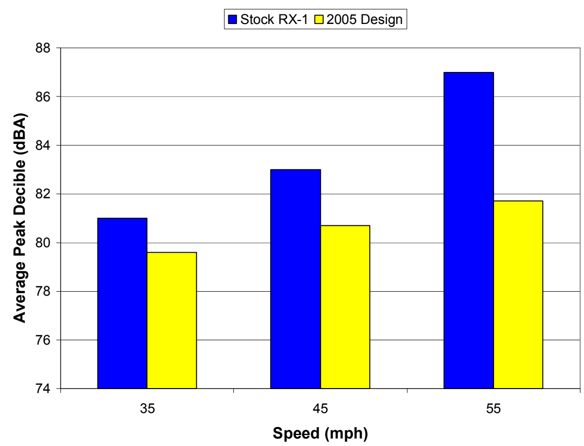

Figure 17. Average peak noise level of stock RX-1 and customized 2005 muffler design.

NON-EXHAUST NOISE SOLUTIONS – Because noise testing indicated that non-exhaust related noises were being produced as well, noise insulating material was added under the hood, to the belly pan sides and under the tunnel. Further, wheel kits were added to the stock suspension to minimize the track noise.

Dynamat Extreme, a vibrational damper, was applied to the underside of the hood and to the inside of the belly pans. This was selected due to its resistant to water and easy application. Dynaliner, a thermo-acoustic foam, was then applied over the Dynamat Extreme on the underside of the hood. Dynaliner as seen in Figure 18, has a combination of open and closed cells to accept and dissipate sound waves. It provides high acoustical absorption that converts sound waves to silent heat energy by creating optimum air flow resistance resulting in maximum noise absorption. In addition, a thermo-acoustic foam with a reinforced aluminized facing called Hoodliner was installed over the Dynamat Extreme on the belly pans. Hoodliner also has a combination of open and closed cells to accept and dissipate sound waves just like the Dynaliner. The reinforced aluminized facing can provide 97% heat reflection and also acts as a water/oil barrier. Hoodliner is works well for absorbing engine noise. We decided to use Hoodliner on the belly pans because of the water and oil resistance of the aluminized facing as pictured in Figure 19.

Figure 18. Dynaliner noise absorbtion material underneath the hood.

Figure 19. Hoodliner noise absorbing material used in the bellypans that is also water and oil resistant.

DURABLITIY

The stock suspension and chassis were utilized for keeping the stock structural integrity of the sled. With the exception of the bore diameter and custom piston, the stock engine was used and therefore there was no need for new engine mounts or frame modifications to be made. Another major factor in durability is the use of the stock designed engine. The dependability of the Yamaha four-stroke engine coupled with conservatively tuned ECU fuel and spark maps surpass the reliability of the common performance snowmobile.

SAFETY AND COMFORT

With respect to both safety and comfort, the RX-1 base sled has several advantages over comparable snowmobiles. The seating position and operator comfort is optimized for increased riding pleasure. Aesthetic\ appearance is enhanced through the aggressive hood and tail design. With respect to safety, a linear ratio stabilizer system is tuned for flat cornering (virtually no ski lift) and exceptional big bump response.[8] Standard to the RX-1 is a dual shutoff system as well as Throttle Override System for stuck throttle conditions. For the benefit of safety for the performance rider and novice alike, a tether cord has been added. Keeping the stock suspension and chassis meant that there was no variance in ride characteristics from that of the stock sled. Since there were no modifications to the chassis, the original safety should be maintained due to having stock engine mounts and stock weight.

FUEL ECONOMY

Implementing the ECU engine management and fuel-injection system has proven to greatly improve the fuel economy compared to the original system. The fuel economy has been increased to over 20 mpg (11.8L/100km), which is nearly 40% as compared with the average 15 mpg (15.7L/100km) for the stock RX-1 [7]. This leads to considerable fuel savings over the life of the machine. Not only does fuel economy show the savings in gasoline, but inherent to the design of a 4-stroke engine, the oil consumption has been dramatically reduced.

ACCELERATION AND HANDLING

Many stock handling characteristics developed by Yamaha were carried through to the competition snowmobile. In choosing the RX-1 base sled, Kettering gained a handling advantage from Yamaha's exclusive *Deltabox* chassis. Superior torsional rigidity, reduced weight for a solid feeling under hard acceleration, quick response when cornering and smoother suspension action in bumpy conditions are several of the inherent characteristics of the *Deltabox*. In addition, the steering linkage is routed along the side of the engine bay for improved center of gravity by lowering the engine in the chassis [8].

Upgrades in the stabilizer bar and arms increase handling characteristics. The stabilizer bar was upgraded from the stock 10 millimeter bar to a 13 millimeter bar while the stabilizer arms where lengthened from 50 millimeter to 75 millimeters. This increase in stabilizer arm length will apply a force to the stabilizer bar quicker into its travel reducing body roll and ski lift. The heavier stabilizer bar will improve handling by keeping the track and skies in contact with the snow during corners and reduce body roll. Keeping the sled flatter will allow for more predictable and aggressive cornering.

Acceleration was also improved though changing the clutch weights and adding a roller secondary clutch. These additions allow for quick back shifting and improvement in throttle response. Smoothing out shifting will also increase the life of the drive belt.

COST ANALYSIS

Assuming production costs, the clean and quiet conversion package cost $905.84 according to the Technology Implementation Cost Assessment (TICA) used for the competition. The additional costs were due to the implementation of fuel-injection, muffler design, catalytic converter, engine and fuel system control, and engine modifications.

Using the TICA method to account for the cost of the stock RX-1 components which were removed during the conversion, a total cost of $708.20 was attributed to these components. Therefore, this analysis implies that the cost of the clean and quiet package used in Kettering University's modified RX-1 is only $197.64 above and beyond the cost of the original sled. Since fuel economy has increased, the cost difference will pay for itself in the long run.

CONCLUSIONS

The goal of this project was to modify a stock snowmobile to achieve substantial reductions in exhaust emissions and noise emissions and to achieve increased fuel economy, while maintaining the performance characteristics of the stock sled. Utilizing the combination of fuel injection, an electronic engine management system, catalytic converters and a customized exhaust, the Kettering University entry in the 2005 CSC has met each of these goals.

The combination of being eco-friendly while maintaining high performance is desirable to performance orientated snowmobilers as well as environmentalists.

ACKNOWLEDGMENTS

The Kettering University Clean Snowmobile Team would like to thank all of the people who have helped us in the successful completion of our competition vehicle. Special thanks to the Kettering University Mechanical Engineering Department Faculty and Staff for the support and the opportunity to work on this project.

The team would also like to thank the following sponsors for their generous support of our project:

Yamaha
Michigan Corn Growers Association
Coldwave (Courtesy of Specialty Sports Unlimited)
Tenneco Automotive
Trelleborg Automotive
Emitec
B & K
Engelhard

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