Minnesota State University, Mankato Clean Snowmobile Design Using a Semi-Direct Injection Two-Stroke

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Abstract

The 2006 MSU-X Clean Snowmobile Challenge team has made significant modifications to the two-stroke cycle engine in a 2005 Arctic Cat F5 APV. The goals of the team were to improve emissions, noise, and fuel economy while maintaining stock performance and handling characteristics. To obtain these results, a semi-direct fuel injection system was developed and the power valves were removed. An engine management system was used in place of stock systems to control fuel and ignition. A two-way catalytic converter and an air pump to reduce hydrocarbon and carbon monoxide emissions was incorporated into the exhaust system. Sound levels were lowered with the use of a custom extended exhaust system and sound dampening materials underneath the hood. These modifications produced a light weight, performance oriented snowmobile that also has reduced exhaust emissions.

Introduction

Snowmobiling is an American past time. The great outdoors can be quickly and efficiently explored using a snowmobile. It is also the basis for the economy of many parts of the northern portion of North America. However, traditionally the sport of snowmobiling has been noisy and polluting. This is primarily due to the inherent characteristics of two-stroke cycle engines which, until recently weren't governed for emissions. This combined with poor fuel economy, a large amount of toxic exhaust pollutants were introduced into the atmosphere. The high emissions combined with the large number of snowmobile enthusiasts traveling to ride in national parks throughout the northern United States has caused concerns over the impact of snowmobiles on the environment. This spurred the National Park Service to propose a rule in December of 2000 that would cap the use of snowmobiles and by the 2003-2004 season eliminate the use of snowmobiles in the park [1]. On January 22, 2001, the National Park Service published the "Snowcoach Rule," it allowed snowmobile use to continue in 2001-02, significant reductions in snowmobile use in 2002-03, and the elimination of snowmobiles in national parks in favor of snowcoaches in 2003-04, this would be the end of snowmobiles in the parks [1].

The National Parks Service then published an alternative to the "Snowcoach Rule" in 2003, allowing for a set number of snowmobiles to enter national parks. Each snowmobile allowed in the park would then have to be in the category of best available technology. This in itself would reduce snowmobile emissions drastically. Also to reduce the areas these snowmobiles traveled 80 percent of them allowed had to be guided. On December 16, 2003, a U.S. District Court Judge ordered the final 2003 rule of the National Park Service be vacated. This left the January 22, 2001, Final Rule in effect, as modified by the November 18, 2002 Final Rule. Now the number of snowmobiles allowed into the park for the 2003-04 season was regulated to 493 snowmobiles per day and being phased out in favor of snowcoaches in the future. This did not permanently close the door on snowmobiles entering National Parks such as Yellowstone. The National Park Service now had to scientifically determine the full environmental impact of allowing snowmobiles in the park. This has forced the National Park Service to continue its research on “safe” ways to include snowmobiles in Yellowstone as well as other National Parks.

Then on February 10, 2004 a U.S. District Court Judge stated that the January 2001 Rule is not valid, and required the National Parks Service to provide temporary rules for the 2004 snowmobile season that are fair and feasible to all parties [2]. The National Parks Service then produced an amendment describing the temporary rules. These rules allowed for 780 snowmobiles, to enter Yellowstone each day. These additional snowmobiles allowed into the park had to meet the Best Available Technology standards, and each snowmobile had to be commercially guided. The 2003-2004 Best Available Technology standard required all snowmobiles achieve a 90% reduction in hydrocarbons, and a 70% reduction in carbon monoxide, compared to the Environmental Protection Agency’s baseline emissions testing for conventional two-stroke snowmobiles [1]. Beginning with 2005 model year, snowmobiles must be certified under the 40 CFR 1051, to a Family Emission Limit no greater than 15 g/kW-hr for Hydrocarbons and 120 g/kW-hr for Carbon Monoxide. In addition to these emissions standards for the Best Available Technology, the snowmobiles must also pass a 73 decibel sound test measured using the SAE J192 test procedure [3]. Effective on December 10, 2004 the final rules from the National Parks Service went into effect. The only change made was to limit the number of snowmobiles per day to 720 [4].

This debate over snowmobile usage and the many businesses and communities that rely heavily upon it attracted a lot of interest. These aspects as well as the emissions and sound regulations prompted the Society of Automotive Engineers to begin the Clean Snowmobile Competition for collegiate students to compete in designing a snowmobile that would meet and exceed the standards for snowmobile usage in the National Parks. Reducing the emissions and sound levels would greatly increase the chances of allowing less restricted access to these parks, allowing us to experience the joy of snowmobiling in some of the most beautiful parts of our country, without harming the environment.

MSU, M Snowmobile Design

INTRODUCTION- The team chose to design and build a semi-direct fuel injection two-stroke cycle Suzuki 499 cubic centimeter engine. Using wet flow testing the team chose to inject fuel into the transfer port of each cylinder at a 30 degree angle to the cylinder bore. A MoTeC engine management system was used to control fuel and ignition in an effort to decrease emissions and optimize performance. A lengthened exhaust system incorporating a two-way catalyst was designed and implemented to further reduce the emissions as well as noise. All of these changes were housed in an Arctic Cat F series chassis. To assist in the performance and handling studs were placed in the track, carbides were added to the skis, a handlebar riser, Boss seat, and Powermadd hand guards all combine to produce a comfortable and competitive snowmobile.

CHASSIS CHOICE- The team looked deeply into choosing the optimum chassis for the competition. The weight, handling characteristics, engine compartment size, and overall quality were all taken into account. The Arctic Cat F series chassis was chosen due to being one of the lightest, best handling chassis on the market as well as having more room under the hood then the Polaris IQ and Skidoo Rev chassis. These characteristics were determined to be important for the competition in order to produce a snowmobile that would perform well in the events.

ENGINE CHOICE- The team chose a two-stroke cycle engine for the 2006 Clean Snowmobile Challenge. Four-stroke cycle engines are fundamentally more efficient than many of the current two-stroke cycle engines. The higher level of efficiency allows them to have better fuel economy characteristics, lower emissions as well as a lower exhaust note. However, a tradeoff for these characteristics is a significant specific power output penalty in terms of both power to weight and power per unit displacement. In addition, technologies can be incorporated into the design of two-stroke cycle engines to improve many of their shortcomings.

The simplicity of the two-stroke cycle engine also has some traits which have become the benchmark for snowmobiles throughout history. The light weight, simple design, and performance characteristics of the two-stroke cycle engine make it an excellent combination for the typical needs of the average snowmobile enthusiast.

The team chose to use a 499 cubic centimeter power valve Suzuki power plant as the base engine. To gain improvements in exhaust emissions an estimated twenty horsepower reduction was taken. The engine was modified to a non-power valve 499 cubic centimeter Suzuki power plant by replacing the cylinders with non-power valve components.

Further improvement in emission levels were gained with the implementation of a semi-direct fuel injection system. Semi-direct fuel injection has been used by Skidoo improving their emissions and fuel economy to nearly equal or better than that of the four stroke cycle snowmobiles on the market today [10].

FUEL SYSTEM- Semi-direct fuel injection (SDI) has stopped the extinction of the two-stroke cycle engine from snowmobiles. When the first four-stroke cycle engines were introduced in snowmobiles it appeared that the demise of the two-stroke engine seemed inevitable with the quickly approaching 2007 emissions standards.

Skidoo was able to produce a two-stroke cycle engine with comparable emissions and fuel economy to the four stroke cycle snowmobiles it was competing with in its' class. The semi-direct injection engine allows significantly less short circuiting of fuel as well as metering the fuel more accurately at all engine speeds.

The ability to create a compliant two-stroke cycle engine was a large factor in the teams' choice to step away from the four-stroke cycle engines used in the past, and start from the beginning. The team had to first examine the engine positioning in the F-series chassis to see where there was enough room to place the injectors in the engine. Due to the space limitations of the chassis there were only a few choices. In addition to the space requirements for injectors the team had to research the number of injectors to use per cylinder, as this would increase the space needed drastically. Skidoo and Polaris both incorporate two injectors per cylinder. One of which is a smaller injector which is used for idle and low RPM performance. The second is slightly larger and is run together with the smaller one at higher RPM and load.

The injectors' on-time and injection timing is controlled by the ECU. The earlier SDI models in watercraft, and snowmobiles incorporated one large injector per cylinder. This option produces slightly higher emissions, less control over idle, and low RPM due to the difficulty of controlling the small amount of fuel needed in these conditions with an injector that must also be able to accommodate high RPM high load conditions as well [8].

Primarily due to space and time constraints, the single injector per cylinder design was chosen. The team chose to use a single injector per cylinder, sacrificing fuel control accuracy at low RPM due to the large injector. Bosch 52 pound per hour low impedance fuel injectors, part number 0552 from Marren Fuel Injection, at 60 psi fuel pressure were selected for the engine. These fuel injectors provide a 25 degree cone angle combined with a light mist spray pattern. They also use a pintle nozzle, instead of a disc style, which helps control the flow more accurately. This was an important aspect for the team to improve the low RPM emissions and idle characteristics.

The injectors were placed into the transfer ports on the outside of each cylinder. On the Suzuki 499 cubic centimeter engine chosen, there are two transfer ports on each side of the cylinder. The outside port of each cylinder was selected based on packaging requirements.

The team modified one of the bulkhead supports slightly, but overall fit and accessibility was determined more desirable than other possible locations. The other injector placement options were the back side of the cylinders. While this location would have been feasible there would have been no access to the injectors without removing the engine from the chassis due to the lay-down engine design. Finally, the injectors could have been placed in the bottom of the crankcase, but the team didn't expect to see a drastic decrease in engine emissions because this design would be very similar to the fuel injection used on many snowmobiles currently in production along with accessibility limitations once again.

WET FLOW TESTING - Once the general injector location was identified, a technique called wet flow was used to determine the best injector angle into the transfer port. The wet flow system consists of a SuperFlow 1020 flow bench, device to meter in a liquid into the air stream, fluorescene, a black light, an acrylic cylinder head, and the engine block and cylinders.

The SuperFlow 1020 flow bench provides the air flow by supplying air to air inlet opening of the engine as shown in Figure 1. A small amount of water with a fluorescent die is injected into the airstream at possible injector locations to simulate fuel. The liquid is delivered through a carburetor jet into the transfer port as shown in Figure 2. A combustion chamber was CNC machined out of acrylic plastic to the specifications of the stock cylinder head. The acrylic head allowed the team to view the flow patterns and fuel distribution in the combustion chamber using a black light.

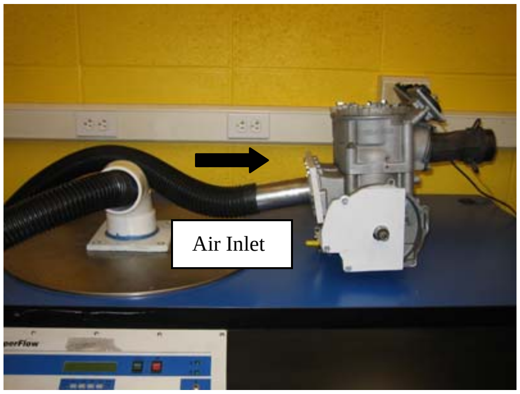

Figure 1

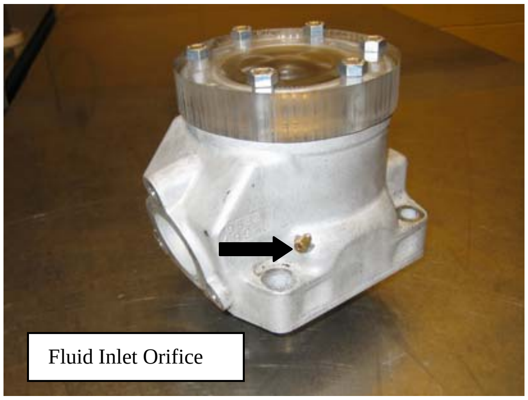

Figure 2

The team tested the flow at 30 and 60 degrees into the side of the cylinder, as well as stock flow through the crankcase. Figure 3 shows the final placement of the injector at the 30 degree angle into the cylinder.

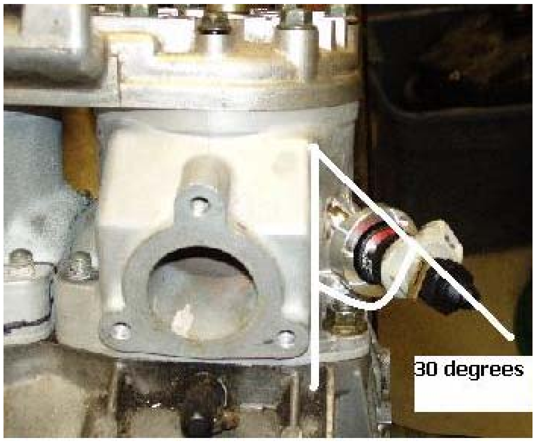

Figure 3

Based on visual dynamic flow characteristics, the 30 degree position was chosen over the 60 degree and stock flow placements. This was chosen because the 30 degree had a more even distribution of fluid. There was a visual difference in the mixture of the fluid and air in the combustion chamber observed at different angles. The “mixture” was significantly more homogeneous and the liquid was much more evenly distributed with fewer concentrated areas of liquid.

The flow through the cylinder didn’t appear to promote short circuiting. This was accomplished due to the fluid enriched air flow being injected into the cylinder opposite the exhaust port. The movement of fluid followed the counter clockwise movement of the air entering the cylinder allowing for better fuel atomization. The 30 degree also fit the best for packaging the injector within the available under hood space. All data was subjective, based on visual observations. Figure 4 shows the concentration of liquid in the cylinder while wet flowing. The neon green in the combustion chamber is the flourescene, and the purple is the black light used to make the flourescene standout.

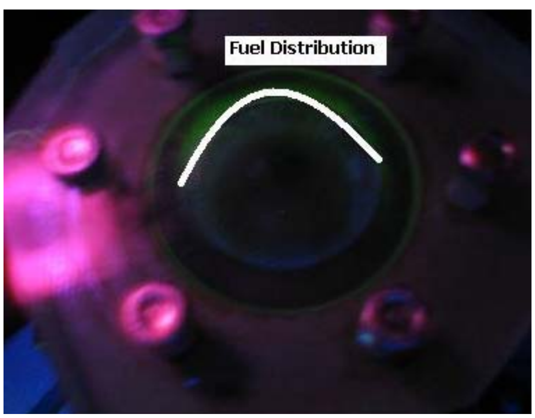

Figure 4

The 30 degree angle injects fuel tangent to the cylinder wall allowing the fuel to enter the combustion chamber before the exhaust port is completely closed, which appears to reduce short circuiting. This also aids in the creation of swirl in the combustion chamber, when combined with the freshly scavenged air. This occurs due to the intake port and transfer port shape. The teams’ research concluded the swirl increases fuel mixture, improving the efficiency of the engine [6].

Noise Reduction

With the sound levels of snowmobiles becoming more of an issue for the industry, the team had to consider its’ options to reduce the sound levels of the new engine. Due to the base engine being a two-stroke cycle engine, sound levels were an important aspect to improve upon. Specific areas the team focused on in an effort to reduce noise were the incorporation of sound deadening materials to the inside of the hood and the addition of a large diameter exhaust extension that incorporated the catalytic converter.

EXHAUST SYSTEM- The exhaust team chose to add approximately six feet to the exhaust system to help cancel sound frequencies and decrease the overall sound of the snowmobile. A two and a half inch diameter exhaust pipe accomplished this goal. This piping was used to keep the addition of backpressure to a minimum. Applying the equation for head loss *[Head Loss = f* (Lv^2/D)*]* where; frictional loss (f), length (L), velocity (v), and diameter (D) are used to show as the diameter increases the head loss in a pipe will decrease. Higher head loss can be compared to adding more restriction [7].

The exhaust pipe was routed around the brake caliper and underneath the right side foot rail as close as possible to the foot rail (Figure 6). At the end of the tunnel, the tubing was turned in towards the inside of the snowmobile, to direct exhaust flow between the tunnel and the track

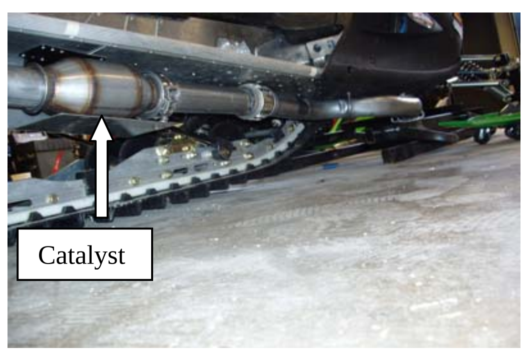

Figure 6

The team chose this method as an effective way to be able to use the stock silencing box combined with a catalyst and muffler. Along with utilizing the stock silencing box, the team also evaluated a resonator type muffler to help reduce sound. This type of muffler was chosen because it balanced noise reduction characteristics with reasonable size and backpressure traits.

Figure 7

Flow testing was done to measure the amount of increased backpressure each component added to the system. This testing was done at 25 inches of water, 77 degrees Fahrenheit, and on range five of the SuperFlow 1020 bench. Figure 7 above shows the exhaust on the flow bench.

Table 1 below shows the flow data obtained through attaching the different exhaust setups to the flow bench. The flow data shows the amount of flow through the exhaust system from the stock setups through the addition of the 100 and 200 cells per square inch catalysts. This data can be used to determine whether or not adding the exhaust extension and catalyst will reduce performance or create too much back pressure due to the added restriction. The slight difference in flow between the two catalyst options indicates that either catalyst would be acceptable based on exhaust restriction criteria.

Test	**Setup**	**Flow (CFM)**
1	Stock Sabercat	161
2	Stock F5	152
3	Sabercat and Modified Silencer (90 degree elbow)	150.5
4	Sabercat, Modified Silencer, Resonator	148
5	Sabercat, Modified Silencer, Resonator, 100 cell per inch Catalyst	137.4
6	Sabercat, Modified Silencer, Resonator, 200 cell per inch Catalyst	127.3

Table 1

SOUND DAMPENING MATERIAL- Thermal sound dampening material was added to the inside of the hood and belly pans to help reduce noise. The material that was used is called VB-TS, and was purchased from Cascade Audio Engineering. It was chosen because of its' ability to control mid-band sound frequencies, oil resistant characteristics along and desirable weight and thickness options. The team found through research that typically two-stroke cycle engines produce the highest decibel readings in the mid-band frequencies (250-1000 Hz) [11]. This quality will be a key factor in reducing the noise created by the teams' snowmobile.

At only 0.375" thick, the material's lower profile was beneficial to fit into the tight areas throughout the engine compartment. The material's thermal barrier of aluminum mylar, which can withstand 400 degrees Fahrenheit, also deflects heat away from the hood and belly pan, allowing more placement options for the barrier. The ability of the VB-TS to absorb the sound frequencies helped lower the sound level of the snowmobile during sound testing by two or three decibels as shown in Table 2. Finally, after two months of exposure to oil and grease, they do not penetrate inside the material. This is an important characteristic for a material such as this when being used in a snowmobile.

SOUND TESTING- The noise reduction testing began with evaluating the stock Arctic Cat F5 using the SAE J192 standard. The test was executed four times, with the snowmobile going two directions past the audiometer, as prescribed by the J192 standard.

Table 2 below shows the decibel average for each setup of the snowmobile from the left hand side (LH) and the right hand side (RH). "Modified #1" is the F5 with the full exhaust (no catalyst) in place. "Modified #2" is the F5 with the modified exhaust (no catalyst) and the addition of sound dampening material under the hood. During the sound testing the team found the stock system was quieter than the additional exhaust pipe including the second muffler.

An average sound level of 84.7 decibels was measured. After adding the modified exhaust and sound dampening material under the hood the sound level was decreased to 83.6 decibels.

The team chose to use the lengthened exhaust, without the resonator, in order to allow for location of the catalyst down stream in order to reduce the probability of melting the catalyst. The optimum temperature for catalyst efficiency is just under 1000 degrees Fahrenheit. Using a thermocouple during testing the team found the catalyst must be located along the tunnel in the modified exhaust.

Setup	**RH dB (Average)**	**LH dB (Average)**
Stock	83.8	85.6
Modified #1	85	86.8
Modified #2	82.6	84.8

Table 2

Engine Controller

The team used a MoTeC M48 engine management system. The M48 allowed injection to be controlled sequentially in order to conserve fuel. In addition, the fuel and ignition could be controlled three dimensionally, this allowed precise control over the ignition and fuel delivery, which ensured optimum performance for the full range of operating conditions. The ECU also gave the team an infinite variety of choices for the ignition coil, module, and trigger system. Additional reasons the team chose the M48 include a sensor sampling rate of 480 times per second, low physical weight, low current draw, and compatibility with the sled's relatively high RPM range.

In order to take full advantage of the controllability of the low impedance injectors, a number of inputs were used for ECU compensation. These included:

- 108 kPa Manifold Absolute Pressure (used for barometric pressure)
- Intake air temperature sensor
- Engine temperature sensor
- Stock throttle position sensor

The ECU reads the RPM of the engine, controls the ignition and injector timing by inputting signals from a reference and a synchronization sensor. The reference input allows the ECU to read the RPM status of the engine while the synchronization input tells the ECU where the engine is in relation to Top Dead Center of cylinder 1. To achieve these inputs, a trigger wheel with 12 teeth, 30 degrees apart was designed. Using 12 teeth allows for higher resolution of the engine RPM, allowing the ECU to compensate more accurately than with the stock two teeth. Figure 8 below shows a CAD drawing of the 12 tooth trigger wheel.

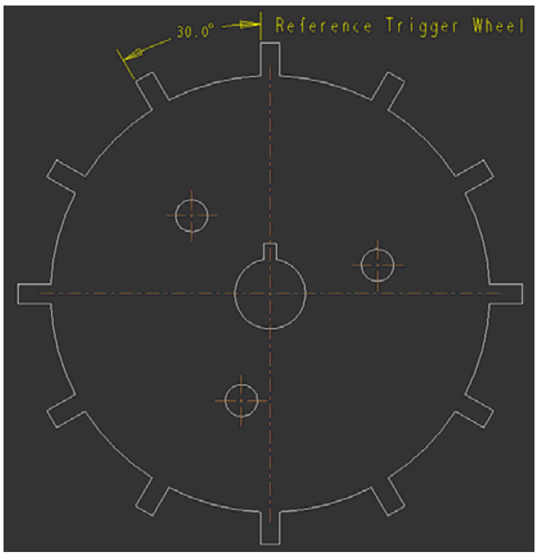

Figure 8

The stock Arctic Cat ignition flywheel trigger system was then modified. The stock flywheel had two teeth, 180 degrees apart and was modified to only have one tooth.

The position of this extra tooth was then programmed in the ECU to be used as the synchronization sensor. The trigger wheel was mounted to the flywheel, and a spacer was designed and fabricated to space the recoil starter out the proper distance. The sensors were located using the stock mounting location with minimum modification to the mounting studs.

The ECU's internal drivers were able to trigger the injectors using a small electrical draw while providing an injector pulse width accuracy of 10 microseconds, while keeping heat buildup inside the ECU to a minimum. These sensors combined with the M48 engine management system allowed the team to map the fuel system for peak torque and low emissions using a Land and Sea water brake dynamometer (Figure 9).

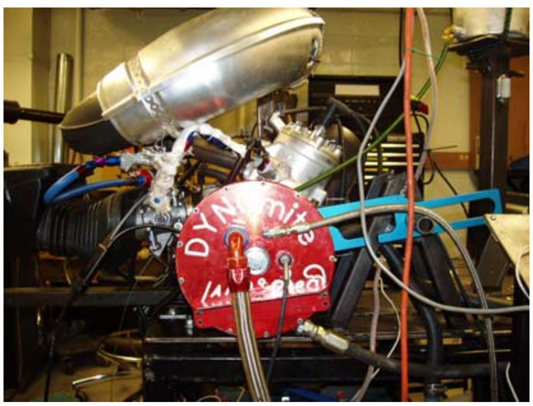

Figure 9

Emissions Control

The team chose to incorporate an exhaust catalyst and air pump to decrease the emissions of their snowmobile. The team was able to have 100 and 200 cell per inch catalysts designed for their testing. They also designed and fabricated a combination engine and air pump mounting bracket in order to save under hood space.

EXHAUST CATALYST- The catalyst used by the team was a two-way oxidation catalyst, approximately 105 mm in diameter by 120 mm long, using 100 cells per square inch, and loaded with 50 grams of precious metal per cubic foot. Due to the fact that two-stroke cycle engine emission characteristics are high in HC and CO with lower NOx levels, an oxidation catalyst was utilized. The precious metals used were platinum and rhodium at a ratio of 5:1. The catalyst will convert the hydrocarbons (HC) and carbon monoxide (CO) to water (H_20) and carbon dioxide (CO_2).

An air pump was also incorporated to inject additional air into the exhaust system to improve the efficiency of the catalyst The equations below show the changes.

$$4HC + 5O_2 \Rightarrow 2H_2O + 4CO_2$$

$$2CO + O_2 \Rightarrow 2CO_2$$

These modifications will significantly reduce emissions compared to a typical carbureted or throttle body fuel injected two-stroke cycle engine.

The air pump selected was a mechanical Moroso Racing vacuum pump. Using a Gilmore style belt and pulley system with a gear ratio of 1.32:1, the pump has a flow rating of 32 cubic feet per minute at 6000 RPM. This ratio was required to reduce the speed the pump is spun by the engine. The maximum pump RPM is 6000 RPM and the engine can achieve over 8000 RPM. The pump is driven by a pulley mounted on the end of the primary clutch mounting bolt. Figure 10 shows the air pump mounted onto a custom designed and fabricated engine mount that also incorporates the air pump mounting points.

Figure 10

Performance

The performance aspects of the competition include acceleration and handling events. The competition purpose clearly states, “the competitors’ snowmobiles are to retain or improve upon the stock snowmobiles performance characteristics”. In order to accomplish this task the team chose to use the Arctic Cat F5 due to its light weight, crisp power, performance oriented suspension, and chassis. These aspects combined with the ability to use traction products such as studs and carbides will allow the team to keep the modified snowmobile up to par with the stock sled.

The team chose to install 102 Woody’s Gold Digger studs in the track using the 2004 Arctic Cat Sno Pro stud pattern, the only standard pattern, legal for the competition stud rule, available for the standard 13.5 inch wide track. In order to compliment this stud pattern on the F5, Woody’s suggested the team install six inch Trail Blazer ski runners. This combination will produce a performance oriented snowmobile, with decreased braking distance and spot on handling for the competition events [9].

Acceleration testing with the snowmobile in the stock configuration was conducted to serve as a baseline. Subsequent tests were compared to measure any changes in performance. Individual runs were five hundred feet long from a standing start, timed with a stop watch. Three runs were taken with multiple different riders in order to have accurate numbers. Table 3 below shows the acceleration data recorded during testing.

As Table 3 illustrates, the studs accounted for an average of one third of a second reduction for each run. In addition to the acceleration portion of the competition, this modification will also contribute to reduced braking distance and the tendency to slide during cornering.

Rider	Test Number	Time (Stock)	Time (Modified)
1	1	8.12	7.85
	2	7.97	7.7
	3	7.91	7.85
2	1	8.41	7.98
	2	8.24	7.6
	3	8.08	7.54
3	1	8.46	7.98
	2	7.75	7.98
	3	7.85	7.82

Table 3

Rider Comfort

The competition is geared toward the average trail touring rider. In order to produce a good trail snowmobile and one that also performs well enough to excite the typical snowmobile enthusiast can be a difficult task. The modifications made for performance and handling such as the traction products and the race proven F-series chassis sufficiently fulfill the performance for the typical trail snowmobile. In order to accommodate the “non stop all day long” snowmobile enthusiast the team incorporated some aftermarket products to increase the ride ability and comfort.

The team chose to add a Boss seat. This seat is not only six pounds lighter; it is also available in a three inch taller seat. The extra three inches of height as well as the firm structure of the seat allows the rider to retain a more upright seating position. This not only allows quicker transition to the upright riding position, it also narrows near the top to allow easier rider position changes for those unexpected bumps, and corners.

To compliment the new seating position, a handle bar riser one and one-half inches taller than the stock equipment was added to move the bars to a higher position. This position allows the rider to sit comfortably while maintaining better control, and a more aggressive riding position for the performance oriented rider. To compliment rising the handlebars to this new height, a set of Powermadd hand guards were also installed. These guards also reduced the amount of cold winter air coming into direct contact with the riders' hands, while protecting them from the unexpected tree branch or track spray from another snowmobile. These additions combine to increase the comfort, control, and assist the "non-stop all day long" snowmobile enthusiast with a comfortable and enjoyable riding experience.

Modification Cost

The sled was constructed with materials that were readily available and cost effective. For example, direct fuel injection was first considered, but the fuel system components are expensive and many aren't readily available in the United States. The semi-direct fuel injection system developed by the team uses fuel system components such as the injectors, pump, and ignition components that are common automotive technology. These parts were found to be much more cost effective and at the same time easy to attain for building multiple units. Theoretically comparing the two designs, a drastic increase in fuel economy as well as decreased exhaust emissions are accomplished using the semi-direct fuel injection.

Table 4 displays the additional costs associated with modifying a stock F5 snowmobile, to a semi-direct fuel injected snowmobile with a two way catalyst and air injection. A total cost increase of $761.97 or 10 percent was calculated using the competition TICA. Using the competition formula the Minnesota State University, Mankato snowmobile would have a total cost of $8261.97. By comparison, the suggested retail price of a Polaris FST Classic four stroke is $9199.00 [12].

Item	**MSU X Snowmobile**	**2006 Arctic at Sabercat**
Stock with 499 cc Suzuki motor	7500	7500
Electronic modifications	135	
Fuel System modifications	161	
Exhaust system modifications	465.97	
Total =	8261.97	7500
Difference =	761.97	

Table 4

Conclusion

The Minnesota State University, Mankato Clean Snowmobile Challenge team has developed a cost effective semi-direct fuel injected two-stroke cycle engine. It uses easily accessible automotive technology and quality components promising a long lasting, fun, economical and environmentally friendly snowmobile. This along with further development of the fuel and ignition maps, as well as further catalyst research will allow this design to be improved upon.

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