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Development of Clean Snowmobile Technology for the 2006 SAE Clean Snowmobile Challenge

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ABSTRACT

Kettering University's entry for the 2006 Clean Snowmobile challenge utilizes a Polaris FST Switchback. This snowmobile having a two cylinder, four-stroke engine has been modified to run on ethanol (E-85). The student team has designed and built a new exhaust system which features customized catalytic converters to minimize engine out emissions. A number of improvements have been made to the track to reduce friction and diminish noise.

INTRODUCTION

Ever since their development in the mid-1950's, snowmobiles have been used extensively for recreational purposes in the snowbelt states of the US and Canada. In some cases snowmobiles are the main mode of transport available and are used by snowmobilers for work. However snowmobiles are not without their disadvantages as they pollute the environment with noxious emissions and noise. [1]

The environmental hazards of snowmobiles have come under the scanner of environmental protection organizations and the federal government. These hazards are especially of concern to ecologically sensitive areas such as Yellowstone national park along with other national parks where snowmobile use is prevalent. The first action taken to control the use of snowmobiles in the national park system was taken in President Nixon's time. Through an executive order issued by the president, it was directed that snowmobiles be used only if they do not harm the aesthetics and ecology of the park [2].

In more recent times, a record of decision was issued by the National Park Service (NPS) for Yellowstone and Grand Teton national parks along with John D. Rockefeller, Jr. Memorial Parkway that proposed to eliminate the use of snowmobiles from the parks by the winter of 2003-2004, and provide access via a mass transit snow coach system. This record of decision issued in November 2000 was in response to a lawsuit challenging winter use of snowmobiles in the parks. However, this snowcoach rule was temporarily restrained from being enforced by a US District Court in February 2004 on basis of a petition filed by International Snowmobile Manufacturers Association (ISMA).[3]

Currently, parks are operating under a temporary winter use plan which restricts the number of snowmobiles entering the parks per day. All snowmobiles are required to be Best Available Technology (BAT), which are the cleanest and quietest commercially available snowmobiles [4].

The ISMA estimates that over 27 billion dollars worth of economic activity is generated by snowmobiling in the US and Canada. The majority of this money is generated by tourism related activities and the rest by sales of snowmobiles, their spare parts, apparel and accessories [5].Approximately 10 % of the aforementioned amount is directly collected by the state as taxes. In addition to this the snowmobile industry provides employment to thousands of people directly and indirectly. Hence snowmobiling is an important revenue generator especially for rural America, apart from being a winter pastime.

Clearly a blanket ban on snowmobiling is not feasible. But it is equally important to prevent snowmobiles from polluting the environment. Since snowmobiles are used in winter, cold weather conditions can worsen the adverse environmental effects [6]. To counter this US EPA has mandated a three phase reduction of snowmobile emissions. This requires a 30 % reduction by 2006, 50 % reduction by 2010 and a 70 % reduction by 2012. Moreover there has been a gradual shift towards four stroke snowmobiles from the manufacturers. Four Stroke engines being inherently cleaner burning and quieter have helped to bring down the emissions considerably.

The purpose of this paper is therefore to document efforts of the student design team towards building a cleaner and quieter snowmobile using technologies and innovative methods which can be applied in the real world with a minimal increase in cost. This is the main idea behind the Clean Snowmobile Challenge (CSC) organized by the Society of Automotive Engineers (SAE).

DESIGN OBJECTIVES

The Kettering University team chose to implement a new chassis and engine in order to meet the stringent 2012 EPA regulations. The team chose to focus their efforts on the following areas:

- Performance Modifications
- Noise Reduction
- Emissions Reduction
- Maintain Durability
- Rider Comfort
- Cost Effectiveness
- Rider Safety

PERFORMANCE MODIFICATIONS

After researching the market of commercially available snowmobiles produced in the last five years, the team chose the Polaris FST Switchback as the basis for the design. The team strived to improve noise and emissions while maintaining or improving the stock performance of the sled.

ENGINE – The snowmobile came factory equipped with a four stroke, two cylinder, 750cc, turbo-charged engine. Given the robust, lightweight design of the engine and the limited space in the engine compartment, the team chose to utilize the stock engine and modify it for use with ethanol (E-85) to improve power and emissions.

Table 1. Snowmobile specifications. [7]

Displacement:	749 CC
Configuration:	Parallel Twin Cylinder
Block Material:	Aluminum
Cam system:	8 Valve-DOHC
Ignition:	Coil on plug
Valves per cylinder:	Four
Compression ratio:	9.0:1
Bore in/mm:	3.45/85
Stroke in/mm:	2.60/66
Aspiration:	Turbocharged
Engine Control System:	Bosch M7.4.4
Snowmobile Weight:	268 kg (590 lb)
Front Suspension Travel	25.2 cm (9.92 in)
Rear Suspension Travel	33 cm (13 in)
Track Length	366 cm (144 in)

POWER – The engine had a published power rating of 135 hp (100 kW) although initial testing showed peak power numbers of only 110 hp (82 kW). The difference in power was attributed to the snowmobile being a prototype which was not tuned to production standards and issues of preload on the internal waste gate of the turbocharger. Upon further investigation, the team also found the snowmobile to have a built in safety feature which caused the rev limiter to engage at a lower engine speed when the track was not moving. Due to the use of an engine dynamometer, the primary and secondary clutches were removed. Therefore during dynamometer testing, the engine never produced peak horsepower. After switching to E-85 power increased to 120 hp (89 kW).

FUEL SELECTION – With prices of gasoline climbing at record setting paces, the demand for alternative fuels is immense. Flex fuel vehicles (with the ability to run gasoline or ethanol) have comprised a large portion of vehicles being sold in the United States. According to a report from the U.S. Energy Information Administration (EIA) more than 4 million flex fuel vehicles were operating in the U.S. in 2002. [8] With such increases in alternative fuel usage in the auto industry, the team chose to implement ethanol (E-85) into this year's snowmobile.

Ethanol has been used in racing for years because of its ability to increase engine mean effective pressure, in turn, increasing torque and horsepower. With the addition of fuel injection over the last 20 years, many vehicles made use of an exhaust gas oxygen (EGO) sensor in an attempt to make air to fuel intake mixtures as close to a perfect stoichiometric ratio as possible. The stoichiometric air to fuel ratio of E-85 is lower than that of gasoline as shown in table 2.

Table 2. Fuel Properties. [9]

Physical Fuel Properties			
	Gasoline - Regular Unleaded	**Ethanol**	**E-85**
Formulation	C_4 TO C_{12} H/C-chains	C_2H_5OH	85% ethanol (by volume) 15% gasoline (by volume)
Average Analysis (%mass)	C: 85-88 H: 12-15	C: 52 H: 13 O: 35	C: 57 H: 13 O: 30
Octane - R+M/2	87	98-100	96
Lower Heating Value KJ/Kg (Btu/lb$_m$)	43,000 (18,500)	26,750 (11,500)	29,080 (12,500)
Lower Heating Value - KJ/liter (Btu/gal)	32,250 (115,700)	21,240 (76,200)	22,830 (81,900)
Heat of Vaporization - KJ/Kg (Btu/ lb$_m$)	330-400 (140-170)	842-930 (362-400)	812 (349)
Stoichiometric A/F (mass)	14.7	9	10
Conductivity - mhos/cm	$1x10^{-14}$	$1.35x10^{-9}$	-

With a lower stoichiometric ratio, engines operating on E-85 use approximately 1.48 times more fuel for the same amount of air. When looking at the amount of energy released by combustion, 1.4 times more E85 is required to obtain the energy of gasoline on a volume basis. Therefore, burning ethanol at the stoichiometric ratio creates a 7% increase in power [9]. The added benefit of Ethanol allowed the team to increase engine brake power output.

FUEL PLUMBING AND SUPPLY - With the addition of E-85 fuel supply became an issue of paramount importance. Although typical pump gas contains 10% ethanol, many standard fuel components will not stand up to ethanol mixtures in the range of 85% necessary for this application.

The stock snowmobile came equipped with an in-tank fuel pump. Problems arose when attempting to place a quick disconnect prior to the pump for emissions testing. To solve the issue an external in-line fuel pump was utilized. At the time of fabrication, no in-line fuel pumps could be found with E-85 compatibility. Although popular belief surrounded the idea that pumps could not handle E-85 due to the corrosive nature of the alcohol, the team found the most problems with the increased conductivity of the fluid when compared to gasoline. Ethanol is approximately 135,000 times more conductive than gasoline [9]. The issue is compounded when using an in-line fuel pump as the fuel is passed through the pumps motor and circuitry. In order to create a pump for use with E-85 the internals had to be replaced with those of an in tank pump which was E-85 compatible.

The stock fuel filter made use of a paper element to eliminate dirt and particles in the supply fuel. With the increased flow required for E-85, the team chose to go with a more efficient 35 micron sintered bronze filter as shown in figure 1.

Figure 1. Sintered Bronze Fuel Filter.

An E-85 compatible adjustable fuel pressure regulator with gauge was also utilized. The regulator allowed quick, accurate adjustment to fuel pressure.

A synthetic rubber hose reinforced by a full coverage interior braided fabric sheath (figure 2) was chosen to plumb fuel lines.

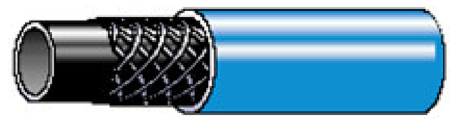

Figure 2. Synthetic Rubber Fuel Line. [4]

The hose was robust as it was rated to handle pressure in excess of 1724 kPa (250 psi). Many professional alcohol racing teams have adopted this hose for fuel plumbing applications. [10] Specialized Army Navy (AN) pressure fittings made specific to the synthetic hose were utilized to connect various fuel components.

Since more fuel was consumed due to the difference in stoichiometric fuel ratios, problems arose with carrying enough fuel to complete the 161 km (100 mile) endurance run. Based on early dynamometer runs, fuel economy with E-85 was estimated to be 4.656 km/l (11 miles per gallon). The stock fuel tank capacity was measured to be only 35 liters (9.2 gallons). The current tank would only give the snowmobile a range of 161.4 km (101 miles). With fuel economy being a highly non-linear function based upon conditions and driver input, the team choose to fabricate a custom tank (figure 3) in order to assure a range of at least 161 km (100 miles) under most trail riding conditions.

Figure 3. Custom Fuel Tank.

The fuel tank allows the snowmobile to carry an additional 7.56 liters (2 gallons) of fuel while maintaining the snowmobile’s sleek look. The new tank ties directly into the original tank utilizing three hoses to function as one unit. The tank was constructed out of 1.65 mm (0.065 in) thick 6061 aluminum. The team placed samples of the aluminum in a solution of E-85 to monitor degradation and saw no noticeable effects to either the material or the solution after a 2 week period. To assure compatibility, the team acquired a chemical tank coating specifically designed to prevent material corrosion when in contact with alcohol fuels.

Testing was conducted to assure E-85 compatibility of stock fuel plumbing components. Samples were taken from injector seals, fuel rail, fuel tank, and in-tank pickup. Overall size, thickness, color and surface texture were recorded. The samples were placed in a solution of E-85 and sealed to avoid evaporation. After two weeks, the samples were removed and checked once again for overall size, thickness, color and surface texture. No effects of degradation by E-85 were observed.

Typical gasoline in the state of Michigan contains a 10% ethanol mixture with some states having mixtures as high as 20% ethanol. With the change in fuel blends across the United States, manufacturers have been forced to address the issue of ethanol compatibility even if they are not marketing their vehicles to run on E-85.

ENGINE CONTROL UNIT (ECU) – The snowmobile was factory equipped with a Bosch M7.4.4 engine control unit (ECU) with closed loop wide band oxygen sensor feedback. Closed loop engine control allows the ECU to monitor exhaust gases and make adjustments to the intake air to fuel mixture. Mixtures were adjusted at each speed and load point to reduce engine out emissions while maintaining fuel economy by avoiding excessively rich situations. The ECU uses manifold absolute pressure (MAP) and engine speed to predict spark timing and fuel injector pulse width. This control scheme allowed more adjustability than other available schemes such as throttle position versus engine speed.

The team had multiple exhaust designs to implement on the snowmobile, with each having a different back pressure. This would cause the motor to consume a different amount of intake air at the same engine speed and throttle position. Utilizing the engine MAP sensor for calibration allowed such exhaust manifold changes to be made without recalibration.

With the difference in fuel characteristics as displayed in table 1, optimizations were made for E-85 use in the snowmobile. Using a water brake dynamometer, the team was able to place varying loads on the snowmobile to simulate trail riding conditions while monitoring power output and air to fuel ratio. From the standpoint of the oxygen sensor, a complete burn of the stoichiometric mix of any ethanol blend fuel will result in the same oxygen content in the exhaust stream as would be seen by gasoline. Since the octane rating (resistance to pre-combustion) of E-85 is higher (96) than that of regular gasoline (87), spark timing could be safely advanced before encountering a knock condition.

As previously mentioned, the amount of fuel burned per engine cycle increases with the use of E-85. In order to increase fuel delivery one must either increase the injector pulse width, increase fuel pressure, or increase density. [11] Since the stock supplied injectors (400 g/min; 53 lb/hr) were already running at the upper limit of their duty cycle, increasing pulse width was not an option. The density of ethanol 773 kg/m^3; 1.50 slugs/ft^3) is slightly greater than that of gasoline (680 kg/m^3; 1.32 slugs/ft^3) but not enough to provide the mass of fuel required using the stock injectors and fuel pressure. Calculations were performed to find the pressure necessary to provide adequate fuel delivery with several different injector sizes. A list of common injectors with the corresponding pressure needed to operate each was compiled. An injector size was chosen (453 g/min; 60 lb/hr) which made use of a reasonable fuel pressure (64 psi; 441 kPa). The new injectors were slightly longer than the stock injectors and required the fuel rail to be modified.

While running the engine on the dynamometer, several air to fuel mixtures were tested to find the optimal range for best brake specific fuel consumption and engine out emissions.

GUAGES – In order to make accurate adjustments to the ECU, engine monitoring became important. The team chose to implement engine oil temperature, engine oil pressure, intake boost pressure, and lambda gauges to the snowmobile. Lambda is a measure of the actual air to fuel ratio divided by the theoretical stoichiometric ratio. Under perfect conditions the lambda meter would read a value of 1 with richer mixtures reading less than one and leaner mixtures reading higher than 1. Addition of the lambda meter required addition of another wide band oxygen sensor into the exhaust stream. Although the cost was increased, the team felt the addition was justified based on the valuable feedback information received.

TURBOCHARGER – The stock engine came equipped with a turbocharger which was utilized to increase intake MAP. The turbocharger makes use of an internal waste gate system allowing the exhaust gasses to bypass the turbocharger to prevent excessive turbine shaft speeds. In order to adjust the pressure at which the waste gate opens, two different boost valves were tried. A mechanical boost valve allowed quick adjustment of boost with the turn of a screw, but the team found more success while using an electronically controlled boost valve run by the ECU. With the use of an electronically controlled boost valve, the team was also able to adjust the intake manifold pressure at various conditions for improved power while maintaining fuel economy.

COLD START CHARACTERISTICS – The heat of vaporization of E-85 is much higher than that of gasoline as shown in table 1, which causes problems when addressing cold starting. Ethanol will not form air to fuel vapor mixtures suitable for combustion at temperatures below 11^0 C. For this reason gasoline is added to the fuel mixture to aid in cold starting. Mixtures of ethanol are adjusted seasonally to provide more gasoline during months of cold temperatures.

Several team affiliates have experimented with heating intake air and fuel supply, both proved little to no advantage with cold starting. The team chose to use cold start enrichments to give the engine more fuel and in turn more gasoline during a cold starting event. Several cold start enrichments were implemented and tested to find the optimum enrichment for E-85.

CHASSIS – In an attempt to improve snowmobile design for riders in mountainous and deep snow regions, the team chose to optimize a long track chassis. The stock chassis did not have a steel supported front bumper structure to allow suspending of the front portion of the snowmobile necessary to pass technical inspection. A new front bumper was fabricated and tied into the existing chassis. The new bumper provides added strength while maintaining the overall aesthetic appeal of the snowmobile.

TRACK AND SUSPENSION - The track utilized by the snowmobile was longer (366 cm, 144 in) than most trail snowmobiles. The extended track length allows more of the track to be in contact with the ground at any given time. More contact area creates less slippage which results in higher efficiency. To further reduce track slippage carbide traction studs were utilized as shown in figure 4.

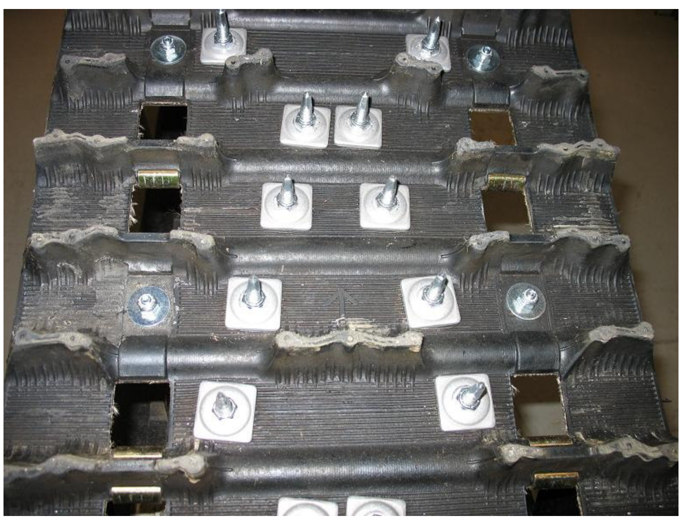

Figure 4. Traction Studs and wear plates.

Studs were placed with 2 in each bar in a repeating “V” pattern between the track clips to optimize traction. Each “V” was slightly offset from the previous to prevent any studs from running in the groove cut by prior studs.

Typical snowmobile tracks have open windows in each track bar to provide snow to access the slide system. The track chosen for competition closes each third window as shown in figure 4. This causes increased heat and friction as the track moves over the slide system. To reduce friction, steel wear plates were placed in each closed window.

To further reduce friction and increase fuel economy, slides with Teflon composite inserts were utilized as shown in figure 5.

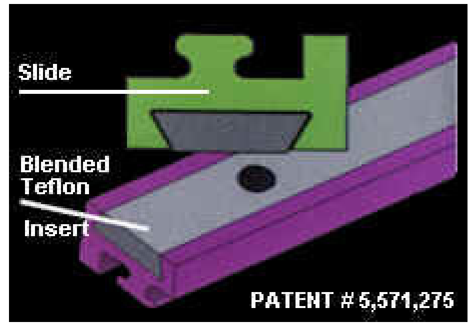

Figure 5. Composite Teflon Insert Slides. [12]

Regular snowmobile slides have a melting point of 149-163^{0}C (300-325ºF). Under conditions of hard or little snow, slide operating temperatures can exceed 163^{0}C (325ºF). For this reason occasionally slides stick. The Teflon inserts utilized on the new slides have a melting temperature above 372^{0}C (702ºF) allowing the slides to remain rigid and reduce friction. [12]

CONTINUOUSLY VARIABLE TRANSMISSION (CVT) – The CVT system used in most snowmobiles has long been criticized for efficiency loss in the form of belt slippage and heat. When looking at the belt squeezing force in a typical clutch, there is insufficient force in the primary or drive clutch at high gear ratios (low engine speeds) as shown by figure 6.

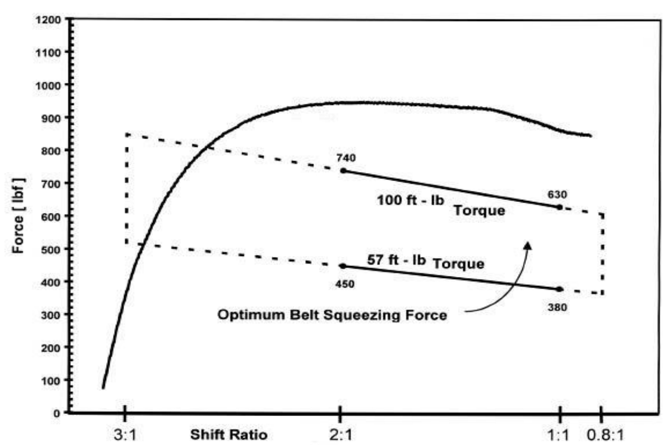

Figure 6. Belt Squeezing Force Chart of Typical Snowmobile. [13]

The primary clutch makes use of 3 weights which convert centrifugal force to belt squeezing and up shift forces as the engine output shaft rotates. Figure 7 shows several positions of a clutch weight as engine speed is increased.

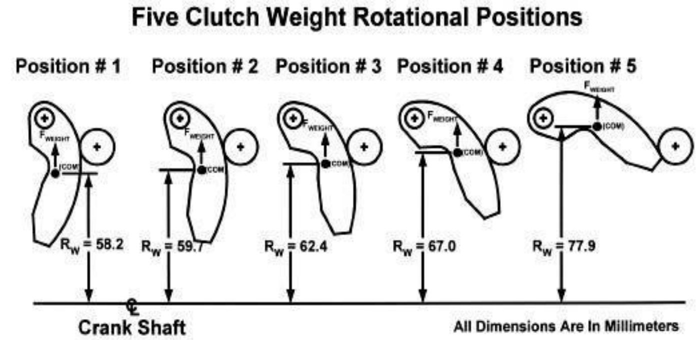

Figure 7. Clutch Weight Rotational Positions. [13]

At low engine speeds the weight remains in a retracted position with the center of mass (COM) creating a force that acts mainly on the weight pivot pin. As engine speed increases the weight begins to "fly out" creating a moment about the weight pivot pin. This moment is opposed by the roller pin which causes the sheave to move. As the sheave moves in, a force is exerted on the belt. Depending on sheave angles this force is divided into belt squeezing and up shifting forces as shown in figure 8.

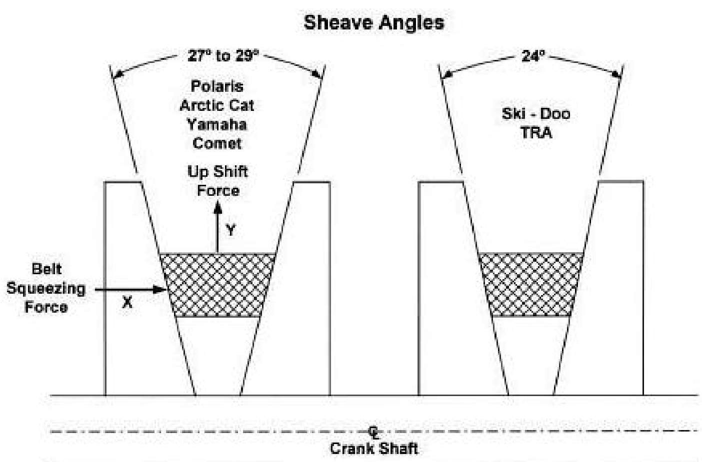

Figure 8. Belt Shifting and Squeezing Forces Based on Sheave Angles. [13]

In order to increase belt squeezing forces at lower engine speeds, an additional mass was added with a different COM which creates a larger moment at lower engine speeds as shown by figure 9.

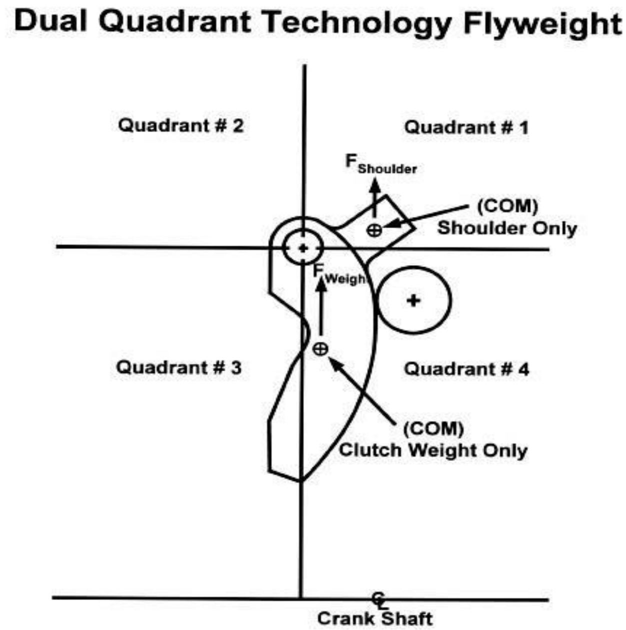

Figure 9. Clutch Weight with Added Shoulder. [13]

The added belt squeezing force with use of the new HC54-7 clutch weights can be seen in figure 10.

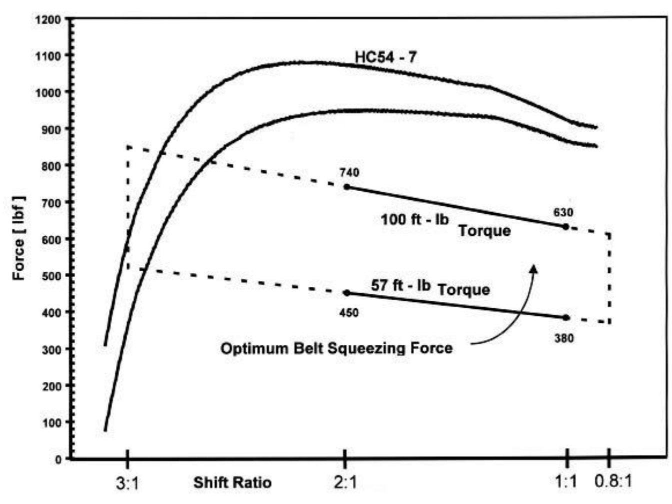

Figure 10. Belt Squeezing Force with New Clutch Weights. [13]

NOISE REDUCTION

Noise is defined as unwanted sound according to Tenneco Automotive's Exhaust Systems Acoustics manual, sound is an airborne wave-phenomenon that gives rise to the sensation of hearing. [14] Snowmobiles have a tendency to emit sound through various sources such as the track, exhaust, engine, and intake. Steps were taken to determine overall noise output of the stock snowmobile.

INITIAL TESTING – To obtain sound information pass by testing was performed. Pass-by noise is a combination of all the noise sources present while the snowmobile passes the microphone. With the help of FEV's ½" pre-polarized condenser microphone, the team set up a course according to the SAE standard for snowmobile noise testing (J192). The course layout is shown in Figure 11. [14]

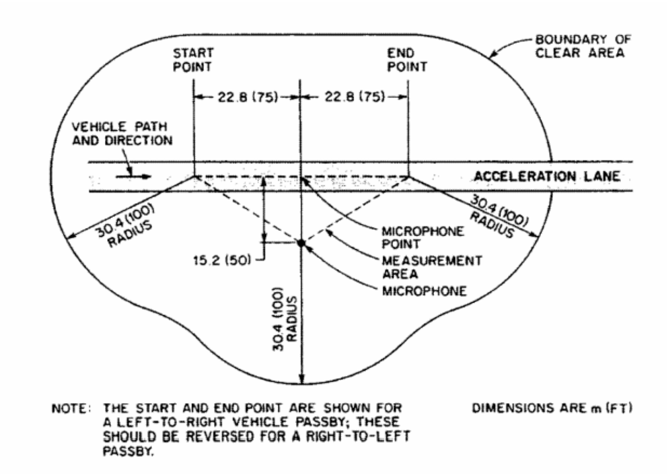

Figure 11. SAE J192 Microphone Locations. [15]

SAE Test J192 specifies that the snowmobile must enter the measurement area at 15 mph. Upon entering the measurement area the rider must hold the throttle wide open and accelerate for the entire 150 ft. while sound levels are recorded. Three passes in both directions were taken then averaged together. Results from both directions reported in the form of dB(A) are shown in figures 12 and 13.

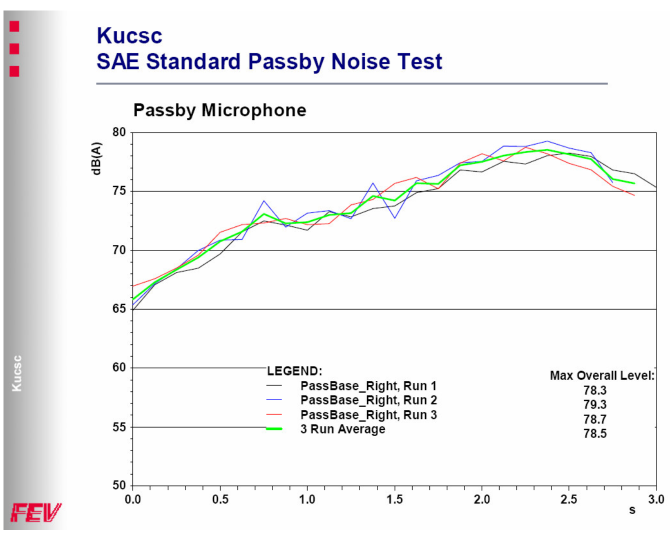

Figure 12. Noise Test, Right side.

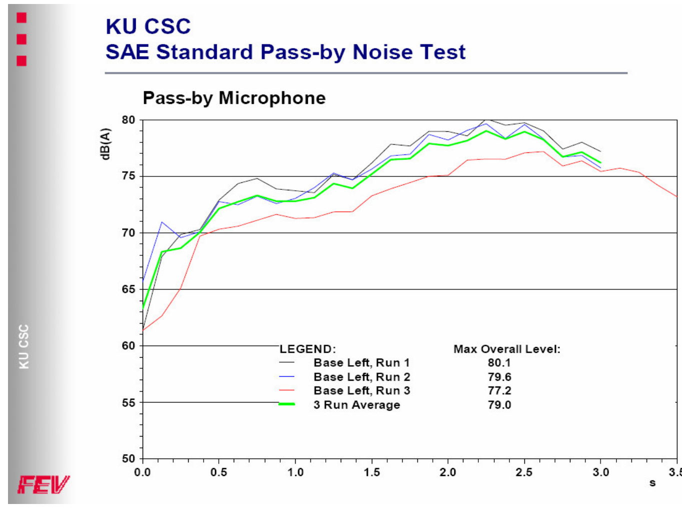

Figure 13. Noise Test, Left Side.

The team also conducted testing to discover what affect the number of bogie wheels had on the overall sound level of the snowmobile.

The rear set of bogie wheels were removed and three passes in both directions were made using the J192 test standards. Upon completion, the set of bogie wheels toward the front of the track were removed and the test procedure was run again. The test results are displayed in Figure 14 and Figure 15.

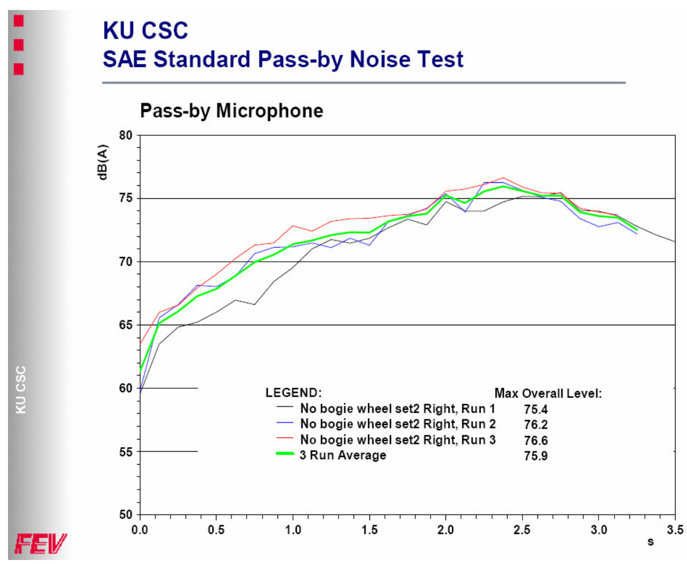

Figure 14. Bogie wheels removed, Right Side.

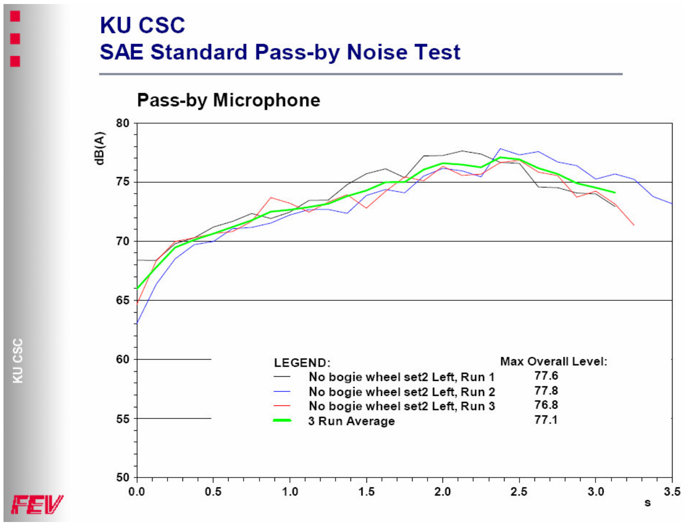

Figure 15. Bogie wheels removed, Left side.

Pass-By Results – Two plots were constructed showing noise levels on both the right and left side of the snowmobile in Figure 12 and Figure 13 respectively. The A-weighted versus time graphs were constructed to determine the peak decibels recorded. Baseline testing showed that the stock snowmobile had an average 78.5 dB(A) on the right side, and 79 dB(A) on the left side.

Upon removal of the rear set of bogie wheels, the average decibel level decreased an average of 1.5 dB(A). Because of the effect on the maximum decibel readings, the team proceeded to remove the front set of bogie wheels. Again a decrease in noise level was observed. On the right side, the peak average decibel reading was 75.9 dB(A), and on the left side was 77.1 dB(A).

MUFFLER – The stock muffler was very heavy and created high back pressure. This muffler was removed in favor of two quieter, lighter mufflers connected in series. The data recorded from the sound tests was used to design custom mufflers according to the frequencies emitted by the snowmobile. The mufflers were mounted under the running board of the snowmobile using rubber grommets to isolate vibration from being amplified by the chassis.

Muffler Design – The muffler design chosen by the team incorporated a combination of one carbon fiber ovulate shell diffusing muffler, and one absorption muffler with fiberglass packing. (Figure 16)

Figure 16. Carbon Fiber Muffler.

Based on the frequency at which noise was emitted by the snowmobile, acoustic velocity was calculated. Knowing the cross sectional area of the ovulate mufflers, the length was cut to create a volume equivalent to 9 times that of engine displacement. [16]

To find the reduction in dB of a diffusing silencer muffler, physical and material characteristics were used with Equation 1.

$$\beta_{tr}(L_b, d_b, L_1, d_1, L_2, d_2, L_t) := 10\log\left[\left[\frac{\pi \cdot d_b \cdot L_b}{\pi \cdot \left(\frac{d_2}{2}\right)^2} \cdot \frac{\sin(\kappa \cdot L_b) \cdot \sin(\kappa \cdot L_t)}{\cos(\kappa \cdot L_1) \cdot \cos(\kappa \cdot L_2)}\right]^2\right]$$

Equation 1. Muffler Sound Reduction. [16]

The calculated drop in dB for the diffusing silencer muffler was found to be 9.87 dB.

The absorption silencer muffler was also investigated by utilizing Math Cad and a variation of Equation 1. The calculated drop in dB for the absorption silencer muffler was found to be 11.03 dB.

MECHANICAL NOISE – In order to test for mechanical noise emitted, the snowmobile was placed on a stationary warm-up stand and ran at several different speeds. Sound readings were taken with a decibel meter at different points around the snowmobile. Raised noise levels were found coming from the engine compartment and the tunnel.

In order to make the snowmobile as quiet as possible, supplemental sound deadening material was added. A thick sound deadening paint was spread on the underside of the tunnel to reduce vibrations. On the underside of the hood the team installed foam specifically designed to absorb noise while being able to stand up to the water and under hood heat both typical in many snowmobile applications.

EMISSIONS REDUCTION

The strategy used to reduce emissions of the snowmobile involved converting the four-stroke to run on E-85 through fuel system and ECU modifications. In addition, 2 custom catalytic converters were built for reduction of CO, HC, and NOx while burning E85.

INITIAL TESTING – The team tested engine out emissions while running the snowmobile on a water brake dynamometer. The dynamometer test matrix was set up to replicate the 5 mode emission test cycle currently under consideration by the EPA and discussed in SAE Paper No. 982017 [15]. The test matrix is shown below in table 3.

Table 3. Emissions Test Procedure. [17]

5-Mode Emissions Test (SAE Paper No.982017)					
Mode	**1**	**2**	**3**	**4**	**5**
Speed, %	100	85	75	65	Idle
Torque, %	100	51	33	19	0
Wt. Factor, %	12	27	25	31	5

A sampling tube was placed in the exhaust stream and emissions were measured using a Horiba Mexa-7100 Exhaust Gas Analyzer. The baseline emissions were recorded and are shown in table 4 below.

Table 4. Baseline Emissions using Gasoline

Brake specific mass emissions rate (g/kW-hr)	
Hydrocarbons (HC)	4.1051
Carbon Monoxide (CO)	157.615
Nitrous Oxides (NOx)	3.770

After the baseline emission test was complete, the team tested E-85 using a quick calibration to obtain rough emissions numbers. The data acquired was used to design a custom catalytic converter tuned to minimize emissions.

The catalyst “brick” provided by Engelhard Corporation was a metallic substrate with cell density of 300 cells per square inch measuring 90 mm (3.54 in.) in diameter and 75 mm (2.95 in.) long. The small catalyst with added radiant heat shielding easily mounted in place of the stock muffler. The packing ratio of the precious metals within the substrate was not disclosed by the manufacturer as it was deemed proprietary information.

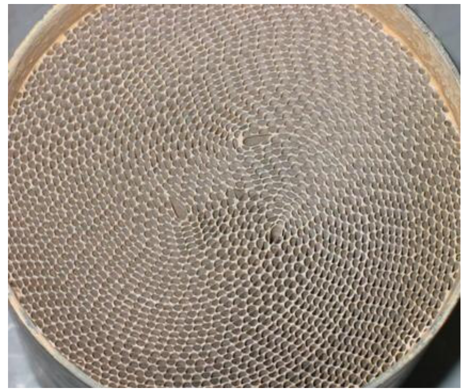

Figure 17. Catalytic Converter Cross Sectional View.

E-85 typically comes from renewable resources such as corn which reduces net greenhouse gas emissions drastically [9]. Argonne National Laboratory estimated that burning 1 gallon of E-85 reduced greenhouse gas emissions by 16-28% when compared to gasoline [16]. E-85 is also safer to transport as it is water soluble and biodegradable.

Data from a snowmobile powered by a four stroke, spark ignited engine modified to operate using blends up to E85 is shown in figure 18 [9, 20].

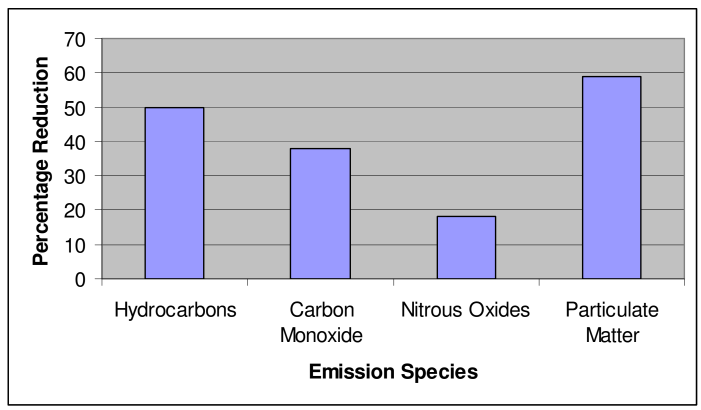

Figure 18. Reduction in emissions from a snowmobile running on E-85. [9]

As seen by the graph, snowmobiles have experienced reductions in emission species as high as 80% by switching to E-85.

The test results from an automotive engine tested by the EPA, optimized to run on E-85 are shown in figure 18.

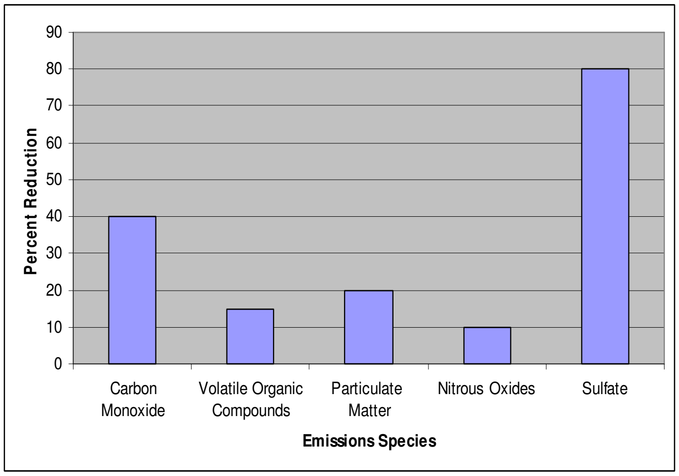

Figure 19. Reduction in emissions when using E85 compared to E10. [9, 19]

At the time of writing this paper, the exhaust gas analyzer was not functioning properly so final emissions numbers with catalytic converters were unavailable but the team believes that numbers will surpass those shown in figure 18 due to the combination of E-85 fuel and catalytic exhaust after treatment.

DURABILITY

The stock structural integrity of the snowmobile was maintained through out the design process. The chassis was made more durable than stock by addition of strategically placed reinforcing members. Several plastic and composite materials were removed in favor of more robust steel and aluminum structures.

By maintaining much of the stock snowmobile and adjusting certain characteristics to suit the needs of the clean snowmobile competition, the team was able to field a reliable snowmobile.

RIDER COMFORT

Rider comfort became an important issue when selecting a chassis for the competition. The stock chassis came equipped with adjustable handle bars to allow for relaxed trail riding or aggressive performance riding. The handle bars made use of bent tips to allow leaning into corners when riding aggressively. A digital display allows the rider to easily scroll though multiple displays to view real time snowmobile information. In order to have complete engine information, several gauge pods were secured to the dash in areas of easy viewing. The snowmobile also made use of an easily adjustable headlight through a turn of a knob.

The front and rear suspension were calibrated to allow comfortable trail riding while maintaining aggressive performance capabilities without bottoming the suspension against the tunnel.

COST EFFECTIVENESS

Throughout the design process, attempts were made to keep solutions low cost. By thoroughly investigating the market of commercially available snowmobiles, a snowmobile was selected which provided the team with many options for calibration and optimization. Although the team did not acquire out of pocket expense for the items already implemented on the snowmobile, the items were still added to the Technology Implementation Cost Assessment (TICA) based on the competition rules.

The TICA is designed to analyze the cost required to implement the team's design on the snowmobile if it were mass produced. This year's competition entry totaled $1,546. However much of the cost was related to items which came standard on the stock snowmobile. To implement the team's design strategy to the stock FST Switchback the increased cost in production would total $256.

When dealing with E-85 much attention was paid to material compatibility and robustness. At several points through the design, the team was confronted with the choice of using cheaper fuel components which would work for the competition but would never last in real world applications or more expensive E-85 certified components. Although several items such as a high pressure fuel pump, lines, regulator and fuel rail increased the cost significantly, the team chose to stand behind engineering ethics of what would be implemented in real world production situations.

The addition of another wide band sensor for the lambda meter also increased the TICA by $110. This additional cost would not be necessary in real world production as one sensor could be used to control engine air to fuel mixtures and display real time values.

The external alternator which comes with the stock snowmobile package also causes the TICA to elevate. Although, based on the TICA, there is no implementation cost for the use of a stator charging system utilized by most production snowmobiles. Once again this situation leads to a higher TICA value for technology already existent on the snowmobile which would not be as significant in production application.

The price of implementation was compared to the actual gain for purchasing a catalyst. The team decided that based upon the significant reduction in emissions the catalyst would provide, the overall emissions gain outweighed the cost.

The stock snowmobile utilized a Bosch ECU to allow precise control over snowmobile parameters. When considering the physical combustion process of most engines is upwards of 97% efficient, attempting to improve upon the 3% exhaust gas residual requires precise engine controls such as that provided by the ECU. Therefore, the team deemed the cost necessary to achieve a cleaner, quieter, more fuel efficient snowmobile.

RIDER SAFETY

The clutch of the snowmobile rotates at speeds in excess of 8000 revolutions per minute which can cause serious damage in the event of a blown belt or blown clutch. To protect the rider, the team created a clutch cover that encloses both the primary (drive) and secondary (driven) clutches. The guard was covered with Kevlar belting used as explosion containment on drag racing cars per competition rules. [17]

The long chassis of the snowmobile caused the rear snow flap to be suspended high off the ground as compared to other snowmobiles. In the event of a traction stud coming lose at high speeds, riders following behind are put in danger. To address the issue a snow flap extension was built from aluminum plate to allow the snow flap to contact the ground while a rider is on the snowmobile.

The battery was placed inside a sealed battery box constructed of aluminum to avoid acid spills. The aluminum was then coated with a non-conductive material to avoid arcing across the battery terminals.

CONCLUSIONS

The goal of the team was to create a snowmobile to run clean, quiet, and fuel efficient without compromising performance. Utilizing a combination of optimized fuel injection, E-85 fuel supply, catalytic converters, and a customized exhaust system the team met each of these goals.

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