Development of the Kettering University Snowmobile for the 2009 SAE Clean Snowmobile Challenge

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ABSTRACT

Clean snowmobile technology has been developed using methods which can be applied in the real world with a minimal increase in cost. Specifically, a commercially available snowmobile using a two cylinder, four-stroke engine has been modified to run on a range of ethanol blended fuels. Additionally, a new exhaust system which features customized catalytic converters and mufflers to minimize engine noise and exhaust emissions has been developed. Finally, a number of additional improvements have been made to the track to reduce friction and diminish noise. The results of these efforts include emissions reductions of 94% when compared with snowmobiles operating at the 2012 U.S. Federal requirements.

INTRODUCTION

The first snowmobile was developed in 1935 and was capable of carrying 12 people. The introduction of the snowmobile meant that emergency medical personnel could get to those in need of care even during heavy snowfall. This often meant the difference between life and death. Snowmobiling as a recreation did not gain popularity until the late-1950s. Within a decade, dozens of manufacturers began producing snowmobiles. Only four primary manufacturers remain today, with global industry sales of approximately 164,000 snowmobiles annually [1].

Due to rising concern pertaining to the noise and exhaust emissions of snowmobiles, they have come under increasing scrutiny by the federal government. As snowmobiles are used in the winter season, the environmental impacts are the greatest due to colder denser air. The pollutants passed through the tailpipe into the cold, dense ambient air will not disperse as rapidly as they would in warmer conditions. 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 International Snowmobile Manufacturers Association (ISMA) estimates that snowmobiling generates over 29 billion US dollars (USD) of economic activity annually in the world economy. New snowmobile sales account for about 1.2 billion USD, while the remainder is accounted for by apparel and accessories, registrations, permits, tourism and spare parts. The snowmobiling industry accounts for over 90,000 fulltime jobs and nearly 2,200 dealerships [1].

Considering the economic impact in troubled times such as these, a blanket ban on snowmobiling is not a feasible option. The Clean Snowmobile Challenge (CSC), which is part of the collegiate design series created by the Society of Automotive Engineers (SAE), was created to challenge students to reduce the impact of snowmobiles in environmentally sensitive areas.

Currently, U. S. national 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. Further, 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. The specific limits are shown below in Table 1.

Table 1 Exhaust Emission Standards for Snowmobiles [2]

	Phase In	Emissions (g/kW-hr)		
Model Year	**% of sales**	**HC**	**HC+NOx**	**CO**
2006	50	100	-	275
2007-2009	100	100	-	275
2010-2011	100	75	-	275
2012 & later	100	75	90	275

This has forced a rapid change upon manufacturers; they have responded by further developing two-stroke technology and shifting to four-stroke engines in place of the typical two-stroke engines. While the two-stroke engine offers the advantage in terms of weight and power output compared to a four-stroke engine, the disadvantage is that it emits much higher levels of exhaust pollutants. The four-stroke engine is also quieter, and more fuel efficient when compared with an equivalent two-stroke engine. Nonetheless, the four-stroke engine weight and volume disadvantage is a substantial challenge to overcome in a lightweight vehicle like a snowmobile.

Kettering University has chosen to use four-stroke engine technology reasoning that this technology offers the best long-term potential to meet exhaust and noise emissions levels.

DESIGN OBJECTIVES

The design team was tasked with reducing exhaust emissions to levels which are below the 2012 standard. Additionally, noise levels were to be reduced to below the noise mandates of 78 dB(A). Achieving these goals would be a hollow victory if the cost and performance of the snowmobile were severely compromised. Snowmobiling is, after all, a recreational sport; thus the snowmobile must remain fun to drive and cost effective.

Additionally, in accordance with competition mandates, the snowmobile will use flex fuel technology to allow it to operate on a wide range of ethanol blended fuels. The use of ethanol blends will have an added benefit of allowing the snowmobile to more easily meet emissions standards and become even more environmentally friendly.

In order to meet these objectives, a commercially available 2007 Yamaha Phazer GT was modified for the 2009 CSC competition.

SYSTEM MODIFICATIONS

The base snowmobile was chosen because it came with a four-stroke engine, under-seat exhaust system, and it was lightweight. The team focused on reducing emissions and noise, while maintaining the performance, comfort, safety and durability of the sled.

ENGINE

The Yamaha Phazer GT is equipped with a 499cc four-stroke naturally aspirated two-cylinder engine (see Table 2). Given the lightweight design of this engine and limited space in the engine compartment, the original engine was retained and modified for use with ethanol blended fuels to improve power and emissions.

In original form the Yamaha Phazer GT was rated to produce 80 hp (60 kW) at 11,000 rpm while operating on gasoline. Initial dynamometer testing revealed a power output of 70 bhp (52 kW) at 10,500 rpm. The team did not run the engine to its maximum engine speed due to concerns with the ability of the dynamometer to hold steady state at high speeds.

Table 2 Yamaha Phazer GT Specifications

Displacement:	499 CC
Configuration:	Twin Cylinder
Block Material:	Aluminum
Cam system:	DOHC
Ignition:	Coil on plug
Valves per cylinder:	Three
Compression ratio:	12.4:1
Bore in/mm:	3.03/77
Stroke in/mm:	2.11/53.6
Aspiration:	Normal
Engine Control System:	BigStuff3 & Mitsubishi
Snowmobile Weight:	221 kg (487 lb)
Front Suspension Travel	229 mm (9 in)
Rear Suspension Travel	409 mm (13.9 in)
Track Length	3070 mm (121 in)

FUEL SELECTION

Competition requirements outlined that the snowmobile must be able to run on a range of ethanol blended fuels in a flex fuel mode. The use of ethanol provides a benefit of improved emissions. Since ethanol is an oxygenated molecule, it provides cleaner combustion, reducing the formation of both carbon monoxide and unburned hydrocarbons.

Having been the first organization to demonstrate operation using E85 during testing at Southwest Research Institute in 2002, Kettering University is well positioned to utilize E85. Results of this and subsequent work are summarized in Figure 1. This work has demonstrated that a switch to E85 or other ethanol blended fuels can yield substantial reductions in exhaust emissions.

Ethanol blended fuels have several advantages over gasoline in terms of power output and emissions production. In comparison to pump gasoline, E85 is safer to transport since alcohol is water soluble and biodegradable. Further, ethanol is made from renewable resources such as corn or sugarcane.

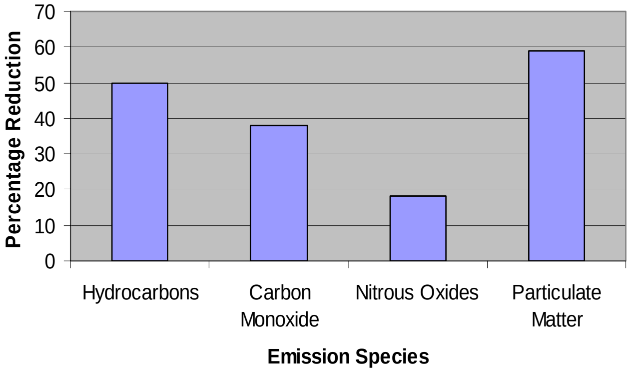

Figure 1 Reduction in Snowmobile Emissions Using E85 as Compared with Gasoline [3]

The energy density of E85 on a volume basis is about 71% of gasoline; therefore, in order to deliver the same power (all other factors being roughly equal), an engine will consume about 1.4 times more E85. This would lead to a reduction in fuel economy, on a miles-per-gallon basis, of about 29%. However, in practice, automobiles have shown only about a 25% reduction [4].

Operating an engine at stoichiometric air-fuel mixtures will produce an increase in power because E85 has a stoichiometric air to fuel ratio of about 10 to 1, whereas that for gasoline is 14.7 to 1. Therefore, by running E85 and assuming similar volumetric efficiencies, more fuel can be delivered to the engine. For the same amount of air as the equivalent gasoline fuelled engine, an engine operating on E85 can use approximately 1.48 times more fuel, while only 1.4 times as much fuel is required to release the same amount of energy. This potentially increases the power and torque output by about 6%. Of course, in practice, many other operating variables can influence the performance. For example, sizing of the fuel injectors can limit upper end performance due to time and fuel flow limitations.

FUEL SYSTEM MODIFICATIONS

Before ethanol blended fuels could be used in the snowmobile several of the standard fuel system components had to be upgraded due to the corrosive nature of ethanol. Further, the fuel system also had to meet the increased volumetric fuel flow rate.

The in-tank fuel pump was replaced with an ethanol compatible, inline external fuel pump with a larger flow rate. The stock paper fuel filter was replaced to accommodate the required increase in fuel flow. An ethanol compatible adjustable fuel pressure regulator with gauge was also installed.

Table 3 Fuel Properties [4]

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	$1x10^{-14}$	$1.35x10^{-9}$	$1.4x10^{-9}$

In the past the Kettering CSC team has sampled fuel system components and performed immersion testing in E85 in order to ensure that they were compatible with the high-blend ethanol fuel. The team recorded the initial condition of these component samples, and then placed them in a solution of E85 and sealed the containers. The samples were examined after a two week soaking period with no visual effects of deterioration observed. They were then returned to the container for a year with still no visible deterioration. Based on this past experience, the team believes that the stock fuel system parts that are retained will be durable in contact with ethanol blended fuels.

The original injectors were running near the upper limit of their pulse-width duty cycle, therefore increasing pulse-width was not an option. In order to enhance the fuel delivery capability to compensate for the increased fuel volume requirement, the original injectors should have been replaced with larger units. Unfortunately, the injectors used were of an unusual design which is not physically compatible with prevailing injector types; therefore over-sized injectors could not be procured. To meet the increased flow demands when using ethanol blended fuels, fuel system pressure was increased. The team increased the fuel system pressure from 290 kPa (42 psi) to a new pressure of 655 kPa (95 psi). This required changing fuel line components to ensure that they withstood the increased pressure. The downside to this approach is that the fuel spray pattern can sometimes change causing wall wetting leading to transient operation problems. Fortunately, this did not occur.

ENGINE CONTROL UNIT

The snowmobile was factory equipped by Yamaha with a Mitsubishi engine control unit (ECU); however there was no way for the team to access and reprogram it. Therefore, a new ECU was needed. Further complicating matters, the cylinders of the Yamaha fire 180° offset, then go through their exhaust and intake strokes and repeat the process, as seen in Figure 2. This uneven firing sequence significantly limited the number options for usable ECU's.

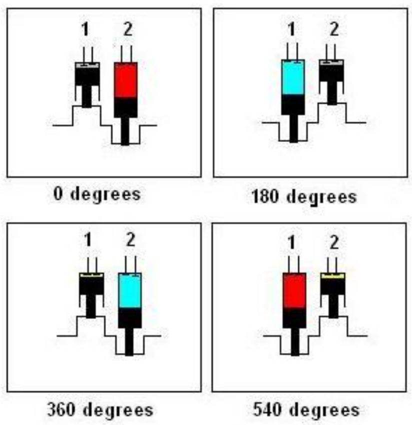

Figure 2 Yamaha 499 cc Four-stroke Engine Cycle

In time, a BigStuff3 (Hartland, MI) ECU with closed loop wide band oxygen sensor feedback and flex fuel adjustment capabilities was chosen. Closed loop engine control allows the ECU to monitor the oxygen content of the exhaust gases and adjust the air/fuel mixture accordingly. The flex fuel adjustment allows the ECU to adjust the engine mapping to best fit the gasoline/ethanol ratio that is present.

The new ECU was not originally designed to control a 2 cylinder, odd firing, engine. The team had to "fool" the ECU into thinking it was controlling cylinders in an eight cylinder engine.

Through the use of the BigStuff3 calibration software, the engine map was adjusted to avoid undesirable, excessively rich mixtures which increase emissions. Maintaining fuel economy based on speed and load conditions with the switch to ethanol blended fuels was also a goal of the new engine calibration. The new ECU also allowed for tuning of the fuel delivery for individual cylinders, which gave the team even greater capabilities in adjusting for improved emissions.

GAUGES

The stock Mitsubishi ECU was retained in order to operate the factory gauge cluster. Any information that a potential rider might need to monitor was provided by this system. All other connections and functions were removed.

COLD START CHARACTERISTICS

As shown in Table 3, the heat required for vaporization of ethanol blended fuels is much higher than that of gasoline. In cold weather starting conditions this presents a problem as ethanol will not vaporize at temperatures below 11°C [4]. Just as gasoline and diesel pump fuel is switched to a winter blend during the colder months, ethanol blended fuels are also adjusted to compensate for colder ambient temperatures. For example, winter blend E85 is a blend of 70% ethanol and 30% gasoline. This is more appropriate for proper vehicle starting and operation of a vehicle during cold winter months. For marketing simplicity, however, this blend is still advertised as E85 [5].

In addition to the use of blends with more gasoline, the team programmed the ECU to adapt for the cold at startup using fuel enrichment. This is done by injecting a greater volume of fuel into the cylinder during a cold start in order to allow enough gasoline into the cylinder to vaporize and initiate combustion. The cold start enrichment levels were determined through testing.

The final change that was made to the snowmobile to improve its cold starting was a switch to "hotter" spark plugs. Through producing a more energetic spark, the plugs were more able to ignite the cold air/fuel mixture and start the engine. As with the enrichment levels, proper plug characteristics were determined through testing.

CHASSIS AND BODY

Chassis modifications were kept to a minimum since the base Phazer was already a relatively light sled with a dry weight of only 221 kg (487.2 lb). Replacement side panels were fabricated (see Figure 3) from glass fiber reinforced plastic (GFRP) to provide clearance for the Kevlar belted aluminum clutch guard and allow for the addition of sound deadening insulation on both sides of the machine. The GFRP panels also had to be fit tight enough to reduce risk of damage from sources such as the ski when the suspension is fully compressed or due to low branches hanging into the trail.

In addition to the GFRP side panels, neoprene rubber side skirts were added to the sides of the track tunnel in order to enclose them and contain some of the noise generated by the track as seen in Figure 4.

Figure 3 Fabrication of Mold Plug for Side Panel

Figure 4 Track Side Skirts

TRACK AND SUSPENSION

The 2007 Yamaha Phazer GT came with a 307 cm (121 inch) track, which performed well enough during testing to forego modifying it with studs or replacing it with a different track.

For the 2008 competition, the forward set of idler wheels in the suspension of the snowmobile had been removed in an attempt to reduce noise. However, it was found that this had only a minimal effect on noise levels and no one was sure if the elimination of the wheels significantly increased drag on the track. To test this, the snowmobile was dragged behind a vehicle while attached to a load cell at speeds of 16 kph (10 mph) and 24 kph (15 mph). Multiple runs were made and averaged both without and with the forward idler wheels. As is shown in Table 4, when the forward idler wheels were put into the suspension, drag was reduced by 20.6% and 29.2% at 16 kph (10 mph) and 24 kph (15 mph) respectively. Although speeds were not increased beyond these levels because of safety concerns, it seems logical that these drag reductions would increase, or at least remain constant, at higher speeds.

Another logical conclusion that can be drawn from the drag testing results is that additional idler wheels would make further reductions in drag. Because of this conclusion, extra idler wheels were added in strategic locations on the suspension. A fourth large idler wheel was added on the rear axle of the suspension. This was intended to reduce drag by maintaining track alignment during operation. Also, two small idler wheels were added at the bend at the front of the suspension rails. These were intended to relieve drag caused by high loads of the track on the hyfax as it comes around the bend. Unfortunately, at the time of publication of this report, drag test data from these added wheels was unavailable.

Table 4 Drag Test Results

	Drag (N/lb_f)			
	16 kph (10 mph)		24 kph (15 mph)	
	With Wheels	Without Wheels	With Wheels	Without Wheels
Trial 1	338 (76)	423 (95)	360 (81)	494 (111)
Trial 2	347 (78)	440 (99)	347 (78)	507 (114)
Average	343 (77)	432 (97)	354 (80)	501 (113)
Delta		89 (20)		147 (33)
Reduction %		20.6%		29.2%

The suspension had a several other slight modifications performed on it in an attempt to further reduce drag and improve ride quality. The stock hyfax were replaced with Hiperfax slides which contain drag-reducing graphite inserts. Also, all shock absorbers were overhauled or replaced by high quality upgraded units. This improved ride quality by reducing sag in the stock shock setup and increased efficiency of the suspension by better damping excess motion and thereby reducing wasted energy.

NOISE REDUCTION

Noise from snowmobiles can be attributed to a variety of different sources, including the engine, intake, exhaust and track. To determine overall noise emissions of the snowmobile the team performed testing as specified by SAE Recommended Practice J192.

INITIAL TESTING

The course layout for the SAE Recommended Practice J192 for snowmobile noise testing is shown Figure 5. Using a ½" pre-polarized condenser microphone from FEV, the team performed pass-by testing. Pass-by noise is the combination of all noise sources present when the snowmobile passes the microphone [6].

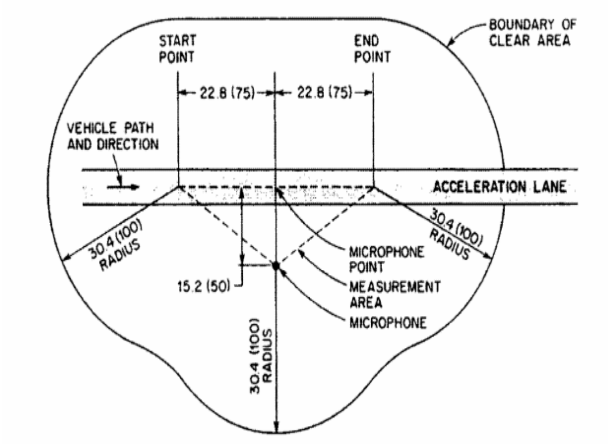

Figure 5 SAE J192 Microphone Locations [6]

To perform the SAE J192 test, the snowmobile must approach the measurement areas at 24 kph (15 mph). At the entrance the rider must hold the throttle wide open and accelerate for 45.6 m (150 feet) while sound levels are recorded. This is performed for three passes in each direction. The results are averaged and both directions are reported in the form of dB(A).

MUFFLERS

The muffler setup presented several opportunities for improvement. The OEM muffler reduced much of the noise caused by the exhaust; however, the addition of a glass-pack muffler in series after the stock one further reduced the exhaust system noise. The exhaust outlet is routed to exhaust into the tunnel housing the track, which was closed off by neoprene rubber side skirts. This allowed free expansion of exhaust gases post-outlet into an enclosed sound isolating area without inducing further backpressure to the system. Noise results from initial testing before modifications were measured at 83 dB(A) on unpacked snow. After modifications the sound was measured at 80 dB(A) on hard packed snow.

EXHAUST ROUTING DESIGN

The goal of the muffler design was to reduce noise from exhaust picked up in pass-by testing. On the Yamaha Phazer GT the space provided by the stock exhaust routing was limited. The exhaust ports exit the back of the engine just in front of where the fuel tank is located. The exhaust primaries in the stock configuration are separate for 53 cm (21 inches) before the collector routed almost straight down the middle of the sled. From the collection point there was only 46 cm (18 inches) before the stock muffler location. Packaging was therefore a major concern in the design with the need to add a catalytic converter in addition to the noise reducing features.

The design for the 2009 competition is an exhaust system comprised of two mufflers in series, as seen in Figure 6. Muffler one is the stock Yamaha muffler unit. The exhaust system exits the stock unit and makes approximately a 180° bend into muffler two which is placed next to the stock Yamaha unit in the tail of the snowmobile. Muffler two is a glass-pack style muffler. After the second muffler unit, the exhaust turns down and dumps into the track area which has been closed off with the side skirts.

Figure 6 Exhaust System Layout

NOISE TESTING

Preliminary pass-by noise testing was performed to determine which systems were contributing to the total noise level. The baseline data showed a high half-order contribution. This was determined to be caused by the uneven firing of the Yamaha engine. This was an unforeseen benefit of the Yamaha engine in terms of noise emissions. The half-order contribution of the engine helps to reduce overall noise levels due to the use of an A-weighting filter. A-weighting attempts to emphasize the frequencies of sound most audible to the human ear. An even firing engine, such as the 750cc turbocharged one in the Polaris FST Kettering used in the 2007 competition contributes a first-order signal to noise emissions. This will contribute a greater amount of noise using A-weighting since it has a higher order frequency contribution, and therefore is not compensated for to the same degree.

A comparison of the noise emissions of each side of the sled was also done. This showed that the CVT side (right side) of the sled contributed a greater degree of sound than that of the opposite side. This was further shown by comparing a run without the factory side panel on the CVT side to the runs with panels as seen in Figure 7.

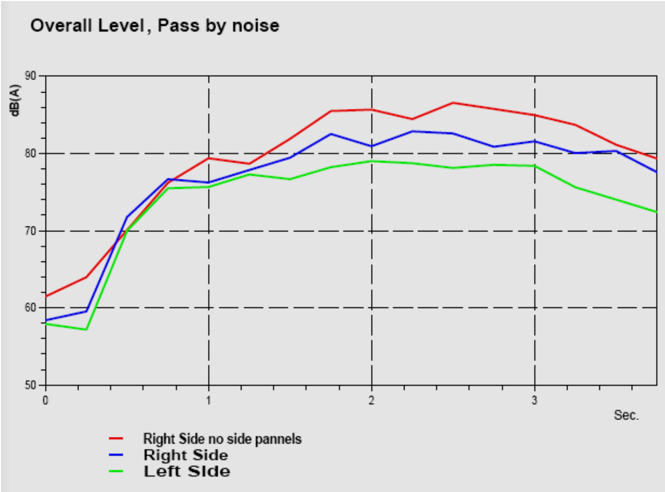

Figure 7 Side Dependent Noise Comparison

In an effort to further understand the noise contributions of the CVT, the runs with and without the factory panels were plotted in a 3rd octave plot as seen in Figure 8. As shown, the CVT contributes to the noise level as engine speed increases. The run without the panels has even more noise at these higher engine speeds. To reduce the noise emissions from this major contributing area of the snowmobile, sound deadening mat was added to the inside of the side panels.

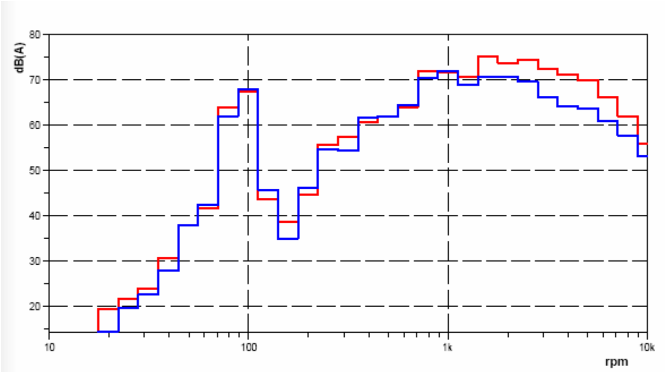

Figure 8 Phazer Panel Dependent Noise Comparison (Red-no panel, Blue-with side panel)

MECHANICAL NOISE

To isolate the mechanical noise, the snowmobile was placed on a stationary warm-up stand and run at different speeds. Sound readings were taken from different points around the snowmobile. The greatest noise levels contributed by mechanical systems were found to be coming from the engine compartment and the track tunnel.

In an effort to reduce mechanical noise, water and heat resistant foam insulation was installed under the hood deadening mat already used in the engine compartment. New side panels were constructed for both sides of the snowmobile and their extra size over the stock side panels allowed for generous use of this foam mat. The panels were also designed to seal the engine compartment off from the outside better than the stock panels; and holes, such as those for the radiator, were either closed off if feasible or ducted to allow for air flow without allowing any excess sound out of the compartment.

The track noise is reduced through the use of a sound deadening coating on the inside of the track tunnel, as well as the addition of the neoprene rubber track side skirts. The combination of these solutions will help to contain noise generated by the track in an enclosed area. As discussed in the section on exhaust noise, the noise reducing techniques used to reduce the contribution of the track to overall levels also help to reduce the contribution of the exhaust further. This will result in lower noise levels experienced by bystanders or in pass-by testing.

EMISSIONS REDUCTION

In addition to the conversion to ethanol blended fuels and altering the engine management accordingly in an effort to curb emissions, the team employed the use of a 3-way catalytic converter designed to handle carbon monoxide (CO), hydrocarbon (HC) and nitrogen oxide (NOx) emissions.

AFTER TREATMENT SYSTEM

A three-way catalytic after-treatment system was added to the exhaust. The catalyst brick is a custom unit from Umicore. It features a metallic substrate with cell density of 300 cells per square inch measuring 90 mm (3.5 in.) in diameter and 108 mm (4.25 in.) long. This catalyst is mounted just before the stock muffler. Figure 9 shows the "brick" catalyst.

TESTING

Emissions' testing was done on the complete snowmobile using the exhaust after treatment system. Running the snowmobile on a water brake dynamometer, the team was able to test the emissions using an industry standard Exhaust Gas Analyzer. The dynamometer test matrix followed the 5 mode test cycle detailed in [7]. The matrix is detailed in Table 5.

Figure 9 Catalyst Brick

Table 5 Emissions Test Procedure [2]

5-Mode Emissions Test					
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

Testing revealed that the snowmobile provided substantial emissions reductions as compared to a snowmobile operating at the 2012 standard. This data is shown in Figure 10. Emissions from other snowmobiles are shown for comparison. A typical 2001 production two-stroke snowmobile operating on gasoline was used as the control (2001 Control). Notice that this snowmobile does not meet 2012 emissions standards. The 2004 and 2005 control snowmobiles represented early industry efforts using four-stroke engines while operating on gasoline. Kettering University 2006-2009 snowmobiles were all operated using E85 fuel.

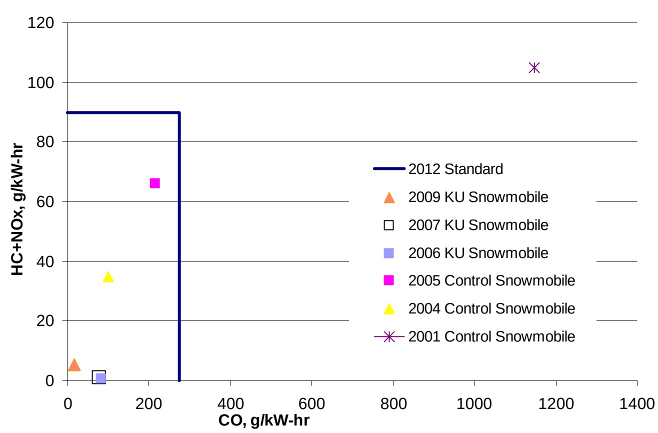

Figure 10 Emissions Results of Various Snowmobiles

Specifically, the 2009 Kettering University snowmobile emissions (running on E85) are shown in Table 6. The snowmobile achieved a reduction of approximately 94% when compared to snowmobiles operating at the 2012 standard.

Table 6 Comparison of 2009 Snowmobile with 2012 Standard

Snowmobile/Std	CO, g/kW-hr	HC+NOx, g/kW-hr
2012 Standard	275	90
2009 KU Snowmobile	17	5
% Reduction	94%	94%

RIDER SAFETY

As with any recreational vehicle there are safety hazards to consider. As per competition rules, the clutch was enclosed with a guard made of aluminum wrapped with Kevlar explosion containment belting. A leak proof gel cell battery was placed inside of a sealed aluminum box to prevent any potential hazards. In an effort to avoid arcing across the battery terminals, the interior of the box was lined with a rubberized, non-conductive material.

COST EFFECTIVENESS

The original Yamaha Phazer GT has a base Manufacturer's Suggested Retail Price (MSRP) of $7,799. However, added technology and performance enhancements drove this number up significantly. By the time various fuel system improvements, a more advanced ECU, custom body panels, suspension upgrades, significant sound deadening treatment, and a catalyst had been added to the snowmobile, the additional component cost combined into an estimated base MSRP of $11,200. However, with the average base MSRP of a new snowmobile sold in North America in 2008 being $9324, this MSRP seems reasonable when the added technology is considered [1].

CONCLUSIONS

The original Yamaha Phazer GT has a base Manufacturer's Suggested Retail Price (MSRP) of $7,799. However, added technology and performance enhancements drove this number up significantly. By the time various fuel system improvements, a more advanced ECU, custom body panels, suspension upgrades, significant sound deadening treatment, and a catalyst had been added to the snowmobile, the additional component cost combined into an estimated base MSRP of $11,200. However, with the average base MSRP of a new snowmobile sold in North America in 2008 being $9324, this MSRP seems reasonable when the significant amount of added technology is considered [1].

ACKNOWLEDGEMENTS

The Kettering University Clean Snowmobile Team would like to thank everyone who lent a helping hand in successfully completing the snowmobile. Special thanks to the Kettering University Mechanical Engineering Department faculty and staff for the support throughout the design and build process.

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

- Yamaha Motor Corporation
- BigStuff3
- FEV
- Michigan Corn Growers Association
- Robert Bosch Corporation
- Umicore
- Walbro
- Michigan Dept. of Commerce/ Biomass Energy Program

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