2010-xx-xxxx / 2010xxxx

Development of the Kettering University Snowmobile for the 2010 SAE Clean Snowmobile Challenge

Gregory Lazorcik, Gregory W. Davis
Kettering University

ABSTRACT

Affordable clean snowmobile technology has been developed. The goals of this design included reducing exhaust emissions to levels which are below the U.S Environmental Protection Agency (EPA) 2012 standard. Additionally, noise levels were to be reduced to below the noise mandates of 78 dB(A). Further, this snowmobile can operate using any blend of gasoline and ethanol from E20 to E30. All of these goals should be achieved while keeping the cost affordable. Snowmobiling is, after all, a recreational sport; thus the snowmobile must remain fun to drive and cost effective to produce.

The details of this design effort including performance data are discussed in this paper. Specifically, the effort to modify a commercially available snowmobile using a three cylinder, four-stroke engine is described. This snowmobile was modified to run on a range of ethanol blended fuels using a closed-loop engine control system. Additionally, a new exhaust system which features customized catalytic converter and mufflers to minimize engine noise and exhaust emissions has been developed.

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 the rising concern pertaining to noise and exhaust emissions of snowmobiles, they have come under increased scrutiny by the federal government. As snowmobiles are used in the winter season, the environmental impacts are greater 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 as well as 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.

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 overall emissions by 2006, a 50% reduction overall by 2010, and a 70% reduction overall by 2012. The specific limits are shown 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 legislation 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 through reasoning that this technology offers the best long-term potential to meet exhaust and noise emissions levels.

DESIGN OBJECTIVES

The design objectives included 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). Minimizing the cost and performance compromises were also major considerations. Snowmobiling is, after all, a recreational sport; thus the snowmobile must remain fun to drive and cost effective.

Finally, the snowmobile will be flex-fuel capable and will operate on blends of ethanol and gasoline ranging from E20 up to E30. Therefore, the engine control system must determine the actual fuel blend and compensate accordingly without any intervention.

In order to meet these objectives, a commercially available 2010 Yamaha FX Nytro was modified for the 2010 CSC competition.

SYSTEM MODIFICATIONS

The base snowmobile was chosen because it was equipped 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 FX Nytro comes factory-equipped with a 1049cm^3 four-stroke, 130 horsepower, naturally aspirated three-cylinder engine. Due to a horsepower limit of 130 for the 2010 CSC competition, the team decided to swap the standard 130 horsepower Nytro motor for the 120 horsepower engine from a Yamaha Vector. The only difference between these two engines is the camshaft. The camshaft in the Vector engine has a different lobe pattern which reduces power (to allow room for compensation of the increase in power resulting from the use of ethanol), but will also result in improved fuel economy. The engine was then modified for use with ethanol blended fuels to improve power and emissions.

In original form the Yamaha Genesis 120 engine was rated to produce 120 bhp (90 kW) while operating on gasoline. Olav Aaen at Aaen Performance had performed dynamometer testing on the Genesis 130 engine versus the Genesis 120 engine for Snow Tech Magazine. The testing revealed a power output of 122.6 bhp (91 kW) and 82.9ft-lbs (112.5Nm), which is 2.6 bhp more than Yamaha claims [8].

Table 2 Yamaha Genesis 120 Specifications

Displacement:	1049 cm^3
Configuration:	Inline Triple Cylinder
Block Material:	Aluminum
Valve Actuation:	DOHC
Ignition:	Coil on plug
Valves per cylinder:	Three
Compression ratio:	11.3:1
Bore:	82 mm (3.23 in)
Stroke in/mm:	66.2 mm (2.61 in)
Aspiration:	Normal
Engine Control System:	BigStuff3
Snowmobile Weight:	237 kg (522 lb)
Front Suspension Travel	216 mm (8.5 in)
Rear Suspension Travel	368 mm (14.5 in)
Track Length	3073 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. Fortunately, the use of ethanol also provided a benefit of improved emissions, reducing the formation of both carbon monoxide and unburned hydrocarbons.

Kettering University first demonstrated snowmobile operation using E85 during testing at Southwest Research Institute in 2002. 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.

For the competition, this engine will only operate on blends of ethanol up about 30%; however, the engine is designed to operate on fuel blends up to 85%. The benfits shown below for E85 will be reduced somewhat with lower blends, but the trend in improvement should still be seen.

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.

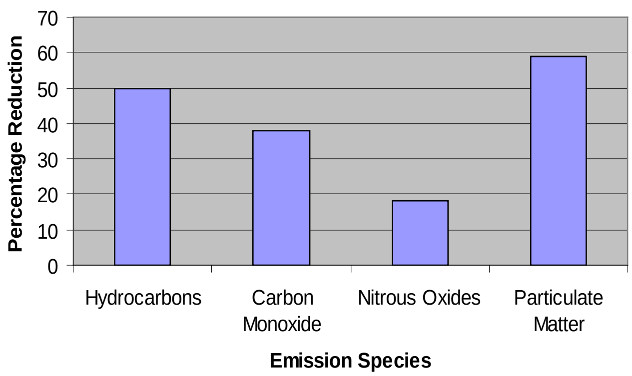

Figure 1 Reduction in Snowmobile Engine Emissions Using E85 as Compared with Gasoline [3]

The energy density of E85 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 on a volumetric basis. 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 Walbro fuel pump that provided a higher 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 remain durable when in contact with ethanol blended fuels.

The original injectors were retained for the 2010 CSC competition, but the stock fuel system could not supply enough fuel to the motor without straining the pump. To meet the increased flow demands when using ethanol blended fuels, the fuel system pressure was increased. The team increased the fuel system pressure from by installing a Walbro GSL393 inline fuel pump. The pump will provide fuel pressures higher than needed, so a fuel pressure regulator will also be used. This also 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 crankshaft has 120° intervals, as seen in Figure 2. In previous years, the team had chosen the BigStuff 3 ECU, and decided to use it again for the 2010 CSC competition.

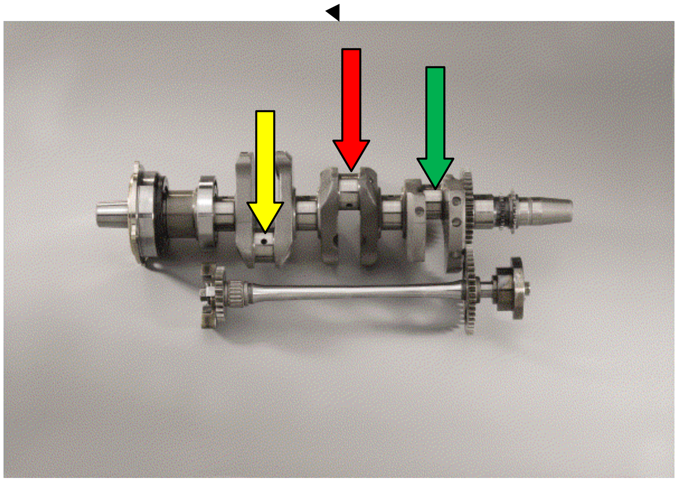

Figure 2 Yamaha 1049cm^3 Crank Cycle

The aftermarket ECU with closed loop wide band oxygen sensor feedback and flex fuel adjustment capabilities 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.

Through the use of the ECU calibration software, the engine map was adjusted to avoid undesirable, excessively rich mixtures which increase HC and CO 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

An aftermarket gauge cluster was installed in place of the factory gauge pod. This allowed for better monitoring of critical engine data. Monitored data included engine speed, water temperature, oil pressure, throttle position, and ethanol/gasoline blend as well as other basics of snowmobile operation such as ground speed.

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. By operating at higher temperatures, the plugs were more able to avoid fouling and ignite the cold air/fuel mixture, leading to reliable engine starting. 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 FX Nytro was already a relatively light sled with a dry weight of only 237 kg (522 lb). Some sound deadening material was added to the body panels to reduce engine and clutch noise.

TRACK AND SUSPENSION

The 2010 Yamaha FX Nytro came with a 307 cm (121 inch) track, which performed well enough during testing to forego modifying it with studs. To reduce some of the weight of the sled, the standard Camoplast Ripsaw Dual Ply track was removed and replaced with a Camoplast Single Ply Ripsaw Track. The tread pattern and depth did not change, just the overall thickness of the track, which helped to reduce weight and rotational mass.

In 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 for the 2009 competition, 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. This logic will be used for the 2010 competition as well and the idler wheels will remain in place.

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%

NOISE REDUCTION

Noise from snowmobiles can be attributed to a variety of different sources, including the engine, intake, exhaust and track. The course layout for the SAE Recommended Practice J192 for snowmobile noise testing is shown Figure 5.

In previous years, noise testing was performed before competition and it was found that with the rear facing exhaust, the noise levels were close to sufficient until the snowmobile got closer to the end of the course, when the microphone would then pick up more noise from the exhaust. This resulted the team to focus on exhaust routing to minimize noise.

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).

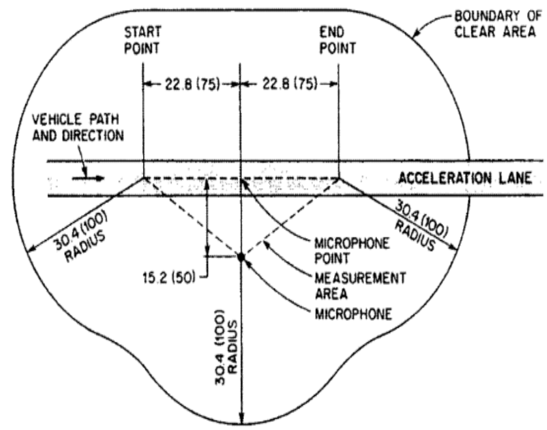

Figure 3 SAE J192 Microphone Locations (m/ft) [6]

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. This allowed free expansion of exhaust gases post-outlet into a partially enclosed area that would prevent the noise from being pointed (reduce direct noise) without inducing further backpressure to the system. Of course, an increase in exhaust back pressure will reduce the engine output, so efforts were made to reduce this negative impact by increasing the diameter of the exhaust.

EXHAUST ROUTING DESIGN

The goal of the muffler design was to reduce noise from exhaust picked up in pass-by testing. On the Yamaha FX Nytro 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 then goes beneath the tunnel and is cooled by snow on the track. The muffler is mounted under the seat and exits behind the seat. With there being only approximately 254mm (10 in) of exhaust tubing between where the 3 exhaust pipes collect into 1, packaging was 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 2010 competition is an exhaust system comprised of two mufflers in series. Muffler one is the stock Yamaha FX Nytro muffler unit. The exhaust system exits the stock unit and makes approximately a

90° bend through the tunnel into muffler two which is placed within the confines of the tunnel at the tail of the snowmobile. Muffler two is a glass-pack style muffler. After the second muffler unit, the exhaust points into the track area.

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.

The track noise is reduced through the use of a sound deadening coating on the inside of the track tunnel. 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 Heraeus. It features a metallic substrate with cell density of 600 cells per square inch measuring 105 mm (4.1 in.) inside diameter and 74.5 mm (2.9 in.) long. This catalyst is mounted just before the stock muffler.

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 FX Nytro has a base Manufacturer's Suggested Retail Price (MSRP) of $10,669. However, added technology and performance enhancements drove this number up. By the time various fuel system improvements, a more advanced ECU, sound deadening treatment, and a catalyst had been added to the snowmobile, the additional component cost combined into an estimated base MSRP of $13,600. However, with the average base MSRP of a new snowmobile sold in North America in 2009 being $8800, this MSRP seems reasonable when the added technology is considered as well as the higher base price [1].

CONCLUSIONS

The members of the 2010 Kettering University Clean Snowmobile Challenge team believe that the best snowmobile has been produced utilizing the collective engineering knowledge of the team members to attain the goals of the competition. The team has been able to deliver a quieter, cleaner, more efficient snowmobile without compromising the cost, durability, rider safety or performance. Through the use of ethanol blended fuels and add-on technology, the snowmobile should have much lower emissions than in original stock form.

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
- Heraeus
- Walbro
- Michigan Dept. of Commerce/ Biomass Energy Program

REFERENCE

1 International Snowmobile Manufacturers Association (ISMA), www.snowmobile.org/pr_snowfacts.asp

2 Recreated from Code of Federal Regulations, 40CFR Part 1051.103

3 Davis, G. W., Pilger, C., "Effect of Biomass-based Fuels and Lubricants on Snowmobiles," American Institute of Aeronautics and Astronautics (AIAA), AIAA-2004-5681, 2004.

4 Davis, G. W., "Using E85 in Vehicles," Chapter 8, *Alcoholic Fuels*, CRC Press, Minteer, S. Editor, Final Submission, 2005.

5 U.S. Department of Energy, Handbook for Handling, Storing, and Dispensing E85, http://www.e85fuel.com/pdf/e85_technical_booklet.pdf

6 Maximum Exterior Sound Level for Snowmobiles. SAE Surface Vehicle Recommended Practice. J192.

7 Wright, Christopher W., and White Jeff J., "Development and Validation of a Snowmobile Engine Emission Test Procedure", SAE Paper No. 982017, 1998.

8 Snow Tech Magazine, "Yamaha Genesis 130 FI"., http://www.snowtechmagazine.com/category/tech-shorts/page/2/

CONTACT

Greg Lazorcik
Team Leader
lazo0024@kettering.edu

Dr. Gregory W. Davis, P.E.
Faculty Advisor
gdavis@kettering.edu