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Iowa State University Clean Snowmobile Challenge Team

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Abstract

Iowa State University's Clean Snowmobile Challenge Team has prepared an environmentally friendly and high performance Polaris Indy 800SP for the 2016 SAE International Clean Snowmobile Challenge. The objectives of this competition are to improve the fuel economy, noise levels, and emissions of an industry available snowmobile. The platform chosen by Iowa State was based on market research along with established team goals. This Indy 800SP was modified to use a flex fuel system to operate on a range of ethanol blended gasoline. The exhaust system was improved using a Heraeus HeraPur® two-way oxidation catalyst in conjunction with a redesigned muffler to reduce engine emissions and noise levels substantially. Using a Dynojet Power Commander V in series with the Polaris engine control unit, the fuel curves and ignition timing were adjusted to allow the motor to perform under a lean burn condition improving emissions and horsepower. With these changes, Iowa State University produced a high performing, fun to ride snowmobile that exemplifies the expectations of a machine designed for use in the most sensitive environments.

Introduction

The SAE International Clean Snowmobile Challenge was introduced as a collegiate design competition to combat the detrimental effects that power sports can have on the environment. Throughout the years, this challenge has provided an innovation center for sustainable modifications from which the snowmobiling industry has benefited greatly. Teams are tasked with developing a snowmobile that excels in three main categories: emissions, noise levels, and fuel economy. The rules have varied in the past, however, for the 2016 Clean Snowmobile Challenge, teams are required to run a corn-based ethanol fuel mixture ranging in composition from 0%-85% ethanol (E0-E85).

The following report details how Iowa State University (ISU) has prepared a snowmobile for use in the most sensitive of areas including nature reserves and national parks. The key changes made to a 2014 Polaris Indy 800SP are revolved around exhaust treatment, noise reduction, and performance management. The emissions reduction strategy consisted of a lean burn tune and implementation of a two-way oxidation catalyst. Noise levels were reduced by a custom muffler along with sound deadening material. With these changes made, Iowa State University was able to produce a clean and efficient machine while maintaining the high performance levels desired by power sports enthusiasts.

Snowmobile Selection

In 2016, Iowa State University chose to enter a 2014 Polaris Indy 800SP. This chassis and motor combination resulted in a clean, efficient, and quiet snowmobile while retaining the elements of performance that snowmobile customers require. In order to confirm the choice, Iowa State's Clean Snowmobile Team completed a market survey where likely customers were asked an assortment of questions about buying preferences. The survey was completed by users of the online forum, snowmobileforum.com, and recorded a total of forty-one unique responses. Three main questions are reported below in figures 1-3, detailing the breakdown of responses.

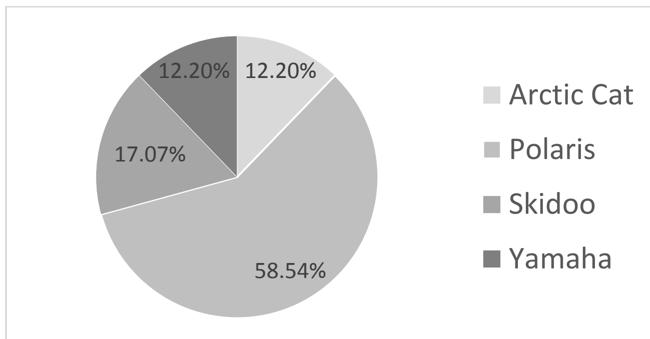

Figure 1. Potential customer brand preference results.

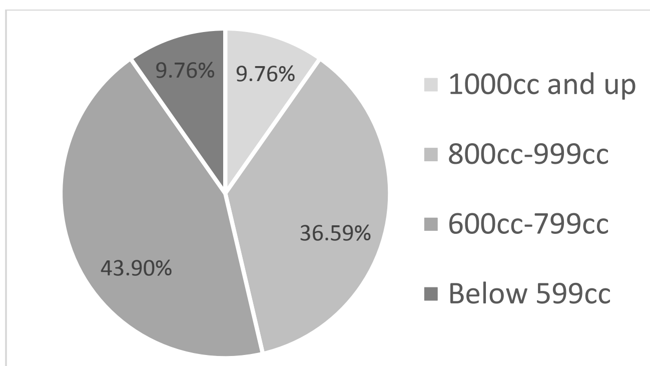

Figure 2. Potential customer engine displacement preference results.

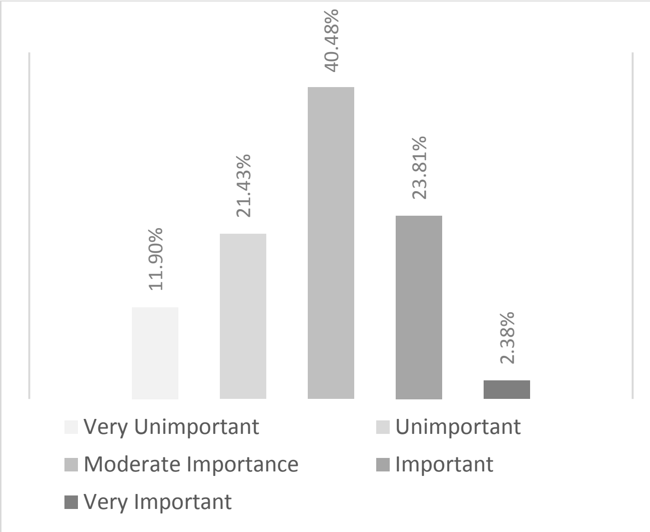

Figure 3. Potential customer fuel economy preference results.

From the responses to this survey, today's snowmobiler preferences were very clear. When asked which engine type is preferred, 77.5% of responses chose a 2-stroke over a 4-stroke. It is shown that a majority would purchase Polaris over other brands, with 58.5% of responses choosing Polaris. According to the survey, the preferred displacement was between 600cc and 799cc. The fuel economy associated with larger displacement motors was a concern to ISU, however the majority of buyers were only moderately concerned by fuel economy when purchasing a snowmobile. By looking at these responses, the choice that Iowa State University made in entering a Polaris Indy with a 2-stroke 795cc engine was clearly a highly preferred sled by the end customer.

Chassis Improvements

The Pro-Ride chassis design utilized by a 2014 Polaris Indy 800SP played an important role in the strategy of Iowa State University. This chassis offers an aluminum construction which allows for a significantly lighter frame while maintaining the structural rigidity required for strong handling. In order to further decrease the weight, this chassis uses an advanced acrylic adhesive to cut down on weight typically added by bolt and rivet type fasteners. In addition, it increases the strength of the chassis as no stress concentrations are introduced through rivet holes and little to no heat stress is added, such as can happen with welding [1]. With these characteristics, the Pro-Ride chassis is an excellent candidate for an efficient snowmobile.

Track Selection

In the 2015 Clean Snowmobile Challenge, it was observed by ISU that many teams struggled with track slippage under acceleration. In addition to this, the market research completed by ISU concluded that over 50% of riders spend most time riding on ungroomed trails and in the boondocks (off-trail areas) where the best traction possible is a necessity.

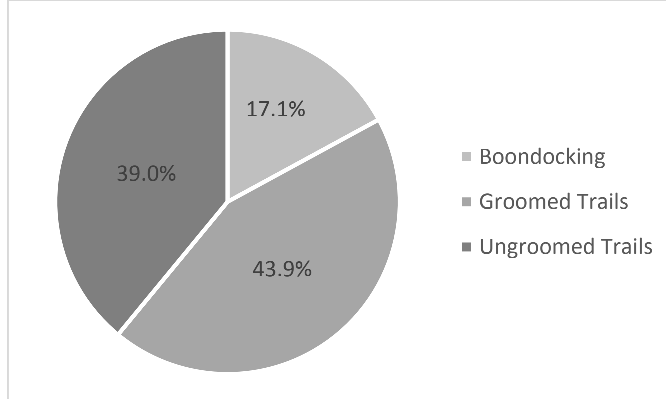

Figure 4. Result of riding condition preference.

Iowa State University chose to address this area by selecting a track with large paddles and studs. The track that was installed for the 2016 Challenge was a Camoplast Ripsaw 1.5 with 1.5" height lugs for grip in soft and deep snow. To improve the amount of power making it to the ground, the team installed Woody's Traction studs in a 96 stud single pattern. This stud pattern allowed ISU to mitigate the weight addition typical of studded tracks. To show the effect studs have on a large displacement snowmobile's acceleration, the team utilized a standard drag type test. The test was completed on a small test area, where a rider accelerated at wide open throttle from rest. Times were recorded for a 60 foot distance. The results from this test are shown in Table 1 and indicate a 9.06% faster 60 foot time while using a studded track. Although weight reduction is an important factor when looking at efficiency, Iowa State University proved that the traction control strategy used allows more power to be transmitted to the ground resulting in more effective performance.

Table 1. Times for acceleration tests of unstudded track compared to studded track.

Trial	Time for Unstudded (s)	Time for Studded (s)
1	1.97	1.83
2	2.08	1.88
3	2.13	1.91
Average	2.06	1.87
	Improvement:	9.06%

Noise Mitigation

The internal combustion process produces sound waves that resonate through the engine bay in a snowmobile. To combat this unwanted noise, Iowa State University installed sound deadening material to the interior surfaces of the engine bay.

RAAM Audio RAAMmat BXT II was added in addition to the stock low density foam. The supplemental material targets high frequency sound waves for when the engine is operating at a high rpm. The audio mat transfer sound wave energy into heat. This energy transfer occurs faster and in larger magnitudes at higher frequencies. Stock Low-Density Foam mats were mated onto the exterior of the RAAM Audio Mats. These lighter foam mats target mid-range frequency sound waves for when the engine is running at a low to moderate rpm. The stock foam mats contain cubic cells with connecting pores allowing sound waves to travel into cavities and become absorbed [2]. Through experimental data, the higher porosity material proved to work well with mid-range frequency waves but lacked effectiveness with high frequency waves.

For testing, a set of speakers was inserted into the engine bay to emit a range of frequencies from 0 to 2900 Hz while volume was held constant as a control. Sound measurements were taken with a Vernier SLM-BTA sound level meter on the front, right, and left sides of the sled. The sound levels were measured for three cases: stock foam, RAAM mats, and the combination of the two mats. The figure below shows the results of the experimentation for decibel readings on the left side of the sled (other tests shown in appendix). In the trial with the RAAM Mats, decibel readings drop significantly in frequencies ranging from 2000 to 2900 Hz. In the trial with the RAAM Mats united with the low density foam mats, decibels associated with mid-range frequencies plunged while slightly decreasing readings from high range frequencies. Utilizing this material in conjunction with the factory deadening allowed Iowa State University to successfully dampen engine bay noise levels.

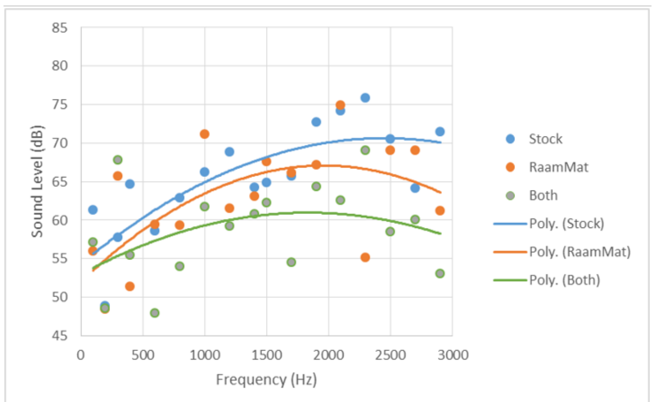

Figure 5: Sound level data measured from driver's left of snowmobile.

Testing Systems

In Iowa State's first season, the team struggled to record accurate and repeatable dynamometer testing results. Major problems included: insufficient water pressure at high dynamometer (dyno) loads, overheating, and poor air quality conditions. To combat these three distinct challenges, the team created water, coolant, and external exhaust systems. Reference the appendix for a full schematic for each of these systems.

The servo load valve used to control the water brake dyno requires greater than thirty pounds per square inch of dynamic water pressure. Typical residential water supplies are not able to produce adequate pressure. Multiple alternatives were evaluated. The most feasible options were:

- Decreasing the flow rate of the shop water supply, which in turn would increase the pressure. This calculation was made using Bernoulli's mechanical energy equation including head losses and volumetric flow rate, resulting in 16.9 psi.

$$\frac{p_1}{\rho} + \frac{v_1^2}{2} + g * z_1 + W_{shaft} = \frac{p_2}{\rho} + \frac{v_2^2}{2} + g * z_2 + h_f \qquad (1)$$

$$Q = v * A \qquad (2)$$

- Increasing the gravitational potential energy of the water supply. Mounting a water tank in a lofted storage area generates additional pressure, however, calculations proved this alternative would not meet the dyno requirement.

- Utilizing a pump to increase pressure. The correct size pump was selected based on pump flow rate and corresponding pressure. Iowa State selected this alternative, producing 47 psi of dynamic water pressure.

The external cooling system allows Iowa State to execute longer duration dynamometer runs. The coolant mixture is gravity fed through stock cooling system path until it exits the top end of the engine block at the thermostat. The heated coolant is then pumped through a small automotive radiator with a fan blowing across it, creating enough cooling capacity to maintain an engine temp at or below 127°F.

The external exhaust system created safer working conditions for the team by redirecting the exhaust fumes out of the building. Back pressure at the muffler was mitigated by placing the blower downstream of the snowmobile's exhaust, allowing the gasses to be pulled from the muffler, instead of being pushed back into the snowmobile's exhaust system. The creation of these systems allowed for effective and repeatable testing when using the Land and Sea™ engine mounted dynamometer.

Exhaust Treatment

Emission Analysis of 2-Cycle Oil

In a typical 2-cycle engine, main constituents of exhaust emissions are unburned hydrocarbons and carbon monoxide. The main source being unburned fuel and oil. In order to minimize this effect, Iowa State University tested five commercially available 2-cycle lubricants (Amsoil Dominator, Amsoil Interceptor, Polaris VES Gold, Green Earth Technologies G-Oil, and Klotz Super Techniplate) to determine which product would offer the lowest emissions.

Each oil sample was connected to the oil system using a clean external container. The oil system was then bled between every trial to ensure all passageways contained the oil being tested. Emissions were collected while carrying out a stepped dyno run. The five step run started at 3000 RPM and ended at 5000 RPM with each step increment of 500 RPM lasting twenty seconds. Additionally, two seconds between each interval were given to allow engine RPM to balance, resulting in a test duration of 110 seconds. The fuel (E70) and tuning map were held constant for the entirety of the test, which was performed prior to catalyst installation and exhaust treatment.

CO % and hydrocarbons (ppm) were analyzed. The team chose these two measures because carbon monoxide and hydrocarbons are naturally high in 2-cycle engines. With increased environmental friendliness being the goal, lower levels of CO and fewer hydrocarbons are preferred. The team computed the definite integral, representing the area under the curve, in order to quantitatively compare the oil specimens tested. The smallest integral value corresponds to the cleanest burn. The emissions data graphs can be found in the appendix.

Table 2: Definite integral, calculated using the midpoint method for carbon monoxide emissions vs time for the tested oil.

Oil Tested	Definite Integral (Cumulative % over 110 seconds)	Percent Increase Compared to Lowest
Interceptor	191.884	N/A
Polaris VES	202.515	5.25%
Dominator	203.008	5.48%
Klotz	229.758	19.74%
G-Oil	205.375	7.03%

Table 3: Definite integral, calculated using the midpoint method for hydrocarbon emissions vs time for the tested oil.

Oil Tested	Definite Integral (HC parts per million cumulative over 110 seconds)	Percent Increase Compared to Lowest
Interceptor	601,577	N/A
Polaris VES	662,111	10.06%
Dominator	780,694	29.77%
Klotz	629,608	4.66%
G-Oil	644,463	7.13%

The Amsoil Interceptor proved to have the best emissions results for both carbon monoxide and hydrocarbons. Polaris VES, Amsoil Dominator, and Klotz Super Techniplate all were within 5.5% of Amsoil Interceptor in one of the two metrics, however, each of these three lubricants tallied over 10% more emissions than Interceptor in the other emission measurement. Green Earth Technologies G-Oil produced slightly over 7% higher emissions than the interceptor over the span of the test in both categories. From these results, it is clear that the Amsoil Interceptor produces the most favorable and environmentally friendly emissions.

Catalytic Converter

For the 2016 competition, one major aim for improvement was emission control. Two cycle engines tend to produce high levels of hydrocarbons from unburnt fuel that leaks through the cylinder before ignition [3]. Also, after baseline emissions testing was completed, the carbon monoxide levels being exhausted from the engine were quite high. In order to effectively combat these emissions, Iowa State University chose to install a HeraPur® two-way oxidation catalyst provided by Heraeus Group. A two-way catalyst converts harmful gases into the more environmentally friendly components of carbon dioxide and water is detailed in the following equations [4].

$$2CO + O_2 \rightarrow 2CO_2 \qquad (3)$$

$$C_xH_{2x+2} + \left[\frac{3x+1}{2}\right]O_2 \rightarrow xCO_2 + (x+1)H_2O \qquad (4)$$

The catalyst consisted of a mixture of precious metals. The composition of these metals were 1 part platinum, 20 parts palladium, and 1 part rhodium. This mixture is then deposited on a honeycomb substrate, shown in figure 6. In order to reduce the exhaust back pressure, the team elected for a high-flow type catalyst where the cell density was 200 cells per square inch. Although this will lower the effect on the emissions treatment, this was necessary to retain the performance desired from the engine.

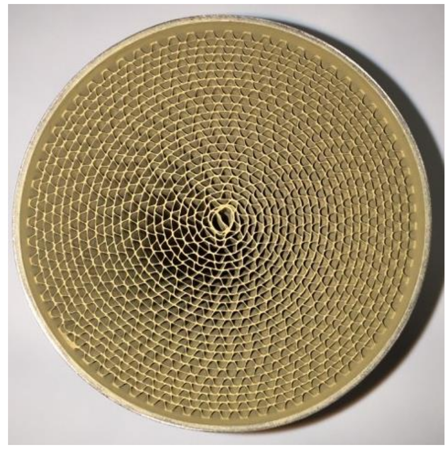

Figure 6. Picture illustrating substrate density of catalyst.

This catalyst was installed near the end of the tuned pipe and upstream of the custom muffler developed by ISU Clean Snowmobile Challenge. The challenge of installation was the length of the catalyst in addition to the space constraints of a snowmobile engine bay. In order to effectively add this feature, a catalyst of 83mm outer diameter with a length of 100mm was chosen, shown below in figure 7. Emissions data was not yet available prior to design paper submission to show the result this catalyst had on emissions. With this installment, Iowa State University is confident that the 795cc Liberty motor will perform with greatly improved emissions.

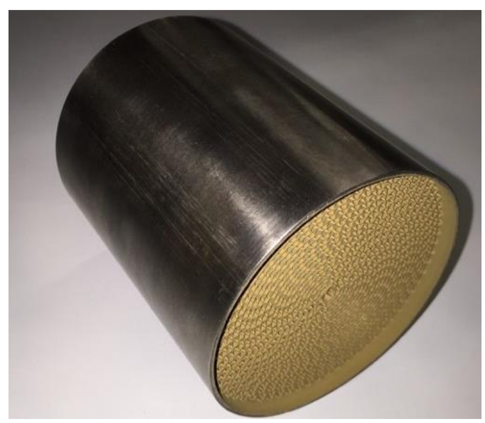

Figure 7. Picture illustrating size and shape of catalyst.

Muffler Design

In addition to implementing a catalyst into the exhaust system for the 2016 competition, Iowa State University designed and manufactured a muffler to work in conjunction with the catalyst and to reduce sound pressure levels created from exhaust gases. A split flow exhaust system was utilized in the design in order to increase the surface area of the exhaust exposed to sound attenuation material. Perforated tubing was used to form and control the exhaust flow while still exposing sound pressure waves to sound absorbing material. Sound attenuation material consists of thousands of small fibers that vibrate with sound pressure waves and this process dissipates the sound by converting it to heat [5]. Stainless steel wool was used as the first layer of sound absorption in the muffler design and was wrapped around the perforated tubing as it has a much higher heat resistance than fiberglass. Fiberglass packing was used to fill the rest of the area around the stainless steel wool for another layer of sound absorption. A combination of stainless steel wool and fiberglass packing increases the lifespan of the muffler by protecting the fiberglass from exposure to extreme exhaust temperatures and preventing the packing from blowing out of the muffler while still effectively reducing exhaust noise. The exhaust flow is then merged back together before exiting the muffler. As the separate exhaust streams come together, a destructive interference between the sound waves is introduced, further reducing exhaust noise [6]. With additional back pressure already being introduced to the exhaust from the catalyst, the muffler was also designed to maximize air flow after the catalyst. Three dimensional modeling and flow simulation aided in the design and testing stages to validate exhaust gas velocity exiting the muffler and non-restrictive flow. Designing a custom muffler allowed Iowa State University to not only significantly reduce emissions by incorporating a catalyst in the exhaust, but also effectively attenuate exhaust noise by more efficiently reducing sound pressure waves from exhaust gases.

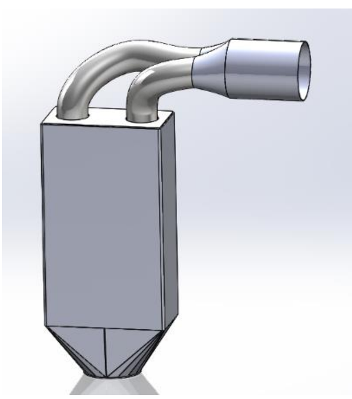

Figure 8. Three dimensional model showing muffler and catalyst design.

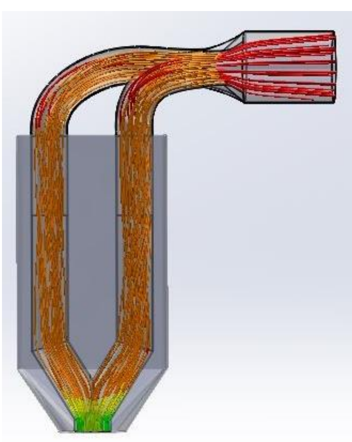

Figure 9. Flow simulation showing flow trajectories through muffler design.

Engine Modifications

The decision that Iowa State University Clean Snowmobile Challenge Team made about an engine to use was based on the power-to-weight ratio, efficiency, and rideability that the 795cc Liberty motor offered over other options. Another large advantage of utilizing a Polaris Liberty 2-stroke is the addition of Cleanfire® Technology, using semi-direct injection, increasing efficiency while at the same time lowering emissions. The factory specifications are shown in table 4.

Table 4. Engine specifications for 2014 Polaris Indy 800SP.

Number of Cylinders	2
Displacement	795cc
Stroke	70mm
Bore	85 mm
Fuel Capacity	43.5 liters
Estimated Dry Weight	204 kg

Engine Management System

To make adjustments for the blended fuel mixture, ISU installed a Power Commander V (PCV) Fuel Injection Module. This system is a popular addition to snowmobiles and is built specifically for use in power sports applications. Using this system with an Indy 800SP engine control unit (ECU) allowed for adjustments of fuel amounts of up to 100% leaner and 250% richer, only constrained by injector volumetric flow limits. This unit is also able to adjust ignition timing allowing for advancement and retardation of spark by 20 degrees. In addition to the Power Commander V, ISU installed a Dynojet POD-300 Digital Display that will make viewing critical engine parameters possible. The 5V signal input on the PCV was employed by ISU for the addition of a fuel sensor to monitor ethanol content of the fuel. This sensor was used alongside a wideband O_2 sensor to analyze the air-fuel ratio in the exhaust stream which is also viewable on the POD-300 display. Utilizing this Power Commander V with additional sensors has allowed Iowa State University to modify the fuel and ignition while producing a truly flex fuel capable vehicle.

Adjustment to Ethanol

For the 2016 Challenge, Iowa State University Clean Snowmobile Challenge was given the task to run an ethanol-gasoline blend ranging from E0-E85. There are many pros and cons with the use of ethanol. The biggest positive is that ethanol is extremely resistant to knocking, better known as detonation, where there is ignition of the fuel in the cylinder at undesired times [7]. This resistance to detonation allows the tune to be more aggressive, making more power while maintaining engine reliability. Ethanol also is very environmentally friendly and produces significantly less greenhouse gases, saving our irreplaceable atmosphere for another generation [8]. One of the negatives includes the decreased fuel economy due to a lower energy content compared to gasoline. Ethanol requires 30% more fuel to be equal to the same power as gas. This is because E85's specific energy is 33.1 MJ/kg and gasoline's (average 10% ethanol 90% gasoline) specific energy is 43.52 MJ/kg. The decrease in fuel economy along with ethanol's smaller availability are the biggest disadvantages facing a successful ethanol industry. With the positives being far greater than the negatives, ethanol is a suitable replacement to other gasoline additives and can contribute to lower emissions for future fuels.

Flex Fuel Sensor

In most commercially available flex fuel automobiles, a dielectric sensor is employed to monitor alcohol levels in the fuel in order to adjust fueling and ignition accordingly. The ISU Clean Snowmobile Challenge Team implemented a commercially available flex fuel sensor, a Continental 13577429, into the fuel return line to monitor ethanol levels. This sensor provides a frequency based signal which most engine control units are capable of reading, however, the Power Commander V installed does not have this capability. In order to overcome this issue, a Zeitronix Ethanol Content Analyzer (ECA) was used in conjunction with the sensor. This ECA provides a single 0-5V linear signal to the Power Commander, shown in figure 11 [9]. From these readings, the Power Commander V is able to interpolate fuel and ignition adjustments accounting for changes in ethanol amounts. Using this easily accessible part along with proper engine adjustments, Iowa State University was able to produce a snowmobile that is able to run ethanol blends from 0% to 85% without any further user input.

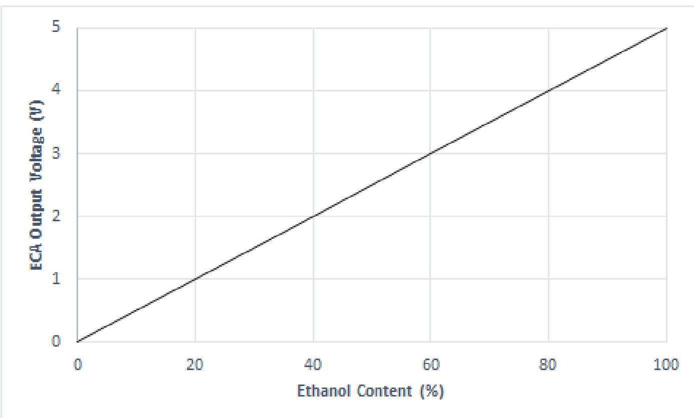

Figure 11. Graph of relationship between ethanol content percentage and ethanol analyzer output.

Tuning Strategy

For the 2016 Clean Snowmobile Challenge, Iowa State University decided to run a lean burn strategy to decrease emissions while increasing power. All tuning was based on lambda values in order to quantify the air to fuel ratio. A stoichiometric level for lambda is 1.0, indicating the chemically balanced ratio of fuel and air. In order to run an effective lean burn, Iowa State University targeted lambda values around 1.1 throughout the tune. These measurements were taken using a Bosch wideband O2 sensor installed before the catalytic converter.

To begin tuning the 795cc Liberty motor, the team started by increasing the overall fuel percentage by 20% across the fuel map (a table of fuel adjustments based on engine RPM and throttle position). The 20% increase gave the snowmobile a good baseline but further adjustment was needed. These next adjustments were made by indexing the throttle position while mounted to the dynamometer system explained above. The throttle positions indexed from 10% to 100% throttle by steps of 10%. The tests were run in a stepped RPM from 2000 to 8000 by increments of 500 RPM. The target lambda value through these tests was 1.1. This lean air-fuel mixture is attainable while on ethanol because of the extreme knock resistance of the fuel. Prior to design paper submission, a completed tune had not been finished but an example fuel map is shown below prior to installation of the catalyst. The numbers shown indicate a percentage increase over stock fuel delivered to engine. After completion of the fuel map, ignition was adjusted to retard timing in the low RPM range while advancing ignition on the top end. This allowed the sled to produce plenty of power while ensuring the most complete burn of the fuel.

Engine Speed (RPM)	Throttle Position (% open)									
	0	2	5	10	15	20	40	60	80	100
0	0	0	4	8	8	8	8	8	8	8
500	5	5	4	8	8	8	8	8	8	8
1500	6	6	6	8	8	8	8	8	8	8
2000	7	7	8	8	8	8	8	8	8	8
2500	8	8	12	14	14	15	16	18	22	20
3000	10	12	12	20	24	27	26	26	25	21
3500	16	18	18	22	23	25	26	25	23	20
4000	18	18	18	22	23	25	26	25	24	21
4500	18	18	18	22	23	27	26	25	24	21
5000	18	18	18	22	23	25	26	25	24	20
5500	18	18	18	22	23	25	26	25	24	18
6000	18	18	18	22	23	25	28	27	24	16
6500	18	18	18	22	23	25	26	25	24	16
7000	18	18	18	22	28	25	25	23	21	19
7500	18	17	18	18	28	25	23	23	21	19
8000	19	16	17	18	28	25	23	22	21	19
8500	19	15	16	17	28	25	23	22	21	19

Figure 10. Example fuel map showing percentage increases over stock.

Conclusion

Iowa State University has designed, manufactured, and tested a snowmobile that is suitable for use in national parks and other sensitive areas while maintaining high performance characteristics. This was done through extensive exhaust treatment, dynamic engine tuning, and a focus on cost effective and performance driven solutions. With the detailed changes being made, the Polaris Indy 800SP is a low emitting, quiet, and fun to ride snowmobile.

References

1. “Constructing the Polaris Pro-Ride Chassis,” Snowmobile.com, last modified October 7th, 2010. Accessed February 15, 2016.
2. Jorge P. Arenas, Malcolm J. Crocker, “Recent Trends in Porous Sound- Absorbing Materials,” last modified July 2010
3. Jalal, Aminu. "Pollution by 2-Stroke Engines." The Nigerian Conference on Clean Air, Clean Fuels, and Vehicles, Abuja, February 18, 2016.
4. "Eastern Catalytic." Eastern Catalytic. Accessed February 21, 2016.
5. "10 Things You Need to Know About Muffler Packing." Motorcross Action Magazine. Accessed February 17, 2016.
6. "Understanding Muffler Design and Sound Absorption Strategies - Street Legal TV." Street Legal TV. 2014. Accessed February 22, 2016.
7. "Ethanol Fuel Basics." Alternative Fuels Data Center:. Accessed February 21, 2016.
8. "Ethanol as a Transportation Fuel." Ethanol as a Transportation Fuel. Accessed February 21, 2016.
9. "Zeitronix ECA : SEMA Award Winning Ethanol Content Analyzer and Flex Fuel Sensor for E-85 and E-85/gasoline Blends." Zeitronix ECA : SEMA Award Winning Ethanol Content Analyzer and Flex Fuel Sensor for E-85 and E-85/gasoline Blends. Accessed February 21, 2016.

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Definitions/Abbreviations

dB	decibel
ECA	ethanol content analyzer
ECU	engine control unit
ISU	Iowa State University
PCV	Power Commander V
ppm	parts per million
RPM	revolutions per minute

Appendix

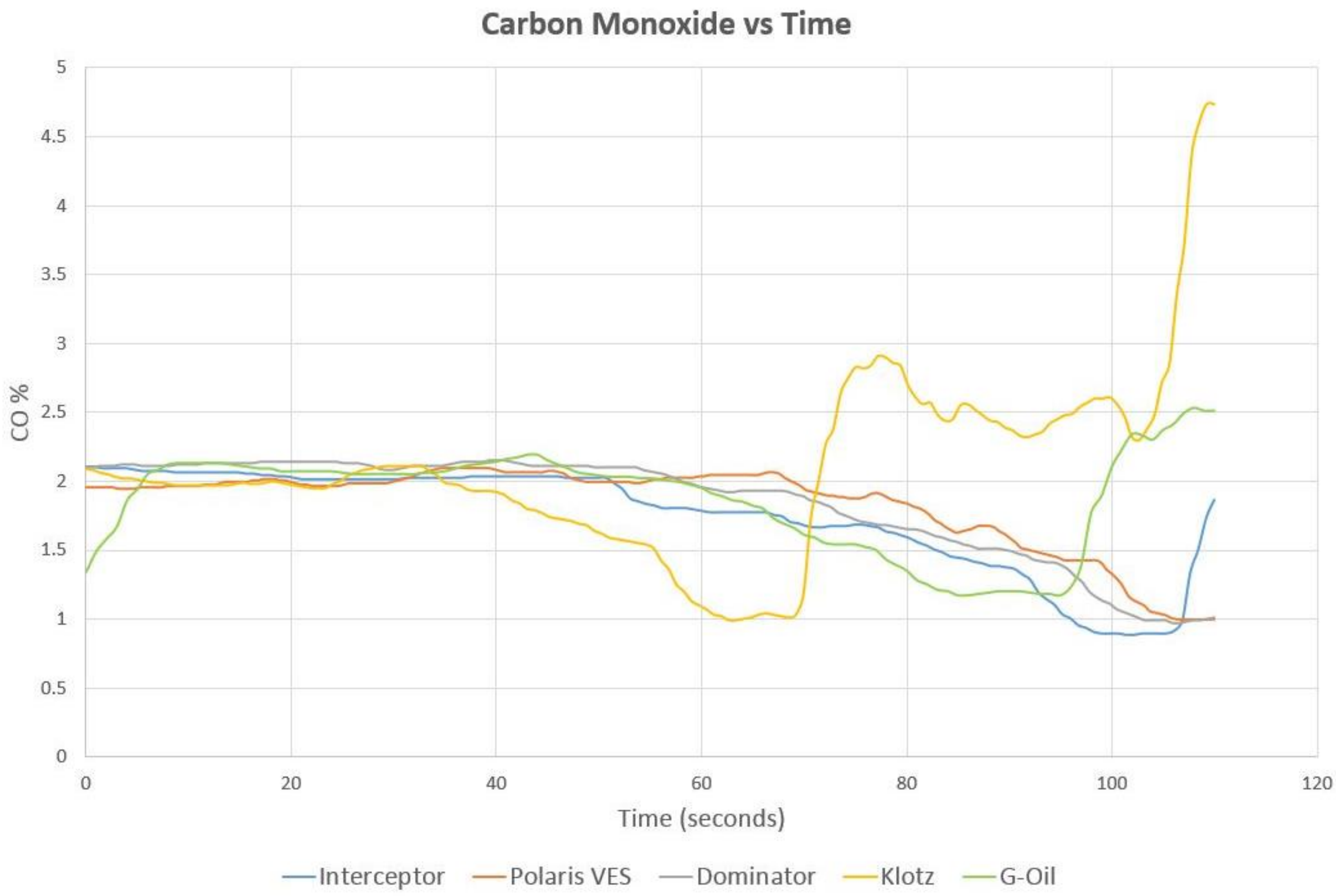

Figure 12. Results from emissions testing, plotting carbon monoxide vs time.

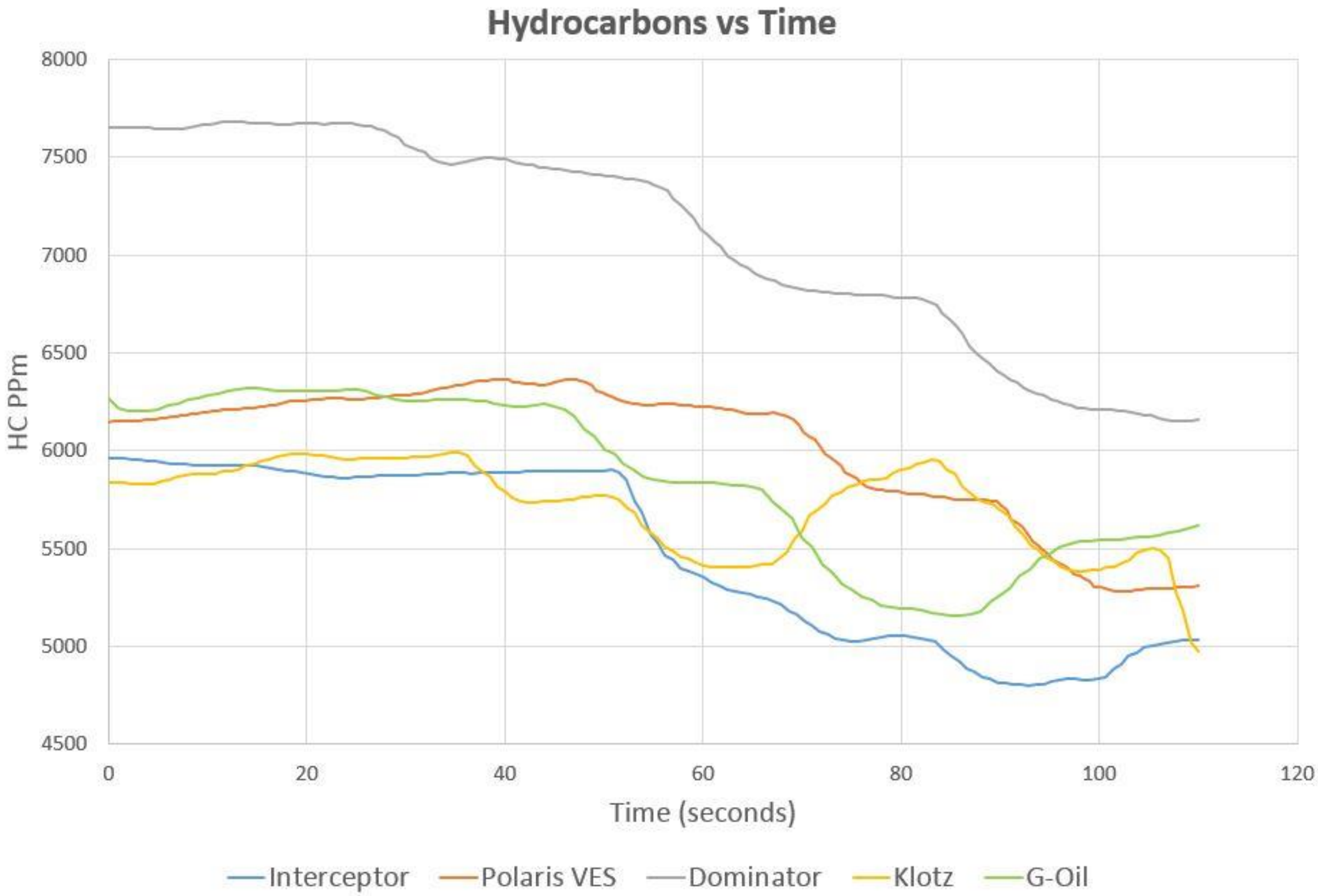

Figure 13. Results from emissions testing, plotting hydrocarbons vs time.

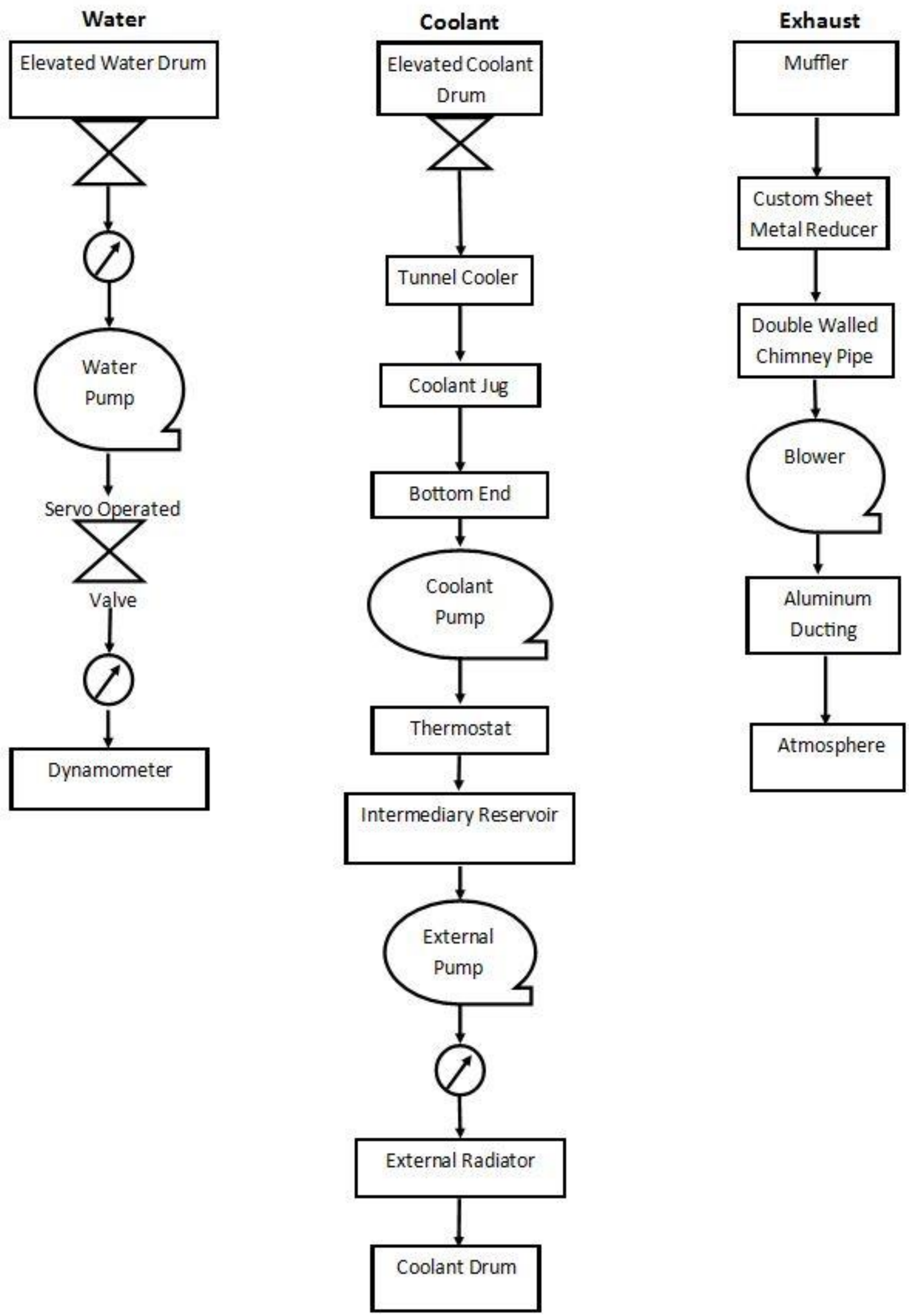

Figure 14. Flow chart outlining Iowa State's water, coolant, and external exhaust systems.

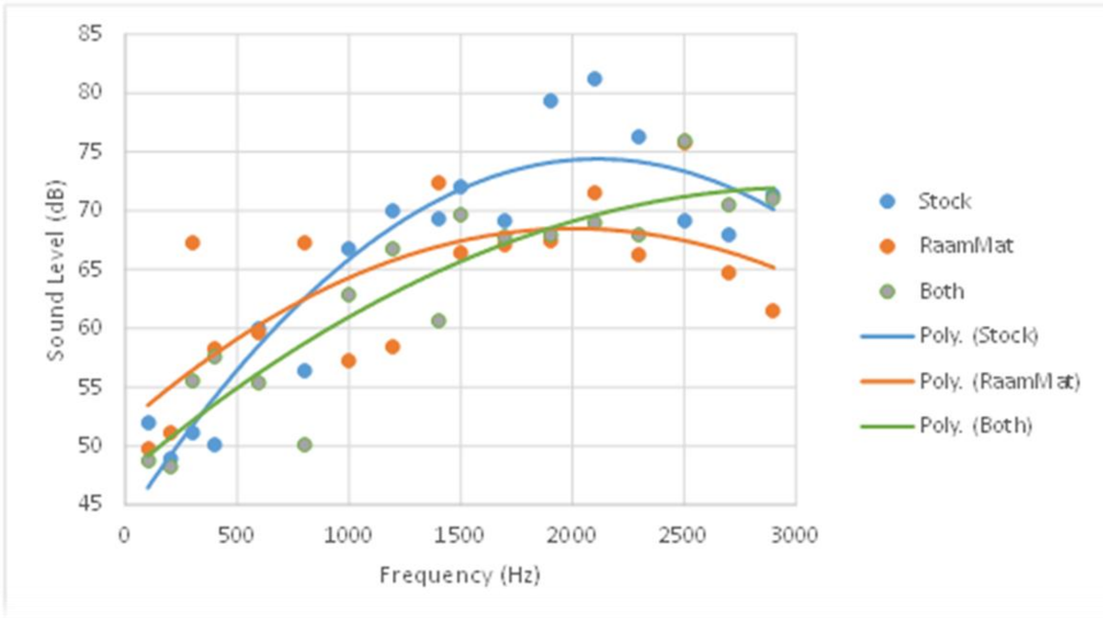

Figure 15. Sound level data measured from front of snowmobile.

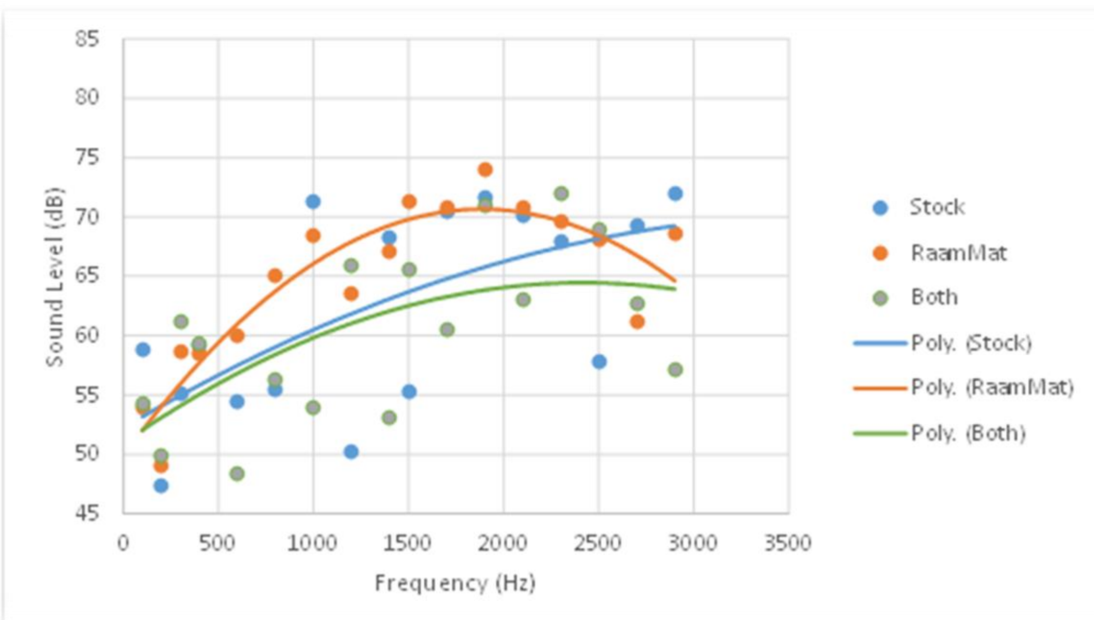

Figure 16. Sound level data measured from driver's right side of snowmobile.