Iowa State University Clean Snowmobile Challenge Team

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ABSTRACT

The Iowa State University (ISU) Clean Snowmobile Challenge Team has designed, modified, and tested a Polaris Indy 800SP for entry into the 2015 SAE International Clean Snowmobile Challenge (CSC). Using a 795cc Liberty 2-stroke motor, with semi-direct Cleanfire® injection, Iowa State has made several adjustments to improve the environmental friendliness of the stock snowmobile. Utilizing a Power Commander V, the machine has been modified to run on isobutanol-gasoline fuel blends with increased fuel efficiency. To ensure a quiet ride, the stock muffler was repacked with new fiberglass insulation and RAAMmat BXT II sound deadening material was strategically installed in the engine bay and tunnel. With these modifications, the ISU Clean Snowmobile Challenge Team was successful in transforming the Indy 800SP chassis into a cleaner and quieter machine suitable for use in environmentally sensitive areas.

INTRODUCTION

SAE Int'l Clean Snowmobile Challenge was introduced as a collegiate engineering design competition to combat the detrimental effects that power sports can have on the environment as well as introduce new technologies to the industry. The purpose of the challenge is to redesign current snowmobiles to increase efficiency, lower fuel use and emissions, as well as decrease noise to ensure continued use in more sensitive areas such as national parks and wildlife reserves.

Beginning in the 2014 CSC, teams were required to use a new fuel additive, isobutanol, ranging from 16% to 32% isobutanol content to gasoline. That requirement has remained for the 2015 competition on the basis that this new additive is not only less corrosive to elastomers such as gaskets and tubing, but also contains more energy than current ethanol additives [1]. This innovative fuel aligns precisely with the efficiency and emissions goals set by SAE Int'l.

SNOWMOBILE SELECTION

For the 2015 SAE International Clean Snowmobile Challenge, ISU was tasked with selecting an appropriate base platform snowmobile for competition. When deciding on what attributes were imperative to a clean and efficient machine, several characteristics were organized into a Quality-Function Diagram (QFD) by the team to decide between two platforms, see Figure 1.

Importance	Customer Requirements	Indy 800SP	Indy 600SP
		Correlations	
1	Weight	3	3
9	Power	9	3
9	Emissions	1	3
9	Efficiency	3	1
3	Rideability	3	1
1	Size	3	3
3	Cost	1	3
	Ranking:	63%	38%

Figure 1. Quality-Function Diagram used to select snowmobile platform.

The most critical attributes discussed by ISU were power, emissions, and efficiency. Although both the 800cc Indy and the 600cc Indy use 2-stroke motors with higher emissions, Iowa State Clean Snowmobile Challenge Team believed the efficiency outweighed the negatives that come along with 2 cycle motors. Using this QFD allowed ISU to quantify the characteristics of each sled and make a factually based decision on which snowmobile to modify.

Indy 800 SP

After analyzing the importance of each characteristic, a 2014 Polaris Indy 800SP was chosen by ISU as the base snowmobile to be modified for competition. This selection was made based on the power-to-weight ratio, efficiency, and rideability that the 800cc Indy offered over its smaller counterpart, the 600cc Indy. 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 figure 2.

Number of Cylinders	2
Displacement	795 cc
Stroke	70 mm
Bore	85 mm
Fuel Capacity	43.5 liters
Front Suspension Travel	22.9 cm
Rear Suspension Travel	35.3 cm
Track Size	15 in. x 121 in. x 1.0 in.
Estimated Dry Weight	204 kg

Figure 2. Baseline specifications for a 2014 Polaris Indy 800SP.

Pro-Ride Chassis

The Pro-Ride Chassis used by the Polaris Indy 800SP is an important aspect that aligns with ISU's focus on efficiency. An aluminum construction allows for a significantly lighter chassis while maintaining critical structural rigidity to retain handling abilities. The structural bonding method used to construct these sleds is a technologically advanced acrylic adhesive. When used in part with aluminum components, this method allows significant weight savings over traditional methods such as riveting or welding. 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 [2]. Together, these two traits combine to make a lightweight, high-performing chassis that increases efficiency and rideability.

Engine Rebuild

A 2014 Polaris Indy 800 SP snowmobile was acquired from Polaris that had previously been used as a test sled. Being a test sled, upon receiving the snowmobile the engine was disassembled and inspected for engine related issues and for any prospective problems. During the disassembly process it was learned that a 2009 Indy 800 Dragon SP engine had been modified to run in the 2014 Polaris Indy 800 SP chassis. The 2009 engine utilized a four injector Cleanfire® system with two injectors in each cylinder, whereas the 2014 engine would have only used a two injector set up. In order to overcome this issue a 2011 cylinder block was used as it had the same bolt patterns to fit the 2009 engine but had the two injector system required for the 2014 fuel rail. The 2009 Polaris Indy 800 Dragon SP engine came equipped with a 2009 stator which didn't fit the 2014 wiring harness so the 2009 stator was replaced with a 2014 model as both operate on a 14 AC/DC voltage system.

Inspection of the 2009 Indy 800 Dragon SP engine quickly led to an engine rebuild as the edges of both pistons were melted on the intake port side. It is speculated the engine had been operated in a lean burn scenario to improve both fuel efficiency and emissions. As in any lean burn scenario, a direct outcome is an increase in exhaust temperature causing the pistons to overheat and melt. The pistons, cylinder head, connecting rod bearings, bolts, and all gaskets and seals were replaced. The cylinder block was taken to an automotive machine shop to ensure the cylinder bores had not warped from the increase in exposed temperature. All dimensions were well within Polaris specified tolerances. A cylinder crankshaft run out inspection was also performed, which also met Polaris' design stipulations. Having completed the inspection and rebuild, the motor was reinstalled having been made more efficient and reliable.

Cylinder Measurements (Cyl. # 1)	
Top	X = 3.3466"
	Y = 3.3464"
Middle	X = 3.3471"
	Y = 3.3469"
Bottom	X = 3.3473"
	Y = 3.3467"
Out-of-Round = Top X – Top Y	.0002"
Bottom Y – Bottom X	-.0006"
Taper = Top Y – Bottom Y	-.0003"
Top X – Bottom X	-.0007"

Figure 3. Cylinder measurements from cylinder #1.

<u>CHASSIS</u>

Traction Control

In order to increase efficiency across the sled, it was decided that track slippage was a key issue to address. The high output Indy 800SP showed during testing that it was prone to spinning the track while under heavy acceleration. To improve the amount of power making it to the ground, the team installed Woody's Traction studs in a 96 stud single pattern. Although weight reduction was a portion of Iowa State Clean Snowmobile Challenge Team's focus, using this stud pattern allowed ISU to mitigate the weight addition typical of studded tracks. Even with the minimal weight gain, the overall efficiency of the sled was improved due to the increase in traction especially during acceleration.

Handling

As handling is a significant portion of scoring with 100 points of the total score, the team elected to replace the worn ski carbides with new 6", 60° Trail Blazer IVs supplied by Woody's Traction. Carbides play a huge roll in hard turning, especially while under heavy braking conditions [3]. The replacement runners were a drastic improvement over the current pair installed, shown below in figure 3. The 6" carbides will be more than sufficient to assist the studded track on groomed trails as well as occasional powder riding. The ISU Clean Snowmobile Team's decision to replace this component will play a key role in improving the handling ability of a clean Polaris Indy 800SP.

Figure 4. Top: new Trail Blazer IV ski carbides. Below: Worn stock ski carbides.

Noise Mitigation

It was decided that the enclosure surrounding the engine bay was a key area to improve upon on sound levels due to the high frequencies the engine outputs as a result of the internal combustion process. The team researched various heat resistant noise cancellation materials to line the plastic hood, side panels, and undercarriage with that attacked sound waves generated by the Polaris Liberty 800 engine. The rear snow flap was another key area focused on to reduce sound levels caused by the high amount of sound that exits the muffler, engine bay, and tunnel (from the track) that is reverberated off the flap.

A dual-material lining was mated onto the plastic panels enclosing the engine and exhaust components to deaden the sound in the interior of the snowmobile. RAAM Audio RAAMmat BXT II was incorporated along with the stock low density foam. The butyl based and aluminum lined RAAM Audio Mats target high frequency sound waves for when the engine is operating at a high rpm. Vibrations travel through the stiff aluminum surface and hit the viscoelastic butyl-based rubber layer. Due to the viscoelastic material property of the butyl rubber, the butyl expands and contracts at a higher rate than the aluminum [4]. The different rates of expansion and contraction between the butyl rubber and the aluminum layers result in a cyclic shear strain corresponding with the frequency of the engine outputs. This shear strain converts the sound vibrations into a negligible amount of heat and therefore reduces the magnitude of noise in the engine bay. When the engine operates at a high rpm and produces high frequencies, the RAAM Audio Mats convert more sound waves to heat through the increase in cyclic shear strain. Stock Low-Density Foam mats were mated onto the exterior of the RAAM Audio Mats. These foam mats target mid-range frequency sound waves for when the engine is running at a low to moderate rpm. The foam mats contain cubic cells with connecting pores allowing sound waves to travel into cavities and become absorbed [5]. From testing, porous materials 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 kept constant. 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 for the engine bay lined with just the RAAM Audio Mats and the RAAM Audio Mats combined with the stock foam mats were compared to the original decibel readings obtained from the stock sled. Figure 5 shows the results of the experimentation for decibel meter readings on the left side of the sled (other tests show in appendix). The stock sled was effective in deadening low frequencies, but decibels increased almost linearly with frequencies until 2000 Hz where readings began to level off. In the trial with the RAAM Mats, figure 5 shows decibel readings drop significantly from frequencies ranging from 2000 to 2900 Hz. However, the RAAM Mats did not make any substantial changes to frequencies below 2000 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.

The same RAAMmats were chosen to line the interior of the newly created snow flap to target sound generated from the exhaust and track movements. Speakers were laid on top of the track in the tunnel facing right and left and decibel readings were taken 2 ft. behind the bumper. Figure 8 shows the results of the RAAM Mat-lined snow flap compared to the original design. The RAAM mat was effective in reducing mid-range to high dB levels of sound emitted from the sled.

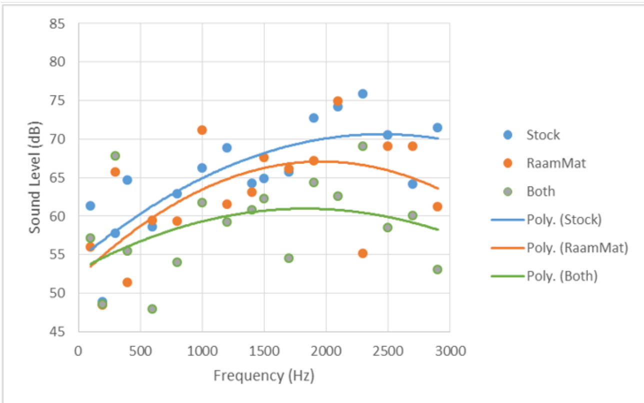

Figure 5. Sound level data from left side (from driver's perspective) of snowmobile.

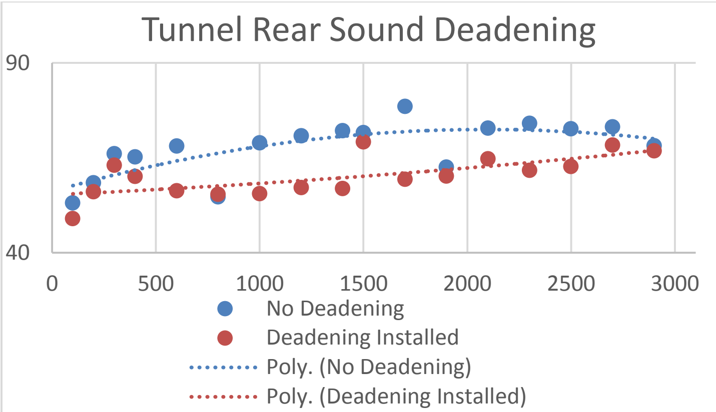

Figure 8. Sound level data from rear of tunnel.

Snow Flap

ISU chose to design its own snow flap for a variety of reasons which make the riding experience slightly more enjoyable for the customer. The focus was on three main criteria: durability, sound reduction, and manufacturability. With each as important as the other, balancing these attributes was task in itself. The flap bracket was made out of 12 gauge standard steel with a flat pattern print of 24”x10” utilizing 87.5% of the stock required to manufacture the part. This reduction on scrap saves on cost and is environmentally friendly. With the pattern either laser cut or punched, only three bends need to be made to complete the bracket. RAAMat sound deadening mat was installed to the back side of the bracket once all bends were made. Although this adds cost in both material and labor hours, the sound waves that vibrate off the bare metal counter one of the original criteria of the flap, to reduce track noise. The pre-cut piece of high-density rubber was then fastened onto the bracket while covering the entire rear of the track. Sound testing frequencies ranging from 100Hz to 2900Hz of the two snow flap designs (stock snow flap and ISU’s newly designed) was conducted and compared. Percentage differences of recorded decibel readings at all frequencies was reduced ranging from 3.68-24.45% with an average decibel change of 10.8% corresponding to 7.5dB. The reduction in sound directly parallels with the mission of the Clean Snowmobile Challenge to reduce noise emmision.

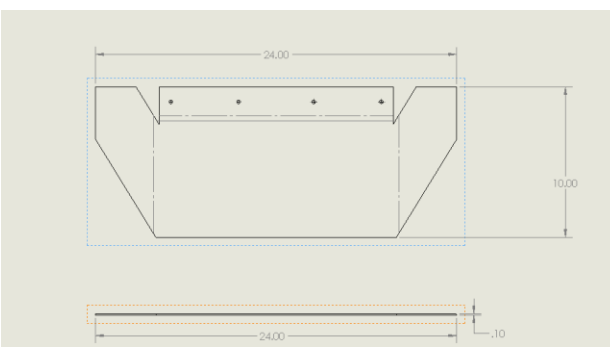

Figure 9. Dimensional view from snow flap design.

Figure 10. Rear snow flap installation.

Weight Reduction

To fulfill the team’s weight reduction strategy, Hydrobead© was implemented to reduce snow buildup in the tunnel. The proprietary mixture was applied to the underside of the tunnel in order to reduce the potential weight of snow building up on these surfaces during operation. This substance allows for the sprayed snow to slip off of these metallic surfaces, due to its chemical properties.

To test the mixture’s effectiveness, the team conducted an experiment proving that friction between a metal surface and snow was decreased after application. A 9.5 pound (34.5” x 16.5”) rectangular piece of sheet metal was pulled across the snow while bearing a 21.4 pound weight in the form of a bucket and contents inside the bucket (Figure 1). A string and scale (combining for a total of 36”) were used to measure the force required to start motion (static) and maintain motion (kinetic) across the snow.

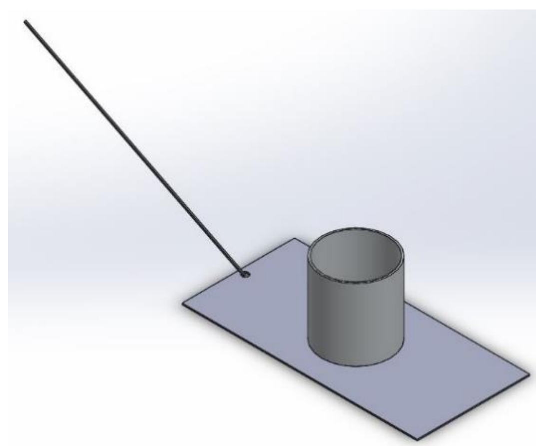

Figure 11. The mechanism used in the experiment, with the addition of a scale attached to the free end of the rope, drawn in SolidWorks.

Trials were conducted before and after the Hydrobead© mixture was applied to the piece of metal to test the static and kinetic forces. Once the Hydrobead© was applied, the minimum static force was reduced from 12.2 lbs. to 7.6lbs and the kinetic force was reduced from 7.5 lbs. to 3.5 lbs. (Figure 2). This reduction in forces led to the reduction in friction calculated by using the equations below:

$$F * \cos(\theta) = m * g * \mu$$

$$F * \cos(\theta) = w * \mu$$

$$\%\,Reduction = \left(\frac{\mu_1 - \mu_2}{\mu_1}\right) * 100$$

	Before Hydrobead Treatment	After Hydrobead Treatment	Percent Reduction
Minimum Static Force (lbf)	12.2	7.6	37.70%
Kinetic Force (lbf)	7.5	3.5	53.30%
μs	0.353	0.219	37.70%
μk	0.217	0.101	53.30%

Figure 12. The table above shows the results from the experiment. The static force was reduced by 37.70% and the kinetic force was reduced by 53.30%

ENGINE

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 piggyback system with an Indy 800SP engine control unit (ECU) allowed for adjustments of fuel amounts of up to 100% leaner, to 250% richer, only constrained by injector volumetric flow limits. In addition to the Power Commander, Iowa State installed a POD-300 Digital Display that will make viewing critical engine parameters possible while away from shop computers. The 5V signal input on the PCV was employed by ISU for the addition of a fuel sensor to monitor isobutanol composition. Also, a wideband O_2 sensor was installed to analyze the air-fuel ratio in the exhaust stream, which is also viewable on the POD-300 display. Using a Power Commander V in conjunction with the stock ECU has allowed ISU to dynamically modify air-fuel mixtures while in operation.

Isobutanol Fuel

For the 2015 SAE Clean Snowmobile Challenge, a requirement is for teams to run an isobutanol blended gasoline ranging in volumetric composition from 16-32%. Isobutanol has been shown to be much more environmentally sustainable than ethanol. It is far less corrosive and does not have an issue with water solubility like ethanol [6]. In addition to these positive attributes, isobutanol can be manufactured in existing ethanol plants that could otherwise be demolished and increase environmentally sensitive waste [1]. Isobutanol typically has an energy content of about 90-95% that of gasoline. In order for the motor to run efficiently, the fuel mixture needs to be richened to overcome this energy difference. This presented a complex tuning challenge for Iowa State's Clean Snowmobile Team.

Flex Fuel Sensor

In most commercially available flex-fuel automobiles, a dielectric fuel sensor is employed to monitor alcohol levels in the fuel and adjust injection amounts accordingly. Since isobutanol has a slightly different dielectric constant than that of ethanol, the sensor readings, normally ranging from 50-150Hz for 0-100% ethanol respectively, needed to be adjusted [7]. However, these calculations were not finished prior to submission. The Iowa State Clean Snowmobile Challenge Team implemented a Continental 13577429 Flex Fuel Sensor in the fuel line. In order for the Power Commander V to communicate with this fuel sensor, a frequency to voltage converter circuit needed to be designed. The schematic is as follows.

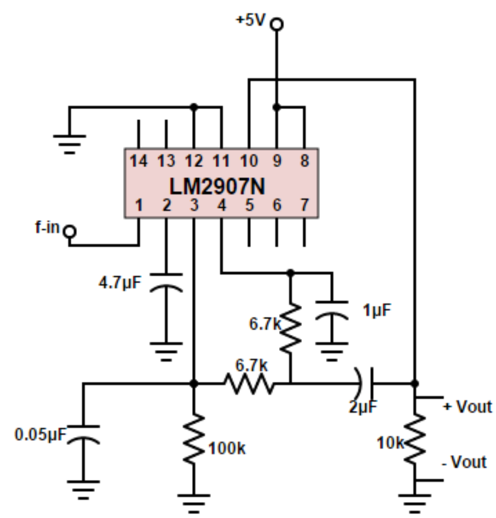

Figure 13. Frequency to voltage converter utilized in conjunction with GM 13577429 Flex Fuel Sensor.

The values for C1, C2, and R1 were calculated (presented in equations to follow) to maximize the voltage range for frequencies between 0-150Hz. The capacitance of C2 is fairly arbitrary and was chosen as 4.7μF to increase discharge time and reduce response of the converter. As well, R1 is dependent on the value of C1. The value of this capacitor was chosen as 100μF mainly because the club had it readily available. Using the equations below, a simple theoretical linear relationship can be modeled to predict voltage outputs based on frequency input as seen in figure 13.

$$R_1 = \frac{1}{C_1 * f_{max}} = \frac{1}{150Hz * (1.0 * 10^{-6})F} = 6.7\ k\Omega$$

$$V_{out} = \left(\frac{Vcc}{f_{max}}\right) * f_{in}$$

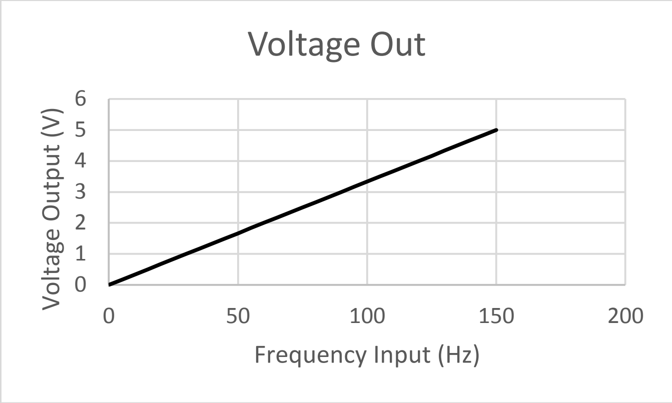

Figure 14. Linear interpolation of voltage output from converter circuit compared to frequency input.

At the time of this submission, further testing still needed to be carried out before values could be quantified. Once these signal responses are calculated, the Power Commander outputs a fuel adjustment based on AFR ratios between regular 91-octane gasoline and the isobutanol blend.

Isobutanol Comp (%)	Energy Density (MJ/l)	Stochiometric AFR (kg-air/kg-fuel)	Fuel Adjustment Required (%)
0	32.075	14.7	0
30	30.54	13.6	8
50	29.515	12.9	14
70	28.49	12.2	20
100	26.95	11.2	31

Figure 15. Table showing fuel composition characteristics including energy density, stoichiometric air-fuel ratio, and fuel adjustment required ("Politehnica" University of Timişoara).

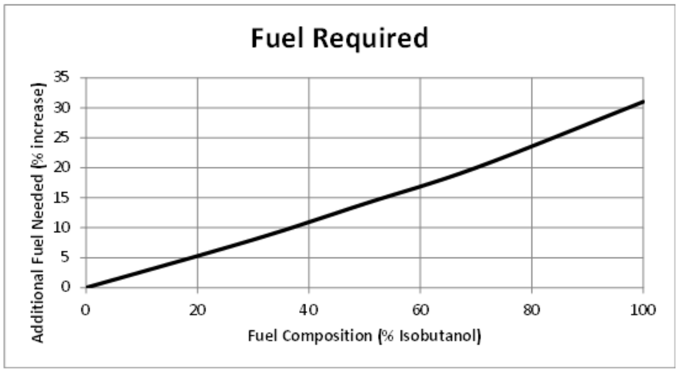

Figure 16. Fuel enrichment requirements by percentage over stock based on fuel composition by percentage of isobutanol.

This relationship worked out to be a quite linear relationship which allows the fuel curves to be easily modified by the Power Commander based on the flex fuel sensor's reading.

SUMMARY/CONCLUSIONS

Iowa State University Clean Snowmobile Challenge Team has developed and tested a clean machine for entry into the 2015 Clean Snowmobile Challenge. Making cost effective and environmentally conscious decisions has allowed for the production of a snowmobile that can be used in sensitive areas without a great increase in retail price. With these changes made, the Polaris Indy 800SP platform retains high performance characteristics sought after by enthusiasts. ISU's first entry into the annual CSC completion is an economical, efficient, and high-performing solution to an industry in need of sustainability.

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ABBREVIATIONS

AFR Air-Fuel Ratio

CSC Clean Snowmobile Challenge

ECU engine control unit

ISU Iowa State University

PCV Power Commander V

QFD quality-function diagram

APPENDIX

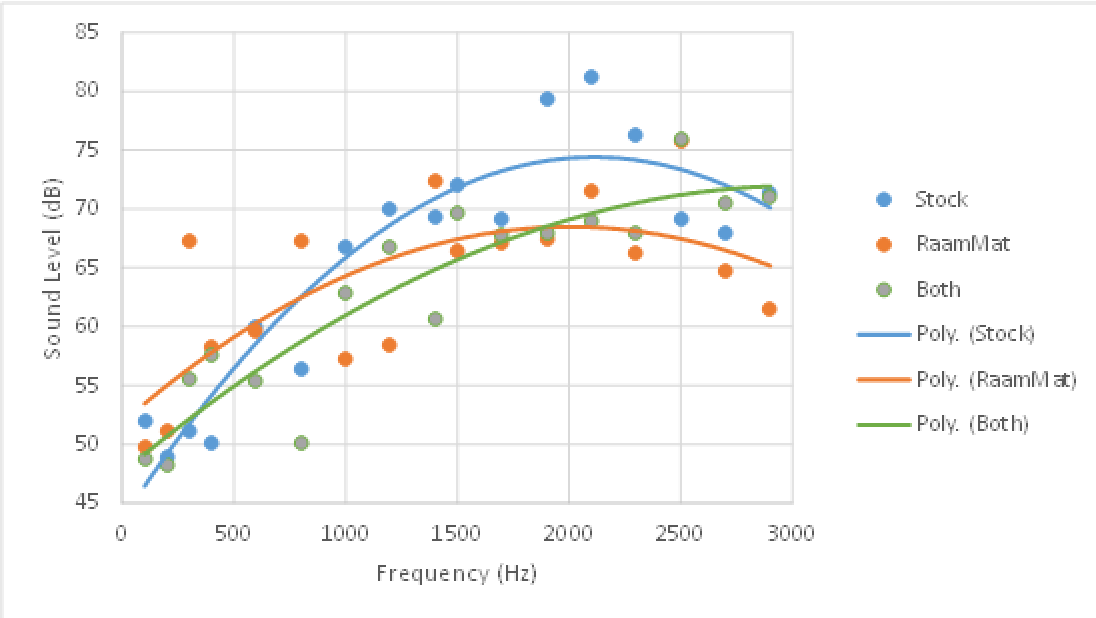

Figure 5. Sound level data from front of snowmobile.

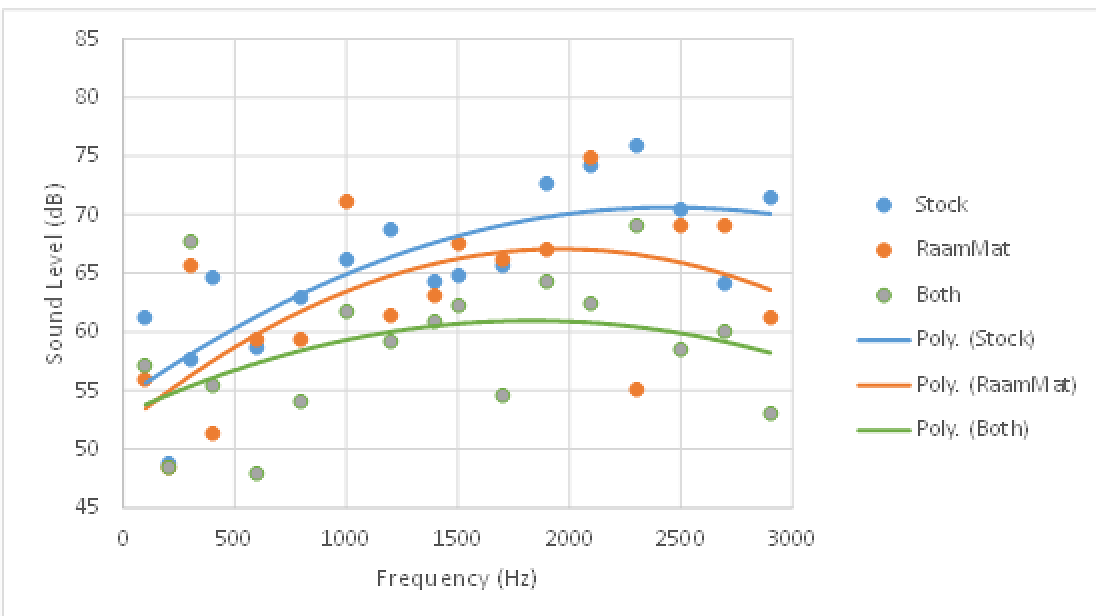

Figure 6. Sound level data from driver's left of snowmobile.

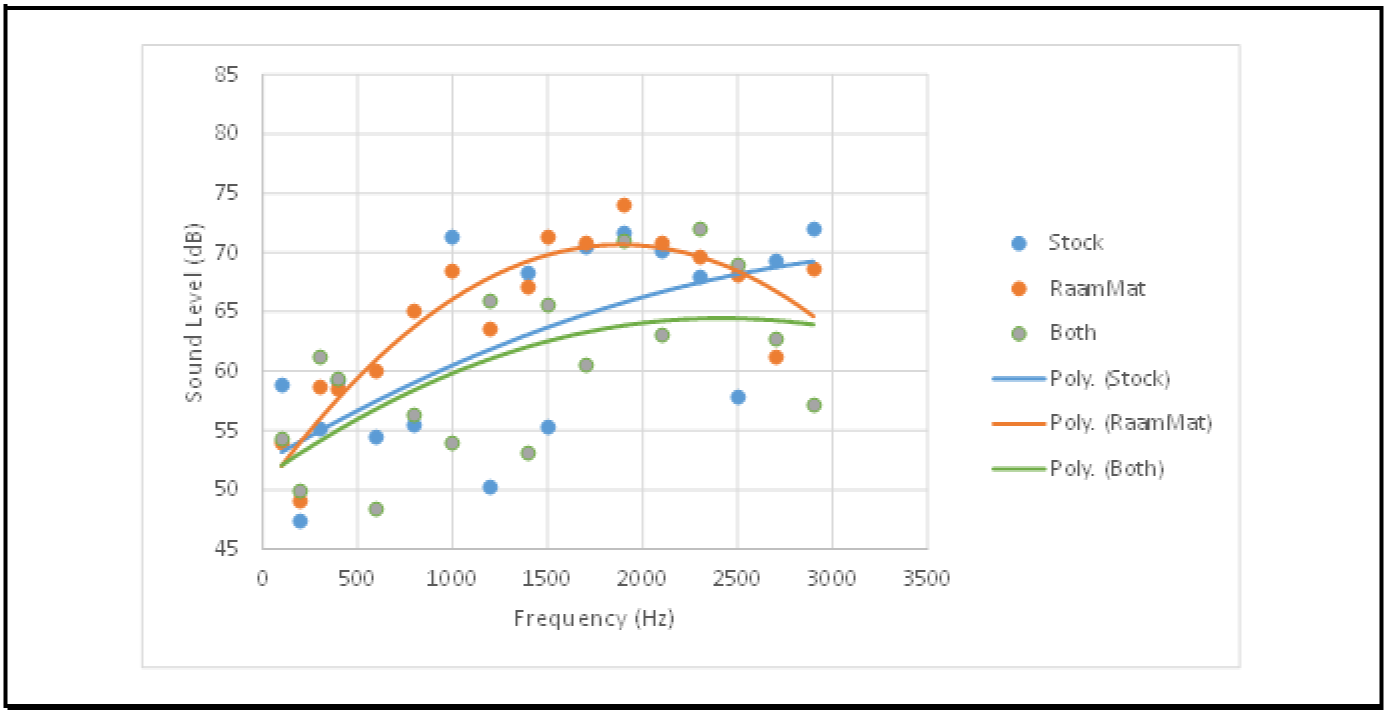

Figure 7. Sound level data from driver's right of snowmobile.

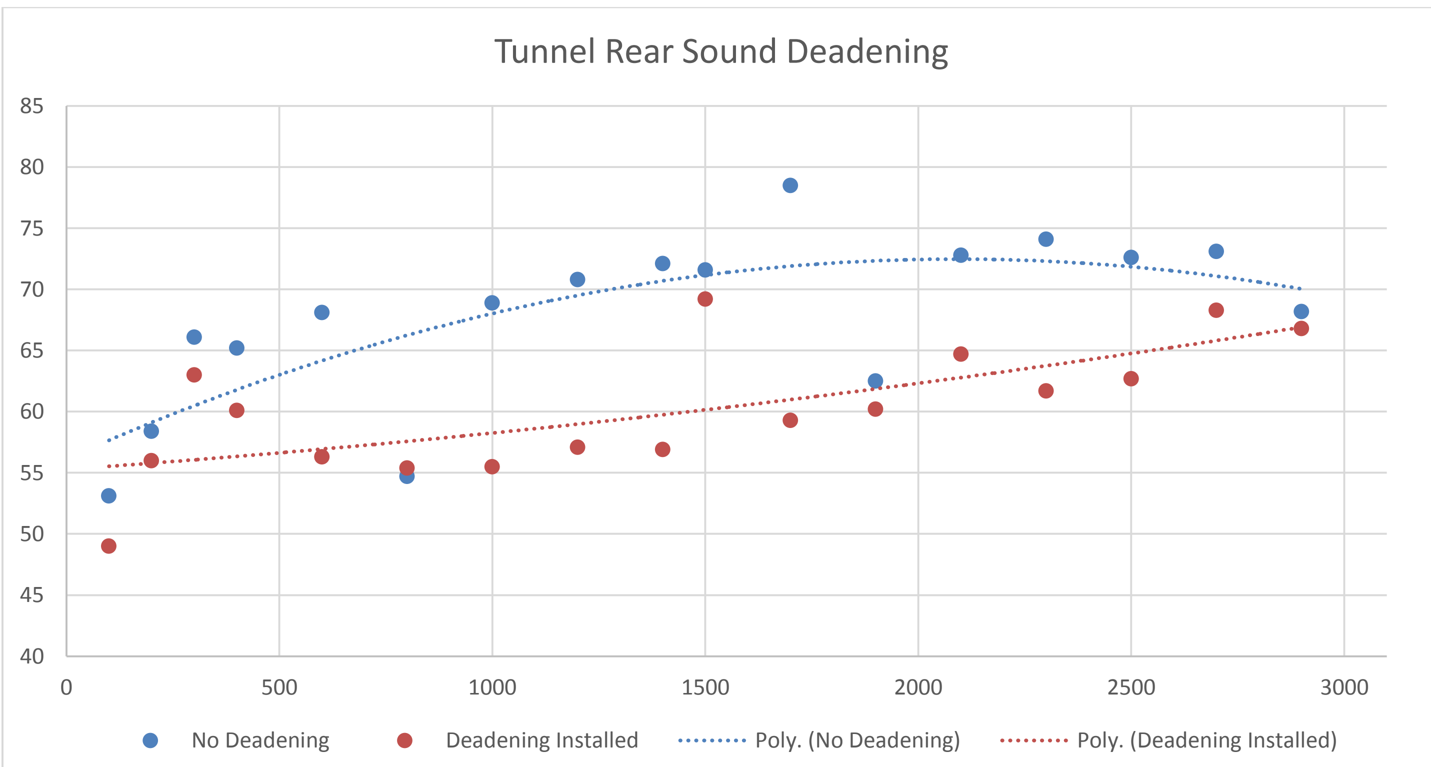

Figure 8. Sound level data from rear of tunnel.

	Before Hydrobead Treatment	After Hydrobead Treatment	Percent Reduction
Minimum Static Force (lbf)	12.2	7.6	37.70%
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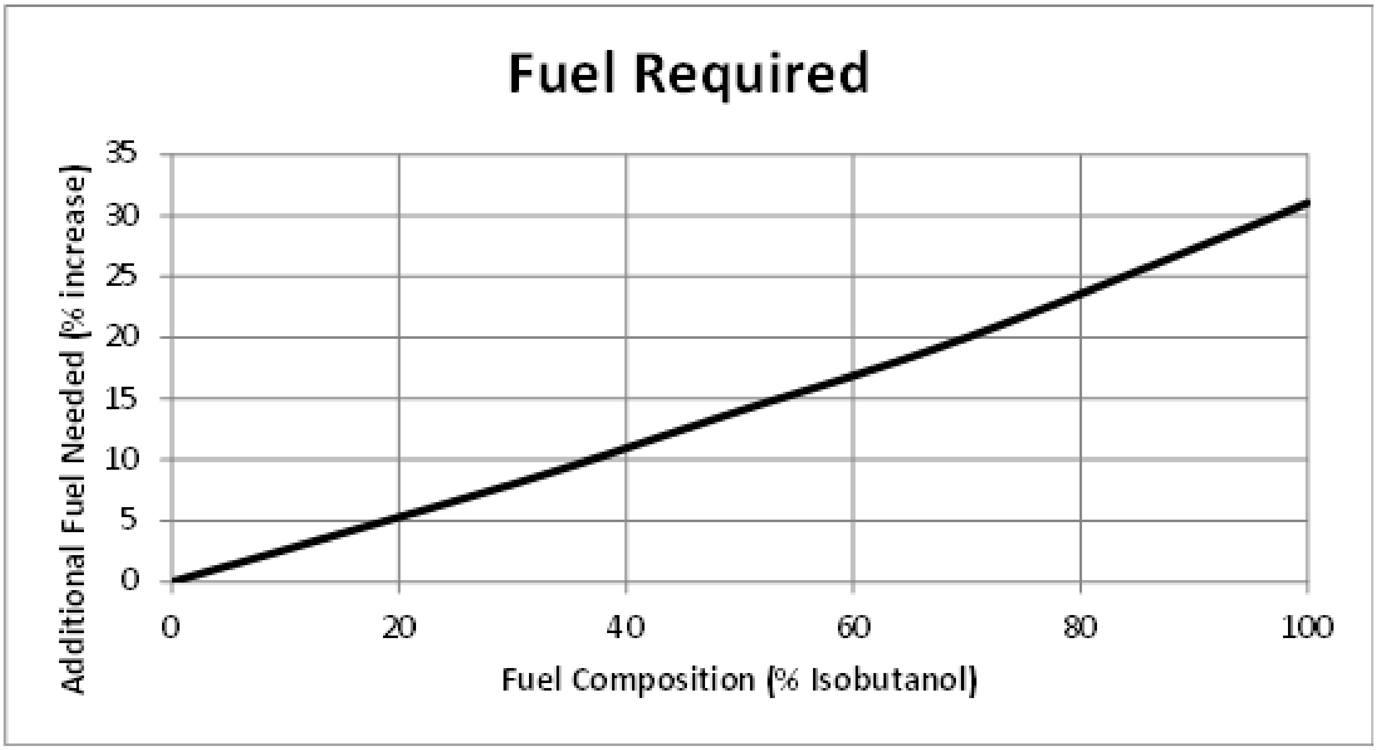

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