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2018 Ferris State University Clean Snowmobile Challenge Design Summary for a Two-Stroke Snowmobile Featuring Clutching, EFI Tuning, and Custom Exhaust

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Innovations Overview

2018 marks the founding of the Ferris State University SAE International Clean Snowmobile Challenge team. Thanks to the generosity of Polaris Industries®, the team has been able to start off strongly with the donation of a 2017 Polaris 800 Switchback Assault 144 equipped with an 800 Cleanfire H.O.® two-stroke engine.

The engine was modified to be Ethanol compatible and reduce emissions using the following modules: Dynojet PowerCommander V®, Dynojet AutoTune Module, and Zeitronix® Ethanol Sensor. These modules allow the team to modify air-fuel ratios in the tuning process, dynamically adjust trim during standard operation, and automatically adjust stoichiometric air/fuel ratios with the introduction of different concentrations of ethanol, respectively.

To further reduce overall emissions, a catalytic converter was sized and installed in conjunction with a custom muffler/resonator. The muffler concept is driven heavily by packaging. The main restraint in packaging a catalyst in a sled with a two-stroke engine is the expansion chamber, which connects directly to the muffler, leaving no space for a catalyst. The solution is to place the catalyst next to the muffler so the exhaust gasses can flow into the lower chamber, redirect upward, then downward through the outlet pipe. This maximizes the distance the gas will flow in the muffler allowing for the maximum amount of space to insert baffles and perforated pipes. The baffles and pipes have been through rigorous design modifications and simulations to maximize insertion losses of the system at peak frequencies produced by the engine.

Team Organization and Time Management

For many on the team, this project has been a long time coming. The team originated as a group of sophomore students who wanted to be involved with a student organization that is different from the design teams that Ferris State University had already offered. Prior to this year, the school had teams competing in SAE events such as Formula SAE, Formula Baja, and Formula Hybrid, as well as the ASME Human Powered Vehicle event. The Clean Snowmobile Challenge (*CSC*) provided a way to use cutting-edge technology in production vehicles for practical purposes that none of the other teams could match.

A team of interested students quickly formed upon the discovery of the *CSC*, starting with the three captains Luke Summey, Adam Makarewicz, and Josh Heckroth. To increase their understanding of the challenge, Luke and Josh spectated on the 2017 event; taking notes, asking questions and networking with other teams. After leaving the competition, the camaraderie and ingenuity of the event motivated the captains to push for a team to get started.

Various design groups formed including Engine Control, headed by Luke Summey (President) and Ben Shrivers (Co-Secretary), Emissions, headed by Josh Heckroth (Vice President), and Adam Makarewicz (Treasurer), Muffler, headed by

Savanah King (Co-Secretary), and Driveline headed by Matt Crawford (Co-Secretary).

Once design groups were formed, the next step was to secure sponsorships. Lakeside Motorsports in Mecosta, MI was the first to jump on board offering an annual monetary sponsorship and a substantial parts discount. Shortly after, Polaris Industries offered to donate a test snowmobile to the team. This lifted the burden of purchasing a sled with the limited funds that the team had at the time, but did restrict the ability to perform a selection of an ideal sled for the competition. Several other sponsors have helped with their services, most notably, Faurecia and Bikeman Performance, who gave great advice on acoustics and ethanol tuning.

Timelines were set largely by the project group heads, with the President mediating between them to ensure there were no scheduling conflicts. This was the best approach because Luke spent Fall 2017 out of state on a co-op, so he could perform project manager duties remotely.

Fabrication was made possible due to the help from Welding Engineering students who volunteered their time and expertise to assemble the complex baffle and shell design in the muffler. Once the muffler was finished, the catalyst was fitted to the side of the muffler and heat shielding was installed to protect temperature-sensitive components.

Preliminary emissions and noise tests were performed in November 2017 using equipment from several departments within the College of Engineering Technology. Unfortunately, there was not an option to do dynamometer testing at the time because no one in the area had the correct equipment. In an unfortunate turn of events, the Mechanical Engineering Technology department did purchase a DYNOmite water-brake dynamometer, but it was faulty upon delivery, so no torque measurements were possible as of the writing of this paper. To ensure that there were improvements made to the sled, the team performed several tests which will be discussed in detail in the appropriate sections.

After emissions, efficiency and noise accommodations were made, performance was finally able to be considered. Matt Crawford selected flyweights that could maximize chassis performance to compensate for the reduced maximum power of the engine.

Vehicle Description

Because this is the team's first year, the modifications were kept to a minimum, and qualifying for the challenge was held paramount. Due to this, the sled is mostly in its stock condition with additional modifications done to the engine, exhaust, and clutch. Below is a list of specifications for the competition sled.

Chassis:

- 2017 Polaris AXYS

Engine:

- Polaris 800cc Cleanfire H.O.
- Two-stroke gasoline engine
- Estimated stock horsepower of 160
  - Unable to measure horsepower due to faulty dynamometer
  - Horsepower will be limited using a Rev-Limiter tool in the DynoJet PowerCommander V if necessary
- Zeitronix Ethanol Sensor
- DynoJet PowerCommander V
- DynoJet AutoTune AFR Sensor

Track:

- Polaris, 15 x 144 x 1.35 Cobra
- Woody's Traction Control Studs

Muffler:

- A custom design incorporating an arrangement of perforated baffles and tubing

Catalytic Converter:

- MagnaFlow Three-Way catalytic converter

Skis:

- Stock skis
- Woody's Traction Control runners

Other:

- 62-gram Primary Clutch Flyweights

Chassis

The AXYS chassis is designed for endurance and mountain riding. It is one of the lightest chassis systems available on the market, and is factory stock on Polaris models between 2016-2018. The raised chassis is primarily aluminum, making it lightweight and durable, and the lift makes riding on hills easier. The AXYS chassis also gives the sled incredible balance and stability making it one of the best chassis on the market for mountain riding. No alterations were made to the chassis.

Engine

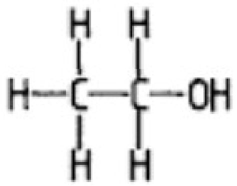
An 800 Cleanfire® H.O. two-stroke engine compatible with ethanol fuel mixtures has been utilized for the *2018 SAE International Clean Snowmobile Challenge*. This two-cylinder engine has 795cc of displacement, with 70mm of stroke. The manufacturer boasts a stock horsepower of 160 at 8250 RPM, which exceeds the maximum horsepower allowed at the *2018 SAE International Clean Snowmobile Challenge*, but the conversion to ethanol fuel, modifications for fuel mapping, and installation of a rev-limiter will reduce the output power to an eligible level when dynamometer tests are performed.

Impact of Ethanol Fuel

Ethanol fuel introduces a unique challenge that most production snowmobiles do not currently face; it is not chemically compatible with many rubbers and sealants used in fuel systems for primarily gasoline engines and, more importantly, requires significantly different mixtures of air and fuel to properly combust.

The air/fuel ratio required to completely combust fuel in the combustion chamber is called the stoichiometric (*stoich*), which is 14.7 parts air for every one part fuel in pure gasoline applications. As ethanol content increases, the stoich decreases linearly, resulting in a value of 9.87 for E85, meaning that it takes less oxygen to completely combust the same amount of fuel. This is a direct result of the fact that ethanol is an *oxygenated fuel*, meaning that the chemical makeup of ethanol contains oxygen atoms shown below.

Ethanol (Ethyl Alcohol) (C_2H_5OH)



Ethanol is 34.73% oxygen by weight, equating to a stoichiometric ratio of 9.00. A linear relationship from 9.0 to 14.7 can be interpolated to accommodate for any concentration of ethanol. A Zeitronix ethanol sensor is utilized in the return fuel line allowing the engine control unit to adjust air/fuel ratios accordingly.

Effect of Lambda on Emissions

The percent variance from the operating air/fuel mixture to the stoich can be represented by *Lambda* (λ). An air/fuel mixture with a Lambda of 1.0 means that the air/fuel ratio in the combustion chamber is exactly in line with the stoich. Any Lambda value less than 1.0 refers to an air/fuel ratio with more oxygen than stoichiometric, while anything greater than 1.0 contains more fuel than stoich. These conditions are called *Lean* and *Rich* respectively. Lean and rich mixtures create predictable levels of Hydrocarbons (HC), Carbon Monoxide (CO), and Oxides of Nitrogen (NOx).

The two-stroke engine cycle has an inherent disadvantage on hydrocarbon emissions due to the mixing of exhaust gasses with the air/fuel mixture. Improper exhaust and engine tuning can cause excessive unburnt fuel to be expelled from the tail pipe, so it is crucial to properly balance the air/fuel mixture in the combustion chamber with the exhaust system. Due to the installation of a catalytic converter, special considerations must be taken. A *selectivity window* can be determined by measuring the effect of changes in Lambda on concentrations of HC, CO, and NOx. (Figure 1)

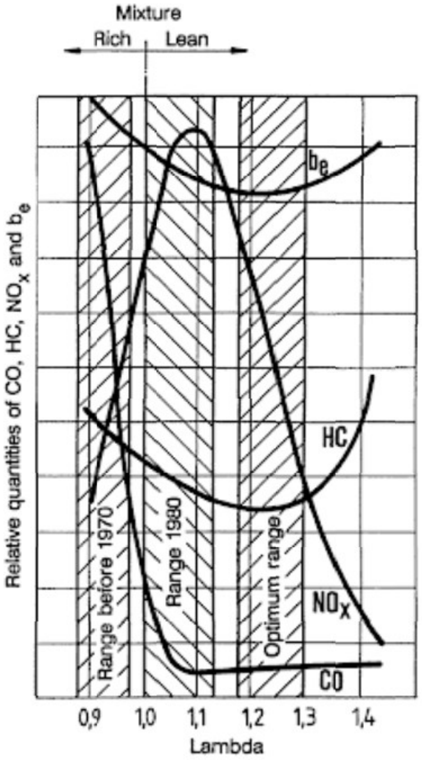


Figure 1 Lenz, 1992

A major issue that arises when running an engine with a lean mixture is the increased possibility of detonation. It is important to monitor the temperature of the engine during testing to verify that cylinders are not generating too much heat for the engine to handle. This can cause both a catastrophic failure of the engine and an uncontrolled thermal event. Lambdas of 1.2-1.3 cover a range that is considered optimal for emissions, but due to the safety concerns regarding detonation, the team will be targeting a range between 1.06 and 1.1. This is not ideal for reducing NO_x, but the reduction of HC emissions is held at a higher importance to the team.

Effect of Lambda on Fuel Economy

Fuel economy is also dictated greatly by Lambda. Balancing Lambda is done by performing dynamometer testing in conjunction with emissions testing to optimize air/fuel ratios at different throttle position/RPM combinations. A chart of these ratios is called a *fuel map*. The fuel map is programmed into the engine control unit, and can be controlled using a Dynojet PowerCommanderV® and adjusting lambda as preferred.

The graph below suggests that a lean fuel mixture will increase fuel economy, but it will also decrease engine power.

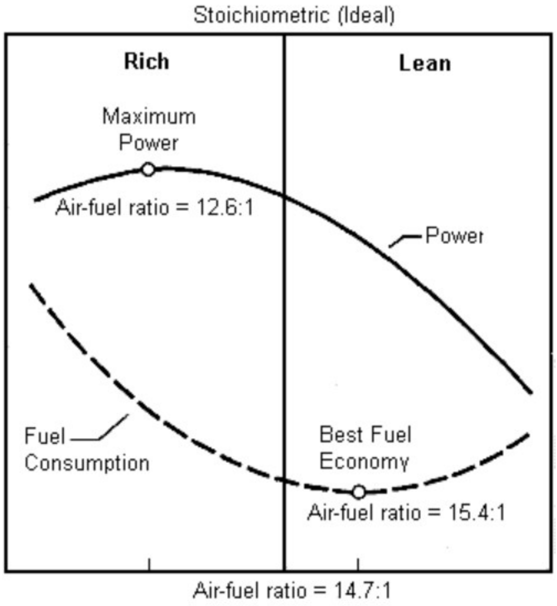
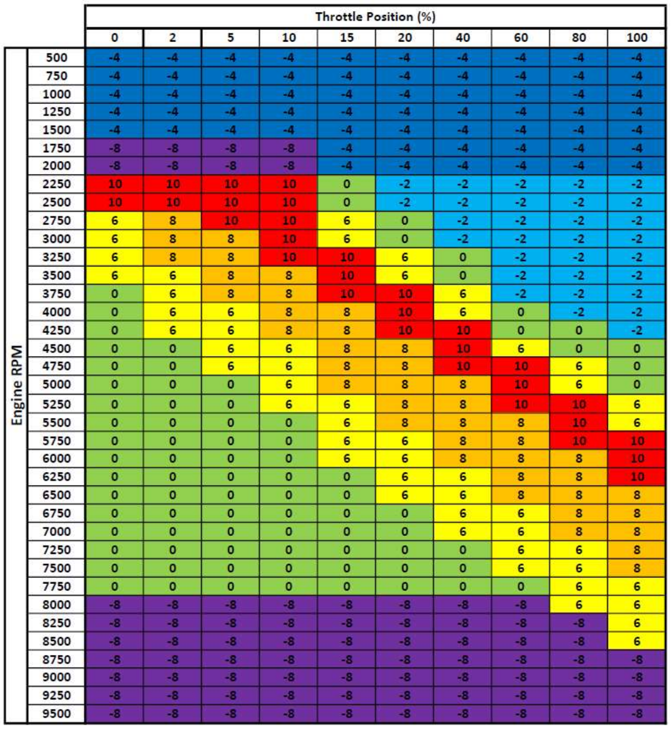


Figure 2 Air-Fuel, 2018

Fuel Mapping

Compromises were made with considerations of both fuel economy and emissions.



	Throttle Position (%)									
Engine RPM	0	2	5	10	15	20	40	60	80	100
500	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
750	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
1000	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
1250	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
1500	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
1750	-8	-8	-8	-8	-4	-4	-4	-4	-4	-4
2000	-8	-8	-8	-8	-4	-4	-4	-4	-4	-4
2250	10	10	10	10	0	-2	-2	-2	-2	-2
2500	10	10	10	10	0	-2	-2	-2	-2	-2
2750	6	8	10	10	6	0	-2	-2	-2	-2
3000	6	8	8	10	6	0	-2	-2	-2	-2
3250	6	8	8	10	10	6	0	-2	-2	-2
3500	6	6	8	8	10	6	0	-2	-2	-2
3750	0	6	8	8	10	10	6	-2	-2	-2
4000	0	6	6	8	8	10	6	0	-2	-2
4250	0	6	6	8	8	10	10	0	0	-2
4500	0	0	6	6	8	8	10	6	0	0
4750	0	0	6	6	8	8	10	10	6	0
5000	0	0	0	6	8	8	8	10	6	0
5250	0	0	0	6	6	8	8	10	10	6
5500	0	0	0	0	6	8	8	8	10	6
5750	0	0	0	0	6	6	8	8	10	10
6000	0	0	0	0	6	6	8	8	8	10
6250	0	0	0	0	0	6	6	8	8	10
6500	0	0	0	0	0	6	6	8	8	8
6750	0	0	0	0	0	0	6	6	8	8
7000	0	0	0	0	0	0	6	6	8	8
7250	0	0	0	0	0	0	0	6	6	8
7500	0	0	0	0	0	0	0	6	6	8
7750	0	0	0	0	0	0	0	0	6	6
8000	-8	-8	-8	-8	-8	-8	-8	-8	6	6
8250	-8	-8	-8	-8	-8	-8	-8	-8	-8	6
8500	-8	-8	-8	-8	-8	-8	-8	-8	-8	6
8750	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8
9000	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8
9250	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8
9500	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8

Figure 3 Fuel Map Adjustment Table

The table above represents a percentage increase of air/fuel ratios from the stock fuel map and is color coded for clarity.

Region 1: Rich Idle Position

- Violet region at low RPM and low throttle position
- Rich mixture to apply adequate oil to cylinders upon startup

Region 2: Lean Idle Position

- Red region with slightly higher RPM than region 1
- Lean mixture to decrease warmup time

Region 3: Draw Bar Pull Test

- Light blue area in high throttle position and low RPM
- Rich mixture to increase power during draw bar test and acceleration events

Region 4: Optimal Trail Conditions

- Red, orange, and yellow regions along diagonal
- Lean mixtures maximize fuel efficiency and emissions

Region 5: High RPM

- Violet region at RPMs above 8000
- Keeps the engine cool and prevents thermal events at high RPM

Noise

Preliminary Testing

The OEM exhaust anatomy consists of an expansion chamber and resonator. The internals of the stock resonator are shown in figure 4, with a student-made custom muffler in figure 5.

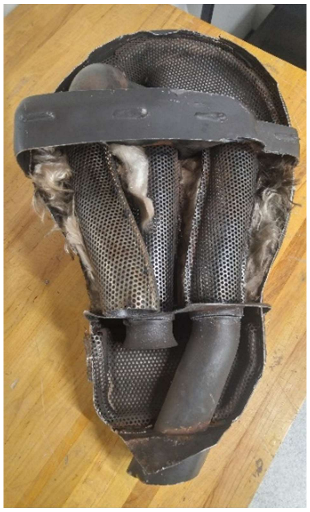


Figure 4 Stock Muffler

Figure 5 Student Designed Muffler

Initial sound levels were recorded with an octave band analyzer. dBA measurements were taken on each side of the snowmobile at five feet and then at 50 feet. Measurements were also taken at idle and then at a speed of 35 miles per hour to simulate testing conditions. Noise levels ranged from 70 dBA to 80 dBA. These are higher than the levels accepted at the *Clean Snowmobile Challenge*. Decibel levels were higher on both the left and right sides of the snowmobile leading us to believe most of the noise came from the engine.

A straight pipe test was conducted by removing the stock muffler and placing a two-inch diameter pipe at the end of the expansion chamber to get a baseline sound level of the engine. Results showed 80 dBA to 90 dBA levels at 250 Hz and above. For the competition, we decided to concentrate on *attenuation* or reducing the sound level of these frequencies.

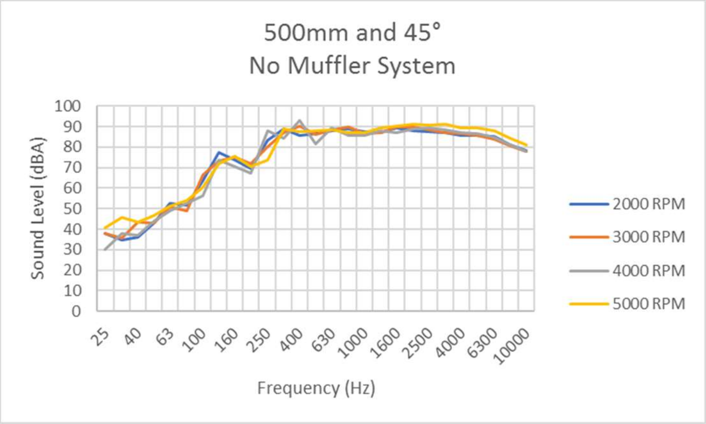


Figure 6 Straight Pipe Octave Band Analysis

Muffler Design

A new muffler was designed to make room for the addition of a catalytic converter. The shell was designed to optimize packaging restrictions with plates for ease of fabrication. The custom muffler contained different types of geometry to help attenuate engine noise including: several large chambers, baffles, a perforated plate, and a perforated outlet pipe.

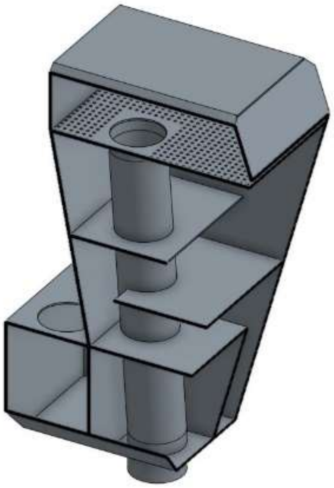


Figure 7 Student Designed Muffler 3D Model

These mentioned features were simulated by Faurecia to predict the amount of *insertion loss*, or the amount of noise reduction each would have. An example of an insertion loss graph produced by these simulations is shown below. This graph suggests that perforations in the bottom of the outlet pipe (violet), instead of the middle or top, will lead to higher attenuation of frequencies above 400 Hz. The baffles showed slightly higher insertion loss readings than an empty chamber. Smaller, more restrictive perforates in the top baffle also showed higher insertion loss levels than bigger perforates. These features were selected because simulations indicated higher insertion loss values at high frequencies, which tend to be unpleasant to the human ear.

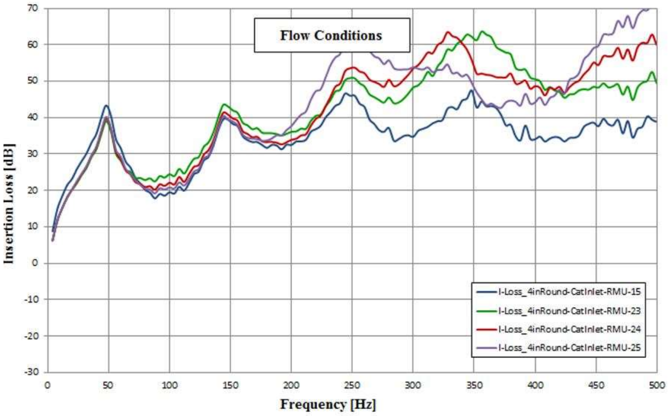


Figure 8 Insertion Loss of Variable Pipe Perforations

Noise Results

A follow-up octave band analysis showed lower dBA levels for higher frequencies as RPMs increased with the most attenuation being seen from 1250 Hz and above at 5000 RPM. These results show the dampening of broad band higher frequencies, which was a design goal. These lower levels are easier on human hearing and make the snowmobile more tuned for trails. The design, however, does not attenuate lower frequencies as much but these frequencies are not as noticeable.

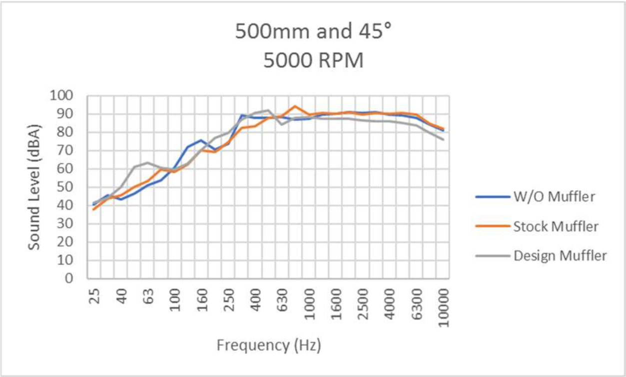


Figure 9 Sound Level Comparison

Emissions

In consideration of implementing a custom exhaust system to meet emission requirements, the stock system was analyzed for baseline values such as emissions, mass flow, backpressure, and heat. These values were gathered before any further modifications so that a custom design could take shape with target values.

Two stroke snowmobiles emit nearly 95 times the pollutants of automobiles because they pass roughly 20% - 30% of fuel straight through the exhaust unburned. This, along with the lubricating oil mixed with the gasoline, contributes to the harmful pollutants and the visible haze. (Millner, 2018)

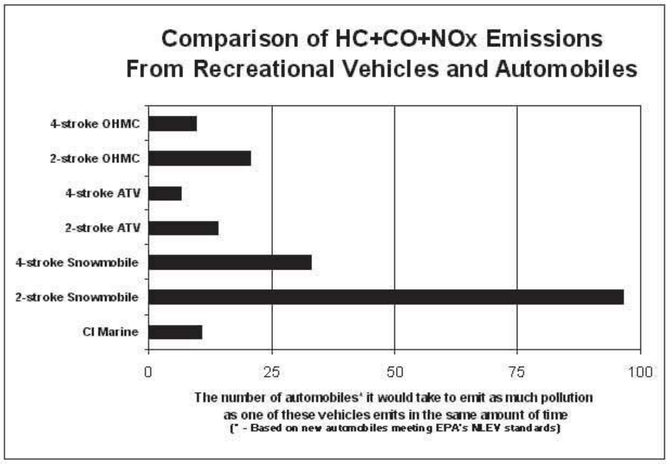


Figure 10 Millner, 2018

Preliminary Testing

To begin, the stock system was tested to give benchmark numbers for exhaust flow rate, emissions content, and flow restriction. Instruments such as a Pacer Instruments Volume Flow Anemometer model DA10, a HORIBA Automotive Emissions Analyzer MEXA-584L, and backpressure simulations provided by Faurecia were used respectively. A summary of the test results can be found in figures 11 and 12.

Exhaust Summary		
Stock System		
Average Velocity	1818.3	FPM
Volume Flow Rate	44.76	ft^3/min
Density	0.078	lb/ft^3
Mass Flow Rate	3.474	lb/min

Figure 11 Exhaust Flow Characteristics

Exhaust Gas Content						
	Speed (mph)					
	Idle	10	15	20	25	30
RPM	1750	3300	3750	4100	4300	4450
%CO	1.49	2.73	3.23	2.5	2.71	3.95
%CO2	2.52	3.68	4.16	5.26	6.68	5.82
%O2	15.73	12.63	11.55	10.91	8.5	8.44
%HC	0.561	0.66	0.662	0.486	0.491	0.534
%NO	0.0048	0.0065	0.0081	0.0032	0.003	0.0067
%Air	79.694	80.294	80.390	80.841	81.616	81.249
Percent Emissions	20.306	19.707	19.610	19.159	18.384	18.751

Figure 12 Exhaust Gas Content

Catalyst Selection

To reduce the overall emissions of the snowmobile, a three-way catalytic converter was added parallel to the custom muffler design. The above information determined the selection of the catalytic converter.

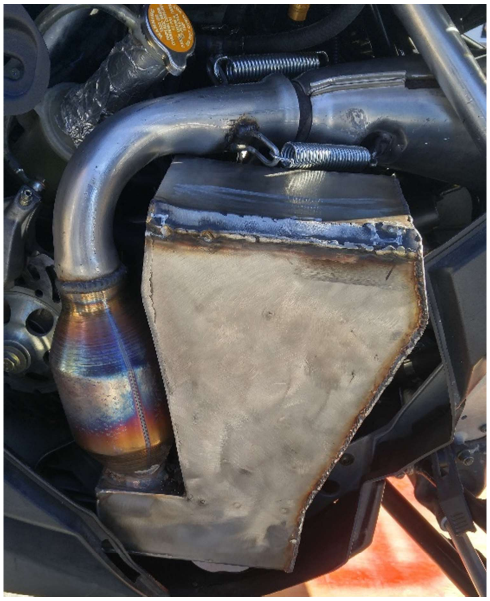


Figure 13 Student-Built Design

Compared to a two-way catalyst, a three-way catalyst will better reduce the overall emissions due to the basic oxidation and reduction reactions that take place, shown below.

$$2CO + O_2 \rightarrow 2CO_2$$

$$C_xH_y + O_2 \rightarrow CO_2 + H_2O$$

$$2NO \rightarrow N_2 + O_2$$

Due to the passing of unburnt fuel through the exhaust, backpressure must be considered. For this reason, a high flow MagnaFlow metallic substrate catalytic converter was chosen. With 200 cells per square inch, the lower cell density and performance-spun catalyst will reduce restriction on the engine.

Compared to a ceramic substrate, a metallic substrate is rated to better resist higher temperatures. Due to high temperatures at the catalyst interface, rapid expansion of the exhaust gasses will occur and increase the amplitude of the reflected pressure wave on the engine, negatively effecting the performance. (McDowell, 1997) The metallic substrate will dissipate heat faster to reduce this effect, and is more durable than a ceramic substrate. Efficient operating temperatures of the selected catalytic converter have been measured to exceed 800 ºF.

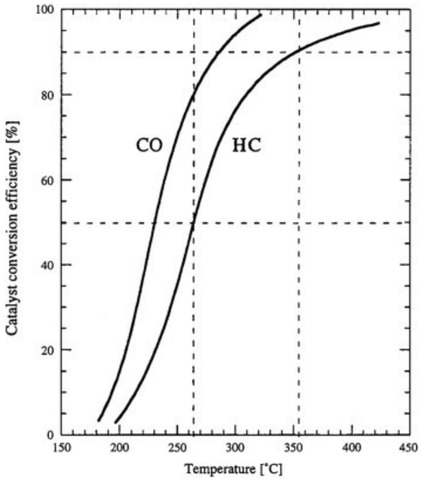


Figure 14 Roberts, 2014

Keeping the surrounding components cool while letting the catalytic converter operate efficiently is a key component to the design. Heat shielding considerations have been made to give appropriate protection of surrounding components.

Final Exhaust Test Summary

The installation of a catalytic converter drastically improved the emissions compared to the stock system. This was done without decreasing performance significantly and flow characteristics were not radically changed.

Exhaust Summary		
New System		
Average Velocity	1632	FPM
Volume Flow Rate	40.16	ft^3/min
Density	0.084	lb/ft^3
Mass Flow Rate	3.407	lb/min

Figure 15 Final Exhaust Characteristics

Based on exhaust simulations provided by Faurecia, the backpressure of the new design was only 0.2 psi greater than the back pressure of the stock system. This verified that the new system is acceptable for the purposes of the *Clean Snowmobile Challenge.*

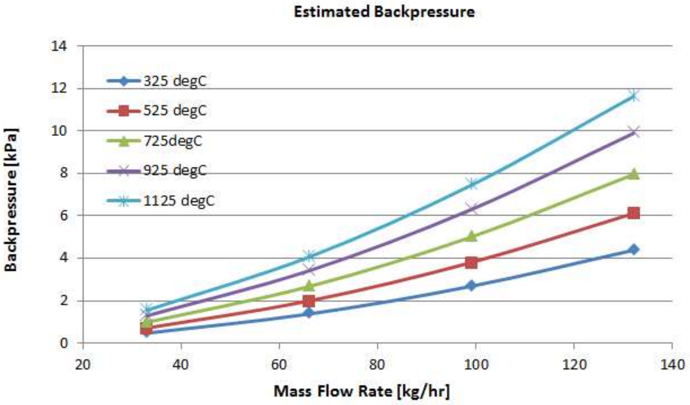


Figure 16 Backpressure Simulation Data

The tables below show the effect of temperature with catalyst efficiency, and overall emissions values.

Stock Emissions with Flex Fuel					
RPM	%CO	%CO2	HC (ppm)	NO (ppm)	%O2
1750	1.94	2.14	5580	99	15.69
3000	3.19	4.32	7440	154	11.65
4000	3.17	4.84	6630	193	10.53
5000	3.29	8.96	3950	208	5.61
6000	2.69	9.86	2980	203	4.54
7000	4.67	8.84	2470	177	4.28

Emissions Test with Flex Fuel and Catalytic Converter					
RPM	%CO	%CO2	HC (ppm)	NO (ppm)	%O2
1750	5.47	7.34	573	10	6.01
3000	5.82	8.26	506	21	4.08
4000	5.51	9.34	423	21	2.83
5000	3.43	10.56	314	27	3.82
6000	3.14	12.22	266	32	1.7

Figure 17 Effects of Catalytic Converter on Emissions

Performance

As a result of engine tuning, the horsepower has been tuned within the constraints of the competition. The remains of the drivetrain must accommodate for this major modification. The stock Continuous Variable Transmission (CVT) is designed to operate at a peak horsepower of 160. In most cases, adjustments would be made to a CVT by method of trial and error, creating combinations of flyweight and pressure spring arrangements. To quantify this tuning process, CVT research was conducted to comprehend the dynamics driving the snowmobile transmission.

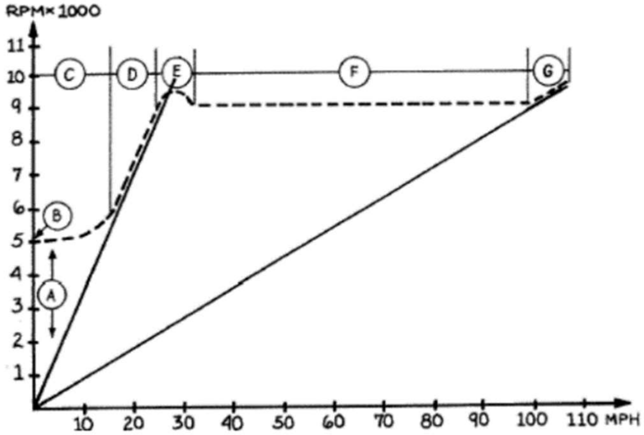


Figure 18 DeGreenia, 2011

The diagram above illustrates the four shift phases of a CVT with constant track resistance on flat ground. Region A to B is referred to as the "Idle" phase. In this phase, the primary clutch is spinning at a constant RPM without gripping the sheave; therefore, no power is transferred to the secondary clutch.

$$\omega_{\text{Secondary}} = 0$$

$$r_{\text{Secondary}} = Max$$

$$r_{\text{Primary}} = Min$$

In region C, the belt is slowly gripped by the primary clutch. The centripetal force of the flyweights is exerted onto the spider which in turn applies a force onto the pressure spring, slowly beginning to turn the secondary clutch. This low ratio, high torque situation can be seen in region D. This phenomenon is known as the "engagement" phase.

$$\omega_{\text{Primary}} > \omega_{\text{Secondary}}$$

$$r_{\text{Primary}} < r_{\text{Secondary}}$$

At point E, the belt radii for each sheave begin to equalize. This creates a 1:1 gear ratio, as displayed in region F. For an instant, the angular velocities and belt radii of the clutches are equal.

$$\omega_{\text{Primary}} = \omega_{\text{Secondary}}$$

$$r_{\text{Primary}} = r_{\text{Secondary}}$$

The vehicle is accelerating as the engine's RPM remains constant. The secondary clutch opens further and increases its RPM throughout the entire horizontal portion of the curve; therefore, the radius of the secondary clutch decreases as the radius of the primary clutch increases. This is referred to as the "Straight Shift" phase.

$$\omega_{\text{Primary}} < \omega_{\text{Secondary}}$$

$$r_{\text{Primary}} > r_{\text{Secondary}}$$

The final shifting sequence of the CVT is called the "Shift Out" phase (DeGreenia, 2013). Region G depicts a high ratio situation when the belt radius is the smallest it will be on the secondary sheave. This increases the secondary clutch to its maximum RPM which in turn increases the engines RPM.

$$\omega_{\text{Secondary}} = Max$$

$$r_{\text{Secondary}} = Min$$

$$r_{\text{Primary}} = Max$$

To change the RPM of both clutches there are four input variables:

1. Flyweights – Located in the primary clutch, higher horsepower needs more flyweight mass to engage the clutch, assuming the RPM remains constant. This will yield a faster upshift scenario. If the weights are too heavy the primary clutch will open too fast, resulting in less acceleration and lower top speed.

2. Pressure Spring – Located inside of the primary clutch, the higher the spring rate, the higher the primary sheave RPM will be before engagement occurs.
3. Torque Spring – Located inside of the secondary sheave, this spring controls the backshift of the clutch. The higher the spring constant, the slower the clutch will open. If the spring rate it too low, this may result in belt slippage.
4. Helix – Located within the secondary clutch, the driven cam reacts to the torque applied to the track throughout various driving conditions and applies proper pressure to the belt. The steeper the helix angle, the more aggressive the clutch will shift and accelerate.

This research concludes that the only variable that needs adjustment are the flyweights. Since the secondary clutch is primarily used for back shifting and top speed purposes, the torque spring will remain stock. The helix cam is torque sensitive; therefore, the angle of this component does not need to be changed solely off engine horsepower decrease.

To solve for the flyweight mass needed to shift the clutch the same as the original horsepower reading, a recommended clutch weight calculator from Bikeman Performance was used.

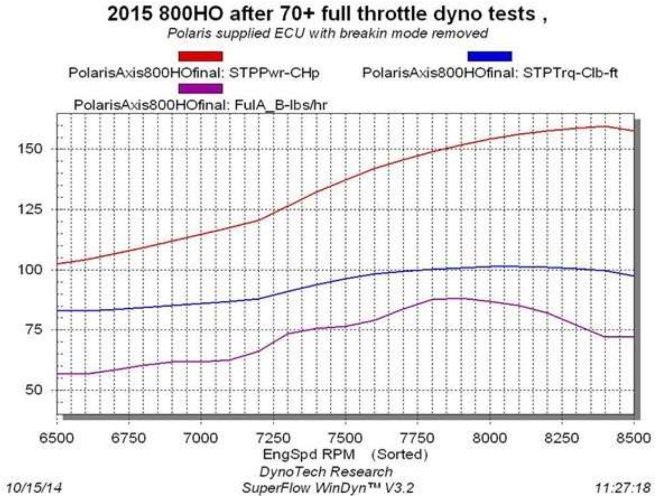


Figure 19: Czekala, 2014

The torque curve illustrated in figure 19 for this engine shows the operating angular velocity at 125hp is 7275 RPM. This yields a calculates mass of 61 grams, compared to the stock 66 gram flyweights. This modification has been made to uphold the performance of the vehicle.

Conclusion

The *2018 Ferris State University SAE International Clean Snowmobile Challenge* team would like to thank everyone who has contributed to the team's success. Starting a competition team is always challenging, and with the help of many sponsors and the university community, next year's team will be equipped to be highly competitive. Many learning experiences have taken place over the last twelve months, most notably, always install the knock sensor, and use the correct sealants when closing the crank case.

With the benefit of hindsight, the 2018 team would like to recommend design opportunities for future students including: Active noise cancellation, supplemental cooling system for dyno testing, pressure relief valve for excess back pressure, exhaust gas recirculation, catalytic converter temperature control system, aerodynamics testing, chassis dynamometer adaptation, and an effective organizational system.

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