Michigan Technological University's Strategies for a Greener Tomorrow

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ABSTRACT

The Michigan Technological University (MTU) Clean Snowmobile Team is entering the 2016 SAE International Clean Snowmobile Challenge with an improved 2014 Yamaha Phazer 500. The snowmobile has been redesigned to operate with a reduction in noise and exhaust emissions while maintaining competitive performance characteristics with an increased fuel efficiency for the on-trail snowmobile market. There are many aspects that the 2016 MTU CSC team has targeted as goals in the design and calibration of the 2016 competition entry. The engine calibration strategy goal was to attain a stoichiometric and lean combustion. The target lambda values were increased from stock of 0.85 to 1.0, with the exception of mode one, which targets 0.9 lambda. The goal of reducing overall noise, to comply with the 67dBA of the 2016 competition guidelines, was completed through the implementation of a redesigned air box along with exhaust system and chassis modifications. The exhaust system was modified to produce less noise than a stock 2014 Phazer configuration and included a new 3-way catalytic converter. The competition vehicle was calculated to have an additional value of $2,647 over the initial MSRP cost of $8599.00. The total estimated suggested retail price of $11,246 includes all implementations and additions to the snowmobile.

INTRODUCTION

To address concerns and the banning of snowmobiles due to environmental impact of snowmobiles in Yellowstone National Park, The Society of Automotive Engineers (SAE) developed the Clean Snowmobile Challenge (CSC) in 2000. The Clean Snowmobile Challenge was introduced in the winter of 2000 in Jackson Hole, Wyoming. The goal was to invite university students to design and produce a clean and quiet touring snowmobile to be ridden primarily on groomed snowmobile trails throughout the park. Competitors of the Clean Snowmobile Challenge use modified original equipment manufacturer (OEM) designed vehicles to compete. The challenge implements various types of flex fuel applications and expectations of demonstrating a reduction in unburned hydrocarbons (UHC), carbon monoxide (CO), nitrous oxide (NO_x), and noise level while still maintaining a consumer accepted level of performance. For teams competing in the snowmobile challenge to be deemed successful, the vehicle must demonstrate reliability, increases in efficiency, and cost effectiveness of the improvements. In 2003, the competition was moved to the Upper Peninsula of Michigan and was hosted by the Keweenaw Research Center (KRC).

The Clean Snowmobile Challenge is sponsored by SAE International as part of the collegiate design series. The snowmobiles are evaluated in several static and dynamic events, including manufacturer's suggested retail price (MSRP), technical presentations, emissions, noise, and fuel economy. For 2016, the competition remains at the KRC and runs from March 7th to the 12th. The competition has evolved to include both internal combustion snowmobiles and zero emissions electric snowmobiles.

2016 MTU CSC team is composed of 20 members from various educational disciplines, including Mechanical Engineering, Mechanical Engineering

Technology, Chemical Engineering and Environmental Engineering. The team is divided into three sub-teams: engine, chassis, and business. The chassis and engine teams are focused primarily on the design, fabrication, and calibration of the snowmobile, while the business team is dedicated to public relations, sponsorship opportunities, and inter-team relations.

2015 SNOWMOBILE CONFIGURATION

Table 1 displays MTU's competition results for the 2015 snowmobile configuration. This data was used as a starting place for the generation of ideas of improvement to the snowmobile for the 2016 competition.

Table 1: 2014-2015 MTU competition results

Category	Result
Weight	289.4 kg (638 lb_f)
Fuel Economy	14.08 L/100km (16.7 mpg)
EPA Five Mode Emissions Score	189.37
J192 Noise Level	89 dBA

For the 2016 Clean Snowmobile Challenge, the MTU Clean Snowmobile team focused on the important aspects of the Clean Snowmobile Challenge. The aspects in which the team focused, were on being fundamentally sound with the goal of being competitive in every event entered. This was done by making improvements to the design from the 2015 CSC Yamaha Phazer. This paper discusses how the Michigan Tech Clean Snowmobile team has made improvements to the Yamaha Phazer chassis as well as the engine to optimize all aspects, with the common goal of achieving maximum efficiencies while preserving the stock ride and performance characteristics. The first section of the paper includes a breakdown of the MTU CSC team's snowmobile for the 2016 competition. The second section addresses choices and design implementation made by the team to reduce emissions. The third section of this paper describes the implementation made to reduce the snowmobile's overall noise. Finally, improvements for vehicle performance and cost are discussed.

INNOVATIONS FOR A GREENER TOMORROW

This section gives a brief breakdown of MTU's 2016 snowmobile in table 2 and includes a list of engine parameters seen in table 3.

Table 2: Primary component breakdown of the 2016 MTU Clean Snowmobile

Component	Description
Chassis	2014 Yamaha Phazer
Engine	499 CC stock Genesis 80
Fuel System	Standalone engine management and ethanol content analysis with OEM Yamaha Phazer injectors and fuel pump
Intake System	OEM throttle body with MTU redesigned air intake
Exhaust System	**Catalyst:** Umicore ceramic 3-way catalyst **Catalytic Converter:** Designed and fabricated by V-Convertor **Muffler:** Stock muffler with tunnel dump exhaust.
Drive Train	**Clutches:** OEM YXRC-Yamaha **Drivers:** Custom Isolated 10 tooth drivers.
Suspension	**Front Suspension:** OEM Yamaha Phazer control arms and shocks. **Rear Suspension:** OEM Yamaha Phazer 121" rear skid with isolated chassis mounts
Track	Camso Hacksaw – 128"x14"x2.52"

Table 3: 2016 Engine parameters

Parameter	Description
Engine	Yamaha Genesis 80
Engine Type	Four-Stroke
Cooling	Liquid
Cylinders	2
Displacement	499 cc
Bore and Stroke (mm)	77 x 53.6
Ignition	Digital Transistor Coil Ignition with Throttle Position Sensor (TPS)
Exhaust	2 into 1
Fueling	Port Fuel Injection
Compression Ratio	12.4:1

EMISSIONS CONTROL

ENGINE CONTROL

The 2016 competition snowmobile utilizes a PE3-8400A Engine Control Unit (ECU) from Performance Electronics Ltd (PE). Due to Mitsubishi manufacturing both the performance electronics ECU as well as the stock Yamaha ECU it was able to utilize the stock ECU placement and location. To adapt the PE ECU to the stock wiring harness, a piggy back harness was made. The piggy back harness bridged the gap between the stock ECU and the team's standalone ECU. The piggy back could be removed quickly and thus easily allowing the stock ECU to be plugged back in. This is useful if there are any questions or concerns about the sled or engine integrity and also allows chassis testing before engine calibration is completed. The PE ECU manipulates fuel and ignition based on real time engine operating conditions. Using the controller, modifications were made to the fuel injector open times and ignition timing of the engine. The ECU monitors real time engine parameters and sensor inputs which are then used in closed-loop control with compensation factors to ensure the engine is running at peak efficiency and performance during all operating conditions. The PE ECU was coupled with a wireless modem, which allowed for the MTU Clean Snowmobile Team to operate the snowmobile at a wide range of in-service testing modes while adjusting the timing and injection parameters remotely to the desired air/fuel ratios. For transients in snowmobile operation, there were controls of the acceleration and deceleration to ensure that the engine was receiving the necessary amount of fuel on acceleration and removing it on deceleration to conserve fuel. Utilizing the calibration capabilities of the ECU, the team was able to optimize the engine's designed stoichiometric combustion to calibrate to the approximate 1 lambda running conditions on ethanol blended fuel for the Yamaha Phazer 500cc engine.

CALIBRATION TECHNIQUES

A majority of the calibration was completed on the team's engine dynamometer, shown in figure 1, which allowed for proper construction of a base tune under controlled conditions. The dynamometer also allowed for the testing of the stock engine calibration emissions and performance. Stock emissions and performance were measured for a baseline comparison of production data to the goals of the 2016 CSC calibration.

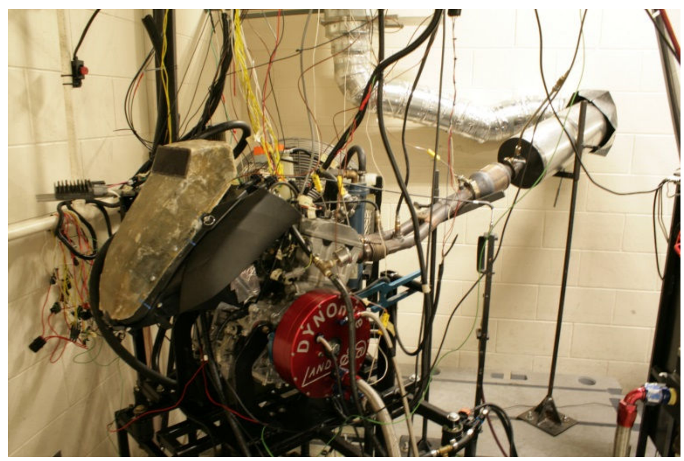

Figure 1: MTU CSC team's engine dyno and configuration for engine calibration.

With the stock engine and ECU in place, three power pulls were completed and averaged to determine the location of the five modes for testing emissions. The engine was then run at each mode and steady state emissions data was collected.

After collection of the stock emissions data, PE was used to create custom fuel and ignition maps. The maps were created using an alpha-n tuning method. Alpha-N method uses engine speed based on revolutions per minute (RPM) and an engine load based on the throttle position in percent open to create a map of all engine operating locations. Fuel at each map location is controlled with injector open time to reach a lambda 1.0, or stoichiometric, burn. After the injector open time was set, a spark sweep was completed. The spark timing was chosen based on the location of optimal emissions observed in the spark sweep. This stoichiometric burn, lambda 1.0, was chosen for its reduced unburned hydrocarbons (UHC) and carbon monoxide (CO) exhaust emissions. After the map was completed, three power pulls were completed and averaged to determine the new location of the five modes emissions test. Steady state emissions were collected at each of the five modes and compared to the emissions collected with the stock engine calibration.

The final base calibration on the dyno was done with the competition ready intake, catalytic converter (CAT), and exhaust in place. The previous lambda 1.0 map was used as a starting map but had to be manipulated due to the changes made to the intake and exhaust. Like the previous tuning process the injector open time was controlled to obtain a lambda 1.0 burn and spark sweeps were completed to find the optimal spark timing. Once this map was complete, three power pulls were completed and averaged to determine the five mode locations. Steady state emissions data was collected at each mode and compared to the stock and previous lambda 1.0 map. Table 4 shows the location of each of the 5 modes in relation to engine speed and engine load.

Table 4: 5 Mode Parameters

Mode	Crankshaft Speed (rpm)	Crankshaft Torque (N-m)
1	11250	47.5
2	9560	24.2
3	8435	15.7
4	7315	9.0
5	Idle	0

Figure 2 shows a comparison of the Final lambda values at each mode for the stock and MTU CSC team calibrations. The trend seen in the plot is the operation of the stock calibration below lambda 1.0 at all modes to improve the torque and power output of the engine. Since emissions are a large focus in the clean snowmobile challenge, lambda 1.0 was chosen to improve emissions while maintaining acceptable engine performance. The lambda value at mode 1 for both the MTU CSC calibration and the stock calibration is well below lambda 1.0. This is due to the engines inability to run safely at lambda 1.0 at wide open throttle (WOT) due to high exhaust gas temperature (EGTs). A lambda value of approximately 0.9 was chosen for safe exhaust gas temperature operation, below 840°C (1544°F) with an improvement over stock emissions.

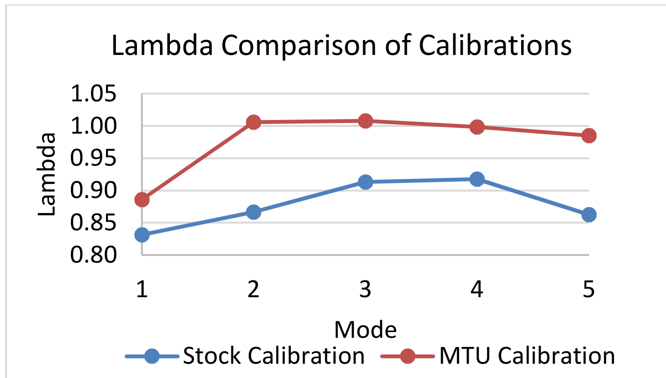

Figure 2: Comparison chart of lambda value for stock and MTU CSC team calibration at each of the 5 modes.

Figures 3 through 7 show a comparison of the average emissions data collected for the 5 mode test for each of the three engine calibrations. It can be seen that the MTU CSC team calibration reduces the output of the UHC, and CO from the stock calibration. This is due to the absence of extra hydrocarbons during the stoichiometric combustion process. The reduction in CO is also due to the complete burn of carbon and oxygen molecules in the stoichiometric combustion of the fuel. The increase in available oxygen and full combustion of carbon molecules in a stoichiometric burn, the MTU CSC tune increases the carbon dioxide (CO_2). There is also an increase in nitrous oxide (NO_x) emissions in stoichiometric burn. The implementation of the catalytic converter reduces the CO an UHC emissions to levels well below that of the stock engine calibration and exhaust system. The CAT also aids in reducing the increased NO_x emissions associated with a stoichiometric burn.

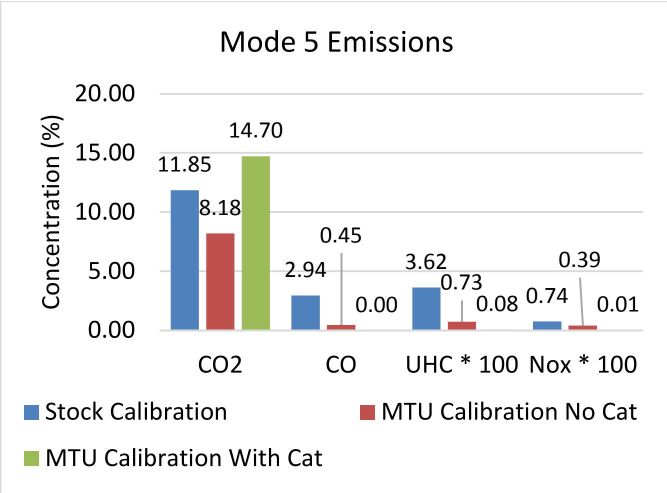

Figure 3: Mode 5 comparison of the CO_2, CO, UHC, NOx of the three calibrations

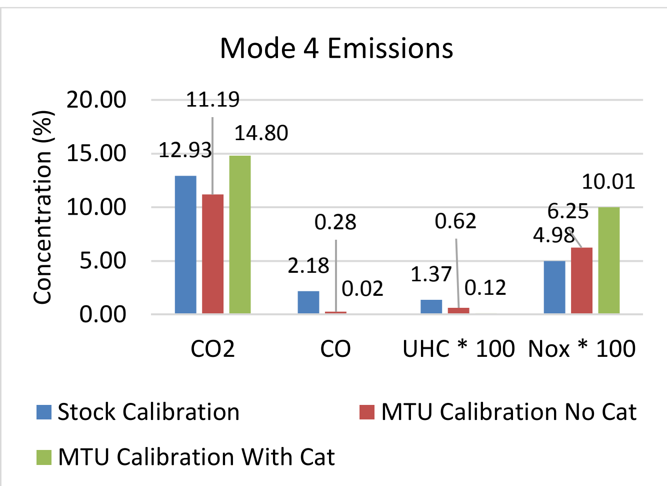

Figure 4: Mode 4 comparison of the CO_2, CO, UHC, NOx of the three calibrations

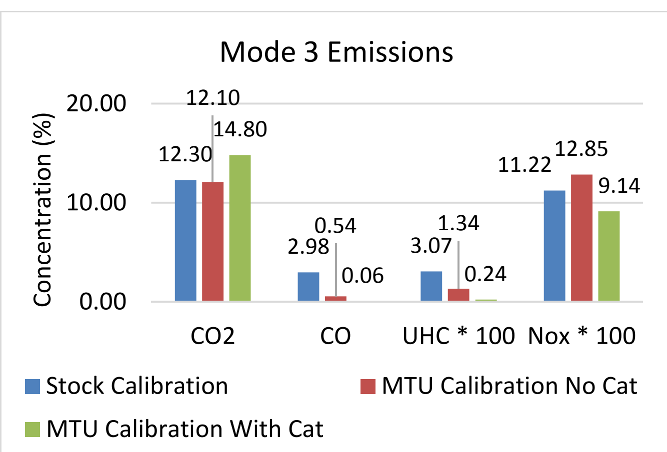

Figure 5: Mode 3 comparison of the CO_2, CO,

UHC, NOx of the three calibrations

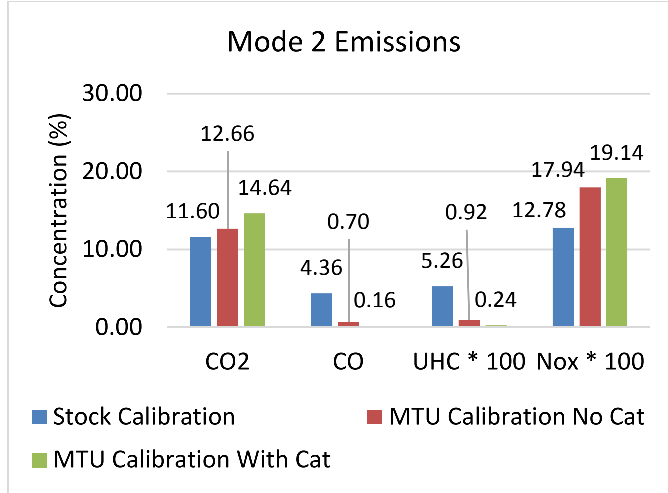

Figure 6: Mode 2 comparison of the CO_2, CO, UHC, NOx of the three calibrations

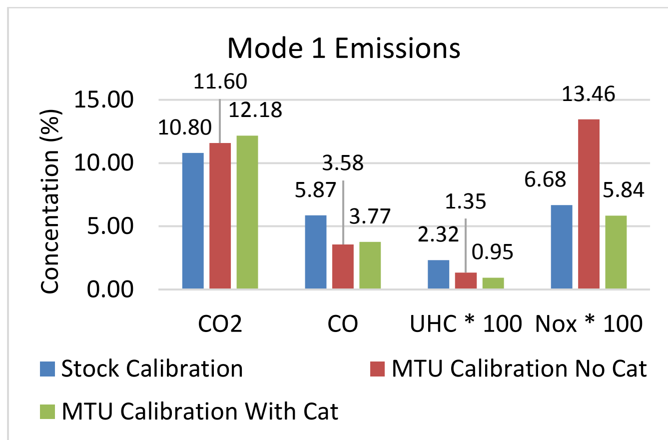

Figure 7: Mode 1 comparison of the CO_2, CO, UHC, NOx of the three calibrations

CATALYTIC CONVERTOR

For the 2016 MTU Clean snowmobile exhaust system, a Umicore substrate was used in a three way catalyst canned by V-converter. This catalyst will improve the oxidation and conversion of unburned hydrocarbons (UHC), carbon monoxide (CO) and nitrous oxides (NO_x). Made up of the precious metals: Platinum, Palladium and Rhodium, this catalyst will increase conversions of harmful emissions and optimize the use of the precious metals. In the design of the CAT, a long inlet cone, seen in Figure 8, is utilized and allows for more evenly dispersed exhaust gases across the substrate.

This will help increase the surface area used of the catalyst's inlet face and optimize the reduction of emissions. Found in table 5 are the dimensions for MTU's 2016 competition CAT.

Figure 8: The catalytic convertor that will be used in the MTU exhaust system that will reduce the levels of UHC, NOx and CO

Table 5: Catalyst and catalytic convertor parameters

Component	Description
Catalytic Converter	12.7 cm D x 38.1 cm
Substrate	11.84 cm D x 10.16 cm
	Ceramic- 380 cells per square inch (CPSI)

Found in figure 9, catalyst conversion efficiency can be seen and through engine calibration an air-fuel ratio (AFR) can be targeted to reach optimal conversion of emissions. With an AFR of 14.7 or lambda value of 1.0, stoichiometric combustion can be obtained. However with an increase of AFR and lambda value, lean combustion can be reached furthering the reduction of emissions. During lean combustion the concentration of oxygen (O_2) increases, allowing for a greater conversion of CO to CO_2 and greater conversion of UHC.

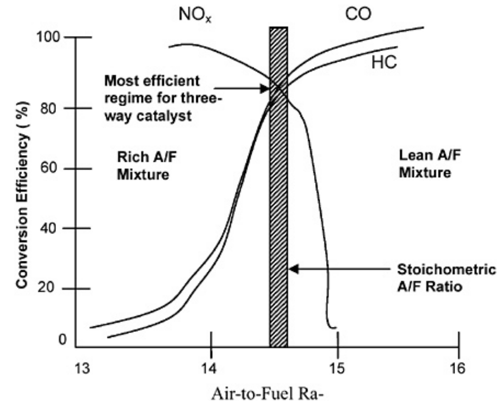

Figure 9: Catalyst conversion efficiency at different air-fuel ratios [Heywood, J.]

By targeting these air-fuel ratios and lambda values for stoichiometric and lean combustion, the MTU CSC team was able reduce the number of emissions produced by the snowmobile. In Table 6, the measured emissions produced by stock calibration and by MTU's calibration after the addition of the new catalytic converter can be found.

Table 6: Comparison of collected stock calibration emissions data and 2016 MTU CSC calibration emissions data

	Stock Calibration				2016 MTU CSC Calibration			
Mode	CO_2 (%)	CO (%)	UHC (ppm C_6)	NO_x (ppm)	CO_2 (%)	CO (%)	UHC (ppm C_6)	NO_x (ppm)
1	10.8	5.87	232	668	12.2	3.77	95.1	584
2	11.6	4.36	526	1278	14.4	0.60	31.7	343
3	12.3	2.98	307	1122	14.8	0.06	24.1	914
4	12.9	2.18	137	498	14.7	0.01	16.4	914
5	11.8	2.94	362	74	14.7	0.00	17.0	84

The resulting changes in emissions include an overall reduction of CO and UHC for all five modes, as well as a reduction in NO_x in modes four and five.

NOISE REDUCTION SOLUTIONS

MTU's snowmobile did not pass noise testing in 2015's competition. It is a high priority to reduce the snowmobile's subjected noise for the 2016 competition. This section discusses the methods that are used to reduce the overall noise level on our 2016 competition snowmobile.

NOISE

This section discusses the methods that are used to reduce the overall noise level on our 2016 competition snowmobile. All testing was performed on snow under SAE J1161 2016 Competition standards which is run at a constant 35 mph for 150 feet at a distance of 50 feet. All data is based off an average of 3 runs and is A weighted.

Figure 10 illustrates the 1/3 octave noise produced by the snowmobile at various frequencies. The main sources of noise occur between 60 and 80 Hz and 1250 and 2000 Hz. Due to the range frequencies, this concludes that there are multiple sources of noise on the snowmobile such as exhaust, engine noise, chassis vibration, intake noise, and track noise.

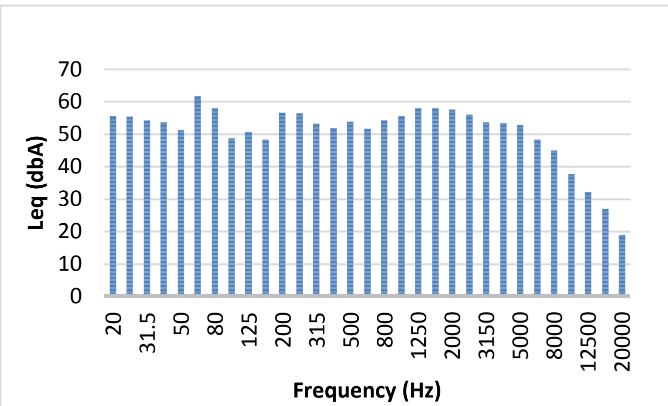

Figure 10: 1/3 Octave Spectra Graph of stock 2007 Yamaha Phazer

The exhaust, intake, and mechanical noise were the three areas primarily targeted for noise reduction. A new exhaust system was designed and implemented on the snowmobile, featuring a catalytic converter and tunnel dump. Here the scope was to design an exhaust system to reduce engine noise carried through the exhaust, without sacrificing performance of the engine. Furthermore, a new intake/air box was designed to reduce engine pulsations exiting through the intake caused by valve overlap, while improving the flow of air into the motor.

To reduce mechanical noises coming from the snowmobile, the method of isolation was applied in various areas of the snowmobile to reduce the vibrations and noise generation of moving parts. The drivers used to drive the track are isolated from the steel driveshaft with an epoxy material, to reduce vibrations. Rubber skid isolators were installed to fully isolate the rear skid from the tunnel reducing noise and vibration. Belt and clutch noise was targeted by the team, by adding Sound Down noise reduction foam to the inside of the panels and clutch guard to absorb noise coming from the clutches or engine.

The implemented systems on the snowmobile were tested by performing a series of sound tests that measured the effective improvement of each modification. MTU CSC found that our 2016 Competition snowmobile produced an average sound level of 68.3 dBA. This is an improvement of 2.60 dBA from the baseline snowmobile. Figure 11 displays the improvements of each modification. As shown in Figure 11, the intake had largest effect on noise reduction. This implementation reduced the overall noise of the snowmobile by 1.70 dBA. The second largest improvement on noise level was the exhaust system. This reduced noise by 0.80 dBA. The isolated drivers and isolated skid reduced noise by 0.10 dBA.

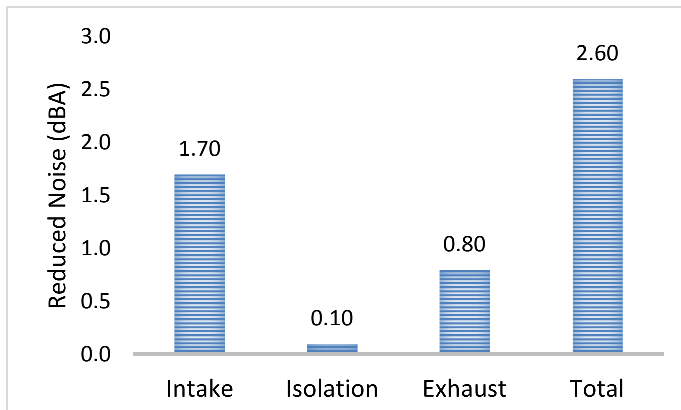

Figure 11: Noise Reduction by Implementation

Figure 12 is a 1/3 Octave Spectra Plot of the 2016 Competition snowmobile vs the stock Yamaha Phazer. It can be inferred that the noise has been reduced on the snowmobile, especially at the targeted frequencies of 100 Hz and below. Furthermore, noise was reduced at frequencies greater than 1000 Hz.

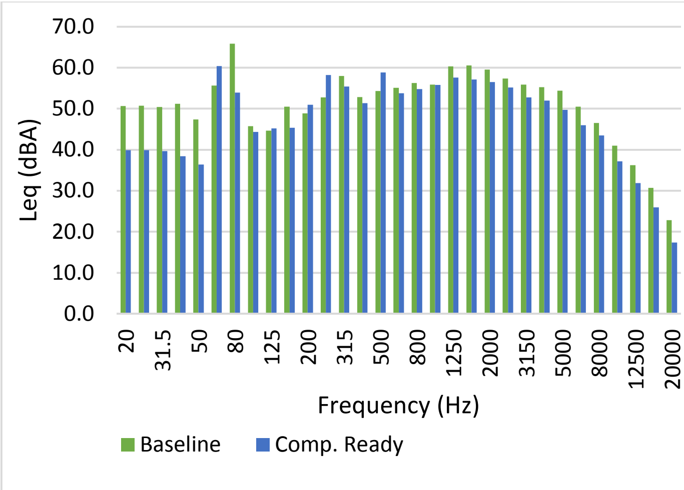

Figure 12: 1/3 Octave Spectra Graph of 2016 Competition Snowmobile and Stock Yamaha Phazer

MUFFLER DESIGN FOR NOISE REDUCTION

The design for this years competition muffler began by using a Matlab code that simulated the noise reduction of a round chambered muffler over a frequency range. Various internal chamber lengths were simulated in the code to determine which lengths would have the largest noise reduction with our engine under normal operating frequencies. The Matlab code generates a frequency versus transmission loss plot, which was used to determine the noise level that would be produced by the exhaust system. The muffler, shown in figure 13, was constructed out of 8" diameter thirteen gauge exhaust tubing. Layers of sound dampening exhaust packing were secured to the inside of the muffler using studs and mesh to ensure the packing would remain tight to the inside walls. The initial design was chosen for the design performance in the Matlab program. Upon further testing, on the engine dyno, it was found that it produced too high of a backpressure. This backpressure increased the EGT's which remained below the 830°C limit on a tune of lambda 0.85, but exceeded the limit while attempting to tune at lambda 1.0.

Figure 13: Initial MTU muffler design

After discovering that the initial muffler design would not allow for tuning at lambda 1.0 a new design was developed. The second proposed option was to utilize the sound dampening paint on our tunnel through the use of a tunnel-dump exhaust shown in figure 14. This design utilized the stock muffler with a rerouted exhaust path to exit under the tunnel. The tunnel-dump system will dissipate the sound waves down into the snow and the sound dampening paint covering the tunnel, instead of straight off the back of the sled. Once fabrication was completed and the tunnel-dump muffler was installed on the sled, noise data was collected. Testing was completed in a way that compared the stock exit muffler to the newly fabricated tunnel-dump design. The data, seen previously in figure 11, shows a 0.8 dBA decrease in the noise level compared to the stock exhaust exit system.

Figure 14: MTU final muffler design for competition

INTAKE

This section discusses the methods that are used to reduce the noise level and improve the quality of air flow of the intake of the MTU CSC 2016 competition snowmobile.

Since the 2015 MTU CSC snowmobile did not pass noise testing in 2015's competition, it was a high priority to reduce the snowmobile's noise level for the 2016 competition. Therefore, one of our focuses is to design a quieter and more efficient air box. In this design, the team focused on two goals: 1) reduce intake noise from the snowmobile and 2) provide better air flow into the engine.

The main source of induction noise on the snowmobile is due to alternating air pulses traveling through the air intake caused by the change in pressure due to the intake valve opening and closing. To reduce these pressure pulses, baffles and sound absorbing material are included in the air box design. The new air box lid features two walls that are backed with SoundDown noise absorbing foam. Due to the air flow path, pressure pulses will hit these barriers and will be absorbed before escaping the inlet of the intake. Furthermore, this foam material is also placed in various places inside the air box to absorb more sound. Figures 15 and 16 are 3D renderings of the new intake as modeled in Solid Works.

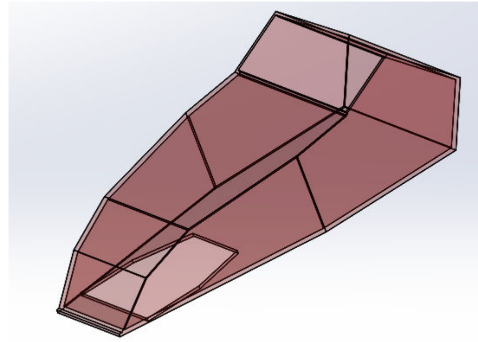

Figure 15: SolidWorks model of new intake

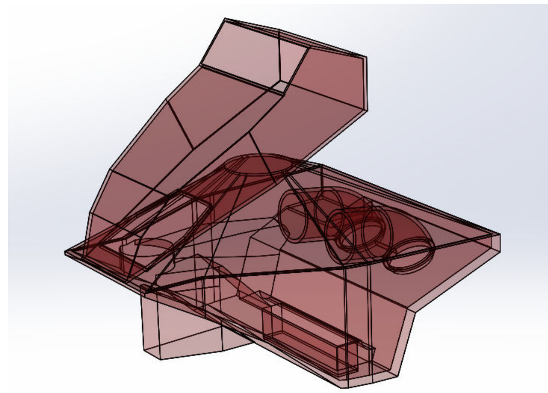

Figure 16: SolidWorks model of new intake mounted on existing air box

For the ease of implementation, it was decided to build the new air intake off the existing air box lid, as shown in Figure 17. This lid is easily accessible and changing between the stock intake and modified intake can be done quickly. Furthermore, this design allows cold, dense air from the outside to enter the motor. This intake location is an improvement over the original intake location, which drew warm air from the engine bay. Frogskinz material is placed over the inlet to keep debris and moisture out, while allowing sufficient air flow in.

Figure 17: Original air box lid vs prototype lid

A Superflow 110 Flow Bench was used to compare the flow of air between the stock intake and the redesigned intake. From testing the team found that the stock air box flowed 8.0 cfm at a 5 inch pressure drop (H_20). The modified air box was found to flow 7.9 cfm at the same pressure drop, which is only a 1.25% difference. It is also important to note that while tuning the stock air box to a specific pressure drop, the flow rate fluctuated, indicating that resonance was occurring within the stock air box. This did not occur while tuning the modified air box. Furthermore, it is expected that the flow rates of the modified air box will increase during vehicle operation. This is due to the fact that the inlet is mounted at the front of the snowmobile, which will result in air being forced into the air box during snowmobile operation.

Noise testing was performed to validate the sound reduction of the new intake design. Testing MTU CSC performed under SAE J1161 competition standards. It was found that our competition snowmobile produced an average sound of 70.9 dBA with the factory intake. With the new intake, the sled produced an average sound level of 69.2 dBA. These results are based off an average of 3 runs. Therefore, the modified intake reduced noise by 1.7 dBA on average. Figure 18 is 1/3 Octave Spectra graph from noise testing the 2016 Competition sled with and without the modified air box. This compares the noise levels at various frequencies. The data shows the new intake caused a large decrease in noise at a frequency of 80 Hz. And further reduction in noise at higher frequencies.

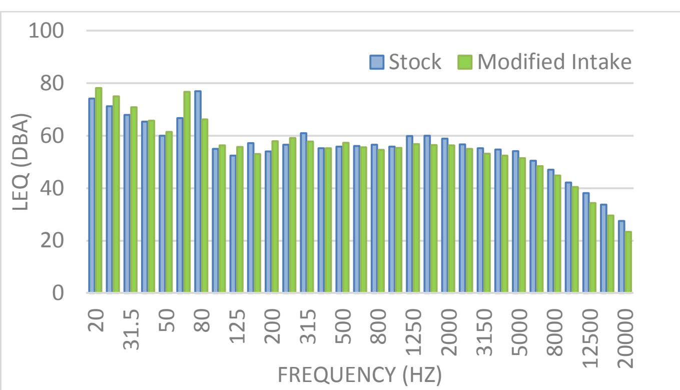

Figure 18: 1/3 Octave Spectra Graph

Additionally, air temperature sensors were placed inside the air box to measure the temperature of the air entering the engine. This was tested in 2 locations: at the dyno and during field testing. From the dyno, intake temperatures have dropped from 98˚F to 72˚F (26˚F difference), when switching between the original intake system and the modified one. Furthermore, the temperature difference found at the dyno was validated during field testing. With an outside temperature of 6˚F, the team experienced a very similar temperature drop. Inlet temperatures were 58˚F with the stock intake and dropped to 28˚F with the modified intake, a 30˚F temperature difference. This temperature drop is due to the change in location of the air intake. The stock intake pulls warmed air from around the engine. The redesigned intake draws cold external air from in front of the snowmobile.

MECHANICAL NOISE REDUCTION

In an effort to improve the overall noise and rider comfort of the 2016 MTU CSC snowmobile, vibration analysis was carefully looked at for improvement. Multiple modifications were made to the snowmobile to reduce the vibrations produced by the rotation of the track. This was accomplished in two ways; isolators were implemented at each of the four mounting points of the rear suspension, and a custom pair of isolated drivers was designed. The isolated drivers have a 9.525 mm gear shaped slot machined out of them, along with a pattern of small holes drilled around the outer radius of the driver, this can be seen in figure 19. The machined slot and holes were then filled with a urethane material to isolate the two pieces of the driver from each other. This isolation damped the transfer of vibrations produced by track and driver contact.

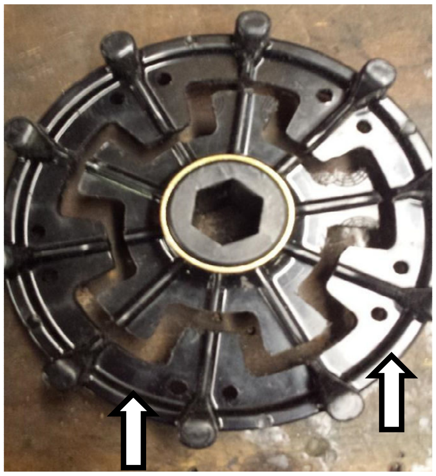

Figure 19: MTU custom driver before isolation rubber installed. Arrows depict the slots cut to be filled with the isolation rubber.

To determine the durometer of the rubber that would be needed to withstand the torque applied to the drivers, calculations were done based on the output of the motor with the stock, peak output, and a safety factor of two applied. Based on the calculations, it was found that the durometer of the rubber needed to be such that each driver was capable of performing up to a torque of 1125.3 N-m (830 ft-lb). This torque was computed from a maximum engine output including gear reductions from the clutches and chain drive to the drivers. For additional safety measure, steel safety plates were designed to be fit on the sides of the drivers to prevent a catastrophic failure if the rubber isolation material were to fail. The newly designed drivers weigh 1.12 kg (2.47 lb_f), the stock drivers weigh 0.54 kg (1.19 lb_f) per driver. Figure 20 shows the side by side comparison of the stock drivers and the completed isolated drivers.

Figure 20: Stock drivers (left) and completed custom isolated drivers (right)

An additional measure to reduce vibrations transferred from the rotation of the track was the implementation of isolators for the rear suspension mounting locations. To determine the correct isolators to use for these locations, calculations were performed for the 254 kg (560 lb_f) snowmobile with a 117.9 kg (260 lb_f) rider being dropped from a height of three feet with the assumption of no damping from the suspension. With these calculations, it was determined that isolators from Tech Products Corporation with a max radial load of 145 kg (320 lb_f) would be used on the front two mounting points of the suspension, and isolators with a max radial load of 117.9 kg (260 lb_f) would be used on the rear mounting points. Figure 21 below shows the isolators used for mounting the rear suspension.

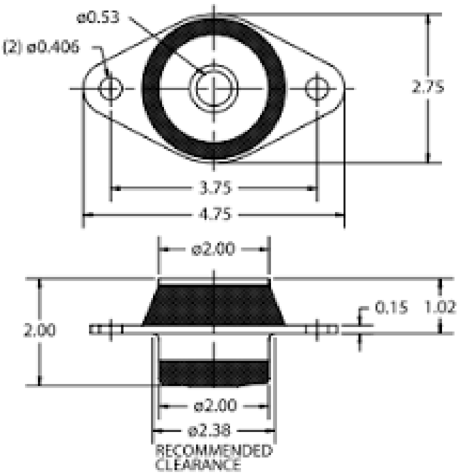

Figure 21: Isolators used for mounting of rear suspension

To test the implementation on the snowmobile, the team performed a series of sound tests to find the effective improvement of each modification. It was found that the isolated drivers and skid produced a 0.1 dBA decrease in the overall snowmobile noise level.

VEHICLE PERFORMANCE

WEIGHT DISTRIBUTION

This section covers the team's focus on weight distribution to maintain the comfortable and confidence inspiring handling of the snowmobile.

The stock 2014 Yamaha Phazer weighs 234 kg (515 lb_f), the competition ready 2016 MTU CSC team Yamaha Phazer weights 265 kg (584 lb_f). To determine the weight distribution, the snowmobile was placed on three scales, one under each ski and one under the track. The weight distribution on the skid was found to be 149.5 kg (329.6 lb_f). The right ski carries a load of 65.1 kg (143.5 lb_f). The left ski carries a load of 50.5 kg (111.4 lb_f). The weight distribution is 24.6% on the front right ski, 19.1% on the front left ski, and 56.4% on the track. This weight distribution is taken without a rider on the snowmobile. The increase of weight on the right side of the snowmobile is due to the stock placement of the oil reservoir and coolant radiator along with the increase in electrical systems, such as the PE ECU piggyback, and larger brake system to implement Hayes anti-lock brakes done by the team. The implementation of these components were restrained to the right side of the snowmobile due to the clutches on the left side.

COMPENSATION FOR LOW FUEL OCTANE

The 87-92 octane 0%-85% ethanol fuel blends used in the 2016 competition cause the concern for knock in the 500cc Phazer engine. The high compression engine is designed to run 91 octane fuel. The use of 87 octane fuel at lean combustion can result in high chances of knock in the engine under normal operating conditions.

The stock 2014 Yamaha Phazer has a knock control system equipped. This is designed to protect the engine when knock is detected. In the stock system, when knock is detected the ignition timing will be adjusted accordingly to prevent engine damage without indicating the change to the rider.

The 2016 MTU CSC team has implemented a Phormula KS-4 knock detection system to monitor knock. If knock is detected, the KS-4 system will send a voltage signal to the PE ECU which will cause the ECU to retard the spark timing to protect the engine from further knock. Knock is detected as a certain frequency depending on the size of the engine. The detection for theses frequencies is 6-9 kHz and has been set to reduce picking up background noise from normal engine operation. Based on the 77mm bore of the Phazer engine the knock frequency, from the Phormula frequency calculator [7], will occur around 7.4 kHz. Since knock will occur at 7.4 kHz the KS-4 system is set to monitor frequencies of 7.5 kHz. The KS-4 knock system was also used during dynamometer calibration of the engine to monitor knock while creating the custom engine calibration.

FLEX-FUEL IMPLEMENTATION

In the stock 2014 Yamaha Phazer there is no provision for monitoring, or more importantly, compensating for fluctuating ethanol content in the fuel because at most snowmobile destinations it is common to find gasoline with an ethanol content of less than 5%. At the 2016 Clean Snowmobile Competition the blind fuel blend supplied to the teams will have an ethanol content ranging from 0% to 85%, the ability of the MTU IC snowmobile to run effectively and efficiently on any blend of fuel within that range is dependent on an adequate ethanol content analyzer (ECA) system. For pure gasoline at ideal mixture conditions stoichiometric combustion occurs at an optimum air-fuel-ratio (AFR) of 14.6:1. For E85 stoichiometric combustion occurs at an AFR of 9.77:1. This fluctuation in AFR for optimum combustion is solely dictated by the input from the ECA to the ECU and the pre-determined fuel compensation factor.

Fuel compensation factors were determined using energy density calculations for 12 different fuel blends ranging from E0-E100 in equal increments. With the E0 energy density taken as the scale value the fuel energy percentage was found for the remaining fuel blends and tabulated. Because the base engine calibration was done using an E0 fuel blend the compensation factor for varying blends is the difference in the fuel energy percentage needed to meet the stoichiometric combustion criteria. For fuel blends falling in between the calculated set points a linear scale factor was used between the two points. Once processed by the ECU the injector open times are adjusted accordingly to allow for the optimum fuel input.

MTU CSC IC team opted to incorporate a Zietronix ECA-2 kit into this year's competition snowmobile design. The kit comes with a digital display, analyzer, flex fuel sensor, and all of the necessary wiring harnesses. The flex fuel sensor outputs a frequency to the analyzer which processes this signal into a 0-5 V analog output which can be input directly into PE without any subsequent signal processing. The raw analog signal is a linear output from E0-E100, by applying a correction factor of 20% per volt the actual ethanol percentage can be determined within 5% accuracy of the actual blend. The flex fuel sensor itself is an in-line style sensor which is mounted on the fuel supply line.

ANTI-LOCK BRAKING SYSTEM

The 2016 MTU CSC Team implemented the Hayes TrailTrac braking system. The TrailTrac system is an anti-lock braking system that consists of both a hydraulic control unit (HCU) and a Hayes electronic control unit (HECU). This system, in combination with the Camoplast Hacksaw Track, will allow the machine to slow with greater control by controlling the brake pressure based on the vehicle reference speed that is calculated off of a tone ring attached to the drive axel of the snowmobile. The calibration for the ABS uses a slip/mu curve to define the brake modulation to prevent long term locking of the track based on the reference speed as well as the vehicle yaw.

Brake lines are run from the master cylinder on the handlebars to the HCU, and then from the HCU to the brake caliper on the snowmobile. The HECU is mounted near the air box to keep it away from heat that is produced by the engine and exhaust components. The HCU is located near the HECU and mounted in between the intake plenum and gas tank, also keeping it away from heat that is produced by the exhaust system, seen in figure 22. The orientation of the HCU is known to cause issues when bleeding the system, therefore, the MTU Clean Snowmobile Team mounted the unit horizontal to the direction of motion and with the fittings upright to ease bleeding the system.

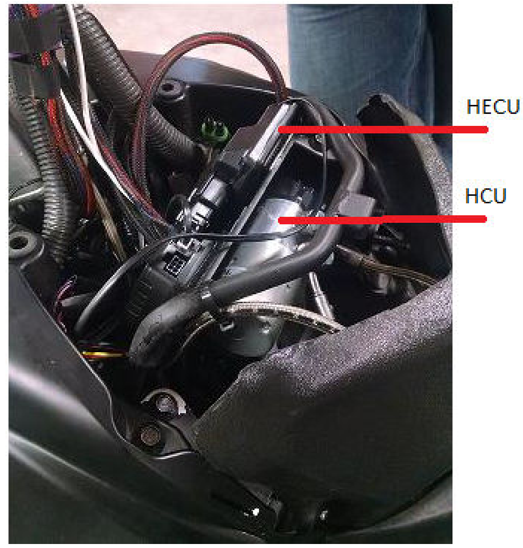

Figure 22: Hayes HCU and HECU mounting locations.

COST

In an effort to keep manufacturing costs as low as possible, every component added to the 2016 MTU IC entry was carefully analyzed. After Implementation of new components, the final MSRP value of the 2016 MTU IC entry was calculated to be $11,246. Since the 2016 MTU IC entry includes advancements in chassis, flex fuel technology, fuel management, significant emissions reductions, the MTU CSC Team feels the additional $2,647 is well justified.

SUMMARY/CONCLUSIONS

The 2016 MTU IC entry uses a state of the art chassis and suspension technology to increase drive efficiency, and improves rider ergonomics. Comprehensive data collection and analysis of exhaust systems for emissions after treatment, as well as for noise reduction have been utilized in the design of the exhaust system. Through the many changes made to reduce noise level, the team was able to bring the noise level of the sled from 70.9 dBA to 68.3 dBA. The utilization of a standalone engine management system allowed the overall calibration to be maximized for lean and stoichiometric combustion through the five modes targeting specific lambda values of 1-0.9 to produce overall cleaner emissions. The implementation of all systems on the 2016 MTU IC snowmobile has preserved stock performance while reducing noise and emissions. The 2016 MTU IC entry blends proven four-stroke emissions and noise characteristics with modern lightweight chassis technology and reliable advanced engine technology.

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- PCB Piezotronics Inc
- Pat's Motor Sports

DEFINITIONS/ ABBREVIATIONS

ABS Anti-lock Braking System

AFR Air-Fuel Ratio

CAT Catalytic Converter

CPSI Cells per Square Inch

CO Carbon Monoxide

CO_2 Carbon Dioxide

ECU Electronic Control Unit

EMS Engine Management System

EPA Environmental Protection Agency

FEA Finite Element Analysis

UHC Unburned Hydrocarbon

HCU Hydraulic Control Unit

HECU Hayes Electronic Control Unit

IC Internal Combustion

KRC Keweenaw Research Center

MSRP Manufacturer Suggested Retail Price

MTU Michigan Technological University

NOx Nitrous Oxides

OEM Original Equipment Manufacturer

O_2 Oxygen

PE Performance Electronics

PPM Parts per Million

RPM Revolutions per Minute

TPS Throttle Position Sensor

WOT Wide Open Throttle