Michigan Technological University's Eco-friendly Snowmobile Solutions

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ABSTRACT

The Michigan Technological University (MTU) Clean Snowmobile team is entering the 2017 SAE Clean Snowmobile Challenge (CSC) with a modified 2014 Yamaha Phazer 500. The modifications on the snowmobile were designed and verified to improve key metrics of snowmobile operation, such as reduced operational noise, reduced engine emissions, and improved rider comfort. While striving to meet these goals, the competitive performance characteristics of the snowmobile were not permitted to be adversely affected, in order to maintain a marketable snowmobile. For the 2017 MTU CSC team, specific goals were set regarding the improvements of the snowmobile to meet competition expectations. The engine team's calibration strategy was to obtain lean stoichiometric combustion. The target lambda values were increased from a stock value of 0.85 to between 1.0 and 1.1 for modes two through five. Mode one was permitted a lambda value of 0.9 to prevent engine damage at wide open throttle (WOT). The goal of reducing operational noise to the competition test guideline of 67 dBA was accomplished through modification of the exhaust system and chassis. A redesigned air intake from the 2016 competition was utilized to reduce engine intake noise, and functions as a cold air intake. Rubber isolated track drivers developed and built for the 2016 competition were again utilized for the 2017 competition. The muffler prototyped in 2016 was modified, and is being utilized for competition, as it deadens the exhaust noise of the snowmobile better than the stock muffler. A 3-way catalytic converter was utilized in addition to the lean burn to reduce engine emissions. The value added components on the snowmobile were calculated to add $2,111.76 to the original manufacturer suggested retail price (MSRP), resulting in a final estimated retail price of $12,341.81. This price reflects the cost of OEM parts, and the material and fabrication costs for all custom parts.

INTRODUCTION

The Society of Automotive Engineers (SAE) Clean Snowmobile Challenge was born in the year 2000, to address concerns about the banning of snowmobiles in Yellowstone National Park due to negative environmental impact. The first CSC competition was held in Jackson Hole, Wyoming, during the winter of 2000. The goal of this first event was to invite university students to design and build a clean and quiet touring snowmobile intended for use on groomed trails throughout the park. Over time, the event has evolved, and is now run competitively, encouraging innovation and creative problem solving to overcome obstacles. In 2003, the competition relocated to the Keweenaw Research Center (KRC) in the Upper Peninsula of Michigan, where the event is hosted to this day.

Although the nature of the competition has evolved, many of the original elements of the original event live on. Competitors in the CSC use original equipment manufacturer (OEM) designed snowmobiles to compete, but must modify the platform according to sound engineering practice and innovative ideas. According to the SAE website, "The intent of the competition is to develop a snowmobile that is acceptable for use in environmentally sensitive areas such as the National Parks or other pristine areas. The modified snowmobiles are expected to be quiet, and emit significantly less unburned hydrocarbons and carbon monoxide than current production snowmobiles, without significantly increasing oxides of nitrogen emissions." For teams competing in the challenge to be deemed successful, the snowmobile must demonstrate reliability, increased efficiency, and cost effectiveness of improvements.

The Clean Snowmobile Challenge is sponsored through SAE International as part of the collegiate design series. During competition, the snowmobiles are evaluated in several static and dynamic events, in addition to MSRP, technical presentations, operational noise, emissions, and fuel economy.

The 2017 MTU CSC team is composed of 24 members from various disciplines of study, including Mechanical Engineering, Mechanical Engineering Technology, Electrical Engineering, Computer Engineering, and Engineering Management. Within the team are three divisions: engine, chassis, and business. The engine and chassis teams focus primarily on the design, fabrication, and calibration of the snowmobile. The business team assists engine and chassis team as needed, although their primary focus is public relations, recruitment, budgeting, sponsor relations, and inter-team relations.

2017 SNOWMOBILE CONFIGURATION

Table 1 below displays MTU's results for the 2016 snowmobile configuration at competition. This data was used to generate ideas for snowmobile improvement for the 2017 competition.

Table 1: 2015-2016 MTU competition results

Category:	Result:
Weight	291.2 kg (642 lbf)
Fuel Economy	5.1 gal/92.6 miles (18.2 mpg)
EPA Five Mode Emissions Score	185.77
J1161 Noise Level	73.0 dBA

For the 2017 Clean Snowmobile Challenge, the MTU Clean Snowmobile team focused primarily on the events in which the team had performed poorly during the spring 2016 competition. The primary area in which the team focused was operational noise, in addition to the goal of being competitive in every event entered. This was done by making improvements to the design from the 2016 CSC Yamaha Phazer. This paper discusses how the MTU 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 optimizing the operation of the snowmobile, great care had to be taken to preserve the stock ride and performance characteristics. The first section of the paper includes a breakdown of the MTU CSC team's snowmobile for the 2017 competition. The second section addresses choices and design implementation made by the team to reduce emissions. The third section of this paper describes the implementations 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 2017 snowmobile in Table 2 and includes a list of engine parameters in Table 3.

Table 2: Primary component breakdown of the 2017 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:** MTU custom muffler
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 Viper 137" rear skid with isolated chassis mounts and 10" Billet Wheel kit
Track	Camso Hacksaw – 144"x14" 2.52 pitch

Table 3: 2017 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 2017 competition snowmobile utilizes a PE3-8400A Engine Control Unit (ECU) from Performance Electronics Ltd (PE). Since Mitsubishi manufactured both the performance electronics ECU as well as the stock Yamaha ECU, the stock ECU placement and location was utilized. To adapt the PE ECU to the stock wiring harness, a jumper harness was made to accommodate the plug connection on the stock wiring harness of the Yamaha Phazer. This allowed for the team's standalone ECU to be removed in a timely manner and replaced with the stock Yamaha ECU if needed. The PE ECU functions by manipulating fuel and ignition based on real time engine operating conditions. 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 MTU Clean Snowmobile Team utilized a wireless modem with the PE ECU 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, the acceleration and deceleration compensation factors were altered 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 1.1 lambda running conditions on ethanol blended fuel for the Yamaha Phazer 500cc engine.

CALIBRATION TECHNIQUES

Majority of the Yamaha Phazer engine calibration was completed on the team's engine dynamometer, shown in Figure 1. Tuning using the engine dynamometer allowed for generation of base tunes 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 2017 CSC calibration.

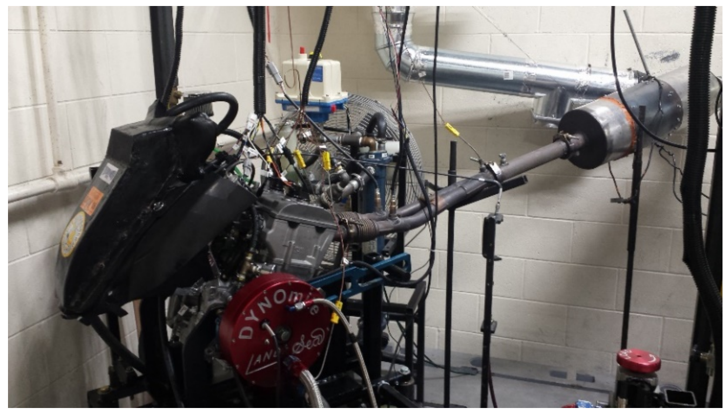

Figure 1: MTU CSC team's engine dyno and configuration for engine calibration.

With the stock engine and ECU in place, three power sweeps 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. For the 2017 season, the MTU Clean Snowmobile Team focused on generating a lean-burn fuel map to reduce fuel consumption. Fuel at each map location is controlled with injector open time to reach a lambda 1.1 value. After the injection open time was set, a spark sweep was completed. The spark timing was chosen based on the location of optimal engine performance to accommodate the lean fuel/air mixture entering the cylinder. For a lambda of 1.1, higher unburned hydrocarbons (UHC) and carbon monoxide (CO) emissions compared to the stock emission data were present. To compensate for the higher UHC and CO emissions, a catalytic converter was utilized. 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 1.1 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 1.1 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 1.1 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 1.1 was chosen to reduce fuel consumption, improve emissions, and maintain 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.

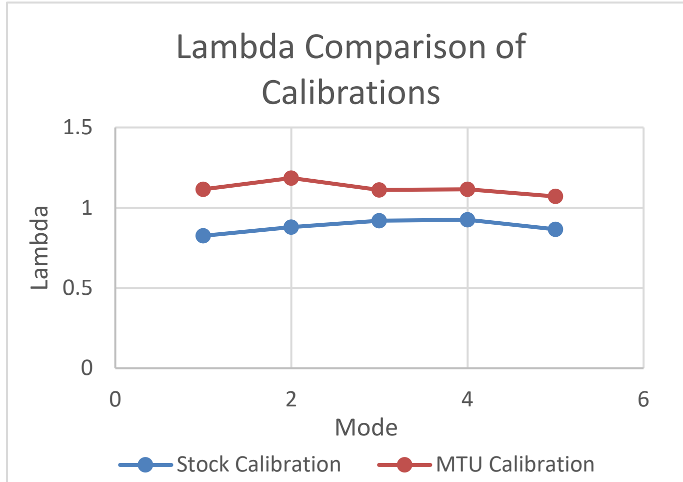

Figure 2: Comparison chart of lambda value for stock and MTU CSC team calibration at each of the 5 modes.

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 and 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. Although the MTU engine tune generates more carbon dioxide than the stock tune, it generates significantly less unburned hydrocarbons and carbon monoxide, which are far more harmful contaminants than carbon dioxide.

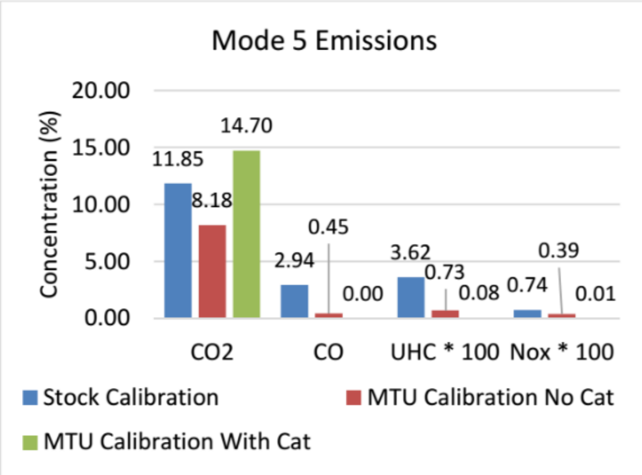

Figure 3: Average Mode 5 comparison of the CO_2, CO, UHC, NOx of the three calibrations

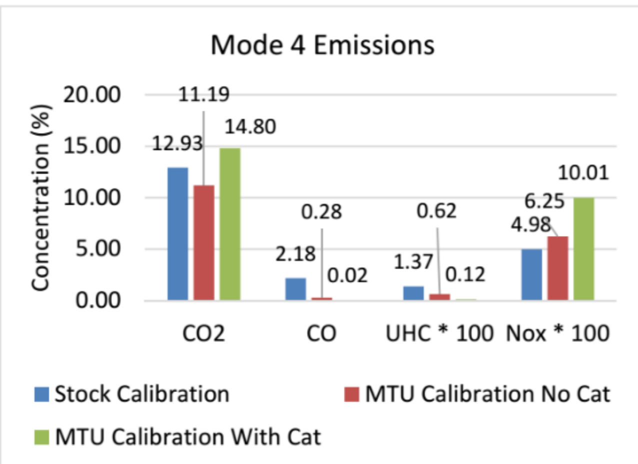

Figure 4: Average Mode 4 comparison of the CO_2, CO, UHC, NOx of the three calibrations

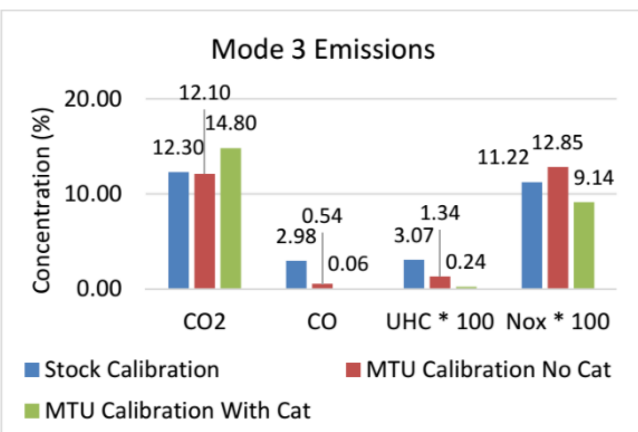

Figure 5: Average Mode 5 comparison of the CO_2, CO, UHC, NOx of the three calibrations

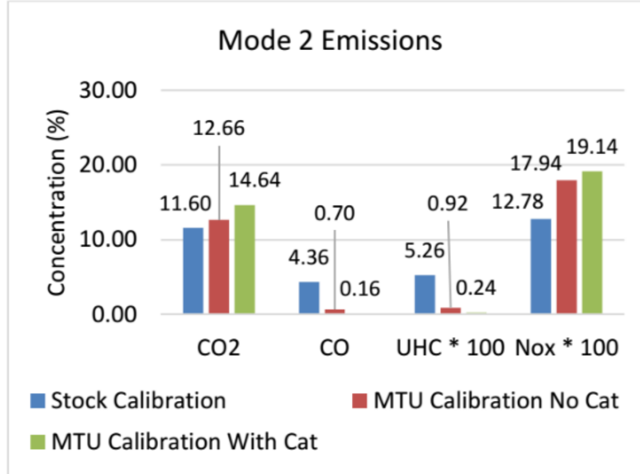

Figure 6: Average Mode 5 comparison of the CO_2, CO, UHC, NOx of the three calibrations

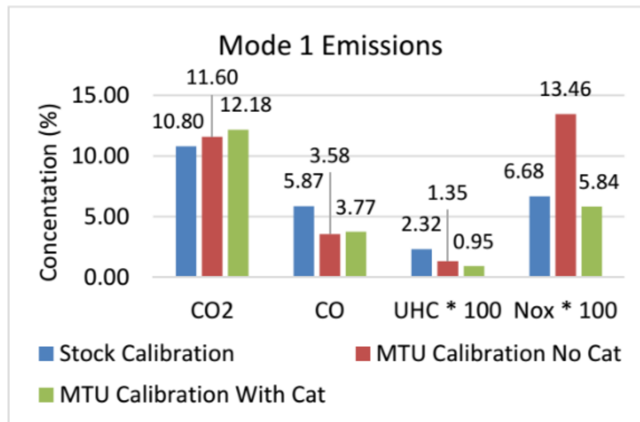

Figure 7: Average Mode 5 comparison of the CO_2, CO, UHC, NOx of the three calibrations

CATALYTIC CONVERTOR

For the 2017 MTU Clean snowmobile exhaust system, a Umicore substrate was used in a three way catalyst packaged by V-converter. This catalyst will improve the oxidation and conversion of unburned hydrocarbons (UHC), carbon monoxide (CO) and nitrous oxides (NOx). 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 2017 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)

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. 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.

Table 6: Comparison of collected stock calibration emissions data and 2017 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

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 a 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 (O2) increases, allowing for a greater conversion of CO to CO2 and greater conversion of UHC.

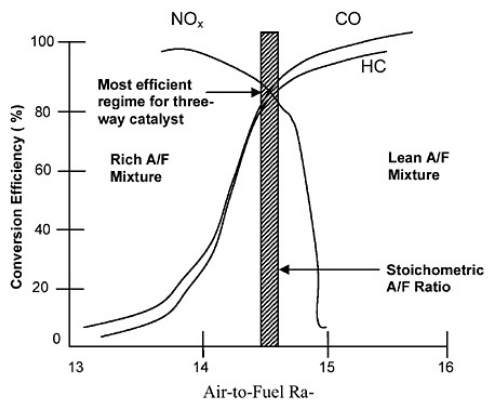

Figure 9: Catalyst conversion efficiency at different air-fuel ratios [Heywood, J.]

NOISE REDUCTION SOLUTIONS

MTU's snowmobile did not pass noise testing in the 2016 competition. It is a high priority to reduce the snowmobile's operational noise for the 2017 competition. This section discusses the methods that are used to reduce the overall noise level on the 2017 competition snowmobile.

NOISE

This section discusses the methods that are used to reduce the overall noise level on the 2017 competition snowmobile. All testing was performed on snow under SAE J1161 2017 Competition standards, in which the snowmobile is run at a constant 35 mph for 150 feet, with the recording equipment placed a distance of 50 feet perpendicular to the test track. All data is based off an average of three operational 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.

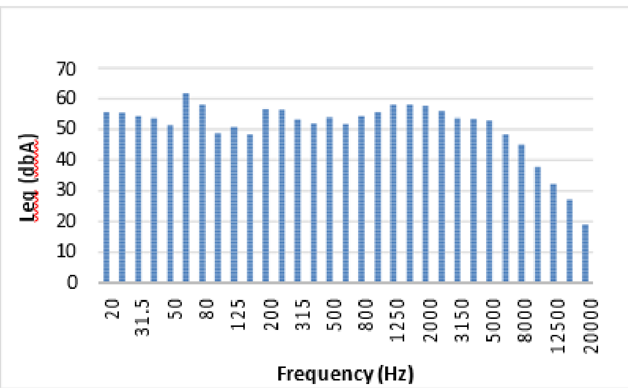

Figure 10: 1/3 Octave Spectra Graph of stock 2007 Yamaha Phazer

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 custom muffler. 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 the 2017 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.

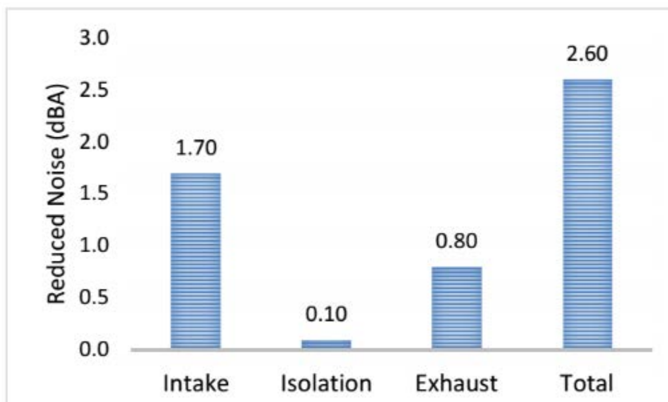

Figure 11. Overall Noise Reduction

Figure 12 below is a 1/3 Octave Spectra Plot of the 2017 competition snowmobile compared to the stock Yamaha Phazer. It can be inferred from the plot 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.

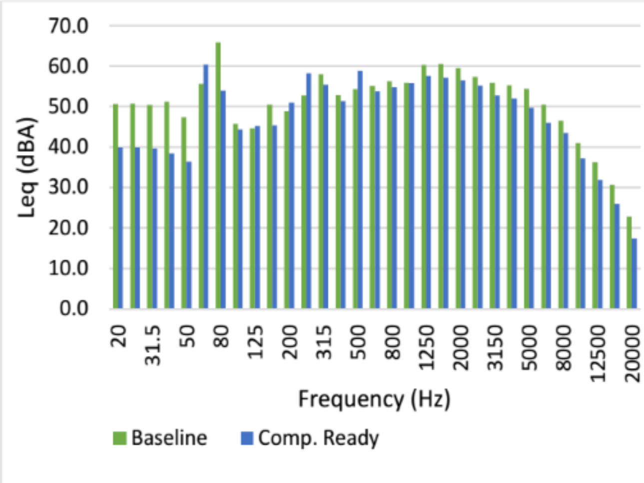

Figure 12: 1/3 Octave Spectra Graph of 2016 Competition Snowmobile and Stock Yamaha Phazer

Figure 13: Initial MTU muffler design

MUFFLER DESIGN FOR NOISE REDUCTION

The design for this year's competition muffler began by updating a Matlab code from 2016 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 the 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 830ºC limit on a tune of lambda 0.85, but exceeded the limit while attempting to tune at lambda 1.0.

COST

In an effort to keep manufacturing costs as low as possible, every component added to the 2017 MTU IC entry was carefully analyzed. After implementation of new components, the final MSRP value of the 2017 MTU IC entry was calculated to be $12,342. Since the 2017 MTU IC entry includes advancements in chassis, flex fuel technology, fuel management, and significant emissions reductions, the MTU CSC Team feels the additional $2,112 is well justified.

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 2017 competition snowmobile.

Since the 2016 MTU CSC snowmobile did not pass noise testing in 2016's competition, it was a high priority to reduce the snowmobile's noise level for the 2017 competition. Therefore, one of the team goals 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.

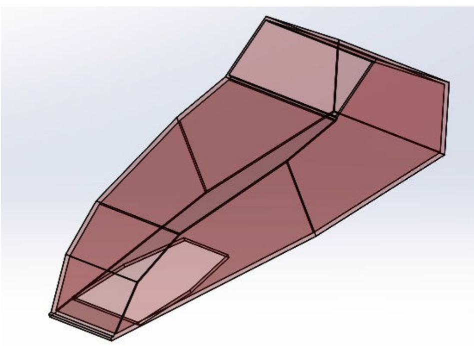

Figure 15: SolidWorks model of new intake

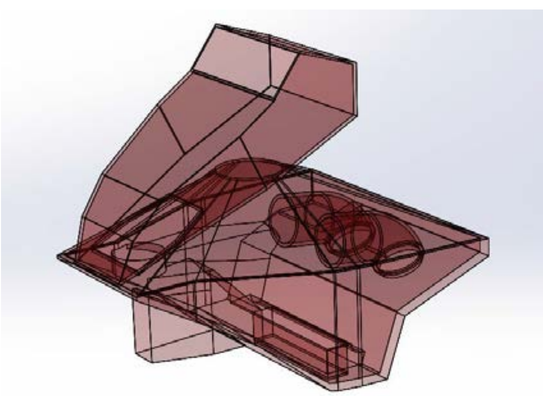

Figure 16: SolidWorks model of new intake mounted on existing air box

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 vs. prototype air box intake

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 (H20). 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, due to the ram-air design of the intake.

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 the MTU 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 2017 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.

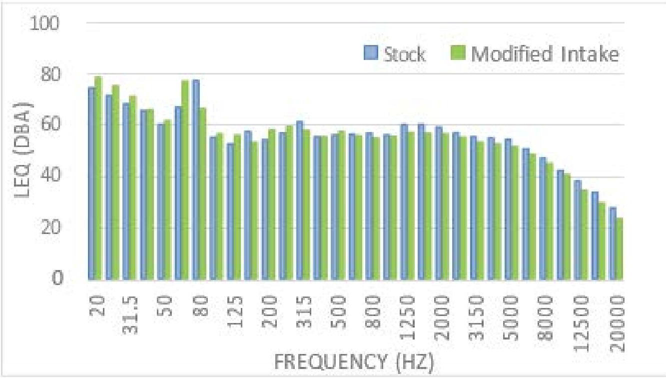

Figure 18: 1/3 Octave Spectra Graph

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 2017 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 by implementing isolators at the two 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.

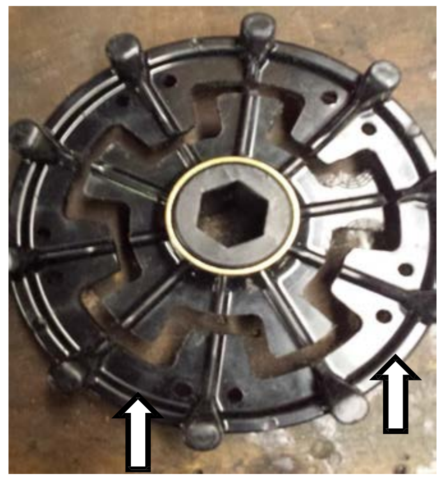

Figure 19: MTU custom driver before isolation rubber installed. Arrows depict the slots cut to be filled with the isolation rubber.

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 lbf), the stock drivers weigh 0.54 kg (1.19 lbf) 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 lbf) snowmobile with a 117.9 kg (260 lbf) 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 117.9 kg (260 lbf) would be used on the rear mounting points. Figure 21 below shows the isolators used for mounting the rear suspension. Due to the location of the skid mounting bolts in the foot well, isolators were not a viable option, as they would prevent the rider from safely operating the snowmobile.

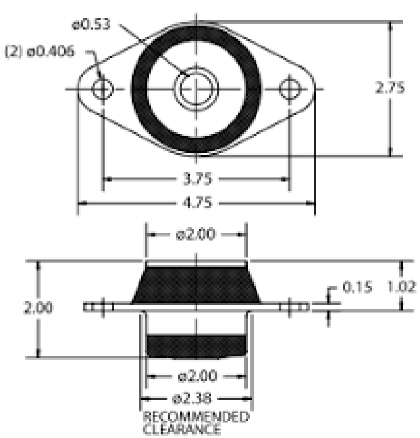

Figure 21: Isolators used for mounting of rear suspension

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.

SUSPENSION

To make the suspension better for rider comfort, rolling resistance, and mechanical noise reduction, the team decided to implement a 137" Yamaha Viper RTX skid. Starting with a new suspension is key in the movement of mechanical parts, freshness of the shocks, and being able to try new components. A 10" Billet Aluminum Big Wheel kit was added on the rear axle in order to accommodate the 144" camso track. The big wheel kit also reduces rolling resistance. Less rolling resistance improves fuel economy because the larger radius requires less force to bend the track around the rear axle. To fit the 137" Viper suspension in the Phazer chassis, rear brackets had to be made. The center to center length of mounting points on the suspensions were different. The 137" Viper suspension had to have a rear mounting point roughly ¾ of an inch closer tothe rear of the tunnel.

The rear brackets were designed to accommodate the rubber isolators to reduce vibrations generated in the suspension. Finite Element Analysis was completed on the new rear brackets. The force applied to the bolt hole was 113.39 kg (250 lbf). This force took into account that there would be two plates distributing and overall load of 226.8 kg (500 lbf). The results concluded the plates can withstand the load. The max stress was 3.131e+006 N/m², with a yield strength of 6.204e +008 N/m². The max displacement produced by the force was 1.323e-004 mm. This confirms the plates can withstand the extreme loads and force applied to the plates during snowmobile operations.

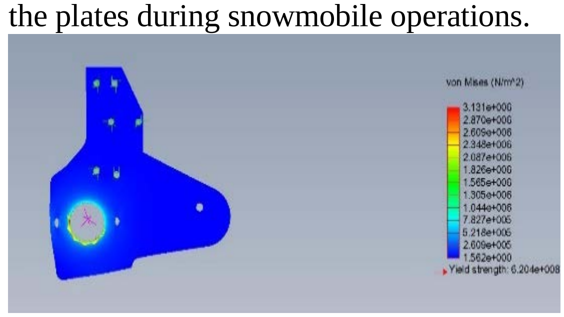

Figure 22: FEA Stress Results

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 wet weight is 263 kg (580 lbf). The competition ready 2017 MTU CSC team Yamaha Phazer weights 291.2 kg (642 lbf). 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 147.4 kg (325.0 lbf). The right ski carries a load of 68.9 kg (152.0 lbf). The left ski carries a load of 74.8 kg (165.0 lbf). The weight distribution is 23.7% on the front right ski, 25.7% on the front left ski, and 50.6% 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.

TRACK TESTING

This year, the MTU CSC team wanted to examine track length efficiency and performance. To do this, the currently installed 128" track from spring 2016 competition was tested against the stock 144" track. Table 7 shows the results of testing, where the top speed and time required for 500 foot acceleration runs were recorded. The results proved that the 144" track achieved higher accelerations, faster lap times, but lower top speeds. Another test performed was pulling the sled attached to a load cell behind a truck at a constant 20 mph with both track configurations. The load cell results can be seen in Table 8, and show that the 144" track has lower roller resistance. Due to the testing results, the team decided that the 144" track is more efficient, and that it was the track that the team wanted to implement for the spring 2017 CSC competition.

Table 7: Track speed comparison

128"		144"		
Time	Speed	Time	Speed	
8.6		8.16	52	
8.8		8.66	51.7	
8.64	61.8	8	52.8	
8.7	60.5	8.53	51.6	
8.93	61.1	8.55	52.5	
8.734	61.13333	8.38	52.12	Averages

Table 8: Track load cell comparison

Load Cell		
128"	144"	
0.4	0.3	
0.35	0.35	
0.4	0.38	
0.383333333	0.343333333	Averages

GEARING

Once the team decided to utilize the 144" track with the custom 10-tooth drivers and big wheel kit, calculations were run to determine what gearing would be needed to maintain the stock gearing ratio while compensating for the larger drivers.

In order to calculate the chaincase gearing required to compensate for the larger 10-tooth drivers, the gear ratio between the primary and secondary clutches needed to be determined when fully engaged. To do this, the top speeds with the different drivers from track testing data was used to back-calculate the clutch ratio. These calculations can be seen in Table 9. It was determined that when the clutches are fully engaged, the ratio between the clutches was determined to be approximately 1.22.

Table 9: Chaincase gearing ratio

Test Data Calculations						
mph	ft/s	Driver RPM	Jackshaft RPM	Max RPM	Clutch Gearing	Clutch Ratio
52	4576	2752.6	6664	7840	1.18	1.22
61	5368	2563	6205	7840	1.2	

Once the clutch ratio had been determined, the stock chaincase gearing was used to calculate what the theoretical top speed would be with a custom chassis setup and the MTU custom tune. The maximum attainable speed the snowmobile would be able to achieve is approximately 56 mph. Table 10 shows this calculation. Using this top speed, different chaincase gearing combinations were tested and compared to stock performance. Table 11 shows the gear combination currently in use with the 10 tooth drivers to compensate for their larger size. It was determined that a 17 tooth jackshaft gear and a 46 tooth driveshaft gear would compensate for the larger drivers.

Table 10: Chaincase gear ratio calculations

Drivers	mph	ft/s	Driver RPM	Jackshaft PRM	Max RPM	Clutch Ratio
8 tooth driver.	56.2	4950.7	2978	6426	7840	1.22
10 tooth driver	56.5	4974	2374.9	6426.2	7840	1.22

Table 11: Gear compensation factors

	Chaincase Gearing Comb.		
	Jackshaft Gear	Driveshaft Gear	Ratio
Installed During Testing	19	46	2.42
8 tooth stock perf.	19	41	2.15
10 tooth stock perf.	17	46	2.70

COMPENSATION FOR LOW OCTANE FUEL

The 87-92 octane 0%-85% ethanol fuel blends used in the 2017 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 2017 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 2017 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 2017 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 by a tone ring attached to the drive axle 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 produced by the exhaust system, seen in figure 23. 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.

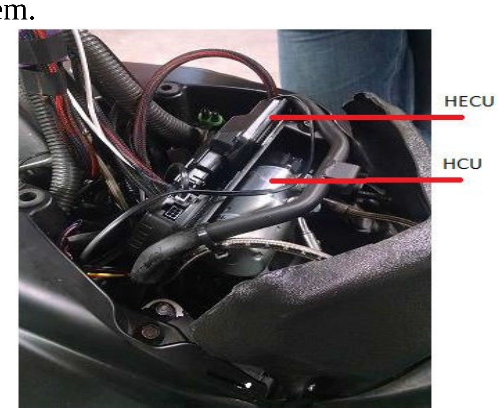

Figure 23: Hayes HCU and HECU mounting locations.

SUMMARY/CONCLUSIONS

The 2017 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 1.1-1.2 to produce overall cleaner emissions and reduce fuel consumption. The implementation of all systems on the 2017 MTU IC snowmobile have preserved stock performance while reducing noise and emissions. The 2017 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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- Nexteer
- Meritor
- Mitsubishi Electric

DEFINITIONS/ ABBREVIATIONS

ABS Anti-lock Braking System
AFR Air-Fuel Ratio
CAT Catalytic Converter
CPSI Cells per Square Inch
CO Carbon Monoxide
CO2 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
O2 Oxygen
PE Performance Electronics
PPM Parts per Million
RPM Revolutions per Minute
TPS Throttle Position Sensor
WOT Wide Open Throttle