Michigan Technological University's Solutions for a Greener Future of the Snowmobile Industry

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ABSTRACT

The Michigan Technological University (MTU) Clean Snowmobile Team is competing in the 2018 SAE Clean Snowmobile Challenge with a 2016 Yamaha RS Venture TF BAT. The snowmobile was reverse engineered and designed to reduce operating noise, improve emissions, and promote a greener future for the snowmobile industry.

INTRODUCTION

The snowmobile industry, after its inception, has been a shrinking industry run by a few centralized manufacturers. Although rider safety equipment has improved on the snowmobiles, the power and emissions generated were mostly unregulated. Noise levels generated by snowmobile operation are primarily regulated by state departments of natural resources, until noise and emission restrictions were placed by Yellowstone National Park to preserve the environment and wildlife.

In response to the restrictions by Yellowstone National Park, the Society of Automotive Engineers (SAE) began a student design competition called Clean Snowmobile Challenge (CSC) in the year 2000 to address the potential banning of snowmobiles within the park. The intent of the competition was to allow university teams to introduce new technologies to the industry in a competitive design environment.

Although the likelihood of snowmobiles becoming banned within Yellowstone National Park has been greatly reduced, the movement toward cleaner and quieter snowmobiles has continued. The implementation of the Best Available Technology (BAT) requirement in the park has jump-started this movement and has led to the latest National Park snowmobile standard: Enhanced-Best Available Technology (E-BAT).[1]

INNOVATIONS

For the 2018 Clean Snowmobile Challenge, the MTU team has partnered with Yamaha to develop the first production E-BAT certified snowmobile in the industry. This project began with the BAT certified 2016 Yamaha RS Venture TF BAT. The goal was to reduce the overall operational noise level by 2 decibels (dBA) to achieve the E-BAT certification and be a competitive participant in the 2018 CSC competition. Key innovations by the Michigan Tech Clean Snowmobile Team in 2018 include the use of temperature calibrated quarter wave resonators on the intake and exhaust system, implementation of a ported track, utilization of a three-way catalytic converter, and increased sound deadening in the Original Equipment Manufacturer (OEM) panels. The team has focused on innovative noise reduction solutions to meet the next generation of environmental standards and is confident that these solutions will provide greater rider comfort and less environmental impact, all while upholding the reliability and performance modern snowmobiles are known for.

TEAM ORGANIZATION AND TIME MANAGEMENT

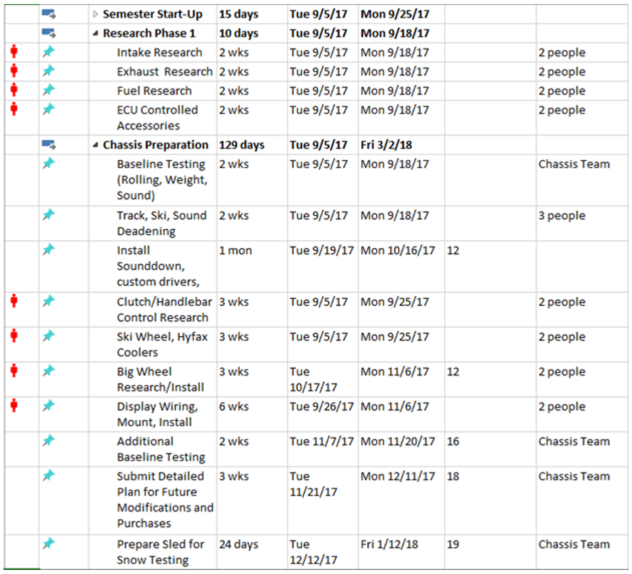
The Michigan Tech Clean Snowmobile Team was formed in 2000 as one of the original seven university teams selected to compete in the inaugural Clean Snowmobile Competition in Jackson Hole, Wyoming. Today, Michigan Tech's Clean Snowmobile Team is a member of the Michigan Tech Advanced Motorsports & Enterprise Program. The Advanced Motorsports Program is comprised of the SAE Student Design Teams at MTU - SAE Clean Snowmobile, Formula SAE, SAE Supermileage, and SAE Baja.

The Michigan Tech Clean Snowmobile Team consists of two primary subteams - chassis team and engine team. The team is led by an executive board. Shane Severn is team president, Austin

Dohse is chassis team lead, and Paul Hanafin is engine team lead. The team has a business team for sponsor relations, budget management, and Manufacturer's Suggested Retail Price (MSRP) development. Anthony Rettig and Josh Carpenter lead the business team.

The Michigan Tech Clean Snowmobile Team organizes its time by setting goals at the beginning of each season, organizing them into a Gantt chart, and assigning projects to each team member. Team members are responsible for completing at least three shop hours per week in addition to an hour long weekly general meeting to receive passing course grades. Gantt chart organizations and incentive to contribute allow the team's project to be completed with quality and innovation in mind while meeting timeline goals. A portion of the 2018 Gantt chart is seen in Figure 1.

Figure 1. Example of Team Gantt Chart



Semester Start-Up	**15 days**	**Tue 9/5/17**	**Mon 9/25/17**		
Research Phase 1	**10 days**	**Tue 9/5/17**	**Mon 9/18/17**		
Intake Research	2 wks	Tue 9/5/17	Mon 9/18/17		2 people
Exhaust Research	2 wks	Tue 9/5/17	Mon 9/18/17		2 people
Fuel Research	2 wks	Tue 9/5/17	Mon 9/18/17		2 people
ECU Controlled Accessories	2 wks	Tue 9/5/17	Mon 9/18/17		2 people
Chassis Preparation	**129 days**	**Tue 9/5/17**	**Fri 3/2/18**		
Baseline Testing (Rolling, Weight, Sound)	2 wks	Tue 9/5/17	Mon 9/18/17		Chassis Team
Track, Ski, Sound Deadening	2 wks	Tue 9/5/17	Mon 9/18/17		3 people
Install Sounddown, custom drivers,	1 mon	Tue 9/19/17	Mon 10/16/17	12	
Clutch/Handlebar Control Research	3 wks	Tue 9/5/17	Mon 9/25/17		2 people
Ski Wheel, Hyfax Coolers	3 wks	Tue 9/5/17	Mon 9/25/17		2 people
Big Wheel Research/Install	3 wks	Tue 10/17/17	Mon 11/6/17	12	2 people
Display Wiring, Mount, Install	6 wks	Tue 9/26/17	Mon 11/6/17		2 people
Additional Baseline Testing	2 wks	Tue 11/7/17	Mon 11/20/17	16	Chassis Team
Submit Detailed Plan for Future Modifications and Purchases	3 wks	Tue 11/21/17	Mon 12/11/17	18	Chassis Team
Prepare Sled for Snow Testing	24 days	Tue 12/12/17	Fri 1/12/18	19	Chassis Team

The Michigan Tech Clean Snowmobile Team participates in the SAE "A World in Motion" program to help develop the next generation of STEM students and give back to the community that has supported Michigan Tech and the Clean Snowmobile Team since its inception. The Team participates in school preview days to encourage prospective students to attend Michigan Tech and current students to join SAE Student Design Teams. The Michigan Tech Clean Snowmobile Team raises funds collectively with the other MTU SAE teams, and provides tours of team facilities to current and potential team sponsors.

2018 SNOWMOBILE CONFIGURATION

The factory specifications for the 2016 Yamaha RS Venture TF BAT used in the 2018 Clean Snowmobile Challenge can be seen in Table 1.

Table 1. Primary Component Breakdown of the 2018 MTU Competition Snowmobile

Parameter	**Description**
Engine	Yamaha Genesis
Engine Type	Four-Stroke
Cooling	Liquid
Cylinders	3
Displacement	1049cc
Bore and Stroke (mm)	82 x 66.2
Ignition	Digital Transistor Coil Ignition with Throttle Position Sensor (TPS)
Exhaust	3 into 1
Compression Ratio	11.3:1

For the 2018 competition, the team focused primarily on reducing operating noise, while staying competitive in other aspects of the competition by making improvements to the stock snowmobile donated to the team by Yamaha. While improving upon the operation of the snowmobile, great attentiveness was used to maintain ride quality and level of performance. To ensure that the proper steps were taken to improve the snowmobile, the team used a five step process. These five steps consisted of research, design, testing, development, and validation.

DATA ACQUISITION - SOUND

VEHICLE SOUND ATTENUATION

In order to characterize the sound profile of the stock snowmobile, the team built “overkill” hardware to minimize noise generation of critical components and implemented them during testing to determine the maximum component performance. The largest noise generator on a snowmobile is the engine, with the primary sources of noise generation being air intake, mechanical noise of engine rotation, and exhaust. The next major contributor to noise is the chassis, as the power transmission from the engine to the ground occurs through this component. The skid also transfers energy from encountered terrain features back into the chassis.

INTAKE ATTENUATION

To attenuate intake noise, the team built an airbox that exceeded the stock airbox static volume. By increasing the static volume, the required velocity of air being pulled into the box was reduced, decreasing the audible noise generation. The airbox was constructed with an 18 gallon storage tote lined with R11 fiberglass insulation to dampen ambient noise and vibration. Figure 2 displays a side by side comparison of the modified “overkill” intake and the OEM airbox.

Figure 2. Overkill Airbox Compared to OEM Airbox

EXHAUST ATTENUATION

The exhaust was attenuated using the same method as the intake. A steel 55 gallon drum lined with fiberglass insulation was used to mitigate vibration. The drum was connected to the OEM muffler outlets. Figures 3 and 4 show the overkill muffler manufactured by the team and the deployment method on the snowmobile.

Figure 3. Overkill Muffler Internals

Figure 4. Venture with Overkill Muffler

CHASSIS ATTENUATION

Chassis attenuation was the most challenging goal of the team this year. Vibration of a single component mounted to the skid or chassis is amplified by the system and can easily be misdiagnosed until further testing is conducted. The OEM Venture had a medium density foam installed inside the plastic panels. The team retrofitted the plastic panels, forward bulkhead, and vertical outer faces of the tunnel with Soundown™ high density foam as shown in Figure 5.

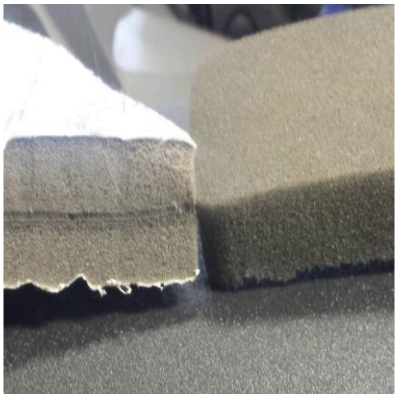


Figure 5. Body Plastics and Stock Foam

TEST PROCEDURE

Per SAE Clean Snowmobile Competition rules for the IC engine class, sound pressure data A-weighted, slow response, and the maximum overall sound pressure level will be recorded. The team utilized the Larson Davis LXT to record all sound pressure level data. All sound meter settings were followed per competition rules and the sound meter unit was properly re-calibrated before every testing session. Noise testing was conducted per SAE J1161 noise test requirements as required by the competition rules for the IC engine class.

STOCK DATA ACQUISITION

To determine the details of the OEM engine calibration, data from the OEM Engine Control Unit (ECU) needed to be collected and interpreted.

Acquiring stock calibration data required referencing spark and injector timing, and injector duration to the engine load, throttle position, speed, and crankshaft position.

The engine parameters were measured using Data Acquisition Modules, recording 5 channels of data. The stock crankshaft position sensor (CPS) was used to acquire engine speed and crankshaft position, while manifold absolute pressure (MAP) and throttle position (TPS) were used to characterize engine load and throttle position. Two methods were used to measure the engine calibration parameters: jumper harnesses and current clamps. The parameters measured by these methods are shown in Table 2.

Table 2. Data Acquisition Modules

Jumper Harness Connections	Throttle Position Sensor (TPS) Crankshaft Position Sensor (CPS) Manifold Absolute Pressure (MAP)
Current Clamp Measurements	Injector Waveforms Ignition Waveforms

Current clamp signal acquisition was limited to components with instantaneous current consumption of 30 mA or more. This was to ensure clean signal acquisition. The crankshaft and throttle position, along with MAP sensors are voltage based measurements and were measured by placing a jumper harness between the stock wiring harness and the data acquisition unit using BNC cables.

The crankshaft position sensor is a hall-effect type sensor that outputs a square wave voltage signal. The output waveform is a binary high in the presence of a tooth on the crankshaft trigger wheel shown in Figure 6.

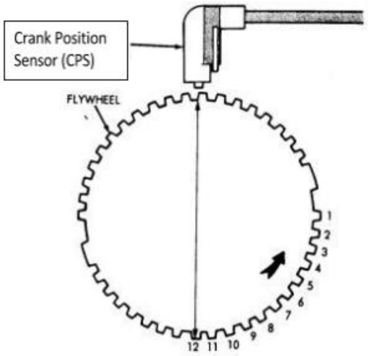


Figure 6. CPS Diagram

The MAP Sensor is a constant 0 to 5 V output pressure sensor, which has a linear transfer function with output voltage being directly proportional to manifold pressure. The calibration of the OEM Yamaha MAP sensor was not known, so a reference MAP sensor with a known calibration was used to derive the Yamaha MAP sensor calibration.

The TPS voltage output was characterized by taking resistance readings at 0% (idle) and 100% throttle blade openings. The transfer function for a potentiometer is linear, so two points were able to completely define the transfer function.

DATA PROCESSING

IDENTIFYING TOP DEAD CENTER (TDC)

The square wave output from the crankshaft position sensor was used to measure engine speed and crankshaft position. The waveform was measured at idle, and is shown in Figure 7. The CPS output has a series of evenly spaced pulses, each corresponding to a tooth on the crankshaft trigger wheel. Additionally, as can be seen in Figure 7, there is a large gap, corresponding to missing teeth used to identify TDC.

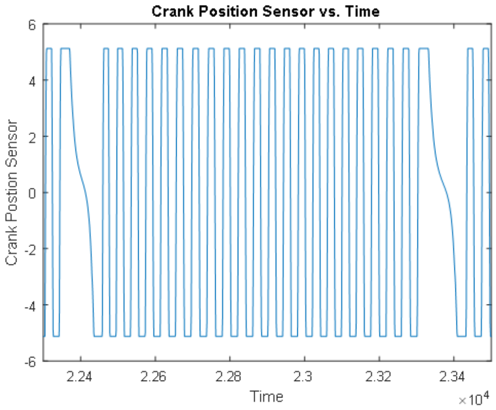


Figure 7. CPS vs Time

The CPS waveform shows 22 tooth pulses and a blank space equal to a two-tooth gap for a total of 24 teeth on the flywheel. From this waveform it was calculated that each pulse corresponds to a 15 degree change in crankshaft angle. TDC is signified by the beginning of the space or missing teeth on the crankshaft trigger wheel, at 2.33 seconds.

IDENTIFYING IGNITION TIMING

In a similar fashion to finding TDC, the pulses from the engine coils are able to determine when the ignition is occurring in a relation to degrees to the crank position. The ignition fires once per two revolutions. With TDC known this was set to a zero point from which ignition and fuel timing was built. The value of relevance for ignition will be a “time” (measured in degrees) before TDC. This measurement of time in degrees for the Yamaha Venture in reference to Figure 8 is 15 degrees before TDC. In Figure 8, the inverted peak represents when an ignition event occurs. This takes place every two revolutions of the crankshaft.

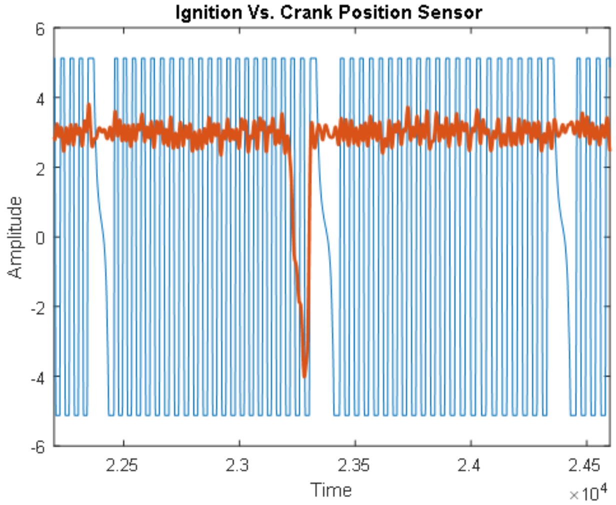


Figure 8. CPS (blue) Waveform with Ignition Timing (orange) Waveform vs Time

IDENTIFYING INJECTOR TIMING

The injector timing data from this engine can be processed in a very similar way as the ignition timing data. The injection cycle, like ignition, occurs once per two revolutions. Fueling was measured to occur 165 degrees after TDC for 3.9 milliseconds as shown in Figure 9.

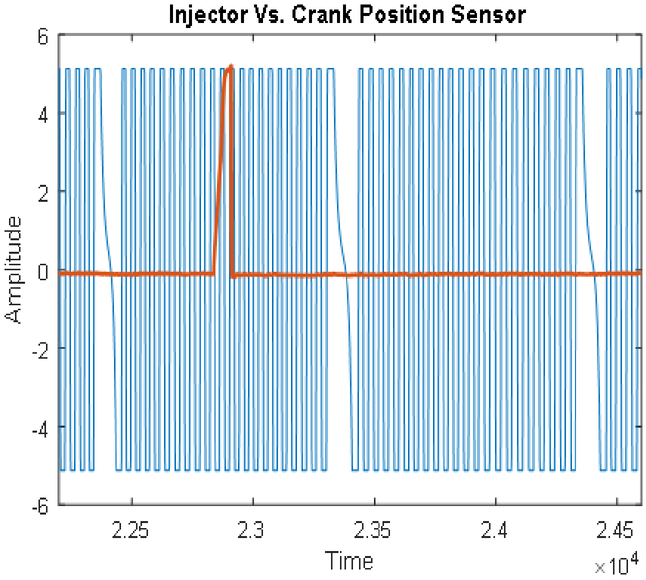


Figure 9. CPS (blue) Waveform with Injector Timing (orange) Waveform vs Time

IN FIELD DATA ACQUISITION - EVO4

For in field testing, the MTU Clean Snowmobile team implemented an EVO4 data logger to develop an understanding of engine parameters during a wide range of operational maneuvers. The purpose of utilizing the data logger was twofold: collect relevant information for the noise reduction team, and collect information for the engine calibration team.

DATA LOGGER FEATURES

The data logger system offers a range of data logging capabilities. The unit on the snowmobile is capable of recording 5 analog inputs, 2 digital inputs, 1 Revolutions Per Minute (RPM) input, and data from the stock ECU. Additionally, the unit has an internal tri-axial accelerometer and an internal Global Positioning System (GPS).

DATA COLLECTED

The data logger was configured to record thermocouple temperatures from the air intake, exhaust header pipes for each of three cylinders, and exhaust temperatures in both pre and post-catalytic converter positions. The unit also recorded engine speed and oxygen sensor information during operation. With the GPS and accelerometer always active, the team was able to gain considerable insight into temperature ranges experienced throughout the intake and exhaust system.

The engine team was able to select the best catalytic material for the application, due to an accurate understanding of exhaust temperatures. The team also learned what exhaust manifold temperatures were acceptable to maintain engine longevity, while still maintaining a performance envelope. The oxygen sensor also gave valuable insight into stock engine air/fuel ratio, which assisted in reverse engineering an efficient ECU calibration. The sound team utilized thermocouple temperatures from the intake and exhaust to design ¼ wave resonators to reduce the overall sound pressure level of the snowmobile generated during operation.

CALIBRATION TECHNIQUES

CALIBRATION GOALS

The team intends to create a lean burn calibration that can operate with the addition of a 3-way catalytic converter and any additional modifications that are made. A lean burn allows the engine to run with a lower fuel consumption while also reducing the production of most emissions.

For 2018 the MTU IC team is utilizing the MoTeC M130 Development Package ECU. This ECU allows for a fully controlled and unlocked calibration experience. The MoTeC ECU was chosen due to its vast customizability and its ability to control features such as electronic throttle control. The ECU also offers the ability to be packaged in the factory ECU location, allowing for a seamless installation into the 2016 Yamaha RS Venture TF BAT.

The method of engine calibration utilized by Yamaha for the Venture is known as speed density. With this calibration technique, the fuel and ignition maps are created based on manifold air pressure (MAP) versus RPM. This allows the engine to compensate for changing loads and environment conditions more efficiently than the typical Alpha-N or TPS tuning method which does not consider load effects efficiently.

The method of calibrating with speed density was transitioned over to the MoTeC ECU to take advantage of the existing hardware on the snowmobile. The team did however, install an oxygen sensor into the exhaust system to allow for a closed loop calibration experience. The addition of the O2 sensor further improves the tuning equipment that the Yamaha Venture already includes.

DEVELOPMENT

It is important when developing a new engine calibration to be able to operate and monitor the engine extensively in constant conditions. The team used a dynamometer from Land & Sea to regulate engine load during calibration. The Land & Sea DYNO-mite water brake is mounted to the crankshaft to be used as an engine dynamometer as seen in Figure 10.

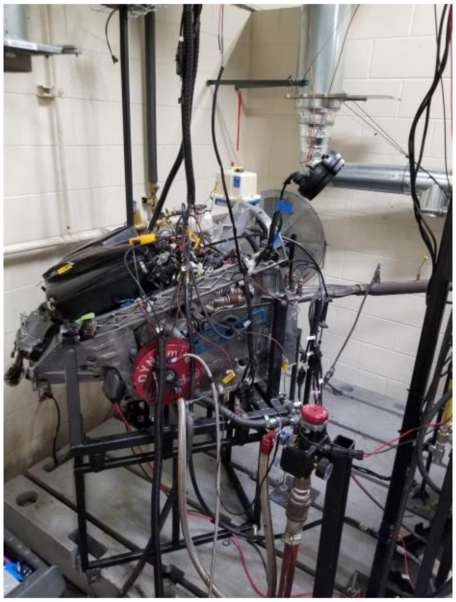


Figure 10. Dynamometer Setup

The team uses the DYNO-mite water brake to tune the 5 target modes as described in the snowmobile emission standard, listed in Table 3.[3]

Table 3. Five Target Modes

Mode	Crankshaft Speed (rpm)	Crankshaft Torque (lb-lbs)
1	8300	32.4
2	7140	16.52
3	6300	10.69
4	5460	6.16
5	Idle	0

Beyond the use of the 5 mode system, power pulls were completed from a 4,000 RPM to a max RPM scale. This allows transients of the ECU calibration to be tested on the dyno.

The team first measured the lambda ratio the factory ECU achieves during operation. In Figure 11, lambda is plotted of time during an operation cycle that consisted of idle, cruising, deceleration, and acceleration.

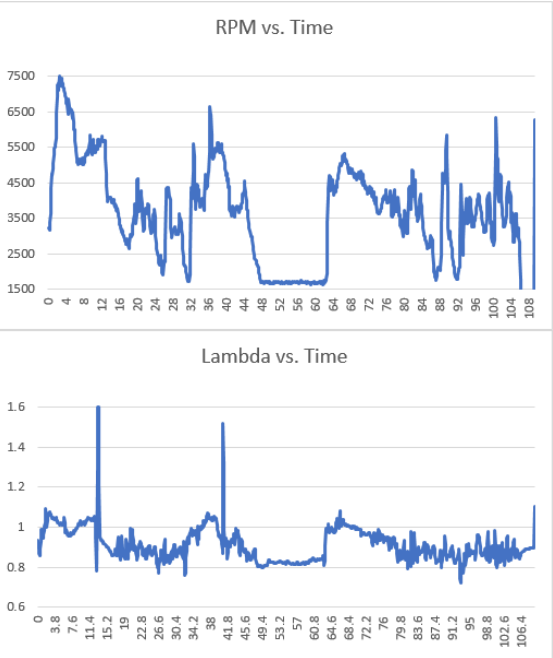


Figure 11. Lambda vs Time Graph with RPM Reference

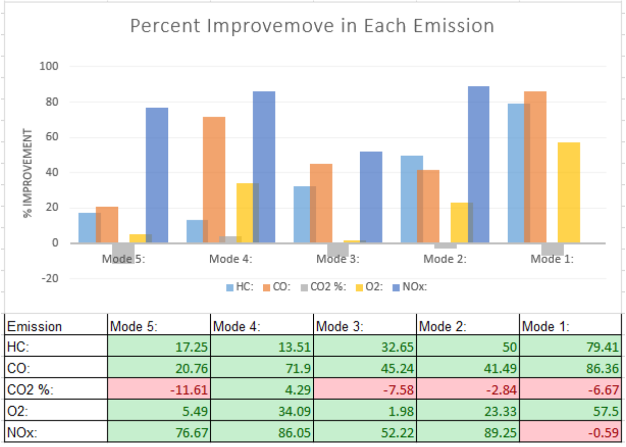
From Figure 11, it was determined that the snowmobile targets lambda 1.0 aggressively from the factory in steady state conditions. However, the data also showed that the lambda value dropped to 0.8 upon acceleration. This lead the team to set a goal of achieving a slightly leaner burn than stock. The goals for 2018 were set to achieve a lambda ratio of 1.05 during steady state conditions and between 0.85 and 0.9 upon acceleration to allow a safe but efficient lean burn.

EMISSIONS TESTING

When calibrating for emissions, testing is done on the amount of carbon monoxide (CO), carbon dioxide (CO2), unburned hydrocarbons (UHC), and nitrous oxide (NOx) emissions. Figure 12 shows the concentration of the emitted particles throughout the different testing modes. In order to achieve a clean burn throughout the entire map, a lambda value of 1 is the target for calibration purposes. Unfortunately, tuning for lamba 1 does not solve all of the emissions issues. High UHCs and CO levels are present. In order to solve this issue, a catalytic converter is needed. The use of a MoTeC ECU allows for simple adaptation to the Yamaha RS Venture as well as easy adjustments to timing and injection parameters.

CALIBRATION

In order to simulate real world operation in a dynamometer setting, a Land & Sea DYNO-mite system with a water brake is being used. This allows for proper calibration throughout the RPM range that will translate well to use while on the snow. The data collected from tuning with the MoTeC ECU was then compared with the stock data that was gathered before the calibration process began. The team followed the same ramped modal cycle emissions test performed in the CSC competition. From these observations, further changes and tuning can be performed on the system. Figure 12 compares the emissions data gathered at each mode test.



Emission	Mode 5:	Mode 4:	Mode 3:	Mode 2:	Mode 1:
HC:	17.25	13.51	32.65	50	79.41
CO:	20.76	71.9	45.24	41.49	86.36
CO2 %:	-11.61	4.29	-7.58	-2.84	-6.67
O2:	5.49	34.09	1.98	23.33	57.5
NOx:	76.67	86.05	52.22	89.25	-0.59

Figure 12. Emissions Composition Improvement

CATALYTIC CONVERTER

For the 2018 MTU snowmobile emissions control system, a three way catalyst package produced by V-Converter was utilized by the team. This converter will reduce the amount of UHC, Carbon CO, and NOx. Made of the precious metals platinum, palladium and rhodium, this catalyst will increase conversions of harmful emissions. The team selected a catalyst as seen in Figure 13 in order to meet the 2018 competition requirements.

Figure 13. 2018 Three-Way Metallic Catalytic Converter

The 2018 Clean Snowmobile Challenge point distribution relies heavily on the emissions test, which is directly correlated to the engine calibration and the performance of the catalytic converter. The E-score to gain points in the Lab Emissions portion of the competition is calculated using Equation 1.

$$E = \left[1 - \frac{(HC+NO_x)-15}{150}\right]*100 + \left[1 - \left(\frac{CO}{400}\right)\right]*100 \geq 100 \qquad (1)$$

By reducing UHC, NOx, and CO, the overall E-score increases. The catalytic converter, assuming optimal temperatures, will convert about 90% of these harmful exhaust gases into carbon dioxide, nitrogen, and water vapor.

The catalytic converter selected by the team has an optimal temperature performance of 800 degrees Fahrenheit. The exhaust pipe is currently exposed along the underside of the tunnel. The only viable location is to place the catalytic converter in the section of pipe between the Y-pipe and muffler, toward the rear end of the tunnel as shown in Figure 14.

Figure 14. Proposed Catalyst Location

FLEX-FUEL IMPLEMENTATION

For the stock 2016 Yamaha Venture there is no factory system for analyzing and compensating for varying ethanol content. The ethanol content of gasoline purchased at different locations can vary and typically contains less than 10% ethanol. Similarly to gas stations providing various ethanol mixtures, the 2018 Clean Snowmobile Competition consists of a blind fuel blend supplied to each team. This blend can be anywhere from 0% to 85% ethanol. Stoichiometric combustion of pure gasoline at ideal mixture conditions occurs at an optimum air-fuel-ratio (AFR) of 14.6:1. E85 (ethanol blend) has an AFR of 9.77:1 for stoichiometric combustion to occur. In order to compensate for varying fuel blends, MTU IC is dependent on an Ethanol Content Analyzer (ECA). The ECA then provides the ECU with an input that can be interpolated to provide a proper injector compensation factor to ensure stable operating conditions for all ethanol compositions.

Energy density calculations were then completed for 10 different fuel blends in 10 percent increments from E0-E100. Using the E0 energy density as the scale value, the fuel energy percentage for the remaining fuel blends was found and recorded. Since the baseline engine calibration was performed using ethanol-free fuel, a compensation factor for high ethanol content fuels must be included in the competition calibration. A linear scale factor was used between points to compensate for fuel blends falling in between the calculated data points. Note that the compensation factor through the ethanol range is near linear and at an ethanol rating of 85 there is typically a 140% compensation.

INTAKE NOISE REDUCTION

The final intake design utilized a quarter wave resonator due to the ease of implementation and available space. Figure 15 displays a generalized quarter wave resonator.

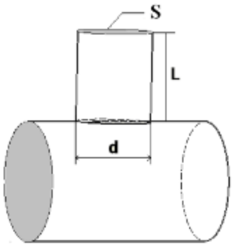


Figure 15. Quarter Wave Resonator

The frequency the resonator was designed to target was 265 Hz. The equation to determine resonator length for each fundamental frequency can be seen in Equation 2 while the respective harmonics of the resonator is defined by Equation 3:

$$f_0 = \frac{C}{4L} \tag{2}$$

Where:

f_0 is the fundamental frequency (Hz)
C is the speed of sound (m/s)
L is the length of the quarter wave resonator (m)

$$\text{Odd Resonator Harmonic} = (2n+1)f_0 \tag{3}$$

Where:

f_0 is the fundamental frequency (Hz)
n is the harmonic order (1,2,3,...,n)

After testing with the overkill intake, the sound pressure level was displayed in a ⅓ octave filter as observed in Figure 16.

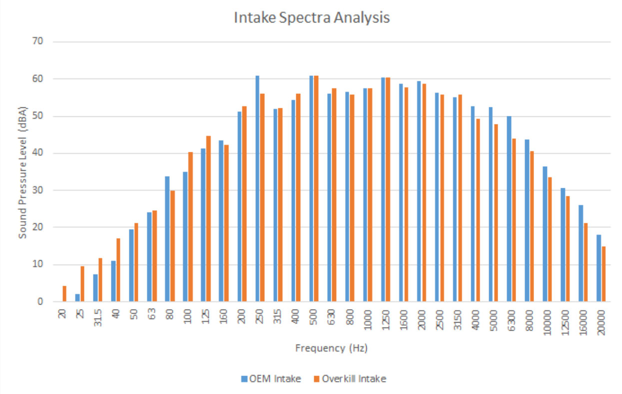


Figure 16. Intake ⅓ Octave Spectra Analysis

As seen in Figure 16, a large amount of intake noise is generated at 250 Hz, which is noticeably reduced by the overkill intake. This coincides with the second harmonic of the Firing Frequency (2 x 132.5 Hz =265 Hz), and the frequency the quarter wave resonator was designed to attenuate.

During sound testing, it was determined that intake resonator temperature was heavily dependent on ambient air temperature. The intake resonator was designed for an internal temperature of 50 degrees Fahrenheit, which equates to a resonator length of 12.5 inches. To combat temperature fluctuations in the resonator, a heating element was added to the resonator in order to maintain a constant temperature.

The intake resonator was built with two heating elements inside concentric insulated tubes and is shown in Figure 17.

Figure 17. Intake Resonator

The temperature was controlled using an OEM Yamaha air intake temperature sensor and a heater control circuit. The temperature sensor was characterized by the team by measuring the resistance across the sensor in 10° F and 70° F ambient temperatures, developing the transfer function is shown in Figure 18.

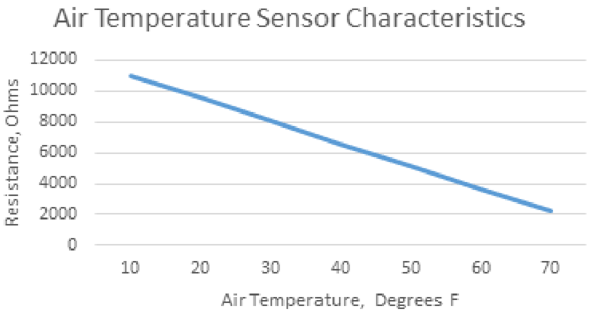


Figure 18. Air Temperature Sensor Characteristics

From the resonator temperature sensor curve, the target temperature corresponded to a resistance of 5.1 kΩ.

The heater control system was implemented using an op-amp comparator circuit shown in Figure 19. The output of the op-amp goes to +12V when the intake temperature sensor resistance goes above 5.1 kΩ, or temperature drops below 50° F.

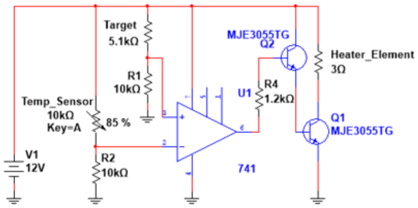


Figure 19. Op-Amp Temperature Control Circuit

The heating elements were measured to have a combined resistance of 3 Ω. A Darlington pair of NPN transistors was used to drive the low side of the heaters, with the base resistor chosen to overdrive the output of the power transistor by 3X to minimize power losses in the control circuit.

INTAKE RESONATOR RESULTS

An SAE J1161 sound test was performed with modified and OEM intakes. Figure 20 displays the ⅓ sound spectra with the modified and OEM intake configurations. It was observed the modified airbox was 3.1 dBA quieter than the OEM at the frequency of 265 Hz.

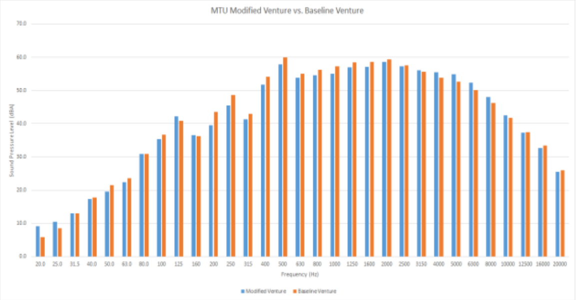


Figure 20. Final Intake Results

EXHAUST

An overkill exhaust was utilized in order to determine the sound contributions from the OEM exhaust. An SAE J1161 sound test was conducted with the overkill and OEM configurations. Figure 21 displays the ⅓ spectra from the overkill and OEM configurations.

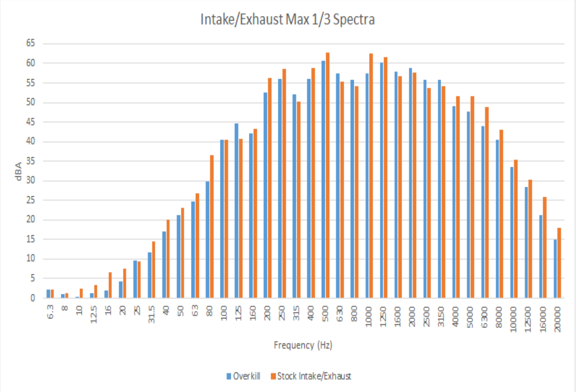


Figure 21. Intake/Exhaust Max ⅓ Spectra

The OEM exhaust was observed to have a higher sound pressure level than the overkill configuration at several frequencies. From the sound pressure level comparison, it can be concluded that the OEM exhaust could be improved to reduce frequencies associated with the firing frequencies of the engine.

The team implemented quarter wave resonators to increase sound attenuation at the firing frequencies of the motor. The team targeted the second and third harmonic of the engine firing frequency with two quarter wave resonators. The resonators will be able to target every firing frequency from 265 Hz to 3578 Hz. Table 4 indicates the target frequency and respective harmonic frequency for each resonator.

Table 4. Target Frequencies and Respective Harmonic Frequencies

	Resonator 1	Resonator 2
Fundamental Frequency (Hz)	265	397.5
Harmonic 2nd order (Hz)	530	662.5
Harmonic 3rd order (Hz)	795	927.5
Harmonic 4th order (Hz)	1060	1192.5
Harmonic 5th order (Hz)	1325	1457.5

Figure 22 shows the quarter wave resonators the team implemented in the OEM Yamaha Venture exhaust. The exhaust was then wrapped with fiberglass wrap to retain heat to insure the resonators remained at a constant temperature in order to maintain resonator performance.

Figure 22. Modified Exhaust with Quarter Wave Resonator

An insertion loss was performed on the OEM exhaust to gain an understanding of the performance before the quarter wave resonators were implemented. The same insertion loss test was then repeated with the quarter wave resonators and catalyst to determine exhaust performance improvement. Figure 23 displays the OEM exhaust insertion loss and the MTU modified exhaust insertion loss. As shown in Figure 23, the modified exhaust proved to have superior attenuation at the target frequencies of 250 and 400 Hz as a result of the implemented quarter wave resonators.

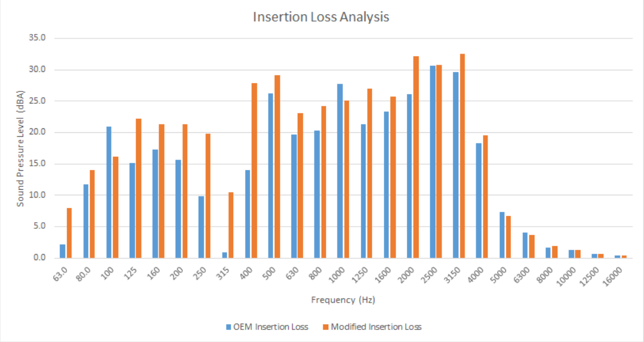


Figure 23. Stock vs Modified Exhaust Performance

TRACK/SUSPENSION NOISE REDUCTION

The MTU CSC team examined the effects of ported vs. non-ported tracks on the snowmobile's sound profile. The goal of utilizing a ported track was to help displace suspension noise and reduce natural frequencies created by the track motion that resonate within the chassis.

The OEM track on the snowmobile originally was a Camso Ripsaw 15 x 151 x 1.25 in. The new ported track is the Crossover model 15 x 151 x 1.5 in. with the addition of 1 x 1 in. port windows evenly distributed down the center and can be seen in Figure 24. The ported track is identical in length, width, and pitch.

Figure 24. Camso Crossover Ported Track

One of the primary causes of mechanical noise that can be reduced on the snowmobile is the suspension system. One method to reduce noise and vibrations was to relocate one of the front wheels. On the Venture, the torsion spring mount serves a dual purpose as a mount for the torsion spring and bogey wheel. When in motion, the ribs of the track come into contact with this set of wheels translating a force upward into the torsion springs, then into the chassis. These small repeated impacts have potential to lead to resonating frequencies within the chassis. Two testing configurations were attempted to reduce these frequencies. First, two sets of bogey wheels were removed from the skid completely. The removed sets are shown in Figure 25.

Figure 25. Removed Bogey Wheel Sets

Second, one bogey wheel was offset by 3.78in from the other. Testing with data acquisition equipment was performed to validate if these frequencies are suppressed with the offset. This offset was calculated with clearance for the torsion spring. The calculation can be seen in Equation 4.

$$\frac{Track\ Pitch}{2} + Track\ Pitch = \frac{2.52}{2} + \ 2.52 = 3.7in \tag{4}$$

Testing concluded that the offset was insignificant in reducing frequencies. Figure 26 shows removing the front bogey wheels was the most effective in reducing the overall sound pressure level of the snowmobile while offsetting the bogey wheels had little effect in the sound profile of the vehicle.

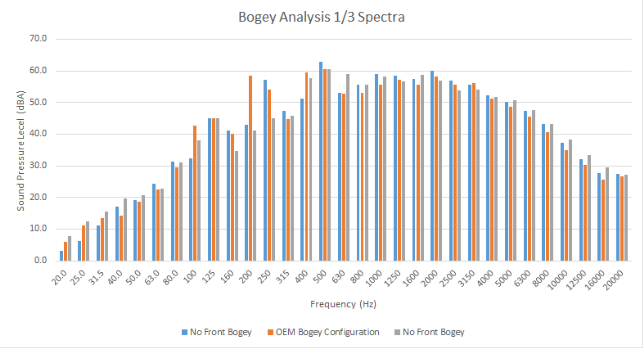


Figure 26. Bogey Wheel Analysis ⅓ Spectra

TRACK SKIRTS

In an effort to further reduce mechanical noise, the team prototyped a set of track skirts using ⅛" rubber mat. Figure 27 shows a picture of the prototype track skirt. Upon completion of the SAE J1161 sound test, the prototype track skirts proved to reduce the sound pressure level at the frequency of 500 Hz as seen in Figure 28.

Figure 27. Prototype Track Skirt Made of Thick Rubber

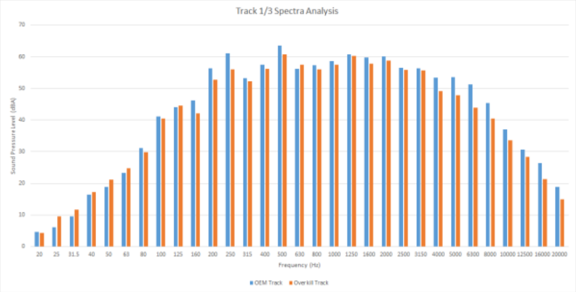


Figure 28. Track Sound Profile Analysis

Through testing, the team found the durability of the rubber track skirts and associated mounting system to be substandard. To address durability concerns, a new track skirt system was developed using a flexible, bristle material instead of solid rubber, shown installed on the snowmobile in Figure 29.

Figure 29. Snowmobile With Brush Track Skirt Installed

The team tested the finalized track skirt design to determine if the brush material would reduce sound levels as much as the solid rubber skirts. Figure 30 displays the ⅓ spectra with and without the final track skirt design. It was observed that the bristled skirts had no effect at the 500 Hz frequency of interest and therefore were not included in the final design.

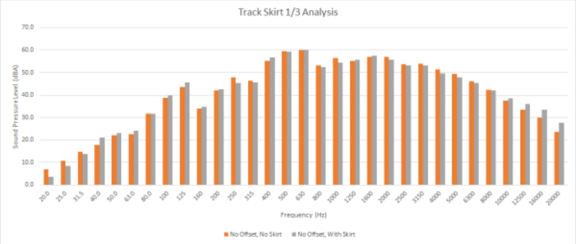


Figure 30. Bristled Track Shirt Analysis

BOSCH DISPLAY

For the 2018 IC sled the team decided to enhance the usability and features of the snowmobile by integrating a programmable Bosch DDU9 Motorsport display. Having a programmable display allows the team to implement their own graphics to display data and gives the team the ability to monitor key engine operating parameters during research and calibration efforts.

The DDU9 display uses three primary means of communication: RS232, CAN bus, and analog inputs. With a custom programmable ECU the bulk of data transmission is carried out through CAN bus. The ECU transmits all engine data over the bus in individual messages. Using an application known as Vector, all messages communicating over the bus are interpreted and entered into the Bosch display software. Key information displayed on the 2018 competition snowmobile includes RPM, fuel level, lambda values, and ethanol content.

Analog inputs were also used to display useful indicators to the rider, such as headlight hi-beam indication and other warnings. In compliance with competition rules, the dash was also used to display the vehicle speed. This was done by implementing a GPS receiver through an RS232 connection. Although this feature is rather expensive it is for research purposes only and does not affect the overall MSRP.

COST/MSRP

In an effort to keep manufacturing costs as low as possible, every component added to this year's IC entry was carefully analyzed. After implementation of new components, the final MSRP value of the 2018 MTU IC entry was calculated to be $15,454.78. Since the entry includes advancements in noise reduction, emission reduction, and rider comfort, the MTU CSC Team is confident that the extra $2,455.78 will provide increased value to the customer.

SUMMARY/CONCLUSIONS

Michigan Technological University's snowmobile for the 2018 Clean Snowmobile Challenge is a carefully tested and modified iteration of the 2016 Yamaha RS Venture TF BAT. All modifications were completed with manufacturability in mind to ensure future implementation would be feasible if desired. The shown modifications were also all carefully tested and validated to prove their worth for the team's goals.

Finally, the snowmobile entered for the 2018 competition is a reliable, quiet, and efficient solution for meeting the upcoming E-BAT standards to allow environmentally sensitive riding locations such as Yellowstone National Park to continue to be accessible to the snowmobiling community.

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DEFINITIONS/ABBREVIATIONS

AFR	Air-Fuel Ratio
BAT	Best Available Technology
CO	Carbon Monoxide
CO2	Carbon Dioxide
CPS	Crankshaft Position Sensor
ECU	Engine Control Unit
ECA	Ethanol Content Analyzer
GPS	Global Positioning System
HC	Hydrocarbon
IC	Internal Combustion
MAP	Manifold Absolute Sensor
MSRP	Manufacturer's Suggested Retail Price
MTU	Michigan Technological University
NOx	Nitrous Oxides
O2	Oxygen
OEM	Original Equipment Manufacturer
RPM	Revolutions per Minute
SAE	Society of Automotive Engineers
TPS	Throttle position Sensor
UHC	Unburned Hydrocarbon