Michigan Technological University's Solutions for an Environmentally Sustainable Future of the Snowmobile Industry

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INNOVATIONS

For the 2019 SAE Clean Snowmobile Challenge, the Michigan Technological University (MTU) team has partnered with Yamaha to continue development of 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 for the 2019 CSC competition include increased muffler volume, advanced catalyst selection, significant engine calibration, tunnel mounted vibration reduction plates, and billet aluminum track drivers. Prior innovations kept in use from the 2018 CSC competition include the use of temperature calibrated quarter wave resonators on the intake and exhaust system, implementation of a ported track, and 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.

Table 1. Innovations of Michigan Tech's 2019 SAE Clean Snowmobile Challenge SI Entry

INNOVATION	SUBSYSTEM	YEAR OF IMPLEMENTATION
MTU Designed & Fabricated Secondary Muffler	Exhaust System	***New Innovation for 2019 Competition***
Optimized Catalytic Converter	Exhaust System	***New Innovation for 2019 Competition***
Custom Engine Calibration on Motec M130 ECU	Engine Control	***New Innovation for 2019 Competition***
Tunnel Vibration Damping Plate	Tunnel	***New Innovation for 2019 Competition***
Custom Aluminum Drivers	Drivetrain	***New Innovation for 2019 Competition***
Induction and Exhaust Quarter-Wave Resonators	Exhaust, Intake System	Retained from 2018
Ported Track (optimized for fuel efficiency)	Drivetrain	Retained from 2018
Enhanced Sound Deadening Treatment on Panels	Panels	Retained from 2018

TEAM ORGANIZATION AND TIME MANAGEMENT

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

The Michigan Tech Spark Ignition (SI) Clean Snowmobile Team consists of two primary sub-teams: chassis team and engine team. The team is led by an executive board. Josh Carpenter is team president, Alex Spiess is chassis team lead, and Logan Eide 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 Rob Falzon 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 timeline, and assigning projects to each team member. Team members are responsible for completing at least five shop hours per week in addition to an hour long weekly general meeting to receive passing course grades. Each week, the Clean Snowmobile Executive Board meets before the team's general meeting and discusses the progress of the past week and makes updates to priorities and timelines as needed. The 2019 SI team timeline is depicted in Table 2.

Table 2. 2019 MTU Spark Ignition Timeline

2019 SI SNOWMOBILE WORK TIMELINE		
OBJECTIVE	**TARGET COMPLETION DATE**	**OBJECTIVE COMPLETE**
Engine reconfigured in dyno and running on Motec	10-30-2018	Y
Additional engine team members trained on Motec M1 Tune	10-30-2018	Y
Fuel flow measurement equipment determined & ordered	11-06-2018	Y
SI wiring harness rebuilt	11-10-2018	Y

OBJECTIVE (continued)	TARGET COMPLETION DATE (continued)	OBJECTIVE COMPLETE (continued)
Take stock emissions data with new Horiba bench and fuel flow equipment	11-13-2018	Y
On-snow base tune in Motec ready	11-13-2018	Y
Lambda 1.0 tune with closed-loop fueling complete in Motec	11-20-2018	Y
Motec tune refined and ready for catalytic converter testing	02-09-2019	Y
Catalysts compared and selection complete	02-14-2019	Y
On-snow transients testing with catalytic converters	02-15-2019	Y
Cold start compensation complete	02-16-2019	Y
Final dyno verification testing complete	02-22-2019	
100 mile shakedown testing complete	02-23-2019	
Post-endurance shakedown inspections	02-25-2019	
2019 SAE Clean Snowmobile Challenge	03-04-2018	END

Community Involvement: 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. Last year, the team implemented the program with fuel cell cars (see Figure 1) at Houghton Middle School and will be participating in the program again with two classes at Houghton Middle School following the 2019 Clean Snowmobile Competition.

Figure 1. The Toy Fuel Cell Car used in Michigan Tech's Volunteer Efforts with Houghton Middle School as a Part of the SAE AWIM Program.

The team also 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 other MTU SAE teams and provides tours of team facilities to current and potential team sponsors.

BUILD ITEMS OF THE SNOWMOBILE

The Michigan Tech Spark Ignited entry in the 2019 SAE Clean Snowmobile is a 2016 Yamaha RS Venture TF BAT (depicted in Figure 2).

Figure 2. 2016 Yamaha RS Venture TF BAT Snowmobile

The Best Available Technology certified 2016 Yamaha RS Venture TF BAT provides an excellent starting point for a snowmobile that is clean, quiet and fuel efficient since it was engineered by Yamaha with these goals in mind. The build specifications of Michigan Tech's 2019 SI entry are listed in Table 3.

Table 3. Build Description of Michigan Tech's 2019 Clean Snowmobile Challenge SI Snowmobile Entry

2019 MTU SI CLEAN SNOWMOBILE ENTRY BUILD SPECIFICATIONS	
Parameter	**Description**
Chassis	2016 Yamaha RS Venture TF BAT
Engine	Yamaha Genesis (3 cylinder) Combustion Volume: 1049cc Factory Measured Engine Power Rating: (26 kW) 34.9 HP (per EPA data [8]) 2019 MTU CSC Configuration Engine Power Rating: 58 HP
Track	Ported Camso Crossover Length: 151 inches Width: 15 inches Lug Size: 1.5 inches Studs/Traction Aids: None
Skid	Factory Yamaha skid
Muffler	Yamaha factory muffler in series with MTU designed muffler
Catalytic Converter	Magnaflow CARB compliant three-way ceramic catalytic converter (Magnaflow part number 337304
Skis	Factory Yamaha Skis
Engine Control Unit (ECU)	Motec M130 Programmable ECU with engine tuning by Michigan Tech

LESSONS LEARNED FROM 2018 AND DESIGN OBJECTIVES FOR THE MTU SI TEAM IN 2019

The Michigan Tech Clean Snowmobile Team used the 2016 Yamaha RS Venture TF BAT as a SAE Clean Snowmobile Challenge starting platform for the first time in the 2018 competition. For 2018, the team primarily targeted noise reduction while working to implement a custom engine calibration on a Motec M130 ECU. The general strategy for 2018 was to enter with a competitive snowmobile and learn as much as possible about the potential of the Yamaha Venture as possible to direct future modifications. In 2019, after placing a respectable but improvable 6th place at competition, the Michigan Tech Clean Snowmobile Team is bringing its Yamaha Venture back after strategically targeting items that limited its performance at competition in 2018. The following lessons were learned in the first iteration of the MTU Yamaha Venture:

Lesson 1) Modifications made in 2018 reduced engine noise with moderate efficacy in 2018 but chassis noise needs improvement and should be focused on in 2019.

Lesson 2) An insufficiently validated engine calibration left the team unable to complete in-lab emissions. Engine calibration should be a focus of 2019, and improvements to the emissions measurement capabilities of the team should be prioritized.

Lesson 3) The team should complete more engineering work to select optimized catalytic converters instead of opting for any three-way catalytic converter.

Lesson 4) Engine noise can be reduced effectively by pairing quarter wave resonators with as much exhaust muffler volume as possible. The team should investigate means of increasing muffler volume.

Lesson 5) The rolling resistance of the Yamaha Venture in stock configuration is high. Improvements to rolling resistance can lead to increased fuel economy and should be investigated.

The Michigan Tech Clean Snowmobile Team focused on each of the five primary lessons from 2018 above when considering new modifications to the Venture, ensuring that each modification was done in a targeted manner with supporting observations and data. The following five design objectives were developed directly from the five primary lessons the team learned in 2018.

2019 Design Objective 1) Develop a method of tunnel noise attenuation to reduce sound pressure levels in the frequency ranges corresponding to chassis noise.

2019 Design Objective 2) Plan and develop a new engine calibration to target low emissions and validate through multiple testing sessions, both on snow and at the dynamometer facility. Use the team's new Horiba emissions analyzer in conjunction with a professional fuel flow system to enable calculation of specific emissions and E-Score.

2019 Design Objective 3) Choose a variety of three-way catalytic converters and use new emissions and fuel flow equipment to calculate an E-Score using each catalytic converter under the same conditions. Choose the catalytic converter for the 2019 competition based on emissions data & E-Score.

2019 Design Objective 4) Engineer a solution to increase muffler volume in a manner that ideally allows the team to keep the stock Yamaha muffler which has been determined to be extremely effective at reducing sound pressure levels corresponding to engine firing frequencies.

2019 Design Objective 5) Investigate and implement a solution to reduce rolling resistance of the Yamaha Venture.

Using the aforementioned 2019 design objectives, the team set to work to engineer solutions to improve upon 2018's performance and build the quietest, cleanest, and most fuel efficient snowmobile possible based on the 2016 Yamaha RS Venture TF BAT.

CHASSIS SOUND ATTENUATION

To reduce noise and vibration, multiple design aspects in the Venture chassis have been incorporated in the 2019 MTU CSC snowmobile. The objective was to keep handling, performance, and comfort in mind while validating a solution that meets and exceeds the SAE J1161 noise standard. The sound levels are recorded while the snowmobile is operating in a controlled area at 35 mph. The controlled course is a 150 ft zone, with the sound meter placed 50 feet perpendicular from the midpoint of the course.

Custom Track Drivers

The OEM track drivers on the Yamaha Venture are configured of injection molded ABS plastic with 9 teeth. These drivers create significant contact noise while in motion. The team worked to resolve this noise issue by testing different driver configurations. By adjusting to a 10-tooth driver, the teeth are able to alternate contact with the track, reducing the contact noise. These drivers were machined out of billet aluminum, and the teeth machined as small cylindrical rollers. One side of the prototype 10-tooth driver is shown in Figure 3. Figure 4 depicts the 10-tooth prototype driver configuration compared to the OEM drivers.

Figure 3: Ten Tooth Driver Configuration (Depicted Before Mounting Lugs in Drive Wheel)

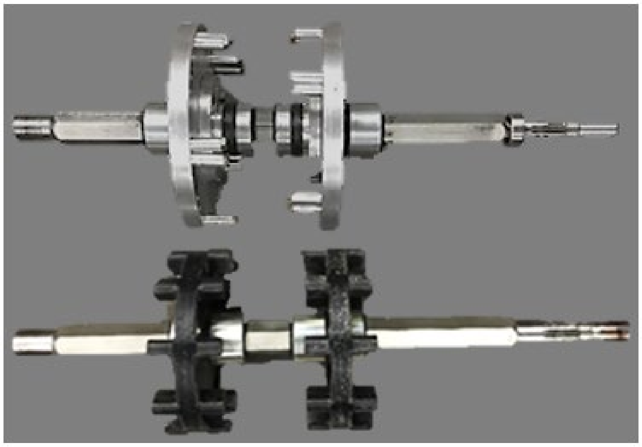

Figure 4: Prototype 10 Tooth Alternating Drivers (Top) and OEM Drivers

The track contains metal clips, and the OEM drivers come in contact with each clip as they rotate. The contact of the OEM drivers on the metal clips generates large amounts of noise. The prototype drivers are designed to avoid contact with the metal clips (which can be seen in Figure 5).

Figure 5: Metal Clips on Camso Ported Track

In the final configuration of the drivers, the drive studs were placed on both the inside and outside of the drivers so that the drive studs contact the track knobs in an alternating pattern. This allows the drivers to grip the track more securely and eliminate ratcheting problems with the initial prototype. The final driver configuration is depicted in Figure 6.

Figure 6: Final Driver Configuration

Front Torque Arm Improvements

The front torque arm is where the front of the suspension mounts to the tunnel of the snowmobile. The factory Yamaha configuration consists of metal guides on the torque arm shaft. The reasoning behind replacing these guides with rubber wheels is to reduce impact noise of the track contacting this area and to maintain a more circular track while rotating to reduce rolling resistance. The stock and modified front torque arms can be seen in Figure 7 and Figure 8 respectively.

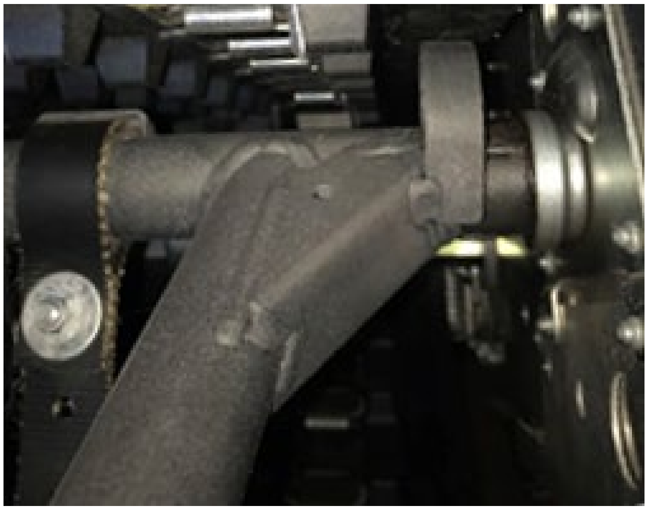

Figure 7: Factory Yamaha Front Torque Arm

Figure 8: Modified Front Torque Arm with Circular Roller

Tunnel Vibration Damping Plates

During field testing, the team noticed significant amounts of chassis vibration. To determine where the excitation was coming from, impact testing and modal analysis were performed. Reference Figure 9 for the grid map, this illustrates some of the chosen 100 impact locations that were analyzed. The tunnel was placed on a sheet of R-11 insulation in order to isolate the tunnel from external vibrations. Using Siemens LMS software, the data is analyzed and represented in a 3D animation to show where excitation and chassis flex occur.

Figure 9: Yamaha Venture Tunnel with Impact Testing Locations

From previously collected sound data, it was determined that the lower track harmonic frequency ranges are 250, 400, 500, 1250, and 2000 Hz. At these frequencies, excitation occurs when the snowmobile is operating at 35 mph for the SAE J1161 test. Harmonic firing frequency of the engine also has a presence.

The 2nd Harmonic Firing Frequency of 265 Hz can be found within the frequency range of the mode shapes. These frequencies correlate to the mode shapes found in the modal analysis and animation. The potential track frequencies that were determined to look for were 244, 488, 732, 976, 1220, 1464, 1708, 1952, 2146, and 2440 Hz, in which are multiples of the first frequency at 244 Hz. From the LMS analysis, mode and bending shapes were found at 282, 482, 728, 976, 1233, and 1489 Hz.

These shapes are within the frequency range the track frequencies, which indicates that the track causes resonance within the tunnel while rotating. Figures 10 through 12 depict the results of the isolated tunnel impact testing to show the mode and bending shapes of the Yamaha Venture Tunnel.

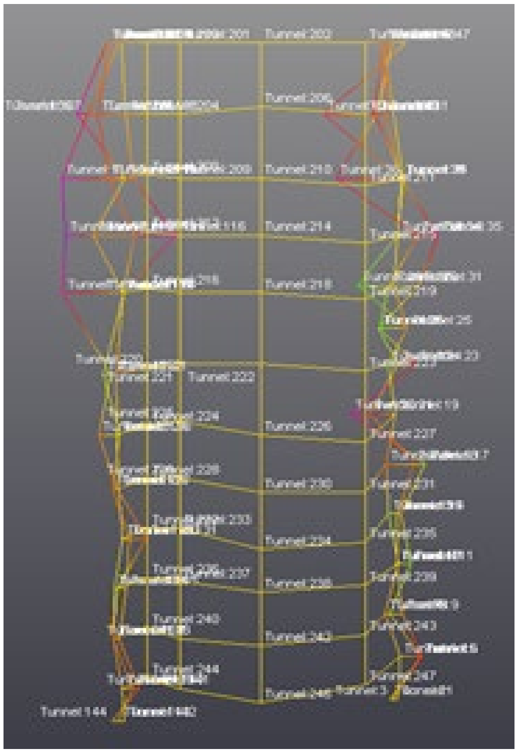

Figure 10. Mode and Bending Shapes of the Venture Tunnel at 282 Hz.

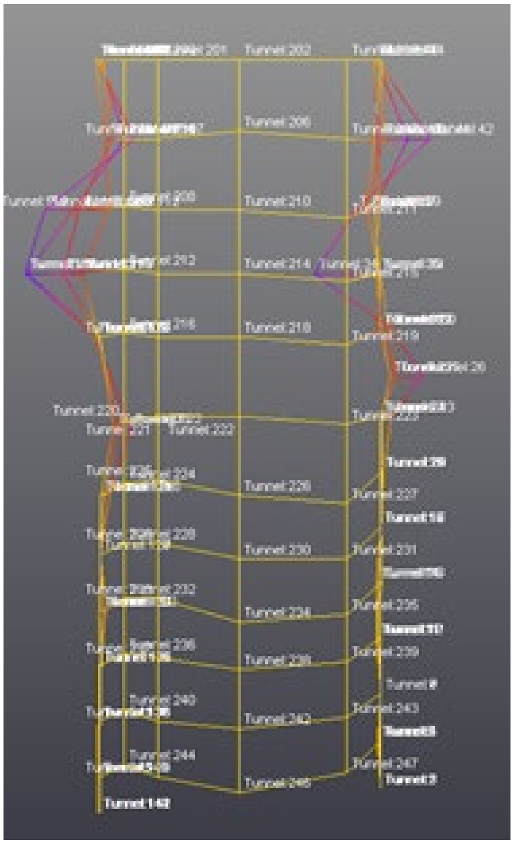

Figure 11. Mode and Bending Shapes of the Venture Tunnel at 982 Hz.

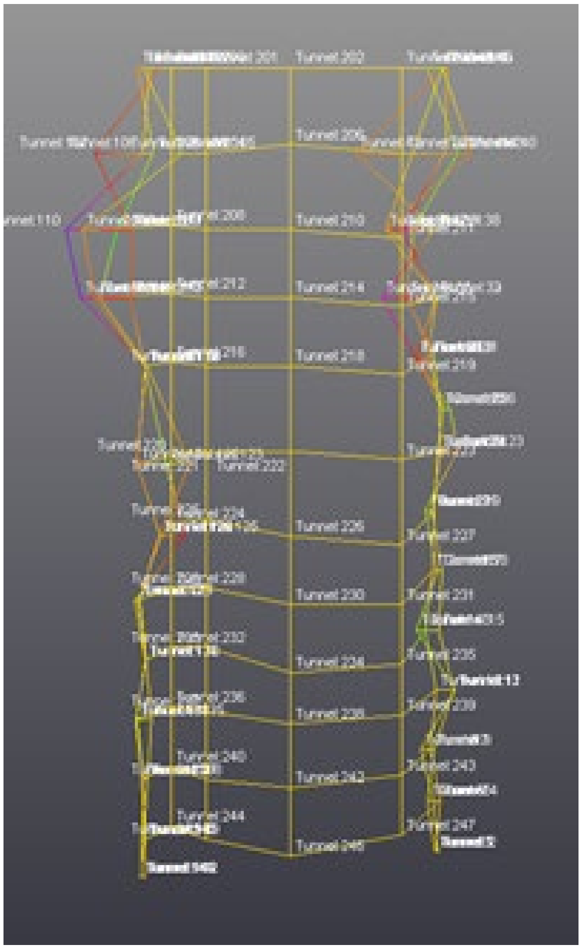

Figure 12. Mode and Bending Shapes of the Venture Tunnel at 1223 Hz.

To combat chassis vibration, metal plates with a rubber liner have been implemented in the locations where highest excitement occurred. The plates increase the rigidity of the tunnel in the area with the highest excitement, therefore reducing resonating vibrations. The ⅛ inch steel tunnel plate was designed in NX, manufactured, and riveted to the tunnel in seven locations. Each stiffening plate weighs 2.41 lbs., adding a total of 4.82 lbs. to the snowmobile. The tunnel stiffening plates are shown attached to the tunnel in Figure 13.

Figure 13: Vibration Reduction Plates Mounted to Tunnel

Sound Testing Procedure

The Baseline snowmobile used for the SAE J1161 test is a completely stock Yamaha Venture TF BAT. At the start and end of testing, the baseline snowmobile completes five passes through the 150 foot course. It can be seen that overall sound levels change throughout the day due to wind patterns, snow conditions, and other external factors. Once the initial baseline sled went through the course, five passes were made on the competition sled with tunnel plates, and then another five passes on the competition sled without the tunnel plates.

Sound Data from Chassis Noise Attenuation Testing

Sound testing was performed on the Yamaha Venture to determine the effectiveness of the Vibration Reduction Plates. The above procedure was utilized, and five tests were performed with the plates installed, and another five tests were performed without the plates installed. The rider noticed a reduction in vibration at their feet, and the data shown below in Figure 14 verifies that the plates reduced vibrations in the tunnel. The selected frequencies shown in the figure were targeted as these were a few of the loudest frequencies when sound testing the baseline Venture snowmobile. Finding solutions for these frequencies allows for the greatest reduction to the overall sound level of the Venture.

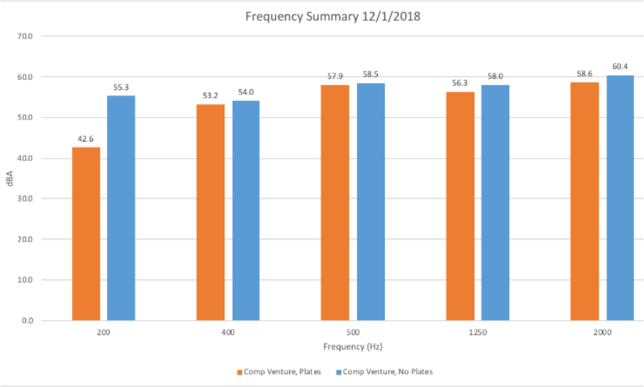

Figure 14: Sound Data for Tunnel Vibration Damping Plates

CALIBRATION STRATEGIES AND GOALS

The Michigan Tech Clean Snowmobile Team is utilizing the same Motec M130 Development Package ECU from last season to control the Venture's engine functions. In order to continue to improve our usage of Motec's capabilities, it was decided that developing a consistent strategy to calibrate the Venture's engine would be crucial. By defining a calibration strategy, the project timeline was better maintained and specific engine performance goals were able to be identified. Some of these specific goals include further refining the stoichiometric calibration from last season to better handle transients while relying less on the fuel trimming capabilities of Motec, and utilizing emissions data to select the most appropriate catalyst for our engine and exhaust configuration.

Base Fuel Map

To build a base fuel map within Motec, a specific strategy was established. The calibration method used for the team's application is known as speed density, the map is split into rows and columns, where rows represent load (Manifold Air Pressure) and columns represent engine speed (RPM). The fuel table for the 2019 calibration is shown in Figure 15.

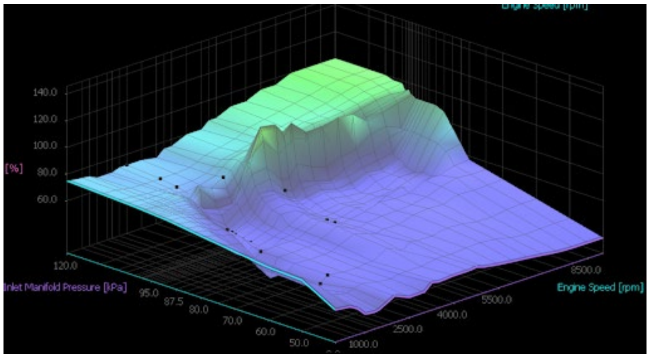

Figure 15. Fuel Map of MTU's Calibration for 2019

The engine team decided to start at the bottom of a column and sweep up the map. This was done for each column from low load to full load. This strategy was thought to make calibrating as accurate and efficient as possible. In order to obtain an accurate calibration throughout the sweeping process the team went up one cell at a time and adjusted fuel trims to achieve our target lambda of 1.00. Lambda values were monitored with 3 wideband O2 sensors, each sensor displayed a reading from each individual cylinder. As the team was calibrating, all three displays were monitored to ensure consistency within each cylinder. The lambda value displayed is based upon stoichiometric properties of the fuel burning regardless of the ethanol content. This is important for changing fuels, because the stoichiometric air to fuel ratio changes based upon the chemical composition of the fuel. Using lambda was therefore beneficial, as the target remains 1.00 regardless of ethanol content.

Base Ignition Timing Map

The base ignition map in Figure 16 was calibrated in a similar fashion to the base fuel map, going column by column sweeping up the map. As the team inspected the base ignition map, the ignition timing was scanned at each calibration site. Three aspects were considered in the base calibration when choosing an ignition timing.

First, torque was considered throughout the calibration. The goal was to achieve maximum brake torque (MBT), timing was advanced until reaching MBT. However, at MBT steady engine performance cannot always be achieved. One concern was high exhaust gas temperatures (EGTs), spiking past 1600 degrees Fahrenheit. To remedy this issue, timing was advanced to cool the exhaust gas temperatures in that area. The second area of concern was engine spark knock. To eliminate a spark knock issue on the map, timing was retarded to prevent auto-ignition. Although MBT was the goal, a compromise was required to keep high EGTs and auto-ignition from preventing steady engine performance.

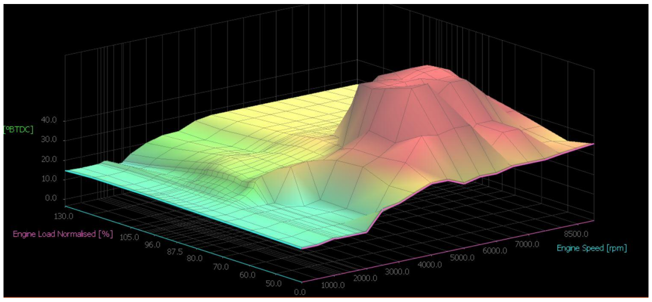

Figure 16. Ignition Timing Map of MTU's Calibration for 2019

The ignition map shown in Figure 16 is from the Motec calibration. As seen in the figure, there is a high spot located in the near right corner, which is an area where achieving MBT timing proved to be very difficult because of high EGTs. The factory solution to this problem is to allow the engine to run slightly fuel rich in this area to reduce EGTs, however as this area aligned with the mode 4 emission target, it is crucial that the team maintains a stoichiometric combustion to maintain the efficiency of the catalytic converter. The team discovered that with a heavily advanced timing, EGTs were able to be controlled while operating at a calibrated stoichiometric air to fuel ratio. Auto-ignition was carefully monitored in this advanced zone to protect the longevity of the engine.

Iterative Engine Calibration Process

Once a safe and tested base map was created, the snowmobile could then be tested in service as further refinements were completed on the dynamometer. Utilizing the same strategy to create the base maps, the team alternated between fuel and ignition maps, calibrating them in sequence. Changes were made in a greater resolution at this stage of the calibration process, leaning heavily upon the on-site calibration function of Motec. The on-site calibration function is designed to calibrate in either table while the engine is held at that operating condition in the table. This was used to locally calibrate a single cell in the fuel map then switched to the ignition map to calibrate that same cell if necessary. This iteration was performed many times in order to achieve an engine performance the team was satisfied with. This methodology of calibrating fuel and ignition maps locally in sequence worked well, as these engine parameters overlap in their effect on engine performance.

Closed Loop Fueling and Transients

After an adequate base calibration was constructed using the methods outlined above, Motec's closed loop functionality was activated. This system relies upon real time feedback from a single wideband O2 sensor installed after the 3 into 1 collector in the Venture's exhaust. The real time lambda value is compared with the target value and fuel delivery is adjusted accordingly.

During last year's competition a fuel trim timeout error caused the team to be unable to complete in lab emissions. This forced the engine team to not only correct the issue causing the timeout error last season, but spend a significant amount of time testing the closed loop system's functionality to ensure its reliability. This testing was performed primarily at the dyno, where target and actual lambda values can be compared in real time. Monitoring the amount of trim required to achieve the target lambda also served as a method of further refining the base calibration.

The transient performance of the calibration was also a point of interest, as it directly translates to the objective performance and subjective feel of the snowmobile under normal operating scenarios. The auto run feature of Land & Sea Dynomax was utilized to simulate transients on the dyno, in which a power pull of a specific engine speed (RPM) range and step can be easily completed. On snow testing was the most realistic measure of the calibrations response to transients. The iterative process between objective results on the dyno and subjective results in the field takes a considerable amount of time, but paid large dividends in balancing emissions and performance for the Venture.

Calibration for Ethanol Blend Fuels

On 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.

Similar to gas stations providing various ethanol mixtures, the 2019 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 (an ethanol blend of 85% ethanol and 15% gasoline) has an AFR of 9.77:1 for stoichiometric combustion to occur. In order to compensate for varying fuel blends, the engine 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 determined 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.

EMISSIONS MEASUREMENTS AND CATALYTIC CONVERTER SELECTION

Reducing exhaust emissions produced by the Yamaha Genesis engine was a primary goal when creating the calibration. For 2019, the Michigan Tech Clean Snowmobile Team has two new tools to measure emissions more accurately than any previous MTU team: a Horiba MEXA 584L five-gas emissions analyzer and a Tricor Coriolis flow meter. Coriolis flow measurement technology is expensive, but is the only type of flow meter that can measure fuel flow in all modes with the accuracy and precision needed to calculate mass emissions of each pollutant measured at competition and calculate an E-Score. Coriolis flow meters operate by generating a vibration in a tube filled with a flowing fluid. The subsequent twisting of the tube due to the Coriolis Effect is correlated to the mass flow rate of the fluid flowing in the tube. Coriolis flow meters directly measure mass flow rate. MTU's Yamaha Venture operates on a returnless fuel system with pressure regulation inside the fuel pump. Michigan Tech's dyno fuel flow system consists of a fuel cell with a fuel pump identical to the one used on the snowmobile in line with a 50 micron filter and fuel flow meter. Fuel exiting the flow meter is routed directly to the engine.

Measuring Specific Emissions and Calculating E-Score & Specific Emissions

It is important to determine the specific emissions for each exhaust component gas considered in competition scoring. MTU's CSC team has developed a document in Microsoft Excel to calculate specific emissions and E-Score.

The accuracy of the calculations performed by the spreadsheet was tested by comparing it to AVL's E-Score for a team that successfully completed the in lab emissions test during the 2018 competition. The MTU SI engine team used AVL's raw data available from the 2018 competition to fill fields in the team's calculation spreadsheet.

Calculations by the Michigan Tech SI Engine team match the professional calculations by AVL to within 99.63% accuracy. Specifically, the spreadsheet developed by MTU overcalculates E-Score by 0.37%, which is likely due to rounding differences or incomplete data on fuel. The team is comfortable claiming an ability to calculate E-Score within 0.50% of what will be calculated at competition given identical emissions data.

The greatest uncertainty in the team's E-Score calculations come from the differences in accuracy between setups like the lab at the SAE Clean Snowmobile Competition and lower budget setups with portable emissions analyzers similar to the one operated by the MTU SI Engine Team. We believe that we will be able to improve our emissions measurement accuracy once we have data from this year's competition and can directly compare E-Scores from AVL's In-Lab emissions equipment and our own, but that 2019 is regardless an important step forward in our capabilities as a team.

In addition to estimating E-Score, unlocking the ability to measure specific emissions allows the team to accurately monitor the effects of control strategies. The immediate control strategy consisted of developing the most optimal fuel and ignition maps to ensure complete combustion and lowest emissions. To do this the team tests a variety of different lambda values and targets MBT timing if possible at each operating condition. After these tests, the team decided to use a stoichiometric burn (lambda 1.00) in the majority of the map to ensure the most optimal combustion and effective use of the team's aftertreatment system.

Catalytic Converter Selection

In recent years, the MTU Clean Snowmobile Team has obtained one single catalytic converter and utilized it without testing other available options. This year, the team opted for a more data-focused selection method and tested a variety of three-way catalytic converters. Two-way catalytic converters were excluded since they are not optimized for stoichiometric engine calibrations. Parameters for each catalytic converter are listed in Table 4.

Table 4. Catalytic Converter Comparison

PARAMETERS	CATALYTIC CONVERTER 1	CATALYTIC CONVERTER 2
ID #	22889-4	TEX0587
Manufacturer	V-Converter	V-Converter
Substrate Monolith	Three-way Ceramic - 380 CPSI	Three-way Metallic
Dimensions	4.66" D X 4.00" L	3.66" D X 3.93" L
E-Score (Measured and Calculated by MTU)	205.0	202.5

PARAMETERS (continued)	CATALYTIC CONVERTER 3 (continued)	CATALYTIC CONVERTER 4 (continued)
ID #	AMX97-33	P/N 337304
Mfg.	V-Converter	Magnaflow
Substrate Monolith	Three-way Metallic	Ceramic Honeycomb
Dimensions	4.66” D X 4” L	4.0” D X 8” L
E-Score (Measured and Calculated by MTU)	205.9	205.9

Final Aftertreatment Configuration and Specific Emissions Data for Each Catalytic Converter

All of the catalytic converters that were tested performed in excess of the team’s emissions goals. The two larger volume V-Converter catalytic converters and Magnaflow catalytic converter tested exceptionally close. Specific emissions data for each catalytic converter (tested under the same engine calibration, with modes given in Table 9) is included in Tables 5 through 8.

Table 5. Engine with Catalytic Converter Specific Emissions Comparison (Magnaflow 337304)

Specific Emissions for Magnaflow 337304			
HC (g/kW-hr)	**CO (g/kW-hr)**	**CO2 (g/kW-hr)**	**NOx (g/kW-hr)**
0.10	13.17	1329.15	1.05

Table 6. Engine with Catalytic Converter Specific Emissions Comparison (V-Converter 22889-4)

Specific Emissions for V-Converter 22889-4			
HC (g/kW-hr)	**CO (g/kW-hr)**	**CO2 (g/kW-hr)**	**NOx (g/kW-hr)**
0.14	19.36	1326.81	0.10

Table 7. Engine with Catalytic Converter Specific Emissions Comparison (V-Converter AMX97-33)

Specific Emissions for V-Converter AMX97-33			
HC (g/kW-hr)	**CO (g/kW-hr)**	**CO2 (g/kW-hr)**	**NOx (g/kW-hr)**
0.06	15.94	1331.13	0.04

Table 8. Engine with Catalytic Converter Specific Emissions Comparison (V-Converter TEX0587)

Specific Emissions for V-Converter TEX0587			
HC (g/kW-hr)	**CO (g/kW-hr)**	**CO2 (g/kW-hr)**	**NOx (g/kW-hr)**
0.22	23.07	1321.89	2.30

Table 9. Emissions Measurement Modes

Mode	RPM	Torque (lb-ft)	Power (hp)
1	**8200**	**37.20**	**58.08**
2	**6970**	**18.90**	**25.08**
3	**6150**	**12.30**	**14.40**
4	**5330**	**7.07**	**7.18**
5	**1498**	**1.50**	**0.43**

The Magnaflow catalytic converter and V-Converter AMX97-33 have identical E-Scores, but differentiate themselves in other parameters. Since startup emissions are not a part of emissions measurement at the SAE Clean Snowmobile Competition, the faster light-off time of metallic catalytic converters can be ignored. However, since MTU’s catalytic converter is located underneath the tunnel in an area in frequent contact with snow thrown by the track, the benefits of a ceramic catalytic converter that conducts heat less readily cannot be ignored. Additionally, the smaller diameter of the Magnaflow catalytic converter allows it to be wrapped in a high temperature blanket to retain heat and still clear the track and other suspension components. The Magnaflow catalytic converter will be implemented on Michigan Tech’s 2019 SI Snowmobile entry.

ENGINE NOISE REDUCTION

Intake & Airbox Design

The intake design on the 2019 MTU CSC snowmobile utilizes the same quarter wave resonator that was implemented previously. The frequency of the resonator was designed to target 265 Hz. This frequency was chosen to target the 250 Hz from the intake as well as the 265 Hz caused by the second harmonic of the firing frequency. To remain effective, the quarter wave resonator integrated in the airbox needs to remain at a constant 50 degrees Fahrenheit. Op-amp comparator circuit controlled heating elements are retained from 2018 to maintain temperature control. In 2018 testing, the modified airbox was to be 3.1 dBA quieter than the factory Yamaha airbox at 265 Hz, so the airbox configuration was kept as part of the team's 2019 strategy to reduce engine noise.

Exhaust System Design

Michigan Tech's 2019 SI entry continues the use of two quarter wave resonators implemented into the Venture exhaust located in the mid-pipe between the headers and catalytic converter (depicted in Figure 17).

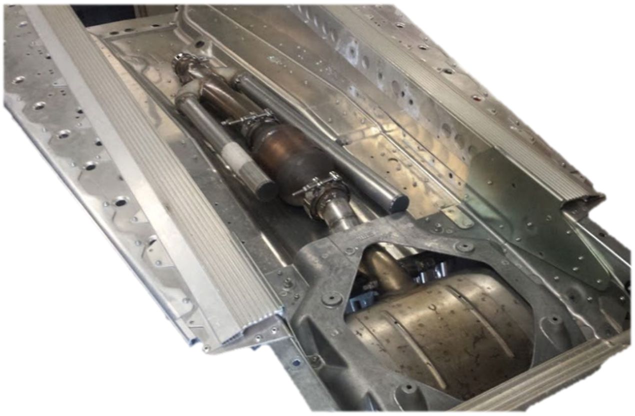

Figure 17. Quarter Wave Resonators in Exhaust Mid-Pipe

These resonators are engineered to target firing frequencies between 265 and 3578 Hz. In 2018, a "overkill" system was fabricated and fitted to the Venture for testing. The overkill exhaust system was a means of testing the gains that could be expected from increasing exhaust (and intake) volume to a level not practically achievable, but valuable for testing. The overkill exhaust testing configuration consisted of a 55-gallon drum packed with R11 insulation in series with the factory Yamaha dual exit muffler as depicted in Figure 18.

Figure 18. MTU Yamaha Venture with Overkill Muffler during 2018 Testing

Overkill exhaust testing in 2018 indicated that increasing exhaust system volume as much as possible would reduce engine noise, but also suggested that the factory Yamaha muffler was very effective at engine noise attenuation. The team opted to leave the factory muffler in place but add a secondary muffler in series with the Yamaha muffler. The secondary muffler collects from the dual exits of the Yamaha muffler, enters a chamber of packed with Silkosoft fiberglass matting, and exits through dual exits toward the rear of the track & snowpack. In addition to creating additional exhaust volume, the secondary muffler redirects exhaust noise from the open air behind the snowmobile to the sound-deadening snowpack. A CAD image of the secondary muffler is depicted in Figure 19.

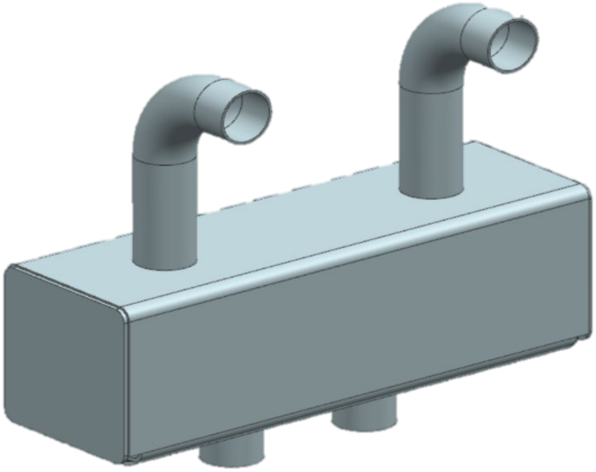

Figure 19. CAD Drawing of Secondary Muffler

REDUCING ROLLING RESISTANCE FOR INCREASED FUEL ECONOMY

Reducing the rolling resistance of the RS Venture was another goal for the MTU Clean Snowmobile Team in 2019. The team investigated a combination of a shorter skid & track with a 10-inch big-wheel kit to reduce the bend radius of the track. In testing, the shorter skid & track with big wheel kit reduced rolling resistance by 5% on average. To confirm that the modifications would correspond to an improved overall competition score, the team sound-tested the Venture in its new configuration with reduced rolling resistance. While the skid and track length reduction with big-wheel kit did successfully reduce rolling resistance, it increased overall sound levels by 0.5 dBA. The team has elected to run the factory Yamaha skid despite the modest rolling resistance reduction of the short skid with big-wheel kit in order to prevent increasing the sound levels of the Venture.

ADDITIONAL SNOWMOBILE FEATURES

For the 2019 SI snowmobile, the team continued the use of 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 DDU 9 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 2019 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. In factory production, the programmable dashboard would be switched to a dashboard of the same cost and features of the original Yamaha dashboard.

VALUE ADDED AND MSRP

Yamaha achieved BAT certification by implementing two primary changes between the BAT Venture and non-BAT Venture. First, the engine calibration for the BAT Venture targets lambda 1.0 during steady state conditions (constant RPM and load) for more complete combustion. The factory ECU runs on an open loop process. Second, the BAT Venture uses the electric throttle control available on all 2016 RS Venture versions to limit the maximum throttle position to less than 100% wide open throttle. This is a cost-effective way of reducing emissions, but it comes at a performance cost. According to Yamaha's emissions certifications with the US EPA, the non-BAT RS Venture makes a maximum engine power of 94 kW (126 hp) at 8750 RPM. The BAT Venture in factory Yamaha configuration makes a maximum engine power of 26 kW (34.9 hp) at 6000 RPM [8]. The BAT Venture is significantly detuned to meet emissions requirements. The Michigan Tech Clean Snowmobile Team believes that the snowmobile industry can have a more sustainable future while keeping performance figures as high as possible. Michigan Tech's 2019 SI entry improves peak power figures by 24 horsepower over the base snowmobile platform with a reasonable price premium.

Especially in a future where emissions regulations from the automotive industry may increasingly carry over into the snowmobile industry, the Michigan Tech Clean Snowmobile team believes that consumers will be willing to pay a reasonable premium for snowmobiles that utilize industry leading technologies to maximize performance and meet emissions standards instead of opting for detuned snowmobiles without automotive-grade emissions control equipment.

In an effort to keep manufacturing costs as low as possible, every component added to this year's SI entry was carefully analyzed. After implementation of new components, the final MSRP value of the 2019 MTU SI 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. Michigan Tech's 2019 entry into the SAE Clean Snowmobile Challenge is a clean, quiet, reliable, and comfortable trail machine that allows snowmobilers now and in the future to enjoy the sport they love and keep their favorite riding locations clean and beautiful for generations of snowmobilers to come.

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John Deere
Milwaukee Tool
HMK
Braap Wraps

DEFINITIONS/ABBREVIATIONS

AFR	Air-Fuel Ratio
BAT	Best Available Technology
CO	Carbon Monoxide
CO2	Carbon Dioxide
ECU	Engine Control Unit
ECA	Ethanol Content Analyzer
GPS	Global Positioning System
HC	Hydrocarbon
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