Michigan Technological University's Innovations and Improvements to the 875cc Polaris Indy

Cody Fackender, W. Gielda, J. Keepers, D. Loeks, C. Little, J. Loesche, A. Mattson, M. Plant, J. Strauch, N. Wolak, T. Wolak
(Do NOT enter this information. It will be pulled from participant tab in MyTechZone)
Affiliation (Do NOT enter this information. It will be pulled from participant tab in MyTechZone)

ABSTRACT

The Michigan Technological University (MTU) Clean Snowmobile Team is entering the 2014 SAE International Clean Snowmobile Challenge with a redesigned 2013 Polaris Indy. The snowmobile has been redesigned to operate with reduced noise, reduced emissions, and with greater fuel efficiency, while also maintaining competitive performance characteristics for the trail snowmobile market.

INTRODUCTION

To address concerns about the environmental impact of snowmobiles in Yellowstone National Park, the Clean Snowmobile Challenge was introduced in the winter of 2000 in Jackson Hole, Wyoming. The goal was to invite university students to design and produce a clean and quiet touring snowmobile to be ridden primarily on groomed snowmobile trails throughout the park. In 2003, the competition was moved to the Upper Peninsula of Michigan and was hosted by the Keweenaw Research Center (KRC), just north of Michigan Technological University's campus.

The Clean Snowmobile Challenge is sponsored by SAE International as part of the collegiate design series. The snowmobiles are evaluated in several static and dynamic events, including manufacturer's suggested retail price (MSRP), technical presentations, emissions, noise, and fuel economy. For 2014, the competition remains at the KRC and runs from March 4th to the 9th. The competition has evolved to include both internal combustion snowmobiles and zero emissions electric snowmobiles.

In 2013 the MTU Clean Snowmobile Team placed sixth overall in the internal combustion category. Table 1 shows a breakdown of the team's performance from the 2013 competition.

Table 1: 2013 MTU Clean Snowmobile Competition results

Event	Score	Place (out of 12)
Design Paper	79.2/100	3
Static Display	50.0/50	-
MSRP	36.2/50	6
Subjective Handling	37.9/50	6
Fuel Economy	100/200	6
Oral Presentation	64.2/100	4
Noise	18.9/300	7
Acceleration	43.6/50	3
Lab Emissions/BSFC	190.5/300	6
Fuel Economy/ In service Emissions	2.5/100	8
Cold Start	0/50	-
Objective Handling	75/75	1
Penalties/Bonuses	100/100	-
Overall Score	798/1525	6

For 2014, the team focused on the benchmark and improvement of the competition vehicle used in 2013. The team fell short in emissions and fuel economy in 2013 as well as noise. The team improved the tune for emissions and compensated for iso-butanol. A cold air intake and new dual muffler exhaust system were also implemented to help in the sound category. Table 2 below shows the goals for the 2014 team compared to last year.

Table 2: Comparison of MTU team goals from 2013 to 2014

2013 Goals	2014 Goals
Implement 875cc Polaris Pro-Star Four-Stroke engine in 2013 Polaris Indy Chassis	Benchmark and improvement of the 875cc Polaris Pro-Star engine and 2013 Polaris Indy Chassis
Pass 2013 EPA Emissions regulations while operating on ethanol fuel blends ranging from E40 to E85	Pass 2014 EPA Emissions regulations while operating on iso-butanol blends ranging from 16 to 32%
Achieve a sound pressure level lower than 73 dBA per SAE J192 specifications	Achieve a sound pressure level 10% lower than the 2013 competition vehicle
Implement a more capable closed-loop Engine Control Module to improve emissions and fuel economy	Reduce overall vehicle weight by 20% while maintaining ergonomics and appearance

Michigan Tech's 2014 Clean Snowmobile Team is composed of 33 members from various educational disciplines, including Mechanical Engineering, Mechanical Engineering Technology, and Civil Engineering. The team is divided into three sub-teams: engine, chassis, and business. The chassis and engine teams are focused primarily on the design, fabrication, and calibration of the snowmobile, while the business team is dedicated to public, sponsor, and inter-team relations.

INNOVATIONS FOR A GREENER TOMORROW

With pressure mounting from states and the federal government, as well as the public and many corporations, there is a large effort to increase fuel economy and reduce emissions. This greatly affects the power-sports industry. There are also federal noise limits as well as many local noise ordinances, which stress the importance of minimizing the overall noise of the snowmobile.

To design a comfortable and fuel-efficient touring snowmobile, the 2013 team implemented a Polaris Pro-Star 875cc four-stroke engine in a 2013 Polaris Indy Chassis. The excellent handling of the Indy chassis in combination with the efficiency of the Pro-Star engine provides an ideal snowmobile for the trail-riding enthusiast.

The goal for the 2014 MTU entry was to benchmark and redesign the 2013 vehicle to better meet the needs of the competition. The largest changes made to the sled include: the exhaust, intake, weight reduction, and engine calibration.

Table 3 shows a list of components and equipment specifications used to meet the 2014 goals of the MTU Clean Snowmobile Team. Key vehicle components include chassis, engine, fuel system, intake, exhaust, drivetrain, track, and suspension systems.

Table 3: Primary component breakdown of the 2014 MTU clean snowmobile

Component	Description
Chassis	2013 Polaris Indy
Engine	875 cc Polaris Pro-Star
Fuel System	Standalone P.E. engine management with stock Polaris RZR injectors and Indy fuel pump
Intake System	Polaris RZR throttle body with MTU designed and fabricated air box
Exhaust System	**Catalyst:** V-Converter 3-way catalyst
	Muffler: MTU designed and fabricated dual-muffler system
Drive Train	**Primary Drive:** OEM P-85 Polaris
	Secondary Drive: Team Tied Rapid Reaction Roller
Suspension	**Front Suspension:** Stock Polaris A-Arms with Fox Floats
	Rear Suspension: Stock Indy Rear Suspension
Track	121”x1.063”x15” Camoplast Ice Attak

ENGINE

For the 2014 competition, the MTU Clean Snowmobile Team decided to keep the same Polaris Pro-Star 875cc Dual Overhead Cam (DOHC) four-stroke engine that was ran in 2013. This engine proved to be very reliable and tolerant to the wide range of ethanol blends tested during the 2013 competition. Equipped with the Performance Electronics ECU, a new dual exhaust muffler system, and intake; the team was able to calibrate the Pro-Star engine in order to achieve better marks at the 2014 Clean Snowmobile Competition.

PERFORMANCE ELECTRONICS

The 2014 competition snowmobile utilizes a PE3-8400A Engine Control Unit (ECU) from Performance Electronics Ltd. The compact size and light weight of the stand-alone control unit allowed for easy mounting into the Indy chassis. The control unit manipulates fuel and ignition needs for the engine, based on different operating conditions. Using the controller, modifications can be made to the fuel flow and ignition timing of the engine as well as numerous other engine parameters to optimize performance and fuel efficiency. In addition, the control unit allowed for real-time tuning of the engine with on-board data logging of engine parameters and external inputs. Performance Electronics also supports wireless tuning, which allowed for the MTU Clean Snowmobile Team to operate the snowmobile at a wide range of in-service testing modes while adjusting the timing and injection parameters remotely. Utilizing the tuning capabilities of the ECU, the team was able to optimize the capabilities of the Pro-Star 875cc engine.

A cam position sensor was added this year to change the engine from batch injection to sequential injection. Currently the engine would inject fuel and spark in both cylinders when each cylinder reached TDC. This results in over-fueling of the cylinders causing inefficiencies as raw fuel was blown directly out of the exhaust. This is inefficient for fuel mileage as well as undesirable for emissions. The flywheel is set up to have 36 teeth minus 1. This gap is picked up by a crank position sensor. In batch injection, fuel is added according to the gap every time it is seen because the ECU doesn't know which is the compression stroke and which is the exhaust stroke. With the addition of the cam position sensor and sequential injection the compression stroke is known resulting in less over fueling, resulting in improved emissions as well as fuel economy.

CALIBRATION TECHNIQUES

The Michigan Technological University Clean Snowmobile Team divided the base fuel and ignition tables into zones as a means for applying criteria to different engine operating conditions. **Zone 1** correlated to the idle region of the engines base tables. The commanded fuel was determined while targeting lambda of 1.00. This was created for both emissions output and fuel consumption. Great care was taken to ensure proper engine operation within this zone. Due to a lack of idle control, the idle speed was maintained by the force balance between the friction of the engine and the torque output created by combustion. **Zone 2** contains the tip-in portion of engine operation. The tip-in portion in this case was the event when the primary clutch engaged the drive belt. The delivered fuel was still a function of the target lambda value of 1.00. The ignition advance was set to maximum brake torque (MBT) timing to account for the clutch engagement. **Zone 3** can be described as the cruise region of the base tables. This region contains the speed-load points that the competition vehicle would experience during the Endurance Run. In contrast to an automobile, snowmobiles experience greater engine loads during cruising due to the added drag forces created by the skis and rotating track. MBT timing was used to extract the maximum amount of energy from each combustion event. This allowed for an increase in mechanical efficiency during this relatively light-load engine operation. **Zone 4** contains the area of the tables that are related to a slight acceleration event. The throttle blade in this case would not be completely open, but moderately open. The lambda value of 1.00 was still targeted due to Zone 4 not being a wide open throttle (WOT) condition. MBT timing was still utilized to extract as much energy from the air-fuel mixture as possible. **Zone 5** is the region of high engine speeds and relatively low engine loads. The engine does not spend much time in this region, but will pass through Zone 5 after a throttle-chop. Delivered fuel still pursued the lambda value of 1.00 and ignition values the team set high enough, in order to protect exhaust components. Ignition advance values of 35**deg** Before Top Dead Center (BTDC) and 45**deg** BTDC were commonly used on Zone 5. These ignition advance values released the heat of combustion into the cylinder walls instead of the exhaust valves and catalyst. **Zone 6** was treated as the WOT portion of the base tables. The intent when operating an engine within Zone 6 is maximum power production. Some fueling enrichment was used to better guarantee the reaction of the oxygen molecules within the intake charge resulting in a more complete burn. The ignition advance values were kept a significant distance away from the knock limit**. Zone 7** contains low manifold pressures typically associated with engine braking. The continuously-variable transmission (CVT) on a snowmobile does not let the engine experience extreme engine braking conditions. This provides for a rather small region that the engine passes through very briefly. The light-load allows for a target lambda value of 1.00 to be pursued as well as moderate ignition advance values. The ignition advance values in this zone are very similar of those occurring in Zone 3.

FLEX-FUEL IMPLEMENTATION

As per the 2014 Clean Snowmobile Challenge rules, each competition vehicle must have the capacity to operate on corn-based bio-isobutanol fuel. The flex fuel range for the 2014 competition is 16% to 32% iso-butanol content. The Michigan Technological University Clean Snowmobile Team

performed calculations to determine the stoichiometric air-fuel ratio (AFR) of each iso-butanol blended fuel.
To do this the team used the latent heating value (LHV)(MJ/kg), stoichiometric values, and fuel densities(kg/m^3) . The values obtained allowed the team to calculate the mass of oxygen and the measured iso-butanol content for this year's competition and equate them to the equivalent percentage of ethanol. The team also formed calculations that would allow the team to compute what the stoichiometric values were for different percentages of iso-butanol. The calculations for the iso-butanol, gasoline, and iso-butanol blended fuels can be reviewed in **Appendix A**.

The high cost associated with iso-butanol fuel pushed the team to use ethanol-based equivalents during engine calibration development. It was determined that a 16% iso-butanol blend corresponded to a 10% ethanol blend based and a 32% iso-butanol blend was equivalent to a 21% ethanol blend, both of these calculated values are based on the mass of oxygen in both E10 and E21. The base fuel table was created for engine operation on gasoline with an octane rating of 91. The alcohol content within the competition fuel was accounted for through the means of an alcohol content analyzer. The commanded fuel injector pulse-width included a positive adder that accounted for the required increase in fueling due to the alcohol content. The magnitude of the positive adder changed relative to the alcohol content detected by the alcohol content analyzer. For example, the positive adder associated a 32% iso-butanol blend would be greater than that for a 16% iso-butanol blend. While the majority of the positive adder fuel trim was developed based on ethanol-blended fuels, iso-butanol was later tested to verify proper engine operation.

IGNITION TUNING

To help with dynamometer tuning, the team implemented a cylinder pressure transducer utilizing a spark plug style pick-up made by PCB Piezotronics Inc. as shown in Figure 1.

Figure 1: PCB pressure transducer

With implementation of a pressure transducer, the team was able to collect raw pressure data from one cylinder, as shown in Figure 2 Part A, in addition to collecting raw voltage pulses from a hall-effect crank position sensor. The crank position sensor consists of 36 equally spaced triggers with one trigger missing, as shown in Figure 2 Part B.

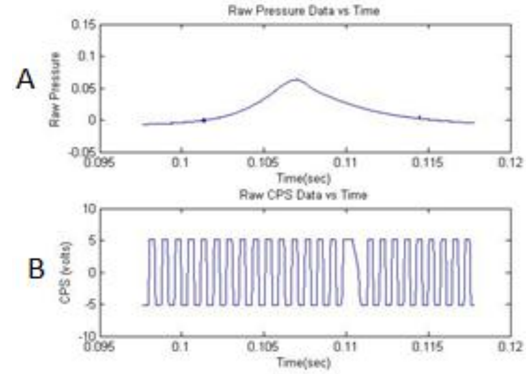

Figure 2: Pressure Data vs. Crank Angle

The team developed a MATLAB software program that analyzes this pulse data, locates the missing tooth, and then calculates the cylinder volume based on the degree of crankshaft rotation and specific engine geometry. This tool allows for an in depth analysis of the combustion process through calculations based on the first law of thermodynamics. The raw pressure data in volts is converted into actual pressure and the crank teeth are converted to absolute crank angle with angle zero being top dead center (TDC). From this, a pressure versus volume diagram can be generated to model the cycle. The area under this curve corresponds directly with horsepower, thus indicated horsepower can be calculated. The best benefit to the team from this software is calculating the mass fraction burn (MFB) in the engine. The rate of heat release (ROHR) must be calculated first to determine the MFB. The rate of heat release is the amount of energy released by the combustion at any given time. By taking the percentage of heat release at each point and dividing it by the overall total, the mass fraction burned can be calculated as shown in equation 1.

$$\text{instantaneous MFB} = \frac{\text{rate of heat release}}{\text{sum of heat released}} \qquad (1)$$

The MFB gives data on the amount of raw fuel left in the cylinder at a given point in time. This helps the team because it is known that 50% mass fraction burn should occur at 10 degrees after TDC for optimal efficiency, based on industry standards. Figure 3 shows the progression from pressure data to MFB. (A) Is a pressure versus volume diagram, (B) Is ROHR versus crank angle and (C) Is the MFB versus crank angle. On the graph is a crosshair indicating ideal MFB.

The timing can be advanced or retarded to shift the graph in order to achieve the correct MFB. Using iterations of recorded data and MATLAB analysis the ignition timing can be corrected to the ideal MFB, resulting in increased thermal efficiency, better emissions, and increased fuel mileage. By controlling the mass fraction burn, the first advantage is that there is no destructive knock working against the engine. This can also be used to ensure that only positive work is added to the cylinder. The amount of work performed is also increased when the burn range is optimized. When this occurs, almost all of the fuel energy is being extracted by completing combustion of all the fuel in the cylinder. This also means that emission outputs are greatly decreased, as there are low levels of unburned fuel leaving the cylinder.

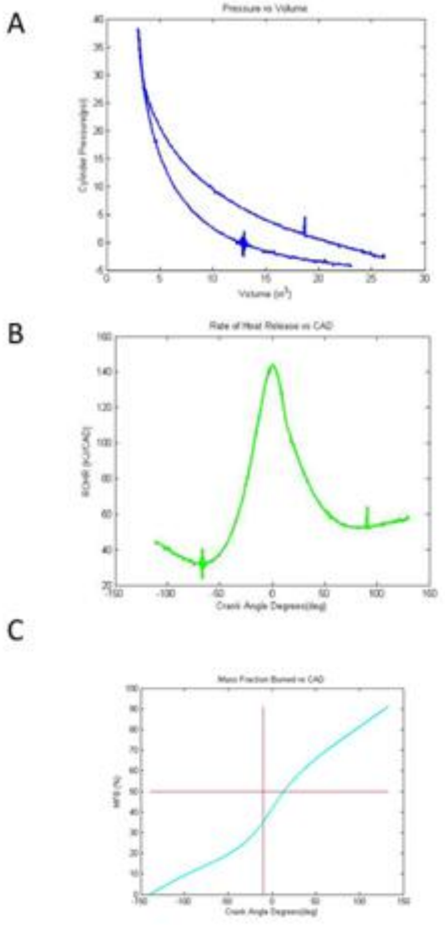

Figure 3: Pressure Data to Mass Fraction Burn

INTAINTAKE MODIFICATION

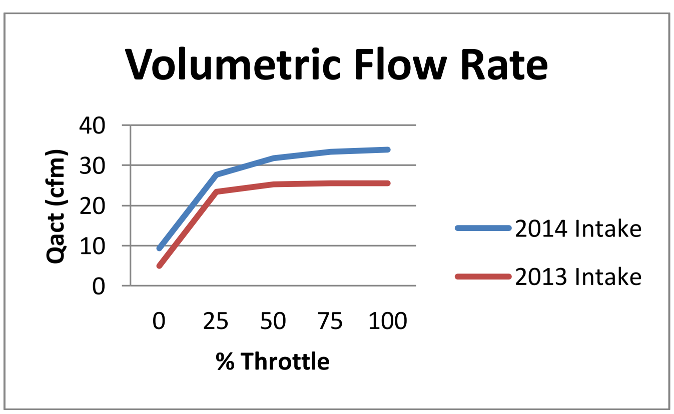

Figure 4: Volumetric flow rate graph

The 2014 MTU Clean Snowmobile Team had concerns with the air induction system used on the 2013 competition snowmobile. The first step in improving the air induction system was to benchmark the 2013 setup. After modeling an intake bracket and having it 3D printed, the team was able to record data from the 2013 design as seen in Figure 4, which was taken at 5 different throttle positions on the MTU School of Technology flow-bench.

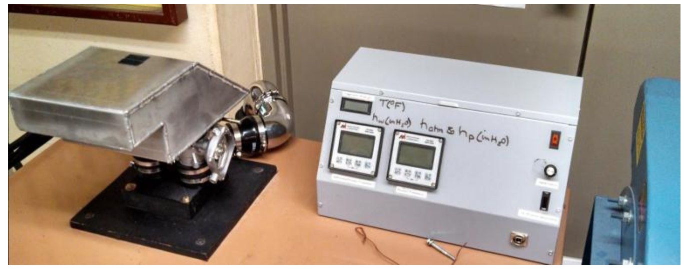

Figure 5: Flow Bench Testing

The data observed and recorded showed that the air flow restrictions were not in the plenum, but rather in the air box. Another problem taken into consideration was that the 2013 air box produced a significant amount of noise under heavy acceleration. The 2014 intake system was designed to eliminate these problems found in the previous year's air box. Looking at Figure 4, the data shows that the new intake has increased air flow rate through all throttle positions, compared to the old model, which flattened above 50% throttle. The relocation of the air box not only reduced noise but also allowed for clean cold air intake from a vent located in the side panel. With the new design, the MTU Clean Snowmobile Team has achieved increased airflow while decreasing engine noise.

EXHAUST

For the 2014 competition, the MTU Clean Snowmobile Team decided to go with a different design for the exhaust system. The previous system used in the 2013 competition failed to meet the desired noise and weight expectations. This led the team to make an entirely different model. The new exhaust will generate for better marks in this years competition.

HEADER

After seeing last year's results, the team chose to pursue a different route in header design choices. Once the team benchmarked the 2013 exhaust, the team began designing a new system to better meet the needs addressed. Taking into consideration the angle of the engine, and the amount of space between the engine and the A-frame, the team was able to produce with a 3D printed model, as seen in Figure 6. This gave the team a physical representation to look at, and helped aid in the fabrication of the actual header.

Figure 6: Test fit of 3D printed model of header

Once the design was finalized, material was purchased and the team made the header to the specs of the 3D model, as seen in Figure 7.

Figure 7: Initial stages of fabrication

With the lack of space in the engine compartment, V-bands were implemented to allow for ease of assembly and fitment. Once the header was fully built, it was sent out for ceramic coating in order to allow for better heat displacement. The finished product is show in Figure 8.

Figure 8: Completed header with ceramic coating

DUAL MUFFLER SYSTEM

As seen in Figure 9, the rest of the exhaust is comprised of a V-converter catalytic converter (CAT), custom built Y-pipe, and a dual muffler system. The catalyst has an inlet size of 2.5" and outlet of 2", this was done in order to allow the exhaust more time to be treated by the catalyst, helping reduce emissions. To finish off the exhaust, 2 AP 700179 automotive mufflers were added to reduce sound. These mufflers were packaged to take up less space than the OEM design while still providing adequate sound dampening.

Figure 9: Final stages of exhaust fabrication

Figure 10 displays the flow analysis performed on the dual-muffler exhaust. Although the sharp bends and smaller pipe diameter may lead one to believe restrictions would build up, the analysis shows that the system is fairly efficient with regards to airflow.

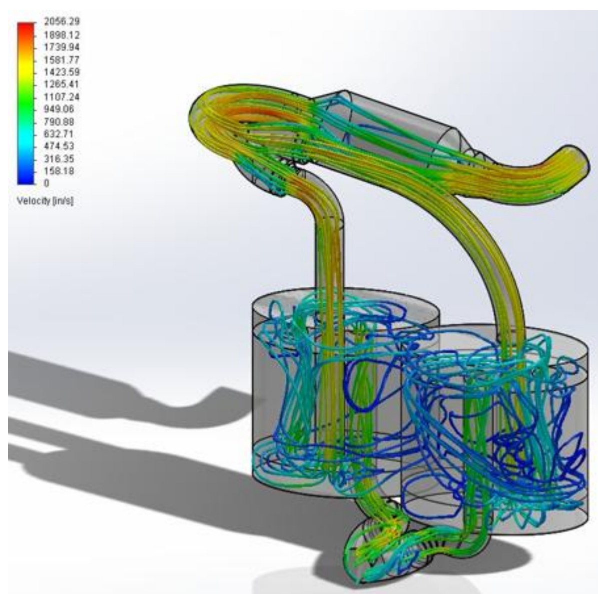

Figure 10: Dual exhaust flow analysis

CHASSIS

The 2014 MTU Clean Snowmobile Team chassis is a modified 2013 Polaris Indy. This is the same chassis set up that was used for the 2013 vehicle. For the 2014 competition, the team benchmarked and improved upon the design. The chassis offers several important advantages over other available chassis in the industry, including weight reduction and improved rider ergonomics. The Indy also uses a similar platform to the Switchback and Rush models, which allowed for previous knowledge to be utilized. While the snowmobile uses the same Pro-Ride chassis as higher-end snowmobiles, it also offers a consumer friendly MSRP of $11697.58.

VIBRATION ANALYSIS

Noise accounts for two events totaling 300 points in competition. Snowmobiles have considerable amounts of vibrations, mainly caused by the engine and its air flow. Work has been done to eliminate noise caused by vibrations from the exhaust and intake, leaving the chassis as the next source to address. A vibration analysis was conducted on the rolling chassis of the snowmobile in order to determine which areas needed to be addressed. Noise is created by the snowmobile because of the fiberglass rods and metal clips in the track impacting the bogey wheels and suspension rails as it rotates. This impact force causes vibrations which results in a significant amount of noise produced. The way to reduce the noise is to cancel out the vibrations before they get to the tunnel. This can be done at different points throughout the chassis, including the bogey wheels, suspension components, and the mounting of the skid to the tunnel. The team decided to evaluate how different bogey wheel designs and orientations affected vibrations.

The chassis team decided to do tests pulling the sled as this would eliminate the noise created by a running motor. The tests were conducted by pulling the snowmobile behind a vehicle at 35 miles per hour, as this is the upper limit of noise testing in SAE standard J192 used for Competition. Accelerometers were placed at various points on the sled, including the rails of the skid, foot well near the mounting bolts for the skid, and on the seat. Sound level was measured for each run, as well at a distance of 20 feet. Three different wheel orientations were tested. This was done because it can be controlled which bogey wheels hit the track rods at the same time. Stock/symmetric, left staggered from the right, and front staggered from the rear were all tested to determine the best orientation. Four different wheel designs were also tested. Two different sets of stock wheels were tested along with two custom designs. FEA was used to ensure that the two custom designs were at stress levels below the shear strength of the plastic. Figure 11 shows the results.

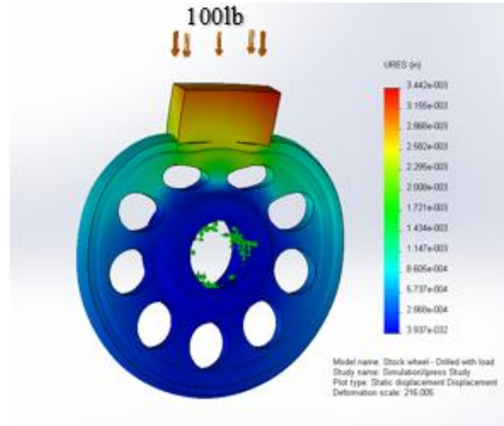

Figure 11: FEA of custom designed bogey wheel

The results of the test showed that the front to rear stagger pattern reduced vibration the most, while the left to right stagger showed a small improvement over stock. The stock bogey wheel design with one hole in it was determined to be the best design for reducing vibration. MATLAB was used to compare the mean of peaks of different runs, as well as visual inspection of the graphs. Figure 12 shows a trace from one accelerometer with the three different runs. It can be seen that the red line corresponding to front to rear staggering has lower peak values than the other two stagger combinations.

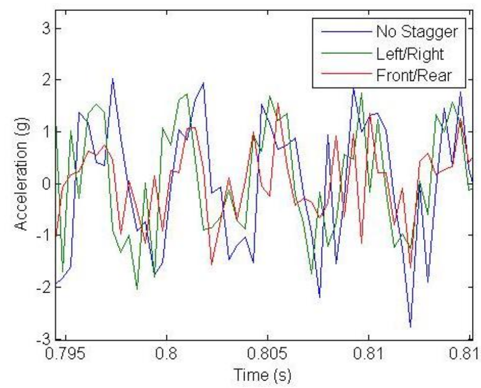

Figure 12: Accelerometer data comparing wheel orientation

Figure 13 shows four runs with different wheel designs. It can be observed that the one-hole design has the lowest peak acceleration values. The drilled design is improved from the solid but not as much as the one hole design. The front to rear staggering and the one-hole design have both been implemented on the snowmobile for the 2014 competition.

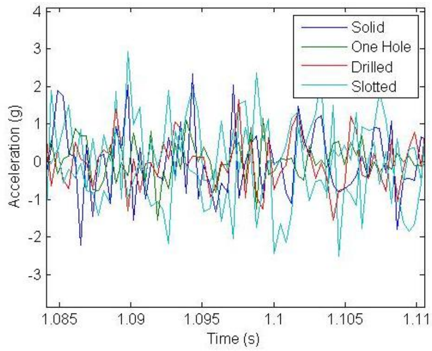

Figure 13: Accelerometer data comparing wheel design

WEIGHT REDUCTION

One of the ways that the team improved the snowmobile for this year's competition was by reducing the overall weight of the sled. the team looked into over-engineered components on the snowmobile and decided to lean out parts with excess material, while still keeping its original function in mind. A key area the team looked at on the snowmobile was the engine mounts that were deigned last year. The engine mounts were designed around a Polaris 875cc Pro-Star engine that produces 60 HP. There are two loads on the engine mounts that were calculated which include the static weight of the engine at 220 lbs, and the applied torque from the motor at 65 ft-lbs.

Figure 14: Original front engine mount with bracing

The front engine mount was analyzed because it was the most practical to reduce weight on while not diminishing the function or performance. The goal for the current front engine mount was to reduce the weight by 30 percent. The model was to have no internal sharp corners that would yield stress concentrations and have radiuses, which would enhance weight reduction and be easily manufactured. The components were designed with a minimum wall thickness of 0.250" and internal radiuses were designed at minimum 0.0625". The revised component can be seen in Figure 15.

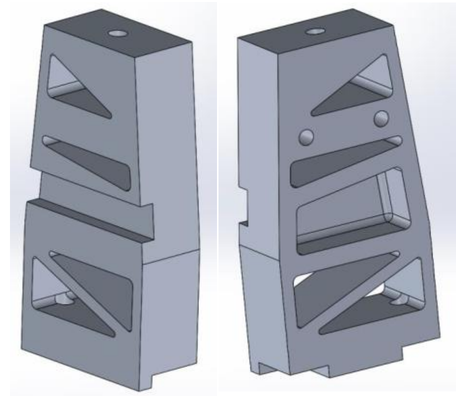

Figure 15: Front engine mount model

FEA results produced the deflection of each mount. The original mount yielded a deflection of 0.00013 inches and the modified engine mount revealed a deflection of 0.00028 inches under maximum applied load.

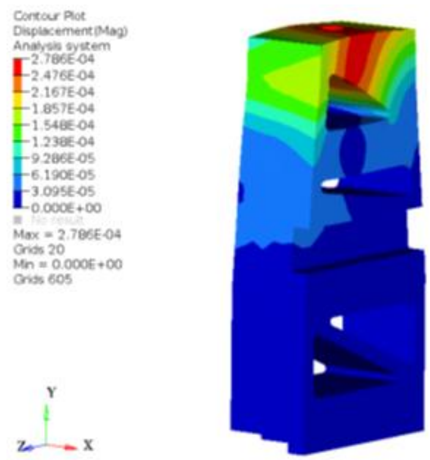

Figure 16: Deflection of modified engine mount

The FEA analysis for the maximum stress on the lightened engine mount can be seen below.

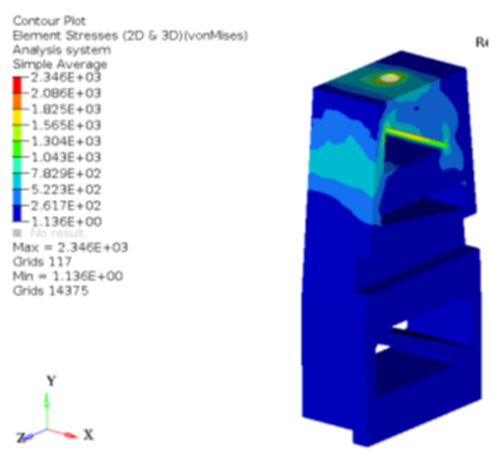

Figure 17: Stress results of modified engine mounts

The result of maximum stress of the engine mount for the modified configuration is 2,346 psi. 6061-T6 Aluminum has a yield stress of approximately 40,000 psi, which yields a safety factor close to 20. In conclusion, the aluminum mounts will not fail due to the load.

Table 4: Weight reduction comparison chart

Part Name	Initial Weight	Final Weight	Weight Difference
Bottom Front Engine Mount	2.67 Lbs	1.87 Lbs	0.8 Lbs
Shocks	10.2 Lbs	4.2 Lbs	6 Lbs
Body Panal Spacers	0.2116 Lbs	0.06 Lbs	0.1516 Lbs
Carbon Fiber Side Panels	2.09 Lbs	1.12 Lbs	0.97 Lbs
Spindle/A-arms Assembly	16.71 Lbs	14.62 Lbs	2.09 Lbs
Exhaust	35 Lbs	20 Lbs	15 Lbs

As seen in Table 4 above, other changes implemented on this year's competition snowmobile included designing the exhaust system. The team not only improved on the overall engine performance, but substantially reduced the weight of the overall system. The exhaust system from the 2013 competition sled weighed a total of 35 pounds. There were two exhaust systems designed this year; one with a similar design to the 2013 competition snowmobile, and one radically different with a dual muffler design. After both designs were completed, the new dual muffler design came out to be 20 pounds, while the other exhaust was 65 pounds. the team decided to run the dual muffler design because of the major benefit of the weight loss, compared to the other design.

To go along with improving upon the 2013 design, multiple body panels were made with carbon fiber. Because of the combination of a Polaris Indy chassis and body panels, with a Ski-Doo seat and over-structure, custom panels had to be made to bridge the gap between the gas tank and the cowl. Last years snowmobile featured thermo-plastic molded panels. This year, the team implemented custom carbon fiber panels that are lighter, stronger, and more aesthetically pleasing.

By swapping out current OEM parts, the team was able to reduce weight, starting by converting the front Walker Evans suspension to aftermarket Fox Floats shocks. This was a direct swap into the sled that saved a total of 6 lbs between the shocks. The non-essential hardware on the snowmobile including long bolts, steel bushings, and spacers were also considered. By decreasing the diameter on some parts, changing steel material out for aluminum, and shortening bolts. A total weight savings of 1.54 lbs was accounted for.

ANTI-LOCK BRAKING SYSTEM

The 2014 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 Ice Attak Track, will allow the machine to slow with greater control by pulsing the brake pressure to prevent long term locking of the track.

Brake lines 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 on 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 removed from heat that is being produced. 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 as shown in Figure 18.

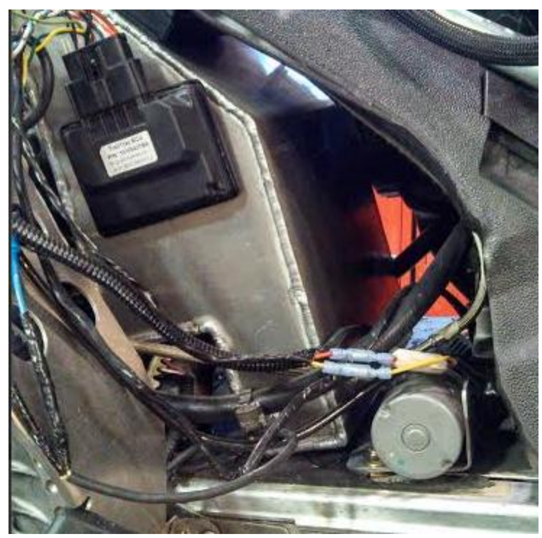

Figure 18: Hayes HCU and HECU mounting locations.

The HCU was also bled by splicing the wire harness to cycle the electric motor, as brake fluid was present, in order to fill the piston with fluid and force out excess air.

COST

In an effort to keep manufacturing costs as low as possible, every component added to the 2014 MTU IC entry was carefully analyzed.

Since the 2014 MTU IC entry includes advancements in chassis, flex fuel technology, fuel management, and produces significantly less emissions, the MTU Clean Snowmobile Team feels the additional $9148.15 is well justified.

SUMMARY/CONCLUSIONS

The 2014 MTU IC entry used a state of the art chassis and suspension technology to reduce weight, increase drive efficiency, and improve 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 selection of an exhaust system. Through utilization of standalone engine management, stock performance has been preserved while reducing noise and emissions. The 2014 MTU IC entry represents a first-of-its-kind engine and chassis combination which melds proven four-stroke emissions and noise characteristics with modern lightweight chassis technology.

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CONTACT INFORMATION

Dr. Jason R. Blough is an Associate Professor in the department of Mechanical Engineering at Michigan Technological University and the faculty advisor for both the MTU Clean Snowmobile Team and the SAE Student Chapter at the Michigan Technological University.

ME-EM Department
Michigan Technological University
1400 Townsend Drive
Houghton, MI 49931
Phone: (906)-487-1020
Email: jrblough@mtu.edu

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DEFINITIONS/ ABREVIATIONS

ABS Anti-lock Braking System

AFR Air Fuel Ratio

ATDC After Top Dead Center

BSFC Brake Specific Fuel Consumption

BTDC Before Top Dead Center

CAT Catalytic Converter

CNC Computer Numerical Control

CO Carbon Monoxide

CVT Continuously Variable Transmission

ECU Electronic Control Unit

EMS Engine Management System

EPA Environmental Protection Agency

FEA Finite Element Analysis

HC Hydrocarbon

HCU Hydraulic Control Unit

HECU Hayes Electronic Control Unit

IC Internal Combustion

KRC Keweenaw Research Center

LHV Latent Heating Value

MBT Maximum Brake Torque

MFB Mass Faction Burn

MSRP Manufacturer Suggested Retail Price

MTU Michigan Technological University

NOx Nitrogen Oxide

OEM Original Equipment Manufacturer

PE Performance Electronics

PTO Power Take Off

ROHR Rate of Heat Release

TDC Top Dead Center

WOT Wide Open Throttle

APPENDIX A: *Calculations for Butanol Percentages*

Balanced Stoichiometric Combustion Equations(Ideal)

Butanol- $C_4H_9OH + 6(O_2 + 3.773N_2) = 4CO_2 + 5H_2O$ (1)

Gasoline- $CH_{1.87} + (1 + \frac{1.87}{4})(O_2 + 3.773N_2) = CO_2 + \frac{1.87}{2}(2H_2O) + 3.773((1 + \frac{1.87}{4})N_2$ (2)

Stoichiometric AFR Calculations-Base Fuels

Butanol- $AFR_{stoich} = \frac{M_{air}}{M_{fuel}} = \frac{(MW_{air} * n_{air})}{MW_{fuel} * n_{fuel}} = \frac{(28.97\frac{kg}{mol})(6\text{ kmol})(4.773\text{ kmol})}{(4\text{ kmol})(12.011\frac{kg}{kmol}) + (10\text{ kmol})(1.008\frac{kg}{kmol}) + (1\text{ kmol})(16\frac{kg}{kmol})} = 11.19$ (3)

Gasoline:-$AFR_{stoich} = \frac{(28.97\frac{kg}{kmol})(1 + \frac{1.87}{4}\text{ kmol})(4.773\text{ kmol})}{(1\text{ kmol})(12.011\frac{kg}{Kmol}) + (1.87\text{ kmol})(1.008\frac{kg}{kmol})} = 14.60$ (4)

Stoichiometric AFR Calculations-Blended Fuels

Assumed Densities		
Gasoline	719.7	kg/m^3
Butanol	810.0	kg/m^3

AFR's are on a mass basis, so densities were chosen.

$$0.84 * \rho_{gasoline} = 0.84(719.7\frac{kg}{m^3}) = 604.548\frac{kg}{m^3} \quad (5)$$

$$0.16 * \rho_{butanol} = 0.16(810.0\frac{kg}{m^3}) = 129.6\frac{kg}{m^3} \quad (6)$$

$$\rho_{16\%butanol} = (604.548 + 129.6)\frac{kg}{m^3} = 734.148\frac{kg}{m^3} \quad (7)$$

$$\%\text{mass gasoline} = \frac{604.548\frac{kg}{m^3}}{(743.148\frac{kg}{m^3})} = 0.8235 \approx 82.35\% \quad (8)$$

$$\%\text{mass butanol} = \frac{129.6\frac{kg}{m^3}}{(743.148\frac{kg}{m^3})} = 0.1765 \approx 17.65\% \quad (9)$$

$$AFR_s = 0.8235(14.60) + 0.1765(11.19) = 13.9981 \approx 14.00 \quad (10)$$

32% Butanol

$$0.68^*\rho_{gasoline} = 0.68(719.7\,\frac{kg}{m^3}) = 489.396\ \frac{kg}{m^3} \quad (11)$$

$$\rho_{32\%butanol} = (489.396 + 259.2)\,\frac{kg}{m^3} = 748.596\,\frac{kg}{m^3} \quad (12)$$

$$\%\text{mass gasoline} = \frac{489.396\frac{kg}{m^3}}{748.596\frac{kg}{m^3}} = 0.6538 \approx 65.38\% \quad (13)$$

$$\%\text{mass butanol} = \frac{259.23\frac{kg}{m^3}}{(748.596\frac{kg}{m^3})} = 0.3462 \approx 34.62\% \quad (14)$$

$$AFR_s = 0.6538(14.60) + 0.3462(11.19) = 13.4195 \approx 13.42$$