Development of the Polaris Switchback Assault:

A Fusion of Advanced Technology with Proven Reliability

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ABSTRACT

The Michigan Technological University Clean Snowmobile Team is entering the 2011 Society of Automotive Engineers Clean Snowmobile Challenge with a redesigned 2011 Polaris Switchback Assault. The snowmobile has been redesigned to operate with reduced noise, reduced emissions, and with greater fuel efficiency. The snowmobile has been equipped with a turbocharged four-stroke 750cc Weber engine, AEM engine management system, lightweight electric charging system, and MTU designed intake and exhaust system.

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 cleaner and quieter touring snowmobile to be ridden primarily on groomed snowmobile trails throughout the park. This event was sponsored by the Society of Automotive Engineers (SAE) and consisted of universities from across the United States and Canada, all of which arrived with snowmobiles they had designed and built. The snowmobiles were evaluated in several static and dynamic events, including acceleration, handling, and hill climbs. 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 (MTU's) campus. For 2011, the competition remains at the KRC and runs from March 7th to the 12th. The competition has evolved to include both internal combustion snowmobiles as well as zero emissions electric-powered snowmobiles.

In 2010 the MTU Clean Snowmobile Team placed second overall in the internal combustion category with awards for Best Performance, Best Design, and Best Simulation Driven Design. Table 1 shows a breakdown of the team's performance from the 2010 competition.

Table 1: 2010 MTU Clean Snowmobile Team Competition Results

Event	Score	Place
Design Paper	89.3/100	2
Static Display	50/50	
MSRP	13.7/50	9
Fuel Economy	0/200	DNF Endurance
Oral Presentation	97.4/100	2
Noise	109.7/300	3
Acceleration	27.3/50	7
BSFC/Lab Emissions	200.9/350	3
Fuel Economy/In Service Emissions	25.5/250	5
Cold Start	50/50	
Objective Handling	44.2/50	4
Penalties/Bonuses	100	

For the 2011 Clean Snowmobile Competition the team has focused on meeting three primary goals which form the basis of the competition: increasing fuel economy, decreasing emissions, and maintaining or increasing performance. The MTU team aims to achieve these goals by decreasing weight through the use of a new chassis, increasing efficiency with engine calibration and drivetrain modifications, and decreasing emissions with all new exhaust aftertreatment.

CHASSIS UPDATE

The 2011 MTU entry is based on the all new 2011 Polaris Switchback Assault. The 2011 chassis offers several important advantages over other available chassis in the industry including weight reduction, improved rider ergonomics, and high quality adjustable suspension for varying riding conditions. A major difference between MTU's previous IQ chassis and the new Switchback Assault chassis is the fact that the Weber MPE750 was never designed to be used in the new bulkhead configuration, requiring new MTU-designed motor mounts. The MTU motor mount system securely holds the engine in three locations- at one main location on the power take off side of the engine, and on two lower locations, front and rear on the stator side of the engine. The PTO motor mount has been CNC cut from aluminum and the stator side mounts have been CNC machined from billet aluminum, and all three have been fitted with vibration isolating bushings. Because the motor mounts bolt into the bottom of the bulkhead of the snowmobile, the bottom plate in the bulkhead was replaced with a thicker piece of plate aluminum to withstand the heavier MPE750. Figures 1-4 below show the bulkhead reinforcement plate as well as the PTO and front and rear stator side motor mounts.

Figure 1: Bulkhead Reinforcement

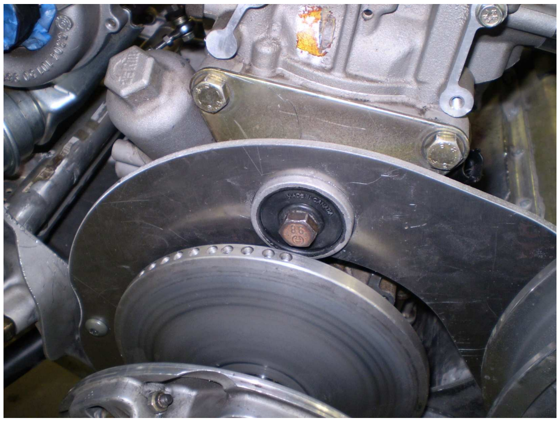

Figure 2: PTO Motor Mount

Figure 3: Front Stator Side Mount (next to stock mount)

Figure 4: Rear Stator Side Mount

Other chassis updates include the implementation of a Team Tied driven clutch. The Tide clutch offers efficiency improvements as compared to the stock TSS-04 driven clutch; this is due to the change in its designed operation. The Tide clutch sheaves open axially rather than rotationally; this motion produces less belt heat and friction while increasing drivetrain efficiency. The increase in efficiency is due to the reduction of energy required to open the driven clutch sheaves.

STEERING RELOCATION

The steering linkage for the 2011 competition sled was modified to accommodate the implementation of a turbocharged engine. On the stock 2011 Polaris Assault, the lower half of the steering post is mounted on the PTO side of the sled and is attached to the lower spindles by aluminum tie rods and bars. Since this steering column was directly in the path of the protruding turbo and hoses, it was relocated to the opposite side of the bulk head. A new bracket was machined and was welded to the angled tubular frame that connected to the steering hoop. The connecting tabs on both the upper and lower steering posts were removed and welded to maintain the same steering dynamics as stock but from a mirrored position. The aluminum support in the bottom of the bulk head was flipped and cut so the tie rods would still clear the stationary components. Lastly, the steering links were machined to remove excess material that was not needed for strength. This helped reduce weight and gave the steering components a custom fabricated look. Final steering modifications can be seen below in Figure 5.

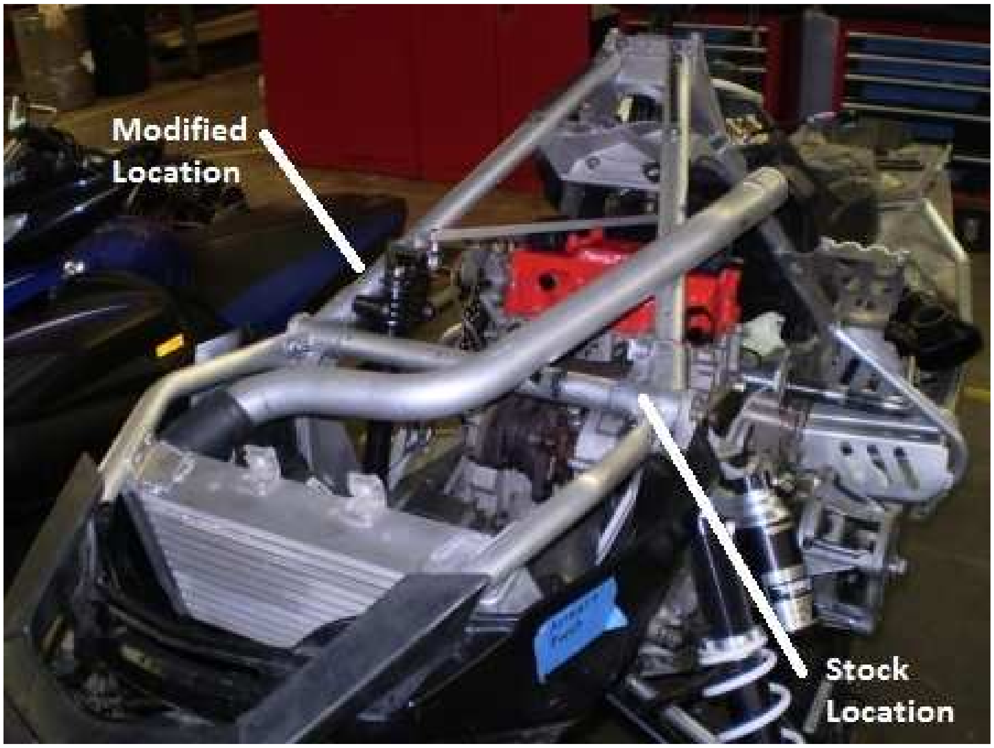

Figure 5: Steering Relocation

SC-5 REAR SUSPENSION

In a further effort to reduce the weight of the snowmobile, the rear suspension of the 2011 Switchback was replaced with the Ski-Doo SC-5 rear suspension. The SC-5 suspension weighs 6 lbs lighter than the stock 144” suspension. The 144” rear suspension, commonly referred to as a skid, that came stock with the chassis was not well suited for the Clean Snowmobile Competition events. The long skid was heavier and decreased the efficiency of the drive train due to an increase of contact area with the snow and suspension rails (drag force). The longer skid also decreased the cornering ability of the sled which would hinder performance in the subjective handling portion of the competition. With the team’s success last year with the implementation of the SC-5 skid, the team again chose the 120” skid as the rear suspension for the 2011 IC entry.

To determine the effects of the suspension change, from the suspension found on a stock FST trail sled (the M-10) to the modern SC-5, accelerometers were placed on the seat of a 2006 FST Classic and the 2011 competition snowmobile. Acceleration data was collected while the snowmobiles were driven over a constructed course at 15 mph. From analysis of the data, it was determined that the SC-5 did provide a reduction in acceleration at the seat; this result can be viewed in Figure 6. Notice the maximum acceleration achieved by the SC-5 was 1.2 g’s less than the stock Classic M10 suspension. In addition to objective data, a subjective ride quality test was performed using 4 riders of varying stature. From this experiment it was determined that the ride quality characterized by the

SC-5 was indeed superior to that of the stock M10 suspension. The combination of the subjective and objective results reinforced the team's confidence in their suspension selection.

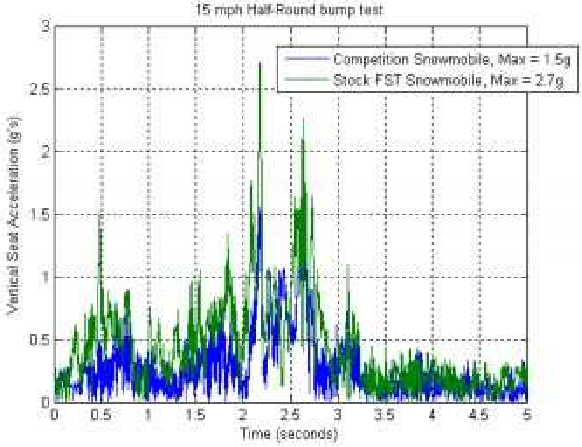

Figure 6: Acceleration Data

In order to fit the Ski-Doo skid in the Polaris tunnel, the rear scissor arm was narrowed 0.25" on each side. The front torque arm had to be narrowed 0.375" on each side to accommodate the 0.125" structural plate added to each side of the tunnel. Since the front torque arms are tubular in design, a flat plate was welded to the machined surface in order to maintain structural rigidity. New aluminum spacers were machined to fit the narrowed skid which could then be mounted in the tunnel as seen in Figure 7. A set of drop down brackets were also fabricated and mounted to fit the shortened skid and can be seen in Figure 8. The height and distance of the brackets location with respect to the driveshaft were determined by combining measurements from a stock Ski-Doo snowmobile equipped with the SC-5 and from the 2010 IC entry. The skid was also equipped with Hyperfax slides which replaced the stock polymer slides. The Hyperfax slides have a higher melting point, 2.5 times higher, than that of stock; this leads to a reduction in friction and an increase of service life. The application of Hyperfax slides has shown an increase in the snowmobile's drivetrain efficiency; previous tests with Hyperfax showed a decrease of 6.2 lbs of force to rotate the track around the SC-5 rear suspension.

Figure 7: SC-5 Suspension Mounted

Figure 8: Drop Down Brackets used for SC-5

For the 2011 IC entry a 15" x 120" Camoplast XC-Pro track was used in an effort to further increase driveline efficiency and decrease weight, also a shorter track was required to accommodate the use of the Ski-Doo SC-5 skid. This track replaced the 15" X 144" track that came stock on the Polaris Assault. The 120" track weighs 14lbs less than the 144" track. In order to turn this shorter track, a hex driveshaft and 2.86" pitch track drivers were used instead of the hydro-formed shaft and 2.52" pitch drivers. One issue that arose was the change in chain case/brake packaging from the 2010 competition sled to the 2011. On the previous snowmobile, the brake rotor and caliper were located between the chaincase and bulkhead. This offset the chaincase 0.4" away from the bulkhead and allowed a longer drive shaft. The 2011 chassis used the same Polaris Dragon chain case and brake set up but mounted the caliper on the outside of the chain case and the brake rotor on the end of the jackshaft. In order to reduce costs, the solid hex shaped drive shaft was used from the 2010 IC entry. However, the hex driveshaft needed to be machined down to fit inside the chaincase and not push the drive bearing out. The solution was to remove 0.4” of material from the PTO side of the driveshaft and then machine down 0.4” on the same side to accommodate the diameter of the drive shaft bearing. Once machined, a set of 2.86” pitch drive sprockets were pressed onto the modified hex driveshaft and spaced correctly to match the internal drive cogs molded into the track.

TUNNEL MODIFICATION

The tunnel on the 2011 competition sled was modified to better house the shortened suspension. In order to maintain rigidity, the tunnel was cut behind the structural supports of the running boards. Cutting the tunnel at this point meant shortening the cooling extrusions, which primarily compose the upper surface of the tunnel. A new aluminum cross over rail was welded in place and pressure tested to ensure its quality. The bumper was reattached to maintain a stock look and the aluminum tabs from the running boards were bent up to give the end of the tunnel a cleaner look. A major concern which arose after shortening the coolers was an increase in engine operating temperature due to the reduction in surface area for heat transfer in the coolant extrusions. Though minimal testing was performed, because of time constraints, it was still determined that the reduction in coolant extrusion length did not increase the engine temperature to unsafe levels.

Both the stock tunnel configuration and the modified shortened tunnel were modeled three dimensionally in order to ensure that the structural integrity of the chassis was not compromised. Once modeled, the proper constraints were placed on both tunnel sections and the same loads were placed on each piece of the chassis. Comparing the finite element analysis results from each version of the tunnel it can be seen that the reduction in length of the modified tunnel decreases the total deflection of the chassis. The reduction in length decreases the effect that a torsional load at the rear of the snowmobile can have by reducing the total length of the tunnel. The deflection results obtained from FEA are shown in Figure 9 for the stock tunnel and Figure 10 for the MTU modified tunnel.

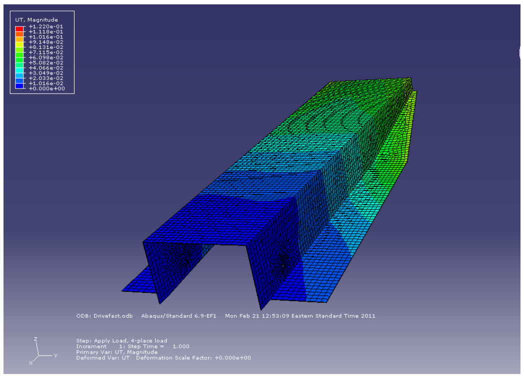

Figure 9: Stock 144” Tunnel Deflection

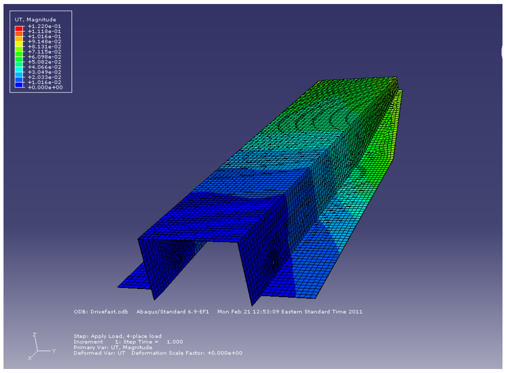

Figure 10: Modified 120” Tunnel Deflection

Additional chassis modifications to the 2011 chassis include tunnel stiffening plates. These tunnel stiffening plates are used in a critical area of the chassis, where the bulkhead of the snowmobile meets the tunnel, and ensure that the two main components of the chassis remain aligned and are structurally sound. High forces are transmitted from rear suspension mounts to this area of the chassis as the snowmobile moves over uneven terrain at speed and reinforcing this area ensures that the chassis does not buckle or kink. Figure 11 shows the inside of the tunnel with steel reinforcing plates in place.

Figure 11: Tunnel Reinforcement

CARBON FIBER WEIGHT REDUCTION

In past years the MTU IC entry has scored poorly in the weight category. Since reducing overall parts on the snowmobile is difficult, the team decided the best way to reduce weight is to incorporate lightweight materials that do not cause performance to suffer. Carbon fiber has been used as a lightweight material since the 1950s. The team, in order to begin the learning process and the incorporation of carbon fiber to the sled, began this year by making simple parts that were not highly crucial to the overall function of the sled. Through the implementation of carbon fiber and other weight reductions, the 2011 IC entry achieved a final weight of 535 lbs (without fuel); this is significantly lighter than previous MTU entries and will undoubtedly lead to increased efficiency and fuel mileage.

The first carbon fiber parts made were flat sheets which were used for vent and headlight covers. 3K 2x2 twill fiber was laid out, measured, cut and a mixture of high temperature high impact resin and hardener was applied. Care was taken to ensure as little resin as possible was used in order for the carbon fiber to remain lightweight and strong. The sheets were left for 4 hours on a flat surface in a vacuum pump in order to harden. Once dried, the desired pieces were cut out of the sheets and sanded down to fit properly into their respective positions.

The most complicated carbon fiber component fabricated for this year's competition was the airbox which required a lost foam process. First, measurements were taken of the space available and a cardboard model was constructed. From the cardboard model a Styrofoam mold was carved out eliminating sharp edges in order to make the carbon fiber layout easier. This Styrofoam mold was then covered in several layers of plaster and sanded down to a smooth finish. The mold was then painted with a water-based paint in order to avoid having resin stick to the plaster. The final green painted mold can be seen below in Figure 12. This mold was covered with three layers of carbon fiber and a mixture of resin and hardener and allowed to dry in vacuum. Once dry, a hole was drilled and acetone was poured in and allowed to eat away the Styrofoam, plaster, and paint leaving the final carbon fiber product. The box was then cut into two pieces to allow the air filter to be placed inside and hinges and a fastener were added to keep the box sealed.

Figure 12*: *The Finished Airbox Mold with raw 3K 2x2 twill Carbon Fiber and some needed Supplies

INTAKE

Because the Clean Snowmobile Challenge is centered around making a snowmobile clean, quiet, and more fuel efficient, engine choice is critical. The MTU IC entry utilizes a 750cc, turbocharged, four-stroke engine manufactured by Weber Engines called the MPE750. This engine is commercially available from Polaris but only in the IQ chassis. The combination of the MPE750 and the new Switchback Assault chassis pairs a proven reliable engine with a lightweight modern chassis. Several modifications to the MPE750 were made in order to make the engine lighter and more efficient.

After mounting the engine in the chassis, the first two major concerns for the engine were intake and exhaust. The intake of the snowmobile utilizes stock Polaris FST throttle bodies, shortened intake runners, stock plenum, stock intercooler, and a modified FST charge pipe. The motivation behind utilizing stock Polaris FST intake components where possible is to take advantage of the proven synergy in the parts as well as to shift focus more towards engine calibration rather than custom intake part fabrication. The stock intercooler was fitted with custom brackets, and the Switchback Assault plastics were exchanged for Polaris Rush plastics in order to allow a front air intake for the intercooler. From the intercooler, charge air passes through an extended stock FST charge pipe into the stock intake plenum where it passes through stock throttle bodies, through shortened intake runners, and finally into the engine.

In an effort to increase the volumetric efficiency of the stock MPE750 cylinder head, the rough stock aluminum casting was ported. Porting is a simple process in which both the intake and exhaust ports of the cylinder head are finely ground to make them as smooth as possible. The stock MPE750 intake ports have a rough uneven texture from casting which can lead to lower volumetric flow as well as to turbulent flow into the engine. The MTU engine team porting was intended to smooth out the uneven finish from casting in an effort to achieve smooth laminar flow as well as to increase the amount of air that can flow through the ports overall. In much the same way the exhaust ports were given a similar treatment. Pumping loss in an internal combustion engine serves to decrease the net work the engine can produce and therefore should be decreased as much as possible. Decreasing the amount of pumping work for a given air intake system, exhaust system, and throttle position is therefore a function of making it easier for the engine to draw in air via intake porting and expel air via exhaust porting.

The MTU engine team ported head and a stock MPE750 head were both mounted onto a test block to replicate flow into a cylinder, which is critical to the flow pattern of the head. Without a mock cylinder for the air to travel down into, data for flow through the intake and exhaust ports would be erroneous. The cylinder head is then bolted onto the mock cylinder and the mock cylinder was attached to the flowbench used to collect data. After being attached to the flowbench, intake runners are fixed to the cylinder head in order to provide accurate air flow data in much the same way that the mock cylinders are used. The intake runners replicate air flow conditions as closely as possible to the engine in its usual running condition, and intake and exhaust valves were left in the cylinder head in order to further replicate operating conditions. Figure 13 below shows the flowbench and cylinder head used for flow testing. After both heads were tested in the same fashion, the pressure differential between each side of the flow was measured, and discharge coefficients were determined for each condition. Figure 14 below is a plot of the discharge coefficients of both the intake and exhaust ports from the stock head as well as the ported head. Equation 1 was utilized in the determination of the discharge coefficients; where rho is air density and delta rho is the orifice plate's differential pressure.

$$m_{act} = 5.770 * 10^{-3} * [\rho * \Delta\rho]^{1/2} * [1.6367/0.7416]^2 \qquad (1)$$

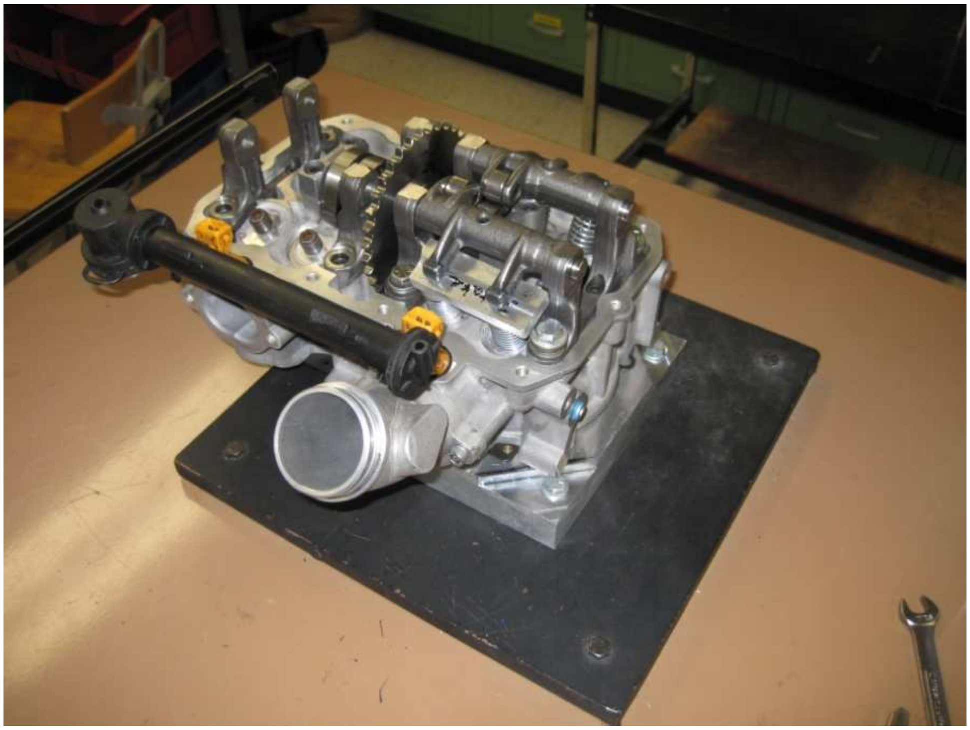

Figure 13: Cylinder Head Flowbench Test Setup

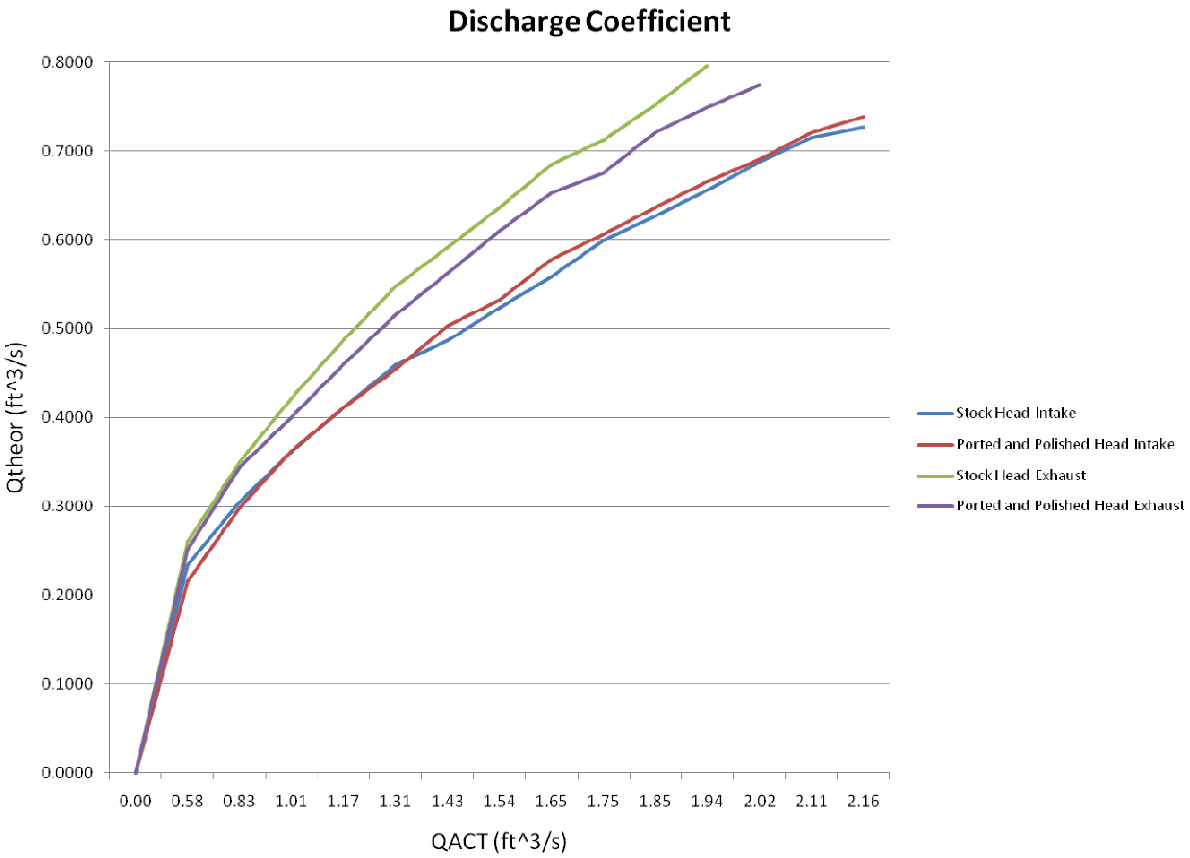

Figure 14: Discharge Coefficients for Stock and Ported Head

Figure 14 above clearly shows that on the exhaust side of the head there is an advantage to using the stock head and leaving it unmodified. However, Figure 14 also shows that there is a slight advantage to using the ported head on the intake side of the head. Because the advantage of the ported head is so small on the intake side when compared to the disadvantage of running the ported head on the exhaust side, a stock cylinder head has been used on the MTU IC entry. Future flow testing will implement a cylinder head which is lightly ported on the intake side and is left stock on the exhaust. This test was prohibited due to time and resources for the 2011 competition.

EXHAUST

The MTU 2010 IC entry was naturally aspirated. The 2011 IC entry utilizes boosted charge air from a stock MPE750 turbocharger. A major difference as well as design constraint for the 2011 IC entry was the decision to use a conventional front exit exhaust system. This choice was made due to the heavy duty construction of the stock header and the extreme conditions in which it must perform. Dynamometer testing has shown exhaust gas temperatures in excess of 1500° F for several seconds at a time. The robust construction of the cast exhaust header is the only reliable and realistic means by which to have a functional exhaust header for real world applications. Previous IC entries from the MTU team have featured a rear exiting exhaust that ran through the tunnel which allows for extra room to mount a large muffler as well as a catalytic converter. While this system was good from a noise and emissions perspective, it often led to cracked exhaust components due to thermal shock and torsional loading from the chassis. Additionally this system led to poor fit and finish of snowmobile components that had to be moved to account for exhaust routing. The front exit exhaust fabricated for the 2011 IC entry features both the noise cancelation and emissions properties of the 2010 exhaust but with simpler, more compact packaging and greater reliability.

Before exhaust fabrication, several exhaust configurations were tested using the standard five mode dyno test in order to compare each setup from both a noise and emissions standpoint. Table 2 below shows a comparison between three different exhaust setups. The engine used for comparison was a stock MPE750 from a Polaris FST using stock engine calibration. E29 was used for testing in order give an indication of how the catalysts would perform with E2X fuel, which is to be used during the 2011 competition.

Table 2: Emissions Data (E29 Fuel)

Mode	Configuration	Pre/Post Cat	HC (ppm)	CO (%)	Nox (ppm)	% Diff HC	% Diff CO	% Diff Nox
1	Straight Pipe	-	46	4.93	583			
	2010 Comp.	Pre	42	4.39	824			
		Post	19	3.63	18			
	3 Pass	Pre	36	4.7	761			
		Post	17	3.18	20	-10.53	-12.40	11.11
2	Straight Pipe	-	23	0.59	1618			
	2010 Comp.	Pre	20	0.81	2229			
		Post	7	0.12	527			
	3 Pass	Pre	14	0.71	2012			
		Post	5	0.04	1277	-28.57	-66.67	142.31
3	Straight Pipe	-	71	1.34	1260			
	2010 Comp.	Pre	38	1.14	1803			
		Post	7	0.02	845			
	3 Pass	Pre	50	1.23	1606			
		Post	12	0.08	929	71.43	300.00	9.94
4	Straight Pipe	-	60	1.23	1110			
	2010 Comp.	Pre	46	1.29	1601			
		Post	5	0.01	1076			
	3 Pass	Pre	53	1.33	1379			
		Post	10	0.04	609	100.00	-96.00	-43.40
5	Straight Pipe	-	128	2.33	203			
	2010 Comp.	Pre	56	2.19	239			
		Post	4	0.01	37			
	3 Pass	Pre	54	2.29	198			
		Post	16	0.48	22	300.00	4,700.00	-40.54

Emissions data collected through dyno testing showed that the three-pass-catalyst is very competitive with the catalyst used in the 2010 IC entry. The three-pass-catalyst provides significant emissions reductions in hydrocarbons and carbon monoxide in high speed, high load applications (modes 1 and 2), reductions in carbon monoxide and NO_x at cruising speed (mode 4), as well as significant NO_x reduction at idle (mode 5). The MTU IC entry utilizes an AEM universal engine management system which will allow for fuel and ignition tuning to reduce both hydrocarbon and carbon monoxide emissions in test modes 3-5. Emissions data collected served to focus emissions tuning in areas where its performance did not exceed the 2010 catalyst. Additionally the three pass catalytic converter is still in the process of being broken in and is expected to perform better with additional usage and heat cycling.

In addition to collecting emissions data, sound data for several exhaust configurations was collected as well. Sound data was collected at each of the five testing modes used for emissions data collection, and all exhaust systems were aimed parallel to the ground into an open space and measured from approximately 1m away. All sound levels were average levels at that mode, not peak or minimum values. Table 3 below shows the sound data collected for the exhaust systems tested.

Table 3: Exhaust Sound Data

Webber 750cc Sound Pressure Levels (dB)					
Mode	**Straight Pipe**	**5.66" 3 Pass**	**3 pass w/ Resonator**	**3 Pass/Resonator/Cherry Bomb**	**2010 Exhaust**
1	115.2	107.1	105.1	102.2	106.3
2	113.3	108.2	101.3	98.7	101.3
3	112.0	103.1	96.7	96.1	98.8
4	109.5	101.3	94.8	92.7	95.1
5	100.1	86.9	83.7	84.0	82.8

Table 3 shows that the combination of a tuned resonator, the three-pass-catalyst, and a Cherry Bomb together are quieter than the 2010 exhaust system used for the Clean Snowmobile Competition by MTU. This exhaust system is unique in that it employs a sound reduction operation both before and after catalysis. The three-pass-catalytic converter was developed in conjunction with V-Converter, a catalyst manufacturing company, and is the first product of its kind. This combination of exhaust parts was chosen for implementation on the 2011 entry for its clean and quiet operation as shown by both emissions and noise data collected. This exhaust configuration also flowed better and allowed for increased power output through reduced backpressure.

After selecting the exhaust configuration to be used for the 2011 MTU IC entry, a list of critical design constraints were developed for mounting the exhaust system in the chassis. Table 4 below lists the major design constraints used for exhaust fabrication.

Table 4: List of Critical Exhaust Design Constraints

Exhaust Design Constraints	
1	Keep exhaust components under/inside of existing hood and side-panels
2	Maintain a minimum of .25" between exhaust components and moving parts/plastics
3	Exhaust must contain tuned resonator/three pass catalytic converter/Cherry Bomb
4	Exhaust should mate to a standard ball coupler exhaust interface
5	Exhaust should exit snowmobile aimed at the ground
6	Design must account for heat management and heat expulsion

After carefully considering the six critical design constraints, exhaust fabrication was completed using 2 inch mandrel bent tubing. The exhaust pieces were laid in place in the side panel of the chassis, stacked from top to bottom on an approximate 45° angle with the tuned resonator on the bottom, the three pass catalyst in the middle, and the Cherry Bomb muffler on the top. After exiting the Cherry Bomb muffler additional 2 inch muffler tubing is used to route exhaust gases behind the catalyst to a hole in the bottom of the bellypan. Figure 15 below shows the exhaust system completed as one piece out of the chassis and Figure 16 shows the exhaust completed and mounted inside of the chassis.

Figure 15: Finished Exhaust System

Figure 16: Exhaust Mounted in Chassis

Using Matlab simulations based on acoustic impedance modeling, a transmission loss curve was generated for the final exhaust configuration. This curve can be viewed in Figure 16. This graph signifies the frequencies in which the exhaust works best at absorbing unwanted sound waves. The information provided through this transmission loss plot is useful for proper selection of sound absorbing materials. The transmission loss curve for the 2011 exhaust can be compared to that of the 2010 exhaust in the Figures 16 and 17; overall the 2011 exhaust system shows an increase in ability to absorb high frequency sound waves. This high frequency absorption is beneficial to MTUs turbocharged engine, which produces significant amounts of high frequency sound.

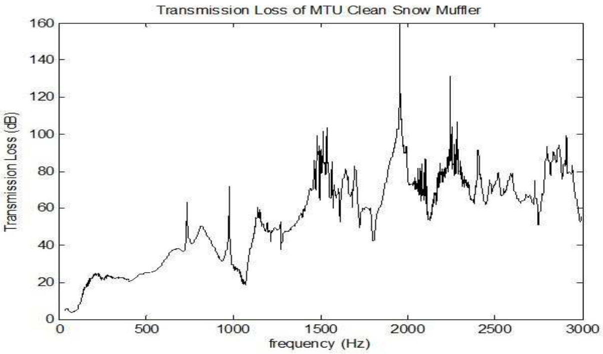

Figure 16: 2011 Exhaust Transmission Loss

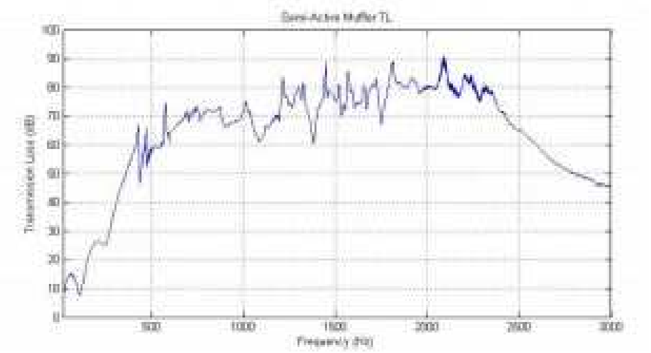

Figure 17: 2010 Exhaust Transmission Loss

OIL SYSTEM

Several modifications were made to the oil system compared to that of a stock Polaris FST. Due to the size and location of the exhaust system fabricated, the stock plastic oil bottle would not function well in the 2011 chassis. The MTU team fabricated an all new oil bottle out of aluminum to fit the unique size constraints at hand as well as to further reduce the weight of the snowmobile. The stock FST oil bottle was disassembled and the internals were cut down and reused in the MTU design. The MPE750 is a dry sump engine which means that oil is not collected and stored in an oil pan underneath the engine. The dry sump engine has several advantages over its wet sump counterpart. These advantages include but are not limited to being able to mount the engine lower in a chassis because of the lack of a large oil pan, the ability to increase or decrease oil capacity of the engine, and controlling the movement of the oil in the system preventing sloshing and oil starvation when the engine may be at an unusual angle.

The oil bottle design has three critical functions which had to be met in order to ensure reliable and safe operation. First, the oil bottle must supply an adequate amount of oil to the high pressure supply pump. The scavenge pump sends low pressure oil to the oil cooler and returns it to the oil bottle. Second, the oil bottle must remove any air from the oil before it reaches the high pressure pump. This is done by swirling the oil inside of the cylinder internal to the bottle. The heavy oil is centrifuged to the outside of the oil bottle, and the lighter air moves towards the middle and out of the vent built into the oil bottle. Third, the oil bottle must function to relieve excess pressure in the oil system with a breather that leaves the top of the oil bottle. All three of these critical functions are performed by the internals of the oil bottle that were modified from the stock design and placed into the MTU-designed oil bottle. Figure 18 below shows the MTU designed oil bottle and its basic components next to a stock oil bottle and its components. The MTU designed oil bottle accounts for a weight reduction of 1.29 lbs and reduces oil capacity by 1.18 quarts. Through sufficient engine run time, it was concluded that the reduction in oil capacity will not prohibit efficient or safe engine operation.

In addition to redesigning the oil bottle from the FST, the oil cooling system was redesigned for decreased weight and for reduced cooling. The MPE750 engine responds well to an increase in oil temperature to approximately 200°F, approximately 20°F higher than stock. This reduction in weight and reduction in cooling was accomplished by switching from a stock oil-to-water oil cooler to an oil-to-air oil cooler. The oil cooler used came from Earls Performance Plumbing and consists of 10 narrow cooling cores for the oil to flow through. In addition, -10 barbed AN fittings made to fit a 5/8' inch oil line were placed on the bottom of the oil cooler to transfer oil at a similar flow rate to a stock FST snowmobile. 2010 Polaris Rush nose plastics were used to replace the 2011 Switchback Assault plastics in order to take advantage of the air intake incorporated for the stock Rush cooler.

Figure 18: MTU Designed Oil Bottle and Stock Oil Bottle Internals

CHARGING SYSTEM

Additional modifications were required in order to mount the MPE750 into the 2011 Switchback Assault chassis. In its stock configuration in the IQ chassis, the MPE750 is equipped with an automotive-style alternator in order to power the electrical system on the snowmobile as well as to charge the battery. However, due to space constraints, an alternator was not an option for the electrical system. Polaris personal watercrafts also use the MPE750 and in this configuration the alternator is replaced by a stator. The MTU clean snowmobile team has attempted using the stock Polaris watercraft stator on the MPE750 in years past but has found that in a snowmobile application, and with the electrical demands placed on the system, the stator wattage is not sufficient for sustained engine operation. However, for the 2011 IC entry, the stock Polaris stator has been replaced by a high output unit, from Watcon, designed for use with the MPE750. The Watcon stator is a prototype unit and is in development for high performance MPE750 applications.

In addition to implementing the new high output stator, measures have been taken to reduce the electrical demands of the snowmobile for 2011. The 2010 IC entry used an oversized external Mallory fuel pump which had high current demand for proper operation. The 2011 IC entry replaces the Mallory fuel pump with the stock Polaris in-tank fuel pump. The benefit of the stock Polaris in-tank pump is threefold. First, the in-tank pump draws less current and therefore lowers the demands placed on the snowmobile's electrical system, making implementation of the stator more feasible than in years past. Second, the in-tank fuel pump frees up valuable space under the hood of the snowmobile and keeps the fuel pump from being exposed to high temperatures. Third, the in-tank fuel pump operates quieter, as its noise is dampened inside of the fuel tank rather than being transmitted from under the hood. Further efforts to reduce the electrical demand placed on the snowmobile include the deletion of hand and thumb warmers as well as the use of more energy efficient and compact LED lighting for headlights and tail lights.

ENGINE TUNING

In order to achieve the high emissions standards required to be competitive in the Clean Snowmobile Challenge, full control of the MPE750 engine is an absolute necessity. Stock snowmobiles are tuned to be safe in a variety of conditions and often times, especially in turbocharged applications, these safety factors can be as high as 1.5. For example, safety factors built into the lambda values of many commercially available turbocharged vehicles can be as rich as .65 lambda. This high amount of safety is necessary, however, because of the often unpredictable nature of the fuel available and the driving conditions that may be encountered. Because fuel for the Clean Snowmobile Challenge is definitively between E20 and E29, this safety factor can be decreased and the engine can be tuned closer to its stoichiometric value.

In order to achieve full control over the MPE750 engine, an AEM Universal Engine Management System was mounted on the snowmobile, and a custom wire harness was used to connect the flying lead harness with which it came to the engine. Before attempting to start the engine, consideration was given to the E2X blend of fuel that would be run. Because the MTU team had access to 55 gallons of sealed E22 fuel, engine tuning focused on the E22 blend and closed loop O_2 feedback was used to compensate for varying fuel compositions. The stoichiometric value for gasoline is well known at approximately 14.55:1 AFR. However, the stoichiometric air-fuel ratio for E100 is approximately 9:1. Although the octane rating of a fuel increases with increasing ethanol content, the energy content of the fuel decreases, thus requiring a richer air-fuel ratio. The change in the stoichiometric air-fuel ratio with respect to ethanol content can be modeled as a linear relationship. Interpolating the stoichiometric air-fuel ratio from E22, using the values from E0 and E100 as bounds, the new target value is found to be 13.33:1. Figure 19 below shows the linear interpolation of the stoichiometric air-fuel ratio for E22.

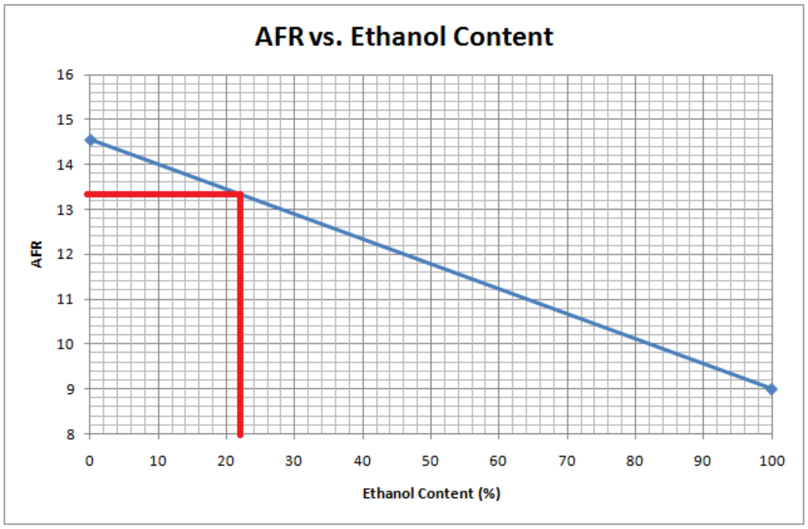

Figure 19: Plot of Effect of Ethanol Content on AFR

Because the MTU Clean Snowmobile Team tunes based on lambda values, the stoichiometric air-fuel ratio found for E22 can be converted to a lambda value which will be displayed by the AEM UEGO using the formula for lambda shown in Equation 1 below:

$$\lambda = \frac{AFR_{actual}}{AFR_{stoichiometric}} \qquad \lambda = \frac{13.33}{14.55} = \boldsymbol{.92} \tag{2}$$

After calculating a new value for lambda, the usual stoichiometric target for pump gas has been readjusted. Where 1.00 lambda used to be a perfect stoichiometric mix of fuel and air for pump gas, .92 is now used as a target for a stoichiometric mix for E22. Engine tuning done on the MPE750 for the 2011 competition targeted .92 lambda for HC, CO, and NO_x reduction. Engine tuning for the 2011 competition engine calibration is performed on a dyno stand which exactly replicates the hardware found on the MTU IC entry. This is critical because the engine management system is configured to run a system referred to as speed density. Speed density tuning involves the acquisition of intake pressure, temperature, and engine speed to determine the mass flow rate of air into the engine. This is in contrast to mass airflow systems which use a current value used to heat a wire in order to determine the flow rate of air. Speed density is sensitive to intake and exhaust hardware changes which necessitates exact duplication of components from the dyno stand used for tuning and the setup used for competition.

COST

In an effort to keep manufacturing costs as low as possible, every component added to the 2011 MTU IC entry was carefully analyzed. The benefits and costs associated with each additional component were scrutinized; the result was a realistic estimated MSRP of 12,707.33 dollars. When this estimated MSRP is compared to that of a 2011 Polaris Turbo IQ, which has an MSRP of $11.099.00, the additional cost is not substantial. Since the 2011 MTU IC entry utilizes a newer chassis, weighs less, and produces significantly less emissions, the MTU Clean Snowmobile Team feels the additional $1608.33 is well justified.

CONCLUSION/SUMMARY

The 2011 MTU IC entry used 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 aftertreatment as well as for noise reduction have been utilized in the selection of an exhaust system. The 2011 exhaust system has reduced noise from 2010, and maintained emissions characteristics, all while increasing durability, reducing size, and reducing weight. Through the implementation of a turbocharger as well as through the utilization of standalone engine management, stock performance has been preserved while reducing noise and emissions. The 2011 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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- National Instruments
- Oshkosh Corporation
- Polaris Industries
- Soundown
- Team Industries
- V-Converter
- Yamaha

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