# Clarkson University's Flex-Fuel Polaris FST Classic

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## ABSTRACT

Clarkson University's entry for the 2009 Clean Snowmobile Challenge utilizes a 2006 Polaris FST Classic chassis and engine. The engine, a 749cc twin cylinder turbocharged four-stroke engine, has been modified to run smoothly and efficiently on flex fuel. The exhaust system has been re-engineered to more cleanly incorporate a catalytic converter. A new rear suspension and track increase efficiency and handling. Clutching modifications allow for the snowmobile to accelerate smoother and faster, and obtain better fuel economy on the trail. Additional measures were taken to reduce noise emissions and improve fuel economy. These modifications have all been performed and carefully tested in an effort to reduce emissions and noise while maintaining a desirable level of performance and efficiency.

## INTRODUCTION

According to the National Park Service, the average two-stroke produces 150g HC/kW-hr and 400g CO/kW-hr at an average noise level of 78dBA. In an attempt to save its environmental integrity, the National Park Service has set stringent emissions regulations to be met in order for a snowmobile to enter the park. These regulations have been set based on what is known as Best Available Technology (BAT). BAT requirements are as follows: 15g HC/kW-hr, 120g CO/kW-hr, and a noise level of 73dBA. Currently, the only snowmobiles that meet this requirement are four-stroke non-turbo snowmobiles such as the Polaris FS Classic and the Arctic Cat 660 Touring [1]. These snowmobiles lack the familiar power that most consumers demand. Consumers desire the most power they can get for their money. The challenge, therefore, lies in engineering a snowmobile that is powerful, cost efficient, and clean enough to be accepted into the national parks.

Considering this challenge, it seems that a four-stroke turbocharged snowmobile is best able to achieve this status. Although not currently accepted into national parks due to emissions, these snowmobiles offer plenty of power that the non-turbocharged versions lack. This type of engine also has an exceptional potential to run cleaner than it does presently, allowing it to meet present and future national park regulations. The addition of E85 Ethanol into the economy has brought us the capability to further reduce emissions. The translation of this development into the snowmobile industry allows for beneficial decreases in emissions while maintaining or even improving performance. It is therefore the main purpose of this team to modify a four-stroke turbocharged snowmobile to run cleanly, efficiently, quietly, and reliably on any mixture of ethanol between E10 and E85 Class 3 ('flex-fuel').

Last year, the team chose to keep design simple yet robust. The snowmobile was converted to run on E85 by keeping the stock ECU programming and raising the fuel pressure. A catalytic converter was also added to the stock exhaust. This robust simplicity ended up paying dividends, as the snowmobile was the only one at the 2008 SAE Clean Snowmobile Challenge (CSC 2008) to pass and/or finish all of the events.

This year, the team has chosen the same route. Intentions are to create a snowmobile that runs on flex-fuel while decreasing emissions, improving efficiency, and decreasing noise levels. Also, modifications were done in an effort to reduce the snowmobile's 'worst at competition' weight of 719lbs. No modifications done were allowed to decrease the power or pleasure of the ride. Care was taken such that each modification is done as simply as possible to avoid problems arising from over-complication.

## FLEX-FUEL

The team chose to utilize the stock Weber motor from the 2006 Polaris FST Classic chassis. The German-designed motor is a turbocharged 8-valve SOHC Parallel Twin Cylinder 749cc engine with a Bosch Motronic injection system. Rated at 140 horsepower, this engine has plenty of power to satisfy the average consumer.

This engine is the same engine that is in the BAT recognized Polaris FS, with the exception of the turbo. It is a goal of this team to modify this Polaris FST to achieve emissions and noise levels equal to or lower than that of its non-turbo brother without hurting the performance. The first step of this process was to convert the snowmobile to run any ‘flex fuel’ mixture of gasoline and ethanol between E10 and E85 Class 3.

As per requirements for the 2008 Clean Snowmobile Challenge, the fuel delivery system had already been converted to withstand the corrosive properties of ethanol. This included the selection and replacement of proper fuel line (SAE30R3 Buna-N hydraulic hose), fuel pump (Mallory 110FI), fuel filter (Ford Taurus FFV Filter), fuel pressure regulator (Venom Adjustable), and O-Rings (Viton). These materials and components are known to be ethanol resistant, and have not shown any sign of failure in more than a year of immersion in E85. Figure 1 shows the modified fuel delivery system used for both E85 and flex-fuel.

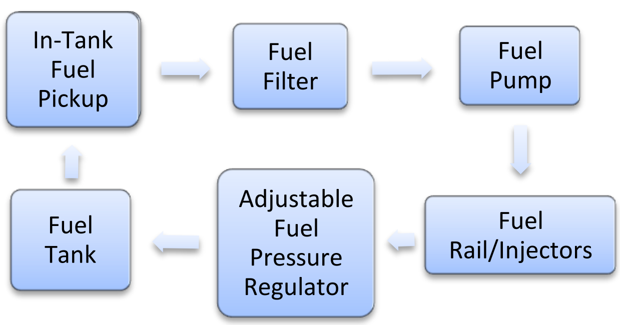


**Figure 1: Fuel Delivery System**

Last year, the engine was converted to run on E85 by simply raising the fuel pressure using the adjustable fuel pressure regulator. Raising the fuel pressure from 44PSI to 58PSI compensated for the lack of energy contained in ethanol. The Bosch Motronic Engine Control Unit (ECU) uses a lambda sensor positioned at the exhaust manifold to properly tune the engine. The closed-loop injection system measures the readings taken by the lambda sensor and controls injection length to achieve a complete combustion of the injected fuel. By increasing fuel pressure, this allows the ECU to inject the correct amount of fuel to achieve the target stoichiometric burn ratio at a lambda value of 1. The knock sensor also controls ignition and is able to eliminate engine knock generated by the higher-octane E85 by delaying the ignition timing.

The ECU tunes for complete combustion, regardless of the fuel injected. For gasoline, the engine targets the stoichiometric 14.7:1 air to fuel ratio (AFR). For E85, the engine targets a stoichiometric 10.71:1 air to fuel ratio. The lambda sensor does not measure the specific air to fuel ratio, but rather how close it is to complete combustion. The increase in the fuel pressure therefore serves as a ‘rough tune,’ and allows the ECU to fine tune the injected amount.

Testing was completed to determine the extent of the fine tuning ability of the ECU. The system was first tested with 93 octane gasoline. The fuel pressure was raised incrementally from 44 PSI to 68 PSI with the engine at idle. Lambda values and injector pulse width was recorded. This process was then repeated for each of the 5 modes used in the emissions testing. This data is used to prove that the engine is able to tune itself properly, regardless of fuel pressure. Injector timing decreased as pressure increased, proving that the engine was correcting itself for the higher fuel pressure. The tank was then drained and filled with E85, and the test repeated starting at 58PSI and going down to 44 PSI. Once again, lambda values and injector timing prove that the engine is able to tune itself regardless of the fuel.

The original design was for a flex-fuel composition sensor to be fitted between the fuel tank and the fuel pump. This outputted value would then have been used to turn a servo and adjust the fuel pressure accordingly. As a result of this testing, it was decided that the engine management unit is able to tune itself to run at a stoichiometric ratio, regardless of the fuel composition or fuel pressure. This eliminates the need for the more complicated and expensive system to automatically adjust the fuel pressure.

Although lambda values could not be attained while riding, the ECU did not record any errors during field testing. If the engine was not able to tune itself to within an acceptable AFR range, it will record it as an error.

**REAR SUSPENSION/TRACK**

One of the places to lose weight is in the rear suspension and track. The stock suspension of a 2006 Polaris FST Classic is a 128” M-10 suspension and the stock track is a 15” x 128” Camoplast Ripsaw with a 1.25” lug height. Last year 96 Woody’s studs were added to the track for traction. Overall the rear suspension and track combined to weigh 111 lbs with studs and 103 lbs without. The rear suspension and track are seen as areas where weight could be lost and a place for possible noise reduction. The 128" rear suspension could be reduced to 121" without compromising the ride or stability of the snowmobile. A touring rider has no need for a 128" suspension. Touring riders look for ride and comfort when purchasing snowmobiles. As long as the ride of the snowmobile is not compromised, putting a 121" suspension and track on the snowmobile will reduce weight and noise emissions.

After researching different 121" aftermarket suspensions, AD Boivin's $ZX^2$ suspension was chosen to replace the 128" FAST M-10 made for Polaris. There are many benefits to the $ZX^2$ suspension. The $ZX^2$ has wheels and swingarms made of UHMW polyethylene, while the rails are made of UHMW composite. Being made from types of plastics make this suspension much lighter than the M-10, The M-10 weighs 61.99 pounds whereas the $ZX^2$ weighs 52.14 pounds. This weight loss improves stability and efficiency. The weight loss not only helps stability but it will also make the snowmobile easier to maneuver for the operator. The UHMW polyethylene and composite are more flexible so it will not break as easily. Also, the types of plastics used have much more noise dampening characteristics compared to the noise created from the movement of metals in the M-10. The $ZX^2$ also have four 8" diameter rear idler wheels, which are larger than those on the M-10. The 8" idlers reduce rolling resistance which improves speed and efficiency.

The resistance between the track and suspension is further reduced because of the low coefficient of friction of the plastic used on the slides. The slides are made of this plastic which are more durable and slicker than the Teflon slides used on the M-10. This continues to reduce the rolling resistance and increases efficiency. This increased efficiency allows more power to be transferred to the ground. This will help improve the fuel economy.

This suspension contains no welds or any paint so there is no need to worry about the welds breaking or the formation of rust. The welds in a typical suspension like the M-10 can fatigue and cause cracks while the welds can also fail in cold temperatures. The $ZX^2$ is maintenance free, unlike the M-10 which needs to be greased at least once a season. The UHMW polyethylene and composite are self-lubricating so the shocks are the only parts of the suspension that will need to be maintained.

The dual G-Force Position Sensitive shocks are valved to prevent bottoming when the last quarter of stroke is reached, which makes the ride smoother when the trails get rough. The first three-quarters of the stroke of the shocks allow for a smooth ride in the small and medium bumps. Shock valving on this suspension makes it smooth in any condition. Furthermore the suspension's geometry allows for a smoother ride. As the suspension hits a bump the suspension moves up while the rest of the sled moves down. This suspension is adjustable with seven pre-loading positions of the spring and the weight transfer is adjusted easily with the use of pins. The $ZX^2$ suspension cost $1302.97 with an exchange rate of 1 CA equaling $0.79US. The M-10 cost $1399US. There is a $96.03 reduction in the MSRP of the snowmobile. Though the $ZX^2$ is maintenance free and has no future costs unlike the M-10 which requires maintenance. [2]


**Figure 2: AD Boivin $ZX^2$ and Camoplast Cobra**

A new 15" x 121" track was needed for this new suspension, and the Camoplast Cobra track was chosen. It has a 1.352" lug height. The previous 15" x 128" Camoplast Ripsaw track weighed 41 pounds and 49 pounds with 96 studs. The new Cobra weighs 37 pounds and has a deeper lug. This track was chosen because of its claimed weight, quietness, and handling. It saves four pounds of weight and the lugs have angled cutting edges to improve traction and control. The Ripsaw track retails for around $686 whereas the Cobra retails for $633. This is a $53 savings on the MSRP.

The replacement track and rear suspension can be seen in Figure 2.

With the addition of the new suspension and track there has been a decrease in noise emissions.  At last year's competition the snowmobile had a sound reading of 78dBA at 50ft. Sound testing was completed again after the installation of the new track and rear suspension, this time from only 30ft away. As a note of comparison, there was a light snow falling at last year's competition and it was clear when the resultant tests were done.  The right side of the snowmobile measured in at 74dBA and the left at 75dBA. So the new suspension and track are quieter than the previous set up.  This is doing the testing at 20ft. closer, which demonstrates how the advancement of materials makes the snowmobile quieter.

This lighter setup weighs in at 89.14 pounds, saving roughly 22 pounds over the setup used in CSC2008. These weight savings are important for improving efficiency, especially the 4 pound reduction in rotating weight from the shorter track. Although snowmobile efficiency is heavily dependent on trail conditions, the snowmobile did show noticeable improvement in fuel economy. Before the track and suspension changes, the snowmobile was tested at 13.47mpg. Post testing with the same driver at the same relative speed attained a fuel economy of 14.80mpg, almost a 10 percent improvement in fuel economy.

## CLUTCHING

Although the snowmobile was able to attain a respectable 13.47mpg at CSC2008, it is clear that there is room for improvement. Aside from the efficiency improvement due to the track and rear suspension, one of the key areas to improve fuel economy is in the clutching. The stock clutching is well designed for the overall riding experience, but can be better tuned using new technologies now available to the industry.

Modification of the primary clutch was accomplished using adjustable clutch weights. The Heel Clicker adjustable clutch weights from Supertorquer were chosen for this application because they allow for two types of adjustment. The first adjustment is a threaded hole located on the heel of the clutch weight. This 'heel' is what separates the Heel Clicker weights from other weights currently available. The heel adjustment has the effect of adding much needed belt squeezing forces at lower RPM's. This more efficient transfer of power puts less wear on the belt and transfers more power to the ground, effectively improving fuel economy. The second adjustment is located on the tip of the weight. Adding weight to the tip of the weight results in a faster upshift, meaning that the snowmobile will run consistently at a lower RPM at each speed. [3]

One gram of weight was added to the heel of the clutch weight, which had the effect of reducing the clutch engagement from 3800 to 3200 RPM. The lower engagement point is smoother yet does not sacrifice acceleration from a full stop. Figure 3 shows the heel of the clutch weight with the added mass as it is installed in the primary clutch. Two grams of weight were also added to the tip of the weight. This effectively increases the moment of inertia of the weight, as the center of mass is moved further away from the axis around which the weight rotates. The weight will therefore swing outward faster as the clutch is spun, causing a faster shift to a lower drive ratio. So long as the engine has enough torque to drive the lower gear ratio without straining the engine, the engine will be able to operate at a lower RPM than the stock configuration. This effectively increases the fuel efficiency of the snowmobile at trail speeds.

**Figure 3: Adjustable Clutch Weight in Drive Clutch**

The team also experimented with changing the stock driven clutch to a Paragon Secondary Clutch from Hi-Tech Performance (as seen in Figure 4). The main advantage of the secondary is that the sheaves shift parallel to each other instead of twisting outward as they do in any other clutch on the market. This, combined with the encapsulated roller technology, allows for smoother, faster, and more responsive up and downshifting. The parallel shifting also puts less strain on the belt, allowing it to run cooler and last longer. [4]

Although this design is in theory more effective, the team ran into several problems working with the Paragon Secondary. The main problem arose with the fact that the helix in the secondary does not match the desired tuning of the primary clutch weights. Because of this, the shift pattern in the primary does not match the shift pattern in the secondary. This mismatch has been tested and found to have unsatisfactory results. Also, the Paragon secondary clutch weighs considerably more than the stock primary, adding to rotating weight of the drive train. Price also comes into factor, as the Paragon secondary retails for $789.00 as opposed to the stock clutch's MSRP of $475.83. This is a $313.17 difference, or almost a 40% increase in cost. It was decided that the disadvantages outweighed the advantages of this system and the Paragon Secondary Clutch was removed for this year's design. Pending further research and clutching experience, this clutch may be added at a later time.

The end result of the clutching modification, although not finalized, has shown both promising improvements in performance and efficiency. The snowmobile accelerates much harder than it did with the stock clutching, as it can now lift the skis off of the ground on hardpack snow. Also, it should be noted that noise figures remained constant after the clutch work, as they remained at 75dBA on the clutch side. Unfortunately, finalized efficiency numbers are not available at this time, although they will be available in the Oral Report component of CSC2009.

**Figure 4: Paragon Secondary Clutch Installed**

**EXHAUST**

The design for CSC2008 is clearly proven to be effective, as the snowmobile was the cleanest at the competition. Table 1 shows tabulated data regarding the emissions of three competitors from CSC2008, Clarkson, Michigan Tech (who use the same engine), and the cleanest burning two stroke.

| | **CO** | **UHC** | **NOx** | **UHC+ NOx** | **EPA Number** |
|---|---|---|---|---|---|
| Clarkson's FST | 115 | 0 | 3.78 | 4.25 | 178.4 |
| MTU's FST | 145 | 1 | 0.17 | 1.14 | 172.9 |
| Cleanest 2-stroke | 330 | 87 | 0.36 | 87.27 | 69.4 |

**Table 1: CSC2008 Emissions Results** [5]

It is immediately clear that the four-stroke engines ran cleaner than the two-stroke counterparts, as even the cleanest two-stroke failed emissions testing. Although Clarkson and MTU both used the same engine and both used catalytic converters, Clarkson's emissions were lower in both CO and UHC levels, yet higher in $NO_x$. This is very predictable given the location of the catalytic convertor in the Clarkson snowmobile: within the stock exhaust. Locating the catalytic converter in the muffler allows the sustained temperature to be higher than an unenclosed cat because it is constantly surrounded by hot exhaust gas approaching 925$^{o}$C. Catalytic converters are (to an extent) most effective at high temperatures, at which CO and UHC emissions are drastically reduced. The downside to the high temperatures is that $NO_x$ emissions are readily developed, as is exemplified in the high value of the Clarkson snowmobile's $NO_x$ emissions (highest at competition).

Clarkson's FST performed very well at CSC2008, as it was the cleanest-burning snowmobile at competition. For this reason, the same catalytic convertor and design strategy was re-used this year with slight modifications that focus more on noise than emissions. CO and UHC emissions should remain unchanged for CSC2009, while $NO_x$ emissions are expected to be lower as per hydrogen injection. This is to be explained later in the paper.

Although the design used for the CSC2008 was effective, sacrifices were made in order to fit the catalytic converter cleanly inside the muffler. The stock muffler, originally a four-chamber design, was reduced to three chambers to accommodate the catalytic converter. This came at the cost of lowering the noise-reduction potential of the exhaust. The redesigned modification to the stock muffler still allows for the integration of the same catalyst used in CSC2008, but retains the four chambers. The resulting exhaust is just as effective with emissions reduction while increasing the noise reduction potential.

**NOISE CONTROL**

Noise control is one of the hardest challenges to overcome when working with any performance vehicle, whether it is a snowmobile or a performance car. Noise is created from every moving mechanical piece on the snowmobile, with the engine, clutches and track making the majority of the noise on the snowmobile. From last year's competition, the team knew that it was right on the cusp of acceptable noise levels (at 78dBA). This year, the team took efforts to reduce noise emissions using a unique solution through the application of a product called Lizard Skin Sound Control. This is a unique product for sound controlling purposes because instead of it being a stick-on mat product, it is actually a spray-on combination of acrylic binders and sound dampening particles. One of the many benefits to this product are that the Sound Control is smaller by volume, only needing a two millimeter thick coating to attain the maximum sound dampening performance of the product. Lizard Skin Sound Control is also a class A fire rated non combustible product and has been tested to withstand temperatures of over 300 degrees Fahrenheit without burning [6], while the mat sound dampening products are known to combust at much lower temperatures. The application of the Sound Control is also much different than the traditional mat products, instead of there being excessive scraps after the application, the environmentally friendly and non-toxic Sound Control is sprayed directly to the surface, eliminating wasted material from the installation.

Sound Control was applied to the interior of the hood, cowl, side panels, clutch cover, and inside of the tunnel. The Lizard Skin product fit inside the tunnel where a mat-type product would not fit because of clearance issues with the track. Since the Sound Control adheres to the actual surface where there is a noise issue, the product outperforms competing mat products because not only does it dampen noise, but it nearly eliminates vibrations that cause noise as well.

As already noted, modifications to last year's exhaust were made to compliment the sound reductions from the Lizard Skin. Noise reductions were also achieved with the AD Boivin rear suspension and Camoplast Cobra track. Combining these three noise reduction efforts, the team was able to significantly reduce noise levels emitted by the snowmobile. Testing has revealed that if the snowmobile passes at full throttle within ten feet of a group of people, it will hardly have any noticeable interruption or disturbance on a conversation. This noise level is unheard of with any stock snowmobile currently on the market.

**HYDROGEN INJECTION**

The injection of a hydrogen-gasoline mixture into an internal combustion engine has been around for quite some time. In 1977 NASA did a group on experiments with a 7.4 L internal combustion engine to document the effects of injecting a hydrogen-gasoline mixture instead of straight gasoline. In their testing it was found that a hydrogen-gasoline mixture was able to greatly reduce $NO_x$ emissions of the engine while also increasing the fuel efficiency [7]. In an internal combustion engine less than 25% of the potential energy in the gasoline is converted into mechanical energy [8]. Most of the energy is lost as heat and harmful emissions. By adding hydrogen to the fuel mixture efficiency, fuel economy and emissions can be improved upon.

The easiest way to do this is to carry an on-board hydrogen tank and slowly adding the hydrogen to the air intake. However, hydrogen tanks are very explosive and dangerous and hydrogen is a gas not easily found. So the easiest safe solution is to create hydrogen on demand. This is completed by a process known as electrolysis in which pure water is fractured into the two gaseous elements it is composed of, Hydrogen and Oxygen. The gas, containing two Hydrogen atoms for every one Oxygen atom, is commonly referred to as Hydroxy gas [8]. As it turns out, this mixture is optimum for burning hydrogen in the engine. When the gas is formed, it is bubbled up through a bubbler containing water. The bubbler protects the booster in the event of the engine backfiring and causing the gas in the tubes to explode. The hydroxy gas then travels through a hose and is injected into the air intake where it dissipates, is sucked into the engine, and ignited in the cylinders.

Hydrogen, which combusts hotter and more rapidly than gasoline, causes faster flame propagation when the cylinder is firing [7]. With faster flame propagation and a hotter combustion temperature, a more complete combustion of the injected gasoline will occur. This in turn will lead to an increase in horsepower and fuel efficiency as less fuel is needed because more of the gasoline is burned. Since more of the fuel is used less of it needs to be burned off in the catalytic convertor, which leads to a reduction in emissions.

The Hydroxy boosters that can be installed on internal combustion engines generally operate by DC electrolysis or “Brute Force” electrolysis [8]. This type of electrolysis follows Faraday’s laws of electrolysis. A hydroxy booster installed on a car will force a total of 13.8 V (normal alternator operating voltage) through a series of cells. In between the electrically conducting cell walls, the current will pass through a set solution of distilled water and a specific base, usually sodium hydroxide (NaOH) or potassium hydroxide (KOH). Gas production amount is usually limited by the current passing through the cells. For the tero-cell design, an average of 3 liters per minute of hydroxy gas can be produced at 20 amps [8]. Amperage is most commonly limited by the concentration of the base, or electrolyte, through trial and error running.

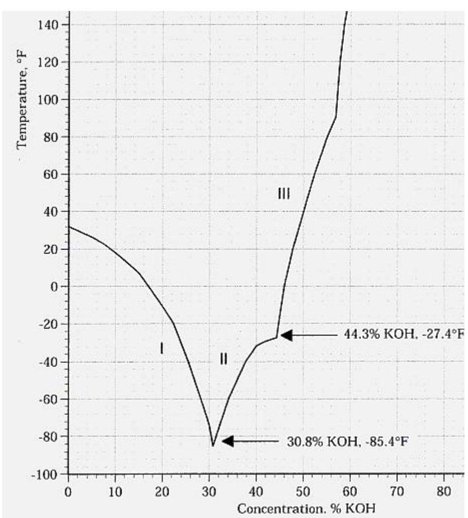


**Figure 5 – Freezing Temperature vs. KOH Concentration** [9]

There are many booster designs that have been tested and used, but the best design to save space and to completely isolate the cells with no current leakage is the tero-cell design. It was originally designed by Bob Boyce and has since been perfected by a hydrogen booster enthusiast by the name of “Smack” [8]. On a sled, space is always an issue so a smaller design is necessary. When in use, the sled experiences a large amount of turbulence and bouncing, and therefore a closed cell design is optimum at keeping the electrolyte in its place. Also, the design chosen offers an automatic refilling system, which will be optimum at competition where no fluids are allowed to be added throughout the duration.

In order to implement a hydroxy booster onto the Polaris snowmobile, there were a few obstacles to overcome. The first obstacle was how to keep the solution and bubbler liquid from freezing at temperatures down to -32$^{o}$ F. If the electrolyte composition is more than 25% KOH by weight, the solution shouldn’t freeze above -32$^{o}$F (Fig 5). Also the same concentration of electrolyte will be used in the bubbler. This will help so the bubbler does not freeze and it will also serve as a refill reservoir for an automatic refilling system. The mixture in the bubbler will flow into the booster as electrolysis uses the water. However since such a high concentration of KOH will be used, the current will have to be limited some other way. A pulse width modulator will be engineered to limit the current draw to between 15 and 20 amps on the snowmobile so the booster does not pull too many amps. The booster will also be wired to a 30 amp automatically-resetting fuse so that the 10 gage wires used to wire the booster do not exceed their maximum amperage. In order to make sure the booster does not run while the sled is not on, the power is wired to the fuel pump relay on the sled.

This hydrogen injection system is promising in its theoretical benefits. Used often by automobile tuners looking to improve efficiency, this system has proven itself as a simple yet effective strategy for gaining fuel mileage and reducing emissions. Unfortunately, this system will not be accepted at CSC2009 as hydrogen can be considered a fuel or fuel additive by the judging panel. It was removed before final results could be gathered.

**HANDLING**

As noted earlier, the rear suspension has greatly improved the handling characteristics. With the stock M-10 rear suspension, the front end of the snowmobile washed out easily and the weight was readily apparent while handling in tight corners. The reduction of weight as well as the shorter-tracked rear suspension has completely changed the dynamics of the snowmobile. The snowmobile now feels much more nimble, as the contact patch of the track has decreased and now allows it to pivot. The composite nature of the suspension also allows it to flex, keeping in better contact with the ground in corners. Although the M-10 is considered at the top of the industry for riding comfort, the *ZX*$^2$ suspension rides more smoothly because of the position sensitive damping in the G-Force Shocks.

The mounting of the *ZX*$^2$ causes the back of the snowmobile to sit up higher, transferring more weight to the front skis. This also effectively steepens the caster angle of the front skis, making them more responsive to rider input. The combined result is a sharpened steering response. The skis dig into the snow better, and turn much sharper where they would have washed out with the stock setup. As one test rider exclaimed, “It’s like driving a Cadillac!” The soft ride and confident steering added by the rear suspension will rate highly with any touring rider.

It was noted that the stock front shocks were suffering from the added weight transfer to the front. They were bottoming out easily even when adjusted as stiff as possible. In an effort to remedy this, the stock shocks were replaced with Walker Evans Clicker shocks. These shocks provided plenty of adjustment to properly accommodate for the difference in weight distribution. It is important to note that these shocks would *not* be the best choice for a touring rider. They are expensive and the reservoir design is overkill for a smooth-trail application. Unfortunately, these shocks were chosen because they were the only ones available to the team at the time.

The stock 4” dual carbides on the snowmobile’s skis were replaced and tested with dual 6” carbides from Woody’s. It was noted that, in the absence of studs, the 6” carbides provided too much grip compared to how much the track was sliding around. The snowmobile simply did not feel balanced in its steering response. The 6” dual carbides provided too much response, and even caused one rider to roll the snowmobile. They were taken off in favor of the stock 4” dual carbides.

Experimentation was also done with studding the track, as it was noted that the Camoplast Cobra track does not grip well in icy conditions. In an effort to save weight, the track was studded with only 48 Woody’s ‘Gold Digger’ studs, with two studs every other lug. Grip increased as expected, especially in icy conditions. Testing, however, revealed various increases in noise level and decreases in efficiency. Also, studs add approximately $100 to MSRP and 3.35lbs to the rotating weight of the track. Considering the negative effects on important qualifications, the benefit in grip is outweighed by their detrimental aspects. The studs have therefore been removed.

Although not on the snowmobile as per present conditions, the studs and dual 6” carbides are available for installation if conditions prove especially icy. If at competition it is determined that studs are absolutely necessary, they will be added before technical inspection as well as the longer carbides.

**SAFETY**

Numerous safety modifications were made in an effort to protect the rider from any malfunctions or accidents. A sealed battery box was fabricated to replace the stock battery box. The battery box was constructed of Kevlar and is completely sealed aside from a vent hole in the bottom as per competition specifications.

A clutch cover was also fabricated out of sheet steel and covered with a layer of Kevlar belting to protect the snowmobile and rider in the case of a belt or clutch problem. A tether was added to the snowmobile as per the safety requirements of the competition. This will automatically cut off the engine in the case that the rider was thrown from the snowmobile in an accident. To prevent objects from being hazardously kicked up from the rear of the track, the rubber snow flap was extended so that it contacts the ground at all times.

**CONCLUSION**

All changes to the snowmobile were made as simple as possible. In essence, this snowmobile was designed well to begin with. Severe modifications risk accidentally breaking important design intentions of the stock snowmobile. Each modification made must anticipate the tenets of the original design that are to be changed, and how these changes will affect other systems on the snowmobile. Many teams in the past have attempted to severely change their snowmobiles via new engine management units, not understanding the benefits of the stock engineering. These teams have historically run into many problems with engine tune, ranging from horrible emissions, to failed cold starting, to loss in efficiency because they failed to take into account every purpose the stock engineering served.

Each successive addition to the snowmobile was tested on two bases, noise emissions and efficiency. Effort was taken that the snowmobile be ridden at least 50 miles with each successive addition for two reasons. First, it was hoped that problems with modifications would arise within each 50 miles. Second, it served as a benchmark to empirically test the fuel efficiency of each modification made. Unfortunately, lack of snow in the middle of the season curtailed this testing procedure.

In essence, this design proves that the high performance clean snowmobile is a reality. Snowmobiles such as this one will be clean and quiet enough to enter the National Parks, while still maintaining sufficient power thanks to the four-stroke turbocharged engine running on flex fuel.

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