University of Minnesota Duluth

2010 UMD Clean Snowmobile Challenge Design Paper

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ABSTRACT

University of Minnesota Duluth Clean Snowmobile Challenge team has modified a 2008 Polaris IQ 700 that has a two stroke two cylinder 700cc clean fire engine, shown in ***Figure 1*** [1], to be clean, efficient and quiet enough to be acceptable in environmentally sensitive areas. This snowmobile will be competing in the 2010 Society of Automotive Engineers' Clean Snowmobile Challenge with other international teams. The event is organized by SAE and Michigan Technological University. At the competition there are two classes of snowmobiles: Internal Combustion (IC) and Zero Emission (ZE), we chose to compete in the former, because it best fit our know-how as well as our budget.

Figure 1: *2008 Polaris IQ 700.*

The competition objective for the IC class was to modify the vehicle so that it is flex-fuel capable. The fuel at which the vehicle will be operated on at the competition will have a corn-based ethanol content anywhere from E20 to E29. For the engine to run efficiently and effectively on the specified fuel, the fuel pump was changed and the fuel system was modified. In order to reduce noise pollution and improve emissions the exhaust system was rerouted and an oxidation catalyst was installed. By implementing the previous changes the team's goal is to introduce a environmentally friendly snowmobile to the consumer with an attractive MSRP for the current economic condition.

INTRODUCTION

In 1935 transportation challenges during the winter season led to the invention of Snowmobiles. Unlike today the snowmobiles were very large and used to carry multiple numbers of people. The first snowmobile carried 12 people and was popular amongst taxi drivers, hospitals and loggers. It was not until fifteen years later that two passenger light chassis snowmobiles were marketed as a recreational vehicle, this brought about a new winter sport and incentive for companies to develop snowmobiles further [2].

In 2009 approximately 147,066 snowmobiles were sold worldwide. Approximately 42 percent of which were sold in the US. The approximated number of registered vehicles in the US is 1.65 million. The United States average retail price of a new snowmobile sold in 2009 was $8,800. The snowmobile industry produces a revenue of about $22 billion annually. It is estimated that the snowmobile industry provides about 95,000 full time jobs. [3-4]

The 2010 UMD Bulldogs have produced an environmentally friendly snowmobile that will compete with the leading manufacturers in the snowmobiling industry. Major modifications that have been implemented on the 2008 Polaris IQ 700 with the goal of improving the snowmobiling experience. The modifications and research that have gone into the snowmobile are described in the following topics and in this order throughout the technical paper, Ethanol research, fuel mileage/horsepower, fuel tuning, emissions, noise reduction, suspension, safety modifications, and a MSRP formulation.

ETHANOL

Today, in a more environmentally conscious world, many are looking for an alternative that can not only reduce the price at the pump, but can also reduce greenhouse gas emissions. E85 is an alcohol based alternative fuel that many vehicle manufacturers are turning to. Composed of 85% ethanol and 15% gasoline, some consider E85 to be a viable solution. The ethanol used in E85 is produced by fermenting and distilling starch crops, such as corn and switch grass. Corn is the most widely used crop at this time but the use of switch grass is becoming increasingly common.

Although E85 sounds like the next best thing for America, its use is controversial. With the large amounts of corn required for production, the price of corn is reaching all time highs, raising feed prices for live stock, in turn affecting your grocery bill.

The efficiency of E85 is also creating controversy. A vehicle that runs on E85 gets on average 25% less energy per volume compared to regular gasoline, but costs 20% to 30 % less [5]. Currently the cost of E85 per gallon is $2.292, this is considerably less than regular 87 octane fuel. However when the estimated mileage per energy is calculated (MPG/BTU adjusted price) the price per gallon rises to $3.016; higher than regular 87 octane at $2.642 per gallon [6].

The biggest reason for many people to purchase an E85 vehicle is the reduced emission levels. Ethanol is highly biodegradable, making it safer for the environment. E85 contains 35% oxygen making it cleaner burning, with lower CO_2 levels; 25% less than conventional gasoline. E85 reduces carbon emissions by seven million tons each year, equal to removing more than one million cars from the road [5].

With the controversy involved in E85 a new fuel alternative is arising, a fuel composed of a lower percentage of ethanol, such as 20% to 30% is becoming more attractive. E20 to E29 is the fuel range required to run in our 2010 SAE Clean Snowmobile, this is also a range that is growing in popularity with many other motorists who are testing the use of the fuel for higher fuel mileage. This blend of ethanol and regular fuel is proving to be a very effective fuel to use; a study co-sponsored by the U.S. Department of Energy and the American Coalition for

Ethanol (ACE) found that mid range ethanol blends improves mileage and reduces emissions [7].

“Initial findings indicate that we as a nation have not begun to recognize the value of ethanol," said Brian Jennings, executive vice president of the American Coalition for Ethanol. “This is a compelling argument for more research on the promise of higher ethanol blends in gasoline. There is strong evidence that the optimal ethanol-gasoline blend for standard, non-flex-fuel vehicles is greater than E10 and instead may be E20 or E30. We encourage the federal government to move swiftly to research the use of higher ethanol blends and make necessary approvals so that American motorists can have the cost-effective ethanol choices they deserve at the pump.” [8]

The University of North Dakota Energy & Environmental Research Center (EERC) and the Minnesota Center for Automotive Research (MnCAR) conducted research using four 2007 model vehicles: a Toyota Camry, a Ford Fusion and two Chevrolet Impalas, one flex-fuel and one non-flex-fuel. They found that three of the four actually improved mileage when running on this mid range ethanol blend compared to regular gasoline. Improvements ranged from 1% with E30 to 15% with E20. Along with the fuel economy results, their research showed that non-flex-fuel vehicles can also operate on ethanol blends beyond 10 percent without any modifications. The non-flex-fuel vehicles operated on levels as high as E65 before any engine fault codes were displayed. Emissions results for the ethanol blends were also favorable for nitrogen oxides, carbon monoxide and non-methane organic gases, showing a significant reduction in CO_2 emissions for each vehicle's "optimal" ethanol blend [8].

These results can be applied to different internal combustion motors to improve fuel economy and reduce tailpipe emissions. Specifically in snowmobiles this technology can be applied to reduce our effects in pristine areas such as our national parks and forests.

The bulldog’s clean snowmobile will be capable of running fuel from E20 to E29. In testing these fuels in the snowmobile we had to make our own fuel blends by combining 91 octane pump gas and E85. The chart for fuel blending a range of ethanol based fuel is included in ***Table 1***.

91 Octane	
5 Gallons of E20	
	Gallons
% 91 Octane	4.3333
% E85	0.6667
Resultant Octane	93.53346

5 Gallons of E24.5	
	Gallons
% 91 Octane	4.03325
% E85	0.96675
Resultant Octane	94.67365

5 Gallons of E29	
	Gallons
% 91 Octane	3.7333
% E85	1.2667
Resultant Octane	95.81346

Table 1: *Ethanol Blending Chart.*

Because E20 to E29 fuel does not perform much different from regular pump gas no major modifications are required to run in the UMD snowmobile. The fuel result has a higher octane which is outside of the recommended design of the stock ECU yet still within the capabilities of operating in the snowmobile. A cooler spark plug is the only modification made for the hotter burning E20 to E29 blend. Shorter and cooler temperature rated spark plugs were used for testing to lower the burn temperature and reduce compression in the engine. The electronic fuel control has been tested and has ability to compensate for the change in fuel to a certain extent, the only difference is a hotter combustion that is less than 100°F. The snowmobile is currently under testing and if additional fuel is necessary for extended high rpm operation, a modified fuel map is desired and the team will be adapting a BoonDocker fuel controller to the snowmobile to provide this.

FUEL MILEAGE/HORSEPOWER

To obtain greater fuel efficiency the team has selected a 700cc, semi-direct, electronically fuel injected engine. The 700cc engine will produce the same amount of horsepower at lower RPM's, as for example a 440cc engine would at higher RPM's. The difference in RPM's versus other smaller snowmobiles is the focus for the higher fuel mileage for the team's snowmobile to provide against the competition. A 700c snowmobile is designed to perform up to speeds of approx. 100mph where a trail rider will operate a snowmobile at an average of 55mph. By operating the larger engine at a lower level of performance the fuel consumption will be minimal as compared to an engine that is operating at peak performance and RPM's to produce the same amount of work. One of the regulations for the competition is to not exceed 130 horsepower. The team's stock horsepower for the 700 is 140hp, the team is expecting a loss of ten or more horsepower from the increased backpressure due to the oxidation catalytic converter, the rerouting of the exhaust, and the use of a lower energy content ethanol fuel.

FUEL/TUNING

In order to adapt for the given E20-E29 fuel range, the team implemented a way of comparing vital operating temperatures from running traditional fuel versus the higher ethanol based fuel. To test for the operating temperatures of the two fuels the snowmobile was ran twice indoors and multiple times outdoors to test the snowmobile on the new fuel under load. A UMD welding shop was utilized for the indoor testing to obtain consistent ambient temperature. this can be seen in ***Figure 2***.

Figure 2: *Indoor snowmobile testing.*

The operating temperatures were gathered in two forms, exhaust gas temperatures for each of the two cylinders and the water temperature. To test the worst case scenario and see if our snowmobile's ECU would adapt to the ethanol based fuel, the team ran the snowmobile on 91 octane to get baseline operating temperatures and then compared these to operating temperatures when running E29.

The exhaust gas temperatures were recorded by a Digatron Data Acquisition System, found in ***Figure 3*** that was installed on the snowmobile with probes mounted approx. four inches from the piston on each cylinder. The probes for the Digatron are fast responding Exhaust Gas Technology probes, ***Figure 4***, that give live data on the temperature of the flame exiting the cylinder upon ignition [9]. Exhaust gas temperatures versus rpm for the two cylinders when the snowmobile was ran on 91 octane and E29 indoors are shown in ***Table 2*** and ***Table 3***.

Figure 3*: Digatron EGT.*

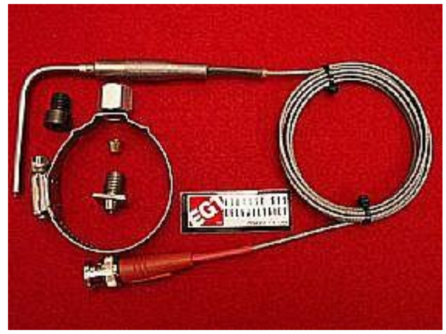


Figure 4: *EGT Temperature Probe*

The water temperature of the snowmobile was recorded through the use of the stock cylinder head water temperature sensor and vehicle display. When operating the snowmobile the ambient temperature was 70°F and there was no external source of cooling for the stock cooling system on the snowmobile. Since there was no additional cooling, the snowmobile was operated for a short duration of time testing the two fuels at 1,000 degree rpm increments starting at idle and going up to 5,000rpm.

91 Octane Operating Temperatures (°F)				
	RPM	**Magneto Side Cylinder**	**PTO Side Cylinder**	**Water**
Idle	1500	350	295	93
	3000	430	450	109
	3500	467	488	110
	4000	555	587	115
	4500	715	689	122
	5000	910	890	125

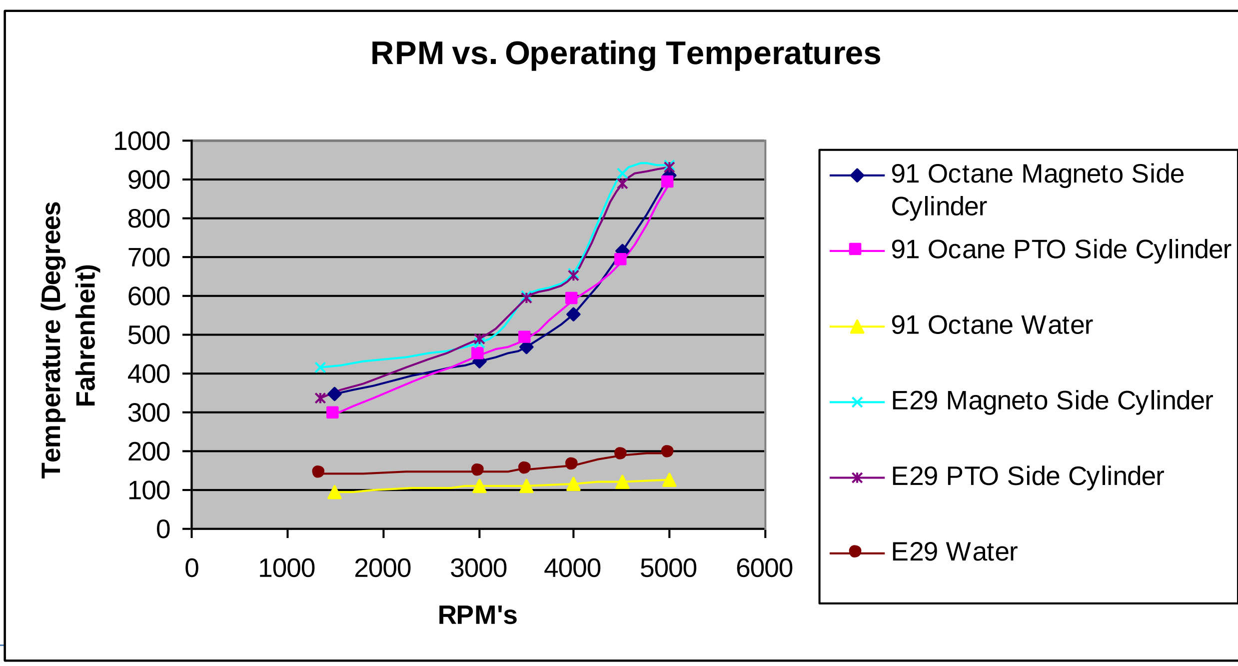
Table 2: *91 Octane Operating Temperatures.*

E29 Operating Temperatures (°F)				
	RPM	Magneto Side Cylinder	PTO Side Cylinder	Water
Idle	1350	418	335	144
	3000	480	489	146
	3500	600	595	151
	4000	660	655	162
	4500	915	889	190
	5000	935	930	194

Table 3: *E29 Operating Temperatures.*

The exhaust gas temperatures obtained when running the E29 throughout the range of rpm's for each cylinder when compared to the temperatures while running 91 octane were slightly higher. The higher temperatures were obtained primarily because of the higher octane level of the E29 and also due to the higher than required stoichiometric level of air to fuel than what was necessary for the lower energy content of E29 when compared to 91 octane fuel. Larger jumps in the exhaust temperatures when running E29 can be seen in ***Graph 1*** and are primarily due to longer wait times between reaching rpm and recording the data at each rpm versus the 91 octane testing. The water temperatures throughout the range of rpm's for E29 are shown in ***Table 2*** and ***Table 3*** and in ***Graph 1*** to be significantly higher. The large increase in water temperature when running E29 is due to running the E29 after the 91 octane and not leaving sufficient time for cooling down between runs. Starting at a higher water temperature when running the E29 and not having any additional external cooling while testing indoors contributed to the higher water temperatures that approached max operating temperature of the snowmobile.

Overall the exhaust gas temperatures and water temperatures when running the E29 versus the 91 octane fuel, were not significantly higher, yet high enough to require modifications to the snowmobile for



Graph 1: *RPM vs. Operating Temperature Comparison.*

operating on the new fuel.

EMISSIONS

Catalytic Converter

The team found that the most effective way to reduce the exhaust emissions from our two stroke internal combustion snowmobile would be to adapt a catalyst into the exhaust system. The intent of the catalyst incorporated into the exhaust was to reduce emissions as well as lower the exhaust noise of the snowmobile.

A two stroke engine is considered to be a lean operating internal combustion engine and runs at much higher combustion temperatures than that of a four stroke. A two stroke is more similar to a diesel engine in terms of combustion temperature and the heat created in the exhaust during operation than the temperatures achieved in a four stroke. Because of the high temperatures produced in the team's snowmobile exhaust system, a catalyst that would be found on a four stroke vehicle would not be robust enough and would simply burn out. A diesel catalyst therefore chosen based on the previously stated facts. A diesel catalytic converter is utilizes oxidation catalyst. Oxidation catalyst performs under much higher temperatures than that of a four stroke catalyst proving this catalyst ideal for our lean combustion engine.

The oxidation catalytic converter that was chosen for our snowmobile is manufactured by Magnaflow and is a universal-fit diesel oxidation catalytic converter, Magnaflow part # 54105D [11]. A manufacturer image of the converter is shown in ***Figure 5***. This particular converter was chosen because of its size and because of the high quality of Magnaflow products proven through their ISO-9001 certificate was received in May of 2000 [11].

Figure 5: *Magnaflow Oxidation Catalyst*

The principle of a diesel oxidation catalyst is to reduce the amount of hydrocarbons produced by an engine and released through the exhaust [10]. The basic function of the catalyst converts the hydrocarbons, carbon monoxide, and soluble organic fraction of particulate matter that it receives, to a lower polluting emission of carbon dioxide and water vapor [10]. When incorporating the catalyst into the exhaust a higher temperature in the exhaust at this point is created due to the increase in back pressure, this higher temperature allows the catalyst to operate more efficiently.

Incorporating a catalytic converter into the snowmobile's exhaust is expected to increase the backpressure in the system a considerable enough amount to lower the noise levels of the exhaust on the snowmobile. Another function of the catalyst in our snowmobile's exhaust system is to divide the flow of the exhaust into multiple parts and then reintroduce the exhaust back together in the pipe which in turn is expected to lower the noise level of the exhaust.

NOISE REDUCTION

Rerouting Exhaust

The primary modification to reduce the noise levels of our snowmobile is to reroute the exit location of the exhaust on the snowmobile from directly straight down out of the belly pan, to down and turned to direct the exhaust towards the snow in front of the track. The purpose of this modification is to reduce the noise levels of the exhaust by having the exhaust broken up by the rotation of the track during operation of the snowmobile.

Figure 6: *Stock Exhaust Location*

In ***Figure 6*** the stock location of the exhaust is shown with a stock snow deflector that is mounted in front of the exhaust outlet. Based on the vertical clearance from the stock exit location of the exhaust to the ground, there is enough room to route the exhaust over back at a 90° to where it will still turn down into the snow. The team is looking to gain up to a 50% reduction in noise levels through the rerouting of the exhaust.

Rubber Skirting

One of the loudest aspects of a snowmobile other than the engine is the moving components of the rear suspension and track. Even an electric snowmobile with no engine noise still shows a significant amount of noise which comes from that specific area. Team Bulldogs addressed this problem by draping a rubber skirt from along the running boards to ensure a safer and quieter ride caused by heavy and quickly moving components in the driven part of the snowmobile. The location of the draped tunnel skirt is shown in ***Figure 10*** below.

Figure 10: *Rear suspension skirting.*

SUSPENSION

Seat Suspension

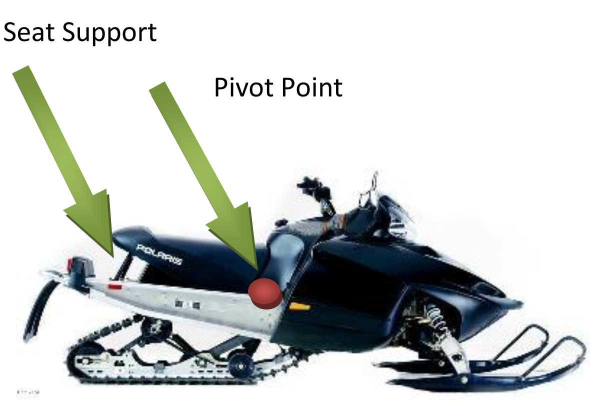
Today, the seat of a snowmobile is one of the more crucial aspects of the riding comfort ability and handling. It determines the positioning and the operator's range of motion. In the earlier years of snowmobiling, between the 60's and 70's, there were many aspects of the early seat designs that have evolved into the general idea of what a snowmobile seat is today. One major difference in seats from the past to seats today is the lack of ergonomics used when designing them. The earlier seats consisted of a wooden piece of plywood or particle board for a base, with foam for the cushion, and a leather or plastic layer for protection shown in ***Figure 7*** [12].

Figure 7: *Seat example.*

In vintage snowmobiles, it is clear that neither rider positioning, nor the ease of weight transfer, were considered in seat designs as well. Although many different ideas have been taken into account to enhance the snowmobiling experience, there were only a few ideas that took off and became part of the snowmobiling industry. As the snowmobile designs began taking on a more generic look following into the 1980's, so did the seats. Manufacturers began taking small steps in helping the comfort of the ride by evolving seats that would conform to the operator. Each brand of snowmobile began taking a more similar look not only in the general design, but also in the seat design. The thing that was missing in these years of snowmobile seat design was the rider positioning. Manufacturers failed to achieve correct rider positioning because earlier snowmobile designs that placed the rider farther back on the snowmobile, which caused a few small problems in the handling of the snowmobiles. One problem with sitting in more of a relaxed position is that the weight distribution of the snowmobiles was focused to the rear. In having the weight to the rear, there is less ski pressure causing handling to be less responsive, especially in times of abrupt acceleration. As the snowmobile evolved, the seats became similar to the seat of a dirt bike. This change achieved greater maneuverability, and increased the ease in which the rider is able to shift their weight. With a narrower, yet still comfortable seat, the rider is introduced to yet another new riding aspect while maintain the new rider forward position shown in ***Figure 8*** [13].

Figure 8: *Rider forward example.*

By locating the operator in more of a forward leaning position, the weight distribution is split more evenly. This helps the rider take on turbulence with a pivoting motion, rather than a "bucking" motion. Due to a more forward center of mass, the rider forward positioning also increases ski pressure, as previously stated, causing the carbides to have a better "bite" on the surface below it. It is truly amazing the progress seats have made over the years, today's seats make early seats look primitive in comparison. The part of this new design that we came to perfect is the abrupt jarring of the riders back on larger scale bumps that are nearly unavoidable cases of trail riding today. Even with today's technical suspensions that are tuned for even the worst terrain, there will always be that chance of an unforgettable pain of fully compressing a suspension from a bump. The team took on a seat modification that would retain all modern day aspects of a seat, yet would allow the ability of a small amount of vertical travel without significantly altering the rider's center of gravity. The team decided to give the existing seat a pivot point shown in ***Figure 9*** [14].



<u>Figure 9:</u> *<u>Seat pivot.</u>*

Having the pivot point towards the front of our snowmobile seat allowed a pair of small 750 lb max mountain bike shocks to be located in place of the small seat support bar that is located in the back of the stock 2008 IQ seat, shown in ***Figure 9*** [15]. The idea of the new seat is to be a "backup" suspension when the primary suspension is under its maximum capabilities. In the scene of when the suspension has either been completely compressed or under an excessive amount of force due to the rider, this newly modified seat will give a small amount of additional travel to the operator. This will benefit the rider with a small, yet satisfying cushion that will produce a significant relief in times of rough riding.

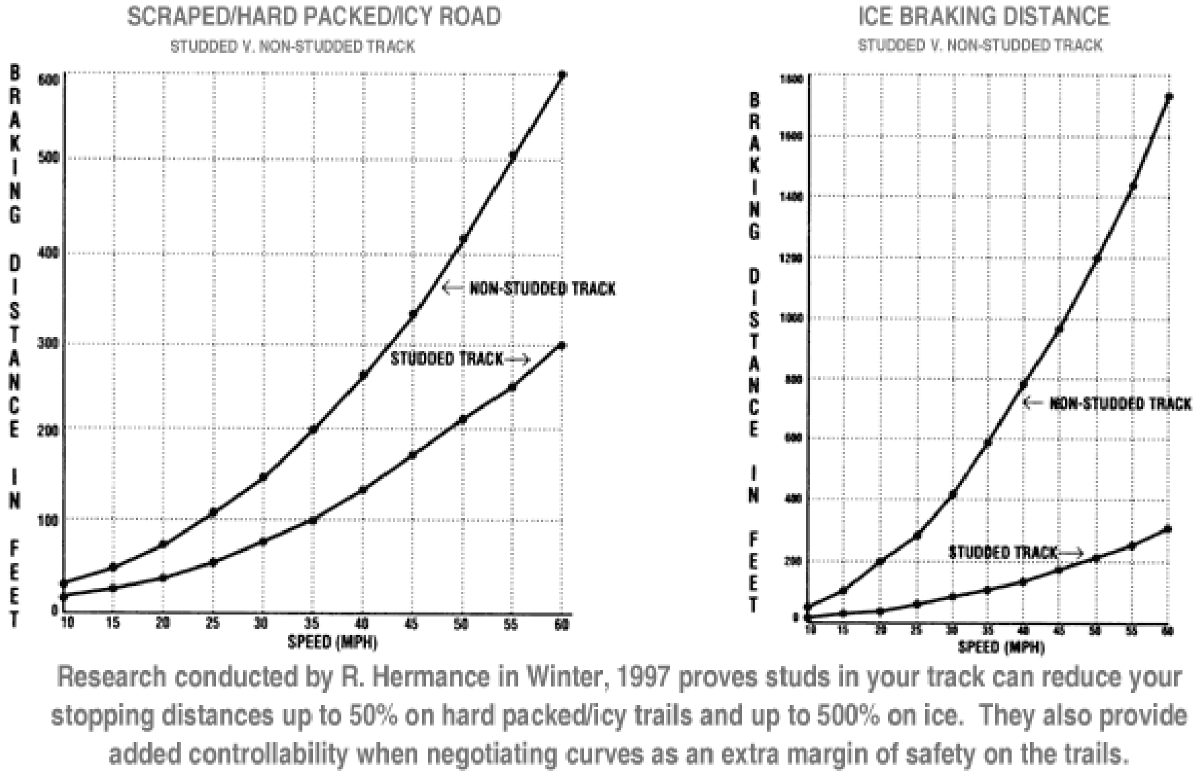
Suspension Tuning

The suspension of the snowmobile has been set up to meet the demands of the avid snowmobiler who plans the majority of their riding to be on the trail. The modifications to the stock suspension set up includes lengthening the front limiter strap to increase the ski pressure and setting the rear suspension main springs to a medium stiffness to create a softer less aggressive feel while keeping the skis pressure still light enough to make steering as effortless as possible. The front shocks of the snowmobile have been set slightly stiffer than the stock setting to provide sufficient ski pressure for improved handling.

SAFTEY MODIFICATIONS

Traction Control:

Studs and carbides are a simple and effective way to increase performance and



Graph 2: *Woody's traction control study.*

handling. Carbides and ski runners provide confidence to the rider to make better turns and maintain control over their machine. Studs in the track provide control in the corners and on ice to allow the rider to ride with confidence. They also greatly increase the stopping capabilities on hard packed snow and icy surfaces shown in ***Graph 2***. The increase in stopping power is so significant in fact that stopping distances are reduced by 50% on hard packed snow and up to 500% on ice, this provides for a safer and more confident snowmobiling experience [16]. Along with the safety factor provided by traction control, it also allows for more power from the track to be transferred to the ground by reducing track slippage. For these reasons we have added studs and carbides to our snowmobile.

Rear Snow Flap

The stock snow flap is designed to keep snow and debris from hitting fellow riders that may be riding behind you. It also helps keep the sled cool when riding on hard pack or poor snow conditions by maintaining snow and snow dust in the tunnel. By keeping more snow and snow dust within the tunnel, it will cool the heat exchangers and keep the sled running cool and efficient. Overall, with the new longer snow flap, our snowmobile will run cooler and provide the needed protection from traction devices or other projectiles thrown from the track. Shown in ***Figure 11***, the snow flap was riveted to the stock mounting bracket to securely fasten it at the center of the snowmobile.

Figure 11: *Snow flap.*

Clutch Cover

We equipped our sled with a standard drag racing clutch cover that will protect the rider and bystanders from any possible explosion in the drive train. The clutch cover is built out of T6 aluminum and lined with Kevlar belting to help contain shrapnel and projectiles should a failure occur. As shown in ***Figure 12*** [17] below, a failure could lead to a substantial injury or damage to the snowmobile.

Figure 12: *Destroyed driven clutch*

Kill Switch/Disconnect Tether

In 1972, the US Snowmobile Association proposed several new rules to protect the fans of snowmobile races after the death of a 6 year old at the world championship snowmobile derby in Eagle River. Along with better fencing at races, racers were required to wear an ignition cutoff tether to prevent fatal accidents in the event that the snowmobiles throttle would stick wide open. The 2008 Polaris IQ 700 does not come with a stock disconnect tether but we wired in our own SLP tether for safety and to meet the Clean Snowmobile Challenge rules [18].

MANUFACTURING SUGGESTED RETAIL PRICE

The team's new MSRP for our snowmobile was created by incorporating the cost of the parts to modify the snowmobile as well as a cushion to implement them on a large scale manufacturing setting. The bulldogs feel that holding the price under the $10K mark capitalizes on the consumer market. Being avid snowmobilers and being familiar with the cost of owning and operating a snowmobile really gave the team an edge on an attractive cost for our snowmobile. An industry that is full of snowmobiles with a baseline sticker price of $15K is going to create a dying sport and is something we would like to avoid. The bulldog's snowmobile sticker price is set to preserve and expand the sport of snowmobiling.

2008 Polaris IQ 700 Bulldog Edition MSRP

	2008 Polaris IQ 700	2008 Polaris IQ 700 Bulldog Edition	Modification Prices ($)
MSRP	$9,099.00	$9,889.00	
Features	Liberty 700 Cleanfire Engine	Liberty 700 Cleanfire Engine	
	Perc Reverse	Perc Reverse	
	15 x 121 x 1 HackSaw Track	15 x 121 x 1 HackSaw Track	
	P-85 Drive Clutch with LWT Team Driven Clutch	P-85 Drive Clutch with LWT Team Driven Clutch	
		Catalytic Converter	90.00
		96 Studs	169.99
		Tunnel Skirts	50.00
		Seat Modification	50.00
		Exhaust Rerouting	50.00
		Accel Fuel Pump	139.99

Table 4: *MSRP information from Polaris Industries [18].*

CONCLUSION

The 2010 UMD Bulldogs Clean Snowmobile Club redesigned a 2008 Polaris IQ 700 to be a more efficient and pleasant riding trail snowmobile. To achieve a more efficient and higher fuel mileage snowmobile, as well as comply with the competition regulations, the fuel of choice is an ethanol based fuel in the range of E20 to E29. The stock fuel pump on the snowmobile was changed to an E85 compatible fuel pump to withstand the higher ethanol content of the fuel and was mounted outside of the gas tank versus inside due to competition regulation. The emissions of the snowmobile have been decreased by implementing an oxidation catalyst into the exhaust system. The oxidation catalyst reduces the amount of unburned hydrocarbons and the amount of carbon monoxide leaving the snowmobile. The noise levels of the snowmobile have been decreased by means of re-routing the exhaust over and down to the snow in front of the track to allow the snowmobile to beat down the sound of the exhaust as it is operating. Track skirting implemented to cover the rear suspension is also working to decrease the track and suspension noise produced when driving the snowmobile. The overall rear suspension travel has been increased by two inches due to a seat suspension system that utilizes mountain bike shocks mounted in the rear of the seat. By increasing the amount of rear suspension travel, the chance of bottoming out the suspension and injuring the rider, is effectively reduced. Overall the Bulldogs have designed a more environmentally friendly snowmobile that has improved ride ability and lower noise levels. This snowmobile has potential to be adapted by national parks for touring purposes while not being an annoyance to the natural habitat of the land. For the avid snowmobiler with the environment on their mind, this is the ideal snowmobile of choice. By creating the more efficient snowmobile the Bulldogs are hoping to preserve the sport of snowmobiling for many generations to come.

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