Re-Engineering a 1996 Ski Doo Formula SLS for The Clean Snowmobile Challenge 2008

Northern Illinois University

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Abstract

A 1996 Ski Doo Formula SLS was chosen to be re-engineered to compete in the Clean Snowmobile Challenge 2008. The objectives of the competition were to modify a snowmobile to increase its performance while lowering it's exhaust and noise emissions. Each snowmobile will be tested and analyzed against the EPA 2012 emission standards. The design will also take rider comfort, cost effectiveness, and costumer appeal into consideration. The 1996 Ski Doo carbureted Rotax two-stroke engine that arrived stock with the Formula SLS was replaced with a 2007 Ski Doo Rotax SDI (semi-direct injection) two-stroke engine. The exhaust system was modified by adding a catalytic converter and a custom built muffler. All modifications were done to accompany to requirements to run on E85.

Introduction

Snowmobiles have been creating winter recreation opportunities for many decades. More recently the increase in snowmobiling activities has raised many issues. The combustion of fossil fuels by a snowmobile engine raises environmental concerns in terms of air and noise pollution. Often snowmobiling takes place in and around environmentally sensitive areas, like state and national parks. This negative impact on the environment has created new objectives for college students [1].

The SAE (Society of Automotive Engineers) Clean Snowmobile Challenge 2008 is an engineering design competition aimed to test the capabilities of college students from different universities around the world. The competition challenges the students to modify an existing snowmobile to compete against one another. The snowmobile will be tested for improved exhaust emissions and reduction of noise while containing events that will challenge the snowmobile in a variety of customs. The events will take place over a period of six days; testing fuel economy, marketability, and overall performance of the snowmobile [2].

Team History

The SAE Clean Snowmobile Team at Northern Illinois University is currently in its inaugural year. The program started in the hands of four mechanical engineering students as a senior design project. The initial idea was just to convert a snowmobile engine to run on E85 to lower its emissions. It would then be used as a basis to start the team in the future, but the idea grew faster than expected. As word began to spread and the team gathered support, the four students realized that they could take it further and modify a whole snowmobile for CSC 2008. The team is now one of multiple SAE affiliated teams at NIU. It is completely organized and managed by the students with the assistance of an advisor and the College of Engineering and Engineering Technology. All funds have been raised by the team from local donors, commercial sponsors, and the College.

Figure 1: Clean Snowmobile Team 2008

Team Objectives

Reduce Exhaust Emissions

The Team's primary objective is to lower the exhaust emissions. A five mode test will be conducted to verify that each snowmobile complies with the 2012 EPA standards. Table 1 clearly identifies each mode and corresponding categories.

Mode	1	2	3	4	5
Speed, %	100	85	75	65	Idle
Torque,%	100	51	33	19	0
Wt. Factor, %	12	27	25	31	5

Table 1: 5- mode emission test cycle

The test results will show the quantities of CO (carbon monoxide), HC (hydrocarbons), and NOx (nitrogen oxides). HC+NOx can not be greater than 90 g/Kw-hr and CO must be lower than 275 g/Kw-hr [2]. The quantities of each are used in formula to calculate the team's emission number, where the emission number (E) must exceed 100. The emission number for each team will be used to calculate their final score. Below is the engine emission formula .

$$E = \left[1 - \frac{(HC + NOx) - 10}{150}\right] \times 100 + \left[1 - \left(\frac{CO}{400}\right)\right] \times 100 \geq 100$$

Figure 2: Engine Emission Formula

Fuel Economy

In addition to the emission test, the fuel economy and endurance of the snowmobile is an important team objective. Each team will compete in an endurance event that will require the snowmobile to operate on a groomed trail for 100 miles. Every snowmobile will follow and maintain progress of the assigned trail judge. The trail judge can also disqualify a team from the event if the snowmobile does not maintain the set pace of 30 mph to 45 mph. The teams that complete the endurance event will initially receive 100 points, and then be awarded addition points for their energy consumption compared to the rest of the field [2].

Noise Reduction

The noise from a snowmobile can be substantial at times. This objective for the team was to reduce or eliminate as much noise from the snowmobile as possible. There will be two types of tests that are performed; objective and subjective noise tests. The objective test is a SAE procedure J192 sound pressure test set by that the International Snowmobile Manufacturers Association. Each snowmobile cannot produce to an excessive degree of 78dbA [2]. Passing this test will present an opportunity for the subjective noise test. During the process of the subjective noise test, the recording of the snowmobile will be played to a blind jury, who will then evaluate the most favorable snowmobiles for noise control.

Performance Characteristics

On top of producing a snowmobile that is cleaner for the environment, teams are challenged with the objective of maintaining or improving its performance characteristics. These characteristics range from its power to control and handling. There are two events that will help extinguish the differences in performance between each team's snowmobile. Those events are the acceleration and the control and handling event. The acceleration event will test each snowmobile from a standing stop to the maximum speed it can reach in 500 feet. The teams will take the best time of two runs, and the elapsed time must be at most 12 seconds [2]. Also, all snowmobiles will compete in a timed control and handling event. This event will evaluate the maneuverability of each snowmobile by having them completing two individual laps on a slalom style course. The best lap time will be recorded.

Furthermore, there are other objectives including cost effectiveness, cold start, rider comfort, the design paper, and design presentation that each team will be judged on. Each objective is equally important to the design of a snowmobile, especially the conversion to E85 for the Clean Snowmobile Challenge 2008.

Conversion to E85

The Clean Snowmobile Challenge brings a different and new engineering objective each year. This year's challenge is to convert a snowmobile engine to run on E85.

Background Information

E85 has been growing in popularity in the past few years, and is becoming more readily available in many areas. Since E85 is relatively new to the public, there are many myths that can cause confusion. E85 is a mixture of 85% ethanol and 15% gasoline. This alcohol fuel blend has the highest oxygen content of any publicly available fuel, and the reason it burns cleaner than regular octane gasoline [3]. Also, E85 contains 80% less gum forming compounds than unleaded gasoline. It reduces the carbon buildup in the engine which can hurt performance and exhaust emissions.

There are many benefits when using E85 that out-weigh the benefits of unleaded gasoline. The largest benefit is that it is considerably better for the environment. As E85 is burned, it emits tailpipe emissions that contain far less climate altering greenhouse gases. It also has a much higher octane rating than unleaded gasoline, usually 100 to 105 octane. The fuel allows advanced timing for increase in performance. Adjusting for higher compression will lead to greater efficiency and lower emissions. Since E85 is a renewable resource, it will reduce the dependency for oil from other countries as well.

E85 Conversion in Snowmobiles

The conversion to E85 itself is not very complicated. Since E85 is lower in energy content when compared to gasoline, it requires around 30% more fuel to produce the same air to fuel ratio [3]. The fuel system must have the capabilities to supply this added fuel. This requires a fuel pump that produces a higher pressure and larger volume. Also, for fuel injected operations, the injectors will require modifications for larger jetting.

Any alcohol base fuel is much harder on a fuel system than unleaded gasoline, especially the fuel tank, fuel lines, and seals. All of the fuel feed delivery lines and many other components in the fuel system were replaced with E85 compatible products. The upgrade to a fuel pump with the capabilities to supply 120 psi fuel pressure in-line with a fuel pressure regulator was installed into the fuel system.

There are aftermarket E85 conversion kits available that can be wired into many vehicle fuel systems. Conversion kits of this nature are pre programmed to increase the pulse width of each fuel injector. Alternatively, they do not allow for adjustments that should be made to run an engine efficiently. Given this information, decisions were made to install one of two programmable controllers available, to assist with all modifications to the fuel delivery system.

The two programmable controllers available are manufactured by BoonDocker Performance or Flex Fuel International. Each system will allow for fuel injector adjustment. The adjustments will increase the pulse width to supply the fuel needed to convert to E85. Each system can be programmed to enable an increase or decrease of fuel with reference to the engine's data parameters.

Snowmobile Design

Snowmobile Chassis

The team chose a 1996 Ski Doo Formula SLS Chassis. The mid 1990's snowmobile chassis is a lightweight design that allows enough hood space for many of the modifications necessary to the team's design. The engine chosen also mounted easily onto the chassis. The Team chose the Ski Doo Formula SLS specifically because it is rumored to be the greatest snowmobile ever manufactured.

Selection of Engine

For the selection of a proper engine suitable for the Clean Snowmobile Challenge 2008, the team gathered information on different types of engines that are currently manufactured today. Noise and Exhaust emissions were among the most important criteria. A decision matrix was created for many important categories that were to be considered. A decision matrix is a spreadsheet structure that prioritizes and compares information to assist selecting the best solution. As shown in Table 2, the results show a trend that leads towards a decision of the 4-stoke EFI forced induction or the 2-stroke EFI / SDI. This matrix resulted in the most reasonable choices for the competition. Due to availability and the popularity of the 2-stroke engine's involvement in snowmobiling, a Ski Doo 600cc Semi Direct Injection 2-stroke was ultimately chosen.

Figure 3: Ski Doo 600 Semi Direct Injection [4]

Decision Matrix

Key

1	+
0	S
-1	-

#	Criterion	Importance	Alternatives: 2 Stroke- Carburated	2 Stroke- E.F.I/S.D.I	4 Stroke- E.F.I	4 Stroke- E.F.I Forced Induction
1	Durability	10	1	0	1	1
2	Cost	10	1	0	-1	-1
3	Functionality	14	1	1	1	1
4	Maintenance	6	0	1	0	0
5	Manufacturing Feasibility	5	1	0	0	0
6	Parts Availability	8	1	0	0	0
7	Weight	7	1	1	-1	-1
8	Performance	6	0	1	-1	0
9	Fuel Mileage	8	-1	1	1	1
10	Noise Emissions	13	-1	0	1	1
11	Exhaust Emissions	13	-1	0	1	1
	Totals	100	20	41	35	41

Table 2: Decision Matrix

Engine Modifications

All engine modifications made where for the specific purpose of running as efficient and clean as possible on E85. The modifications include the addition of a Boondocker EFI control box to modify fuel delivery, an advance timing key way, and the milling of the cylinder head [5].

The Boondocker control box was added to compensate for the additional fuel required when running on E85. The Boondocker system is installed in series with the stock injectors/ ECM. It works by modifying the injector pulse width of the injectors sent by the stock ECM. This is more advantageous than a completely new timing and fuel system because it allows the ECM to modify the fuel and timing as it normally would be based on air temperature, barometric temperature, throttle position, and exhaust gas temperature. The Boondocker box does however allow for modification of fuel delivery based upon specific RPM and load ranges [5]; meaning there is the option to correct any obvious factory faults or program for cold start.

Vehicles running on larger proportion of Ethanol, such as E85, are difficult to start in temperatures below freezing [2]. To correct this, fuel enrichment is needed when starting the vehicle. The use of the Boondocker allowed programming for the maximum injector pulse width for under 500 RPM. The result is fuel enrichment when starting, while normal operating is unaffected since the engine never drops below 1000 RPM.

An advance timing keyway was also installed to take advantage of the performance gains associated with the higher octance of E85. The advance timing key rotates the flywheel so that it passes the crank position sensor earlier, relative to the rotation of the crank shaft. Like the Boondocker system it does not alter the manor in which the stock ECM functions, it simply shifts the entire timing curve up. In the NIU clean snowmobile a .020" inch keyway was chosen, which approximately equals 2.6° of timing advance. This was chosen over a .030" keyway due to reliability concerns as too much timing advance can cause engine knock, especially in the warmer weather that will likely be encountered at the competition.

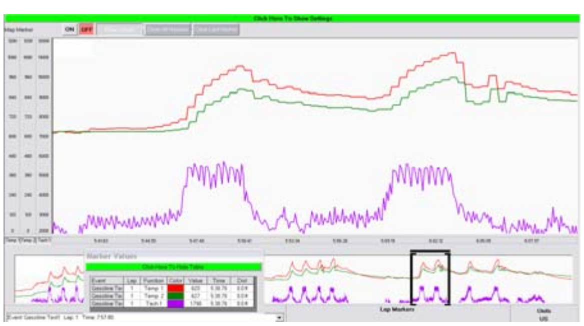

Figure 4: Exhaust Temp Readings

A Digitron tachometer/data logging device was used to record exhaust gas temperatures in the pipe. Probe 1 was placed immediately after the Y=pipe, approximately 6 inches from the cylinder. Probe 2 was approximately placed in the middle of the expansion chamber. The burning of oil in a two stoke engine prevents the usage of an oxygen sensor, so exhaust gas temperatures are deemed the most reliable method of determining the engine tuning. This will serve as the baseline for E85 conversion.

The stock compression ratio was also raised to take advantage of the increased octane of ethanol. The compression ratio was raised from approximately 11:1 to 13:1 by milling the cylinder heads, specifically, reducing the squish area. Since E85 has a higher octane than gasoline, the engine is able to run reliably with a higher compression ratio, and squish velocity, without detonation. From the Otto cycle, which best approximates a gasoline engine, it is understood that with raised compression there is an increase in thermal efficiency [6]. It is important to capitalize on every opportunity to increase efficiency (and therefore mileage) because of the lower energy content of ethanol compared to gasoline. Although the ideal case of 5%, as shown below, will not be realized, it will help to ensure that the NIU clean snowmobile team is able to complete the 100 mile endurance event.

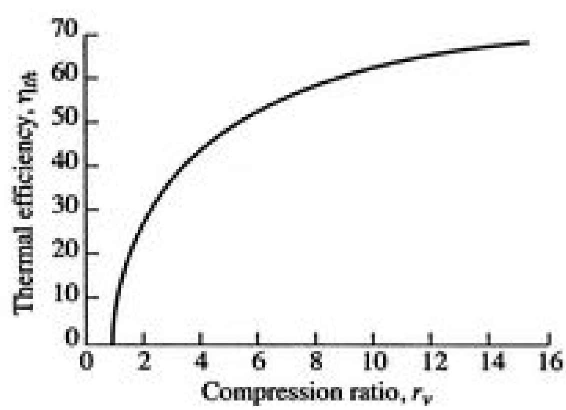

Figure 5 – Ideal Otto cycle [6]

Exhaust Design

With the implant of a 600 SDI engine into a 1996 Ski-Doo SLS, the vehicles exhaust system needed much attention due to factory exhaust pipes not conforming to our sled design. Given the base body of the sled, the front and right side of the engine compartment had enough room to adapt an exhaust system.

The first issue involved accommodating room for the expansion pipe to fit in the appropriate area of the compartment. After design, planning, and preparation, the team measured the dimensions of the stock pipe for the engine. It was then modified through precision cuts, forming, and welding to utilize the space in front of the engine. With respect to implanting the pipe in a way to accommodate the limitation of allowable space, the team also managed to achieve a similar volume and cross-sectional area of the expansion pipe in regards to the factory pipe dimensions. Through this result, the team hoped to achieve or out perform the performance levels of the factory pipe.

The second issue involved fitting a muffler and catalytic converter in the remaining space available. The position of both pieces was achieved through design, planning, and trial and error. Mock prototypes that took the shapes needed were built for the analysis. This was due to the lack of industry mufflers that would not fit properly. The final design resulted in the catalytic converter attached after the muffler. This design was chosen because after extensive testing it was found that the catalyst temperature was too high if placed before the muffler. Placing that catalyst after the muffler should greatly increase the catalyst reliability, while still reducing the emissions significantly. This decision required complete custom fabrication of a new muffler. It was designed to assist with noise reduction thru exhaust gas baffling and fiber packing material.

Reduction of Exhaust Emissions

Emissions of a snowmobile are quite high in reference to a typical automobile driven on the road. Due to this, emissions of snowmobiles have been under a lot of scrutiny, especially the two-stroke motors. For cleaner air and to better our environment, snowmobile emissions have been regulated in recent years, but there is a lack of effort due to the 25% more hydro-carbon emissions released into the environment from a typical 2-stoke engine as compared to a four-stroke [7].

Due to the nature of a two-stoke motor, unburned fuel release is greatly increased along with other harmful gases and particulates. The increased emissions are difficult to lower and is partly why the 600 SDI motor was chosen. When the team modified the snowmobile to have better emissions, the use of E85 was incorporated and a Catalytic Converter was installed to reduce CO and HC. This procedure went thru trial an error testing, due to the catalytic converter design. The catalyst is intended to be used on a four-stoke engine. The team although installed it onto the two-stoke engine. It produced much more HC, which in turn overheats up the catalytic converter. It was a problem to get the suitable temperature for operation of the catalyst without meltdown.

To achieve this feat, the team installed a catalyst at the end of the exhaust system after realizing the air velocity was too high at the beginning of the exhaust. Another test yet to be done is expanding the catalyst area by using two in parallel, but this experiment is still in the work. As for the emission testing, the results were recorded with a OTC Genisys gas analyzer, and proved the usefulness of the catalytic converter incorporated with E85 to lower the snowmobile's emissions. Fine tuning and catalyst placement will be optimized throughout the week prior to the competition. Below is the data achieved from the emission testing.

Emissions test results					
	Gas at Mid thottle (g/mi)	Alcohol at Idle w/ no Catalyst (g/mi)	Alcohol at Mid-Throttle w/ no Catalyst (g/mi)	Alcohol with Catalyst at beginning of exhaust (g/mi)	Alcohol with Catalyst at the end of exhaust at Idle (g/mi)
CO2	216.4	211.29	98.59	199.67	383.87
CO	54.86	74.89	97.38	83.8	10.91
HC	40.69	32.3	57.87	31.55	9.38
Nox	0.11	0.02	0.01	0	0

Figure 6: Emission Test Results

E85 Fuel can provide a great reduction in exhaust emissions compared with regular unleaded gasoline. The primary reason for this reduction is that E85 contains large amounts of oxygen. The oxygen content assists the burning process, allowing a cleaner and more complete burn of the fuel. 100% combustion of the fuel charge will give the greatest efficiency, but getting as close as possible is the first step to reducing exhaust emissions of the engine. E85's low carbon content compared to regular gasoline greatly reduces hydro-carbon emissions in comparison to unleaded gasoline, as well as reduced carbon monoxide (CO) and nitrogen oxide (NOx) compounds.

As previously mentioned, to reduce tail pipe emissions a catalytic converter was installed into the exhaust system. A catalytic converter is composed of a metal housing which contains a honeycomb of maximum surface area coated with platinum and rhodium. This material catalyses a reduction reaction with the unburned hydrocarbons, carbon monoxide and nitrogen oxides to form nitrogen, carbon dioxide and water vapor. Normally, excessive amounts of oil in the exhaust stream can coat the honeycomb matrix and cause overheating, slowly rendering the converter useless. On a normal two stroke engine, a catalytic converter would not be practical due to the large amounts of oil that exits the exhaust un-burnt.

However, the 2007 Ski-Doo 600cc SDI engine uses far less oil than a normal two stroke. Since the semi-direct injection introduces the fuel just before the combustion chamber, fuel washing over the crankshaft is eliminated and the need for oil on the crank bearings is greatly reduced.

Reduction of Noise Emissions

Sound is formed from pulses of alternating high and low pressure waves [7]. These waves will vibrate your eardrum for your brain to interpret. As it goes for most types of machinery, especially snowmobiles, sound is an unpleasant result that should be minimized. This dilemma is one of many arguments for closing snowmobile trails to the public; whether it is environmentalist concern about frightening animals, or land owners displeased with the noise pollution primarily during night hours.

As a result of this concern, the demand for quieter snowmobiles has grown. For now, sound levels emitted by snowmobiles are required to be at most 78dbA. This is in accordance to the SAE standard test J192 which is also a regulation for all snowmobiles currently being manufactured [2]. The team's muffler design is one way to comply with the standard noise levels according to the SAE standard test.

Muffler Design

The muffler design implemented the use of multiple sound dampening theories. These included sound wave reduction by chambers, reflection or back pressure, absorption, and fish tail theories. Chambers in series were incorporated into our muffler to trap short sound waves in each chamber, so they are progressively reduced when traveling from chamber to chamber. Baffles and reduction in pipe diameter was used to create sound interference. The reflection of sound waves off each-other cancels many of the waves out, reducing the noise initially emitted [7]. It is also assumed to produce an amount of back-pressure which is a proven exhaust noise reduction technique.

In two of the four chambers the absorption method was used by having multiple holes in the directional pipes inside the muffler box, and the pipes were wrapped with long strands of fiber-glass. The absorption method is used to eliminate high frequency waves [8]. Towards the end of the muffler box there is a fish tail shaped tube that reduces in cross sectional area. This helps dampen the exiting exhaust noise.

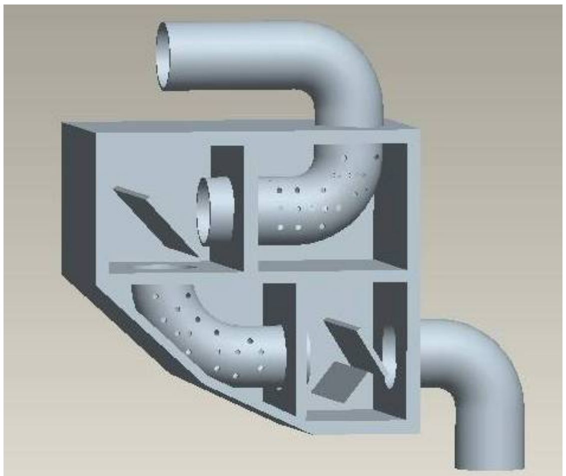

Figure 7: ProEngineer Drawing

After these ideas were implemented and designed, the muffler was constructed out of steel, similar to the original muffler. The first chamber is thicker to prevent drumming created by the mufflers box shape design. This area is where the exhaust pressure waves are at their highest [7]. A heat shield with thermal and noise insulation was also wrapped around the box, helping to dampen out any drumming noise concerns.

Figure 8: Section Cut of Actual Muffler

Air Intake Box

The stock air box from neither the Formula SLS nor the 600 SDI motor were an option with the NIU Clean Snowmobile Team due to fitment issues. An unexpected large area opened up after mounting the SDI into the chassis. This gave the team innovation to design and construct an air box. Pressure pulses eliminate from both the exhaust and intake ports, just as these waves are dissipated in the exhaust, a similar approach was taken for the intake.

A large volume air box was constructed in the first chamber, followed by a second chamber containing baffles exiting near the bottom of the motor. The baffles will help to eliminate pressure waves that are not diminished in the first chamber, and the proximity to the engine should further help cancel out noise [7]. Due to problems with the sound metering equipment, data for a comparison between the stock and baffle box are not available, but the perceived noise to a listener is lower, both while riding and observing.

Insulation of Hood and Body

Using sound reducing insulation on the hood and body of the snowmobile surrounding the engine was found to be an effective way to reduce noise emissions from the engine. Sound insulation effectively dampens noise vibrations reducing the magnitude of the sound waves emitted. Since the sound insulation is directly attached to the belly pan and the hood of the snowmobile, the insulation will also dampen mechanical vibrations in these areas.

Consumer Appeal

As the consequences and costs of non-renewable fuel sources are exposed, new technology providing renewable alternatives is pushed to the forefront of scientific and engineering efforts. In response, designers are striving to satisfy the desires of both the conservationist and consumer/enthusiast. Motor sport designers are thus at the forefront in the endeavor to sustain the performance consumers expect from traditional fuel sources all the while decreasing the hazardous environmental consequences that are inherent. It is to this end that the Northern Illinois University Clean Snowmobile Team has been formed.

Reduction in harmful pollutants, such as carbon monoxide and unburned hydrocarbons, is the not the singular focus of the team. Noise pollution and its negative effects in popular snowmobiling venues operated by the National Park Service are identified as the other major targets in appeasing the desires of environmental activists [9].

Safety of the Rider

In order to increase safety for the rider, the integration of various shields within the snowmobile and added elements to the suspension of the snowmobile. Aluminum and Steel covers enveloping both the braking system and clutch assembly were added to contain projectiles should any failure occur. Improved stability and handling are consequences of additions to both the track and skis. Carbide track studs were introduced to increase traction and braking performance. Triple- point carbide skegs were also added to the new plastic Pilot© skis to improve control and handling. They will help prevent darting into previously laid tracks, and give stability for turning on any icy surface.

Cost Effectiveness

The cost of the NIU clean snowmobile is inline with the snowmobiles on todays market. The MSRP for the NIU clean snowmobile calculates to $10381.00. The majority of this cost was associated with reducing emissions and the engine control for E85. These cost have to be seen as justifiable, because the previously mentioned area are the biggest threat the sport of snowmobiling in North America. It should also be noted that although the MSRP of the NIU clean snowmobile is significantly higher than the actual moneys invested, meaning that there exists a realistic possibility of producing this snowmobile for little to no more monies than current snowmobiles.

Conclusion

Recreation Roundtable conducted a recent study on people who spent time outdoors. The results showed that these people lead “happier, healthier, and more productive lives [9].” They also were better citizens and neighbors in their community. As snowmobiling increasingly becomes more popular in future years, the effort for improved, dependable, and environmentally friendly vehicles will take manufacturers to a new level. SAE takes an additional step by challenging engineering students to perform many of these efforts.

The SAE Clean Snowmobile Team at Northern Illinois University re-engineered a snowmobile for better exhaust and noise emissions. Throughout the weeks prior to the competition, the team has designed, tested, and modified a snowmobile to the best capabilities possible. It is a cost efficient snowmobile proven to have costumer appeal, rider safety, and practicality while passing the 2012 EPA emission standards.

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