# Implementation of a Small High-Performance Turbo Diesel Engine in a Snowmobile Chassis

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## ABSTRACT

For the 2011 SAE Clean Snowmobile Challenge the University at Buffalo Clean Snowmobile Team is implementing a small 3 cylinder turbo diesel engine in a 2005 Polaris IQ chassis. The engine of choice is a Daihatsu made, Briggs and Stratton marketed DM950DT indirect injected engine. The base engine in its stock form meets 2012 CARB regulation.[1] In order to increase power and torque, the emissions scheme was changed to include a diesel oxidation catalyst and a diesel particulate filter.

## INTRODUCTION

Due to the increasing regulations on exhaust and noise emissions on modern snowmobiles, there is an ever-growing need for further development of new technologies that assist in making snowmobiles cleaner and quieter. The Clean Snowmobile Challenge is a collegiate design competition for student members of the Society of Automotive Engineers (SAE). "The intent of the competition is to develop a snowmobile that is acceptable for use in environmentally sensitive areas. The modified snowmobiles are expected to be quiet, emit significantly less unburned hydrocarbons, carbon monoxide and particulate matter than conventional snowmobiles, without significantly increasing oxides of nitrogen emissions." The modified snowmobiles are also expected to be cost effective. The intent of the competition is to design a touring snowmobile that will primarily be ridden on groomed snowmobile trails. Guidelines for the 2011 SAE Clean Snowmobile Competition state that this year's entries into the competition must exceed the EPA 2012 emissions standards just as the manufacturers must do. Additionally, entries must pass the current Snowmobile Industry noise test minus two decibels. Our team has chosen a diesel engine as the engine of choice for this competition as it has great potential that has yet to be exploited in the recreational vehicle market. The diesel engine is vastly superior to gasoline two and four stroke engines with respect to efficiency, emissions, and torque output, all of which are required of modern snowmobiles.

## DESIGN INTENT

The University at Buffalo Clean Snowmobile Team choose a diesel platform over a flex fuel ethanol platform for multiple reasons. One such reason is due to the "compromise" in the engine design for a flex fuel vehicle. As reported by the Department of Energy, a flex fuel vehicle operating on gasoline alone compared to diesel has a fuel economy of approximately 20 to 40% less. When E85 is run, the fuel economy drops from 40% to as much as 65%[5]. Another reason for our choice of a diesel is due to the lower total energy and carbon footprint of a biodiesel blend compared to an ethanol blend. As simulated in an Argonne National Laboratory GREET Well to Wheel analysis using default setting comparing E15 and BD5, biodiesel has a lower overall energy use and lower overall CO2 emissions[6]. Another reason for the choice of a diesel power plant was due to the ease of changing to a bio-fuel. With regards to the amount of fuel, no change is needed. Unlike a gasoline-fueled vehicle that needs to stay near to its stoichometeric ratio for operation and control its power output with a throttle body, a diesel changes its power output via the amount of fuel it injects every power cycle. Therefore, if the energy content of the fuel changes, it will only hinder the full power operation, and have no effect at partial throttle.

| Year: 2010 | GV: Low-Level EtOH Blend with Gasoline | CIDI Vehicle: BD5 |
|---|---|---|
| Total Energy | 7.7% | -13.4% |
| Fossil Fuels | -4.0% | -18.9% |
| Coal | 37.7% | -15.7% |
| Petroleum | -7.5% | -18.7% |
| CO2 (w/ C in VOC & CO) | -3.1% | -17.3% |
| CH4 | -2.9% | -22.2% |
| N2O | 92.1% | -15.9% |
| GHGs | -2.1% | -17.4% |
| VOC: Total | 3.9% | -59.8% |
| CO: Total | 0.2% | -84.5% |
| NOx: Total | 4.8% | -12.1% |
| PM10: Total | 17.4% | -9.7% |
| PM2.5: Total | 9.1% | -7.8% |
| SOx: Total | 10.4% | -21.3% |
| VOC: Urban | -0.4% | -64.6% |
| CO: Urban | 0.0% | -85.2% |
| NOx: Urban | -1.3% | -5.8% |
| PM10: Urban | -2.0% | -3.5% |
| PM2.5: Urban | -2.1% | -2.2% |
| SOx: Urban | -4.2% | -24.0% |

**Table 1: Comparing emissions of E15 vs. B5 to conventional gasoline.**

| System | Subsystem | Description |
|---|---|---|
| **Engine** | Base Engine | Daihatsu DM950DT |
| | Turbocharger | Garrett GT15V Variable Nozzle Turbocharger |
| | Intake | Custom Made Aluminum Log Type Manifold |
| | Fuel Injection | Robert Bosch VE type Injector Pump |
| | Exhaust | Custom Made SS304 Log Type Manifold |
| | ECU | AMTEL ATmega328 |
| **Chassis** | Base Chassis | 2005 Polaris IQ |
| **Suspension** | Front Suspension | Stock A-arms with Fox AIR shocks |
| | Rear Suspension | M-10 Air Suspension |
| **Clutching** | Primary Clutch | TEAM Industries Rapid Response Drive Clutch with 110 gram Flyweights |
| | Secondary Clutch | TEAM Industries Tied Secondary Clutch |
| **Exhaust** | DOC | EMITEC substrait with Aristo Coating |
| | DPF | EMITEC PM-Metalit substrait with Aristo Coating |
| **Track** | Track | Camoplast 15" x 121" Ripsaw Track |
| | Studs | 96 Woody's Gold Digger studs |

**TABLE 2: SYSTEM DESCRIPTIONS**

# ENGINE SELECTION

The base Daihatsu DM950DT engine was chosen for its small size it fit within the frame rails and for its 2012 EPA compliance. The engine is a three cylinder, indirect injected turbocharged diesel engine. Other applications of this engine include 2003-current year Kawasaki Mule diesel utility vehicles, and Husqvarna commercial lawn mowers.

## *Intake and Exhaust Manifold*

Two areas in need of vast improvement were the intake and exhaust manifolds. The stock design intent of this engine was for its use as an industrial power generator and thus these systems were not optimal for our intentions. The turbo manifold was a cast iron, constant pressure log type with restrictive geometry that did not allow for optimal use of exhaust gas velocity. The design of the exhaust manifold this year is that of a log type design. This design was chosen for the overall size, strength, lower heat loss, and the correct inlet angle for the VNT turbo. Last year we has a serious problem with the turbo being too far off axis that it was leaking oil out of the seals and contaminating the exhaust stream. The exhaust manifold consists of a laser cut flange, and schedule 10 SS 304 pipe fittings. When assembled, this setup provides a short, rigid exhaust manifold. On the other side of the engine, the intake was redesigned. The stock intake manifold was a small-volume, log type cast aluminum design with numerous flow obstructions. We designed a larger volume intake manifold that fits within the tight special constraints of the engine bay. The larger volume will ensure an adequate supply of air even at high engine speeds. See appendix figure 4 for the solid model design and actual design picture for comparison.

## *Turbocharger and Intercooler*

The addition of a Garrett GT15 variable nozzle turbocharger and intercooler is a major design change for this year. By matching our engine flow rate and desired intake pressure ratio to the compressor maps of various turbochargers, the GT15 VNT was chosen as the best match. This turbocharger is designed for use on the Volkswagen 1.9L TDI engine and thus is desirable for use in our diesel engine. The variable nozzle design allows for a more dynamic operating range which can spool quickly when the vanes are closed and flow a greater amount of air at fully open. An intercooler was chosen in order to cool the intake charge air in an effort to maximize the density of air and thus increase the engines ability to cleanly and efficiently burn the fuel.

## CHASSIS SELECTION

For the 2011 Clean Snowmobile competition the team has utilized a 2005 Polaris Fusion as a base snowmobile. This is a modern chassis that uses A-Arm front suspension as well as rider forward position while reducing overall weight. This chassis was selected due to its large engine bulkhead and excellent cooling capacity. Even with the relatively large engine compartment on the Polaris IQ chassis, significant modification and relocation to engine systems was required. The oil filter was relocated remotely through the use of a custom adapter. The oil pan was also cut down ¾" to allow clearance for steering linkages. A single v-belt accessory drive was replaced by a custom multi-belt design to avoid interference with the side of the bulkhead.

## COOLING SYSTEM

Due to issues last year with cooling system reliability and use, a custom aluminum coolant was added to the snowmobile this year. This addition allows any air bubbles in the coolant system to separate from the coolant flow. Last year the team had an issue with a thermoplastic radiator cap mount. The issue turned up due to an airlock that caused high temperature steam to destroy the sealing surface of the mount. In order to keep a uniform coolant temperature inside the engine block, the thermostat is equipped with a bypass valve to keep a steady circulation of coolant system.

## EMISSIONS CONTROL

With the increase in power and fueling, the stock emissions strategy no longer works with our engine. To keep the emissions level down, we have utilized the use of a Diesel Oxidation Catalyst, PM-Metalit diesel particulate filter, and a variable boost program to control diesel soot, carbon monoxide, nitrogen dioxide, and unburnt hydrocarbons. The function of the diesel oxidation catalyst is to convert unburnt hydrocarbons, carbon monoxide, and excess oxygen into H2O, carbon dioxide, and nitrogen dioxide. While nitrogen dioxide is a measured pollutant, it is used in the filter to burn the diesel soot. The PM-Metalit Diesel Particulate Filter is unique in many ways. First, it is a partial flow technology is beneficial that it will never clog with ashes like wall filters. In addition, this system has the advantage of not needing to use excess fuel for filter burn-offs due to the continual burn-offs[3]. To optimize the conversation ratios of NO2 and the burn-off of the soot, an electronic linear actuator was mounted on the turbocharger to vary the boost pressure. This actuator was programmed using varying loads from a water brake dynamometer and the O2 and NOx was read using a NTK NOx Sensor. With a constant load applied, the boost was varied to have the least amount of NOx coming out of the treated exhaust.

**FIGURE 1: Picture of an EMITEC partial flow DPF**

# ELECTRICAL SYSTEM

The electrical system of the snowmobile consists of a starting battery, starter, alternator, and chassis wiring. The battery consists of a 1164 cranking ampere Absorbed Glass Mat battery supplied by Braille Battery. The battery is located in the seat box of the snowmobile. To conform with rule 4.8.5[2] the battery is located in a non conducting Lexan box located under the seat. To facilitate the work on the electrical system in the front of the snowmobile and to protect the power wire running under the seat, a battery disconnect switch is locating in the back of the snowmobile too. For the shutdown of the engine and the fuel pump, all of the chassis power is run through a relay driven by the kill switches.

# COLD START PERFORMANCE

Cold staring has historically been a perceived disadvantage of diesel engines. However, we have made changed to enable the engine to start easier in cold weather. The first and foremost difference is the change from shielded metal glow plugs to ceramic self-regulating glow plugs. The advantage of these glow plugs is the ability to heat to 1100ºC within 3 seconds, then self regulate to 1000ºC after. They also have the advantage of no needed external current control[4]. Another problem inherent to diesel engines is the possibility of the fuel gelling due to cold temperature. If the fuel were to gel, the injector pump has a fuel return line that returns warm fuel from the pump back to the fuel tank to warm up the fuel. Once the engine is running, the turbocharger will work as an exhaust brake to speed up the engine warm-up. With the ECU sensing cold coolant and no throttle applied, it will signal the linear actuator on the turbo to close the vanes all the way to produce a parasitic load on the engine. This load will in turn cause more heat to be rejected to the coolant jacket and warm the block. Once the computer sees that the coolant is up to temperature, it will signal the LEA to move the turbocharger vanes to a less restrictive position.

# MAINTENANCE AND SERVICEABILITY

Maintenance and service on a diesel snowmobile is as easy as that of a conventional gas powered snowmobile. Engine oil needs to be changed approximately every 7500 miles or every year at minimum. Long drain periods are possible due to the robustness of the oil used for compression ignition engines and the synthetic properties needed for cold temperature operation. Engine oil changes are aided by the addition of a remote oil drain hose and a remote oil filter located in the space under the clutches. The fuel and ignition system needs very little maintenance due to the face that fueling and ignition are both controlled by the injection pump. The injectors and injection pump only need to be checked if there is a noticeable change in engine performance. Also, if a problem did arise, the injectors and injection pump can be serviced at any reputable diesel engine shop. One thing that needs to be checked regularly is the fuel filter/ water separator. Due to the very close tolerances in the injection pump and injectors, the fuel must be clear of any debris or water. Changing the fuel filter is facilitated with the filter being located in the open area above the chain case. Bleeding the fuel system is facilitated with a fuel lift pump and a bleed screw on top of the fuel filter. Glow plugs that aid in cold start up only need to be replaced if they have malfunctioned and there is noticeable white/blue exhaust smoke at start up. Obviously, the absence of spark plugs removes the hassle of worn and fuel fouled plugs and reduces maintenance costs and labor. The robustness of the diesel engine increases the time before rebuild or major engine overhaul is necessary, in stark contrast to the conventional gas powered snowmobile. All of the above benefits for ease of maintenance and serviceability highlight the attractiveness of a diesel powered snowmobile for the consumer market.

# SUSPENSION AND TRACTION

The rear suspension has been upgraded this year with an M-10 Airwave skid. The suspension is superior in both allowed travel and weight. The suspension allows a more aggressive rider-forward stance and also a higher viewing position to allow proper navigation of snowmobile trails. The front suspension used this year will be a pair of FOX FLOAT Airshox. They eliminate the need for standard shock springs by using an internal floating piston coupled with high-pressure nitrogen gas. There is also a weight savings of about 6 lbs. due to the lack of an external spring. FLOAT Airshox also have a great amount of adjustability via a miniature air pump that changes the internal pressure of the shock. This allows for adjustability from race to trail conditions as well as rider weight in a matter of minutes.

# SKIS

C&A Pro Trail XT skis are used on the 2011 sled. These skis are lightweight and offer a great amount of durability and prolonged wear. The patented design on the bottom of the ski allows for reduced darting and improved cornering because of the big footprint it makes when cutting through the snow. More responsive steering is imperative in this design since the diesel engine adds a significant amount of weight to the front of the snowmobile. Additionally a pair of Woody's carbides will be used to give the snowmobile better traction in unfavorable conditions.

## CONCLUSIONS

The University at Buffalo 2011 SAE team has successfully designed and implemented a high performance clean burning turbo diesel engine for use in a snowmobile chassis. The engine is a highly efficient alternative to a traditional gasoline powered snowmobile. With fuel mileage at least twice that of the competition and the performance that snowmobilers come to expect, our entry for this year exceeds the expectations of the CSC. With currently available technology, the diesel snowmobile can meet the demands of snowmobilers, the EPA, and manufacturers.

## REFERENCES


1. http://www.daihatsu.com/catalogue/engine/emission/
2. http://students.sae.org/competitions/snowmobile/rules/rules.pdf
3. http://www.emitec.com/index.php?lang=en&mid=e4&doc=128
4. http://www.ngk.de/en/products-technologies/glow-plugs/glow-plug-technologies/ceramic-glow-plugs/self-regulating-ceramic-glow-plugs/
5. http://www.eia.doe.gov/oiaf/servicerpt/lightduty/chapter3.html
6. http://greet.es.anl.gov/


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