# North Dakota State University – Clean Snowmobile Challenge 2015

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# Abstract

The North Dakota State University (NDSU) Clean Snowmobile Team will be utilizing a 2014 Polaris Indy Voyageur chassis retrofitted for the application of a 904cc Yanmar diesel engine with an IHI RHF3 turbo for improved power and efficiency. Due to the stock engine's compliance with Tier-4 emission standards, it is anticipated that this engine will produce low emissions prior to the addition of modifications. However, the addition of both a diesel oxidization catalyst and diesel particulate filter will be incorporated to further reduce the pollutants released to the atmosphere. Modifications will need to be made to the stock chassis to allow for the application of the larger diesel engine and its necessary sub-components. Over-structure and steering linkages will be modified to maximize available space in the engine cavity. In an effort to provide well rounded performance in both power and efficiency, a high-low gearbox will be implemented between the jackshaft and driveshaft. The continuous variable transmission (CVT) will be changed from the provided stock configuration, as the output characteristics of the diesel engine differ greatly from the stock engine. A pre-studded track will be used in an effort to increase the traction capabilities of the snowmobile, allowing for enhanced power delivery. Finally, there will be additional changes made to smaller sub-systems in an effort to optimize the snowmobile's performance. With this reengineering process well laid out and completed, the resulting product will be a snowmobile that provides power and efficiency performance, while exceeding stringent environmental standards.

# Introduction

In today's current markets, including the automotive industry, companies and individuals are striving to provide solutions to their customers that are found to be both efficient and environmentally friendly. With the cost of fuel rising, and public awareness of global climate change becoming ever more prominent, the automotive industry is striving to do its part in developing innovative solutions to increase operating efficiency and reduce its environmental footprint. The Society of Automotive Engineers Clean Snowmobile Challenge is a perfect chance for young and upcoming engineers to discover and implement innovative ways to provide feasible solutions that make snowmobiles more efficient and environmentally

to perform well on all levels of competition as well as have the innovative strategy it takes to show the striving steps that are being taken within the industry in a cost effective manner.
Marketing Standpoint
Marketability is an important aspect of the off-road vehicle industry. The snowmobile discussed in this report was designed for use as a utility vehicle. Due to the implementation of a diesel engine, the fuel economy of this snowmobile is an engineered.

of a diesel engine, the fuel economy of this snowmobile is greatly increased compared to similar vehicles using conventional gasoline engines. It is estimated that on a single tank of gas, the snowmobile will be able to travel over 400 miles. Aside from the improved fuel economy, the snowmobile is capable of towing small trailers. A receiver was installed to the rear bumper and is able to accommodate any standard two inch receiver hitch.

friendly. This challenge poses collegiate teams with the

problem of re-engineering a production snowmobile to maintain performance in both efficiency and power, while reducing the

amount of pollutants produce as well as noise production.

Each team competing will take their snowmobile through a

series of tests that will outline its performance in all desirable

aspects of the snowmobiling industry. This will include, but is

not limited to, fuel economy, acceleration, pulling power,

emissions and noise. The winning snowmobile will be required

Incorporated in the snowmobile is a transmission including high, low and reverse gears. When parking a trailer, the reverse feature is very beneficial, as the need for the rider to get off the snowmobile and manually move the trailer into place is eliminated.

The heavy duty bumper is another complementing feature for a utility vehicle as it will allow for driving over small obstructions without worrying about damaging the critical components of the snowmobile.

# **Engine/Turbo Selection**

In selecting an engine, it was desired that it provide the snowmobile with the capability to provide the user with sufficient power and efficiency performance, while keeping emissions at low levels. Also, the automotive industry is

trending to more renewable and alternative fuels in order to create a more eco-friendly future for the industry.

It was decided that the best way to meet these criteria was through the application of a diesel engine. Diesel engines are noted as having higher efficiencies than traditional spark ignition gasoline engines. In addition to having higher efficiencies, biodiesel has been proven to contain energy contents higher than that of ethanol, 121,000 BTUs per gallon and 75,000 BTUs per gallon, respectively [1]. This shows that fuel requirements for the diesel engine of tomorrow will be less than that of a traditional spark ignition engine, creating a great desire for innovation of the future in the internal combustion engine industry.

It has also been noted that the addition of a turbo to a diesel engine greatly improves the performance of the engine. This is seen both in the power output of the engine as well as the engine's efficiency. This will prove to be beneficial in both power as well as efficiency based categories. The resultant gain in power is created by the greater mass of air that is able to be added to the cylinder for combustion versus a traditional naturally aspirated engine. With more air available for each piston stroke, more fuel is able to be burned, resulting in a power increase. However, this gain in power has some inefficiency due to the high back pressures that the turbine of the turbocharger will induce. Efficiency gains can be associated with the increase in volumetric efficiency by improving the ability to inject more air into the cylinder. This phenomena will be further improved through the application of an intercooler between the turbo and the intake manifold of the engine.

## Selected Engine

For this particular application, a Yanmar 3TNM72-APL diesel engine was selected. It demonstrated substantial torque and power capabilities, having a maximum power output of 23.6 Hp and 40.9 ft-lbs of torque. However, it was noted that the addition of a turbo would allow for increases to be obtained in both the power and torque of the engine. Other reasons this engine was selected are seen as follows.

- Compact design allows for easy fitment
- Complies with 2008 Tier 4 Emission Standards
- Achieved 28.7 mpg at competition last year
- Two engines in inventory allows for backup engine
- Budget did not allot for new engine purchase

The compact design allows for easy installation under the hood of the snowmobile where space is very limited. In addition, it complies with 2008 Tier 4 Emission Standards meaning that it has already been engineered to comply with stringent off road emission standards. This will ideally allow for a more competitive advantage on the emissions front of the snowmobile's performance. Achieving a MPG of 28.7 at competition last year landed the snowmobile with a first place finish in the endurance run and provides another appealing aspect to the engine. Having two engines in stock will allow for having a backup engine on hand in the case that the original engine should experience a substantial failure at competition or during testing. Finally, the budget allotted for this competition made obtaining new engines another obstacle as sponsorship efforts were seen as having a better return on investment in different aspects of the snowmobile.

# Selected Turbo

The turbo being used is a RHF3 turbocharger from IHI. This turbocharger was chosen based on the following chart from the manufacturer which is shown below in Figure 1 [6]. The diesel engine has a displacement of .904 liters, and 23.6 horsepower. Dynamometer testing performed on the turbo-charged engine setup showed increases of 11.83 hp (50.1%) and 7.1 ft-lbf (17.4%).



#### Figure 1: IHI Turbocharger selection chart

### Chassis

A new chassis was obtained this year through the generosity of Polaris Industries. As entry will be in the diesel utility class, a utility style chassis was deemed as being the best option for this particular application. Two styles were considered, the IQ WideTrak and the Indy Voyager. The primary specifications considered can be seen in Table 1.

#### Table 1: IQ WideTrak and Indy Voyager Comparison

|                       | IQ WideTrak  | Indy Voyager         |
|-----------------------|--------------|----------------------|
| Track                 | Width: 20"   | Width: 15"           |
|                       | Length: 156" | Length: 144" or 155" |
| Dry Weight (lbs)      | 671          | 498                  |
| Gearing (jackshaft to | High-Low     | Chain Drive Fixed    |
| driveshaft)           | Transmission | Gearing              |
| Cargo Rack            | Yes          | Yes                  |

After consideration was given to multiple aspects of each style, it was deemed that the Indy Voyager would provide the best option for this application. This selection was made based on the fact that the IQ WideTrak's increased chassis weight, as well as the increased mass moment of inertia of the associated track would result in losses in fuel economy. Also, the addition of a diesel engine provides added weight in comparison to a traditional spark ignition engine, so reduced chassis weight played a key role in selection. Although the larger track of the IQ WideTrak would provide increased traction, it was hypothesized that the losses in fuel economy would outweigh the gains in traction. Finally, it was discovered that a high-low transmission is offered as an aftermarket part and could be retrofitted for application on the Indy Voyager. This high-low gearing will provide the snowmobile the capability to operate in both an economy mode (high) as well as a power mode (low). This operation will be further explained in a later portion of this report.

# **Chassis Modification**

The stock chassis had to be modified in order for the team to be eligible to compete in this year's competition. These modifications will be outlined in the following sections.

### **Engine Bay**

To accommodate the larger diesel engine, modifications were necessary beneath the hood in the engine bay area. This included raising the over-structure as well as raising the steering linkage. The front steering column of the steering linkage was raised approximately 3" such that the linkage between the base of the handle bar and front steering column would clear the top of the engine. The modified steering column is depicted below in Figure 2.



Figure 2: Steering Mount with Modified Steering Column

The angle of the support over-structure was also modified in order to allow for clearance between the structure and engine. This modification can be seen in detail in Figure 3. It can be seen that with the modified angle, the over-structure was required to have two vertical members implemented to relieve added stresses caused by removing the lower section of the steering mounts. In addition, it can be seen that the cross member between the over-structure had to be re-fabricated with a bend in order to allow for installation of the custom exhaust manifold and turbo.



#### Figure 3: Modified Support Over-structure

Custom engine mounts were also fabricated as the Yanmar engine selected required a mounting setup significantly different than that of the stock gasoline engine. These mounts were fabricated out of aluminum having slotted fittings between the base and support arms. These slotted fittings allow for the engine to be maneuvered side to side in an effort to simplify clutch alignment as well as fitment of other components under the hood. In order to allow for proper installation of the engine mounts, one of the stock heat exchangers had to be removed from the rear wall of the engine bay. This heat exchanger was replaced by an aluminum member to allow for the engine installation.

#### Tunnel

Very few modifications were made to the tunnel, as structural integrity could not be compromised.

The rear bumper of the snowmobile was modified and a receiver hitch was attached. This was done to satisfy requirements for the two events that involve connecting to a sled; drawbar pull and acceleration with a load.

#### **Cooling System**

In order to keep the engine cool, a cooling system must be implemented. The cooling system includes a heat exchanger that is placed in the rear of the tunnel and coolant lines that run down the sides of the tunnel. There will be three different types of heat transfer present; convection, conduction and radiation. Ordinarily, a heat exchanger is placed at the front of the tunnel. Due to engine mounts not fitting on the stock heat exchanger with the stock fittings on it. The fittings were cut off, which made this heat exchanger no longer usable. To make up for this loss heat exchanger, a new one was mounted at the rear of the tunnel. The snow kicked up from the track will hit this new heat exchanger and cool down the coolant running through it. The coolant will also run down the sides of the tunnel. A schematic showing a visual representation of the coolant system is shown in Figure 4.



Figure 4: Schematic of Cooling System

# **Emissions Control**

Internal combustion engines utilizing diesel fuel have been found to emit several compounds that have been deemed as harmful to the environment. The major pollutants that have been identified are as follows.

- Nitrous Oxides (NO<sub>x</sub>)
- Carbon Monoxide (CO)
- Particulate Matter (PM)
- Hydrocarbons (HC)

In an effort for diesel engines to meet today's stringent emissions standards, and to prevent the release of the previously-stated components to the environment, exhaust after-treatment products have been introduced. This snowmobile will incorporate the application of both a diesel oxidation catalyst (DOC) as well as a diesel particulate filter (DPF). Although the addition of these components will increase the overall price of the snowmobile by upwards of \$1,500 it will be seen as more beneficial to provide an environmentally friendly solution.

# Diesel Oxidation Catalyst (DOC)

Diesel oxidation catalysts are introduced to the exhaust path in an effort to reduce the release of CO, HC and PM. The catalyst is formed of a substrate that is coated usually with a precious metal, which, when elevated to adequately high temperatures, begins a catalytic reaction. This reaction is the process of oxidizing CO, HC and PM with the excess oxygen located in the exhaust. The products of this reaction traditionally consist of carbon dioxide (CO<sub>2</sub>) and water (H<sub>2</sub>O), both of which have been deemed as less harmful to the environment than typical compounds found in the exhaust. If selected properly, a functioning DOC can result in reductions of PM by 20 to 40 percent, HC by 40 to 75 percent and CO by 10 to 60 percent according to the EPA [2]. Issues with this aspect of the design included that there are not may DOCs currently in production for engines of this small displacement. However, for this application, a small-engine style DOC has been obtained via BASF The Chemical Company. The product that is to be utilized is traditionally used for engines on the magnitude of 1.0 Page 4 of 8

Liter. It will be tested and idealized that the Yanmar engine being used will be able to run hot enough in an effort to keep the DOC at high enough temperatures to sustain the reaction process.

# Diesel Particulate Filter (DPF)

Diesel particulate filters are used solely for the purpose of removing PM, also often called soot, from the exhaust stream. Like a traditional filter, the DPF works on the principle of trapping the PM as it flows through the filter, which is composed of a ceramic material. Particulates are accumulated during normal operation until threshold levels are collected in the filter. The particulates are then burned off into an ash using a regeneration process. Proper application of a DPF can result in particulate matter reductions greater than 85% [3].

#### **Passive Regeneration**

Passive regeneration is accomplished when normal operating conditions produce exhaust temperatures high enough to combust the particles trapped within the DPF. This requires no application of an additional heat source. Exhaust temperatures on the realm of 650 °C must be present in order for the process of passive regeneration to occur. During dynamometer testing, exhaust gas temperatures for the selected engine reached a maximum of 491 °C, therefore passive regeneration was not a viable option.

### **Active Regeneration**

Active regeneration requires the application of an external heat source to elevate the temperature of the DPF to levels that induce combustion of the trapped particulates. This can be achieved in a multitude of ways, most of which include one (or more) of the following process.

1. Increase the exhaust temperature via late fuel injection or fuel injection on the exhaust stroke.

2. Use a fuel-borne catalyst that reduces the combustion temperature of the soot.

3. Implementation of a fuel burner or fuel injection after the turbo to increase the exhaust temperature.

4. Resistive heating coils to increase exhaust temperature.

Complexity of the system ruled out the possibility of implementing process number one, rule constraints eliminated the idea of adding a catalyst to the fuel and large enough resistive heating coils require an electrical load too great for the alternator selected. This implies that the best option for this particular application would be introducing a secondary combustion after the turbo in the exhaust path.

### **Exhaust Fuel Injection**

To actively regenerate the DPF, a method will be used to inject fuel into the exhaust stream. In order to accomplish this, a tee connection will be placed in the fuel line from the tank to the engine. The branched connection will be routed to a fuel shutoff solenoid valve that will be operated by the driver via a switch located on the dash. When the switch is operated, the valve will open to allow flow, where the fuel will be injected into the exhaust path. This point of injection will occur before the DOC and after the turbo in the exhaust path. This design will be tested prior to competition in an effort to assure that flow is occurring. Should there be issues with inducing flow through this line, a pump will be placed within in the line to induce flow. If necessary, this pump would be placed between the tee connection and the fuel shut-off valve. Schematic for this design can be depicted below in Figure 5.



#### Figure 5 Fuel System Schematic

Determining how long the valve should remain open during this injection process will also be determined via testing. The methodology used for determining when injection should take place is going to occur from measuring the differential pressure across the filter. When the pressure difference across the filter reaches threshold levels, it will be desired that regeneration occur for the safety of the engine as well as to optimize performance. In the case that pressure monitoring proves unsuccessful, regeneration frequency will be based off of a per-mileage basis.

# **Track Selection**

Track selection plays a key role in a snowmobile's performance. It has the direct role of transferring the power delivered from the driveshaft to the ground to allow for motion of the snowmobile to occur. Track options for the Indy Voyager chassis include the application of either a 144" or 155" track. Upon further analysis, it was found that the 155" track saw an increase in contact between the track and ground of 9%. However, by constructing circles with the circumferences of 144" and 155" in SolidWorks to achieve an estimate of the mass moment of inertia for each of the track lengths, it was found that the 155" model has a mass moment of inertia that was 25% greater than the 144" model. This, along with its increased weight, would result in the track being harder to spin by the engine and would therefore decrease the overall fuel economy of the snowmobile. Due to the significance of the role that fuel economy plays in scoring of the competition as compared to events such as the draw bar pull and acceleration with load (which would benefit greatly from increased traction), it was decided that the 144" track would provide a better solution for this application.

In addition, assuming that there is not notable snowfall during the competition, a majority of the competition is to take place on packed snow. This environmental prediction provided the conclusion that the use of longer lugs would provide minimal benefit for traction as well as add unneeded weight to the track while also increasing the overall rolling resistance of the track. These criteria guided the decision to select a track that is made primarily for riding on groomed trails.

### ICE Attak-XT

Upon further research, the ICE Attak-XT by Camoplast was selected as the best option for this application. This track is noted as being a trail track that provides superior traction on groomed trails. It has pre-studded lugs that allow for improved traction and control, and its lug length of 1.22" will allow for traction on the groomed trails without folding the paddles caused by the snowmobile's weight. In addition, the 1.22" lug length provides a good balance of increased traction, while keeping rolling resistance of the track within a tolerable range.

## **Drivetrain Modification**

Significant changes were made to the drivetrain of the 2015 NDSU snowmobile. This includes but is not limited to continuous variable transmission, as well as the addition of a high-low transmission. This section will outline and further explain these components.

## Continuous Variable Transmission (CVT)

The Indy Voyager snowmobile is propelled with two different clutches, the drive (primary) clutch and a driven (secondary) clutch. These make up the continuous variable transmission, more commonly known as a CVT. At rest when the drive clutch is spread all the way out and the driven clutch is clamped shut there is a 3:1 ratio from the drive to the driven. This 3:1 ratio continuously changes as engine speed changes. As engine speed increases the drive clutch starts to close while the driven clutch is fully closed, and the drive clutch is fully spread out, causing the ratio to change to 0.75:1, this gives an overall ratio of 4:1 for the CVT [4]. This is depicted below in Figure 6.



Figure 6: CVT Schematic

Like stated before, a Dynamometer test was performed on the engine. The results from the Dynamometer, which can be seen in Figure 7, helped determine what characteristics are needed in the Drive and Driven clutches.



Figure 7: Dynamometer Hp vs. Engine RPM Curve

With this data available, selections of the proper characteristics of the clutches were able to be made. Table 2 below shows the characteristics of each clutch that is to be used in the 2015 NDSU snowmobile.

#### Table 2: Specifications for Drive and Driven Clutch

| Drive Clutch  |                |  |
|---------------|----------------|--|
| Model         | Rapid Response |  |
| Flyweights    | 243-gram       |  |
| Spring        | 140-320        |  |
| Driven Clutch |                |  |
| Model         | TSS-04         |  |
| Helix         | 42-44          |  |
| Spring        | 140-200        |  |

# Gearbox Implementation

As previously stated, the Indy Voyager came with a fixed chain-driven gearing setup, which is shown below in Figure 8. With the addition of the two new events added to competition this year (acceleration plus a load and draw bar pull) it was deemed that having the ability to switch between a high and a low gear would be beneficial [5]. The dropcase from the Polaris IQ Widetrak, featuring high, low, and reverse gears was implemented into the 2015 NDSU snowmobile. A visual representation of the new dropcase is shown in Figure 9. The use of this new dropcase allowed for lower engine speeds at higher velocities, leading to superb fuel economy in the endurance event, as well being able to provide high engine speeds at low velocities for increased torque output required for acceleration plus load and draw bar pull events. The gearing for the high gear is 2.15:1, and a gearing of 3.77:1 for the low gear. With this gearing ratio, it is estimated that a top speed of 47.28 mph can be achieved at 3800 RPM. This is

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much higher than the required 30 mph requirement for the endurance run. To adopt this dropcase and as well as drivetrain, parts needed to be modified to fit into the Indy Voyager chassis. A new jackshaft and driveshaft had to be used to couple into the dropcase and the dropcase had to be mounted differently to the snowmobile.



Figure 8: Original Drivetrain



Figure 9: New high-low dropcase with gears

# Shaft Modifications

The driveshaft and jackshaft from a Polaris IQ Widetrak chassis were retrofitted to be implemented in the new chassis. As stated earlier, this chassis uses a 20" wide track whereas the Voyageur chassis uses a 15" wide track. This means the driveshaft and jackshaft both had to be shortened to ensure proper fitment. Also the gears on the driveshaft were not

compatible with the new track. The Widetrak uses a driveshaft with four drivers, but the narrower track only requires the use of two, so two had to be removed. One challenge that arose upon shortening the driveshaft was that the shaft is hollow. To overcome this, a collar had to be fabricated to be sure the welds would hold up to torques applied during track rotation. Shortening the jackshaft was less difficult, as it is it is a solid steel shaft rather than hollow. In this shaft the team was not worried about welds holding up to torques applied. Both shafts were brought to a professional welding and drive company for modification.

## **Tunnel Modifications for new Dropcase**

The original dropcase and the new dropcase were significantly different in size and as well as its mounting locations. The tunnel on the snowmobile had to be modified to allow the new dropcase to be mounted to it. Another difference between the old and new dropcase was that the center-to-center distance from the jackshaft and driveshaft was different. The old dropcase center-to-center distance was 7.53," whereas, the new dropcase center-to-center is 6.62." Due to this difference in center-to-center distance, the driveshaft was moved upwards 0.91" and the tunnel was modified to allow this.

# **Sound Treatment**

### Exhaust

The path of the exhaust system is routed such that it will exit the bottom of the snowmobile directly ahead of the chain case. The sound created by the exhaust will be dampened by the snow underneath the snowmobile's engine cavity. Figure 10 depicts where the exhaust exits the snowmobile's engine cavity.



Figure 10: Exhaust Directed Into Snow

### Track

The track is typically responsible for a significant portion of the noise created by a snowmobile. To help muffle the audible noise produced by the track, rubber skirts that surround the side and the back of the snowmobile from the tunnel to the

ground were installed. The skirt system contains the sound vibrations created by the track and keeps them isolated within the tunnel of the snowmobile. The isolated sound vibrations are then dampened by the snow. Qualitative testing verified that this method was effective for reduction of unwanted sound vibrations with frequencies audible to the human ear.

# Summary/Conclusions

Through the design and implementation of the ideas outlined in this paper, it is anticipated that a production snowmobile will be produced that provides a healthy balance of cleanliness and performance. Care has been taken to account for performance parameters based on power production as well as efficiency of the snowmobile. While keeping the performance of the snowmobile at high levels, efforts have also been taken to reduce the overall environmental foot print of the snowmobile. Through innovation and proper installation, it is believed that a snowmobile worthy of competition has been produced and will be able to perform at high levels.

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# **Definitions/Abbreviations**

| Dropcase        | Gearbox or commonly known as a Chaincase |
|-----------------|--|
| СVТ             | Continuous Variable<br>Transmission      |
| DPF             | Diesel Particulate Filter                |
| DOC             | Diesel Oxidation Catalyst                |
| NDSU            | North Dakota State<br>University         |
| NO <sub>x</sub> | Nitrous Oxides                           |
| CO <sub>2</sub> | Carbon Dioxide                           |
| РМ              | Particulate Matter                       |
| НС              | Hydrocarbons                             |
| EPA             | Environmental Protection<br>Agency       |