Design of a Clean Diesel Snowmobile

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Abstract

Diesel fuel, by chemical makeup, contains more expendable energy per unit than standard gasoline. This, combined with higher compression ratios, gives diesel engines larger thermal efficiencies compared to their gasoline-powered counterparts. Despite the higher efficiency of a diesel engine, the mass majority of passenger and recreational vehicles are powered by gasoline engines. Potential reasons for this observation might be a result of higher air-pollutants emission, poor cold-weather performance, lower engine speeds, and the underlying “loud and dirty” stigma diesel engines carry with them.

There are currently no diesel-powered snowmobiles being produced by OEMs for logical reasons. A diesel engine works against every aspect of the modern snowmobile. It has poor cold-weather performance, low engine speeds, and is more harmful to the environment. However, as technology advances, engineers strive to take advantage of the higher thermal efficiencies that diesel engines produce, while reducing the negative aspects at the same time. This ideology is what drives our team to design a clean, environment-friendly diesel-powered snowmobile.

The 2018 model of the commercial Polaris Titan SP snowmobile has been converted from its original 2-stroke gasoline engine to a clean 3 cylinder, indirect injected, Kubota Super Mini Series D902-E diesel engine [1]. The primary goals of this overhaul are to produce a utility snowmobile that produces clean emissions, a low decibel rating, as well as an improved drawbar rating. More specifically, the 2019 IUPUI DUC intends to have a sled that passes the SAE J1161 steady state noise test, meets the Environmental Protection Agency’s (EPA) emissions requirements for off-road vehicles at the fuel-neutral level, and meets all of CSC minimum requirements detailed in Article 1, Section 2, Paragraph 3 (1.2.3) of the 2019 Society of Automotive Engineers Clean Snowmobile Challenge Rules [2].

Innovations/Modifications

Overview

Indiana University-Purdue University Indianapolis has picked up where its 2017 Diesel Utility Class left off with a major overhaul from original designs. This year, the team has acquired and converted a 2018 Polaris Titan SP to operate with the Kubota D902-E engine from the 2017 competition. Given such an overhaul, the 2019 IUPUI design team has turned their focus towards perfecting the conversion and ensuring the entire system maintains a stock appearance along with structural stability, mechanical reliability, and clean emissions.

Figure 1: 2018 Polaris Titan SP [3]

The 2019 IUPUI DUC Team will be incorporating their Kubota D902-E Super Mini Series 3-cylinder indirect injection engine (figure 4) along with a Volkswagen Jetta TDI diesel particulate filter and diesel oxidation catalyst unit (figure 5) used previously on the team’s 2017 sled.

Figure 2: Kubota D902-E Super Mini Series Diesel Engine [1]

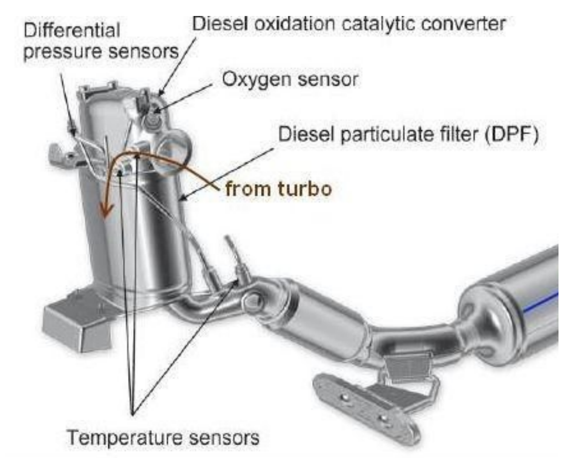

Figure 3: Volkswagen Jetta TDI DOC/DPF Unit [4]

Many modifications were needed to perform this engine-swap in order to retain functionality and reliability of the 2018 Polaris. These modifications include, but are not limited to: engine mounts, exhaust system integration, electrical integration, alternator relocation, battery relocation, engine-cooling system integration, and clutch / CVT system modifications. All of the modifications listed above were integrated in such a manner to optimize overall performance and functionality. A detailed description of each modification is outlined below.

Supercharger

The main innovation that is currently being developed for the diesel snowmobile is the pressure wave supercharger. The supercharger will allow for increased efficiency, better performance, and reduced emissions. The supercharger reduces emissions by using exhaust gases to force air into the intake, during this process some exhaust gases re-enter the intake where unburnt fuel can be burnt, see figure 1. The entire process can reduce NOx, and CO emissions due to the oxidation process.

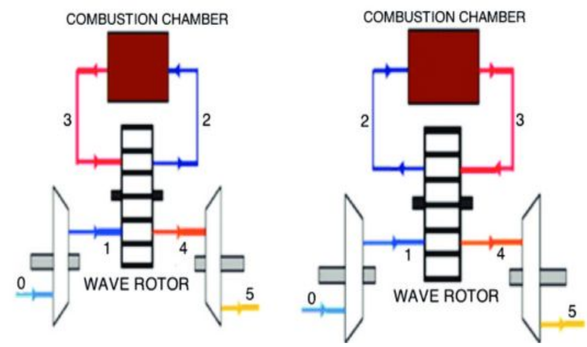

Figure 4: Supercharger Diagram [5]

Many modifications were needed to perform this engine-swap in order to retain functionality and reliability of the 2018 Polaris. These modifications include, but are not limited to: engine mounts, exhaust system integration, electrical integration, alternator relocation, battery relocation, engine-cooling system integration, and clutch / CVT system modifications. All of the modifications listed above were integrated in such a manner to optimize overall performance and functionality. A detailed description of each modification is outlined below.

Exhaust System

Arguably the most important component in consideration, the exhaust system needed to be engineered to surpass the expectations while limiting the parasitic-effects as much as possible. The team integrated a DOC / DPF from a Volkswagen Jetta TDI in order to reduce the emission of hydrocarbons, particulate matter, and nitrous oxides.

In the future, we plan to also add an exhaust gas recirculation system that will help in reducing emissions even farther. You can see a preliminary drawing of this design in Appendix A.2. This would significantly reduce the amount of unburnt hydrocarbons and NOx in the exhaust system by passing them back through the cylinders and allowing them to be burnt off.

Although our team looked into an EGR system, we ultimately decided not to add it to the snowmobile this year because we need to collect data about how efficiently our engine runs for its first year at the competition. This will help up spec out exactly how much we should return based on our hydrocarbon and nitrous oxide emission levels. Also, an EGR would be most effective if controlled by an ECU in tandem with a pressure wave supercharger so we have looked into the process of installing both of these to our snowmobile.

Engine Mounts

With the goal of retaining structural integrity in mind, the team decided to make no chassis modifications. The team utilized the preexisting motor mounts provided by Polaris from the factory. A bracket was designed in such a manner that would hold the engine in the appropriate position while utilizing the preexisting chassis-bound motor mounts. The bracket was fabricated to work with the preexisting attachment points and then was welded to the bottom of the motor.

Because diesel engines are heavier than gas, we ran a FEA on the brackets to test if they would withstand the weight, and we can clearly see by the figure below that they can easily withstand the weight of an engine over one thousand pounds.

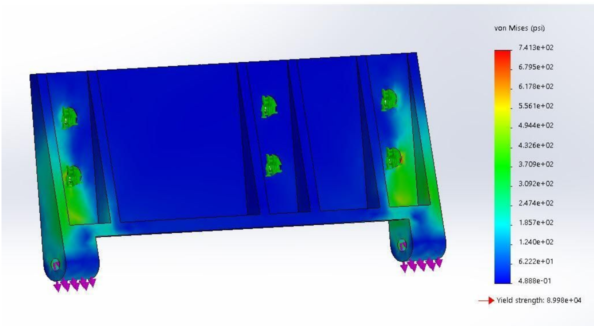

Figure 5: Mounting Brackets FEA

Electrical System

The stock snowmobile was equipped with an ECU and complete electrical system, however, due to the engine-swap, the team was unable to retain the mass majority of the electrical system. Retaining only the wiring for the headlights, taillights, and running lights, an electrical system was designed to ensure functionality and reliability. A wiring diagram for the chosen engine was provided by Kubota, which was used as a starting point for the overall wiring schematic. The team was challenged with the necessity of integrating the headlights, taillights, running lights, kill switch, and tether-kill switch as required by the SAE competition [2]. In order to meet these requirements, all unnecessary wiring was removed, leaving only the wiring for the headlights, taillights, and running lights. A Kubota key switch was utilized as the central electrical control source. In order to integrate the required kill switch and tether kill switch, these components were placed in series with the "ON" position of Kubota key switch. This ensured safe operation of the snowmobile by cutting power to the fuel system when it was appropriately required. The electrical system was bundled into a heat resistant harness that provided stability while still allowing mobility.

CVT / Clutch

The biggest challenge of using a diesel engine in a snowmobile lies within the nature of the diesel engine itself and the drive system of a snowmobile. First, a diesel engine (i.e. compression ignition) is more limited to its peak engine speed when compared to a spark ignition engine. The reason for this lies in the ignition method. Diesel engines' engine speed is limited by the injector capabilities and timing characteristics. Diesel engines, ideally, ignite at a constant pressure, which ultimately resolves to a timing and injection-timing concern. These two considerations lead to an innately limited lower engine speed. This directly works against the drivetrain system of a snowmobile, which works off of a larger engine speed range when equipped with SI engines.

In order to cope with the lower engine speeds of a diesel engine and the necessity of higher engines speeds required by snowmobiles, the team focused on changing the characteristics of the clutch, CVT, and drive-belt. The team chose a Ski Doo clutch with a lighter spring so that the clutch would engage the drive belt at a lower engine speed. The Ski Doo clutch was chosen due to its aggressive change in gear ratio characteristics. This allowed the snowmobile to harness the low-end torque advantages of a diesel engine.

A belt with a smaller width was also chosen in order to take advantage of the previously-stated low end torque. Because the driven clutch was not altered, it allowed the snowmobile to engage at a lower gear ratio to promote top-end speed. While reducing acceleration, this was an essential part of the design process in order for the snowmobile to reach its 35 MPH requirement.

Team Organization and Time Management

Proper team organization and time management is paramount when attempting to develop a competitive product. The team used skills they have developed throughout their educational and work careers to work together in a highly effective manner towards a common goal.

Team Organization

In order to enter the 2019 SAE Clean Snowmobile challenge with a competitive diesel sled, our team utilized a common project management approach of task disbursement with a core team manager. Based on individual strengths and task priorities, assignments were split amongst the team. From our core team, smaller teams such as our exhaust, electrical, mechanical, and management teams were formed.

The team was formed with a project team leader and two functional managers/leaders. A single manager was responsible for overseeing snowmobile production operations. The snowmobile production operations included the following sub groups:

- Electrical
- Exhaust
- Powertrain
- Fuel and Cooling Systems
- Mechanical

Due to the small number of people on the team, many, if not all group members were involved in all functions of the snowmobile production at some point.

The second functional leader was responsible for many of the clerical responsibilities of the project, such as the writing of the design paper, understanding and analyzation of rules, and the research and development aspect of the project. Again, due to the limited number of project members, all members were involved with almost all aspects involved with the clerical side of the project. Below you can see an organizational breakdown of the project:

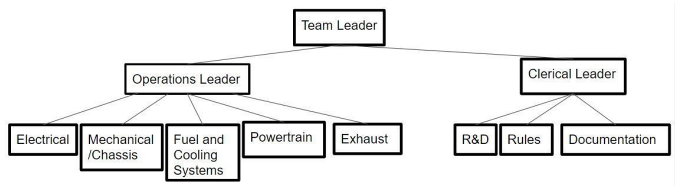

Figure 6: Team Organization Flow Chart

Time Management

The team decided at the beginning of the project to have weekly meetings with all members of the group to keep track of progress throughout the project, this type of time management was chosen due to the differing schedules of each member.

Snowmobile Specifications

Table 1 contains a list of specifications for the IUPUI 2019 DUC

Table 1. IUPUI 2019 DUC Specifications [1] [3]

Base Sled	2018 Polaris Titan
Track	155
Engine Model	Kubota Super Mini Series D902-E3B
Muffler	Kubota DF752-D902
DOC/DPF	Volkswagen Jetta TDI DOC/DPF Unit
Skis	Stock
Fuel	Diesel
Displacement	898cc
Peak Power	20.4 HP @ 3,000 rpm
Peak Torque	37.1ft-lbs
Combustion System	Indirect Injection/ Compression Ignition

Design Content of Snowmobile

The main goal of the entire competition is to design and build a diesel snowmobile that is both quieter and has reduced emissions when compared to production snowmobiles. The Indiana University-Purdue University Indianapolis team set out to design and build a Diesel snowmobile that could compete at a high level with the competition. The team set out the following goals when designing the snowmobile [2]:

- Build an operable snowmobile powered by a diesel engine
- Integrate an exhaust system that reduces hydrocarbons, nitrous oxide, particulate matter, and carbon monoxide
- A snowmobile that produces less than 67 dB at a distance of 150 feet while at steady-state operation
- Snowmobile that sustains at least 35 miles per hour for over 100 miles while consuming less than 14 gallons of fuel [2]
- Snowmobile that properly balances performance, reliability, and affordability
- Snowmobile that maintained the appearance of a production snowmobile
- Snowmobile that is competitive in the draw bar pull event

The team created these goals by understanding the rules of the competition, while also striving to design and build an innovative snowmobile that could be used to further engineering innovation in not only the snowmobile market but across the automotive market. The team used a QFD: House of Quality to work through their design considerations, see appendix A.1. and A.1.1.

Our house of quality primarily takes into account all of the scoring criteria and competitive results of the 2018 SAE DUC CSC. The scoring criteria has been captured under the vertical “Customer Requirements” section of the QFD where they can be cross referenced with the horizontal “Functional Requirements” of the diesel sled. Analysis of the relationships between the “Customer Requirements” and “Functional Requirements” of the DUC provided our team with a clear list of priorities when rebuilding IUPUI’s 2019 DUC snowmobile. Determination of the team’s highest priority, per the QFD, was a wash with all indications pointing towards the diesel engine and its components. Without careful selection of an appropriate diesel engine and flawless conversion of the chassis to operate with said engine, the IUPUI DUC would stand no chance in the 2019 SAE CSC (see “Engine” subsection of the Design Content). Following the priority of the diesel engine, the QFD pointed towards appropriate selection of DPF, DOC, and NOx filters for clean emissions as the next highest priority. Considering the entire competition revolves around building a clean, diesel powered snowmobile, this only made sense (see “Exhaust & Emissions” subsection of the Design Content).

With our design priorities set, a competitive analysis of our previous standings when compared to other DUC teams further defined our design criteria. Given the determination of the 2019 IUPUI DUC team to be as competitive as possible this year, we have set our sights on pulling above and beyond our competition. This means refining our design criteria to targets much more stringent than those defined in the 2019 SAE Clean Snowmobile Challenge rules sheet. Due to not competing in the 2018 competition, it was difficult to determine how our current build compares to the competition. Without knowing our current standing in the competition, it is nearly impossible to use the results of the competitive analysis to further define our design priorities.

Engine

Installing an engine that was not stock into the snowmobile caused many issues that had to be resolved. The first of these issues was mounting the engine. The way the Kubota D902 was designed to be mounted was slightly different than the original engine. This required brackets to be designed and fabricated. The brackets were then welded to the motor mounts, and the engine was installed onto these new brackets. These mounting brackets are displayed in the figure below.

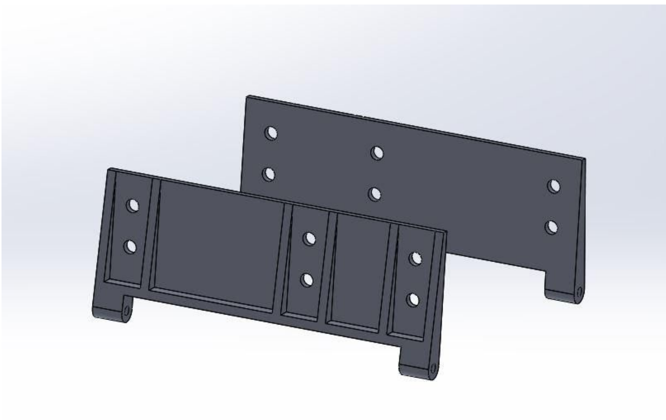

Figure 7: Mounting Brackets

With the engine mounted, the rest of the snowmobile could be assembled. When this was done, a few issues arose. One of those issues was interference between the steering column and the alternator. This interference prevented the snowmobile from turning to the right. Mounting the alternator in a different spot was considered, but this would require multiple mounting brackets to be fabricated. To reduce the amount of mounting brackets needed, simply rotating the alternator 90 degrees and putting a longer belt on it was the solution that was chosen. This solution only required one mounting bracket to be fabricated. The concept for this mounting bracket is shown in the figure below.

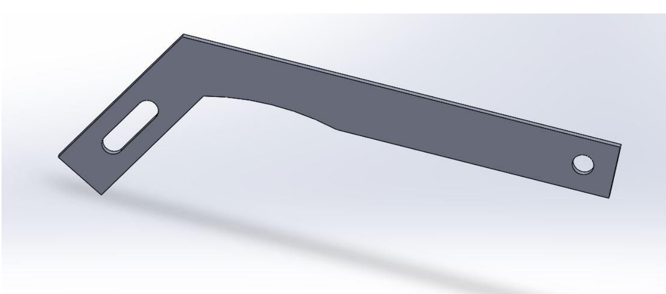

Figure 8: Alternator Mount

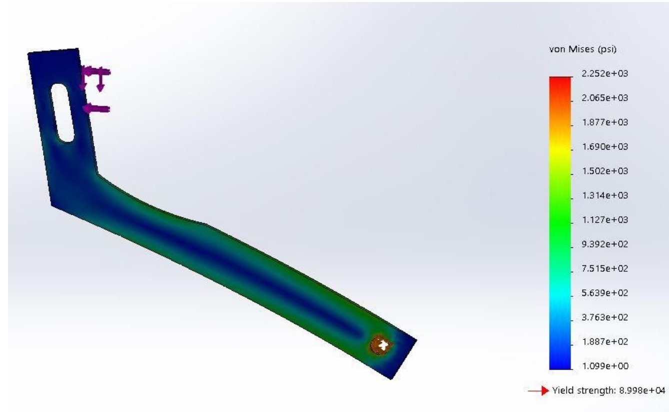

Figure 9: Alternator Mount FEA

Figure 9 shows the FEA that was done on the alternator bracket. The bracket was fabricated from a 12 gauge steel plate. The max force the bracket would experience was calculated to be around 25 pounds. Once this information was entered into the analysis, the force on the bracket was calculated. As shown in figure 9, the yield strength for this material is 89,990 psi, and the max force that the bracket experienced was 2,252. This proved that the design chosen was sufficient for the mounting bracket.

The team chose the Kubota D902 3-cylinder diesel engine due to its size, rated power output, emission standards, and quiet nature. The team did not design the snowmobile to utilize forced-induction, instead the engine will simply be naturally aspirated. The Kubota D902 engine complies with EPA tier 4 emissions regulations. The engine piston recesses were optimized to achieve lower particulate matter levels. The pistons were also coated to reduce noise.

The Kubota D902 diesel engine is capable of producing up to 21.6 HP or 16.1 kW, and slightly below 60 N*m torque [1]. The engine is designed to be operated between 1600 and 3200 RPM [1]. The engine specs can be seen below:

Table 2. Kubota D902-E3B Specifications [1]

Model	D902-E3B
Cylinders	3
Bore (mm)	72
Stroke (mm)	73.6
Displacement (mm)	0.898
Dry Weight (kg)	72

Proper engine temperature during normal engine operation is especially important. The group utilized an engine cooling system that will allow the engine to stay at a safe operating temperature even during long periods of use with heavy loading. The engine is cooled using a liquid-cooled system that not only involves flow through a radiator, but also the utilization of snow off of the sled track to cool the liquid that is flowing through a system of pipes. To further improve the efficiency of the cooling system, the team utilized a radiator fan that will operate when the engine temperature gets to 210 degrees Fahrenheit.

Exhaust & Emissions

The exhaust system for IUPUI's 2019 SAE CSC DUC sled is nearly identical to their 2017 sled with the exception of an added Kubota DF752-D902 muffler to ensure an acceptable noise level per the SAE J1161 steady state noise test. Due to the lack of baseline emissions testing, the exhaust and emissions team has had little data to base their design off of. Given such constraints, the IUPUI DUC exhaust and emissions team has deemed it necessary to reimplement their Volkswagen Jetta TDI DOC/DPF unit in order to meet the required EPA standards for a fuel-neutral offroad vehicle. With this in mind, the exhaust and emissions team spent most of their time and resources on redesigning the exhaust piping for their system so that routing does not interfere with critical components of the chassis and diesel system while also ensuring optimal performance and minimal air flow resistance/friction. The team decided that it would be best to utilize the OEM Kubota D902 exhaust muffler. The team decided to further improve noise reductions by utilizing exhaust wrap to reduce the amount of noise produced in the exhaust system. Another component utilized to further reduce engine noise was the usage of rubber mounting sleeves. The rubber mounting sleeves not only allow for some movement during engine loading to reduce component stress and fatigue, but the sleeves also help to reduce rattling and excessive shaking that is magnified by the usage of a diesel engine.

In order to verify our emissions design, testing was performed using the Huapeng HPC501 Automotive Exhaust Analyzer. This test was performed according to the five modes specified in Section 10 of the rules (see Table 3). Data was captured for hydrocarbons, carbon monoxide, and NOx at each mode in parts per million (ppm) then the emissions rate was calculated using the following equations:

$$ER = (1.912 \times 10^{-3})\frac{C_dQT}{HP\cdot hr} \quad \textit{(NOx Equation)}$$

$$ER = (1.164 \times 10^{-3})\frac{C_dQT}{HP\cdot hr} \quad \textit{(CO Equation)}$$

$$ER = (1.833 \times 10^{-3})\frac{C_dQT}{HP\cdot hr} \quad \textit{(HC Equation)}$$

In these equations, Cd represents the measured concentration of the gas in ppm, Q is the dry stack gas volumetric flow rate (measured in cubic meters per hour), T is the time of the test in hours (1 minute for the test), and HP-hr is the engine's brake work in HP-hr. Q is calculated by using the following equation:

$$Q = \left(\frac{Exhaust\ Temp.(°F) + 460}{540}\right) \times Intake\ Airflow$$

With an assumed exhaust temperature of 1200 degrees Fahrenheit and an intake airflow rate of 34 cfm (using 3000 RPM and a 0.8 volumetric efficiency), the final emissions rates can be calculated (see Table 4).

These emissions rates can then be weighted accordingly and a representative E-score calculated by using the prescribed equation [2]:

$$E\text{-}score = 100\left(1 - \frac{HC+NOx-15}{150}\right) + 100\left(1 - \frac{CO}{400}\right)$$

As seen in Table 5, the estimation for the current exhaust system setup will yield an E-score of around 200.65. This calculation can be treated as a worst case scenario since the highest tolerances for the emissions tester were added to the recorded values for the provided calculations. Consequently, it is reasonable to assume that the previously discussed exhaust design will be able to comply with emissions constraints for a minimum E-score of 175.

Figure 10: Installed Jetta TDI DPF/DOC and Kubota DF752-D902

Table 3. Emissions Test Engine Modes

Mode	**RPM**	**Torque**	**HP**
1	3000	37.1	21.19147
2	2550	18.921	9.186502
3	2250	12.243	5.244889
4	1950	7.049	2.617147
5	1200	0	0

Table 4. Emissions Rates per Engine Mode in g/kW-hr

Mode	HC ER	CO ER	NOx ER
1	0	0.7563	2.159737
2	0	1.7447	5.200355
3	0	3.0559	8.825938
4	0	4.0963	22.01791
5	0	10.721	43.15269

Table 5. Weighted E-score Calculation

Mode	E-Score	Weighed
1	208.3710918	25.005
2	206.0969176	55.646
3	203.3520674	50.838
4	194.2973207	60.232
5	178.5513906	8.9276
	Total:	**200.65**

Fuel Economy

The team designed the sled to complete the 100 mile range test with excess fuel left in the tank. The snowmobile is equipped with a 14-gallon fuel cell. Diesel engines are more fuel efficient than gasoline engines, and diesel fuel contains 10%-15% more energy than gasoline. It is not uncommon for diesel engine vehicles to travel up to 35% farther on one gallon of diesel than a gasoline powered car [6].

The team set a conservative fuel mileage goal of at least 10 mpg, this fuel mileage would allow for the completion of the 100 mile range event with plenty of fuel in reserve.

Noise Reduction

Utilizing the Benetech® GM1351 Digital Sound Level Meter, multiple steady state sound tests were performed before wrapping the exhaust. Testing was performed in downtown Indianapolis with an ambient sound of around 60db and the engine cover off. Due to a lack of snow and driveable terrain, the tests were performed with the snowmobile in neutral and at a distance of 50 feet and various RPMs.The idling noise level of the snowmobile at 50 feet averaged around 69db and the noise level at full throttle averaged around 76db. Given a target of 67db during steady state testing at a speed of 35mph, additional noise reduction was deemed necessary and therefore the 2019 IUPUI DUC exhaust team decided they will wrap their exhaust with a sound blanket.

Performance

The team developed multiple ideas and designs when attempting to improve overall snowmobile performance in events like the Draw Bar Pull, Acceleration, and Handling events. The team relocated the battery system to a position that is directly above the sled track suspension system. The relocation of the battery system will improve traction and reduce slippage as the loading increases in the Draw Bar Pull event. The suspension system was tuned in order to improve sled handling during the Acceleration, and Draw Bar Pull event [2].

References

1. Kubota, comp. "Kubota." D902-E3B: 1-2. Accessed February 18, 2019. http://www.kubotaengine.com/assets/documents/05_d902_32.pdf.
2. Society of Automotive Engineers International. "2019 SAE Clean Snowmobile Challenge® Rules." May 10, 2018. Accessed February 18, 2019. http://www.saecleansnowmobile.com/cdsweb/gen/DocumentResources.aspx.
3. Polaris. "800 TITAN™ XC 155." Polaris.com. Accessed February 18, 2019. http://www2.polaris.com/en-ca/snowmobiles/2018/800-titan-xc-155.
4. "Diesel Particulate Filter DPF FAQ, Repair, Cleaning, and Pictures - TDI." VW TDI Forum, Audi, Porsche, and Chevy Cruze Diesel Forum. Accessed February 18, 2019. https://www.myturbodiesel.com/wiki/diesel-particulate-filter-dpf-faq-repair-cleaning-and-pictures-tdi/.
5. Suzanne Drumm. “Pressure Wave Super Charger Notes,” DOCX. Indianapolis.
6. "Diesel Vehicles." Fuel Economy. Accessed February 18, 2019. https://www.fueleconomy.gov/feg/di_diesels.shtml.
7. SolidWorks®. SolidWorks® Student Edition. Computer software. Version SW2018. Vélizy-Villacoublay, France: Dassault Systèmes, 2018.
8. Joshua Manis et al., “Design of Diesel Snowmobile With Pressure Wave Supercharger Phase 1,” IUPUI, (February 2017).

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Acknowledgments

The Indiana University-Purdue University Indianapolis 2019 Society of Automotive Engineers Clean Snowmobile Challenge Diesel Utility Class Design Team would like to thank:

- Polaris for the donation of their 2018 Polaris Titan 800
- Kubota for the donation of their Kubota Super Mini Series D902-E3B engine

Definitions/Abbreviations

Table 6: Definitions and Abbreviations

IUPUI	Indiana University-Purdue University Indianapolis
DUC	Diesel Utility Class
SAE	Society of Automotive Engineers
EPA	Environmental Agency
CSC	Clean Snowmobile Challenge
FEA	Finite Element Analysis
DPF	Diesel Particulate Filter
DOC	Diesel Oxidation Catalyst
EGR	Exhaust Gas Return
IDI	Indirect Injection
CI	Compression Ignition
RPM	Revolutions Per Minute

Appendix A

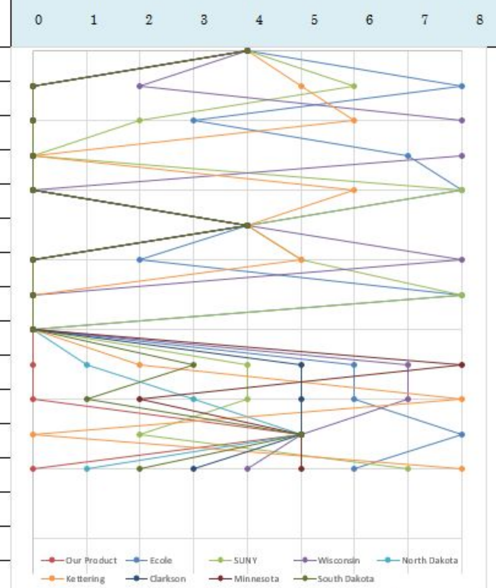
A.1. Quality Function Deployment
A.1.1. Competitive Analysis
A.2 Supercharger and EGR Design

A.1. Quality Function Deployment

					Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
					Direction of Improvement	▲	◇	▲	◇	▲	◇	◇									
Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Functional Requirements / Customer Requirements (Explicit and Implicit)	Diesel Engine and Components	DPF/DOC Filters	Muffler	Track/Studs	Wiring	Continuous Variable Transmission	Ample Electrical Storage									
1		13%	5	9	Diesel-powered	●						●									
2		10%	4	9	Noise level below SAE requirement	○	○	●	▽												
3		13%	5	9	Emissions level below SAE requirement	●	●				▽										
4		10%	4	9	Minimum of 35 mph (acceleration)	●	▽		○		●										
5		8%	3	9	Fuel Economy	●	▽	▽	▽		●										
6		8%	3	9	"Stock" design apperance	▽	▽	○	○	●	▽	▽									
7		5%	2	9	Load (drawbar pull) capabilities	●	▽	▽	○		▽										
8		8%	3	9	Cold Start	●				○		●									
9		5%	2	9	Tether kill switch					●											
10		5%	2	9	Low MSRP	●	○	○	○	▽	▽	▽									
11		3%	1	9	Presenting	●	○	○	▽	▽	▽										
12		5%	2	9	No Maintenance	○	○	○	▽	▽	▽	▽									
13		10%	4	9	Design Paper	●	●	●	▽	○	▽	○									
14		0%																			
15		0%																			
16		0%																			

A.1.1. Competitive Analysis

Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit)	Customer Competitive Assesment: Our Product	Ecole De Technologie Superieure	SUNY - Buffalo	Univ of Wisconsin - Platteville	North Dakota State Univ	Kettering Univ	Clarkson University	Univ of Minnesota - Duluth	South Dakota School of Mines & Tech	Row #
1	IIIIII	13%	5		Diesel-powered	4	4	4	4	4	4	4	4	4	1
2	IIIII	10%	4		level below SAE requi	0	8	6	2	0	5	0	0	0	2
3	IIIIII	13%	5		ns level below SAE req	0	3	2	8	0	6	0	0	0	3
4	IIIII	10%	4		um of 35 mph (accele	0	7	0	8	0	0	0	0	0	4
5	III	8%	3		Fuel Economy	0	8	8	0	0	6	0	0	0	5
6	III	8%	3		tock" design apperan	4	4	4	4	4	4	4	4	4	6
7	II	5%	2		d (drawbar pull) capabi	0	2	5	8	0	5	0	0	0	7
8	III	8%	3		Cold Start	0	8	8	0	0	0	0	0	0	8
9	II	5%	2		Tether kill switch	0	0	0	0	0	0	0	0	0	9
10	II	5%	2		Low MSRP	0	6	4	7	1	2	5	8	3	10
11	I	3%	1		Presenting	0	6	4	7	3	8	5	2	1	11
12	II	5%	2	9	No Maintenance	5	8	2	5	5	0	5	5	5	12
13	IIIII	10%	4	9	Design Paper	0	6	7	4	1	8	3	5	2	13
14		0%													14
15		0%													15
16		0%													16



A.2 Supercharger and EGR Design