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Implementing a Kubota Diesel Engine into an Arctic Cat Bearcat Chassis

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Innovations

The most significant part of the diesel utility snowmobile this year is the Team's custom-made exhaust DPF system that allows us to regen the exhaust. The exhaust then consists of four particulate filters that catch "soot" produced by the diesel engine. Blackthorn Industries made this possible, as they allowed the Team to run their DPF exhaust system last year for the Clean Snowmobile Challenge. This exhaust system was originally designed for a mini-excavator. Other innovations include a smaller gas tank to reduce weight and several modifications to the skid. The modifications to the skid include multiple anti-stab kits so we can reduce the number of boggy wheels in the skid. One kit was installed at the very front of the skid with a second implemented on the shaft that holds the front shock, and lastly the third was implemented in the rear of the skid to keep the track from walking back and forth against the big wheel kit. The big wheel kit was also improved from past years to reduce weight and to have a more secure mounting system.

Team Organization and Time Management

This year, the Team corresponded with the shop supervisors to create a schedule that worked with the machining times. This schedule was not just for Clean Snow, but it was for all the clubs that use the machines in the shared shop. The shop is shared between the four SAE clubs, robotics, and senior design. The time management within the Team was divided into certain projects and based on prior knowledge and experience. If one had a busy schedule, it was one's responsibility to make time. If one could not find the time in-between school and other responsibilities, the responsibility was passed onto another teammate. SAE as a whole attends several events, such as Pioneer Previews, which is a preview for new students who are considering attending UW-Platteville. All SAE teams at UW-Platteville attend this event whenever it is held on campus. Usually one or two teams bring a vehicle. Another event held on campus every year is Engineering Expo. This event is held for middle school through high school aged students to experience what engineering is all about.

Design

Chassis

Dependability, practicality, and ergonomics made the Arctic Cat Bearcat 3000 LT chassis an appealing choice. The chassis allows for an enjoyable and comfortable ride. One of the features removed from the chassis was the heat exchanger. It was no longer needed due to low running temperatures in the motor during the conditions at competition.

This year, the seat bracket was reengineered to have a sleeker look. This design change was due the decreased size of the fuel tank. The seat bracket was drawn in SolidWorks 2018 and put the Finite Element Analyst (FEA) Simulation. The metal used was a 1020 Steel Alloy. There was a gravitation force of 10G's, 3860 in/s^2, load applied over the entire seat bracket to represent gravity. Another 450 lbs was added to specific parts of the bracket to imitate a rider. The seat bracket has a safety factor of 16.9.

When the new seat bracket prototype was designed, the steel pipe was bent, cut, welded and notched to hold the fuel tank in a safe position while supporting the seat. The main goal of the innovated seat bracket was to remove the rear seat framing to reduce weight. This was a challenge since the framing holds the fuel tank in place using factory mount points. After the mock up version was constructed and the Team further researched the correct placement of supports, the final version was made by being bent, notched, welded and painted for installation on the snowmobile.

An additional modification to the chassis was the motor mounts. The stock motor mounts were bulky and heavy which was not ideal. The new mount designs were to create strong, light weight brackets. The new bracket consists of two pieces that hold the motor in place, one in the front and one in the back. Design ideas from the old mount were able to help inspire the new design. The motor mounts were made of a 6061 Aluminum Alloy.

The motor mounts were drawn in SolidWorks 2018 and put through the FEA Simulation. Loads that were applied to the mount were 10Gs over both mounts and a force at each hole where the motor attaches to the mount. The motor is 160 lbs. and after 10G's were applied to it, the holes were holding an uneven distributed force of 1600 lbs. through 12 holes, 6 on each bracket. The weight was unevenly distributed due to the center of gravity in the motor. The motor brackets had a factor of safety of 1.5.

Engine

The UW-Platteville Clean Snowmobile Team decided to power their utility style snowmobile with a Kubota D902 diesel engine. The D902 is a small displacement, naturally aspirated diesel engine. The main reasons this engine was chosen is for its proven durability, low emission output, compact size and ability to be paired with a turbocharger. This engine is shown in Figure 1.

During engine selection, engine speed was put into consideration. The D902 engine speed was set at 3600 rpm from the factory. With an increase of 200 rpm, a larger window to tune the continuously variable transmission was created. The engine was tuned for proper speed and efficiency while accounting for boost pressure.

The Kubota E-TVCS (Three Combustion System) gave way to another reason as to why the D902 was a promising choice. This technology is known for its talent to reduce exhaust emissions, engine noise, and increase performance. The system takes advantage of an optimum stoichiometric ratio where it creates three vortexes inside of its spherical-combustion chamber. The swirl chamber is shown in Figure 2. Compressed air is forced into the swirl chamber due to the redefined concave recesses piston. This concludes in achieving an ideal air/fuel ratio and smooth combustion gas exhaust. Throttle nozzle injectors control the injection quality at the beginning of combustion, assisting in reducing the known diesel knocking noise that results from excessive fuel injection. The half floating valve cover isolates engine vibrations and reduces the noises that resonate in the crankcase. Rubber ring seals in the engine valve cover also reduce vibrations and sounds.

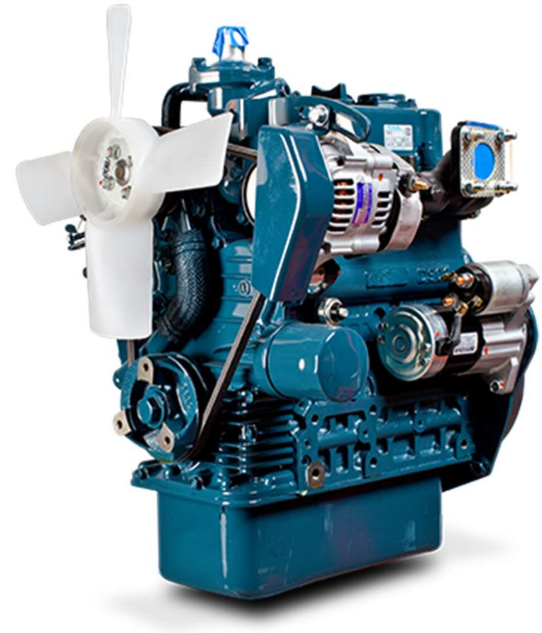

Figure 1. Kubota D902 Engine [5].

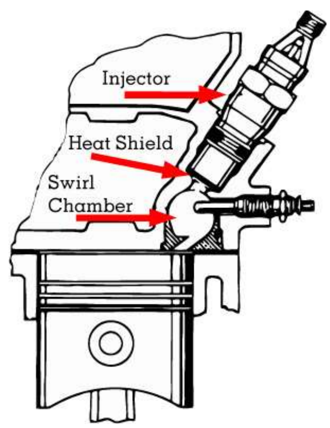

Figure 2. Swirl Chamber [6].

The D902 is known to be highly versatile for a wide range of applications due to its dimensional size and weight. The weight increase from the OEM Bearcat engine to the D902 is 43 lbs. The weight increase of the snowmobile withholding the D902 is significantly less than the most common small diesel engine that could be implemented. Weight is a concern for engine selection as it has an impact on fuel efficiency, stability, and ride quality.

In order to determine the most efficient engine calibration, an emissions analyzer collected baseline data. Data points were collected at various timings with set fuel delivery as the engine was ran through a ramped modal dyno session. The main goal was to reduce the engine deliver blocks to midrange to create a manageable power range. This justified the pairing of the turbo with the given fuel supply. An increase in horse power from 23 to 27 horse power was gained with the addition of a 26mm turbocharger. Maximum horsepower seen for this engine with a turbo is 35 horsepower. To implement the turbocharger, the size of the compressor and the turbine wheel had to be considered. The turbocharger installed was chosen over those of larger diameter due to its rapid response time. Since it is a relatively small turbocharger, it produces a smaller boost lag and operates more efficiently. By collecting data from the emissions analyzer and the dyno, it was determined that 10 psi of boost best met the Team's design goals for competition. To accommodate for the additional air flow from the added turbo, the D902 also needed to be re-tuned.

Track

The track that was selected was designed by Camso which can be seen in Figure 3. This track is lighter than the stock track offered on the snowmobile. The Camso track weighs only 40.8 lbs, and the stock track weighs 42.3 lbs. The weight savings were accomplished by the new track having ports in it through the track being ported, shown in Figure 3, and being only a single ply track. The new track also improves track noise, helping it fall into the given sound regulations for the competition. In addition to sound and weight improvements, the Camso track incorporates other design elements. The track imitates the ripsaw track with a 2.8 pitch and an additional feature the new track provides is the in-lug studs. This increase the traction of the sled, while also being slightly lighter in weight than traditional studs.

Figure 3. Camso track.

Muffler

The stock Arctic Cat Bearcat 3000 muffler was modified to fit the custom DPF system. This was done by cutting the top and the bottom off the muffler. All the internals were removed and were replaced with the components for the DPF system. No additional baffles were needed in the muffler. This decision was made because of the DPF system that was run last year without a muffler and stayed within the noise constants.

Catalytic Converter

The catalytic converter that was chosen was designed to be run with the Blackthorn DPF that had been implemented into the muffler. The catalytic converter is designed and built by Blackthorn. It features two stages of coatings each working to reduce emissions. The compact size of the catalytic converter allows it to easily be placed into a canaster for the exhaust system. This allows for simplistic replacement of the catalyst without having to completely replace the entire pipe to the muffler.

Skis

The Bearcat chassis is equipped with trail OEM Arctic Cat skis verses the stock utility style skis which come on the Bearcat. This change was made to conserve weight and reduce noise.

Driveline & Suspension

To maximize the performance of the drivetrain, a C3 belt drive system was utilized. This system increases efficiency, alleviates friction, and reduces mass. The belt drive reduces noise due to the nature of a belt drive system versus a chain driven system. Additionally, it is a loss of weight throughout the drivetrain. The total weight savings of the belt drive system resulted in an 8 lbs loss compared to the traditional system. The belt drive system requires much less maintenance without the need to check the oil. In fact, it is more environmentally friendly because it does not use an oil lubricated system.

The UW Platteville Cleans Snowmobile Team has decided to run graphite infused UHMW slides. These were chosen over the standard factory Arctic Cat slides because of their reduction in friction and increased life.

By using a big wheel kit in the rear, replacing the standard boogie wheels it reduces the torque required by minimizing the angular acceleration of the track. Not only that but with the larger diameter that the wheels create, it decreases the track deflection, minimizing energy that is wasted with the bending of the track. This is displayed in Figure 4.

Another performance improvement that has been added to the drivetrain would be the usage of a machined rotor. Not only does this rotor reduce the drivetrain weight by 1.5 lbs, but it runs at cooler temperatures allowing better airflow through the whole brake system itself. Another feature utilized for reduced sound is an introvert drive axle. This also assisted in weight reduction compared to the traditional extrovert drive axle.

Along with the other changes, the Team decided to make changes to the skid with hopes to reduce weight, prevent track derailment, prevent hyfax wear, and ensure a better ride. To do that, the front gas shock was recharged, and the oil was changed to proper manufacture specification to ensure a smoother ride. Small inner idler wheels were added to the bracket that the shock rests on. This prevents wear to the hyfax in order to compensate for lack of idler wheels near the front. Furthermore, in the middle of the skid, there were four larger idler wheels, so one pair was removed to reduce the weight and sound. The larger pair of idler wheels was replaced by a smaller pair that was placed further back, which helps reduce the wear of the hyfax in the back and prevents the chance of track derailment. New bogie wheels were added to reduce the weight with the new design which requires less material than the previous design. To reduce more weight, the bracket for the rear shock was changed and the inner idler wheels were added to the bracket rather than the front. However, that attempt failed because it requires a cross brace to keep the shock working and the bracket from collapsing. Once the failure was observed, it was decided to keep the original bracket and add smaller idler wheels in front of it.

Figure 4. Custom idler wheels.

Clutching

The factory Arctic Cat clutching on the Bear Cat 3000 was replaced with the Team Rapid Response Primary and BOSS Secondary. The primary clutch features a 30mm tapper with custom weights, springs and a steel spider. The benefit of the steel spider is added strength as well as a wider roller bearing for wider, heavier weights. The main benefit of this primary is the roller bearing on the post. This allows the use of a tighter belt with less belt wear while idling. It will also auto tension the belts. The BOSS secondary is built onto the jack shaft allowing for a lighter set up. The design of the secondary allows the belt to go further into it allowing for a possibly higher overdrive. This secondary also features a custom helix and spring.

Cooling

The stock coolant locations were used on the snowmobile, but the hose routing was modified to fit around the diesel engine. The radiator from the stock sled was removed to gain more heat retention. While running with the radiator, the engine ran steady around 155 F under load and operating conditions. While idling, it would reach a maximum temperature of 175 F. With the radiator removed, operating temperatures reached 170 F, when idling it reached a maximum temperature of 190 F. The temperatures without the radiator are still within recommended operating temperatures. They are closer to the ideal temperatures the engine should run at to achieve maximum efficiency. After removing the radiator, a tunnel heat exchanger was fitted to see if there would be any additional benefits to running a cooling system of that type. After trying the heat exchanger, it was found that this was more efficient at keeping the engine cooler than the stock radiator.

Undercoating

In an effort to reduce resonation, the underside of the tunnel was coated with automotive undercoating. The mass of the undercoating mitigates the vibration amplitude of the tunnel connecting points to reduce the level of noise produced.

Exhaust *Manifold*

Since a turbo kit was implemented on the diesel engine last year, the Team cast a custom manifold to accommodate that change. The reason behind this was because the original stock manifold needed an adaptor, so the turbo could attach to it. With the adaptor given, it would extend the exhaust out a total of two inches. With the casted manifold, the correct distance was maintained of the exhaust from the engine so everything would fit under the stock plastics and bolt up directly without the use of adaptors. A flow bench test was completed on both manifolds and the cast manifold had almost the same amount of air flow, with flowing .1 CFM over the stock manifold. This is shown n Figure 5.

Figure 5. Casted Exhaust Manifold.

Steering

The original steering from the stock Bearcat chassis was modified to accommodate the new diesel engine. This is shown in Figure 6. The stock steering post was modified by adding two knuckle joints and a smaller diameter shaft to reduce weight. The top steering post, where the handle bars attach to, is still stock. The two knuckles were implemented so the shaft could be re-routed over the engine since there was no other way of getting a steering shaft to the tie rods except for going over the engine. To keep the steering shaft in place, a bracket was made to house a ball bearing that goes around the shaft. The bracket was mounted to a cross member for the bulk head which was also manufactured in house.

Figure 6. Steering system.

Emissions

With a focus on reducing particulate emissions, the UW-Platteville Team deployed a diesel particulate filter downstream from a diesel oxidation catalyst. The DOC and the original DPF was manufactured by Blackthorn, but only the principles of the DPF where kept when redesigning it for the D902 and the Bearcat 3000 chassis. The Blackthorn DPF is also sized for the output of the Kubota D902, however not for the Bearcat chassis. We worked with Blackthorn to utilize the design of their DPF but instead reengineered it for a specific purpose. Just like the Blackthorn DPF, the new DPF utilizes ceramic fiber filters that offer a filtering efficiency of 85% [5]. This configuration is ideal for the diesel snowmobile application because it catches soot particles regardless of temperature. After testing their product, it was found that the regeneration process is only needed approximately after every 10 hours of run time. The regeneration process takes place when the sled is off duty, using a separate rechargeable battery back that plugs into the DPF. It uses a heating element along with an air pump to heat and move air through the filters. The DPF also acts as a muffler for sound attenuation. The Blackthorn DPF can be seen in Figures 7 through Figure 10.

With an emphasis on reducing particulate emissions, the UW-Platteville Team positioned a diesel particulate filter to back up the diesel oxidation catalyst. Blackthorn has proudly manufactured both products. The purpose of the two-module exhaust system is to minimize the output of the following: hydrocarbons, carbon monoxide, nitrogen oxides, and soot. Trial runs revealed that the application of the Kubota D902 in a snowmobile creates an average exhaust temperature of approximately 260°C (500°F). This temperature is quite lower than common diesel engines, making the process more difficult to oxidize or burn off soot. The DOC was specifically created for use on the Kubota D902 and consists of a low temperature coating on a metallic monolith substrate. This substance allows for better conversion of hydrocarbons, carbon monoxide, and nitrogen oxide over a great range of exhaust temperatures. Blackthorn's DOC was made with a conversion efficiency of 70-90% [4]. Figure 11 represents the conversion efficiency of the Blackthorn DOC with correlation to the exhaust gas temperature. The top of the temperature range for conversion efficiency begins around 250°C or 480°F and above. The DOC was positioned close to the exhaust manifold and wrapped in 1/16 Accel exhaust heat shield wrap to help hold a high exhaust temperature.

Figure 7. Top View of the DPF.

Figure 8. Bottom view of DPF with inside chamber.

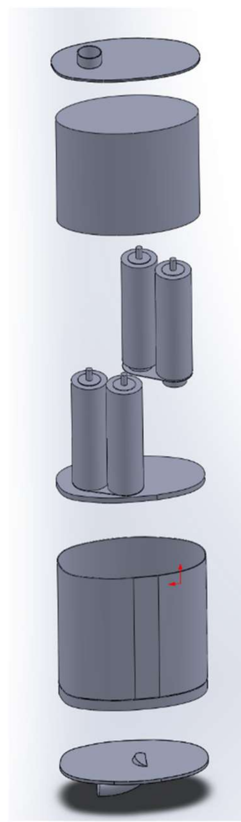

Figure 9. Exploded view of the DPF.

Figure 10. Solid view of the DPF.

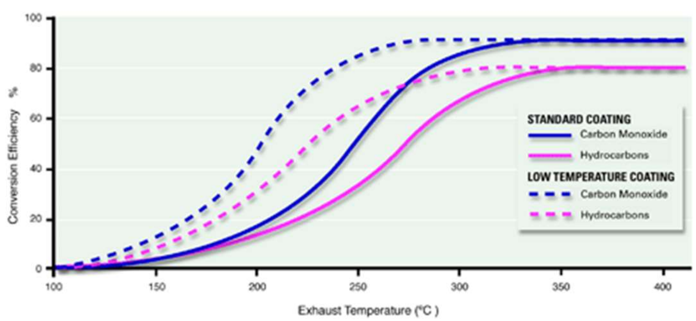

Figure 11. Effect of Temperature on the operation of a diesel oxidation Catalyst [3].

Emissions were monitored using an e-score to verify how well the catalyst was working. The e-score is a rating based on the number of unwanted compounds that leave the exhaust system. The score considers hydrocarbons, carbon monoxide, and nitrogen oxides. Equation 1 is the equation used to calculate the score. The HC, NOx, and CO values are measured in ppm using an exhaust gas analyzer and then later converted to g/kW-hr based on fuel flow, H/C ratio, and weather data for that day.

$$\boldsymbol{E = \left[1 - \frac{(HC + NO_x) - 15}{150}\right] * 100 + \left[1 - \left(\frac{CO}{400}\right)\right] * 100}$$

Equation 1. E-score calculation equation.

The max E-score that can be attained is 210 and must be 175 to pass in the competition. Also needed to pass is no more than 90 g/kW-hr of HC+NOx and no more than 15 CO g/kW-hr.

Cost

With the main goal of re-engineering a snowmobile ideal for utility usage, the Kubota D902 engine replaced the stock motor out of the MSRP chosen base model, the 2019 Norseman 3000 ES. The snowmobile's performance was then improved by implementing various modifications for an estimated added value of $4,150.59 over the stock snowmobile MSRP for a total of $14,349.59.

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Information

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Definitions

Cubic Feet per-minute	CFM
Carbon Monoxide	CO
Clean Snowmobile Challenge	CSC
Diesel Oxidation Catalyst	DOC
Diesel Particulate Filter	DPF
Hydrocarbon	HC
Miles per Hour	mph
Nitrogen Oxide	NOx
Original Equipment Manufacturer	OEM
Revolutions per minute	RPM
Society of Automotive Engineers	SAE
University of Wisconsin	UW