Ford 1.0 L EcoBoost Implementation into a Conventional Snowmobile Chassis

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Innovations

Innovations for this year's competition sled include but are not limited to variable valve timing calibrations and an altered engine mounting position. Variable valve timing has been one of the main focuses for this year's machine. Last year the variable valves were fixed at a specific point in relation to the cam gear in comparison to now. Currently the camshafts change the valve opening timing in respect to intake manifold pressure and engine rpm. The new timing table targets the Atkinson cycle during cruising low load engine operations and while under high load (acceleration) the timing tables revert to an Otto cycle. The theory behind the Atkinson cycle is to lengthen the power stroke while decreasing the length of the compression stroke, since with the 1.0L EcoBoost changing stroke length is not feasible. The same principle can be achieved by changing the valve timing. The Atkinson cycle acts much like an EGR in the sense that the exhaust valve remains open while the intake valve is also opened, this then pulls already combusted fuel and air back in with fresh air. The Otto cycle is the same principle as a four-stroke engine which is far less fuel efficient but has a much higher power density.

The new engine mounting position has allowed the use of the stock chassis over structure. It has also allowed for all aspects and parts of the sled to be contained within the factory plastics, which includes being able to run the headlight in the original location.

Team Organization and Time Management

The University of Wisconsin-Platteville team has been competing since 2002. Each year after competition a few members are nominated to become the new captain. Then each of those members give a brief speech on their plans for the team's future. The remaining members then anonymously vote for their next captain. This year's captain is Camden Stoppleworth. He oversaw organizing and assigning projects for individual members to complete. He also led discussions with the team, debating what needed to be improved and what projects were priorities. One way the team stayed organized was using SharePoint through OneDrive. By using that, projects were able to be assigned and the list of tasks was easy to find. At the team's weekly meetings timelines for certain projects were regularly set. Not only did members go to the shop to work on the snowmobile throughout the week, there was also a set schedule of being in the shop every Friday night. Along with being in the shop, the team stays very involved with the entire Society of Automotive Engineers. As a club our members participate in a highway cleanup every year and maintain Platteville's M. The team also regularly promotes our club by going to involvement fairs, admitted student's days, and being in the homecoming parade. Team bonding occurs at least once a week when team dinner takes place prior to our Wednesday meetings.

Build

Chassis Selection

The University of Wisconsin Platteville CSC Team has selected the Arctic Cat ProCross chassis as the base for the 2019 competition. Due to the heavier and larger 1.0L Ford Ecoboost engine being utilized, selecting a base chassis that would accommodate the additional weight and size was important. With the near 70 lbs of added weight from the EcoBoost engine and its larger size, the stiffness of the ProCross chassis and its larger engine compartment was an important deciding factor. The ProCross chassis selected is made up of an inner and outer-formed shell with a boxed support structure and utilizes a two-piece tunnel which saves weight and adds the additional strength needed. Arctic Cat's ProCross chassis has proven its performance for years and has developed into a snowmobile that handles extremely well, this is a result of its slide action rear suspension and distinctive A-arm architecture. Handling directly correlates to the strength of a vehicle's design. According to Brian Dick, Arctic Cat's Performance Team Manager, "The ProCross chassis is a very strong chassis. It's got a two-piece tapered tunnel design that gives you great stiffness as well as good [ergonomics] with the side walls being tipped in, [and it] allows the rider to stand up, sit down, [for a] nice transition." [1]

Engine

When discussion started about what engine would be the best for our team to utilize, the gasoline, turbocharged, direct injection (GTDI) Ford 1.0L EcoBoost engine had locked members' attention. This recognized International Engine of the Year is displayed in Figure 1. Not only did the team wish to stand out by doing something unique, the members' research discovered all of this engine's advantageous features including variable cam timing, turbo charging, direct injection, a variable displacement oil pump, and fly-by-wire.

Figure 1. Ford 1.0 L EcoBoost.

The use of direct injection results in less fuel being used, when correctly tuned, compared to traditional port injection. Another benefit of this feature is its capability of multiple injections per stroke which creates a more efficient fuel combustion. Another result is a quieter running engine [4].

During the acceleration process, the small low-inertia turbo results in minimized lag response [5]. The turbine's blade design reduces the engine sound as it creates less exhaust noise and turbo whistle. Engines that are not fitted with a turbo have higher fluctuations in exhaust gas velocity which will increase the overall sound due to additional exhaust noise. Whereas this engine has a spinning impellor which generates a uniform exhaust flow compared to an engine without a turbo.

This engine is also equipped with a variable oil pump. This pump provides a precise amount of oil pressure for various operating conditions. By having this specificity, there is a reduction of unnecessary pumping losses which causes the engine to be more efficient overall. This year is the first time the team has chosen to utilize this advantageous feature.

Another feature that minimizes engine losses is the oil bathed timing belt. This component reduces weight and friction, compared to a traditional timing chain.

The fly-by-wire creates the ability to stabilize the idle control at any temperature without needing to cut ignition timing. Having this feature also creates the future opportunity to implement cruise control.

Three-cylinder engines require engine balancing due to inherent rocking. To solve this challenge, Ford incorporated a unique balancing system. The need for a countershaft becomes eliminated by utilizing an unbalanced flywheel and a harmonic balancer. Since there is no longer a need for a counter balancing shaft, a chain is also eliminated. This results in less overall friction losses and minimized engine vibrations.

To improve throttle response of the engine, the flywheel was lightened to compensate for the added weight of the primary clutch. The flywheel used in past years weighs 18.7 lbs. whereas this year's is much lighter coming in at 10.7 lbs. The test procedure used to conclude the 8 lbs. lighter flywheel has a lower inertia value included taking a string wrapped around each wheel with a constant mass attached to the end of the string. The mass was dropped from a specific height, and the time in which it took for the mass from the release point to the ground was recorded and used in the calculations for inertia. This setup is displayed in Figure 2. With this data the new flywheel can be concluded to have 50% less inertia.

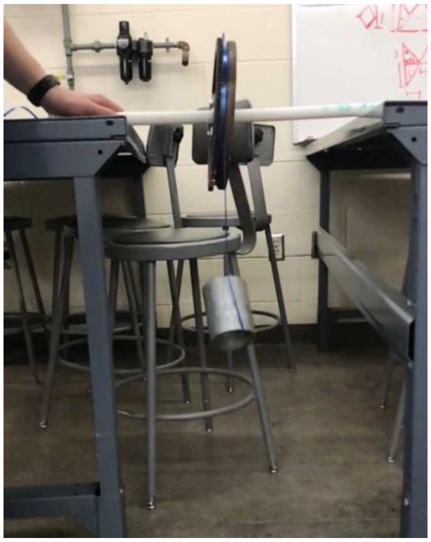

Figure 2. Flywheel inertia testing.

Another beneficial feature of this engine is Ford's Split Cooling System. This system has two thermostats, which allow critical engine components to achieve operating temperature in less time. When the coolant within the block reaches operating temperature, the rest of the engine begins circulating. The oil then heats up quicker and as a result, the amount of emission released during cold starts is reduced.

To reduce weight and exhaust temperature, the exhaust manifold is integrated into the head. NOx emissions are also minimized as a result of keeping the exhaust temperatures low.

The advanced alternator adds to the list of benefits of the Ford 1.0L EcoBoost engine. This feature enables charging control far beyond that of any current production snowmobile. The achievement of complete alternator disengagement for optimum fuel economy in the appropriate operating conditions is due to the ECU control of this alternator. In combination with the fly-by-wire throttle body, the engine can actively compensate for the extra torque required for the charging load. Therefore, there will be a smoother transition between charging cycles.

Since this engine is so technologically advanced, a MoTeC M142 ECU has been fitted to precisely control the engine. This is displayed in Figure 3. Many pulse width modulated (PWM) actuators and the direct injections is managed by the ECU. The abilities of the ECU will further allow innovative projects in the future. As the team learns more about the tuning software, it is anticipated that more capabilities will be utilized in future competitions.

Figure 3. MoTeC ECU.

Track

In order to reduce noise, a custom Camso track replaced the stock track. This track is displayed in Figure 4. The track's design utilizes quiet ramp technology to prevent the bogie wheels from contacting the track window rods. Instead of studding the track, in-lug studs were chosen along with clips in every lug. These features reduce weight and are quieter than traditional studs. Another noise diminishing feature includes the rectangular cutouts in the track. These ports also lessen the total rotating mass and increase the track's flexibility to improve the driveline efficiency.

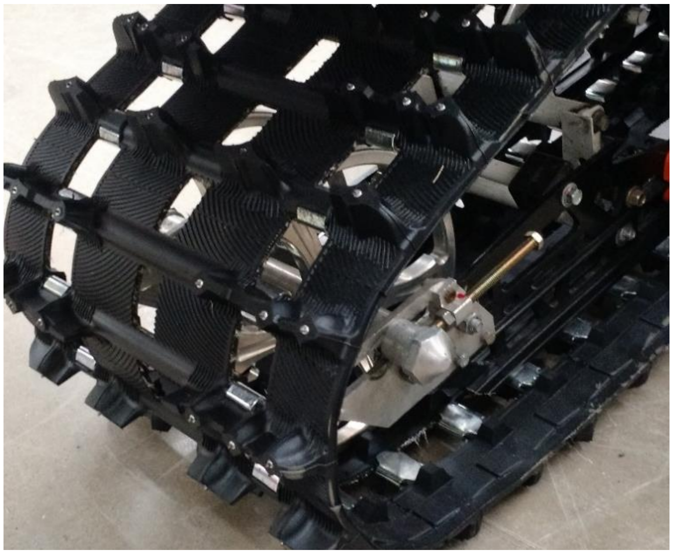

Figure 4. Ported Camso track.

Muffler

The UW-Platteville team broke down the NVH attenuation into three categories. These are exhaust, intake, and chassis/track noise. The goal throughout the development process was to lower the sound that was making the biggest sound contribution at any given time. For example, if it was determined that the intake was producing a higher noise level than any other part of the snowmobile, then the intake was modified, and the snowmobile was retested to figure out which area was contributing to the overall noise level. Through this process the team was able to focus most of its attention efforts on the greatest noise source.

The first area the team assessed was the exhaust. The original exhaust was used as a baseline measurement for subjective sound quality targets. While the SAE J1161 standard was used as an objective sound target. The SAE J1161 pass by test was preformed to obtain this base line test. The results for both the left-hand and right-hand sides are shown in Table 1.

Table 1. Arctic Cat Muffler Data.

Sled Setup Description	Run #	L.H.S.	R.H.S.
	1	71.3	77.5
Arctic Cat Muffler	2	72.3	76.1
	3	71.8	75.4
	4	71.5	76
	Avg	71.725	76.25

The team then replaced the stock muffler with the muffler from a Ski-Doo 900 Ace. This muffler was chosen because the 900 Ace also has 3 cylinders and a turbo. Since both engines have 3 cylinders, they both have a first and most prevalent/attenuated order of 1.5 that is calculated by using Equation 1. They will also have the same fundamental firing frequency obtained with Equation 2.

$$First\ Engine\ Order = \frac{Cylinder\ Number}{2}$$

Equation 1.

$$Freq = \frac{RPM}{60} \times \frac{Cylinder\ Number}{2}$$

Equation 2.

Finally, since the 900 Ace motor also has a turbo, it was hypothesized that the muffler would be designed to be more restrictive with that the stock Arctic Cat muffler from a ZR 7000 LXR which has no turbo. The same pass by test was ran a second time the data is shown in Table 2. The numbers seen in Table 1 and Table 2 are all above the SAE J1161 standard of 67 decibels and the team theorized this is because the exhaust side panels were not able to be in place when preforming the pass by testing for the 900 Ace muffler. In order to keep the consistency within the data the panels were removed for the stock muffler test as well. The averages in the data are only about 0.5 decibels apart so there was no real gain in reducing the overall objective noise level. However, the subjective order noise produced by this muffler was agreed upon by the team to be better than the stock muffler at both the idling RPM and pass by testing RPM. Therefore, it will be used for the 2019 competition.

Table 2. 900 Ace Muffler Data.

Sled Setup Description	Run #	L.H.S.	R.H.S.
	1	70.6	75.9
900 Ace Muffler	2	70.9	77.7
	3	71.2	78.5
	4	71.5	74.4
	Avg	71.05	76.625

Catalytic Converter

A three-way catalytic converter was implemented into the exhaust to combat harmful exhaust gases. The catalytic convert is considered a three-way catalyst because of the wash coat that is applied to the honeycomb substrate within the converter. This wash coat coverts NOx, hydrocarbons, and carbon monoxides into N2 , H2 O, and CO2 respectively. This conversion process requires very high temperatures which is why the location of the catalytic convert was placed as close to the manifold of the engine as practically possible. This also allows for a faster light off of the converter so it can begin to convert the unwanted gases into less harmful gases in minimal time. This short light off time is essential according to industry professional Claudinei Hijazi of Faurecia Clean Mobility who has stated "Before light off of the converter is where 80% of emissions are produced in the first 5 minutes of an engine running."

Skis

The factory Arctic Cat skies were used due to their flexibility and good handling characteristics with the Zr 7000 chassis.

Other Modifications

Driveline

To maximize the performance of our drivetrain, we utilize a C3 belt drive system. This is displayed in Figure 5. This system increased efficiency, alleviated friction, and reduced mass. The belt drive reduces a lot of noise due to the nature of the system versus a chain driven system. Another benefit includes it being a huge loss of weight throughout the drivetrain. The total weight savings of the belt drive system resulted in an 8 lb loss compared to the traditional chain drive. Not only that, the belt drive system also requires much less maintenance, with sealed bearings and a belt the need for an oil bath is eliminated. In fact, it is more environmentally friendly because it does not use an oil lubricated system. Due to the C3 system a gearing ratio that was more favorable to the high torque engine being used.

Graphite slides are used instead of the standard polymer hyfax slides. This is due to their lower coefficient of friction, lower operating temperatures, and increased durability it provides an overall better drivetrain performance and efficiency.

By using a big wheel kit in the rear and replacing the standard boogie wheels, the torque required is reduced by minimizing the angular acceleration of the track. Also, the larger diameter that the wheels create decrease the track deflection, which minimizes energy that is wasted with the bending of the track. This is displayed in Figure 6. Along with that, throughout the rest of the skid we have removed boogie wheels to help reduce our overall noise by letting it ride on the hyfax.

Figure 5. C3 belt drive system

Figure 6. Custom idler wheels.

Air Box

The entire airbox was designed around the use of S&A Industries porous duct. S&A Industries describe it as "…a porous duct that helps attenuate resonances in engine air induction systems…" and that it "helps minimize noise propagation generated from the engine compartment." The porous duct works by eliminating the standing wave created in the intake pipe by alleviating the acoustic pressure in the system. When the acoustic waves are able to expand into the volume of the engine compartment, they do not resonate the pipe that connects the air box to throttle body. This then allows for a smaller volume to be used for the airbox and any resonators in the intake system. The airbox volume was determined by looking at the mass airflow data provided by the MoTeC and by figuring out how much air might be needed at a moment notice and under a high load. The airbox was then designed to have a large enough volume to meet the mass airflow needed by the engine while also having a large enough opening to refill the space of the air that is consumed by the engine. Designing the airbox with a large intake opening allows for minimal high frequency flow noise and maximum air coming into the airbox. Therefore, the engine does not create a powerful vacuum in the intake system. By designing the airbox this way we were able to reduce noise while maintaining proper engine efficiency.

MSRP

This year's competition-bound snowmobile implemented advanced technology of the 1.0L EcoBoost engine along with various modifications for improved performance. Due to this, additional costs were procured in comparison to a similar snowmobile model, such as the 2019 Yamaha L-TX SE. The final MSRP price of the snowmobile was concluded at $18,412.70 the value was $2,613.70 over the base model stock price.

Fuel Tank

A custom designed and fabricated fuel tank was used this year. Location, fuel capacity, and weight were all factors in the building of the tank. With the motor repositioned and the stock over structure being used in this design, much of the area previously used for the fuel tank was no longer an option. This lost volume was replaced by using previously unused space under the seat. This design also allowed for a seat latch to be mounted directly to the tank, making a sturdier connection. A pathway for wiring and an intake hose from a rear mounted airbox, as well as a storage location for electrical components were also incorporated into the design. The tank was built to hold approximately 8 gallons of fuel, based on estimated fuel consumption over 100 miles, and 11-gauge aluminum was used to reduce weight. The tank is displayed in Figure 7.

Figure 7. Fuel tank.

Cooling System

With the implementation of the Ford 1.0L EcoBoost into the Arctic Cat XF 7000 LXR, the cooling system was reworked to compensate for the new engine. Due to the Ford engine requiring an intercooler to lower intake charge temperatures, the stock radiator had to be removed and replaced with a different system. An Arctic Cat XF 8000 under tunnel cooling system was installed in place of the radiator. In addition to the Arctic Cat heat exchanging assembly, a Davis Craig electric water pump was installed. The water pump was chosen in order to keep coolant flowing without the original Ford pump cavitating.

Emissions

Emissions are measured through the use of an e-score. The e-score is a number generated based on the number of unwanted compounds that exit the exhaust system. The compounds measured consist of hydrocarbons, carbon monoxide, and nitrogen oxides. Equation 3 is utilized to calculate a team's e-score. Using an exhaust analyzer HC, NOx, and CO are measured in parts per million, and then later converted to g/kW-hr based on fuel flow, H/C ratio, and weather data for the day.

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

Equation 3. E-score calculation equation.

The max e-score you can achieve is 210 and a score of 175 is needed in order to pass the emissions portion of the competition. Also needed to pass emissions is a score of 90 g/kW-hr of HC-NOx or less, as well as less than 15 g/kW-hr of CO.

Engine calibration

The engine tuning was conducted in the chassis this year. The team decided this was best so engine mounts and thermal management could also be validated while doing the engine tuning. Due to our choice to build a second more optimized Ford chassis, most of the engine tuning was done on last year's sled. This allowed us to have a team working on implantation of the new motor while letting the tuning team take on the challenge of tuning the variable value timing. This eliminated any struggle for resources and engine time that has plagued us in the past. The engine controller is still a MoTeC M142 with a development license. This allows us to write custom controls for our unique implantation.

Since the Ski-Doo 900 Ace Silencer was implemented in an effort to improve the sled sound level, the maps had to be started from scratch in order to compensate for the increased back pressure. With such an advanced engine tuning strategy, Microsoft Notebook was utilized to help organized what steps and in what order the tuning should be done in. Shown in Figure 8 is a snip from Notebook's contacts, which gives an idea of the order of relevance the tuning was completed. The VVT system affects the volumetric efficiency of the engine by adjusting, then the intake and exhaust camshafts open and close. This affects all the other systems, making this project the top priority. With the help of the team's

Ford contact we started to formulate a strategy as to how we want the cams to behave. One main benefit that the VVT system offers is the ability to overlap the cams to allow the engine to flow better. This is beneficial at higher RPMs and loads to make more power. Another advantage is that it can also close the valves early to trap some exhaust gas in cylinder. This allows the engine to run at stoic with less fuel making the engine more fuel efficient. Though testing last years sled we were able to find the load and RPM of the engine when it is cruising down the trail at 45 MPH. With this information we can tune the cams to make the engine as efficient as possible in the area off the map. This allows us to increase the fuel economy of the engine without sacrificing the power of the engine. After the desired strategy was laid out, tuning was completed to achieve these results. To do this, steady state dyno tuning was used to tune the VVT maps. In areas that maximum power is desired the map was tuned to a value that made the most torque on the dyno. In areas where cruising was conserved, a value where fuel consumption was minimal was targeted. Lastly for all other areas the five gas analyzer was used to find a value where emissions were most desirable. After the VVT system was completely tuned, the rest of the engine maps were tuned like normal.

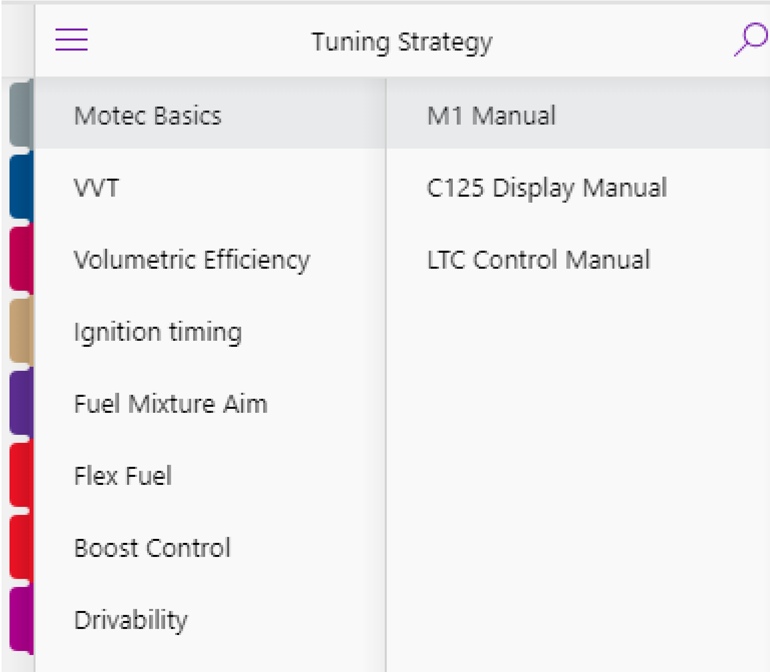

Figure 8. Microsoft Notebook organization.

Based on the feedback from last year judges, our engines boost control affected drivability by coming on and off boost abruptly. To solve this, we replaced our slow vacuum actuated wastegate solenoid with an electronic servo like the type found in many higher performance turbo charged engines. The speed and accuracy of the servo motor allowed for much greater control over boost pressure. This improvement has made the snowmobile much more intuitive to ride.

Engine Mounts

The engine was lowered this year to fit the stock over structure and steering post. New engine mounts had to be made to fulfill these requirements. Altair Inspire structural optimization software to give inspiration for an optimized design. First a design space was constructed to allow Inspire to utilize the maximum available package space. The results shown below shows a perfectly optimized part to be light weight and strong. The mount was then modeled in SolidWorks to emulate the features seen in the Inspire model. The mount was then constructed and analyzed in Inspire to check for failures. The loads for all the cases are 200 lb per load point for 400 lb total.

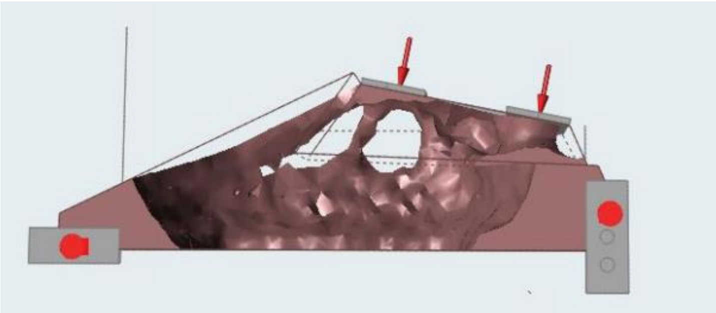

Figure 9. Right side engine mount.

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Abbreviations

Clean Snowmobile Challenge	CSC
Engine control unit	ECU
Exhaust Gas Recirculation	EGR

Gasoline turbocharged direct injection	GTDI
Nitrogen Oxides	NO_x
Pulse width modulated	PWM
Revolutions per minute	RPM
Society of Automotive Engineers	SAE
University of Wisconsin	UW