Ford 1.0 L EcoBoost Replaces Conventional Snowmobile Engine

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Abstract

The University of Wisconsin-Platteville Clean Snowmobile Challenge (CSC) Team established a dream for this year to set their design apart from those in the past. The Team's main goal was to build an environmentally friendly, quiet and efficient snowmobile to compete with at the 2018 Society of Automotive Engineers (SAE) Clean Snowmobile Challenge. This year's competition snowmobile was built on the 2017 Arctic Cat ZR 7000 LXR platform. However, the key design element was the engine. The UW-Platteville CSC snowmobile is powered by GTDI Ford 1.0 L EcoBoost. This is a one-liter, three-cylinder, four-stroke engine. To control the engine, a MoTeC M142 engine control unit (ECU) is used. The team has the ability to control engine parameters for better fuel economy and less exhaust emissions. The engine's leading technology gives the team many possibilities for emissions and performance advancements in the future. The engine's downfall is its size. Because of the increased engine size, a typical snowmobile steering system was not an option. The snowmobile utilizes hydraulic steering which is similar to that of a helm-operated marine engine. This was optimal due to the small amount of space it occupies and the flexible lines that can be routed around the engine. Other implements were made to increase fuel economy such as a lightweight belt drive system and larger rear idler wheels. To reduce unwanted noise, designs such as undercoating in the tunnel, lower engine rpm through custom gearing and clutching, an anti-stab kit, and a custom track were utilized. These specific modifications, along with many others, have assisted the UW-Platteville CSC Team in achieving the goal to build an environmentally friendly, quiet and efficient snowmobile.

Innovations

This year's design had multiple innovations. First, a Ford 1.0 L EcoBoost replaced a conventional snowmobile engine. This engine is controlled by a MoTec ECU which required several hours of research and implementation. With this, better fuel efficiency is achieved compared to the stock system. With the implementation of a large engine, a hydraulic steering system was needed. Because of the nature of a boat steering system, a 4-1 gearbox was added for normal operation of the handlebars.

Team Organization and Time Management

Organization played a key role in the team's progress this year. The shop was completely rearranged over the summer and space was reduced. With less space, it was important for everyone to stay updated and understand the work in progress. To accomplish this, an Excel spreadsheet on OneDrive was created and shared with the team. There, information on current projects, parts that needed to be ordered, and individual responsibilities could be found. A white board was also hung in the shop for the same purpose.

Build

Chassis Selection

It was important to select a chassis that has been proven to hold up to the stresses that a 1.0 L sized engine creates. Arctic Cat's ProCross chassis has not only been a rider favorite since its release but has also proven itself as a performance machine on the racing circuits. This chassis has been tested and has proved its ability on and off the racetrack for many years. These years of development on the ProCross chassis have resulted in a snowmobile that handles extremely well because 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]. With the near 70 lbs of added weight from the EcoBoost, the stiffness of the chassis was needed. The largest draw to the chassis was the fact that it has a large enough engine compartment to enclose the selected engine. With the wide panels, the slightly taller EcoBoost was able to be implemented into the snowmobile.

Engine

While researching engines, the gasoline, turbocharged, direct injection (GTDI) Ford 1.0 L EcoBoost engine, seen below in *Figure 1*, stood out as a clear leader in the automotive industry. This engine was recognized as International Engine of the Year [2]. A variety of features such as variable cam timing, direct injection, turbo charging, a variable displacement oil pump, and fly-by-wire were influential in choosing this engine.

Figure 1. Ford 1.0 L Ecoboost [3]

Variable cam timing provides benefits well beyond any other feature of this engine. For instance, this technology provides the ability to

instantly change the performance and emissions characteristics of the engine. Through tuning, it is possible to realize Exhaust Gas Recirculation (EGR) results. This technique results in lower Nitrogen Oxide (NOx) emissions. Improvements can be made not only in emissions and fuel economy, but also torque. A wider torque curve provides smoother and stronger power delivery. Power curves are also affected and can be modified for a less dramatic drop after peak power is reached.

The second most notable feature of this engine is direct injection. The primary benefit of direct injection is the precise fuel injection timing. With correct tuning, less fuel is needed compared to traditional port injection. Direct injection is also capable of multiple injections per stroke resulting in a more efficient combustion of fuel and a quieter running engine [4].

Equipped with a small low-inertia turbo, this engine minimizes lag in response during the acceleration process [5]. Because of the turbine's blade design, this engine runs quieter with less exhaust noise and turbo whistle. The spinning impellor creates a uniform exhaust flow compared to an engine not equipped with a turbo. This is because engines not fitted with a turbo have larger fluctuations in exhaust gas velocity resulting in additional exhaust noise.

Other unique features of this engine provide many advantages. For instance, the variable oil pump provides a precise amount of oil pressure for a given operating condition. This helps overall engine efficiency by reducing unnecessary pumping losses.

Engine losses are further minimized through the oil bathed timing belt which reduces weight and friction over a traditional timing chain.

Fly-by-wire provides the ability have a more stable idle control at all temperatures without the need to cut ignition timing. Fly-by-wire also presents the opportunity for the implementation of cruise control in the future.

Engine balancing is necessary on a three-cylinder engine due to inherent rocking. Ford solved this issue by incorporating a unique balancing system. Utilizing an unbalanced flywheel and harmonic balancer, this engine eliminates the need for a countershaft. Without a counter balancing shaft, a chain is eliminated which results in less overall friction losses and less engine vibrations

Ford's Split Cooling System, with two thermostats, allows critical engine components to reach operating temperature faster. Once the coolant within the block reaches operating temperature, the rest of the engine begins circulating. This is beneficial because the oil heats up more quickly while keeping head and exhaust temperatures down, thereby reducing emission during cold starts.

In addition to the split cooling system, the exhaust manifold is integrated into the head. This reduces weight and lowers exhaust temperature. NO_X emissions are reduced by keeping the exhaust temperatures low.

Yet another benefit to the 1.0L EcoBoost is the advanced alternator. This enables charging control well beyond that of any current production snowmobile. The ECU control of this alternator allows for complete alternator disengagement for optimum fuel economy in the appropriate operating conditions. Furthermore, in combination with the fly-by-wire throttle body, the engine can actively compensate for the extra torque required for the charging load. This provides smoother transitions between charging cycles.

With the selection of a technologically advanced engine, a MoTec M142 ECU has been fitted to precisely control the engine *Figure 2*. The ECU has the ability to manage many pulse width modulated (PWM) actuators, as well as direct injection. This ECU allows for many innovative projects in the future. It is anticipated that these capabilities will be further utilized in future competitions as the team becomes more familiar with the tuning software.

Figure 2. MoTec ECU

Track

Made by Camso, the track features quiet ramp technology which reduces noise by preventing the bogie wheels from colliding with the track window rods. The rectangular cutouts in the track not only reduce noise, but also reduce the overall rotating mass and increase the flexibility of the track. These ports can be seen in *Figure 3*. This increases the efficiency of the driveline. This track also features clips in every lug along with in-lug studs to reduce weight and sound.

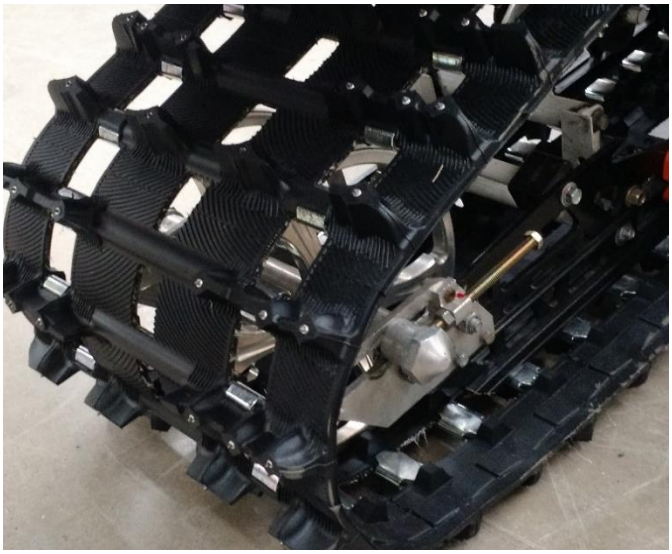

Figure 3. Ported Camso track

Muffler

For the exhaust system, components from an Arctic Cat ZR 7000 were implemented. These parts were chosen because they were tailored to the specific exhaust frequencies and flow requirements for a similar 1.0 L, three-cylinder, four-stroke engine. This system was also chosen because of its small footprint and low weight.

Catalytic Converter

For emissions reduction, the stock Ford 3-way catalyst, developed for use with the 1.0L EcoBoost in the Fiesta line, was installed. The Ford catalyst was chosen due to the fact that it was designed for the 1.0L EcoBoost and was cost efficient. The catalytic converter was placed near the exit of the turbo for quick ignition of the catalyst during cold starts.

Skis

Stock skis were kept on the snowmobile due to the high quality design that Arctic Cat uses. With price taken into consideration, aftermarket skis were not deemed necessary.

Other Modifications

Driveline

To further improve efficiency, a C3 Powersports Syncro Drive system was used, as seen in *Figure 4*. This system increased efficiency, alleviated friction, and reduced mass. In fact, the belt drive reduces rotating mass by 8 pounds with an overall weight savings of 11 pounds. The belt drive has no need for oil, therefore, it is more environmentally friendly and requires less maintenance. One of the largest benefits to the belt drive is a reduction in noise compared to the traditional chain drive resulting from the materials used.

Figure 4. C3 belt drive system

An anti-stab kit is mounted to the front of the skid and acts as another row of small bogie wheels that eliminates rail tip failure. This helps eliminate vibration caused by the rail tips clicking on track clips as the track rides onto the slide rails [6]. To further increase efficiency in the driveline, it was important to reduce contact with the hyfax and the clips. To do so, bogie wheels were added along the front bend of the rails to create a gap between the track and the slides. Advantages of creating a gap include increased skid frame lubrication and reduced hyfax temperature. The custom designed and fabricated rear idler wheels, shown in *Figure 5*, reduce the torque required by minimizing the angular acceleration of the track due to the larger diameter. By following the enlarged diameter, the amount of track deflection was mitigated, minimizing the energy wasted on bending the track.

Figure 5. Custom idler wheels

Graphite-infused slides were chosen over standard polymer hyfax slides due to their lower coefficient of friction, lower operating temperatures, and increased durability.

The engine specs of a stock 1000cc engine compared to the Ford 1.0L EcoBoost engine is similar to the point that there is not much work needed on the clutches. The main difference is that the current engine will not pull as many RPMs as stock but it has higher torque. Because of this, shims and heavier weights were added to the primary. The springs on each clutch and the helix on the secondary are stock.

Steering

Because the 1.0L Ford EcoBoost takes up much more space in the chassis than the stock Yamaha Genesis engine, the traditional steering column needed to be replaced. A Mercury Marine outboard hydraulic steering helm was implemented to solve this issue, as seen in *Figure 6*. To transfer motion from the hydraulic cylinder to the tie rods, a connecting link was designed and fabricated to make full use of the cylinder's stroke length in either direction. Heat-resistant, automotive-grade hydraulic lines were implemented to transfer fluid between the helm and the cylinder.

Figure 6. Mercury Steering Helm

Since boat steering requires three full turns of the wheel and helm to completely extend and retract the cylinder, a reducing gearbox was fixed inline on the input shaft of the helm. This gearbox allows the skis to be turned completely while maintaining the steering angle used on stock snowmobiles. The helm and gearbox were secured to the top of the bracing with a custom-fabricated aluminum mount, with the handle bars fastened to the gearbox shaft using a steel adaptor.

The hydraulic steering provides unique handling characteristics for the rider. Feedback from ruts, bumps, and other terrain oddities is eliminated. This attribute can reduce rider fatigue and provide a smoother, more controlled overall ride; however, it may also cause handling drawbacks. The hydraulic helm and cylinder will not self-center the skis without rider input. Although these handling characteristics will require a significant adjustment, riders may learn to accept and enjoy the added rider control and lack of terrain-induced feedback provided by the hydraulic steering.

Battery

With having an engine with high electric draw, more cold cranking amps were needed. Instead a larger and heavier automotive style battery, a lithium ion battery was chosen. It weighs 4.28 lbs, compared to last year's OEM battery that weighed 14.62 lbs. This saves 10.34 lbs, which is a 71% weight reduction. The new cold cranking amps are 780, compared to last year's 610, giving us an extra 170 cold cranking amps for more reliable cold starts.

Throttle

This year a Ski-Doo electric fly-by-wire throttle has been implemented instead of the stock Ford throttle to simplify the system and create space under the hood. This makes for a smooth and rapid throttle response. Another benefit of an electric throttle is to allow for better idle control by the ECU.

Air Box

A custom designed air box replaces the OEM intake due to space constraints. However, the purpose is the same, having no added value to the rider compared to the stock system. Because of the location, the air box was designed to have similar air flow to the engine. Baffling has been placed in the compartment to not allow the sound waves to have a direct path to the rider. This design consideration is especially important because of the turbo resonance that is created by the 1.0L Ford EcoBoost. Also implemented into the design is an oil vapor catch can to help catch oil vapor produced by the positive crank case pressure system. Without the catch can, the vapor would be free to enter the intake and combust resulting in harmful emissions. The catch can does need to be emptied out regularly, typically as the engine oil is changed. The air box has been made using the additive manufacturing process of selective laser sintering. This allows for the unit to be printed in one piece, reducing weight for fasteners and giving the design freedom for more complex geometries. This airbox can be seen in *Figure 7*.

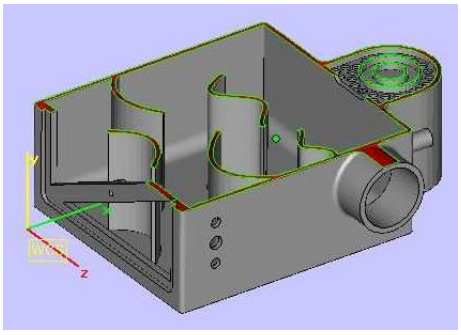

Figure 7. Airbox

Fuel Tank

The current fuel tank is far from stock, we had to build a custom cell to fit behind our engine under the chassis bracing. The new fuel cell holds approximately 7.2 gallons of fuel. This decision was made to remove weight from excess fuel that would not be needed for a standard 100 mile trip. The tank was designed using SolidWorks and fabricated out of 1/8” aluminum for strength and weight savings. The tank can be seen in *Figure 8*.

Figure 8. Fuel tank

Cooling System

In the process of condensing parts of our build, the coolant bottle was relocated from the top of our chassis brace to below the intake manifold in front of the fuel cell. We used an empty dead space in the sled to house the bottle. This new coolant reservoir is a recirculation bottle much like the old one, just relocated and without a pressure cap. Because the coolant reservoir is pressurized, unlike on an automobile, the coolant recirculates through the bottle. The purpose behind having a coolant reservoir is to allow the engine to recirculate through a small cooling system allowing for quicker warm up times.

With the intercooler taking up the stock location for the radiator, more cooling power was required to keep the engine operating within parameters. In order to make the desired cooling efficiency, the small, tunnel heat exchanger was replaced with a longer, full length heat exchanger.

Bracing

Incorporated into this year's frame brace, two roll cage joints were implemented, allowing for ease of brace removal. With these new joints, there is no longer a need to remove the exhaust, cooling lines and two turbo-charged pipes. Along with the incorporation of the new joints, more lateral bracing was added to each side of the chassis stiffener to increase chassis rigidity. The brace also doubles as an additional mount support and enclosure, in case of a rollover or crash. This brace can be seen in *Figure 9*.

Figure 9. Brace

ABS Brakes

The Ford 1.0 L EcoBoost is a performance based snowmobile that requires a quality braking system. The team decided that the Hayes Trail Trac ABS system is the perfect combatant to the power of the snowmobile. Increased braking ability allows the operator to let off the throttle and prepare for corners later than a stock system would. Since the ABS will not allow the snowmobile to lock the brakes up, the snowmobile will not slide out and holds a consistent line while braking. A great feature of the Hayes Trail Trac ABS system provides operators the option to use ABS or stock braking configurations on the fly with the flip of a switch.

Undercoating

Resonation was reduced by coating the underside of the tunnel with automotive undercoating. The additional mass mitigates the amplitude of vibration of tunnel connections which results in minimizing sound level.

Emissions

Emissions were monitored using an e-score. 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. *Figure 10* is the equation used to calculate the score. The HC, NOx, and CO values are measure 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.

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

Figure 10. 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.

Conclusion

The UW-Platteville CSC Team successfully designed an environmentally friendly, quiet and efficient snowmobile. The team believes that this could be a new stepping stone for the snowmobile industry. The integration of an automotive engine into a snowmobile will continue to have many obstacles and will not be an immediate transition for the industry. Lastly, the advanced technology of the 1.0L EcoBoost engine presents complexity and added costs over a similar performing snowmobile. The final MSRP price of the snowmobile was $18,811.67, the value was $3,512.67 over the stock price.

The SAE Clean Snowmobile Challenge has been a large influence on the improvement of snowmobile designs for the industry. The Team's implementation of a 1.0L EcoBoost engine is in hope of continuing the tradition of engineering excellence.

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Abbreviations

Antilock braking system	ABS
Clean Snowmobile Challenge	CSC
Engine control module	ECM
Engine control unit	ECU
Exhaust Gas Recirculation	EGR
Gasoline turbocharged direct injection	GTDI
Nitrogen Oxides	NO_x
Original Equipment Manufacturer	OEM
Pulse width modulated	PCM
Revolutions per minute	RPM
Society of Automotive Engineers	SAE
University of Wisconsin	UW