Efficiency and Emissions Improvements of the Arctic Cat ZR7000RR

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ABSTRACT

The University of Minnesota-Duluth's Clean Snowmobile Team, The Snowdawgs, reengineered a 2015 Arctic Cat ZR7000RR to reduce emissions, improve fuel economy, and increase the overall efficiency of the machine. The team has submitted entry to compete in the 2015 SAE International Clean Snowmobile Challenge with big intentions. Yamaha's C-Tec Genesis engine was utilized in the 2015 Arctic Cat ProCross chassis along with the team's multiple improvements. With the competition's unique fuel mixture, the engine has been adapted to run any mixture of unleaded fuel and iso-butanol through the implementation of a flex-fuel sensor paired along with Performance Electronics standalone ECU. The entire driveline was examined and tested on a newly designed chassis dyno to determine the best combination of driveline parts for efficiency gains. An innovative carbon fiber roller bearing drive sprocket paired with C3 Powersports's belt drive system along with custom tuned clutches comprised of large efficiency gains in the driveline system that were proven out not only through chassis testing on the dyno, but through on snow evaluation. Implementation of a servomotor controlled exhaust gas recirculation (EGR) system along with a completely redesigned exhaust system comprised of a 3-way catalyst from Haraeus and an inline baffle in conjunction with an intricate resonator network that dumps the exhaust out the back of the machine. Precise engine tuning with updated emissions collection strategies led to a validated engine control system. With the addition of these proven modifications, this snowmobile will surpass industry standard expectations as well as decrease its environmental impact.

INTRODUCTION

Since their invention in the 1960's, snowmobiles have been a means of transportation, a work vehicle, and a fun pastime in the northern United States and Canada. They have revolutionized the way people travel across snow-covered terrain, and allowed exploration of new areas during the long winter months. One of the areas that saw increased snowmobile exploration was Yellowstone National Park. Over the years, however, unrestricted snowmobile traffic has had detrimental effects on the wildlife, air quality, and serenity of the United States oldest National Park [1].

The SAE Clean Snowmobile Challenge (CSC) was founded in 2000 as a response to the demand for more environmentally friendly snowmobiles. The Challenge puts teams of college and university students against one another in friendly competition in an effort to create clean, quiet, and practical alternatives to the current snowmobiles on the market. The demands of a successful CSC entry are simple: take a production snowmobile, clean up the emissions and reduce sound levels while maintaining a high level of performance. This, however, is much easier said than done.

For the 2015 CSC competition, the Snowdawgs have prepared an entry with extensive improvements across the board. From the precision tuned flex fuel motor, to the ultra-clean exhaust, coupled with numerous driveline efficiencies, the Snowdawgs's 2015 Arctic Cat ZR7000RR is a big step forwards for the snowmobiling industry. The improvements detailed herein will make snowmobile riding in our National Parks a reality for future generations.

EMISSIONS AND NOISE REDUCTION

Reducing the emission and noise levels are the primary concern of the competition. This year the team spent many hours on the engine dyno getting the emissions and noise levels down. This was done through a complete re-map of the motor and precise engine tuning, a new Exhaust Gas Recirculation system, and a brand new exhaust system.

Engine Tuning

The engine used this year is the same Yamaha Genesis 130 FI engine that was used in last year's competition. Yamaha's 3-cylinder powerplant was selected for multiple reasons. The first being that it is a lightweight, high-performance four stroke that is being utilized in every segment of the snowmobile market, from trail performance, mountain and backcountry riding, and utility snowmobiles. The second is that this engine has a much greater potential to be cleaner, more efficient, and simply perform better than at last year's competition.

Table 1. Yamaha Genesis 130 FI Specifications

Engine	Yamaha Genesis 130FI
Displacement (cc)	1049
Configuration	Inline Triple
Valve Layout	Dual Overhead Camshaft
Fueling	Full Sequential Port Fuel Injection
Compression Ratio	11:1
Bore x Stroke (mm)	3.23 x 2.61
Ignition Type	Coil on Plug
Block Material	Aluminium

The first step to improving the engine was to administer baseline testing to the engine in competition trim from the year prior. A dyno cell, utilizing a Land and Sea Dynomite crankshaft water brake was set up to meet the requirements of our vigorous baseline testing. Results from the testing highlighted the areas where improvements could easily be made. The first area that needed to be addressed was the fact that the engine stopped producing power after 7000 rpm. In stock trim, the strong part of the powerband is from about 6000-9000 rpm. Another area of concern was that during testing it was found that volumetric efficiency was lower than expected, and brake specific fuel consumption was relatively high for the horsepower output. In a typical high performance dual overhead cam engine, one can expect between 100-110% volumetric efficiency, however, testing yielded a peak VE of 102%, but for a very short time.

$$Volumetric\ Efficiency = \frac{airflow_{observed}}{airflow_{theoretical}}$$

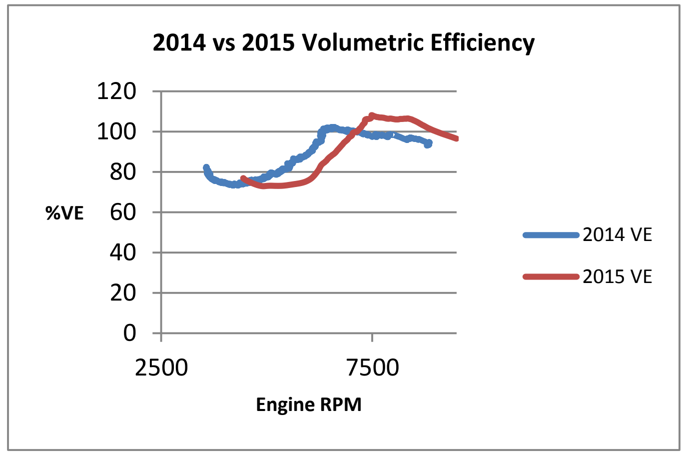

Figure 1. Graph shows 4% increase in volumetric efficiency.

Correlation of the decreased horsepower and lack of airflow was suspected to be in the ignition timing [2]. A further confirmation of this hypothesis was in the form of very hot (1700°F+) exhaust gas temps. Through testing it was determined that the ignition timing was nearly 20° past Maximum Brake Torque (MBT). A new timing curve was developed utilizing the Performance Electronics ECU and the Dynomite to test each individual change throughout the band. Throughout this process, fueling, intake, and exhaust configuration remained constant. The results of the optimized timing yielded a dramatic increase in horsepower, torque, and volumetric efficiency; as well as decreases in brake specific fuel consumption and exhaust temps throughout the rev range. On this engine, timing could be dialed in to MBT without any noticeable detonation.

With the engine vastly improved over last year's in terms of both power and efficiency, it was time to compare the tune of this engine to the stock 2015 ZR 7000. With the factory exhaust installed on the competition engine, the following results were found:

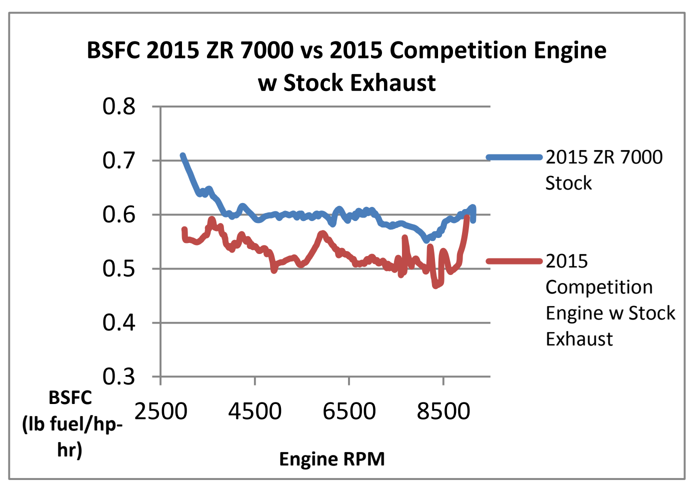

Figure 2. Brake Specific Fuel Consumption was reduced by 11.5%

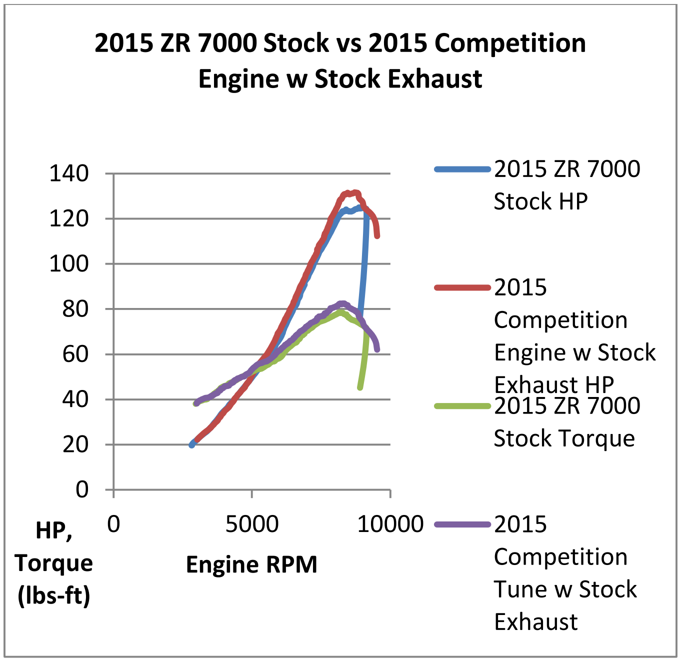

Figure 3. New tune produced 5 more horsepower and 4 more lb-ft of torque.

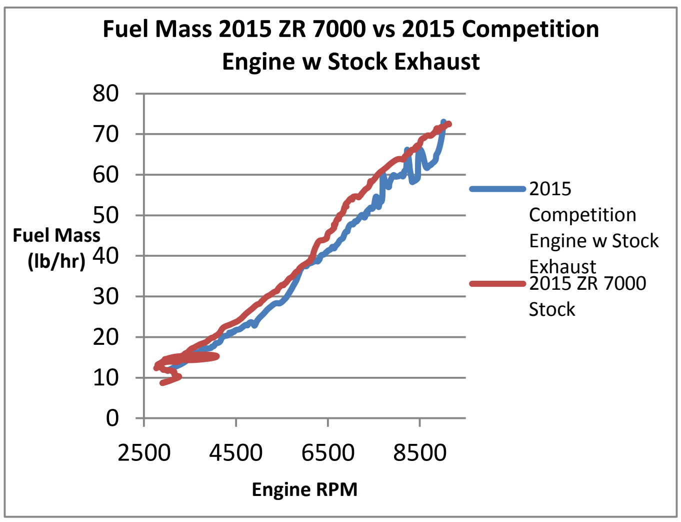

Figure 4. Graph showing 5% decrease in fuel mass over stock with new tune.

After the initial comparison of the stock tune versus the new tune, it appeared that the new tune was more efficient than stock. The new produces 5 more horsepower and 4 more lb-ft of torque over stock while consuming less fuel. Continuing on the same trends of improving over last year, it was decided that a focus should be on improving economy and emissions, while still producing a sled that has the performance a recreational rider desires. A few methods were discussed, including Miller and modified Atkinson cycle operation. It was felt among the team that modified Atkinson cycle operation would produce a vehicle that would lack in performance, as it increases efficiency at a cost of power density [3]. Conversion to a Miller cycle operation also produced many challenges that ultimately didn't outweigh the benefits. The time and cost required to have a custom camshaft made to produce the valve overlap required for modified Atkinson and Miller cycle operation was not feasible and deemed impractical. Especially in the case of the modified Atkinson cycle engine, without variable-valve timing, the effects of the overlapping cams would only be efficient for a part of the rev-range. Although the turbocharger in the Miller cycle would aid in increasing exhaust pressure and increase the effects of cylinder scavenging, we felt a turbocharged setup was not necessary to achieve higher efficiency than stock trim or what went to competition in 2014. Another option was to reduce ignition timing and lean out the fuel mixtures to at or above $\lambda = 1.00$. Again, this possible solution presented undesirable tradeoffs; such as decreased power output due to backing timing off of MBT (retarding timing also increases stress on components and decreases thermal efficiency), as well as reduced run quality. It has been experimentally determined that anything above $\lambda \approx .95$ results in reduced run quality and power output. This is largely due to the design of the combustion chamber and the resulting unsteady combustion from the leaner mixtures.

Exhaust Gas Recirculation System

The solution presented itself in the implementation of a cooled Exhaust Gas Recirculation (EGR) system. The EGR systems most used in spark ignition engines started to appear in the auto industry in the mid-seventies, but these systems operated on engine vacuum, were prone to failure, relatively ineffective and complex, and decreased power output significantly in an attempt to decrease tailpipe emissions. Another downside was that the valves were only usable in the cruise ranges of vehicle operation due to the increase in intake air temps and large volumes of EGR required make an effective reduction of emissions, notably NOx. These effects lead to too much dilution of the intake charge at idle and high speed operation to be used in those ranges [4]. EGR began to be more effective once the addition of coolers and computer controlled valve operation allowed for use in a much wider range of engine speeds and load levels. With the hot exhaust gases being cooled upon entry into the intake airstream, the density of the exhaust gas decreases, allowing a smaller total volume of intake to be occupied by EGR, an important characteristic for times when there is little air entering the cylinder (idle and low speed) and where air entering the cylinder is crucial for power production (Wide open throttle and high rpm). The addition of a cooled EGR system also has the benefit of decreasing peak cylinder pressures during combustion which relates to a higher tolerance for detonation as the end gases are less likely to ignite under less cylinder pressure. Another additional advantage to EGR use is the end gases have a higher tolerance to auto-ignition in the EGR diluted cylinder. This translates to the engine being able to be timed more aggressively, towards MBT, without risk of detonation. Other benefits include reduction of Brake Specific Fuel Consumption (BSFC), and NOx emissions, and compatibility with 3-way catalyst. Disadvantages include power-loss due to replacing intake air with exhaust gas that does not react in the combustion process, and possible unstable combustion conditions if too much dilution was used.

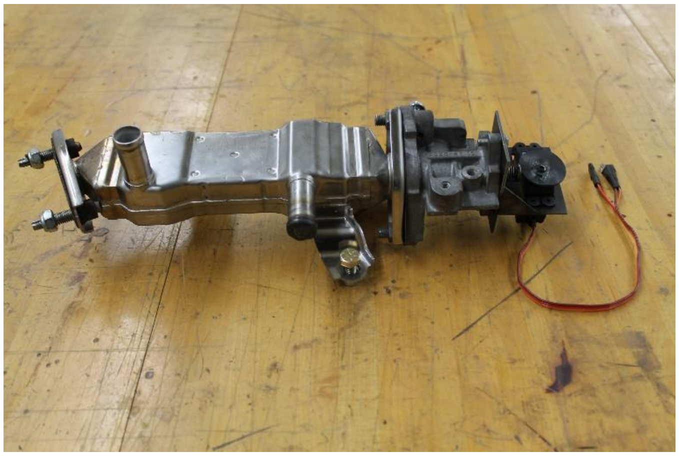

Figure 5. The new EGR.

The considerations for choosing our EGR involved precise control, efficient cooler design, and compact packaging. The decision was made to use an EGR valve and cooler from a second-gen Toyota Prius. The valve is placed on a motor that is slightly larger, (1.8L vs 1.0L) but doesn't rev as high as the Yamaha. It was the hope that this would mean that the valve would supply ample flow throughout the band of the Yamaha, despite lacking actual flow data from the Toyota valve. The valve also has a stack type cooler, which has been shown to be much more efficient at keeping temperatures lower than shell and tube type coolers. The whole assemble was small in size, which made for easy location selection. The valve initially came with a 6-wire stepper motor control, but the ECU currently installed on the snowmobile did not have enough digital outputs to be able to control valve operation properly. Instead, the stepper was removed and replaced with a new system involving a pwm and a cam to control valve operation by means of a 3-D table in the ECU control. The gas flows from the main exhaust header to the valve via an intake pipe inlayed inside the header for maximum flow to the cooler and valve assembly. From the valve, the gas flows directly to the air dam inside the airbox via a 48" line routed over the radiator for further cooling. The inlayed pipe pickup is placed before the catalyst for maximum effect, even though this can be considered a tradeoff, it was also necessary for packaging reasons.

The first iteration of the EGR test system utilized the stock system and a temperature probe pre cooler and post cooler to gage efficiency of the cooling system, as well as a pitot tube setup to a manometer to take a dynamic pressure reading to calculate flow through the valve and back to the airstream [5,6]. The initial set up produced nearly zero back pressure and the consequence of that was nearly zero flow through the EGR. It was then decided to mock up the exhaust system that would be used in the competition sled for 2015 by installing the baffle, and a restrictor to simulate catalyst restriction. Tests were taken at 4000 rpm, where dynamic pressure in the manometer was read. Assuming the exhaust gas as air, in a simple incompressible system in the following conditions:

$$Intake\ air\ temp = 100°F$$
$$P_{atm} = 14.7psi$$
$$P_{exhaust} = .78kPa = .230\ inH_2O$$
$$A_{pipe} = .00212 ft^2$$

$$\left(\frac{1.93\ slug}{ft^3}\right)\left(32.174\frac{ft}{s^2}\right)(.230in)\left(\frac{1\ ft}{12\ in}\right)\left(\frac{1\ lbf}{1\ slug * \frac{ft}{s}}\right) = 1.19\ \frac{slug}{ft^3}$$

$$P_{EGR} = \frac{P_{atm}}{RT_{atm}} = \left(\frac{14.7\frac{lbf}{in^2}}{53.33\frac{ft}{lbm} * °R}\right)\left(\frac{12\frac{in^2}{ft}}{100 + 459.69}\right)\left(\frac{1\ slug}{32.174 lb_m}\right) = .00218\ \frac{slug}{ft^3}$$

$$V = \sqrt{\frac{2(1.19)\frac{lbf}{ft^2}}{.00218\frac{slug}{ft}}} = 33.04\ \frac{ft}{s} = 1982.49\frac{ft}{m}$$

$$1982.49\frac{ft}{min} x .00212 ft^2 = 4.22CFM$$

$$\frac{4.22\ CFM_{EGR}}{53.50CFM_{Intake}} x\ 100 = 8\%\ EGR\ @\ 4000\ RPM$$

Since it takes a bit of time for the fluid manometer to reach an equilibrium point when testing, it was not held at steady state in high rpm state for both preservation of components and safety reasons. At 4000 rpm, the valve was set to be wide open, so the 8% EGR is a max for the system at that range. Progressing to full power sweeps with EGR valve wide open, netted a reduction in required fueling throughout the band, and in some parts of the curve, 10- 15% of the fuel was removed to retain proper A/F ratios. An EMS 5-gas analyzer was installed into the system to measure the emissions gains of the EGR. NOx is the main pollutant affected by EGR implementation, so it was the one the team was most concerned with.

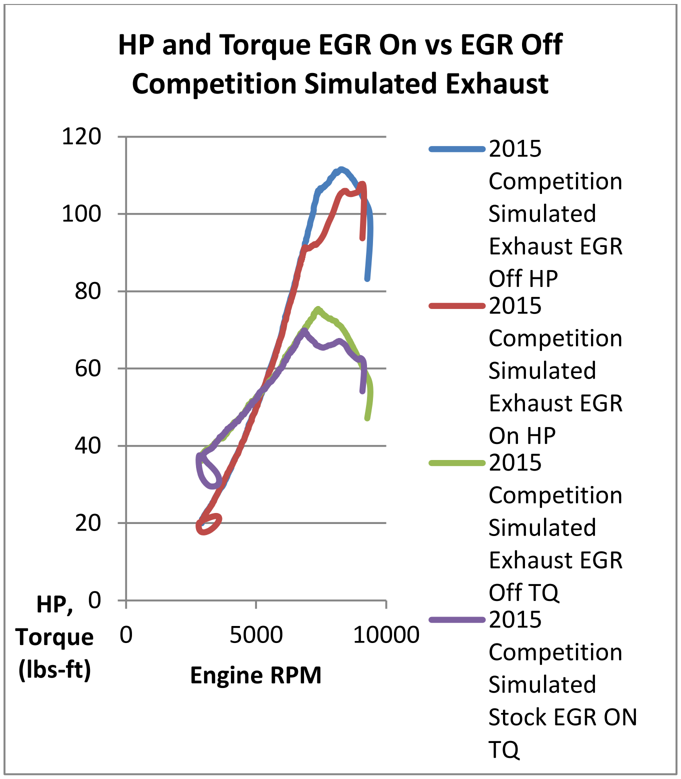

Figure 6. EGR use only lost 2.8 hp and 1.2 lb-ft of torque on average.

Exhaust

In this competition, emissions reduction is essential. In order to improve our efficiency, both a 3-way catalyst and cooled EGR were implemented. Widely known to be implemented in cars, catalytic converters are one of the most effective methods to reduce emissions. The catalyst assists in converting harmful pollutants, including hydrocarbons (HC), Carbon Monoxide (CO), and Nitrogen Oxides (NOx). The team partnered with Heraeus, a company based in Hanau, Germany whom specializes in precious metal technologies. Emissions data was collected and analyzed to design an ideal three-way catalyst specific to the Snowdawgs engine.

Figure 7. A top and side view of the 3 way catalytic converter.

The final design agreed upon based off of baseline data from the stock snowmobile and the designated space available, a three way catalyst was implemented. The cylindrical catalytic converter has a diameter of 4.25 inches, and is 3.94 inches tall. This is .75 inches taller than last year's design in an effort to reduce NOx emissions. The precious metals used to react were platinum and rhodium [7]. Improvements are observed in the comparison to the 2015 ZR 7000 Stock vs. Competition setup, which can be seen in the figures below comparing individual pollutants per engine RPM.

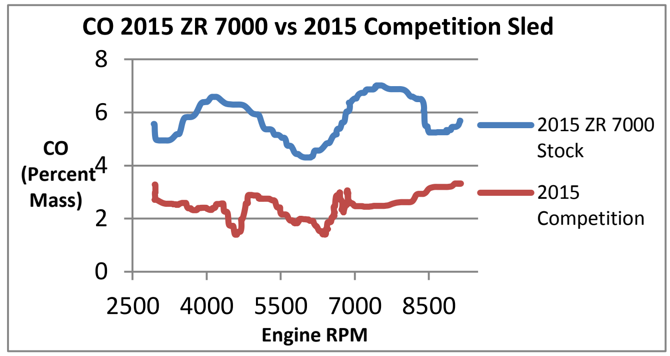

Figure 8. A 41.5% reduction in CO was achieved.

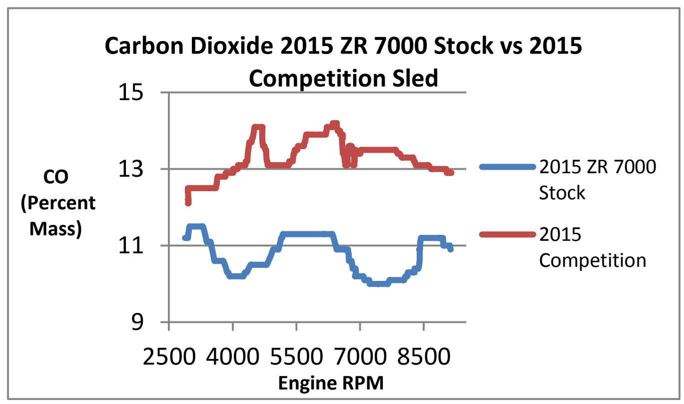

Figure 9. CO2 emissions actually increased by 24% due to a richer fuel mixture.

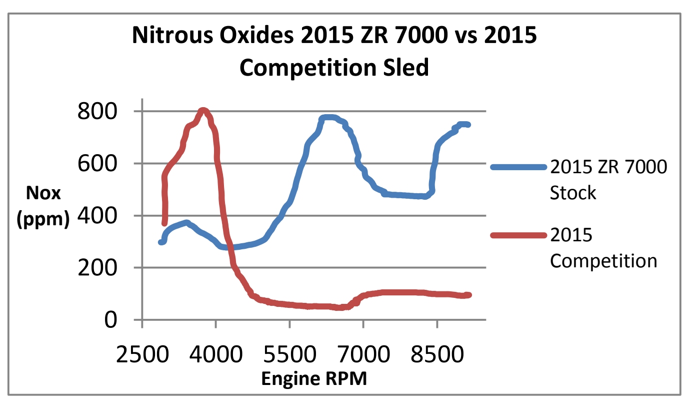

Figure 10. Graph showing 64% reduction in NOx emissions.

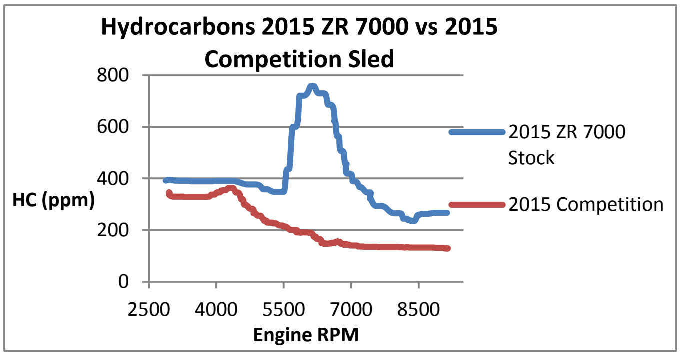

Figure 11. A 53.6% improvement in HC emissions was attained over stock.

During the 2014 competition, the muffler experienced traumatic failure. After the muffler was taken apart, it was confirmed that our then current muffler design was experiencing heat concentrations resulting in melting of side panels. To address this issue, the plan this year was to create distance between the three-way catalytic converter and muffler box. Not only would this separation allow space for the catalyst to have greater exposure to air to cool off, but to prevent muffler insulation to ignite and or become ineffective. After many initial design proposals it was decided to re-route the entire exhaust system.

Coincidently, re-routing the exhaust would also double as a means to reduce sound. Extending the length of exhaust piping would increase frequency cancelation as it travels through the system. Figure 12 shows the entire route of the exhaust starting from the three-way catalytic converter, wrapping around in the preexisting muffler cavity, traveling underneath the tunnel of the chassis, and exiting with the muffler box near the snow flap. This system was manufactured in house with the use of continued 2" diameter pipe to maintain constant flow from the header. To manage heat problems from interfering with other components, aluminum reflection shield and high temp heat tape were used.

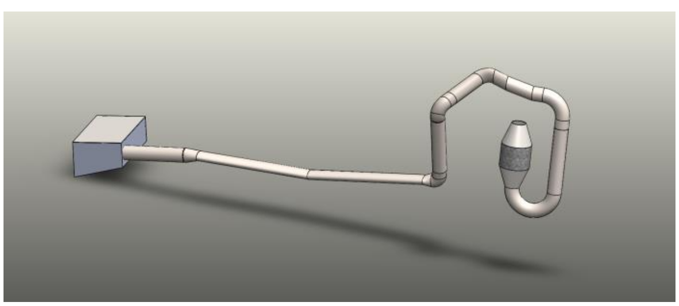

Figure 12. A Solidworks rendering of the new exhaust system.

Furthermore, sound damping was also addressed by the muffler box at the rear of the tunnel. Figure __ shows the aerial view of the inside of the muffler box. Stock resonators were reused based off the notion that they are properly tuned to the engines natural frequency. These components were arranged to fit within the dimensions of the box 13.50" X 7" X 3.5-5". In addition, resonating material including perforated steal sheet metal with a layer of fiber glass was lined throughout the inside of the box. The muffler was manufactured at the University of Minnesota Duluth, utilizing water jet cutting and welding operations. Uniform 16-gage steel was the primary material used which allowed for weight reduction from the 2014 competition muffler.

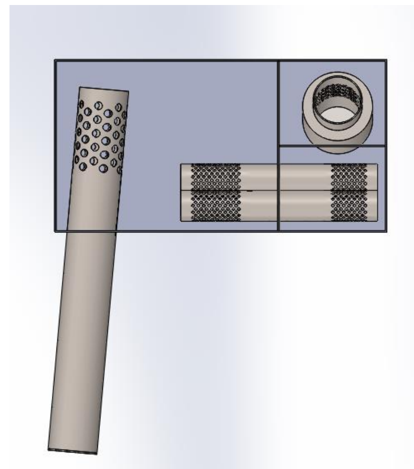

Figure 13. Top view of the 2015 muffler.

A SolidWorks flow simulation was utilized to design the box based on pressure and velocity. This is represented in Figures 14 and 15 below. In order to conduct the simulations, the system had to be analyzed with initial mass flow rate at the inlet of the first resonator and environmental pressure of 14.7 psi at the outlet. Values for mass flow rate at different RPM's were calculated by using the equation below. At the top engine speed of roughly 8000 RPM, the mass flow rate of the exhaust gas equates to about 0.28 lb./s

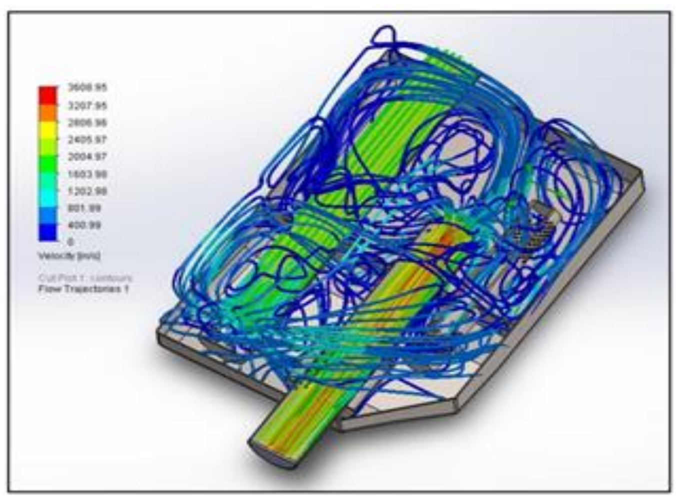

Figure 14. Flow simulation of the stock resonator box

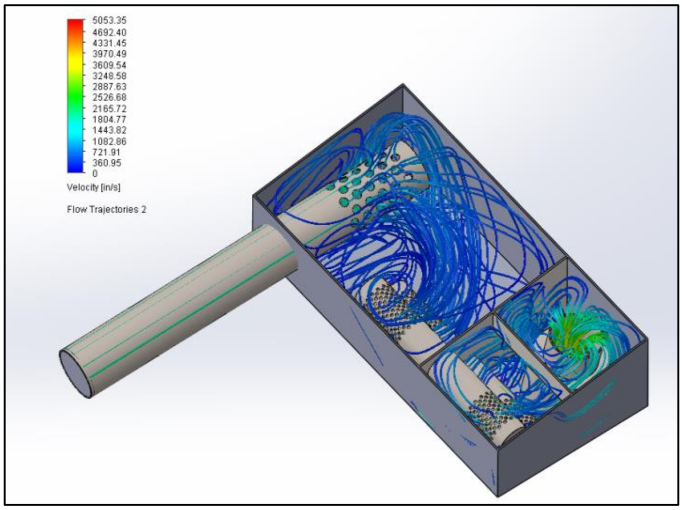

Figure 15. Flow simulation of new resonator box.

As sound is proportional to velocity, a Solidworks flow simulation was conducted comparing the velocity trajectories of the stock and competition mufflers. As shown in figures 15 and 16, the competition muffler had a 7% increase in pressure, which causes a lower velocity trajectory, and finally, lower sound. Using SAE test procedure J192, sound was measured at 77.9 dB (A).

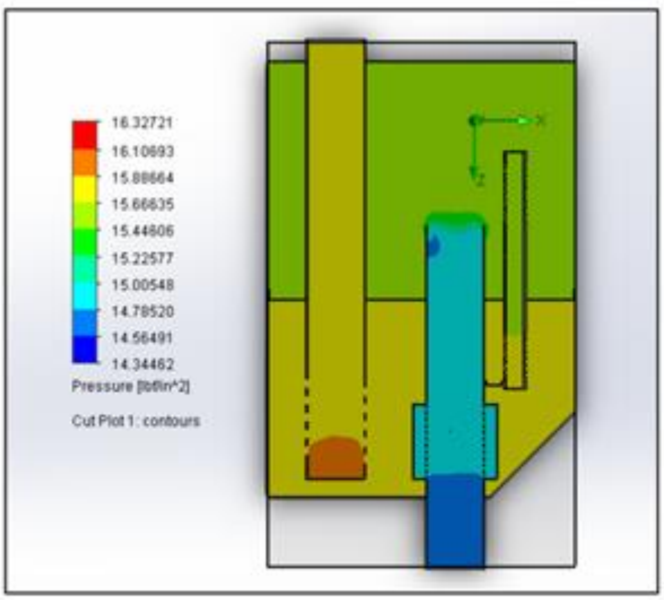

Figure 16. A pressure contour plot of the stock muffler.

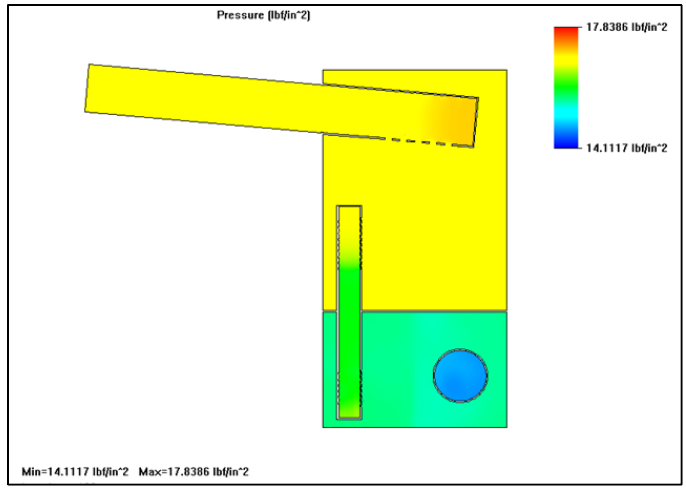

Figure 17. A pressure contour plot of the competition muffler.

For the 2015 competition, the Snowdawgs have a much improved exhaust system. It has tackled emissions, sound reduction, and excess heat concerns. The route of the system fits within the dimensions of the stock sled, making the design hidden and appealing to recreational riders.

DRIVELINE EFFICIENCY

Snowmobiles have an incredibly high power to weight ratio, however a good amount of power is lost through driveline inefficiency. By increasing the efficiency of the driveline, more power can be put to the ground. Ultimately, if more power is preserved through the driveline, the same real world performance can be obtained from a lower horsepower, but cleaner, engine.

This year the driveline segment of the Snowdawgs team had three primary goals. The first was to build a chassis dyno, which was critical for true and consistent testing and data collection. The second was to improve upon the gains made last year with the revolutionary roller drive sprocket. Finally, the utilization of industry leading light weigh technology in the form of a C3 Powersports Belt Drive system, replacing the decades old chaincase.

Roller Drive Sprocket

Last year the University of Minnesota Duluth’s team brought a potential industry changing innovation to competition in the form of a drive sprocket with roller bearings to improve efficiency. This year’s focus was to take this design and improve upon it by using different materials and making adjustments to last year’s geometry. The first task was to find a suitable material. The aluminum sprockets used in the previous design were strong, but also fairly heavy. A lighter weight alternative was necessary, while still being rigid enough to hold up under heavy torque and impacts. To accomplish this, the team had two drive sprockets 3-D printed out of PA802-CF, which is a carbon fiber filled high performance polyamide 11. It is a mixture between carbon fiber and nylon 11 which produces a high strength to weight ratio, good wear characteristics for outdoor applications, high resistance to warping from high temperatures and excellent stiffness qualities. Material properties indicate an ultimate tensile strength of 70 MPa, a density of 0.48 g/cm and a tensile modulus of 6388 MPa [8]. Using this material reduced the mass of the completed drive shaft from the 14.35 pounds it was last year to 11.60 pounds this year.

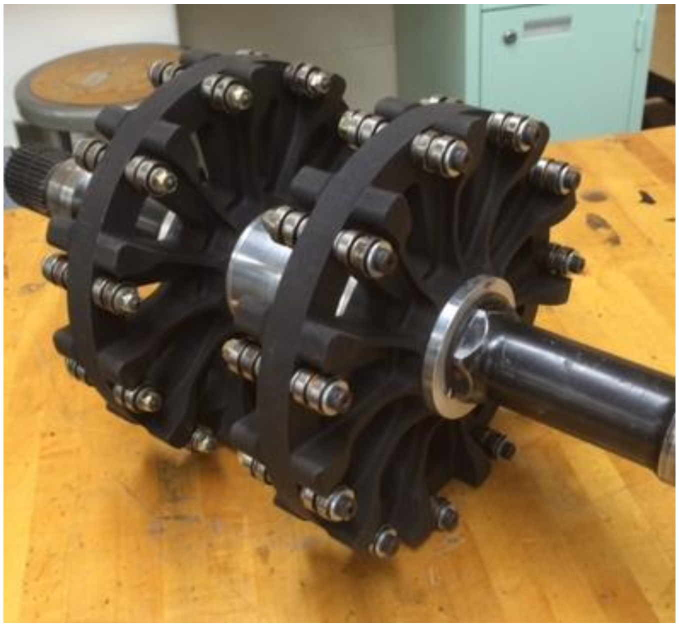

Figure 18. The new carbon fiber drive sprocket with integrated roller bearings.

The design of the drive sprockets involve roller bearings on the driver side of the cogs and a solid stub on the backside. The roller bearings interface with the track while accelerating and reduce friction between the components. This leads to higher efficiency and more power getting to the ground. Driver cogs were fitted with stubs to provide a solid stopping force for braking. If there were just roller bearings, there would be a potential for the track to jump during a hard breaking application. With combination of the roller bearings and the stubs produce a higher efficiency driver without decreasing rider safety. The 3-D printed drive sprockets were installed on the shaft with an interference fit. In order to add lateral stability, they are held in place by aluminum rings on the outside. The internal component of the assembly consists of an aluminum spreader that extends to hold the sprockets and rings in tension. Metal snap rings installed in machined grooves provide the outside support of the assembly. Overall the external dimensions of this year's drive sprockets are similar to last year's but the internal design was completely changed. The new drive sprocket is the same pitch as last year's being a 1:2.52 pitch. Testing in years past has shown that a 2.52 drive pitch was more efficient than a 2.86. The major component of the design adjustment was capitalizing on the customization possible with 3-D printing by creating complex supporting fins. Each cog of the roller drive has its own support running back to shaft to help distribute the stress of impact loading and the torque being applied to the extremities of the sprocket. The design was tested and improved through the use of Finite Element Analysis as shown in Figure 19 below.

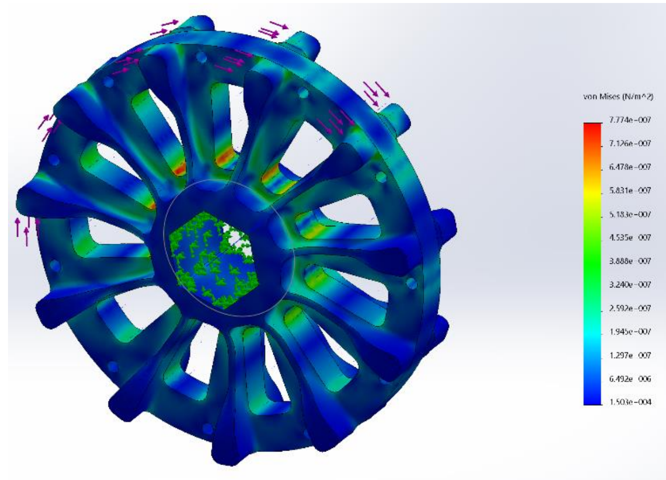

Figure 19. Structural analysis of the drive sprocket run through Solidworks.

The analysis run through Solidworks predicted failure of the sprockets at just over 1200 N*m or 890 ft*lbs being applied the outside cogs. This was slightly less than the model which tested forces applied to the roller bearing bolt holes. After discussions with snocross engineers, it was determined that the torque design point is roughly 400 N*m or 300 ft*lbs [9]. This number is based off the Arctic Cat Peak Torque Limiting System equipped on snocross machines. This system slips and just under 300 ft/lbs of torque. This equates to a factory of safety of 3 for this design.

Belt Drive

While different direct drive style systems have been flirted with off and on, the chain case has been a staple on the snowmobile since the beginning. Since no successful alternative has been accepted industry wide, the decision was made to attempt to reduce the friction and weigh that comes with a traditional chain and sprocket system. After looking to the aftermarket for possible solutions, the C3 Powersports SynchroDrive belt drive system was deemed a suitable alternative.

The C3 Powersports belt drive drops 11 pounds of overall weight, as well as reducing the rotating mass by 8 pounds. The system replaces the chain and sprockets with a belt and lightweight sprockets. The system was able to match the chain case drive system on the chassis dyno in warm temperatures. The belt drive will perform better on the snow, as it reduces the overall snowmobile weight, as well as eliminates the need for chain case oil, which performs poorly in the extreme cold.

Chassis Dyno

In order to test improvements made to the snowmobiles driveline, the chassis team developed a chassis dyno. The premise of this dyno was to run the track of the snowmobile at set speeds while recording the power consumption. The track displaced water when it ran. This was done in order to replicate real life scenarios where there is a fluid load applied to the track and snow to help lubricate the drive system. The design of the chassis dyno involved a built in baffle on the bottom to help break the turbulent flow caused by the track. By doing this it allowed water to flow back to the front under the baffle with a laminar flow. The drive train of the snowmobile was driven by a 10 horse power electric motor. This electric motor ran the snowmobile's driveline through a belt connecting the pulley mounted to the motor driveshaft to the snowmobiles secondary clutch. This can be seen in the picture shown below. The speed of the motor shaft was controlled by a variable frequency drive which allowed the team to vary the speed of the driveline. The range of speeds varied from 5 km/hour up to 25 km/hour. In order to reach these speeds, the 60 Hz motor was ran from 20 Hz up to 72Hz. Along with recording the power off the variable frequency drive, the team was able to record data off a digital speedometer installed on the rear idler wheel. This eliminated error recording track speed that was associated with changing drive sprockets and altering the gear ratios of the belt drive.

Figure 20. The chassis dyno with a 10 horsepower motor and the track suspended in water.

The result of the chassis dyno was power versus speed curves for a variety of variables. These included changing between the stock drive sprocket, last year's aluminum roller drive sprocket, this year's carbon fiber roller drive sprocket, and C3 Powersports belt drive versus the stock chain case. In order to provide accurate data, the track was held constant throughout all the tests. Along with the track, the water level in the tank, the track tension and the drive belt tensions were all held constant throughout the tests. Overall improvements from implementing the roller drive sprocket and the new roller carbon fiber drive sprocket were 6.1%.

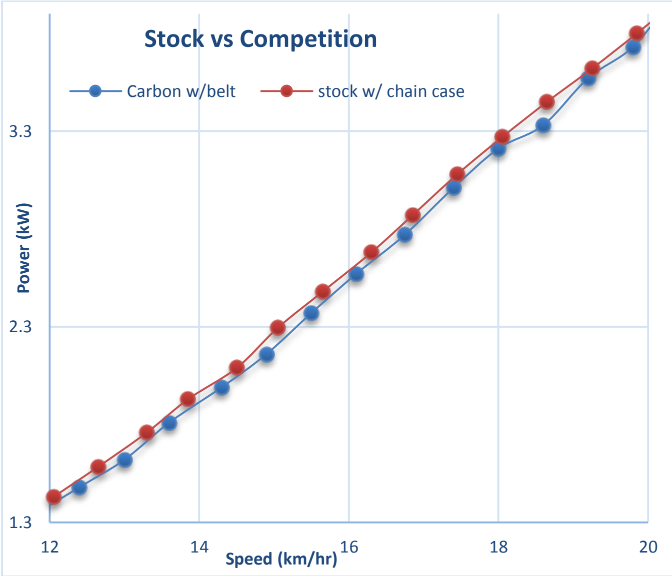

Figure 21. Comparing the stock drive sprocket and chaincase with the new carbon fiber drive sprocket and belt drive.

MARKET VALUE AND APPLICATION

The 2015 ZR7000 RR entered by the Snowdawgs is full of modifications in order to improve the snowmobile in many different ways. All of these modifications, however, were designed and utilized to have a sensible application to the everyday snowmobile. Fit and finish was maintained as a priority throughout the build, and it showed. The EGR and complete exhaust system fit inside the factory side panels and hood. All of the features and accessories that consumers have come to expect are fully functional. The snowmobile still has over 100 horsepower, maintaining the fun factor that is at the root of the snowmobiling tradition. This snowmobile and all the modifications and improvements herein have real world applications, they are not just some off the wall, impractical ideas. It consists of practical, useful modifications

CONCLUSIONS

This year the team made tremendous strides forward, and has a solid foundation for years to come. It was decided very early on that a reliable and legitimate testing facility was an absolute necessity for the club to move forward. A full chassis dyno and engine dyno were developed and utilized for testing every part of the snowmobile.

The great cost and man hours required to build solid, accurate pieces of test equipment has been overcome this year, which means next year the testing process can begin immediately. Even with a great deal of time devoted to building test equipment, the team has brought a very competitive entry to the 2015 competition. Major improvements include:

- New engine tune produced 5 more horsepower and 4 more lb-ft of torque
- Implementation of Exhaust Gas Recirculation system
- Custom designed rear exit exhaust with three-way catalytic converter
- 33.8% reduction in overall emissions
- 13.5% quieter than stock
- Carbon fiber roller drive sprocket
- Driveline is 6.1% more efficient

It is cleaner, quieter, more efficient, and still a blast to ride. It is equipped with technologies that will preserve both the sport of snowmobiling and the environment for generations to come.

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