Low Displacement, Quiet, Performance Snowmobile

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Innovations

For the 2019 Competition, the University at Buffalo Clean Snowmobile SI Team (UB SI) changed chassis from an Arctic Cat Bearcat to a ZR chassis. The goal for this year was to build a running reliable snowmobile to establish a solid foundation to build upon in the upcoming years. The past few competitions resulted in failures that required a rebuild of the entire snowmobile which consumes much of our time each year. Establishing a reliable snowmobile will allow for time to be focused on new innovations in the following years.

Figure 1: Arctic Cat ZR 3000 [4]

The team is utilizing the same engine and turbocharger combination it did the previous two competitions along with the engine management system from the 2018 competition. The wiring harness would be completely redone to ensure no potential problems occur. A focus was put on reducing noise through coating the chassis and lining the plastics of the snowmobile. Also, the fuel system was modified to provide better control over fuel delivery to the engine.

Team Organization and Time Management

The Clean Snowmobile team is part of UB's chapter of the Society of Automotive Engineers which is a club under the school's Student Association. The team shares an E-board with the school's Baja team. The E-Board handles all of the school related functions for the club to operate, including fundraisers, required events, and other logistics. Then both clean snowmobile team's and the Baja team have their own respective captains which are in charge of each team. This year, the UB SI composed of a captain, a few design leads, and a general body. A few of the major areas of the snowmobile were given a design lead such as the engine as well as the chassis. The captain determines the general direction that would be taken for the snowmobile based on the allotted resources for the year. The general body assists in the hands on aspect of work on the snowmobile as well as help with generating new ideas. Weekly meetings are held to update everyone on the status of various projects.

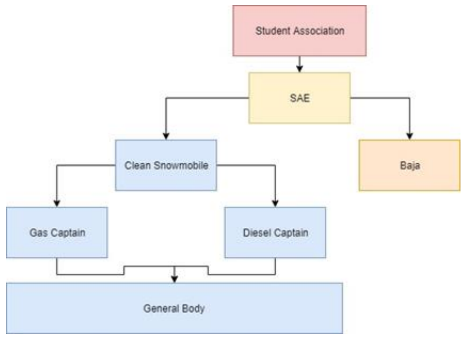

Figure 2: Club Hierarchy

Due to a shortage of new students showing interest towards the program, our club started the Freshman Retention Program. We were the first on campus to nominate someone to hold the position of Freshman Retention Officer and received much praise for it. There is a large learning gap between many students now with getting hands on experience and we found that a lot of them become discouraged quickly. Our new program allows new members to work on small projects to get some hands on experience when they first begin. More experienced members of the club offer lessons on Solidworks to get new members familiar with designing and modeling parts. Once the students learn how to make a drawing from Solidworks, they then proceed to the next step and learn how to make it in the machine shop. The students then make a part using material we have available at the time and learn how to make it step by step using various machines such as the band saw, lathe, mill etc. We have noticed a sizeable difference in the amount of students that have kept their interest towards the club this year

Build Items of the Snowmobile

- Chassis – 2017 Arctic Cat ZR 3000
- Engine – Arctic Cat 700 cc twin cylinder 4 stroke, gasoline, stock rated 65 hp.
- Track – Stock 129 in. (1.00 in. lug)
- Muffler – Honda Turbo Flow design muffler
- Catalytic Converter – 3-way, Magnaflow
- Skis – Stock
- Turbo – Borg Warner KP 35

Design Content of the Snowmobile

Methods

For the 2019 Clean Snowmobile Challenge, the University at Buffalo (UB) Spark Ignition team changed chassis from the prior competition. In 2018, the team ran a 2017 Arctic Cat Bearcat chassis which is a known utility chassis. The team felt that the longer tunnel and track on the Bearcat provided extra weight that was unnecessary to compete in the Spark Ignition class, and while weight isn't a direct category to be scored, it does have an impact on overall performance. That is why the team chose a 2017 Arctic Cat ZR 3000 chassis for the 2019 competition. The chassis was also chosen as it housed the same engine from the factory as the Bearcat and would provide an easy transition.

Since having a reliable running snowmobile has been a problem experienced by the team the last two years, the main goal for our team this year was to bring a snowmobile that would make it through the entire competition even if it meant purchasing certain parts then designing them ourselves. Having a running reliable snowmobile would provide a solid foundation to build off of for future events. Our other main goal for the 2019 competition was to focus on the noise output of the snowmobile. The team knew there was lots of room for improvement in that category so that's where the main focus was set. Lastly, it was important to us that the snowmobile would be marketable. Our goal was to match the performance of a modern 600 two-stroke class snowmobile as that's the bottom line for performance for most consumers.

The build began by taking the chassis down to bare bones and building it up going through each system individually and then looking to see how each system will effect one another both performance wise and physically.

Engine

The engine being used for the 2019 competition will be the same as in the 2018 competition which is the stock Arctic Cat 700cc two cylinder four stroke engine. The engine has a stock 65hp which would see large benefits from a turbocharger application. The engines main downfall is it's 360 degree firing order which causes a significant vibration throughout the engine and exhaust system. This would have to be taken into consideration in the exhaust system design.

Figure 2: 700cc Arctic Cat 4 Stroke Engine [4]

For the 2019 competition, the team decided to have coatings applied to certain parts of the engine to better enhance its performance and efficiency. To start, a lubricating coating was applied to the skirts of the pistons to reduce friction within the engine. A paper written by Pranay Nagar and Scott Miers explains that frictional losses with the engine cylinder can contribute to up to 20% of the losses in the engine [1]. So it was an easy choice to attack this problem. Also, a ceramic thermal coating was applied to the piston tops, combustion chamber, valves, and exhaust ports. This would help with several areas. One, it would protect the piston from any high temperature events it may experience as an added layer of safety. Also, it helps keep heat within the combustion chamber which increases the thermal efficiency of the engine.

Turbocharger

The turbocharger utilized for the 2019 Clean Snowmobile Challenge is a Borg Warner KP 35. This was decided by finding the proper pressure ratio and air flow then utilizing a compressor map to determine if the turbo was a proper fit. To find the pressure ratio, the following equation was used:

$$\boldsymbol{Pressure\ Ratio} = \frac{P_{boost} + P_{atm}}{P_{atm}} \quad (1)$$

Our target horsepower for the year was 115 hp and we estimated it would take 15 psi of pressure to get there. This makes the pressure ratio 2.02. The following equation was used to find the estimated airflow of the engine:

$$\boldsymbol{CFM} = \frac{\frac{1}{2} Engine\ Displacement * Max\ RPM * V.E. * D.R.}{1728} \quad (2)$$

Where engine displacement is in cubic inches, V.E. is 0.8 and represents the amount of the cylinder a typical engine can fill with air on its intake stroke, and D.R. is the density ratio which could be found on the following figure assuming compressor efficiency of 70%.

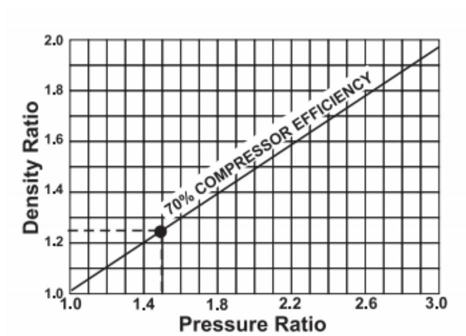

Figure 3: Density Ratio Graph

The CFM is divided by 14.5 to give the corrected air flow requirement for the engine, which was found to be 7.16 lbs/min.

The efficiency found on the compressor map utilizing these parameters is 0.73 which is right near the center of the compressor map for the KP 35 Turbocharger.

An external 38mm Precision Turbo wastegate was chosen to more precisely control exhaust flow into the turbocharger. 15 psi springs were installed in the wastegate to meet the target horsepower set by the team for the year. Since an external wastegate was used, the internal wastegate was removed and welded shut on the turbocharger. The entire exhaust housing of the turbo was then milled to reduce all excess weight that was no longer needed. This reduced the weight of the exhaust housing by almost 40%. All of the flanges were removed and V-Band clamps were directly welded for ease of servicing the turbo.

Fuel Control

The stock snowmobile utilized an in-tank fuel pressure regulator and a return less fuel rail. With the addition of a turbocharger to the system, as the engine builds manifold pressure, the fuel pressure has to be adjusted accordingly. This is necessary to be sure the injectors are still adding the right amount of fuel to the engine while under boost. Since the stock snowmobile did not have a turbocharger, it's fuel system would not accommodate for the added boost pressure. Therefore, the factory regulator in the tank was removed and a 1:1 boost reference pressure regulator was added to adjust fuel pressure based on the amount of boost generated by the turbo. The system was set up to utilize the factory return less fuel rail. This modification would ensure precise control of fuel by the ECU and the injectors.

Catalyst

The combustion process in a gas engine produces waste gasses which include nitrogen oxides, nitric oxide, carbon monoxide, and hydrocarbons. There are two common types of catalytic converters available to reduce these emissions; a 2-way and 3-way converter. A 2-way catalytic converter deals with both converting carbon monoxide into carbon dioxide as well as converting various other produced unburnt hydrocarbons into carbon dioxide and water. A 3-way converter does this as well as converting Nitric oxide and Nitrogen dioxide into nitrogen by combining them with carbon monoxide.

To deal with reducing emissions on the snowmobile, the team chose to employ a 3 way-catalytic converter. Most automobiles now employ 3-way catalytic converters so they are more abundant to find and also deal with nitrogen dioxide which is not done with a 2-way catalyst. Due to size constraints within the cowling, a small universal designed catalyst was chosen.

Exhaust System

The previous two competitions, the UB SI team has experienced failures in the exhaust system, specifically with the in house designed manifold. Due to the large amplitude of vibrations created by the engine, combined with the weight of the turbocharger, and extreme heat cycles, the manifold would fail. After talking with the manufacturer, it was found to be a known issue with this engine combination. Therefore, for 2019 the team decided to use the stock manifold provided by Arctic Cat to prevent failure during competition. The turbocharger was also mounted further forward with a support to the chassis to remove all of the weight from the manifold.

The exhaust tubing size was also reduced. The factory exhaust was 2 in. but was found to be unnecessary due to the small displacement of the engine. All of the exhaust pipe was reduced to 1.5 in. post turbo to cut down on unneeded weight as well as help with fitment. V-Band clamps were used throughout the system to make a modular exhaust system that could be easily serviced.

Engine Sound Control

Sound produced from the snowmobile is emitted by two main sources, the engine and the track. The most prominent noise source on most snowmobile's is the engine, and it plays a large part in the snowmobiling experience. Aside from high performance races, most consumers desire snowmobiles that are quieter. When going on long trail rides the constant droning of a loud engine can be detrimental to the riding experience. Also, snowmobiling is a sport fueled by gracious landowners who allow the trails to pass through their properties all hours of the day. They don't want to be bothered by noisy snowmobiles driving by all day long, or woken by them in the middle of the night. Unfortunately, this problem is causing trail closures throughout the country, which is a burden on the sport. Therefore, there is a push to develop snowmobiles that are quieter and less intrusive to bystanders and wildlife.

The noise on the 2019 snowmobile is largely reduced through both the turbo and the catalyst, however there still remains a decent amount of sound to be dealt with. While the team originally set sights on designing and manufacturing our own compact muffler, time constraints and the realization that there are already plenty of readily available options for quiet mufflers led the team down the path of purchasing one from a Honda automobile. Honda has been known for producing highly reliable, quiet vehicles for many years, so we felt it would be a good match for our 2019 build. It was also a package that could be fit within the constraints of the cowling.

After the incorporation of the muffler, the noise produced by the engine was minimal. However, the team still thought there was room to make it quieter. The decision was made to construct a Helmholtz resonator to eliminate noise at a specific frequency. To determine the dimensions of the resonator, the following equation was used:

$$f = \frac{c}{2\pi} * \sqrt{\left(\frac{A}{V * L}\right)} \qquad (3)$$

Where f is the frequency, c is the speed of sound, A is the area of the pipe leading the resonator, L is the length of the pipe leading to the resonator, and V is the volume of the resonator. The team has to measure the desired frequency to cancel so that it can tailor the dimensions of the resonator accordingly.

Chassis Noise Control

While the engine is the primary source of noise in a snowmobile, the track and chassis still produce a significant amount of sound that can become very audible once engine noise is reduced. The team took several measures to help this issue.

To start, a test was conducted on various materials that would be used to line the tunnel of the snowmobile. To test the materials, a sound chamber was made from 4in. PVC tubing. A slot was cut into the middle to insert various metal pieces in which the material would be applied to. In one of the endcaps a Bluetooth speaker was embedded. Using a smartphone app, a frequency generator would play a desired frequency through the speaker a constant noise level. A wide array of frequencies would be tested. At the other end of the tube, a sound meter was mounted into the endcap to measure the sound level.

Figure 4: VLIKE LCD Digital Sound Meter

The materials would be applied to pieces of 16-gauge aluminum which represents the thickness of the tunnel of the snowmobile. One panel was tested with nothing applied to it as a control, while the others contained the materials to be tested.

Figure 5: Sound Testing Setup

The team chose to test 2 different foam variations, regular spray paint, and lizard skin sound deadening coating. The foam materials and the coatings reduce sound by different methods. The foam acts to absorb sound in all of the pores and reduce the amount of sound reflection. The coatings serve to add mass to the panel which will reduced the amount it can vibrate which in turn limits sound transmission. The results from the tests are shown in Figure 6.

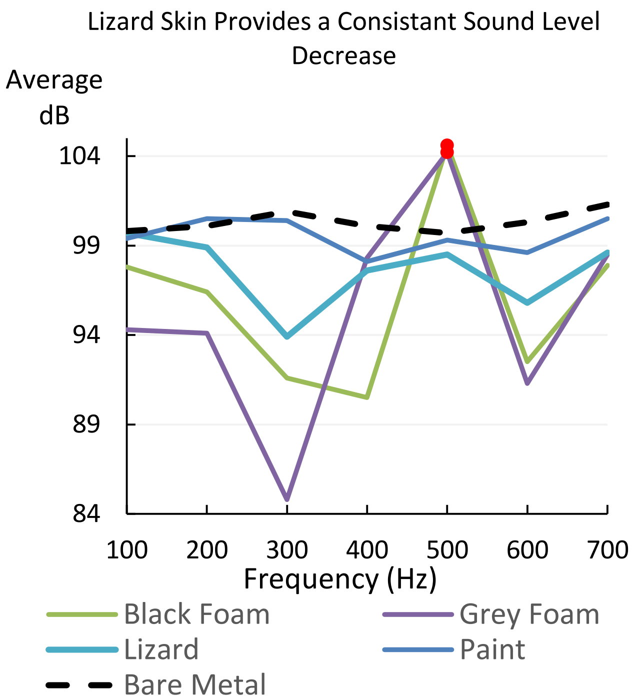

Figure 6: Material Testing Results

Lizard skin was chosen to coat the tunnel for several reasons. To start, it wouldn't absorb water like the foam would tend to. It also provided a consistent decrease in noise levels across all frequencies. There were certain frequencies where the foam actually amplified the sound in the chamber, so we wanted to avoid any chance of falling within one of those resonating frequencies.

Aside from the tunnel, the team chose to line all of the plastics with a foam/mass loaded vinyl combination to further reduce the noise output of the engine bay. The material consisted of two layers of foam to absorb sound with a layer of mass loaded vinyl between to help deaden panel vibrations. This combination of sound reduction methods produced a snowmobile with significantly reduced chassis noise.

Traction

The team will be using the stock 1" lug track on the ZR. Studs will not be added to the snowmobile for the 2019 competition. Since performance of the snowmobile has negligible impact on the final score, leaving the track unstudded would benefit the noise emissions of the track as well as reduce rotating mass which would increase fuel economy. Studs could be added in future competitions when acceleration and need for traction is given more weight and recognition in the Clean Snowmobile Challenge.

Engine Calibration

To calibrate the engine, a Motec M130 ECU and their M1 Tune software was used. A wideband O_2 sensor was installed post exhaust manifold to monitor the Lambda of the combustion.

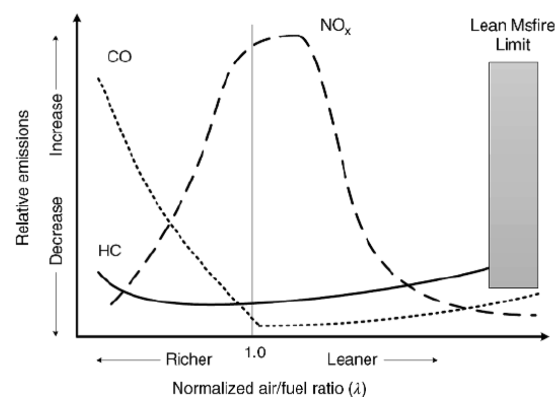

Figure 7: AFR vs. Emissions

It was decided to tune the engine at a Lambda of 1.0 since that's where the combustion of gasoline provides the best compromise of fuel economy, NOx, CO, and HC output, while providing a more stable combustion. The team would have liked to have run leaner to increase fuel economy, but that would result in a less stable combustion as well as requiring a different strategy for dealing with emissions as a traditional catalyst is unable to operate with lean-burn engines. Also, as the engine is run leaner the exhaust temperatures become higher which would reduce the reliability of the engine and exhaust system.

Tuning was accomplished by running the engine with a DYNOmite Dynamometer attached to the PTO to provide load to the engine. The engine was held over every cell of the fuel table to adjust the fuel amount until the lambda was close to 1.0 where desired. Once the base fuel map was tuned, the closed loop tuning function allowed the input of a desired Lambda table and the ECU would automatically adjust fuel trim to meet those values. The ignition timing was then adjusted.

The Clean Snowmobile Challenge requires that the snowmobiles can run on any blend of Ethanol between 0% to 85% ethanol [1]. To account for this, a Continental fuel content sensor was installed in the fuel system to tell the ECU how much ethanol is in the fuel so that the fuel table could be adjusted. To tune for this, the snowmobile is tuned with a primary fuel which we used regular 10% ethanol pump gas. Then, a fuel volume compensation value is entered for the secondary fuel (E85) and the ignition table for the secondary fuel is tuned. Then based on the value given by the sensor, the ECU blends the ignition tables together for all of the compositions in between and adjusts the fuel volume to be injected.

Summary

In conclusion, the UB SI team feels that they accomplished what they were after at the start of the year. A reliable solid foundation was established that could be improved on in the upcoming years. Also, the focus on reducing noise emissions paid off with the result being a snowmobile that is significantly quieter then it’s stock form. The addition of the turbocharger helped increase the top end performance that buyers of new snowmobiles are looking for while maintaining the efficiency of a lower displacement engine.

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Acknowledgments

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Definitions/Abbreviations

UB SI	University at Buffalo Spark Ignition Team
AFR	Air fuel ratio
SAE	Society of Automotive Engineers