University of Waterloo Clean Snowmobile Team Design Paper

ABSTRACT

The 2013 University of Waterloo Clean Snowmobile Team has chosen to further develop the snowmobile platform employed in the 2012 Clean Snowmobile Competition. This design integrates an Arctic Cat T660 Turbo engine with a 2009 Ski-Doo Renegade XP chassis. This combination offers low-displacement efficiency under cruising conditions and significant power under full-throttle operation in a lightweight crossover chassis. Emissions are reduced through the use of a three-way catalytic converter, and noise is reduced through the turbocharger, the catalyst substrate, and an aluminium single-diffuser muffler. Efforts to improve efficiency include the use of a lightweight lithium iron phosphate starting battery and an increased rear idler wheel diameter.

INTRODUCTION

Background

For many years snowmobiling has been a popular recreational sport for families and friends to embrace the winter season and experience the wonders that the North has to offer. In the late 1990’s research called attention to the environmental impact of snowmobiles when a study in Yellowstone National Park found that snowmobiles contributed up to 90% of hydrocarbon emissions and up to 68% of carbon monoxide emissions yet only accounting for 6% of the total vehicles entering the park annually (1). The severity of impact resulted in the prohibition of snowmobiles in the park.

Following this prohibition, manufacturers have since been diligently working towards a cleaner, yet equally satisfying solution. To achieve this goal, the University of Waterloo borrowed two main strategies from the automotive industry: installing four-stroke engines coupled with catalytic converters. The SAE Clean Snowmobile Challenge enhances this design goal by mandating the use of an ethanol blend of fuel. The University of Waterloo’s 2013 snowmobile is capable of running on fuels comprised of 0% to 39% ethanol. Ethanol burns cleaner than gasoline, while still providing the power and performance that riders will enjoy. The UW Clean Snowmobile Team plans to implement all three emission reduction technologies in designing a machine that will provide a clean, enjoyable snowmobiling experience.

Challenge

The SAE Clean Snowmobile Challenge presents a conflicting design challenge; to create a solution that maximizes efficiency, minimizes exhaust and noise emissions, while at the same time maintaining optimal overall performance. Innovation in this challenge lies in developing a strategy to incorporate all of these goals to create a marketable, reliable, and practical solution.

Overall, the greatest challenge faced by the Waterloo team this year was the recruitment of new members and maintaining productivity while integrating new members into the team. The University of Waterloo Engineering program is a co-operative program which results in team members being present for 4 months, and absent for 4 months continuously. In addition, the Clean Snowmobile Challenge provides an attractive design opportunity for fourth year students who will then graduate. It is difficult to maintain a smooth transfer of knowledge as team member’s turnover each year, and it has since been our goal to train and engage junior students in this design challenge. As such, extensive planning and organization was required to ensure that projects were delegated and completed in a timely fashion.
The greatest technical challenges this year included the troubleshooting and repair of the snowmobile from the 2012 competition, as well as a recent emergency engine replacement. Troubleshooting a partially-operational platform and then repairing and improving its design required re-evaluation of projects, and new innovative solutions.

Design Strategy

The objective of the competition is to modify a stock snowmobile to reduce tailpipe emissions, improve fuel efficiency, and reduce noise without adversely impacting performance. These modifications must be done at minimal cost and be practical conversions for common production snowmobiles. The design strategy employed by the University of Waterloo Clean Snowmobile Team for the 2013 competition builds upon the one employed for the 2012 competition. By using an already light chassis and a higher power version of a BAT-certified engine, the Team hopes to develop a well-balanced combination of power and efficiency.

Design Criteria

To ensure the most effective design, all decisions are weighted based on the design criteria outlined by the design team during the preliminary planning phase of the project. These design criteria are:

Maximize performance of the snowmobile.
Minimize emissions of carbon monoxide and unburned hydrocarbons.
Minimize noise.
Minimize weight of installed components.
Minimize overall cost.

Design Constraints

The design must meet the design constraints outlined below in order to be considered successful:

- Designs must ensure safety of the rider.
- Snowmobile must run on ethanol flex fuel ranging from 10-39% ethanol.
- All components must be ethanol flex fuel compatible.
- Snowmobile noise must not exceed 78 dBa.
- The engine must start within 20 seconds and move
- 100 feet within 120 seconds without stalling.
- Maximum of 130 bhp

PERFORMANCE AND EMISSION CONTROL

Chassis

The chassis selected for the 2013 competition is a 2009 Ski-Doo Rev-XP chassis, which at the time of manufacture, was lighter than any chassis on the market (2). The Rev-XP is also very ergonomic, which is important for every-day drivability. Low weight is extremely important when aiming for performance and fuel economy, so the Rev-XP is a good fit with the UW design mentality. In order to keep costs down, the chassis was purchased second hand.

Figure 1: REV XP chassis

Engine

The same criteria (low cost, low weight) applied to the purchasing of the engine, and in the end, it was decided that a 2005 Arctic Cat T-660 engine would power the 2013 sled. The T-660 is a 660 cubic centimetre, three cylinder, four stroke, turbocharged engine. Many snowmobiles come equipped with two stroke engines which produce much more harmful emissions due to the fact that oil (for lubrication) and gasoline must be mixed and sent into the combustion chamber. A well-maintained four-stroke engine will never burn an appreciable amount of lubricating oil. The use of a turbocharged engine allows the cylinder air mass to be controlled based on power demand. Wastegate control can be used to regulate boost pressure so that boosted operation is postponed until the throttle is opened beyond a certain threshold, allowing more efficient cruising operation without reducing available power.

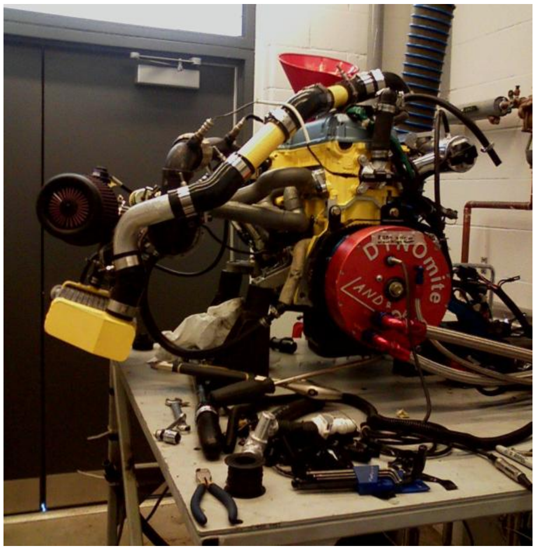

Figure 2: T660 attached to dynamometer

Exhaust Header

The stock exhaust manifold is unacceptable for a number of reasons. First and foremost, it will not fit in the chassis and needs to be redesigned. Second, it is a very restrictive design and this will be accounted for in the redesign. A picture of the stock exhaust manifold can be seen below.

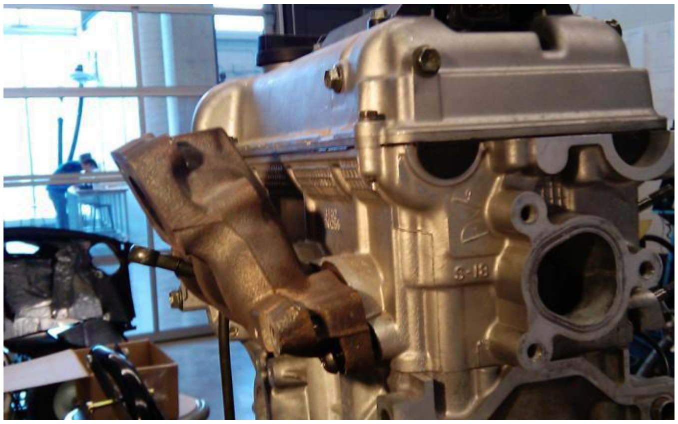

Figure 3: Stock exhaust manifold

Note how the exhaust gases will turn 90° immediately exiting the engine. This is not a smooth transition, and can create a higher pressure at the exit which can hinder performance by not allowing exhaust gases from the cylinders escape efficiently. The first step in designing new headers is to determine the inside diameter. This is done by analyzing the engine at its top speed and calculating the flow rate of exhaust gases escaping. This diameter is determined to be 1.5”. The collector is where the three header pipes meet, and this has to mount to the turbocharger, therefore the diameter was determined.

Once the diameters were determined, the length of the headers needed to be found. This was done using the speed and volume of the cylinders (which corresponds to how much gas is exiting the engine) and also on valve overlap – the length of the headers should be such that when exhaust gas from cylinder 1 reaches the collector, exhaust gas from cylinder 2 is just entering the header. This creates an efficient method of drawing the exhaust gases out and away from the engine. The headers are also required to be equal length.

Once the length and diameters were calculated, a Solidworks model was created in order to determine how the final design should look. The final design needs to integrate with the sled properly without causing any interference, and must also allow the turbocharger to fit within the engine bay. The Solidworks model can be seen below that outlines the final design.

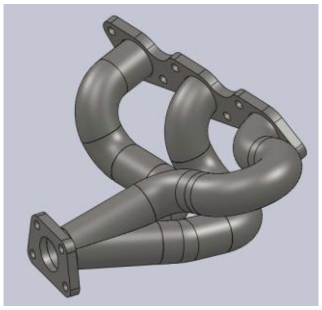

Figure 4: CAD model of header

The system has also been ceramic coated on the inside to reduce heat losses to the engine bay. This helps in two areas: it keeps the exhaust gases hot, which helps them to flow easier and evacuate the headers, and also reduces the heat released to the engine bay which contains many hoses and liquids that will not function properly if heated too far. In addition to determining the fit of the exhaust manifold, Solidworks was used to determine the factor of safety of the system because it is cantilevered to the engine bay, and the turbocharger is on the end. The factor of safety is sufficiently high (more than 15) and therefore will be safe to operate. The newly designed exhaust system is superior to the stock system because it provides a much smoother transition for the gases reducing backpressure and flow separation. The finished manifold can be seen below compared to the stock system, and although it is much larger than the stock exhaust manifold, it weighs slightly less due to lighter components being used.

Figure 5: Stock manifold (top)vs equal-length exhaust header (bottom)

Catalytic Converter

One of the main objectives of the competition is to make a snowmobile cleaner, and while a four stroke engine helps to reduce emissions, a catalytic converter is just important. Adding a catalytic converter also adds weight, but it is a necessary sacrifice in order to achieve a low emissions design. The main aspects considered when selecting the catalytic converter were type and heat shielding to apply. The optimum type of catalytic converter chosen is a cerium additive type because it provides the greatest reduction in emissions compared to air injection and also using two separate catalytic converters. The cerium additive is the most compact design that adheres to the criteria, and is the best fit within the system. A high temperature ceramic spray paint was selected to form an insulating barrier on the converter's exterior to aid in catalyst warm-up and also to protect other interior components from heat damage.

Flex-Fuel Management System

In order to maintain the simplicity and low cost of the stock fuelling system, the team elected to use only three injectors, where some teams have taken an alternate approach that utilizes secondary injectors. Higher-flowing, low-impedance injectors were selected in order to account for the richer stoichiometric air-fuel ratio of ethanol-based fuels while allowing stable idle-operation at the low duty cycles encountered when using pure gasoline. A fuel composition sensor was added to scale the fuel injection pulse-width based on the percent ethanol content of the fuel flowing through the fuel return line. This is achieved through a 2D transform table in the Sled's MoTeC M400 ECU.

NOISE REDUCTION

Exhaust Silencer

Exhaust noise reduction is typically approached by OEMs with complicated steel mufflers which weigh in excess of 20 pounds. The University of Waterloo Clean Snowmobile Team introduced an aluminium dual-diffuser, side-resonant muffler suspended from the running board. The dimensions for this silencer were derived from experimentation with empirical equations from Blair's *Design and Simulation of Two Stroke Engines*. Further experimentation this year yielded a single-diffuser design within the same space could achieve superior results at a further weight reduction and with less protrusion below the running board. A re-entrant diffusion chamber, when dimensioned appropriately can attenuate a wide range of frequencies with several peaks, and several pass-bands. Characteristics of the diffuser were adjusted to place one such attenuation peak at the exhaust pulse frequency of the engine when cruising at approximately 6500 RPM.

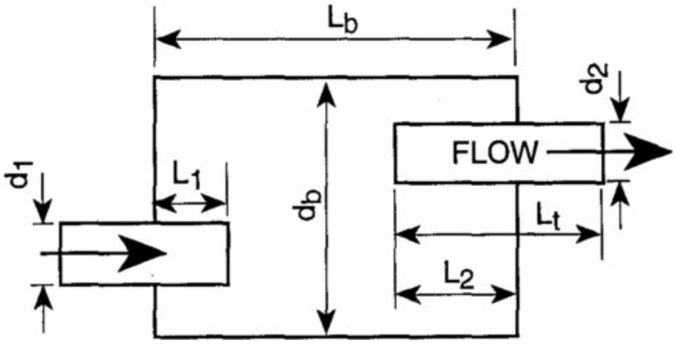

Figure 6: Re-entrant diffusion muffler, Blair

A purchased absorption silencer was then installed downstream to attenuate any flow noise introduced earlier in the exhaust.

Engine Compartment Silencing

The Team has, in the past, used a two-layer absorption approach for engine compartment noise reduction. The base layer consisted of a rubberized asphalt sheet to reduce low-frequency noise and reduce panel vibrations. This layer typically added 3-5 pounds per panel. When applied to both side panels and the hood, this layer added as much as 15 pounds to the weight of the sled. The second layer consisted of a lightweight foam sound insulation covered with foil, typically used for hood-lining applications. The team deemed that a 9-15 pound weight reduction from removing the asphalt layer offered more in fuel savings and performance gains than the perceived noise reduction it would have provided if left in place.

ADDITIONAL WEIGHT REDUCTION

Battery

Most production snowmobiles use absorbent glass mat (AGM) lead-acid batteries for starting. While the lower cranking demand and low number of electrical accessories present on a snowmobile allow the use of relatively small batteries compared to most automotive applications, such batteries still weigh in excess of 15 pounds. Lithium iron phosphate (LiFePO4) battery technology has progressed such that a vast number of aftermarket suppliers offer starting batteries of this chemistry. The Team determined that an 8-cell LiFePO4 battery would be an appropriate replacement for the AGM battery employed in the 2011 competition. The particular unit selected is approximately 2/3 the volume of AGM battery and weighs less than 2 pounds. Reducing the weight of the battery reduced the strength requirements for the battery box, making the entire assembly weigh just over 2 pounds. Despite being smaller and lighter than the previous battery, it produces 300 pulse cranking amps and 240 cold cranking amps, which is suitable for the T660's low 6.8:1 mechanical compression ratio. Furthermore, this modification only increased the snowmobile's MSRP by $45. This modification is therefore highly affordable to the end user and reduces weight by over 10 pounds. This translates into lower fuel usage during acceleration and improved floatation and manoeuvrability.

DRIVE EFFICIENCY

Rear Idler Wheels

Typical track idler wheels are required to rotate at considerably high speeds whenever the track is spinning. Frictional losses in bearings, assuming a constant coefficient of kinetic friction at trail speeds, are proportional to the angular speed of the idler wheel which is, in turn, inversely proportional to the diameter of the wheel. The rear idler wheels are constantly subject to force applied by track tension, the weight of the snowmobile, and by transient force from acceleration. As such, the bearings of these rear wheels present the highest potential for loss/reduction. Furthermore, the track is constantly deformed as it passes over the rear wheels. Energy is converted to heat as a result of the bending strain imposed on the track. Assuming the losses are roughly proportional to the curvature (inverse of radius) of the track passing over the rear wheels, an increase in rear wheel diameter will reduce such losses. The stock rear wheel diameter is 180mm (7.125 inches). A modified diameter of 8 inches would be easily accommodated by an offset axle without requiring a longer track or any modification of the skid frame. Using the theoretical loss relations assumed above, the reduction of losses at the rear idler wheel (neglecting inertial effects) is as follows:

$$Reduction \approx 100 - 100\left(\frac{D_{old}}{D_{new}}\right)$$

Equation 1: Approximate percent reduction in losses due to rear wheels

Using the above formula, the percent reduction in frictional losses and bending losses for substituting 8 inch rear wheels is approximately 10.9%. While the cost of the offset axle and aftermarket wheels inflate the snowmobile's MSRP for the competition, a marginally taller slide rail extrusion and larger rear wheel mold would achieve the same result with less added weight. This latter strategy is a feasible option for manufacturers.

CONCLUSION

A quiet, clean and efficient snowmobile can still meet the performance requirements of the general public. The UW Clean Snowmobile Team has demonstrated this concept and has generated a solution that can be easily implemented and marketed. The biggest solutions to the snowmobile pollution problem can be addressed by switching from a two stroke to a four stroke engine and adding a catalytic converter. Further improvements with regards to pollution can be addressed by converting the snowmobile to run on a gasoline/ethanol blend of fuel. The final product is a snowmobile that hasn’t lost performance despite being environmentally responsible.

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