Design of an Efficient 4-stroke Snowmobile Clean Snowmobile Challenge 2019

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Innovations

The major changes to the snowmobile from the 2018 to 2019 season were related to the intake, exhaust, engine position, and vibration damping. The throttle body size was reduced to improve idle condition issues that arose on past designs. The muffler was fully redesigned using the previous year's results and designs as well as new theories and approaches. The mounting position of the engine was slightly modified to improve clutch spacing and packaging. A vibration damping material (Silent Running) was applied to the interior of the tunnel to reduce track vibration noise.

Team Organization and Time Management

The Rochester Institute of Technology Clean Snowmobile team was formed in 2012. Over the years the team structure has progressed into its current form displayed in figure 1. It was configured in such a way to balance the responsibilities of the Executive Board members by splitting the team into two groups. The team management side which handles logistics, while the project management side handles engineering decisions. The team is specifically structured to allow the transfer of knowledge to new and inexperienced members.

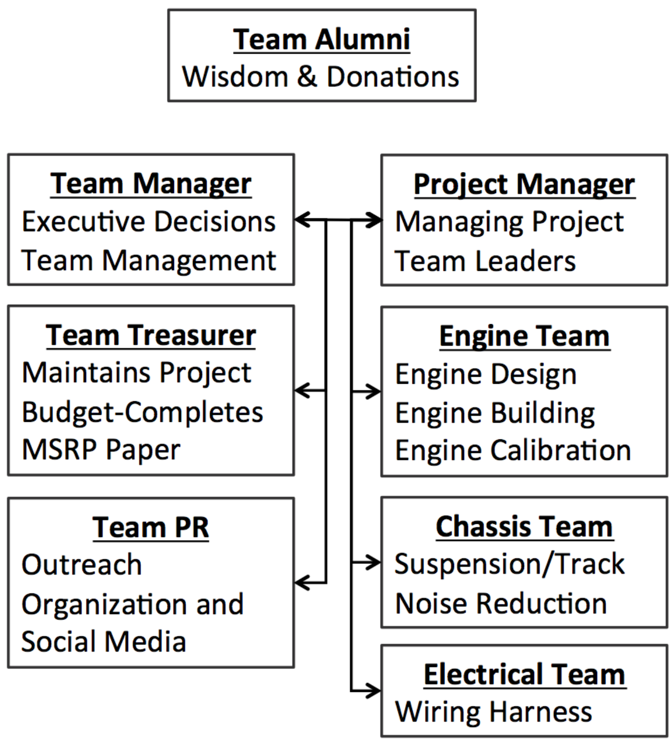

Figure 1. Team structure

Team Structure

After each season, the CST elects a new executive board which consists of a team manager, project manager, secretary, treasurer, and public relations representative. The team manager works closely with all the members of the executive board and oversees purchases and team efficiency. They also communicate and work with the department to organize tours and various campus events. The project manager is responsible for overseeing the engineering of the snowmobile. They have the final say on any and all modifications done to the sled. The remaining positions fall under the team manager. The project manager is in charge of selecting who in the team will be in charge of leads, which are engine lead, chassis lead, manufacturing lead, and electrical lead. With the remaining team members allowed to choose which team to work on.

Time management is done by the executive board at the beginning of the academic year, using a Gantt Chart to set deadlines and figure out what needs to be done to be better than the year before. The major projects that we have are also written on the shop-board for all to see whenever team members are in the shop. The team leads were in charge of getting their respective tasks done on time and to ask for help or assistance if needed from the project manager. Refer to Appendix A to view the Gantt chart.

Build Items of the Snowmobile

- Chassis – Polaris, Rush Pro-S, 2015
- Engine – Weber, Gasoline, 750cc, 4-stroke, 45hp.
- Track – Camso, Ice Attack XT (pre-studded)
- Muffler – Student Designed
- Catalytic Converter – BASF, 3-way
- Skis – Curve Industries XS Ski
- Intake – Student Designed

Design Content of Snowmobile

Engine

The Weber 750 was utilized for the 2019 CSC. This engine can be found stock in the 2008 Polaris IQ Touring FST snowmobiles, meets the minimum CSC brake specific emissions, and has an impressive power to weight ratio at 1.54 kW/kg. This engine will provide a low emission power plant for the snowmobile while still maintaining the power and performance of an environmentally friendly snowmobile. The engine features different technologies built in to reduce parasitic losses which makes it ideal for this application. A dry sump lubrication system ensures the crankshaft and valve train are supplied with adequate lubrication and reduced windage. A dry sump system also has the potential to draw a vacuum underneath the cylinders reducing losses. Another design feature that the Weber has integrated into their engine to reduce losses are roller bearings throughout the camshaft and gear drive system.

Calibration Strategy

The CSC in-lab emissions event follows a combination of test procedure J1088 (proposed in SAE Paper No. 982017) and EPA 40 CFR Parts 89, 90 and 91. An e-score is then determined using the following equation.

Wm=Weighting of mode
UHC=Unburned Hydrocarbons
NOx=Nitrogen Oxide Gases
CO=Carbon Monoxide
P=Power

$$f(x) = W_m * \frac{\left(\frac{(UHC+NO_X)}{1.5}+\frac{CO}{4}\right)}{P}$$

Figure 2. Equation that is used to determine e-score.

Table 1. Weighting of Modes (Wm inf figure above) use to determine E-score is helpful to determine the importance of calibrating to stoichiometric at the load and speed point (White & wright) [4]

J1088 Mode	1	2	3	4	5	6
Speed, % of Rated	85	85	85	85	85	Idle
Load, % of Max.	100	75	50	25	10	0
Weight Factor	9%	20%	29%	30%	7%	5%

From the table above it was determined that the longevity of the engine superseded the importance of a stoichiometric air-fuel ratio at 85% speed full load. The order of in-lab emissions events tests full load first. Any failure during this mode results in a DNF and a loss of points. By calibrating to a richer mixture more hydrocarbons will be present, but cylinder temperatures will be reduced when compared to running stoichiometric. The figure below approximates the penalty for running an AFR (gasoline E0) richer than stoichiometric.

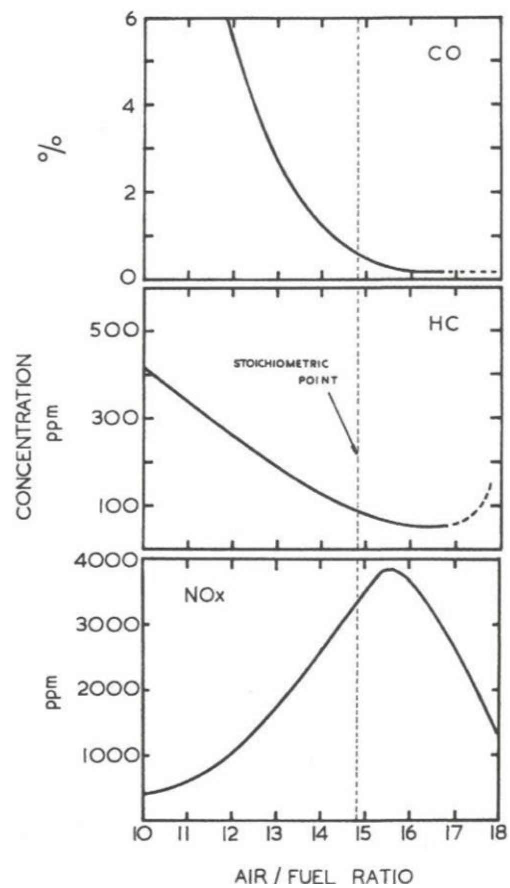

Figure 3. An approximation of the PPM of exhaust gases for each AFR (Smith & Morrison) [2]

In addition, theoretically, a richer mixture should provide for greater power. An increase in power would increase the denominator value of the e-score calculation thus negating some effect of the increased hydrocarbons and carbon monoxide emissions. Higher power during high load will also assist in other events such as the acceleration event.

Other calibration points of lower load (80% and less) will be calibrated to stoichiometric. From the J1088 mode weighting, it is shown that higher weighting is given on modes which load the engine between 75% and 25% of the maximum load. This weighting was determined as a result of trail testing the determined. These were typical values seen during normal operation. Calibrating to stoichiometric at these load points will not only decrease lab emissions but increase efficiency during the endurance testing.

Intake Manifold

The geometry of the intake manifold utilized in the 2018 CSC proved to be beneficial during dyno testing. For calibration of any cylinder bias, the team uses two standalone NGK wideband O2 modules for an accurate reading of the AFR for the individual cylinders. It was observed that no such biased existed and all correction factor multipliers in the calibration could remain untouched at 1. Testing also revealed that the manifold absolute pressure sensor experienced some events of above atmospheric pressure while at wide open throttle on a naturally aspirated setup.

The 2018 intake manifold design did have clearance issues when in the chassis. There was slight interference on the fuel rail tabs that would have originally held the fuel line in place and on a piece of the valve cover initially used to secure the coil packs.

The fundamental geometry of the plenum, cylinder runners, and venturis was retained in the 2019 intake manifold design while adding additional clearance to the components that had slight interference during the modeling stage

Muffler

The main problem in silencing is to reduce the noise to an acceptable degree from the gas discharge, without prejudice to effective cylinder scavenging. In order to understand the design used it is useful to understand theories applicable to the design.

Sound can only die out in an enclosed space (a muffler) by dissipative forces such as thermal conduction and viscosity.

Thermal conduction specifically relates to the use of perforated main tube passing through an outer casing wrapped in a glass-wool jacket. The operating principle is that the sound waves passing down the main tube penetrate into the closed-packed absorbent material through the perforations. In this glass-wool space, the sound is frictionally damped and is typically the most effective on the high-frequency waves. This also tends to have a great effect on apparent noise reduction to the listener because of the elimination of the high-pitched sound waves. From the viscosity principle, the smaller the holes in the perforated tube through which the sound wave has to pass the greater degree of frictional damping. However, the minimum size is limited to prevent the holes obstruction from deposits. Additionally, if the holes are punched in the direction of the glass-wool material, such that it creates a nozzle like shape, it facilitates flow into this matrix while obstructing the reentry.

Without a difference in muffler entry diameter to tailpipe diameter absorption silencers are not as effective. Although some back pressure will be present in an unchanged inlet exit design. The reduction of diameter increases resistance but causes a larger portion of the pressure waves to be transmitted to the jacket. Keeping the reduction of the diameter to less than 8% no noticeable power losses occur but greatly reduce the noise.

Other means of noise reduction that the design utilizes are considered to fall into the back-pressure category. This includes the tapering passages and interference by flow reversal. According to studies, tapering passages cause the sound wave that enters in the large end of the cone to be partially reflected from the surface and therefore it returns on itself. This principle is utilized in combination with an interference flow reversal. The center cone of the two has slots that allow for the exhaust gas to escape. This causes a flow reversal that allows the pressure waves to interfere with new incoming pressure waves.

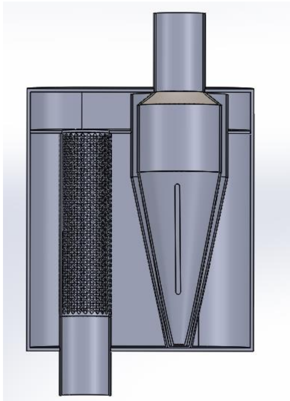

Figure 4. Muffler Section View

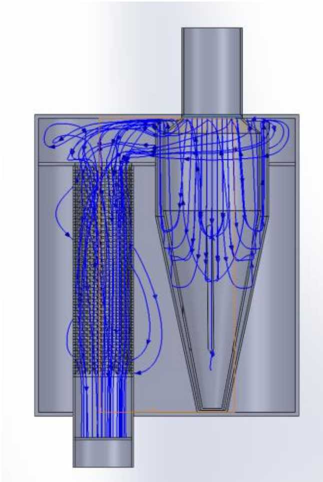

Figure 5. Muffler Flow Trajectories

Throttle Body

Electronic throttle bodies are not a new technology to the automotive or power-sports industry. Nor are they a new concept for the RIT CST. However, in past years of competition, the team had used Bosch electronic throttle bodies that were easy to acquire and primarily used in application on small displacement engines that had turbos.

With the new focus on reliability and simplifying of the engine system, the team is running naturally aspirated for the second year in a row. Idle calibration proved to be difficult in preparation for the CSC with the engine unable to idle down to the desired rpm to prevent lean conditions. It hypothesized that a smaller throttle body would provide less air flow while in its shut position while still maintaining ample airflow for wide open throttle conditions.

For the 2019 CSC, the team is utilizing a Bosch throttle body of 46mm in diameter. It is found on a majority of RZRs and Rangers that are equipped with electronic throttle bodies. Specifically, it is outfitted to both turbo and non-turbo versions of Polaris 1000cc engine architecture that is shared across the two platforms. From simple reasoning, it was determined that our smaller displacement engine would not be restricted by the 46mm diameter throttle body.

Figure 6. Polaris throttle body, Part number 1204455

Engine Mounts

Due to the engine swap, a major challenge to overcome is packaging. The Weber engine is a very different size and shape than the stock 2-stroke. Mounting this different engine requires the use of new mounting hardware specially designed and manufactured to adapt to the existing mounting points. The existing points are used in order to utilize the original rubber vibration dampers. When the Weber 750 was originally mounted into an FST chassis it utilized a specialized rubber mount on the muffler side, this was integrated into the current design approach in an attempt to retain the same constraints on the engine as it had originally.

In order to fit the engine into the bulkhead without modification, the clutch spacing needs to be altered. The clutch center distance was changed from 10.625" to 10.5", allowing the engine to be moved back far enough to clear a crossbar in chassis. In the 2018 CSC, a revised engine mount was designed and manufactured to allow the use of this shorter, standard Polaris CVT belt. This was a much-needed improvement over the engine placement in the 2017 CSC. However, no consideration was given to the side to side alignment of the clutches leading to excessive belt wear, reduced speed, and efficiency. For this year, the team has utilized the existing jig to ensure the correct center to center distance on the clutches while paying special attention to the alignment of the clutches.

During the redesign, the angle of the engine in chassis was also modified to simplify maintenance. During the 2018 season, the intake manifold and fuel rail had to be installed before the engine was installed. Not only was this inconvenient it also put the manifold at risk of being damaged during install. As this is a custom part of a great cost it would be catastrophic if it were to fail. By rotating the engine forward and lifting it upwards slightly the manifold can now be installed in chassis.

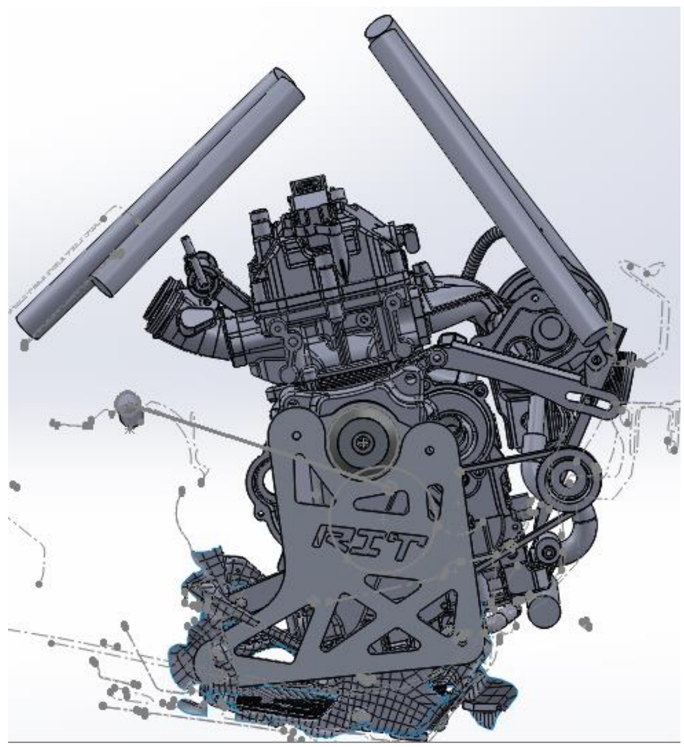

Figure 7. Engine mount modeling to ensure proper fitment

Due to the structural importance of the engine mounts, they were designed with strength as a huge design factor and FEA was run in ANSYS. This simulation was used to ensure that they could handle the belt tension and impact loading as the snowmobile hits bumps or is dropped off trailers or trucks during unloading.

Suspension

To compensate for the additional weight of a four-stroke engine compared to the two-stroke a stiffer spring rate was selected for the front coil overs. The spring rate was calculated by using a motorsport-style scale typically used for corner balancing. This provided the team with a weight measurement at each ski and two measurements under the track. The higher spring rate allows for a greater preload per turn on an adjustable style suspension. The reduction of initial spring compression provides a superior ride over bumpy terrain. The stiffer rate also prevents spring deflection while cornering preventing the snowmobile from diving.

During the weight measurements, the use of two scales under the track ensured an even pressure along the length of the track. The rear suspension was also set with our rider on it to reduce fatigue during the endurance ride.

Track

The track used on the snowmobile is a Camso Ice Attak XT. This track is superior to the OEM track as it a pre-studded track. Although the studs are very small, they provide superior traction and acceleration on hard packed snow and ice. The superior traction should theoretically increase efficiency meaning more of the power used is for forward motion then slipping on top of the surface (assuming there are minimal mass and frictional penalties from the new track). Minimal additional noise is expected as the overall lug height and general track geometry do not differ from the stock track. Additional noise would only be likely on icy surfaces when the studs are required.

Track Noise Reduction

After several ideas were proposed to reduce track noise being amplified in the tunnel it was decided to apply Silent Running to the underside of the tunnel. Given the team's limited resources, manpower for testing could not be spared and testing by competitors had proved the effectiveness of this method. Idaho's testing [1] demonstrated Silent Runnings superiority over PolyDamp. Their empirical results from their test were sufficient reasoning to apply Silent Running to our tunnel.

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3. \Dennis Kirk. "How to Adjust Snowmobile Suspension's Ride Height." Dennis Kirk. https://www.denniskirk.com/learn/how-to-adjust-snowmobile-suspension Accessed Feb. 2019.

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The team would also like to extend gratitude to Dr. James Lee our advisor and Jeffrey Lonneville; their guidance, support, knowledge, and use of facilities were essential to our operation.

Definitions/Abbreviations

CO	carbon monoxide
CSC	Clean Snowmobile Challenge
CST	Clean Snowmobile Team
ECM	engine control module
FEA	finite element analysis
NOx	nitrogen oxides
RIT	Rochester Institute of Technology
SAE	Society of Automotive Engineers

Appendix

Appendix A - Gantt Chart Snapshot

	Task Mode	Task Name	Duration	Start	Finish	Pred
1		Parts Ordered from polaris	7 days	Mon 8/27/18	Tue 9/4/18	
2		throttle body matched	11 days	Mon 9/3/18	Mon 9/17/18	
3		oil leak investigated	6 days	Mon 9/3/18	Mon 9/10/18	
4		engine mount redesign	26 days	Mon 9/10/18	Mon 10/15/18	
5		engine loads calculated	6 days	Mon 10/15/18	Mon 10/22/18	
6		FEA of engine mounts	16 days	Mon 10/22/18	Mon 11/12/18	
7		engine mount plate cut	6 days	Mon 11/12/18	Mon 11/19/18	
8		engine mount machined	6 days	Mon 11/12/18	Mon 11/19/18	
9		engine mounts assembled and installed	6 days	Mon 11/19/18	Mon 11/26/18	
10		Dyno engine built	11 days	Mon 10/22/18	Mon 11/5/18	
11		comp engine built	11 days	Mon 11/5/18	Mon 11/19/18	
12		spare engine built	11 days	Mon 11/19/18	Mon 12/3/18	
13		dyno engine installed	6 days	Mon 11/5/18	Mon 11/12/18	
14		Dyno work	66 days	Mon 11/5/18	Mon 2/4/19	
15		comp engine installed	6 days	Mon 1/21/19	Mon 1/28/19	
16		dyno parts swapped to sled	6 days	Mon 2/4/19	Mon 2/11/19	
17		Comp sled breakin	11 days	Mon 2/11/19	Mon 2/25/19