Improving Noise, Fuel Efficiency, Emissions, Performance, and Reliability in the RIT Clean Snowmobile Team's 2018 Clean Snowmobile

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Abstract

The 2018 Society of Automotive Engineers (SAE) Clean Snowmobile Challenge (CSC), demanded innovation and ingenuity from the teams, The Rochester Institute of Technology Clean Snowmobile Team (RIT CST) approached the task of engineering a cleaner, more efficient snowmobile with the goal of improving upon our 2017 design.

In 2017 the RIT CST's snowmobile consisted of a 2016 Polaris 800 Rush Pro-S Axys Chassis and utilized a 4-stroke Weber 750 CC engine controlled by an MT88 ECM. The engine was turbocharged using a Garret MGT1238. Emissions of the engine were further reduced by adding a liquid cooled exhaust gas recirculation system coupled with a custom muffler containing a catalyst.

The team identified Clutch Alignment/Spacing, Intake Manifold, Engine Tuning/ECM, and Muffler as key areas having room for improvement in our design. Measurement of these areas was taken at the 2017 competition and in the remainder of the spring semester. Analysis was conducted both physically and in simulation. Improved designs were then implemented resulting in the final 2018 snowmobile.

The RIT CST was able to improve upon the 2017 snowmobile design. Creating new engine mounts giving the ideal cultch spacing and alinement, a better flowing Intake Manifold to eliminate cylinder bias, a new exhaust pipe and muffler to reduce noise emissions, and a better tuned engine to achieve the optimal BSFC.

Section 1: Innovations

Introduction

The Clean Snowmobile Challenge (CSC) was created in response to the ongoing discussion surrounding the use of snowmobiles in Yellowstone National Park. Environmental concerns eventually led to a freeze on snowmobiling in the park. Environmentalists continue to disagree with the use of snowmobiles due to emissions and noise pollution which disrupt the wildlife in the park.

The snowmobile industry has responded to this by designing and manufacturing cleaner and quieter snowmobiles which conform to emission standards and park regulations, so the sport may continue for years to come.

The CSC competition tasks the schools for this collegiate event to design and manufacture a snowmobile that will help promote the future of the sport while helping maintain low emissions. The CSC challenge is a weeklong competition in which the teams' snowmobiles are put through a series of events and tests to evaluate the performance of the snowmobile. Snowmobiles are tested and analyzed for emissions, noise pollution level, acceleration, and handling, to name a few. The CSC demands innovation from the teams to come up with innovative ideas and new technology.

The RIT CST approaches this challenge in the same way professional engineering teams approach challenges in industry. The DMAIC process, or Define, Measure, Analyze, Improve, and Control, played a key role in the decisions made by the team

The process was to start with our chassis selection and to design an engine to fit within the given chassis. The work continues after chassis selection through the choice of an engine and optimization of the engine to meet the design constraints of the competition. The final steps are to validate and test through dyno time and riding time.

2017 Benchmark

At the start of the 2017 competition the RIT CST experienced a failure of the MGT1238 Turbocharger. This demonstrated that our design was not robust in construction and we were unable to complete the 100-mile endurance run. As a result of no longer receiving boosted intake pressures, the Webber engine performed very poorly, having not been calibrated under the conditions it was currently running. This led to worse than expected performance in all competition events, however provided a valuable learning experience for the team.

Following competition further analysis was conducted on the snowmobile to determine additional areas of improvement. The following areas were investigated:

Chassis

The 2016 Polaris Rush Pro-S served as the base chassis of our build for the 2017 competition. The chassis was chosen due to its general capability as an all-purpose machine, riding well on and off trail and receiving great reviews from riders and experts alike.

However, in testing and competition, the team observed less than optimal performance from the front and rear suspension of this chassis. Measurements were taken and our local experts at Hygear Suspension were consulted. The team was then able to select front springs which better matched the heavier Webber engine, and tune the rear suspension to better match our rider.

Figure 1 This is an image of the 2016 Polaris 800 Rush Pro- S Axys chassis that was selected for this year's competition.

Track Selection

For the 2017 season a stock Camso Ripsaw II track was utilized due to its "Design for all around trail performance - excellent traction on both hard-pack and loose, less compacted snow with ride comfort features"

Unfortunately, the conditions seen in Michigan were very icy during competition causing reduced traction and control. For the 2018 CSC Camso has provided their Ice Attak XT "A highly aggressive trail model design featuring hundreds of sharp-tip lug studs, giving riders traction and control they can count on." Camso claims the new track provides comparable efficiency while improving traction and control.

Engine

The Weber 750 MPE was utilized for the 2017 CSC. This engine can be found stock in 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 emissions power plant for the snowmobile while still maintaining the power and performance an environmentally friendly snowmobile.

The table below, Table 1, shows the power and emissions rating for the top engines used in the CSC.

Base Engine Comparison					
Engine	Power (kW)	HC	NOx	CO	E-Score
Weber 750	99	4.72	*	122.69	176
600 Cleanfire	84	3.84	*	156.9	129
Ace 600	43	63.2	*	61.69	192
*Note - EPA does not certify snowmobile NOx emissions No NOx data available for E-Score calculation					

Table 1 Shows the comparison of engines to determine the proper engine to select for the 2017 Clean Snowmobile Challenge

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. Another design feature which Weber has integrated into their engine to reduce losses, are roller bearings throughout the camshaft and gear drive system.

Due to the stock engine exceeding the power limit stated in Rule 8.2.1, modification to the engine is necessary. The RIT CST has decided to use the same high-dilution strategy demonstrated by Southwest Research Institute's HEDGE-II (High-Efficiency Dilute Gasoline Engine, Stage II) research consortium with different strategies to obtain the improved BSCF and lower combustion temperatures. Heavy modification to the systems controls is used to achieve this approach.

Due to these features, the prior experience of the team, and the availability of engine, it will continue to be used for the 2018 CSC.

Piston Selection

The Weber 750 offers two different piston geometries which can be used, a low compression piston featured on Weber's turbocharger set-up, or a high compression piston used on the natural aspirated engine. Advanced simulation was used to determine if the high compression piston would offer better emissions and power rating. The higher compression in a cylinder would offer reduced brake specific emissions in NOx and CO emission compared to the naturally aspirated pistons. Below is a figure that shows the % reduction in the emissions generated by our simulation software GT-Power.

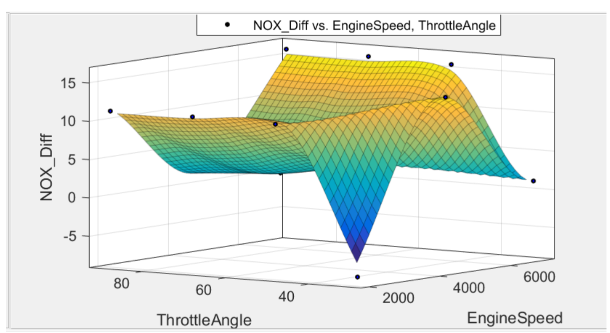

Figure 2 Shows the percent reduction in NOx

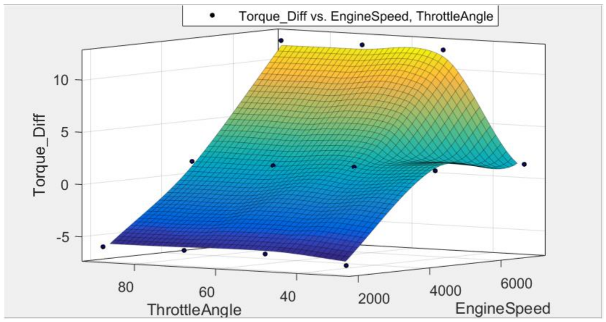

Figure 3 Shows the percent increase in torque

Engine Simulation and Enhancements

Many different engine technologies were brainstormed for the RIT CST's engine build. The software GT-Power, provided through Gamma Technologies, was used to insure educated design decisions. The software uses 1D simulation technique to create an accurate model representation with outstanding correlation results. Heavy use of the model was used in the RIT CST 2017 build and its use continued through the 2018 season. The 2018 model features more parameters to increase types of scenarios that can be ran to acquire data. Running a high quantity of tests allows for the designs to be optimized before production of the components. The engine models used for the 2018 CSC included predictive combustion, knock retard system, predictive wall temperatures, turbocharger control system, and integrated calibration controls. The figure below shows the model and its features.

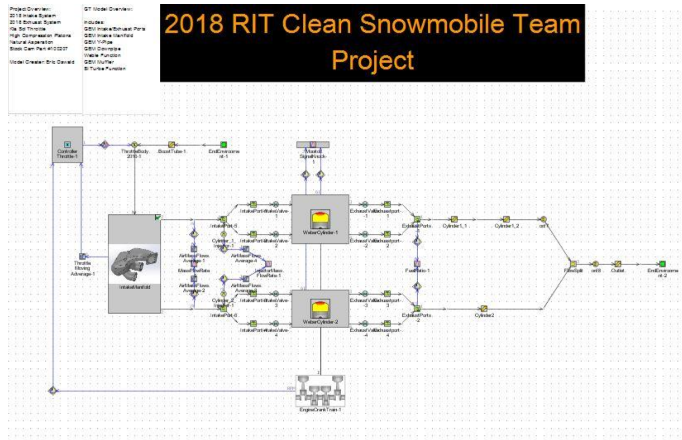

Figure 2 Selected engine Weber 750 CC GT Power engine model map

The team determined that in order to build an engine which was fully calibrated, reliable, and robust for the 2018 CSC the design should be proven incrementally in simulation then on the Dyno. This meant that each new component added to the snowmobile would be verified as having contributed to the goal of better performance and less emissions.

To create a baseline our 2017 competition setup was placed on the dyno and data collected. From this the team was able to determine that the Intake Manifold was causing a strong cylinder bias and severely effecting performance. This generated a list of requirements which guided the 2018 design.

Intake Manifold Design

CFD Flow simulation along with GT-Power were used on the 2017 Intake manifold to determine if scavenging existed between the cylinders under normal operation. Below is a figure that shows the CFD simulation with vector arrows.

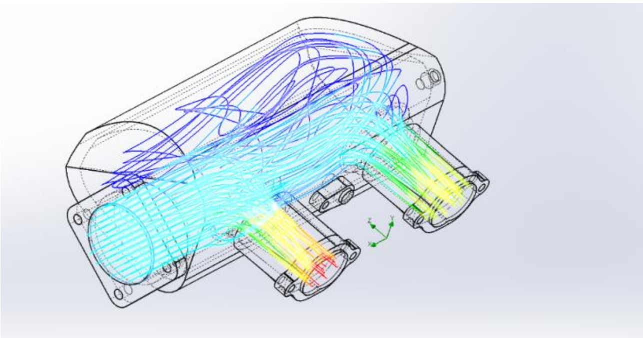

Figure 5 Intake manifold CFD scavenging results.

The simulation shows a strong bias between cylinders which was verified in dyno testing through difficulty achieving equal lamda ratios across cylinders. These factors indicated the necessity of a redesign for the 2018 CSC.

The new design utilizes a symmetrical geometry to prevent cylinder bias issues. Specifically, the air enters the plenum volume, in the middle of the two intake ports. Limitations in space near the gas tank determined the general shape of the upper intake as the electronic throttle body was to directly attached to the plenum volume for optimal throttle response, improving riding characteristics. However, the remainder of manifold was designed using the basic principles of pressure differential, flow type, and velocity. The idea of the manifold is to allow air to enter and immediately begin to reduce velocity while maintaining a low-pressure region, which helps cut down on pumping losses. Subsequently, the intake is designed to rapidly increase the velocity of the air, by utilizing the Venturi effect, as it enters the intake ports while maintaining a laminar flow. To retain laminar flow at a high velocity large radii bends were utilized thus determining the very lower geometry of the manifold. The high velocity allows for sufficient tumbling with in the cylinder to complete mixing of the air and atomized fuel.

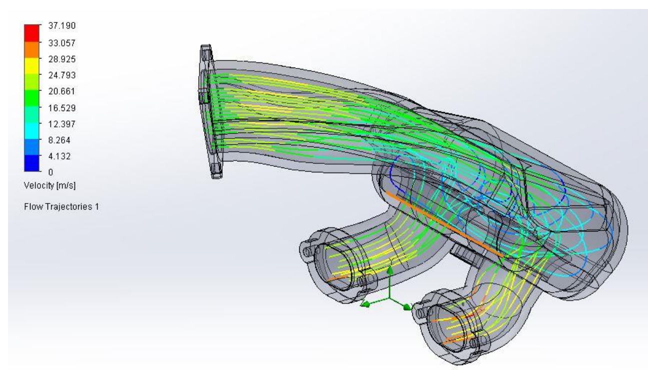

Figure 6 Intake Manifold CFD

Multiple Simulations throughout the design process allowed for iterative adjustments to optimize internal flow velocities

Exhaust Manifold

In the 2017 design, the MGT1238 Turbine housing was an integral part of the manifold design. Due to the unknown failure mode of the turbo and the criticality of design reliability, the team determined it would be in our best interests to design a stand-alone manifold for a naturally aspirated engine.

This approach would again allow for a stepped design and verification process.

The new manifold design pictured below was fully simulated and dyno tested to ensure improved performance over the 2017 design.

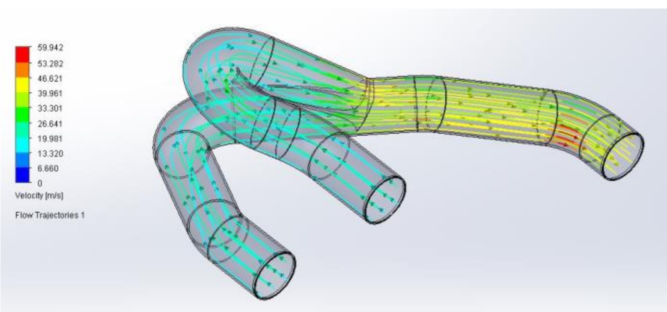

Figure 6 2018 Exhaust Manifold CFD

Exhaust manifold design was optimized for a naturally aspirated setup by using equal length exhaust runners to promote extraction of the exhaust residuals. By effectively removing the residuals the following cycle will have a more consistent fresh air/fuel mixture allowing for a cleaner burn thus creating more power. Extracting residuals also assists in keeping cylinder temperatures low while using high compression pistons resulting in high flame temperatures in the piston combating the enviable creation of NOx emissions.

A plot of percent difference between the flowrates of the two intake manifolds is pictured below.

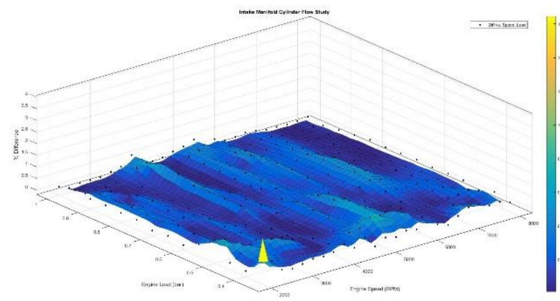

Figure 7 Percent difference of intake flowrates

Muffler Design

For the 2017 CSC the RIT CST utilized a new muffler, designed to have a 0.5 bar back pressure. This number was determined to be an acceptable compromise between flow and sound deadening.

After viewing results of the 2017 competition the team determined it would be necessary to pursue further noise reductions in our design.

The 2017 silencer design allowed for high flow rate but had minimal sound deadening. 2018 Muffler design considered a divergence plane muffler (using multiple "V" shapes) and a glass packed style muffler. Divergence plane mufflers are theorized to promote exhaust extraction while still being effective at sound attenuation. However, fabrication concerns arose with the ability to effectively weld the divergence planes to prevent excessive vibration. Thus, a packed muffler was chosen with several regions utilizing perforated tube and glass packing was chosen as an iteration of the previous muffler.

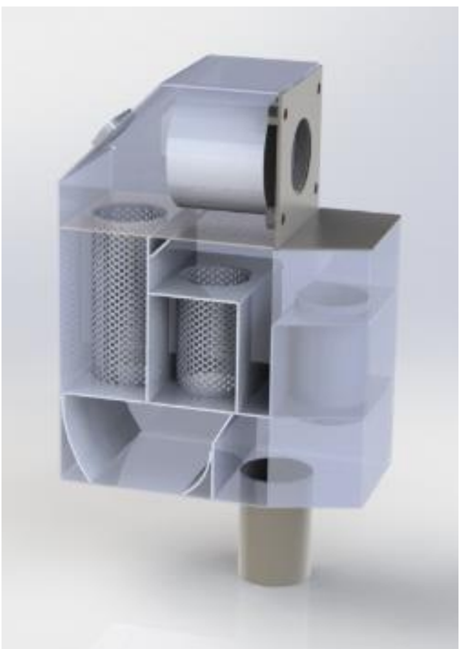

Figure **8** SolidWorks model for 2018 RIT CST custom muffler

After-Treatment

To reduce emissions further an oxidation reduction catalyst was integrated into the muffler design. This is due to the little amount of space that is offered under the hood of the snowmobile. Through the use of precious metals a chemical process of reduction of HC, CO, and NOx emission. Catalysts perform reduction of NOx into O2 and N2, Oxidation of CO to O2 and CO and another oxidation of HC and H2O to CO2 and H2O. With the combustion chamber creating a high amount of NOx during the operation of the engine. The reduction of NOx is the soul reasoning behind a 3 way catalysts as opposed to 2 way catalyst that wouldn't deal with NOx as well.

Flex Fuel

In the design rules there is a need to have the engine burn a range of fuels. This range is defined as: Ethanol content 0% to an Ethanol content of 85%, otherwise known as "Flex Fuel." In order to solve this problem, the Oxygen sensor in the exhaust manifold was utilized to monitor the real time fuel ratio. The ECM reads the fuel ratio and adjusts the injected fuel mass to maintain the fuel ratio. This is a closed loop system that keeps the fuel ratio even with changing ethanol content by changing the fuel injector pulse width.

The ECM is also smart enough to learn from the previous fuel measurements to gain a better fuel control strategy and return the fuel ratio to the correct value quickly. The ECM will be able to determine what fuel is burned after just a few exhaust cycles and can then adjust the fuel mass accordingly.

Another concern with changing fuel is the density of ethanol is different from that of gasoline. It takes roughly twice amount of ethanol to maintain the same fuel ratio that gasoline would result in. The fuel injectors were analized to determine if they could accommodate the larger amount of fuel needed to be injected. GT-Power was used to find the correct flow rate of a full E85 mixture of the engine at full load and speed. The conclusion that can be drawn from the simulation is that the injectors are adequately sized for the E85 mixture.

Engine Control Module (ECM)

This year the RIT clean Snowmobile Team, has chosen a Pi-innovo M220 for their engine control system. Using the Pi-Innovo M220 allow for a customization of the engine code, allowing for high customization to the engine code. This will allow for modern engine control to be integrated into the controller by using MATlab's Simulink, which allows for quick code generation. The basic for the code allowed for a pulse width fuel control base table, then developed into a mass flow fuel table, which allows for greater control in regards to fueling. The customizable ECM also allows for a closed loop fueling to be integrated into the controller using a Lambda Sensor, which is how the ECM calculated Ethanol content. Based on the ethanol content that the ECM calculates, the ECM can make spark changes, allowing for MBT timing based on ethnol content, in order to gain the most torque.

Once the engine model was ccreated the RIT Clean Snowmobile Team used an advanced CCP tool to configure the calibration. The CCP tool used was ETAS INCA allowing for efficient and accurate calibration process, in combination of MATlab's model based calibration, the number of data points tested were reduced, but allowing for accurate generation.

Validation

After the building process of the snowmobile was complete, it was tested to insure complete. The best way for testing the snowmobile is under normal operation on a trail system. Due to the restriction of New York State on our snowmobile and lack of snow, the RIT CST improvised and attached wheels in place of skis on the snowmobile.

In order to determine reliability the snowmobile was taken to RIT's campus loop. The snowmobile will experience similar drive cycle as it would be on public trails. Changes to the calibration were made in order to make the snowmobile more controllable and comfortable for the rider.

Summary/Conclusions

For the 2018 CSC the RIT CST utilized the DMAIC process to improve upon our 2017 design, making it more environmentally friendly in regards to noise and fuel efficiency, and more reliable in terms of performance.

Due to a last-minute failure of the Pi Innovo M220 ECM the team was forced to resort back to the Delphi MT88 ECM to compete in the 2018 CSC. Having only two weeks until competition the team was unable to accomplish our ultimate goal of running an engine with a turbo and EGR.

Section 2: Team Organization and Time Management

Following the 2017 competition the team held elections to determine the positions of: Team Manager, Project Manager, Secretary, Treasurer, and Public Relations. The newly elected Project Manager then has the authority to appoint Leads and Associates for the divisions of: Chassis Design, Engine Design, Electrical Design, and Manufacturing. A flow chart of this structure is pictured below.

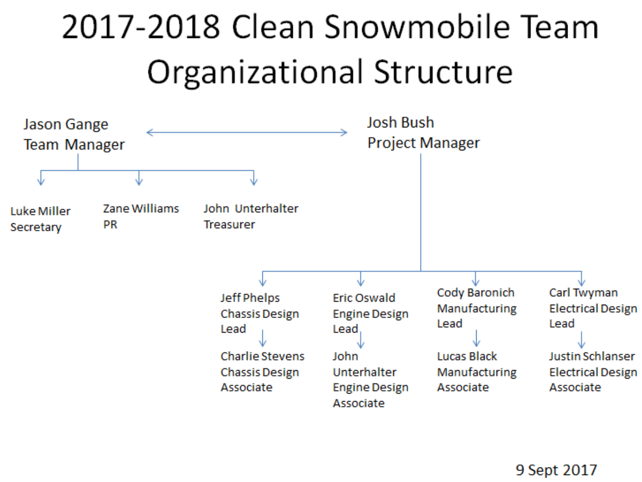

Figure 9 Team Structure

To insure full involvement of all active team members the RIT CST has regular work hours scheduled every Saturday while school is in session from 8am to 12 noon. This meeting is considered mandatory as often important team announcements and event details are shared.

This time is also typically used for the project manager to check in with his leads on the status of all on-going projects to insure the expected completion date is on track with the project timeline.

The project timeline is created by the Project Manager in the first month of his term. The Gantt Chart is then updated on a rolling basis based on project completion and new project development. An image of the timeline is pictured below.

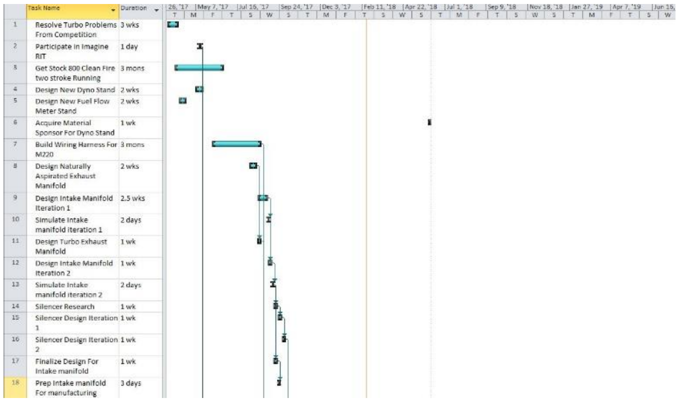

Figure 10 Gantt Chart

Section 3: Snowmobile Build Items

Chassis - Polaris Axys Rush Pro-S, 2016

Engine - Webber, Gasoline, 4-Stroke, 750cc, 70hp *estimated by team.

Track - Camso, Ice Attak (pre-studded)

Muffler - Student designed glass pack style

Catalytic Converter - Aristo, 3-way

Ski -Aftermarket, Curve Industries XS skies

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The team would also like to extend are gratitude and thanks to Dr. James Lee our advisor and Jeffery Lonneville; their guidance, support, knowledge,

and use of facilities were essential in completing this year's snowmobile.

Definitions/Abbreviations

BSFC	Brake Specific Fuel Consumption
CFD	Computational fluid dynamics
CO	Carbon Monoxide
CSC	Clean Snowmobile Challenge
CST	Clean Snowmobile Team
DTC	Diagnostic Trouble Codes
ECM	Engine Control Module
ECT	Electronic Throttle Control
EGR	Exhaust Gas Recirculation
GT	Gamma Technologies
NOx	Nitrogen Oxides
PPS	Pedal Position Sensor
RIT	Rochester Institute of Technology
SAE	Society of Automotive Engineers