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AND ENERGY ENGINEERING

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Indiana University–Purdue University
Indianapolis

SAE Clean Snowmobile Competition

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Abstract

For our capstone project in the 2021 spring semester, our team was assigned to the SAE Clean Snowmobile Challenge, also known as the SAE CSC. This competition was created so that schools and organizations around the United States could compete against each other in an effort to create more efficient and environmentally friendly snowmobiles than the models currently available on the market. This year's competition was held virtually due to the COVID-19 pandemic. Due to these unusual circumstances, the goal of the 2021 competition was to create a realistic simulation model of a competition permitted baseline snowmobile. This model also had to incorporate modifications selected by our team in hopes of increasing certain aspects of efficiency and performance as specified in the competition judging rubric. These areas included lab emissions, acceleration, fuel efficiency, and noise.

GT-Suite was used to create a simulation model of our selected baseline snowmobile, the 2021 Polaris Indy EVO. The modifications implemented in our model included upgrading from a carburetor to electronic fuel injection, upgrading to a high performance muffler, and the addition of a catalytic converter. A functioning model was achieved and the desired plots and data were obtained from the simulation for the competition. In addition to the GT-Suite model, our team was also responsible for creating a manufacturer’s suggested retail price (MSRP) for our modified snowmobile as well as a design paper and competition presentations. As a result of our labor, our proposed model earned 6th out of 10 teams in this year’s SAE CSC. Giving our team the highest finish an IUPUI team has ever received in the spark ignition portion of the SAE Clean Snowmobile Challenge.

Introduction

The SAE International Clean Snowmobile Challenge (CSC) program is an engineering design competition for undergraduate and graduate students. The program provides participants with the opportunity to enhance their engineering design and project management skills by applying learned classroom theories in a challenging competition that tests their designs to reengineer an existing snowmobile to reduce emissions and noise. Participants' modified snowmobiles compete in a variety of events including emissions, noise, fuel economy, acceleration, static display, and design. The CSC is primarily focused on improving engine performance, however the underlying theme is to engineer a clean and quiet trail sled. Current trail sleds are engineered to these standards, but it is still possible to achieve better performance. Fuel efficiency can be increased and noise reduced through the modification of key engine components to further increase performance.

Competition Objectives for IC Engines

The objective of the 2021 SAE Clean Snowmobile Challenge was the same as for previous years' competitions: "to develop a snowmobile that is acceptable for use in environmentally sensitive areas such as our National Parks or other pristine areas" (SAE, Rule 1.2.1). The modified snowmobiles were expected to be quiet and emit significantly less unburned hydrocarbons and carbon monoxide than current production snowmobiles, without significantly increasing oxides of nitrogen emissions. The modified snowmobiles were also expected to be cost-effective and comfortable for the operator to drive. The intent of the competition was to design a touring snowmobile that will primarily be ridden on groomed snowmobile trails. Modern snowmobiles are engineered to meet the current standards for noise and emissions, but are often not optimized. Teams were expected to come up with innovative solutions for improving the performance of the base sled of their choice. Few project boundaries were given other than the requirements of the baseline snowmobile specified in the rules. Design judges looked for these innovations within our verbal presentation, written design paper, and MSRP. From the evaluation of these innovations a score for the competition was given.

Project Management

After the initial formation of the team and brief training in GT-Suite, we began by assigning the responsibilities of the three key positions. These three team roles were filled by Dillon Stangeland (Team Leader), Luc Rulinda (GT-Suite Operations Leader), and Colton Polter (Clerical Manager). The Team Leader was responsible for the overall organization and communications of the team. As the name implies, the GT-Suite Operations Leader was responsible for leading all GT-Suite modeling operations. The final position, the Clerical Manager, was responsible for daily operations including monitoring deadlines. Due to the small size of the team, each member contributed to all the various aspects of the project at some point. During the early stages of team development, a Gantt chart was created to clearly define the project schedule. The schedule in Figure 1 shows the necessary completion dates of each phase of the project in order for on time completion.

	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Initial Meeting	1 day	Wed 1/27/21	Wed 1/27/21	
9		Aquire GT Licence	7 days	Fri 1/29/21	Mon 2/8/21	
7		Engine Modeling Research	17 days	Fri 2/5/21	Sun 2/28/21	
8		GT Training	1 day	Wed 2/10/21	Wed 2/10/21	
4		GT Modeling	31 days	Fri 2/12/21	Fri 3/26/21	8,9
5		Midterm Report	7 days	Wed 2/24/21	Thu 3/4/21	
6		Midterm Presentation/ Proposal	2 days	Wed 3/3/21	Thu 3/4/21	5
10		MSRP Research	4 days	Wed 3/10/21	Sun 3/14/21	
2		Competition Design Paper with MSRP	3 days	Thu 3/11/21	Mon 3/15/21	4,10
3		Training / GT Help with Bhavesh Gandhi	1 day	Sun 3/14/21	Sun 3/14/21	
15		Presentation Prep	4 days	Sat 3/20/21	Wed 3/24/21	2
11		Competition Presentation	2 days	Thu 3/25/21	Fri 3/26/21	15
12		Polish and clean up previously completed assignments	5 days	Tue 4/6/21	Mon 4/12/21	
13		Gather GT Model Data For Prototype and Final Report	14 days	Sat 3/27/21	Wed 4/14/21	
14		Promotional Video	5 days	Fri 4/23/21	Thu 4/29/21	
16		Create Project Poster	2 days	Fri 4/30/21	Mon 5/3/21	
17		Create Prototype Files	2 days	Sun 5/2/21	Mon 5/3/21	
18		Create Final Project Report	17 days	Wed 4/14/21	Thu 5/6/21	
19		Final Presentation	4 days	Mon 5/3/21	Thu 5/6/21	

Figure 1: Team Schedule/Gantt Chart

Since the competition took place on March 25th and 26th, it was essential to have all of the GT-Suite modeling done in early March. Our team accomplished this by beginning engine modeling research and GT-Suite modeling in early February. The engine modeling research consisted of obtaining all of the necessary data and information on the Indy EVO's stock configuration and the selected upgrades that were to be implemented. The modeling then included determining how to properly implement the gathered information into a model. Due to the time constraints of the competition, research and modeling took place at the same time, meaning the model was created as information was obtained. Other key tasks for the competition included the creation of the MSRP and design paper which started on March 11th. These tasks involved documenting the team's process for creating a model as well as estimating a retail price of our modified snowmobile. After the competition, the team's focus shifted to the completion of the capstone course assignments.

In order to meet these tight deadlines, the team met regularly each week via Zoom. During these meetings, the team discussed overall progress, pending issues, and potential solutions. At the end of each meeting the team members were clearly assigned tasks to complete prior to the next meeting. Additional team communications took place through the school Canvas page and GroupMe. The team was also regularly in contact with our faculty advisor and another IUPUI student (not on the team) with previous GT-Suite experience. This mentoring was essential for the project progress due to our lack of experience.

Design Specifications Development

The customer's requirements were based on the scoring rubric for the competition. Figure 2 shows the point distribution of all 11 categories based on the competition's scoring rubric.

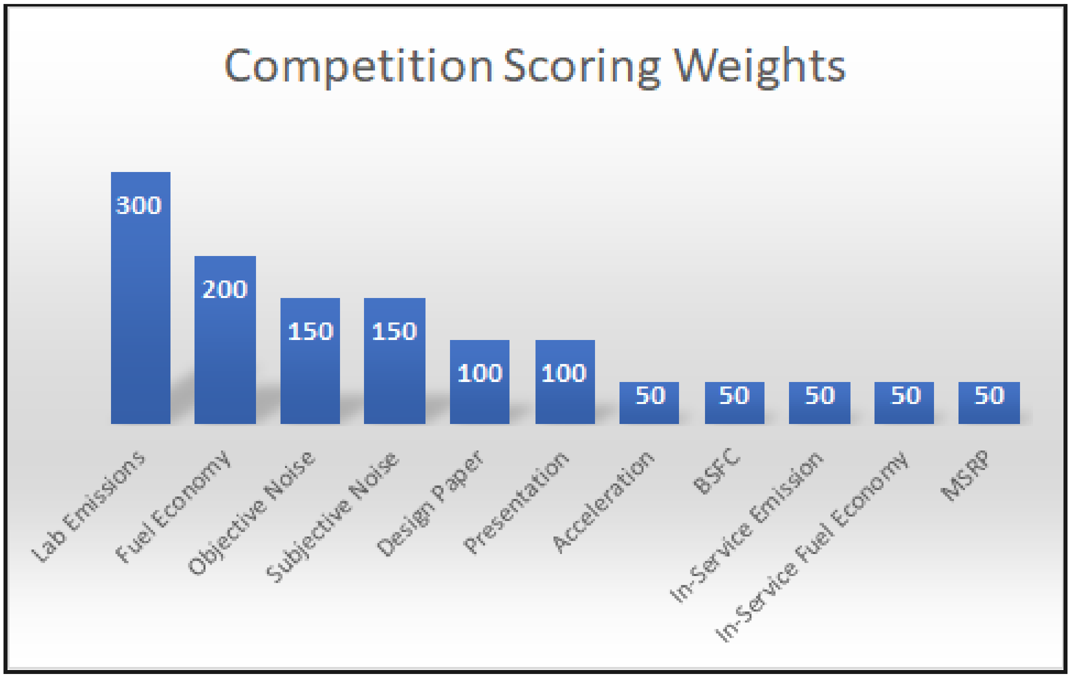

Figure 2: Competition Scoring Weights

The goal for the competition was to obtain the highest number of points with the upgraded model created by our team. This led us to primarily focus on the most heavily weighted components of the competition. The potential for obtaining the highest score was achieved by focusing on the categories of lab emissions, fuel economy, and the noise. This led us to focus the design modifications of the model on these areas to create a more efficient and environmentally safe snowmobile. Additional customer requirements were the completion of a design paper and presentation as well as the lowest possible manufacturer's suggested retail price.

From this initial research, the QFD shown in figure 3 was developed which includes the snowmobile's key customer requirements and functional requirements. The customer requirements were weighted based on their relative importance in the competition scoring. Our team selected the best functional requirements to incorporate into a snowmobile model by determining how effective each one was in addressing the customer requirements. From the QFD, upgrading to a fuel injection system was determined to be the most important. The second most important functional requirement was the completion of our upgraded snowmobile model in GT-Suite. Lastly, the addition of a catalytic converter and an upgraded muffler were found to be the third and fourth most effective choices for addressing the customer's requirements. The reasoning for each selected upgrade is discussed in further detail in the following section.

Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements (Explicit and Implicit) / Functional Requirements	Upgrade Muffler	Install Catalytic Converter	Upgrade to Fuel Injection System	GT Suit Model
25%	20	21	Lower Emisssion	○	●	●	
25%	20	10	Lower Acoustics	●			
25%	20	18	Higher Fuel Efficiency			●	
4%	3	12	Higher Acceleration			○	
4%	3	18	MSRP	○	●	○	
9%	7	21	Paper	○	○	○	●
9%	7	21	Presentation	○	○	○	●
			Max Relationship	21	24	30	18
			Technical Importance Rating	5	7	8	10
			Score	105	168	240	180
			Ranking	4	3	1	2

Figure 3: Quality Function Deployment

This year's competition was unique since it is the first time the SAE CSC has competed in a completely virtual setting. Therefore, a competitive benchmark going into this year's competition was unable to be defined. Additionally, engineering targets and requirements for the competition were mostly undetermined. This was due to the open ended style of the competition. Teams had very few requirements that had to be fulfilled by their snowmobile model.

Muffler

In order to find a muffler that was best suited for the Indy EVO, the team first looked into the types of mufflers that are used and the purposes of each type. Throughout the research process, it was found that certain types of mufflers increase the sound of the exhaust while there are also mufflers that dampen the sound produced. The purpose of upgrading our stock muffler was to reduce the sound emitted. Initially, the team looked for aftermarket mufflers that were advertised as being compatible with the Polaris Indy Evo. Unfortunately, no mufflers were found that explicitly stated they would fit our baseline sled. Therefore, the team decided to find a muffler of approximate size and fit it ourselves. After additional research, a muffler that dampened the sound for the 600 Series Polaris snowmobiles was located. This muffler was called the 2015-2019 POLARIS 600/800 AXYS CHASSIS / 800 KHAOS QUIET CAN. We took the data and cost from this muffler and implemented it into our design for the competition and MSRP.

This muffler reduced the exhaust note to a deeper sound and lowered the overall dB levels that the exhaust would produce. We found this muffler was meant specifically for two stroke engines on the website for a company called GGB Exhaust. In addition, the installation of this muffler resulted in a reduction of weight and required no modifications to the fuel or clutch in a real physical model. These are the reasons that the Quiet Can muffler was chosen to be used for our virtual model.

Fuel Injection

The idea of changing the fuel delivery system from a carburetor to a fuel injection system was the most prioritized upgrade due to the significant increases in efficiency and performance. It was understood that with the original carburetor fuel delivery system, there was no feedback system in place to control the amount of fuel that was being delivered into the system. The option of rejetting the carburetor did exist, but this system was still not capable of continuous adjustment. This was considered as the largest opportunity to optimize our model for the competition.

Our research began with the possible different types of fuel injection and the locations of the fuel injectors. In our initial research, we found that there were two main types of fuel injection, indirect and direct. Most of the time the gasoline fuel injection systems are performed through indirect fuel injection while diesel is performed through direct fuel injection. Therefore, it was decided to go with a more standard system and use indirect port fuel injection. The next decision was about where to locate the fuel injectors. This would require custom work on our end no matter where we placed the ports. We ultimately decided that the best positioning would most likely be on the intake manifold. This decision would still result in custom machining of the ports and mounting system, but would produce the best control for the amount of work required.

Catalytic Converter

Due to competition requirements for cleaner emissions we opted for adding a catalytic converter to our snowmobile. After doing research we decided to use a direct fit catalytic converter. Research showed that there were three main types of catalytic converters including two-way, three-way, and three-way plus oxidation converters. One problem that was quickly encountered was the fact that aftermarket catalytic converters for snowmobiles did not readily exist. This meant we had to get a bit creative on how to select the most appropriate catalytic converter for our application. After doing additional research we found that universal catalytic converters existed for cars which we could use if minor modifications were made to the snowmobile for compatibility reasons. It was assumed that an adaptor could easily be developed for the exhaust. The selected catalytic converter is produced by Magnaflow which develops two-way catalytic converters.

MSRP

Our team needed to create an MSRP, or manufacturer's suggested retail price, for the SAE competition. A template provided by SAE was used for the creation of the MSRP. This template had a bill of materials built into it and was required to complete the MSRP. For the MSRP, we took the previously mentioned upgrade components and implemented them into our model. The Indy EVO stock snowmobile was left untouched in all areas except for our areas of innovation. In the following table are the parts we selected to best address the competition requirements.

Table 1: Snowmobile Modifications

Modifications	Selected Parts	Cost
Muffler	2015-2019 Polaris 600/800 Axys Chassis / 800 Khaos Quiet Can	$299.00
Fuel Injector Kit	ACDelco 217-3028 GM Original Equipment Fuel Injector Kit with Bracket	$650.00
Catalytic Converter	MagnaFlow Standard Grade Federal / EPA Compliant Universal Catalytic Converter	$164.00

With a base MSRP of $5,999 for the 2021 Indy EVO, the total MSRP for the modified snowmobile comes out to $7,112.

Concept Evaluation

The overall evaluation of our upgraded snowmobile model took place during the competition on March 25th and 26th. As previously mentioned, our snowmobile was judged based on its performance in the four main event categories: emissions, acoustics, fuel efficiency, and acceleration. There was very little for us to compare the design and performance of our model to before the competition other than the base model Polaris Indy EVO. Information about the physical component design was accessible, however, very little information existed on the baseline snowmobile's performance characteristics. Due to these circumstances we were unable to make many significant relative comparisons during the design and testing phases.

The competition scoring guidelines acted as our benchmark for absolute comparison. The decisions to implement each of our design upgrades were based on the relative weight of each competition category as addressed in the quality function deployment. Since these three categories were worth the most during the competition, the proposed modifications focused on improving them the most.

GT-Suite was our main tool for modeling, performing analysis, and experimenting on our proposed design for the competition. We developed a model in GT-Suite based on the system parameters of the Polaris Indy Evo snowmobile. We then added all three of our proposed upgrades into the model in order to obtain the necessary results for the competition. The results from this simulation allowed us to determine the significance of the improvements our upgrades made to the Indy EVO's performance.

GT Suite Product Design Process

The team began the process of modeling our proposed design in GT-Suite by first taking all of the information obtained from researching the specifications for the Indy EVO and the selected modifications. However, the team quickly found out how complex of an application GT-Suite was. Due to none of the team members having prior knowledge of the software, the team required additional training on how to fully utilize GT-Suite.

Each team member originally started by doing individual research on GT-Suite by following various videos and tutorials. After a small level of familiarity was achieved individually, the team then moved on to receive additional training from a prior student who was appointed by our faculty advisor. We then spent countless hours learning from the student on a regular basis. Once an initial model was established, the team continued to meet with him to show our progress and ask questions about certain aspects of GT.

Once our team had enough understanding of GT-Suite to start our design process, we then started looking into the templates that GT had to offer. GT-Suite comes with templates for various functions and block diagrams, ranging from automobile exhausts to train engines. Despite the templates that were available, our team found no templates for snowmobiles in GT's library. Additionally, no snowmobile templates were found on the internet. Thus, our strategy shifted to modifying a template that already contained the main components used in our baseline snowmobile. There was an overwhelming amount of information and number of premade templates available. However, the issue the team ran into was deciding which templates were appropriate for our model since there was nothing made specifically for a snowmobile. Many of the templates were originally designed for a single purpose, so finding a suitable model that was applicable to a snowmobile ended up being a challenge.

The team ended up taking models that were similar in layout to the Indy EVO and modifying it to comply with its design specifications. This was the best solution available to our team, since we did not have the time to create our own model that was meant specifically for snowmobiles from scratch. Thus, the team would take template models and then edit the information within them so that they matched the information we found from our snowmobile's manual and data sheets. The process of taking and then editing the information let our team make decent progress with the overall design of our product, but this ended up backfiring towards the end of the project.

Towards the end of the product development of our model, our team was trying to run our design but the model kept returning a failed solution. For some reason, our model kept saying in the post-processor that the snowmobile would stop burning fuel that was injected into the cylinders. Our team tried many different approaches to fix this issue, but nothing at the time worked.

With the competition deadline nearing us at the time, our team started reaching out to try and solve the problem. We contacted various GT employees in hopes of getting a response, and our team also reached out to another team competing in the competition from North Dakota State University (NSDU). Surprisingly, the NDSU team responded and allowed us to meet with them for 3 hours while exchanging various ideas, since both teams had issues achieving a working model at the time. However, this collaboration did not result in the issue being resolved.

At that point, we received a response from a GT employee who was able to determine our issue was within the fuel injector template. This issue was the result of our team taking a wrong template that was not applicable and editing it. He then provided us with a 2-stroke template that was usable for our model. Once equipped with all the correct templates, our team was able to create a working snowmobile model in GT-Suite.

Our team was able to achieve the working model in GT by taking individual templates, and then modifying them so that we achieve the desired model. We started with taking our 2-stroke engine model, and then editing out the extra cylinders that were originally in the template since our Indy Evo only had 2 cylinders. We then found an engine template that had a muffler, and catalytic converter in it, which we then took. We replaced the engine in this model with the 2-stroke engine we modified from before. Since our design still needed a way to measure the sound of the exhaust for the acoustics section of the SAE CSC. We found a template that contained microphones which we then implemented into our design at our air intake and exhaust. After the installation of the microphones, our main engine diagram had everything that was required. It included fuel injectors, a catalytic converter, a muffler, and a way to measure the noise produced, which was everything we planned to implement as our innovations within the competition.

The team then needed to generate the design for the rest of the snowmobile. The main two objects we needed to represent in the model were the transmission, and then the vehicle itself. The team first started to determine how to model and relate our engine to the two components by looking at the available templates that GT offered. By looking at the various vehicle dynamics templates that GT offered, we were able to see that we needed a block diagram for our transmission and another block diagram for our vehicle.

The team attempted to model the transmission by looking for a template of a continuously variable transmission similar to the one used by the Polaris Indy EVO.. This is where our team experienced another main issue. Since GT is a very intricate program, a large amount of information is needed beforehand in order to input into GT. The data required was not contained within the manual and data sheets for the Indy EVO. This is due to most of the specifications being proprietary information possessed by Polaris. We were unable to rely on the specifications sheet for further detail. Furthermore our team did not have access to the physical snowmobile, and were therefore not able to take the measurements of the specifications that were needed. This meant that the template that was available was not able to be utilized.

Since we were unable to model the continuously variable transmission, our faculty advisor Michael Golub told us to model the transmission using a single gear ratio transmission from our given gearbox gear ratio in the specification sheet. By doing so, our team was able to model the transmission using a different template and then incorporate it into our design alongside the engine model.

Lastly, our team then needed to find a way to model the vehicle body and the components that transferred power to the sled's track. For this, the team used a template meant for automobile dynamics. This template was modified for our application by removing three of the template's four wheels. Since the snowmobile uses only a singular wheel to power its sled track, we were able to apply this modified template to our model.

The rolling resistance that the wheel originally had with the road was modified using data that our faculty advisor provided us with from a paper he created in which the rolling resistances for a snowmobile in various types of snow were found. For the simulation, we decided to use the ideal snow conditions for the road. We were also able to connect the diagram to a road block diagram which allowed us to model various parameters on the road such as length and elevation.

The following Figure shows the functional decomposition of our project and the process that was required. The project was split into three main categories: Research, Modeling, and Simulation. Each main category then shows what was required along with the requirements for each subsection.

SAE Clean Snomobile Competition Functional Decomposition																					
Research								Modeling											Simulation		
Engine				Transmission	Vehicle			Engine				Transmission		Vehicle			Connections				
Fuel Injection	Throttle	Muffler	Cat Con	CVT	Envirment	Geometry	Power Delivery	Fuel Injection	Throttle	Muffler	Cat Con	Fixed Gear Ratio	CVT	Envirment	Geometry	Power Delivery	Torque Con.	Chaincase	SAE Plots	SAE Profiles	E-Score

Figure 4: Functional Decomposition

GT Suite Product Design

The team created a function-concept map early in the design process as shown in figure 4. The purpose of this map was to determine an approximate layout of the snowmobile model. This included listing all of the major components of the snowmobile and how they interacted with one another.

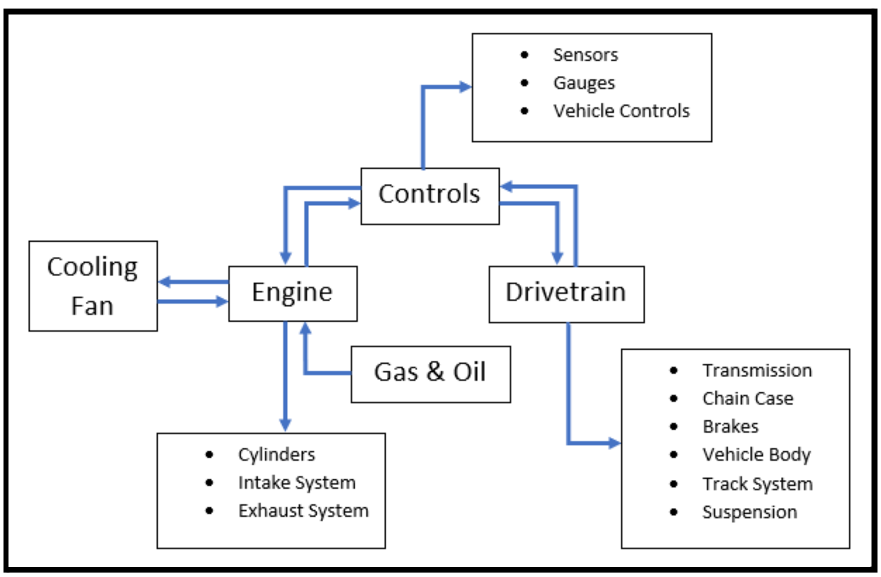

Figure 5: Function-Concept Map

The creation of our proposed model in GT-Suite involved researching all of the required parameters, finding the appropriate templates, and then modifying the templates to mimic our snowmobile, the team was able to produce the model seen below in the following figures. In the following paragraphs, an explanation of the various sections of the model will be provided, starting first with the overall view of our Indy Evo snowmobile model.

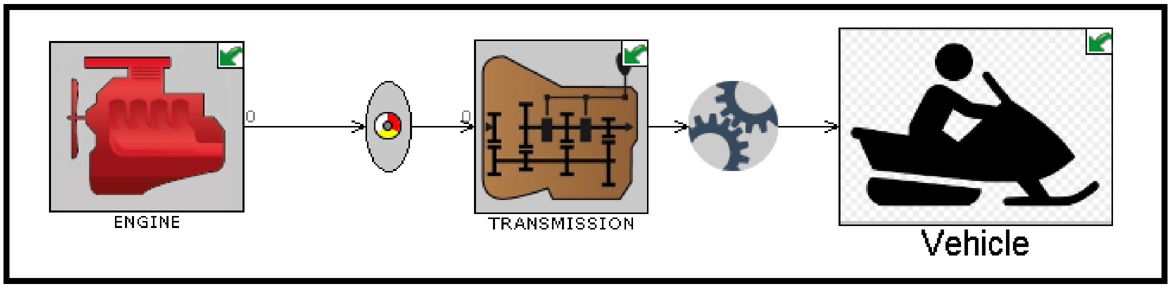

Figure 6: Overall View of the Gasoline Snowmobile Model

Our gasoline snowmobile model shown in Figure 6 consists of an engine, transmission and drivetrain sub-components. A torque converter element can be found between the engine and transmission subcomponents, and a gear connector between the transmission and drivetrain subcomponents. These elements are vital for the connection between sub-components in GT-Suite. The gear connector that is attached to the transmission represents the snowmobile's chain-case with a gearing of 17:44 and a pitch of 72. The vehicle sub-component that comes after the gear connector represents the drivetrain of the snowmobile. This consists of the track, numerous axles, brakes, the vehicle body properties, and the environment the snowmobile is in direct contact with. The following figures give a detailed view of our model engine's sub-components. Figure 7 shows the whole layout of the engine model in GT-Suite.

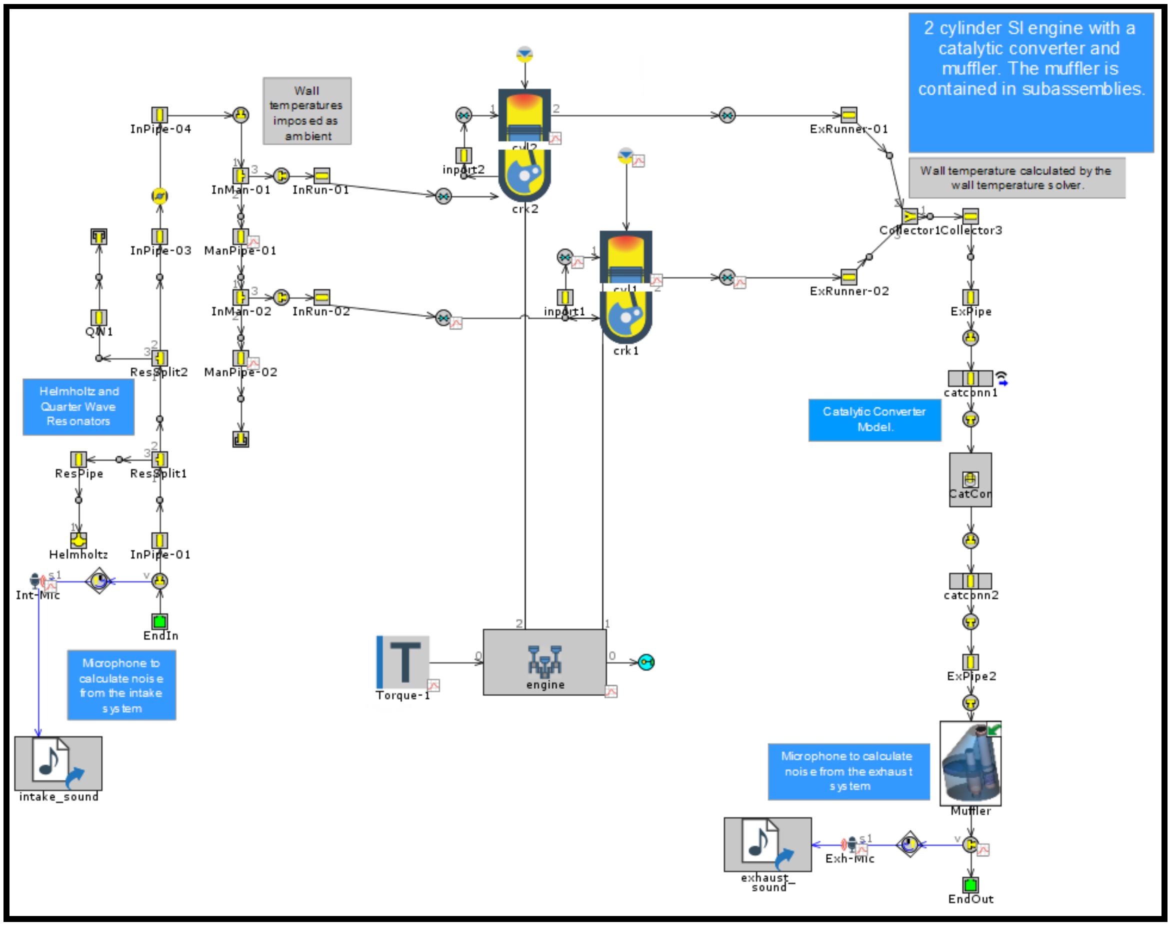

Figure 7: Overall View of the Snowmobile Engine Sub-Component

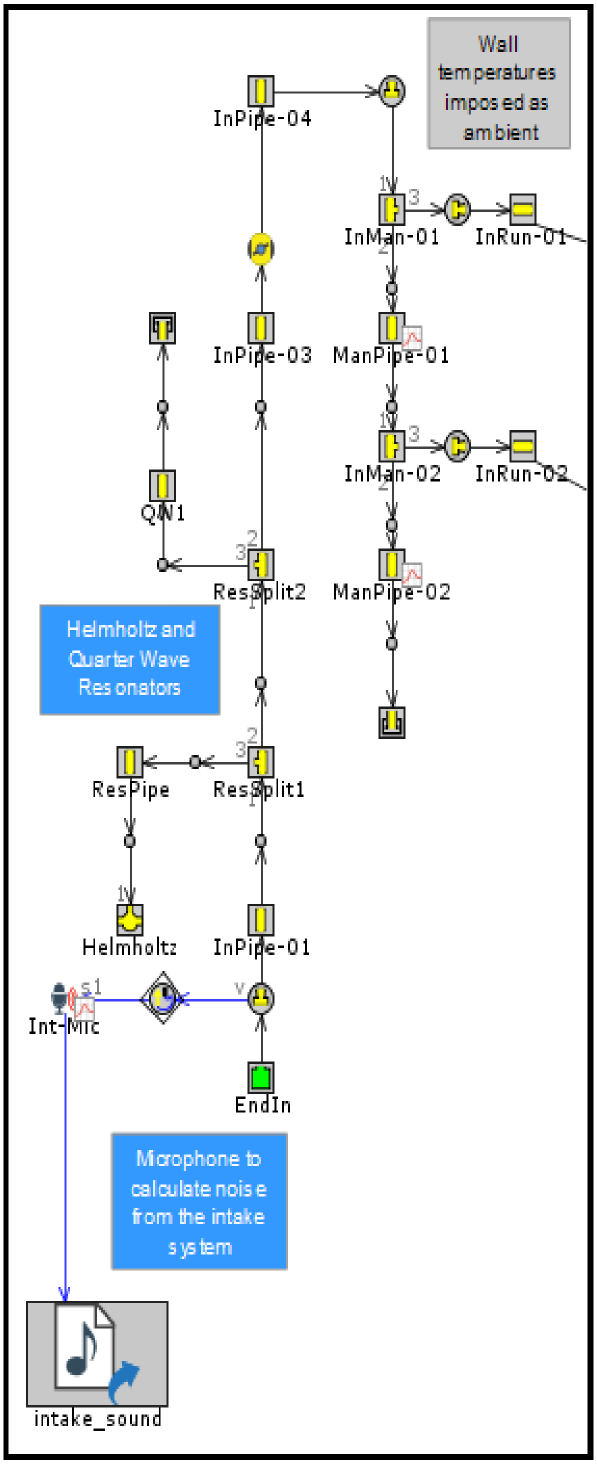

Figure 8: Intake Section Engine Diagram

Figure 8 shows one third of the snowmobile's engine. One can see the air intake system of the engine that leads air to the engine crankshaft. It comprises multiple pipes, orifices, splitters, inlet and outlet valves with specific dimensions.

The design of the air intake is such that air enters at the "EndIn" element, then goes through the numerous pipes, orifices, valves and splitters until it finds its way to the crankshaft. The "int-mic" element represents a virtual microphone that is placed at a fixed distance of 15 meters away from the intake system.

A Helmholtz and Quarter Wave resonator appears near the air entrance of the intake system. Right above the "InPipe-03" pipe element is the air inlet valve that is in sync with the fuel injector above each cylinder (Figure 6). It has the role of letting air in at the right rate during the running cycle of the engine crankshaft. Air finally gets to the engine crank via the "InRun" pipe element.

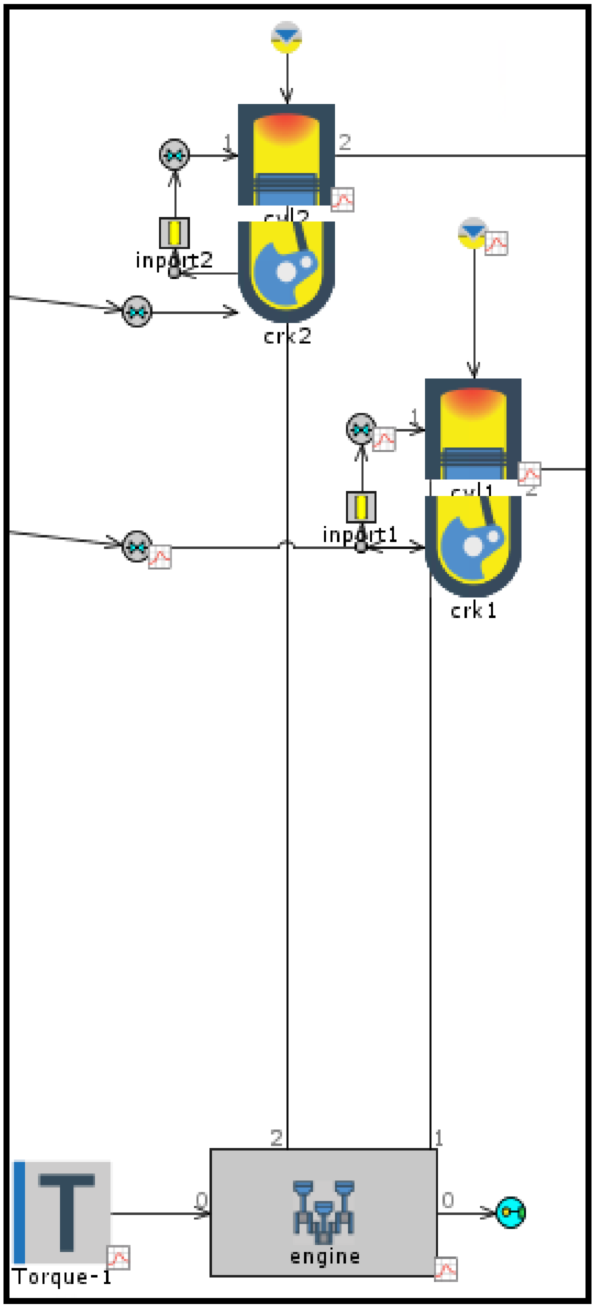

Figure 9: Cylinder Section Engine Diagram

Figure 9 showcases the most important parts of our engine: the fuel injectors, cylinders, crankshafts (crk1 and crk2 elements), and engine mechanism element. The fuel injectors that feature above each cylinder was given an injector delivery rate of 10 g/s. Next to each cylinder is a two-stroke ported valve that controls the exhaust gases going into the cylinder from from the crankshaft.

At the bottom of Figure 9 is our engine cranktrain mechanism which models the kinematics and rigid dynamics of common reciprocating IC engine cranktrain configurations in GT-POWER engine performance models. In this object is where the engine type, speed/load specification, engine speed, engine friction object (FMEP) and the start of cycle parameters are configured.

To the left of the engine crank train is the torque (Torque-1 element) that sets the speed of the engine. Five torque parameters were implemented to match the 5 modes required for the competition: 45 ft-lbf, 23 ft-lbf, 14.85 ft-lbf, 8.55 ft-lbf, and 0 ft-lbf. To the right of the engine cranktrain, is an object that represents a subassembly model that permits the merger of the subassembly into the main model. This receives the engine output such that it can be sent directly to the transmission sub-model.

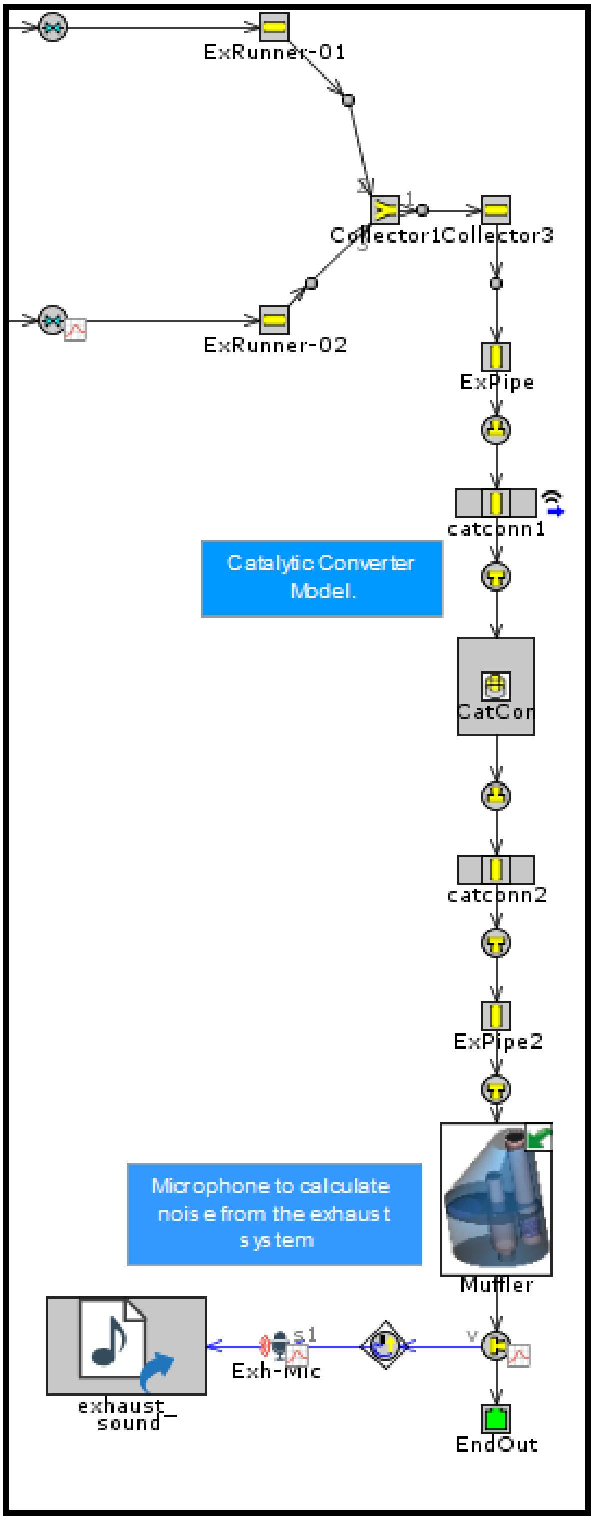

Figure 10: Exhaust Section Block Diagram

Figure 10 represents the emissions part of the engine, whereby the gases produced in the cylinders are discharged. It starts at the level of the cylinder ported valves , undergoes a process of reduction of unburned hydrocarbons and carbon monoxide in the catalytic converter, *CatCon*, before they are oriented to the muffler.

The muffler model shown is a subassembly that comprises numerous pipes and splitters designed to reduce the exhaust noise. The remaining gases are released to the external environment represented by the *EndOut* object.

Close to the muffler is a virtual microphone, *exh-mic*, that represents a microphone placed at a fixed distance of 15 meters away from the exhaust system.The recorded sound is recorded and stored in the *exhaust_sound* element attached to the microphone. Between the microphone and the yellow orifice is a control sensor link that is put between physical parts such as flow, mechanical, electrical, or thermal parts and control component parts. Without it connecting the microphone and the orifice would not be possible in GT-Suite.

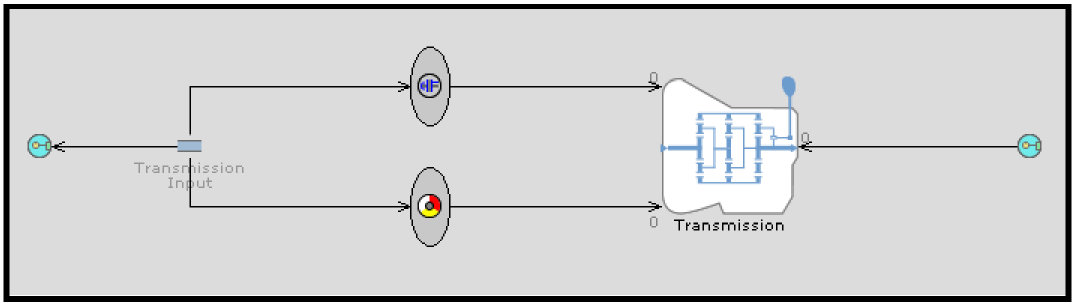

Figure 11: Transmission Diagram

In Figure 11 shown above, the team's transmission diagram can be found. We were unable to implement the continuously variable transmission system, CVTech PB50 - found in the Polaris Indy EVO 550 due to the disclosed Polaris specifications that were necessary for the completion of our transmission model. Due to the very limited resources available concerning the Indy Evo's continuously variable transmission, the team struggled to determine the most appropriate way to model it. After consulting with our faculty advisor Michael Golub, we were advised to simply model the continuously variable transmission as a normal transmission but with only a single fixed gear ratio.

The transmission we created takes input from our engine diagram in the previous Figures 7 - 10, and then converts that data over to our vehicle diagram shown in the following Figure 12. In the vehicle diagram, the engine and transmission data is then transmitted through a drive shaft and into the single axle used to represent our snowmobiles single wheel powering the tread. Some of that data is then also sent to the vehicle body itself.

From the body block, we were able to specify the mass of the vehicle, ambient temperature, and other various parameters that define that vehicle's shape. In the tire block, we were able to use data provided by our faculty advisor on various snow rolling friction values to model how our vehicle would act in snow. Finally, we were able to provide input on different road data, such as elevation and length of the road. Using all of this information, GT-Suite performed a simulation to determine the performance of our modified snowmobile.

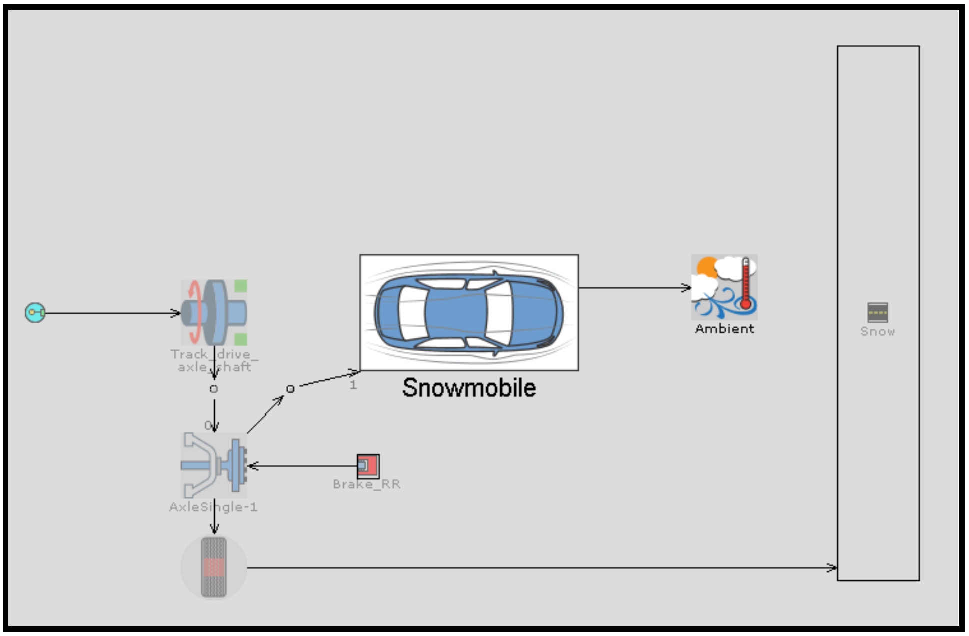

Figure 12: Vehicle Diagram

SAE Competition Rules and Standards

The objective of the 2021 SAE Clean Snowmobile Challenge was the same as for previous years' competitions: "to develop a snowmobile that is acceptable for use in environmentally sensitive areas such as our National Parks or other pristine areas" (SAE, Rule 1.2.1). Although the overall intent of the competition was the same, many of the rules and requirements were significantly modified or completely omitted due to the completely virtual nature of the 2021 competition.

The competition rules were the only guidelines our team had for choosing a baseline snowmobile and the most appropriate modifications for increasing different aspects of its performance. According to SAE Rule 1.3.4, baseline snowmobile had to be a model year produced between 2017 and 2021 by one of four major snowmobile manufacturers including Polaris. Additionally, SAE Rules 8.2.1 and 8.2.2 state the baseline snowmobile engine is limited to 130 peak horsepower and must accept 0% to 85% ethanol fuels. It was from these competition requirements and cost considerations that the 2021 Polaris Indy EVO was selected. SAE provided very few requirements or regulations for the modifications of the baseline snowmobile other than that the upgraded parts must be readily available. The major modification for this year's competition was that a model of the upgraded snowmobile had to be produced in a software capable of running a simulation and retrieving data required for the competition. The only requirement of the competition was that a widely available software was used such as GT Suite.

In addition to the competition rules, there were two standards our model had to follow. The first standard is that our model must comply with the Yellowstone National Park's standard of having an E-score of 175 or higher. This is set so that low emissions and high fuel economy are promoted in snowmobiles. The second standard is set to prohibit excessive noise from snowmobiles. According to section 2.18 of the Electronic Code of Federal Regulations, snowmobiles must not produce noise louder than 78 dB at a distance of 50 feet. Both of these standards are considered a good starting point for the model's initial design.

The 2021 competition consisted of two separate events by which the team was judged. The first event, the static event, required the team to submit a design paper, manufacturer's suggested retail price (MSRP), and perform an oral presentation of both to the judges. The purpose of the design paper was to defend the team's modifications to the baseline snowmobile along with the GT Suite model. The purpose of the MSRP was for the team to determine and defend what was believed to be a fair retail price for the modified snowmobile. The second event, the dynamic event, required the team to pull certain efficiency plots from the GT Suite model for lab emission, fuel economy, acceleration, and sound. All of this data was placed into four separate slideshows and presented to the judges.

Product evaluation

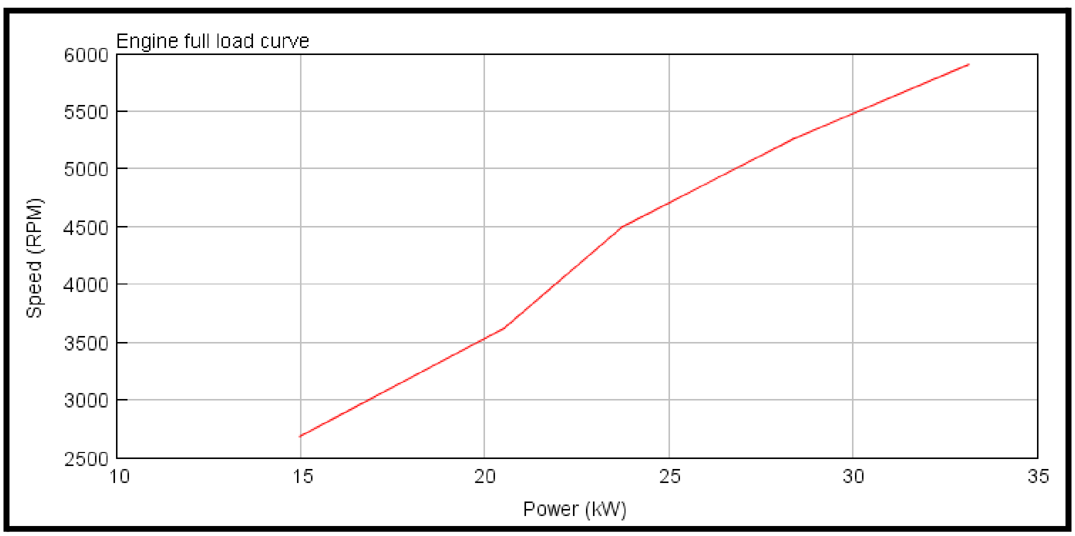

Figure 13: Engine full load curve (Power vs Speed)

Figure 13 was obtained in the simulation results, it shows the snowmobile engine's performance at different power levels. And as expected, the power output of the engine increased as the RPM increased.

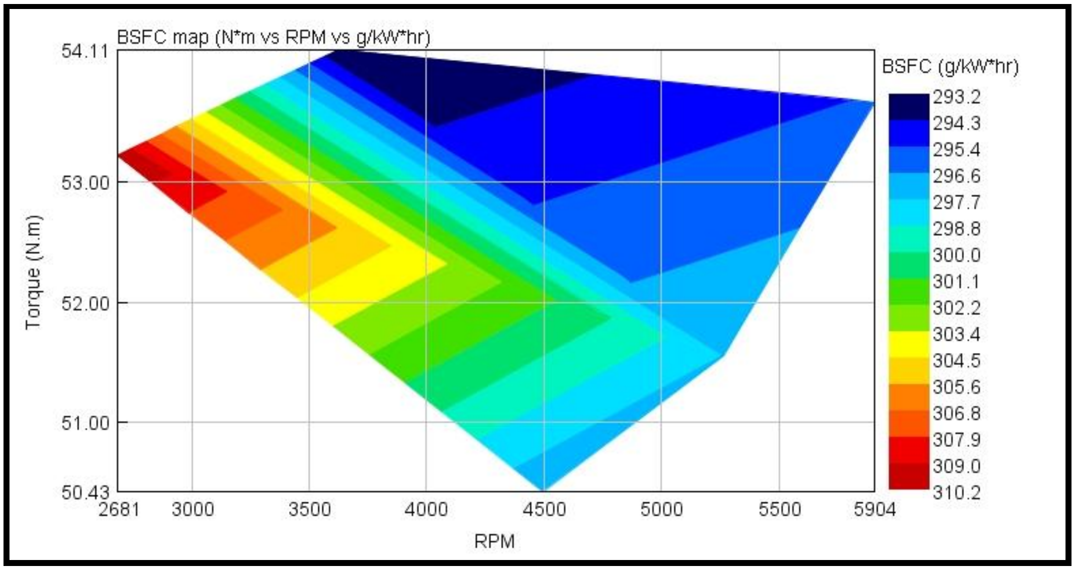

Figure 14: BSFC map (Torque vs RPM vs BSFC)

Figure 14 gives a better understanding of the fuel consumption of our snowmobile model. BSFC which stands for brake-specific fuel consumption is a measure of the fuel efficiency of any prime mover that burns fuel and produces rotational, or shaft power. The simulation results show that our engine consumes the most at its lowest running engine speed (2681 rpm), and consumes the least amount of fuel at a medium running engine speed range (3500 - 4500 rpm).

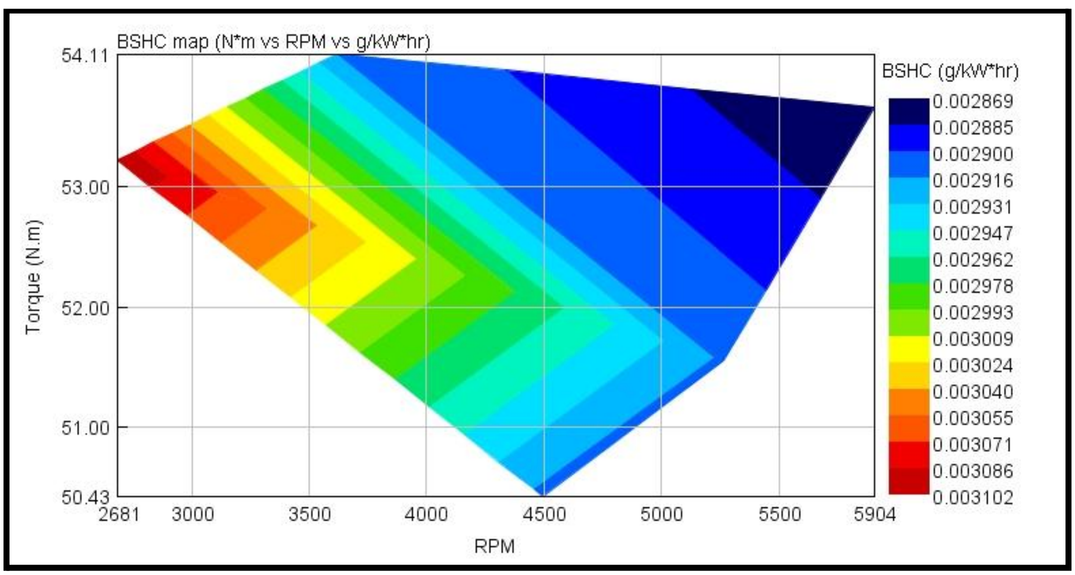

Figure 15: BSHC map (Torque vs RPM vs BSHC)

Figure 15 showcases the hydrocarbon (HC) emission of our snowmobile model. The simulation results above show that our engine produces its maximum amount of HC at its lowest running engine speed (2681 rpm), and the minimum amount of HC at its highest engine speed range.

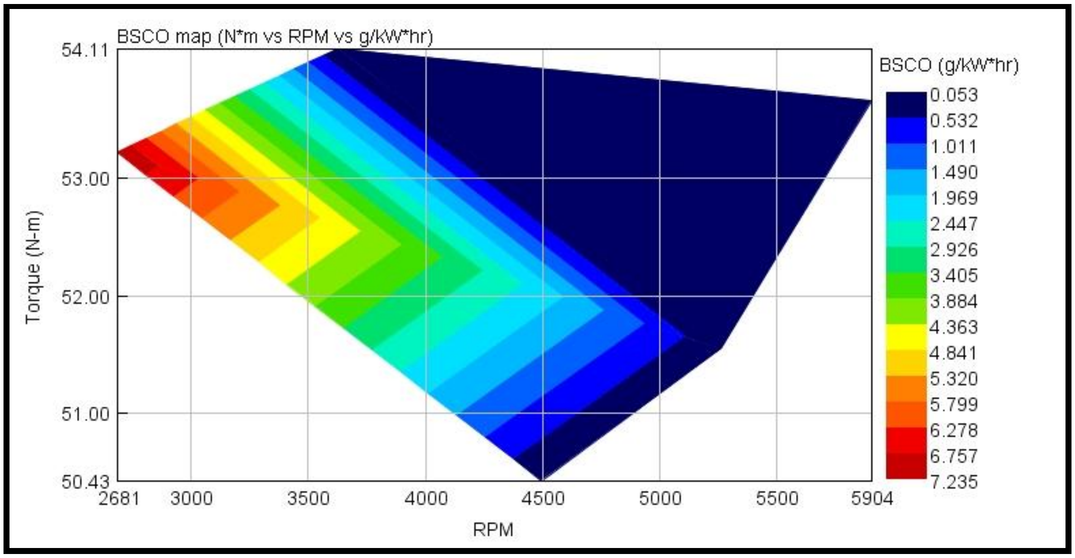

Figure 16: BSCO map (Torque vs RPM vs BSCO)

Figure 16 is a visual representation of the carbon monoxide (CO) emission results of our snowmobile model. The simulation results above show that our engine produces its maximum amount of CO at its lowest running engine speed (2681 rpm), and the minimum amount of CO at the higher engine speed range.

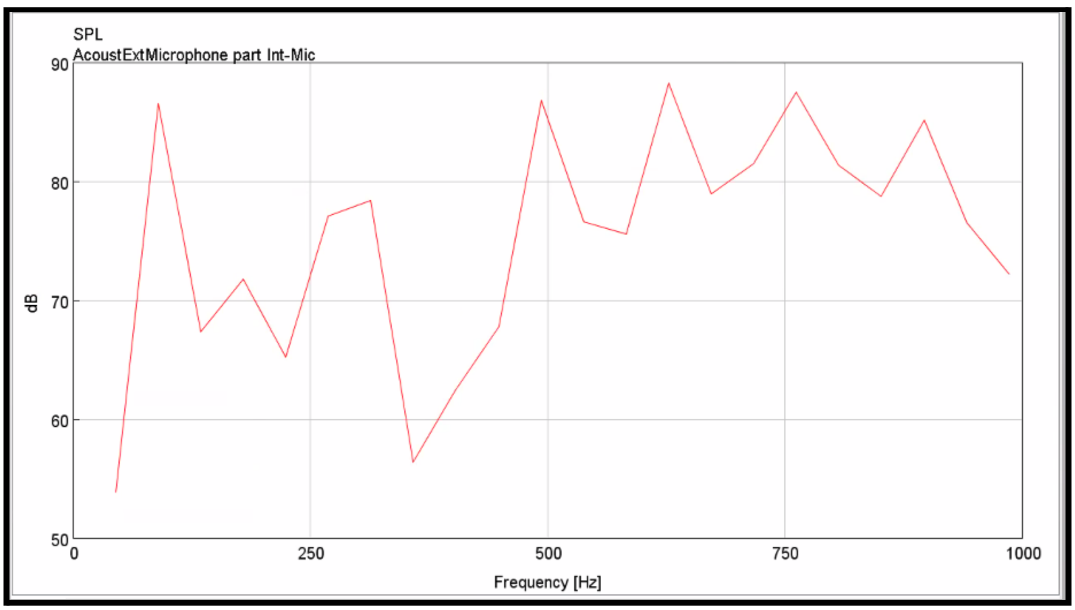

Figure 17: Sound Pressure Level Plot (Frequency vs dB levels)

Figure 17 is the sound pressure level plot of the noise recorded by a virtual microphone that is placed 15m away from the snowmobile's exhaust pipe. It can be seen that our snowmobile model creates a maximum sound output level of approximately 87 dB.

Impact Statement

Based on the results of our output file, our main impact on safety in a negative light would be the sound level our snowmobile model produces. As mentioned above, snowmobiles can only generate a max of 68-73 dB from a distance of 15 meters away. Our team's design generates a max sound of around 87 dB at the intake, which is then reduced to 81.579 dB exiting the exhaust at a distance of 15 meters at the time of the competition. This is due to our muffler settings and inputs in our main engine block diagram. Given time, this is an issue that can be fixed resulting in a more accurate and safe model that is within compliance to the safety standards of the American Council of Snowmobile Association.

The next results focus on both safety and environmental impacts. Our model's lab emission and fuel economy results have both an impact on safety and the environment due to the amount of hazardous emissions our engine and snowmobile produce. Any hazardous emissions has both a lasting impact on the environment, and the people who use the snowmobile. Thus, it was important in our design that we focus on reducing our model's emissions as much as possible alongside having reduced fuel consumption. When looking at the lab emissions and fuel economy results of our model, GT-Suite has returned the following data to us.

With our data from GT-Suite, we were able to calculate the emission score, or e-score, of our snowmobile model. By using the formula provided below, we were able to calculate what the exact e-score of our model would be. The HC stands for the amount of Hydrocarbons emitted, NOx was the amount of Nitrogen Oxide emitted, and the CO was the amount of Carbon Monoxide emitted all in the terms of g/kW-hr.

$$\boxed{E = \left[1 - \frac{(HC+NO_X)-15}{150}\right] * 100 + \left[1 - \left(\frac{CO}{400}\right)\right] * 100 \geq 100}$$

Figure 18: E-Score Calculation

From our data collected at each of the five different modes of operation in our model, we were able to calculate the following e-score at each mode, along with the final weighted e-score using the equation shown in Figure 18.

Table 2: E-Score Results

Mode	E-Score	Weighted
1	209.803	0.12
2	209.993	0.27
3	209.985	0.25
4	209.980	0.31
5	209.988	0.05
	Total:	209.964

With the e-score test, the best possible score is 210. In the real world, this score would be very hard to achieve. Thus, the team realizes that our model at the time of the competition was most likely inaccurate in this regard. However, if this model was accurate it would mean that our design would be very environmentally friendly and have a low impact on the environment. It would also mean that our model is producing safe emissions to be around for it's human riders.

Looking at the results of the fuel economy portion of our model, the impact on the environment can be seen from the GT-Suite calculated BSFC for each of the modes. In general with SI combustion engines, a BSFC of around 240 g/kW-hr is the most efficient operating point. The team's BSFC values can be in Table 3.

Table 3: BSFC Results

Mode	BSFC
1	255
2	297.9
3	294
4	295.7
5	295.8

As shown above, our engine and snowmobile operate very closely to the optimal efficiency in our first mode of operation, but then jumps to a higher fuel consumption in higher modes. Therefore, in some aspects of the operation, our snowmobile is very environmentally friendly, but needs improvements to reduce its fuel consumption at higher modes.

After considering the results of both the lab emissions and fuel economy, the impact our snowmobile has on the environment is low but still needs improvements. The model produces very little hazardous gases from its exhaust, but consumes too much fuel at the same time. Further reduction in fuel consumption is necessary for the model to have the lowest possible impact on the environment.

For our models final impact, the impact on society, it is important to consider two aspects. First, our model is too loud for use within society the way it is now. If our model were to be implemented into a physical model, with the exact data given from GT-Suite, it would not even be possible to operate such a vehicle due to various safety standards. The issue lies with the fact that our model is not truly accurate due to the lack of informational inputs available to our team during the modeling process. If our model were to be made a physical reality, there is the possibility that it would be quieter than what the simulation returned, or even louder.

The second societal impact to consider is the amount of fuel consumed by our design. Given the data returned in our BSFC, our model consumes too much fuel at higher operating RPM's. This would mean that extra fuel is being burnt and would result in a lower fuel efficiency. This in turn would result in the rider needing to buy fuel more often. Therefore, the operating cost of this snowmobile model is higher than it should be. The consumer of this product would be burning more gasoline, and that would impact them and the rest of the snowmobile community.

Conclusions

Based on the results our team received in the competition, our team was able to successfully create a working model of a snowmobile using GT. However, our placement also indicates that even though our model placed well, it still has areas to improve in. Our design placed 3rd in both the acceleration and lab emissions events, but 4th in sound, and 5th in fuel economy. Based on our scoring and placement in the competition and our GT-Post output data, it is clear to conclude that our model needs some improvements in sound and fuel economy. Along with refinement in both our acceleration and emissions so that the team can place first in future competitions.

Considering IUPUI's placement in past years in the competition, our team earning 6th out of 10 teams this year is a marking of meeting our design goal of creating a working GT model that is competitive. The next goal our team met was the installation of a muffler to decrease sound produced by the snowmobile. With data from GT-Post, our team was able to confirm that our muffler did decrease the sound of our engine by around 6 dB. Our next two goals were the installation of the catalytic converter and fuel injectors. This goal was easily accomplished due to the nature of editing a virtual snowmobile, but realistically would have been more challenging on a physical model. Our team was able to conclude that in a physical model, a technician would need to be hired for the installation of the fuel injector kit.

Overall, our team was able to successfully create a snowmobile model that had lower emissions, higher acceleration, and a low MSRP for the competition. Based on our data though, our team was unable to produce a snowmobile that had higher fuel efficiency. Additionally, our model did lower the acoustics of our snowmobile, but in the end it was not low enough to be compliant with safety standards.

Our team believes that the issues with the acoustics and fuel efficiency lie within the fact that our access to information on the Indy Evo was substantially limited. Given a physical model to obtain information from and time to implement it, our model would have been much more accurate than its current state. GT-Suite is a very complicated and intricate software, where every little bit of information on the model goal is needed. Our use of placeholder numbers in certain areas where no knowledge could be found led to many inaccuracies within our model. The ability to reference a physical model for information should solve many of these inaccuracies, resulting in a virtual model that is more true to a physical design.

Recommendations

Over the course of this past semester, the team has received various feedback from the competition on how we can improve our design and the team itself. First, we will talk about the feedback received from the judges pertaining to the team itself. Then, the team will go over the feedback the judges received pertaining to our model.

The team's experience in the SAE Clean Snowmobile Competition, and the feedback of the various judges, has led to a few recommendations for future teams and faculty advisors. The first and most iterated recommendation the team received during the competition was the necessity for the project to have an extended timeline. The amount of time given to our team to complete the model and place well in the competition was not nearly long enough. All of the judges at the competition this year iterated to the team many times how we should have started at least 6 months prior to the competition to be able to complete an accurate model and simulation. With our team starting this project with zero prior knowledge in GT-Suite, the time needed for the team to be ready to start modeling only increased.

Based on the various inputs regarding the time necessary to complete this project, our team recommends that it would best for teams to form and begin preparing in the fall semester. Then, the team members could have the option to choose the competition as their capstone and keep working on the project. This recommendation will improve the competitiveness of IUPUI's future teams at the competition, will result in better placing, and improve IUPUI's credibility among other schools and organizations in the competition.

Another topic of feedback the team received at the competition was the suggestion for some sort of continuity in our schools snowmobile competition program. Other schools generally don't limit the competition to only their seniors to participate in, and as a result their teams are able to build a program where past members mentor the new members and all prior knowledge is not lost on a year-to-year basis.

The recommendation our team has is that for future competitions, the school of engineering should open up the competition to juniors and possibly sophomores to work alongside the seniors as they work on the competition for their capstone. This initiative will allow the snowmobile team to develop, and grow knowledge that is carried and past on to future students. Besides the creation of a legacy here at IUPUI in the engineering department, this recommendation will also improve the competitiveness of the team at competitions due to a higher level of knowledge and experience that the team will have compared to a team of only seniors who are new to the competition. Finally, the recruiting of the lower classes will help promote awareness of the engineering program at IUPUI and increase its reputation.

The largest technical modeling critique that was given was that we only had only one model that tried to encompass a whole snowmobile. There were four main competition categories that the competition was focusing on. These categories were acceleration, lab emissions, noise, and fuel economy. We understood that as pulling the appropriate data from a singular model. However, they explained that it was expected to have four separate models that each focused on an individual aspect of the competition. This resulted in presenting duplicates of output data.

One of the largest critiques that we received from the judges was that our two-stroke engine does not have intake and exhaust valves. The two stroke engine only has ports in the sides of the cylinders. The intake port is located near the bottom of the cylinder stroke while the exhaust port is located on the opposing side and slightly higher up within the cylinder. We had modeled our engine with valves that simulated this type of exhaust and intake flow, but since this was not modeled exactly correctly, this would have a large effect on the actual performance of the snowmobile.

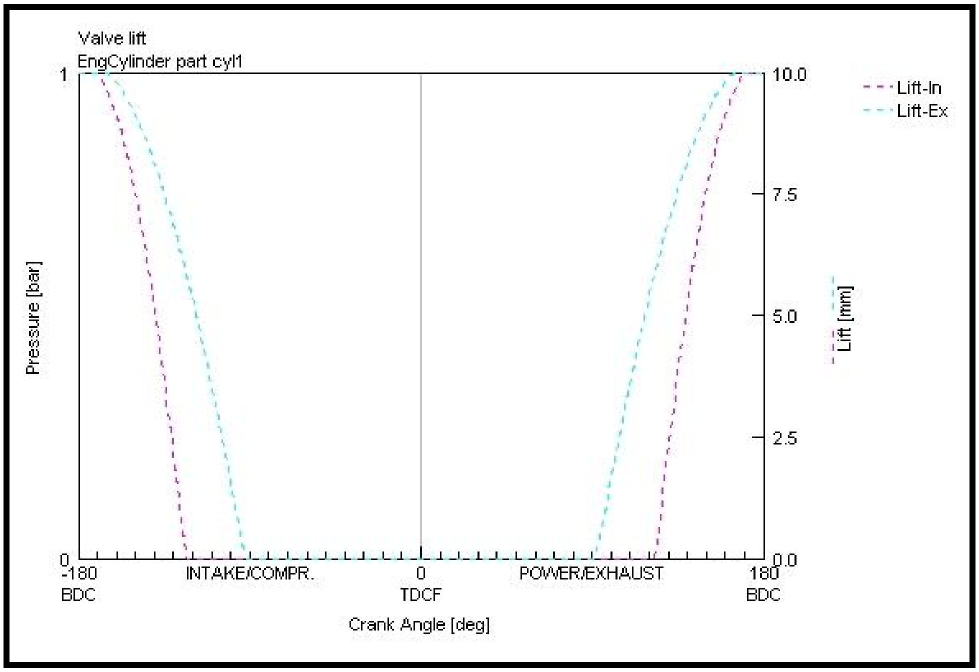

Figure 19: Valve Lift Timing

Another critique that was given was in reference to our tractive force plot. The plot that GT-Suite produced gave a negative tractive force for all the speeds that were tested. We were unable to diagnose this issue before the competition presentation and were told that this should not be negative and that the sudden change at around 70 MPH to a positive slope is very strange to see.

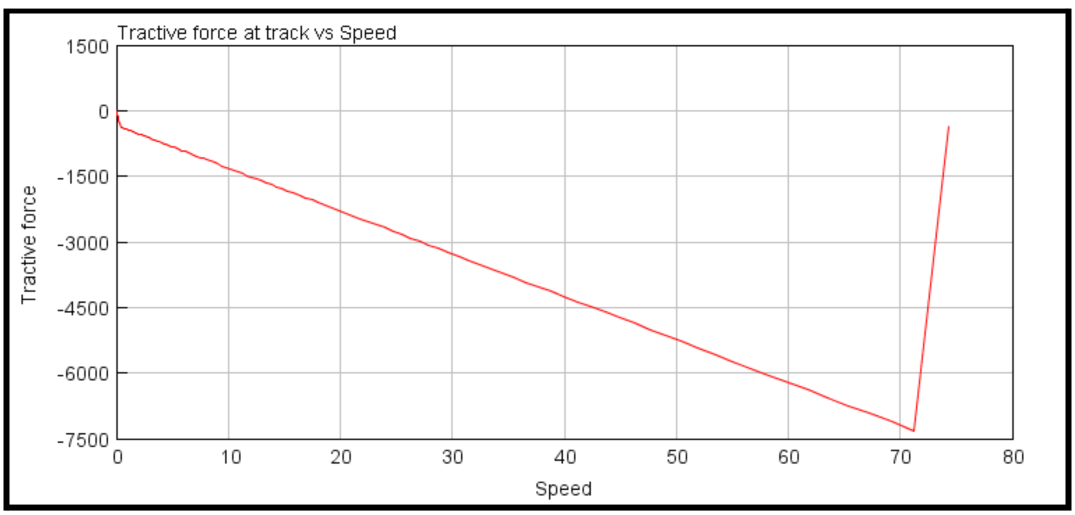

Figure 20: Tractive Force Plot

Additionally, based on the scoring results of the completion, the team has a recommendation that is up to the faculty advisors discretion. Based on the winning team of the competition MTU, a viable strategy for future teams is to focus only on certain areas and excel in them. Michigan Technological University won this year's competition, but did not submit files for every segment of the competition. By focusing on certain areas, they were able to create the models that beat every other team by a large margin. Even though they did not score points in some categories of the competition, they still won the overall competition by exceeding expectations in the areas they did submit in. This strategy is something that can be considered for future competitions, but is also a risk to the overall potential score. If a future faculty advisor desires it, this is a possible strategy for winning future competitions.

Finally, our last recommendation is for the model that our team created to be past down to future competition teams so that they do not have to start from scratch like our team did. They will have a few areas to focus on in our model that they would need to fix, such as reducing the sound model, reducing the fuel consumed at high RPMs, and applying all of the feedback from the judges in the competition. This may take some time, but it should not take longer than it took for our team to create this model from scratch. Using our model, and having access to a physical model to acquire dimensions and other values should greatly improve this current model to be much more accurate. Once the model is more accurate, better readings will be produced which will allow future teams to understand what areas to focus in on improvement. Once future teams produce a more accurate model, they can then apply it to various snowmobiles by simply changing the data. This would help them in the physical competitions as well, allowing them to reference the virtual model for analysis on the physical design. Therefore, passing down this model for improvement to future teams would allow IUPUI to eventually have an accurate model for snowmobile simulations for future SAE competitions.

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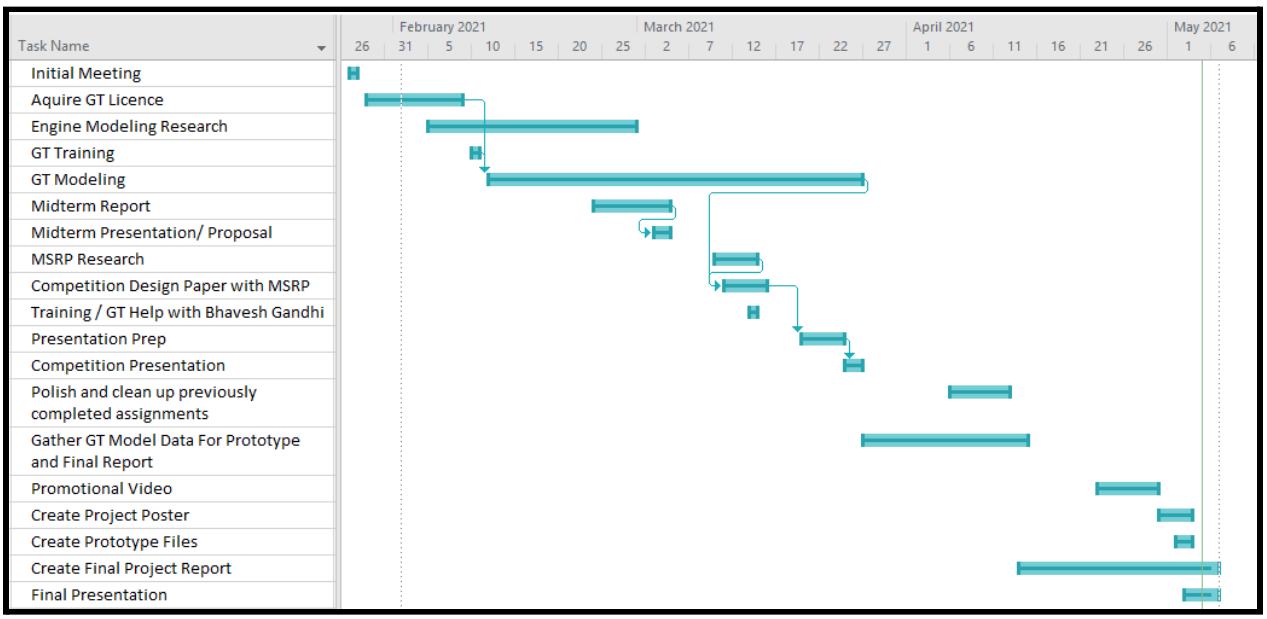
Appendix A (Full Gantt Chart)

	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Initial Meeting	1 day	Wed 1/27/21	Wed 1/27/21	
9		Aquire GT Licence	7 days	Fri 1/29/21	Mon 2/8/21	
7		Engine Modeling Research	17 days	Fri 2/5/21	Sun 2/28/21	
8		GT Training	1 day	Wed 2/10/21	Wed 2/10/21	
4		GT Modeling	31 days	Fri 2/12/21	Fri 3/26/21	8,9
5		Midterm Report	7 days	Wed 2/24/21	Thu 3/4/21	
6		Midterm Presentation/ Proposal	2 days	Wed 3/3/21	Thu 3/4/21	5
10		MSRP Research	4 days	Wed 3/10/21	Sun 3/14/21	
2		Competition Design Paper with MSRP	3 days	Thu 3/11/21	Mon 3/15/21	4,10
3		Training / GT Help with Bhavesh Gandhi	1 day	Sun 3/14/21	Sun 3/14/21	
15		Presentation Prep	4 days	Sat 3/20/21	Wed 3/24/21	2
11		Competition Presentation	2 days	Thu 3/25/21	Fri 3/26/21	15
12		Polish and clean up previously completed assignments	5 days	Tue 4/6/21	Mon 4/12/21	
13		Gather GT Model Data For Prototype and Final Report	14 days	Sat 3/27/21	Wed 4/14/21	
14		Promotional Video	5 days	Fri 4/23/21	Thu 4/29/21	
16		Create Project Poster	2 days	Fri 4/30/21	Mon 5/3/21	
17		Create Prototype Files	2 days	Sun 5/2/21	Mon 5/3/21	
18		Create Final Project Report	17 days	Wed 4/14/21	Thu 5/6/21	
19		Final Presentation	4 days	Mon 5/3/21	Thu 5/6/21	



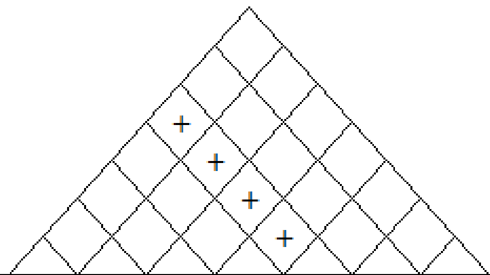
Appendix B (Full House of Quality)

QFD: House of Quality

Relationships	
Strong	●
Moderate	○
Weak	▽

Correlations	
Positive	+
Negative	−
No Correlation	

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Functional Requirements / Customer Requirements (Explicit and Implicit)	Upgrade Muffler	Install Catalytic Converter	Upgrade to Fuel Injection System	GT Suit Model				Row #
					Column #	1	2	3	4	5	6	7	
					Direction of Improvement	▲	▲	▲	▲	▲			
1		25%	20	21	Lower Emisssion	○	●	●					1
2		25%	20	10	Lower Acoustics	●							2
5		25%	20	18	Higher Fuel Efficiency			●					5
6		4%	3	12	Higher Acceleration			○					6
7		4%	3	18	MSRP	○	●	○					7
8		9%	7	21	Paper	○	○	○	●				8
9		9%	7	21	Presentation	○	○	○	●				9
10													10
					Max Relationship	21	24	30	18				
					Technical Importance Rating	5	7	8	10				
					Score	105	168	240	180				
					Ranking	4	3	1	2				