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Formula SAE Final Project Report

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Executive Summary

The Formula SAE team at Trinity University has been working on a race car project since 2015 and has made significant progress in constructing a nearly complete car. This year, the team focused on continuing that progress by working towards implementing a new design, an airfoil, and redesigning suspension components, while also ensuring compliance with various regulations and standards.

This year's team has faced several constraints along the way, including time and budget limitations, complying with safety, technical, and environmental regulations, and following specific design constraints for the airfoil. To achieve set goals and eventually participate in FSAE competitions, the team must also follow applicable codes and standards, including the General Regulations and Rules of Conduct in the 2023 Formula SAE rules and specific standards related to the subsystems of the car, such as bodywork and aerodynamic devices.

The team identified incomplete subsystems that needed to be addressed, one of which was the engine's ability to idle. The team tested the spark and injector timing relative to the crank position using a 120 frame per second high-speed camera. Then using TunerStudio, a software for tuning an aftermarket MegaSquirt ECU, the team came up with four separate tunes that had varying spark and injector timings to get the car to start and idle. Despite getting combustion to occur and for the car to run for a few power strokes, the team was unsuccessful in achieving a consistent and steady idle. The team had ambitious goals for the project, but unforeseen difficulties prevented many of the design requirements from being met. Requirements such as maximum speed, user control, safety belts and seat, steering system, and airfoil mounting system were not fully tested or implemented.

The team identified components that need to be fabricated by future teams, including a brake failure emergency shut off switch and a brake light. The team developed a CFD wind tunnel model to test the proposed airfoil design and conducted a validation test for the CFD model using literature results as the subsonic wind tunnel facility on campus was not available.

The FSAE team planned to compare the downforce generated by a 3D printed model of an airfoil to the Ansys CFD model by testing the 3D printed model in a subsonic wind tunnel, but access to the wind tunnel was not available. Instead, the team compared the Ansys coefficients to those obtained from an experiment, and the results show promising accuracy of the Ansys model. However, the team suggests focusing on the performance and accuracy at higher angles of attack to improve the model.

Furthermore, the team created a hypothetical racetrack to analyze the performance benefit of the airfoil and made several assumptions to simplify the process. The team calculated the lap times by dividing the distance traveled by the velocity of the car at different points of

the racetrack, accounting for the aerodynamic effects of the airfoil, and the effect of downforce on the car.

Overall, the 2022-23 Formula SAE team at Trinity University has faced numerous challenges in their race car project, including adhering to regulations, addressing incomplete subsystems, and conducting validation tests without proper facilities. However, the team made significant progress and will continue to work towards implementing a new design and analyzing the performance benefits of an airfoil.

1. Introduction

The Formula SAE team at Trinity University began in 2015 with the goal of participating in a Formula SAE competition. Over the past few years, several teams have worked tirelessly to make significant progress in constructing the car, turning it from a mere concept into a nearly complete vehicle. The fully constructed frame, mounted suspension, axles, and integrated engine with relevant systems are all a testament to the hard work and dedication of the previous teams.

This year's FSAE team was tasked with continuing the progress made by the previous team while also implementing a new design. The team decided to design and test an airfoil to determine its potential benefits on the car's performance. The main goal of the team regarding the engine was to reach a point where it could consistently start and run. Unfortunately, the previous FSAE team could only get the engine to idle for three seconds, and this process required research and disassembly of the engine to learn the proper way to tune it. In addition, this year's team completed work on redesigning suspension components and creating a new, durable wiring harness.

Throughout their work, the team had to navigate several constraints, codes, and standards to stay on track. These constraints included time and budget limitations, as well as complying with safety, technical, and environmental regulations. By keeping these factors in mind and putting in their best efforts, the Formula SAE team at Trinity University is getting closer to achieving its goals and eventually participating in FSAE competitions.

Constraints of this project

The following constraints have been identified for the completion of the car based on meetings with the project sponsor and consideration of the FSAE competition regulations.

- The car must be completed within the available budget of $6000 plus the $1200 senior design budget. This budget may change if sponsors or donors invest money into the project.

In terms of the airfoil, the following design constraints have been identified. All constraints below apply because they are FSAE competition requirements.

- All forward facing edges on the aero that could contact people, including the nose, must have forward facing radii minimum of 38 millimeters. This minimum radius must extend 45° or more, relative to the forward direction, along the top, sides, and bottom of all affected edges.
- Aero must not go beyond the wheels of the car when the wheels are pointing straight ahead. Aero must also be less than 250 millimeters rearward of the rear tires.

- If aero is between the centerlines of the front and rear wheel axles, it must be inboard of a line drawn connecting the outer surfaces of the front and rear tires at the height of the wheel centers.

Applicable Codes and Standards

In the 2023 Formula SAE rules there are General Regulations (GR) that include Good Engineering Practices and Rules of Conduct. [1] These regulations are provided to give engineering teams an expectation and an efficient transition into the environment of the competition. Then depending on the subsystem of the design, there are a set of standards to follow to ensure the safety of the drivers and sustainability of the racetrack. This year's team is working on the completion of several systems for which sections D, F, T, and VE may be applicable. Formula SAE standards will also be beneficial. After reviewing other codes and standards such as ASME and ASTM; it was decided that the Formula SAE rulebook was sufficient.

SAE:

-D.1.1 Dynamic Events and Maximum Scores

This standard is used to determine which event the car is applicable for and how many points they are worth.

-F.5.11 External Items

This standard applies to the types of ways parts can be added to the car’s chassis. It also describes bracing requirements for all joints on the car.

-T.7 Bodywork and Aerodynamic Devices

This standard defines the constraints in the vehicle’s wings which will be used to establish proper dimensions and rigidity constraints to the team’s design.

-VE.1 Vehicle Identification

This standard describes the extra identification items required on the outside of the car after the new layer of paint has been applied. The team identified a number of incomplete subsystems in the car that needed to be addressed.

2. Overview of the Final Design

The final prototype for the FSAE senior design project is the car, which has been the culmination of 6 years of work (one design team each year).

Due to its incompleteness, this year's team focused on troubleshooting several aspects of the car, and fixing them along the way. Overall, the final design overview for the prototype is the combination of the several subsystems including the wiring, suspension, airfoil, and engine tuning.

2.1 Suspension Subsystem

The suspension on the car was rebuilt due to the previous teams' oversight in accounting for the proper amount of camber needed for the car to race. Although the previous design aligned with the applicable codes, standards, and rules listed in FSAE Rulebook section V.3.1, it was found that some simple dimensional changes were required to achieve an acceptable camber for all four wheels. [1] At the start of the year, all four wheels of the car had positive camber, which is not ideal for cornering. Positive camber reduces the contact surface of the tire when cornering, resulting in reduced grip and diminished cornering speeds. On the other hand, negative camber, as depicted in Figure 2, has advantages in cornering situations, as shown in Figure 1.

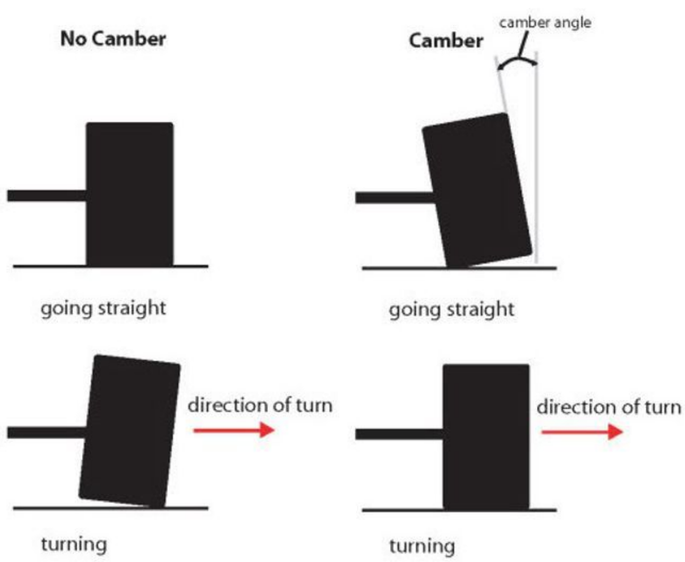

Figure 1: Effects of camber through when cornering

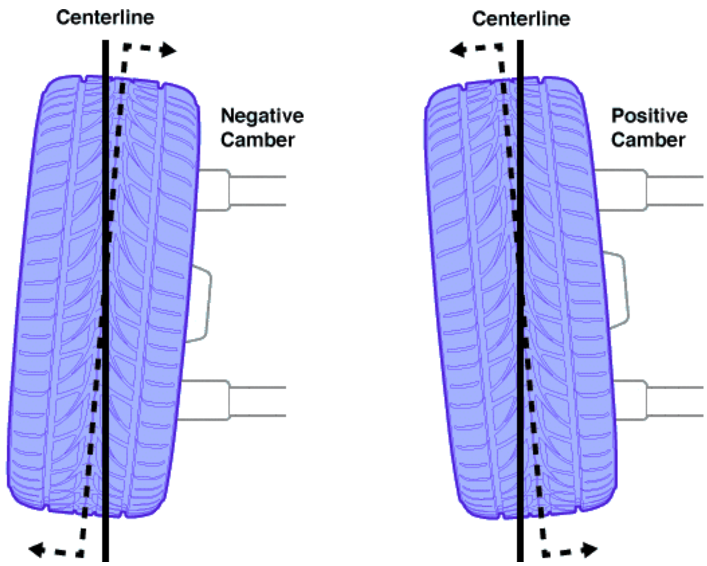

Figure 2: Negative vs. positive camber

To achieve the desired negative camber, the front upper control arms on the car were shortened to adjust the suspension geometry. This modification pulls the top end of the tires inwards, resulting in a desirable negative camber angle, which can improve the car's grip and cornering performance. To accomplish this, the team mainly focused on widening the angle and shortening the arms of the upper control arms; this can best be seen in Figure 3. By increasing the angle and shortening the arms the team was able to bring the upper part of the tire closer to the frame, thus inducing negative camber. In an effort to achieve the desired negative camber for the race car, wood models were created for the upper control arm. These models were used to validate measurements and angles before making any modifications to the actual control arms. Wood replicas were carefully crafted based on the original design's dimensions and specifications, with the original Solidworks files of the arms serving as a reference. The wood models were then attached to the car and final adjustments were made to ensure proper fit and alignment before metal fabrication. Different lengths and angles were tested on the wood models to determine the optimal configuration for achieving the desired negative camber. Once the measurements and angles were satisfactory on the wood models, the actual control arms were modified accordingly. Precision was maintained in cutting and adjusting the length and angle of the control arms to meet the calculated and simulated desired camber angle.

Upon completion of the modifications, the modified control arms were reattached to the car, following proper alignment and tightening as per the manufacturer's specifications. Thorough inspections and tests were conducted to ensure that the desired negative camber was achieved and that the control arms were functioning correctly. The use of wood models proved to be valuable in achieving accurate and efficient adjustments, minimizing the risk of errors and ensuring optimal performance of the suspension system. Specifically, the angle Θ, as seen in Figure 3, was increased from 42° to 59.8°. This adjustment resulted in the correction of the camber angle from +3° to -1.5° on the right side of the car, and from +3.5° to -1.73° on the left side, meeting the design requirements of -1.5° of camber with a 0.3° tolerance.

Figure 3: Upper Control Arms

2.2 Engine Subsystem

The internal combustion engine used for the FSAE car is a 2015 Yamaha Genesis 80FI engine, shown in Fig. 4. It is a four-stroke, parallel, two-cylinder spark ignition engine, with a total displacement of 499cc. How a four-stroke engine operates and generates mechanical power is shown in Figure 5.

Figure 4: Yamaha Genesis 80FI engine from snowmobile.com

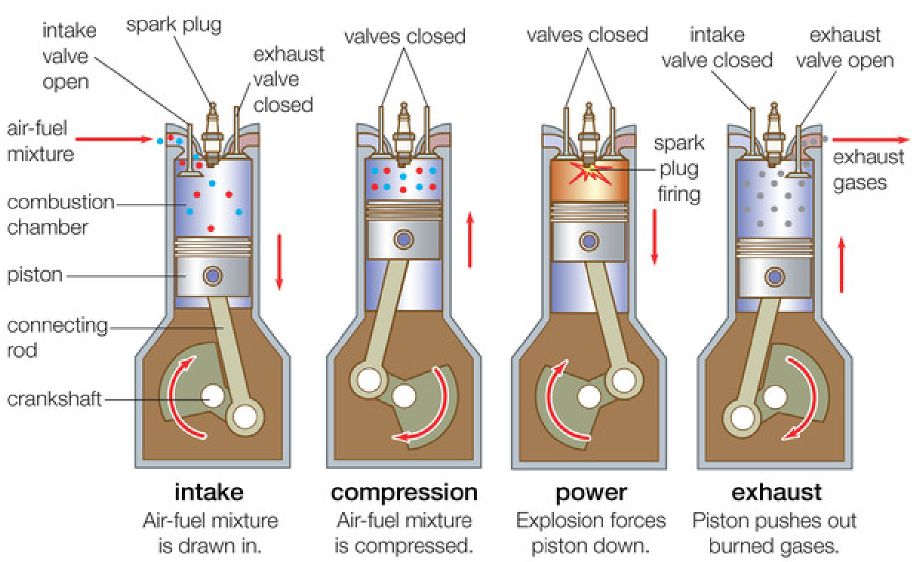

Figure 5: Four-stroke combustion engine diagram

Figure 6 is a simplified diagram of the major components in and around a combustion chamber. This figure does not picture the fuel injector. The car's engine, the Yamaha Genesis

80FI, has port injection, which means the fuel injector is mounted to the intake manifold and injects fuel into the intake rather than injecting fuel directly into the combustion cylinder [4]. Figure 6 shows how the a port fuel injector is mounted.

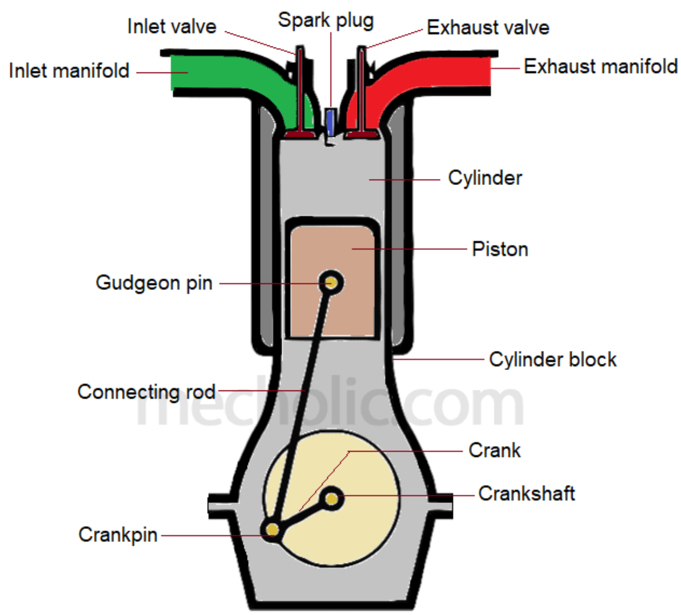

Figure 6: Primary components of a combustion cylinder

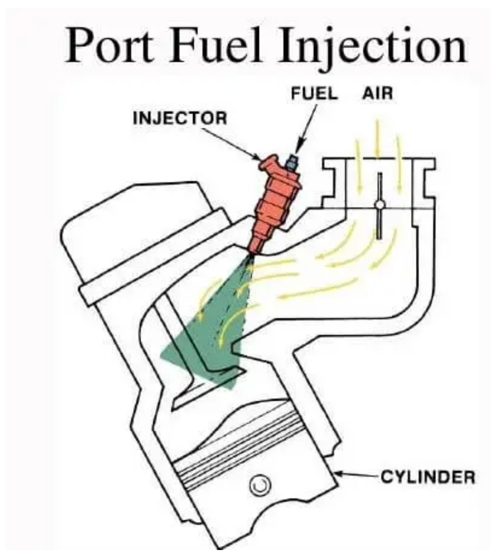

Figure 7: Port injection diagram. Fuel is injection outside of combustion chamber and onto intake valve

The engine also features a 180° offset crankshaft, meaning the firing of the spark plugs of the two cylinders are offset by 180 crank angle degrees (CAD). [4] In other words, the two cylinders of the engine are always one phase apart from each other in the four-stroke combustion process. The engine was chosen by the senior design team from 2016, and it was extracted from a 2015 Yamaha Phazer snowmobile. The output shaft of the engine is mated to the original equipment manufacturer's (OEM) continuously variable transmission (CVT) that came with the snowmobile. The CVT is then mated with a custom-made differential which transfers the engine power to the rear wheels of the vehicle through a pair of custom-made constant velocity axles.

Since the engine came as a complete unit, there was little design involved. However, the team had to take measurements of various parameters to input into the governing program of the electronic control unit (ECU). Using this program, the ECU then communicates with various electrical components around the engine to inject fuel and create sparks at the correct time to create combustion. The most important measurement the team took was the CAD between the ECU's detection of tooth 1 on the crank trigger wheel and when the piston of cylinder 1 reaches top-dead-center (TDC), and begins a new cycle of the four-stroke combustion process. This allows the ECU to know the precious location of the crankshaft, and by extension the piston. The only way the ECU detects the crank position of the engine is through a crank position sensor. It is an electromagnetic sensor which detects a missing tooth (tooth 1) on the crank trigger wheel. The crank trigger wheel rotates simultaneously with the crankshaft of the engine, so by measuring the CAD offset between the detection of tooth 1 and when the piston of cylinder 1 reaches TDC, the ECU can translate the reading from the crank position sensor to the precise position of the crankshaft.

The programming of the ECU, a process referred to as "tuning", is a process in which the team inputs parameters into the tuning software TunerStudios to set the activation timing of the fuel injectors and spark plugs. In order for the engine to function properly while driving, the team needs to tune the engine at different revolutions per minute (RPM), as well as at different engine loads. However, due to the tremendous amount of research and testing required to achieve proper operation at all rpm and engine loads, the main goal of the team this year is to tune the engine only for startup and idling. In order to get the engine to start and idle, the team must understand at what time during the combustion process the injection and spark must occur. What the team currently knows is that fuel injection must be fully completed before the intake stroke begins. This means that the fuel injector must start and finish injecting fuel before the intake valve opens to let the air-fuel mixture into the combustion chamber. The timing of when the spark plug sparks must also be within 5-10 CAD *before* the piston reaches TDC during the compression stroke. Working off of this information, as well as the aforementioned measurements, the team can make changes to the tuning file in TunerStudios.

2.3 Wiring Subsystem

The wiring harness transmits electrical power and control information to and from different car components. The function of this subsystem design was to create a reliable electrical system that is capable of withstanding racing conditions. This implies that the working criteria for this design required a fully protected wiring system capable of withstanding high temperatures, fluid spills, vibrations, and stresses without breaking continuity. This criterion was satisfied by covering all wires with DR-25 heat shrink which is specifically designed for motorsports wiring systems. In addition, Kapton tape and epoxy were used to completely seal off any wire connections. To secure strong connections capable of tolerating vibrations and stresses, open barrel crimps were used to connect wires and terminals. These crimps are specifically used in motorsports since they are capable of stronger connections than other types of crimps or soldered connections. These improvements on the wire harness will satisfy the primary objective of having a reliable harness, which in turn will enable the team to have a reliable engine. Figure 8 and Figure 9 shows the old wiring system compared to the newly designed wiring harness. Figure 10 shows the additional mounts the team has fabricated to improve organization of the wiring system.

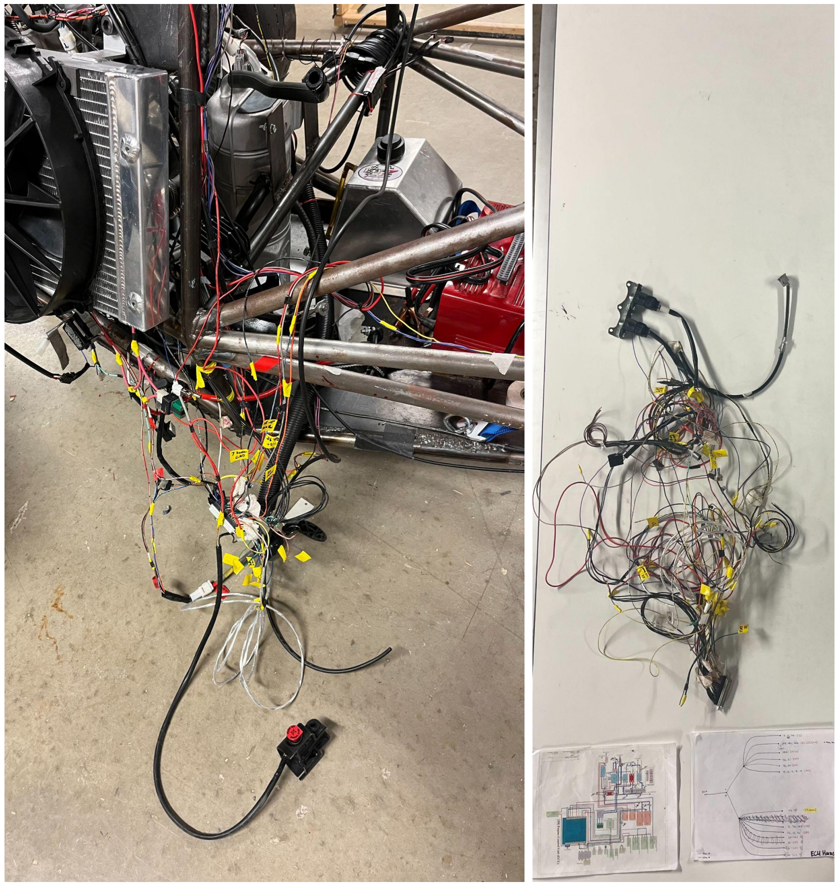

Figure 8: Engine wiring prior to the start of the project

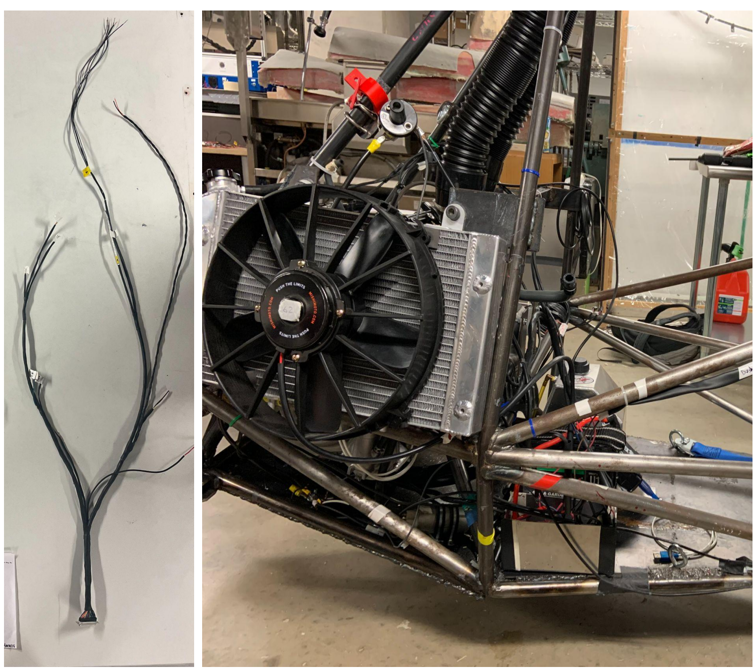

Figure 9: Wiring harness before installed on the car (left), organized cockpit with no loose wires (right)

Figure 10: Other components that were added to improve the organization of the electrical system such as a reuse/relay box and mount for the ECU

2.4 Airfoil Subsystem

The proposed design for this year was a rear airfoil that would serve to generate additional downforce while the car is in motion. The original goal for the amount of negative lift, or downforce, produced was 80 lbs at a speed of 60 mph or ~26 m/s. To produce the maximum amount of downforce, the dimensions of the airfoil were the largest it could possibly be while still being within FSAE regulations. These regulations limit the width of the airfoil to within the inside wheel wells. FSAE rules also lay out the maximum length past the rear of the car the airfoil could be, which places a limit on the chord length or length the airfoil. Taking into account these design constraints and after measuring the dimensions of the car, a width of 0.89 m and chord length of 0.5 m was chosen as the final recommendation for the dimensions of the airfoil. Additionally, the team decided to go with the S1223 airfoil because it is the most commonly used airfoil design in FSAE. Figure 11 is a cross section of the S1223 airfoil design.

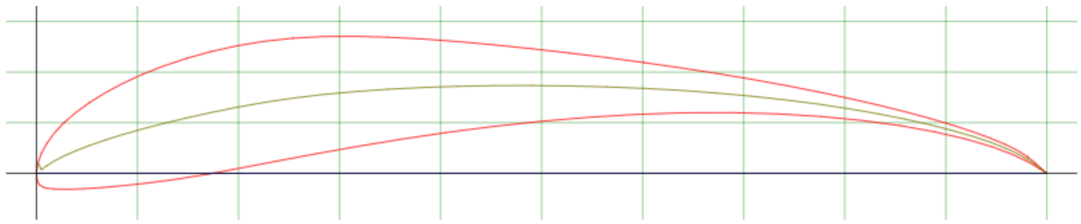

Figure 11: S1223 airfoil design

After the team decided on the dimensions of the proposed airfoil, the airfoil was recreated in Ansys, the CFD software the team would be using to run simulations. A windtunnel model was also constructed that enclosed the airfoil, much like how airfoils would be tested in a real world windtunnel. Simulations were performed for the airfoil at varying angles of attack to determine the optimal angle of attack that would provide a large amount of downforce while limiting the amount of drag. Figure 12 shows the basic dimensions of an airfoil. Figure 13 is the airfoil in Ansys' 3D modeler.

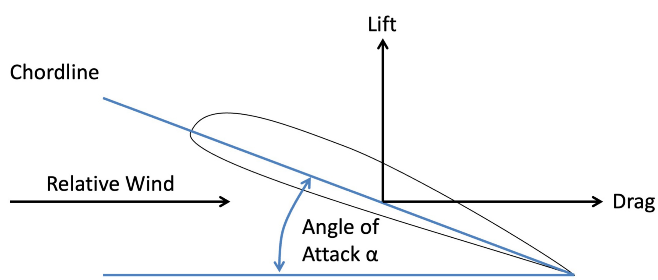

Figure 12: Diagram showcasing chord length and angle of attack

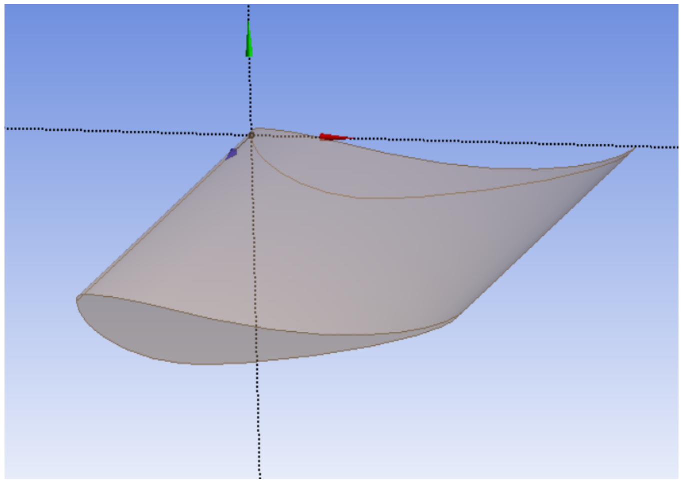

Figure 13: Airfoil geometry in Ansys DesignModeler

The first iteration of the Ansys model was developed in the Fall semester and did produce some results for downforce and drag, though quite rough and could be improved upon. The team continued developing the model to prepare for the validation test where the team would test a 3D printed airfoil in a subsonic wind tunnel and compare the downforce results to what the Ansys model produces. One meshing method that helped improve the accuracy of the CFD model was the inclusion of layers around the airfoil itself that allowed for a boundary layer to be more accurately simulated. Figure 14 shows the meshing method implemented on the airfoil. This allows for a velocity gradient from the no-slip condition on the airfoil surface to the free stream velocity to be modeled.

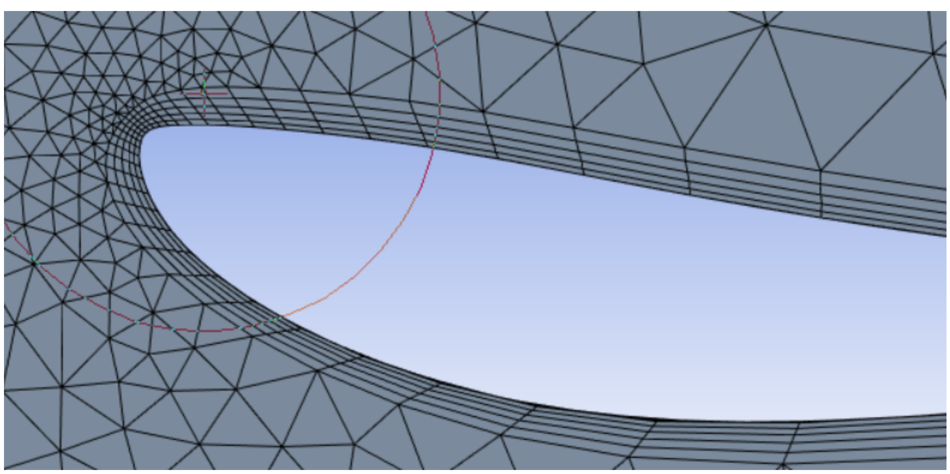

Figure 14: Meshing method to more accurately model a boundary layer around the airfoil

3. Design Evaluation

At the beginning of the project, the team had ambitious goals for the car. Due to unforeseen difficulties with the project, many of the design requirements were not met. These requirements are listed below.

1. The race car shall be able to travel with a maximum piston test speed of 914.4 m/min on the racetrack made for the FSAE competition as stated in IN.10.4.1 of the FSAE rulebook. The subsystems of the car must give the user enough control to participate in the competition.
2. The race car must stay intact during a race for the FSAE competition.
3. The race car must have seat and lap belts for safety during travel. The seat must follow the standards presented in section T.1.5 “Driver’s Seat” of the *FSAE 2023 Rules.* Also, the lap belts must follow the standards presented in section T.2.2.3 “Harness Requirements” of the same rulebook. [1]
4. (The race car must include subsystems such as) Steering wheel following the requirements found in section V.3.2 [1]
5. (The race car must include subsystems such as) Speed indicator for user monitoring and control of the vehicle.
6. The mounting system provides sufficient rigidity in the static condition.
7. The Aerodynamic Devices must not oscillate or move excessively when the vehicle is moving.

Requirements 1, 2, 5, and 7 are requirements which can only be tested while the vehicle is in motion. Due to the car being unable to move by power generated by its internal combustion engine at the time of writing, it was impossible for the team to assess whether or not the car had met these requirements. Requirement 3 stated that the vehicle must be equipped with safety belts and a seat to ensure the safety of the operator of the vehicle. Due to the nature of the geometry of the cockpit, it is difficult to have access to the engine bay to work on it. The car does have lap belts already installed from the previous team, however, since the seat also serves as the firewall of the cockpit, it is currently uninstalled from the car.

Requirement 4 stated that the car must have a steering system, and requirement 6 stated that the mounting system of the airfoil must be rigid under static conditions. As the project progressed over the two semesters, the main focus of the team gradually shifted towards getting the engine to start, which took the majority of attention of all the team members. Therefore, the design and fabrication of the steering system and the mounting system of the airfoil were postponed to be done by the teams in the future.

Apart from the tasks mentioned above, the 2023 FSAE team have also identified several components that would need to be fabricated by the future teams. The first is a brake overtravel switch, as described by section IC.9.1.1.d in the FSAE rulebook. [1] This switch would be able to cut the electrical power supplied to the engine, i.e. shutting off the power output of the engine, when an overtravel in the brake pedal is detected. The second component is a brake light as specified by section T.3.3 of the FSAE rulebook. [1] The brake light must illuminate when the vehicle is decelerating using the braking system, communicating with the following car that the car is slowing down.

Nevertheless, the 2023 FSAE team has tackled a variety of design systems and tests. The progress on these subsystems are detailed in the following sections.

3.1 ANSYS CFD Model Validation

The purpose of this test was to validate the CFD model by comparing the lift values calculated by the CFD model to a real world wind tunnel test with a 3D printed scale model. This test was planned for the spring semester, however, the facility was not available so the team relied on results from literature over the S1223 airfoil design to validate the CFD model.

3.1.1. Test Overview

This test would compare the downforce generated by a 3D printed model of the airfoil in a real world windtunnel to the downforce generated by the Ansys model to determine the accuracy of the CFD model.

3.1.2. Test Objectives

The goal of this test was to validate the CFD model that the team has been building this year.

3.1.3. Features Evaluated

This test would examine the ability of the airfoil design to generate downforce.

3.1.4. Test Scope

The 3D printed airfoil would be tested at around the max speed of the windtunnel available on campus, which is around 60 mph. This aligns with what the average max speed of FSAE cars are on the endurance event.

3.1.5. Test Plan

This test would utilize the subsonic wind tunnel on campus that students have used during their Fluid Mechanics Laboratory class. Once the team has access to the wind tunnel, a mounting system for the 3D printed airfoil can be developed. The downforce the 3D printed airfoil generates can be tested by attaching a spring scale to the airfoil and directly measuring the force generated while the wind tunnel is on. If the max speed of the wind tunnel is 60 mph, tests should be run at multiple speeds at 10 mph intervals.

3.1.6. Acceptance Criteria

The team would consider this test a success if the downforce generated by the 3D printed airfoil is within 10% of the downforce generated by the Ansys model.

3.1.7. Test Results and Evaluation

Result: Undetermined

Due to conflicts with the Fluid Mechanics Laboratory class that is ongoing this semester, the FSAE team has not been able to access the subsonic wind tunnel on campus. The team decided to compare the ANSYS results to the experimental results from [2]. The data from this experiment is relevant to the test because the experimental setup from research is similar to the testing setup. In the experiment, an S1223 airfoil is tested in a subsonic wind tunnel at Re = 2×10^5. The coefficients of drag and lift from the experiment by Selig and Guglielmo are compared to the ANSYS coefficients in Table 1.

Table 1: ANSYS simulation results compared to experimental results from Selig and Guglielmo

Angle of Attack [°]	ANSYS Coeff. of Lift [kg/m]	Selig Coeff. of Lift [kg/m]	% Difference [-]
0	1.162	1.1	5.64%
5	1.693	1.6	5.81%

10	2.047	1.9	7.74%
15	2.034	2.2	7.55%
20	1.956	2.0	2.20%

From the above experimental results, it was observed that there is a maximum percent difference of 7.74% at 10 degrees. While the team was not able to access a wind tunnel, comparison to published literature shows promising results with regards to the accuracy of the Ansys model. The increased difference at 10 and 15 degrees implies that to further improve the Ansys model, performance and accuracy at higher angles of attack should be focused on. This could involve changing meshing settings and rerunning simulations to see if the model performs more closely to literature.

To analyze the performance benefit of the airfoil, the team must create a hypothetical race track and use the downforce and drag produced by the airfoil based on published data to predict the change in lap time. Due to the difficulty of finding a track that is representative of the track the car will be racing on, the team came up with a track layout on which the team will use the published data to calculate the drag and lift force acting on the car, to predict the lap times of the car based on these additional forces. The hypothetical racetrack is shown in Figure 15.

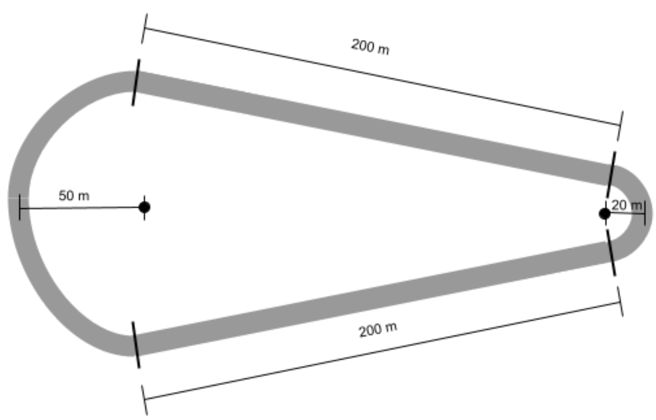

Figure 15: Hypothetical race track on which the analysis is performed on

Auto racing is an extremely dynamic sport. The input of the driver, the condition of the race track, and the dynamic of the car all have major impacts on the lap times of a race car. Since the following analysis calculations are done by hand, and the goal of this analytical exercise is not to find an accurate lap time by any means, but rather to give the team an idea of how the introduction of an airfoil to the car would affect its performance, several major assumptions were made to drastically simplify this analysis. Firstly, the team eliminated the variable of driver input by assuming the racing car is driving at the centerline of the race track, i.e. the car is not taking the "racing line". Secondly, due to the dynamic performance of the car, e.g. the acceleration rate, braking performance, not being available at the writing of this report, an ideal scenario will be assumed where the racing car can instantaneously accelerate to its top speed once it enters the straightaway, and can instantaneously decelerate to the maximum cornering speed once it enters the curved sections of the race track. Based on these assumptions, the team can use basic kinematics equations to calculate the lap times by dividing the distance traveled by the velocity of the car at different points of the race track. With the distance around each section of the track calculable from its geometry, the team must work out the velocity of the car at each section of the track when accounting for the aerodynamic effects of the airfoil.

The first task of the analysis is to account for the effect of downforce on the car. The calculation of lift force is extremely complex in the real world, therefore, the team must make several assumptions to simplify the process. The three main assumptions made for the calculation of performance improvement are 1) the tires are high performance, treadless tires making contact with dry asphalt, and the race track is unbanked and features no elevation changes 2) the airfoil has no pressure loss at its boundaries 3) The ambient condition of the hypothetical race track is 15 degrees Celsius, and the elevation of the hypothetical track is at sea level, with no wind present. In theory, downforce increases the maximum static friction of the tires, allowing a car to corner at a higher speed. The free body diagram of the racing car going around the corner is shown in Figure 16.

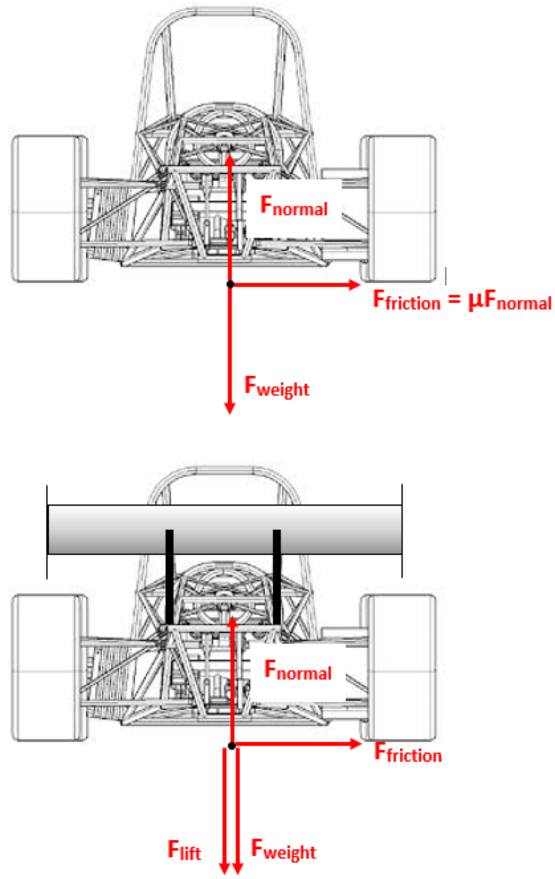

Figure 16: Free body diagram of the racing car going around the corner, with and without an airfoil

Notice in the scenario where the racing car has an airfoil, an additional negative lift force is added to the FBD, and to balance out the additional force, normal force of the racing car increases, therefore the lateral friction force increases as well based on the equation in the figure. The maximum lateral friction force is the maximum centripetal force of the racing car in the direction towards the center of curvature, as seen in Figure 17, and a larger centripetal acceleration equates to a larger tangential velocity, which is why increasing the friction of the tires allows the car to go around a corner faster.

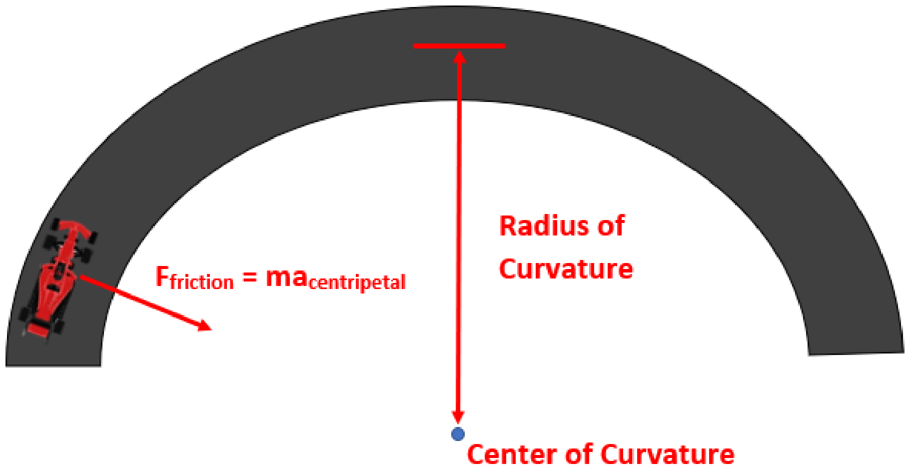

Figure 17: Motion and force of racing car along a curve

Applying static equilibrium to the vertical direction in the free body diagram in Figure 16, the team can get an expression for the normal force, and plug into the equation shown in Figure 17, and gives Eq. (1), which will help the team calculate the maximum tangential velocity given lift force, mass of the car, maximum coefficient of static friction, and the radius of curvature.

$$F_{friction} = \frac{mv^2}{r_{curv}} = \mu_{static}N = \mu_{static}(mg + F_{lift}) \quad (1)$$

From measurements taken from previous years, the team knew that the mass of the car is 363 kg. From [3], the team got an estimated coefficient of friction of 1.1 for a high performance, treadless tire on dry asphalt. In order to calculate for the negative lift force generated by the airfoil, the coefficient of lift (as a function of the angle of attack of the airfoil) acquired from the ANSYS model was used, and plugged into Eq. (2) to calculate the lift force.

$$C_{lift} = \frac{2F_{lift}}{\rho A v^2} \quad (2)$$

In Eq. (2), ρ is the density of the air at sea level at 15 degrees Celsius, and A is the characteristic area of the airfoil. In order to calculate the velocity, the team calculated the maximum cornering speed of the car without any lift force, and used Eq. (2) to find the downforce generated at this speed. The team then calculated the increase in cornering speed due to the addition of the lift using Eq. (1). The team used a range of radii of curvature from 5 m to 50 m with an increment of 5 m, and resulted in a range of speed gain as a function of the radius of curvature. This will be imputed at the cornering speed of the car with and without a spoiler into the hypothetical race track to calculate the overall time difference in the corners.

On a racetrack, there are not only corners but also straight sections, where the car will be traveling at its top speed. The effect of drag is most prominent on these “straigthaways”. Although drag plays a role in the corners as well, since the car is not traveling at max speed, the driver can use the acceleration of the engine to overcome the drag. Similar to drag force, the accurate calculation of drag force is very difficult, and due to the team not knowing important performance figures, most notably the top speed of the car, the team made the following assumptions to simplify the analysis. 1) The top speed of the car is 60 mph, as it is a common top speed among FSAE cars with aero packages. 2) The rotating tires generate outwash, however, the team will ignore its effect on drag in this analysis. 3) The team knows that the flow of air around the bodywork of the car certainly creates a difference in the streaklines of the flow, thus changing the flow of air around the airfoil as well, but the team will ignore its effect on the spoiler and treat the spoiler as a separate aerodynamic entity.

At max speed, the free body diagram of the car is shown in Figure 18.

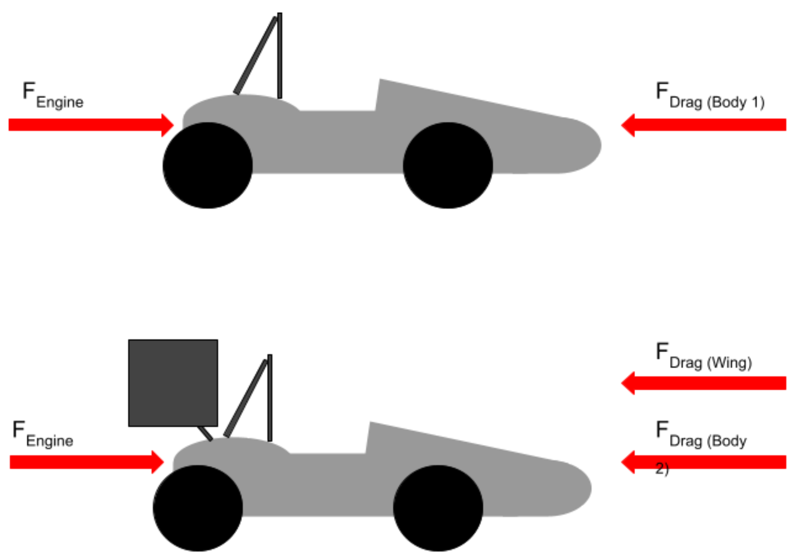

Figure 18: Free body diagram of car traveling at top speed, with and without the presence of a spoiler

Since the force generated by the engine and the drivetrain is the same in both scenarios, and the car is neither accelerating or decelerating at its top speed, the car is in dynamic equilibrium with the sum of forces in all directions equaling zero. With a drag force from the wing (airfoil) present in the second scenario in Figure 18, the drag force produced by the rest of the racing car must decrease in order for the vehicle to remain in dynamic equilibrium. The velocity of the car and the force of drag is related by a coefficient of drag, as shown in Eq. (3).

$$C_{drag} = \frac{2F_{drag}}{\rho A v^2} \quad (3)$$

Due to the coefficients of drag from the simulations being inaccurate to published results, the team was unable to use them to do drag force calculation. The team decided to use the published drag coefficient at different angles of attack to perform this calculation. Applying equilibrium to the car without a spoiler, getting Eq. (4).

$$F_{drag(body)} = F_{engine} \quad (4)$$

From [4], the team found that the engine of the vehicle, a Yamaha Genesis 80FI engine, is producing 51 Nm of torque at 9000 rpm. To simplify the analysis, the following assumptions were made to the calculation of engine force. 1) The drivetrain of the car is perfect and causes no loss of power or torque from the engine to the wheel, i.e. the total amount of torque experienced by the drive wheels is also 51 Nm, and the torque is perfectly distributed between the two drive wheels. 2) The engine is ideal and produces max torque at all rpm ranges, so it is also producing 51 Nm even at a slower speed. With these assumptions, the team calculated the total force of the engine acting on the entire car is 182 N. From Eq. (4), the team got that the drag produced by the body of the vehicle is the same as the total force produced by the engine, therefore, the team could plug in the value for drag force into Eq. (3) to acquire an overall coefficient of drag for the body of the racing car. The characteristic area for the body of the car is calculated with the dimensions shown in Figure 19, and the team ignored the area of the roll hoops and control arms, and assumed the area of the helmet is a circle with a radius of 0.13m.

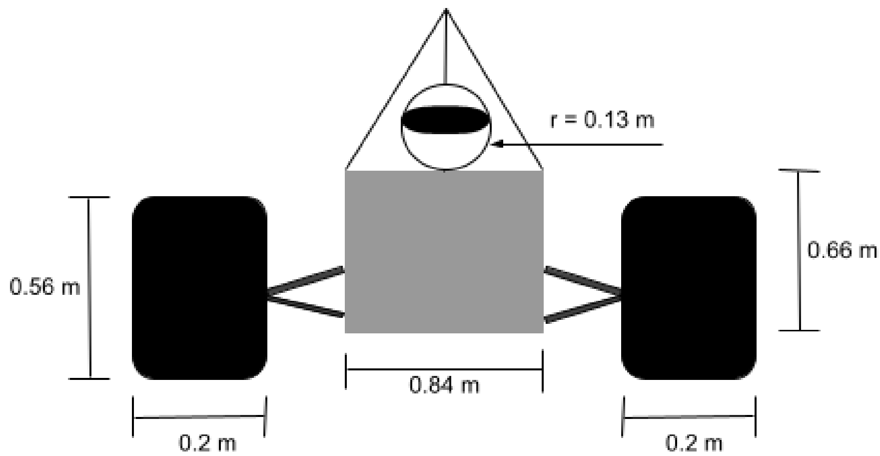

Figure 19: Dimensions used to calculate the characteristic area of the car

Applying equilibrium to the second scenario in Figure 18, getting Eq. (5)

$$F_{drag(wing)} + F_{drag(body)} = F_{engine} \tag{5}$$

Since the team now has the coefficient of drag for both the spoiler and the body, the team is now able to plug in Eq. (3) into Eq. (5) for the drag forces. Making several rearrangements, the team gets an expression for the top speed of the car when taken into account the drag produced by the wing.

$$v_{max} = \sqrt{\frac{2F_{engine}}{\rho(C_{d(wing)}A_{wing} + C_{d(body)}A_{body})}} \tag{6}$$

With Eq. (6), the team calculated the reduced top speed with an airfoil at angles of attack of 0°, 5°, 10°, and 15°.

With the max cornering speed of the car at different radii of curvature, and the top speed of the car on the straightaway calculated, the team can plug these speeds into the hypothetical track, and examine the difference in lap times. The calculated lap times are shown in Table 2.

Table 2: Calculated lap times of car with and without spoiler, at different angles of attack

Angle of Attack [°]	Lap Time w/o Spoiler [s]	Lap Time w/ Spoiler [s]	Time Lost on Straight [s]	Time Diff. in Corners [s]	Lap Time Difference [s]
0	25.952	25.957	0.008	-0.003	+0.005
5	25.952	25.944	0.017	-0.026	-0.008
10	25.952	25.927	0.035	-0.066	-0.031
15	25.952	25.973	0.110	-0.107	+0.003

From the results of the analysis, it can be seen that the lap times were reduced when the wing was set to 5° and 10°, with the biggest amount of lap time reduction at 10° angle of attack. Therefore, the team can infer that there are performance benefits to installing an airfoil onto the FSAE car, and the optimal angle of attack of the airfoil is 10°.

3.2 Engine Ignition System Timing

3.2.1. Test Overview

This test aims to examine the engine of the race car, a 2015 Yamaha Phazer 499cc 4-stroke. It will ensure its ability to successfully time the ignition of the engine. Getting the spark plugs to fire at the correct time during the 4-stroke cycle is crucial for the engine to start and idle.

3.2.2. Test Objectives

In order to reliably idle the engine, this test's primary goal is to verify that the engine ignition timing is correct. This is done by measuring the correct crank angle degree (CAD) at which the spark plugs fire. Based on internal combustion literature [5], a properly functioning 180°, parallel twin, 4-stroke engine has spark plugs firing 180° difference from each other, and should fire 5° to 10° BTDC of the compression cycle. These tests verify whether the engine is currently set up in this manner, or if changes are needed for the engine tune so that it does match the target values.

3.2.3. Features evaluated

This test is directly examining the ECU tune, and indirectly verifying that the engine components such as ignition coils, spark plugs, injectors, and wiring harness are working properly. Within the tune, there are two critical TunerStudio parameters that control the ignition system timing: *tooth #1 angle* and *fixed/cranking advance*. The *tooth #1 angle* parameter allows the crank sensor to properly ready the piston position. It is one of the most important parameters for the tune of the engine since if it is incorrect, all other parameters will be offset and trigger the engine components at wrong times. The *fixed/cranking advance* parameter simply advances the spark firing a certain amount of degrees.

Since these are the definitions given by the manual [4], it follows that if the *fixed/cranking advance* parameter was set to 0 deg, then the spark plug should fire exactly at TDC of compression **only** if the correct *tooth #1 angle* value is being used. That is, only if the crank sensor reads the correct piston position.

3.2.4. Test Scope and conditions

The test conditions include using a high-quality video camera able to capture the movement of the crankshaft at an engine cranking speed of 600 rpm. Additionally, AutoCAD software was used to properly measure angles based on video analysis. The tests were performed with a fully charged battery at 13 V and the Yamaha engine's ignition system components. The actual engine spark plugs were removed from the engine to be able to measure exact firing in relation to CAD.

3.2.5. Test Plan

Equipment used include: a Sony FX3 camera capable of recording up to 240 fps at a quality of 1080p, Fusion 360 CAD software, and all components corresponding to 2015 Yamaha Phazer 499cc 4-stroke engine.

General internal combustion engine knowledge as well as basic mechanic tools were used to remove the ignition system and understand the 4-stroke cycle of a 180 deg 2 cylinder configuration from analyzing the recorded engine cranking (see Figure 20).

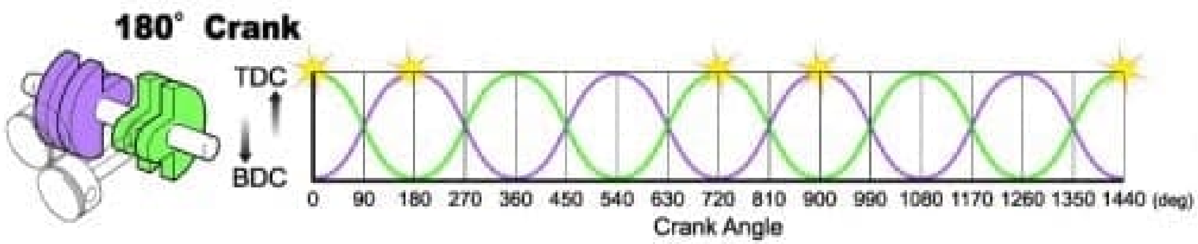

Figure 20: CAD of the pistons of a parallel, two cylinder, 180°-offset crank, four-stroke SI engine, with the time of ignition highlighted

For the ignition system test, a camera was fixed to align with the center of the crankshaft. Engine was set to exactly TDC, and a mark was made at the visible end of the crankshaft (indicating when cylinder 1 was exactly at TDC of compression). Then, the ignition coil and spark plug of cylinder 1 were removed and placed close to the crankshaft in order to record both the crankshaft position, and the firing of spark plug 1. The engine was then cranked, and a video was recorded showing the crank position and the spark. Three different snapshots of the spark plug 1 firing along with its CAD were recorded (see example in Figure 21). The snapshots were analyzed using Fusion 360 to get the CAD measurements. The test was repeated at different engine tunes until the correct CAD was measured.

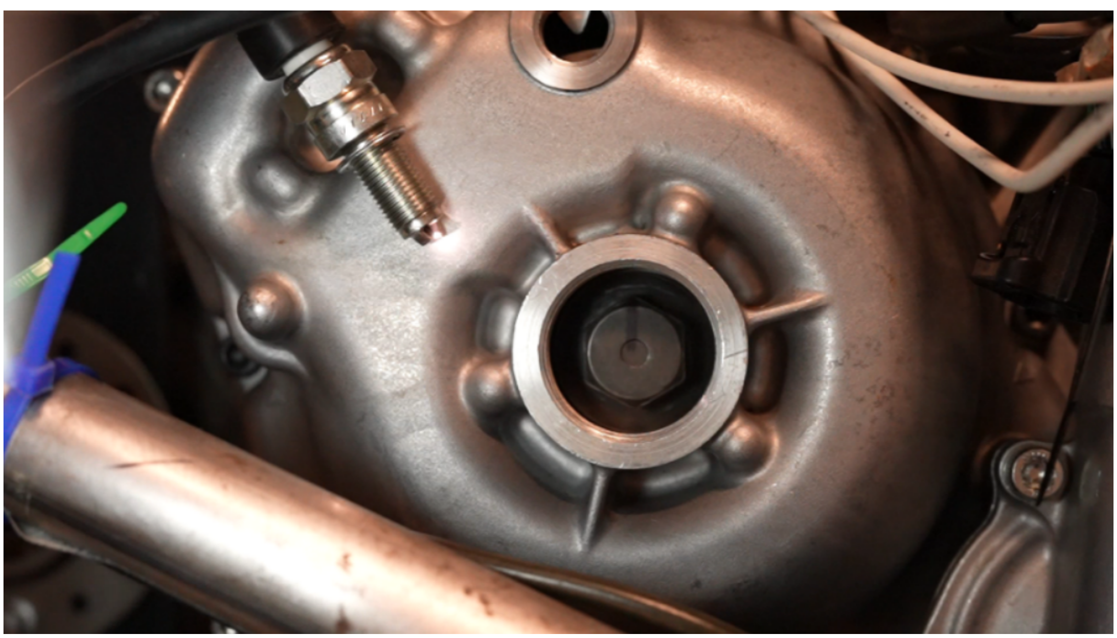

Figure 21: Snapshot of crankshaft end spinning at 600 rpm with spark plug igniting

Some of the assumptions used during this test include:

- The pressure difference between testing the components outside the engine vs inside the engine would not affect the triggering time of the spark plugs.

3.2.6. Acceptance Criteria

Verify that timing parameters lead to ignition at 5-10° before TDC of the compression stroke. This is what I.C.E literature recommends for idling a 4-stroke engine [5]. If the timing of ignition is successfully examined and corresponding changes can be made to the tune file to bring the timing closer to what it should be for the engine to start, this test will be a success.

3.2.7. Test Results and Evaluation

For the initial ignition system testing, 4 different tunes were tested to examine which parameter values lead to the spark plug firing at between 5-10° before TDC of the compression stroke. Table 3 shows the Tunerstudio parameters used and the corresponding CAD before (BTDC) or after (ATDC) top dead center of compression.

Table 3: Parameters set in Tunerstudio and the measured CAD from TDC of ignition

Tune #	Run	CAD to #1 tooth [°]	CAD Adv. [°]	CAD from TDC [°]	Before or After TDC	Average [°]	Data Range [°]
Tune 1	1	40	0	5.8	ATDC	4.6	2.6
	2	40	0	3.2	ATDC		
	3	40	0	4.7	ATDC		
Tune 2	1	25	0	3.7	BTDC	6.3	4.3
	2	25	0	7.2	BTDC		
	3	25	0	8	BTDC		
Tune 3	1	33	0	1.6	ATDC	2.6	2.0
	2	33	0	2.5	ATDC		
	3	33	0	3.6	ATDC		

Tune 4	1	33	8	3	BTDC	3.3	1.9
	2	33	8	1.9	BTDC		
	3	33	8	4.9	BTDC		

Table 3 shows consistency within each tune since all runs of a given set up show either ATDC or BTDC without switching back and forth in a single tune. In addition, the difference between a given tune does not exceed 5 deg. This small difference could be caused by the limitations of the camera to capture the crankshaft. Also, the moment of the snapshot could have been taken at the very beginning of the spark or at the very end. That time difference would have moved the measurement a few degrees and caused differences in the different runs. Tunes 1-3 were intended to approximate the correct value of tooth #1. Since tune 3 results in an average closest to TDC, it is the best value to use for tooth #1. Tune 4 adds on 8° of advance to ensure that the firing is happening at least 3° BTDC.

With this data, the team is able to determine that Tune 4 of ignition will fall within the objective of setting the adequate spark timing. Since tune 4 only reaches 3.3° BTDC, it is suggested to increase the advance to 10-12°, to further push the sparking to the goal of 5-10° BTDC.

Result: Success

3.3 Engine Injection System Timing

3.3.1. Test Overview

This test aims to successfully time the fuel injection of the engine which is also an important step in getting the engine to idle.

3.3.2. Test Objectives

In order to reliably idle the engine, this test's primary goal is to verify that the engine injection timing is correct. This is done by measuring the correct crank angle degree (CAD) at which the injectors fire. Based on internal combustion literature [5], a properly functioning 180°, parallel twin, 4-stroke engine has injectors firing 10° to 20° BTDC of the intake stroke.

These tests verify whether the engine is currently set up in this manner, or if changes are needed for the engine tune so that it does match the target values.

3.3.3. Features evaluated

Within the tune, there is one TunerStudio parameter that controls the injection system timing: the *fixed/cranking timing*. This parameter tells the injectors when to trigger in relation to TDC of the compression stroke. In order to get the correct injection timing, the previous ignition timing parameter (*tooth #1 angle)* must have been obtained. Only if this last parameter has been correctly obtained from the previous ignition test can Tunerstudio read the correct CAD and therefore give the correct *fixed/cranking timing* value

3.3.4. Test Scope and conditions

The test conditions include using a high-quality video camera able to capture the movement of the crankshaft at an engine cranking speed of 600 rpm. Additionally, AutoCAD software was used to properly measure angles based on video analysis. The tests were performed with a fully charged battery at 13 V, an LED in parallel with a 10kΩ resistor to simulate the injector load. This LED will then light up at the same time as when the fuel injector receives a signal to inject fuel, allowing for the injection timing to be visualized. The actual engine spark plugs were removed from the engine to be able to measure exact firing in relation to the fuel injection.

3.3.5. Test Plan

Equipment used include: a Sony FX3 camera capable of recording up to 240 fps at a quality of 1080p, Fusion 360 CAD software, and all components corresponding to 2015 Yamaha Phazer 499cc 4-stroke engine. Some basic soldering techniques were needed to make the LED and 10kΩ resistor circuit for simulating the injectors.

The injection testing involved a similar process to the ignition testing but with the cylinder 1 injector instead of spark plug 1. Injector 1 was detached from the wiring system and a LED and resistor combination was placed in its position instead. The LED was then placed close to the center of the crankcase in order to record both its position and the firing of the LED (simulating injector 1). The engine was then cranked, and a video was recorded showing the crankshaft position and the injection. Three different snapshots of the LED firing along with its CAD were recorded. The snapshots were analyzed using Fusion 360 to get a precise CAD (see example in Figure 22). The test was repeated at different engine tunes, until the correct CAD was measured.

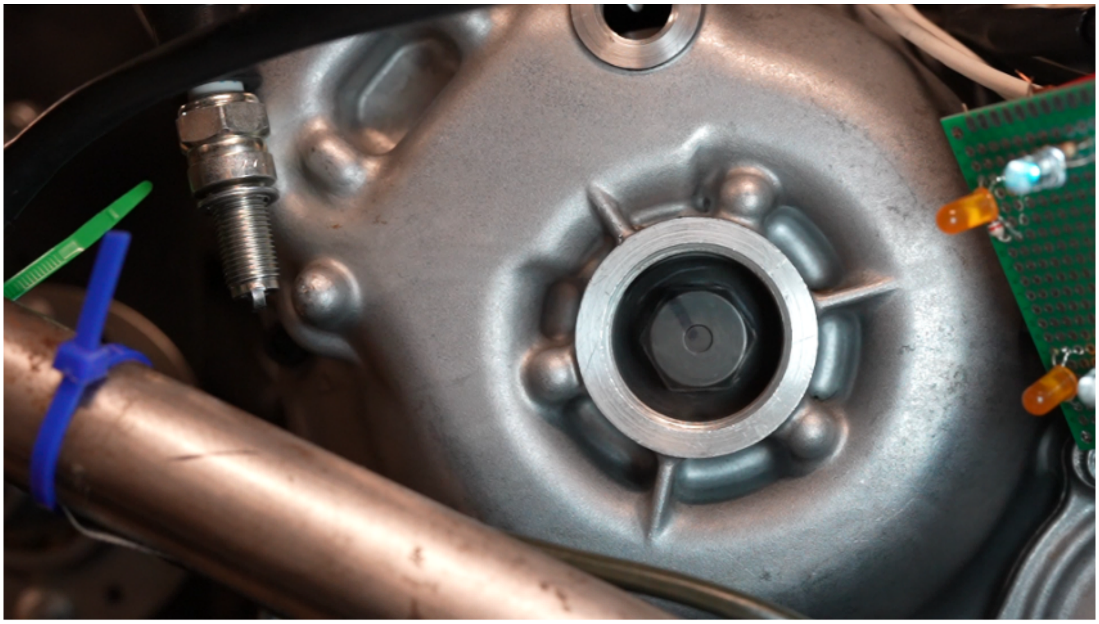

Figure 22: Snapshot of crankshaft end spinning at 600 rpm with LED turning on representing injector 1.

Some of the assumptions used during this test include:

- The pressure difference between testing the components outside the engine vs inside the engine would not affect the triggering time of the injectors.
- The LED and 10kΩ resistor adequately represent the injector and its resistance to the incoming signal

3.3.6. Acceptance Criteria

Verify that timing parameters lead to injection at 10-20° BTDC of the intake stroke. This is what I.C.E literature recommends for idling a 4-stroke engine [5]. If the timing of fuel injection is successfully examined and corresponding changes can be made to the tune file to bring the timing closer to what it should be for the engine to start, this test will be a success.

3.3.7. Test Results and Evaluation

For the injection system testing, 3 different parameters were tested to examine which parameter values lead to injection firing 10-20° before TDC of the intake stroke. Table 4 shows the parameters used and the corresponding CAD before (BTDC) or after (ATDC) top dead center of intake. Note that the crankshaft passes TDC twice every 4-stroke cycle. For injection the optimal time is 10-20° before TDC of intake. To distinguish which TDC has just passed, the team observed the spark plug since it sparks at close to TDC of compression. That way, the team is able to know that the injector is firing BTDC of intake or BTDC of compression.

The corresponding tunes are within 2.4% of their measured value. This confirms that the parameter "Fixed/Cranking Timing" parameter allows the team to set the CAD for injection relative to TDC compression. Note that Tunerstudio interprets 0° as the beginning of power stroke, making 380° equal 20° BTDC of intake stroke (Figure 4 helps visualize the 4-stroke cycle). The negligible error also confirm the validity of the *tooth #1* value equal to 33°, since the ECU is reading the correct crank position to inject fuel.

Table 4: Comparing parameter value inputted in Tunerstudio and measured injection timing

Tune #	Run	Fixed Injection Timing [°]	CAD from TDC of Compression [°]	Percent Error [%]
Tune 1	1	330	328.2	-0.55%
	2	330	332.8	0.85%
	3	330	334.7	1.42%
Tune 2	1	700	696.1	-0.56%
	2	700	698.4	-0.23%
	3	700	699.6	-0.06%
Tune 3	1	166	167.1	0.66%
	2	166	164.0	-1.20%
	3	166	162.0	-2.41%

With this data, the team is able to determine that switching the *fixed/cranking timing* tune parameter to 380° BTDC of compression will fall within the objective of setting the adequate injection timing. Setting the injection timing to 380° BTDC of compression matches the objective of 10-20° BTDC of intake.

Result: Success

4. Discussion and Future Work

With senior year coming to a close, the team can confidently comment on the internal dynamics which enabled the team to achieve the milestones discussed in this report. It became clear from the get go that the FSAE car had a wide array of problems so the decision as to where to focus the team's main efforts was an important first step to make. The team observed and learned throughout the course of the year that a collective meeting of all members to discuss and debate which issues to tackle was an absolute necessity. With the team on the same page, sub groups of two and three were then created and assigned to handle the individual improvements. For example in the first semester, two members were assigned to focus their attention on the suspension, while three others were assigned to handle the wire harness fabrication. The selection of how to divide up the groups was based on individual interest, experience, and personal satisfaction. The team was able to function well as a unit and avoid conflict since most decisions were made collectively and each individual's desires were taken into account. This style of open communication, discussion, and decision making made for a smooth year and the team highly recommends this sort of interaction continue not only for future FSAE design teams, but for TUMS as well.

With this stated, the current design team also has recommendations on the Future of the FSAE car. This year’s tests involving the injection and ignition engine timing have concluded that, despite the engine not idling, the spark and fuel injector timing is not the problem. It is recommended that the next team look into the engine valves and whether they are functioning properly. It is likely that multiple years of cranking the engine with a wrong timing tune would have caused damage to the intake and exhaust valves, causing other unknown difficulties in the startup procedure.

5. Conclusion

This year’s team has primarily focused on fixing the physical problems with the previous wire harness, the suspension cam, and the engine tuning for startup. The first issue that became apparent was the wire harnesses dire need for complete redesign. This took up a large portion of the first semester. After conducting research on the proper design and fabrication of automotive wire harnesses, the team was able to successfully fabricate and install a new, durable, and functional wire harness. The team also installed a fuse box and ECU mount. The suspension was also improved by modifying control arms to create negative camber. Significant progress was also made on the engine tuning. This took up much of the second semester as the team researched and conducted several tests on the engine in order to increase the likelihood of ignition. Although the team made significant progress towards getting the car ready for the race, this year's team did not meet several of the design requirements. Unfortunately, these requirements can only be met when the car is able to drive under its own power, something the car can not yet do at the writing of this report, therefore, there was no way to test for these requirements. For future work, it is recommended to continue tuning the engine so it not only idles, but also is able to perform properly in a racing environment. The radiator should be repositioned in a better location to get proper airflow for cooling the engine at higher speeds. The exhaust system should be modified to incorporate a muffler that reduces the engine dB noise level to the Formula SAE standards. Also, body panels should be painted, and a secure seat should be mounted following Formula SAE standards. Once the engine is running properly, the next FSAE team would primarily focus on running tests during racing conditions. Testing the brake, suspension, and new radiator positioning while the car is running would help understand which systems are adequate for racing and which need to be redesigned because they fail during testing.

Appendices

The most important piece to understanding how to tune an engine is to understand the basic concepts of how an 4 stroke internal combustion engine works. Seen below is an effective inauguration into internal combustion engines along with at what particular crank degree angles that each stroke occurs at.

The first stroke, the intake stroke, occurs as the piston moves downward from the top of the cylinder to the bottom. This stroke is typically timed to occur between 0 and 180 degrees of crankshaft rotation, depending on the design of the engine.

The second stroke, the compression stroke, occurs as the piston moves upward from the bottom of the cylinder to the top. This stroke is typically timed to occur between 180 and 360 degrees of crankshaft rotation, again depending on the engine design.

The third stroke, the power stroke, occurs as the piston is pushed downward by the explosion of the air and fuel mixture inside the cylinder. This stroke is typically timed to occur between 360 and 540 degrees of crankshaft rotation, again depending on the engine design.

Finally, the fourth stroke, the exhaust stroke, occurs as the piston moves upward from the bottom of the cylinder to the top, pushing the exhaust gasses out of the cylinder and through the exhaust system. This stroke is typically timed to occur between 540 and 720 degrees of crankshaft rotation.

The precise timing of each stroke is critical to the efficient operation of the engine, and it is controlled by the engine's camshaft and timing belt or chain. By carefully adjusting the timing of the camshaft, it is possible to optimize the engine's power output, fuel efficiency, and emissions performance. Seen below in Figure AA is a diagram showing each of the engine strokes. For more information on the intake and compression strokes, which are the two most important strokes in terms of tuning the engine. The team recommends reading the engine subsystem section 2.2.

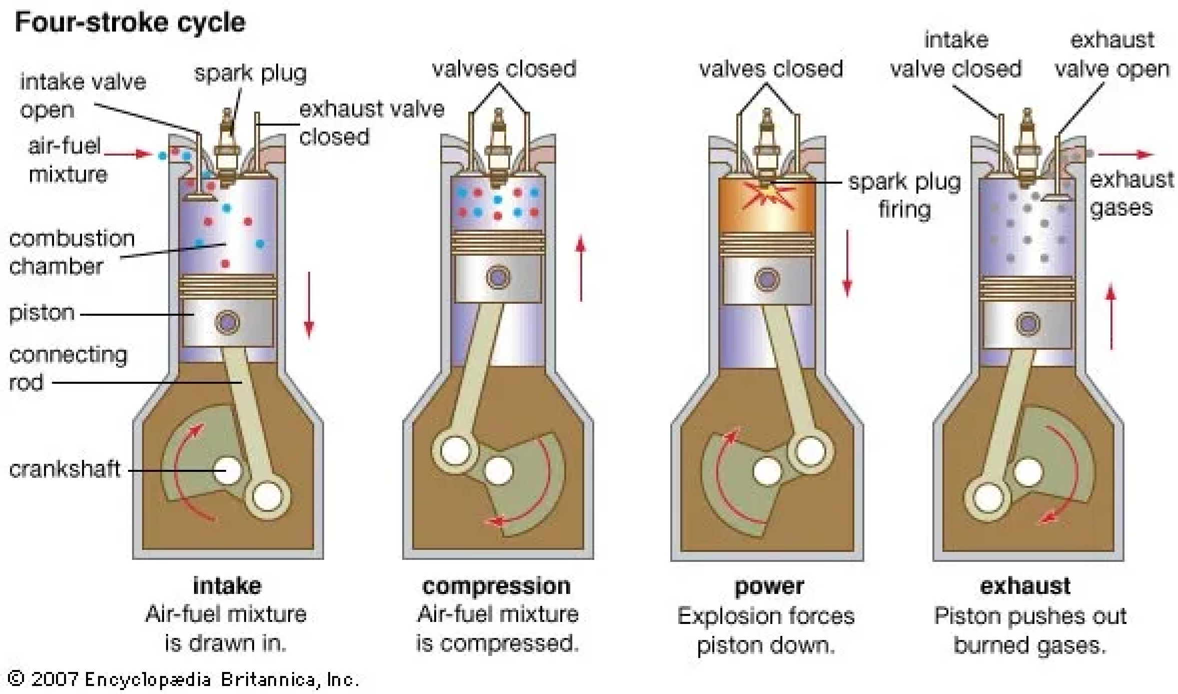

Figure AA: 4 Stroke Internal Combustion Engine

Tuner Studio is a popular tuning software used by automotive enthusiasts and professionals to tune and optimize the performance of various types of engines. It was developed by Phil Tobin, founder of EFI Analytics, and is compatible with a wide range of engine management systems, including MegaSquirt, MicroSquirt, and MSPNP. *This team uses the Megasquirt MS2 V3.* The software allows users to customize and adjust engine parameters such as fuel injection, ignition timing, and engine idle speed, among others. It also includes a range of features that enable users to monitor and log engine performance data, as well as perform diagnostic tests to identify any issues that may be affecting engine performance. Seen below are the TunerStudio parameters. A color scheme was used on all the variables, the variables highlighted in green are variables the team aren't sure are correct, the variables highlighted in blue are the variables the team has made a good estimation of, and finally the variables in red are variables that are largely unknown and are complete guesses.

Lastly, the team team performed multiple tests on the engine such as an injector timing test, first tooth test, tooth #1 cranking advance, dead timing testing for spark plug, and dead time testing for the injectors. How to perform these tests are detailed in sections 3.2 through 3.3. Along with the test plans there is the data from the experiments. The team believes that the test results are successful and can be used to further tune the engine. However, if the new team is struggling with getting the engine to start it would be beneficial to perform these tests again.

Seen below is the tuning parameters that the team used along with the coloring system provided:

UNCLEAR	REASONABLE ESTIMATE	CONFIDENT

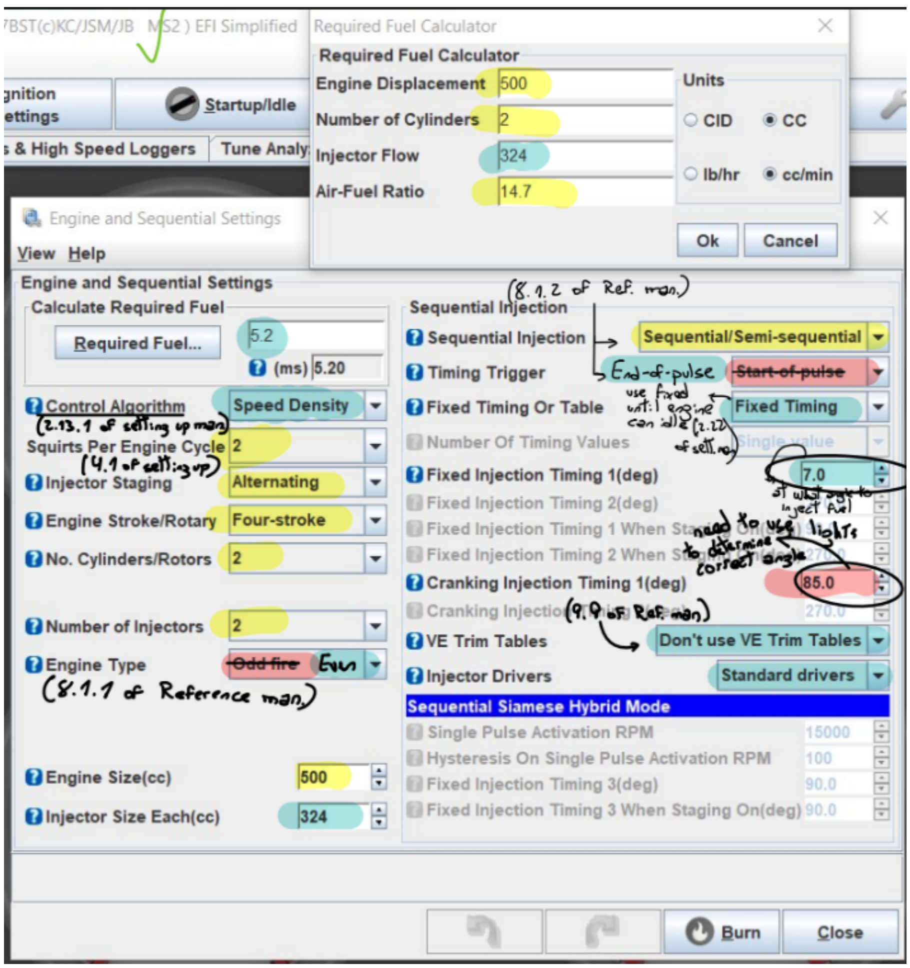

Figure A: Engine and Sequential Settings Page in TunerStudio

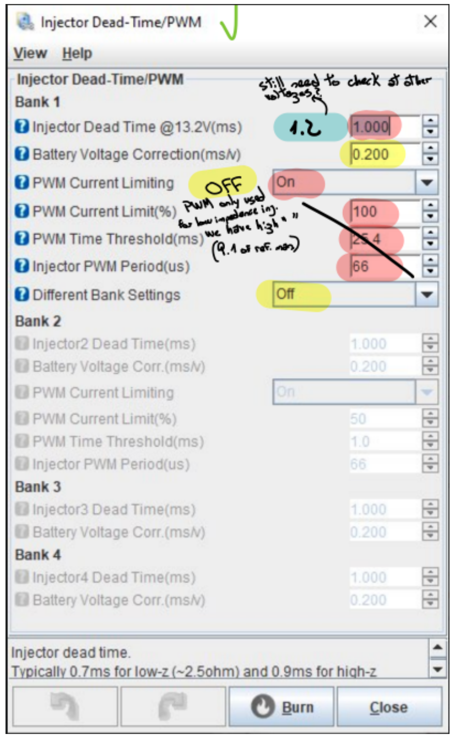

Figure B: Injector Dead Time Setting Page in TunerStudio

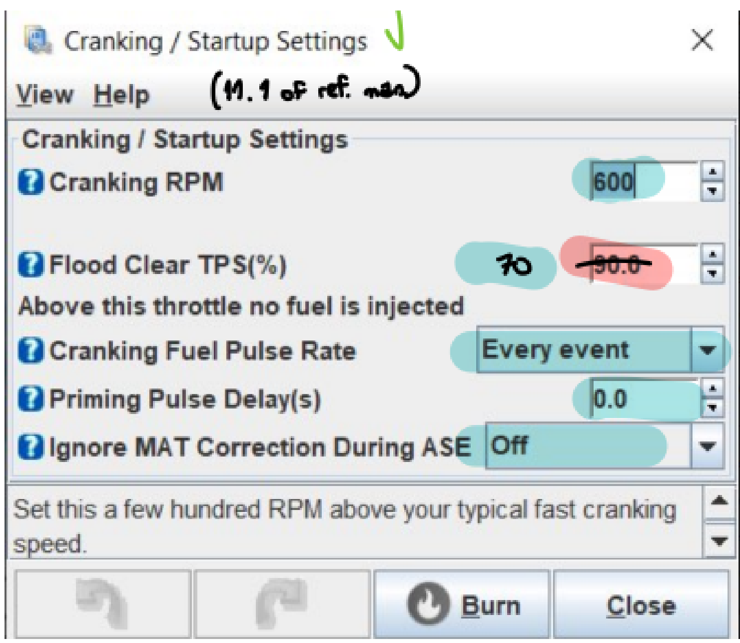

Figure C: Cranking and Startup Settings Pages in TunerStudio

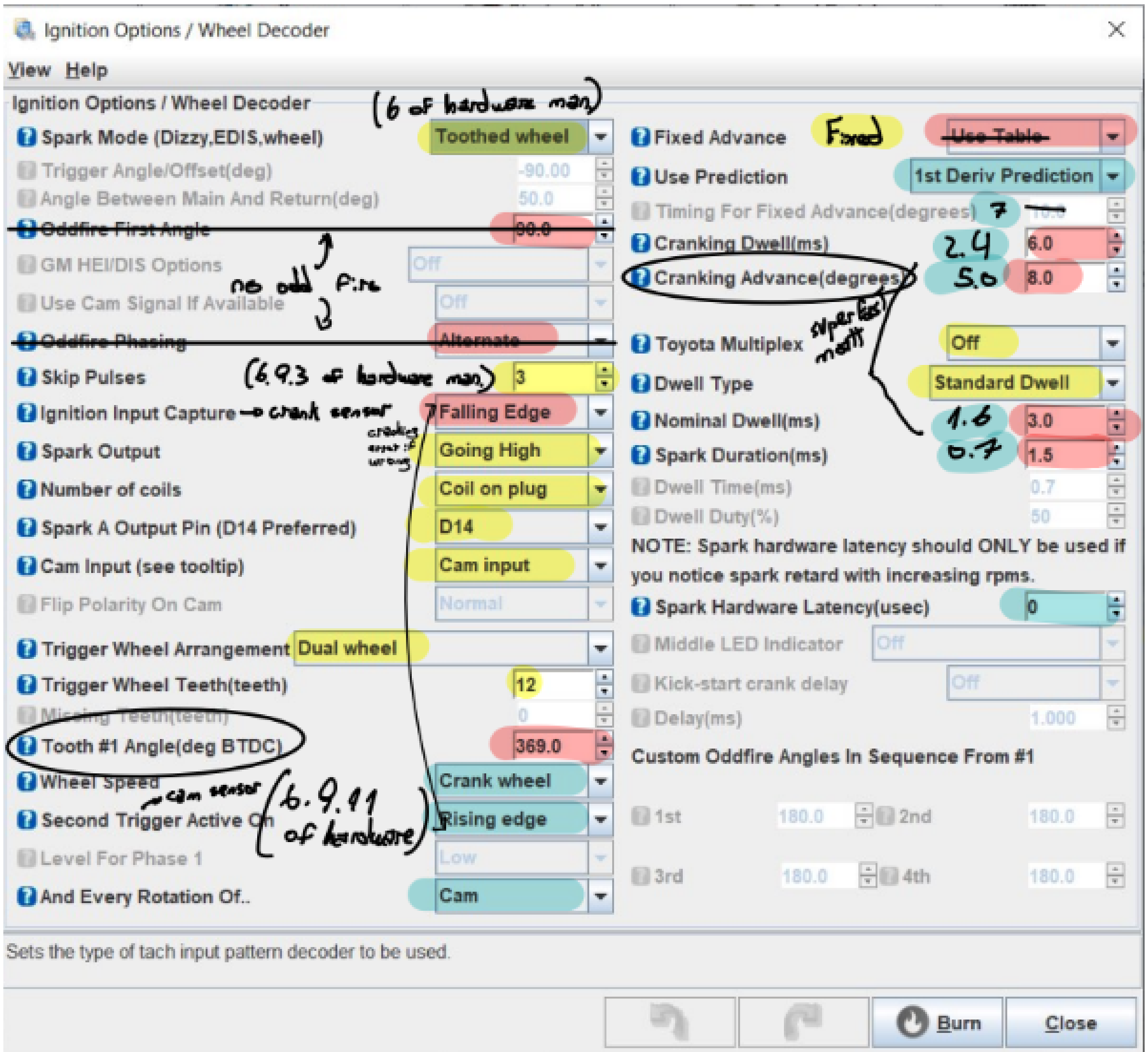

Figure D: Ignition Options and Wheel Decoder Settings Page in TunerStudio

Our team identified the four most parameters that being Cranking Advance(degrees), Tooth #1 Angle(deg BTDC), Fixed Ignition Timing 1(deg), and Cranking Injection Timing 1(deg). These parameters are circled in Figure A and D.

The cranking advance parameter in TunerStudio refers to the amount of ignition timing advance that is applied to the engine during the cranking phase, which is the period when the engine is being started and the crankshaft is rotating but the engine is not yet running. The cranking advance parameter is typically set to a value that provides the best balance between engine starting performance and minimizing the risk of engine damage due to excessive engine knock or detonation. The exact value of the cranking advance parameter can vary depending on the specific engine, its fuel and ignition system, and the ambient conditions in which it is being operated.

In general, the cranking advance parameter should be set to a value that provides enough ignition timing advance to ensure that the engine starts quickly and smoothly, without excessively cranking or flooding. At the same time, the cranking advance parameter should not be set too high, as this can increase the risk of engine knock or detonation, which can cause damage to the engine. TunerStudio allows users to adjust the cranking advance parameter based on their specific engine and operating conditions. This can be done by adjusting the ignition timing advance table, which allows users to set different ignition timing values for different engine speeds and loads. By carefully tuning the ignition timing advance table, it is possible to optimize engine performance and reliability during the cranking phase and throughout the entire operating range of the engine.

The Tooth #1 Angle parameter in TunerStudio refers to the angle of the first tooth on the engine's crankshaft position sensor. This parameter is used to tell the engine management system the position of the crankshaft relative to the timing of the ignition and fuel delivery. In most engines, the crankshaft position sensor is a Hall effect or magnetic sensor (Our engine has an Hall Effect sensor) that detects the position of teeth or gaps on a rotating wheel attached to the crankshaft. The Tooth #1 Angle parameter specifies the angle at which the first tooth on this wheel is located relative to the top dead center (TDC) position of the engine's piston. By specifying the correct Tooth #1 Angle in TunerStudio, the engine management system can accurately determine the position of the crankshaft and control the timing of the ignition and fuel delivery accordingly. This is important for optimizing engine performance, fuel efficiency, and emissions, as well as preventing engine damage due to detonation or misfiring. If the Tooth #1 Angle is set incorrectly, it can cause inaccurate ignition and fuel delivery timing, which can lead to poor engine performance and potential engine damage.

The Fixed Ignition Timing parameter in TunerStudio refers to a user-defined ignition timing value that is used by the engine management system to set a fixed timing for the engine's ignition system. This is typically used in situations where the engine management system is not able to control the ignition timing directly, such as with simpler engine management systems.

The Fixed Ignition Timing parameter is set as a static value in degrees before top dead center (BTDC) and is used by the engine management system to set the ignition timing to a fixed value throughout the entire operating range of the engine. This can be useful for basic tuning and testing, or for engines with a fixed mechanical distributor that cannot be controlled by an electronic engine management system. It is important to note that the Fixed Ignition Timing parameter is not a dynamic or adaptive value like the ignition timing tables used in modern engine management systems. It is a static value that does not change based on engine load or speed, and therefore may not provide optimal performance or efficiency in all operating conditions.

The Cranking Injection Timing parameter in TunerStudio refers to the timing of the fuel injection pulse during the engine cranking phase, which is the period when the engine is being started and the crankshaft is rotating but the engine is not yet running. During cranking, the fuel injection timing is critical for ensuring that the engine starts quickly and smoothly, without flooding or excessive cranking. The Cranking Injection Timing parameter allows the user to adjust the timing of the fuel injection pulse relative to the position of the crankshaft and the ignition timing. The Cranking Injection Timing parameter is typically set to a value that provides the best balance between engine starting performance and minimizing the risk of engine damage due to excessive fuel enrichment or detonation. The exact value of the Cranking Injection Timing parameter can vary depending on the specific engine, its fuel and ignition system, and the ambient conditions in which it is being operated.

In general, the Cranking Injection Timing parameter should be set to a value that provides enough fuel enrichment to ensure that the engine starts quickly and smoothly, without excessively cranking or flooding. At the same time, the Cranking Injection Timing parameter should not be set too high, as this can increase the risk of engine knock or detonation, which can cause damage to the engine. TunerStudio allows users to adjust the Cranking Injection Timing parameter based on their specific engine and operating conditions. This can be done by adjusting the fuel injection timing table, which allows users to set different fuel injection timing values for different engine speeds and loads. By carefully tuning the fuel injection timing table, it is possible to optimize engine starting performance and reliability during the cranking phase and throughout the entire operating range of the engine.

Just like with the current team and the teams before, using the manufacturer's manuals is the most effective way of getting correct and important information, but with this design manual the team hopes to set up the next FSAE team with a solid foundation to getting the Formula SAE car to competition.

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