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Formula SAE: Final Design Report

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Executive Summary

In 2016, Trinity University Motorsports (TUMS) and a senior design team started Trinity's path to compete in Formula SAE. Since then, preparing the car for competition has been the objective of the project. The work that was done before this year's team took over included the design and fabrication of the frame, selection and mounting of the engine, and some progress on each of the following: steering, suspension, wheels and tires.

This year, the team was tasked with delivering a fully functional car with the hopes of being able to compete in the June, 2020 FSAE California Competition. To meet this goal, the major work items remaining were the design and implementation of the following subsystems: cockpit, ECU, and powertrain. In addition to those tasks, this year's team had to improve and complete the steering, suspension, wheels, and braking. Finally, all of these subsystems needed to be integrated together to achieve a driveable car.

This year, significant progress was made toward completing the car. Unfortunately, work came to a halt in March with the announcement that Trinity University was closing down due to COVID-19. Since the closure of campus, our project requirements have changed from delivering a functional car to delivering documentation that will allow next year's team to compete in next summer's competition. This new goal required the current team to write four manuals to be provided for the next team as appendices to this report. The manuals are as follows: Test Plan Manual, which outlines what tests the next team should perform and provides an overview of why and how to perform them; Test Results and Analysis Manual, which gives detailed instructions regarding the test setup and execution, as well as the collection and analysis of data; Assembly Manual, which provides step-by-step instructions on how to finish the remaining assembly tasks for the car; Competition Manual, which is a brief summary of our advice and recommendations for how to prepare for the competition.

The work that this year's team was able to complete brought us very close to obtaining a functional car. This year, the team successfully redesigned and implemented the rear suspension so as not to get in the way of the axle. Alignment bars were then installed to keep the rear tires oriented straight ahead. The team planned and assembled the brake lines such that all that is left is to mount the calipers onto the rotors and fill the brake fluid reservoirs. The steering system was redone in order to satisfy FSAE guidelines, which state that the top of the steering wheel must be below the top of the front hoop of the frame. This required a new steering column mount be designed and fabricated as well as moving the rack and pinion mounts further toward the front of the car. A metal seat pan was designed and fabricated which also acts as a firewall, and a temporary seat was fashioned out of foam. The pedal assembly was mounted to the floor of the car, and the brake pedal was connected to the brake lines while the accelerator pedal was connected to the throttle cable. Intake and exhaust systems were designed, fabricated, and implemented successfully onto the car. A speedometer was made using an arduino and a magnetic tachometer sensor. Finally, the team assembled most of the powertrain as well as the ECU and wiring harness.

There is still some work remaining for the next team. These future tasks include installing a seat, optimizing the cockpit and dashboard, finishing the ECU/powertrain integration, mounting the brake calipers to the rotors and connecting them to the brake lines, and extensive testing and driver training.

1 Introduction

Formula SAE is an international collegiate competition organized by the Society of Automotive Engineers. Students are offered the opportunity of designing and manufacturing an open wheel Formula-style car and competing in both static and dynamic events. Formula SAE has evolved from a domestic event in the U.S. to an international competition throughout the world being held by countries in Europe and Asia. Trinity University has not participated in the competition prior to its initiation 2016. All the previous senior design teams have yet to finish a working car given their two semester time constraints. The work that was done before this year's team took over included the design and fabrication of the frame, selection and mounting of the engine, and some progress on each of the following: steering, suspension, wheels and tires.

This year, the team was originally tasked with delivering a fully functional car with the hopes of being able to compete in the June, 2020 FSAE California Competition. Competing was not a project requirement, but a desire shared by the members of this year's team. To meet the project requirement of delivering a functional car, the major work items remaining were the design and implementation of the following subsystems: cockpit, ECU, and powertrain. In addition to those tasks, this year's team had to improve and complete the steering, suspension, wheels, and braking. Finally, all of these subsystems needed to be integrated together to achieve a driveable car. The car had to conform to all of the applicable standards described in the Formula SAE competition rulebook. The team planned the following tests to measure whether the car met several of the major standards: steering system freeplay test, skidpad event test, speedometer accuracy test, and ECU functionality test.

However, due to the unexpected outbreak of COVID-19, these tests could not be done, and the original project goals had to be revised. While significant work had been done and the car was nearly operational, the new project requirement became to provide all of the documentation necessary to enable the next team to finish the car and compete in next summer's competition. This involved the creation of a Test Plan Manual and Test Results Analysis Manual in which the current team provides detailed instructions for the next team regarding what tests to run, how to perform them, what data to collect and how to collect it, and how to analyze the data to determine whether a test was successful or not. The current team also had to provide an Assembly Manual detailing every remaining assembly task for the car to be finished, as well as a Competition Manual which provides advice and recommendations for the next team to prepare for the competition. All of these manuals are included in this report as Appendices.

2 Overview of Final Design

2.1 Seat

The design of the seat must abide by the Formula SAE 2020 Rules. In the design of the cockpit sections V.2.1, V.2.2, F.5.5, T.1.1, T.1.2, IN.9.2 and IN.5 were taken into consideration. Section V covers the driver requirements; section F.5 covers the chassis requirements; section T.1 goes over the technical aspects of the cockpit and section IN.5 covers the driver cockpit inspection the judges will conduct at competition. The general concern of each section is to have a cockpit that is able to accommodate both the 95th percentile male (6'11'' and 217 lbs)and 5th percentile female (5' and 110 lbs). Such as the driver having an adequate field vision and minimal head clearance in respect to the main hoop of the chassis. Overall these standards and rules are mandated to ensure the safety and comfort of the driver. Section T.1 of the rules directly governs the standards for the cockpit. In section T.1, sizing templates are given to use for ensuring that there is enough space in the cockpit. The templates are given in Figure 2.1.1 and 2.1.2.

We also considered how the cockpit will be integrated with the remaining subsystems such as powertrain, drivetrain and brakes. In the powertrain, the engine, the intake, exhaust, transmission, oil tank and the coolant system are found. This leaves little to no space for any of the remaining components such as the battery, fuel tank and ecu. Then there should be no direct line of sight between the driver and any dangerous component in the powertrain. This regulation is required for the possibility of hot coolant splashing on the driver. The last concern for the cockpit regarding the powertrain is the heat from the engine and the oil. Thus a firewall was needed to prevent heat propagation from the powertrain to the driver. In the drivetrain we plan on using a mechanical throttle control, where the position of the accelerator pedal controls the throttle body through a mechanical linkage. In the brake system, the position of the pedals will depend on the size of the driver. Therefore, when designing the cockpit, we considered space, line of sight, heat and positioning.

In order to design the seat of the driver, extensive rule reading and research was done. The initial research was done on other university teams with more experience. It was found that most teams either used a seat pan design with replaceable seat inserts or a carbon fiber mold seat, as shown in Figure 2.1.3. Both designs are implemented to give the driver the most comfortable and ergonomic position. It was found that the carbon fiber seat weighs less and is more resistant to deformation after repeated use. Although the carbon fiber was the better option, it was much more expensive and time consuming to fabricate. The team also considered buying a seat as there is no direct rule prohibiting it. The problem with a bought seat was that it takes up space, does not accommodate both drivers and would give an unfavorable center of gravity. In the end the most favorable option was found to be the seat insert, as it was a recommendation from the TUMS president, Antonio Domit, who has experience in motocross racing. His opinion also had weight because he was going to be one of the test drivers.

The team further researched for the cockpit seat, by looking more into driver ergonomics. It was also found important to consider the weight distribution of the car to optimize center of gravity. We initially tested the seat bought by the previous team, by sitting on it while in the cockpit, shown in Figure 2.1.4. We also noticed that the position of the body is dependent on the placement of cockpit components such as the pedals and seat. We later found research done by

NASA on the neutral body posture. The neutral body position was found by astronauts when they were put in a resting position in space, as shown in Figure 2.1.5. In the research it was found that a neutral body position is the closest comfortable position that maximizes productivity. The research helped us realize the importance of angles and position of the body. Using the research from NASA and the size constraint from the cockpit, a driver position close to the neutral body position was found as shown in Figure 2.1.6.

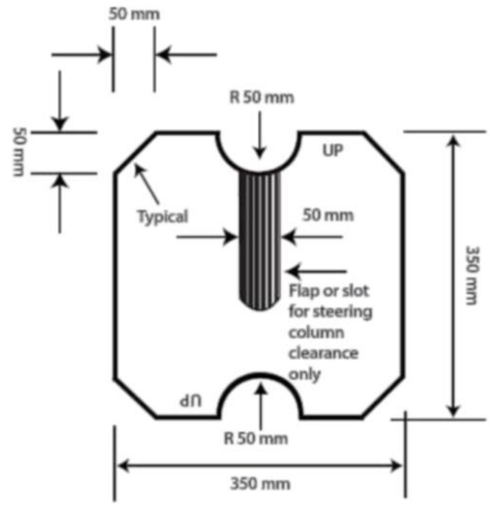


Figure 2.1.1 Template for the internal cross section pertaining to section T.2.1

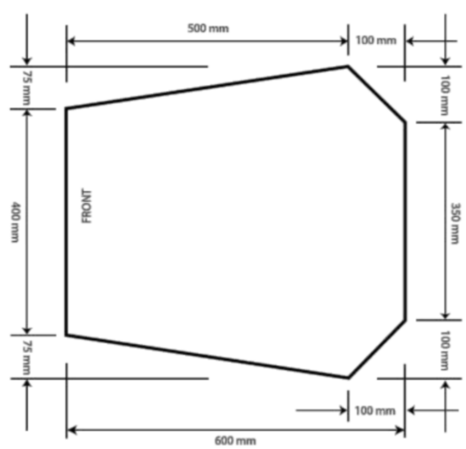


Figure 2.1.2 Template for the cockpit opening pertaining to section T.1.1

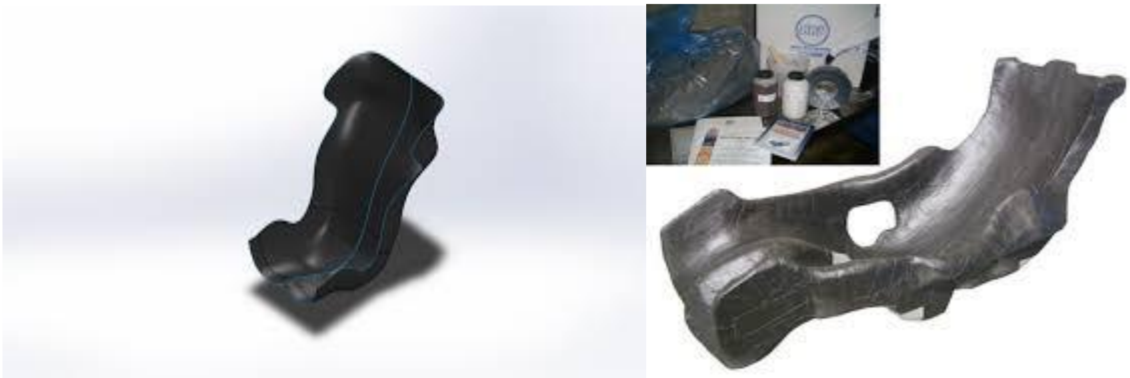


Figure 2.1.3 Carbon fiber seat (left) and creafoam seat insert (right).

Figure 2.1.4 Jegs bucket seat purchased from previous year

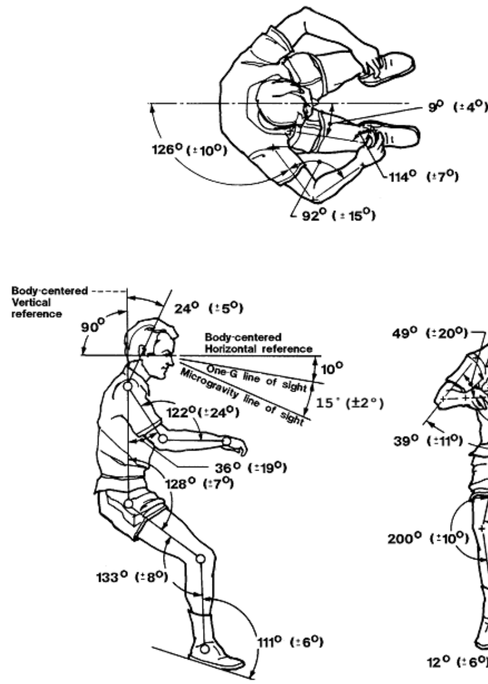


Figure 2.1.5 NASA study of neutral body position

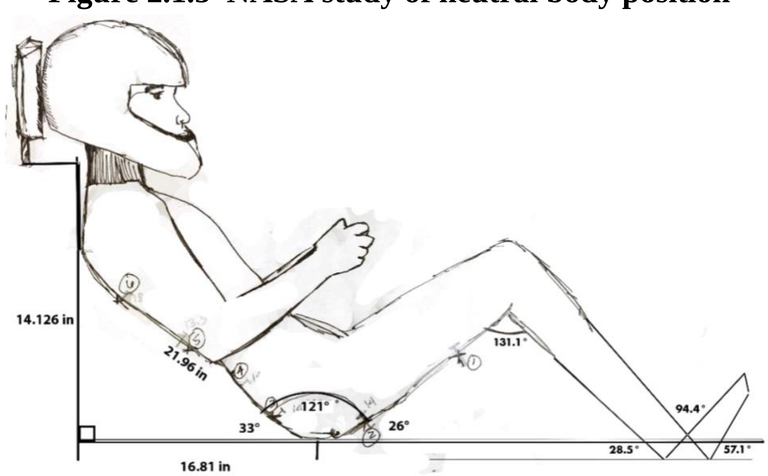


Figure 2.1.6 Driver position in cockpit near neutral body position

Then finally we considered the height of the driver sitting down as it is correlated with the center of gravity. It is favorable to have a low center of gravity as it would keep the car stable when driven. It is also important to consider the center of gravity because the Tilt Test of IN.9.2 is dependent on it. In the Tilt Test, the car will be tilted at an angle of 60° to the horizontal with the tallest of the two drivers seated in it. The 60° angle corresponds to 1.7g. Thus a lower center of gravity is not only favorable but also required by FSAE as well.

The seat pan and seat insert design was chosen for the cockpit. The seat pan satisfies all the FSAE rules, allows for an approximate neutral body position, and achieves a low center of gravity (considering the 95th percentile male). Then seat inserts can be made for both drivers to accommodate and are easy to fabricate. Where the seat pan was fabricated to the dimensions of the 95th percentile male. In competition, during inspection a 95th percentile model (PERCY model) will be implemented to test our cockpit design as shown in Figure 2.1.7. Teams are permitted to move any easily removable seat components for the test. Seat inserts are recognized as easily removable seat components by judges at competitions. The seat inserts can be added onto the seat pan, to give the driver an ergonomic and comfortable fit.

A seat pan was first modeled using Fusion 360 as seen in Figure 2.1.8 and 2.1.9. The most accommodating seat for both drivers was found to be at an angle of 50° to floor closeout. The seat pan then bends 110° for it to connect to the headrest bar on the chassis. In concern of the safety of the driver side panels were added to connect to the chassis at an angle. The seat pan was then fabricated and is shown in Figure 2.1.10. The bend angle of the seat pan was changed to 160°. It was changed because the headrest position was changed because the intake system was found to occupy more space than expected.

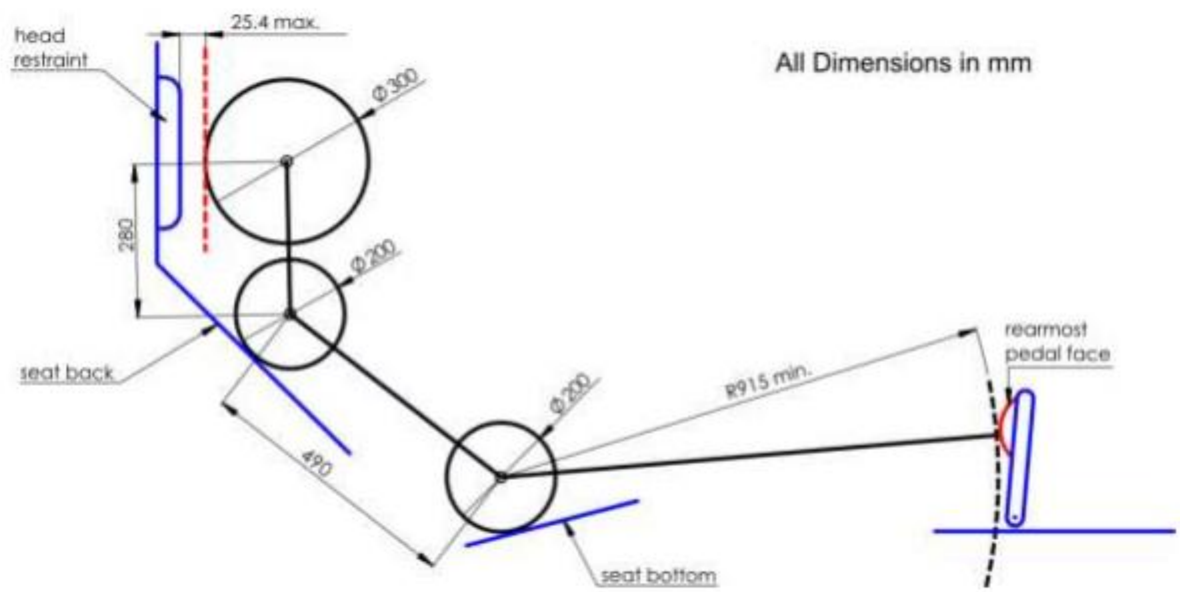


Figure 2.1.7 PERCY position model

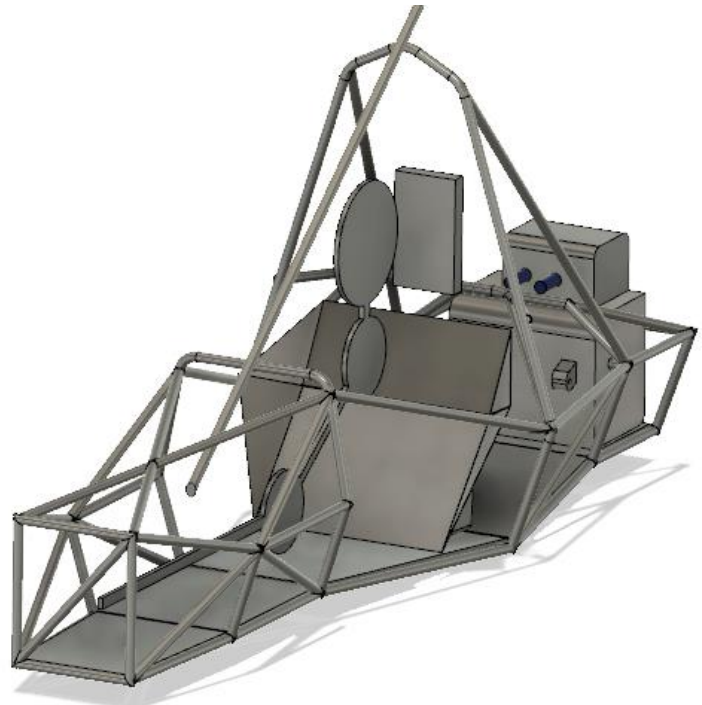


Figure 2.1.8 Isometric view of the PERCY model fit to the seat pan

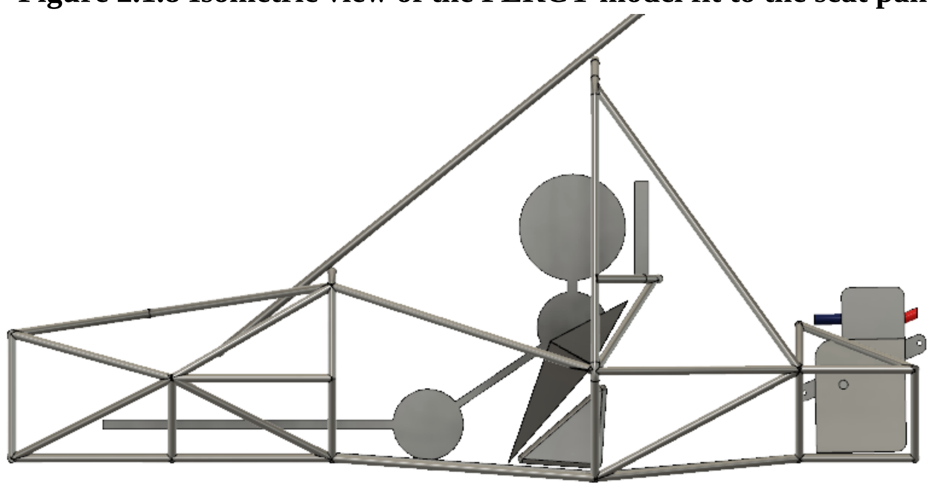


Figure 2.1.9 Side view of the PERCY model fit to the seat pan

Figure 2.1.10 Seat pan prototype

2.2 Instrument Panel and Speedometer

The instrument panel consists of a dashboard that will serve as a user interface for the driver. The instrument panel furthermore consists of a speedometer display, engine and fuel tank sensors, and a possible attachment section for a wireless communication system. The speedometer will ensure the driver adheres to on-site speed limits described in FSAE rules GR.2.4.4 and dynamic events. The instrument panel will be designed to fit a space in the cockpit located between the steering wheel and front bumper of the car. This will ensure the driver has a direct view of the speedometer and sensors while being able to control the car. Its framework will be mounted on the Front Hoop in the cockpit according to FSAE rule F.5.9 as shown in Figure 2.2.1. A cockpit master switch will also be placed on the instrument panel in order to adhere to IC.8.4.4.

The decision matrix focused on the instrument panel selected an Arduino based model for speed display. Using various Arduino parts available at Trinity University, the FSAE team were able to build an LCD display screen capable of displaying the speed readings for the driver as seen in Figure 2.2.2 using a Parallax LCD. The team researched a switch-magnetic reed as an alternative for measuring speed that changes its input value when its magnets align. It would be built similarly using an Arduino board and will send its readings to the LCD screen through the circuit designed in Figure 2.2.3. The design became the final choice after the photoresistor model was weighed against the reed switch. This speedometer design was constructed and completed during the Christmas break and tested during the spring semester. More tests will have to be completed to ensure optimum working conditions.

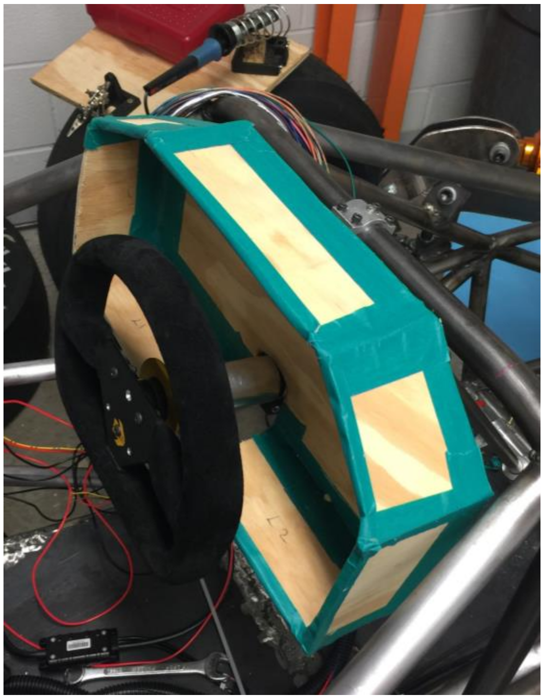


Figure 2.2.1: Current Instrument panel framework mounted on Front Hoop

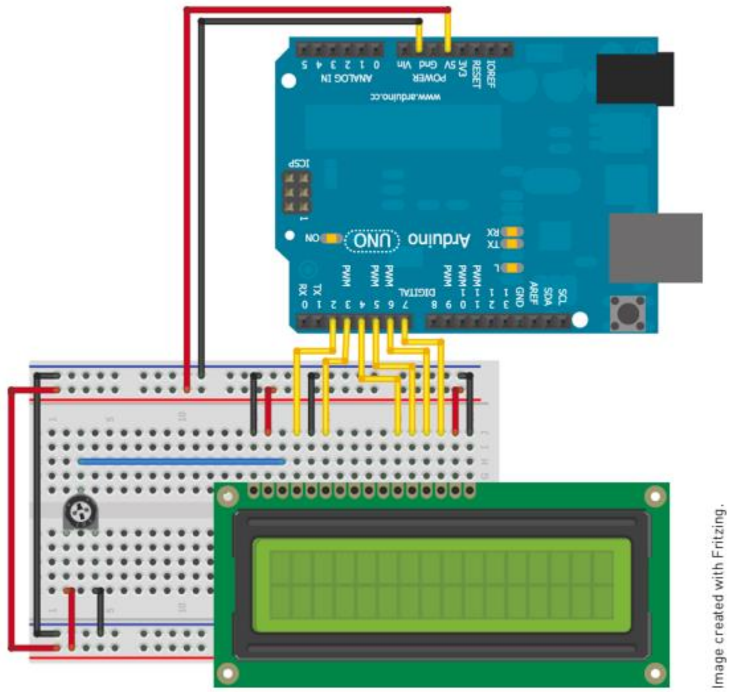


Figure 2.2.2: LCD screen for displaying speed on dashboard from *Exploring Arduino*

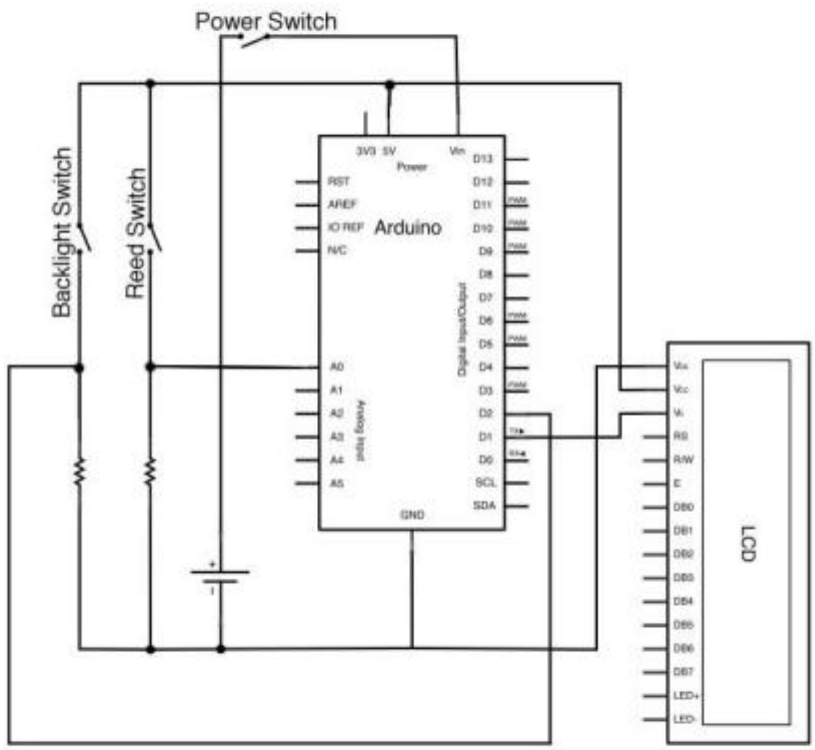


Figure 2.2.3: Final Speedometer circuit using reed magnetic switch

The dashboard of the instrument panel will be designed to have a section for the LCD screen as well as sensor for the engine and fuel tank. The sensors will be attached to outputs from the ECU and will display distinct colors for the driver to discern quickly. There are switches on the dashboard to control the speedometer lighting as well as a keyhole for the cockpit master switch to turn on the car engine as seen in Figure 2.2.4.

Figure 2.2.4: Instrument panel dashboard with switched and keyhole

The next challenge in finishing the instrument panel will be constructing the final engine sensors and wireless communication system and mounting the instrument panel attached to its framework in the cockpit. The instrument panel should also be layered with a rigid material such as carbon fibre. Now that the speedometer has been constructed, the LCD screen showing the cars speed has been attached to the dashboard. The engine and fuel tank sensor outputs and an attachment for wireless communication need to be built by future FSAE teams to complete this subsystem.

2.3 Steering

Section V.3.3 of the 2020 Formula SAE Rulebook describes the required setup of the steering wheel. Item V.3.3.1 of this section states that "In any angular position, the top of the Steering Wheel must be no higher than the top-most surface of the Front Hoop." Figure 2.3.1 provides a visual for teams to follow.

The configuration of the steering wheel implemented by the previous team was in violation of this rule, as the top of the wheel extended about 100 mm above the top surface of the front hoop. Figure 2.3.2 is an image of the original steering wheel placement compared with its desired placement.

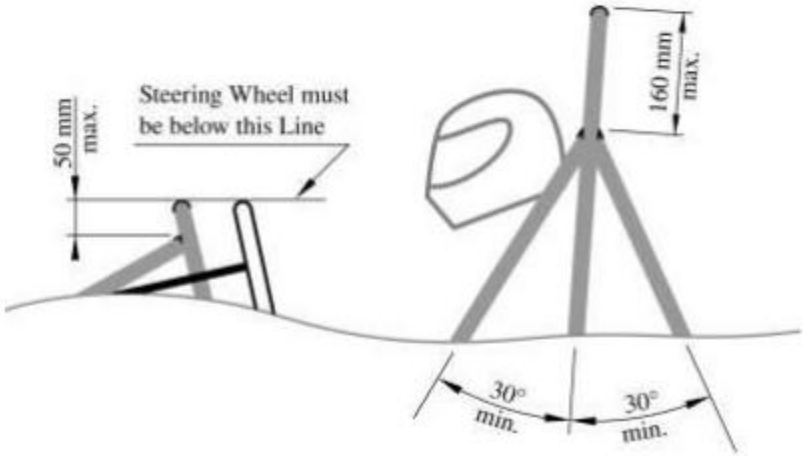


Figure 2.3.1. Depiction of steering wheel and hoop locations for FSAE vehicles

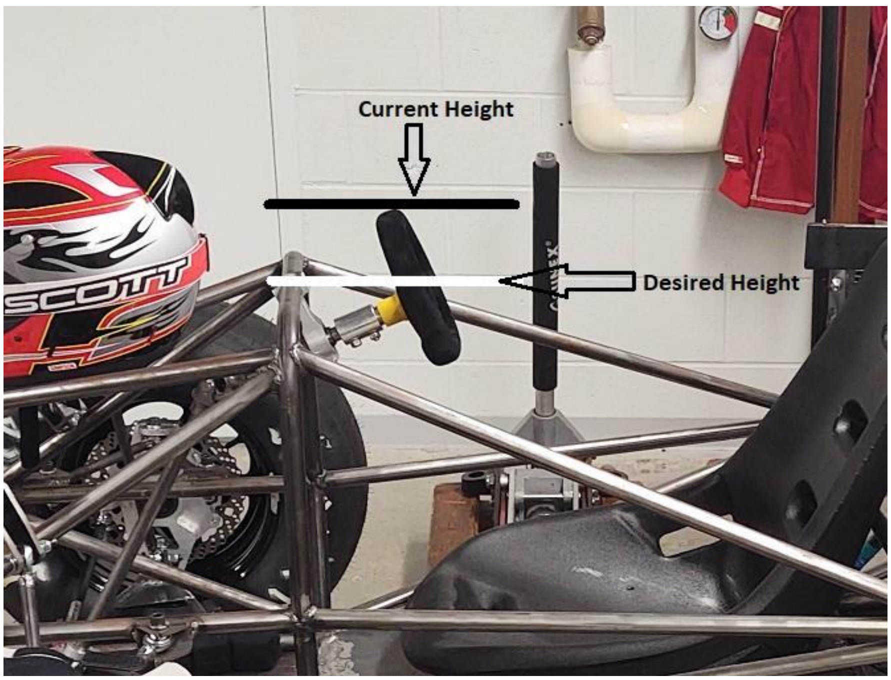


Figure 2.3.2. The original position of the steering wheel compared to the desired position.

To solve this problem, there were two main issues with the design that needed to be addressed. The first design challenge was the relocation of the rack mounts. These mounts attach the steering rack to the frame of the vehicle. The original position of the rack mounts forced the steering column into its maximum vertical angle, which set the position of the steering wheel above the front hoop. We decided that the best solution would be to simply move the rack mounts as far as possible towards the front end of the vehicle frame (See Figure 2.3.3). This allowed for a less extreme angle between the floor of the vehicle and the steering column, which ultimately resulted in a lower steering wheel.

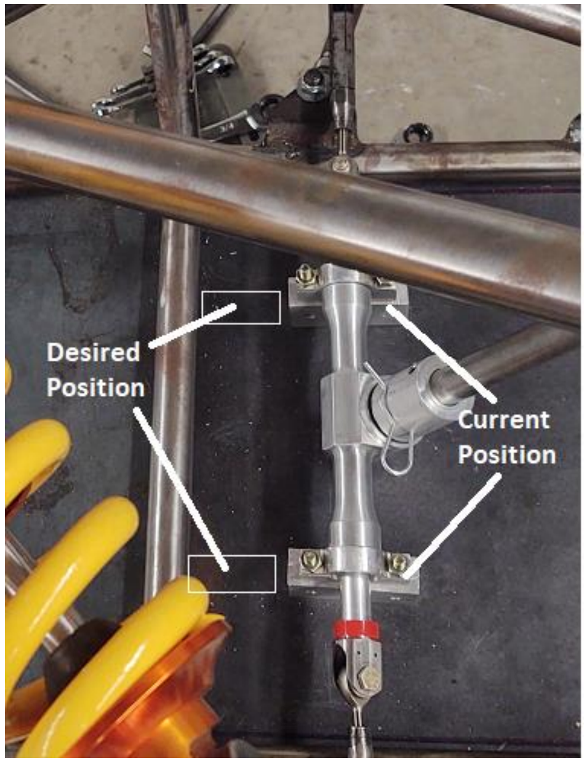


Figure 2.3.3. The original position of the rack mounts compared with the desired position.

The next challenge we need to overcome is the mounting of the steering column to the front hoop, which is required by the FSAE Rulebook. With the steering wheel now in a lower position, the old mount could not be used. Therefore, we decided that a new mount should be designed and fabricated that would secure the steering column to the front hoop while keeping the steering wheel in its optimum position. The new mount that was created was made to be longer to accommodate the lower position of the steering column, and it also needed to be designed at a slight angular offset (about 7°) to compensate for the wheel being further forward into the cockpit. The team designed the part using Creo Parametric CAD software, and a 3-D print was made to confirm the fit. Figure 2.3.4 shows the newly designed part.

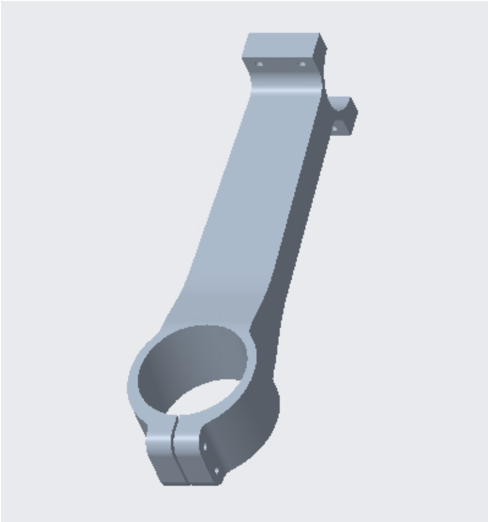


Figure 2.3.4. CAD model of improved steering wheel mount

With the fit confirmed, a new piece was made with the same design parameters, but with less complicated geometry. This made CNC machining the part much easier (See Figure 2.3.5). The part was made, but the university closed down before we were able to put it to use.

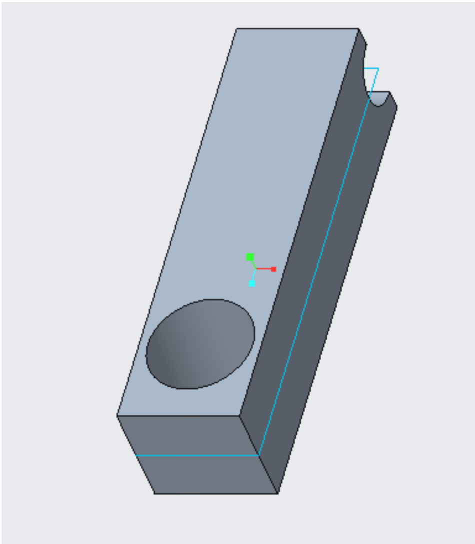


Figure 2.3.5 Simplified steering mount for CNC fabrication

2.4 ECU

The primary function of the ECU is to control the electronic fuel injection system, as well as the ignition. This semester, work concerning the ECU has been dominated by research concerning how to tune the MS2 using TunerStudio and the pending reassembly of the engine, as well as the supporting wiring assemblies. The ECU reads the values from various sensors attached to the engine. The primary inputs to the MS2 are the MAP sensor (Manifold absolute pressure sensor, integrated onto the MS2 board), MAT (Manifold air temperature sensor)**,** CLT sensor (coolant temperature), TPS (throttle position), the crankshaft position sensor, and O_2 sensor. Using the inputs from these sensors, the ECU controls the fuel injection and the ignition timing, allowing the engine to run efficiently.

This semester, all the sensors have been located and accounted for, and they have been installed into the respective places on the engine. Integration of the sensors to the MS2 has proven fairly straightforward, with only one sensor offering any sort of integration issues, The lambda sensor (O_2 sensor) is a seven-wire sensor with a wideband controller, meaning that the controller for the lambda sensor must be programmed, but this can only happen after the engine is started. Chapter 5 of the assembly manual given in Appendix C references the software and the manual required in order to calibrate this sensor. Otherwise, the remaining sensors were integrated successfully into the wiring harness to the ECU.

The primary outputs for the MS2 are the fuel and spark outputs.The spark outputs can be complicated, and the connection of the spark outputs change based upon the architecture of the engine. The simplest is a high-current output from the MS2 that drives a single inductive coil. However, this method will not work with the current engine, as the current engine uses high current output coil on plug ignition coils. Additionally, the MS2 does not support two-cylinder engines, therefore the ignition outputs would have to be implemented as cylinders 1 and 3 on a four cylinder engine program (due to the 180 degree position difference between the cylinders) using a wasted spark output. The MS2 will require a modification to the ECU’s protoboard in order to support this architecture. The design of this modification, using the BIP373 coil driver FET, is discussed in Chapter 5 of Appendix C. The fuel outputs can be integrated using a four cylinder engine design, as shown in the wiring schematic given in Chapter 5 of the Appendix. The injectors for cylinder 1 and cylinder two will have to be connected to their own respective banks, due to the MS2 supporting four cylinder, but not two cylinder engine architectures. Finally, the fuel pump can be immediately integrated into the system following the same diagram.

Lastly, the starting and charging circuits for the engine will have to be constructed. A design was determined for this, however due to the pandemic, construction of the starting circuit was not completed. The starting circuit will be constructed using the original relays and fuses from the old engine’s wiring harness, as these components are already designed to operate with the starter motor and will provide the simplest integration of this circuit. The charging circuit has been integrated into the engine already. The design of the charging circuit used the original rectifier circuits from the original engine’s assembly, and the integration of the circuit proved to be straightforward.

2.5 Brakes

The design of the brake system was largely worked on by TUMS this year. They had previously worked on the brakes, and asked to be in charge of it again. This year they discovered a sizing issue with their caliper mounting adapters and the wheel uprights. The problem was found for both the front and rear tires. They decided to focus on finding a solution for the front tires. They initially used CREO Parametric to design a 3D model of the complete wheel assembly with the adapter. Then they used the CNC to cut out a foam model of the adapter. The foam model was found to solve the problem, and plans were made to fabricate the parts out of aluminum. However, TUMS began to lose participation as the school year progressed, leaving the FSAE design group to pick up where they left off with little time or knowledge of what was needed. Despite this, the group was able to implement the brake line system. This required extensive planning and the purchasing of steel and rubber portions of the brake lines, adapters and fittings, and a cutting and flaring tool kit. The brake lines were bent to shape and cut to size, then flared as necessary to match the fittings. Then, the lines were attached to the master cylinders and connected as planned. The master cylinders were then connected to the brake fluid reservoirs, which the team mounted at the front of the vehicle behind the pedal assembly, which the team also mounted onto the vehicle. The only remaining task is to mount the calipers onto the rotors, which will require fabrication and possible redesign of mounting adapters. Hopefully TUMS will be able to aid next year’s team in this area.

2.5 Suspension

The tie-rods of the rear suspension and axle were found to be in contact with each other. This made it impossible to drive the car, as the axle could not be installed. Therefore we sought to find a solution that would move the tied-rods out the way of the axle. Due to time constraint and recommendations from our sponsor and adviser, we decided to worry less about the mechanics of the suspension and focus more on the simple geometry. We had two initial design solutions for the rear suspension. The first solution was to make one side of the a-arm longer than the other. The extended length would straighten out the tires and move the tie-rod out the way. This solution would require a complete refabrication of the a-arms and tie-rods. The second solution was to move the tie rod by removing the mount from the lower A-arms and relocating it to either the left or right on the base plate of the lower a-arm. This solution would only require a rework of the tie-rods and the mount. For both solutions we studied the book *Race Car Vehicle Dynamics* by William Milliken. In Chapter 17, the book goes over the geometry to consider when designing the suspension. Based on our research, we decided to proceed with the second option.

To remove the existing mount from the A-arm mounting plate, we used a grinder and cut away the welded material until we were able to pry the mount off. We then welded the mount onto a new location on the mounting plate. We then had to acquire new tie rods to fit with the new mounting location. Steel rods were purchased, and the team cut them to size and tapped the rods by hand to allow the ball and socket joints to thread into the rods. Finally, alignment rods were installed to keep the rear tires rigidly oriented forward. To do this, aluminum rods were cut and tapped, similar to the steel tie rods. Then, a mounting hole was drilled into the rear lower A-arm mounts that connect the A-arm to the frame. The rod was then attached at this point and to an existing mounting location on the rear uprights.

2.6 Intake and Exhaust

No work had previously been done on the exhaust, and the work that had been done to the intake was not usable. Therefore, we had to start from scratch for both systems. For the exhaust, we were able to use a portion of the exhaust from the original snowmobile engine. To make it fit with the placement of the engine and frame, we had to cut the ends of the original exhaust at a slight angle. Then, we had to remove an existing metal bracket using a grinder to cut it off. Finally, we were able to attach the exhaust pipes to the engine block using JB Weld.

For the intake, we purchased an expandable plastic hose and cut it in half. This allowed us to run each section directly from each cylinder's intake manifold to a two-outlet K&N washable air filter that a previous team had purchased. While this set-up works, the next team may want to optimize it. For example, the ring between the intake manifold and the intake tubes is missing, making that connection not air-tight. An optimized system would need to address this issue.

3 Prototype Tests Evaluation

Due to time constraints and unforeseen complications, we were not able to complete the powertrain assembly. As a result, we were not able to perform other tests. The planned tests include: a test to evaluate the cockpit seat as a firewall, to test the ECU's performance, engine performance, exhaust performance, skidpad test, steering system free play and brake test. These tests were highly dependent on the state of the powertrain system. We also planned to evaluate our prototypes for the suspension sway bar. The reason for not testing other suspension and sway bars was because of the long wait times for needed parts.

Even though we weren't able to conduct tests the team simulated some of the planned tests. The tests are overviewd and explained in the Test Plan Manual of Appendix E. Then a comprehensive analysis of simulated data for each test is found in the Test Results and Analysis Manual of Appendix F.

3.1 Seat pan

Most of the requirements for a seat were able to be tested as soon as the seat pan was fabricated. The seat pan was first checked to see if it was able to pass the tests in section T.1 of the rule book. The template of Figure 2.1.2 was made and used to see if the seat pan would pass inspection. It was found that the template did fit in the cockpit when held parallel to the ground inserted from above. The seat pan was then tested to observe if it allowed adequate space. The seat pan allowed for the battery and the fuel tank to neatly fit under it. For line of sight criterion, Jesus Ramirez (5'11") was seated in the cockpit with a helmet on. The seat pan was observed to barely cover upto the top of the helmet, which is allowed by FSAE. The positioning criterion was checked by having teammates sit in the cockpit with the seat pan. With some foam padding, the seat pan was surprisingly comfortable. Each team member was able to reach the pedal assembly and see over the front roll bar. Though it is preferred to conduct these checks with the actual drivers picked for competition. The heat criterion was not tested for as the engine was not able to run yet.

3.2 Instrument panel and Speedometer

The prototype test evaluation for the instrument panel and speedometer can be found in Appendix C and D Section 3.1 and Section 3.1 respectively. The results from the speedometer test will be acceptable if the recorded speeds on the LCD screen match the calibration speed from the speed gun within a percentage error of ±5%. The speedometer has to measure speed when it relatively increases and decreases. The results of the instrument panel should be able to adhere to requirement IC.8.4.4. Any similar tests done hereafter should have similar requirements.

3.3 Steering Wheel Mount

Recall that there were two main challenges we faced in the redesign of the steering mounts. Our solution for the position of the rack mounts was to move the mounting position as far toward the front of the frame as possible, per Figure 2.3.3. To test this solution, we removed the mounts from their original location and relocated them to the new position. Before we fixed the mounts to the frame at their new location, we had to ensure that the wheel would no longer be above the front hoop. We did this by simply holding the steering column up at a minimum vertical angle. This test proved that our design proposal would allow the steering wheel to be below the top surface of the front hoop, as required by Formula SAE guidelines. However, we still needed to test our design plan for a new steering column mount.

A 3D model of the new mount was made in Creo Parametric (Figure 3.3.1). It was designed to be long enough to accommodate the lowered steering column, while also having the correct angle to compensate for the new mounting location. A preliminary test performed with a foam mock-up of this part indicated that the new steering wheel position will be about 5 mm below the top surface of the front hoop. Because of this success, the team moved forward with the new design and created a carbon fiber 3D print of the mount. The finished part was attached to the vehicle successfully, fulfilling all of the Formula SAE steering requirements and completing the team's work on this subsystem.

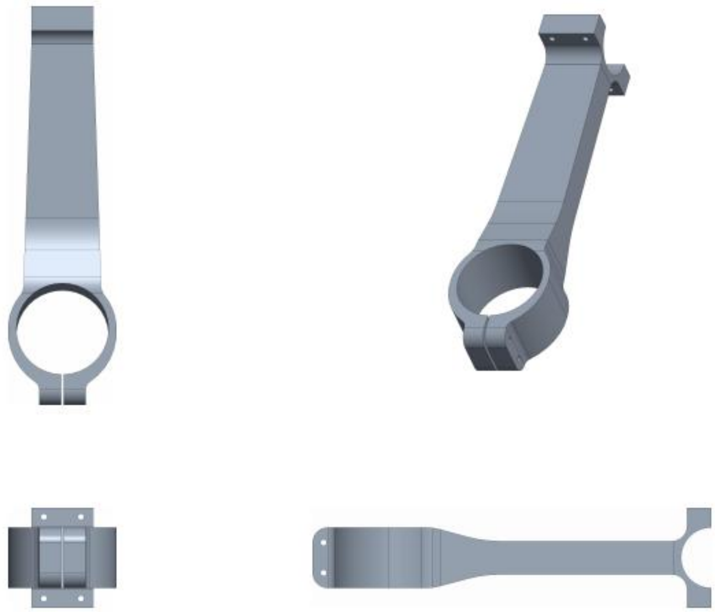


Figure 3.3.1. CAD model of the new steering column-to-front hoop mount

4 Summary of Assembly Manual

Appendix A provides detailed instructions for finishing the remaining assembly tasks on the car. The assembly manual consists of 6 chapters, each of which focus on the tasks remaining for a specific subsection of the car. Prior to Chapter 1 is the Parts Catalog, which is a list of part and tool names, images, and descriptions that you will need to use to complete the remaining assembly tasks. The next six chapters are Cockpit, Suspension and Steering, Powertrain, ECU, Body, and Miscellaneous, respectively. Some of these subsystems, such as the cockpit, still require extensive assembly, whereas others are nearly finished. The following is a list of assembly tasks that are 100% complete and will require no further attention:

- Chassis and frame
- Rear suspension
- Rear alignment
- Front suspension
- Brake lines
- Brake fluid reservoir
- Brake master cylinders
- Pedal assembly
- Throttle cable linkage to accelerator and intake manifold
- Exhaust
- Seat pan / Firewall
- Steering rack and pinion
- Engine mounting
- Intake manifold

While these items have all been completed by previous teams, the Assembly Manual will still include brief instructions on some of these systems. The reason for this is in case any of them get disassembled for whatever reason, future teams will be able to look at this manual and reassemble it with ease.

The main goal of the Assembly Manual, however, is to provide instructions on assembling systems that have been designed or planned, but have never been completely assembled or still require further assembly and mounting to the car. The following list contains items that fall into this category:

- Steering column-to-frame mount
- Seat / seatbelt
- Headrest
- Wiring harness
- ECU
- Oil tank
- Fuel tank
- Battery
- Intake
- Exhaust muffler
- Brake calipers
- Wheel bearings and rotors
- Instrument panel

Most of these tasks require simple assembly using parts that are already available in the storage room. However, some of them, such as the muffler and seatbelt, require parts that have not yet been acquired by previous teams. In these cases, the assembly manual will provide our recommendations for which parts to purchase or manufacture and how to do this.

5 Conclusions

Over the spring semester, the goal was to complete the work started on the various subsystems of the car, as well as to finish the ECU for the electronic fuel injection system. This work involved the fabrication and integration of the subsystems that this design group is responsible for. With the completion of this work, final testing results were analyzed, allowing us to predict the performance of the car as well as it's compliance to FSAE standards. Following the conclusion of the final tests, we will be able to make any adjustments or modifications to our subsystem prototypes. These preliminary designs serve as a proof of concept for the final subsystem prototypes and system integration. Upon the completion of the final prototype with all of the various subsystems fully integrated, more rigorous testing should have been involved so that the complete integration of all of the subsystems can be performed, in order to fully evaluate the performance of the car and it's compliance with FSAE standards. The COVID-19 situation hampered our progress thus requiring us to predict optimum test results for future teams.

6 References

[1] *Formula SAE Rules 2020*. SAE International , 2019.

[2] J. Blum, *Exploring Arduino: tools and techniques for engineering wizardry*. Indianapolis, IN: John Wiley & Sons Inc, 2013.

[3] NASA. *Anthropometry and biomechanics.* 2008.
https://msis.jsc.nasa.gov/sections/section03.htm

7 Appendices

Appendix A: Assembly Manual

Assembly Manual

Table of Contents

This Assembly manual provides detailed information about the subsystem designs of the car and instructions for the remaining work. When reading this manual it is best to be in the storage room with the car.

Parts Catalog

Wilwood Caliper-Black, Part # 120-9688

There are currently two of these in the storage room. They are to be used on the rear wheels.

Wilwood Billet Caliper-Silver

There are two of these in the storage room for use on the front wheels.

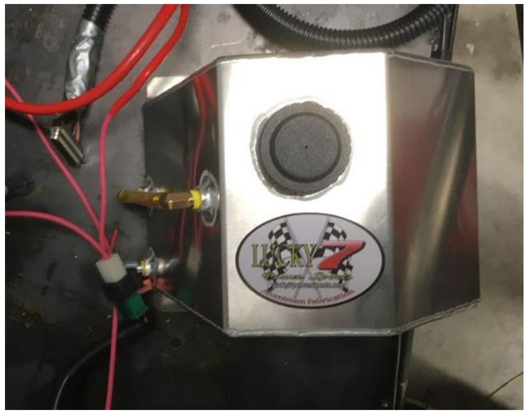
RCV Performance Front Hub Bearing Kit

These will be integral to completing the wheels and brake implementation.

RCV Performance Rear Hub Bearing Kit

These will be integral to completing the wheels and brake implementation.

Current installed Fuel tank

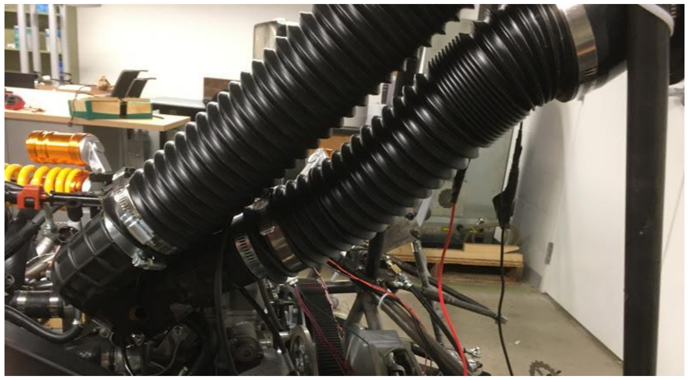


Part of the powertrain

Current installed Oil tank

Part of the powertrain

Current installed Intake manifold

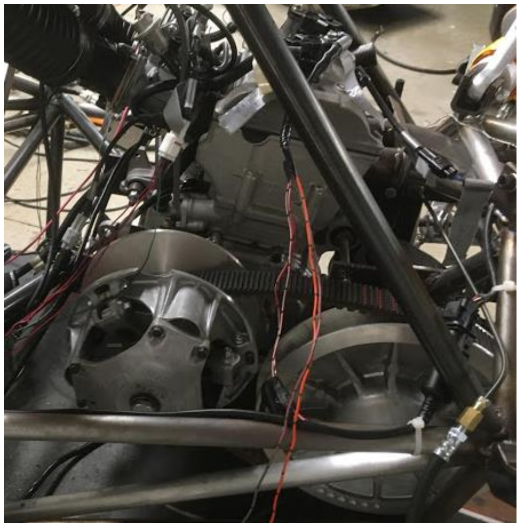


Part of the powertrain

Current installed Battery

Part of the powertrain

Current installed Engine



Part of the powertrain

Current installed Exhaust

Part of the powertrain

Chapter 1: Cockpit

Seat/Fire Wall

The design of the seat must abide by the Formula SAE 2020 Rules. In the design of the cockpit sections V.2.1, V.2.2, F.5.5, T.1.1, T.1.2, and IN.5 were taken into consideration. Section V covers the driver requirements; section F.5 covers the chassis requirements; section T.1 goes over the technical aspects of the cockpit and section IN.5 covers the driver cockpit inspection the judges will conduct at competition. The general concern of each section is to have a cockpit that is able to accommodate both the 95th percentile male (PERCY model:6’11’’ and 217 lbs)and 5th percentile female (5’ and 110 lbs). Overall these standards and rules are mandated to ensure the safety and comfort of the driver. Several FSAE teams have had different ideas on how to design the seat. The first one attempted to buy a prefabricated seat and assemble it to the car. The seat that they bought didn’t meet the FSAE regulations so it was not suitable for this project. There are currently 3 possible solutions for the car that are going to be provided to you. One of them is buying a new seat that actually meets the FSAE guidelines, the second one is to fabricate your own seat, and the third one is to continue following the seat design that the last FSAE team was working on.

Completed Work

The seat pan has been completed, all that remains is the fabrication of the seat inserts for each driver. A 2-part polyurethane mix purchased by the team should be available in the storage. An image of the 2-part mix is shown Figure 7.1.1. A support structure for the headrest has already been made as well. The support structure is a notched square tube made to fit in between the roll hoop such that it is at the intersection between the powertrain section and cockpit. The seat provides both a supportive structure for the driver to sit on in the car as well as a firewall between the driver and the engine compartment. The only step left for the seat pan is to retrofit it to the cockpit.

Figure 7.1.1: 2-part Polyurethane mix

Remaining work

The first task that needs to be done is to weld the completed seat pan to the car. After that is done, the team needs to manufacture and assemble a headrest. Formula SAE rules dictate that the headrest must be in the near vertical position and withstand an impact force of 200 pounds. Through the competition rules there is a constraint on the size of the headrest to be at least 6 inches by 11 inches for a non-adjustable headrest. With the fabricated support structure, the headrest needs to be assembled and integrated into the Cockpit. Next on the list is forming and adding a seat insert, which keeps the driver cradled into the car through a high G turn. The seat insert allows the driver to stay centered in the car and concentrate more in the operation of the car and less on positioning himself. The seat insert will be a two part expanding foam.

Instructions:

Seat Pan

1. Before the seat pan is welded to the frame, the team should have the team drivers sit on it in the cockpit. The seat pan was made with a seat angle of ~50 degrees in mind, to ideally fit a tall and short driver. Such that the sides of the seat pan should meet with the sides of the cockpit when it's set to 50 degrees. If any adjustments need to be made for the drivers, basic metallurgy practice can be done to shape the seat pan. Where the only goal to change the seat pan is to change the seat angle. The seat angle is the angle between the back of the driver to the floor of the car. Note, that whenever the seat pan is tested, the

headrest position should be considered as well. This is because the top of the seat pan and the support structure of the headrest are supposed to be fixed to each other. The support structure has been fabricated so that it fits perfectly in the roll hoop when the seat pan is set to 50 degrees. Our team was able to model the cockpit and seat pan angle using CAD and it is recommended that this team does it too.

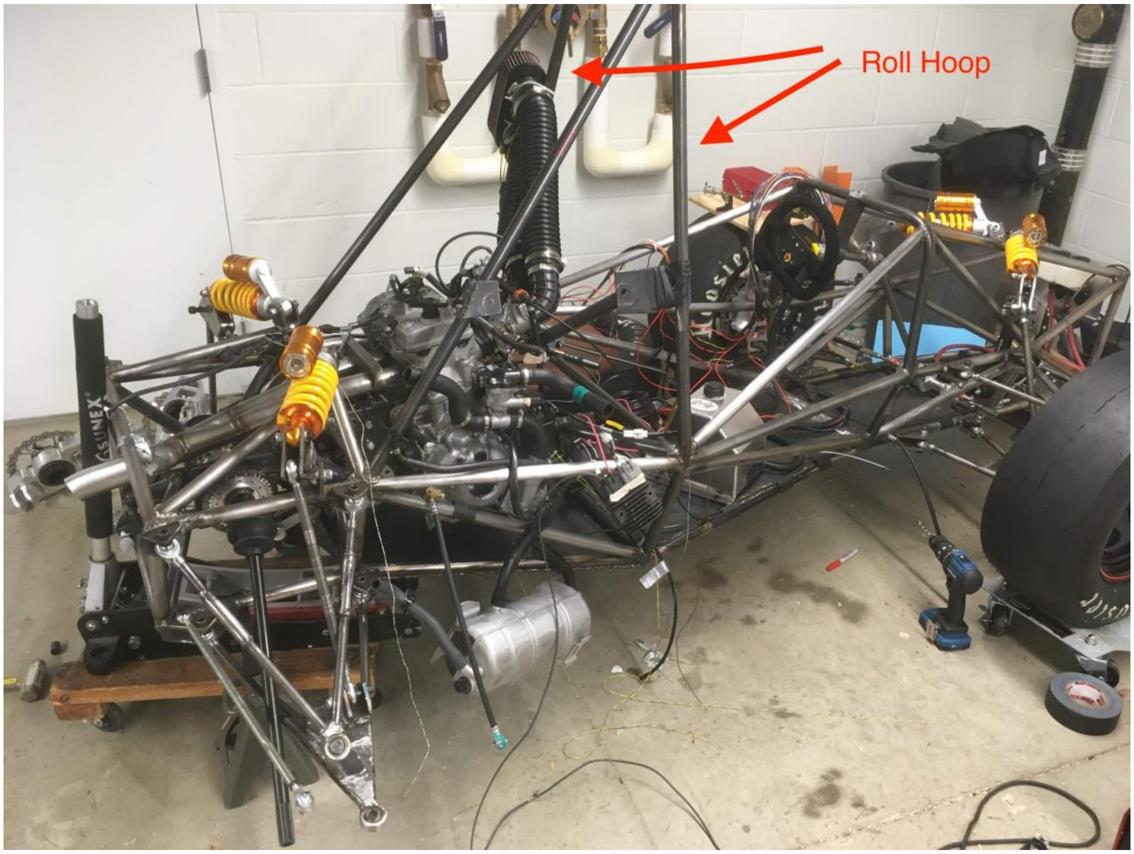


Figure 7.1.2: Main roll hoop of car

2. If a decision is made to change the seat pan angle, the position of the headrest will have to change too. Then the position of the pedal package would also have to change. The angle of the seat pan can be changed by hammering it or bending with the tools provided in the machine shop. While hammering, care should be given to avoid impressing as little dents as possible to the sheet metal. This can be done by placing a block or slab of material such as plywood in between the hammer and seat pan. As a result, the seat pan will be bent without any major concern of denting.
3. Then after adjusting the seat pan, the support structure of the headrest will have to be moved. Based on the new position of the square tube, the ends of it will have to be cut at

an angle to fit in between the roll hoop. Because of the orientation of the roll hoop, the tube has to be cut in a 2D angle. The tube can be cut using the bandsaw at the machine shop. Although the bandsaw can only safely cut one dimensionally. One way around this is to break the 2D angle into two 1D angles. The first angle can be cut with the bandsaw and then a grinder can be used to mill the other angle into the tube.

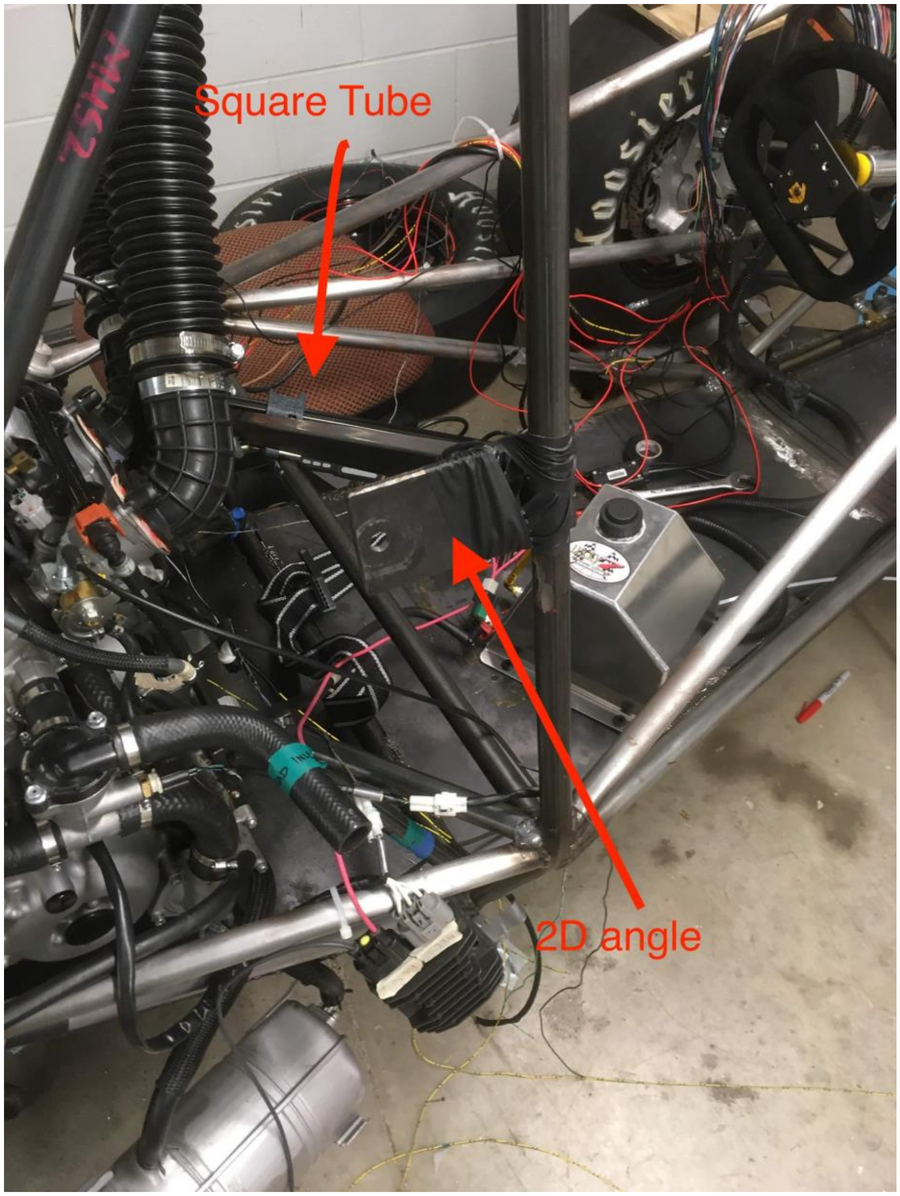


Figure 7.1.3: Square tubing and position

4. The original plan was to weld the seat pan to the chassis, alternatively the seat pan can be fastened to the chassis using bolts. All that matters is that the seat pan is rigid. Depending on the decision the team makes, would dictate when the seat pan can be

coated with paint. If welding the seat pan is decided, then the seat pan should be painted after. The only issue is that when spray painting the team would have to be cautious about spraying on other parts such as the engine. The spray paint is already provided in the storage room, and is used to prevent corrosion.

5. If the team chooses to weld, it is highly advised to atleast get 15-20 hours of training/practice. Even if any of the team members feel comfortable with welding before 15-20 hours. When welding to the chassis, the best method is to first partially weld the desired interface of the two joining parts. This can be done repeatedly at various locations and once satisfied you can fill in the remaining portions.

Headrest

1. Considering the assembly of the seat pan, the support structure has already been determined. All that is left is to build a frame and weld it together.
2. For the headrest itself, the foam can either be bought or made using 2-part mixtures. Then the foam can be upholstered with fabric. The team can also just buy a premade headrest that fits FSAE guidelines.

Seat Insert

1. The procedure of the fabrication of the seat insert will depend on the materials the teams used. There is already a 2-part polyurethane foam mixture in storage that the team can use. There is also the option to buy a professional kit that would come with a guide. Either option should relatively be easy. The kit in Figure is the one preferred by the team.

Figure 7.1.4: End Result of OG Racing kit for five-point harness.

2. The original plan was to use the 2-part mixture to make seat inserts to use only for testing and then buy the kit for the actual competition. As the 2-part mixture is much cheaper than the kits. It would also give the team practice on making seat inserts before using the much more expensive kits. This plan can still be adopted by next year's team.
3. Eitherway, next year's team should have drivers picked out by the time they are making seat inserts. Thus the drivers will have to be present when they are made.
4. For the 2-part mixture the first step is to tape a series of bags together and onto the seat pan. The bags are where the mixture will be poured into. Taping the bag and the seat pan of the car ensures that it is secure against all surfaces. In Figure, it is shown much a 2-part mixture can expand.

Figure 7.1.5: Product of 2-part polyurethane mix.

5. The two part foam is mixed and poured into the bag and the driver has to immediately sit down onto the bag being careful not to tear the bag open. The driver needs to sit in a comfortable race position for 10 minutes until the foam hardens. It is recommended that the driver wear either his uniform or thick clothing. As the expansion of the foam is an exothermic reaction that can get quite hot.
6. Once it’s finished, they can decide if it needs to be shaved down or if anything needs to be cut off. The following step is to wrap the seat insert in a fabric, which can be done by the FSAE team or by an upholstery company.

Instrument Panel

The instrument panel consists of a dashboard that will serve as a user interface for the driver. The instrument panel furthermore consists of a speedometer display, engine and fuel tank sensors, and a possible attachment section for a wireless communication system. The speedometer will ensure the driver adheres to on-site speed limits described in FSAE rules GR.2.4.4 and dynamic events. The instrument panel will be designed to fit a space in the cockpit located between the steering wheel and front bumper of the car. This will ensure the driver has a direct view of the speedometer and sensors while being able to control the car. Its framework will be mounted on the Front Hoop in the cockpit according to FSAE rule F.5.9 as shown in Figure 2.2.1. A cockpit master switch will also be placed on the instrument panel in order to adhere to IC.8.4.4.

Completed work

The instrument panel and framework have been built. A speedometer has been attached to its dashboard as well as switches to control the speedometer. The necessary tests have been done to confirm the speedometer circuit can work. A keyhole for the cockpit master switch has been drilled on the dashboard.

Figure 7.1.7: Current work done on instrument panel prototype

Instructions:

1. Instrument panel framework needs a cockpit master switch space to be drilled on it.
2. The instrument panel framework then needs to be attached to the speedometer framework that already has a keyhole on to complete the instrument panel.
3. The instrument panel needs to be covered up with carbon fibre or any strong material then mounted at an acceptable height in the cockpit.
4. The engine sensors and wireless communication system also need to be mounted on the dashboard.
5. The instrument panel should then be attached to the Front Hoop using FSAE requirements F.5.9.

Harness

The harness should adhere to FSAE requirements T.2.2 and T.2.3. The harness needs to be built to ensure cockpit safety for the driver.

Completed work

There has been no work currently completed on the harness.

Instructions:

1. The parts need to be purchased.
2. The parts are then mounted in the cockpit according to FSAE requirements.

Chapter 2: Suspension and Steering

The suspension system of a vehicle controls the way the chassis reacts with the road surface. A complete design is critical for optimal performance, especially in a racing environment. The suspension system consists of sprung and unsprung masses and must react safely in a range of scenarios, such as acceleration and cornering over a smooth or potentially rough track surface. The suspension assembly for this car is very close to complete. If the next team chooses to improve the design during the testing phase they can address them accordingly, but the basis of the suspension is complete.

Suspension designs are driven by several key factors, such as camber, kingpin inclination, castor, scrub radius, wheel offset, and mechanical trail. Camber is the angle the wheel leans in the front view, and affects cornering dynamics by adding a trust vector inward or outward of the turn. Kingpin inclination is the angle between the two ball joints and the vertical axis in the front view, which affects camber gain with respect to steering angle and can be used to induce a non-linear camber steer. Castor is the angle of the ball joints relative to the vertical axis in the side view, which when projected to the road surface defines the mechanical trail. The scrub radius is the distance from the kingpin at the contact patch to the center of the contact patch, which defines the additional moment the wheel must overcome to be steered.

The way the suspension system was designed, was to address the key factors of suspension geometry and mechanics. An example is the assembly of the tie-rods and tie-ends. The tie-rods are threaded which allows the length of the A-arms to be adjustable. Thus by controlling the length of both the top and bottom A-arm of a tire, the dynamics of the suspension are also influenced. It is encouraged for the team to study the suspension design and even assemble and disassemble it. The only possible remaining work for the suspension is to buy better shock absorbers. The current ones on the car don't seem to be adjustable.

Remaining Assembly

As the team planned to continue working on the car, but had to stop abruptly due to the COVID-19 pandemic, there are some parts of the suspension that aren't currently attached to the car. Specifically, these parts include most of the rear suspension since the wheels are off right now. The new team will have to find the remaining parts that are in the storage room and assemble them to the car. As for the steering, an aluminum mount was made but never attached to the vehicle. It will need to be acquired from the machine shop and installed onto the car.

Suspension

Instructions:

1. Find the rear suspension parts in the storage room, which include the 4 A-arms, 2 axles, 4 axle housings and the 4 boot clamps, and mount them on the car by using the screws available in the storage room.
2. To further improve the suspension of the car, you may buy an anti-roll bar and install it per the manufacturer's instructions. The car has some unique measurements so make sure the sway bar fits the car's dimensions.
3. Perform the mentioned tests to the suspension and see if there is any addition or modification needed to increase its performance.

Steering

Instructions:

1. Locate the new aluminum steering mount (ask Ryan Hodge about it)
2. Remove the old 3D printed mount.
3. Use a tap and die set to tap the holes in the new mount according to the mounting screws.
4. Remove the steering wheel and slide the new mount down onto the steering column.
5. Fasten into place using the proper screws as they were found on the old mount.

Chapter 3: Powertrain

Completed work

The team has already completed the assembly of the exhaust and intake manifold, so no design or manufacture is needed there. The team bought an adequate gas tank for the car, but it hasn't been installed yet. The team was provided with an engine, a battery and coolant system. However, the battery hasn't been started in a long time and it is unsure whether it is going to be a problem or not when it is attempted.

Figure 7.1.8: Completed work on the powertrain

Instructions:

1. Install engine parts such as gas tank, coolant and every FSAE requirement.
2. Test the engine quality with ECU.
3. Complete mounting of tires on car like the other tires already on as well as with accelerator to throttle and brake connections to wheel bearings.

Brakes

The design of the brakes must adhere to section T.3 of the FSAE 2020 rulebook. This requires one brake caliper for each tire, two independent hydraulic circuits such that effective braking is maintained in at least 2 wheels if one fails, be able to withstand a force of 2000N and must be fabricated from aluminium, steel or titanium.

Completed work

The current work done on the brake system involves the attachment of the brake line lines and fasteners. The brake lines have been connected to the master cylinders, and those in turn have been hooked up to the remote brake fluid reservoir. The master cylinders have been installed on the pedal assembly, which itself has been installed on the vehicle.

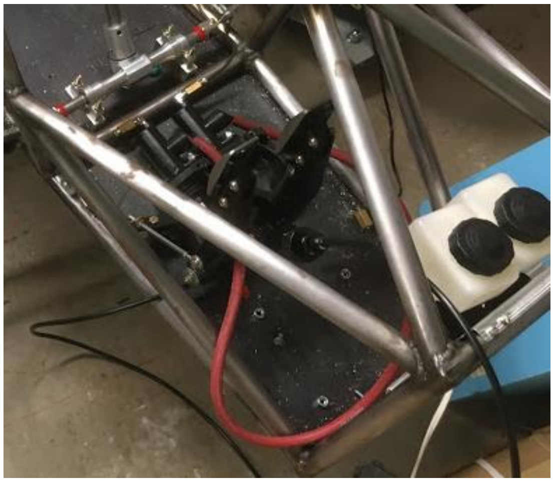


Figure 7.1.6: Brake pedal assembly complete with master cylinders and remote brake fluid reservoirs

Remaining work

There are three remaining assembly tasks for the brake system. First of all, the brake calipers need to be attached to the rotors, and then they need to be connected to the loose brake lines left hanging at all four tires. Also, according to FSAE requirements, a brake light is still needed. Finally, the brake fluid needs to be added to the system and the brakes must be bled to remove any air bubbles.

Instructions:

1. Work with TUMS to create a prototype (foam will be fine) of their caliper-to-rotor adapter. There is a different design for the front and year adapter, so be sure to fabricate both.
2. Test the fit. It is important to ensure that the caliper will a) fit on the wheel, b) firmly squeeze the rotor when engaged, and c) not contact the rim of the wheel.
3. If either of the parts do not satisfy the requirements of step 2, start from step 1 after designing a new adapter.
4. Once you have confirmed a good fit for all four tires, mount the adapters and calipers to the adapters / rotors. There are two different types of calipers; one should be used for the front brakes and one should be used for the rear. See the Parts Catalog for more information regarding the calipers.
5. Mount the uprights with the rotors onto the vehicle.

6. Mount the wheels onto the uprights, making sure that the axles are in place before securing the rear wheels.
7. Purchase a brake bleeder kit from an auto parts store or online.
8. Fill the brake fluid reservoirs with the brake fluid already in the storage room (see Parts Catalog)
9. Follow the instructions for the brake bleeder kit and bleed the brakes of any excess air. NOTE: This step will require at least two team members to complete successfully.

Chapter 4: ECU

In order to complete the ECU subsystem, both assembly and tests will need to be performed. While most of the assembly and design work has been carried out, there are a few things needed in order to complete the assembly for this subsystem. Lengthy discussion will be substituted for references to technical manuals.

Remaining Assembly

Concerning the assembly of the ECU and its integrated systems, there are four major areas: integrating the microcontroller into the MS2, connecting the actuators, building the starting circuit, and tuning the ECU. Each of these areas will be discussed fully in the sections below. Prerequisites: The ECU will have to be configured to run as a four-cylinder engine. The cylinder specific actuators, such as the spark coils and the injectors, will be considered to run on cylinders 1 and 3 in this configuration, with cylinders 2 and 4 unconnected. For those familiar, it will be connected in a “4-cylinder wasted spark” format, and in the diagram Fig. 7.1.9, the injector for cylinder 1 will be on “bank 1” and the injector for cylinder 2 will be on bank 2. This is due for a few different reasons. First, the MS2 does not have support for two cylinder engines, additionally, the cylinders are going to be 180 degrees out of phase, like cylinders 1 and 3 in a 4-cylinder engine.

Integrating the Microcontroller

Over the course of the semester, it was discovered that the microcontroller was not integrated into the MS2. In order to integrate the microcontroller into the MS2, the microcontroller must first be installed onto the main protoboard of the MS2. In order to install the microcontroller onto the main board, the microcontroller should be placed in the UI space denoted in Fig 7.4.1 and soldered into place. Following its physical installation, the firmware must be loaded onto the microcontroller. There is a resource that explicitly goes through the steps on how to accomplish this. A laborious synthesis of the instructions would not prove useful, so it is suggested that you see resource [1] given in the citations section.

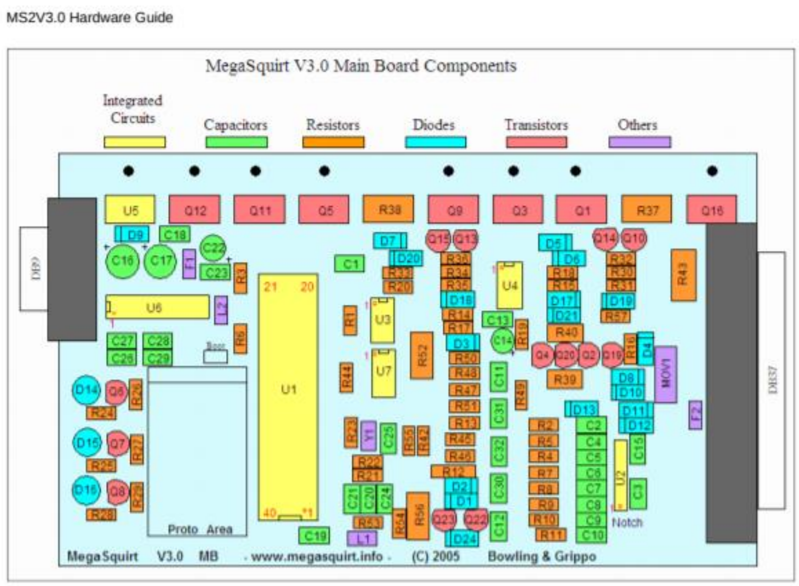


Figure 7.1.9 MegaSquirt Main Board Components [1]

Connecting the Actuators

In order for the engine to start and run, the spark plugs, fuel pump, and fuel injectors need to be properly connected to the ECU and the wiring harness. Concerning the fuel pump, the diagram given in Fig. 7.1.10 describes a circuit that is directly analogous to the required connection for the fuel pump. Similarly, the fuel injectors will connect similarly to the diagram shown in Fig. 7.1.10, with one exception. The injector for cylinder 1 should be connected to “bank 1” and the injector to cylinder 2 should be connected to “bank 2.”

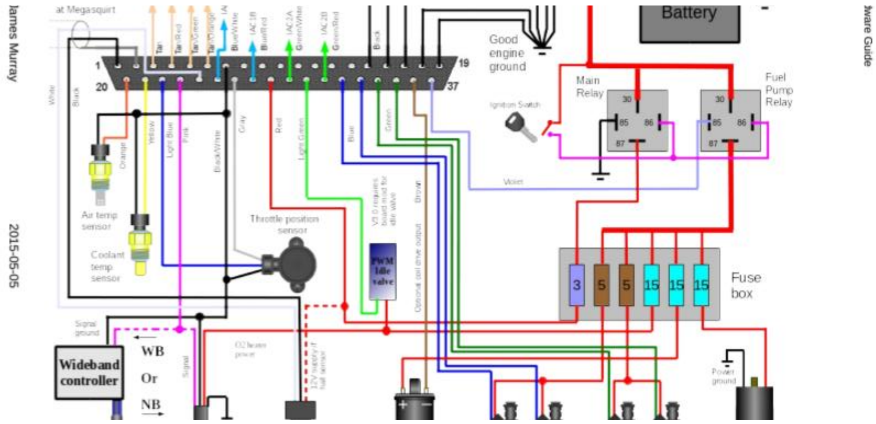


Figure 7.1.10: External Wiring Harness for the MS2 [1]

The most complicated part concerning this assembly will be the spark coils. Unlike the aforementioned diagram, this engine does not have a high output single coil ignition system. The ignition system for this engine is a high output coil on plug ignition system, which requires additional modifications to the MS2 protoboard. The easiest way for this to be integrated for our engine will be as a 4 cylinder wasted spark configuration. The modification requires the installation of the BIP373 coil drivers, which have been obtained from DIYAutotune. More information on this configuration can be found at resource [2]. It is worth mentioning that this configuration requires the most amount of modification to the MS2 board itself as it is the most uncommon. The resource listed is an online article found that offered the most information that was able to be located on this particular configuration. Not much else was able to be found concerning the implementation of high output coil on plug ignition systems such as ours, as most with coil on plug ignition systems seem to be logic level. Adapting from an online forum for tuning using the MS2 [2], the following details a step-by-step process for implementing the BIP 373 coil driver onto the MS2 board. Each of the abbreviations correspond to a labeled pin on the MS2 board:. The following is a restatement and slight adaptation from [2] :

Hardware mods required:

Jumper IGBTOUT to IGN to send to IGBT ignition coil driver signal out of pin 36 on the DB37. (not needed on a V3.57)

Cut out R57 if fitted on a V3.0. .

Our assembled V3.57 boards, if not fitted for direct coil control, will have a jumper from JS10 to the center hole of Q16. Remove the jumper.

Now for constructing the outputs…

Get a 330 ohm 1/4w resistor and cut the leads down to about 1/2″ at each end. Maybe a bit less.

Tin each end of the resistor with a bit of solder.

Cut a 5″ piece of hookup wire (22ga is fine) and strip just a 1/8″ or so. Tin the stripped wire with solder.

Melt the tinned wire tip to one end of the tinned 330 ohm resistor tip and let it cool.

Heatshrink wrap this wire/resistor assembly.

Use this wire/resistor combo to jumper the 'top' (top as in when you facing the silkscreen side of the PCB, with the text so that you can read it normally) lead of R26 to IGBTIN on the opposite side of the PCB. (On a V3.57, this is kind of tricky. It's easier to use pin 7 on the U1 socket instead, on the underside of the board.)

Now, you will be constructing duplicates of this BIP373 circuit for each coil output you need. For a 1 cylinder, you'll use 1 output; for more cylinders, you will use 1 output for every 2 cylinders (for our purposes, we will use two outputs, with coil 1 on our engine connected to spark output 1, and coil two on our engine connected to spark output three). You can mount the additional BIP373s on a second heat sink stacked on top of the first, attached on top with long screws. Or you can mount the BIP373s to the case.

Each BIP373 will need a resistor-on-a-wire assembly, running to its left leg. You will get the BIP373 input signal from the following locations:

Output	Input Location (V3.0)	Input Location (V3.57)
Spark A	Top of R26	U1 pin 7
Spark B	Top of R29	U1 pin 8
Spark C	Top of R27	U1 pin 9
Spark D	JS11	JS11
Spark E	JS5	JS5
Spark F	JS4	JS4

The center leg of the BIP373 is its spark output. We have found that the IAC traces can carry enough current for normal use, so you can use one IAC trace for each spark output. You may need to add an extra connector with the V3.0 on 12 cylinder applications, or if you are running a stepper IAC. You can use this pinout if you are not running a stepper

IAC, for up to 8 cylinders. Note that if you have anything else connected to the IAC pins, you must remove these wires before connecting the BIP373 outputs.

Output Board connection		DB37 pin
Spark A	IGN	36
Spark B	IAC2B	31
Spark C	IAC2A	29
Spark D	IAC1B	27

Connect the right leg of each BIP373 to a ground, preferably the DB37 ground pins, the right leg of R37 or R38, or the bottom hole of R43. The proto grounds can be used but this creates more noise on the signal ground plane.

Starting Circuit

The starting circuit should be built using the original parts from the old snowmobile wiring harness. Since the starting circuit is entirely electrical in nature, the original parts can be utilized in order to ensure that the right amount of current is provided to the starting motor, by using factory original parts. The diagram given in Fig. 7.1.11 of the Yamaha Phazer manual [3] shows the proper connections and identifies the parts involved in the starting circuit. This circuit should be directly implemented in order to build the starting circuit for the car, omitting any connections between the starting circuit and the ECU (which in our case is unnecessary, and should not make any difference in the performance of the starting circuit). The only connection between the starting circuit and the ECU that should exist is the power to the ECU, which should be switched on when the key turns the ignition into the on position, as seen in Fig 7.1.11 of the Yamaha Phazer manual [3].

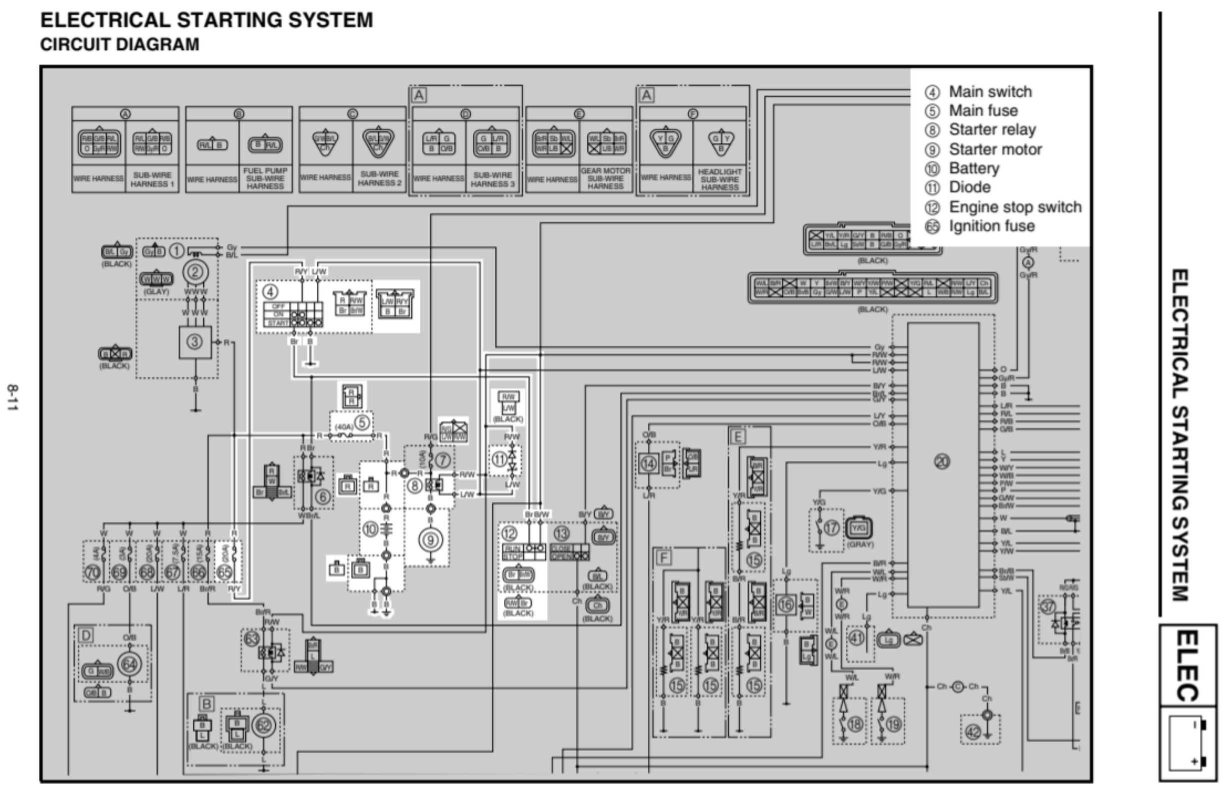


Fig. 7.1.11: Starting Circuit for the Original Engine [3]

Finally, a kill switch should be installed between the power to the ECU (after the starting switch) and the ECU itself. A two lead circuit breaking switch has been purchased for this purpose, and it will be able to handle the current and voltage demands of the circuit. This should be mounted such that the driver has easy access in order to perform an emergency shut off of the vehicle. Because the power to the ECU will be cut, this switch will instantly stop all injection and ignition of fuel, effectively stopping the engine in an emergency.

Tuning the ECU

As far as tuning the ECU, it is recommended that the resource [4] is followed. This resource offers a quick start guide to using the TunerStudio software to tune the engine, and it should be sufficient in order to tune the engine. This resource will only be referenced here and can be found in the TUMS google drive under the resources folder. Keep in mind that the engine should be tuned as a four-cylinder engine, with cylinders 1 and 3 connected to the spark coils 1 and 2 respectively. Furthermore, each of the two injectors should be connected to their own respective banks per the diagram given in Fig. 7.1.10.

Additional Concerns

One miscellaneous concern about the ECU assembly is the screws that hold the fuel rail on to the throttle body. These screws were missing during the reassembly of the powertrain, and substitutes will need to be determined.

Additionally, the fan that has been purchased will need to be fitted behind the radiator and connected to the electrical system. A suggestion for the electrical integration of this fan is to connect in in shunt with the power supply to the ECU (after the kill switch) in order to ensure that the fan is always operational when the engine is running, as well as protected from current overloads due to the in place supporting circuitry.

Chapter 5: Body

Current Prototype

The current prototype of the body involved completing the FSAE requirements of section T.7.2 of the rule book. It would have been built using starch and paper in its foundation and layering with carbon fiber to give a fine finish. The individual section would have been designed as seen in Figure 7.1.12 and put together to form the nose of the car as seen in Figure 7.1.13. This is a reference and not the actual final design that was to be done.

Figure 7.1.12: Individual parts of body panel design

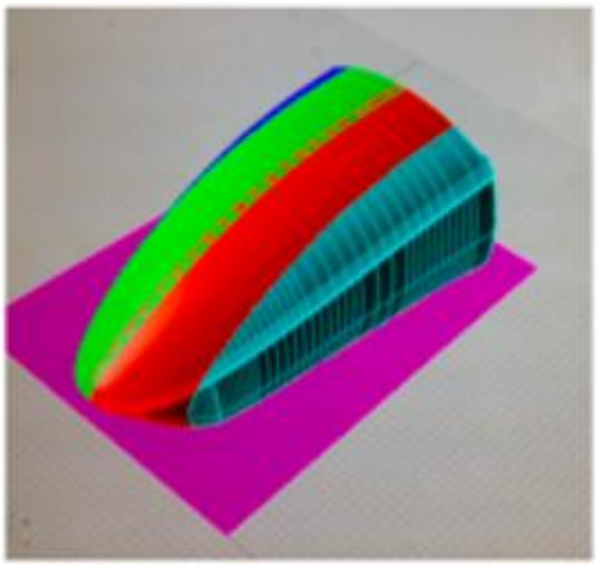


Figure 7.1.13: Complete nose section of body panel

Instructions:

1. The individual parts of the body panel should be manufactured using starch and paper molds.
2. Each individual matching section should be combined to form the complete structure.
3. The structure should be held together using carbon fibre or any other strong material that can replace the car surface.
4. The body panel should adhere to FSAE requirements T.7.2.
5. The side of the body should be made repeating step 1- 4.

References

[1] *MS2/V3.0 Hardware Manual*. James Murray.

[2] “Using Bosch BIP373 Ignition Modules With MegaSquirt,” *DIYAutoTune.com.* [Online]. Available: https://www.diyautotune.com/support/tech/other/bosch-bip373-ignition/. [Accessed: 07-May-2020].

[3]Yamaha Motor Corporation, USA, *Yamaha Service Manual* . Cycle Hippie, 2006.

[4]J. Gant, *Tuner Studio Manual* . 2012.

Appendix B: Competition Manual

Competition Manual

Table of Contents

This competition manual is a detailed guide for navigating the FSAE competition. It is in no means a substitution for the FSAE rulebook and other resources. The manual serves to pass down the knowledge and experience of the 2019-2020 Senior design team. The receiving team should also take the incentive to do their own research on FSAE.

Chapter 1: General Information

There are four competitions the TUMS car is qualified to attend: Formula SAE Michigan, Formula SAE North, Formula SAE Lincoln and Formula SAE California. In 2020 only FSAE California, North and Michigan were available. All four competitions use the same rulebook and submit the same deliverables. The only difference is that FSAE California and North accept both Electric (EV) and Internal Combustion (IC) vehicles. The other competitions exclusively accept IC vehicles. FSAE Michigan accepts more than 100 teams each year and starts competition in early May. FSAE Lincoln accepts more than 70 each year. FSAE North is relatively new and has accepted less than 50 teams, split evenly by EV and IC, in the past two years. Its competition starts in late May. FSAE California debuted in 2020 with a competition start date in June. It accepted 75 IC vehicles and 35 EV's.

There are two important websites that all team members must become familiar with: SAE.org and fsaeonline.com. SAE.org is where the team will register, view information for important dates and manage the teams account. In fsaeonline.com, resources, templates and the rulebook will be available. It is also where the team will submit most of the deliverables required by FSAE. There might be some deliverables submitted to fsaeonline.com that would also have to be submitted to SAE.org.

Depending on the team size, leniency on Senior Design deliverables may be requested, as FSAE related activities will take a good deal of time.

FSAE Judges

Chapter 2: Registration

Each competition registration date corresponds to their competition start date such that FSAE California has the latest. If available for next year, we recommend that the team registers for a competition in June. As the competitions in May will interfere with Trinity's Final Exams days. A later date will also give the team more time assembly and testing of the car. Each competition has 3 registration windows, pre-registration, Window 1 and Window 2. The first registration window for all competitions starts in mid-October. In each competition there is limited space and registration is a first come first serve policy. Thus it is recommended that the team registers as early as possible to ensure they can participate. If the team was not able to register in time, waitlisting is an option. Waitlisted teams are required to submit competition deliverables along with registered teams. From our observations, we found that about 5-10 teams withdraw from competition each year. Yet there can be up to 15 waitlisted teams in a competition. Before the team can register they should discuss among themselves and seek advice from their adviser and sponsor. The cost of registration is roughly $2300 and will be covered by the Trinity University Engineering Department. After deciding which competition you will compete in, the next step would be to contact the Senior Design Administrator, Dr. George and the Chair of the Engineering Department, Dr. Aminian. After confirmation they will direct you to the Administrative Support Coordinator, Clayton Mabry in ASO. In order to register at least one team member will have to create an account on SAE.org and become a member. All teammates are required to become members for a student fee of $30. They can sign up later in the year. Once signed in Clayton can input the billing information and register the team. It is important to save all invoices and other information when registering. Once registration is complete and the whole team has become a SAE member, they will have to sign up on fsaeonline.com. The team is also required to fill out their profile page on SAE.org.

Chapter 3: Understanding FSAE Rule Book

The FSAE rule book is distributed through the fsaeonline.com website. The rule book is updated annually and can even be edited throughout the year. Therefore the team should continuously check the website for revisions. The revisions are usually pointed out in the first pages of the rule book. The rule book details all the requirements and standards for the FSAE car. In the first few sections the administrative and competition rules are given. It provides definitions of vehicle and competition terminology used throughout. It also gives detail on the competition events, deliverables and the technical inspection. It is encouraged that all group members look through the book; the team can plan to split the workload of reading by person. The first thing to note about the rulebook is that it accommodates both the EV and IC vehicle. There is a EV section dedicated only to electrical cars but there may also be sections throughout that consider them too. Thus, keep it mind when looking through the rulebook.

Chapter 4: FSAE Deliverables

The deliverables required for a team to submit depends on the type of car (IC or EV) and the competition. An EV would have to complete all the deliverable required for an IC vehicle and also deliverable pertaining only to EV. Figure 7.4.1 and 7.4.2 show a list of deliverables and events for the 2020 FSAE California Competition. This list is an updated schedule with omitted deliverables and changed deadlines in response to COVID-19. The “Notice of Intent - Electronic Throttle Control Rules” deliverable is the teams declaration of using an electronic throttle control, this for any vehicle type. Our team decided to use a mechanical throttle control between the accelerator and the throttle body. Next year's team can choose to continue with mechanical or switch to electrical. Since the TUMS car is an IC vehicle the team does not have to submit: “ESO/ESA Form”, “Failure Modes and Effect Analysis”, “Electrical Systems Form” and “Electronic Throttle Control Failure Modes and Effect Analysis”.

Action Deadlines

	Opens	Closes/Due By
Team Registration Window 1	Oct. 16, 2019 at 10:00 a.m. EDT	Oct. 29, 2019, 11:59 p.m. EST
Team Registration Window 2	Oct. 30, 2019, 10:00 a.m. EST	Nov. 27, 2019, 11:59 p.m. EST
Notice of Intent - Electronic Control Throttle Rules		Dec. 2, 2019, 11:59 p.m. EST
ESO/ESA Form		Dec. 2, 2019 11:59 p.m. EST
Failure Modes and Effect Analysis (FMEA for EV Class)		Dec. 2 , 2019, 11:59 p.m. EST
Structural Equivalency Spreadsheet		Dec. 13, 2019 at 11:59 p.m. EST
Electrical Systems Form		Jan. 13, 2020, 11:59 p.m. EST

Figure 4.1. FSAE deliverable deadline schedule

Electric Throttle Control Failure Modes and Effect Analysis (ETC FMEA)	Jan. 27, 2020, 11:59 p.m. EST
Online Cost Reports - Online Cost Module Submission - Downloaded PDF Submission - Downloaded eBOM *No paper copies will be mailed.	April 30, 2020, 11:59 p.m. EST
Event Guide Submissions	April 6, 2020 (see below)
Design Report and Spec Sheet	April 30, 2020, 11:59 p.m. EST
Fast Track Roster Affiliation	June 2, 2020

Figure 4.2 FSAE deliverable deadline schedule

The only deliverable our team was able to submit was the “Structural Equivalency Spreadsheet (SES)”. The team's attempt of the sheet can be found in the 2020 folder in the TUMS google drive. A template of the sheet will be released by FSAE at fsaeonline.com. The SES includes a sheet on Impact Attenuator, the chassis and its tubes, welded inserts and bolted members. The Impact Attenuator was originally a separate deliverable but is now included in the SES. The main objective of the SES is for FSAE to determine whether the design of the chassis and the impact attenuator is safe for competition. When filling in the SES template, the rule book should also be open. This is because the template refers to section numbers of the rule book when dimensions of a part are asked for, or the design of a part of the chassis is in question. Everything needed to fill in the SES is straightforward and next year's team will have the 2020 SES completed by our team.

The “Online Cost Report” is a team's submission of a report that explains and defends each cost made for the project. The judges of FSAE expect a rigorous and comprehensive report that details all costs spent on the car. This includes tools, materials, parts and manufacturing costs spent on third-party companies. Our team has already gathered all receipts and invoices cataloged by ASO in the 2020 folder in the TUMS drive. Although it might be incomplete and the team should work with the ASO to find missing invoices. Examples and templates can all be found on fsaeonline.com and a sample cost report is also stored in the 2020 folder. The sample report represents what FSAE judges expect tos see. It is recommended that the team start early on this report as it will take a good deal of time to complete.

All work for the remaining deliverables is left for the receiving team. We recommend that the receiving team start working on these deliverables as early as possible.

Chapter 5: Competition Preparation

Driver training

In order for the team to be ready for competition, they will have to find drivers and train them. Depending on the available time and motivation of the team, the importance of who the driver is and driver training may vary. Our opinion is that the driver is another component to the car, and in order to get the best performance possible for competition the best components are put into the car (there is a reason you don't see Toto Wolf in the seat of an F1 car and its because Lewis is faster). Although TUMS does not have the luxury to have this attitude, as resources, time and connections are at a minimum. It is prefered to find someone with racing experience. The driver can be chosen by either picking a member of the team, a TUMS member or conducting a school search. If the team receives many driver applicants with experience and and the team is motivated to place at competition, they can have tryouts. An option for tryouts is having some races with go-karts. The qualities to look for is not just the fastest lap times but also consistent lap times. The team can then either pick the 2 best drivers or a select few. From there the selected drivers would be the only ones who will get to drive during testing. To avoid having the "well I put x hours into this car therefore I should drive" argument, the team can have a drive day after competition where anyone who went to competition could drive the car. If the team didn’t receive any driver applicants, they can decide who in the team will drive by having races with go-karts. This would also be beneficial as a team building experience.

Before the team starts diver training it is important to first consider the time they have. And to always remember that the car's performance should be the first concern. FSAE cars are built by people who by definition don't know what they're doing and so reliability and tuning is worth so much more than driver pace.

The first step for driver training is acquiring a race track and making sure the track is accessible when needed. Everytime before going to the track they should make sure the car works. The team should also take tools and possibly extra parts for onsite repairing. The team can also consider buying equipment such as instruments that measure and record acceleration For driver training, the team should first start with the basics. The drivers should first learn race car driving essentials and learn the mechanics of the car. Basic training can include having the drivers familiarizing with the car and doing simple test runs around a circular track. Then after driver development the tracks can change to be more complicated. The track can be made to different types of turns. This brings up the topic of racing lines, the best path of a vehicle to take at a turn.The objective for a driver is to maximize the vehicle speed throughout the track. When at a curve drivers have to consider turning dynamics such as the turn radius and the vehicle speed when turning. It is left up to next year’s team to learn about racing lines to determine the best approach at a given curve. Finally after the drivers have become more confident, the drivers can then train on the same tracks that will be held at competition.

Preliminary Tests

The FSAE team attending the competition will have to ensure that preliminary tests are done to ensure that the car is competition ready. These tests will adhere to FSAE rulebook section IN where the technical inspection of the vehicle is explained which includes IN.1, IN.2, IN.3, IN.4, IN.5, IN.6, IN.7, IN.8, IN.9, IN.10, IN.11, IN.12, IN.13, IN.14 and IN.15. Once these tests are complete, the car can be said to be competition ready.

Travel arrangements

The FSAE competition in Summer 2020 was planned to take place in Fontana, California, which is approximately 1310 miles away from San Antonio, Texas. For this reason, we had to think about several options to transport the car and ourselves. The team had three ideas to take the car up to California. The first one consisted of renting a Penske truck that would fit the car and two of our members could drive it there, while the others took a plane flight or a bus. The truck costs approximately $200 for 6 days with unlimited free mileage. The second option was to ship the car using a courier, which could be cheaper depending on the quotes that you are able to get. The third option was to use one of the team member's truck and trailer, and drive all the way to California. The decision depends on the prices that you are able to obtain for the Penske truck and the shipping courier, and whether you think the car is in good enough shape to take the risk and let a third party handle it as they see fit. Most teams ship their cars, and if this is the way you want to go, it is highly recommended to read the vehicle shipping information on the FSAE website.

Lodging

Another important part of the logistics for this competition is arranging a place to stay in California during the 4 days that it lasts. The team had planned to book 6 nights, from the 16th to the 21st so that there was time to settle and be ready for the competition. One good hotel option is the Americas Best Value Inn & Suites that is only 5 miles or 10 minutes away by car from the speedway where the competition takes place, and it has a very inexpensive price. Another option available that was considered too, was renting an AirBnB, which can turn out to be even cheaper and more comfortable for the team. It all depends on the amount of money that team is willing to spend, the kind of deals that the team can find, and the amount of people that will be staying in the same location.

Appendix C: Test Plan Manual

Full Prototype Test Plan for a Formula SAE Car

The Formula SAE Team:
Jonathan McDaniel
Kelechukwu Omegara
Jesus Ramirez
Jose G.Rodriguez
Matthew Thompson

April 21, 2020

1 Introduction

Formula SAE is an international collegiate competition organized by the Society of Automotive Engineers. Students are offered the great opportunity of designing and manufacturing an open wheel Formula One-style car and competing in both static and dynamic events. Formula SAE has evolved from a domestic event in the U.S. to an international competition throughout the world being held by countries in Europe and Asia. Trinity University has not participated in the competition prior to its initiation 2016. All the previous senior design teams have yet to finish a working car given their two semester time constraint. Hence, the design and development of the car is an ongoing project that has 3 years of work done by 3 previous senior design teams. The work that has been done includes the assembly of the chassis, suspension, some of the powertrain, steering and braking. This year the team intends to deliver a functional car that runs and drives. If possible, we would like to compete, but that is not the priority. The major components left are the powertrain and the body. Then the team will also work on improving previous designs and integrating finished subsystems. This document describes the test plan for the finished Formula SAE car prototype.

2 Design Features

Concerning our work on the car, some of the major design systems are the cockpit (which includes the instrument panel on the dashboard, the seat, steering wheel mount, and firewall), the suspension redesign, and the ECU for the engine's EFI system (including the wiring harness, controller programming, Lambda sensor programming, and other important powertrain components such as the gas tank). Many of these components can be tested by directly evaluating their compliance to the standards given in the FSAE yearbook. However, the EFI system poses a significant challenge, as there is no such standard describing such things as emission control or spark timing. This component will be evaluated based upon standards determined by the FSAE team, which will show efficient spark timing and fuel dispensation as well as showing that all of the necessary sensors and actuators are functioning according to their intended purposes.

The proposed test will assess the validity of the following Design Features:

FSAE Competition Rules Compliance: Several tests will compare the planned/manufactured and assembled subsystems to the Formula SAE competition rules pertinent to the respective subsystems. For example, FSAE requires that the steering system free play be no more than 7 degrees. This rule motivates the need for a free play test that will evaluate how much steering input is needed before the front wheels begin to respond. Another example of the application of FSAE rules include the physical dimensions of the track for the skidpad and hairpin turn competition events. Using the size and shape of the competition track we computed a minimum achievable turning radius for the car in the skidpad event, which we will test with the skidpad test.

Optimized Cockpit with Accurate Instrument Panel: The instrument panel, which includes only a speedometer, will be tested in the speedometer test. The speedometer should accurately display the vehicle's speed, and it should be clearly visible to the driver at all times. Also, it must fit within a dashboard that fits within the cockpit.

Based on last semester's test on the speedometer, the team decided to test the second course of action for the speedometer's sensors. Initially, a test plan outlined a light based sensor that read the device's speed based on the amount of time it was exposed to a photoresistor. This plan was replaced with a magnetic reed switch that measures speed based on the time it takes to sense a magnetic field. The tests were successful but an alternate plan was made to accomodate time needed to finish the instrument panel design and the outside effects that environmental light sources may have had on accurate speed measurements.

3 Test Plans

Each of the subsystems that we have continued work on will be evaluated in order to ensure that they are all functioning properly, as well as a final test on the entire car itself, that evaluates the safety of any drivers and observers that will be involved in the process. Fig. 1 shows the dependencies of the subsystem testing and the order in which things can be completed in order to reach the final test involving the completed car with all of its integrated subsystems. Please note that the lambda sensor testing procedure overlaps with the general sensor test. It is important to consider that the lambda sensor requires its own additional controller, requiring that this component be tested in more depth than the other sensors, to ensure the controller for this sensor has been properly programmed.

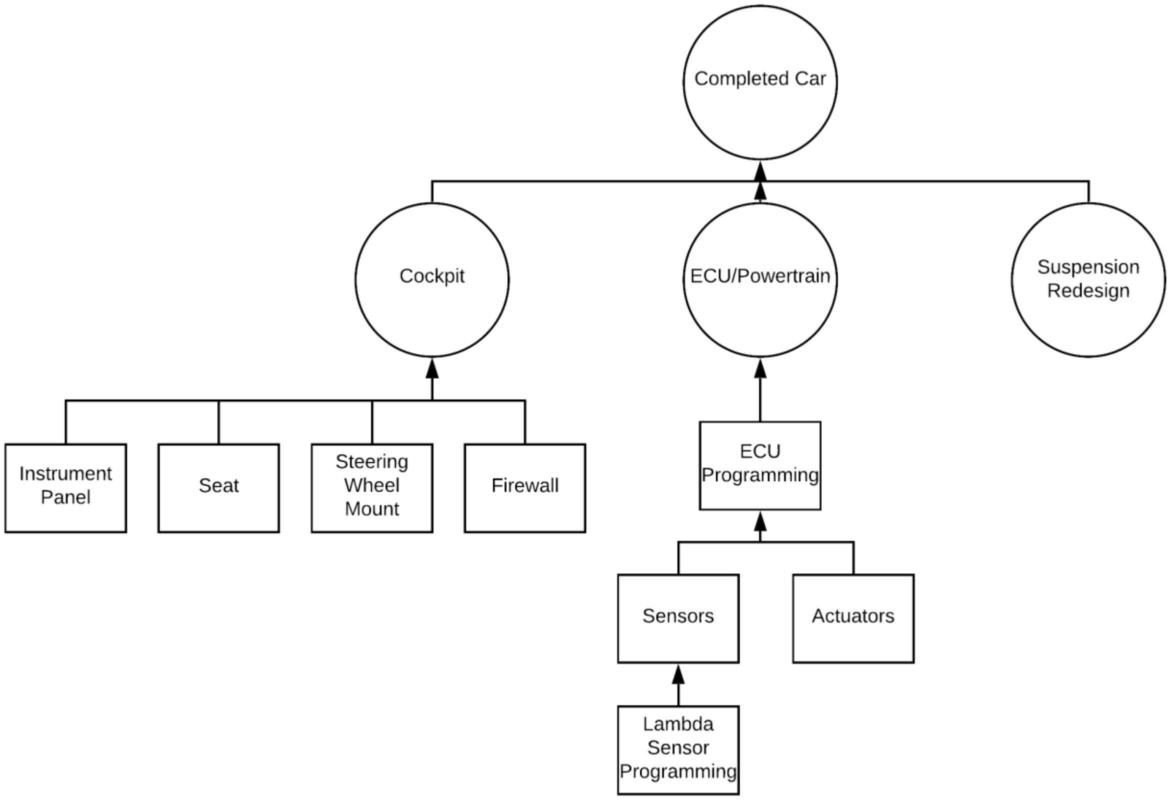


Figure 1. FSAE Car Test Plan Dependencies

The following sections will detail the test plans for each of the subsystems. Each of the subsystems will be broken down under their main subsystems (for example, ECU programming will be under ECU/Powertrain), and each of these main subsystems will be under the completed car test plan.

3.1 Instrument Panel and Speedometer

Test Overview

This test will measure the accuracy and precision of the Arduino-based speedometer located on the instrument panel as well as the strength and positioning of the instrument panel subsystem for engine sensors and cockpit master switch placement.

Objectives

The goal of this test is to ensure that the instrument panel's speedometer can accurately measure the speed of the vehicle. The interface requirements of this project previously stated that the car must include a speed indicator for driver monitoring of the vehicle's speed. This test will show whether the reading on the speedometer corresponds to the actual speed of the moving vehicle. This test will furthermore ensure that the project requirements are met by ensuring the measurement from the speedometer is visible to the user. The instrument panel will also need to adhere to FSAE vehicle requirement IC.8.4.4 and FSAE test IN.10.7.

Features Evaluated

The features of the speedometer to be evaluated are the Arduino system, the LCD screen and the magnetic reed switch sensors. The speedometer's overall quality will be evaluated based on those internal components. The instrument panels strength, structure and positioning will be evaluated as well.

Test Scope

The scope of this test will focus on the speed of the tires based on the radius from its center, where the magnets have been attached. The speed will be measured in miles per hour (MPH) and displayed on the LCD screen which will serve as a base for an output. Three repeated tests will be taken for 5 different speeds of the vehicle. The overall vehicle's speed will be excluded during the speedometer test because it is assumed that the tires, which serve as the device whose speed is being measured, will move the vehicle at the same speed because the same distance is traveled. Data will be collected at different speeds for a quantitative test. The instrument panel's overall ability to hold the cockpit master switch when mounted will also be evaluated.

Test Plan

The test will involve a calibration tachometer reading that senses the position of a reflective tape and measures the speed of the device the reflective tape is attached to. The same process is used to obtain readings from the Arduino-based speedometer on the instrument panel but a magnet is used in place of the reflective tape and the reed switch sensor in place of the tachometer sensor. The test device will be a circular object similar to a tire profile shown in Figure 2 of the Appendix. A magnet will be attached at a known radius from the center of the tire which is coded into the Arduino software. The magnetic reed switch attached to the speedometer will be used to sense the magnet on the tire. A clear knowledge of angular velocity and linear velocity will be important in conducting this test. Furthermore, knowledge of Arduino coding will be important. This is because certain inputs and output signals are involved in ensuring the Arduino works as one complete system. Two sensors for the Arduino were critical to the final speedometer. A magnetic reed switch sensor was chosen over a light-based photoresistor because of time conservation and to prevent the influence of external light sources.

This test will assume that the speed of one tire will match the entire speed of the vehicle. This assumption is made because Speed = Distance/Time and the distance traveled by the vehicle will be the same as one tire. Thus if they move by the same distance within the same time, their speeds will be the same thus allowing us to get a potential view of the measurements the speedometer will give if it were measuring the entire vehicle.

The speed of the device to be measured will be matched with a calibration speed from the tachometer or speed gun used to measure the device as well. Repeated measurements will be taken to ensure a quantitative test. The percentage error between the readings will then be measured using the following equation;

$$\%error = \frac{Speedometer\ Reading - Tachometer\ Reading}{Tachometer\ Reading} \times 100$$

The percentage error will be obtained for each corresponding readings and the mean and standard deviation will be calculated for the percentage error and repeated measurements at each corresponding reading.

The instrument panel's strength and positioning will be tested by mounting its framework on the Front Hoop in the cockpit according to FSAE rule F.5.9 and ensuring it is rigid when the car is finally able to move by meeting either the condition of being attached to a brace node or a fully Triangulated structural node or with additional structural bracing. Figure 3 of the Appendix shows how it will be positioned to complete the test. The instrument panel will be tested further to ensure the cockpit master switch can push-rotate when needed along with the aforementioned rigidity.

Acceptance Criteria

The results from the speedometer test will be acceptable if the recorded speeds on the LCD screen match the calibration speed from the speed gun within a percentage error of ±5%. The speedometer has to measure speed when it relatively increases and decreases. The results of the instrument panel should also be able to adhere to requirement IC.8.4.4. Any similar tests done hereafter should have similar requirements.

3.2 Skidpad

Test Overview

This test will measure the vehicle cornering ability on a flat surface while in constant radius turn. This test can also be useful in testing the overall performance of the car right after being completed.

Objectives

The objective of the test is to evaluate the reliability of the steering system. It tests whether the car can remain on a path while making a tight turn. With a running car, it will also test the driver's capability in driving in a steady path. The secondary objective is to determine which driver will prefered for the skidpad event.

Features Evaluated

The steering system will be evaluated, specifically its performance with the new steering mount. Then based on the results of the test, the assessment of the driver will be important for the final evaluation. The drivers will also be evaluated and depending on the results, the position of each driver will be decided for competition. In the skidpad event in competition, the runs with the first driver have priority.

Test Scope

In the test the driver will first take two full laps of the right circle and the immediately after will take two more laps on the left circle as shown in Figure 1. In the 2nd and 4th laps, they will be timed.

Test Plan

A car's cornering ability will be tested using the course for the skidpad event at the California SAE competition. The course will be designed as a track in the shape of two concentric circles overlapped into a figure pattern. The pattern will be traced with cones and chalk. The chalk and cones will be used to help determine if the car was able to remain on the path. Then during 2 of the laps, the driver will be timed using a stopwatch.

To evaluate the performance, the scoring system from Formula SAE will be adopted. In the test the driver is allowed 4 runs or attempts. For any test run, a penalty of 0.125 seconds per hit cone will be applied to the final time.

- Corrected Time = (right lap time + left lap time)/2 + (cone * 0.125)
- Best - best corrected time
- Tmin - lowest corrected time recorded for any team (get from previous competition data)
- Tmax - %125 of Tmin

When the Best < Tmax, the score is determined as:

Skidpad score = $$71.5 \times \frac{(Tmax/Best)^2 - 1}{(Tmax/Tmin)^2 - 1} + 3.5$$

When Best > Tmax, Skidpad score = 3.5.

Acceptance Criteria

It was observed that the average score for most teams is 45 points, yet the placement in the overall competition is determined by cumulative points. Therefore, a higher score than 45 will be our goal.

3.3 Steering System Free Play

Test Overview

This test will measure the steering system free play, which is defined as the maximum angular displacement of the steering wheel that is reached before the wheels will begin to turn.

Objectives

There are several joints connecting the aluminum rod members of the steering system. Because each joint in the assembly will not return a static reaction force to driver input torsion before it locks, there will inevitably be a small range of motion from the steering wheel before the driver input will result in turning of the front wheels. The objective of this test is to ensure that the steering system free play of our assembly does not exceed the maximum allowable value of seven degrees specified in the FSAE rulebook.

Features Evaluated

This test will evaluate the initial discrepancy between the driver input and the motion of the wheels, one of the many factors in considering the system's operational ability to navigate a hairpin turn.

Test Scope

Since the positioning of the joints when the steering wheel is at its neutral position is unclear, it is necessary to measure its initial angular position when turned to its extreme leftmost or rightmost end. Though input torque is not a parameter varied in this test, a torque wrench must be used to standardize the input torque applied to the steering wheel during each test to minimize any inconsistencies. Additionally, the wheels must remain perfectly stationary for the duration of the test.

Test Plan

To perform this test, we will first turn the steering wheel, with tires free to move, to the extreme leftmost position, stabilize the front two wheels of the car, and mark a reference point of the steering wheel's position. Then, we will turn the steering wheel to the right (clockwise).

When the steering wheel's motion is impeded at the other end, we will mark a second reference point. The angular distance between the first and second reference points will serve as the experimental value for steering system free play. This value will be determined by using a more rudimentary method which involves marking the neutral upright position of the wheel and then measuring the amount of change in angle when the wheel is turned to its maximum position. We will then repeat the same test beginning at the rightmost position of the steering wheel and turning it all the way to the left (counter clockwise). To ensure reliability of this data, we will perform this test ten times and create a discrete array of results. We must then show that with a 95% confidence interval that the angle of free play never exceeds that of 7 degrees.

Acceptance Criteria

Your design will pass this test if the measured steering system free play does not exceed the seven-degree maximum specified in the FSAE rulebook, within a 95% confidence interval.

3.4 ECU/Powertrain Test Plan

Test Overview

This test will provide an overview evaluation of the performance of the EFI system and the powertrain integration as a whole.

Objectives

The objectives of this test plan are to show the satisfactory performance of the EFI system through the healthy idle and running conditions of the engine.

Features Evaluated

The features that will be evaluated include the features of all the dependent ECU/Powertrain subsystems tests, such as all of the sensors and actuators, as well as the ECU programming, and the engine itself.

Test Scope

The engine will be run at various conditions, such as idle, half throttle, and full throttle, in order to determine the overall functionality and performance of the integration of the dependent subsystems.

Test Plan

This test requires that the ECU/Powertrain subsystem test be completed and verified. Once the components are determined to have successfully passed their individual evaluations, the overall test can be completed.

This test will be performed to ensure that the engine is injecting fuel and firing at proper times within the cycle in order to ensure proper fuel and ignition timing. This will provide an overall test to the entire ECU, evaluating all facets of the subsystem at once. The engine will be run at various throttle positions listed here: closed (idle), half open, and fully open. The test will be three times at each throttle position, and the average of each of the runs will be taken to represent that data at that point. In each of these positions, we will be looking at the engine performance using TunerStudio, as well as listening for any misfires and engine skipping. Using TunerStudio, we will observe whether or not the spark and fuel outputs are timed correctly. The spark must fire before the engine reaches 8° before TDC, as determined by the crankshaft position sensor. Additionally, the fuel must be injected before 8° TDC. The test will be performed three times for a minute at each throttle position to confirm repeatability. Using the information given by the MS2 on the Megasquirt website for the RPM measurement, we are assuming an accuracy within 1% for the measurements recorded in TunerStudio.

Acceptance Criteria

In order to pass this test, this system must show that it is operating according to the programming of the ECU within the TunerStudio observation software. The spark must fire between 8° before TDC and 4° before TDC, as determined by the crankshaft position sensor. Additionally, the fuel must be injected before 8° TDC and 4° before TDC. If the test shows that the mean of the data falls outside of a 95% confidence interval of the range specified, the ECU test has failed. Additionally, it must not have audible misfires or skips while the engine is running under any of the loading conditions.

<u>3.5 Performance Checks</u>

The purpose of these tests is to check for reliability of subsystems and parts of the car. They are meant to be quick and easy tests that can be done periodically throughout the year. While these tests do not require rigorous data analysis, they are important to check for FSAE compliance and road safety. Success will be determined simply by observing whether the aspect being tested works or does not work. The following tests are recommended:

- Axle bearing Test - The axle bearings will be tested by rotating the tires to check for stability. This test can be performed without a functioning engine and it can be done on campus. To carry out this test properly, there is an approximate distance of 10 to 15 meters needed as a minimum to be able to rotate the tires at different speeds and many times. An easier, but not as reassuring way to perform the tests is by rotating the tires manually and checking if they hold firmly in place and rotate within the axle housing. There is no test equipment required.
- Brake-Bias - Need to test the brake balance between both wheels. This test can be conducted whenever the car is driven and the engine doesn't need to be working. The testing location can be on campus and it will require a driver that will activate the brakes. There is no necessary testing equipment aside from the safety helmet and harness. It may be a good idea to consider having more safety precautions in case the test goes wrong. However, they won't be necessary if the vehicle speeds are kept low enough to arrive at a full stop without the need of perfectly functioning brakes
- Chassis Rigidity - The welds that hold chassis together are not of concern, but the welds made to mount other components to the chassis, such as the suspension. Verify whether the welds are strong enough to support the loads from other systems. The reason for this is because some of the welds appear to be susceptible to failure of fatigue. The team should add different types of stresses to suspected welds while avoiding damage to the rest of the car. One way could be to take the car to a parking lot on campus and drive it. This test would definitely help to make sure that the welds are firm enough. However, if one of the welds isn't as firm as expected, the car could take some damage. For this reason, this test should be performed at slow speeds at first, and gradually increase it as the team gains more confidence on the rigidity.
- Cockpit Harness - The harness should be tested to ensure it adheres to FSAE requirements T.2.2, T.2.3, T.2.4 and T.2.5. The harness can be installed to an outside Primary structure, then its rigidity should be tested using a dummy of similar weight class to the driver.
- Temperature (Firewall) - This test is done to check for the temperature in the powertrain section of the car. This test can be done periodically throughout the semester. It is recommended that the temperature of both sides of the fire wall be taken. The main

concern is the possible overheating as a result of faulty coolant system, thus the engine temperature should be taken. The test is also conducted to ensure FSAE requirements are met for heat propagation in regards to the cockpit and the driver, thus the temperature of the cockpit side should be taken. The temperature sensor on the engine can be read using the ECU and the cockpit temperature can be measured by any tool the team sees fit to use. A possible option is making a calibrated surface thermocouple using the tools and material available on campus.

- Vibration Check - Make sure nothing is significantly affected by the vibration of the car, assuming a perfectly working suspension system. This test is a preventative measure to ensure no parts become loose when driving. Thus it recommended to check for any displacement of any parts after a test drive. Some parts may include but not limited to the battery, fasteners and the ECU.
- Rear Suspension - One of the main causes of failure for many groups in competition during the Endurance Event is a broken push rod, axle or a-arm of the rear suspension. This is because the rear part of the car carries most of the load. Thus, it is important to routinely stress the structure of the rear suspension to check for failure. It is prefered to have it break during testing than in competition. The test can possibly be performed by applying a load to simulate a bumpy road, such as rocking on it repeatedly.
- Noise check - Since the team hasn't turned on the engine yet, it wasn't possible to test whether the decibels emitted from the car fall under the FSAE guidelines. It will need to be tested for sound and then a muffler should be attached to the exhaust to bring the noise within FSAE guidelines. There are software apps that can permit smartphones to measure decibel levels, or digital decibel meters.
- Fuel consumption - This is a test for the future, but still important for the competition since there is a fuel-economy event. The future team needs to test how long the fuel lasts and ideally try to find a way to extend mileage. In this test the car will be driven until fuel runs out from a full tank. The main criteria is whether the car can drive 24 km without stall. Since fuel consumption is dependent on most systems of the car, it is recommended to focus on the fuel-mapping and power from the engine for improvement.
- Electronics - The electronics should be checked on time-to-time to make sure they are working as expected. This includes sensors, ECU and the Arduino speedometer.

4. Appendices

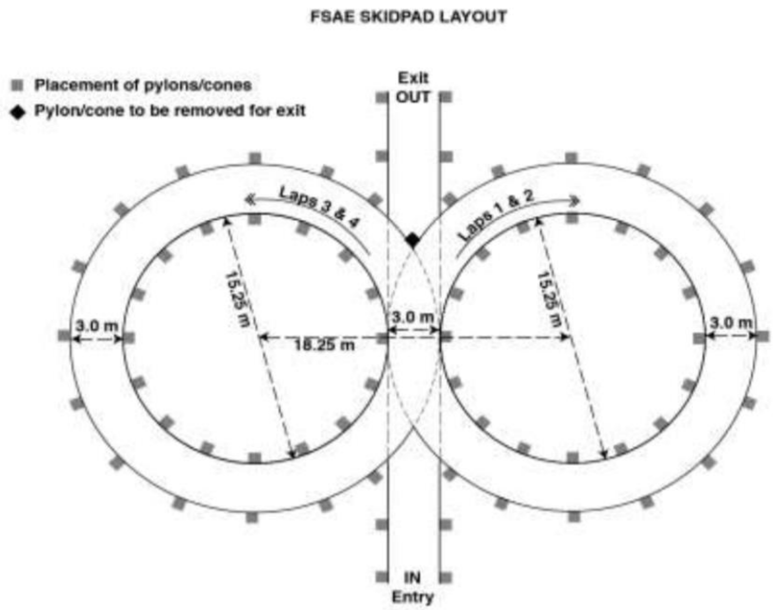


Figure 1. Skidpad test design

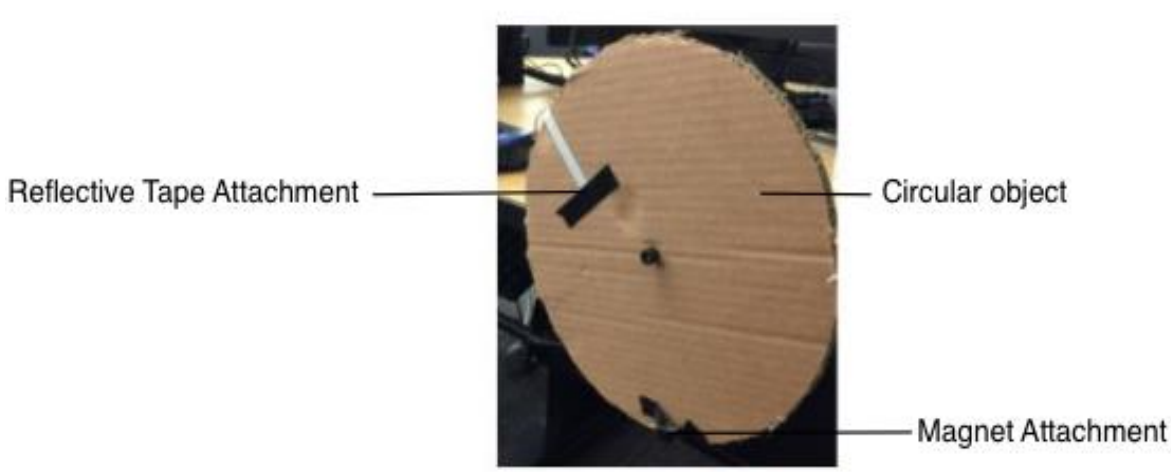


Figure 2. Device for speedometer testing

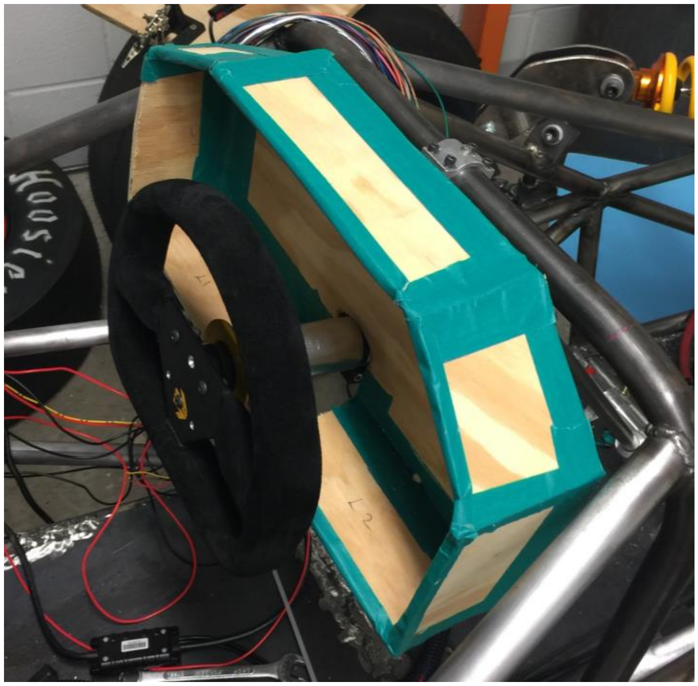


Figure 3. Instrument panel framework attached to Front Hoop

Appendix D: Test Results and Analysis Manual

Full Prototype Test Report for a Formula SAE Car

The Formula SAE Team:
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Matthew Thompson

April 16, 2020

Executive Summary

Formula SAE is an international collegiate competition organized by the Society of Automotive Engineers. Students are offered the opportunity of designing and manufacturing an open wheel Formula One-style car and competing in both static and dynamic events. Formula SAE has evolved from a domestic event in the U.S. to an international competition throughout the world being held by countries in Europe and Asia. Trinity University has yet to become a participating college in the competition. In 2016 the Trinity University Motorsports (TUMS) and the senior design team started Trinity's path to compete in Formula SAE. Since then, getting the car ready for competition has been the objective of the project.

The major design systems of the car are the cockpit , the suspension redesign, and the ECU for the engine's EFI system. Many of these components can be tested by directly evaluating their compliance to the standards given in the FSAE guidebook. Therefore each test will evaluate the cars subsystems in account of the FSAE guidelines, with the exception of speedometer and ECU. The speedometer and ECU will be evaluated by criteria determined by the team. The tests to be administered are: Speedometer accuracy, ECU control of the EFI system, Skidpad event of competition and the Steering degrees of play.

To evaluate the tests of the maneuverability of the car will help us ensure that FSAE guidelines are met, the tests of the speedometer prove our ability to provide correct information to the driver and the test for the ECU will confirm the reliability of the powertrain system.

1 Introduction

Formula SAE is an international collegiate competition organized by the Society of Automotive Engineers. Students are offered the great opportunity of designing and manufacturing an open wheel Formula One-style car and competing in both static and dynamic events. Formula SAE has evolved from a domestic event in the U.S. to an international competition throughout the world being held by countries in Europe and Asia. Trinity University has not participated in the competition prior to its initiation 2016. All the previous senior design teams have yet to finish a working car given their two semester time constraint. Hence, the design and development of the car is an ongoing project that has 3 years of work done by 3 previous senior design teams. The work that has been done includes the assembly of the chassis, suspension, some of the powertrain, steering and braking.

2 Design Features

Concerning our work on the car, some of the major design systems are the cockpit (which includes the instrument panel on the dashboard, the seat, steering wheel mount, and firewall), the suspension redesign, and the ECU for the engine's EFI system (including the wiring harness, controller programming, Lambda sensor programming, and other important powertrain components such as the gas tank). Many of these components can be tested by directly evaluating their compliance to the standards given in the FSAE guidebook. However, the EFI system poses a significant challenge, as there is no such standard describing such things as emission control or spark timing. This component will be evaluated based upon standards determined by the FSAE team, which will show efficient spark timing and fuel dispensation as well as showing that all of the necessary sensors and actuators are functioning according to their intended purposes.

FSAE Competition Rules Compliance: Several tests will compare the planned/manufactured and assembled subsystems to the Formula SAE competition rules pertinent to the respective subsystems. For example, FSAE requires that the steering system free play be no more than 7 degrees. This rule motivates the need for a free play test that will evaluate how much steering input is needed before the front wheels begin to respond. Another example of the application of FSAE rules include the physical dimensions of the track for the skidpad and hairpin turn competition events. Using the size and shape of the competition track we computed a minimum achievable turning radius for the car in the skidpad event, which we will test with the skidpad test.

Optimized Cockpit with Accurate Instrument Panel: The instrument panel, which includes only a speedometer, will be tested in the speedometer test. The speedometer should accurately display the vehicle's speed, and it should be clearly visible to the driver at all times. Also, it must fit within a dashboard that fits within the cockpit.

Based on last semester's test on the speedometer, the team decided to test the second course of action for the speedometer's sensors. Initially, a test plan outlined a light based sensor that read the device’s speed based on the amount of time it was exposed to a photoresistor. This plan was replaced with a magnetic reed switch that measures speed based on the time it takes to sense a magnetic field. The tests were successful but an alternate plan was made to accomodate time needed to finish the instrument panel design and the outside effects that environmental light sources may have had on accurate speed measurements.

<u>3.1 Instrument panel and Speedometer</u>

Procedure

The test will involve a calibration tachometer reading that senses the position of a reflective tape and measures the speed of the device the reflective tape is attached to. The same process is used to obtain readings from the Arduino-based speedometer on the instrument panel but a magnet is used in place of the reflective tape and the reed switch sensor in place of the tachometer sensor. The test device will be a circular object similar to a tire profile. This setup is shown in Figure 3.1.1. A magnet will be attached at a known radius from the center of the tire which is coded into the Arduino software. The magnetic reed switch attached to the speedometer will be used to sense the magnet on the tire.

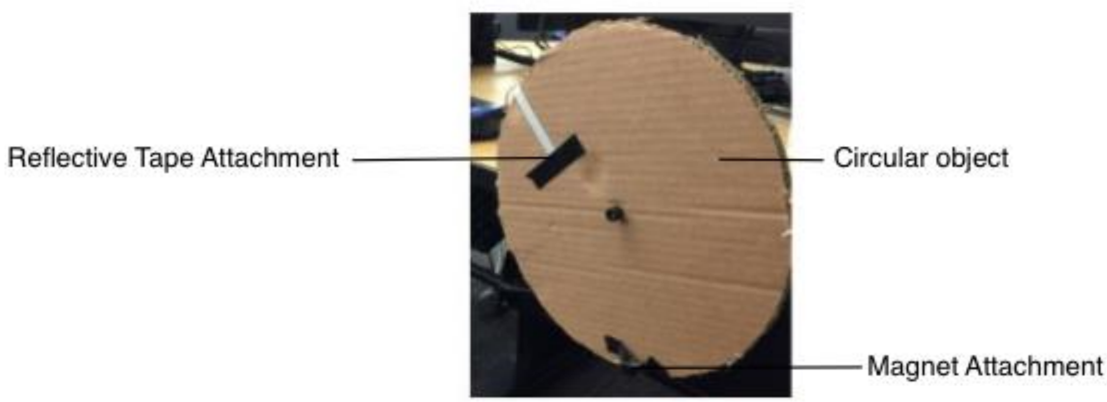

Figure 3.1.1. Setup for first speedometer test

The test procedure involved taking 3 repeated measurements of corresponding speeds by spinning the circular test device that holds the reflective tape and magnet. The calibration tachometer and Arduino-based speedometer sense the speeds of the reflective tape and magnet respectively which corresponds to two readings of the device speed. This process is repeated for 5 different speeds and tabulated.

The speed of the device to be measured will be matched with a calibration speed from the tachometer or speed gun used to measure the device as well. The percentage error between the readings will then be measured using the following equation;

$$\%error = \frac{Speedometer\ Reading - Tachometer\ Reading}{Tachometer\ Reading} \times 100$$

The percentage error will be obtained for each corresponding readings and the mean and standard deviation will be calculated for the percentage error and repeated measurements at each corresponding reading.

The instrument panel's strength and positioning will be tested by mounting its framework on the Front Hoop in the cockpit according to FSAE rule F.5.9 and ensuring it is rigid when the car is finally able to move by meeting either the condition of being attached to a brace node or a fully Triangulated structural node or with additional structural bracing. The instrument panel will be tested further to ensure the cockpit master switch can push-rotate when needed along with the aforementioned rigidity.

Acceptance Criteria

The results from the speedometer test will be acceptable if the recorded speeds on the LCD screen match the calibration speed from the speed gun within a percentage error of ±5%. The speedometer has to measure speed when it relatively increases and decreases. The results of the instrument panel should be able to adhere to requirement IC.8.4.4. Any similar tests done hereafter should have similar requirements.

Speedometer Test Results and Evaluation

Table 1 shows the rough data obtained from the given test plan for the Arduino Speedometer. The tests at each speed was taken from force, which continually increases, applied to a wheel holding a magnet and reflective tape in order to calibrate the speedometer. The speedometer readings are repeated 3 times to confirm reliability of the Arduino speedometer.

Another set of predicted results shown in Table 3.1.2 are documented for an optimal test that would involve a precalibrated spinning system that could be set to needed speeds without needing an applied force. This test would have been done but the COVID-19 situation delayed retesting of the speedometer prototype and would have to be actualised with the next FSAE team.

Table 3.1.1. Actual Readings taken on calibrating tachometer and Arduino speedometer

Tachom	Arduino Speedometer (RPM)	Mean	S. D.	Mean	S. D. (%

eter (RPM)	Meas. 1	% error 1 (%)	Meas. 2	% error 2 (%)	Meas. 3	% error 3 (%)	(Meas.)	(Meas.)	(% error)	error)
68.6	36.1	47.2	36.1	47.2	36.1	47.2	**36.1**	0	**47.2**	0
154.5	212.6	37.6	179.7	16.3	160.8	4.1	**184.4**	21.4	**19.3**	13.8
189.7	250.8	32.2	233.7	23.2	280.9	48.1	**255.1**	19.5	**34.5**	10.3
266.4	305.8	14.8	329.3	23.6	391.6	47.0	**342.2**	36.2	**28.5**	13.6
493.5	447.3	9.4	467.7	5.2	416.5	15.6	**443.8**	21.0	**10.1**	4.3

From the test results above, the test objectives needed to evaluate the actions of the Arduino speedometer are not fully met using a calibrating tachometer. The trends seen in the table shows that as the recorded speed by the calibrating tachometer increases, the Arduino speedometer records corresponding speed increases. This meets one objective of the test plan to increase and decrease respectively with the test disks speed. Another trend seen from the test is when the speed is lower, the readings are less accurate where the mean percentage error is 10.3%±4.3%. The speedometer readings got close to that of the calibrated tachometer at higher speeds. The acceptance criteria of a ±5% error is not met but all speedometer readings are within ±50% of the tachometer readings which is acceptable because of human error.

The results in Table 3.1.2 are predicted to meet the acceptance criteria of ±5% because an optimum testing device is used. All percentage errors are within ±5% and the measured speeds increase and decrease respectively with the devices speed. The speed of the measuring device is also known before testing the speedometer making the percentage errors more accurate than if its speed was being measured during the test. These results would have served as the final tests of the redesigned prototype. If they are obtained with the next FSAE team, the speedometer can be labelled race-ready.

Table 3.1.2. Predicted results from optimal testing device

Meas.	Arduino Speedometer (RPM)	Mean	S. D.	Mean	S. D.

Device (RPM)	Meas. 1	% error 1 (%)	Meas. 2	% error 2 (%)	Meas. 3	% error 3 (%)	(Measurement)	(Measurement)	(% error)	(% error)
50	48	4	52	4	46	8	**49**	3	**5**	2
150	154	3	159	6	155	3	**156**	2	**4**	1
200	203	2	199	1	200	0	**201**	2	**1**	1
250	250	0	251	0	250	0	**250**	1	**0**	0
300	300	0	295	2	300	0	**298**	2	**1**	1
350	355	1	360	3	360	3	**358**	2	**2**	1
400	395	1	400	0	405	1	**400**	4	**1**	1
450	460	2	455	1	450	0	**455**	4	**1**	1
500	500	0	505	1	505	1	**503**	2	**1**	1
550	550	0	550	0	551	0	**550**	1	**0**	0

Instrument Panel Test Results and Evaluation

In order to adhere to IC.8.4.4, the instrument panel should hold a cockpit master switch accessible to the driver within the cockpit. The cockpit master switch on the instrument panel must also be able to push-rotate when needed. The instrument panel should remain rigid when the car rolls over to adhere to FSAE requirement F.5.9.

Accomplishments

The initial speedometer tests were completed in order to test its working capacity. The framework of the instrument panel was also built and mounted to test its strength and structure. The cockpit master switch keyhole was also drilled on the instrument panel.

<u>3.2 ECU</u>

Procedure

In order to test the timing of the engine, the car will be placed on concrete blocks with the tires removed, in order to allow the wheels to turn freely during testing. Figure 3.2.1 shows the proper placement of the concrete blocks for the testing procedure.Additionally, the throttle should be controlled at the throttle body itself, and not from the pedals. Therefore, the testing will be performed under a no load condition. This will enable the team to ensure that the engine runs smoothly with its initial tune. Before starting the engine, the MS2 should be connected to a laptop equipped with TunerStudio software. The software will be used to collect data from the MS2 while it is running. The test will be performed at three different throttle positions three times each, in order to ensure that the timing is within an acceptable range under different engine speed conditions. For each run of the test, the engine will be run for approximately 1 minute each time.

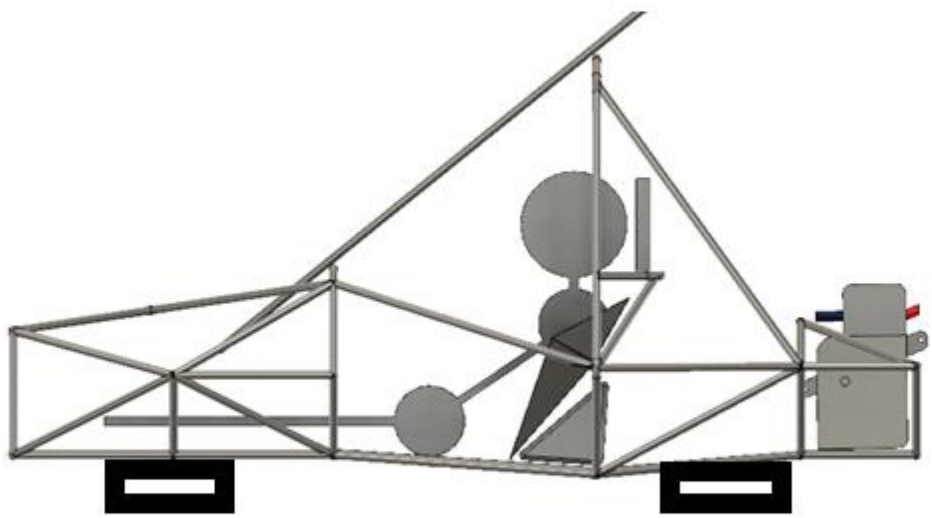

Figure 3.2.1 Placement of Concrete Blocks for Testing Procedure

Acceptance Criteria

In order to pass this test, this system must show that it is operating according to the programming of the ECU within the TunerStudio observation software. The spark must fire between 8° before TDC and 4° before TDC, as determined by the crankshaft position sensor. Additionally, the fuel must be injected 8° before TDC and 4° before TDC. If the test shows that the mean of the data falls outside of a 95% confidence interval of the range specified, the ECU test has failed. Additionally, it must not have audible misfires or skips while the engine is running under any of the loading conditions.

Test Results and Evaluation

Using the random number generator in excel (with the numbers ranging between 0 degrees BTCD and 12 degrees BTDC, in order to give a range of values with 50 percent of the maximum and minimum allowed values on each end of the acceptable range), we came up with numbers to demonstrate an evaluation of data. For each of the engine speeds, the test was run 3 times, for the number of times an ignition cycle would happen at the rpm (for example, considering a four stroke engine at 1,800 rpm, the ignition cycle would occur 900 times, and the intake cycle would occur 900 times as well). Sparing lengthy data tables, this procedure will be demonstrated for the idle throttle position only, for both the ignition and the intake cycles. Table 3.2.1 demonstrates the analysis of the data collected from this test.

Table 3.2.1 Ignition and Intake Position Data

	Ignition			**Intake**		
Degrees BTDC @ Idle (1,800 rpm)						
Mean [°]	6.02	5.92	6.12	6.01	6.09	6.10
Standard Deviation [°]	3.83	3.79	3.74	3.75	3.76	3.78
Confidence Interval [°]	5.77-6.27	5.67-6.17	5.87-6.37	5.76-6.26	5.84-6.34	5.85-6.35

If the 95% confidence level falls outside the range between 8° before TDC and 4° before TDC, the test will be considered a failure. From Table 3.2.1, we see that all of the values determined for the confidence interval for both the ignition timing test and the intake timing test are within this range. Considering this data set, the ECU test has been successful, as the 95% confidence interval is between the acceptable interval for both the ignition and intake cycles.

3.3 Skidpad

Procedure

As of now there are three optional testing sites, SWRI with the help of Dr. Enright, Harrison Hill Raceway or on campus. If the team plans to test on campus, before they can start testing, they will have to get permission by the school first. The team will have to contact Jennifer Adamo from Risk Management and Lieutenant Rowe from TUPD to get permission.

Next the team will have to acquire cones, possibly from TUPD and some sort of lining chalk for asphalt or rope. Other materials required are a timer, a logger and both drivers. It is recommended that the runs are recorded using a camera for documentation and future use. The team could compare the video footage to their results analysis and determine a course of action for improvement. The driving course should be set up in accordance to Figure 3.3.1, with 16 cones for the inner circles and 13 for the outer circles. In Figure 3.3.2 an example setup is shown.

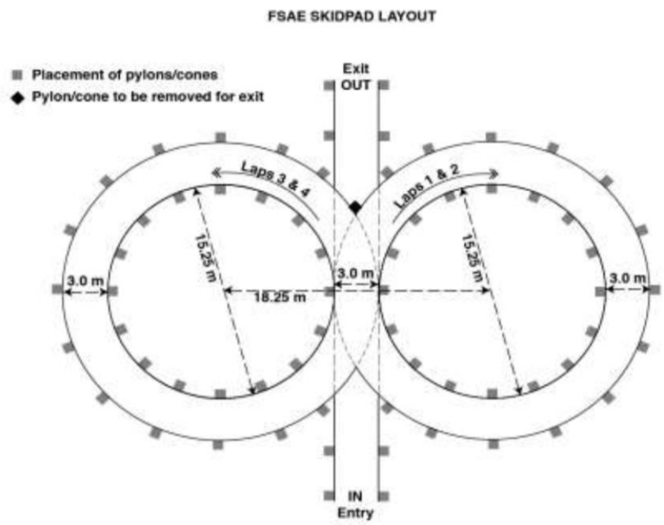

Figure 3.3.1. Skidpad test design

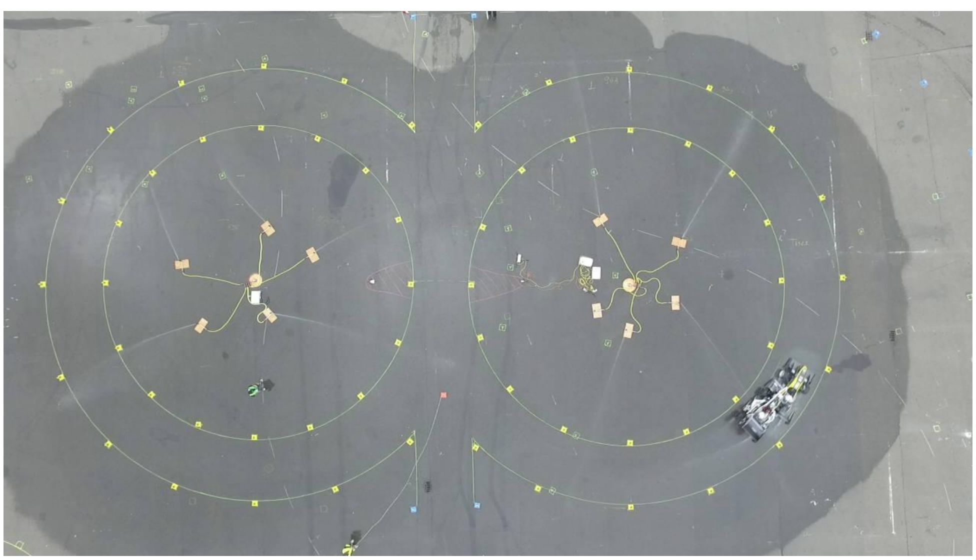

Figure 3.3.2. Skidpad event setup by FSAE Germany

The driver will enter and exit the course perpendicular to where the two circles meet. For the test, the driver will first make a lap on the right circle and then the second lap will be timed. After the second lap the car will enter the left circle and is allowed a third lap. The fourth will lap on the left circle will be timed and after the car will exit the course. After each run the team will calculate the score of the driver and compare it to scores recorded in previous competitions. An example would be the team's driver getting a time of 6 seconds on the second lap of the right circle and 7 seconds on the fourth lap of the left circle. And the driver managed to hit one cone. The corrected time would be 6.625 s. Assuming 6.625 is the drivers best corrected time and Tmin is found to be 6 s, score would be 39.29. The corrected time for each run will always be assumed as the best corrected time. The target speed for each run should be 30-40 km/h. In each run it is recommended that the drivers have their protective gear and are secured with a harness. An example is shown in Figure 3.3.3.

Figure 3.3.3. Protective driver gear, Brown Formula Racing

Acceptance Criteria

It was observed that the average score for most teams is 45 points, yet the placement in the overall competition is determined by cumulative points. Therefore, a higher score than 45 will be our goal.

Test Results and Evaluation

The following data was collected using the random generator function in excel. The right and left times were allowed to vary between 6 and 7 seconds. This was done to reflect the consistent times recorded in previous competitions. The cones were allowed to vary between 0 and 4. In most competitions the amount of cones hit is usually under 3. We chose up to 4 to allow for greater variation in the skidpad score. The corrected times and the scores were found using the formulas mentioned in the test plan. The percent error is calculated by comparing the recorded score to the target score of 45. This test simulation assumes that both drivers have been given adequate time to be familiar and comfortable with the car.

Table 3.3.2. Skidpad scores for Driver 1

Test Run	Right (s)	Left (s)	Cones	Corrected (s)	Score	Percent Error (%)
1	6.22	6.77	2	6.75	33.55	-25.4
2	6.67	6.49	1	6.70	35.43	-21.3
3	6.42	6.82	0	6.50	39.54	-12.1
4	6.54	6.83	0	6.76	36.38	-19.2
5	6.00	7.00	1	6.625	39.29	-12.7
6	6.39	6.45	3	6.80	31.24	-30.6
7	6.12	6.53	2	6.58	41.78	-7.2
8	6.22	6.59	1	6.53	44.07	-2.1
9	6.15	6.08	4	6.62	39.79	-11.6
10	6.24	6.41	1	6.45	48.25	7.2
11	6.53	6.10	2	6.57	42.29	-6.0
12	6.33	6.68	0	6.51	45.36	0.8

13	6.29	6.47	0	6.38	52.05	15.7
14	6.01	6.29	3	6.53	44.33	-1.5
15	6.72	6.24	0	6.48	46.67	3.7

Table 3.3.3. Skidpad scores for Driver 2

Test Run	Right	Left	Cones	Corrected	Score	Percent Error(%)
1	6.48	6.56	4	7.02	21.66	-51.9
2	6.52	6.83	1	6.80	31.02	-31.1
3	6.53	6.84	1	6.81	30.56	-32.1
4	6.24	6.06	4	6.74	33.82	-24.8
5	6.53	6.32	2	6.67	36.87	-18.1
6	6.03	6.46	4	6.75	33.37	-25.8
7	6.29	6.75	2	6.77	32.47	-27.8
8	6.87	6.31	1	6.71	35.11	-22.0
9	6.12	6.17	3	6.52	44.55	-1.0
10	6.84	6.39	0	6.62	39.69	-11.8
11	6.67	6.31	0	6.49	46.19	2.6
12	6.31	6.16	3	6.61	40.02	-11.1
13	6.17	6.55	2	6.61	40.07	-11.0
14	6.66	6.43	1	6.67	37.10	-17.6
15	6.45	6.21	2	6.58	41.48	-7.8

The average score for driver 1 is 41.35 and driver 2's average is 36.27. The standard deviations are 5.72 and 6.21 for driver 1 and 2. Considering a sample size of 15, there is 95 % confidence that driver 1's score falls between 38.46 and 44.25. Then for driver 2, their score is between 33.12 and 39.41. It is observed that averages of both drivers fall under the target score of 45. It is also noted that the maxima of both confidence intervals fall short of 45. The results indicate that either the car is underperforming or the drivers are inexperienced. If the car is underperforming the problem can be in any system. In example, Due to limited data, there is no way of telling whether the car or the driver is at fault. From the data driver 1 seems to be the favorable option for number 1 position.

The majority of percent errors are negative for both drivers. It is preferred that the percent errors are positive and much greater than 1 as it indicates scores higher than 45. For driver 1 initially start large in the negative and then decrease. The largest percent error is -30.6%, this indicates that the driver might need to improve on consistency. Thus the driver should aim for more times around 45. For positive percent errors it is preferred that they are as big as possible with little variation as well. As variation may indicate uncertainty the involved subsystems of the car. For driver 2 the same pattern is observed for the percent error. The largest percent error is -51.9%, thus driver 2 needs more work compared to driver 1.

Accomplishments

The steering wheel and system was assembled in a way that it complies with the FSAE guidelines. The team also found 3 places to perform this test as mentioned in the procedure section above. The car is almost ready since the only thing keeping us from carrying out the test is the proper functioning of the engine and brakes.

Design Requirements Unfulfilled

Only five runs from both drivers recorded scores higher than 45. Based on the analysis of the data for this test, either the braking, steering or driver need improvement. When this test is actually done the team members should pay attention to the car to see if there are any noticeable flaws. Then the team would be able to determine which subsystem needs improvement.

3.4 Steering System Free Play

Procedure

Make sure the car is in a large, open area on flat ground. Start by turning the steering wheel all the way counterclockwise, per figure 3.4.1.

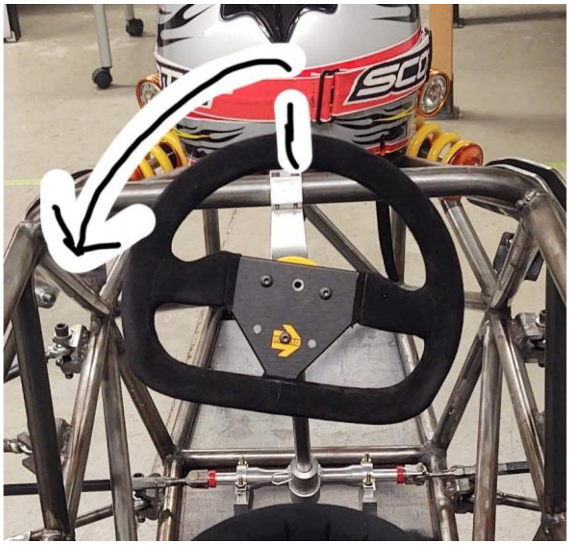

Figure 3.4.1. Turn the steering wheel all the way to the left.

Next, lock the front tires in place so that they cannot move. This can be done with blocks or other heavy objects placed to the right of each wheel, displayed by figure 3.4.2.

Figure 3.4.2. Place something on this side of the front tires so as to restrict any movement of the tires.

Mark the position of the steering wheel. To do this, the team may need to create some sort of apparatus that will stay in place as the wheel is moved, but will remain directly behind the wheel for easy marking and reference. Then, turn the wheel clockwise slowly until you feel resistance.

If the tires are secured properly, you will reach a point where the steering wheel will not turn clockwise anymore. Mark this point, and measure the angle between the two marks, using the center of the wheel as the vertex. Record your angle measurement (along with any uncertainty in the measurement equipment) and reset to the starting position, with the wheel turned all the way clockwise. Repeat this test until you have 10 measurements. Once you have obtained 10 measurements, follow the example below to analyze your data and determine whether the test can be deemed successful.

Test Results and Evaluation

The following data comes from a prototype test done by the 2018-19 Trinity FSAE team.

Table 3.4.1. Test results for steering wheel degrees of play

Test No.	Degrees of play (deg)
1	5.0
2	5.3
3	4.7
4	4.5
5	7.9
6	3.4
7	3.2
8	4.9
9	5.4
10	5.3

Keep in mind that your measurements will have some degree of uncertainty associated with them. Include the uncertainty of any tools or measuring devices you use in your analysis. Use the data to find the mean, standard deviation, maximum, minimum, and a 95% confidence interval; you should be familiar with the methods to find these things. The table below shows the values of these parameters for the data in Table 3.4.2.

Table 3.4.2. Summary of statistics for steering wheel degrees of play

Mean	5.0 deg
Standard deviation	1.3 deg
95% Confidence Interval	4.2-5.8 deg
Minimum	3.2
Maximum	7.9

If the 95% confidence interval falls anywhere outside of 7°, the test cannot be considered a success. Otherwise, if the confidence interval is entirely below 7°, the test is successful. Table 4.3.2 shows that this test would be considered a success because, despite reaching a maximum value of 7.9º, the 95% confidence interval ranges from 4.2º - 5.8º.

Citations

[1] MS2 microcontroller installation resource

[2] Online Resource

[3] FSAE Rules 2020 version 2.0

[4] Yamaha Phazer Manual