Full Prototype Test Plan for a Formula SAE Car

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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.

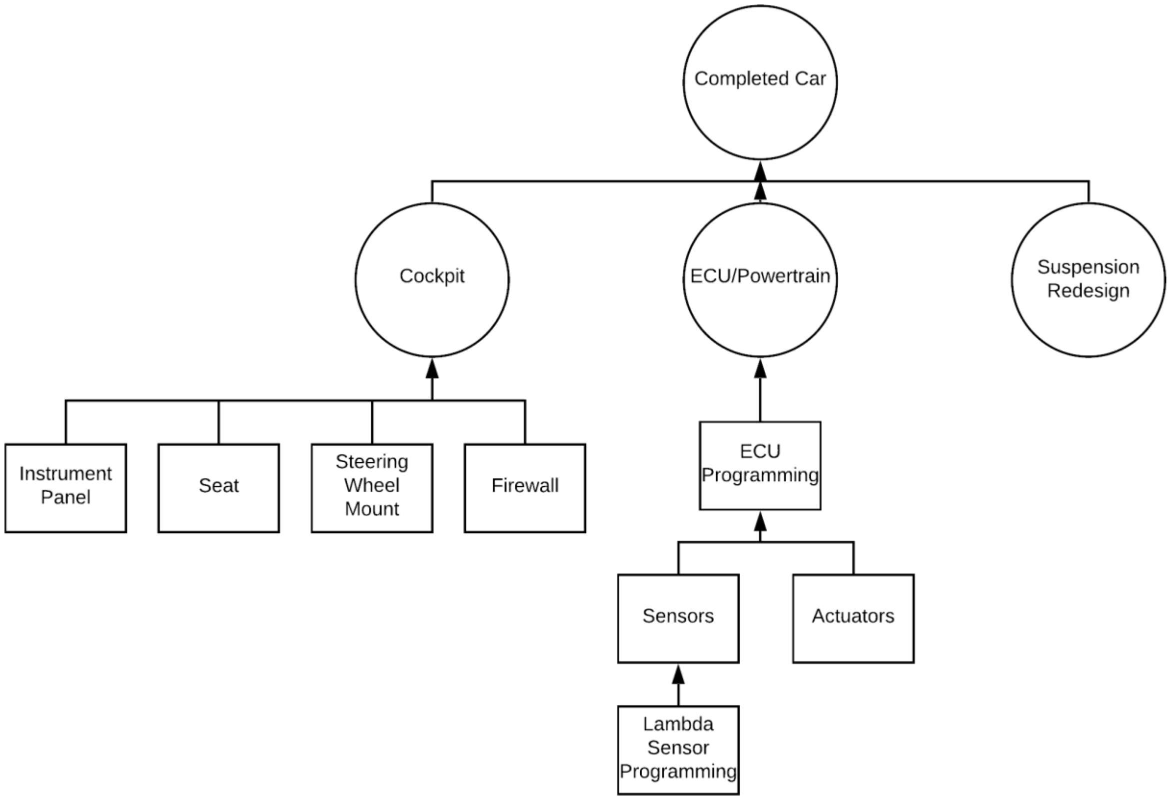

Figure 1. FSAE Car Test Plan Dependencies

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.

3.5 Performance Checks

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

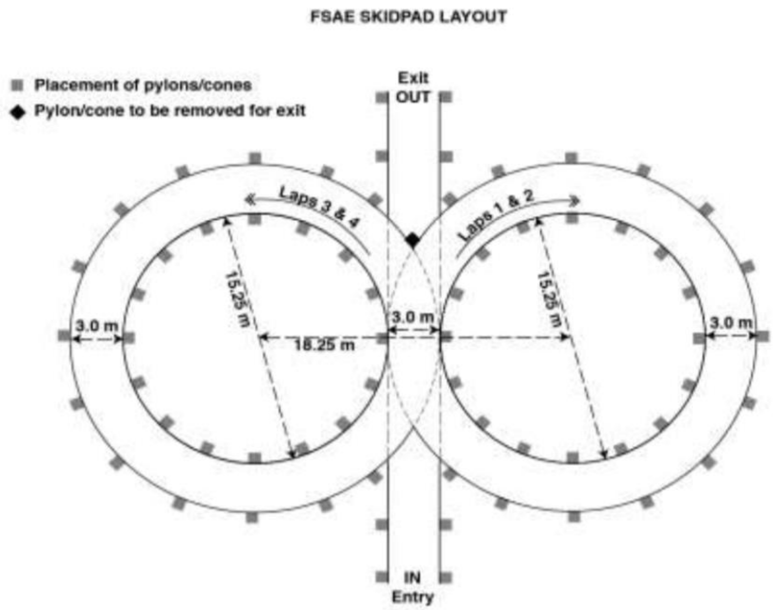

Figure 1. Skidpad test design

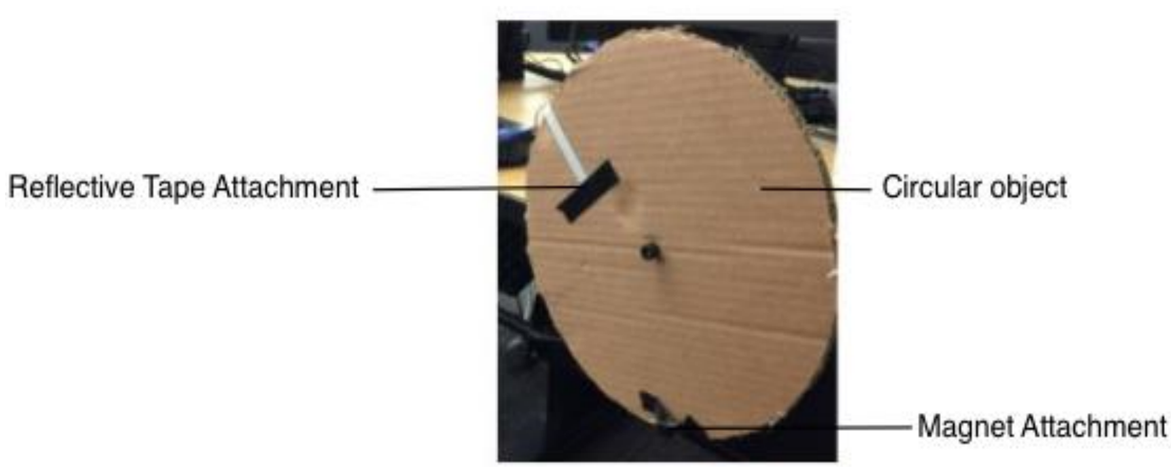

Figure 2. Device for speedometer testing

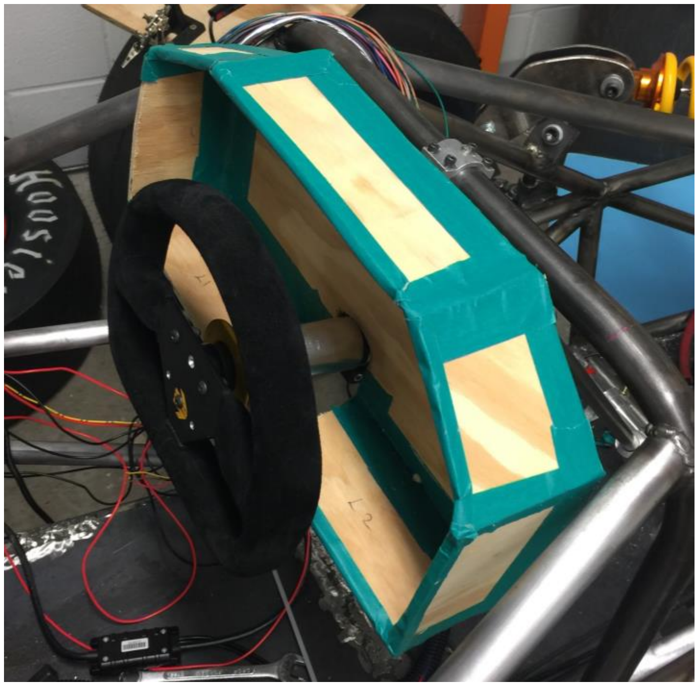

Figure 3. Instrument panel framework attached to Front Hoop

Signatures		
Project Name: FSAE		
The undersigned have reviewed and approved the final version of this document.		
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Team Members: 	**4/16/2020**	**4/23/2020**
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