Full Prototype Test Report for a Formula SAE Car

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

3.1 Instrument panel and Speedometer

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.

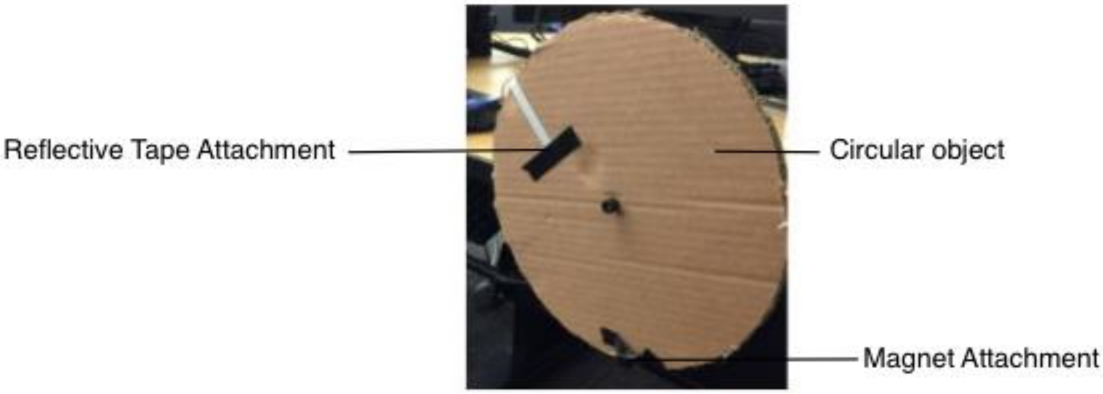

Figure 3.1.1. Setup for first speedometer test

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.

3.2 ECU

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.

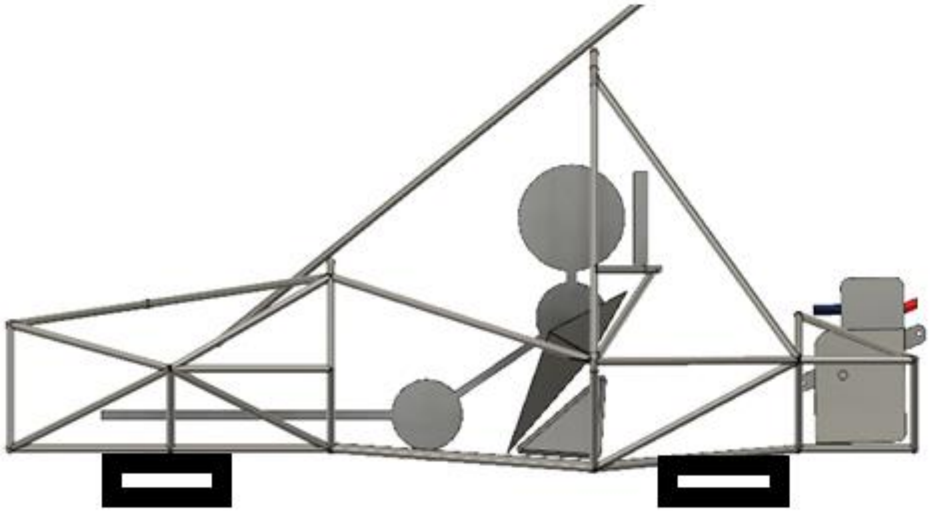

Figure 3.2.1 Placement of Concrete Blocks for Testing Procedure

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.

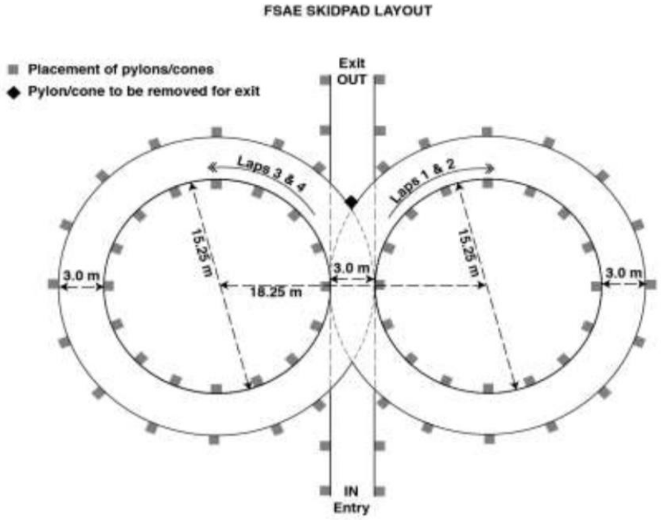

Figure 3.3.1. Skidpad test design

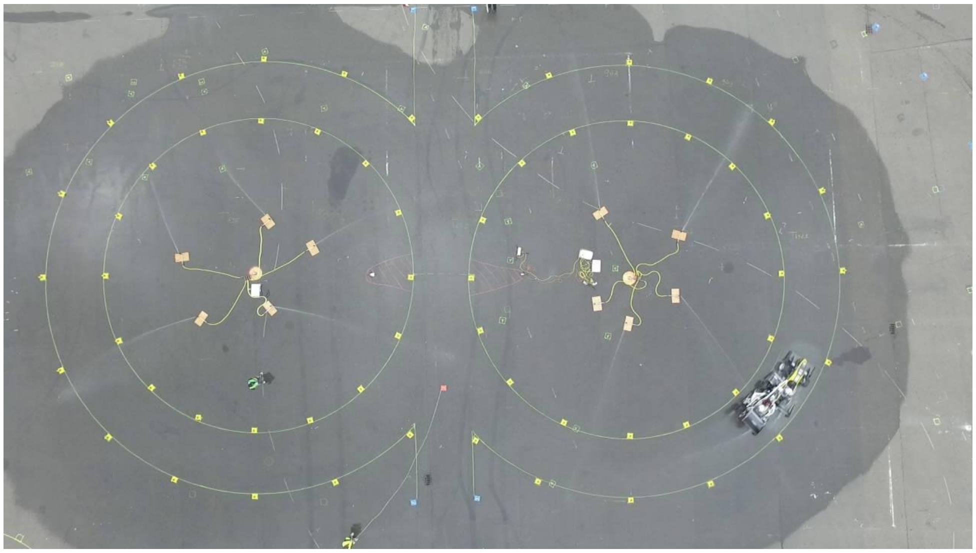

Figure 3.3.2. Skidpad event setup by FSAE Germany

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.

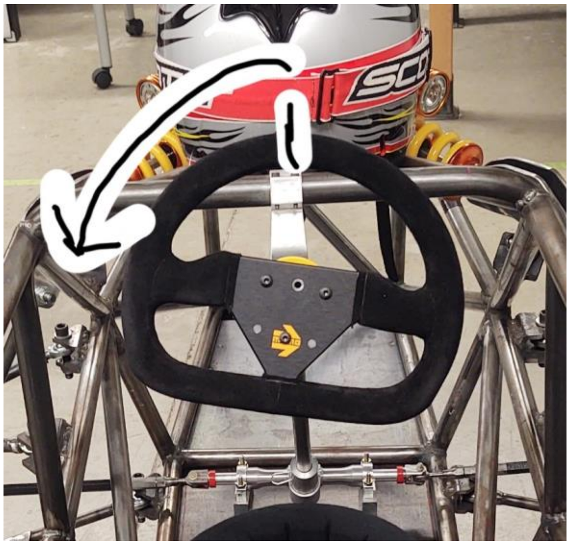

Figure 3.4.1. Turn the steering wheel all the way to the left.

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