Design and Optimization of an FSAE Frame, Suspension, and Business Portfolio

Submitted to the faculty of

Worcester Polytechnic Institute

In partial fulfillment of the requirements for this

Major Qualifying Project

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Abstract

The purpose of this MQP was to design and manufacture a new frame and suspension for use in the 2018 FSAE competition. Through analysis of the car entered in the 2016 competition, research, feedback from the previous designers, and critiques from the competition judges, optimized designs were developed. Improvements were made to the weight, ergonomics, impact strength, and reliability. Components were designed to incorporate the engine and other components from the previous car. Through the use of FEA the frame and suspension were tested to ensure the performance and safety of the final designs. The car's design also took into account the 2018 FSAE rules to ensure the car would be able to enter the competition easily and satisfy the judges' requirements.

Additionally changes were made to ensure an improved placement in the 2018 FSAE competition. Outlines for the business components of the competition were created including a cost report outline, business presentation outline, and standardized process for recording expenses.

Acknowledgements

We would like to thank David Planchard, John Hall, Kevin Sweeny, Zachary Sears, Adrian Pickering, Steven Murphy, V3 Cartesian tubing, Barbra Furhman and WPI SAE for all their help during our project. You all were critical in making this project possible.

Executive Summary

The Formula SAE competition is organized by the Society of Automotive engineers, and was developed to allow college students to design, manufacture, and drive a formula style racecar. The cars are meant to be build and marketed as weekend racers for non-professional drivers. The teams compete against one another is a series of events testing different components of the car to decide who has the best overall design.

The 2016 competition was WPI's best ever placement in the FSAE competition. Due to the strong results, instead of redesigning the entire car the WPI FSAE team will be using the 2016 car as a basis and making improvements to the designs of several subsystems. This represents the first year in a two-year build process. The 2017 project will the focus on making tune-ups and getting the car running for the 2018 FSAE Michigan competition.

The purpose of this MQP was to design and manufacture a new frame and suspension for use in the 2018 FSAE competition. Through analysis of the car entered in the 2016 competition, research, feedback from the previous designers, and critiques from the competition judges, optimized designs were developed.

The frame used in the 2016 competition was designed to be as strong as possible and accommodate any driver. These specifications though made the frame heavy and bulky. Our goals were to lighten the frame and improve the ergonomics. These improvements were made as a weight decrease improves the mechanical performance of the car. While the ergonomics make the car easier to drive. We believe both of these will improve our placement in the 2018 FSAE competition.

The in order to achieve the weight decrease several changes were made to the overall frame. The tubes on the old frame were made at a high outer diameter to increase strength so using the FSAE minimum requirements for tubing we decreased the diameter to tubes to the minimum to decrease weight. Additionally, the front section of the car was made smaller, this cut weight and allowed us to make the car more compact.

To prove that the new frame was comparable in strength to the previous iteration analysis was required. Finite element analysis (FEA) through Solidworks software was performed to determine the strength of our frame. Tests were performed simulation front impacts, side impacts, and the car rolling over. The same testes were also performed on the previous frame in order to equate the two. Through the tests we found that our frame passed the FSAE requirements and was comparable in not stronger that the previous frame.

The major issue with the frame ergonomics was that the front of the car was difficult to see over due to a large front roll hoop. This worked well with the weight decrease as shirking the front roll hoop achieved both goals. Additionally, the size of the front bulkhead was rotated this allows for an overall slimmer can and create a sleeker profile.

The suspension of the car from 2016 also had several issues that needed to be addressed. The bearings in the suspension had issues with binding where the suspension would not return to its rest state. Additionally, the geometry and the strut assemblies needed to be altered to fit the updated frame.

New frame tabs were designed and manufactured to connect the suspension members to the frame with spherical joints to eliminate binding. The springs and shocks were relocated to remain in plane with the suspension to eliminate side loading and bearing wear. Finally, the thickness and diameter of the suspension arms was reduced to save weight. Finite element analysis has determined the thinner arms maintain strength.

In addition to the physical car, there were managerial flaws within the team. The team was made up of entirely engineers with no students to develop the management, marketing, and financial side of the competition. The lack of business minded team members caused the team to not achieve the most points possible while the team was at competition. The team lack of effort into create the proper business materials for the competition caused the teams rank to decrease. With proper attention being pushed to the three major business sections of the competition, there was a guarantee of an increase in points as well as a better understanding of what the project is ultimately trying to accomplish.

The goals of the business team were to develop a set of outlines that could be passed down from year to year. These outlines are set to help future business or even ME team members create the documentation needed to understand, create, and submit each of the two major aspects of the project.

The Business Logic Case was the first document that the team should create. In years past someone on the team who was just aiming to get it completed threw it together. The goal of this document is to teach participants about the factors that need to be considered when a company embarks on development of a new product. These include: cost; identification of market and likely sales volume; profitability; the key features applicable to the selected vehicle concept and target market size.

The second part is the cost analysis. The cost analysis should be submitted prior to the competition before the specified due date. As well as submitting online, the report should be handed in as a hard copy the day of the competition. The main point of the cost analysis is to teach the participants that cost and a budget are significant factors and must be taken into account in any engineering exercise Ensure the teams develop their cars within a reasonable budget, many teams have worked what may seem like an unlimited budget, so it is very easy to get ahead of yourself with purchasing and manufacturing part for the single car, but it is important to remember that the grand scale of the competition is to create a car that car be mass produced.

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Background

The project required research into how the FSAE competition functions and the best way to execute our project. FSAE provides a detailed rule booklet to follow detailing requirement to compete in the competition. Additionally the team felt it important to establish how we would execute the project and what the goals of the project were.

Overview of FSAE competition

Formula SAE is a competition simulating that a manufacturing company contracted our design team to develop a Formula-style racecar. The car is evaluated for its ability to be manufactured and sold as a weekend racer for non-professional autocross. Each student team designs, builds and tests a prototype based on a set of rules whose purpose is both to ensure safety and promote problem solving among the team. The vehicle is inspected with tests to ensure it complies with the competition rules; in addition, the vehicle will be judged in a number of performance tests on track. The rest of the judging is completed by experts from motorsports, automotive, aerospace and supplier industries on student design, cost and sales presentations. The events are broken up into two categories, static events and dynamic events.

Events Breakdown

The static event include any event where the car is not moving and includes three events a presentation marketing the car, the engineering design, and the cost analysis. The presentation is done to a panel of judges who evaluate the business case for the car and are treated as the executives of a corporation. Judges evaluate how it meets the demand of the market, the ability to generate a profit and how well it can be marketed. The design event team are able to explain the design choice they made in developing the car, allowing the teams a chance to showcase their improvements and there they invested time in the car. The cost analysis is done with a standard format to show where the costs we allotted when building the car, along with the total cost of manufacturing the car (2017-2018 Formula SAE Rules). These three events are worth 325 out of the total 1000 point in the competition showing that priority is put on how the car functions.

The dynamic events are broken up into acceleration, skid pad, autocross, efficiency and endurance. Before the car even enters the events it must go through an inspection to test that the car fulfills all the rules of the competition. The acceleration test sees what speed the car can reach over 75m. The skid pad event measures the car's ability to corner through a turn, by having it race through a figure eight pattern. The autocross event is done to evaluate how the car races and is a timed race on a closed course. Efficiency and endurance are done together, the car is raced to test durability, reliability, and to test efficiency the gas level in the car is measured at the end of the heat. Given Below is the point breakdown for the event in 2017-18.

Static Events:		
	Presentation	75
	Engineering Design	150 (may be changed to 200 for 2018)
	Cost Analysis	100
Dynamic Events		
	Acceleration	100
	Skid-Pad	75
	Autocross	125
	Efficiency	100
	Endurance	275 (may be changed to 225 for 2018)
Total Points		1,000

Figure 1: FSAE 2017-2018 Scoring

2016 Competition Results

At Formula SAE 16 Michigan WPI can in 67th out of a total 115 teams with a total of 351.8 points out of the total 1000 figure 2.

Static Events			
	Presentation	38.4	/75
	Engineering Design	80	/150
	Costa Analysis	50.7	/100
Dynamic Events			
	Acceleration	0	/75
	Skid Pad	5.7	/50
	Autocross	14.2	/150
	Efficiency	70.8	/100
	Endurance	92	/300
Total Points		351.8	/1000

Figure 2: 2016 FSAE Scoring Results

This represents the best scores and finishing position that WPI has even had and a huge improvement in score from the 223 WPI received in 2015. Although there are still areas where we can garner more points.

On the Static portion of the events we had issues with the cost of our car. Due to time constraints for the team the cost portion and presentation were put together hastily before the competition. The cost our car came out to be 37,406 dollars. Way above the cost of the other cars which averages to around 16,000 dollars, placing us 109/115 teams. We additionally struggled with the business presentation. Teams will typically bring in business majors for this portion of the competition although ours was done last minute before the competition and suffered for this, the team came 94/115 on the presentation. The design team was solid, the issues here were the mainly with the toe bar and the suspension tabs. The issue with the toes bar was that it was mounted to the frame and not to the a-arms. The suspension tabs did not allow for easy motion as there was friction that stopped the wheels returning to their full unspring position.

For the dynamic competitions there are several areas of improvement. The team missed the acceleration competition because there were issues with the tech and the car was not approved to compete. We had a skid pad time of 5.783 seconds significantly more than the 4.735 for the top team causing to lose significant points. In autocross our lap times were low with the best being 64.588 seconds while the best team had a time of 45 seconds. Even boosting our time to 60 seconds would have been a 15 point increase. The endurance competition is a place for major improvement as we took 1889 seconds to finish while the top came in around 1416 seconds, but the top is so much higher the point drop off is rapid, the 15th team only got 200 points, out of the total 275.

Project Approach

In 2016 WPI competed in the FSAE Michigan competition so this year represents the first year in the build cycle. When starting the project our team first had to take into account the build cycle the WPI SAE club desired for the new car. The consensus was that since the 2016 car was a complete redesign and got WPI its highest score ever in competition, we would stick with the two year build cycle, but not completely redesign the car. The new approach to the project is to spend the first year of the build cycle optimizing and redesigning a couple subsystems on the car. The second year would be spent tuning up the other systems in the car and preparing for competition. In accordance with the needs of the team, the systems chosen to be redesigned were the frame and suspension.

Additionally the weakest part of the 2016 team in competition was its performance in the business portion of the competition. We felt this was important to develop during the first year of the build cycle as purchases for the car to compete in 2018 begin now and recording these purchases accurately are key to the team’s success.

Goals for 2016- 2017 MQP

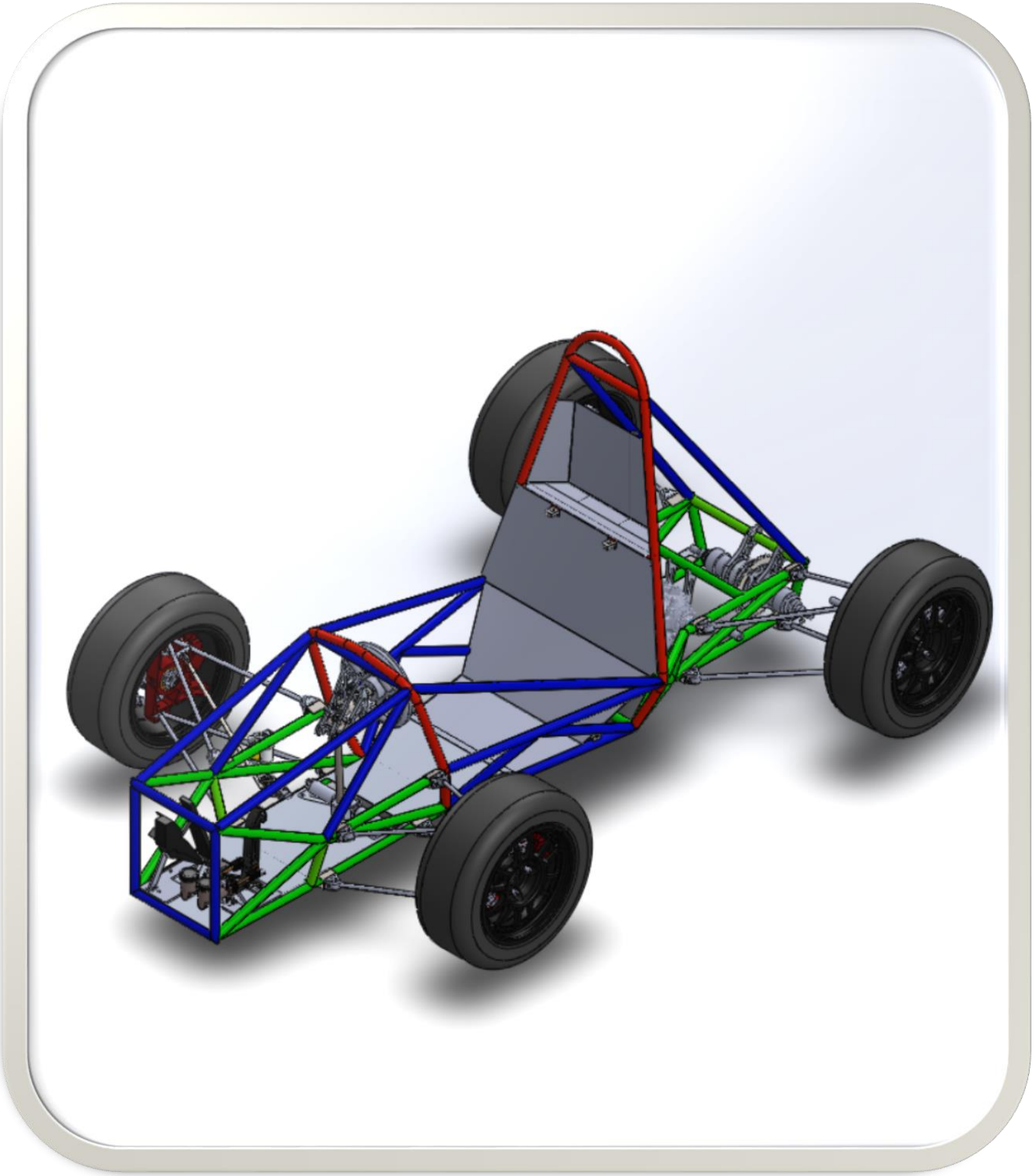
With the 2016 competition the team established a solid baseline for us to work off this year. Although there was substantial information missing about the previous car and its results during competition. We wanted to work through marginal improvements to boost our scores without doing a complete redesign on our 2 year build cycle. We also want to make sure that any work we do is easy to access and edit so future teams have a strong base and can begin work immediately.

The focus our project was to redesign the frame, suspension and business portions of our project to improve scores. Using the comments of the club and the judges last year our goal were:

a. Keep all files accessible, easy to edit, and organized
b. Make Incremental changes to 2016 Car design
c. Cut Weight wherever possible
d. All models and components must meet FSAE 2017-18 rules
e. Frame

    i. Improve frame ergonomics
    ii. Maintain safety for driver
    iii. Make sure current engine, drivetrain other components can be reused
f. Suspension
    i. Change suspension tabs to spherical joints
    ii. Redesign toe bars to be mounted to frame
    iii. Make changes for suspension to work with new frame
g. Business
    i. Create an instructional white paper for Business Logic Case
    ii. Create instructional white paper for the Cost Report
    iii. Evaluate last year's Business Presentation and create a standard format to follow
    iv. Create an organization strategy for the club

Full CAD Model



Frame

The Frame of a car provides the skeletal structure of the vehicle. In the case of FSAE the frame provides the primary means of ensuring the safety of the driver. FSAE rules provide strict requirements of the frame, in particular the material selection and standards for tube thicknesses for various parts of the frame. This ensures that a properly designed frame will protect the driver in the case of a crash. For cars following standard frame rules an excel spreadsheet provided by FSAE called the SES contains sections where frame design information is inputted. This information included tube thicknesses, number of support structures, and their angles and locations in relation to key components such as the roll bar. The SES then calculated a safety factor based on information provided. Highlights from the SES are shown in appendix 3. If a team decides to use nonstandard designs or materials the FSAE provides a series of extreme testing requirements including, front impact tests, side impact tests, and impact tests of the roll hoops along multiple directions. This is to ensure that the nonstandard frame maintains the ability to protect the driver to FSAE's standards.

Frame Introduction

In order to create and test our frame we used Solidworks CAD software and FEA simulations. Using the 2016 frame as a template we recreated the frame from scratch to help gain insight into how the frame was put together and what changes we would want to incorporate into our new design. In the design process of the frame the major issues we had to take into consideration were structural rigidity, manufacturability, ergonomics, and overall weight.

Of paramount concern in any car is the safety and survivability of the frame and by extension the driver. The frame must be tested to ensure that in the event of a crash no part of the frame with break or experience enough deflection to put the driver at risk. To aid in this analysis the Formula SAE rule book defines proper geometric rules in regard to triangulation of structural members and cockpit design. It also provides strict performance criteria and failure definitions for a series of structural tests concerning the roll bars, side impact members, and the front bulkhead, these tests are required for the validation of cars not complying with standard frame rules. Though our car complies with standard frame rules we based our own static FEA analysis of the frame on these same tests.

In order to manufacture our frame with the level of precision required we are had it made by VR3 Cartesian Tubing who is very well known within the FSAE community for their high quality manufacturing and precise fitment. Cartesian has very strict requirements for the manufacturing of FSAE frames particularly with the tube sizes available and the centerline bend radii of and bent tubes in the structure. The Formula SAE rulebook recommends the use of 4130 "Chromoly" steel and specifies the required minimum tube thicknesses for various components of the frame. This material is available through Cartesian and is offered in multiple tube sizes that fit within the requirements for FSAE.

Previous Year's Design

The frame that would be used by the SAE team in competition in May 2016 was originally designed by the 2015 FSAE MQP team and then modified by the 2016 FSAE MQP.

This frame allowed WPI to place higher than ever before in competition rankings, despite the success of the frame there were still areas for improvement to be addressed.

One of the problems with the 2016 car was how the positioning of the front roll bar partially obstructs the field of view for smaller drivers, since several SAE team members who will be drivers at the next competition voiced concerns over visibility we consider this of high importance and in our redesign proceeded to lower the front roll-bar and slim down the frame decreasing overall width and reorienting the front bulkhead. All of these design changes will make it easier for smaller drivers to operate the vehicle while still maintaining enough room for a 95^{th} percentile driver to drive the car.

The main goals of the previous frame design team were to create a strong frame to ensure the safety of the driver and to be able to accommodate a wider range of drivers. Unfortunately due to triangulation errors in the constructed frame additional modifications had to be added to make allow the car to compete in the 2016 FSAE competition, these added structural members increased the overall weight of the car (Figure 3) shows the initial design with the added structural members highlighted. Also in an effort to allow for the accommodation of taller drivers by the repositioning of the front roll hoop the frame created an obstructed view for shorter drivers.

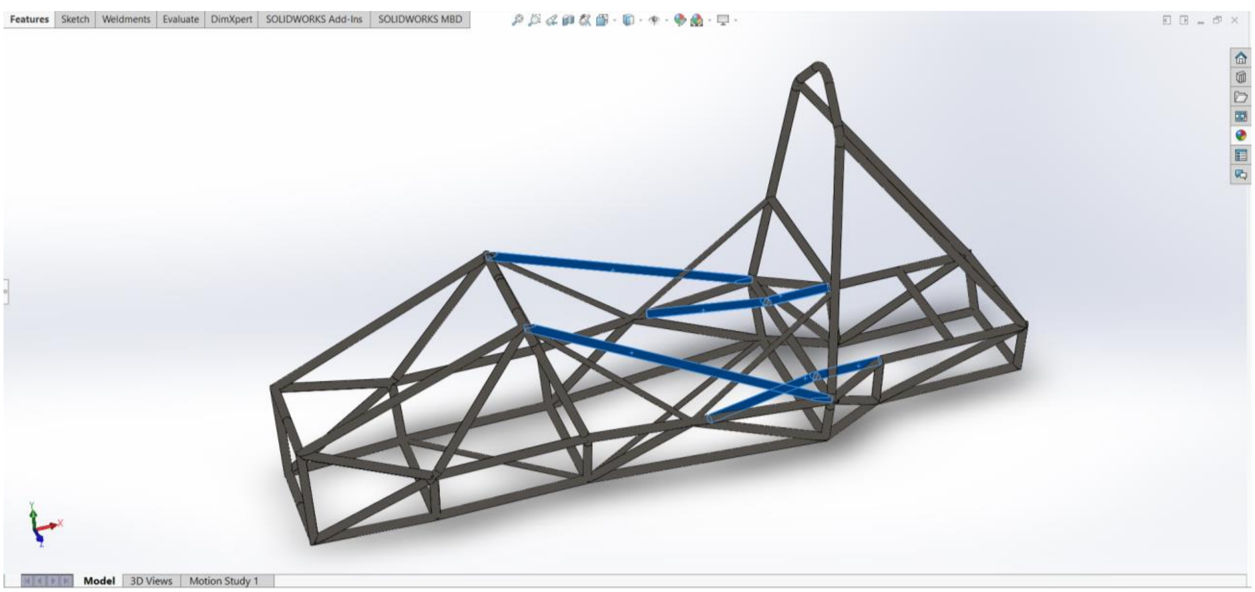


Figure 3: 2016 frame with added structural members highlighted

Our objectives going in to the redesign of the frame for use during the May 2018 FSAE competition was to:

1. Modify to existing design, addressing concerns with triangulation and eliminating redundant structural members to decrease weight while also maintaining high structural rigidity.

2. Adjust cockpit geometry to allow for better visibility for shorter drivers and to also aid in the decrease of overall weight.
3. Provide a Frame that can be used as template by the SAE club to make incremental improvements in the years to come rather than coming up with an entirely new design.

Frame Redesign

During the course of A-term we began work on redesigning the car frame. To start this process we needed a CAD model of last year's frame. The CAD model for last year's frame left over from the previous team was made in such a way that it could not be modified to include any redesigns we wished to incorporate. To solve to issue we recreated last year's frame using the original file as a reference, this time ensuring that the new model could be modified (Figure 4).

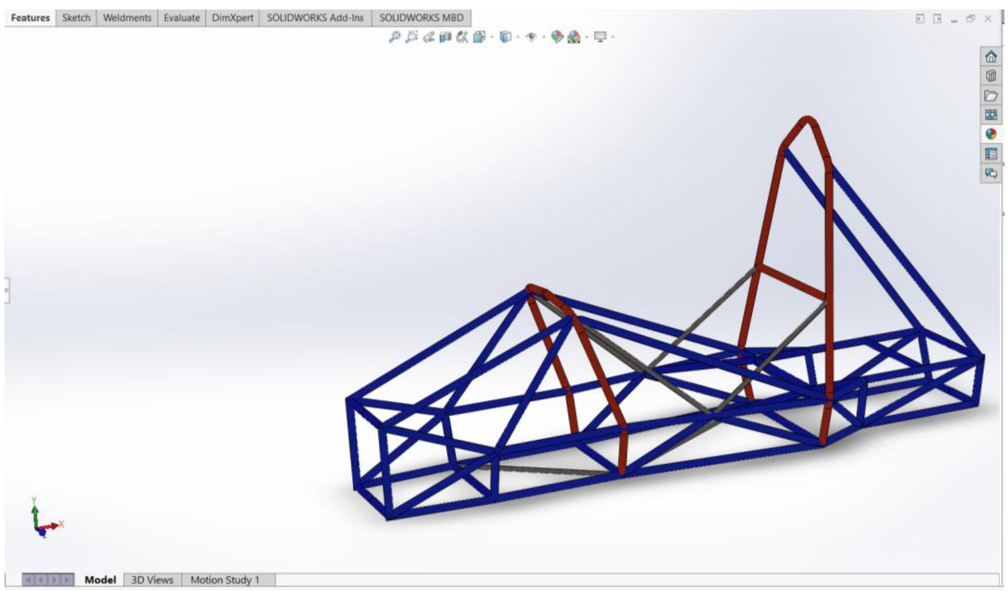


Figure 4: Frame design from last year's car color coded for tube size: blue=1x0.065in, red=1x0.095in, grey=0.625x0.065in

Once we had a working model up and running we began speaking with SAE team members to get an idea of what exactly their needs were for the redesign, we also had the opportunity to get hands on experience driving last year's car giving us a feel of what works, and what would need to change. Areas that we identified as in need of improvement were:

- The weight of the frame: currently the frame alone weighs 72.75 lbs.
- Triangulation of the rear of the frame: due to triangulation errors extra supports needed to be added further increasing the weight of the car
- Cockpit geometry: in the current design the position of the front roll hoop can obscure the vision of shorter drivers

After identifying these issues we created a concept redesign (Figure 5) as a potential way for us to address the different issues. To fix the triangulation errors the concept design featured a widened rear section, this eliminated the triangulation error and allowed me to remove the supports that were originally added to address the problem. Widening the rear of the car would also allow for more space for a larger fuel tank as we were told that endurance was one of the weak points at competition in May. Another set of modifications added was the adjustment of the positioning the roll hoops. The front roll hoop was lowered and the rear roll hoop was moved forward. This would alter the seating position of the driver allowing for better seating posture and would increase visibility for shorter drivers. In addition moving the rear roll hoop forward also helped increase more room in the rear of the frame.

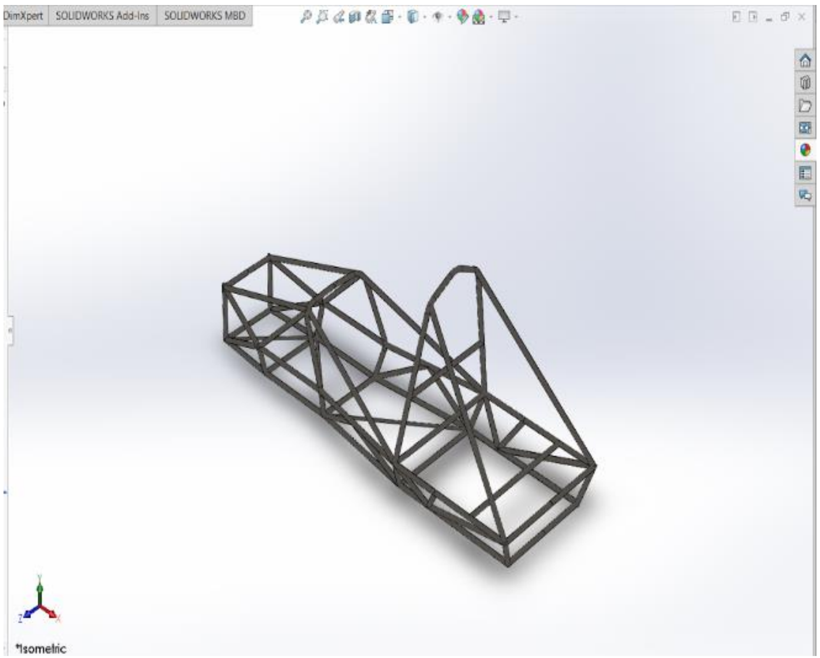


Figure 5: Redesigned Frame with wider rear and adjusted roll hoop positions

Improvements to Frame Design

After speaking again with the SAE team and showing them the concept design we decided to focus more on optimizing the current frame design rather than drastically changing it. As previously mentioned the club plans to make incremental improvements to the car, improving on previous versions rather than simply making a completely new design every year. Keeping the same basic shape our new goal was to decrease weight by removing redundant structural members and altering the geometry of the cockpit to remove excess space and create a tighter fit for the driver. After having an SAE team member sit in the car we took measurements to determine just how much we could alter the frame. Our next redesign (Figure 6) narrows the cockpit and lowers the front roll hoop.

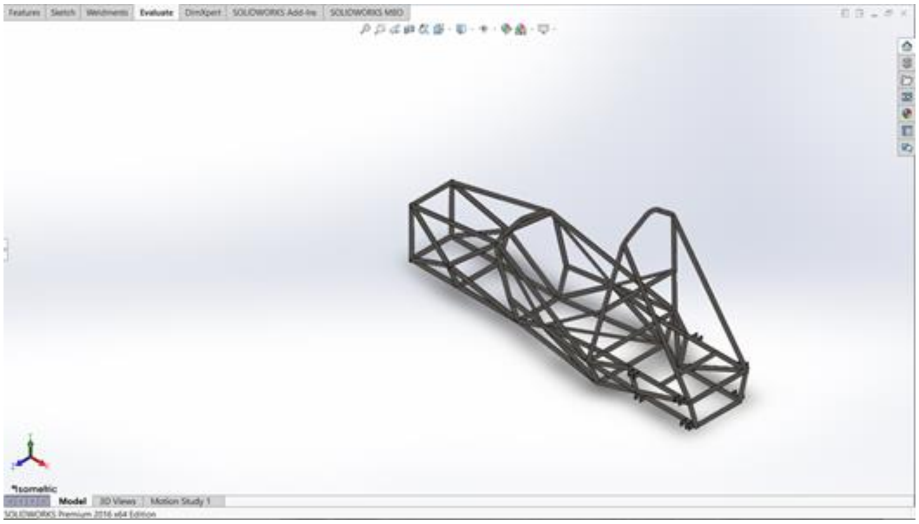


Figure 6: Redesigned frame with narrowed cockpit and lowered front roll hoop

While the modifications did decrease the frames weight (from 72.75 to 70.62 lbs.) it was not as big a weight reduction as we had hoped. Instead it seems like the most weight reduction will come from removing redundant supports and adjusting the tube sizes used in the frame construction. As a team we had an opportunity to speak with Zach and Adrian members from last year's team and we discussed our redesign with them. In regards to removing redundant supports they told us that in certain areas we may be able to replace support rods with sheet metal or gussets welded to the frame. One of the problems the SAE team encountered during the last competition was that several structural members used in the frame, mainly the 0.625x0.065in tubes were too small to be considered structural members. Since the judges in their analysis could not count these members we removed them from the design further decreasing our weight.

In reviewing the Formula SAE rules we looked at the minimum required tube sizes required for the frame (Figure 7) and realized that we could drastically reduce weight by reducing tube thickness in various parts of the frame. Particularly the front bulkhead supports and the main roll hoop bracing supports which could be reduced from 1x0.065in tubes down to 1x0.047in tubes. However due to the available tube sizes through Cartesian 1x0.049in tubes were selected. (Figure 8) shows the frame design with the new tube sizes. Changing these tube sizes gave us our most drastic decrease in weight at 60 lbs.

ITEM or APPLICATION	OUTSIDE DIMENSION X WALL THICKNESS
Main & Front Hoops, Shoulder Harness Mounting Bar	Round 1.0 inch (25.4 mm) x 0.095 inch (2.4 mm) or Round 25.0 mm x 2.50 mm metric
Side Impact Structure, Front Bulkhead, Roll Hoop Bracing, Driver's Restraint Harness Attachment (except as noted above) EV: Accumulator Protection Structure	Round 1.0 inch (25.4 mm) x 0.065 inch (1.65 mm) or Round 25.0 mm x 1.75 mm metric or Round 25.4 mm x 1.60 mm metric or Square 1.00 inch x 1.00 inch x 0.047 inch or Square 25.0 mm x 25.0 mm x 1.20 mm metric
Front Bulkhead Support, Main Hoop Bracing Supports, Shoulder Harness Mounting Bar Bracing EV: Tractive System Components Protection	Round 1.0 inch (25.4 mm) x 0.047 inch (1.20 mm) or Round 25.0 mm x 1.5 mm metric or Round 26.0 mm x 1.2 mm metric
Bent Upper Side-Impact Member (T3.24.3a)	Round 1.375 inch (35.0mm) x 0.047 inch (1.20mm)

Figure 7: excerpt from 2016-2017 Formula SAE rule book detailing minimum tube sizes needed for different sections of the frame

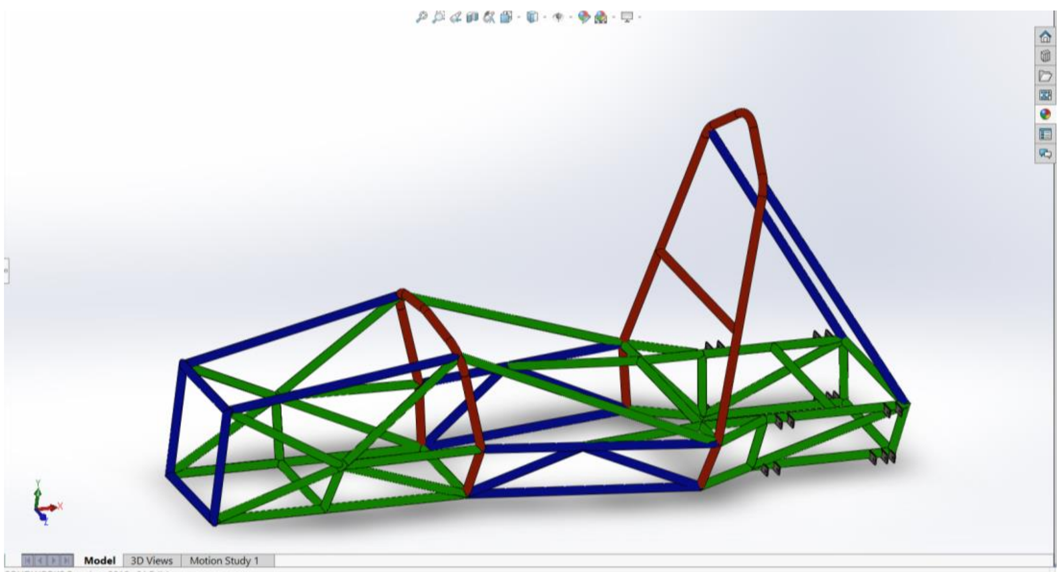


Figure 8: color coded redesigned slim frame: Red = 1x0.095in tubes, Blue = 1x0.065in tubes, green = 1x0.049in tubes

Final Frame Design

In order to finalize our design we had to ensure that we conducted finite element analysis of the frame. These test included a front impact test, a side impact test, and impact tests on both roll hoops. As stated earlier these tests were based off of validation tests described in the Formula SAE rule book for the validation of a frame design that does not follow standard SAE design rules and all of our test parameters were examined by a certified Solidworks expert to ensure that all assumptions made in fixtures and simulation set ups were valid. After testing our concept frame we made adjustments to the roll hoops, redesigning the hoop bends and addition additional supports shown in (Figure 9)

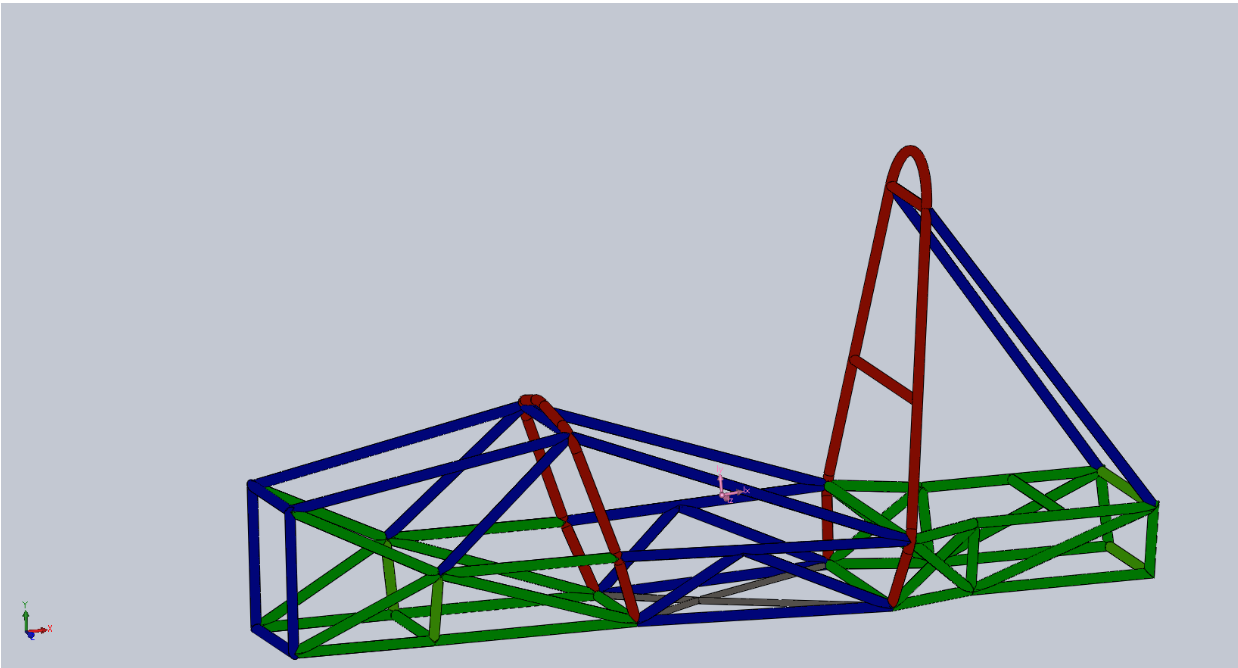


Figure 9: final frame design featuring redesigned roll hoops with added supports

FEA Simulation Results

This new design was tested again using the following tests based on the FSAE alternate frame rules impact tests. These tests were created with the aid of a certified Solidworks expert who helped us ensure our fixtures and force application points were appropriate for ensuring accurate testing results. These results of are shown below.

1. Front impact test:
    a. This test applies force to the front bulkhead at the approximate locations of the impact attenuators, in this case the 4 joints on the bulkhead. The rear of the frame is fixed at the approximate locations of the rear suspension tabs, the reasoning behind this choice is that since the engine block attaches to these tubes they are relatively ridged compared to the rest of the frame. The force applied is 59 KN which is the calculated force of a 20g impact with a 300kg car.
    b. During the test the frame experienced a max deflection of 10mm (Figure 10), and had a factor of safety of 1.07 (Figure 11), passing the test.

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 1	9.87335 mm Node: 554

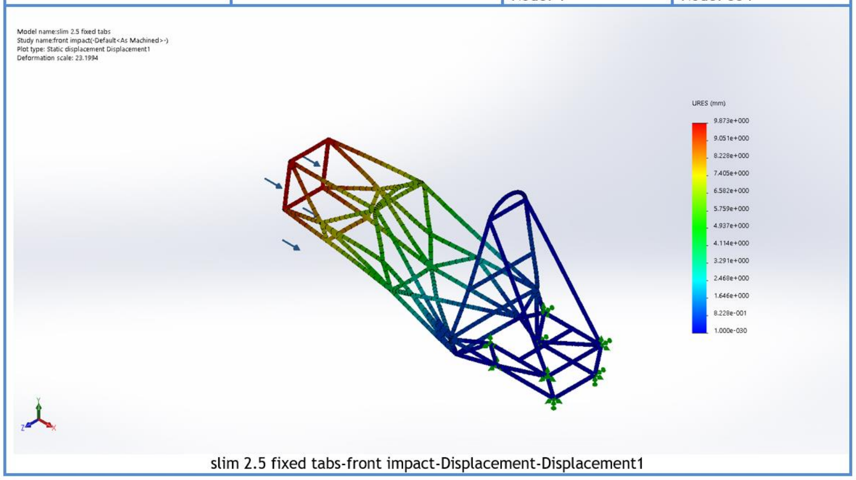


Figure 10: Displacement chart for front impact test

Name	Type	Min	Max
Factor of Safety1	Automatic	1.07019 Node: 11	1e+016 Node: 1

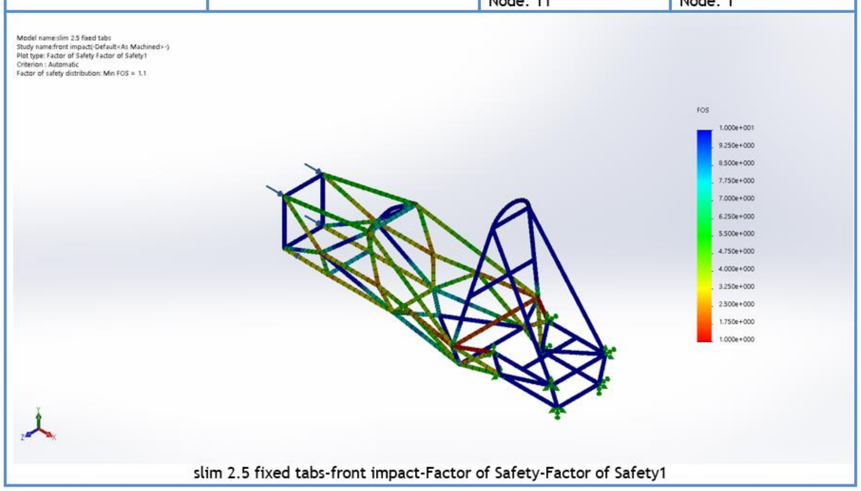


Figure 11: Factor of safety chart for front impact test

2. Side impact test
    a. This test applies a 7kN load evenly along the side impact members of the frame. Fixture points for this test are the approximate locations of the front and rear suspension tabs. The reasoning behind this choice is that since the suspension components attach to these points they can be considered relatively rigid to the rest of the frame.
    b. During the test the frame experienced a max displacement of 2mm (Figure 12) and had a factor of safety of 1.74 (Figure 13), passing the test.

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 1	1.79058 mm Node: 183

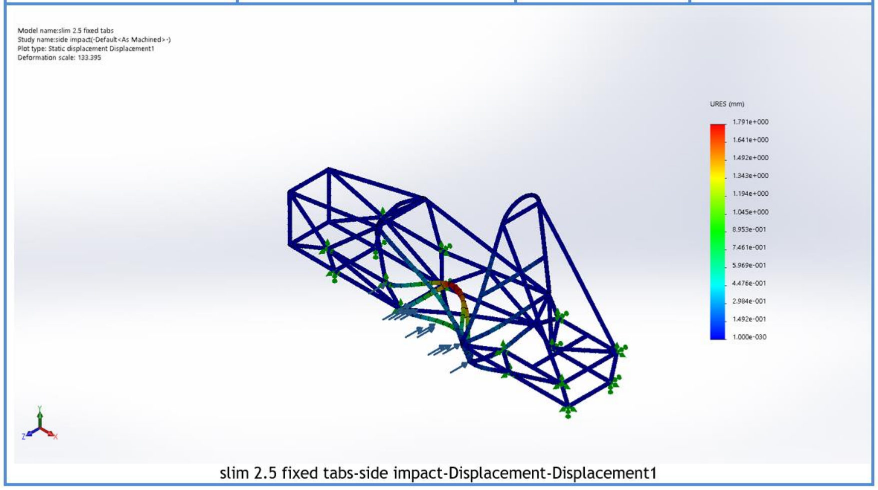


Figure 12: displacement chart for side impact test

Name	Type	Min	Max
Factor of Safety1	Automatic	1.74431 Node: 45	1e+016 Node: 1

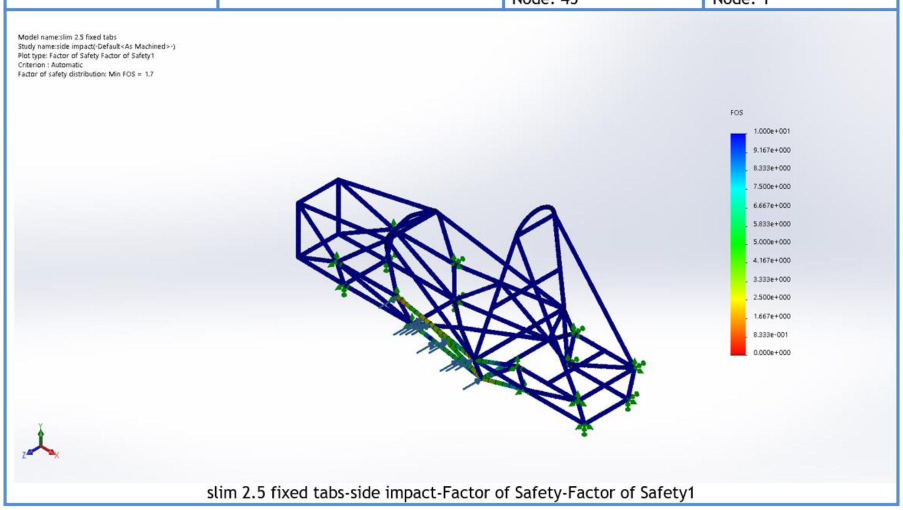


Figure 13: factor of safety chart for side impact test

3. Main Roll Hoop impact test
   a. This test was the sole impact test conducted the 2016 FSAE MQP team as part of their frame validation and thus gives us a direct comparison between our new frame and last years. During the test last year's frame experienced a max deflection of 15mm during a 6kN impact (Figure 14).

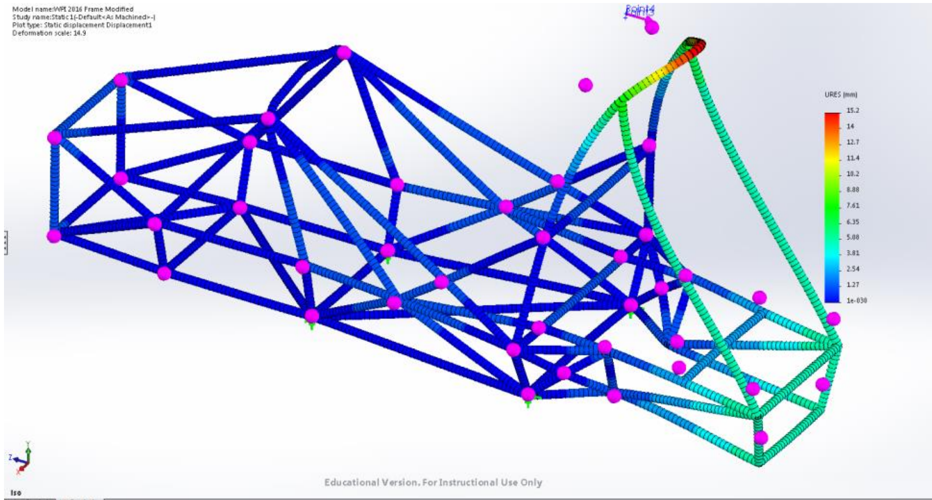
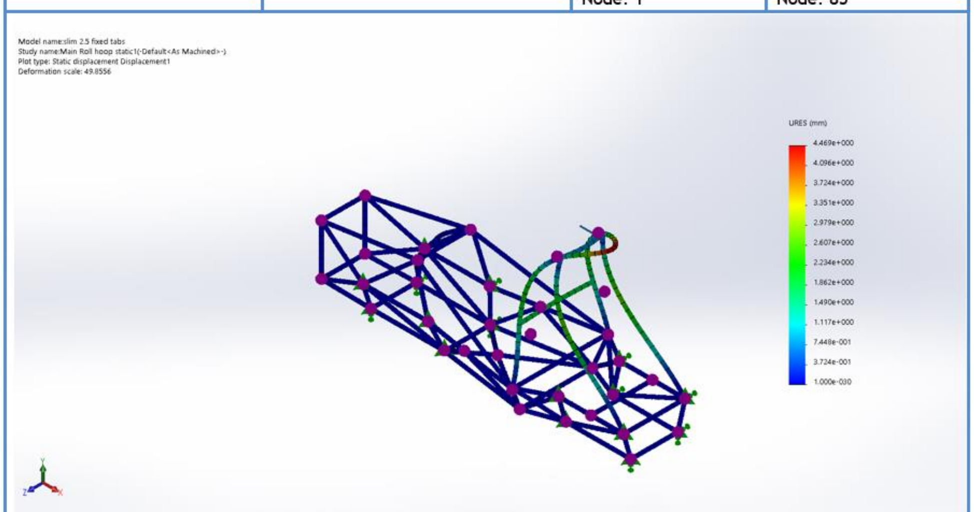


Figure 14: Displacement chart for main roll hoop 2016 car

b. We conducted the same test on our frame using the same fixture points described in the side impact test and applying the same 6kN impact.
c. During the test our frame experienced a max deflection of 4.5mm (Figure 15) and a factor of safety of 1.07 (Figure 16) passing the test.

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 1	4.46863 mm Node: 85



slim 2.5 fixed tabs-Main Roll hoop static1-Displacement-Displacement1

Figure 15: Displacement chart for main roll hoop impact test

Name	Type	Min	Max
Factor of Safety1	Automatic	1.0742 Node: 77	1e+016 Node: 1

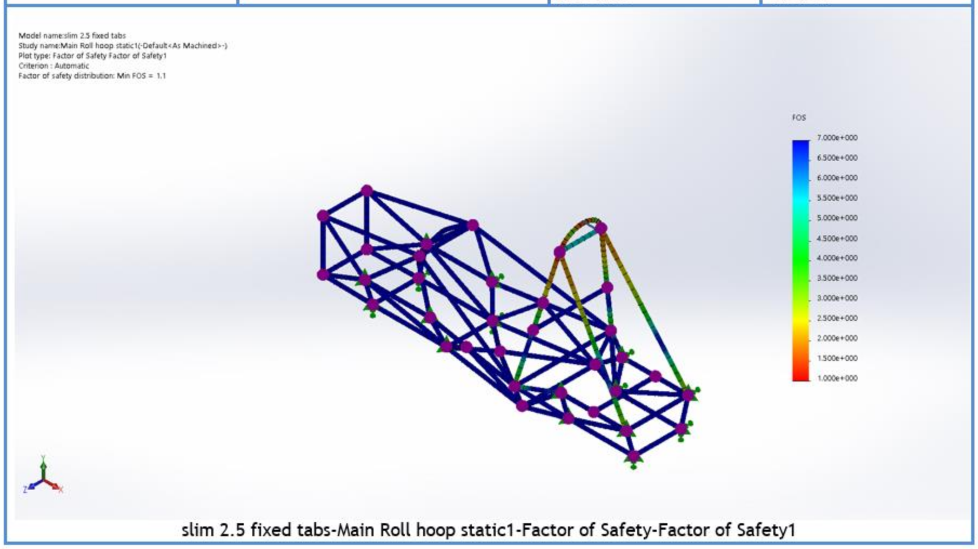


Figure 16: Factor of safety chart for main roll hoop impact test

4. Front Roll Hoop impact test
    a. This was the final test conducted on our frame and applied the same 6kN force seen in the Main Roll Hoop impact test to the top of the Front Roll Hoop. Fixtures in this test are the same as in the side impact and Main Roll Hoop impact tests.
    b. During the test the frame experienced a max deflection of 1.6mm (Figure 17) and a factor of safety of 1.38 (Figure 18) passing the test.

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 1	1.59603 mm Node: 26

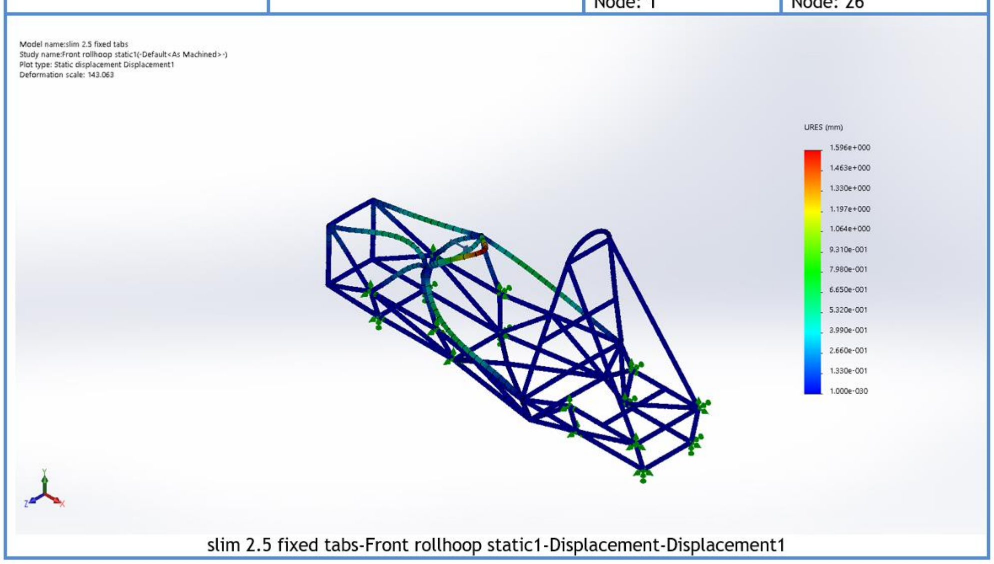
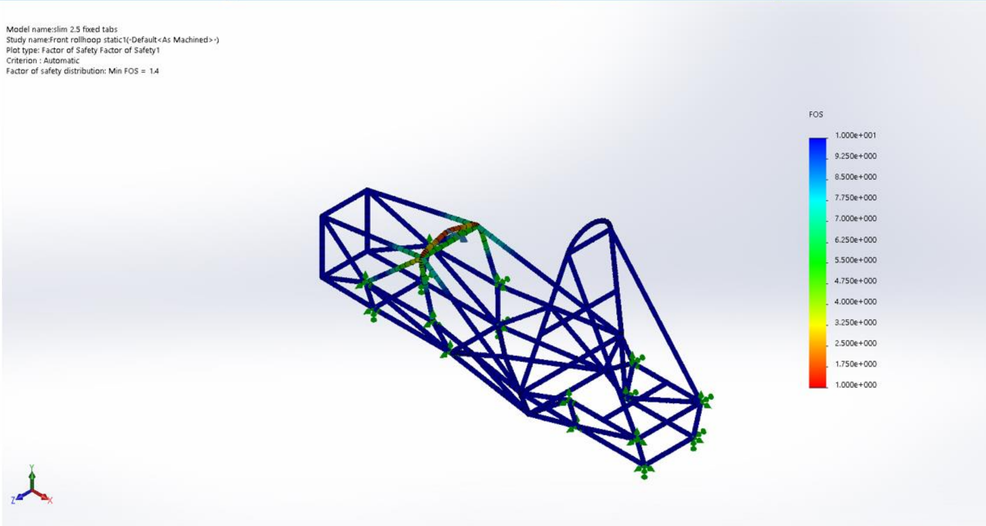


Figure 17: Displacement chart for front roll hoop impact test

Name	Type	Min	Max
Factor of Safety1	Automatic	1.37991 Node: 25	1e+016 Node: 1



slim 2.5 fixed tabs-Front rollhoop static1-Factor of Safety-Factor of Safety1

Figure 18: Factor of safety chart for front roll hoop impact test

Final Frame Ergonomics

Following FEA testing of the frame we had to ensure that all sizing templates used by SAE would fit within the frame. These templates are made to ensure that the car can accommodate a 95th percentile male driver. For these fittings car can be stripped down to the frame though the fire wall between the cockpit and the engine compartment must remain in place. The cockpit opening sizer (Figure 19) is inserted vertically into the cockpit and must have clearance along its descent all the way down to the upper side impact member. At its closest point the template has 4mm of clearance between itself and the frame on either side (Figure 20).

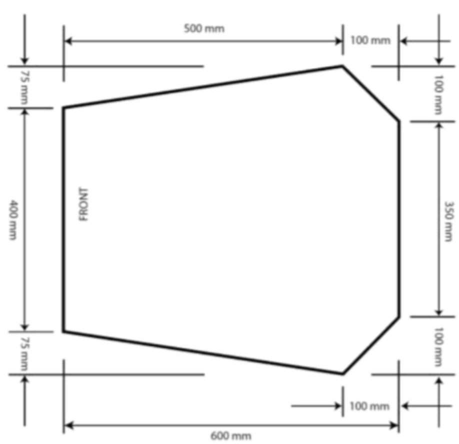


Figure 19: cockpit opening template as shown in the Formula SEA rulebook

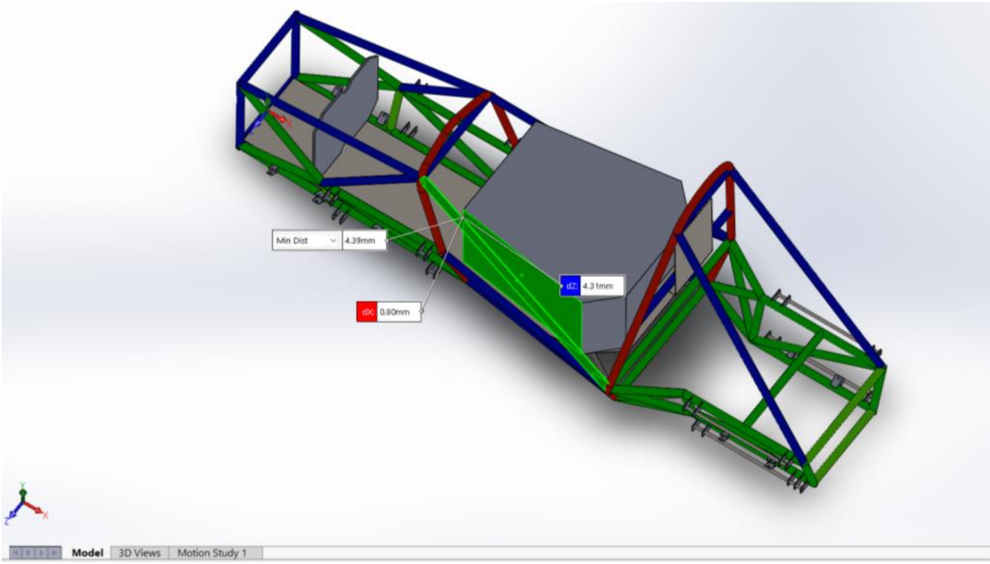


Figure 20: cockpit opening template test showing minimum clearance of 4mm

The next template that we tested for is a stand in for a 95th percentile male driver (Figure 21). This template is inserted into the car taking the approximate seating position of the driver, 2 in of clearance must be maintained between the template's "head" and a line running from the top of the main roll hoop to the top of the front roll hoop (Figure 22). And the template's "feet" measuring 36 inches must not extend further then then rearmost face of the rearmost pedal, the leg can be angled so long as it is still in contact with the pedal. Since the SAE team already intends to redesign the pedal system in the car we aimed to give them as much room as possible to work with. In our design the rearmost pedal can extend as far as 7.92 inches from the rear face of the impact attenuator attached to the front bulk head while still maintaining the required 2 inches of clearance between the templates "head" and the line connecting the roll hoops, this assumes that the pedals used follow the same shape and height of those used on the 2016 car (Figure 23).

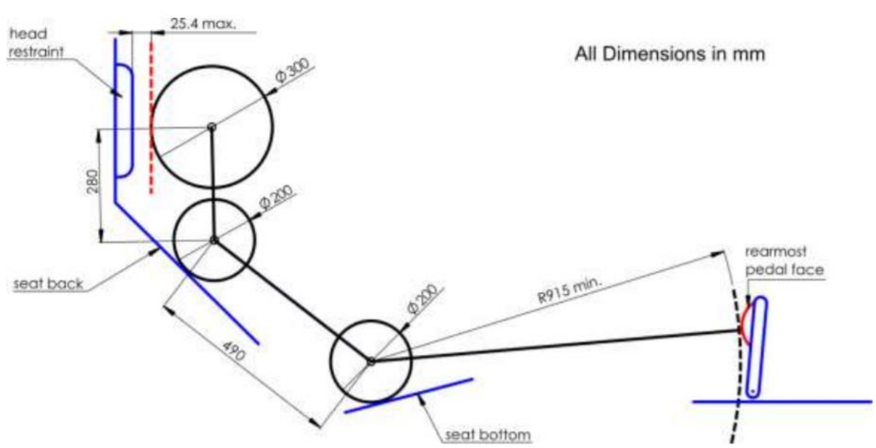


Figure 21: 95th percentile male driver template as depicted in the Formula SAE rule book.

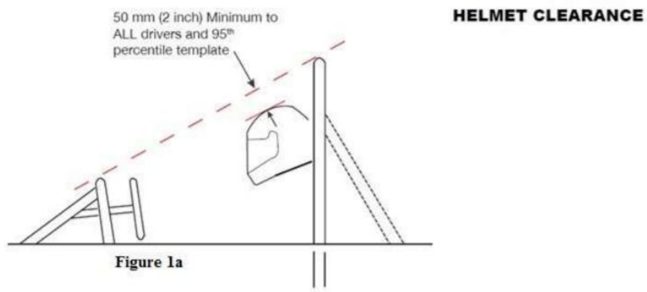


Figure 22: excerpt from Formula SAE rulebook depicting 2 inches minimum clearance during 95th percentile driver template test

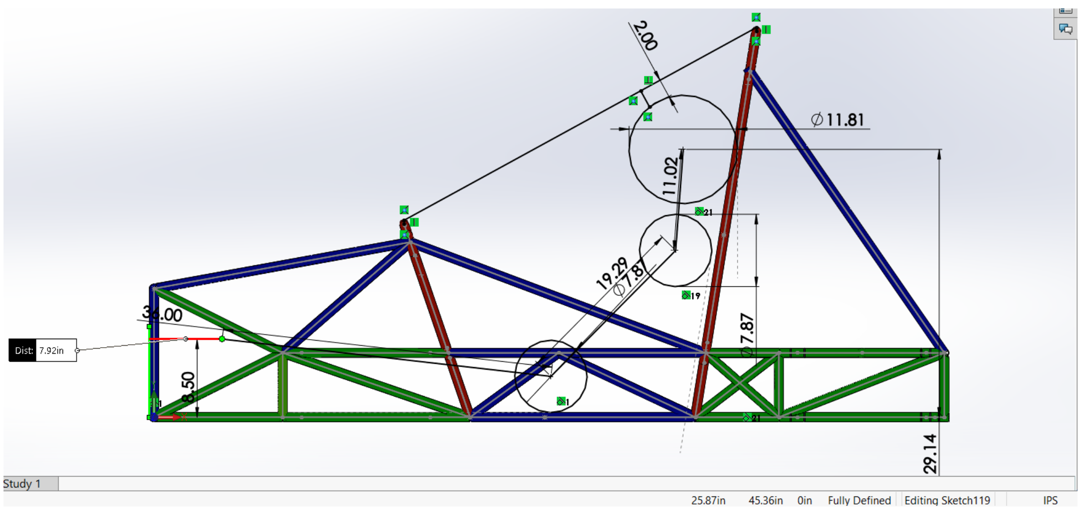


Figure 23: 95th percentile driver test showing 2in helmet clearance and 7.92 inches leg clearance from impact attenuator

The cockpit internal cross-section template (Figure 24) was the final template used and is moved horizontally through the cockpit to a point 4in rearward of the rearmost pedal. Since the SAE team intends to redesign the pedal system in the car our placement is based on the estimated location of the pedal rearmost pedal determined by the 95th percentile male driver test, thus the testing location is approximately 11.92 inches behind the impact attenuator. In this test the template has a minimum of 16mm clearance between the frame and itself (Figure 25)

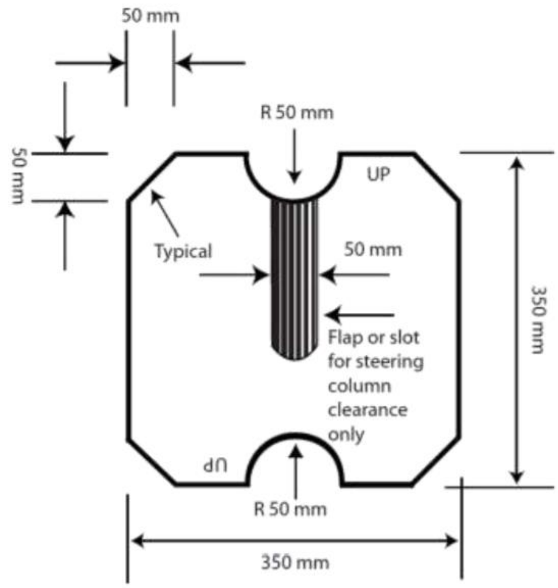


Figure 24: Cockpit internal cross-section template as depicted in the Formula SAE rulebook

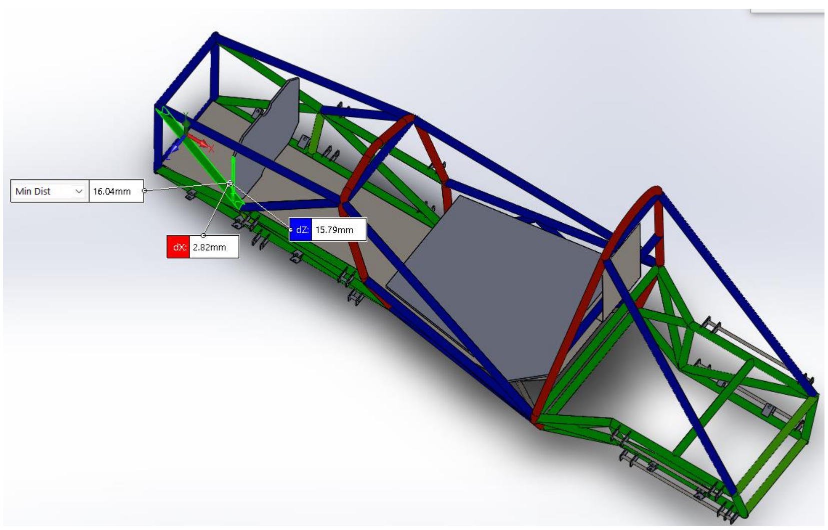


Figure 25: Cockpit internal cross-section template test showing 16 mm of clearance

Following the conclusion of both our FEA simulations and sizing tests were able to finalize our frame. This new design weighs 62.42lbs achieving a weight reduction of 15% over the previous frame which after the addition of extra supports to be fix triangulation errors weighed 73.48lbs. The side by side comparison of the main roll hoop impact test shows that the new design is substantially stiffer that the previous frame. Based on this we believe that our new frame design accomplishes our design goals and will help the SAE team perform even better in the next competition.

Frame Manufacturing

Following the completion of designing and testing of the frame we contacted VR3 Cartesian Tubing for a quote on the manufacturing of the frame. Based on our CAD files Cartesian gave us a quote of $1800 for them to cut the tubes that would comprise the frame. To fully manufacture the frame, cutting the tubes and welding them into place would cost a total of $5240. Based on the cost report from the previous team we had set our budget for frame manufacturing at $8000. Going through Cartesian not only would the frame be manufactured with the precision that we could not achieve ourselves, but we would come up several thousand dollars under budget. Our order for the frame was placed on December 24th 2016, and the completed frame was delivered to WPI on January 20th 2017 (Figure 26). Since our project schedule aimed to have the frame completed by mid C-term the delivery was several weeks ahead of our team's deadline. Inspection of the frame by the team confirmed that it had been manufactured to our specifications allowing us to focus on finishing suspension design and analysis and complete our project.

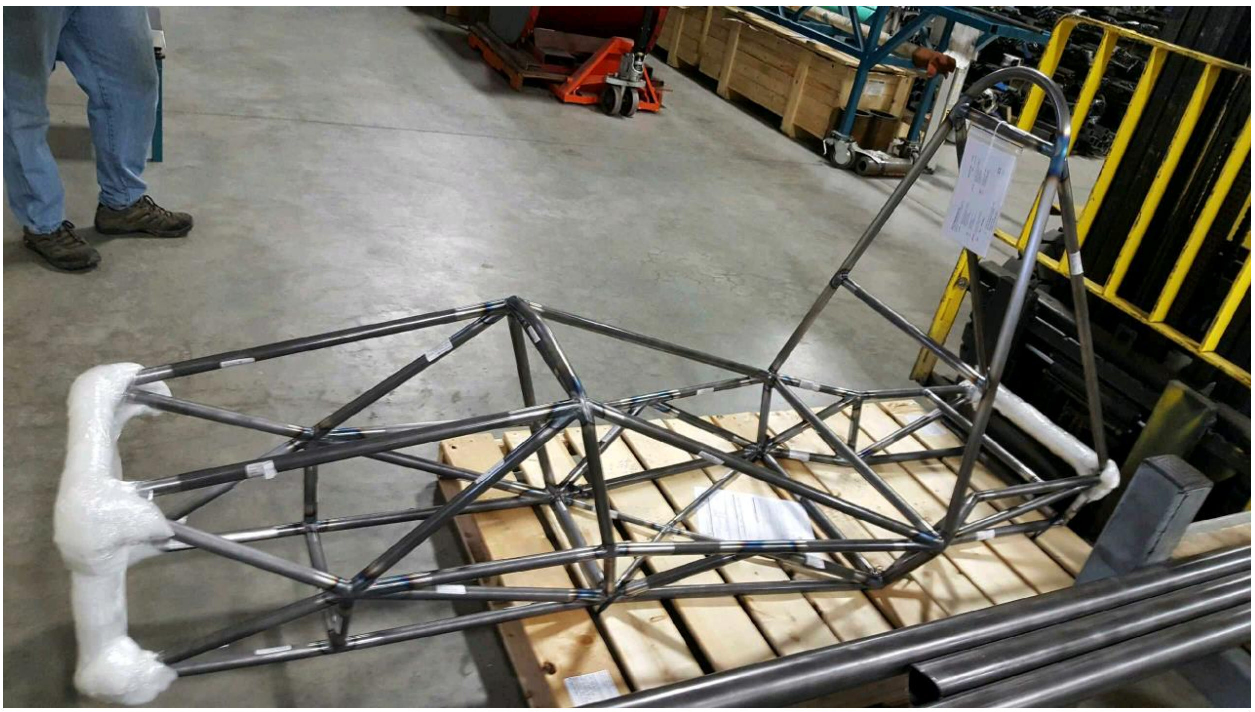


Figure 26: Frame

Frame Recommendations

Due to the FSAE team working on a 2-year design and build cycle, the MQP team for 2018-2019 will work on redesigning our frame. To aid them in that process we have prepared a series of recommendations to assist them based on lessoned learned from our project. Firstly, one of the most important things we learned is to ensure that accurate information of frame validation is recorded from year to year. When we started this project we were told that last year's car passed validation using "alternate frame rules" when in reality last year's car passed inspection using standard frame rules with extra validation as requested by the judges. Alternate frame rules for FSAE include a battery of extreme testing to ensure proper safety when using nonstandard designs or materials, since we worked under the assumption that this extra validation was required we ended up designing a frame that had redundant supports in order to pass alternate rules which added to the overall weight and lessened the effects of light weighting.

Another matter of importance for the next design team is to pay close attention to FSAE rules and regulations when designing the frame, we found that we were able to achieve significant weight reductions by recognizing the FSAE rules set different requirements for tube sizes based on what part of the frame they are located on. By decreasing tube thicknesses in areas allowed by the rules we were able to maximize weight reduction.

Also the order of design when building the new frame and suspension is important. When we started organizing our project we decided since the frame was the biggest deliverable we needed to make that the design of the frame would take precedence and the suspension would be worked on afterwards. This proved to be a mistake since the two systems have to be designed in tandem to ensure that redundancies are eliminated and all the components work together as intended.

Lastly and perhaps the most important to ensure that each subsequent design team improves upon the work done by the previous year is to maintain a library of accurate and modifiable CAD files from previous years. This allows new design teams to see the design process the previous team went through, learning what worked, what did not, and what was already tried. This would decrease the time spent by the new team "reinventing the wheel" rather than building on the work of their predecessors.

Suspension

The purpose of the car's suspension is to keep all four wheels in optimal contact with the ground under any and all conditions. A well-designed suspension must handle bumps and uneven surfaces as well as dynamic cornering, braking, and acceleration. The FSAE car is a racecar purpose built for a prepared track, so performance and handling will be prioritized over smoothness and suspension travel.

Previous Suspension Design

The previous 2016 FSAE car is fitted with a double wishbone; pull rod actuated suspension front and rear. The pull rods are connected to rocker arms that compress and extend the spring and strut assemblies. The upper wishbone members (A-arms) are shorter than the lower members for optimal performance. This setup is referred to as short-arm long-arm. The chassis does not utilize anti-roll bars or any other anti-roll device to reduce weight and increase simplicity. FSAE cars are extremely light, low to the ground, and have stiff springs, all of which limit their tendency to roll during cornering. Most Formula teams do not use anti-roll bars.

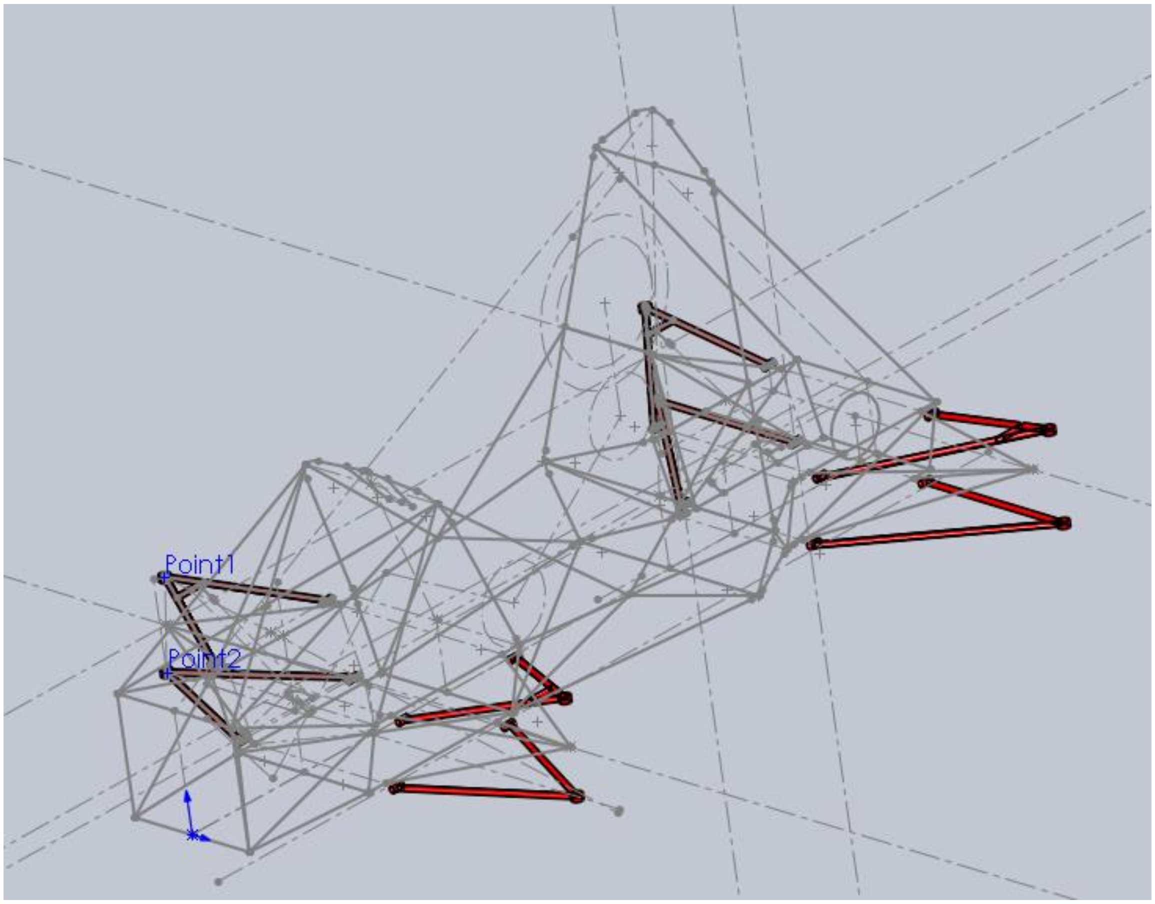


Figure 27: Previous suspension

A-Arms

The A-arms on both the front and rear of the car are made from welded 4130 chrome-moly steel tubing, the same as the frame. Together with the hub assemblies, referred to as the uprights, these arms form a four bar linkage that controls the movement of the wheel relative to the frame. The most important design factor in this linkage is allowing the wheel to move up and down without it also moving laterally or tilting excessively. This leads to unpredictable handling, however a small amount of negative camber during compression (wheel tilting inward) helps compensate for body roll. This is accomplished by having the upper A-arm be shorter than the lower A-arm.

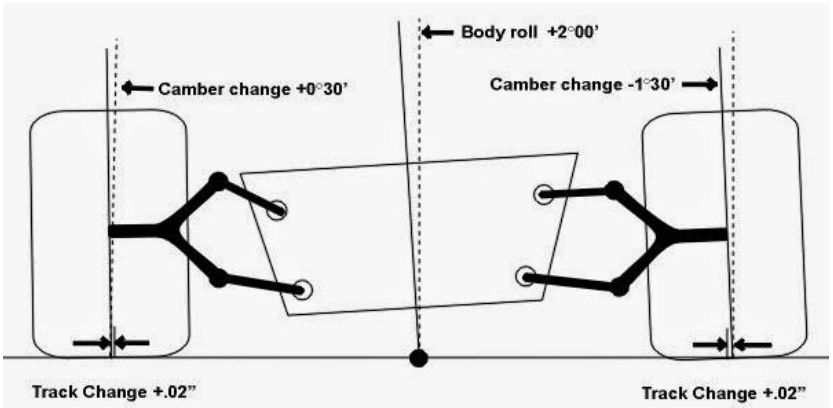


Figure 28: Camber gain in a double wishbone suspension

Taken from last year's report, the previous suspension was designed to have 1.5 degrees of front camber gain and 0.5 degrees of rear camber gain, per inch of suspension travel upwards (compression).

Steering

The steering of the front wheels can be affected by changes in the suspension so it is necessary to analyze the steering when designing an effective suspension. It is undesirable for the wheel's steering angle to change when the suspension moves (bump steer) or for steering to cause the wheel to "scrub" the pavement. Bump steer can be minimized by designing the tie rod to be as close to parallel to the lower control arm as possible, and tire scrub can be reduced by minimizing the scrub radius. Scrub radius is the distance on the ground between the projection of the center of the tire and the steering axis.

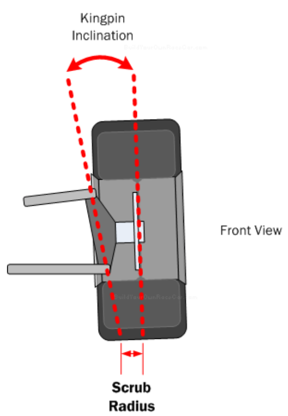


Figure 29: Scrub radius explained

While excessive scrub radius is undesirable, it should not be zero or negative either as driver feedback through the steering wheel will be unpredictable. An ideal value is 0.5-2", and the current design measures to be 1.8". Slightly angling the steering axis backwards helps the wheel gain camber during cornering proportional to how far the wheel is turned. This helps keep the contact patch flat during cornering.

Improvements to Suspension Design

In the beginning of the project seemed necessary to completely redesign the whole suspension to accommodate the proposed changes to the frame. One of the preliminary modifications to the frame was to widen the rear section. This was to eliminate a bent structural tube that was frowned upon by the judges because WPI lacked adequate documentation to prove its strength.

	Attribute	**Weight**	**Current Design**	**Widen frame**	**Re-triangulate**	
	Roll Center	7	8	3	8	
	Frame weight	10	4	4	1	
	Unsprung weight	7	3	7	3	
	Engine space	2	3	9	5	
	Customer Satisfaction	8	7	7	7	
	Total score		179	184	153	

Figure 30: Rear frame weighted design matrix

Widening the rear frame required redesigning the entire suspension geometry including the pullrods, rocker arms, and spring/damping parameters. About a month into the project, after speaking with the team, we decided it would be too ambitious to redesign the whole suspension when we still need to redesign and analyze the whole frame. Despite the advantages, we abandoned our plan to widen the rear frame and instead provide thorough calculations to justify keeping the original design. The small point difference is not worth the redesign time.

As our design progressed during the second half of the project, it became apparent that suspension redesign was unavoidable. Improvements to the front of the frame had moved locations of the suspension members, and the geometry would have to be changed to compensate. Based on feedback of last year's car from the FSAE club and previous MQP team, we decided to add spherical joints to the suspension A-arms as well as lighten them, and lower the car as much as possible. The following weighted design matrix shows the intended changes.

	Cost	Binding resistance	Strength	Time	SAE rules	Weight savings	Handling	Total
Weight:	6	8	9	4	10	6	4	
Unmodified suspension	TBD	5	5	1	5	5	5	189
Cylindrical joints	TBD	10	10	5	7	3	6	302
Thinner Tubes	TBD	5	4	9	5	7	5	224
Upgraded A-arm tabs	TBD	5	8	4	6	3	7	234
Lowered 2.5 in	TBD	5	5	9	0	5	7	179
Lowered 1 in	TBD	5	5	3	10	5	7	255

Figure 31: Suspension weighted design matrix

From the matrix it can be determined all our considered changes have advantages that outweigh the drawbacks in strength, weight, and completion time. The biggest concern at the moment is with our ride height being too low that the side impact test will fail. FSAE rules state that the side impact member must be a minimum of 11.8” off the ground. Under our lowered configuration, the worst case scenario puts this member at just 10.8”. While ride height can be raised with stiffer springs, our range of motion from the suspension would be compromised and the judges would be skeptical upon visible inspection.

Spherical Joints

One notable design problem with the current FSAE car is the use of cylindrical (Single degree of freedom) joints between the A-arms and the frame. Figure 32 shows a photograph of this design. When the suspension arms are placed under load, the joints bind up due to miniscule deformation and misalignment of the two rotation axes due to manufacturing tolerances. The best solution for this is to replace the cylindrical joints with spherical joints offering additional freedom of motion without requiring pinpoint manufacturing tolerances. With the rear frame finalized, it was then necessary to redesign how the suspension members connect to the frame while maintaining the same geometry as the current car. In order to do so, all the axes and link lengths of the double A-arm design must remain the same. Our first idea was to use rod ends like the one shown in Figure 33 below, however concerns were raised about the bending strength of the thin cross section.

Figure 32: 2016 Single DOF suspension joint

Figure 33: Cylindrical rod end with male threads

While many teams are successful in spite of this, our team opted to use weld cups with spherical bearing inserts. The inserts are press-fit into the cup, which is welded to the A-arm. This method will allow us to reuse the old tab locations and shoulder bolts and keep the joint in the same place. A website called www.chassisshop.com sells the necessary parts. Using engineering drawings provided on the manufacturer's website, we were able to model this joint in Solidworks.

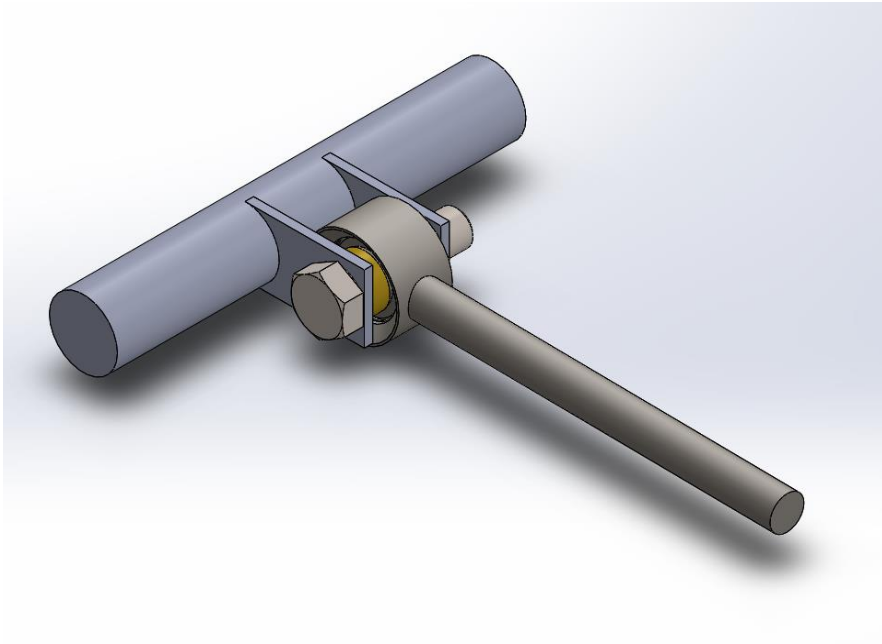


Figure 34: Spherical joint assembly

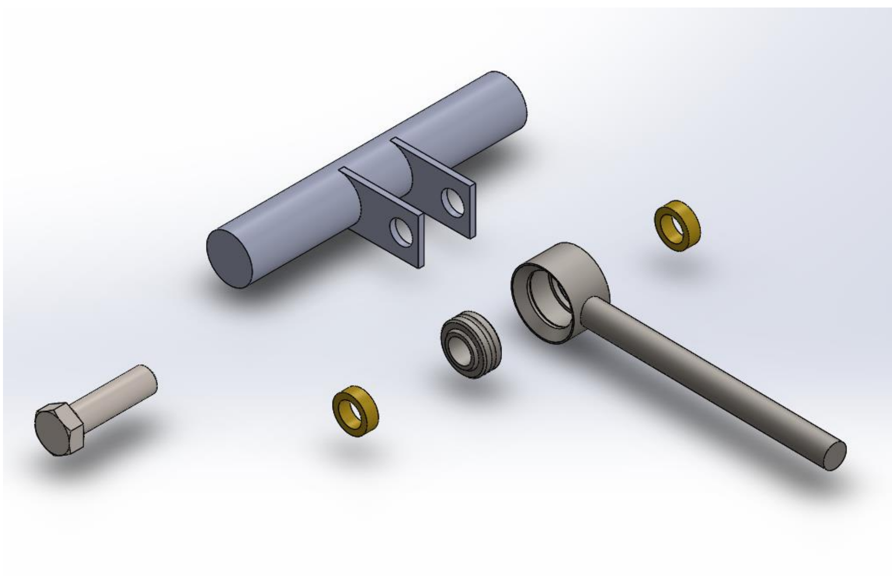


Figure 35: Spherical joint assembly exploded view

Suspension Tabs

A small yet significant task was to add features to the tube frame that allow us to mount the suspension components. Last year's team opted to weld two dimensional tabs made from sheet metal to the frame and bolt the A-arms to them with shoulder bolts. We considered adapting this idea to our new frame. Additional tabs were added to the rear to accommodate the toe bars, shown in Figure 36, and all suspension tabs were moved slightly to give the thick spherical joints adequate range of motion. More information on the toe bars is found in later sections. This design has potential however, a redesign could offer many improvements as per our weighted design matrix.

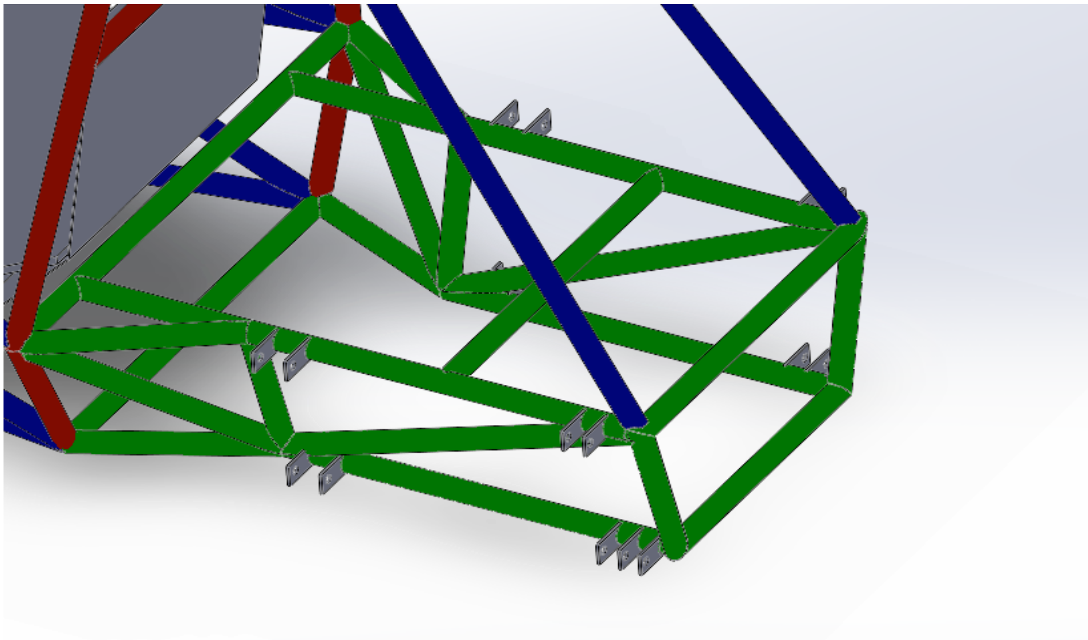


Figure 36: Rear suspension tabs with extra toe bar tab

We designed the new A-arms for the rear suspension using the aforementioned cylindrical joints. However, the angles between the A-arm tubing and weld cup in some places created an elliptical cross section in the tube that was longer than the length of the weld cup. We realized we could rotate the weld cups 90 degrees, since it is a spherical bearing not limited to one degree of freedom. This would solve the manufacturability problem without adding bends to the tubing requiring bracing for stiffness. A diagram of the proposed design is shown below in Figure 37

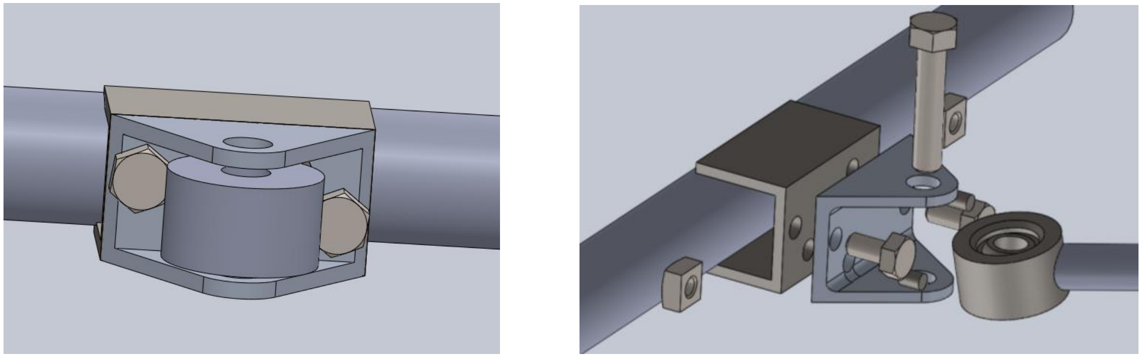


Figure 37: Example and exploded view of redesigned tab and bracket system

The new system consists of an aluminum bracket and a weld on steel tab. The tab is welded to the frame, and the bracket bolts to the tab for added adjustability (static camber). The shear load is held by dowel pins and the tensile load is held by bolts. This avoids shear stress on the threads of the bolt. The weight of the revised tab system versus the old is shown in Figure 38 and strength analysis of the aluminum bracket is shown in Figure 39. The minimum Factor of Safety under maximum stress is 2.3, with a maximum deflection of 0.003 inches.

	Tab weight	Bracket and hardware	Total weight per tab	Total weight for all 16 tabs
Revised	0.19 lb	0.4 lb	0.59 lb	9.44 lb
Original	0.28 lb	0.19 lb	0.47 lb	7.52 lb

Figure 38: Weight analysis of suspension tabs

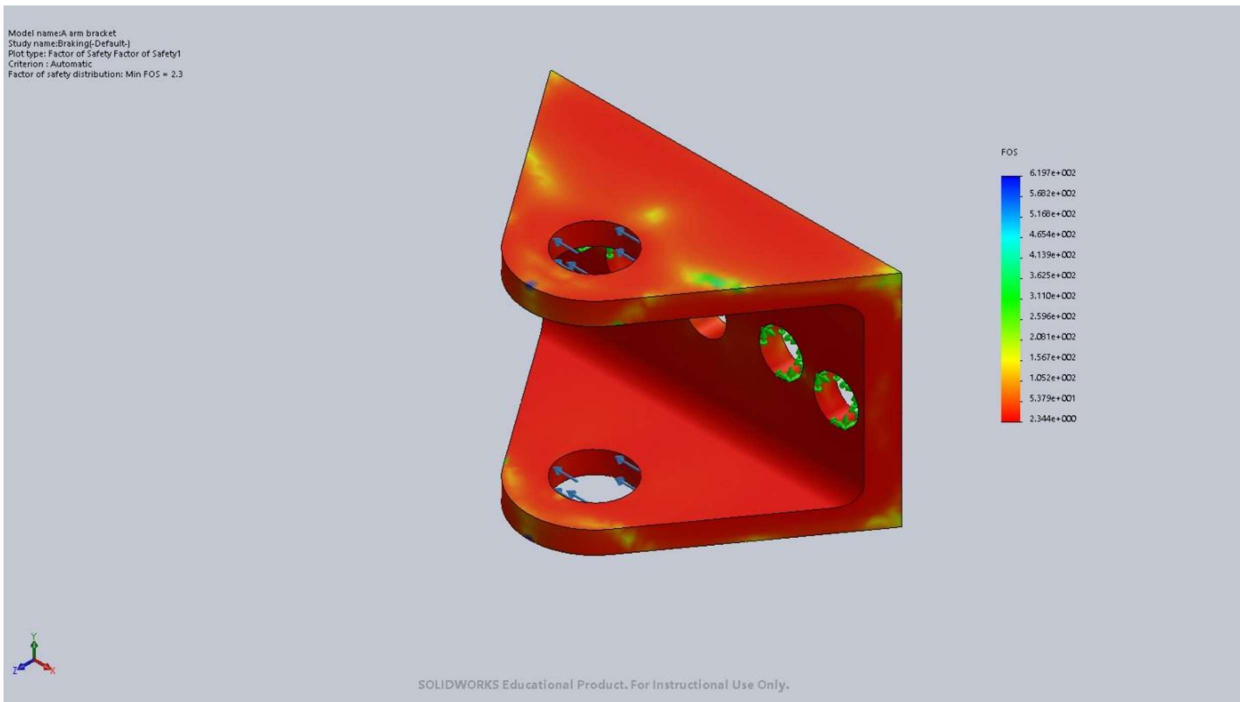


Figure 39: Factor of Safety analysis of A-arm bracket

The strength and manufacturability benefits in my opinion outweigh the added two pounds. There will be no issues breaking tabs, and the suspension geometry can be fine-tuned by creating new brackets of different lengths or adding spacers between the tab and the bracket.

Reduce Size of A-Arm Tubing

The FSAE club would like us to reduce the diameter and thickness of the A-arm tubing to save weight. The existing profile is overbuilt. In order to ensure performance and safety however, we need analysis to confirm the arms are strong enough and will not fail or deflect. Derivations of applied forces under extreme conditions can be shown in Figure 40. For this analysis we are only assuming one side of the car will be handling the forces for additional safety. Under dynamic driving conditions, the loading can shift drastically from an even split between left and right to heavily biased, especially in cornering. Figure 41 shows a sample of the cornering analysis.

Condition	Type of Force	Magnitude (g's)	Weight of car (lbs)	Total force (lbf)
Braking	Horizontal shear	3	500	1500
Cornering	Compress-ion	1.5	500	750
Acceleration	Horizontal shear	1	500	500
% Front	% Rear	Force Front (lbf)	Force Rear (lbf)	Min. Factor of Safety
80%	20%	1200	300	3.5
40%	60%	300	450	2.4
0%	100%	0	500	7.9

Figure 40: Force Derivations

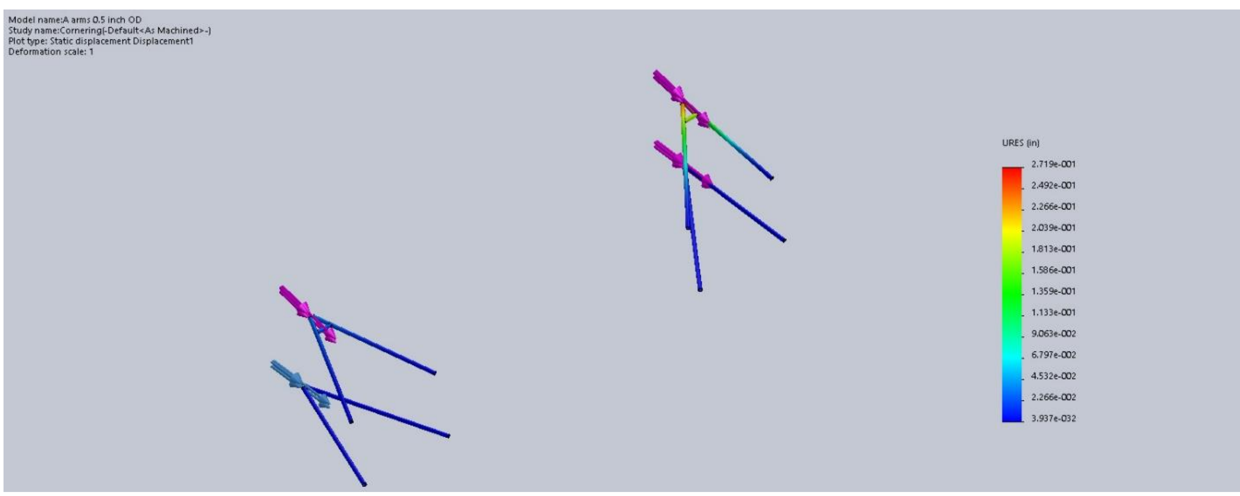


Figure 41: Deformation analysis of A-arms during cornering

The minimum factor of safety is 2.43 and the max deflection is 0.2 inches, within our original specification.

Front Suspension Geometry

The front portion of the frame had been changed to save weight, requiring the front suspension to be completely redesigned. As a precise fourbar linkage, if the length of any one dimension changes, the entire linkage must be modified. Since we are keeping the wheelbase the same, the A-arms have to be lengthened by about two inches each. This is only a change of around 13% however there are important effects of simply lengthening the arms. As the wheel travels up (compression) the suspension needs to add a few degrees of camber for optimum grip. The longer the arms, the lesser the camber gain as the endpoints of the arms sweep larger arcs. Infinitely long arms would produce a straight line movement. Further exacerbating this problem is the geometry of the frame. Lengthening the upper control arm, which sits at an 8.6-degree angle, will bring it closer to horizontal and cause it to not pull the top of the upright in as it moves up. This leads to even less camber gain. Another side effect of longer control arms is lowering the roll center of the car. This adds performance potential but gives the car more of a tendency to roll during corners. Since we do not have anti roll bars, this means additional camber gain is needed from the suspension to compensate. Figure 42 shows the design process in SolidWorks.

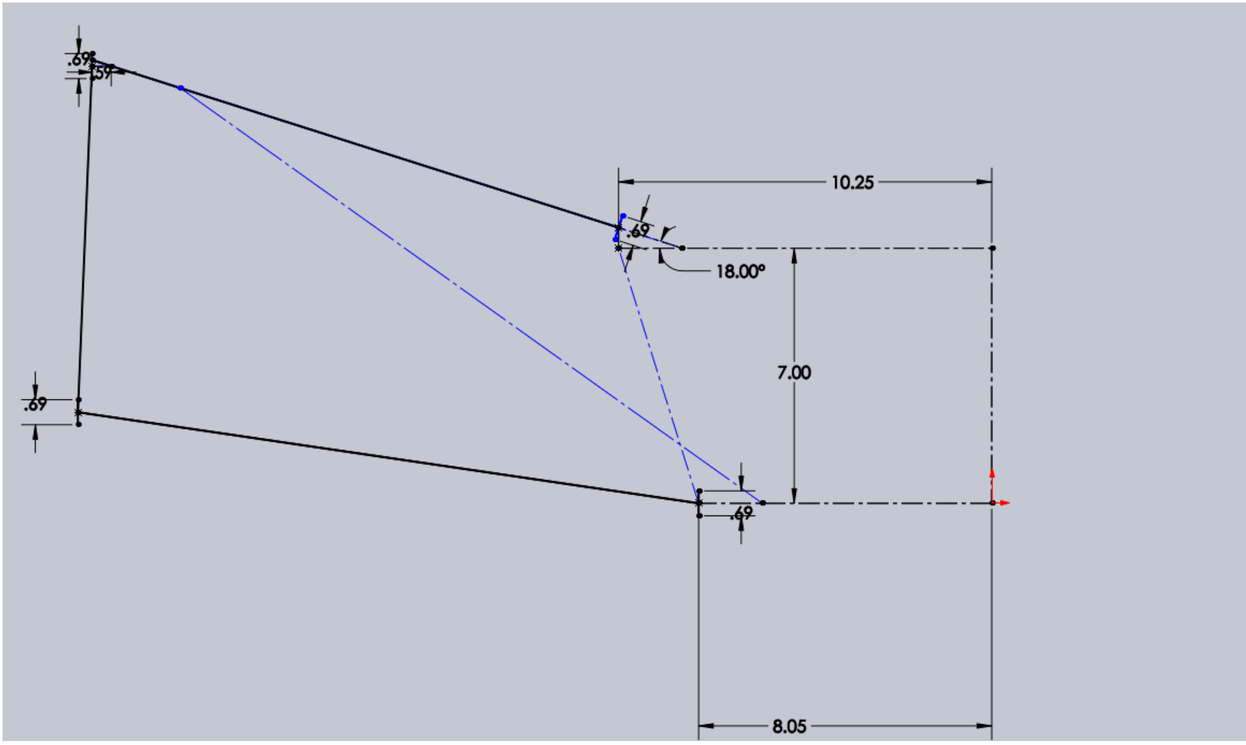


Figure 42: Designing the front suspension geometry

We explored two possible solutions to increase the camber gain of the front suspension. We considered adding external structure to the frame to move the upper A-arm more outboard leading to a shorter link length. However, the extra weight, triangulation, and analyses of this would be detrimental to performance and time consuming. A different way to accomplish this would be to redesign the upright to move the upper ball joint upwards along the kingpin axis. The inside of the wheel limits the length of the upright, however physical measurement has shown an additional half inch can be added to increase camber gain. The scrub radius and bump steer remain identical, and camber gain is restored. The longer A-arms also inherently lead to a lower front roll center.

Toe Bars

The turning motion of the front wheels (toe) is controlled by the steering wheel through the tie rods, however the rear wheels require a form of static tie rod that is adjustable to change the toe. The previous Formula car accomplished this with links attached to the rear lower A-arms, as shown in Figure 43.

Figure 43: Previous toe bar design

Unfortunately, this design transfers the force from braking/acceleration to the middle of a relatively long tube. Under normal driving conditions this tube can bend significantly and cause unpredictable handling. The solution to this problem was to extend the toe bar all the way to the frame and anchor it there, as shown in Figure 44. It remains parallel with the lower A-arm to eliminate any bump steer.

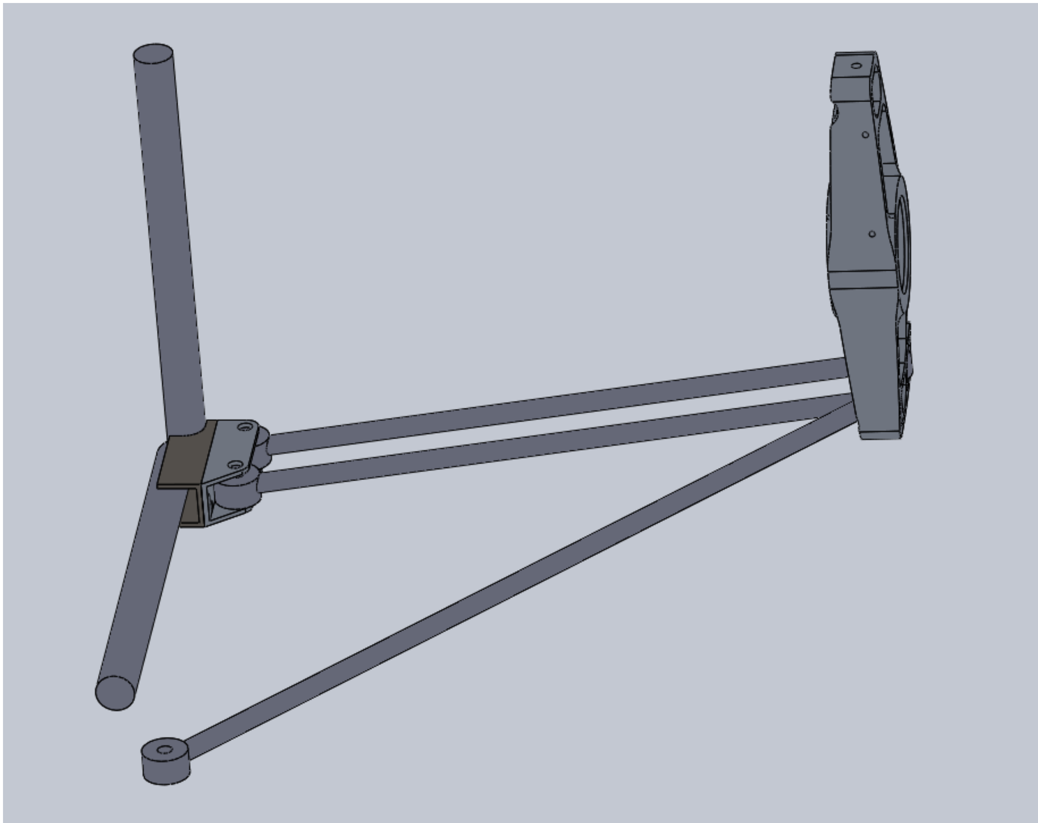


Figure 44: Updated toe bar design with new tabs

Redesigned Pullrod System

An additional source of binding in the suspension was the pullrod-activated suspension system. As the upper A-arm travels up or down, the mechanism is no longer two dimensional and side loading is introduced in the rocker as shown in Figure 45. Figure 46 shows our updated linkage that was designed to keep all forces in plane as the suspension actuates.

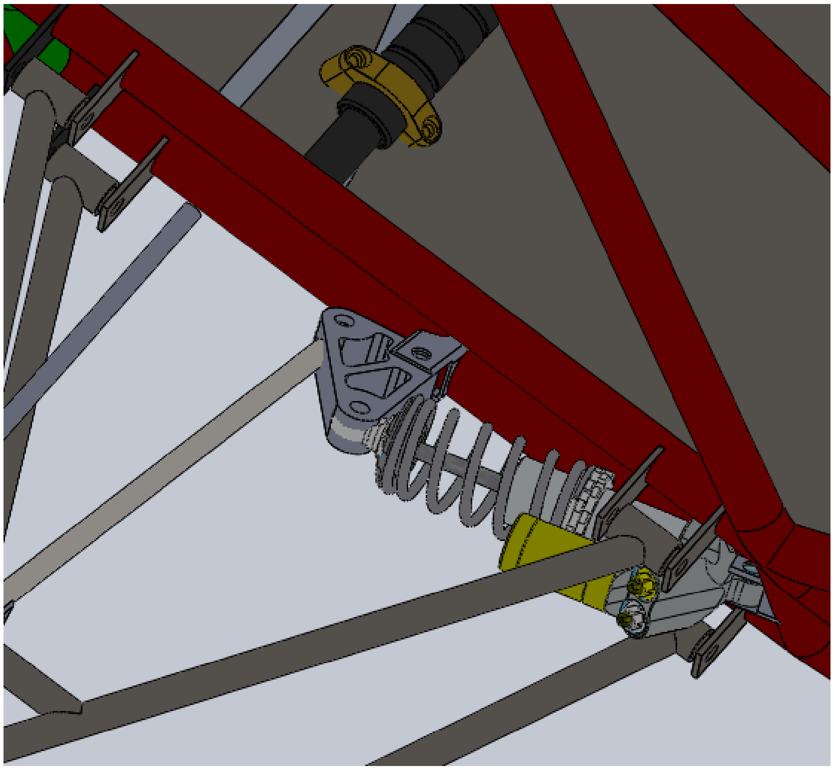


Figure 45: Previous pullrod suspension

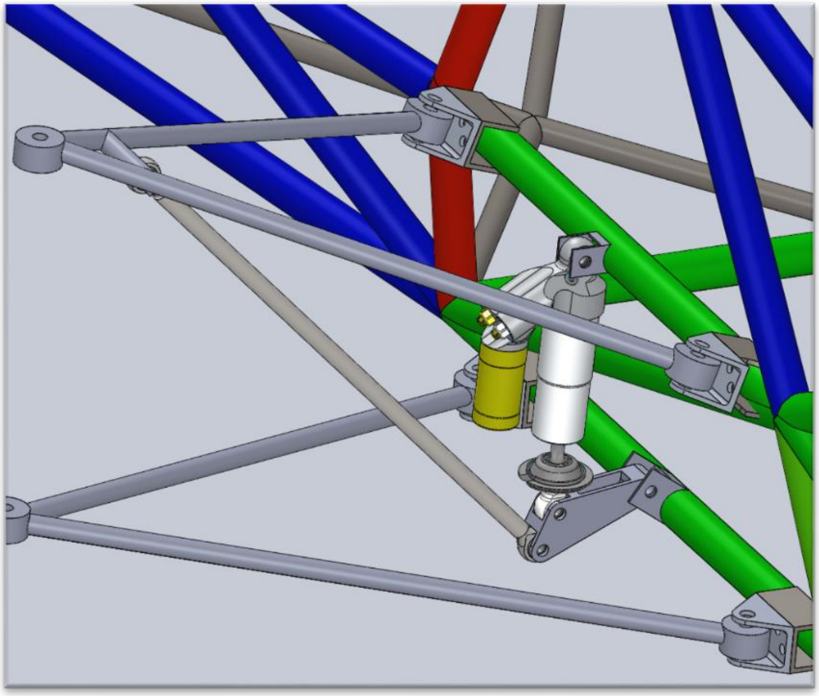


Figure 46: Updated design

The tabs used to locate the rocker and strut assembly are made from steel box tubing similar to the legacy design. This design will require more aggressive springs as the mechanical advantage is significantly less. FEA of the rocker is shown in Figure 47. The minimum factor of safety is 1.6

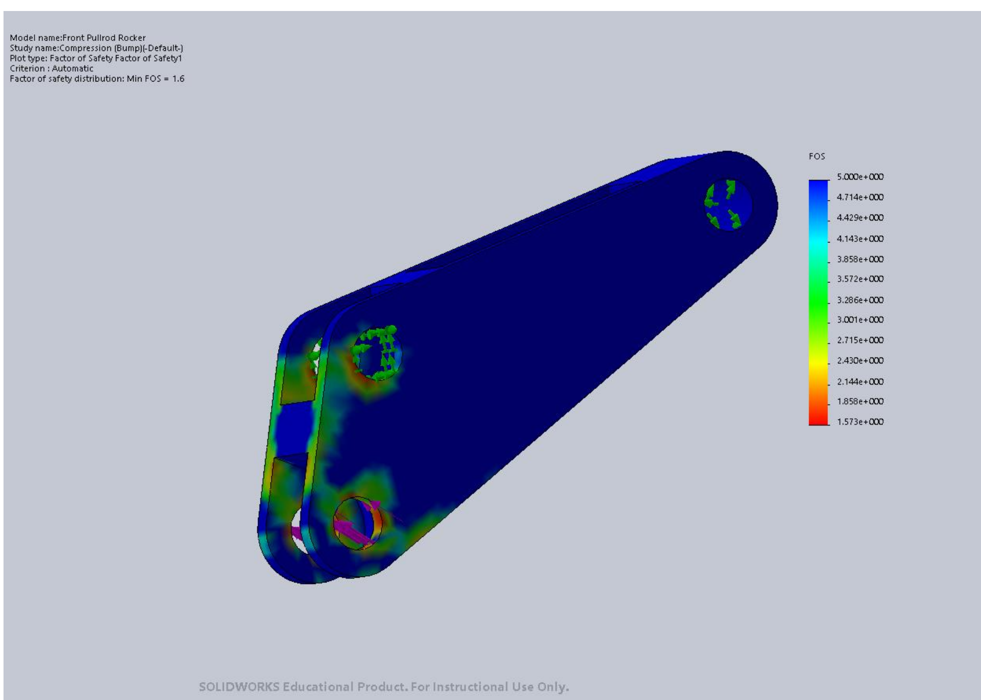


Figure 47: Rocker Deformation Test

Suspension Recommendations

Most of the areas for further improvement of the suspension lie in the tuning of the car, the pullrod rocker, and the redesigned suspension tabs. The suspension geometry is engineered to have similar performance to last year's setup (scrub radius, castor, camber gain) however hands on seat time will be the best judge of handling performance. Once the suspension is manufactured and installed, we will have more information as to optimizing track performance.

A major physical improvement that can be made is with the aluminum pullrod rocker. The part can be greatly improved by redesigning it from a manufacturing standpoint. There is significant extra material in low stress areas, and the slots are difficult to machine. Our team recommends replacing the slots with speed holes.

The redesigned suspension tabs can additionally be optimized. The system is complex and heavy, with most tabs being custom fit to the frame for interference and adequate welding contact. Something that can be considered in the next design cycle is accomplishing the same result with a simpler means of attachment. Further design improvements to the tabs can also reduce weight.

Overview of Business

The goal of the project is to create a sustainable Business MQP that will be focused on the development of the business aspects of the FSAE competition. This will be achieved by developing a series of outlines that show the best practices that lead to efficient development and presentation of a budget and eBOM, business logic case, and cost report for the FSAE competition team along with associated timelines. This will be accomplished by utilizing the previous year's data to redo the content and develop the best strategies to complete the material that will be submitted for the competition.

MQP and FSAE Team Connection

Miscommunication

One of our team's biggest struggles is the less than cohesive unit that is the FSAE MQP and the SAE Club. The divide between the two aspects of the team negatively affects the performance and severely limits the team's ability to transfer information from year to year. The current state of the organization is as follows. The MQP team is assembled at the start of the year, there is no formal introduction to the team other than having the team members sit in on the MQP weekly meetings. There is little conversation between the team and MQP members unless a separate meeting is scheduled. There is no goal setting at the start of the year, there is no motivational meeting to get students excited and involved on sub teams, there is only a push to create a car with little attention being paid to how to most efficiently utilize the students and faculty resources the team currently has.

In the provided resources from FSAE Online, there is an article from Dick Golembiewski, an FSAE advisor for more than 20 years. In his article, "Managing Student Vehicle Projects" (Golembiewski, 2008) he talks about how goals are everything in creating a team that thrives throughout the year. The team must sit down and discuss what they are trying to achieve, whether it is winning the competition, or directing their attention to a more micro view of the competition and trying to win one category. This is something the WPI FSAE team needs to apply focus too. Below we have listed several suggestions that we will be testing with our MQP team and the current team to see how they feel on the matter.

Weekly Team and MQP Meetings

We would like to propose that for next year the MQP team and select members of the FSAE club sit down at the start of each term to discuss goals make sure everyone is on the same page. After the first meeting, which could be longer, we will schedule shorter meetings to have weekly updates and work on issues that arise. These should be separate from the advisor meetings every week to allow for in depth discussion and problem solving in real time.

Sponsorship Opportunities

Below we will talk about several different areas of interest with respect to funding the organization and maintaining records of who has supplied the club with funds. Sponsorship is a major aspect within the WPI Formula SAE club.

Requesting Sponsorship

The team over the past couple of years has gotten lucky with the sponsorships but we need to create a process to continue that success whether it is monetary or parts donations. The current sponsorship material that was created for the team is clean but lacks the data that sponsors are looking for. Following my research into this topic, we found that it is critical to outline to mutual benefits for the club and the company or individual.

An article from FSAE Online, "Organizing a Formula SAE Team" (Gruner, 2017) talks about the importance of first creating a plan and doing your homework to ensure you will not be wasting their time and money. Second, creating a sponsor friendly budget and marketing materials. This material needs to be rich with pictures and data showing that the investment they will be making into the car is one that will benefit both the sponsor and the team. In the appendix we have included a copy of Cornell Racing's 2016 Sponsorship Packet which is what we are using the update our marketing materials. Their packet includes the following key data points that sponsors look for when determining if it is worth their investment.

- Information about the program
- Information about the schools involvement
- Highlights from the team
- Information on the engineering of the car
- Team history
- The direct benefits to the sponsor
- Sponsorship levels and returns

Database of sponsors

Over the course of the last couple years the team has done well obtaining sponsorship, but there is no real database that shows that has given to the team and contact information. There are several lists but they are all scattered. The team should work to compile one spreadsheet of who our sponsors are, their level of involvement, donation amount, and feedback on our sponsorship process. The team should also be working to try to develop an easy way to connect with potential leads. We want to develop something similar to a Google form, so when you fill it out with a personal message, the contact information, and a personalized thank you, it automatically sends the lead an email with all of the sponsorship materials and logs the message into the master database for sponsors.

Business Logic Case

The Business Logic Case is a form that is to be filled out by the team prior to going to competition. The Formula SAE judges supply this form and you are expected to submit it at least 6-9 months prior to the competition. Below we have listed the key points that you should address in the Business Logic Case.

- Analysis of Market Data
- Company Strategy
- Target Selling Price
- Target Vehicle Production Cost

- Target Production Volume
- Target Annual Profit
- Vehicle Strategy and Performance
- Plans for Efficient Design and Manufacturing
- Key Design Features
    - Chassis / Body Type
    - Power Train Type
    - Power / Engine
    - Target weight, kg
    - Data Acquisition
    - Information Display
- Key Performance Targets
    - Acceleration. 0-75 Meters
    - Fuel Economy

All of these categories are meant to make the team think about how they plan to design the car. The Objectives of the Business Logic Case as listed in the rules are as follows.

- Teach participants about the factors that need to be considered when a company embarks on development of a new product. These include: cost; identification of market and likely sales volume; profitability; the key features applicable to the selected vehicle concept and target market size.
- Ensure teams develop the concept of their entry with all of these aspects correctly considered, from the outset.
- Ensure that all three static events are approached with a single common concept and presented to each set of static judges in the same manner.
- Ensure participants gaining experience in producing a business case and balancing potentially conflicting attributes.
- Ensure that students determine the corilation between cost and price of the car and how to best balance the cost and price.

To this point we have analyized the previous two years Business Logic Cases and have determine the major differences to show which represents the best method of completing the Business Logic Case. Last year the team went for a high cost of the car, $28,000.00, with a lower production volume, just 25 units and the year before the car was a lot cheaper, $14,000, with a much higher production rate, 625 vehicles.

Business Logic Case Outline

The Business Logic Case requires knowledge about how to do market research, calculating data such as projected selling cost, and how to determine plans for efficient design and manufacturability. To tackle this issue, an outline was created for a step-by-step guide on how to fill in the Business Logic Case. See appendix 4 for the document.

2018 Business Logic Case Sample

In appendix 5, please see a sample of a completed business logic case. This utilizes data from the outline to best answer the questions included in the business logic case. For competition next year, the team should simply sit down, understand what purpose each of the questions means, then simply adjust the answers to best fit their current strategy.

Understanding the Budget and Cost Analysis

During the start of the project we worked to decipher the code that was the budget from last year's cost report that was submitted. There were several categories that were not making much sense but after meeting with Colin, we were able to see the four categories that are listed below and create a description for them.

Area Totals		Materials	Processes	Fasteners	Tooling	Total
	Brake System	$ 1,335.80	$ -	$ 35.80	$ -	$ 1,371.60
	Engine & Drivetrain	$ 6,404.37	$ 2,145.00	$ 76.15	$ 49.50	$ 8,675.02
	Frame & Body	$ 3,443.30	$ 3,469.00	$ 44.69	$ 910.00	$ 7,866.99
	Instruments & Wiring	$ 5,680.31	$ 485.00	$ 0.36	$ -	$ 6,165.67
	Miscellaneous, Fit & Finish	$ 349.00	$ 445.00	$ -	$ -	$ 794.00
	Steering System	$ 1,214.37	$ 1,113.00	$ 33.14	$ -	$ 2,360.51
	Suspension & Shocks	$ 4,827.20	$ 4,036.00	$ 81.28	$ -	$ 8,944.48
	Wheels & Tires	$ 1,424.00	$ -	$ -	$ -	$ 1,424.00
	Total Vehicle	**$ 24,678.35**	**$ 11,693.00**	**$ 271.42**	**$ 959.50**	**$ 37,602.27**

Figure 48: Previous Years Cost Report

The Materials cost was the number that was actually spent by the club and the team on the whole car. The Processes cost was the amount that it would have cost the team if they were to pay to have the parts manufactured by a company and pay for them. There are specific numbers you use to calculate the price of each processes. The fastener cost was the amount it cost to put together each of the subsystems, all of the hardware costs. The tooling cost was the amount the team spent on tools for each of the subsystems. All in all the team said they spent $37,602 on the car, but they were missing a huge part of the Cost Report, The Materials Spreadsheet.

The Materials spreadsheet is a document provided by Formula SAE that is for all of the teams to use to help document the cost of the car when taking wholesale pricing into account. The team had just been recording the cost of each individual part we were purchasing, when in actuality the team should have been taking the list of purchased parts, determined the price from the materials spreadsheet, then recorded.

Recreating the Cost Report

After realizing the rather large mistake that was made by the team, we decided it would be best to redo the Cost Report using the appropriate tools. Below is the new total cost report that should have been submitted for the car.

Cost Summary Basics

for: **Worcester Polytechnic Institute**
Car # 58

Area Totals		Materials	Processes	Fasteners	Tooling	Total
	Brake System	$ 623.14	$ -	$ 31.00	$ -	$ 654.14
	Engine & Drivetrain	$ 2,256.07	$ 480.50	$ 73.67	$ 49.50	$ 2,759.74
	Frame & Body	$ 3,302.30	$ 1,709.00	$ 44.69	$ 70.00	$ 5,125.99
	Instruments & Wiring	$ 1,668.22	$ 485.00	$ 0.36	$ -	$ 2,153.58
	Miscellaneous, Fit & Finish	$ 349.00	$ 107.50	$ -	$ -	$ 456.50
	Steering System	$ 884.37	$ 820.50	$ 33.14	$ -	$ 1,738.01
	Suspension & Shocks	$ 3,287.20	$ 2,212.00	$ 69.68	$ -	$ 5,568.88
	Wheels & Tires	$ 642.80	$ -	$ -	$ -	$ 642.80

Figure 49: Recreated Cost Report

Just redoing the spreadsheet showed a 49% decrease in cost, with the new number being $19,099.64. We believe there is also a lot more than could be taken off that by using smarter manufacturing techniques as well as better implementing the cost development stage of the Cost Report and eBOM.

Moving Forward with the Cost Report and eBOM

It was clear that the team had a lack of knowledge that was critical to complete a budget that was fit to gain the points required to gain some spots in the competition. The cost report is a critical step to show the judges that the car was created with cost effective strategies and techniques. To help the team create a budget and cost analysis that will help gain them points in the competition instead of hinder them, we have created an outline and step-by-step guide.

Cost vs. Price Form

The Cost vs. Price form is a simple Google Form that is used to help determine the cost of a part as opposed to the price that the team paid for it. As the team is purchasing parts, in order to keep track of everything purchased as well as easily transferring the price of a part into the cost you should be documenting in the Cost Analysis. In Appendix 7, you can see the form that covers the major information that you need.

- Students name
- Area of commodity
- Assembly the part will be used in
- The component name
- Short description of the part
- Source
- Was it donated?
- Price you paid to obtain the part

Cost Analysis Outline

The Cost Analysis Outline included background information that can be used to understand the process as well as what the final product needs to be. See appendix 6 for the final product. In this outline, it talks about how to best go about calculating the cost of the car.

Future Business Recommendations

Below I have listed the recommendations for future business MQP's.

- Follow all outlines
  - The outlines needs to be updated biyearly to reflect the change in rules
- Develop a new structure for managing the subsystem teams
  - The team lacks proper communication between the MQPs, Professors, and students working on ISPs
- Develop a better system for retaining information from year to year
  - Something we started working on but have not properly executed was the ability to push information from one MQP to another. We have made a large step in the right direction by obtaining next year's MQP team, but the transfer of CAD files, calculations, and business materials is seriously lacking

References

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Gruner, A. (n.d.). Organizing a Formula SAE® Team. Retrieved April 24, 2017, from http://students.sae.org/cds/formulaseries/fsae/reference/orgteam01.htm

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Appendix

Appendix 1: Cornell University FSAE 2016 sponsorship packet

ABOUT FSAE

Founded in 1979, Formula SAE challenges students to design, manufacture and race a formula-style racecar. Over 400 university teams participate in competitions hosted worldwide. Teams navigate various static and dynamic events to defend their design processes and test their drivers' abilities. Each team's race car must excel in multiple events in order to win top honors at the Formula SAE Michigan competition. Competitors are judged not only on their car's performance on the track, but also in its design, affordability, and marketability.

The structure of the competition is as follows:

STATIC EVENTS:

Engineering Design	150 points
Cost Analysis	100 points
Business Presentation	75 points

DYNAMIC EVENTS:

Endurance	300 points
Autocross	150 points
Fuel Efficiency	100 points
Acceleration	75 points
Skid-Pad	50 points

TOTAL:	1000 points

HIGHLIGHTS

2015 - 6th in Acceleration & 7th in Marketing

2014 - 8th in Design & 11th in Skidpad

2013 - 1st in Accel & 6th Overall

MIS World Champions:

‘88, ’92, ‘93, ‘97, ‘98, ‘01, ‘02, ‘04, ‘05

With several world championship titles, Cornell Racing has always been a prominent contender in FSAE. The team has competed at the Formula SAE Competition in Michigan for the past 29 years, at the University of Toronto Shootout for the past 6 years, and at Formula Student Germany in 2011. In May 2016, the team will be competing for their tenth World Championship title.

THE TEAM

Cornell Racing is Cornell University's Formula SAE team and one of FSAE's top contenders. From the team's humble origins as Rookie of the Year in 1987, Cornell Racing has grown to become one of the most well-respected teams in the world. With an unparalleled nine World Championship titles at FSAE Michigan and awards from the Society of Automotive Engineers, Road & Track magazine, Goodyear, and Hoosier, Cornell Racing has a strong history in Formula SAE racing.

The 2015-2016 team is made up of 70 students from a plethora of majors. Cornell Racing has a unique advantage in that it brings together a variety of skill sets to form a team with immense diversity and charisma. Strong team work and dedicated members enable our team to succeed each year. Each member devotes at least 20 hours per week designing, building, and testing the car.

During the month of January, team members forego their winter breaks to stay in Ithaca, New York to manufacture the car and prepare for the upcoming competitions. Even after competition, several members of the team remain on campus for the summer to plan for the following season.

Cornell Racing provides an unrivaled learning experience that allows engineers to integrate classroom concepts with practical application. A large part of the experience is connecting with sponsors and alumni. The team compels students to overcome intellectual and collaborative challenges and provides a tight knit community for students interested in the automotive and related industries. The final racecar is a testament to the team's incredible work ethic and dedication.

THE CAR

For ARG16 we will take what we have learned from ARG15 and previous cars to design a car that is even better suited to win the competition. This year, we are focused on designing a car that is well-packaged, lightweight, and easy to manufacture in order to allow for full testing time before leaving for Michigan at the end of the school year.

ARG15 led Cornell Racing to a 6th place victory in the acceleration event in Michigan and 18th place in design. The car featured a steel subframe coupled with a carbon fiber monocoque, an active drag reduction system, and a 600CC turbocharged engine. ARG15's design was focused on reliability and serviceability. Here are the detailed specifications of ARG15.

ARG15

POWERTRAIN

- Turbocharged Honda CBR600RR engine
- BorgWarner KP-35 Turbocharger with custom, laser-sintered turbine housing
- Dry sump lubrication
- Fueled by E85
- Chain drive
- Modified transmission for custom gearing

ELECTRONICS

- MoTeC M400 ECU
- Modular CAN data collection
- Launch and traction control
- MoTeC M400 & ADL3
- Pneumatically - activated front wings elements

FRAME

- 3/4 carbon fiber moncoque
- Steel rear space frame

PERFORMANCE

- Power: 95 bhp
- Torque: 72 ft·lb
- Top speed: 100 mph
- Lateral acceleration: 1.5 g
- Acceleration 0-60 mph: 2.7 sec

SUSPENSION & UNSPRUNG

- 4-wheel independent double A-arm suspension
- Pushrod-actuated Penske 7800 2-way adjustable dampers
- 6.0x10" Hoosier racing slick tires
- Adjustable front and rear bladed anti-roll

GENERAL SPECS

- 470 lb, without driver
- 44/56 front-to-rear weight distribution

CORNELL RACING

• HISTORY •


1986 Cornell Racing is founded.

1987 Cornell Racing's first car wins third place at the FSAE Michigan Competition and is awarded Rookie of the Year.

1988 Cornell Racing wins its first World Championship in Michigan.

1992 Cornell Racing wins its second World Championship in Michigan.

1993 Cornell Racing wins its third World Championship and receives awards for Spirit of Excellence, Best Engineering Design, Best Performance, and Best Prototype.

1997 Cornell Racing wins its fourth World Championship due to the addition of new engine electronics, inboard suspension, and innovative composite design.

1998 Cornell Racing wins its fifth World Championship, taking first place in several events and setting the record for most points scored at an FSAE competition (an impressive 924.62 out of a possible 1000 points).

2001 Cornell Racing wins its sixth World Championship.

2002 Cornell Racing wins its seventh World Championship.

2004 Cornell Racing wins its eighth World Championship with the first ever electronically controlled turbocharger wastegate.

2005 Cornell Racing wins its ninth World Championship and receives a perfect score of 350 points in the Endurance event.

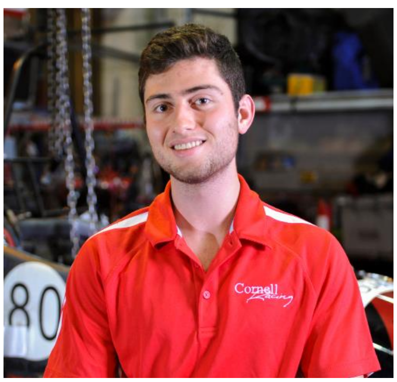
2007 Cornell Racing wins its first title at the University of Toronto Shootout Championship.

2011 Cornell Racing competes at Formula Student Germany.

WHAT STUDENTS ARE SAYING

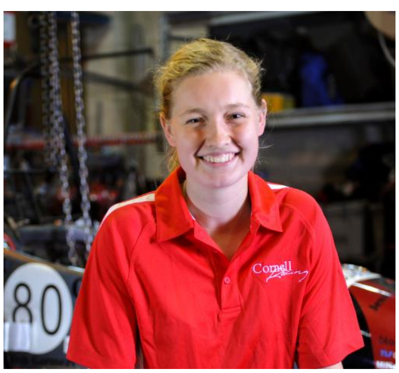
Sam Wormuth

Hometown: Syracuse, New york
Year: Senior, class of 2016
Major: Mechanical Engineering
School: College of Engineering
"I chose to be on Cornell Racing because I wanted hands on experience to compliment the theory offered by Cornell's curriculum. I have always loved cars and want to end up working in the automotive industry, so this seemed like a natural stepping stone. Getting the opportunity to drive a race car every weekend helps!"



Larry Lenkin

Hometown: Bethesda , Maryland
Year: Junior, class of 2017
Major: Mechanical and Aerospace Engineering
School: College of Engineering
"Cornell Racing has provided me with extensive knowledge on the design and manufacture of race cars. It is an experience beyond what is possible in a class room and has aided my education just as well as any class I could take. I believe that a complete engineering education cannot be truly complete without the experience of working on a real engineering project,"



Sarah Behringer

Hometown: Old Lyme, Connecticut
Year: Senior, class of 2016
Major: Electrical and Computer Engineering
School: College of Engineering
"I joined Cornell Racing because I wanted to gain experience in the shop. Since then I have not only learned about electronics and their importance in automotive engineering. I also believe that I have gained project management and problem solving skills that class experience doesn't even come close to. Being on the team reminds me why I wanted to go into engineering."

BENEFITS
OF SPONSORSHIP

Cornell Racing FSAE relies on sponsors and cannot succeed without your support. While Cornell University provides the team with laboratory space and testing facilities, the team's budget comes mostly from sponsors. Without such support, the team would not be able to produce a race car.

VISIBILITY

Cornell Racing has been featured in magazines such as Road & Track, Winding Road, and Race Car, and has been highlighted in a Discovery Channel special. The team and car, and therefore our sponsors, are constantly promoted across Cornell's campus and make regular appearances at national Formula SAE competitions. Our team also works on several social media platforms, giving our sponsors visibility to our fans.

NETWORKING

Cornell Racing reaches out to all our alumni through regular newsletters that prominently feature our sponsors, and provides a channel for your business to be marketed to the immense Cornell University alumni network. Your business will gain recruitment access to top engineering and business students at Cornell University.

Cornell University is a 501(c)(3) organization. All donations are tax deductible.

SPONSORSHIP LEVELS

TITLE

Platinum Sponsorship plus:

$10,000

- Extra-large company logo on the car
- Sponsor will be featured in all event public relations announcements to the media. Their logo will be featured on Cornell Racing's website and apperal.
- Promotional team visit with the car
- Other custom benefits upon request

PLATINUM

$5,000

Gold Sponsorship plus:

- Large company logo on the car
- Large company feature on the team website
- Large company feature in the team's alumni-network newsletters

GOLD

$2,000

Silver Sponsorship plus:

- Medium company logo on the car
- Company logo on official team apparel

SILVER

$1,000

Bronze Sponsorship plus:

- Company logo on the car
- Full access to the team for recruitment purposes

BRONZE

$500

- Company feature on the team website
- Company feature in the team's alumni-network newsletters

DONATION FORM

Cornell Racing provides one of the most exciting and rewarding educational opportunities available on campus: the chance to design, build, and drive a high-performance racecar. This experience not only expands the academic knowledge of our team members, but also encourages the development of real world engineering and project management skills. While Cornell University provides the team with laboratory space and testing facilities, the team's entire budget must come from sponsors and individual donors. Without contributions like yours, the team would not be able to make design advancements, or even produce a car.

If you are interested in making a donation to the Cornell Racing team, please fill out and return this form to the address listed below. Cornell Racing welcomes and greatly appreciates donations of any amount. Please do not hesitate to call or email us with questions. Thank you for your support!

Name / Organization: ______________________________

Mailing Address: ______________________________

City: ______________ State: __________ Zip Code: ______________

Phone Number: ______________ Fax Number: ______________

Email: ______________ Website: ______________

MONETARY DONATION

What is the amount of your gift? ______________

(Please make checks payable to Cornell Formula SAE and attach to this form.)

or

GIFT IN KIND

What is the nature of the gift in kind? ______________

What is the fair market value of the gift in kind? ______________

How was the fair market value of the gift of kind determined? ______________

____

Cornell University is a 501(c)(3) organization and all donations are tax dedictible.

Is an income tax receipt required? ____Yes ____No

______________________________ ______________

Signature Date

Please return this form to:
Cornell Formula SAE
Attn: John R. Callister
291 Grumman Hall
Ithaca, NY 14853

Contact us with any questions:
Kern Sharma
Business & Management Team Leader
email: ks869@cornell.edu

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- KAMAN
- Transducer Techniques
- SPACEX
- RICARDO
- ROYAL PURPLE Synthetic Oil
- SKF
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- AIRTECH Advanced Materials Group
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- BOSCH
- Monster Tool Co.
- Watkins Glen International
- Jesse Yorio
- destiny usa
- Sensata Technologies
- Barnett
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- Cornell AAs
- iS Motorsport
- RAM Fabricating Corp
- PLASCORE
- DRESSER-RAND
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Cornell Leadership

Appendix 2: Frame Comparison Analysis handout

Frame Comparison Analysis
FSAE 2017 frame to FSAE 2016 frame

Created by:

WPI FSAE 2017 MQP Team

Constantine Scaperdas, ME

Jonathan Ross, ME

Christian Strobel, ME

David Powers, MGE

Professor David C. Planchard, ME Advisor

Professor John C. Hall, ME Co Advisor

Professor Kevin M. Sweeny, Business Co Advisor

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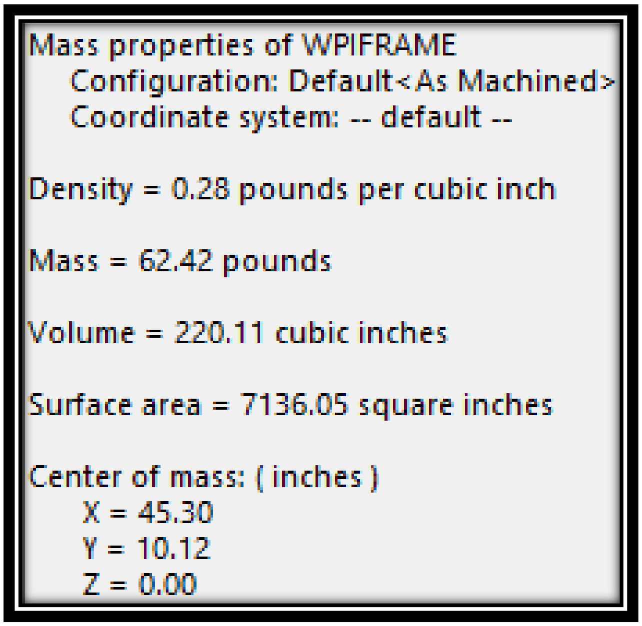
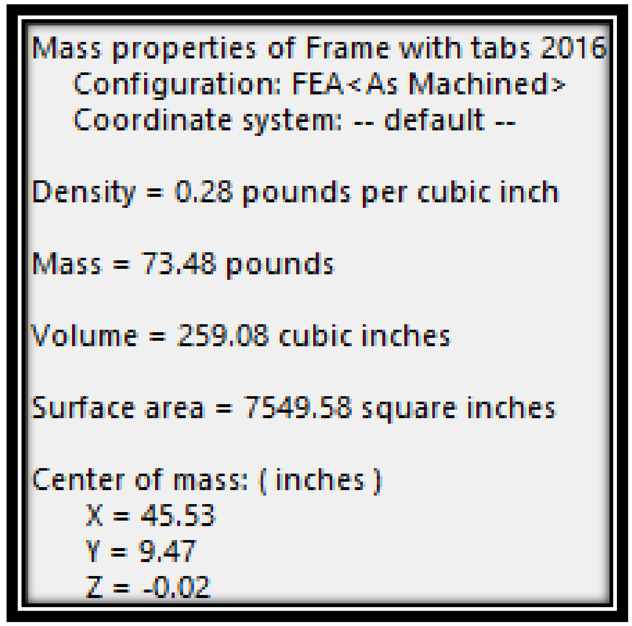
Weight and Center of Gravity comparison

2017 Frame



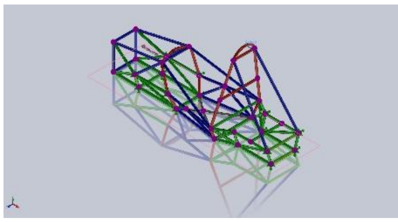
2016 frame



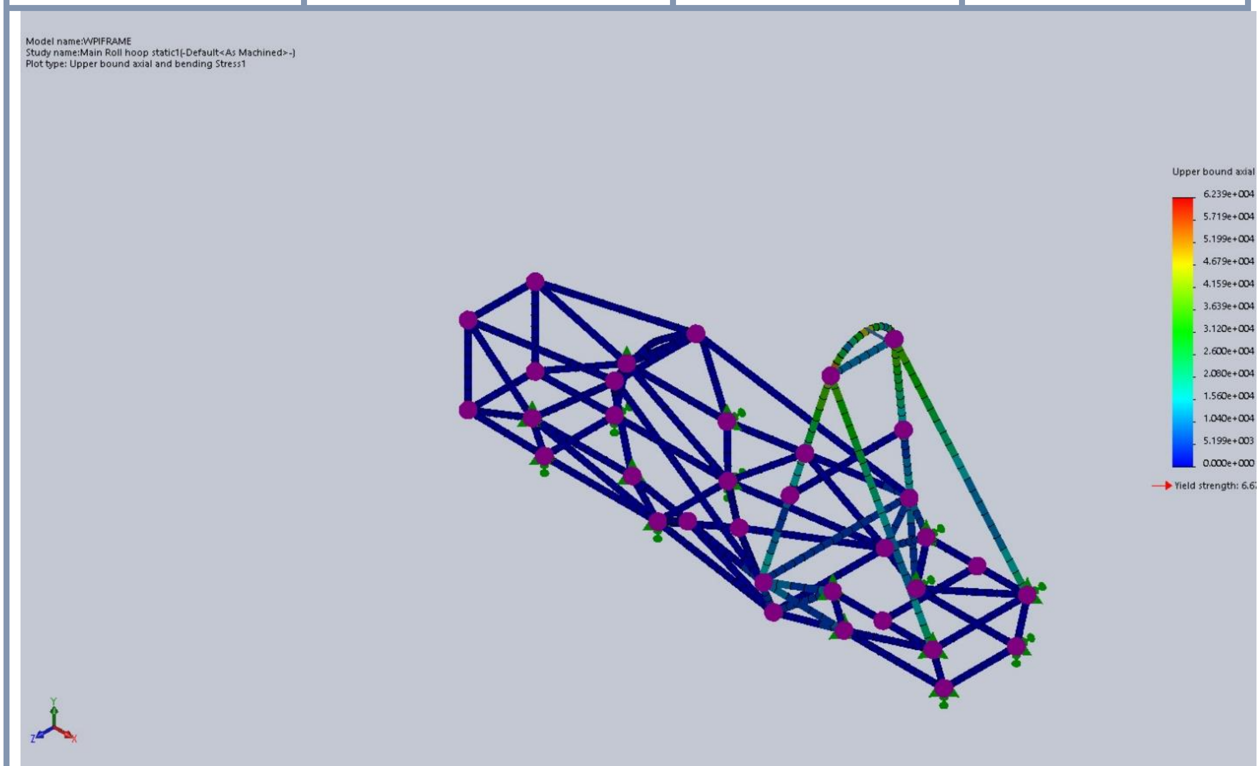
The new 2017 frame has a total weight of 62.4 lbs. with is a weight reduction of 15% or 11 lbs. over the previous frame. However the new frame features a slightly higher center of gravity at 10.1 inches high vs 9.5 inches in the old frame.

FSAE 2017 frame Main Roll Hoop impact test Study Results

For this impact test the fixture points were the 16 joints at the rear and front of the frame at the approximate locations of the suspension components. The force applied was 6kN applied to the top of the main roll hoop directed to the rear of the vehicle

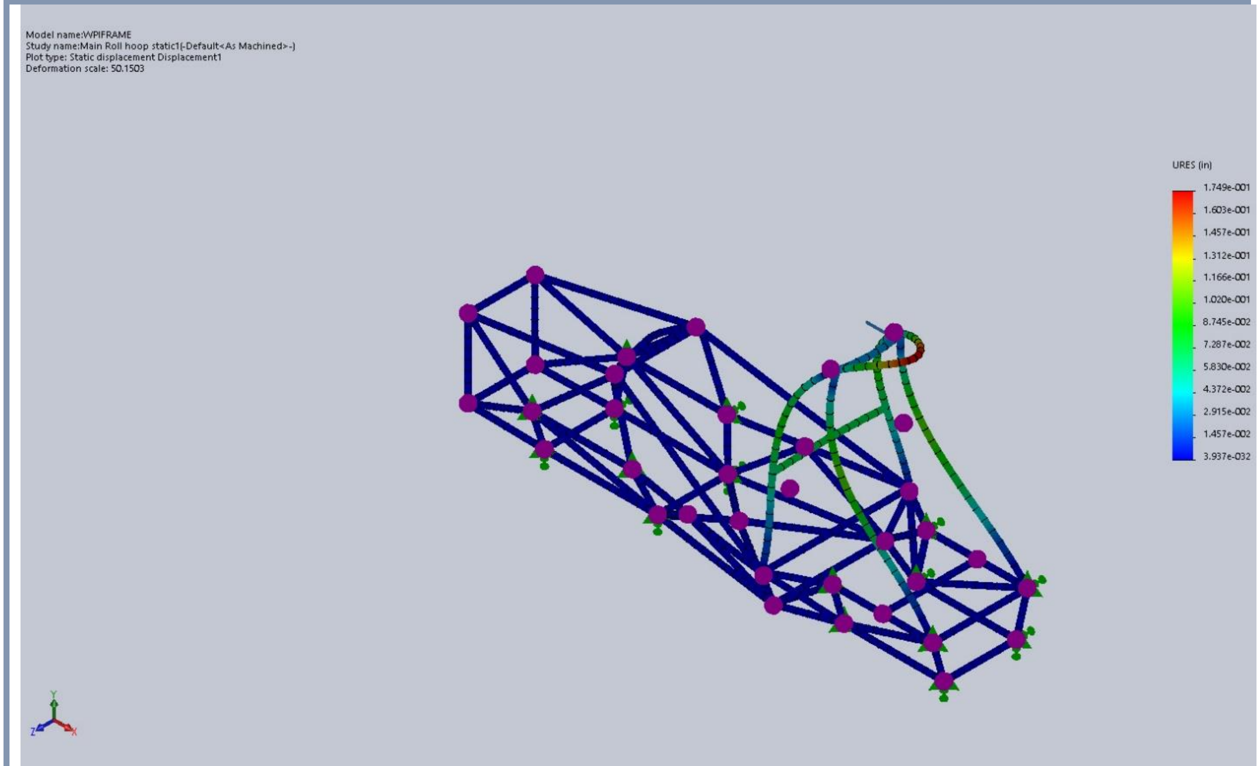
Load name	Load Image	Load Details
Force-1		**Entities:** **1 plane(s), 1 Point Load(s)** **Reference:** **Ground** **Type:** **Apply force** **Values:** **1348.85 Lbf** **Moments:** **---, ---, --- N.m**

Name	Type	Min	Max
Stress1	TXY: Shear in Y Dir. on YZ Plane	0 psi Element: 1	62390.7 psi Element: 78



WPIFRAME-Main Roll hoop static1-Stress-Stress1

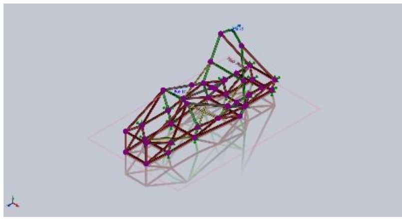
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 in Node: 1	0.174896 in Node: 86



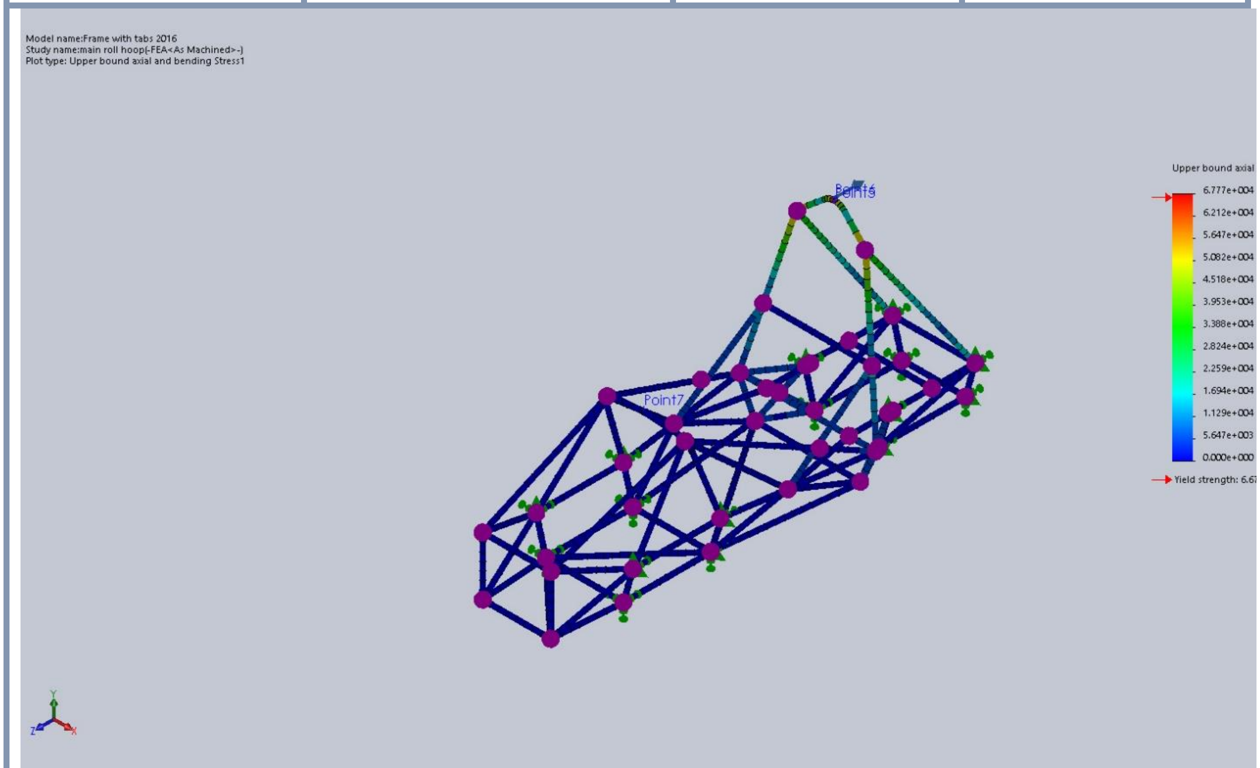
WPIFRAME-Main Roll hoop static1-Displacement-Displacement1

FSAE 2016 frame Main Roll Hoop impact test Study Results

For this impact test the fixture points were the 16 joints at the rear and front of the frame at the approximate locations of the suspension components. The force applied was 6kN applied to the top of the main roll hoop directed to the rear of the vehicle

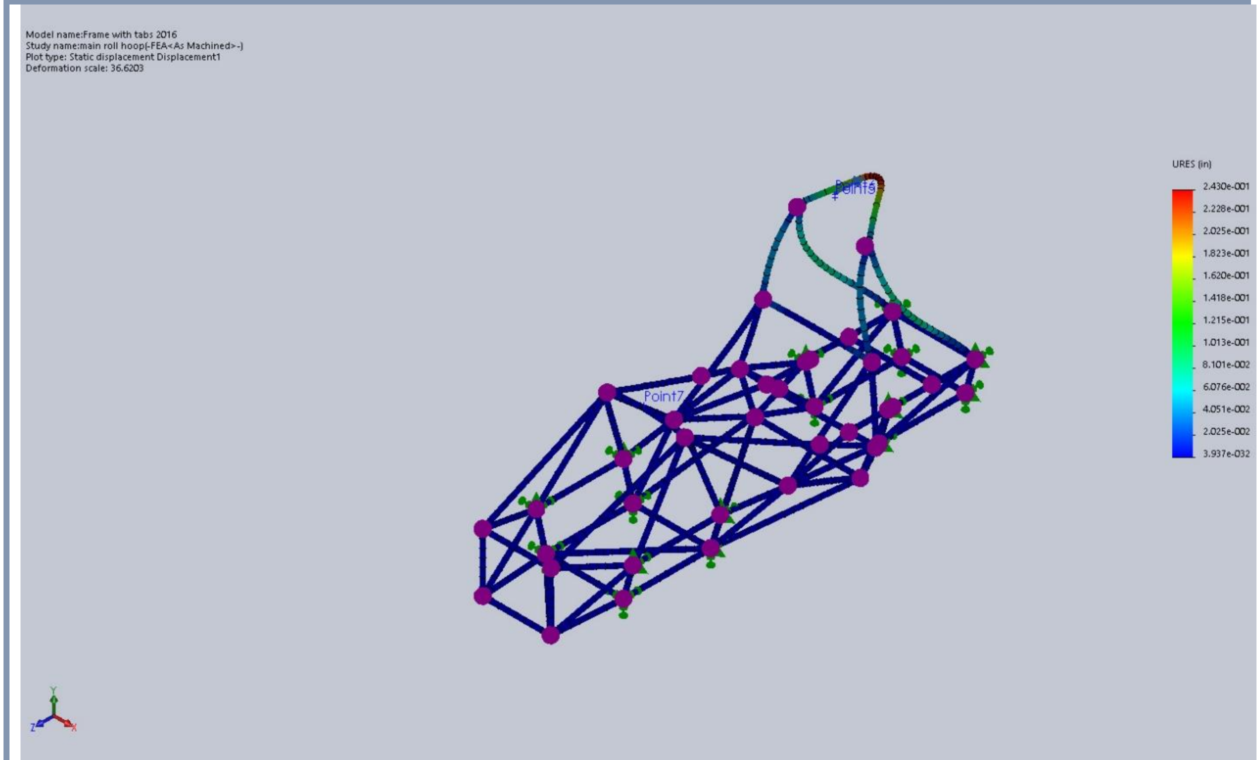
Load name	Load Image	Load Details
Force-1		**Entities:** 1 plane(s), 1 Point Load(s) **Reference:** Top Plane **Type:** Apply force **Values:** 1348.85 Lbf **Moments:** ---, ---, --- N.m

Name	Type	Min	Max
Stress1	TXY: Shear in Y Dir. on YZ Plane	0 psi Element: 1	67766.6 psi Element: 455



Frame with tabs 2016-main roll hoop-Stress-Stress1

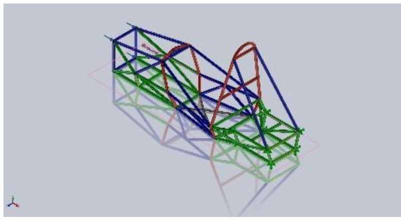
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 in Node: 1	0.243038 in Node: 454



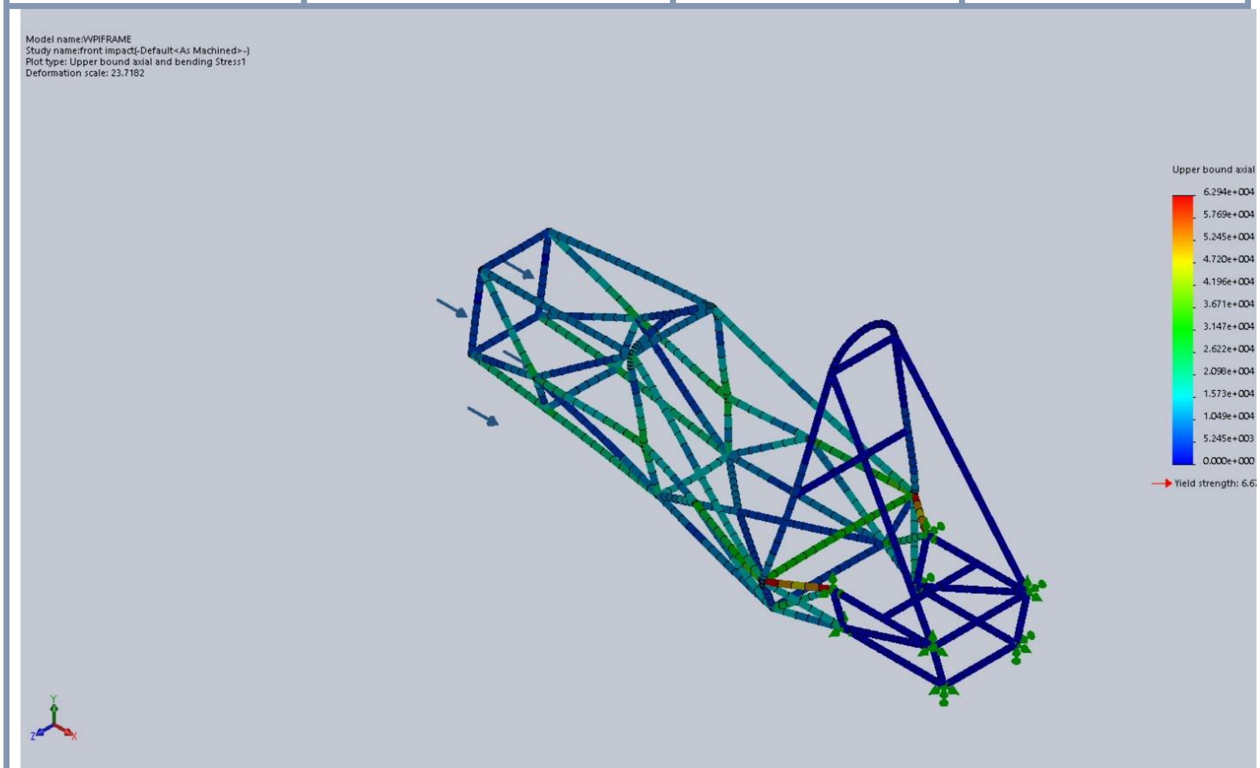
Frame with tabs 2016-main roll hoop-Displacement-Displacement1

FSAE 2017 frame front impact test Study Results

For this impact test the fixture points were the 8 joints at the rear of the frame at the approximate locations of the rear suspension components. The force applied was 58.86kN distributed evenly among the 4 joints of the front bulkhead directed to the rear of the vehicle

Load name	Load Image	Load Details
Force-1		**Entities:** 1 plane(s), 4 Joint(s) **Reference:** Ground **Type:** Apply force **Values:** 3308.6 Lbf **Moments:** ---, ---, --- N.m

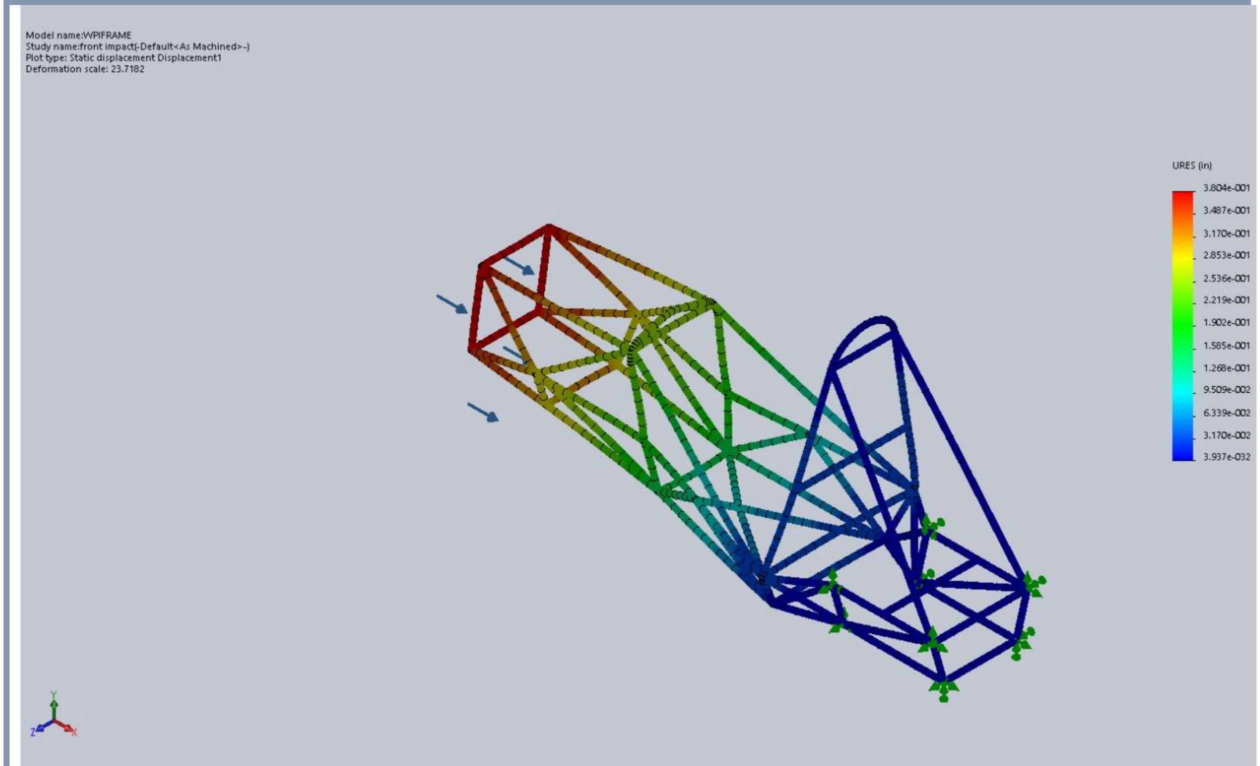
Name	Type	Min	Max
Stress1	TXY: Shear in Y Dir. on YZ Plane	0 psi Element: 114	62938.2 psi Element: 244



WPIFRAME-front impact-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 in	0.380367 in

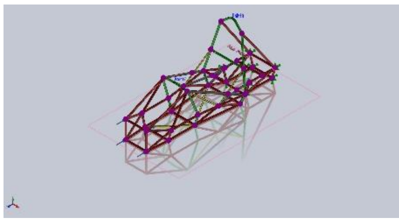
Name	Type	Min	Max
		Node: 1	Node: 307



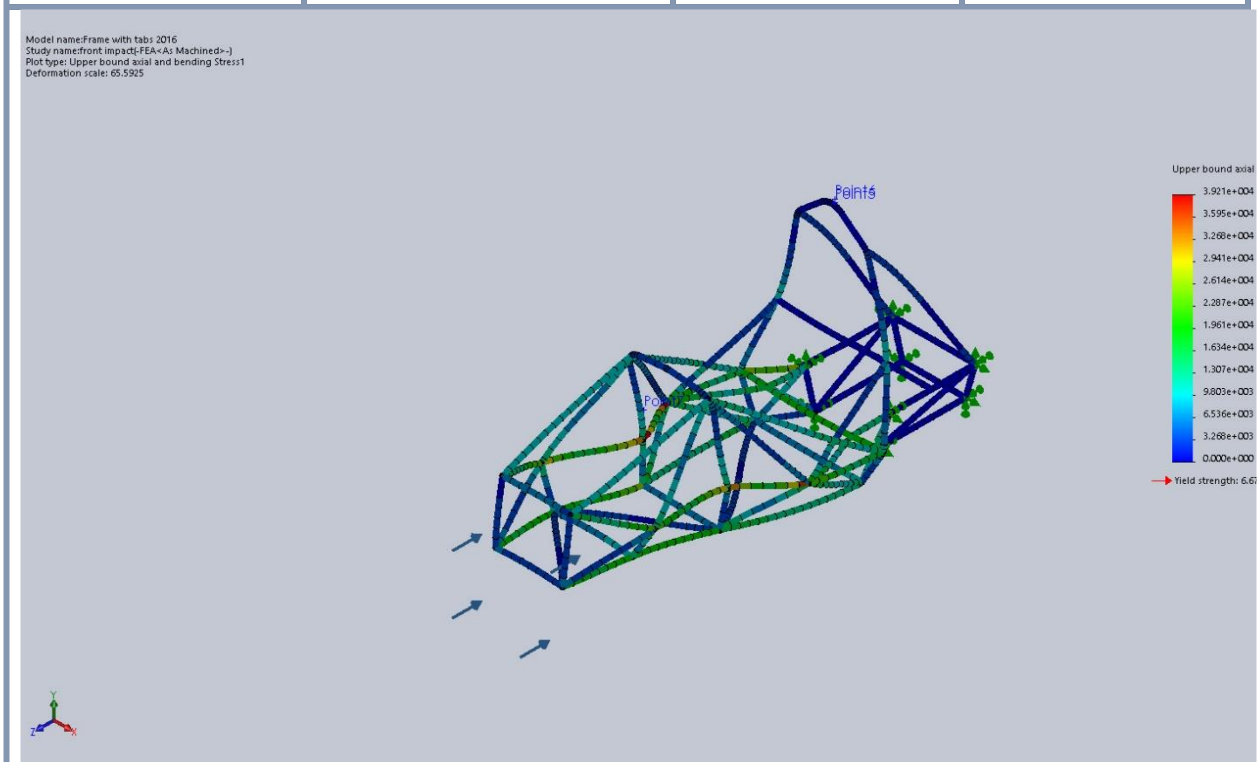
WPIFRAME-front impact-Displacement-Displacement1

FSAE 2016 frame front impact Study Results

For this impact test the fixture points were the 8 joints at the rear of the frame at the approximate locations of the rear suspension components. The force applied was 58.86kN distributed evenly among the 4 joints of the front bulkhead directed to the rear of the vehicle

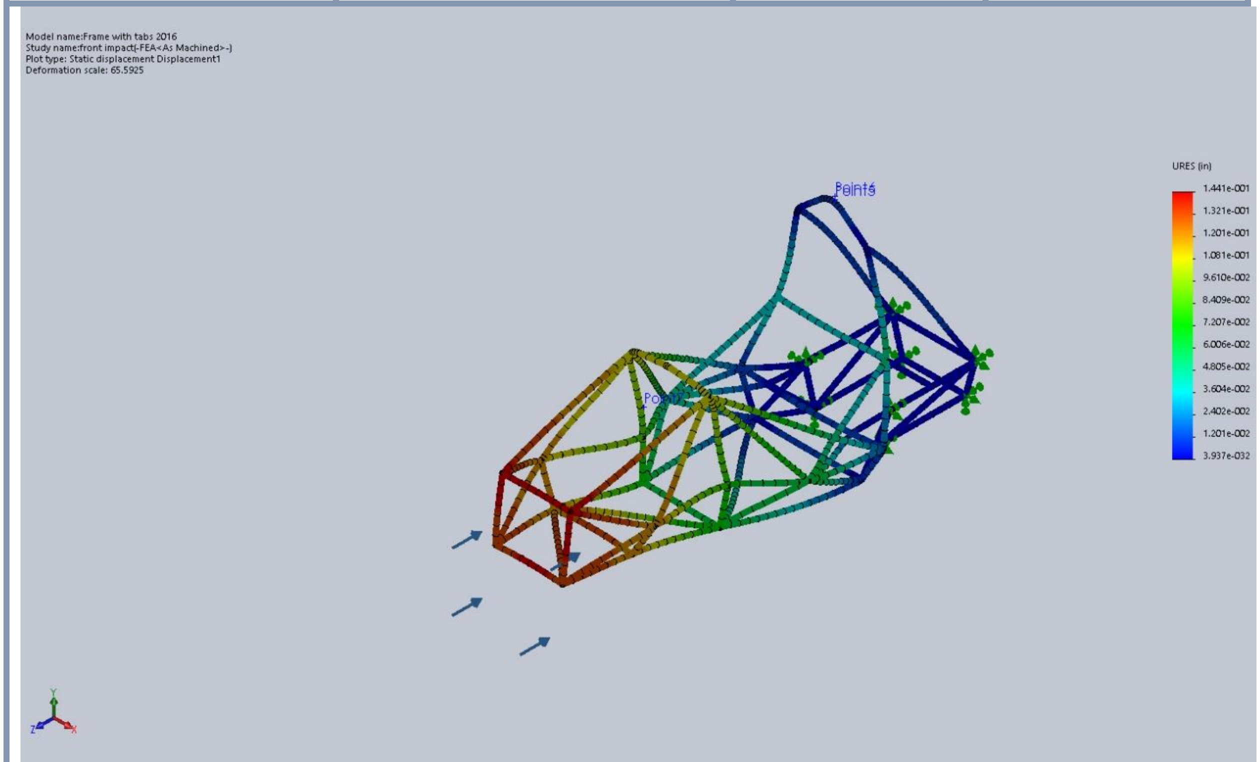
Load name	Load Image	Load Details
Force-1		**Entities:** **1 plane(s), 4 Joint(s)** **Reference:** **Top Plane** **Type:** **Apply force** **Values:** **3308.6 Lbf** **Moments:** **---, ---, --- N.m**

Name	**Type**	**Min**	**Max**
Stress1	TXY: Shear in Y Dir. on YZ Plane	0 psi Element: 29	39213.6 psi Element: 297



Frame with tabs 2016-front impact-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 in Node: 31	0.14415 in Node: 404



Frame with tabs 2016-front impact-Displacement-Displacement1

Appendix 3: Structural Equivalency Spreadsheet Highlights

Main Hoop Structural Equivalency - note, only steel may be used

Material Property	**Baseline**	**Your Tube**
Material type	Steel	Steel
Tube shape	Round	Round
Material name /grade	Steel	Steel
Youngs Modulus, E	2.00E+11	2.00E+11
Yield strength, Pa	3.05E+08	3.05E+08
UTS, Pa	3.65E+08	3.65E+08
Yield strength, welded, Pa	1.80E+08	1.80E+08
UTS welded, Pa	3.00E+08	3.00E+08

Tube OD, mm	25.4	25.4
Wall, mm	2.4	2.4

	Baseline	**Your Tube**	
OD, m	0.0254	0.0254	
Wall, m	0.0024	0.0024	
I, m^4	1.1593E-08	1.1593E-08	
EI	2.32E+03	2.32E+03	100.0
Area, mm^2	173.4	173.4	100.0
Yield tensile strength, N	5.29E+04	5.29E+04	100.0
UTS, N	6.33E+04	6.33E+04	100.0
Yield tensile strength, N as welded	3.12E+04	3.12E+04	100.0
UTS, N as welded	5.20E+04	5.20E+04	100.0
Max load at mid span to give UTS for 1m long tube, N	1.33E+03	1.33E+03	100.0
Max deflection at baseline load for 1m long tube, m	1.20E-02	1.20E-02	100.0
Energy absorbed up to UTS, J	7.98E+00	7.98E+00	100.0

Front Hoop Structural Equivalency

Material Property	Baseline	Your Tube
Material type	Steel	Steel
Tube shape	Round	Round
Material name /grade	Steel	Steel
Youngs Modulus, E	2.00E+11	2.00E+11
Yield strength, Pa	3.05E+08	3.05E+08
UTS, Pa	3.65E+08	3.65E+08
Yield strength, welded, Pa	1.80E+08	1.80E+08
UTS welded, Pa	3.00E+08	3.00E+08

Tube OD, mm	25.4	25.4
Wall, mm	2.4	2.4

	Baseline	Your Tube	
OD, m	0.0254	0.0254	
Wall, m	0.0024	0.0024	
I, m^4	1.1593E-08	1.1593E-08	
EI	2.32E+03	2.32E+03	100.0
Area, mm^2	173.4	173.4	100.0
Yield tensile strength, N	5.29E+04	5.29E+04	100.0
UTS, N	6.33E+04	6.33E+04	100.0
Yield tensile strength, N as welded	3.12E+04	3.12E+04	100.0
UTS, N as welded	5.20E+04	5.20E+04	100.0
Max load at mid span to give UTS for 1m long tube, N	1.33E+03	1.33E+03	100.0
Max deflection at baseline load for 1m long tube, m	1.20E-02	1.20E-02	100.0
Energy absorbed up to UTS, J	7.98E+00	7.98E+00	100.0

Main Hoop Bracing Supports

Enter construction type	**Tubing only**

Material Property	**Baseline**	**Your Tube**	**Your Composite**	**Your Total**	
Material type	Steel	Steel	Composite 1		
Tubing Type	Round	Round	NA		
Material name /grade	Steel	Steel	T3.30_Laminate		
Youngs Modulus, E	2.00E+11	2.00E+11	0.00E+00		
Yield strength, Pa	3.05E+08	3.05E+08	0.00E+00		
UTS, Pa	3.65E+08	3.65E+08	0.00E+00		
Yield strength, welded, Pa	1.80E+08	1.80E+08	N/A		
UTS welded, Pa	3.00E+08	3.00E+08	N/A		

Number of tubes	2	3			
Tube OD, mm	25.4	25.4			
Wall, mm	1.20	1.2			

Thickness of panel, mm			22		
Thickness of core, mm			18		
Thickness of inner skin, mm			2		
Thickness of outer skin, mm			2		
Panel height,mm			250		

OD, m	0.0254	0.0254			
Wall, m	0.0012	0.0012			
I, m^4	6.70E-09	6.70E-09	Tubing Only	6.70E-09	
EI	2.68E+03	4.02E+03		4.02E+03	150.0
Area, mm^2	182.5	273.7		273.7	150.0
Yield tensile strength, N	5.57E+04	8.35E+04		8.35E+04	150.0
UTS, N	6.66E+04	9.99E+04		9.99E+04	150.0
Yield tensile strength, N as welded	3.28E+04	4.93E+04		4.93E+04	150.0
UTS, N as welded	5.47E+04	8.21E+04		8.21E+04	150.0
Max load at mid span to give UTS for 1m long tube, N	1.54E+03	2.31E+03		2.31E+03	150.0
Max deflection at baseline load for 1m long tube, m	1.20E-02	7.98E-03		7.98E-03	66.7
Energy absorbed up to UTS, J	9.22E+00	1.38E+01		1.38E+01	150.0

Front Bulkhead

Enter construction type	**Tubing only**

Material Property	**Baseline**	**Your Tube**	**Your Composite**	**Your Total**	
Material type	Steel	Steel	Composite 1		
Tubing Type	Round	Round	NA		
Material name /grade	Steel	Steel	T3.30_Laminate		
Youngs Modulus, E	2.00E+11	2.00E+11	0.00E+00		
Yield strength, Pa	3.05E+08	3.05E+08	0.00E+00		
UTS, Pa	3.65E+08	3.65E+08	0.00E+00		
Yield strength, welded, Pa	1.80E+08	1.80E+08	N/A		
UTS welded, Pa	3.00E+08	3.00E+08	N/A		
UTS shear, Pa	2.19E+08		0.00E+00		
Number of tubes	2	4			
Tube OD, mm	25.4	25.4			
Wall, mm	1.6	1.6			
Thickness of panel, mm			22		
Thickness of core, mm			18		
Thickness of inner skin, mm			2		
Thickness of outer skin, mm			2		
Panel height,mm			60		
OD, m	0.0254	0.0254			
Wall, m	0.0016	0.0016			
I, m^4	8.51E-09	8.51E-09	Tubing Only	8.51E-09	
EI	3.40E+03	6.81E+03		6.81E+03	200.0
Area, mm^2	239.3	478.5		478.5	200.0
Yield tensile strength, N	7.30E+04	1.46E+05		1.46E+05	200.0
UTS, N	8.73E+04	1.75E+05		1.75E+05	200.0
Yield tensile strength, N as welded	4.31E+04	8.61E+04		8.61E+04	200.0
UTS, N as welded	7.18E+04	1.44E+05		1.44E+05	200.0
Max load at mid span to give UTS for 1m long tube, N	1.96E+03	3.91E+03		3.91E+03	200.0
Max deflection at baseline load for 1m long tube, m	1.20E-02	5.99E-03		5.99E-03	50.0
Energy absorbed up to UTS, J	1.17E+01	2.34E+01		2.34E+01	200.0
Perimeter shear, N (monocoques only)	4.27E+05	N/A		N/A	NA

Appendix 4: Business Logic Case Outline

Business Logic Case Whitepaper
FSAE MQP 2017
David Powers

Background

The Objectives of the Business Logic Case are to:

a. Teach participants about the factors that need to be considered when a company embarks on development of a new product. These include: cost; identification of market and likely sales volume; profitability; the key features applicable to the selected vehicle concept and target market size.
b. Ensure teams develop the concept of their entry with all of these aspects correctly considered, from the outset.
c. Ensure that all three static events are approached with a single common concept and presented to each set of static judges in the same manner.
d. Ensure participants gaining experience in producing a business case and balancing potentially conflicting attributes.

2 The Design, Cost and Business Presentation judges will use the business logic case to verify that the information presented at each static event is consistent with the overall objectives as outlined in the Static Events Rules.

a. In the Design event, the business logic case will be used to identify how the team determined the trade off between design for performance and design for manufacture and cost, how these requirements were considered in the overall concept and whether these were achieved in the final vehicle.
b. In the Cost event, the business logic case will be used to determine that the cost target was met for the same design solution and how Cost was integrated into the overall concept and the iterative design process.
c. In the Business Presentation event, the business logic case will be used to assess whether the business presentation is appropriate for the market and business strategy that the team has identified
d. For some Formula Student/FSAE Events, if the event is over subscribed, then the entry selection process may include assessment of the quality of the Business Logic Case supplied.

3 All teams must submit a Business Logic Case report in accordance with the general format applicable for the year of competition "FSAE Business Logic Case 201X". The report must be submitted on the 1 page template.
Refer to the applicable competition website to acquire the templates

4 This report must be submitted ~ 6-9 months before the competition.
Refer to the deadlines posted on the website for each specific competition.

General Requirements

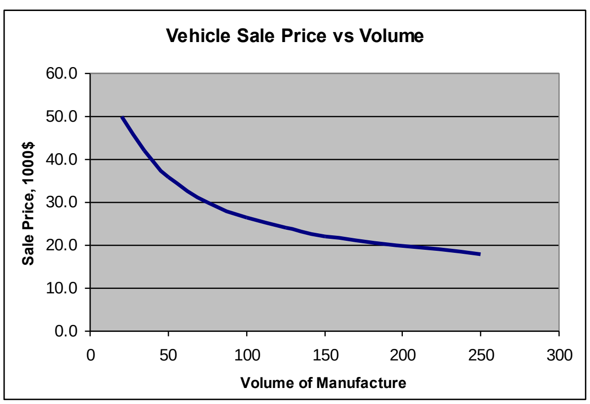
The steps in developing the case generally will consist of

- Benchmarking (analysis of previous competition results, competitor vehicle specifications and costs etc.)
- Short listing preferred concepts
- Assessing your team (company) capability to deliver different concepts recognizing the budget and team that you have
- Selecting your initial concept and developing targets to be achieved by the total vehicle (these will include target overall cost; likely sales potential; major performance and handling targets; timing plan for progressing the project;)
- Deciding on how to break down the total vehicle cost into different areas of the vehicle, recognizing the performance targets you have set.
- Commencing your design to deliver the design concept and related targets recognizing that the ensuing process will often be iterative and trade-offs will be necessary but if you have never defined the overall concept and what you plan to achieve, you will not be able to control your program and measure your progress

Market Data

Table 1 below defines the maximum number of autocross vehicles that can be sold annually for a given price, but this can only be achieved if the vehicle has sufficiently high performance. 1,000 units per annum is the maximum volume available.

Your selection of Price and Volume must correlate to this table. (Interpolate as necessary). Obviously your target Vehicle Cost must also relate to your planned Price.



Volume of cars sold per year	Sale Price, $
20	50000
35	42000
50	36000
75	30000
100	26500
125	24000
150	22000
250	17900
500	14600
750	13400
1000	12600

Table 1 – Volume of sales vs. sale price

Step-by-Step Guide

Strategy Table

Instructions

1. The first step in creating a good Business Logic Case is to first go over the previous years Case and evaluate how close to your target vehicle production cost you were. Using this data is a good point to start with. Once you determine whether the cost will be higher or lower, you can determine your selling price and production volume using Table 1.

Target Selling Price	28,000
Target Vehicle Production Cost	24,000
Target Production Volume (from Table 1)	25
Target Annual Profit	100,000

Logic

2. Using the previous years data as a baseline is always a good practice when starting out. Even if the team has different goals, it's easy to point out what worked and what didn't. Some of the best teams in the competition consistently keep a similar plan from year to year; they just iterate the process to better the process. The process that we followed was the University of Wisconsin's Business Logic Case. We used their case to compare our previous years submission to determine if what we submitted was accurate to what the judges were looking for.

Analysis of Market Data

Instructions

3. Once you have completed the above table, it is critical to sit down with the team and discuss your analysis of the of the market data to back up your choice of production volume. Showing the data from the previous year, you have hard facts to prove to the judges that you understand your target audience, whether it is a professional autocross racer or the standard hobbyist.

Analysis of Market Data

The market research we conducted all leads to one thing, faster lap times, more efficiently utilizing track time, and ease of use. Production and engineering methods place us in the perfect place to develop an easy-to-tune platform, that is both cost effective to purchase, developed with enough of a safety factor not to break under continued use, and has the ability to upgrade the car. Utilizing all of these key factors, our research concludes the car should be sold for $17,900.00.

Logic

4. When picking a target audience it is critical to sit down with the team to come up with a target consumer. The target consumer will point you in the direction of the budget the owner of the car has. Once you know your appropriate budget you can determine the target-selling price, which shows you your production volume and then you can do annual profit. This is a simple way that you can analyze the market.

Company Strategy

Instructions

5. For the company strategy portion of the form, you will need to sit down with the team and ask the following questions.
   a. Who is our target customer?
   b. Using our target vehicle production cost, how much room does this give us for innovation?
   c. Are we aimed at a cheap reliable car, or a technologically superior but expensive car?
   d. Are you working to obtain repeat customers?

   Using the answers to this question put together a description of what you are aiming to accomplish. This will show the judges the direction your company is trying to take.

Company Strategy

> Diving into a deeper analysis of the market, we targeted the most likely buyer of this product to be a moderately experienced autocross enthusiast. The product will offer more than just the minimum build, with customization in driving style, and a very thoroughly engineered vehicle, the product will attract many buyers. With many successful first time buying experiences, return customers and references will follow and add to the sales for the company.

Logic

6. These questions that are posed help you use information from the previous portion to piece together a company strategy portion of the paper. This portion of the case is completed easily using this information. This area is simply used to tell the judges exactly what you are expecting from the customer.

Vehicle Strategy & Performance

Instructions

7. The vehicle strategy and performance portion is used by the judges to determine the direction of the company as far as subsystems development, and strategy for how the car is engineered. Also this is an appropriate area to talk about driver aids in the car.

Vehicle Strategy & Performance

> In order to stand out from our competition, this product was developed to be within 20% of the top cars available for purchase. The product is designed to be within 20% to help cut costs, but still obtain a high level of performance. Each subsystem of the car was developed with a dedicated team to ensure each subsystem is up to our company's standards. In addition, there are many technological upgrades to help make up for driver shortcomings and cut the learning curve for newer drivers.

Logic

8. This area is designated to state the advanced components that will be in the car. The judges will use this area to determine if the team is shooting for something that is unobtainable within the budget constraints. If you plan to have a full ABS system as well as traction control, then odds are the cost of your car will be higher, as the systems require advance technology.

<u>Plans for Efficient Design</u>

Instructions

9. The judges use this portion to determine if the team has put thought into creating a sustainable and easily manufactured car. The judges are looking for how in-depth the team utilizes advanced manufacturing techniques as well as any trade-offs the company has made to decrease cost and increase safety. I.e. steal frame vs. aluminum frame.

Plans for Efficient Design (and Manufacture)

In order to decrease the cost of the car, we are using simple, simple and known manufacturing techniques. In addition to a simple, one cylinder engine, with a simple manual five speed transmission. The frame is comprised of cost effective, but strong steel frame. This decreases cost and increases safety.

Logic

10. In combination with the previous entry, you can defend the strategies you plan to implement into the car. This entry gives you an area to talk about how you plan to make your innovations cost effective and reliable. This is so the team thinks about potential issues that could come up.

<u>Key Design Features</u>

Instructions

11. An engineer on the team should complete the following two sections. The key design features list 4 key trains the car will have. This includes the material and body type of the frame, the powertrain type, the engine size, and your target weight. These can also be used to add key points to the efficient design section.

Logic

12. This is fairly straightforward; again it is to show the judges that some forethought has been put into the process. If the engine is super high powered and high quality, the cost of your car goes up. It's easy to get over ambition when planning, so this areas makes you step back and look at the core details to ensure there are little to no flaws.

<u>Key Performance Targets</u>

Instructions

13. An engineer on the team should also do the calculations to determine the answers for these questions. The acceleration time for 75 metres, lateral acceleration in g's, and the average fuel economy. These can be easily completed by the engineering team utilizing the team's numbers from the previous year and then taking a percentage of improvement.

Key Design Features		Key Performance Targets	
Chassis/Body Type	Steel Tube, Fiberglass Body	Accn. 0-75 Metres	4.7s
Power train type	Eg IC engine / electric	Lateral Accn. (g)	1.5g
Power / engine	450cc Single Cylinder, 48kw	Fuel Economy	
Target weight, kg	191.25 kg		

Logic

14. These key details can help show the judges that you are effective at planning and doing the basic calculations to determine the key details of the car. If your fuel economy and acceleration numbers are close to the accurate numbers, then you will score higher as you have proved to the judges that you understand how to do the calculations.

Appendix 5: Business Logic Case

2016 FSAE® BUSINESS LOGIC CASE

Integrated Systems Design

Commencing with the 2013 year Formula SAE Competition, a new integrated business/design concept summary is to be submitted by all teams, 6-9 months ahead of the competition. This summary (entitled The FSAE Business Logic Case) should not be an onerous task and will assist teams to follow an integrated systems approach. In order to give students the maximum benefit, it is intended that this task is completed before the design process is engaged with the objective to define an integrated overall vehicle concept with consideration of but not limited to: vehicle performance, cost and target market.

It will assist students understanding of, and correlation with, the real world approach to vehicle design, whereby a Total Systems Overview and Vehicle Level Targets are developed (Cost; Price; Profit; Volume; Performance), and a sanity check completed, before any detail design is undertaken. This approach can help avoid conflicts later in the design process between systems and ensure realistic targets for your total vehicle are set which can then be deployed into the function and cost targets for each of the vehicle Systems and Sub-Systems.

Why Make this Change?

At various events worldwide a rise has been observed in the number of entrants that appear to have lost their way with regards to cost, value and the logic of design for manufacture and profit. These aspects are critical in the real world you will encounter within the global automotive OE and Supplier industry. The intent of this additional submission is to help you to guide yourselves to produce a better vehicle and advance your education in line with future reality.

Seldom is the biggest budget or most expensive and technologically advanced vehicle the best solution. Getting the balance right is the key. Thinking at the higher (overall vehicle) level before plunging into the detail (the front suspension or monocoque body) will help you produce the best result within the resources available to your team. The aim of the event series is to improve a student's knowledge in a manner that will be real world useful, as soon as possible, and thus provide a shortcut of "experience" to the benefit of the student, their educational establishment and also their first employer. Uniquely, everyone wins here.

Remember that this is not a motorsports competition but the development of expertise and understanding of what is necessary to design, build and develop an actual vehicle that can be compared to others but which recognises the importance of cost and understanding of design and function, inside a reasonable business case. The small open wheeler with specification limits is chosen as it provides a vehicle type which can realistically be designed and built within the available time, and its actual performance then demonstrated vis a vis design intent.

This document will not be formally marked and no specific points will be allocated but it will be used to aid the Design, Cost and Business Presentation process and help teams to represent themselves consistently across the 3 static events

The Integrated Plan

The general rules which apply to this submission are summarised on Page 2. The general steps vehicle project teams would follow in developing their Business Case and related initial vehicle concept and features (in Business as well as for this event) are outlined on Page 3 along with the instructions for filling in the 1 page submission (Page 4).

The organisers appreciate that things may change; it is not intended to limit or restrict the benefits of "learning by doing" but rather to ensure that changes which arise are recognised and related back to the overall objectives. This will assist explanations to Judges at the event in a logical (and desirably documented) manner and avoid being surprised by obvious questions on the rationale for various design or feature selections.

Rules

Business Logic Case

1 The **Objectives of the Business Logic Case** are to:

a. Teach participants about the factors that need to be considered when a company embarks on development of a new product. These include: cost; identification of market and likely sales volume; profitability; the key features applicable to the selected vehicle concept and target market size.

b. Ensure teams develop the concept of their entry with all of these aspects correctly considered, from the outset.

c. Ensure that all three static events are approached with a single common concept and presented to each set of static judges in the same manner.

d. Ensure participants gaining experience in producing a business case and balancing potentially conflicting attributes.

2 The Design, Cost and Business Presentation judges will use the business logic case to verify that the information presented at each static event is consistent with the overall objectives as outlined in the Static Events Rules.

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b. In the Cost event, the business logic case will be used to determine that the cost target was met for the same design solution and how Cost was integrated into the overall concept and the iterative design process.

c. In the Business Presentation event, the business logic case will be used to assess whether the business presentation is appropriate for the market and business strategy that the team has identified

d. For some Formula Student/FSAE Events, if the event is over subscribed, then the entry selection process may include assessment of the quality of the Business Logic Case supplied.

3 All teams must submit a Business Logic Case report in accordance with the general format applicable for the year of competition "FSAE Business Logic Case 201X". The report must be submitted on the 1 page template.
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General Requirements

The steps in developing the case generally will consist of

- benchmarking (analysis of previous competition results, competitor vehicle specifications and costs etc.)
- short listing preferred concepts
- assessing your team (company) capability to deliver different concepts recognising the budget and team that you have
- selecting your initial concept and developing targets to be achieved by the total vehicle (these will include target overall cost; likely sales potential; major performance and handling targets; timing plan for progressing the project;)
- deciding on how to break down the total vehicle cost into different areas of the vehicle, recognising the performance targets you have set.

- commencing your design to deliver the design concept and related targets recognising that the ensuing process will often be iterative and trade-offs will be necessary but if you have never defined the overall concept and what you plan to achieve, you will not be able to control your program and measure your progress

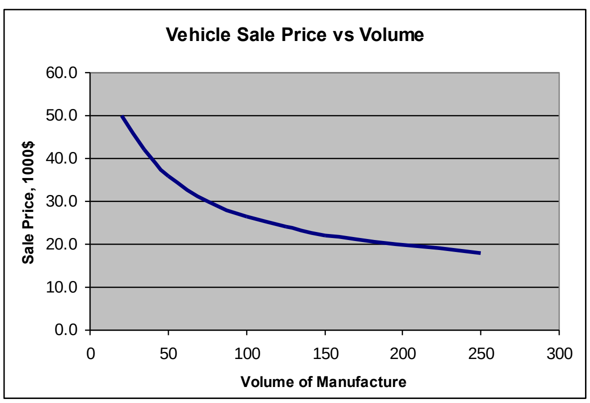
Instructions: Complete the information request fully but the submission is to be only a single A4 page. Please replace all text which is highlighted with a yellow background.
You can re-allocate space between sections versus the indicated box sizes on the pro-forma.

This case outlines the team's decisions made throughout the overall design process and will be used in **all** static events at the competition.

Market Data

Table 1 below defines the maximum number of autocross vehicles that can be sold annually for a given price, but this can only be achieved if the vehicle has sufficiently high performance. 1,000 units per annum is the maximum volume available.

Your selection of Price and Volume must correlate to this table. (Interpolate as necessary). Obviously your target Vehicle Cost must also relate to your planned Price.



Volume of cars sold per year	Sale Price, $
20	50000
35	42000
50	36000
75	30000
100	26500
125	24000
150	22000
250	17900
500	14600
750	13400
1000	12600

Table 1 – Volume of sales vs. sale price

2016 FSAE® BUSINESS LOGIC CASE

A Minimum size Font of Arial 10 must be used for completing the Pro- Forma.

Institution/Team Identification: WPI________________________

Analysis of Market Data

The market research we conducted all leads to one thing, faster lap times, more efficiently utilizing track time, and ease of use. Production and engineering methods place us in the perfect place to develop an easy-to-tune platform, that is both cost effective to purchase, developed with enough of a safety factor not to break under continued use, and has the ability to upgrade the car. Utilizing all of these key factors, our research concludes the car should be sold for $17,900.00.

Company Strategy

Diving into a deeper analysis of the market, we targeted the most likely buyer of this product to be a moderately experienced autocross enthusiast. The product will offer more than just the minimum build, with customization in driving style, and a very thoroughly engineered vehicle, the product will attract many buyers. With many successful first time buying experiences, return customers and references will follow and add to the sales for the company.

Target Selling Price	$17,900.00
Target Vehicle Production Cost	$13,500.00
Target Production Volume (from Table 1)	250
Target Annual Profit	$1,100,00.00

Vehicle Strategy & Performance

In order to stand out from our competition, this product was developed to be within 20% of the top cars available for purchase. The product is designed to be within 20% to help cut costs, but still obtain a high level of performance. Each subsystem of the car was developed with a dedicated team to ensure each subsystem is up to our company's standards. In addition, there are many technological upgrades to help make up for driver shortcomings and cut the learning curve for newer drivers.

Plans for Efficient Design (and Manufacture)

In order to decrease the cost of the car, we are using simple, simple and known manufacturing techniques. In addition to a simple, one cylinder engine, with a simple manual five speed transmission. The frame is comprised of cost effective, but strong steel frame. This decreases cost and increases safetv.

Key Design Features		Key Performance Targets	
Chassis/Body Type	Steel Tube, Fiberglass Body	Accn. 0-75 Metres	4.7s
Power train type	Eg IC engine / electric	Lateral Accn, (g)	1.5g
Power / engine	450cc Single Cylinder, 48kw	Fuel Economy	
Target weight, kg	191.25 kg		

Appendix 6: Cost Report Outline

Cost Report Outline
FSAE MQP 2017
David Powers

Background

The objectives of the Cost Report are to:

1. Teach the participants that cost and a budget are significant factors and must be taken into account in any engineering exercise Ensure the teams develop their cars within a reasonable budget, many teams have worked what may seem like an unlimited budget, so it is very easy to get ahead of yourself with purchasing and manufacturing part for the single car, but it is important to remember that the grand scale of the competition is to create a car that car be mass produced.
2. To learn and understand the manufacturing techniques and processes of some of the components
3. Track the cost of the car and manufactured parts, it is important to note that the number you actually send on the car will be different than the number submitted. The competition judges give you a document called The Materials Spreadsheet, that includes the cost of many of the most commonly used parts on the car and tells you what price to record in your spreadsheet.
4. The cost report is built online using an online spreadsheet that each team will use. Once the spreadsheet is completed, it will have to be printed and have a hard copy mailed to the competition and arrive no later than April 3rd (date may vary next year).
5. To keep track of expenses, the team has a Google form that will be used to compile data on all of the parts used in the car, as something is purchased, the team will push the data into the spreadsheet which provides you with quick access to the information

General Requirements

There are several key items to remember when completing the Formula SAE Cost Report:

- Completed online in the team Cost Module
- A hard copy of the completed Cost Report will need to be printed and brought to the competition
- Make sure to utilize pricing for the Cost Report using the spreadsheets they provide each team with, this significantly lowers the cost of the car as the prices they provide are in wholesaling terms
  - http://www.fsaeonline.com/page.aspx?pageid=5ade9b01-8903-4ae1-89e1-489a8a4f08d9
- Utilize the Google form that is provided to the team to ensure every part from the car is included, there are points awarded for the teams that are very thorough with the analysis
- The pricing reflected in the book should show the methods used to build this prototype vehicle. If another method will be used to create a production level of the vehicle, notate that information in the book as well, so that process decisions can be analyzed.
- You will be producing 4 cars a day for an unspecified period of time, so volume pricing or wholesale cost is not possible.
- The vehicle should cost no more than $25,000. (NOTE: at $25,000 the points for the vehicle's cost are zero.)

- Costs are not based on special pricing, discounts or donated items available to the schools – Items should be costed using retail values from the spreadsheets

Guide

The following information is a guide on how to best complete the Cost Report that will be submitted for the competition.

Google Form

This form will help connect you with the team and provide you with all of the information you will need. It's very easy for information to get lost in translation as well as not documented when the season starts to wind down and students start to get absorbed and only focus on the building the car. This is where you have the ability to take a good team to a great team by filling those missing gaps and holding the team accountable for tracking their spending.

Provided Price Documents

In order to complete the Cost Report, there are several provided documents that you will use to calculate the price of the items. Below I have listed the key documents that can be accessed using the provided link above.

- 2017 Fasteners Table
- 2017 Materials Table
- 2017 Processes Table
- 2017 Process Multipliers Table
- 2017 Tooling Table

Fasteners Table:
The fasteners table should be used to calculate the cost of all of the hardware that will be used in the car. This can include anything that is included in the fasteners table. Although it isn't expected that every nut and bolt is included, it would help the score if all were included as long as the cost isn't driven about $25,000.

Materials Table:
The materials table will be used when you have parts that will be purchased for the car. This document lists the suggested retail price for everything from bearings to shocks and tires. When you are completing the cost report, you should use these numbers to fill in the cost report.

Processes Table:
This table should be used when calculating the cost of the manufactured parts on the car. This can be a difficult process, but the spreadsheet includes process and unit cost, so it should be easy to calculate the parts that are manufactured in-house.

Process Multiplier Table:
This table should be used to calculate the cost of multiple manufactured parts on the car.

Tooling Table:
This table should be used for processes such as welding, die-casting, or metal casting. These are more advanced types manufacturing that are not covered in the Processes Table.

Online Cost Report

New for this year is the online cost report, this is the same version as the regular hard copy cost report, but is now all completed online to make it easier to submit. The form can be accessed by going to the link below.

- https://www.fsaeonline.com/

Once you has access to the portal, it is very simple to fill out the completed cost analysis.

Hard Copy and Due Dates

A hard copy of the materials will be due at the competition as well as to be submitted by April 10th the year of competition.

Appendix 7: Cost vs Price Form

2017 FSAE Part Purchase Form

Please answer every question to the best of your knowledge, if you have any questions please email dmpowers@wpi.edu.

* Required

Your Name? *

Your answer

Area of Commodity? *

- [ ] Brakes
- [ ] Engine & Drivetrain
- [ ] Frame & Body
- [ ] Electrical
- [ ] Fit & Finish
- [ ] Steering System
- [ ] Suspension
- [ ] Wheels and Tires
- [ ] Miscellaneous

What Assembly? *

Your answer

Component Name? *

Your answer

Short Description of Part *

Your answer

Source? *

Your answer

Donation? *

☐ Yes

☐ No

Price? *

Your answer

SUBMIT

Never submit passwords through Google Forms.