

WIKI

Chassis Department

Summary

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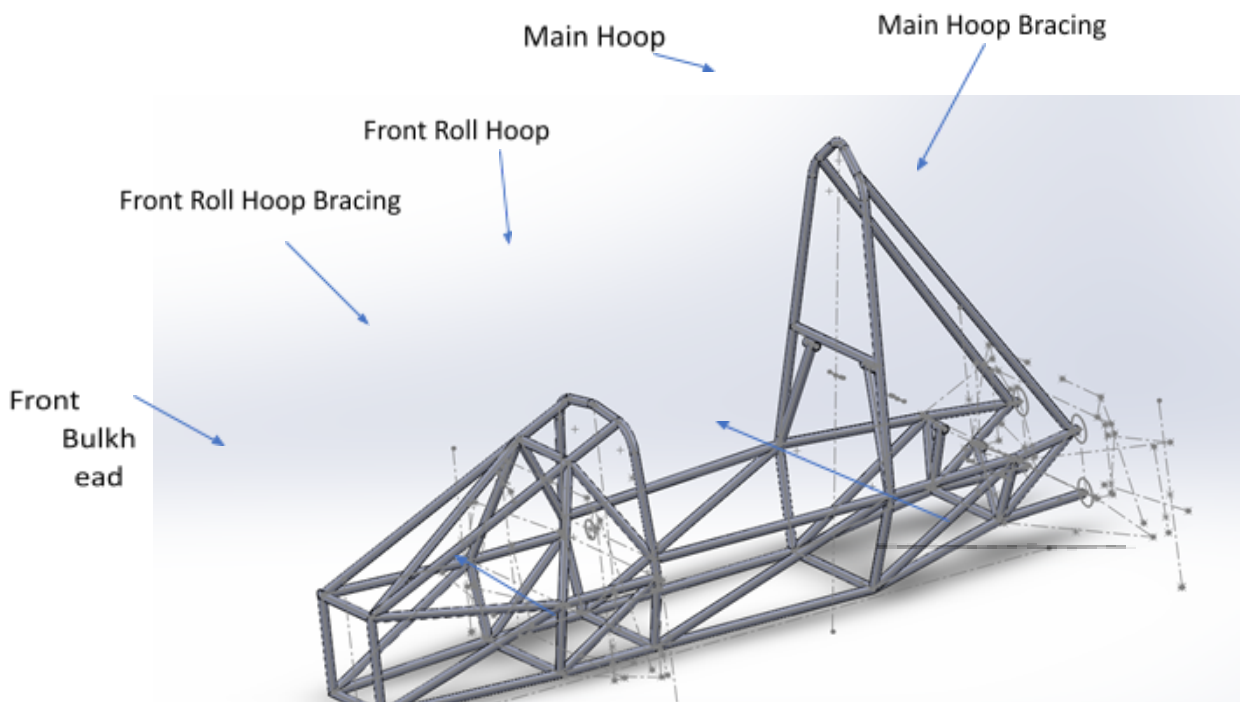
1. What is a Chassis?

The chassis acts as the car's skeleton. Many mechanical parts are fastened to the chassis such as suspension, braking and handling, powertrain and body work. Another function of the chassis is to deal with both the dynamic and static load applied to it with the least amount of deflection or distortion possible.

While all chassis designs will have some amount of flex, our goal is to design a chassis that is as stiff as possible. A high torsional rigidity and low weight is also desirable. The competition rules state that a vehicle's structure must include two roll hoops that are braced, a front bulkhead with support system, an impact attenuator and side impact structures.

Useful links

- A. <http://www.onlinejournal.in/IJRV215/253.pdf>
- B. <https://iopscience.iop.org/article/10.1088/1742-6596/908/1/012042/pdf>



2. Types of Chassis

2.1. Ladder Chassis

This type of chassis, resembling a ladder, is commonly used in heavy duty vehicles. Although it is strong and easy to manufacture, due to low torsional rigidity this type of chassis isn't well suited for our design.

2.2. Box/Four Tube Chassis

This is a box structure that encloses the engine and driver's legs with the suspension attached to the sides of the chassis. Although there are some diagonals there are also

some bars that will experience forces in bending. One major disadvantage to this type of chassis is that damage is often widespread and therefore difficult to repair quickly.

2.3. Space Frame

All beams in a true space frame chassis must be in tension or compression. This type of chassis consists of triangles and pyramids leading to a high torsional rigidity. This design is very stiff which means that less materials are needed resulting in a lightweight chassis. Crash damage is also easier to repair than on a four-tube chassis as it's mostly localised. The disadvantages of a space frame lie mainly in its manufacture; they often require an elaborate jig and complex welds. Space frame chassis are almost always used by Formula Student teams.

3. Roll Hoops

3.1. Front Roll Hoop

The front roll hoop is a roll bar located above the driver's legs, in proximity to the steering wheel.

3.1.1. Rules

The front roll hoop must be constructed from a continuous and closed section; while it can be made from more than one tube if it is then it must be well supported. In side view, the front hoop can't be tilted more than 20°.

3.2. Main Hoop

The Main hoop is a roll bar just behind or alongside the driver's torso. Its function is to protect the driver's upper body from injury should roll over occur.

3.2.1. Rules

Unlike the front roll hoop, the main hoop must be made from a single piece of uncut steel tubing. In side view, the main hoop can't be tilted more than 10°.

3.3. Bracing

The rules require quite specific bracing to support both the front and main hoops. More details on this can be found in section T3.11 of the 2020 rules.

4. Front Bulkhead

4.1. What is it

The rules define a front bulkhead as a planar structure that defines the forward plane of the chassis and provides protection for the driver's feet.

4.2. Materials

If any alternative material to steel is used for the front bulkhead it must have a perimeter shear strength equivalent to a 1.5mm thick steel plate.

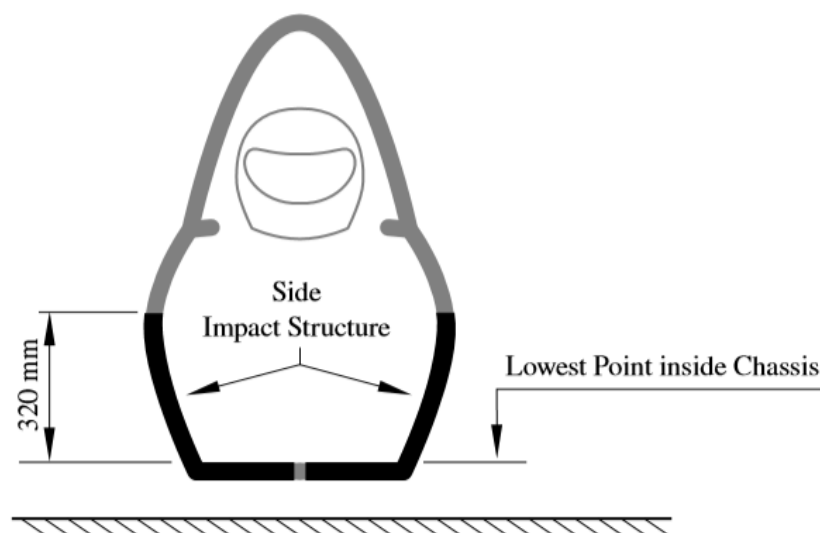
4.3. Front Bulkhead Support

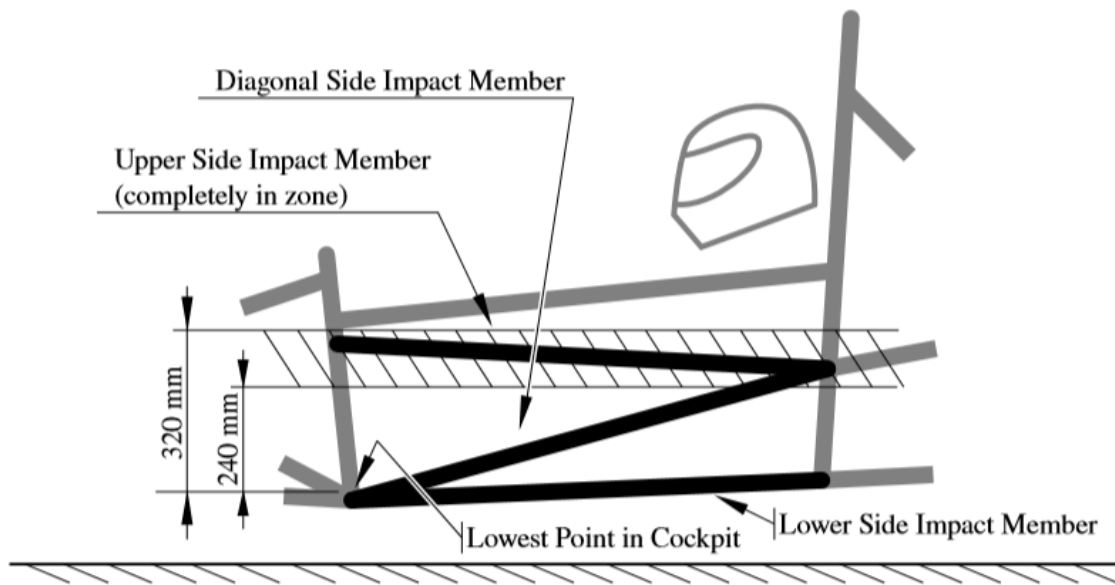
The front bulkhead support is a structure that defines the side of the chassis from the front bulkhead back to the top of the upper side impact structure and the bottom of the front hoop.

4.4. Rules Related Constraints

The front bulkhead must be supported back to the front roll hoop by three chassis members – an upper and lower member and diagonal bracing. The lower support member must be attached to the base of the front bulkhead and the base of the front roll hoop while the diagonal bracing must provide triangulation node to node between the lower and upper support members. This is given by section T3.14 of the rules.

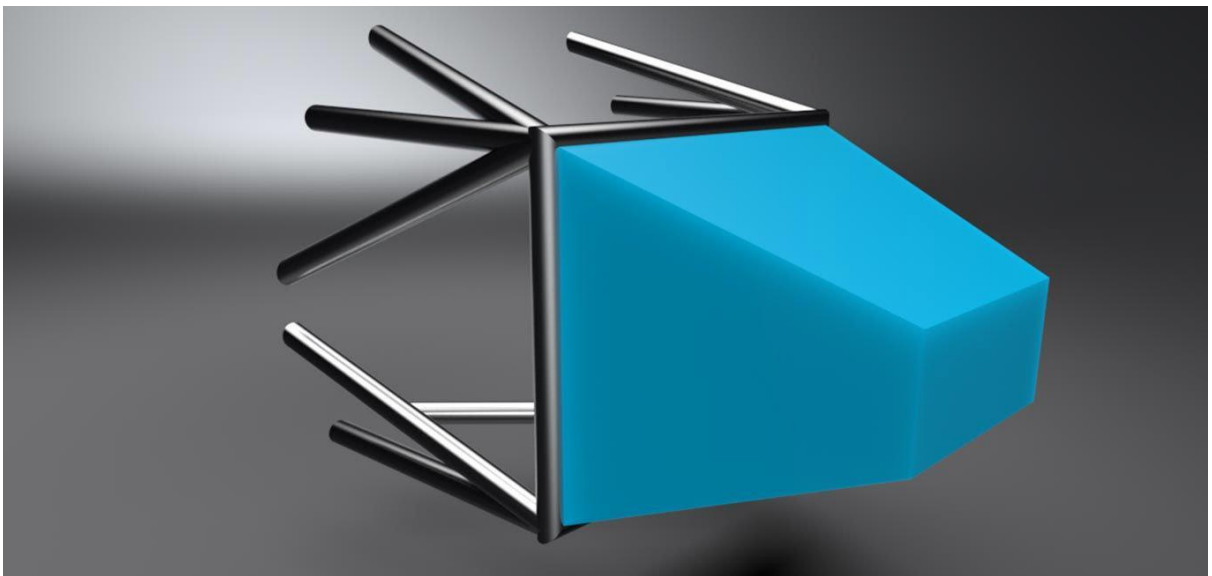
5. Side Impact Supports





The side impact supports are made up of 3 chassis members as seen above. The diagonal member must provide triangulation between the two roll hoops and the upper and lower side impact supports.

6. Impact Attenuator



6.1. What is it

Since 2006 impact attenuators have been compulsory on formula student cars. The purpose of an impact attenuator is to absorb impact energy which minimizes the

damage to the frame in case of an accident. This will be mounted to the front bulkhead of the car.

Useful link:

https://web.wpi.edu/Pubs/E-project/Available/E-project-042710-200525/unrestricted/Final_MQP_FSAE_Racecar_Crash_Protection.pdf

6.2. Related Rules Constraints

According to the 2020 Rules the Impact Attenuator (IA) must:

- Be installed in front of the front bulkhead
- Be at least 100mm high and 200mm wide for a minimum of 200mm forward of the front bulkhead
- Be not able to penetrate the front bulkhead in the event of an impact
- Be attached securely to the anti-intrusion plate (AIP)
- Not be a part of the bodywork
- Be designed with a closed front section
- Not be wider or higher than the AIP

6.3. Design

The IA can be designed on solid works or a standard FS IA can be purchased. The benefit of using a standard IA is that it'll already be rules compliant and no test data is required when submitting the IAD report.

7. Materials

7.1. Related Rules Constraints

Any materials used in the construction of the chassis must meet the following requirements:

- Minimum yield strength needs to be 305 MPa
- Minimum tensile strength needs to be 365 MPa
- Youngs Modulus should be at least 200 GPa
- Steels should have a minimum of 0.1% carbon content

7.2. T45

7.2.1. Applications:

- Often used in motor sports

- Roll cages
- Space frame
- Aerospace impact protection
- Roll bars
- Pilot seats/ Crew Seats

7.2.2. Key Features

- High strength
- Ease of forming
- Easy Welding
- Not necessary to pre or post heat treat
- Can improve structural strength without a dramatic increase in weight

7.2.3. Availability

- Easy to source
- Many tube sizes available
- Relatively inexpensive

7.2.4. Heat treatment

- No

7.2.5. Mechanical Properties

Ultimate Tensile Strength	700/900 MPa
0.2% Proof Stress	620 MPa
Hardness (Brinell)	201 – 262 HB

Useful Link:

<https://www.smithmetal.com/pdf/stainless/tube/t45.pdf>

7.3. Chrome Molybdenum 4130

7.3.1. Applications

- Cycling

- Aviation
- Motoring

7.3.2. Key Features

- Good strength to weight ratio
- Very Malleable
- Easy to weld

7.3.3. Availability

- Tubing
- Available online but could be more difficult to find an Irish supplier

7.3.4. Heat treatment:

- Yes

7.3.5. Mechanical Properties

Ultimate Tensile Strength	97/200 MPa
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Useful Link:

<https://www.smithmetal.com/pdf/stainless/tube/4130-tube.pdf>

7.4. Comparison of Materials

The main advantage of using chromoly over T45 would be the ability to use tubes with a smaller wall thickness in certain parts of the chassis which would save weight. Despite this it's more likely that we will opt for T45 steel. This is because it's both cheaper and more readily available. As well as this it makes the manufacturing process easier. While chromoly must be TIG welded or nickel bronze welded (form of brazing), cold drawn steel such as T45 can be manufactured using MIG, TIG or brazing. As MIG welding is easier than TIG this should decrease our manufacturing costs.

Useful Link:

<https://www.formulastudent.de/pr/news/details/article/pats-column-space-frame-chassis/>

8. Design

8.1. Goals:

Useful link:

<https://www.formulastudent.de/pr/news/details/article/pats-corner-back-to-basics/>

According to Pat Clarke, the three rules of design for a FS car are:

1. All other things being equal, the car with the lowest mass will win.
2. All other things being equal, the car with the lowest c/g of the suspended mass will win.
3. All things being equal, the car with the lowest polar moment of inertia in all axes will win.

In summary, this means that our goals when designing are to:

1. Reduce the weight.
2. Lower the weight.
3. Centralize the weight.

When it comes to chassis, our two main design goals are to reduce the weight while maximising the car's torsional rigidity.

8.2. Torsional Rigidity

Torsional rigidity refers to the resistance of the chassis against torsional loads which are the largest loads transmitted through an FS frame. A chassis should be as stiff as possible to minimise deflection of the chassis and hence the movement of all the mounting points for powertrain and suspension components. This helps to minimise understeer and to allow the suspension to work effectively. Having a stiff chassis is particularly important when driving over any bumps. If a chassis is stiff enough then it won't twist when it hits a bump and therefore the suspension can do its job efficiently.

8.3. Calculating Torsional Rigidity

Useful link:

<https://altairuniversity.com/wp-content/uploads/2014/04/Ahmed-Oshinibosi.pdf>

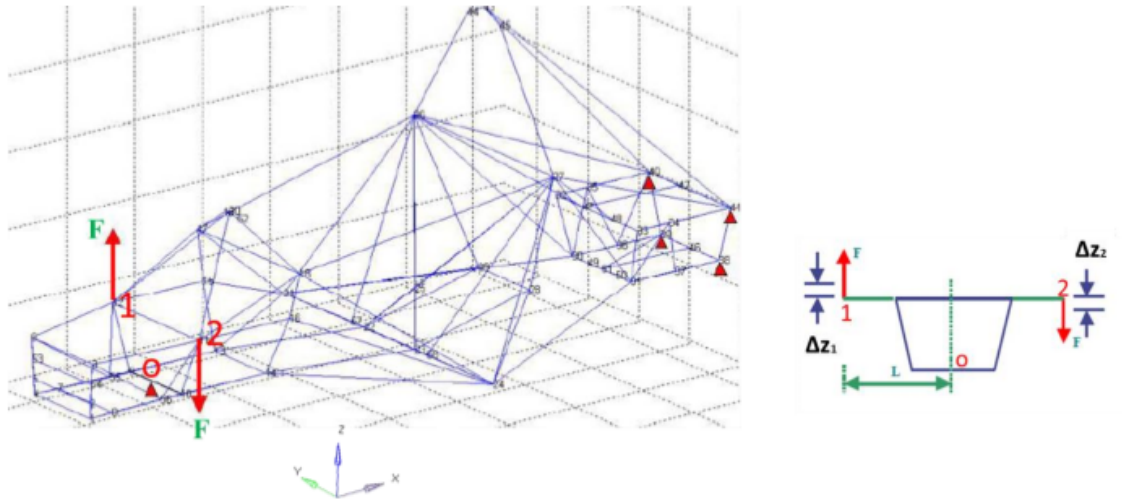


Fig. 6: Frame Finite Element Model Loading Case [2]

With reference to the diagram above, torsional rigidity can be calculated as follows:

$$K = \frac{T}{\theta}$$

Where:

K = torsional stiffness

T = Torque

Theta = Angular deflection

$$K = \frac{FL}{\tan^{-1}\left(\frac{\Delta Z_1 + \Delta Z_2}{2L}\right)}$$

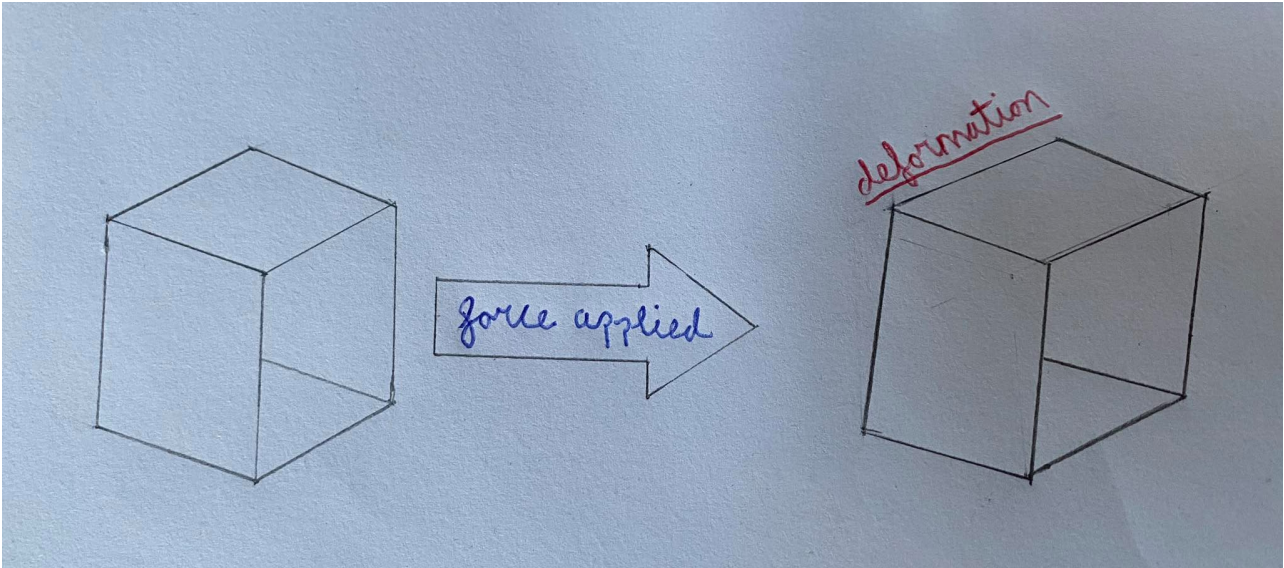
Where:

ΔZ_2 = the vertical deflection points at 1 and 2

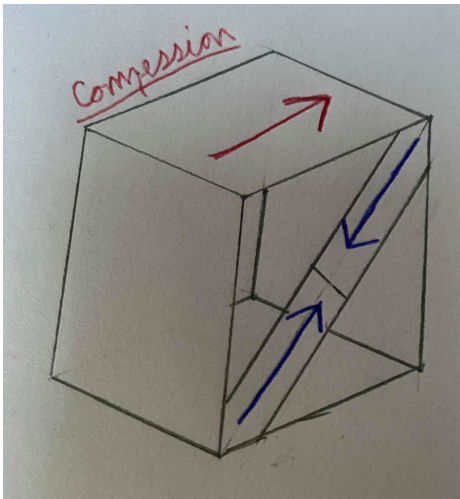
F = the applied force

L = the distance between the force application and O.

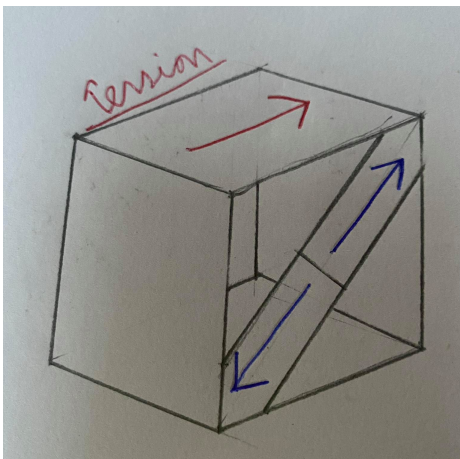
8.4. Triangulation



This is a diagram of a box without any support structures. As seen, without triangulation it will deform to a parallelogram when a force is applied. Adding bracing will significantly increase the strength of this design.



This diagram shows a box with a supporting member in compression. While this will be much stronger than a box without any bracing, the member can still fail due to buckling.



This diagram shows a box with a supporting member in tension. This box is very unlikely to deform. An ideal design will have as many members working in tension as possible as this will be much stronger than in compression.

This tells us that the members in compression will need a thicker gauge than members in tension therefore increasing the number of members in tension will also help us to decrease the weight of the chassis.

8.5. Weight Distribution

Useful Reading:

Herb Adams - Chassis Engineering

Weight distribution refers to how much weight is on each tire. These weights change due to load transfers; changes in loading are a result of forces acting on cars. Understeer and oversteer are common problems related to weight distribution.

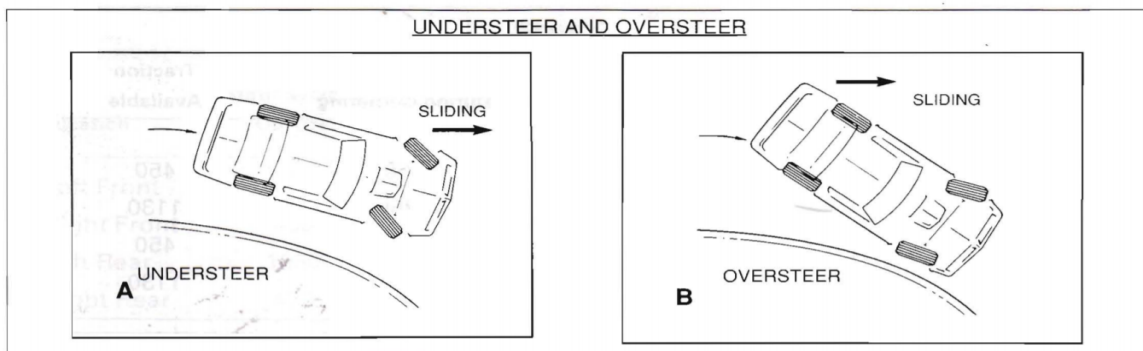
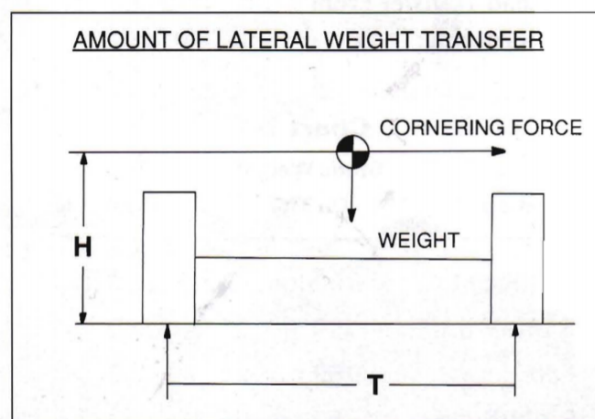
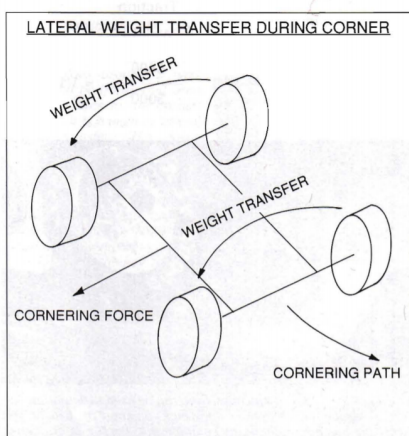


Figure 2-1. Understeer is the condition where a car needs more than normal front-wheel steering angle to go around a corner; the front-end of the vehicle tends to break loose and slide, or push toward the outside of a turn. Oversteer is when a car needs less than normal front-wheel steering angle to go around a corner; the rear end of the vehicle tends to break loose and slide outward.

8.5.1. Cornering Force

$$\text{Total Cornering} = \frac{\text{Total traction on all 4 tires}}{\text{Total static weight on all 4 tires}} = g's$$

As the car develops cornering force, weight will be transferred from the inside to the outside tire. This is known as the lateral weight transfer.



$$\text{Lateral Weight Transfer} = \frac{W \times g's \times H}{G \times T} = \frac{WH}{T}$$

g's = Cornering Force

W = Total Weight

H = Height of Centre of Gravity

G = Gravity

T = Car Track Width

One way to help equalise the weight on each tire during cornering is to preload the inner tires. This is done by moving some weight from the right to the left side of the car. This will only work for cars that will drive on a circular / oval track where they will only turn left.

Equalising the tire load during cornering will produce the max corner force.

8.5.2. Summary

1. The best cornering power is available when front to rear weight distribution is equal.
2. Cars that have front-end weight bias tend to understeer while cornering
3. In general the best cornering power will result when all 4 tires are equally loaded during cornering.

Additionally, for cars racing on circular/oval tracks:

1. Left weight bias increases cornering power
2. Wedging the chassis can reduce understeer and produce faster cornering.

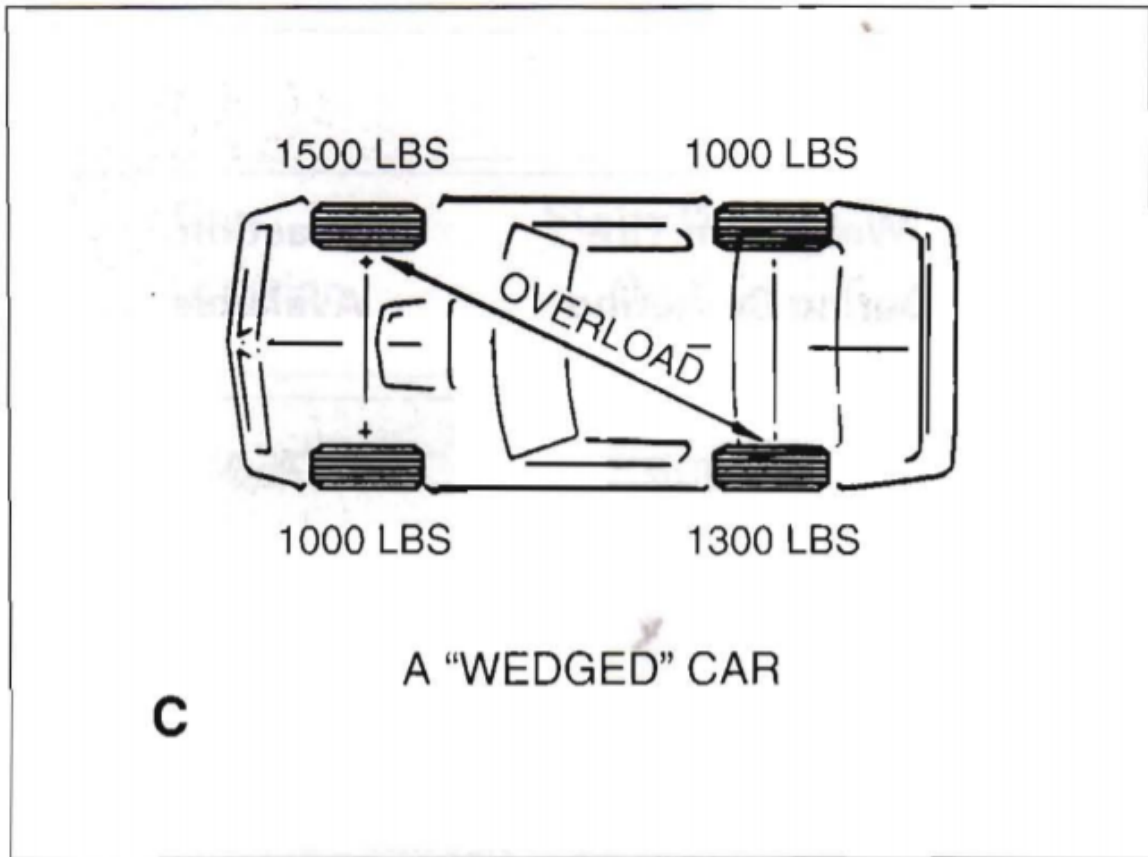


Figure 2-4. Using a chassis wedge is a common method used to cure understeer on circle track cars. Wedging is accomplished by preloading the left front or right rear spring. When 200 lbs. of wedge is added to the right rear, the weight on the left front will also increase about 200 lbs., with a reduction in the weight on the right front and left rear of a similar 200 lbs.

8.6. Loads acting on the chassis

Useful link:

<http://www.mate.tue.nl/mate/pdfs/10019.pdf>

The main loads acting on the chassis will be from the suspension system and the reactional forces from the driver and engine (2 main masses) to the lateral and vertical accelerations. We will also need to investigate the front impact and torsional loads when testing our designs.

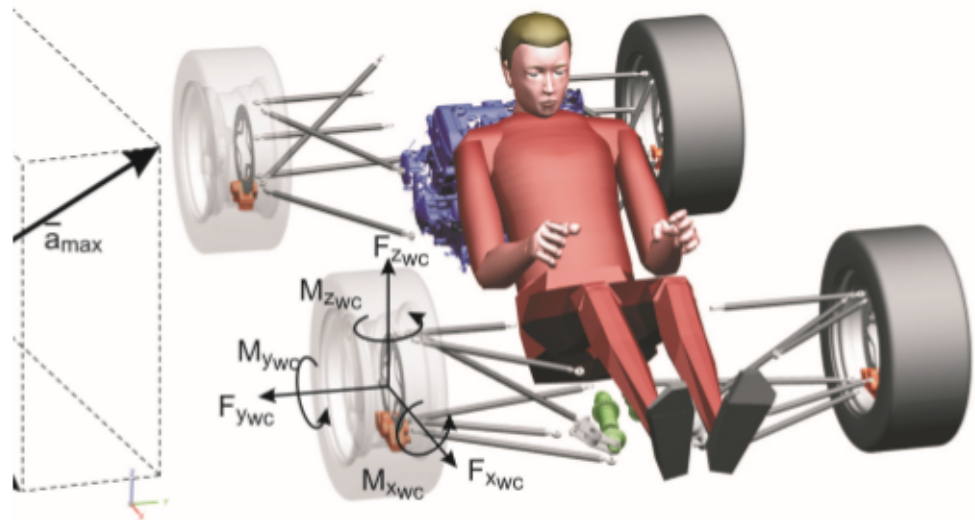


Figure 3.1: The suspension geometry, main accelerations a_x , a_y and a_z and front right tire forces F_x , F_y and F_z

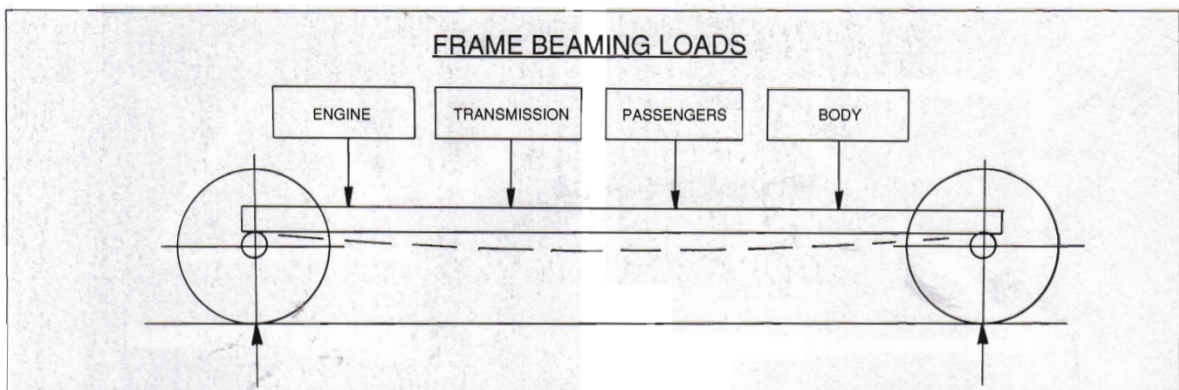
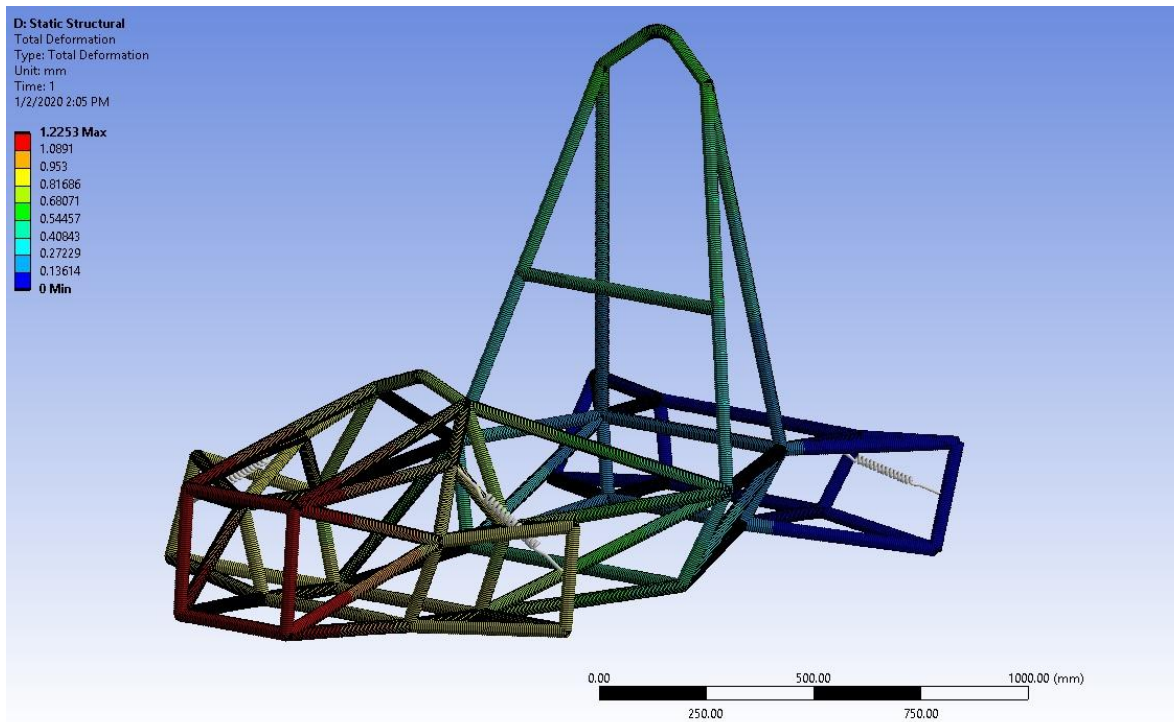


Figure 12-7. Car components can bend the frame because of their weight. It is easy to build a frame that is stiff enough to resist these bending forces in the beaming direction.

9. Testing

9.1. FEA

In order to simulate our chassis designs, we will use ANSYS. This will allow us to gain a better understanding of pros and cons of each design as we will be able to check parameters such as the torsional rigidity and let us perform a cornering test which will yield an easy to understand graphic of the total deformation. As well as that, it will allow us to optimise the tube thickness in each area of the chassis design.



Frontal impact test results

10. Manufacturing

10.1 General

It is very likely that the manufacturing of our chassis will be outsourced due to a lack of both skills and resources to do our own welding. In building the space frame steel tubes will first have to be cut to the correct lengths and shapes. A cut list can be created on Solid works by flattening out each tube and creating patterns to help accurately cut the end of each chassis member. The tubes will then be held in place by a jig and welded together.

10.2 Chassis Jig

Useful link:

https://www.reddit.com/r/FSAE/comments/7g6stn/building_a_jig_for_the_chassis/

Jigs can be made from wood or metal and hold the tubes in the correct place for the welder.

To save costs and for ease of manufacturing, it is more than likely that we will use a wooden chassis jig when manufacturing our car.



This will be designed on solid works around our finalized chassis design like the wooden example shown above. A laser cutter or sawmill then be used depending on the complexity of the piece to cut each member out of sheets of wood. These can be slotted together although glue/nails can also be used to make the jig more durable.

10.3 MIG Welding

Useful Video:

<https://youtu.be/twUAa5LWUvk>

MIG (Metal Inert Gas) welding uses a feed wire that constantly moves through the gun to create the spark, then melts to form the weld. The advantages of MIG welding is that it can be used to join a wide range of metals and thicknesses and it's cheaper than TIG welding.

10.4 TIG Welding

Useful Video:

<https://youtu.be/uO5pVLOAmD4>

TIG (Tungsten Inert Gas) welding uses long rods to fuse two metals directly together. As TIG welding is a more difficult and time-consuming process it is more expensive than MIG. An advantage of TIG is that it produces cleaner welds where no filler materials are used.

10.5 Brazing

Useful video:

<https://youtu.be/f7H5DFtXhm0>

There's also the option of using oxy-acetylene brazing for the joints in the place of welding. Brazing uses a filler material with a lower melting point than the tubes being welded together to join them. It's different from welding as it doesn't involve melting the work pieces and it's done at a lower temperature.

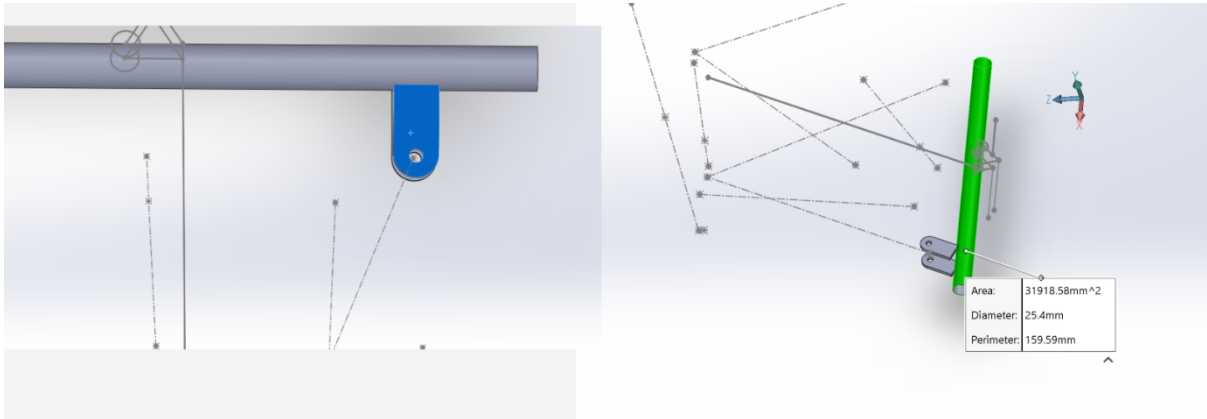
11. Floor

1. All vehicles must have a floor closeout made of one or more panels, that separates the driver from the ground.
2. The closeout must extend from the front bulkhead to the firewall.
3. The panels must be made of a solid, non-brittle material.
4. If multiple panels are used, gaps between panels may not exceed 3mm.

11.1 Materials

The floor is often made from either checkered or plain sheet aluminum as it's lightweight, durable and can withstand weathering and high temperatures.

12. Tabs



The tabs need to be positioned so that they are in line with the forces. They are needed to attach the bodywork, floor and suspension to the chassis. The placement of the engine mounts as well as tabs need to be considered when designing the chassis.

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