WIKI

Ergonomics Department

1. **Brakes**
    a. Wheel lock
    b. Unsprung mass
    c. Rotating mass
    d. Calipers
    e. Pads
    f. Rotor
    g. Master Cylinder
    h. Hydraulics
    i. Lines
    j. Electronics
    k. Heat
2. **Pedal Box**
    a. Pedal Ratio
    b. Master cylinder mount
    c. Adjustability
3. **Hubs**
    a. Wheel fastening
    b. Spigot
    c. Hub fastening
4. **Steering**
    a. Steering wheel
    b. Quick release
    c. Column
    d. Universal joiner
    e. Rack
    f. Tie rods
    g. Geometry
    h. Ackerman
5. **Cockpit**
    a. Percy
    b. Ergonomics Rig
    c. Templates
    d. Rules
6. **General Rules**

Ergonomics

What is Ergonomics?

Ergonomics studies the importance of vehicle design with respect to body dimensions, driver position, posture and comfort, and perception of a clean and easy to use layout.

What is ergonomics responsible for in our team?

Formula Trinity ergonomics deals with the design of all driver input systems and the complete driver environment. The braking system including wheel hubs, the pedal box, cockpit layout, positioning and safety, and the steering system.

This is a very rules heavy department for this reason most relevant rules won't be stated in this wiki but the article in the fsuk rule book may be referenced. Ergonomics engineers should be familiar with chassis and dynamics rules as well as system specific rules such as steering or cockpit and general rules like fasteners.

Brakes

The car's brake system converts the kinetic energy of the moving car into thermal energy through friction. FS cars use conventional disc brake set ups like those found in most cars and motorcycles.

The final part of the scrutineering process is to pass the brake test, this involves locking all 4 wheels and stopping in the allotted distance.

There are lots of variables in the car's brake system so ensure you accurately calculate the system requirements to ensure you make a balanced drivable system. Most formulas that are needed are well established however depending on the set up being used some derivations may be required. A good starting point is Brake Design and Safety by Limpert.

Fundamentally the brake system must be able to provide a resistance force that transfers into a torque greater than or equal to the torque about the axis due to motion and weight transfer.

In short the brake torque must be equal to or exceed the axle torque.
The effects of weight transfer must be considered in this calculation.

Wheel Lock

Wheel lock occurs when the brake torque overcomes the torque of
the wheel causing the tyre to stop rotating and slide on the ground.

The max braking force can only be generated if the wheel does not lock because the friction of a sliding wheel is much lower than a rotating one. It is required by rules to lock all wheels during the brake test event. This is required in order to pass scrutineering so it is essential the car has these capabilities.

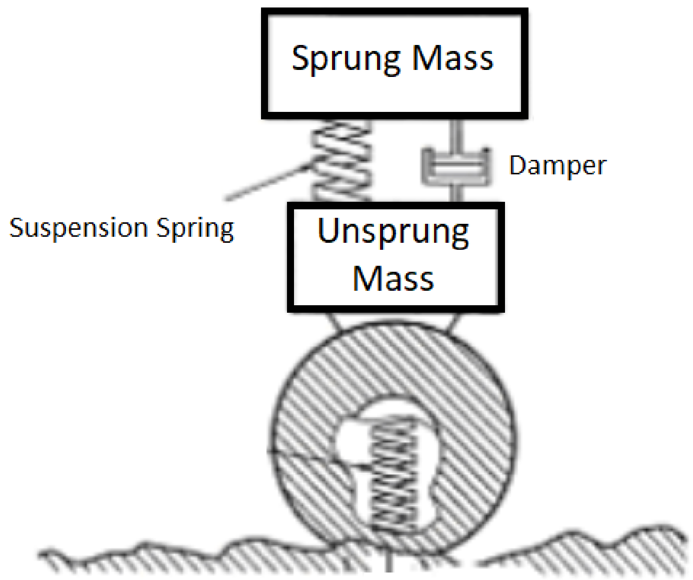
The formula student brake test is an interesting case as it doesn't actually reward the most efficient braking, in normal circumstances downforce and mechanical grip is your friend for brake performance. Both of these increase the car's capacity for braking, meaning the brake performance that the system must reach to lock the wheels is higher.

In order to lock the wheels the force moment caused by braking must overcome the rotational force about the axle.

The force at the axle must be multiplied by the radius of the wheel and tyre. Use the slick dry tyres for these calculations.

While the wet tyres are a marginally larger dia the friction coeff is less and negates this

Unsprung Mass
Parts such as the hubs and brake rotors are unsprung meaning that they are not dampened by the suspension. Reducing weight in these areas greatly reduces the inertia of these sub assemblies aiding vehicle handling

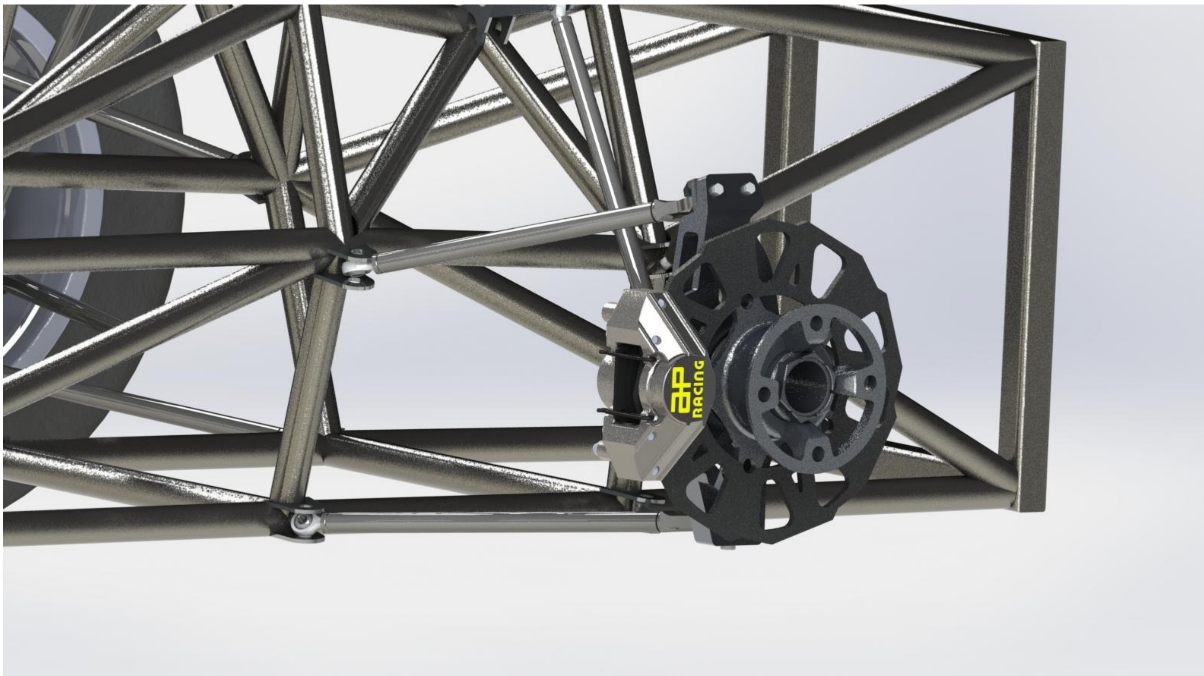


Rotating Mass

The hubs and rotors are both unsprung and rotational so it is important to reduce mass here without sacrificing structural integrity or functionality. Again this is to reduce the interia of these components.

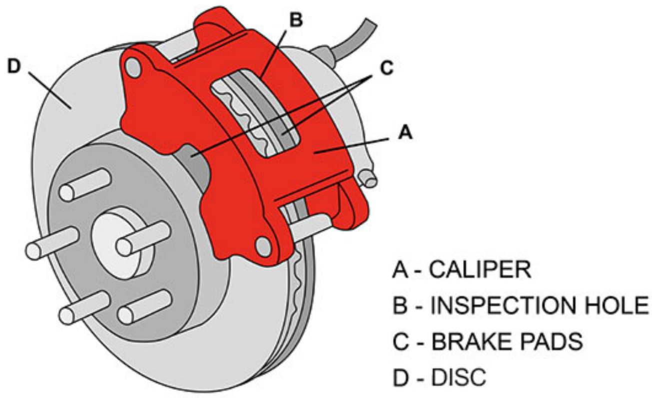
Calipers
The brake caliper is the clamp that engages the friction material with the rotor. The piston diameter of these calipers as well rotor thickness must be

considered when making caliper selection. Caliper sizing and rotor dia must also be in line with internal wheel space to avoid any clearance or assembly issues.



Piston

The diameter and number of pistons in the brake caliper affect how the hydraulic line pressure is translated to the pad. Less piston surface area will increase the force applied to the rotor. If this force is excessive it will cause substantial pad wear.



Friction Material - Brake Pads

The caliper presses the pad into the rotor. The characteristics of this pad will be vital to brake feel. Friction characteristics, material uses, operating temperature, pad compressibility and wear rates must all be considered when selecting a friction material. Most calipers come with a range of friction material to fit them but data sheets provided can vary in detail and accuracy. While you don't need ultimate detail to design an effective brake system, having a good understanding of the friction material is needed for any brake rotor optimisation. Most performance pads only provide acceptable bite when used in conjunction with Iron or steel rotors. The temperature of the friction material must be controlled through the rotor design. For most high performance compounds if the temp is too low there is more potential in the pad and if it is too high brake fade will start to occur due to higher pad compressibility and surface temp.

It is important that pads are only used with one disc surface and not rearranged. When new discs and pads are installed they should first be bedding into the rotor brake surface to prevent glazing of the pad compound. If glazing occurs brake characteristics will suffer for the life of the components.

<u>Brake Fade</u>

A loss of brake power from decreased friction between the pad and rotor, often caused by heat build up.

<u>Brake Bite</u>

The speed at which the friction material reaches its max coefficient of friction after the brake is engaged.

<u>Pad Compressibility</u>

Pad compressibility is the numerical constant that describes the elastic properties of the pad under pressure. Pad compressibility can have effects on the brake efficiency through vibrations and noise.

Rotor/Disc

<u>Fastening: Fixed</u>

Fixed rotors are bottled to the hub and have no freedom for movement. Because of this alignment with the caliper centre is vital. A rotor in bending will shatter immediately. The rotor cannot easily expand under temperature so better suited to lower working temp barke designs.

Fastening: Floating

Floating rotors have the ability to move laterally, this allows them to shift slightly as needed for optimal braking performance. The rotor also has the freedom to expand more uniformly minimising the concentration of internal thermal stresses

Dimensions

Rotor dimensions need to be carefully considered.

Disc Effective Radius is the effective radius is the average of the inner and outer radii. A larger rotor diameter gives the brake caliper more leverage on the hub thus increasing brake torque.

$$r_e = \frac{D+d}{4}$$

where:

r_e = effective radius (m)

D = disc useable outside diameter (m)

d = disc useable inside diameter (m)

The thickness of the brake rotor will also affect how much heat is retained or the speed which it dissipates. High performance brakes typically perform best with some heat in the system.

Features:Holes

Rotor holes have multiple purposes, primarily they allow an evacuation path for brake dust or the gases generated from the friction material under hard braking. This provides a more efficient contact between rotor and pad. Holes also help to dissipate the heat generated under braking that could possibly lead to warping of the rotor. A downside is that fatigue cracks can propagate from holes in the rotor.

Features: Slots

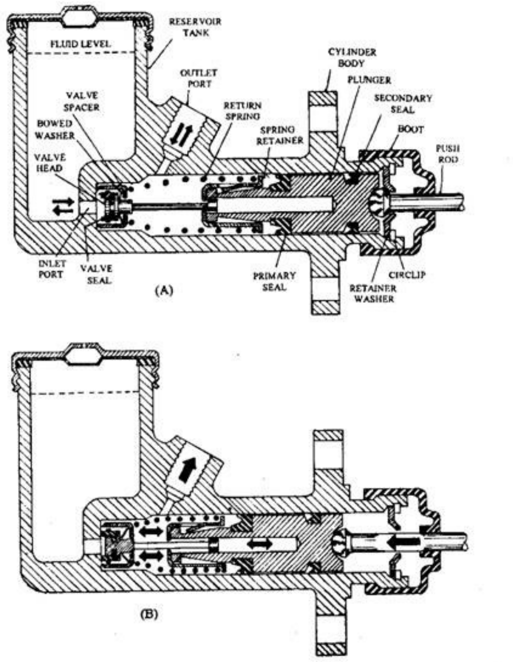
Slots on the surface of the brake rotor help to “wipe” the surface of the pad clean, this ensures a more balanced pad wear and maintains even performance. It can increase pad wear substantially though.

Materials

Brake rotors are usually made from cast iron in North America and steel in Europe. Cast iron has slightly more favourable characteristics for high performance brakes, typically a carbon or nickel steel can also work well. Different materials will respond differently to your friction material so you need to consider both during the design phase.

Master Cylinder

The brake master cylinder converts the linear input force from the pedal into hydraulic pressure.



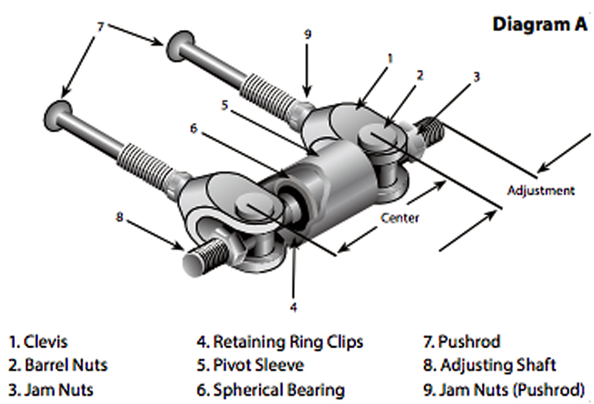
A smaller diameter master cylinder will result in a higher output pressure.Fluid losses in master cylinders increase with bore size and pressure.

Types

Pivoting master cylinders can also be used and allow for more versatile pedal box design. Another common type is the Girling master cylinder like shown above.

Bias

There are 2 hydraulic lines in the car. This is for safety so in the event of a brake failure at least one axle should have brake pressure. The input pressure needs to be distributed appropriately. This is usually done through a bias bar or proportioning valve.



Typically the front axle requires about two thirds of the braking power, due to the mass shift, exact percentages will need to be calculated in order to properly dimension the system. For ultimate performance when cornering you should aim to have the bias as forward as is comfortable for the driver. A forward bias allows the rear to marginally destabilise aiding turn in on corner entry.

Hydraulics

A standardised brake fluid should always be used, DOT 3, DOT 4, and DOT 5.1 are most commonly used. The most important thing when choosing a fluid is to select one that is compatible with the seals in the caliper and master cylinder.

Due to the lightweight nature of FS cars it is unusual to run into problems boiling the brake fluid, while this can happen the fix likely lies not in the fluid.

The brake system needs to be bled regularly. Brake bleeding is the process of removing air from the brake system. Air in the hydraulic lines will cause a spongy feeling brake. Moisture can also enter the brake system and affect the brake fluid properties, for this reason the brakes should be bled after wet running. It is usual to allow about 3% for trapped air in the circuits that can't be removed by bleeding. This air is squashed totally flat during braking.

System losses and compression should be considered when determining the amount of brake fluid required.

Lines and fittings

The brake system components must be plumbed together with the appropriate hose and fittings. Any brake lines must be steel braided and fittings should be the correct specification for this line. Brake lines are exempt from rules regarding pressurised lines. Under no circumstance can brake lines run below the lowest bar of the chassis

Electronics

While not critical for mechanical design is good to consider.

<u>Brake light</u>

A brake pressure sensor is needed to trigger the brake light and some safety systems so factor in the fittings selections

BSPD

If the brake pressure exceeds a certain point while the throttle is still engaged for more than 1 second then the engine cuts off.

Brake over travel switch

Should the brake pedal exceed its max depression point, due to a loss of hydraulic pressure (brake failure), a switch will be tripped cutting the engine.

Heat Generation

The car's kinetic energy will be converted to heat. This heat will enter the system through the rotor and pad surface. For our analysis we calculated the thermal power under hard deceleration and added a transient thermal study to our structural analysis of the rotor.

When completing this work I recommend finding some papers working with similar resources to your team.

Brake Rules Summary

- MUST HAVE:
    - Aluminium, Titanium, or Steel brake pedal
    - LED Brake Light
    - One brake control that acts on all four wheels
    - 2 independent hydraulic circuits
    - Mechanical brakes (not electronic)
    - Mechanical brake over travel switch that turns stuff off but not back on if pushed again
- Have to lock all four wheels in TEST
    - Skid test after acceleration over fixed distance
- No part of brake system should be below chassis
- Scatter shields to protect from crashes, no unarmored brake lines
- Brake pedal must be able to withstand being pressed hard (2000N and made from normal engineering metals

Pedal Box

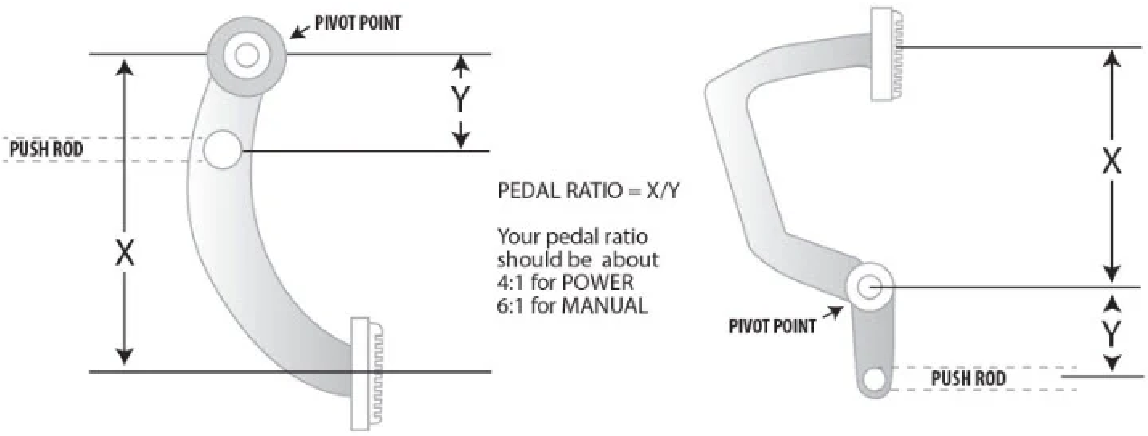
The aim of this sub system is to allow the driver to safely and effectively apply braking force and acceleration to the car. When designing the Pedal Box, chassis dimensions and geometry, brake calculations, safety and driver ergonomics have to be taken into account.

Criteria that has to be met:

- According to the rules, for the Pedal box design to be viable it has to withstand 2000N of force. This tightens the scope of potential materials for the design.
- To allow the driver to perform at their best and get the most out of the car, their interactions with the controls have to be tailored to them. This means an adjustable but secure design is needed.
- Safety is one of the greatest concerns in any brake system, so an effective way of killing the car in case of failure in the controls is essential.

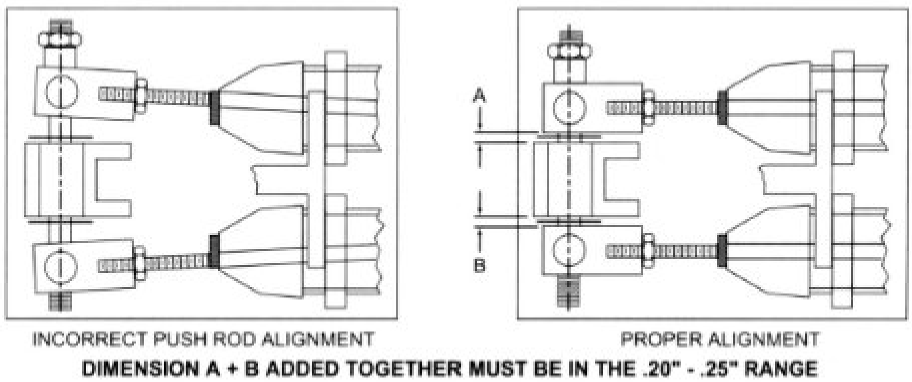
<u>Pedal ratio</u>

The leverage that the pedal has over the master cylinder, a higher ratio yields more brake power but will also increase the brake pedal travel which is not usually desirable in high performance systems.



<u>Master cylinder mounting</u>

Proper alignment of the master cylinders needs to be considered for a smooth



actuation of the brakes

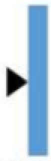
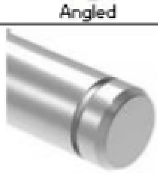
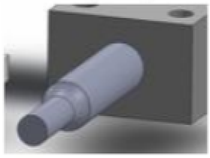
Adjustability

Ensure your pedals can be easily adjusted between different sized drivers while still considering rule T3.2

T 3.20 Non-Crushable Objects

T 3.20.1 All non-crushable objects (e.g. pedals, master cylinders, hydraulic reservoirs) must be rearward of the rear most plane of the front bulkhead and at least 25 mm behind the AIP at any time, except for environment perception sensors, aerodynamic devices and their mountings.

Pedals can be arranged in a few ways

		Solution		
Function	**#**	**1**	**2**	**3**
Axis of rotation	1	 Pedal axis of rotation at the bottom	 Pedal axis at the top	 Pedal axis in the center
Force to return pedal	2	 Return Spring	 Torsion Spring	 Pneumatic Spring
Geometry of Pedal	3	 Straight	 Angled	 Curved
Axle	4	 Shoulder Bolt	 Machined Steel with snap on grooves	 Bearing on the pedal
Axle Support	5	 Bearing and holder	 Bearing	 Machined hole no bearing
Material	6	 Steel (Machined)	 Aluminum (Machined)	

Typically for FS cars the pedal axis is at the bottom of the pedal. Bushings can be used at the pedal pivot but bearings can provide a smoother rotation. Throttle return springs need to be used.

Hubs

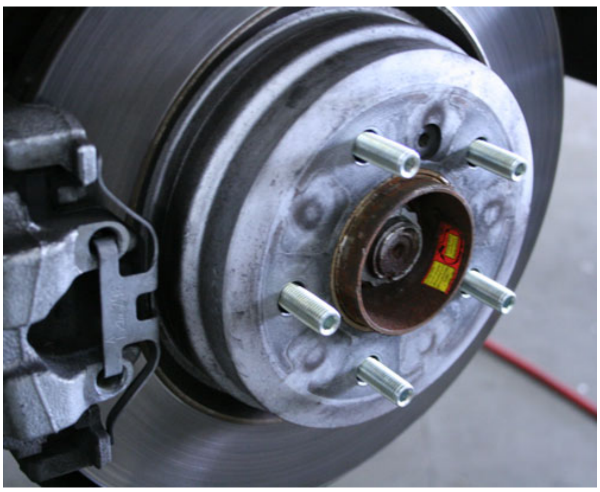
The wheel hub's function is to connect the vehicle body (more specifically the upright) to each of the 4 wheels and also to mount the brake rotor onto so that braking force can be transferred to the wheels.

Methods of wheel fastener

Lug Nuts

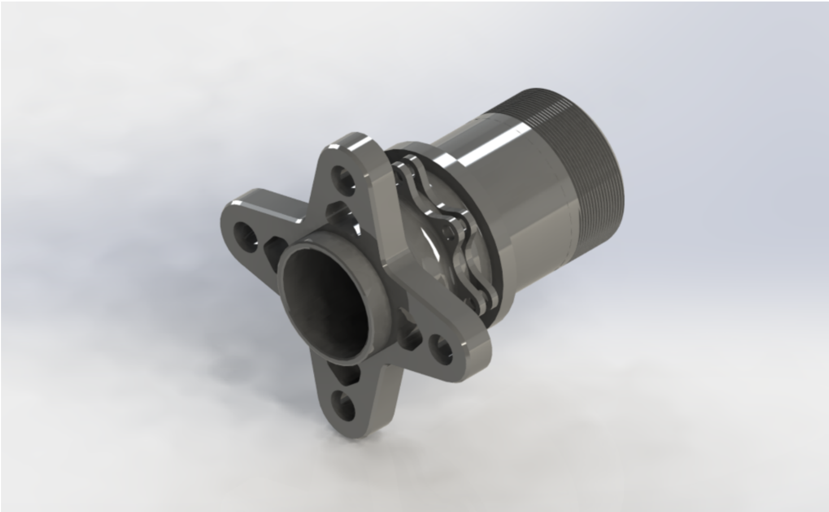
Lug Bolts

Wheel Studs



Spigot

The spigot is a crucial part of the wheel hub. Its function is to transfer any linear movement of the wheel into the hub. By including a spigot in your hub design the wheel fasteners are solely in compression and not shearing. Spigots greatly aid the

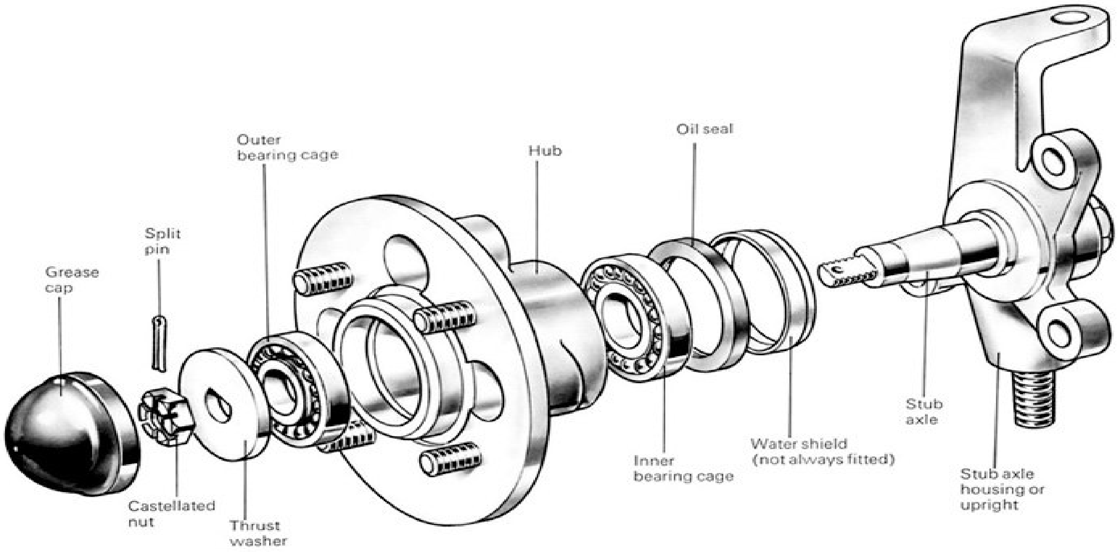


fatigue life of both the wheel rim and hub.

Hub fastening

The hubs are press fit into the wheel bearings H7/p6 and need to be fastened in compression.

Wheel hubs are one of the largest unsprung rotating masses on the car and with the brake rotor the only that a=our team design in house, therefore keeping mass low is crucial.



Steering

Steering is a key part of what makes a car a car. With the driver's input they should be able to transfer enough torque through this system to turn the wheels of the car. It is therefore vital that it is ergonomic in its design.

Steering breaks down into a few simple components:

- Steering Wheel
- Quick Release
- Steering Column
- Universal Joiner
- Steering Rack
- Steering Arms

Steering Wheel

This is the direct input between the driver and the steering system. It is important to consider anthropometric measurements such as shoulder width when choosing a comfortable radius for the wheel. The wheel should be lightweight but resistant to the torque from the driver. We have chosen aluminum for the wheel.

The wheel must not pass over the front roll hoop of the chassis and must be circular in shape. D shaped wheels and other similar solutions are banned in FSUK.

Quick Release

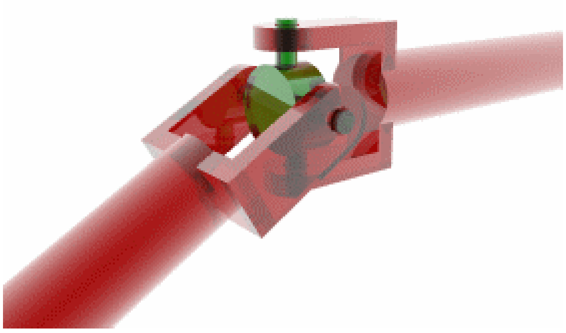
The steering wheel restricts the driver's path in and out of the car. In order to get around this we use a quick release. The quick release chuck connects the column, with the boss bolted to the steering wheel. When the paddle of the quick release pulls towards the driver, the boss and chuck release and the wheel can be removed. This is an integral safety requirement for an FSAE car.

Steering Column

The column transfers the torque from the wheel through to the steering rack. The most common steering column type is tubing, with better funded teams experimenting with carbon hex bar and other set ups. Our column will be mechanically bound to the rack with bolts in double shear.

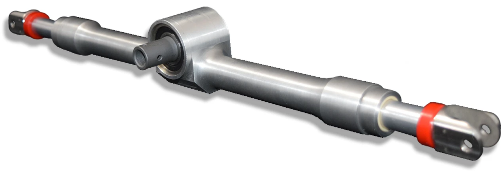
Universal Joiner

If a straight steering column does not work for your setup you must use something to change the angle the forces are acting through. We use a universal joiner. This then allows us to adjust our steering geometry to optimise driver position and packing.



Steering Rack

The steering rack is an encased rack and pinion. The column transfers torque to the pinion causing it to rotate. This results in the rack moving side to side. It essentially converts our driver's torque to a linear force. The rack has cleavises which attaches to the steering arms.



Manual

-https://cdn.shopify.com/s/files/1/0368/1989/files/NARRco_Rack_Mk_II_14.4_T13_181108.pdf?6

Steering Arms/Tie Rods

These two tie rods connect directly to the upright. Their orientations determine the bump steer and ackermann setup which I will develop on later. The linear force from the rack transfers through these tie rods to push/pull on the uprights. This results in the wheels of the car turning.

Steering Geometry

Useful Intro to Steering Setups

https://www.youtube.com/watch?v=oYMMdjbmQXc

Parallel

Not a good steering geometry. If wheels turn parallel, in order to turn the corner the outside wheel will scrub. This will produce understeer in the car and has no notable performance benefits.

Ackermann

We want an ackermann setup. This means the inside tire turns on a tighter radius than the outside tire. This setup aims to minimise scrub. This allows for less understeer and for more grip in tight radius low speed corners. Ackermann assumes no lateral forces so a perfect ackermann will in fact still cause understeer as the tires slip.

Anti Ackermann (Reverse)

Outside Tire turns on a tighter radius than the inside. This can be seen to be used in F1 and faster race series. When a car is cornering the outside tire is under greater load. This creates a larger slip angle on the outside wheel compared to the inside. The tightened radius of the outside wheel combats the greater slip angle and helps correct the path of the car, improving grip. This is not ideal for our car. Our car is light and will be cornering mostly at low speed. This means we won't produce the loads necessary to justify a setup like this.

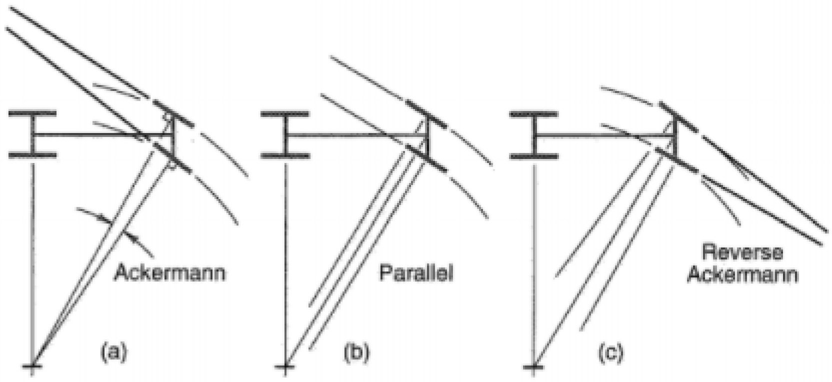
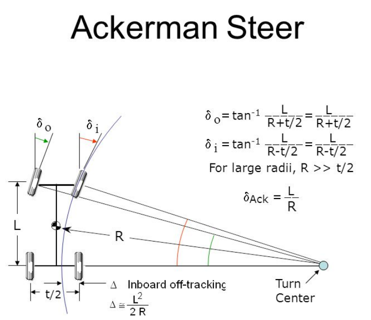
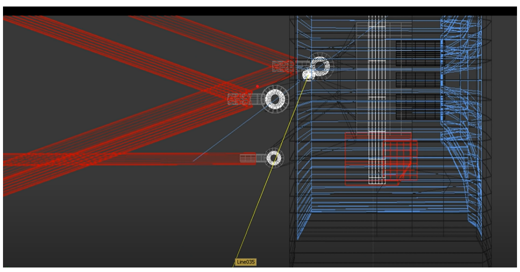


Figure 19.2 Ackermann steering geometry.

Ackermann Geometry



Here are the equations for ackermann steering. As you can see the front wheels are turning on different concentric radii.



To achieve this we draw a line from the steering(kingpin) axis that intersects the eye of the tie rod and meets the midpoint of the centreline of the rear tires

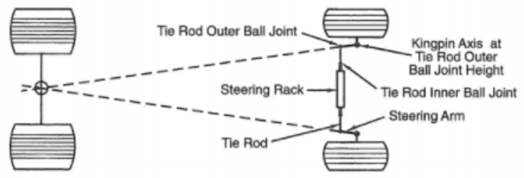


Figure 19.3 Ackermann geometry, with steering rack behind the axle line.

We can see an expanded example above. This is what we want to achieve with our car.

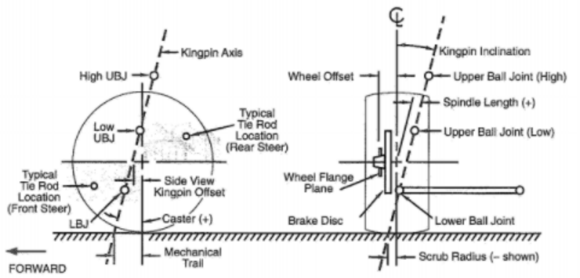


Figure 19.1 Kingpin geometry.

Pg 710 Race Car Vehicle Dynamics

Steering Rules Summary

Note: This is just a summary. When designing any part rigorously consult the rulebook.

- Steering wheel must mechanically actuate the front wheels. No steer by wire.
- Steering Rack must have stops to prevent lock up.
- 7 Degrees is the maximum allowable freeplay.
- There must be a quick release and it must be operable with gloves on.
- Wheel can not be more than 250mm out from the front hoop. Measured from front face of wheel and back face of roll hoop.

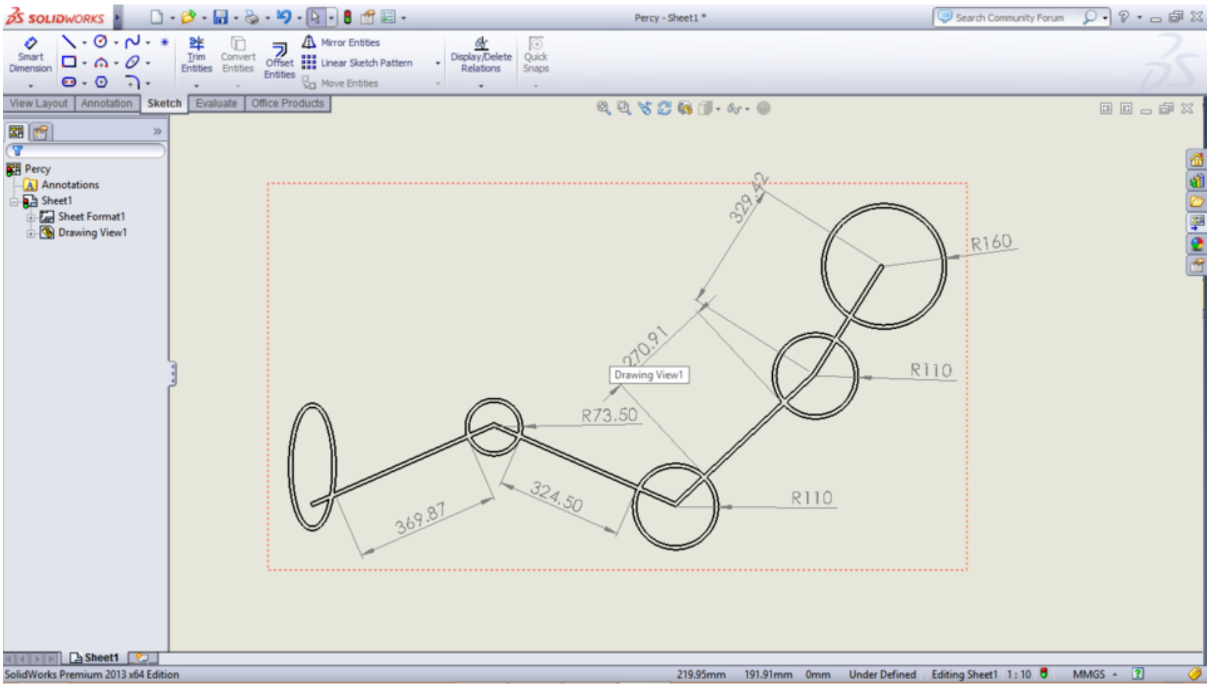
- Steering wheel must be near circular or oval. No concaves
- Top of wheel must be lower than Front Roll Hoop
- Bonded joints need mechanical backups

Cockpit

The cockpit is a highly safety critical area for this reason it is the subject of a lot of rules. These rules will create a safe driver environment but not necessarily a high quality position. The cockpit must be able to fit a large variety of people ranging from the 95th percentile male to the 5th percentile female.

Percy

Driver models such as Percy, seen below, can help dimension the cockpit and establish an ergonomic layout. Percy is a model of a seated 95th percentile male.



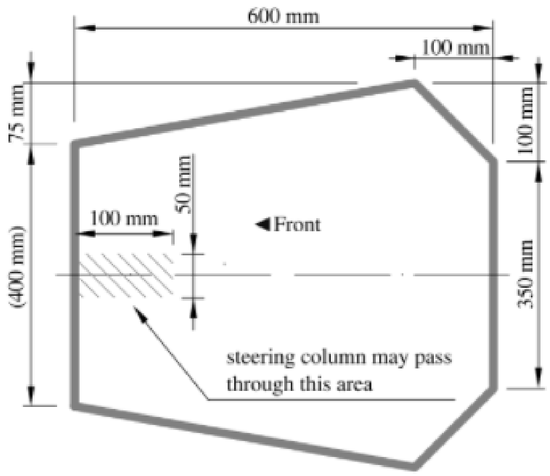
fErgo Rig

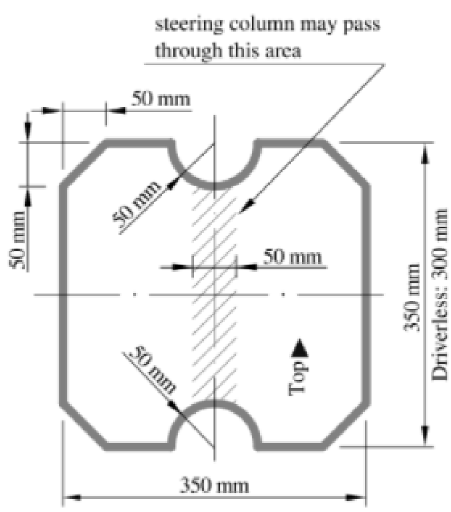
An ergonomics rig like shown below is the best way to achieve a comfortable driving position for the drivers. By cycling team members through and recording their preferred position a comfortable and efficient layout can be achieved.

Packaging constraints and aero may require some compromise, it is important to limit this as much as possible however as a cramping driver will never extract the most from the car.

Templates

The cockpit must pass the template test at the competition so any opening must be able to pass these templates without obstruction. These are not foolproof however so the opening may not be big enough for some drivers.





In order to test the pedals the judges/scrutineers will need to sit into the car so don't go too aggressive making a cockpit for your 60kg drivers.

Cockpit Rules

T 4 COCKPIT
T 5 DRIVER RESTRAINT SYSTEM
T 13.3 Driver Equipment

General Rules to be considered

T 10 FASTENERS
T 10.1 Critical Fasteners
T 10.1.1 Critical fasteners are defined as bolts, nuts, and other fasteners utilized in the primary structure, the steering, braking, driver's harness, suspension systems and those specifically designated as critical fasteners in the respective rule.

T 11 Electrical Components
T 10.1.2 All threaded critical fasteners must be at least of either 4 mm in diameter or of the diameter specified in the referencing rule, whichever is larger.

T 10.1.3 All threaded critical fasteners must meet or exceed metric grade 8.8 or equivalent.
T 10.1.4 All threaded critical fasteners must be of the type hexagon bolts (ISO 4017, ISO 4014) or
socket head cap screws (ISO 4762, DIN 7984, ISO 7379) including their fine-pitch thread
versions. Alternative fasteners are permitted if the team can show equivalence.

T 10.1.5 Bolts may be shortened in length as long as T 10.2.3 is fulfilled.
T 10.1.6 Any bolted joint in the primary structure using either tabs or brackets, must have an edge
distance ratio "e/D" of 1.5 or greater. "D" equals the hole diameter and "e" equals the distance from the hole centerline to the nearest free edge of the tab or bracket. Any tabs
attaching suspension members to the primary structure are not required to meet this rule.

T 10.2 Securing Fasteners
T 10.2.1 All critical fasteners must be secured from unintentional loosening by the use of positive

locking mechanisms.

T 10.2.2 The following methods are accepted as positive locking mechanisms:

- Correctly installed safety wiring.
- Cotter pins.
- Nylon lock nuts (ISO 7040, ISO 10512, EN 1663 or equivalent) for low temperature locations (80 ◦C or less).
- Prevailing torque lock nuts (DIN 980, ISO 7042 or equivalent, and jet nuts or K-nuts).
- Locking plates.
- Tab washers.

Any locking mechanism based on pre-tensioning or an adhesive is not considered a positive
locking mechanism.

T 10.2.3 A minimum of two full threads must project from any lock nut.
T 10.2.4 All spherical rod ends and spherical bearings on the steering or suspension must be in double
shear or captured by having a screw/bolt head or washer with an outer diameter that is larger
than the spherical bearing housing inner diameter.

T 10.2.5 Adjustable tie-rod ends must be constrained with a jam nut to prevent loosening.