MEE30003

Machine design report

Formula SAE: Uprights

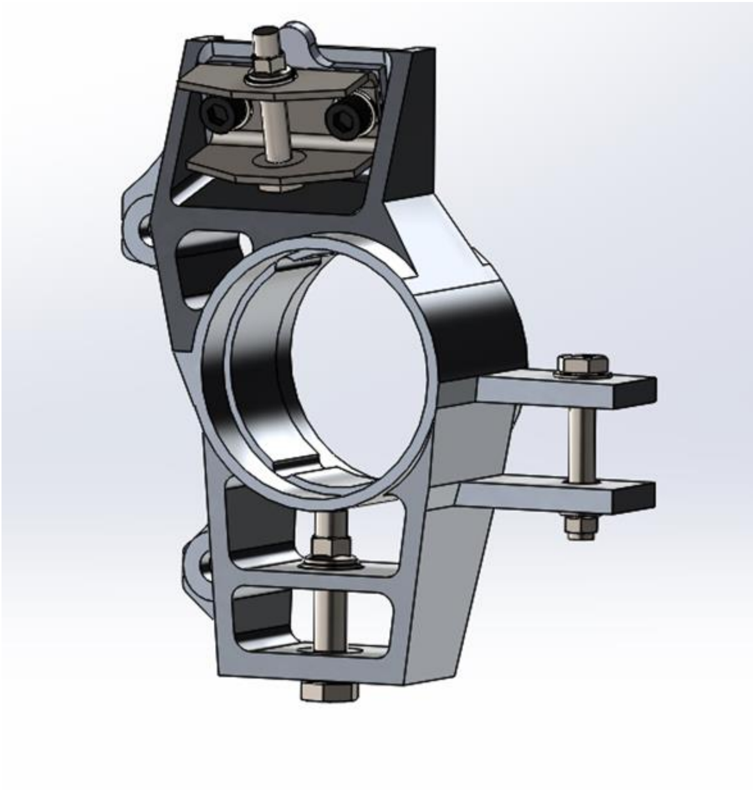

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Table of Contents

Abstract

Formula Society of Automotive Engineers (FSAE) competition is held every year, this year again Swinburne Team will be taking part in the competition. In this competition Formula race cars are being built by university students and competed against other universities all over the world.

Our group was posed with the problem of designing, developing and optimising the uprights according to the new reference geometry which is the main part of the vehicle. Before the start of the design period a brainstorming session took place to put out general ideas on what the design should look like, and we need to draw some of the hand sketches before finalizing. The design which is created has to withstand different levels of forces at different situations of the car for this aspect force analysis have to be applied practically. The design is made using SOLIDWORKS® software and Finite Element Analysis (FEA) is done using ANSYS® software which enables to check the stresses, deformation as well as the factor of safety at different situations. While in the process of designing number of milestone were carried out such as 80% and 100% design evaluation where feedbacks, suggestions and improvements related to the design concept were given by the current students, alumni and Industry professionals.

Introduction

Swinburne Formula SAE car report will show all the following development and production of the uprights. Detailed design of all components of the car from small parts design to suspension components have all been laid out in depth for better understanding. The functionality of the car depends on the suspension components and the wheel bearing attached to the uprights.

Details documents of this particular project have been compiled in brief, it includes all the necessary information, discoveries and the step by step process taken by each individual and the team to design all the components as well as the creation of uprights. The report contains all the resources collected by the team from making design decisions. Extensive market research on designs created by other groups and how these can aid in improving our own design. Responses to reviews of our designs explaining how suggestions will or will not be implemented and why this is the case, documentation of our designs with drawings to AS1100 standard which will allow the reader to recreate the design if he so chooses, and reflection on the design and the steps taken to reach the final design stating any different approach that might have been more effective for the design.

In addition this report contains summary, in depth design process, literature review, suspension force analysis.

This report in general will allow the reader to have a better and precise knowledge and understanding of the design, fine-tuned uprights manufacturing process and how the suspension components works for a formula SAE car.

Literature Review

The purpose of the uprights is to join all suspension A-arms to the wheel bearings and hub. It also needs to have mounting holes for the brake calliper to attach to. The required goals for this project are to be manufactured using 5 axis and 3 axis CNC machine, to have equal or less weight than ts_16 uprights. As the uprights used had far too much compliance and lacked torsional stiffness. The constraints and considerations that need to be considered when designing the uprights are that it needs to suit the suspension points provided and needs to accommodate the wheel bearings. Compliance of the uprights should be within an allowable amount however smaller compliance is better. The considerations for the design are that it should be manufactured out of 7 series Aluminium but other material will be considered, all testing results and procedures for varying load cases including acceleration, braking and cornering compliance should be documented and all computer FEA testing should be done in ANSYS. The tolerance for the wheel bearing needs to be considered as an appropriate fit will be required.

Uprights

The role of the uprights is to connect all the parts of the suspension to the wheel. When Designing he uprights a high amount of stiffness is wanted due to the high loads experienced during use which will cause unwanted plastic deformation. The uprights are an important part to consider when designing the a-arms since the mounting points at which the a-arms will connect to the uprights are pre-determined. The other important reason for basing the design of the a-arms on the position of the mounting points is that all the forces that will pass through the a-arms will pass through the uprights first.

Suspension Geometry

The suspension geometry was pre-set by the team when starting this project by using data Collected from previous year's race cars. As previously mentioned the suspension system on this car is a double wishbone suspension system and therefore an understanding of how all the forces throughout this system interact with each other and more specifically how these forces affect the a-arms. The double wishbone suspension system is a setup where upsets in one wheel will not have any effects on the other wheels. The tires must also have enough vertical wheel movement as to not affect toe.

Bump & Droop

Bump and droop are some important factors when looking at suspension geometry that will impact the a-arms and must therefore be taken into consideration in the design process. Bump is the upward movement of the wheel and droop is the downward movement of the wheel. Paying attention to these factors is necessary as if not accounted for the car can bottom out and become unstable.

Springs & dampers

The springs and dampers while not all too important to the system must still be considered since an understanding of the loads which pass through them to the a-arms must be taken into consideration. The role of the spring and damper is to give the driver a more comfortable and controllable ride by reducing the forces received from the road, and to keep the contact patch from the wheels constant to provide the maximum traction available

Tyres and Contact Patch

In order to understand the dynamics of an automobile first we need to understand the four little area of contact that the vehicles make with the road surface.

> *'Tyres are the only contact between the car and the ground. Therefore, an understanding of wheel and tyre characteristics is fundamental to the understanding of vehicle behaviour and suspension design.'*

In order to transmit torque to the road surface, to brake the car, to maintain a grip under centrifugal cornering forces those four contact patches must be held firmly to the road surface. This is the major function of the suspension system on a racing car.

The force applied to the tyre is a normal of vertical force to the road and varies significantly under different load conditions. These different load conditions include acceleration, deceleration and cornering. The target of any racing tyre is to provide maximum grip one hundred percent of the time and if components around this aren't designed and implemented correctly the tyre won't perform optimally.

Diameter of the Tyre

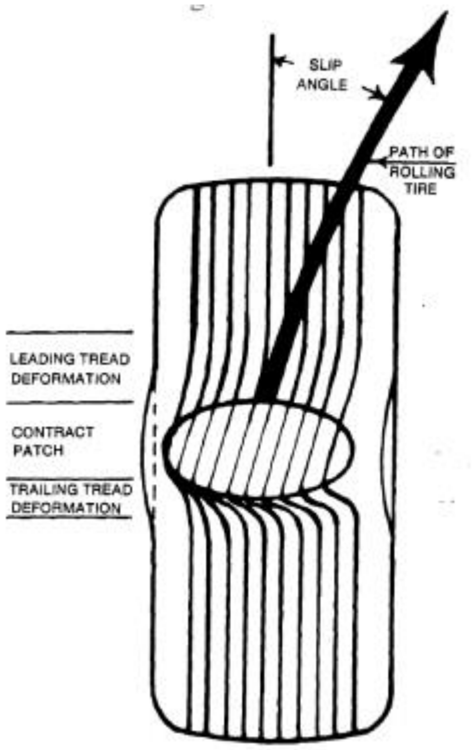
It is very important that the left side tires on your racer be the same diameter as those on the right side. If they are not, then the static corner weight and the load transfer characteristic will not be what is calculated.

Tyre Compound

Tyres are composite material made up of rubber which is then reinforced with cords of varying materials. For racing, nylon is the preferred reinforcement material as it is flexible, lightweight and heat resistant. The alignment of these cords is crucial for the characteristics of the tyre. If the cord is wound radially the tyre has a soft ride and is self-damping as well as having no lateral stability, if the cords are wound circumferentially it provides the best lateral stability with the sacrifice of ride comfort as well as not being able to hold its shape. For racing the tyres cords are wound on the bias providing strength in 3 planes and are wound tighter to reduce the tyres slip angle. Slip There are two different types of slip transverse and longitudinal. Transverse slip is referred to slip angle and is directly related to the cornering forces. Longitudinal slip effects acceleration and braking and is sometimes referred to as slip ratio or slip percentage.

Slip angle

Slip of a tyre is the angular displacement between the plane of rotation of the tyre and the direction it is actually pointing, as seen in figure 4, this is also induces tyre sidewall deflection. In order for the vehicle to turn each tyre need to have degree of slip angle. The



slip angle comes about because of a tyre having elastic properties and being able to twist. Due to the friction between the road and the tyre, the tyre will deform and the contact patches angle will move away from the angle of the rim.

This will cause the car to actually turn a corner on less of an angle than the angle of the rim. Nature of slip all starts due to friction, or grip between the tyre and the road. As discussed previously the grip of the road and the irregular elasticity of the rubber leads to the contact patch deforming and a different angle to the rim. Due to the characteristics of friction there is molecular adhesive effect between the road and the tyre and this is why when cornering Figure 4 9 hard and losing traction there is some tyre compound left behind on the road surface in the form of black marks. It is important to note that the coefficient of friction has a relationship with the slip angle and as one changes it affects the other

Contact Patch

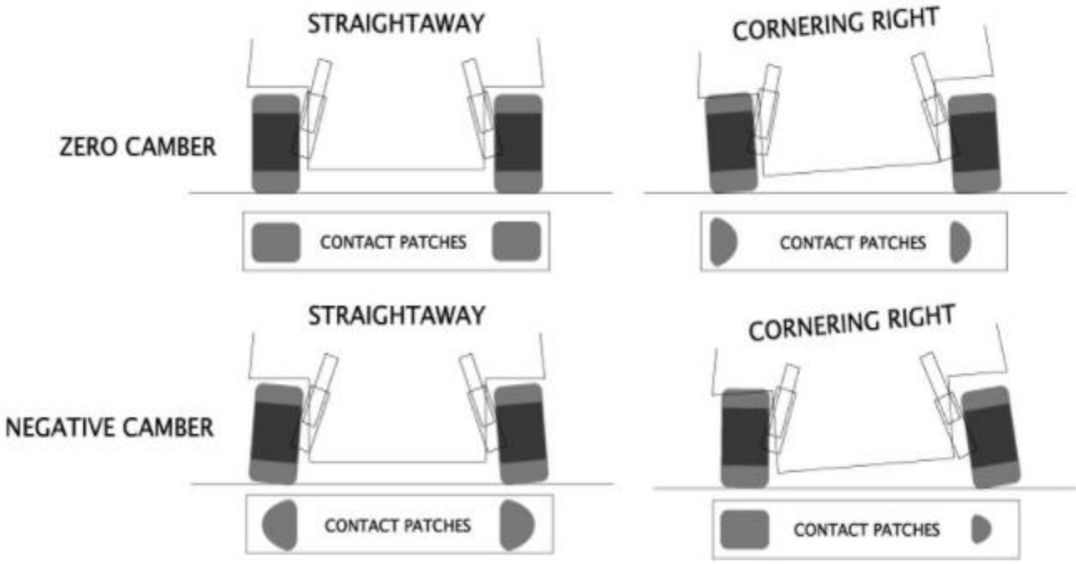
Contact patch is the portion vehicle's tyre in contact to the road/surface. It's the most important fundamental thing in car because it gives stability to the car while accelerating, braking and cornering. The contact patch decreases during cornering and there are few methods by which we can minimize the decrease of contact patch such as **camber angle, caster angle** and **roll centre**.

Mass

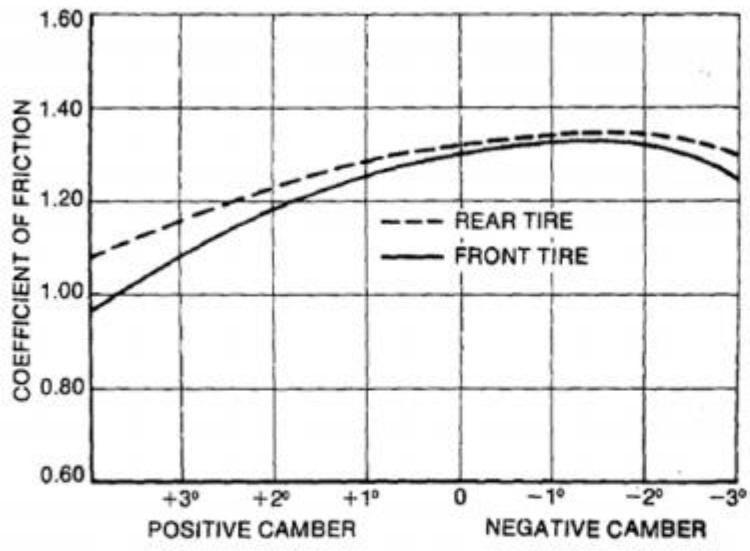
We can describe that the mass of the car is higher than any other force acting upon the system by using newton's second law of motion F=m*a. To minimize the forces in the longitudinal and lateral directions the weight of the car should be as small as possible. This second law of motion tells us that to maximise the grip and the speed of the car, it should be as light as possible.

Camber Angle

Camber angle is amount of angle between the vertical axis of the car and contact patch or in other words by tilting upright at angle. The advantage of having camber angle as it increases the contact patch between the tyre and road during cornering as shown in the figure

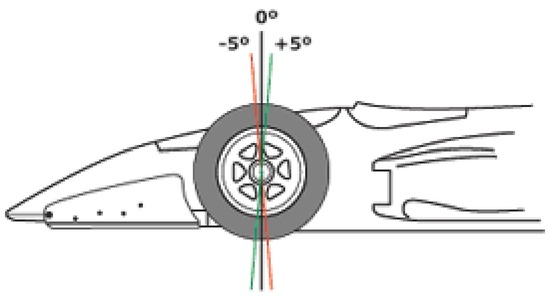


Camber angle has a characteristic of being able to change the cars coefficient of friction as well as the cornering power relative to the road. To a degree, negative camber increases the frictional force allowing for better cornering as seen in figure



Caster Angle

Caster is the measure of how far forward or behind the steering axis is to the vertical axis, viewed from the side. Caster is a very sensitive adjustment! Adding or removing a few degrees of caster can transform typically, positive caster will make the vehicle more stable at high speeds, and will increase tire lean when cornering. This can also increase steering effort as well as the steering balance of a car.



Roll *Centre*

The roll centre is an imaginary, but accurately defined, point on the centre-line of the car around which the car rolls on its suspensions. The roll centre can be high off the ground, low, or even underneath the ground (it's only imaginary, remember). A line connecting the rear suspension roll centre with that of the front is called the roll axis. If the axis runs nose-down, the car tends to oversteer. If the axis runs nose-up, the car tends to understeer. The roll centre of a car is where the car will roll (when cornering) when looked at from the front (or behind)

The actual grip that a tyre can generate is dictated by the coefficient of friction of the rubber compound used in the tyre. The higher the coefficient, the more grip which can be generated. The relation that is used is called Amonton's Law, and the equation is:

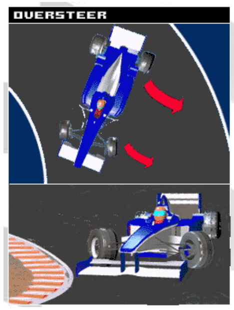
F=uN,

Where F is the force generated, u is the coefficient of friction, and N is the weight on the surface considered (in our case, the weight on the tyre).

So, if you increase the weight on the tyre, then the frictional force will increase as well, in proportion to the increase in weight on the tyre - but the coefficient of friction will remain the same. The level of grip of the tyre (forgetting about suspension niceties - we are only discussing tyres here) is totally dictated by the coefficient of grip of the tyre and the weight acting on it - not the area of the contact between the tyre and the road.

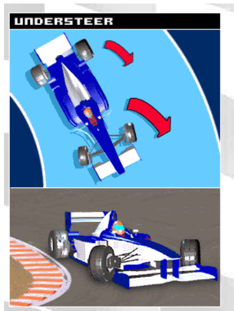
Oversteer

It is the tendency of the car's front to slip out in the mid corner which results in turning the front of the car too much to the corner.



Understeer

It is the condition in which car's front show lack of responsiveness to turn into the corner. The car does not want to turn to the corner. Generally, 4 wheel drive have this problem.



Coefficient of Friction

A tyres coefficient of friction is dependent on the amount of frictional force resisting the motion of the tyre on the road and determines how much of the applied force is translated into horizontal and vertical components. However the racing tyre does not follow Newton's

Laws of friction as is can generate a force larger than the load applied to it (RTW) This is due to the horizontal and vertical forces being able to be translated into one larger component in a single direction under a load case such as acceleration and cornering or deceleration and cornering. Calculating the coefficient of friction that the tyre creates is extremely important as this affects all forces transferred into the suspension components and if this coefficient is calculated incorrectly it would make the calculated forces in each suspension part wrong. The variables that make this hard to calculate include heat and tyre pressure as these can change depending on how hot or cold the ambient temperature is. To make our calculations safe it is advisable to take the worst possible value under ideal conditions and calculate from there.

The Centre of Gravity (CG)

The CG of any body is defined as that point about which, if the body were suspended from it, all parts of the body would be in equilibrium –i.e. without the tendency to rotate. It is the three dimensional balance of the race car. All accelerative forces acting on a body can be considered to act through the centre of gravity of that body. In order to get our car best on the road we want our CG to be just as low as we can get.

Loads On tyres

Vertical Load

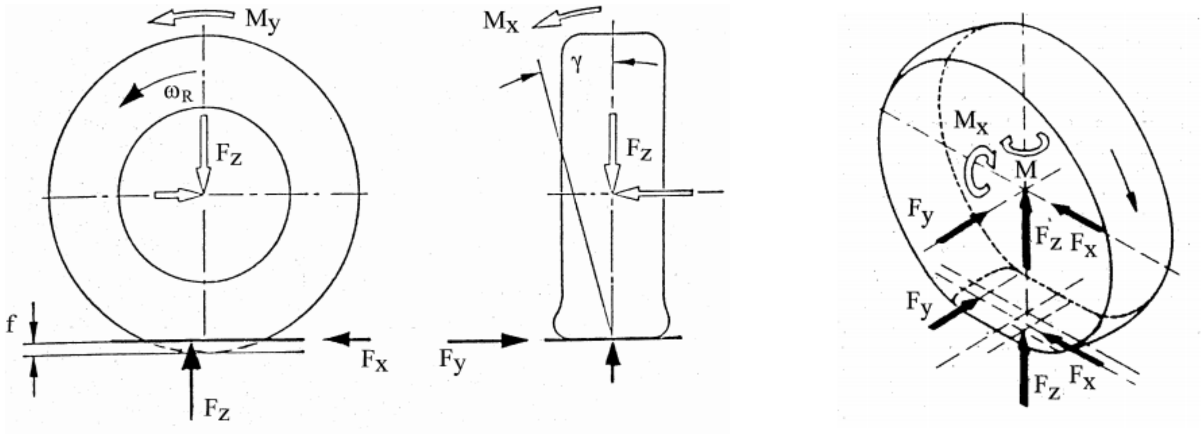
Normal or Vertical Load Characteristics As stated above this load is applied through each tyre and is perpendicular to the road. To calculate this it is required to obtain the instantaneous load of that is applied to each wheel and tyre considering the weight as well as the induced downforce from the car, an example of this can be seen in figure 3.

Lateral Force

At the tire, the forces are defined according to the main plane, which is defined as the plane perpendicular to the rotational axle of the wheel. The force perpendicular to this plane and in parallel to the rotational axle is called lateral force (Fy). The characteristic value for the lateral force it’s the lateral slip angle (alpha) (also called side slip angle) which is defined as the angle between the wheel main plane and the direction of the wheel centre velocity.

Longitudinal Force

The longitudinal force (Fx) is the force in direction of the main plane, the characteristic value is the longitudinal slip, calculated as the relative velocity in the contact patch (velocity difference of wheel centre speed and wheel circumferential speed) divided by the wheel centre speed or the wheel circumferential speed accordingly (depending on the definition for acceleration or braking).



Static Weight Distribution from CG

Static Weight distribution is the amount of weight supported by vehicles front and rear wheels in vertical direction from CG.

The static weight distribution is important because it effects the polar moment of inertia and polar moment of inertia is important because it changes during accelerating, braking and cornering because of load transfer.

Load Transfer

Load transfer is the amount of load transferred from one wheel to another in vertical direction during acceleration, braking and cornering because of lateral and longitudinal forces due to the moments about the vehicles CG or its roll centre as the vehicle is accelerated in one sense or another.

It doesn’t change the overall weight of the car but changes the amount of load in every wheel.

Due to change in load it changes the contact patch between the tyre and road.

G’s

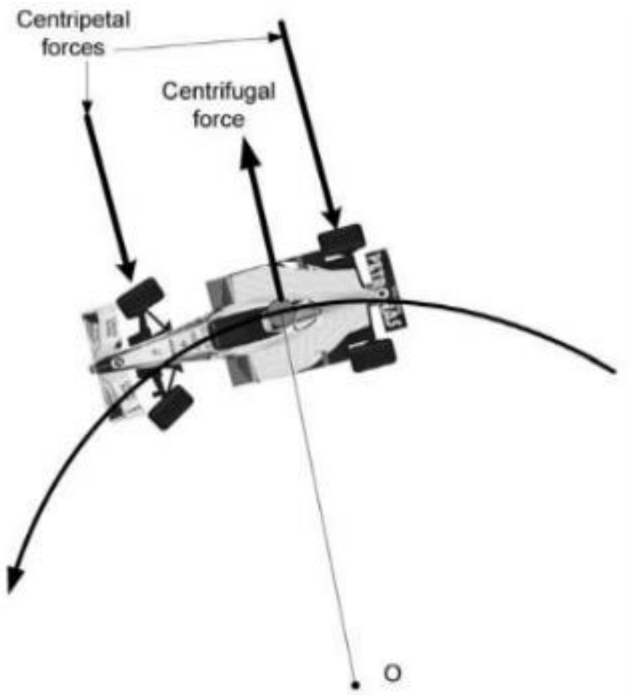
G force is a measurement of an object's acceleration expressed in *g*-s. It is proportional to the reaction force that an object experiences as a result of this acceleration or, more correctly, as a result of the net effect of this acceleration and the acceleration imparted by natural gravity.

The limits of performance for a competition car are largely dictated by three factors, Acceleration

Braking

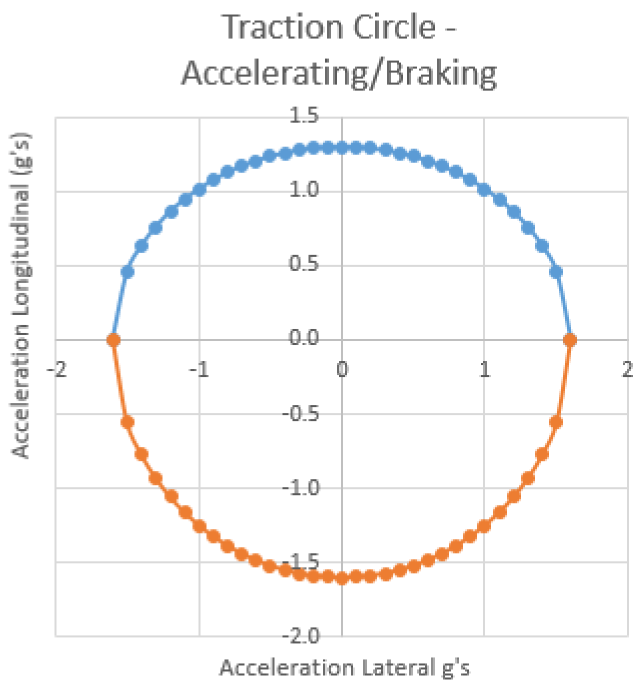
Cornering

Since a car accelerates by applying torque to the driving wheels, which in turn create a forward thrust between the tyre contact patches and road surface, the limiting grip of the driven tyres on the road surface is one factor that controls the unlimited rate of acceleration and deceleration.



Traction Circle of 2017 Swinburne's Formula 1

Each type of tyre has different characteristics that can be displayed on a traction circle. This circle shows the maximum and minimum longitudinal and lateral force that it can be applied to the tyre as seen below in figure 6. For optimal performance from each of the tyres the force on the tyre should always be pinned to the circumference of that circle.



To carry out the force analysis of the uprights we have taken six (6) important cases according to our situation in which we will be driving the car.

Considerations

All the calculations have been carried out in System International (SI)

The table below shows all the important values needed before carrying out the force analysis

Following are the six cases which we derived from the starch,

The first three cases are,

- Static
- Accelerating
- Braking

Then we will combine these cases with cornering (turning)

- Cornering
- Accelerating and Cornering
- Braking and Cornering

Throughout the report forces in the Up direction are positive and negative in the down direction.

Forces in the Horizontal direction on right hand side are positive and left hand side are negative

Moments in the Anti clockwise direction are positive.

The y-axis is up direction which is normal or vertical direction, x-axis is lateral direction and z-axis is longitudinal direction as shown in the figure

Overview of an upright

The function of the upright is to connect all suspension parts as well as hold the brake calliper and wheel. The uprights affect all of the above suspension characteristics depending on how it is designed and manufactured. Listed below are the most important qualities of the upright.

Stiffness

Stiffness is a key factor in an upright as if it's not stiffs it will deflect and become useless at holding all the suspension in unison. One of the main reasons an upright needs to be stiff it to reinforce all suspension components and combine them rigidly. If the upright has too much deflection the bearing housing can warp and cause bearing wear, increase rolling resistance and result in more energy being used than necessary.

Shear

Shear stress is defined as: material deforming due to a load being applied to it. The equation given for single shear is $\tau = F/A$ where t is shear F is force and A is area.

Double shear

Double shear is better than single shear as the load is distributed between two planes as opposed to one. This will make the upright safer and reduce the strain and fatigue on the bolts. The equation for double shear is $\tau = \frac{F}{\ }$ and it can be seen that with double area the shear will be reduced.

Load pathing

Load pathing is the path that the stress is mainly distributed through. Taking this into account will help the design be optimised later to distribute the load throughout the upright rather than have a large concentration in one spot.

Fatigue

Throughout the uprights lifetime it will be subjected to cyclic loading, which over time will cause the upright to degrade. As this happens the upright will lose its characteristic of stiffness. As these forces are loaded and unloaded the bonds within the metal will break and in turn reduce the structural rigidity of the metal. This is a material consideration when selecting an appropriate material.

Bearings

Bearings are an important element to many machines, as they reduce friction between two objects, allowing moving parts to move more smoothly. Bearings are split into two basic categories, radial and thrust bearings. Radial are in turning shafts, and thrust support axial loads.

Wheel Bearings are pretty simple parts. They're made of high quality steel and are engineered to last for thousands kilometres or more if properly cared for. The bearings do two very important jobs: First they allow the wheel to freely rotate with as little friction as possible. Second, they support the weight of the vehicle.

Even though wheel bearings are relatively simple, they need to be in near perfect condition to do their job. The bearings are packed with heavy grease to lubricate and protect them. A seal keeps the grease in and water and dirt out. It's when the seal starts to leak that problems begin. The grease can become contaminated; causing the wheel bearings to overheat and ultimately fail.

Friction in Bearing

The friction in a rolling bearing is made up of several components. Due to the large number of influencing factors, such as dynamics in speed and load, tilting and skewing resulting from installation, actual frictional torques and frictional power may deviate significantly from the calculated values.

Frictional component	**Influencing factor**
Rolling friction	Magnitude of load
Sliding friction of rolling elements Sliding friction of cage	Magnitude and direction of load Speed and lubrication conditions, running-in condition
Fluid friction (flow resistance)	Type and speed Type, quantity and operating viscosity of lubricant
Seal friction	Type and preload of seal

Bearings Working Principle

Made up of basically a ball and an inside and outside smooth surface for rolling, the ball will carry the load weight, and the force associated is what encourages rotation. The way the force is placed depends on if it's a thrust load or radial load.

Radial loads put weight on the bearing making it rotate from tension, while thrust loads put stress directly on the bearing from an angle. Some bearings even handle both radial and thrust loads. One example is a car tire, in which it supports a radial load on a straightaway and a thrust load when taking on a corner.

Types of Bearings

	Pros	**Cons**
Ball Bearing	Handle both radial and thrust loads Very common -	cheap Can only handle a small amount of weight Prone to deformation if overloaded
Ball Thrust Bearing	Serviceability is proficient due to the bearings being separable Excels at handling thrust loads	Handle almost exclusively thrust loads Used in low speed low-weight applications
Roller Bearings	Capable of carrying heavy loads Primary roller is cylindrical – load is distributed over a larger area Low starting friction	Primarily used for applications with radial loads, rather than thrust loads
Roller Thrust Bearing	Capable of supporting large weight loads Capable of handling thrust loads Low starting friction	Cannot handle radial loads
Tapered Roller Bearings	Capable of handling large thrust and radial loads Can withstand large weights Low starting friction	Generally mounted in pairs, takes up more room.

Bearing Selection for ts_17

After doing the Force Analysis and going over all the properties of bearings we wanted bearing which are capable of bearing both i.e. Radial and Thrust Loads.

Our area of research narrow downs to these three bearings on the bases of scientific reasons,

	Pros
Deep Groove Ball Bearing	Forces In Radial Direction(It can bear 20 to 30 of axial Load) High Dynamic Load Rating High Limiting Speed (Grease)

	Less Rolling Friction
Angular Contact Ball Bearing	Force In Radial & Axial Direction High Dynamic Load Rating High Limiting Speed(Grease) Less Rolling Friction
Roller Tapered Bearing	Loads In both direction i.e. Radial and Axial High Durability High Limiting Speed High Rolling Friction

High Acceleration is one of the main objective in our competition, out of these three bearing we narrowed down our research to two bearings i.e. Deep Groove Ball Bearing and Angular Contact Ball Bearing because Tapered Roller Bearing have high Rolling friction which will reduce our rolling.

Material selection

The material that is chosen to manufacture the upright must be able to withstand the loads, stresses, heat and cyclic loading as discussed above. These factors have narrowed the material choice dramatically as only a select amount of materials can satisfy these criteria. The four main material choices we have are Aluminium, Carbon Fibre, titanium and steel. Each of these materials are discussed below.

ALLUMINIUM

Aluminium is the most abundant metal and the third most abundant element in the earth's crust, after silicon and oxygen. Metallic aluminium was first prepared by Hans Oersted, a Danish chemist, in 1825. He obtained the metal by heating dry aluminium chloride with potassium metal.

$AlCl_3$ + 3 K ---- Al + 3 KCl

Further to this there was one more scientist called Robert Bunsen prepared aluminium metal in 1850 by passing an electric current through molten sodium aluminium chloride. Aluminium is a silvery-white metal with many valuable properties. It is light (density 2.70 g/cm3), nontoxic and can be easily machined or cast. Pure aluminium is soft and brittle, but can be strengthened by alloying with small amounts of copper, magnesium, and silicon. Recycling of aluminium saves considerable energy. Because the aluminium is already in the metallic state, all of the energy spent in purifying the ore and reducing it to the metal is saved when aluminium is recycled. The aluminium needs only to be melted to be reused and melting process is very commonly used in the processing of metals. The use of aluminium cast components as the uprights is as old as racing; nevertheless this traditional technology is still a standard on budget racing cars.

Types of aluminium

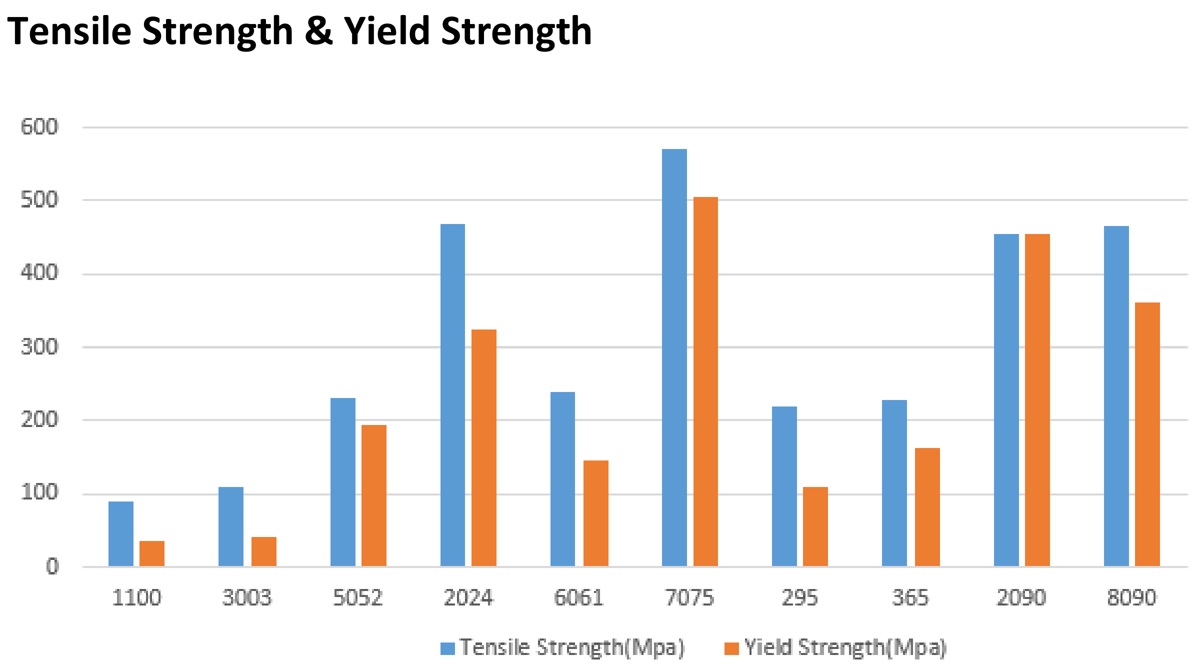
There are different types of aluminium alloys which are named below and are also characterized according to their strength.

- Alloy 1100 – Not used for high-strength or high-pressure applications
- Alloy 2011 – A high mechanical strength alloy
- Alloy 2024 – A high strength aluminum alloy
- Alloy 3003 – Medium strength
- Alloy 5052 – Medium to high strength alloy
- Alloy 6061 – Medium to high strength alloy
- Alloy 6063 – Medium strength
- Alloy 7075 – A high strength aluminum alloy

Alloy 7075 is the one that we have used to manufacture our upright, with it being strong it can also be manufacture in high temperatures which is good plus point to consider.

Comparison with other metals

ALUMINIUM	STAINLESS STEEL	STEEL
1. Better strength & malleability	Average	Average
2. Resistant to corrosion	Can be corroded easily	Also corrosion prone
3. Better workability	Quite difficult to work with because of being hard.	Not that bad with the workability.
4. Efficient with cost	A bit expensive	Also expensive
5. Low density	High density	High density
6. Much better Thermal conductivity	Lack in Thermal conductivity	Average in Thermal conductivity
7. Difficult for welding	Easy for welding	Relatively easy for welding as compared with aluminium
8. High electrical conductivity	Poor electrical conductivity	Fine electrical conductivity.
9. Light in weight	Heavier as comparison with aluminium	Heavier as comparison with aluminium



So, we are using aluminium 7075 and the tensile strength of Al 7075 is 570 (MPa) and its yield strength is 505(MPa) which is way more than the other types of aluminium. This makes it stronger and reliable than the other.

Applications

1. Aerospace companies build Aircraft with this material.

2. Gears and shafts, fuse parts, meter shafts and gears are manufactured using Aluminium 7075.

3. All-terrain vehicle and bike frames are also manufactured using this material.

Titanium

Titanium in its most pure form has a low density of 4.5g/cm^3, a high melting point of 1660C and elastic modulus of 107 GPA. These properties make titanium a strong high tensile material at room temperature with a tensile strength as high as 1400 MPa. Titanium can be forged, machined and even 3D printed making it a highly versatile material for many applications. One design consideration for titanium is that it has a high reactivity with other materials at room temperature. This has made the development of refining titanium expensive as it goes through numerous processes and is categorised into different types of titanium as can be seen in table.

Material name	Tensile Strength	Yield Strength	Typical Applications
Unalloyed	484	414	Engine shrouds, airframe skins
Ti-8Al-1Mo-1V(R54810)	950	890	Jet engine components
Ti-5Al-2.5Sn	826	784	Gas engine components, chemical processing equipment
Ti-6Al-4v	947	877	Prosthetic implants, chemical processing equipment
Ti-10V-2Fe-3Al	11223	1150	High strength airframe components
Ti-6Al-6V-2Sn	1050	985	Rocket engine case frame

Why we didn't choose Titanium billet?

The ease of machinability is very less for titanium billet as it is quite difficult to machine the final design. It also lacks in strength when compared to Aluminium 7075 and is very expensive material which is barely found in the market.

Steel

Steel is a very commonly used material and is suitable for many different applications due to its high tensile strength and its cost effectiveness. This is due to the iron and carbon being able to be combined with many other elements and its ability to be refined in various different ways. The main component of steel is the carbon content, and steel is categorised into different concentrations depending on this carbon content into 3 main categories; low, medium and high. This has the majority effect on the density of the steel which is 7.85g/cm^3 for mild steel. The other elements that steel is made out of also has an effect on the properties but are subclassed within the larger categories and have only minimal effect on the structure. As mild steel is the most common type, suppliers of it must keep their prices relatively low due to how common it is. A comparison of steels can be seen below in table 5.

Steel Number	Tensile Strength	Yield Strength	Applications
1010	325	180	Car panels, wire
1020	380	205	Sheet metal
A36	400	220	Bridge structures
A440	435	290	Bolted or riveted structures
A516	485	260	Pressure vessels
A663	520	380	Low temperature structures

Why we didn't choose steel?

Its maintenance cost is very high and has very small resistance against fire. Steel cannot be mould into any shape. It has very high expansion rate with changing in temperatures. Weight of this material is also an issue as it is very heavy which further make it expensive to transport.

CAD software

Throughout the design process only one piece of computer aided drawing software. Computer drawing software is used within the engineering industry to 3D model complex parts using computer software. There are many advantages of using CAD software over conventional hand drawing as a digital file can be saved and distributed to multiple locations and offers many different perspectives as it is a 3D model. Using a software package like SOLIDWORKS which is the software that we used offers the user easy compatibility with different file formats for creating other views like orthographic or isometric. The perspective views are used in industry for the manufacturer to further understand the design that they have been given. It also has the advantage of making the CAD to CAN conversion much shorter as the program as the capability of shortening this conversion through optimisation.

Manufacturing Processes

3 axis

3 axis CNC machining has a huge tool arsenal (several hundred) and is used to subtractive machine materials into a desired shape based on a 3D model. The machine uses heads that rotate to cut away unnecessary material with extreme accuracy. This is achieved by moving the head of the tool in 3 axes X, Y and Z. The head is moved by the machine's internal mechanisms controlled by a computer. CNC stands for 'Computer Numerical Control' meaning that this whole process is done by a machine to minimise human error. Eliminating the human error creates a very small amount of tolerance issues as the machine can mill out to 0.2 of a millimetre. Most 3 axis CNC machines can be entirely automated which includes the changing of tools, automatic probing cycles which automatically finds the starting point of a work piece as well as automated cooling cycles to decrease the warping in the designated material.

5 axis

5 axis machining offers some unique advantages over 3 axis. As well as introducing another 2 axis's it also has tighter tolerances and can machine more of the inside of the work piece. This extra functionality allows for 5 sides of a part to be machined without an operator needing to reposition the work piece. 5 axis machining can be split into 2 different types, 3+2 and 5 axis simultaneous. Simultaneous machining allows for more complex geometries to be machined, a common use for this process the creation of flow impellers for turbocharges. 5 Axis machining has the ability to position the cutting tool normal to the required surface, independent of the angle. 3+2 machining techniques clamp a work piece in a set position and to prevent rotary movement before cutting. After cutting the clamp is released and the work piece is then clamped into the next required position. It then machines from this orientation before repeating the process. 3+2 machining is the cheaper way to machine in 5 axis as a less complicated computer is required and the machine is out under less rotary stress.

Water jet cutting

Water jet cutting involves a water jet cutter which is an industrial tool capable of cutting a wide variety of material using a very high pressure jet of water or a mixture of water and an abrasive substance. Water jet cutting is often used during fabrication of machine parts. It is the preferred method when the material being cut are sensitive to high temperatures generated by other methods. Water jet cutting is used in various industries including mining and aerospace for cutting, shaping and reaming.

Fasteners

Fasteners are used to attach most parts to the chassis or body of the car. These consist of mostly nuts and bolts and range in size and grade. The grade of a bolt determines the maximum yield and tensile stresses and when paired with the correct application provide enough force not to sheer. Looking into the official FSAE rules all fasteners require a grade of at least 8.8. Using the force calculations it can determine the stresses in each component and an appropriate fastener can be selected and implemented

Finite element analysis

Finite element analysis (FEA) is a computerized method for predicting how a product reacts to real- world forces, vibrations, heat, fluid flow and other physical effects. Finite element analysis shows whether a product will break, wear out or work the way it was designed. It is called analysis but in the product development process, it is used to predict what is going to happen when the product is in used.

Design approach/strategy

As a part of the Machine Design SAE assignment a design brief was supplied at the beginning of the project. This brief contained a list of constraints/considerations which needed to be taken into account. This was due to the assignment being a part of a larger project which was required to interact with different parts, all of which were required to work and fit together under extreme conditions.
The design constraints stemmed from the section goals which were set as targets for the dynamics sections, which the uprights fell under. These goals included; have equal or lesser weight when compared to last year and have part interchangeability. The part goals are mentioned below

Part Goals

- Optimization of design according to new reference geometry
- Weight should be equal or less than ts_16 uprights
- The Front Upright must be manufactured by 5-axis CNC machining
- The part must be safe to use and last longer **Defining the Problem**

In order to reach these goals the approach that the team has decided to take toward the problem was breaking it down into several smaller steps. These steps were; define the problem, Concept building, Design concepts, Develop design, Evaluation develop, Implement Design. Defining these steps allowed the design process to run smoothly with minimal disruptions, a layout of these steps is given below in Table 1.

Define the Problem	• Look at the given design brief • Consider design constraints • Discussing with team members for better understanding
Concept Building	• Research on previous designs • Talk with ts_16 upright group • Literature review
Design Concepts	• Hand-sketches of initial designs • Forces calculations on paper • Refinement of force calculations in excel • Suspension points and constraints
Develop Design	• Draw design in Solid works • Design to considerations and constraints • Design for Manufacture • Refine Design
Evaluation Develop	• Solid works stresses and deformation • Run FEA analysis

Implement Design	• Communicate with A-arms, brakes and wheel sections • 100% Design review • Optimise for manufacture • 2D - drawings

Table 1

As these are the goals that were set by the team we decided it was best break down the problem to understand what was actually needed and to have a plan to make our part work with the rest of the ones that connect to ours. We then used this strategy to research and fill in the gaps in our knowledge about the upright, the surrounding parts and the theories that directly impact on it. After discussing the most important information about how to delegate the tasks it was decided that the whole team would do some research before splitting up. Two people would proceed to draw, conceptualise and refine the designs in SOLIDWORKS while the other two started on the report, written assessment tasks as well as any other documentation.

Concept Building

The research started off with each group member reading the relevant sections in 'tune to win' a book by Carroll Smith. This book was a valuable resource as most of the information that was required was readily available in that book. Tune to win was a great resource as it gave a well-rounded in depth explanation into each part and what its relevance to the car was. Research consisted of understanding how vehicle dynamics worked especially suspension as well as the tyre and how it handles forces. Additional research was also done into bearings, this research stemmed from various sources. All necessary information was recorded and taken down into the group's literary review. After understanding what each individual part does, the ts_15 team was contacted and we had a conversation with them. This was beneficial as all the problems that they had in previous years was noted and taken into consideration in order to achieve the part goals. At this stage that it was decided that each group member would obtain a copy of SOLIDWORKS to help build on later designs. The group also committed to meeting up each Monday to work on the design thoroughly and work out all the problems that we had by discussing them with the team leaders. In addition to this dynamics section meetings, as well as the team meetings were scheduled on Monday nights, which means that any type of questions we had could be answered. In one of the early meetings it was stated that all students designing a part would need to read the FSAE rules in order to work a cohesive team.

Design Concept

The next stage of design was to build on our concepts and to gain more knowledge as to why the uprights needed to be re designed. In the conversation with the ts_15 year's team it was discovered that their main goal of the part was to decrease weight and was the leading factor as to why the rear uprights deflected so much, they also recommended gaining access to T-drive in order to look at previous designs to gain some inspiration. Conversely to this the issues with the ts_15 year's bearings were also discussed and aspects to focus on when choosing a new one were noted. With this information the team allocated a single person for doing rough calculations on paper to obtain a rough benchmark of what forces the uprights would take as well as their direction and to conceptualise a free body diagram from the information discussed in the literature review to aid in these calculations, separate calculations were also done for the bearings and the reaction forces going through them. During this period the reference geometry was changed and we need to rebuild our design. This gave us much needed reference points to start building on our designs in SOLIDWORKS. Later in this process the force calculations were duplicated in excel to further refine and make the information available for the future use in FEA.

Develop Design

After designing the concepts the group moved on to further develop and refine our concepts. This involved constructing a CAD model for our part taking into account the constraints and considerations. As we were working in a larger team, following the CAD rules implemented by the chief of manufacturing in order to be able to collaborate all the CAD files for each individual part was a must for everything to run smoothly. This also included researching what material we were going to make our upright and the manufacturing process. Aluminium 7075 was chosen for its material properties of having a high modulus of elasticity, easy to machine, light weight as compare to titanium and resistance to deflection.

It was also capable of withstanding a large number of load cycles and as the temperature of the uprights last year didn't go above 120 degrees that was the maximum temperature that was allowed for. Other factors that influenced this decision were the availability and ease of manufacturing, the team's previous experience with the material also added to the benefits of the material.

When it comes to clevis the material was change from Aluminium 7075 to steel 4130 considering the purpose of clevis and the impact of the total cost on the part, however later when FEA was done it was seen that the factor of the clevis is not safe to use in order to increase the strength several options were considered like increasing the thickness, changing the material and few more. In the end the final decision was to make a gusset on each side of the clevis which will be welded in order to increase the strength. The Manufacturing process used for manufacturing of clevis was water jet cutting. The reason of choosing this process was the effectiveness of water-jet cutting as the process is environmental friendly, it saves raw material because of its nesting capabilities, it involves Omni-directional cutting and it faster than many other conventional cutting tools

While, considering Shim the material was changed from Aluminium 7075 to shim steel so that it is easier to adjust camber.

while choosing the bearings there were few constraints, the Inner diameter of the bearing has to be 40 mm we can't change it because it will change the wheel hub and eventually moment of inertia and the outer diameter for the bearings can't be greater than 64mm because it will lead to an increase in the bearing housing in the upright which caused interference with other parts. These restrictions were definite in their limitations.

Other design aspects of the bearing choice included the availability of the bearing, the bearing life, and the type of fit required.

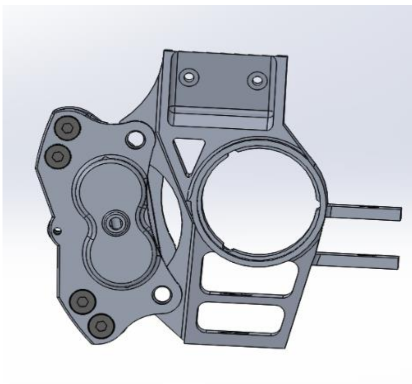
Bearing Selection	
NTN Deep Groove Bearing 6908VV	NSK Angular Contact Ball Bearing 7908C
• NTN Bearing 6908VV • Forces In Radial and Axial Direction but mainly Radial Direction • Dynamic Load Rating 13.7 kN • Bore & Outer Diameter 40 & 62 mm • Limiting Speed 11000 rpm (Grease)	• Force In Radial & Axial Direction • Dynamic Load Rating 14.2 kN • Bore & Outer Diameter 40 & 62 mm • Limiting Speed 16000 rpm (Grease

Deep groove ball bearings (fig. 1+) have deep, uninterrupted raceway grooves. These raceway grooves have a close osculation with the balls, enabling the bearings to accommodate radial loads and axial loads in both directions.

In terms of cost and availability Deep Groove Ball Bearings are 20 times cheaper than Angular Contact Ball Bearing.

Evaluating

After all the cad work was done it was time to check, was our part good enough to be manufactured for which the part was inserted in Master Cad to check if the part is working fine in the assembly and having enough clearances. Starting with Brake Calliper the Calliper was rotated to have an enough clearance for the both holes from centre to the edge of the fillet, As a result the Braking calliper had enough clearance and was installed successfully as shown in fig



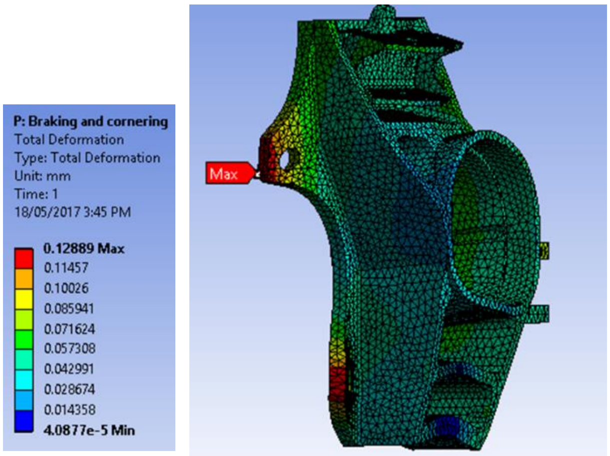
FEA was done whiling using cylindrical support on upper, lower and steering rod

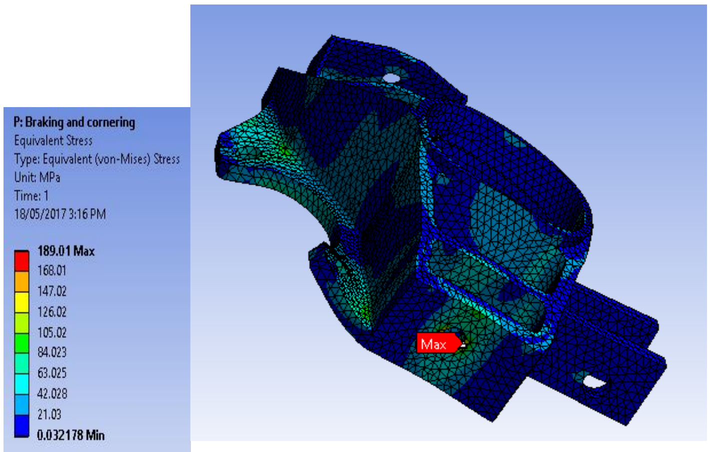
Direction	Upper A-arm	Lower A-arm	Steering rod
Radial	Fixed	Fixed	Fixed
Axial	Fixed	Free	Free
Tangential	Free	free	Free

FEA was done on the upright for 5 different scenarios including accelerating, cornering, braking, braking and cornering and accelerating and cornering. The forces applied includes two forces one is from the contact patch which acts directly to the centre of hub and the other one is the force due to braking which will be vertical in pure braking scenario and tangential in braking and cornering scenario. The FEA was success as the two critical scenarios which are braking and cornering and braking both where having safety factor above 2.

The following figures shows the results of different scenarios.

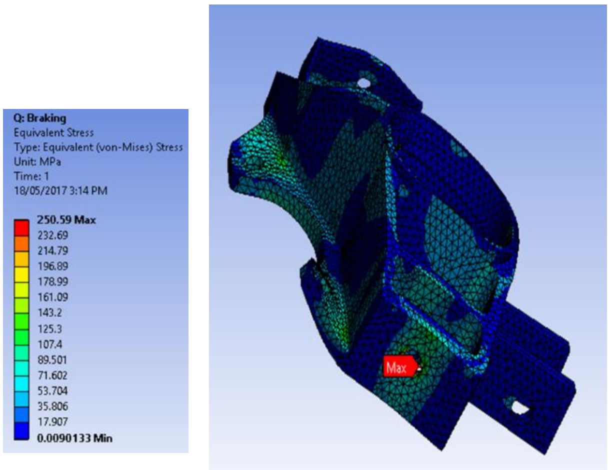
Braking and cornering

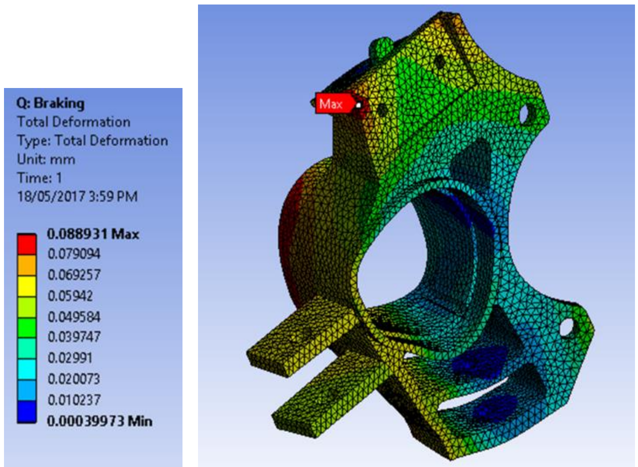




In fig the results of FEA are shown for braking and cornering scenario and it is seen the maximum deflection 0.12mm which is really less to previous year upright however the safety factor o this scenario was 2.5.

Braking





In fig the results of FEA are shown for braking and cornering scenario and it is seen the maximum deflection 0.088mm with safety factor 2.1

The FEA results of all scenarios are tabulated below

Scenarios	Max Deflection (mm)	Max Stress (MPA)	Safety Factor
Braking and cornering	0.128	189.01	2.5
Pure braking	0.088	250.59	2.1
Pure accelerating	0.053	107.78	4.6
Pure cornering	0.138	235.96	1.97
Accelerating and cornering	0.166	227.98	2.01

As seen from the results the maximum deflection that the upright will experience is 0.166mm in accelerating and cornering case which is half the deflection as compare to last year upright further the lowest safety factor is 1.97 which means the upright is strong enough and also safe to use.

Further FEA also helped us to locate stress concentrated areas shown in the figures below

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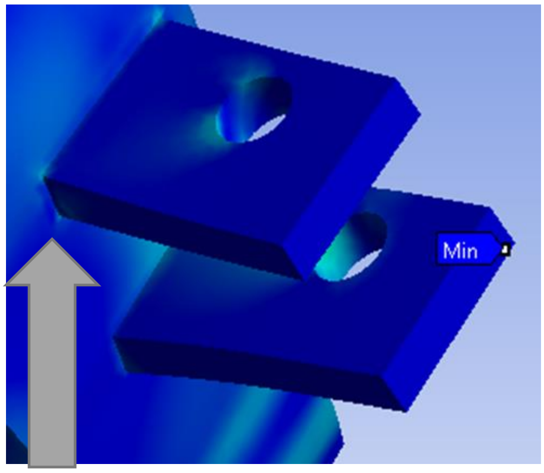
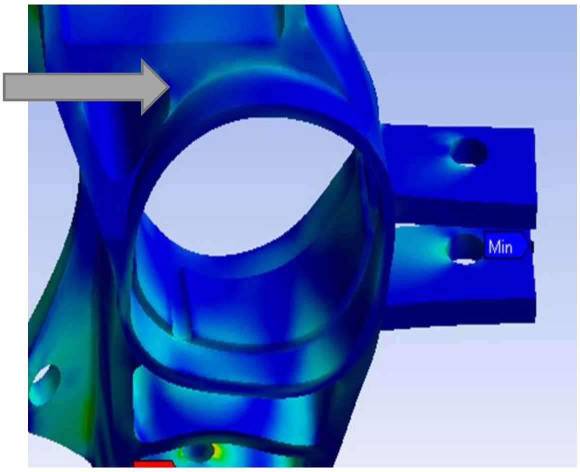




To avoid cracks and fatigue on the stress concentrated edges fillets were done to make the upright more reliable and to make sure it last longer.

Implementing the design

Implementation started with a final review of all dynamics parts double checking that there was going to be no conflict between parts and that the designs were ready for manufacture. Upon inspection it was found that some parts collided with each other and needed to be rectified. The parts included the brakes, clevis, between bolts and A-arms. After these issues were rectified as seen below in the creativity section, the material was ordered in bulk with all the other similar material for the car as well as the fasteners. As the team is still waiting for these lists to be finalised the design was frozen and is waiting on the required materials to be delivered before moving on to manufacturing it. While the design is frozen engineering drawings were created to make the manufacturer have a clearer idea of what the final design should look like including tolerances and the surface finish.

Creativity

Throughout the design process there were a number of issues that were encountered and a solution needed to be implemented in a systematic way. The overlying issue was that the deflection needed to be decreased compared to last years. The other minor issues that were discovered during the design process of the uprights were allowing for clearance for the A-arms under all load conditions including bump, droop and cornering. As well as having numerous CAD issues and spanner clearances for mounting the upright to the other suspension and the chassis points. Checking bolt head clearance as well as bearing choice. Manufacturing was also a minor issue finding out if our final design could be machined using a 3 or 5 axis machine and who could manufacture it. When considering the different bearings that may be possible with the restrictions applied a systematic spreadsheet was created with all of the different possible bearing that met the restrictions and then the different ones were considered under the load conditions. Due to later changes in design, we needed to fully redesign the front uprights clevis to allow for more clearance when turning allowing for more room for the upper A-Arms. To do this, we decided to go for a bent Steel sheet metal clevis, rather than a machined aluminium 7075 design, this allowed for an extra 3mm of clearance which is well in the range of what was needed. After some final ANSYS calculations, the material of the sheet metal upright was decided to me 4130 steel that has been normalized at 870°, this allows for a yield strength of 435 MPa, giving us a factor of safety of 2.1 in the clevis.

Manufacturing Process

Due to the design of our Upright, 3 axis machining is an option, but this will involve multiple re clamping situations. This will further cause errors with the precision milling of the machine because of a moving datum point, causing either our designs integrity or possibly the suspension geometry to be at risk. To minimise this risk, we can use 5 axis machining process to design this upright, with only 1 re clamp due to the rear face needing to be machined as well. 5 axis machining also allows for a much more accurate tolerances ranging between 1-10. Due to the complexity of 5 axis machining, this generally increases the machining time compared to 3 axis, this taken into account the machining of the upright can be anywhere between 40-60 hours per piece, with 2 pieces being made on the front this can be very, very time consuming. Along with needing to take into account the availability of 5 axis machines this can take a few weeks from handing it to the manufacturers to getting the finished product. This has been taken into account in our available timeline have allowed over a month for it to be manufactured according to our deadlines.

Deflection

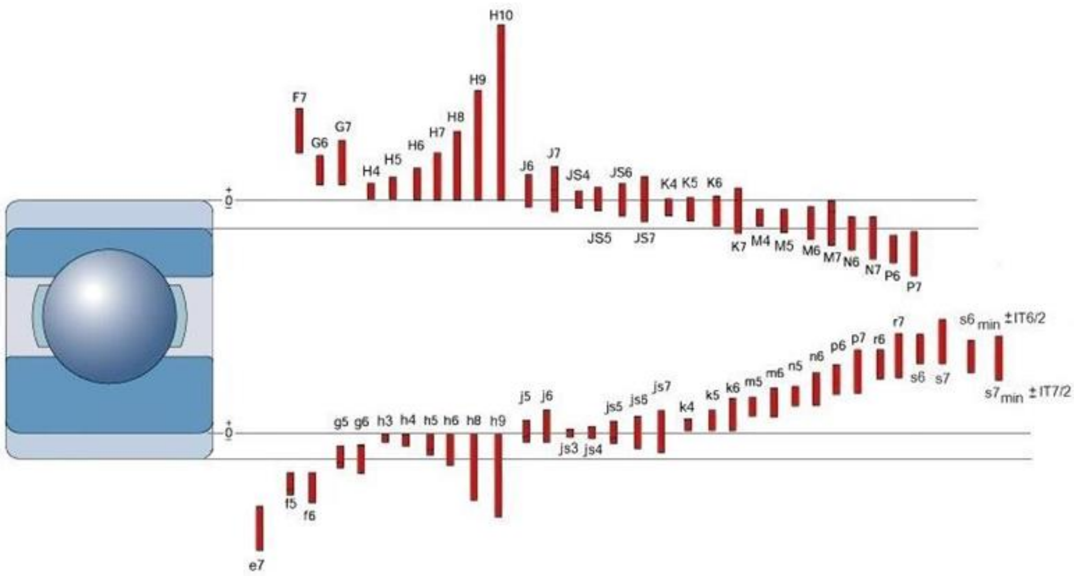
While we were designing to survive the stress applied, minimising the deflection was one of the main aspects that were focused on the design brief, supplied to the team at the start of the project. As the main part goals also included having equal or lesser weight than ts_16, part interchangeability with ts_16, 500 grams or less per corner and 3 axis machine able, it was required to select a material that was suitable for the best heat conditions as well as being able to take infinite load cycles. As the Aluminium 7075 was the main considered material because it has the largest yield stress in the temperature range that the upright will be subjected to. Other materials that were considered were Ti-6Al-4v titanium and steel A36. However steel A36 cannot handle the same amount of cyclic loading as 7075 at the required temperature despite having the same modulus of elasticity. Ti-6Al-4v titanium was considered as the FSAE team has a sponsor that is willing to 3D print titanium, however the lack of experience that the team has with this material and the increase in density would result in the titanium upright being 40% heavier than an identical upright made out of aluminium.

Spanner and Bolt clearance

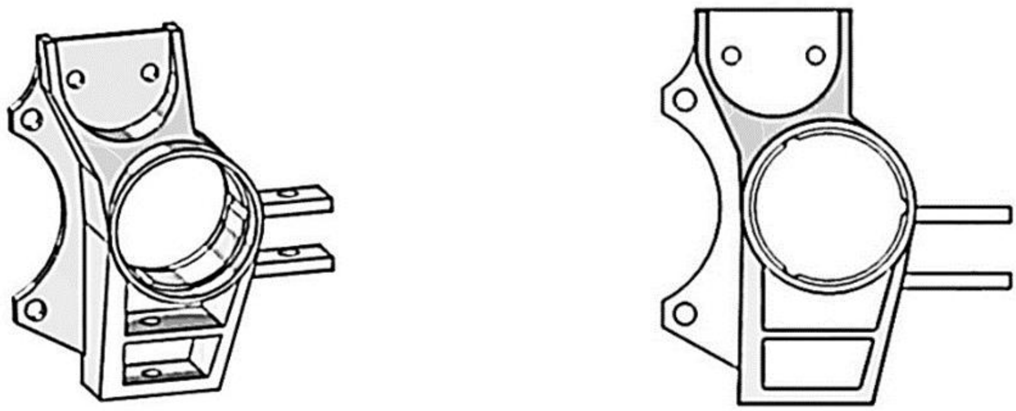
The assembly of the upright requires fasteners to protrude through the clevis and the shims in order for it to be able to be attached to the lower A-arms. The clearance required for a closed spanner to be able to go over the bolt is about 10mm this needed to be considered in the design to ensure that the upright could be properly secured to the rest of the suspension components. This clearance was especially difficult on the front upright as the A-arm group wanted the bottom mounting point in the upright to be a total of 20mm, however with this adjustment it would have been impossible to attach the feral as a nut would not fit on the upright as the space needed wasn't there. It was decided that the feral would be adjusted to solve this issue.

Tolerances

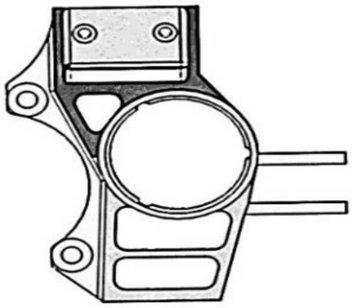
Looking at figure below it is possible to see the different types of tolerancing that a radial ball bearing can have, the ones on the top, with capital letters, indicate the bearing housing tolerances and vice versa. In both cases a positive tolerance was unacceptable, as there can be no creeping of the bearing. As such a k5 tolerance and a M7 tolerance were chosen. When machining the upright in the CNC machine it is imperative that particular points are as accurate as possible, as such when the engineering drawings are sent to the machinists, with the CAD files from SOLIDWORKS they, the key dimensions are the main aspect of the drawings. The dimensions are taken from the centre of the bore due to the way it is machined. All engineering drawings were run by the chief engineer of team Swinburne to confirm that they were accurate and of the correct layout. Key dimensions such at the brake mounts had a tolerance of 10 microns, as if these were off centre it would have directly impacted the assembly of the car. Similarly the bearing housing has a very specific accuracy, as they have to flip the part, so when doing so it is noted that each sided bust be to 10 microns of each other, if this is not the case then the shaft may not go through smoothly. There are some parts which have a lax tolerance, such as the speed sensor slot, as this will not critically affect the design of the upright if it is fractionally off.

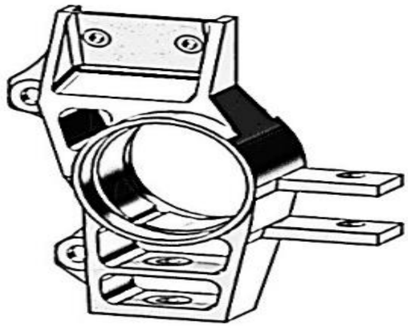


Cad challenges

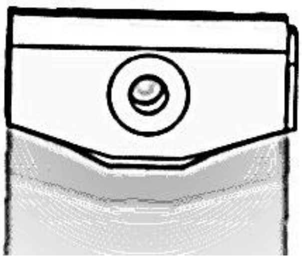


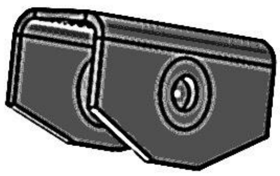
Initially we came up with this design for our front upright, which actually have many defects such as not having enough clearance from the centre of the brake mounts to the edge. We at least require 10mm of clearance distance. The distance between the upper A-Arm is also not appropriate as there is more distance left from the edge to the centre of the holes. In this design material consumption is very high which would lead to increase the cost and weight of upright. It have many sharp ends which will be stress concentrated areas and can be the regions where a crack may occur. Also sharp ends may lead to a sudden accident. We made some amendments in the dimensions of upright which is explained in the next design.





So, this is our second design which is pretty much our final one basically first of all we tried to give enough clearance between the brake mounts centres to the fillet edge i.e. 10mm and also we fixed the upper A-Arm holes clearance. This design is compact and will have less material involved in its manufacturing because some of the material has been deducted in the shape of triangle near the bearing circle to the left. More fillets are added to the design in order to make it safe to use. The position of the brake mounts are rotated at some extent in order to mount the brake calliper as there wasn't enough space for the brake calliper to bolt in the earlier design. Also keeping in mind distance from the centre to centre of brake mounts and the centre of upright, which should be 70.29mm exactly.





This is the design of our clevis which will be placed on the upper part of the upright in order to accommodate the bolts and nuts required to attach the A-Arms. When we made the whole assembly with the bolts and nuts. We conclude that clevis is experiencing more force and won't be safe to go with just a clevis sitting there. It may result in the breakdown of clevis.

So, we came up with this new design of clevis with a gusset attached to the both faces. This results in increasing the strength of the clevis and can hold the bolts, nuts and A-Arms attachment more effectively.

Material selection:

The next issue we bump into was the selection of material that needed to be used to create upright. This issue required a more in depth look as the incorrect choice could lead to shattering results if not considered carefully. Multiple materials were taken into account as each of their properties were desirable for our design.

The first material series that we took into consideration was iron series because of its strength and rigidness. But it had high density and is heavy material so we discarded iron.

The second material we choose was Titanium series because of its low density and being light but it does not have less density than aluminium.

The third and the last material we consider was the aluminium series. This was due to the fact of its low density which was a desired factor, since one of our goals in designing our upright was to have as low of a weight as possible.

Design	Material Cost	Ease of machinability	Strength	Total
Aluminium	4	5	4	13
3D printing Titanium	1	5	5	11
Titanium billet	1	1	3	5
Steel	5	3	3	11

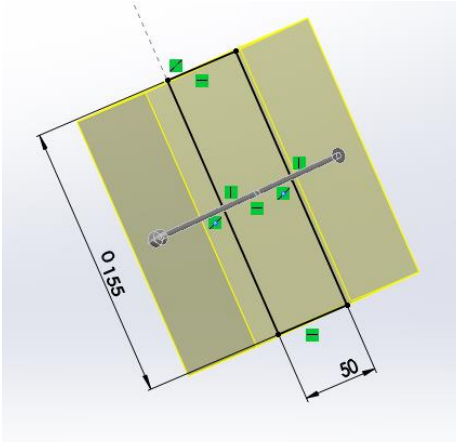
Out of 5

So, this explains that aluminium ticks all the boxes and is a fair choice to use it as a material with high strength, ease of machinability and low material cost.

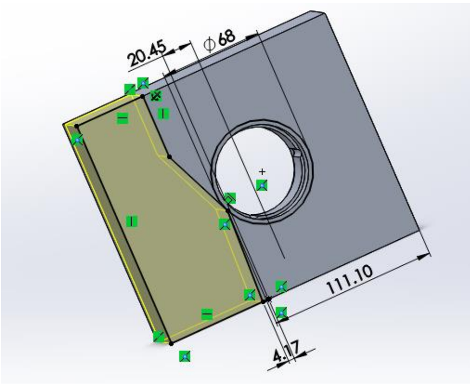
Modelling and calculating

Modelling

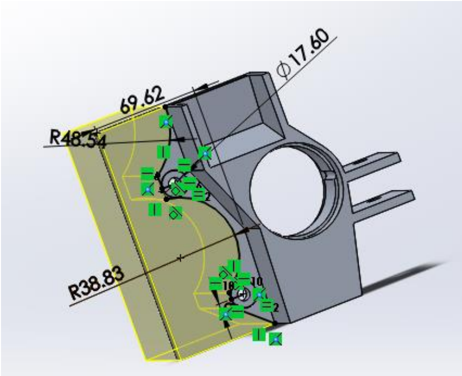
Designing an upright



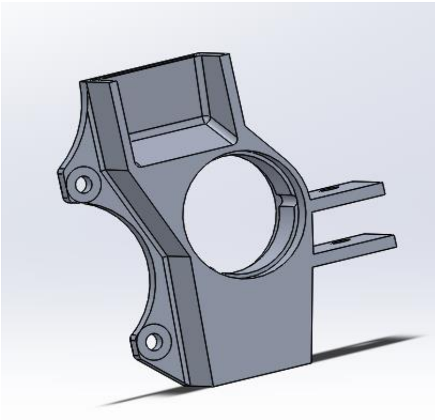
1. Step one was to start with a block shape of approximate dimensions and then cut away, using sketches outlining what we didn't need. This is much like how a CNC machine would make our part as discussed in the literature review. The position of this block is placed in the required area within SOLIDWORKS according to the given suspension geometry of the car.



2. Next we drilled the centre Bore from the block using a revolved cut. The bore dimensions were according to the chosen bearings that are to be placed in the hub

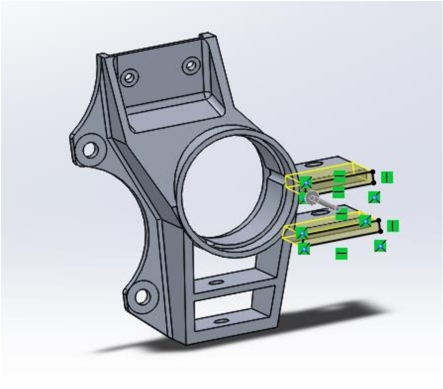


3. Once the hub was in place, we then sketched and cut out the brake calliper mount so the brakes can be attacked, multiple tests was needed to ensure that the dimensions of this part was correct due to the given CAD designs were incorrect of what is being used and we needed to work around this to ensure that everything would fit correctly.

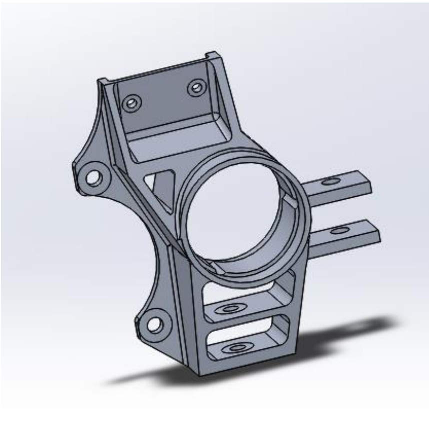


4. A cut was then made to account for the area where the upper clevis is to be attacked to the A-Arms. This face is attached perpendicular to the plane that the A-Arms are positioned across. This allows for a more stable and stronger connection to the upright. This has also been designed to allow for 5mm worth of shims to be attached for more camber.

5. The steering mount was then attached to the front side of the upright to allow for turning of the car



6. The lower wishbone of the clevis was then cut to allow for it to be mounted to the A-arms. The front face was also cut on an angle both above and below the centre bore to allow for clearance for turning of the car, avoiding interference with the A-Arms.



7. Holes were then drilled into the steering mount and the lower wishbone to allow for the connections to be made. Also material was cut out in unnecessary spots to reduce weight while still maintaining the structural integrity of the upright

Calculating

Force Analysis

The Force Analysis is the most significant aspect while designing uprights because the forces experienced by the wheel directly transfers to the uprights(bearings) then from the uprights to the bottom and top A-arms and then to chassis.

The Force analysis is not just important for the fact that how much force an upright is experiencing in lateral, longitudinal and vertical direction but it's important in choosing the Bearings for the uprights because bearing bearings literally enable devices to roll, which reduces the friction between the surface of the bearing and the surface it's rolling over. It's significantly easier to move, both in a rotary or linear fashion, when friction is reduced—this also enhances speed and efficiency.

Bearings need to resist combined radial and lateral forces.

If we choose wrong bearings it can lead to catastrophic incidents or it can increase the rolling resistance which eventually helps in slowing down the speed of car.

The Bearings will be discussed in detail further in the report.

The second important use of Force Analysis will be in Finite Element Analysis (FEA) which is the backbone of the whole process.

To carry out the force analysis of the uprights we have taken six (6) important cases according to our situation in which we will be driving the car.

Considerations

All the calculations have been carried out in System International (SI)

The table below shows all the important values needed before carrying out the force analysis

Following are the six cases which we derived from the starch,

The first three cases are,

- Static
- Accelerating
- Braking

Then we will combine these cases with cornering (turning)

- Cornering
- Accelerating and Cornering
- Braking and Cornering

Throughout the report forces in the Up direction are positive and negative in the down direction.

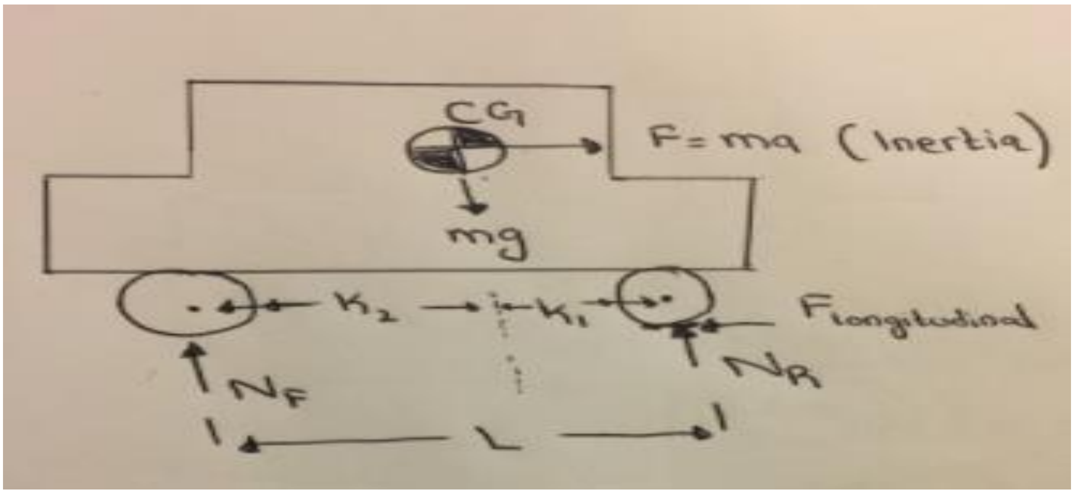
Forces in the Horizontal direction on right hand side are positive and left hand side are negative

Moments in the Anti clockwise direction are positive.

The y-axis is up direction which is normal or vertical direction, x-axis is lateral direction and z-axis is longitudinal direction as shown in the figure.

Static

In static situation the car is standing then the moment was taken about the contact patch of Front tyre as shown in the figure,



Sum of all the forces in the vertical direction,

FF + FR – mg = 0

Sum of all the moments at the front contact patch taking anti clockwise as positive,

-FR x L + mgk2 = 0

FR = mgk2/L

Putting the value in equation(i) gives

FF = mg*(1-k2/L)

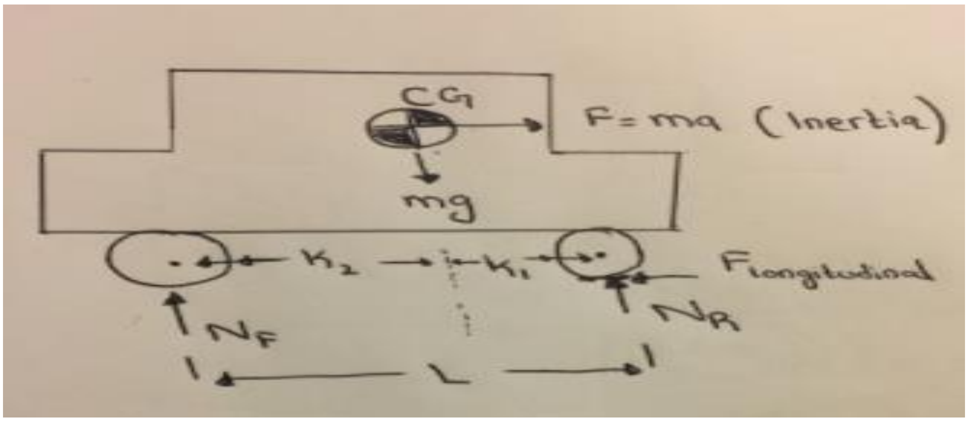
FF = mg*(L-k2/L)

FF = mgk1/L   where, k1 + k2 = L

From the above equation it's proven that the static load is divided 0.57mg at the rear and 0.43mg at the front from CG.

Accelerating

During Acceleration the car is moving in the forward direction as shown in the figure and the force about Centre of Gravity CG) is acting in the opposite direction because of Inertia.



Sum of all the forces in the vertical direction,

FF + FR – mg = 0

Where F = ma

Taking moments about the front contact patch gives,

-NR x L + mg x k2 + F x h = 0

NR = mgk2/L + Fh/L

As we can notice that the load transfer from the front axle to the rear axle is Fh/L .

Where mgk1/L and mgk2/L are static loads.

The loads in the Individual tyre for the front is FF = 800 N and FREAR = 1200 N

Hence it's proven that the load transfers from the front axle to the rear axle.

Note : Forces In the normal and longitudinal direction will be same

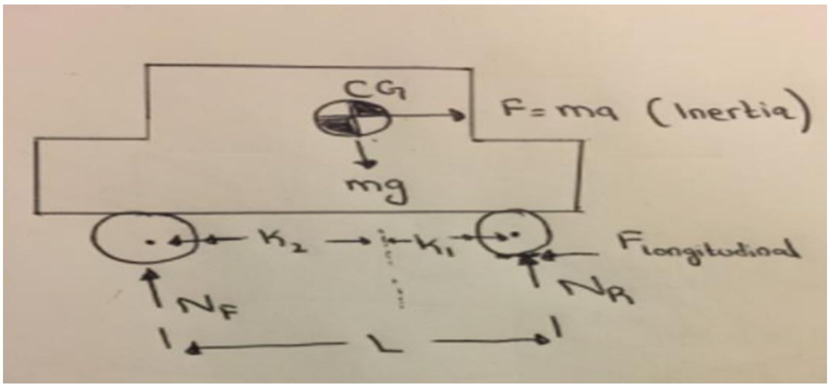
The other important force to calculate is longitudinal force. There will be no force in the longitudinal direction of the front tyre because the force is coming from the rear wheels because rear wheels are connected to the drive shaft.

To calculate longitudinal force in the rear wheels (z-axis)

$F_{longitudinal}$ = (FRL/Total force In the rear wheels) x a x g x m

Braking

In Braking the longitudinal force is acting on all the four wheels because we have got brakes in all the four wheels.



Sum of all the forces In the vertical direction

FF + FR – mg = 0

Sum of all the moments about contact patch of front wheel,

-FR x L + mg x k2 –FB x h = 0

FR = mgk2/L – FBh/L

FF = mgk1/L + FBh/L

Since it has been proven that during braking the load is transferred from the rear wheel to the front by a factor of FBh/L.

From the braking we can evaluate that the load transfers from the rear axle to the front axle by a factor of Fh/L.

Where FB= deaccelection and is equal to F= mag

Now we will be calculating the Longitudinal force in individual tyres

- FBR = (NRr/NR)xaxmgx0.3(Braking Ratio)
- FBF = (NFr/NF)xaxmgx0.7(Braking Ratio)

Accelerating and Cornering

To calculate the forces on the contact patch during Accelerating and Cornering we have divided the case into two half first we will calculate forces on the contact patch during pure accelerating and then we will calculate forces on the contact patch during pure cornering.

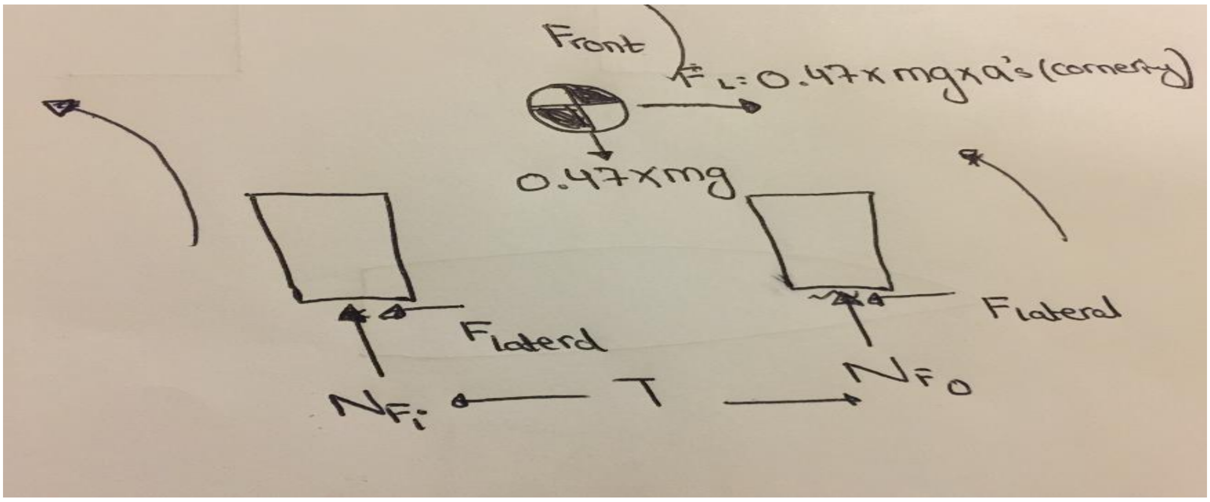
The forces on contact patch during acceleration will be calculated in the same way as they were calculated previously.

Therefore we get,

NR = mgk2/L + Fh/L

NF = mgk1/L – Fh/L

As shown in the figure (5) we can observe that the lateral forces are acting at the contact patch in x-direction and centrifugal force is acting at CG in the opposite direction because of Inertia.



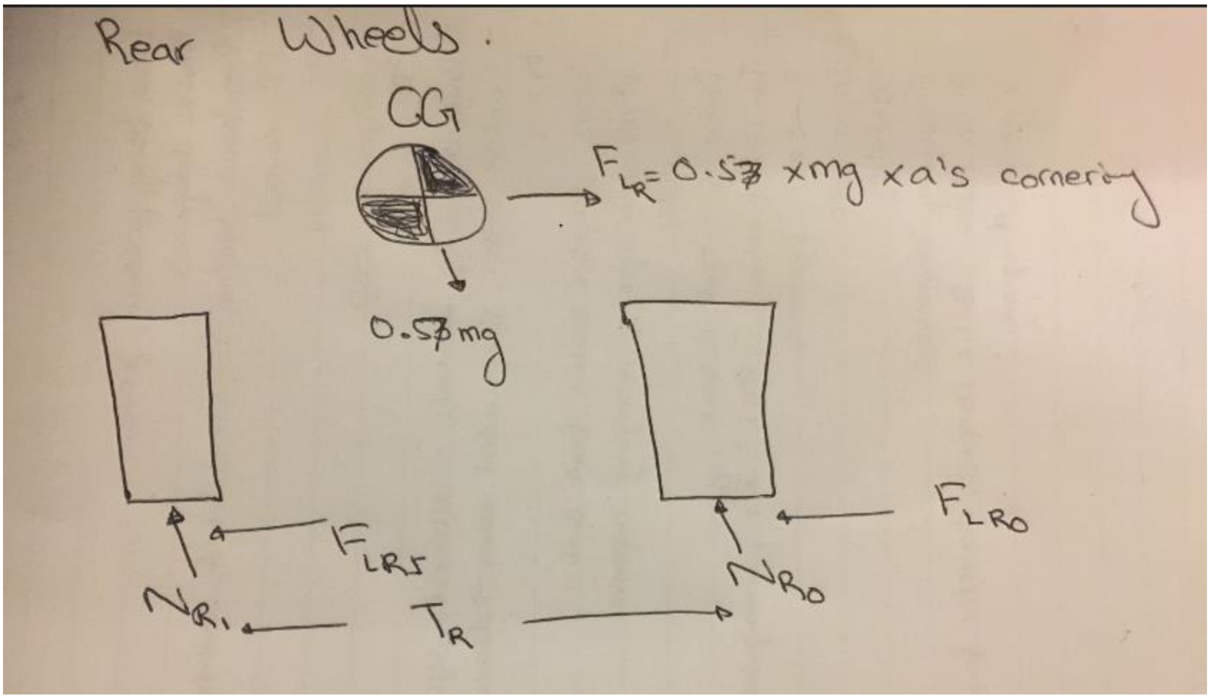
Sum of all the forces In the vertical direction

NFi + NFo =0.47 mg

Sum of all the moments about contact patch, _Normal Force In the Front Tyres_

- NFI = NF/2 – Fc x h/T
- NFO = NF/2 + Fc x h/T

Similarly we carring out the calculations in the same way for rear wheels and we get,



Normal Forces In the Rear Tyres

- NRI = NR/2 – Fc x h/Tr
- NRO=NR/2 + Fc x h/Tr

Braking and Cornering

We calculated all the forces during braking and cornering in the same as we did for acceleration and cornering.

Bearing Life Analysis

The individual life of a rolling bearing is expressed as the number of revolutions or the number of operating hours or kilometers at a given speed that the bearing is capable of enduring before the first sign of metal fatigue (spalling) occurs on a raceway of the inner or outer ring or a rolling element.

Due to the statistical nature of bearing life, it must be pointed out that the observed time to failure of an individual bearing mounted in an application can be related to its rated life only if the failure probability, of that particular bearing, can be determined in relation to the general population of bearings running under similar conditions. For instance, if a bearing failure is observed in a bearing fan application counting a total of two hundred mounted bearings working under similar conditions, this represent a failure probability of just 0,5%, thus a reliability for the installed application of 99,5%.

Several investigations performed throughout the years regarding the failures of bearings used in a variety of applications have shown that in a very large population (several million bearings), the observed failures are a relatively rare event and not directly related to typical raceway spalling. This shows that the design guidelines based on 90% reliability and the use of static and dynamic safety factors can lead to robust bearing solutions.

Therefore to calculate the life of a Bearing we will use this formula,

L = KrLR(C/FeKa)^3.33

Where,

Kr = Relability Factor(1)

LR = life corresponding to rated capacity (10^6 revolutions)

C= Dynamic Load Rating(13.7 kN)

Fe = Equivalent Load

Ka = Shocking Load Factor(3)

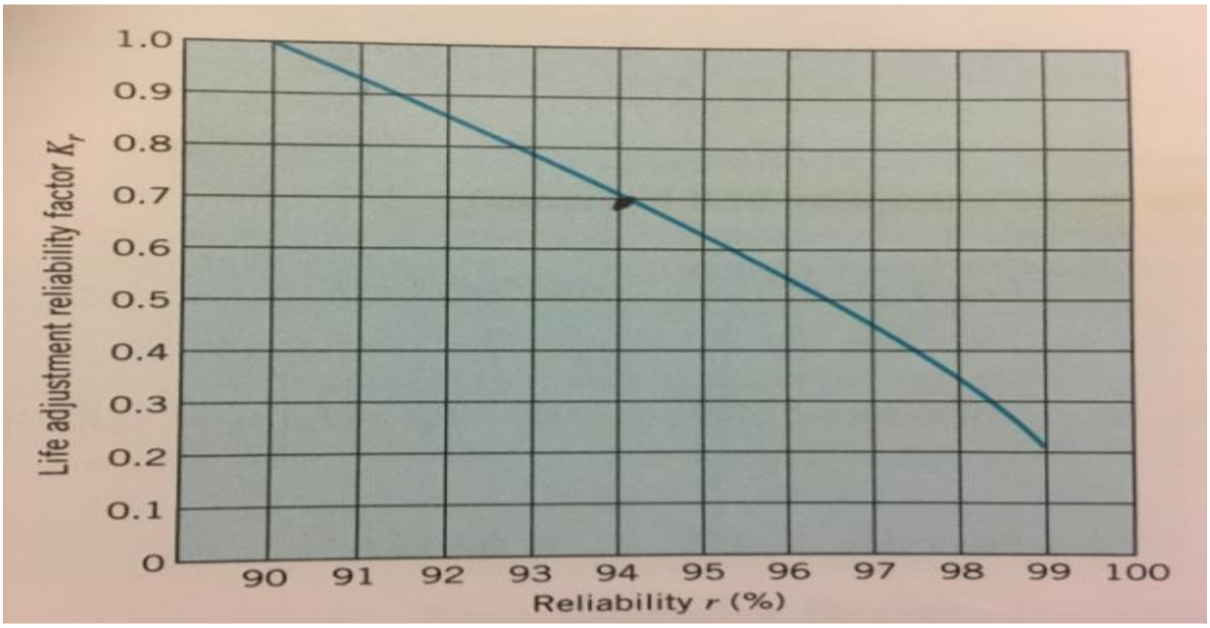
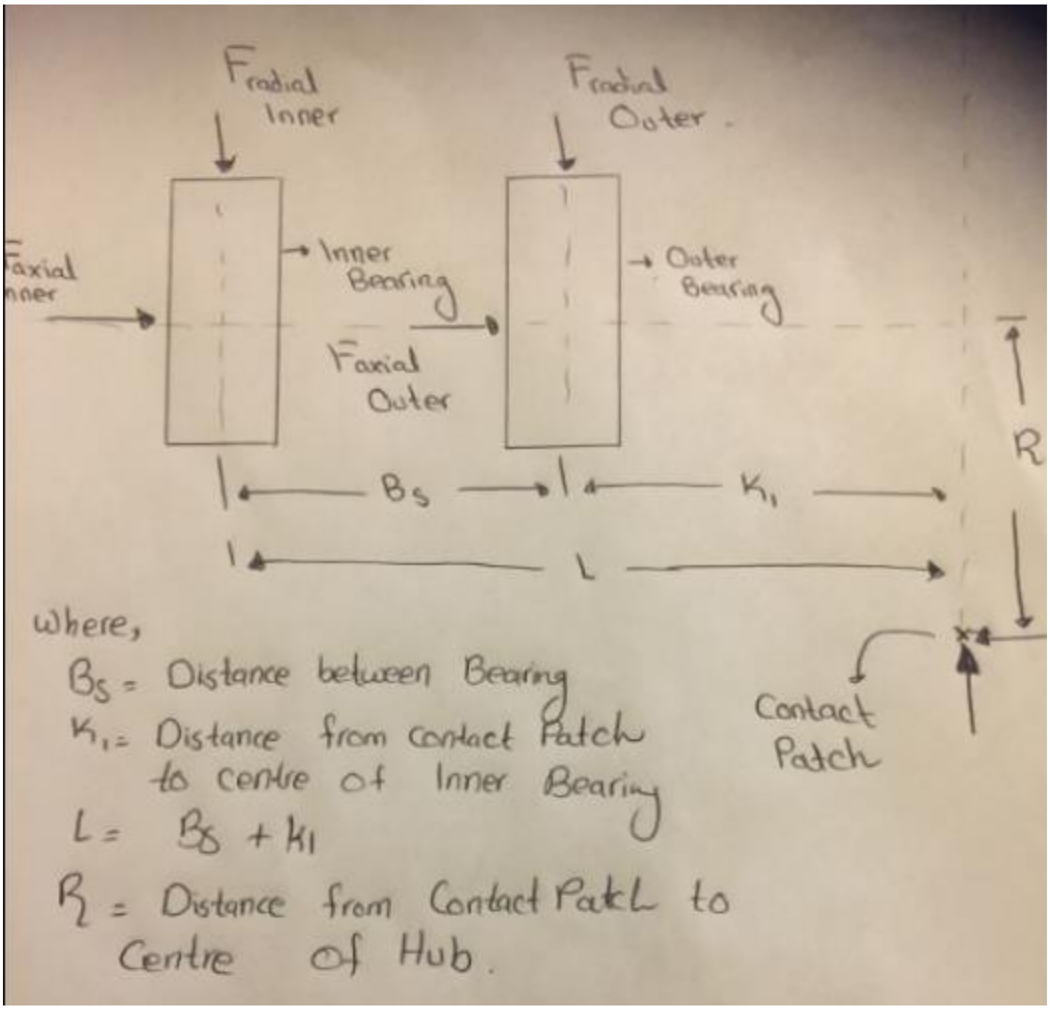


TABLE 14.3 Application Factors K_a

Type of Application	Ball Bearing	Roller Bearing
Uniform load, no impact	1.0	1.0
Gearing	1.0–1.3	1.0
Light impact	1.2–1.5	1.0–1.1
Moderate impact	1.5–2.0	1.1–1.5
Heavy impact	2.0–3.0	1.5–2.0

Bearings Free Body Diagram



Sum of Forces In the Vertical direction

Fri + Fro = N

Sum of Forces In the Horizontal direction

Fai + Fao = Flateral

Taking moments about the centre of Inner Bearing(anti clockwise positive),

In Bearings Lateral Force is Axial Force and Normal Force is Radial Force

-FlateralxR +NxL-FroxBs= 0

Fro= NxL – FlateralxR/Bs

Fri= Flateral – Fro

Fai = Fa/2 Fao = Fa/2

Now calculating Equivalent Load equations taken from SKF website,

Single bearings and bearing pairs arranged in tandem:

$F_a/F_r \leq e \rightarrow P = F_r$

F_a/F_r > $e \rightarrow P = X F_r + Y F_a$

Where,

table 1 - Calculation factors for deep groove ball bearings

	Single row and double row bearings			Single row bearings					
	Normal clearance			C3 clearance			C4 clearance		
$f_0 F_a/C_0$	e	X	Y	e	X	Y	e	X	Y
0,172	0,19	0,56	2,3	0,29	0,46	1,88	0,38	0,44	1,47
0,345	0,22	0,56	1,99	0,32	0,46	1,71	0,4	0,44	1,4
0,689	0,26	0,56	1,71	0,36	0,46	1,52	0,43	0,44	1,3
1,03	0,28	0,56	1,55	0,38	0,46	1,41	0,46	0,44	1,23
1,38	0,3	0,56	1,45	0,4	0,46	1,34	0,47	0,44	1,19
2,07	0,34	0,56	1,31	0,44	0,46	1,23	0,5	0,44	1,12
3,45	0,38	0,56	1,15	0,49	0,46	1,1	0,55	0,44	1,02
5,17	0,42	0,56	1,04	0,54	0,46	1,01	0,56	0,44	1
6,89	0,44	0,56	1	0,54	0,46	1	0,56	0,44	1

Fai/Co = Number/8900 = 0.1524

e= 0.19

Therefore,

X= 0.56 & Y=2.3

Fai/Fri = 0.064

Fai/Fri > e

Calculating Equivalent load and Using eq1

Now putting this value of Fe in our 90% life equation

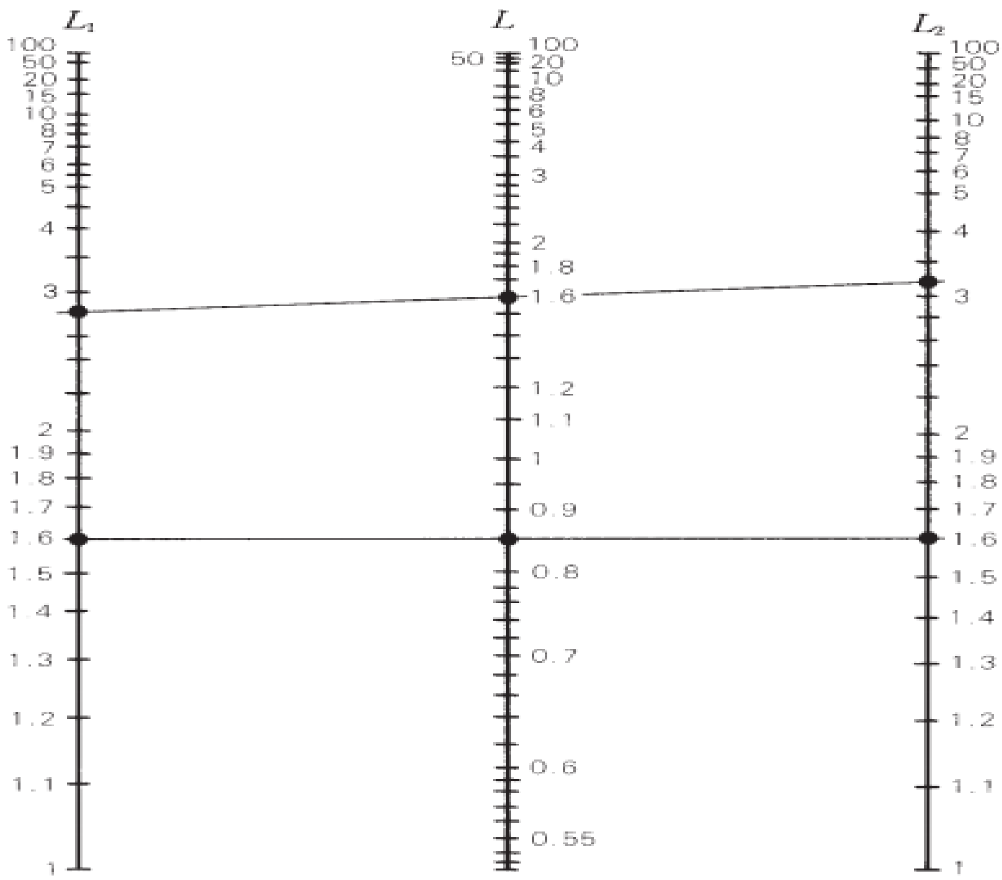
L= 3700 km

Now we will be calculating the life for Outer Bearing using the same equations and procedure,

We get

L =3500 km

Now we will calculate the equivalent life of Bearings using this graph or equation,



We get a life of L = 1900 km

Again we will calculate the equivalent life of Bearings for the rear wheels using the same graph, We get an Equivalent life of L = 1000 km for rear wheels

For the Front wheels we will calculate the life of Fronts, Inner and Outer Bearings

Therefore we get an equivalent life of L = 1100 km for the Front Bearing,

Now finally we will calculate the average life of Bearing using the same graph we get,

One bearing could be failed after 560 km.

But in reality the equivalent of bearings are going to be much higher than this because we calculated the bearing during pure cornering which means bearing are experiencing high amount of axial and Vertical load but in reality we are not going have this situation all the time while driving.

Hence, it’s also proven that Deep Groove Ball Bearing are capable of Bearing all the load and have a good overall life compared to their design and cost.

Market Research

Design Review

- Design Review is mainly about reviewing parts designed by other teams this year. So that the teams can get more views for their part and change accordingly to make their part work more efficient and safe way.

Tire Changer

Items checked*	Corrections required*
Swing arm	Increase the diameter of the tube to increase the safety factor of the swinging arm otherwise rethink the material being used as the safety factor is less than 2
Steel bead breaker	Use a plastic protector otherwise it may damage the wheel
Impact driver	Not enough torque to rotate the table
Table	To make it more stronger increase the thickness of table or add more vertical arms
Duck head	Too big for its own use, it may damage the tyre make it smaller so that it is easier to remove the tire
Impact driver	Output torque could be too strong. Recalculate and determine if impact driver output is appropriate for application
Impact driver coupling	Possibly use a hex shaft to transmit torque between impact driver and wheel clamp assembly
Bead breaker	Breaker force needs to be quantified to avoid toppling of structure
Ease of use	Current design to complex and difficult for a single person to operate.

Accumulator lifter

Items checked*	Corrections required*
Trolley	Make sure calculations are done for toppling and use appropriate counter-weights. As when the accumulator is rotated the centre of mass of the system would change.

Items checked*	Corrections required*
Supports	Do the appropriate calculations to find out the exact positon to place the supports. (sideways/front &back)
Trolley Legs	Buckling could occur for the current system try to use a stronger or a thicker square tube.

A-arms

Items checked*	Corrections required*
A-arm	Clearance between the spherical housing and the Uprights due to alignment problems.
	Increasing the diameter of tube for better FEA results
	Cutting of material is done in shape of two triangles with sharp edges due to which the stress is acting on one point more sensible way is required to reduce the weight otherwise it may generate a crack on stress concentrated areas
A-arm (FEA)	The FEA is done in a wrong way, it's better to do FEA while using the two assemblies of A-arms to get more appropriate results.
A-arm (FEA)	The safety factor is 1.2 which is not good enough especially when the mesh type being used is also ordinary and the mesh size is also big. It's obvious that safety factor will decrease further if appropriate mesh size and type is being used.
Tests Jigs	All essential test jigs needs to be organized
Spherical Housing	Make sure when removing material, edges needs to be replace by fillets

Brakes

Items checked	Corrections required
Bleed screw seat	The drawing was lacking for the bleed screw seat and this needs to be completed as soon as possible due to time factor
Rear calliper	As the rear calliper is a key component of the brakes, the required factor of safety needs to be confirmed
Piston return seal	Guaranteed suitable stiffness and elasticity for the piston retraction must be ensured

External reviews

Reviews were exchanged by the Machine Design Students who were appointed for making other parts of the car. The following Design Documentation Verification are the forms which were given by other groups and appropriate actions were taken for the correction to make our part work better.

DESIGN DOCUMENTATION VERIFICATION (CHECKING) RECORD

Management System for Engineering Education
MaSEE

Course MACHINE DESIGN Assignment title Uprights Document/Calculation Originator

Document (calculation) title Verifier's (Checker's) Name Date 21/05/2017

Items checked*	Corrections required*	Description of corrective action taken**	Corrective action taken by (signature)**

DESIGN DOCUMENTATION VERIFICATION (CHECKING) RECORD

Management System for Engineering Education
MaSEE

Course MACHINE DESIGN Assignment title Uprights Document/Calculation Originator

Document (calculation) title Verifier's (Checker's) Name Date 21/05/2017

Items checked*	Corrections required*	Description of corrective action taken**	Corrective action taken by (signature)**
Clevis	The material of clevis was changed from aluminium 7075 to steel 4130	The material of clevis was changed from aluminium 7075 to steel 4130	
Clevis	Rethink the design of the clevis to increase the strength	To increase the strength of clevis gusset was made which was welded on the sides of clevis which increased the strength of clevis	
Calliper mount holes	Increase the hole size to reduce Stress	Hole size increased to 8.3mm	

All design documentation checked and requested corrections satisfactorily incorporated ______________________ Date ________

(Signature of Verifier/Checker)

** Completed by the verifier. The form should not be signed off / closed out by the verifier until the verifier is satisfied that the appropriate corrections have been made.*

DESIGN DOCUMENTATION VERIFICATION (CHECKING) RECORD

Management System for Engineering Education
MaSEE

Course Machine Design Assignment title Uprights Document/Calculation Originator

Document (calculation) title Verifier's (Checker's) Name Date 21/05/2017

Items checked*	Corrections required*	Description of corrective action taken**	Corrective action taken by (signature)**
Brake mount holes	The clearance between the brake mount holes and the fillet on the edge of an upright as the distance is not enough and it may result in collision of calliper and the upright	Brake calliper mounts were rotated in order to get enough space for the calliper and also to have at least 10mm clearance from the centre of whole to the fillet of the upright	
Clevis	Rethink the design of the clevis to increase the strength	To increase the strength of clevis gusset was made which was welded on the sides of clevis which increased the strength of clevis	
Bolts	The bolt lengths had to be checked as well so they could make sure that you could fit a wrench into the uprights to be able to do up the bolts. An O Wrench is the best option but a C wrench is acceptable.	The Bolts were checked and replaced by the appropriate ones. After putting Bolts in the assembly it was checked there was enough clearance for wrench and no hindrance	

- External reviews not only help in discovering possibility flaws in the design but also it helps you to make the changes required which may lead you to your final design. During the design phase several reviews were taken which helped us improve our model. These reviews were taken from alumni, dynamics leader. All reviews are mentioned in the table below and also the actions that were taken to fix the problems and get better result.

External reviews related to design

Items checked*	**Corrections required***	**Action taken***
Bolts	Make sure there is enough clearance with a-arm	Low profile bolt were used
Clevis	Reconsider the material of clevis keeping cost in mind	The material of clevis was changed from aluminium 7075 to steel 4130
Upright	Reduce sharp edges	Fillets were done on edges where required after checking the result of FEA
Bolts	Reconsider the size of bolt used in clevis so that it may have enough clearance	The whole size was reduced to m5 and the central distance of bolts were 25mm giving the required clearance
Clevis	Increase the strength of clevis	Different options were considered finally to overcome this problem Gussets were designed which will be welded to clevis to increase the strength
Upright	Relocate The position of brake calliper mounts with enough clearance with the fillet of an upright	Brake calliper mounts were rotated in order to get enough space for the calliper and also to have at least 10mm clearance from the centre of whole to the fillet of the upright
Calliper mount holes	Increase the hole size to reduce Stress	Hole size increased to 8.3mm
Upright	Optimize the design to reduce the weight of the upright	Cutting of material was done after knowing the area where stress was less
Upright	Steering rod hole size	Steering rod hole size was changed to 9.53mm
Upright	Speed sensors are ignored	M5 hole was done for installation of speed sensor

External reviews related to FEA

Items checked*	Corrections required*	Action taken*
Upright (FEA)	Use of remote displacement in FEA.	Instead of remote displacement cylindrical displacement was used
Upright (FEA)	Wrong coordinate system being used	The coordinate systems were rechecked and corrected later and it was seen the coordinates system was wrong as all the origins were not the same in cad so the origins were mated to the car origin
Upright (FEA)	Wrong coordinates of forces being used for brake force making the force to be vertical in braking and cornering scenario	The correct coordinates were corrected as a result force acted tangential than vertical
Upright (FEA)	Mesh size and type being used is too big and general	Mesh size was reduced several times until we started to get same res

External review related to 2D Drawing

Items checked*	Corrections required*	Action taken*
Clevis	Proper drawing needed showing bends properly	Drawing was done which consisted of a flatten view showing bends line and also a normal view to make it easy for manufacture to understand

Reflection

The overall performance of the design was considered very precisely throughout the upright getting designed and was closely tested, optimised through finite element analysis. There were some very important considerations made along our journey of designing upright which were material choices, bearing types and appropriate fasteners to choose from which would further suit our application. We have accessed many resources by consulting some industry professionals, current and past team members throughout our designing process. As a result we came up with an improved design by polishing our knowledge about uprights.

These principles of design process stated above gave us a relatively clear path to follow and hence helped us to plan our timeline. This design process further help us to get significant enhancements over the last year's design and was reinforced through FEA results.

Some of the aspects that this project has taught us include the importance of finalising the sections that make up design constraints as early as possible. It was observed that changing the bearings once most of the design had been completed, negatively impacted not only the overall design, and applied strain on the team to get the best result possible, it also limited the bearing choice significantly due to restriction implemented by other parts. Whilst the bearing choice that was made was ultimately ideal for this purpose, finalising it earlier would have led to more time being spent on the design of the upright itself. The calculations and free body diagrams were also of utmost important to get right the first time around, as it was seen that if this is not done correctly at the beginning the upright, which has been designed to withstand those maximum forces and resulting stresses may no longer be sufficient.

Originally when producing an FEA (finite element analysis) using ANSYS, we had very little knowledge and little teaching in the process but understood the basics of it. But because of this from our calculations being all about the contact patch of the wheel, we assumed that all forces input into ANSYS were about the wheel base. From further inspection, we realised that this was not the case when it came to bearings and force acting in the Z direction (forces applied by acceleration or braking). Instead of this force acting as a remote displacement alongside the X and Y forces (turning and normal force) at the contact patch, a direct bearing force is applied directly on the bearing due to the way they distribute the force.

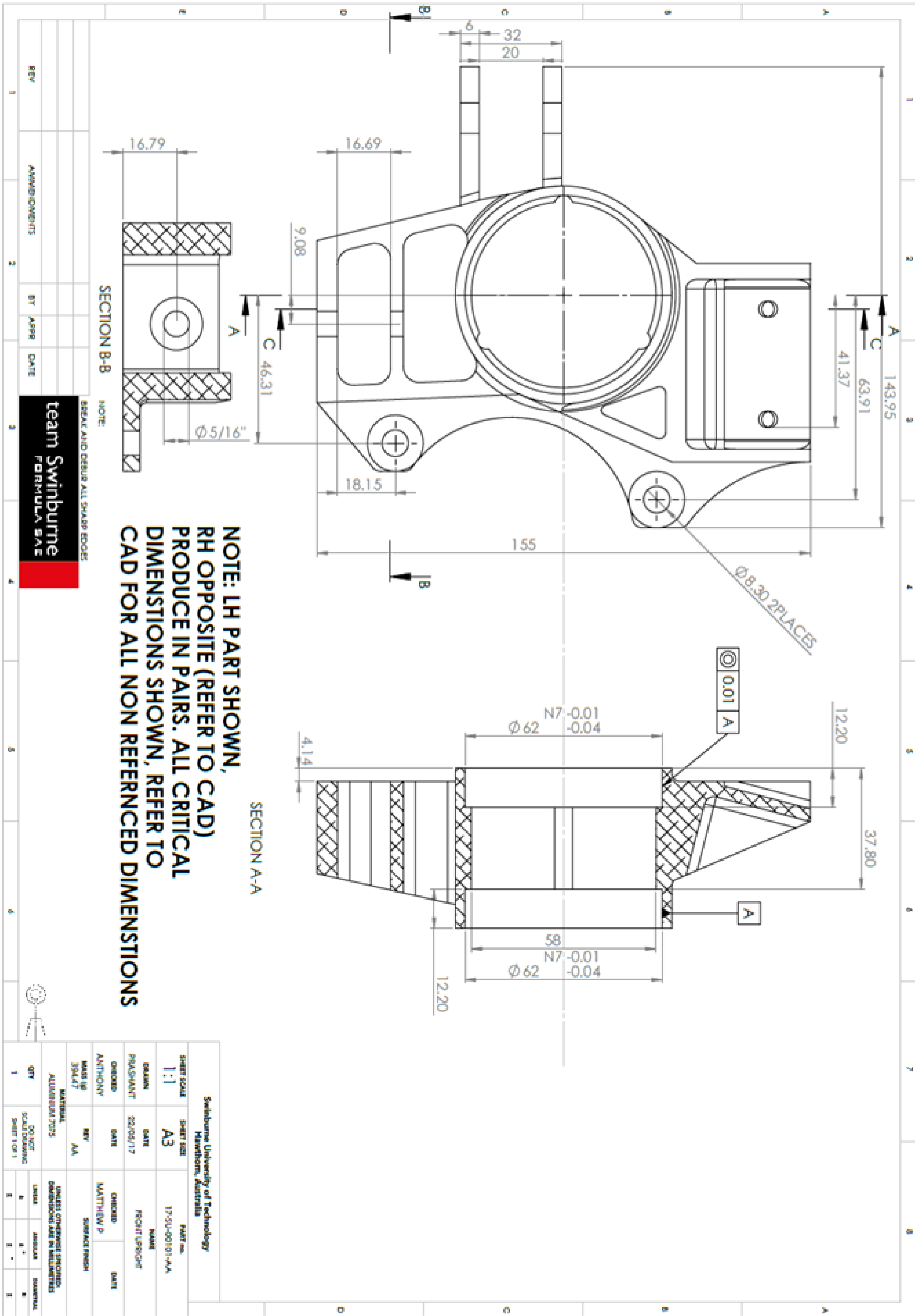
Another slight problem that we originally faced with FEAs was the force applied to the brake mount. At first this was applied in the position directly between the two mounting points acting vertically, although this was close, it wasn't fully correct as the force was acting from the brake disk which would induce a slight moment on the mount. We changed this by measuring the distance between the mount and the brake disk, then within ANSYS offset the force by this amount. This slight change that changed the deflection by a fair amount in the mount, going from roughly 0.05mm to 0.25mm deflection, although this amount is perfectly normal as the mount has a 1mm tolerance allowed for it to bend.

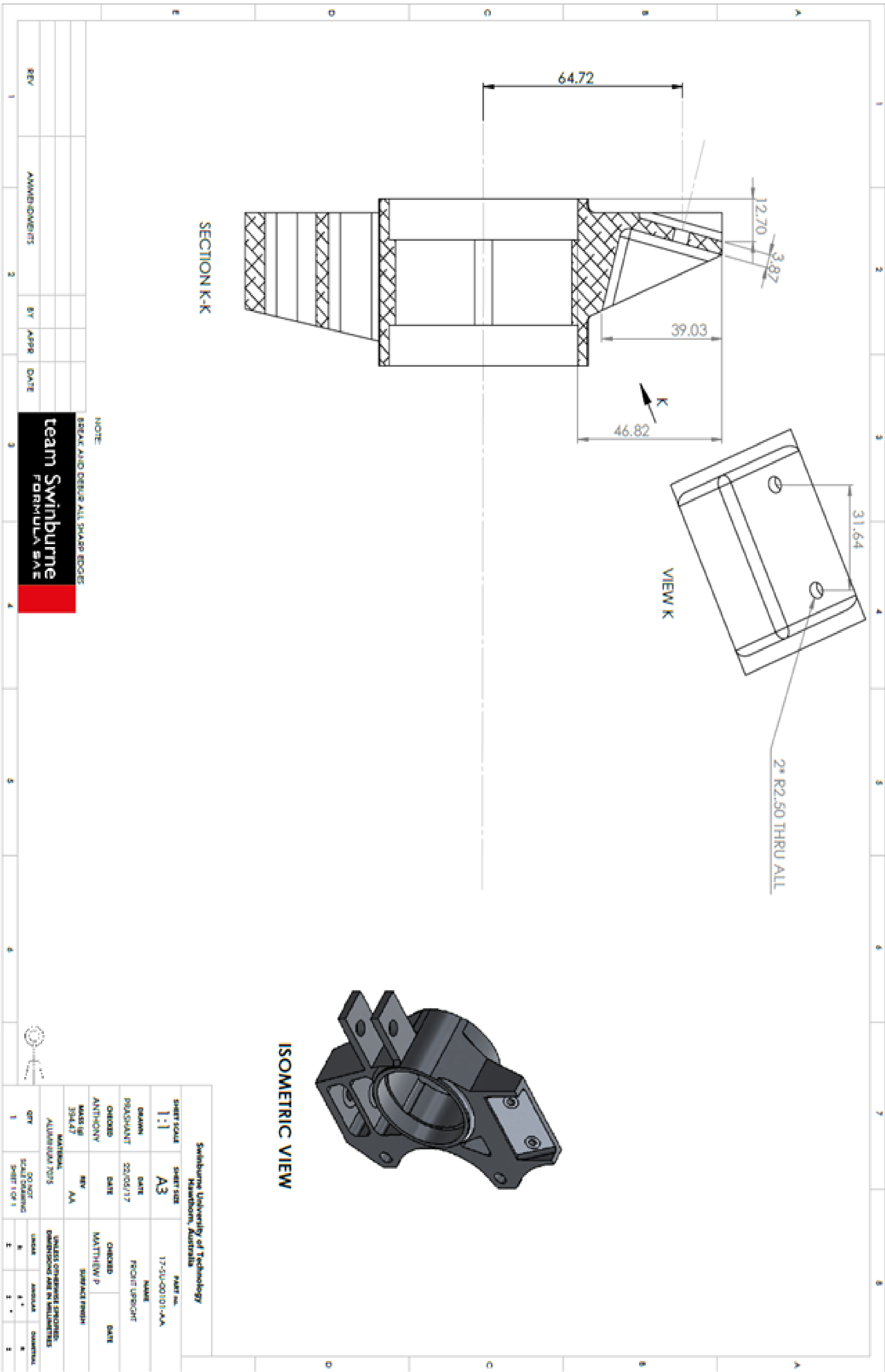
If this project was to be undertaken again better time management strategies would be put in place in order to not fall behind and the workload would be distributed more evenly. Using these strategies would allow for better flow between the design stages and allows for multiple people to work on a given task at the same time.

System designed steps

a. Heat Upright in oven to expand the bearing housing
b. Place a single bearing in a freezer to contract the structure. This allows for an easier fit when pressing it into the upright
c. Due to the bearing being pre sealed and greased, we do not need to grease it up, and all that needs to be done is to press the bearing into position.
d. Press frozen bearing into housing on the outside face of the upright.
e. Press Hub into bearing.
f. Press remaining bearing into A-Arm side of upright.
g. Attach the Clevis to the A-Arms before attaching it to the upright; this is due to the bolt position for connecting it.
h. Once the clevis is on the A-Arms, connect the upright to the lower A-Arms, then partially connect it to the upper A-Arms, this is so you can adjust the shims to the desired wheel camber.
i. Once the shims are at the desired amount, tighten it all up.
j. Now you have a clevis attached to the A-Arms with a working Hub.

Front upright

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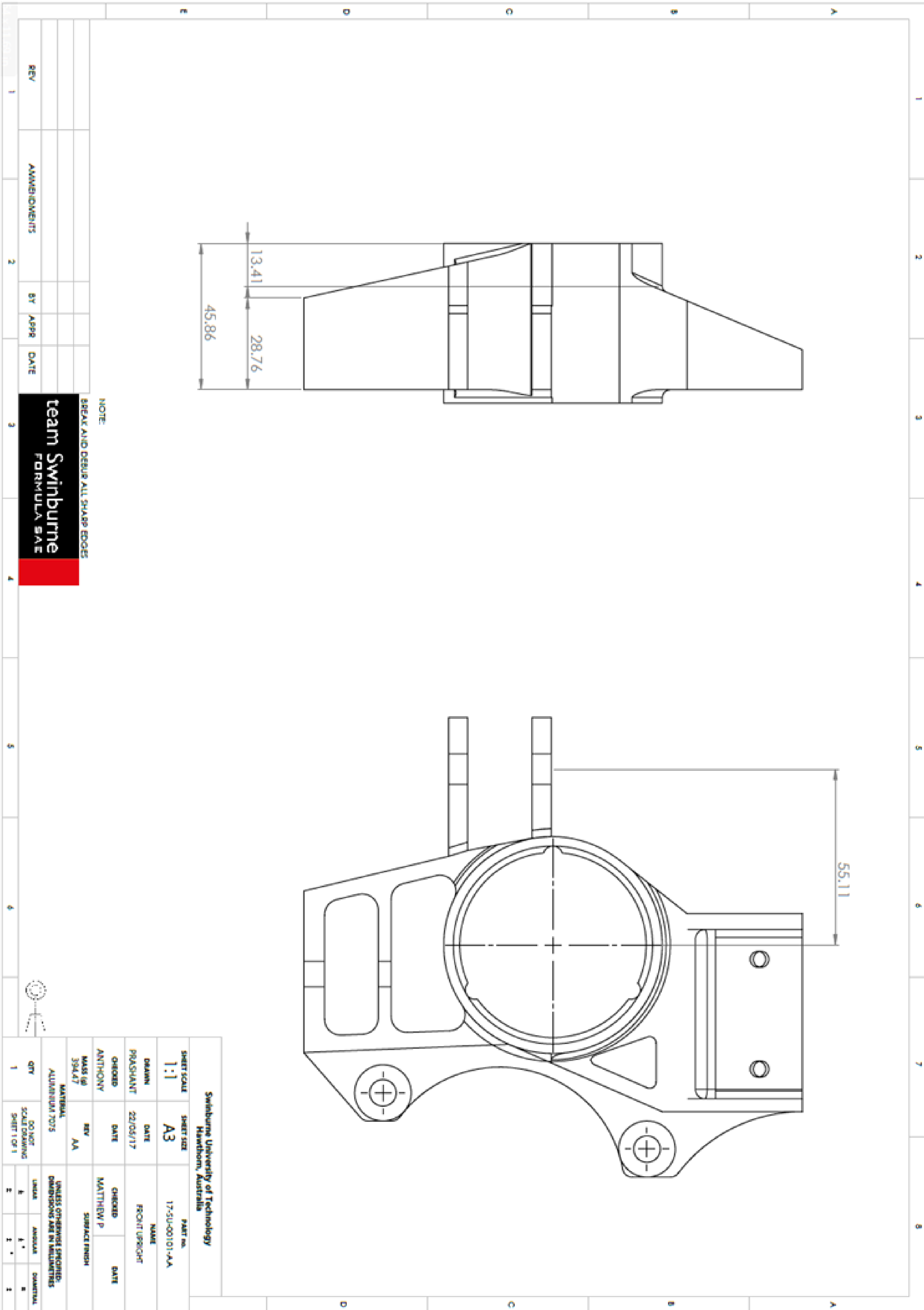
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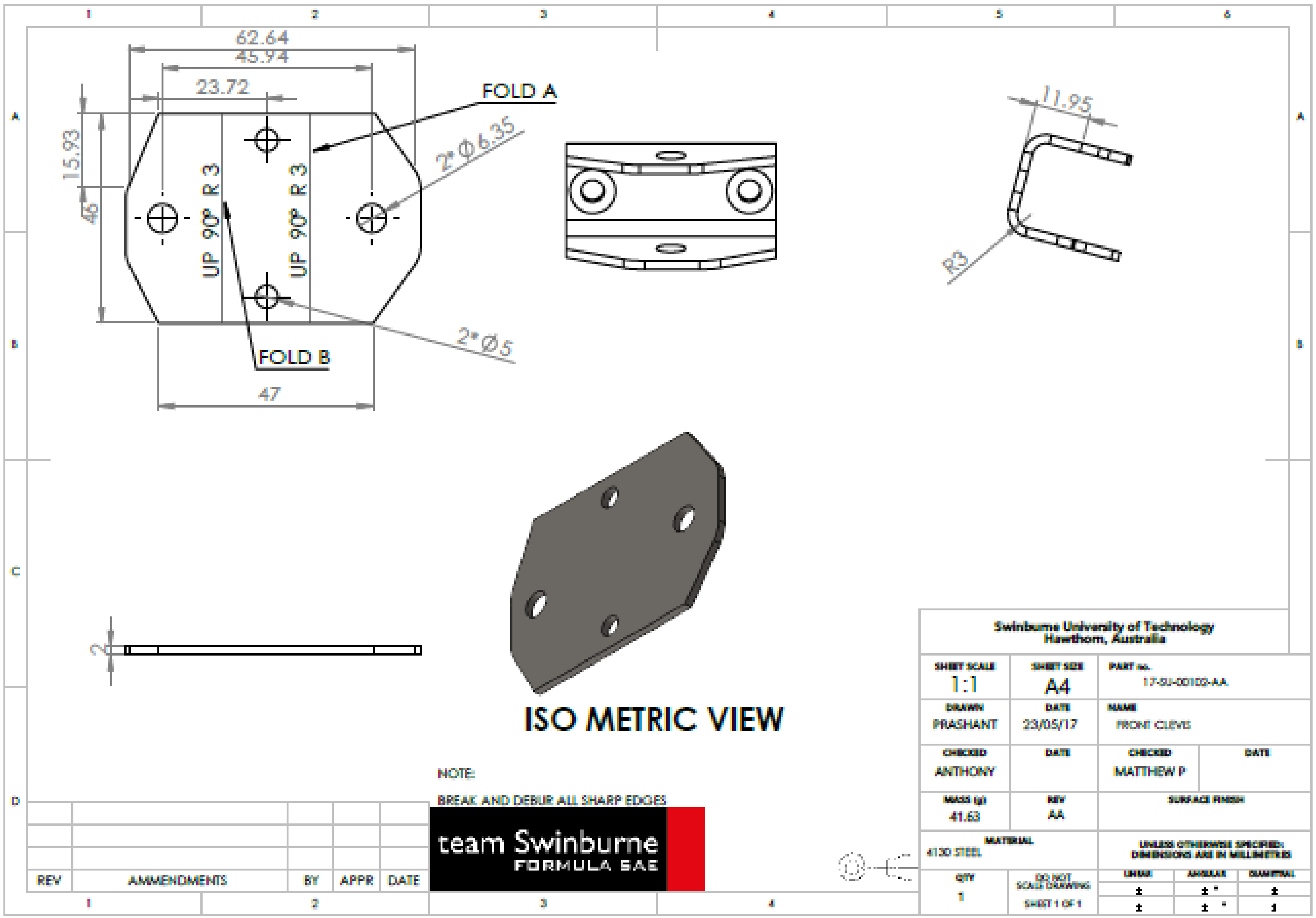
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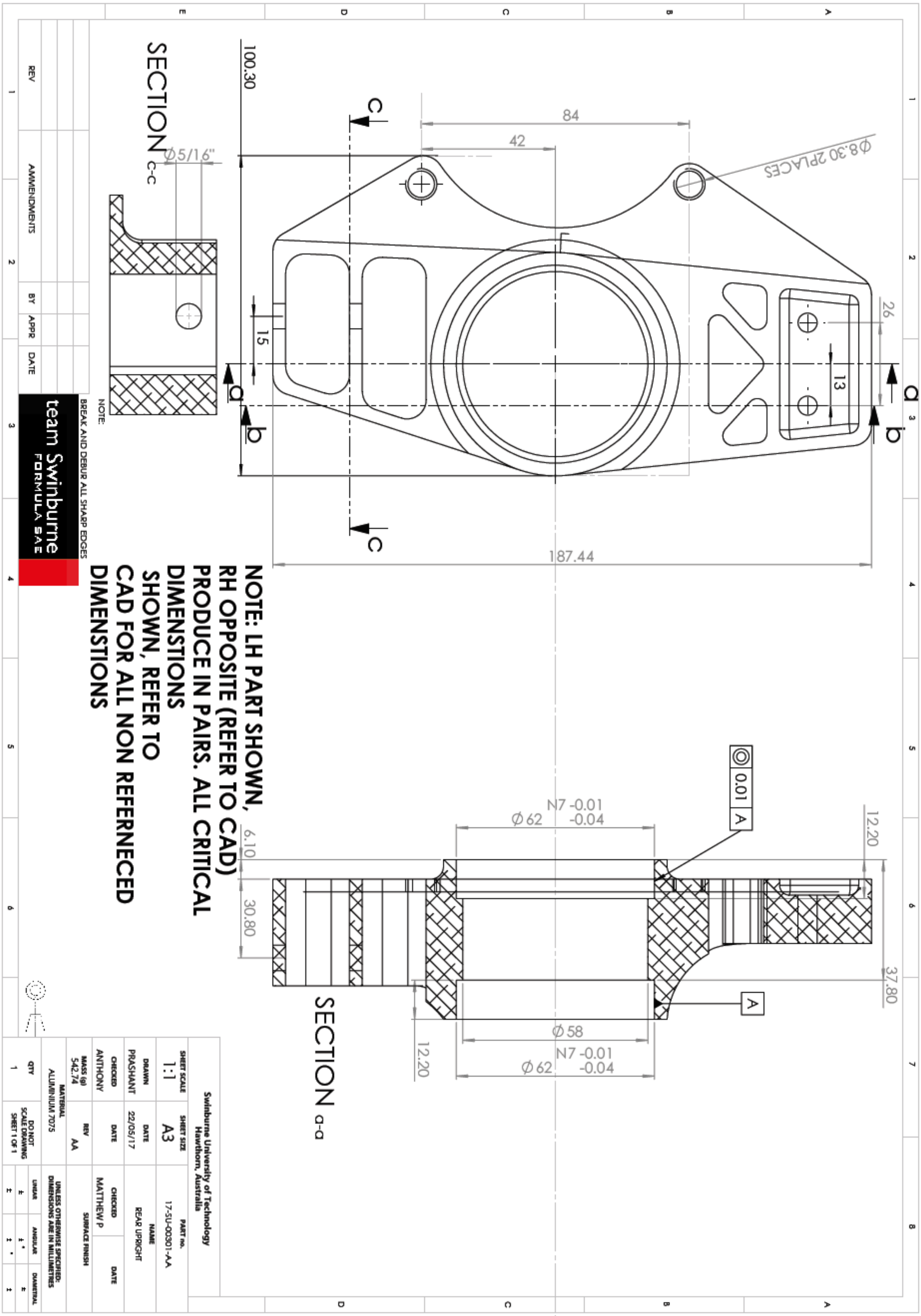
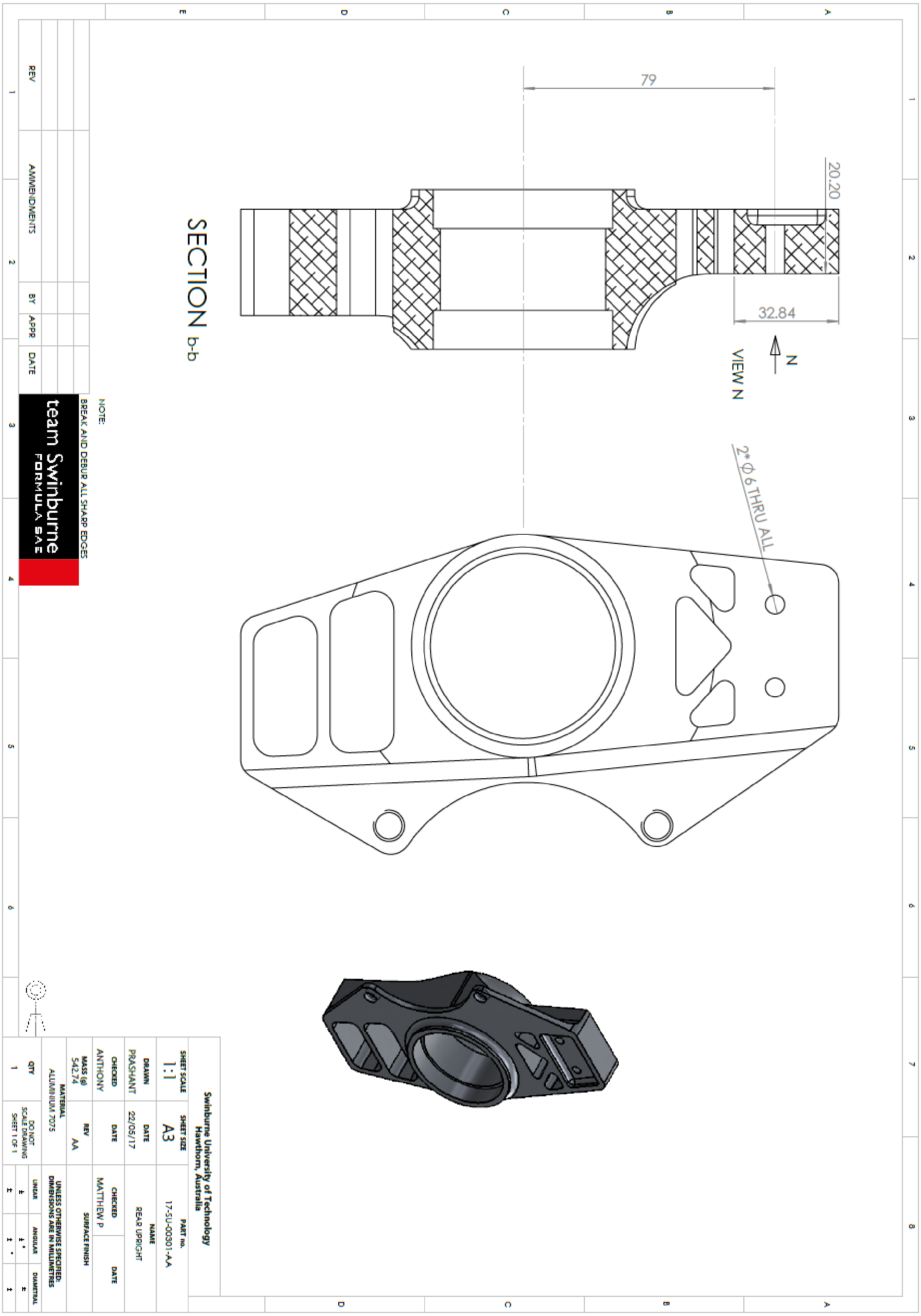
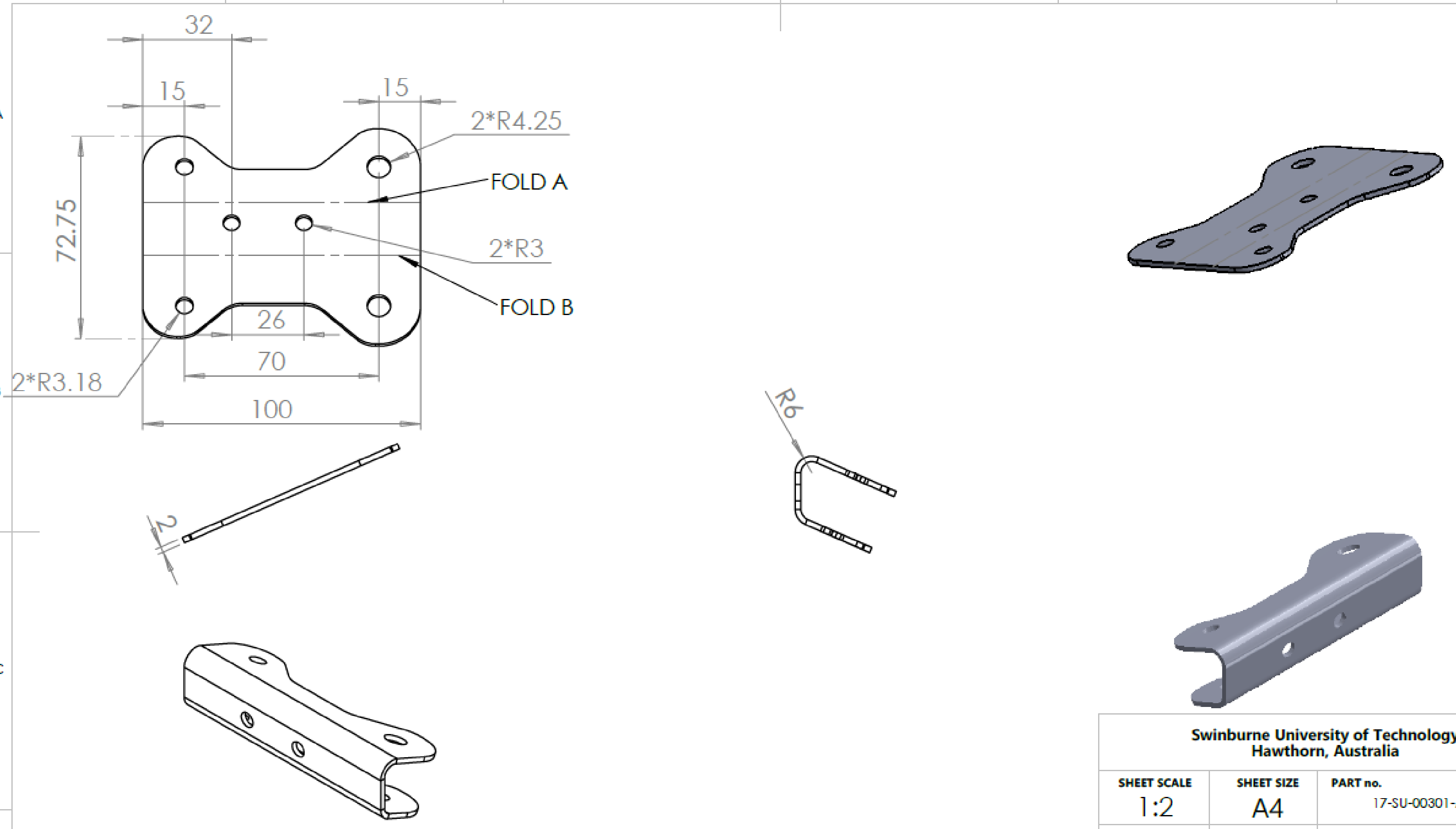
MATERIAL
4130 STEEL
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETRES
QTY
1
DO NOT
SCALE DRAWING
SHEET 1 OF 1
LINEAR
ANGULAR
DIAMETRAL

Rear Upright




79
20.20
32.84
N
VIEW N
SECTION b-b
2*Φ6 THRU ALL
REV
AMMENDMENTS
BY
APPR
DATE
NOTE:
BREAK AND DEBUR ALL SHARP EDGES
team Swinburne
FORMULA SAE
Swinburne University of Technology
Hawthorn, Australia
SHEET SCALE
1:1
SHEET SIZE
A3
PART no.
17-SU-00301-AA
DRAWN
PRASHANT
DATE
22/05/17
NAME
REAR UPRIGHT
CHECKED
ANTHONY
DATE
CHECKED
MATTHEW P
DATE
MASS (g)
542.74
REV
AA
SURFACE FINISH
MATERIAL
ALUMINIUM 7075
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETRES
QTY
1
DO NOT
SCALE DRAWING
SHEET 1 OF 1
LINEAR
ANGULAR
DIAMETRAL



NOTE:
BREAK AND DEBUR ALL SHARP EDGES

REV	AMMENDMENTS	BY	APPR	DATE

team Swinburne
FORMULA SAE

Swinburne University of Technology
Hawthorn, Australia

SHEET SCALE	SHEET SIZE	PART no.	
1:2	A4	17-SU-00301-AI	
DRAWN	DATE	NAME	
PRASHANT	22/05/17	REAR CLEVIS	
CHECKED	DATE	CHECKED	DATE
ANTHONY		MATTHEW P	
MASS (g)	REV	SURFACE FINISH	
100.87	AI		
MATERIAL		UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETRES	
4130 STEEL			
QTY	DO NOT SCALE DRAWING	LINEAR / ANGULAR / DIAMETRAL	
1	SHEET 1 OF 1	± / ± ° / ±	

Rear Upright (shim)