University of Southern Queensland

School of Engineering

Conceptual Design of an Ultra High-Performance and Durable Wheelchair for Recreational Outdoor use

A dissertation submitted by

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(This is a 2-unit research project in Bachelor of Engineering Honours Program)

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ABSTRACT

Recently, there has been a significant rise in inclusivity, including for the disabled. A significant aspect of this can be said to be the disabled in sports, with avenues such as the Paralympics, with numerous differing sports on offer with the aim of including the disabled such that they can play in their own 'top tier' of sports. This, however, begs the question of how society can be increasingly more inclusive of the disabled, in this case, within sports. An avenue for this is enabling equipment, such as wheelchairs and other pieces of equipment the disabled use, which can be modified so that they become safer and more effective for use in respective sports. In this case, this project aims to design a conceptual product that acts as an enabling device for the disabled, specifically the paraplegic, so they have a similar experience to what the non-disabled would have when participating in recreational mountain biking. In saying this, the needs of the paraplegic in this area have been studied, as well as the problems that the disabled encounter when participating in recreational sports. This knowledge, combined with thorough background research and Finite Element Analysis using Autodesk Inventor, has produced a product that not only replicates the experience within reason but is safe, reasonably sustainable, user-friendly, and cost-effective.

From research, multiple concepts were considered to get a basic understanding of what would be required from a design standpoint such that the concept delivers equally or better to concepts currently on the market. To begin, two initial sub-system combinations were made, these being a mixture of motors, wheels, braking systems and other componentry that would be switched or replaced to reduce costs. Calculations were undertaken to determine what would be required of a motor and braking system, as well as what is required from suspension componentry and other componentry relating to concept performance, safety, user-friendliness, cost-effectiveness and sustainability. FEA was undertaken through Autodesk Inventor to determine the validity of self-designed chassis and suspension components, allowing an articulating front suspension system capable of transversing more considerable obstacles than what is seen on most aMTBs. The analysis, paired with in-depth research on concepts currently on the market and materials, led to many design decisions that led to the final design paired with the materials required for the concept to work sufficiently. Cost analysis was also undertaken to gain insight into the cost versus

performance capabilities which then assist in making the design decisions for the final concept, with the chosen sub-systems.

From the methodology, a final concept could be designed, with a mixture of both initial concepts, these being both performance orientated, and cost orientated to give a resulting product that had the capability of both areas. This led to a final product that was on-par with concepts currently on the market, while only being a fraction of the price. Albeit testing of the main two components was unsuccessful, the materials used can be backed via research and as such is sufficient. This was paired with off-the-market products that were used and underwent a final cost analysis to determine the final approximate price of the concept, however, it is worth nothing that this final price is an approximation, and a physical version once manufactured and built may be less or more expensive depending on several variables. The overall weight of the concept can also be said to be at or under the 45kg assumed. Therefore, this makes all calculations accurate and proves that the chassis with the sub-system combination will work sufficiently. A lot of information throughout this process was learnt about the ductility of metals and the different structural components that can improve safety within vehicles.

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GLOSSARY

AD	= After Date
AL6061	= Aluminium Alloy 6061
aMTB	=Adaptive Mountain Bike
Approx.	= Approximately
AUD	= Australian Dollars
CAD	= Computer-Aided Design
Chromoly	= 4130 Chrome Moly
eMTB	= Electric Mountain Bike
FEA	= Finite Element Analysis
FoS	= Factor of Safety
MTB	= Mountain Bike
NDIS	= National Disability Insurance Scheme
USA	= United States of America
USD	= United States Dollars
VM Stress	= Von Mises Stress

CHAPTER 1 INTRODUCTION

It is known that in the present day, there has been a large rise in emphasising inclusivity, this being including people no matter what race, gender, religious belief, or other factor. (Lee, 2023) This includes people who are disabled, physically and/or mentally. This therefore begs the question; how can we be more inclusive of the physically disabled in competitive and recreational sports? Numerous avenues exist for the disabled in terms of participating in sports, with large competitive events such as the Paralympics being one of them. With numerous inclusive sports on offer, this allows the disabled to compete at the highest level, but also with others within the disabled community at their same or similar level. Examples of sports offered in the Paralympics include Wheelchair basketball, Wheelchair Curling, and many more. (Paralympics Australia, 2024)

So, on the topic of the disabled in sports, it is important to note that to enable the disabled to compete in such sports, additionally, modified equipment is often used. An example of this can be said to be the modified wheelchair, as seen in Paralympic sports such as Wheelchair Basketball and other Wheelchair sports previously mentioned.

Figure 3: Depiction of a modified wheelchair used in Paralympic Sports, Source: (Stinson, 2024)

For this project, the idea is centred around the design of a 'conceptual Ultra-high-performance and durable wheelchair for recreational outdoor use.' Now, before going any further it is important to note that the statement uses the word 'wheelchair,' therefore making the insinuation that the user will only have partial or no mobility when it comes to the use of their legs, however, still the user has use of their arms. In this instance, it can then be said that the user may be partially or completely paraplegic. Therefore, this project will be based upon the assumption that the user is completely paraplegic. When thinking about this statement, there are already several products on the market that meet these requirements, such as Handcycles, and Adaptive Bicycles, which are both used in road and offroad situations, for recreational purposes. (Disability Sports Australia, 2024) However, in saying this, many of these products are expensive and have a long list of both advantages and disadvantages when it comes to comparing them side by side. So, in saying this, it is obvious that just like in most industries, there is always room for improvement and more refinement.

1.1. Project Aims and Objectives

This project aims to produce a conceptual design for an ultra-high-performance and durable wheelchair for recreational outdoor use. This can be thought of as a conceptual product design that acts as an enabler for the otherwise immobile to have a similar recreational experience using the product, as an able-bodied person would using a normal version. In saying this, the design is purely conceptual, and as such no practical testing shall be conducted, nor a prototype built during the design and development process. As the main aim is that of a wheelchair for recreational outdoor use, the assumption can be made that the vehicle must be All-Terrain. However, the main overall objectives for this product include:

Objectives:

- Design and develop a product that meets the performance requirements of an All-Terrain wheelchair-type vehicle tailored towards the paraplegic, using a mixture of FEA and CAD Inventor analysis for further refinements.
- Ensure the product meets consumer safety standards via safety factors from research and ensure the product retains an ‘ultra durable’ nature with a long lifespan.
- Develop an understanding of what is needed from a design perspective for members of the disabled community, specifically those who are paraplegic, to perceive the product as reasonably safe.
- Design the product with the targeted consumer base in mind, such that the product does not become overly expensive, while also being easily used by consumers within day-to-day operation.

- Ensure that the product is designed with consideration taken towards sustainability, such that the product does not have significant impacts on the environment towards the end of its lifecycle.
- Produce a product that can similarly replicate the experience of an able-bodied person on a normal Mountain Bike.

1.2. Chapter Summary

In recent times there has been a large rise in inclusivity, including the disabled. A large aspect of this can be said to be the disabled in sports, with avenues such as the Paralympics, with numerous differing sports on offer with the aim of including the disabled such that they can play in their own ‘top tier’ of sports. This however begs the question of how society can be increasingly more inclusive of the disabled, in this case within sports. An avenue for this in enabling equipment, this being wheelchairs and other pieces of equipment the disabled use that can be modified such that they become safer and more effective for use in respective sports. In this case, this project aims to design a conceptual product that acts as an enabling device for the disabled, specifically the paraplegic, such that they have a similar experience to what the able-bodied would have when participating in recreational mountain biking. In saying this, the needs of the paraplegic in this area have been studied, as well as the problems that the disabled encounter when participating in recreational sports. This knowledge combined with thorough background research and Finite Element Analysis using Autodesk Inventor, has been used to produce a product that not only replicates the experience within reason, but is safe, reasonably sustainable, user-friendly, and cost-effective.

CHAPTER 2 LITERATURE REVIEW

2.1. INTRODUCTION

The following chapter reviews and provides information on the literature surrounding the disabled and more specifically, wheelchairs in professional sports and other key areas which are relevant to the project and crucial for the stages of design.

It is well known in recent times there has been a rise in inclusivity for the disabled, this being the support services offered, products offered, and avenues the disabled can utilise to have a more ‘normal’ seeming life without being held back by their disability. There are many different sorts of disabilities known to the world today, they can be physical, developmental, behavioural/emotional, and/or sensory impairments. Physically, this can range from small things such as asthma, all the way to more significant conditions such as paraplegia or quadriplegia. (*Special Needs Children – Know the Types and Know Your Rights*, 2024) On this topic, it is important to note that many pieces of equipment have been engineered, changed, and refined to help as enablers to the disabled, this being everything from specifically modified glasses to electronic wheelchairs. (*Powered / Electric Wheelchairs*, 2024)

The industry itself surrounding the disabled can be said to have a significant level of opportunity for further refinement and development, to further benefit the disabled community. This can be said to be through numerous avenues; however, the focus of this literature review will be sporting. Within sports, in modern history, society and the world have become more inclusive of the disabled in sports, with events such as the Paralympics allowing disability-affected athletes to compete at the highest level (*Latest Para Wheelchair basketball News*, 2024), alongside others with similar disabilities. This also extends downwards in terms of levels of competition, with numerous options and opportunities locally for the disabled to participate in many forms of sport.

Figure 2: Wheelchair Basketball within the Paralympics, Source: (*Latest Para Wheelchair basketball News*, 2024)

This gives athletes at all competition levels a chance to compete and enables them to have an experience like that of the able-bodied. This in a sense is the essence of engineering within this industry, which seeks to help the disabled through further engineering research and development.

2.2. SCOPE OF REVIEW

This task aims to produce a purely conceptual product, tailored towards the paraplegic that enables them to have a similar experience to the average able-bodied person mountain biking. In saying this, there are many parameters and limitations to this, as the targeted consumer base is the paraplegic a close consideration for safety and user-friendliness is a must. In saying this, the product must also be competitive with those already on the market, this being through performance and sustainability. Overall, the project aims to design and develop a concept that improves upon already made concepts whilst making them adequately cheaper and more cost-effective for the average consumer. In saying this, prior research will also be used to adequately design a concept that suits the needs of the paraplegic and creates a better experience overall.

2.3. BACKGROUND INFORMATION

2.3.1. General Information

The disability support industry in Australia can be said to be large, with around 325,000 workers supporting NDIS participants, their families, and carers. (*A responsive workforce that delivers quality supports*, 2024) This doesn't include the rest of the world, however, as it is said that the global disability devices market in 2024 is estimated to be worth 21.24 billion USD. (*Global Disability Devices Market Size*, 2024) It is obvious then, that there is a large market for products and services involving the aid or care of the disabled.

In terms of the physically disabled, there are numerous examples of products that help as an enabler to these people. This can be anything from the common wheelchair to mobility scooters. One example that has been used extensively in modern and ancient history is the disabled access or wheelchair ramp. The disabled ramp was first invented in 525 AD, in China as wheelchairs were being used at that time, prompting the need for accessibility to buildings and areas via wheelchair. (*Wheelchair*, 2024) Following this, they were also used to move large objects and eventually refined further to have a variety of uses, these being tailored towards people who are wheelchair-bound, on crutches, or needing to use a cane and otherwise cannot use stairs. This hence enables those in wheelchairs and otherwise disabled in some form to access the area in which the ramp leads. (*The History of the Wheelchair Ramps*, 2019)

Figure 3: Example of a Wheelchair Ramp, Source: (*6 Important Factors To Remember Before Building A Wheelchair Ramp*, 2021)

It is important to note that with modernisation and constant engineering developments and/or refinements, the specifications to which such devices must be built have become much stricter, and with good reason. Adequate safety measures developed over time have further increased the usability of these devices, proving them more safe day by day for the disabled to use. An example of this is a technical regulation in Australia that prohibits disability access ramps over 1900mm in length to have a gradient of any more than 1:14 (5.12%) incline. (*6 Important Factors To Remember Before Building A Wheelchair Ramp*, 2021)This is only one example of regulations based around safety when using these devices, and handrails, abrasive ‘grip’ tape and high visibility edges are even more examples of refinements for this device.

Another great example that has proven revolutionary for the disabled is that of the mobility scooter, as shown in Figure 4 below.

Figure 4: Example of a Mobility Scooter, Source: (*Afikim Afiscooter Breeze S4, 4-Wheel Electric Mobility Scooter – Sliver*, 2024)

The mobility scooter, as pictured in Figure 2 is one such device previously mentioned that acts as an enabler for the physically disabled, which allows them to become much more mobile. This can be for people suffering from partial or complete paraplegia, partial quadriplegia (retaining some mobility in the arms) or many other physical disabilities hindering the user's mobility over short or long distances. This therefore enables the disabled to have a much normal life, as they can now travel short or long distances using the mobility scooter. The system usually utilises hand controls and acts as a motorised bicycle of sorts, however with four wheels. This enables the user to travel with ease, while also taking into consideration safety through speed limiting so that it prevents the vehicle from tipping or going at speeds that could seriously injure the user.

Another significant device, on the topic of vehicles targeted towards to disabled which improve mobility, is the wheelchair-accessible car.

Figure 5: Wheelchair Accessible Cars, Source: (*Wheelchair Access Vehicle Conversions*, 2024)

The wheelchair-accessible car has revolutionised the disabled travel industry, as it removes the difficulty that comes with trying to ride as a passenger in a car. In modern times, a large amount of the disabled have struggled consistently with getting in and out of cars, this being lifting themselves out of wheelchairs into seats or vice versa. A study conducted by the National Library of Medicine in 2007 found that 'Among those ages, 25 to 64, for example, almost 9 out of 10 travellers reported using a personal vehicle to travel to the doctor and drove that vehicle almost 70 per cent of the time.' (Rosenbloom, 2007)This therefore shows that there has been a rise in private vehicle usage among the disabled, with a large portion of these vehicles being wheelchair accessible. The benefit of their vehicles is their ease of use when it comes to transporting the wheelchair-bound, as a ramp like that of what was seen in Figure 2 is used to allow those who are wheelchair-bound to access the vehicle without having to leave their wheelchair and 'lift' themselves into the car. Alongside this, it also means that putting away the wheelchair is no longer required, which not only improves ease of use and space efficiency but also improves usability as multiple carers and/or support people are no longer needed to complete the process in its entirety, this being putting away the wheelchair and stowing other items, etc. The only downfall of these devices is the cost involved, with the lower prices ranging between 15,000 AUD and 30,000 AUD. (*Wheelchair Vehicle Sales and Rentals*, 2024)This can make it difficult for the average disabled consumer to afford, albeit there are options more budget-friendly, around 15,000 AUD, comfort and reliability can be brought into question.

The most significant area when it comes to the disabled and equipment can be said to be safety. Safety in general is paramount for all people, whether fully abled or disabled in any way, shape, or form. However, the significance of safety is extreme when talking about the disabled, as by nature they are unfortunately less capable than a regular able-bodied person. This can refer to anything from the ability to react promptly, to having balance issues due to lower mobility issues. Safety within such devices previously mentioned is paramount when developing and refining the designs shown. An example of safety features implemented within a design is shown in Figures 6 and 7 below.

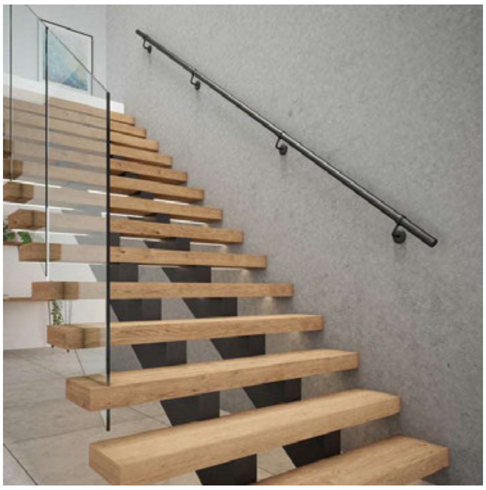


Figure 6: Handrail on a set of Stairs, Source: (*Rothley Internal Handrail Kit*, 2024)

Figure 7: Anti-slip Adhesive Tape, Source: (*Anti Slip Adhesive Tape Strips. Grip Tape Treads For Stair Treads & Steps. Clear Non Slip Indoor/Outdoor Adhesive Strips 1"x15" Non-slip Grip Strips/Tread Runners. Wooden Steps, Safety for Pets/Kids*, 2024)

Figures 6 and 7 above show two extremely simple examples of safety measures implemented in design to help both the average able-bodied person but also the disabled. The handrail pictured in Figure 6 can help those with stability issues when climbing the stairs, this being if they require crutches, a cane, or any other sort of walking aid and require support. The anti-slip adhesive tape also assists all parties as it prevents slippage on any surface to which it is applied. This helps all parties, this being able-bodied and disabled, as less focus is required, and therefore less worry is placed upon slippages with potential for serious injury or death, especially if the surface is wet.

Overall, it can be said that the disabled community in general are much more prone to requiring further assistance when it comes to basic mobility but also staying safe in general. As stated, this can be quite challenging depending on the disability however the few devices implemented through the design shown above are proven to help with assuring the safety of users, this being both able-bodied and disabled. ‘Demand for assistive devices is growing. In 1992, some 941,800 people in Australia required some sort of technical aid or self-help device to perform one or more of normal day-to-day activities.’ ("Assistive devices for people with disabilities," 1994) This therefore shows there is an increasing demand for assistive devices in Australia alone, and the publication in question is from pre-2000. This therefore shows the industry is ever-growing, and therefore there is a very large avenue for further development in assistive devices for the disabled in many areas, which can include anything, such as comfort, safety, affordability, product life span, performance of the device, and in this sense, how well it caters to the needs of the disabled.

2.3.2. The Disabled in Sports

Building upon the ideas already discussed, this brings an entirely new level to the topic of sports, this being disability sports, whether recreational or highly competitive such as the Paralympics. The disabled on a general basis struggle day-to-day with a variety of things, as mentioned this can be anything from mobility to balance. Aid devices for the disabled when it comes to the topic of sports becomes a much more complex problem, as on top of the already known issues, this being as stated, mobility, balance, etc, there also is a need for a much greater understanding of the safety requirements, as well as device life span and performance requirements when designing such devices to enable the disabled to compete. As the devices will be used in a much harsher environment, this being recreational or competitive, the design choices implemented must reflect this increase in demand for a stronger, more reliable design able to withstand the continuous stresses that are associated with sport. An example of design changes when it comes to regular aid devices versus sports-orientated devices is shown below in Figures 8 and 9.

Figures 8 and 9: Examples of Regular (Left) and Paralympic (Right) Wheelchairs, Sources:(*Drive Medical Silver Sport 1 Wheelchair with Full Arms and Swing away Removable Footrest*, 2024), (*Basketball Professional Sports Wheelchair With Removable Wheels*, 2024)

Figure 8 shows a standard wheelchair, found commonly in local areas, it is aimed at comfort and usability, featuring comfortable seating, and comfortable footrests, while also being able to be folded up and stored quite easily and conveniently. The frame overall is much thinner than that of Figure 9 and features a handbrake when the user doesn't want to move. Figure 9 shows a Paralympic Basketball wheelchair, with many key differences. These key differences include a thicker frame, tilted wheels for better stability when turning and making tight turns at speed, no armrests so that the arms have free range of motion, very basic footrests, a crash bar at the front when in close quarters, as well as smaller caster wheels for quick changes in direction, including a rear one for stability. Overall, it is obvious looking at the two designs that one is tailored for more regular, everyday usage, as opposed to the sports-orientated one being more for Paralympic sports. This further proves that when looking to design such a device when used in a sports situation, the device must be up to standard, much more advanced than the regular design, and able to withstand the harsher conditions it will face.

On the topic of more refined, and overall better design when it comes to equipment the disabled use in sports, it is important to note that although a level of danger is assumed when participating in sport, safety for all competitors and the user of the sports-orientated device is paramount. Using the above figures once again, this is evident, as the Paralympic wheelchair has the front crash bar and the rear caster wheel. The crash bar prevents injury to the feet, legs, and other lower appendages, meanwhile, the rear caster wheel helps maintain balance when sudden forward movement occurs. On top of this, the angled wheels allow for stability not only when tightly cornering but also when the players 'lean' or 'reach' for the ball, sometimes even on one wheel and balancing. The camber of the wheel means a lesser chance of the wheelchair tumbling over, potentially injuring the participant in the process. (*2021 Official Wheelchair Basketball Rules*, 2021)

Figure 10: Paralympic Wheelchairs in action, Source: (*Latest Para Wheelchair basketball News*, 2024)

It is also important to note that as a part of the design of these wheelchairs, safety straps or 'restraints' are used to keep the competitor in the wheelchair and prevent them from falling out. This is an important safety measure and significantly reduces the risk of self-injury or accidental injury.

2.4. ADAPTIVE MOUNTAIN BIKING (AMTB)

Another large industry when it comes to the disabled in sports can be said to be that of cycling, or Adaptive biking/mountain biking. This sport is based on the principle of cycling, however with modified equipment such that it allows those without the use of arms or legs to cycle and have a similar experience to that of an able-bodied person using a normal mountain bike.

Figure 11: An example of an Adaptive Cycle, Source: (Macias, 2023)

As seen in Figure 11, the concept builds upon the usual design of a bicycle, however, adapts it such that it fits the user's purpose. In this instance, as the user has an arm impairment, the cycle relies upon the feet for control.

Another version of this is the Handcycle, which is a similar product however targeted towards consumers with leg impairments instead of arms. As the name suggests, the primary method for controlling the cycle is the arms and hands. The arms are used to power the vehicle (like pedalling) but also are used to brake and steer. As the arms are significantly weaker than the legs, appropriate gearing is used to accommodate for the strength difference, to give a somewhat similar experience to the user of riding a bike normally unimpaired. (Balfour, 2022)

Figure 12: Example of a Handcycle, Source: (Balfour, 2022)

Figure 12 shows a very basic example of a handcycle, also known as an Adaptive bike. This handcycle as seen is targeted towards people who are paraplegic, or without the use of their legs. The one pictured above as mentioned is extremely basic, without any external motors or suspension. Higher quality products surrounding this general idea introduce some of these concepts, which branch from budget-friendly and targeted towards the average everyday consumer, to quite expensive and meant more so for extremely competitive or even professional-level para-athletes. Either way, there are many varying options depending on the physical disability, as well as how significantly the disability affects the intended user.

2.4.1. Materials used in aMTBs

Bicycles in general can be said to be made from a range of varied materials, these being anything from standard steel or aluminium alloy to titanium and carbon fibre. (Norman, 2024)These materials all have their strengths and weaknesses, with much of the decision based upon the intended use of the bicycle, and what needs must be met such that the rider is satisfied with the product and the product works as advertised.

Aluminium Alloy Frames

Aluminium alloy bike frames are one of the most common frames on the market and are preferred by many customers over their counterparts, as it is both cheap and strong enough for the average rider day-to-day. A large part of the overall design of the aluminium allows the frame of the bike is 'butting' the material where there is a high level of stress. This can be in places such as joints, or other areas enduring high levels of stress. Butting refers to making the material used thicker in areas of high stress, and thinner in areas of less stress. For example, this could be making joints thicker, as well as where the shock absorbers meet the forks on a normal bicycle. On the other hand, this could also be making the centre part of the main frame rail thinner due to a lack of stress in that area.

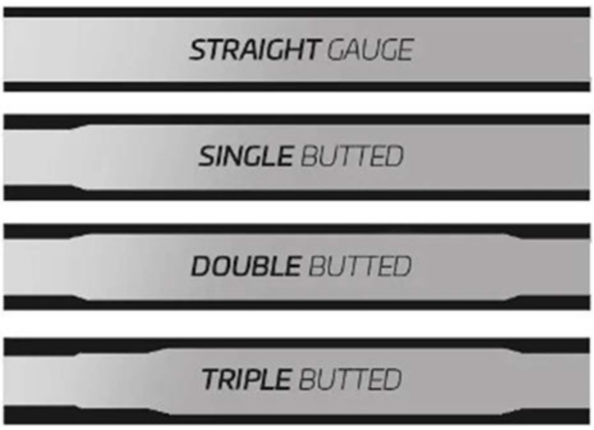


Figure 13: Examples of Types of Butting used in Bicycles, Source: (Norman, 2024)

Each type has its use and purpose, however, this type of material design allows for the Aluminium alloy used to be more cost-effective and efficient, as it is used to save on weight as well as cost.

Steel Bike Frames

Steel has been used in bike frames for over 100 years, with many bike builders adopting the old-fashioned 'steel is real' attitude. The benefits of using this material include rigidity and durability. When compared to other materials on the market a main downside is the cost of the material and the weight. As steel is much denser than the other options, when comparing it to Aluminium alloy for instance, the material provided if it isn't stressed beyond its yield limit will remain rigid compared to that of Aluminium which will wear noticeably over time. (Norman, 2024)It is also worth mentioning that steel frames tend to be much easier to fix, as they can be welded or bolted together with ease.

Figure 14: Example of Steel used in a Bicycle, Source: (Norman, 2024)

Titanium Bike Frames

Titanium when referring to bike frames can be seen as a more upper-class material no matter what is used. It is heavily known for its ability to withstand repeated load cycles, as well as having a higher quality ride. Titanium and its alloys are known for reducing weight, while also being extremely durable when it comes to material properties. Bikes made from Titanium alloys can be said to be extremely high quality, suited for performance or even competition use. The main drawback of such material is cost; however, it is also said that it can be hard to work with.

Carbon Fibre Bike Frames

Carbon fibre bike frames are the most expensive when talking about materials used to make such frames. Albeit the material is easily shaped and can be 'fine-tuned' to match the purpose the rider is looking for; the material is extremely expensive and not extremely durable compared to the other materials previously mentioned. As the bikes themselves are extremely expensive and not durable, albeit outdoing every other material in the short term when it comes to performance applications, their cost-effectiveness compared to the others is a major drawback.

Figure 15: Example of a Carbon Fibre Bike Frame, Source: (Norman, 2024)

2.5. COSTS INVOLVED IN AMTBS

A large area when it comes to Adaptive Mountain Biking is cost. There are numerous designs on the market, with everything from extremely basic hand cycles to motorised recumbents with extremely complex suspension systems and power delivery functions. In this instance, it is important to understand what the market pricing looks like on some of these models, therefore giving an idea as to the cost-effectiveness of buying such a product.

2.5.1. Reactive Adaptations – Recumbent Handcycle

Reactive Adaptations is one such company that has made a Recumbent Handcycle. This design can be said to be upper-class when it comes to the broad scale of pricing and designs.

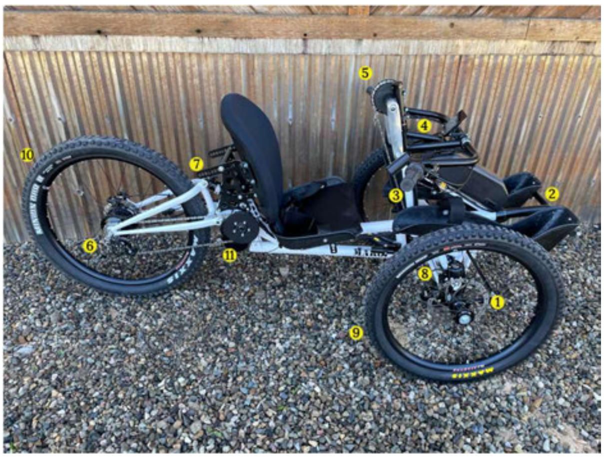


Figure 16: Recumbent Handcycle made by Reactive Adaptations, Source: (*MAKO OFF ROAD RECUMBENT HANDCYCLE*, 2024)

This design for the handcycle can be seen as utilising the recumbent position and using the hands as the primary source of control. The design features suspension at all three wheels, with suspension travel exceeding 4 inches front and rear. There are well-built footholds, with restraints in place to hold the rider in position while in use. This is also the case for the seat with a lap belt being fitted to the product for added safety. The cost of this product is said to be 17,800 USD, without any optional extras or upgrades. (*MAKO OFF ROAD RECUMBENT HANDCYCLE*, 2024)

2.5.2. Bowhead Corp – Rogue

Figure 17: Bowhead Corp's 'Rogue' design, Source: (*BOWHEAD ROGUE™ FS/E ADVENTURE-E BIKE*, 2024)

Bowhead Corp is yet another company who have developed a product in the market of recumbent handcycles. This design can be said to be more 'budget-friendly' starting at 12,500 USD without any optional extras. This is different to the previous design, as shown in Figure

17, as the layout of the wheels is different, as well as safety features incorporated into the design. The footrests on this design are much less developed than what was previously seen. Although both the rider's body and feet are strapped to the aMTB, the feet are quite exposed to what is coming. In saying this, it still features leaning capability, like the one shown in Figure 16, alongside a significant level of suspension travel.

2.5.3. Outrider USA – Coyote

Figure 18: Outrider USA 'Coyote' 4WD, Source: (*Coyote (Extreme Off-Road) | All Electric (A)*, 2024)

The 'Coyote' 4WD from Outrider USA is an all-electric, extremely rugged offroad targeted aMTB which again is controlled by the hands. It has optional 4WD, depending on what the customer orders. The design features again the recumbent position, however, the entire design from the wheels used to the frame is extremely rugged and durable. This can be said to be much high-end when it comes to aMTBs, however in saying this, as the design is extremely rugged and rigid, the weight of the product becomes a drawback. The cost of the aMTB starts at USD 17,485, with the option to add four-wheel drive to the aMTB for an additional USD 2,500, bringing the total with 4WD to almost USD 20,000. The aMTB like the other designs features a long-travel suspension system as well as safety belts for the body and legs.

2.6. SAFETY AND AMTBS

As previously mentioned, when a participant commits to participating in any sort of sports, disabled or able-bodied, they also accept the risks that are involved with said sport. However, in saying this, mitigation strategies are a large portion of today's sport, and as such also apply to the industry of aMTBs. As seen in the three designs covered, all three of the designs have lap belts or torso restraints, as well as foot restraints. However, all three of these designs have the option or are completely motorised, this being with electric motors of varying power levels. This in a sense can then be compared to an electric dirt bike or electric motorbike of sorts, and as such safety precautions must be taken to ensure the user in the event of an accident is protected and although there is potential for serious injury, prevention strategies must be implemented to reduce the chances of this. Motorbike helmets and goggles are one example of safety measures implemented to protect riders, as well as knee pads, shoulder pads, torso protectors, and motorbike boots which are all designed to keep the rider safe in the event of catastrophe.

2.7. WHEEL LAYOUTS

The wheel layout of the system plays a large factor, and as such this will be the first assumption made of both preliminary concepts. Most adaptive mountain bikes, (as shown in Figures 17 and 18) have either a three- or four-wheel layout. This being two rear drive wheels and one front wheel, one rear drive wheel and two front wheels, or four wheels with two rear drive wheels. An in-depth analysis of all these wheel/drive layout types is shown below.

Four-Wheel Layout

Like what is seen in current road-going cars, the Four-Wheel Layout incorporates four wheels having contact with the ground, with usually two wheels being drive wheels. In this case, the drive wheels are the rear wheels. An example of this is shown below.

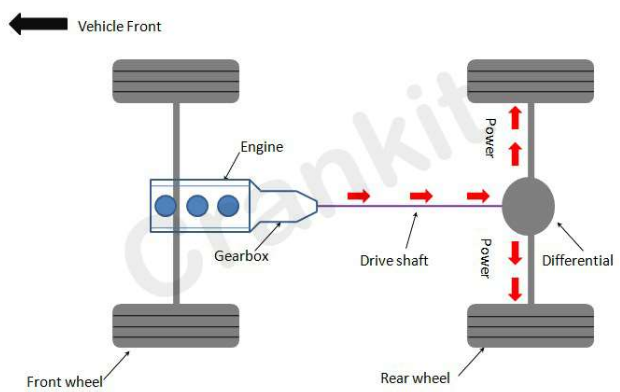


Figure 19: Example of 4-wheel layout with Rear Drive Wheels, Source: (*What Is Rear Wheel Drive (RWD) in cars? It's Design And Features*, 2024)

This layout has pros and cons, with these being outlined below.

Pros

Four-wheel layout systems have a significant level of stability when compared to that of three-wheeled counterparts. As there is a supporting wheel on each corner of the vehicle there is more support for the system and the overall contact patch of the tyres with the surface is greater, therefore improving grip. With the increased level of stability, also allows the system to have an increased ride height due to the added stability. The product however being more supported may have a longer life span than other layouts.

Cons

More wheels mean more weight, as suspension will have to be included for the extra wheel, as well as potentially drivetrain components and other necessary pieces of equipment. There would also need to be a system introduced like a differential for the drive wheels, such that when cornering the inside and outside wheels can rotate at different speeds and therefore allow the vehicle to turn without increased difficulty or putting significant levels of strain on the chassis or other components. As the ride height can be made much higher this introduces potential problems with the centre of gravity and centre of mass, as the vehicle may become top heavy. The vehicle may also be observed as more rigid compared to thee-wheel options as there are more supporting wheels. Overall, the product would prove to be heavier and more expensive.

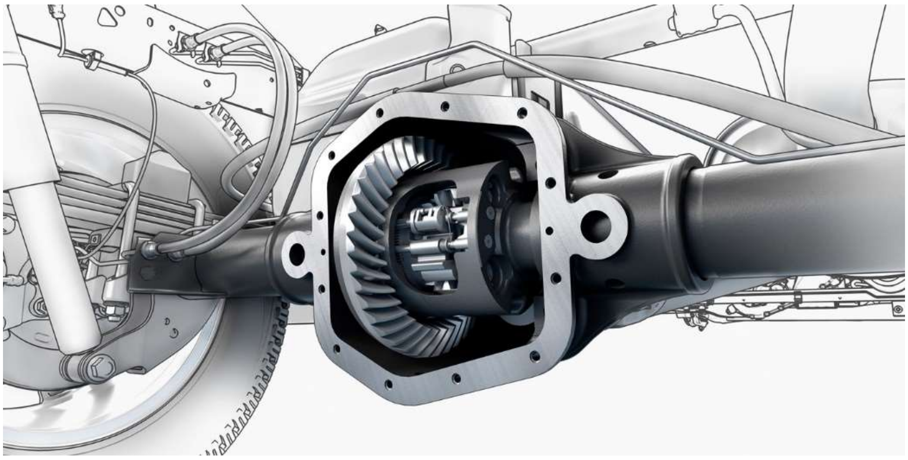


Figure 20: Example of Differential used on Cars, Source: (Garbe, 2024)

Three-Wheel Layout (One Front, Two Rear)

The three-wheel layout, utilising one front wheel and two rear drive wheels is commonly seen on motorised tricycles, like that of a quadbike however with only three wheels. This layout can be said to be less popular due to a list of cons when compared to the reverse layout of two front, and one rear, however, this layout is still seen in multiple cases. A list of pros and cons of this layout is shown below:

Pros

This layout being three wheels has a significant weight reduction when compared to the likes of four-wheel layouts and allows the rider extra space for their legs on the front of the frame as they can straddle the front wheel and/or supporting members. Allows more opportunities for use of space over the rear of the frame as the two rear wheels allow for more room underneath or behind the rider. Allows more flexibility in terms of suspension than the four-wheel layout as the system overall will be less rigid.

Cons

Albeit having more suspension flex than the four-wheel layout, it still is less than the reverse three-wheel layout of two front, and one rear. Leaning with cornering will prove more difficult as the rigidity of the rear will oppose movements made by the rider. This can cause handling issues such as understeer. There would also need to be again a differential designed such that the rear drive wheels can move at different speeds. This layout is seen in Figure 17.

Reversed Three-Wheel Layout (One Rear, Two Front Wheels)

The reverse Three-Wheel Layout, or for simplification purposes, the standard Three-Wheel Layout is commonly seen on road-going motorised trikes, as well as many adaptive mountain bikes seen in the literature review. This layout is known to be preferable when compared with four-wheel and the other three-wheel layout. This will be further discussed in the Pros and Cons list shown below:

Pros

Having one drive wheel removes the need for a differential-type system, therefore saving further on weight and cost. On top of this, the rider also has more ability to lean, and suspension can be designed such that the bike leans with the rider having more flex compared to both the other three-wheel layout and the four-wheel layout. This also allows for better handling as there are two support/steering wheels that in theory are adjustable. The motor can also be mounted 'on the wheel' of sorts, or a chain drive system can be used, which makes the system much less complex, and easier to work on and parts are much more easily accessible as well as affordable.

Cons

As the system is smaller, lighter and cheaper, this reduces space to put extra components on the vehicle. On top of that, as the vehicle is lighter it can be said that it will be more unstable when cornering and when under load. Significant articulation in the front suspension may prove uncomfortable for the user, however, this is dependent on the said user and how the concept is ridden. Loss of traction in the rear of the concept is more likely as there is only one tyre contact patch instead of two, however, when offroad this may not prove to be a negative.

2.8. RIDER POSITIONING

A large factor when it comes to aMTBs and anything that a user rides or drives is the user's positioning on or within the vehicle. In this instance, as the project is based upon the paraplegic, positioning of the rider is an extremely large factor as not only does it contribute towards rider comfort, but also safety and usability. The positioning of the rider must be comfortable, while retaining safety but also allowing the concept to perform adequately all at once. In this sense, there are two main positions seen when researching concepts on the market, these being Recumbent rider positioning and Prone Rider positioning.

2.8.1. Prone Rider Positioning

Prone rider positioning, as the name suggests is where the rider adopts a more prone position, this being sitting on a seat leaning forward, supporting a lot of weight on the handle bars, like what is seen on normal bicycles. Albeit this positioning gives the rider multiple areas for support, as well as theoretically moving the centre of gravity of the concept forward, it also puts increased pressure on the shoulders, as vibrations and shock from riding will be absorbed by the arms and shoulders as well as through the seat. On top of this, if a chest-supported solution were to be adopted to try and relieve pressure from the shoulders, there would be increased pressure on the chest which can lead to other difficulties. In terms of performance, the centre of gravity for the concept would be much higher, therefore making the concept easier to roll or 'tip over' sideways. As the centre of gravity is more forward, in theory, this would mean a lesser chance of tipping over backwards if the concept were to be taken up an extreme incline, however, as the product is targeted towards recreation and the paraplegic this can be said to be unnecessary.

2.8.2. Recumbent Rider Positioning

Recumbent Rider Positioning sees the rider in a more laying position, this being with their legs in front of them and sitting on a seat, further towards the rear of the concept. This moves the centre of gravity backwards however it also lowers it significantly. In this sense, albeit there is more chance of the concept tipping over backwards, the cornering ability of the concept will be much greater due to the lower centre of gravity, while also improving rear traction as there is more weight towards the rear of the concept. On top of this, as the rider is more so in a lying down position, this is said to keep the spine in a more neutral position, while also providing more comfort for the user. (*Exploring the Advantages and Disadvantages of Recumbent Bicycles*, 2023)This therefore allows the user to ride the concept for longer periods without having to worry about becoming uncomfortable or pain from prolonged pressure in the joints, specifically the shoulders as the rider's weight is evenly distributed and as the rider is more so sitting or lying down, the pressure is also mostly evenly distributed. In theory, this also allows for more front-end articulation as the legs can move independently of the body (within reason). This therefore allows more flexibility and the ability to transverse harsher terrain if the rider is willing and capable.

2.9. KNOWLEDGE GAP AND PROPOSAL

So, now that the main aspects of the industry have been outlined, as well as the comparison of a small number of designs for aMTBs, it is obvious that there are challenges that the industry is facing in multiple areas, mainly including the following, which inter-link with each other heavily.

- Performance Optimisation
- Safety of User/Product Usability
- Cost-efficiency of the Product
- Sustainability of the Product

It is obvious looking at the industry and designs that no design is extremely budget-friendly and targeted towards disabled, recreational use consumers. Although some are extremely well developed and can be classed as ‘robust,’ the cost-effectiveness of these products may not be appropriate for the average disabled consumer. Although some high-performance able-bodied bicycles can cost upwards of 5 figures, for the average disabled person this is not achievable. However, in saying this, every other avenue of the product depends on the cost, as the higher the quality of the product, obviously the more it will cost.

Therefore, it is proposed that based upon already-made designs and products on the market, a new design is designed and developed, which further engineers and refines the ideas used in already-made designs to produce a product that is more cost-effective for the disabled, specifically the Paraplegic, while giving them more usability, the assurance of adequate safety, all the meanwhile sufficiently performing such that while in use the Paraplegic recreational use consumer can have a similar experience to that of an able-bodied person. Summarised, can a cost-effective yet high-performance application be achieved through concept design changes?

2.9.1. Chapter Summary

Enabling devices for the disabled are seen in many areas throughout society. These can be anything from custom-designed electric wheelchairs for the partially paraplegic, vehicles with only hand controls and overall designs that act as enablers for the disabled to have similar experiences in doing things as what the able-bodied would have. In saying this, the disability aid industry has a constant need for innovation and refinement, such that equipment designed for the disabled is better and more fit-for-purpose than previous ideas or variants. In this sense, many sources of literature were studied to better understand the current market for enabling equipment, as well as the needs of the paraplegic in terms of recreational sports. It is evident throughout the research that the paraplegic and disabled generally have issues with independence as well as safety and injury prevention. Meanwhile, the products designed to act as enablers are extremely expensive, being anything from wheelchair-accessible cars to mobility scooters and specialised wheelchairs. It is then reasonable to ask if a cheaper product can be designed, with similar performance characteristics using differing combinations of sub-systems, there being things such as motors, brakes, and wheels, which all make up a large portion of the cost for these pieces of equipment.

CHAPTER 3 METHODOLOGY

To begin with the methodology, it is important to establish the design process which will be applied to this project. This design process is called the 'engineering design process,' and is shown in Figure 19 below.

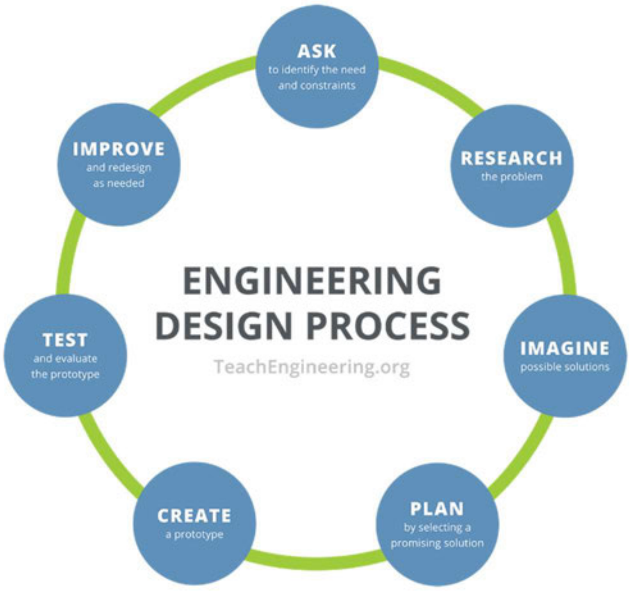


Figure 21: The engineering design process, Source: (TeachEngineering, 2024)

This design process will be used throughout this project, to design the best possible conceptual product that fits the requirements which will be outlined later in this report. This design process will further continually loop until a sufficient product design is achieved that satisfies all requirements outlined in the design criteria below.

It is important to note that for most of this assignment, prior designed products on the market will be analysed and the systems that are used and implemented will be researched and improved to make an improved and further refined product. This will be done through the thorough analysis of products on the market currently, which then will allow the systems they already have in place to determine initial concepts, acting as a foundation for the project design. As this is the case, this removes slightly the need for factor of safety (FoS) considerations as the design will already have it implemented, unless the design is significantly changed, in which case safety considerations will be analysed adequately.

3.1. Design Methodology

It is important to note the sub-systems that must be considered when designing the system. As the project is based upon making an 'ultra-high-performance and durable' wheelchair, the performance of said sub-systems will be a large factor, however, other design criteria must also be taken into consideration. In terms of design criteria, there are many requirements for this project, however, the main objective is creating a product that is user-friendly, cost-effective, and sustainable, while in the meantime delivering a similar experience to the paraplegic as what an able-bodied person would experience when recreational mountain biking. In saying this, it therefore means that while the product must meet the previously mentioned requirements, it must also perform adequately to ensure a similar experience to normal able-bodied MTB is achieved. In this instance, it can be said that the design can be then split into four main categories, these being:

1. User-friendliness and Safety
2. Cost-effectiveness
3. Sustainability
4. Performance Capability

Each of these categories will be discussed in further detail below, this being their purpose, and how they all relate to the project and 'interlink' so to speak.

3.1.1. Each Category and a Brief Description

User-friendliness and Safety:

The most important part of the design process for this project is safety and user-friendliness. As the project is based on designing a product to suit consumers with little to no use of their legs, both factors arguably are the most important when it comes to the design process. Safety is paramount and will be taken into consideration through research, and calculations with the help of CAD and FEA, which will determine the properties of materials used, as well as dimensions and many other important factors. A thorough analysis will be undertaken when a system design is significantly changed from what was researched or if a new sub-system design is implemented that has not been tested prior.

In saying this, as the project is for a majority research-based and based upon products already on the market, as they have already factored in design regulations re-evaluating some sub-systems would prove redundant, albeit if new sub-systems are to be designed from scratch thorough analysis will be undertaken such that it is confirmed that the sub-system is safe and capable. While meeting standards in terms of law and safety, the product must also be designed such that using the product and maintaining the product is possible for the intended user, this being the partially or completely paraplegic. This can be said to be highly related to ergonomics, with examples like the controls for the aMTB which are easily used, and components that are more prone to fatigue and/or subject to higher frequencies of failure and therefore replacement must be designed such that it is reasonably easily replaced or maintained by the intended user. Size is also a very large design element that must be considered as a part of this, as the product must be able to be transported to and from locations where it is used, while also being able to fit onto trails and into other areas that the user wants to go.

Cost-effectiveness:

A major part of this project is cost-effectiveness. As the main concept surrounding this is further developing existing Adaptive Mountain Bikes (another example of one is shown below), cost plays a major role in creating a product that will be budget-friendly and viable for the disabled user to purchase while also delivering a similar experience to that of the able-bodied.

Figure 42: Example of an aMTB, Source: (Collins, 2024)

It is noted that budget-friendly versions of aMTBs can range anywhere from 8000 USD to 12000+ USD as seen in the literature review, as such when trying to further engineer and re-design concepts already on the market, the cost must be put under significant consideration such that while the product brings a positive experience to the disabled, it isn't significantly over-priced and unable to compete with current models on the market. Therefore, the cost of building and manufacturing the design must be taken into consideration, this being considering manufacturing processes needed to build the product, whether it be welding, bending, riveting, bolting, etc, all the while knowing that a profit margin of sorts will be placed upon the design such that it is profitable, but also still reasonable for the consumer. It also will prove beneficial if components can be designed and built locally, such that the quality of materials is assured as well as the quality of craftsmanship.

Sustainability:

A large part of engineering is sustainability, this being for both the environment but also the life span of the product over its working life. Concepts must be taken into consideration, such that the product does not have negative effects on the environment while in use, but also has a significantly long lifespan and life cycle, such that it can handle all terrains, which is a requirement of the design. This will include surviving accidents and still being usable or easily repaired, while also surviving typical weather conditions when riding, and fatigue over its lifetime. This also allows the aMTB to be more cost-effective as if fewer parts need to be replaced less cost is involved in maintenance or replacement of worn systems.

Performance Capability:

While delivering in every other area already mentioned, the product must deliver an experience like that of what an able-bodied person would experience, this being enjoyment and a feeling of fun when in use. So, in saying this, the product must bring a significant level of performance when it comes to all terrains, however with a focus on aMTB style riding, this being trail riding and overall offroad riding over rougher terrain (within reason). In this instance, material selection will play an important role as the product must be light and must have adequate ability to be tuned using various systems implemented in the design, all the meanwhile being cost-effective and structurally sound enough to meet the requirements. A flowchart of this process can be found in Appendix C.

3.2. Design Approaches

In terms of approaches to the design, throughout the entire process, each of the four categories has simultaneously been taken into consideration, however with a large emphasis on

Performance, Cost, and Safety. This includes the creation of two initial concepts, these being in the form of sub-system combinations, one focussed on performance, and the other focussed on cost-effectiveness. These then have undergone further refinements and therefore led to producing a preliminary final concept, which then has been turned into a final product. This was based upon a mixture of generalised pros and cons to each design, mathematical calculations, regarding analysis of material properties, stress, and other aspects that relate to the design requirements. Finite Element Analysis (FEA) has been used to help with the analysis of each system and sub-system design such that further refinements could be made while minimising human error due to calculation errors or other factors. This can be anything from locating maximum stress points on the chassis of the aMTB that need to be reinforced or 'butted,' to looking at axial stresses under varying force loads to determine if the design is sufficient and meets the requirements outlined above.

As such the final concept was modelled on CAD and tested accordingly to ensure that the analysis for each initial sub-system combination is correct and adequate in determining each system's viability when being compared to another system with a different design but with the same purpose. The sub-system analysis process will be repeated, as needed, changing each sub-system such that the benefits of each sub-system design idea are combined as necessary to create the best possible combination of sub-systems for the requirements outlined above, which then creates in theory a better complete system, and therefore a better product than what is on the market currently for recreational needs.

The engineering design life cycle will be used throughout this entire process, this being mentioned and illustrated in Figure 21. This is needed at every step in the design and development process as it will ensure that the design is developed correctly and efficiently.

3.3. Design of Preliminary Concepts

3.3.1. Assumptions Applicable to Preliminary Concepts

To begin, there were necessary assumptions to be made before making calculations surrounding the design of the first initial concepts. Analysis of certain other non-mathematical concepts was undertaken such that the overall layout of the system was determined. The main sub-system categories put under analysis are as follows:

- Brakes
- Powertrain
- Chassis
- Suspension
- Steering
- Body Panelling
- Rider Ergonomics

The main sub-system that has undergone thorough design and testing was mainly that of the chassis, as this is the largest part of the product, and the main structural component holding the design together. Researched products on the market for the other sub-systems have been considered and modified or replaced accordingly when undergoing analysis, this being analysis using the four previously mentioned categories. In terms of assumptions, the following table represents the list of assumptions that have been applied to the design process for both initial concepts. It is important to note that throughout the design process, the assumption has been made that the system must be designed such that it can undergo double the maximum vertical force calculated. This is assumed as a factor of safety measures and ensures the rider is always safe even when the product is older and worn. Before initial designs were produced, calculations were conducted such that the force required from the motor was known, as well as the force required from braking such that sufficient products on the market could be selected for use in the design. These calculations are shown after the initial assumptions shown in the table below:

Table 1: Table of Assumptions Applicable to both initial concepts

Assumption	**Assumption Value**
Maximum Weight of Rider (kg)	100
Maximum Weight of System (kg)	45
Maximum Vertical Force Experienced during use (G)	2
Acceleration due to Gravity (m/s^2)	9.81
Maximum Vertical Force Experienced during use $F(V)_T$ (including sprung and unsprung weights) (N)	$F(V)_T = \big((100 + 45) * 9.81\big) * 2$ $F(V)_T = 2844.9$

So, using the maximum weight of the system and rider, this being 145 kg as an initial assumption, we can use this figure to calculate how much driving force is required from the motor, as well as the amount of braking force required. The maximum attack angle of the vehicle when negotiating rough terrain is said to be 40 degrees. Usually, mountain bikes can negotiate much more steep terrain, however, this is because the rider can lean forward and therefore transfer their centre of gravity and mass forwards, therefore keeping the mountain bike stable. As the rider in this case is paraplegic, leaning backwards and forwards significantly is not possible, and as such the maximum attack angle will be assumed as 40 degrees.

Layout of the System:

A part of the assumptions for both initial concepts is that of layout, this being wheel, drive, chassis, suspension, brakes, steering and ergonomic layout. Although the layout of certain sub-systems will have a direct effect on the performance of the product when analysed using the four categories, preliminary assumptions can be made that will not be changed throughout the course of design and analysis.

As per section 2.4. of the Literature Review, the Reversed Three-Wheel Layout (now referred to as the Three-Wheel Layout), paired with the Recumbent Positioning of the rider, is deemed most sufficient and best suited to solve the task at hand due to the factors mentioned in previous sections. It is also notable that a chain-driven system will be the assumed driveline throughout the entirety of the project, this being for all concepts and the final concept. This is due to cost and availability as chain-driven systems are cheaper and relatively easy to maintain, with replacement parts being available locally. The motor and battery in this concept will be positioned behind the user and mounted to the main chassis. This is to help aid in centralising weight distribution on the vehicle.

User Safety – Seatbelts and Restraints

Like what is seen on the Bowhead Reach and other aMTBs, it will be assumed that restraints are used on the legs and across the lap of the user. This always keeps the rider in position, stops the user's legs moving around during use and makes sure the user doesn't fall out during operation. This also keeps the rider safe if external componentry is to fail, as the design will be made such that external componentry fails before the chassis parts where the rider is positioned do so, to keep the rider safe in the event of a catastrophic failure.

Now that we have the overall layout of the vehicle decided, as well as the positioning of the rider, initial concepts can now be thought of and designed using the before mentioned assumptions.

3.3.2. Design of Initial Concept 1 – Performance Orientated

For the first initial concept, a performance orientated concept needed to be designed, which then could be mixed later with a more budget-friendly design to provide the best of both worlds as a final concept. It is important to note that the concepts themselves mainly differ in materials and what motors, batteries, and other components are used. As this is the performance-optimised configuration, a cost analysis has been performed however the design will be based on the performance of the product, rather than keeping it budget-friendly.

To begin, the material the performance concept is made of this being frame, and other structural components is titanium, specifically 3AL2.5V or 'Grade 9.' (Porter, 2024)It has been said that titanium has benefits over the use of carbon fibre. This is an increase in feel for the rider, as well as having a longer life span while also being similarly priced with carbon fibre. It is said that 'Titanium frames are 10 times as strong and 10 times longer lasting than carbon.' (*Titanium vs Carbon Frames: What are the differences?*, 2024)

The size of the wheel and tyre also has a large effect on the performance of the vehicle when accelerating and braking. For mountain bikes in general it is said that sizes vary from 16-inch diameter to 29-inch diameter, with the main differences being if the bike is a folding or compact variant, if the bike is designed to have a short wheelbase and be nimble, or if there is more of a comfort and performance orientation. (*Ebike Wheel Sizes*, 2024)Previous research has shown that for adaptive mountain bikes, the wheel and tyre sizes range from 20 inches to 29- inches. The tyre that is going to be used on this concept is the 'Maxxis Aspen 3C Maxx Speed Exo/TR tyre,' for the sake of analysis it will have an assumed size of 29 x 2.4 inches. For the sake of calculations for initial concepts, an assumed coefficient of friction between the tyres and the terrain has been assumed as 0.7(Andersson, 2024). Albeit this coefficient of friction will change depending on the surface that is being ridden on, this value was needed for calculation purposes and as such is an assumed constant. For the sake of making an initial concept, the weight distribution of the vehicle will be assumed to be 60/40, with most of the weight being towards the rear with a wheelbase of 1400mm axle to axle assumed as a starting point. This was decided upon via looking at data from the 'Bowhead Corp Reach' aMTB with a wheelbase of 1291mm. (*BOWHEAD REACH™ ADVENTURE-E BIKE*, 2024)

To begin with the specifics, the power required from a motor for this vehicle to operate was needed, as well as the necessary force required to stop the vehicle from going down a decline. So, to begin, calculations were undertaken for the force required to transverse a steep incline, in this case, as the vehicle is made for the disabled and the centre of gravity should in theory not move forwards of backwards significantly due to the rider movements, the angle of max incline will be assumed as 40 degrees.

To begin, we must find the force pulling the vehicle back due to gravity. This can be found using the following equation:

$F_{Gravity} = mgsin(\emptyset)$, Source: (*How do you determine the effective force on an incline?*, 2024)

Where:

- m = Mass (kg)
- g = Acceleration due to Gravity (9.81 m/s^2)
- $(\emptyset)$ = Angle of Incline (degrees)

$$F_{Gravity} = 145 * 9.81 * sin(40)$$
$$F_{Gravity} = 914.33\ N$$

As this force is the force pulling the vehicle downhill, we must therefore overcome such force with a motor to drive the vehicle up the incline. If we then assume that the maximum speed to be travelled up such an incline is 5 m/s, we can work out the amount of work we need for the vehicle to accelerate and then maintain that speed up the incline. This can then be translated into power, which tells how big the motor needs to be on the vehicle.

For Work, we need to calculate Work done to accelerate ($Work_{Accelerate}$) to 5 m/s, and then Work done to maintain this speed ($Work_{Maintain}$) over a distance, in this instance for calculation purposes, 10m.

$$Work_{Total} = Work_{Accelerate} + Work_{Maintain}$$

Where:

$$Work_{Accelerate} = \frac{1}{2}mv^2$$

$$Work_{Maintain} = F_{Gravity} * d$$

Where:

- Work (Joules)
- v is Velocity (m/s)
- d is Distance (m)

So given these two equations, we can substitute the known values to find the total work required.

$$Work_{Total} = \left(\frac{1}{2} * 145 * 5^2\right) + (914.33 * 10)$$

$$Work_{Total} = 10705.8\,J$$

So, given that we now have the work required to accelerate and maintain the speed, we can now calculate the power needed from a motor. This can be done using the following equation, utilising two forms of the power equation, with one being for the acceleration stage and the latter being for the maintaining of speed while travelling up the incline:

$$P = (\frac{W_T}{t}) + (F_{Gravity} * v)$$

Where:

- P is Power (Watts)
- t is Time (s)

If we assume that the vehicle accelerates up to 5 m/s on the forty-degree incline in a period of 5 seconds, and then substitute in known values:

$$P = (\frac{10705.8}{5}) + (914.33 * 5)$$

$$P = 6711.16\,W$$

$$P = 6.7\,kW$$

Therefore, a motor of 6.7 kW is required, and this is now the baseline for this concept in terms of a motor. In this case, the 'CA-80100 7kW Brushless motor' is to be used. However, although the motor is advertised as a 7kW motor, it is only rated to 4kW. (*CA-80100 7kw Brushless Motor for E-bike*, 2024)In this instance, the motor must be geared accordingly.

To do this, the current force due to gravity can be re-used, however the rolling resistance must be calculated alongside the force of acceleration from the motor. In this instance, the force due to rolling resistance can be calculated via the following equation, alongside the force of acceleration. (For layout purposes these calculations will be split into two columns.)

$$F_{Rolling} = C * F_{Gravity}$$

Where:

- C is the rolling resistance coefficient (Assumed as 0.005) (*Rolling friction and rolling resistance.*, 2024)

$$F_{Accel} = m * a$$

Where:

- a is the acceleration

Acceleration can then be calculated using the following equation, which then can be substituted into the equations above. This is shown below:

$$a = \frac{v - u}{t}$$

Where:

- v is final velocity (m/s)
- u is initial velocity (m/s)
- t is time (Seconds)

Doing the simple calculation equates to an acceleration of 1 m/s^2. This can then be substituted in:

$$F_{Total} = F_{Gravity} + F_{Rolling} + F_{Accel}$$
$$F_{Total} = 914.33 + (0.005 * 914.33) + (145 * 1)$$
$$F_{Total} = 1063.9\ N$$

Now to get the gearing required, the torque required at the wheel must be calculated. This can be done using the following equation.

$$T_{Wheel} = F_{Total} * r$$

Where:

- r is the radius of the wheel (m)

$$T_{Wheel} = 1063.9 * 0.3683$$
$$T_{Wheel} = 391.83\ Nm$$

Now that this value has been calculated, the torque produced by the motor can be used to find the gear ratio needed for this concept.

Therefore, now for the gear ratio:

$$R = \frac{T_{Wheel}}{T_{Motor}}$$

$$R = \frac{391.83}{15}$$

$$R = 27:1$$

Now that a sufficient and capable motor has been selected alongside the needs of the driveline system, we must work out what is needed from the braking system. As the maximum incline the vehicle is assumed to be transversing is 40 degrees, the maximum decline is assumed as the same.

It is a known fact that braking systems that have an increase in rotor diameter and therefore brake pad size, have an increased efficiency when compared to smaller sizes. In saying this, it is researched that the usual size variance in terms of rotor diameter for electric mountain bikes ranges between 140mm and 223mm. (*eBike Brake Rotors*, 2024)As this is the performance variant, the rotor size will be assumed as 220mm for efficiency, 223mm is deemed as rarer, and as such buying the rotor locally may prove difficult, however, the 220mm is widely used and much more widely available. It is assumed that the braking bias for the vehicle will be 70% front and 30% rear, however as the vehicle will have independent systems for front and rear brakes, this will vary depending on the rider's inputs. The caliper chosen was the 'Shimano BR-M7120' brake caliper, with a 4-piston design that is suitable for a range of rotor sizes, in this instance including 220mm. (*Shimano BR-M7120 Brake Caliper SLX with N03A Resin Pads*, 2024)

3.3.3. Design of Initial Concept 2 – Cost Orientated

For this concept, instead of having a large focus on the performance aspect of the product, cost-effectiveness will be considered and focussed on much more such that a scale so to speak of cost vs. performance can be established. The calculations already conducted for the first initial concept will be repeated however with differing values such that sub-systems used can be more cost-effective.

To begin, the main material that the product will be made from will be Aluminium Alloy, specifically, AL6061 as this metal compound is said to have a good tensile strength while also retaining ductility such that the frame in the event of catastrophic failure is more likely to bend rather than shear. (Geisreiter, 2021)This means that the rider has a chance to slow the vehicle down and come to a stop rather than have the failure immobilise the vehicle and potentially lead to significant injury. Aluminium is also said to be relatively inexpensive when compared to titanium and carbon, also making it the ideal choice for a more cost-effective approach. (Kieran, 2022)

The same tyre will be used on this concept as the initial concept, this being the 'Maxxis Aspen 3C Maxx Speed Exo/TR' however this time with an assumed size of 27.5x2.4 inches. This is smaller than the performance concept, however, the reasoning behind this is to attempt to produce a concept more cost-effective. Cost analysis of both concepts will be conducted further along in the report. The power required from the motor and therefore the gear ratio must be calculated, such that the concept performs adequately with a smaller motor. The braking system also needs to be re-analysed with a smaller brake rotor such that further cost reductions can be achieved.

Using calculations for Initial Concept 1, the power to transverse the forty-degree incline will still be 6.7 kW. However, as this is more budget focussed, a smaller motor is required with a differing gear ratio to reduce costs. In this instance, a motor with a rated torque of 10 Nm is instead used. (*63100 140KV Sensored Version Brushless Motor for Electric Skateboard scooter bike go kart propulsion system*, 2024)Now using the same equations and constants from beforehand, the torque required at the wheel with the smaller wheel measurement can be calculated, alongside the required gear ratio. This is shown below:

$$T_{Whe} = 1063.9 * 0.34925$$

$$T_{Wheel} = 371.57\ Nm$$

Now that this value has been calculated, the torque produced by the motor can be used to find the gear ratio needed for this concept.

Therefore, now for the gear ratio:

$$R = \frac{371.57}{10}$$

$$R = 37.2{:}\,1$$

So, in this instance, the gear ratio required for this concept would be 37.2:1. As this is significantly larger than what was seen in the performance-orientated concept, it is recommended that a reduction gearing system be implemented into the concept design, however, this will increase the cost marginally due to extra equipment being needed.

In terms of a braking system, it is said that for eMTBs (Electric Mountain Bikes) the minimum rotor size recommended is 180mm(*E-Mountain Bike Braking Tips*, 2024), with a 4-piston braking caliper. As such, for this concept, a braking system of 180mm will be used while still utilising the 4-piston braking caliper seen in initial concept 1.

3.3.4. Battery to be Used

In terms of batteries, the '72V 16.8 Ah Molicel E-Bike Battery' will be used, which is rated from 3000W to 7000W(*72V 16.8Ah Molicel E-Bike Battery, 3000W to 7000W*, 2024), which in this instance suits both concepts sufficiently as it is rated to work alongside both motors while providing sufficient life span in terms of battery life and health.

3.3.5. Design of Chassis, Steering and Suspension

Before a cost analysis of the two initial sub-system combinations can be conducted, the chassis must be constructed and modelled such that a price for the chassis can be estimated and therefore a more accurate cost analysis can be done for both initial concepts. In terms of designing the chassis itself, the type of chassis was chosen to be tubular, therefore allowing easier fabrication of the chassis. A basis for tube size was selected as 32mm, and 3mm thickness. This will be the dimension used throughout modelling. It is assumed that all mounts, this being mounts for the rear forks to the main chassis, mounts for the control arms within the front suspension box, and the mounts for the motor will all use bushes, like what is seen in car suspension. This will help to mitigate shock while also preventing metal-on-metal contact, therefore prolonging the life span of each component. Many mounts in this case are designed to be in double shear. This adds strength to the design, while also increasing rigidity throughout the mounting section. This idea was influenced by Formula SAE Racing regulations ("SUSPENSION AND STEERING ", 2023), which is for a performance series where students build various vehicles competing in performance-orientated tests. As this project has a basis around performance, this was deemed sufficient.

In this sense, in terms of suspension design, it was decided that double wishbone suspension would be used on the front of the vehicle, and a single-axis point-type of suspension on the rear wheel. The decision to adopt double wishbone suspension allows the front wheels to lean with the rider's movements, or in this case also the steering. An example of this is shown in Figure 21 below, with the image on the right depicting the suspension layout when the rider is leaning:

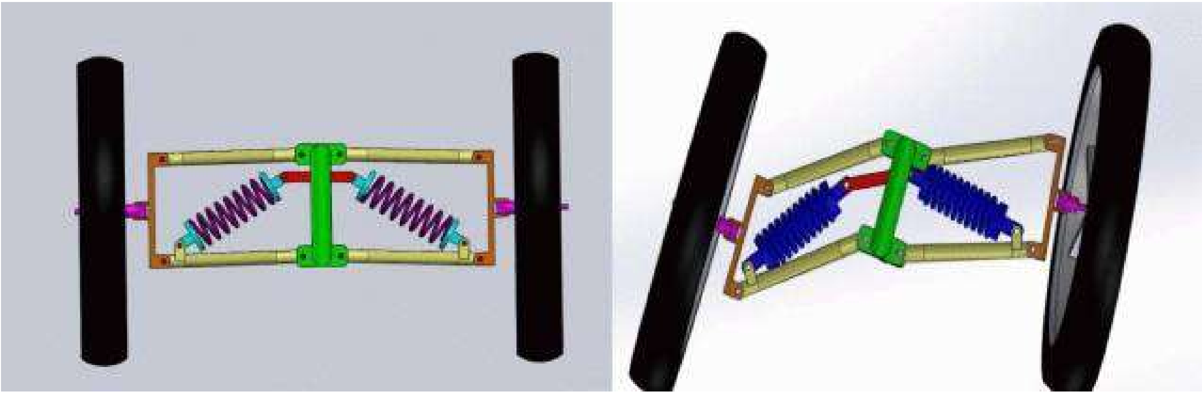


Figure 23: Example of Articulating Double Wishbone Suspension, Source: (K, 2023)

The concept also features a single-axis pivot articulation feature. In this instance, the front of the vehicle is connected to the rest of the vehicle via bearings which create a single axis of rotation, like what is seen when connecting front bicycle forks to the main frame of a bike. This is pin-loaded, which allows the front of the concept to articulate more freely if the point of the pivot doesn't have the pin in. An example of this is shown in the Figure below:

Figure 24: Example of the Single-Axis Point of Pivot – Pin Locked (Close Top View)

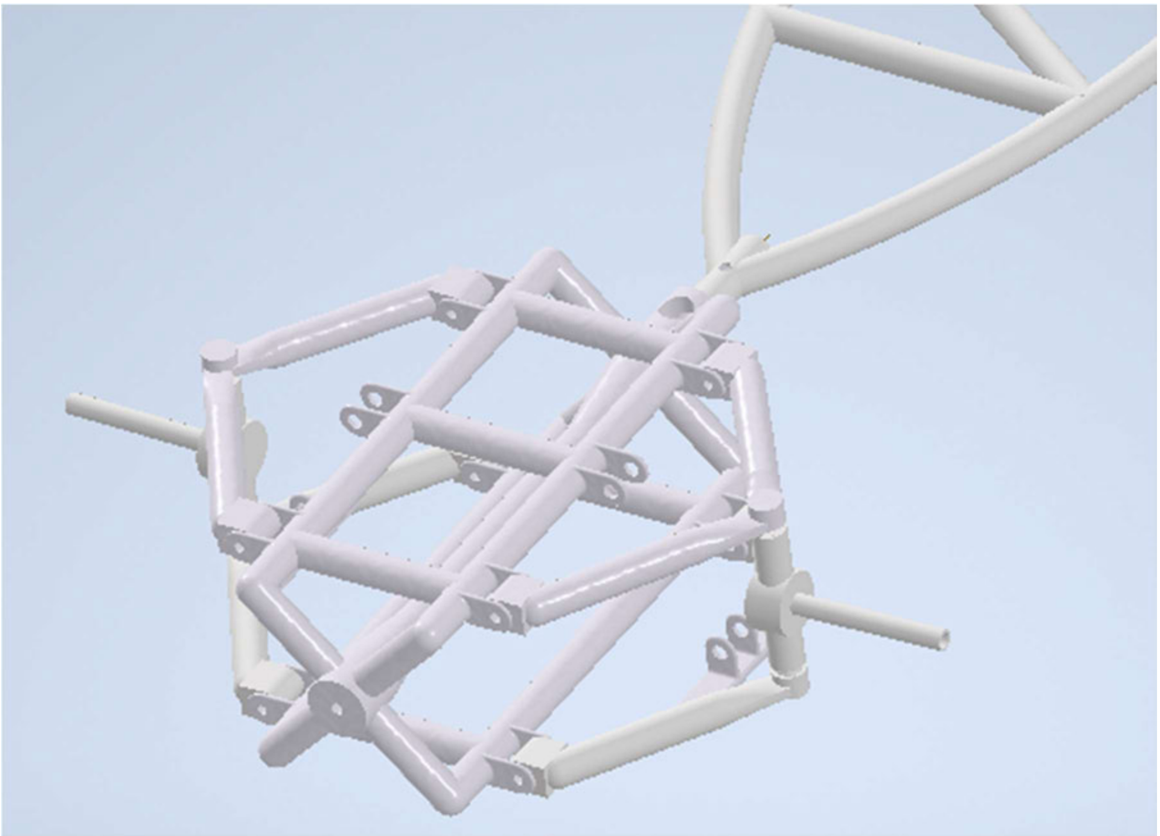


Figure 25: Overview of Front-End when Pin Locked

Figure 26: Example of Single-Axis Point of Pivot – Pin Unlocked

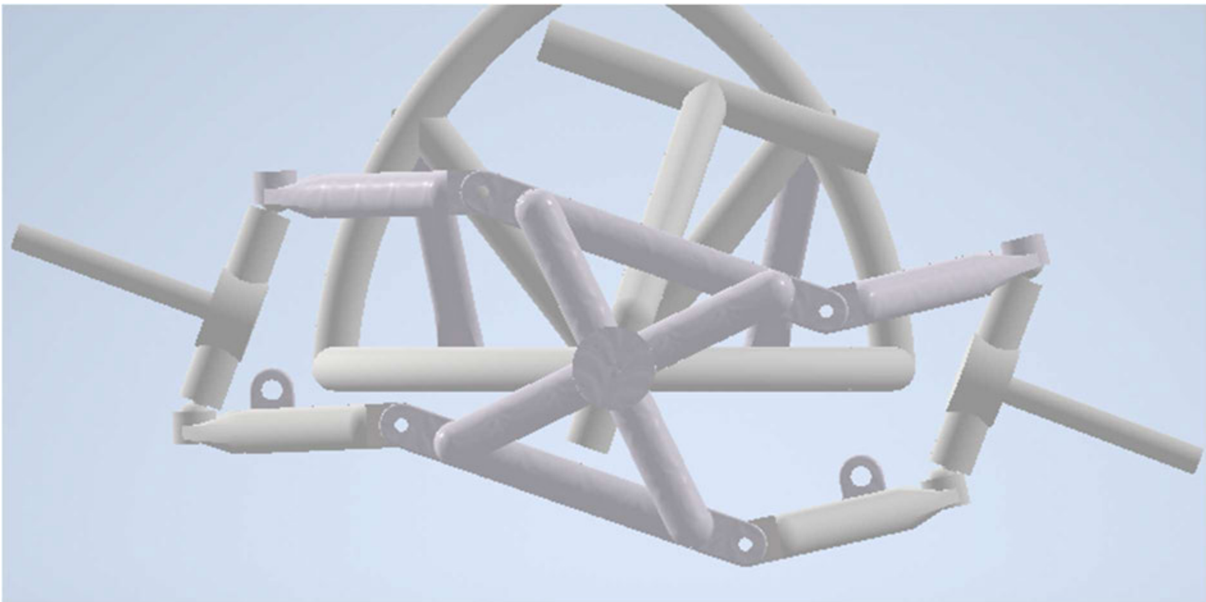


Figure 27: Example of Pin Unlocked and Pivoting

Figures 25 and 27 above show the pin unlocked and locked variants. This allows the front end to have increased articulation, however, if locked, it will act as a normal recumbent tricycle.

The steering for the concept was decided to be a rack and pinion-type set-up, however without the rack and pinion. In this sense, the steering is connected directly to the steering shaft which then extends out to the wheel knuckles through adjustable tie rods. The tie rods in this instance are modelled as one piece however theoretically these are adjustable on either end using locking nuts. An example of this system is shown below, with the steering system itself also shown.

Figure 28: Example of Adjustable Steering Tie Rod, Source: (*12" Aluminum Steering Tie Rod with Ends Kit Set for Go Kart Racing Cart Parts*, 2024)

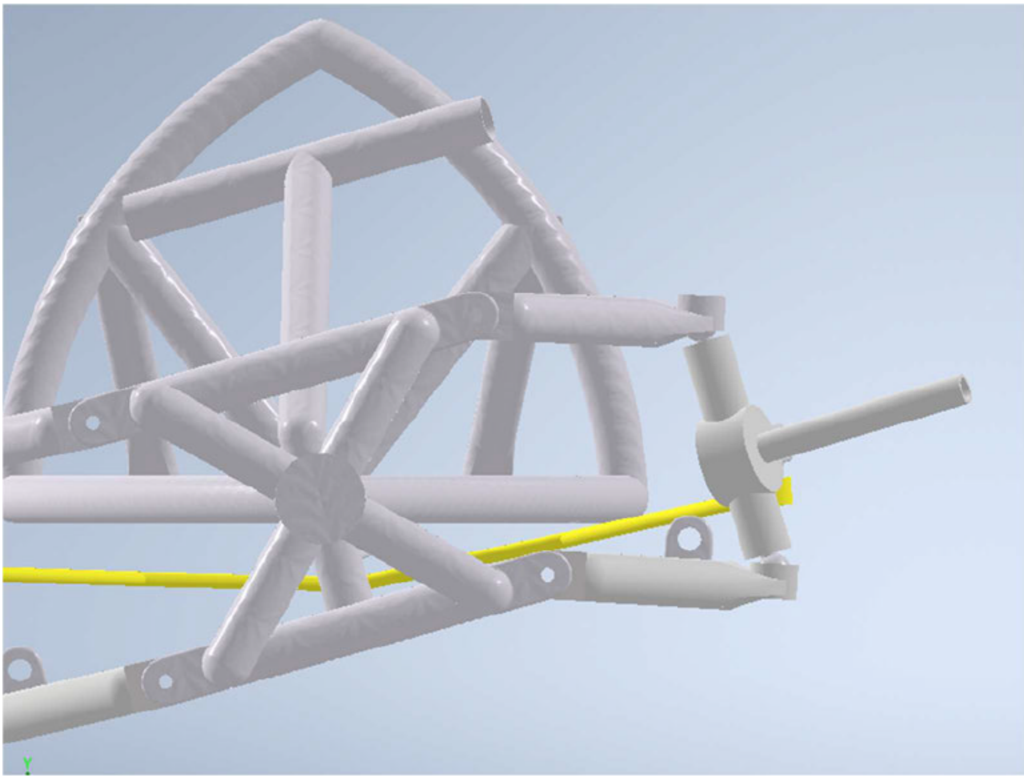


Figure 29: Model of Suspension and Steering, Turning, Pin-Unlocked and Articulating (Front View)

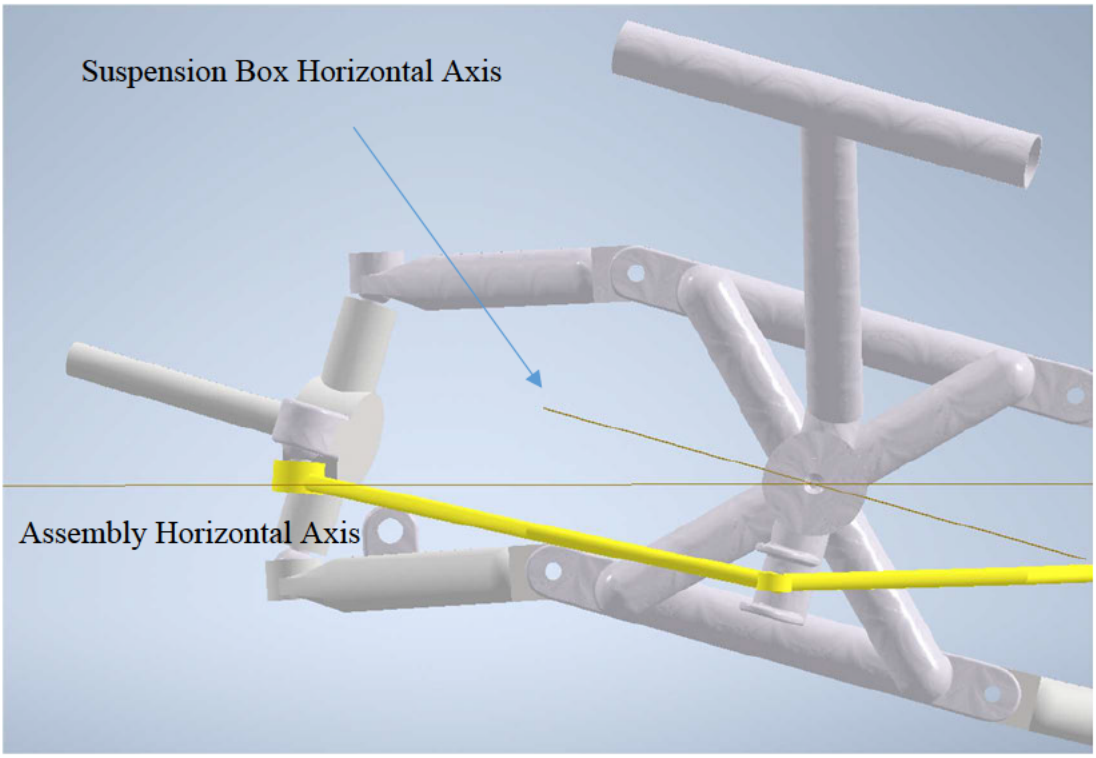


Figure 30: Model of Suspension and Steering, Turning, Pin-Unlocked and Articulating (Back View)

The figure above shows the model with the suspension box pin-unlocked, articulating and turning right. The two horizontal axes are shown to display the difference in angle between the suspension box and the horizontal plane, therefore showing the magnitude of articulation. The tie rod ends are linked to the steering knuckles through ball joints, allowing multiple axes of rotation while maintaining one axis fixed such that the steering can flex with the suspension.

In terms of suspension, it is assumed that throughout all concepts, the 'Fox DHX Factory Series Coil Shock' will be implemented. This shock has a 185mm eye-to-eye length, which fits perfectly into the front of the concept, while allowing adjustability through ride height, as well as Compression and Rebound Damper adjustability(*Fox DHX Factory Series Coil Shock*, 2024), which softens or harshens the rate at which the shock absorber compresses and rebounds respectively. The spring to be used is entirely dependent on the rider, as different riders will use the concept for varying levels with varying rider weights, and as such the spring will be factored into cost analysis with a generalised price for the suspension assembly, however no calculations for spring rate were undertaken.

In terms of the rear of the concept, a similar design to what is currently seen on mountain bikes is seen for the rear forks, this being a lower and upper control arm mounted to the rear bar of the main body. This allows the rear to have a single point of articulation while also minimising the costs involved. The model for this is shown in Figure 31 below:

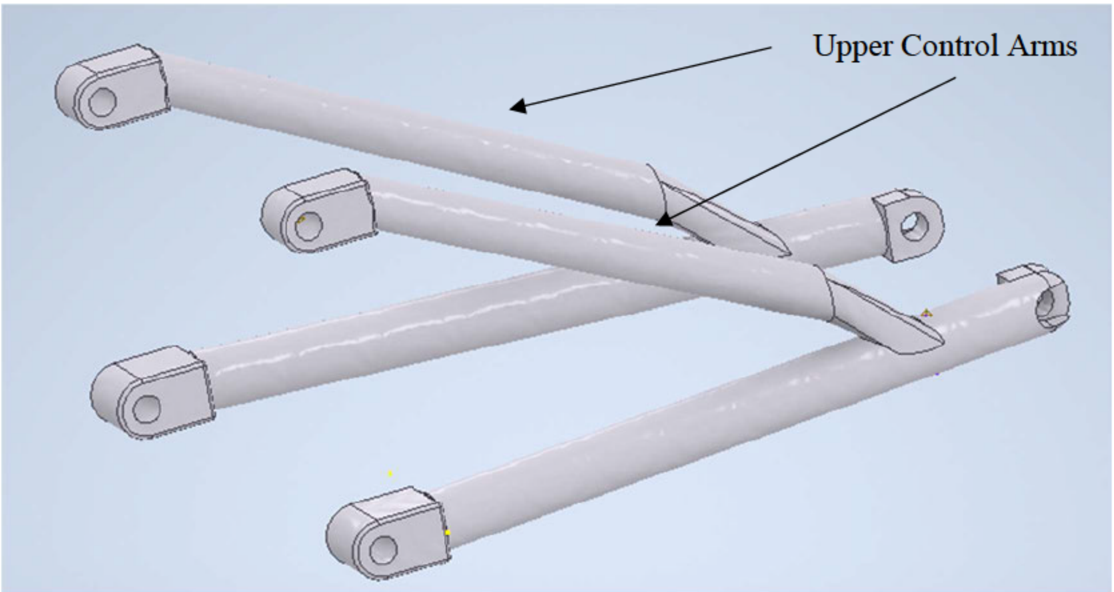


Figure 31: Modelled Rear Forks

The suspension for this system is designed to have two spring and damper assemblies using the same system as previously mentioned, this being one on each upper control arm between the mount on the rear bar and the wheel mount. This model has been taken from an analysis in which suspension was deemed as not required as performance testing was being conducted.

In terms of the chassis itself, a half-oval shape was adopted, such that the chassis is wide enough for the rider to sit on, however, becomes narrower as it reaches the front of the concept. This allows for the single axis point of pivot while also giving the rider enough space to sit comfortably. An example of the rear forks and chassis is shown below:

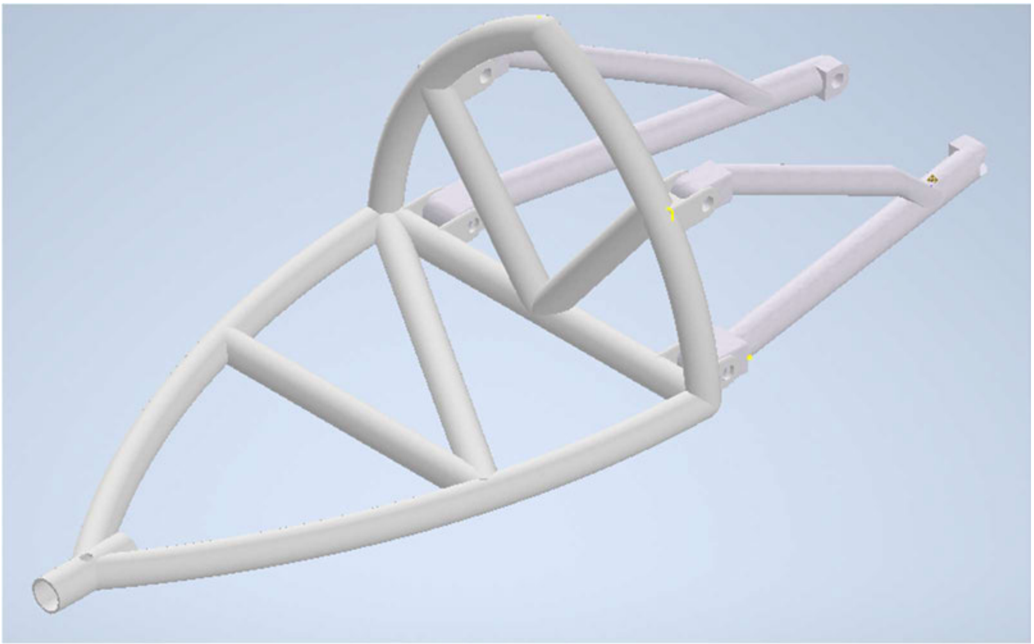


Figure 32: Main Chassis and Rear Forks

Displayed above is the main chassis alongside the rear forks. A cross brace was also added to the main chassis, alongside a support bar where the rider and motor are set to be positioned. This adds added support for where the centre of gravity should be on the vehicle as it is right underneath the rider.

In terms of rider ergonomics, it is assumed that the concept will have an adjustable seat, this being forward and backward, alongside leg rests mounted on top of the suspension box. This allows the rider's legs to move with front-end articulation or when the vehicle is leaning. The motor and battery are thought to be mounted behind the rider's seat, allowing for a much more balanced weight distribution from front to rear. In terms of handlebars, it is thought that any set off the shelf can be used depending on the rider's preference, alongside any slip-over throttles that can also be found in stores.

3.4. Cost Analysis on Chassis and Initial Concepts

Now that the chassis is modelled, we can do a cost analysis on the chassis and subsystems surrounding it to determine the cost of each chassis with differing materials, as well as the cost of both sub-system combinations to add to them. In this sense, the three materials to be compared will be that of Aluminium 6061, Steel, and Titanium. A rough estimate in terms of cost can be derived from the chassis' weight according to the modelling software used. Once this is found, the cost of the chassis can accurately be estimated for each material. It is noted that across the three materials, the wheel knuckles and ball joints will remain the same material, these being cast steel and stainless steel respectively.

The costs of each were determined through material weight, in saying this, as the chassis is mainly tubing, which is also usually sold per meter, calculations must be conducted such that the cost of each per kg is obtained.

3.4.1. Costs of Each Chassis Material

For Aluminium, the cost can be determined through research on current market suppliers of Aluminium 6061. In this case, the price for 6.5 metres of Aluminium 6061 pipe with the measurements specified through modelling, is said to be 121 AUD. (*Tube 32mm X 3mm X 6.5mtr Milled*, 2024)Dividing this by 6.5 to get cost per metre, equates to 18.62 AUD per metre. To then convert this quantity to weight, the weight of 1 metre of the pipe can be obtained, which then can be equated to give price per kilogram (kg). Through research, in the specified measurements used, the weight for 1m of the Aluminium 6061 pipe can be seen as 0.72682 kg (*Aluminium Tube Weight Calculator*, 2024) (5 Significant figures used for calculation accuracy). Therefore, if the price per kg is 18.62 AUD, this can be divided by the value given for weight which will give the price per kg. As such, this equates to 25.62 AUD per kg.

For 440C Steel, the same process can be followed to obtain the price per metre, and then the price per kg. In this case, with the correct dimensions, the pipe is seen as being 64.91 AUD per 6.5m. Dividing the cost by the length it equates to 9.98 AUD per metre. (*Round Steel Pipe 6.5 Metres*, 2024)The weight of 1 metre of the metal is then researched as 2.14 kg. (*Metal Weight Calculator*, 2024a)Now, dividing the price by the weight equates to 4.66 AUD per kg.

For Titanium, the same process can again be followed to obtain the price. In this case, the cost of Titanium with the same tube measurements is 51.38 AUD per 0.5m or 102.76 AUD per metre. (*1PC Titanium Tube TA2 (OD) 32mm X 3mm Thickness Ti Round Tubing Tubes 50cm (L)*, 2024)The weight of the specific Titanium per metre is said to be 1.226 kg. (*Metal Weight Calculator*, 2024b)So, using this, dividing the price by the weight gives 41.91 AUD per kg.

Now, using these prices per kg, Autodesk Inventor can be used to determine the system's weight in each material, and therefore the price of the chassis. Notably, the weights displayed reflect only that of the chassis, it does not include knuckles or ball joints. Each respective weight is shown in Table 2 below:

Table 2: Chassis Material and Each Respective Weight

Material	Weight (kg)
AL6061	8.569
Steel 440C	24.913
Titanium	14.313

Using this data, the approximate cost of materials for each chassis can be estimated. This is shown in Table 3 below:

Table 3: Cost of Chassis in each Material

Chassis Material	Cost (AUD)	Total (AUD)
Aluminium 6061	8.569*25.62	219.54
Steel 440C	24.913*4.66	116.09
Titanium	14.313*41.91	599.86

As seen in the table above, the most expensive was deemed to be Titanium, as it was just under 600 AUD. This is then followed by Aluminium at just under 220 AUD and Steel at just over 116 AUD. In this sense then, a large comparison can be made between Aluminium 6061 and Steel, as the Steel is almost half the price of the Aluminium, however over double the weight, as seen in Table 2.

3.4.2. Costs of Each Sub-system

When analysing cost, each initial sub-system needs to be considered as well to gain an accurate insight into the cost of the concept. Cost breakdowns of each initial concept, these being performance-orientated, and cost orientated are shown below.

Initial Concept 1 – Performance Orientated

Table 4: Cost Breakdown of Performance Orientated Subsystem

Performance	
Part	**Cost (AUD)**
7kw Brushless Motor	256.54
29 Inch Wheel	630
Tyre	270
Drivetrain	200
Brake Rotors	295.98
Brake Calipers (220mm)	278.97
Brake Lever/Lines	180
Suspension	2400
Battery	1350
Seat	300
Labour	4000
Total	10161.49

Initial Concept 2 – Cost Orientated

Table 5: Cost Breakdown of Cost-Orientated Subsystem

Cost Effective	
Part	**Cost (AUD)**
5kW Brushless Motor	166
27.5 Inch Wheel	300
Tyre	270
Drivetrain	200
Brake Rotors	271.5
Brake Calipers (180mm)	278.97
Brake Lever/Lines	180
Suspension	2400
Battery	1350
Seat	300
Labour	4000
Total	9716.47

When analysed, it was extremely obvious that a large price difference comes from the wheel size, this being 27.5 inches compared to 29 inches, with a difference of over 300 AUD. There are also slight variations in price within other components however they are insignificant compared to the wheel size. Notably, labour and manufacturing costs to build the concept were assumed as approximately 4000 AUD. This is purely an approximation and does not accurately reflect real-life costs.

3.5. Finite Element Analysis (FEA) on Chassis and Componentry

For the chassis and componentry, it was important to determine and prove that the systems would withstand the forces necessary to prevent catastrophic failure, alongside a reasonable product life span. In this sense, FEA can be conducted on individual components with differing materials, showing that each component will withstand the forces necessary when in operation. Von Mises Stress (VM Stress) and Displacement were the main methods of determining the sufficiency of each component and material variant. Alongside this, the detailed drawings for each component can be found in Appendix B.

3.5.1. FEA of Front Control Arms

The Front Control Arms are the arms extending from the front suspension box to the wheel knuckles, these being a lower and an upper (both shown below). These, aside from the rear forks are arguably one of the most important parts aside from the suspension, as they are directly absorbing shock and impact force coming from using the vehicle.

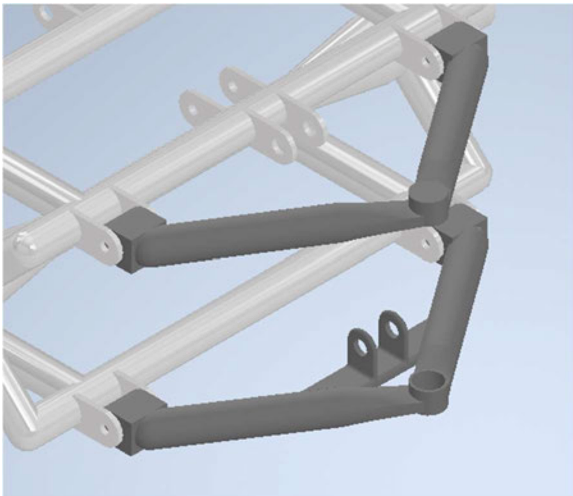


Figure 33: Upper (Top) and Lower (Bottom) Control Arm Models

Assuming a weight distribution from section 3.3.1. of 40% to the front, and 60% to the rear, the force can be adequately tested using the steering knuckles and ball joints to produce a more realistic analysis. Throughout the analysis, it is noted that as both sides of the suspension box are symmetrical, as well as both sides of the control arms, it is deemed that only analysis for one side, in this case of the control arms, is necessary as both sides are identical in design.

In terms of the force used, the maximum force the concept is said to undergo during operation is 2G or 2 times its overall weight, this being both system and rider weights to amass total weight. Also, from section 3.3.1. it displays the maximum force experienced by the concept as 2844.9 Newtons. Utilising this force and weight distribution, the force can be calculated that will act upon each wheel mount, therefore giving a more realistic analysis. These calculations are shown below:

$$F_{Wheel} = \frac{F_{Total} * 0.4}{2}$$

Where:

- F(total) is the Total Force experienced by the system.
- F(wheel) is the Force applied on the centre axis of each wheel due.

As seen in the above equation, the force then gained from multiplying the total force by 0.4 (the weight distribution) is then divided by 2, as there are two wheels on the front of the concept.

This therefore equates to:

$$F_{Wheel} = \frac{2844.9 * 0.4}{2}$$

$$F_{Wheel} = 568.98\ N$$

This value was then applied to the analysis, and the necessary joints were constrained. It is important to note that for this analysis, the suspension has been locked using a solid bar of material that has been replaced where the suspension components are to be mounted. The idea of this is that if the frame can withstand the necessary forces without dampening, it will withstand them more effectively once dampened. An analysis of the control arms with the suspension bottomed out was also undertaken, which is displayed in Appendix B. For analysis, the hub was converted to cast steel as this will allow better transfer of force between the spline on the knuckle and the control arms. The spline is designed such that a 12mmx148mm hub can slide over it, through research this is said to be the nominal size for eMTB and MTB wheels. (*Shimano WH-MT620 12 Speed Micro Spline Rear Wheel*, 2024)The yield strength of the cast steel is said to be between '345 and 1345 MPa,' (*Cast Carbon Steels*, 2024)which will allow for an accurate analysis with forces being transferred elsewhere during analysis.

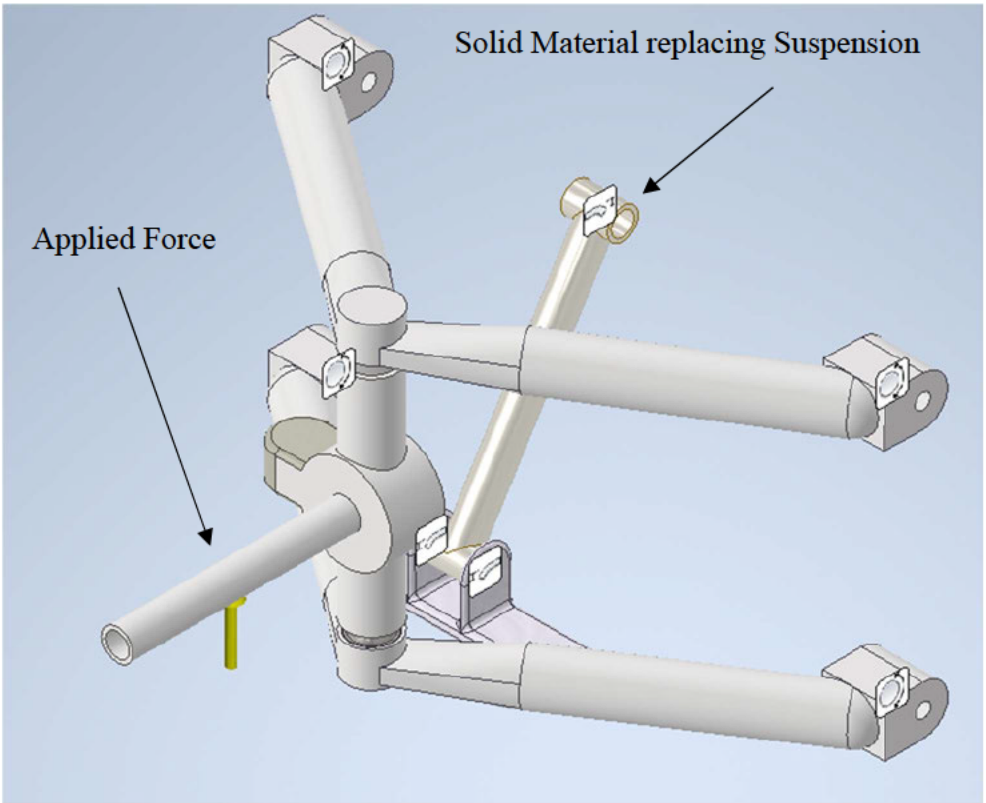


Figure 34: Set-up of FEA on Control Arms (Suspension Square and Locked)

FEA of Control Arms - Aluminium

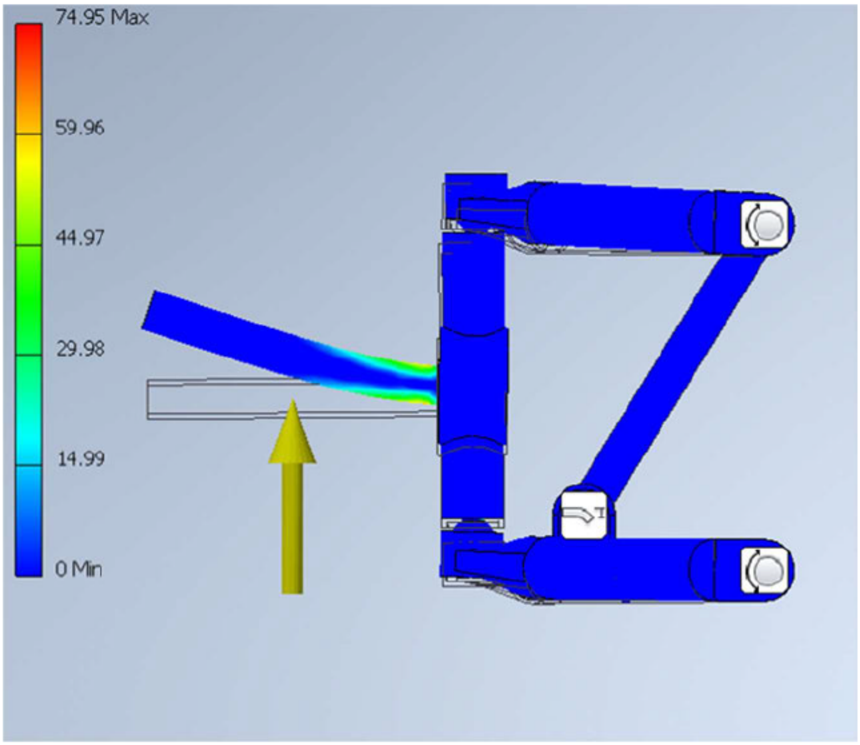


Figure 35: Von Mises Stress Throughout Control Arms (Front View)

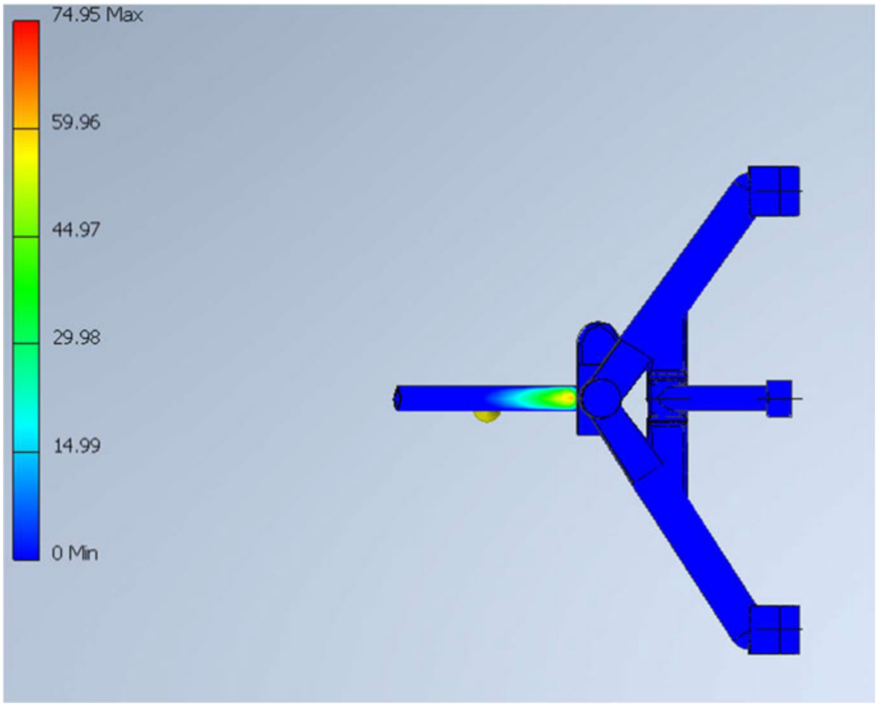


Figure 36: Von Mises Stress Throughout Control Arms (Top View)

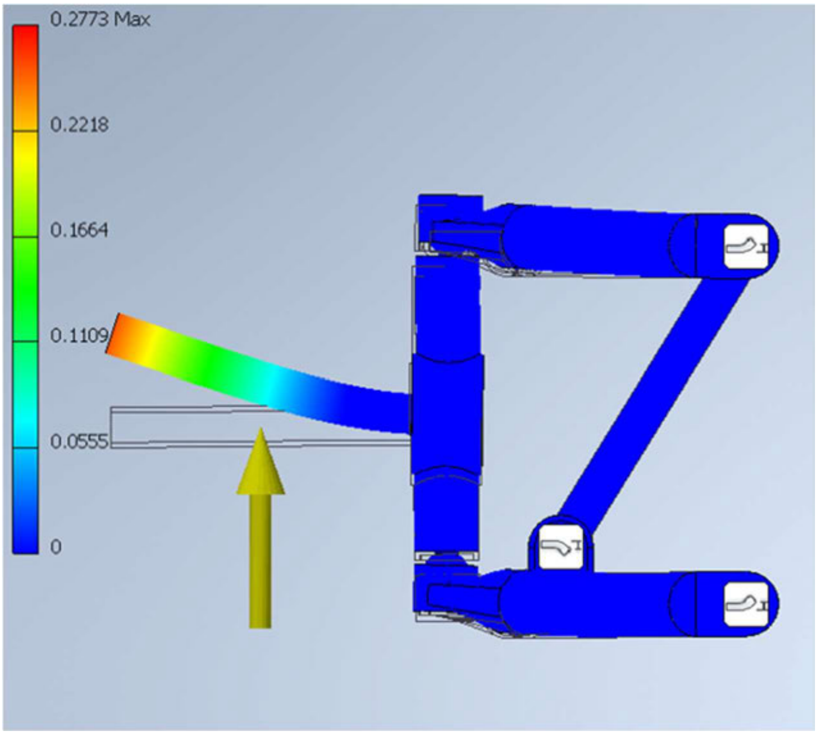


Figure 37: Displacement Throughout Control Arm (Front View)

As seen in the figures above, the main point of stress, in this case, is along the spline in which the wheel is to sit, this being with a maximum of 74.95 MPa when square and locked, with an approximate maximum of 0.28mm of deflection. The control arms themselves do not suffer from any noticeable stress through testing. The displacement is seen to be along the wheel spline, which shows that in terms of if failure is to occur, the joint between the knuckle and the spline will be the first to fail. In saying this, once the wheel and wheel hub are fastened to the spline this will decrease the stress seen in that location dramatically. This therefore proves that this system will be adequate for the design concept.

FEA of Control Arms – Steel 440C

The same process was followed identically to Aluminium, however, both control arms and the suspension replacement piece were changed to Steel, specifically 440C Stainless Steel for the sake of analysis.

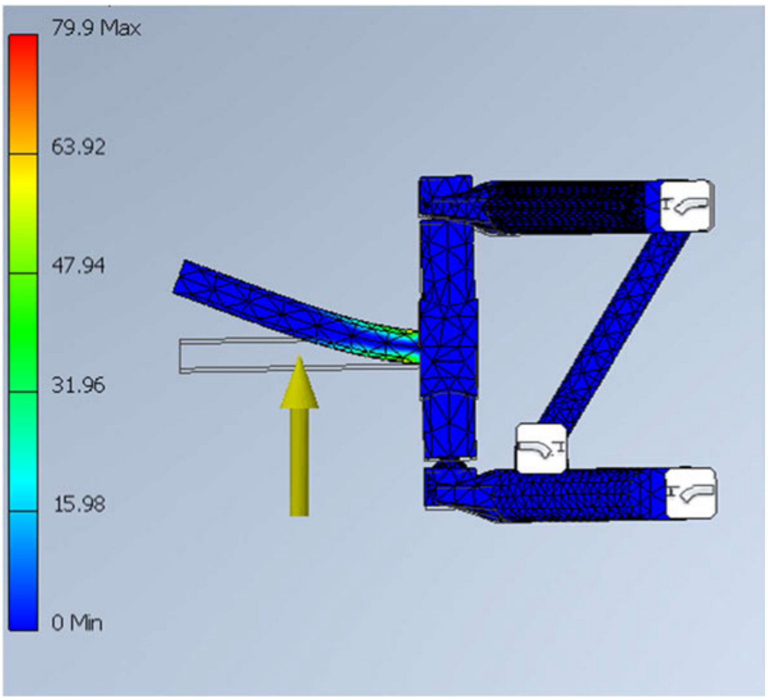


Figure 38: Von Mises Stress Throughout Control Arms (Front View)

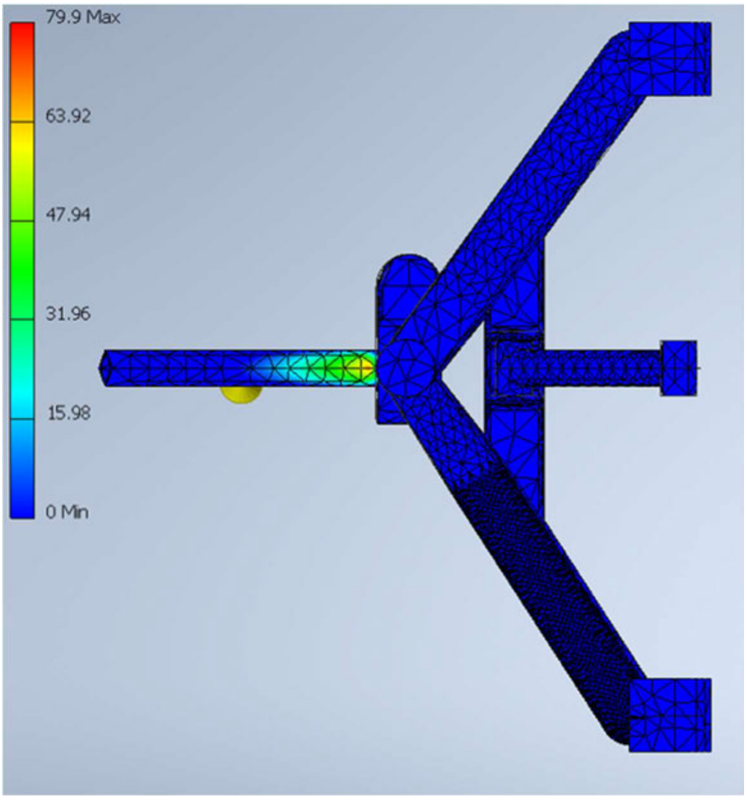


Figure 39: Von Mises Stress Throughout Control Arms (Top View)

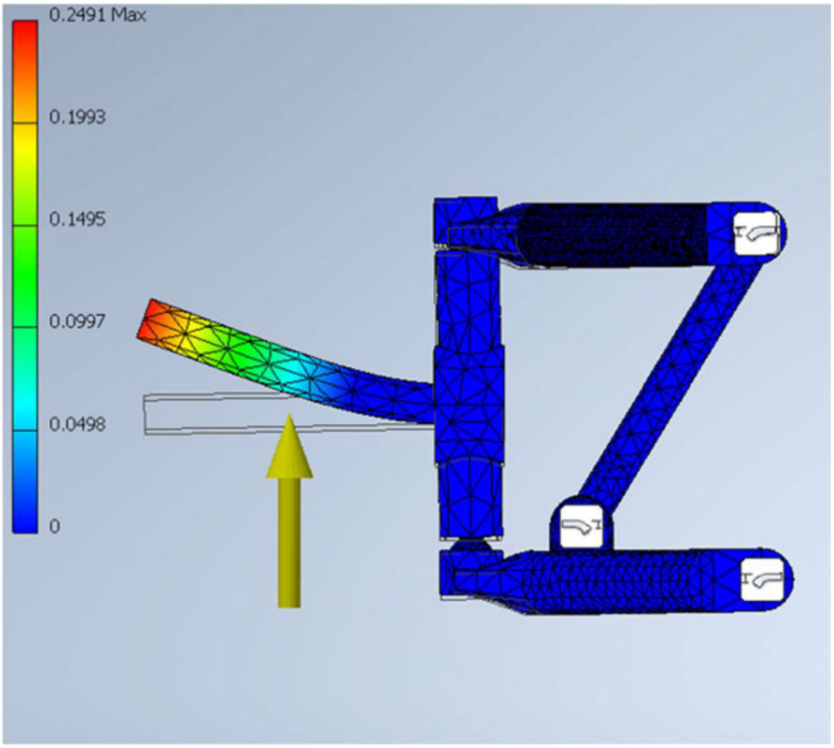


Figure 40: Displacement Throughout Control Arms (Front View)

For Steel, it is observed that the maximum VM stress seen throughout the analysis is lower than what was seen with Aluminium, this being a maximum of 79.9 MPa compared to Aluminium's 74.95 MPa maximum. The deflection is also much less at 0.25mm opposed to 0.28mm. In saying this, all the stress is located once again along the spline, and not on the control arms. In this sense, once again this proves that the control arms and knuckles are sufficient in performing the required task, as once a wheel is mounted the stress will reduce dramatically.

FEA of Control Arms – Titanium

The same process was repeated once again however now with Titanium.

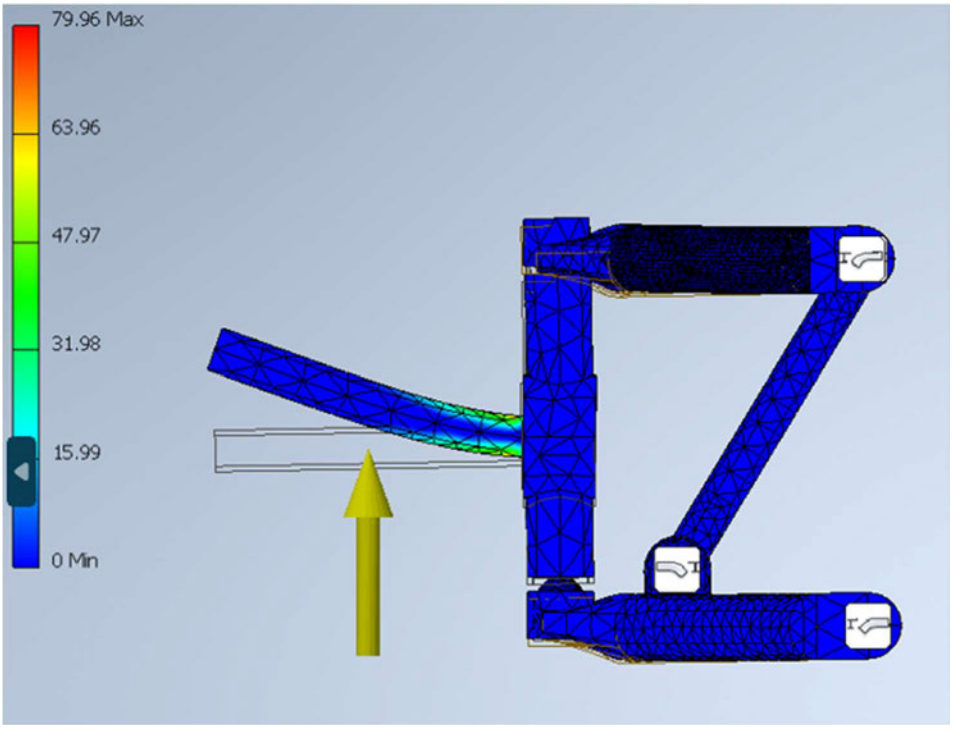


Figure 41: VM Stress Throughout Control Arms (Front View)

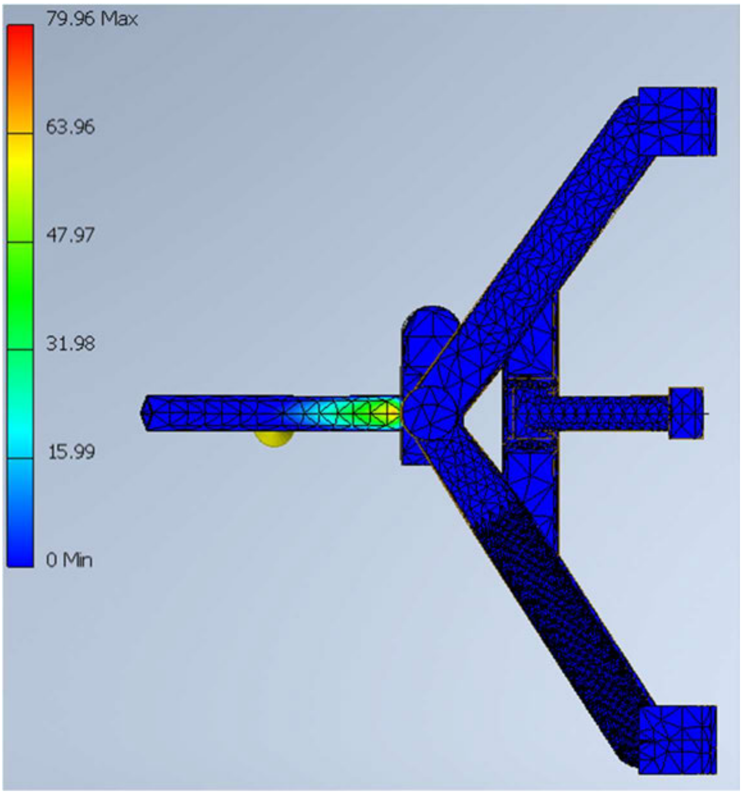


Figure 42: VM Stress Throughout Control Arms (Top View)

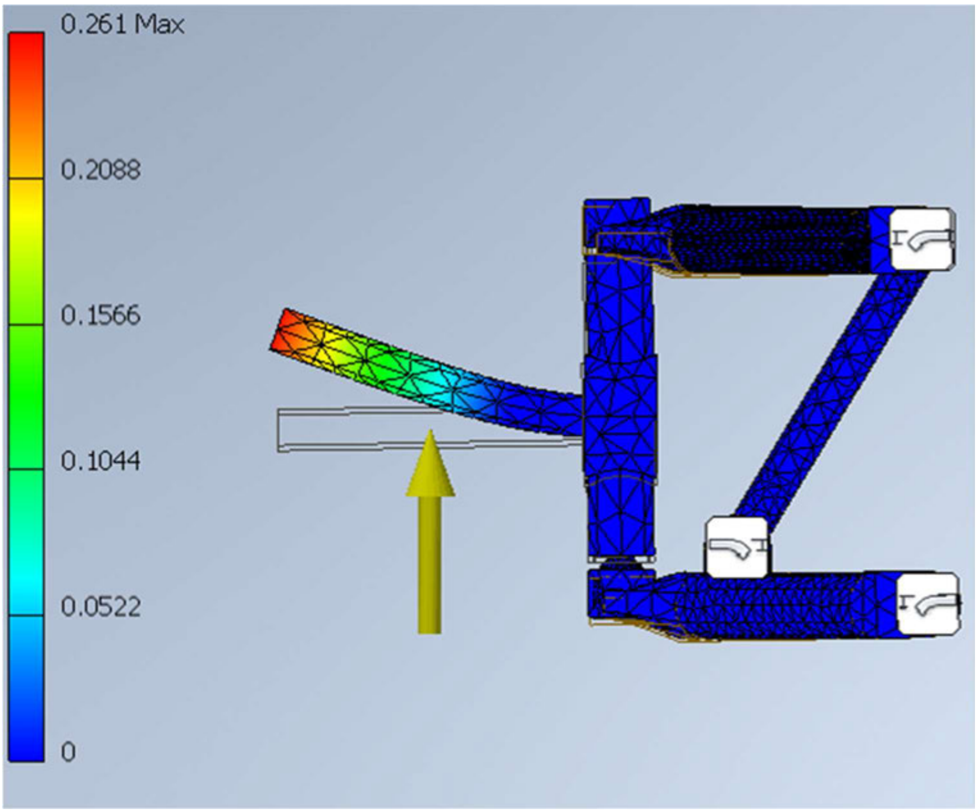


Figure 43: Displacement Throughout Control Arms (Top View)

The figures above show that the stress on the spline further is increasing, with maximum stress using Titanium of 79.96 MPa, however with a maximum deflection of approximately 0.26mm. In this sense then it can be said that the Aluminium distributes the force more efficiently compared to Steel and Titanium, as it is less rigid and therefore allows a significant amount more flexibility when compared to the more rigid Steel and Titanium. In saying this, the analysis above again shows that no significant stress is seen throughout the control arms or wishbone, aside from along the spline. Therefore, this material is also sufficient and can be used for this purpose.

3.5.2. FEA of Rear Forks

For the rear forks, a similar process was followed to what was seen for the front control arms. In this instance, the force on the rear forks must be calculated by multiplying the total force by the weight distribution towards the rear of the concept. This is shown in the calculations below:

$$F_{Whee} = 2844.9 * 0.6$$
$$F_{Whee} = 1706.94\ N$$

Therefore, this force was applied to the rear of the forks, using a straight bar mount replicating a high tensile fastener which will be used to fasten the wheel and hub assembly to the rear forks. This is shown in Figure 44 below:

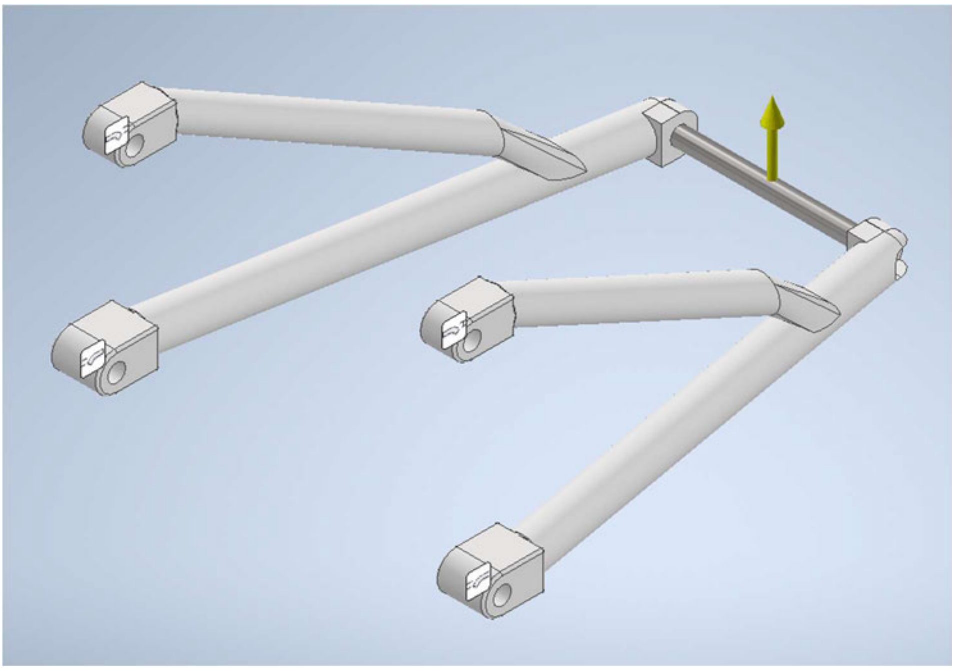


Figure 44: Set-up of FEA Model for Rear Forks

Using this model, like the previously seen control arms, analysis can be run to determine if this design will be sufficient. It is worth noting that similarly to the control arms, the suspension (designed to be on the upper control arms) has been replaced with the same material as the lower control arms, to lock the movement of the component. The theory behind this is the same as with the control arms, if the component can handle the force when solid it can handle the force more efficiently with suspension.

FEA of Rear Forks – Aluminium

As seen in the set-up for the FEA, the force was applied at the mounting point of the rear forks. The results of this analysis are shown below:

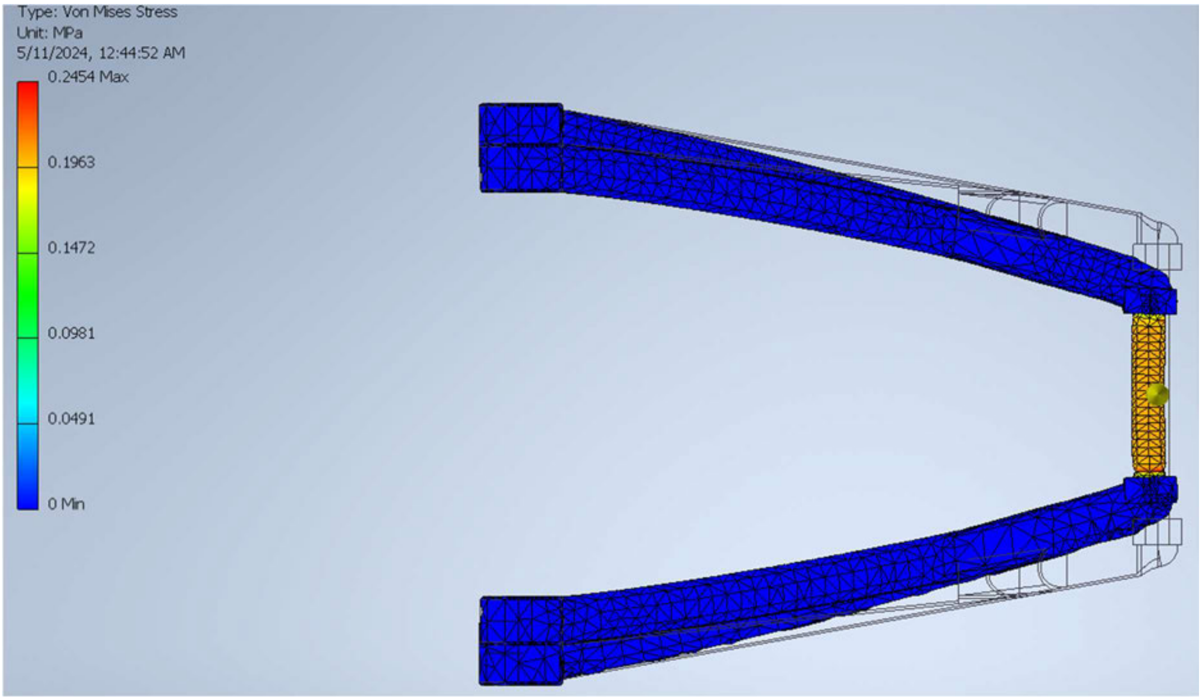


Figure 45: VM Stress of Rear Forks (Top View)

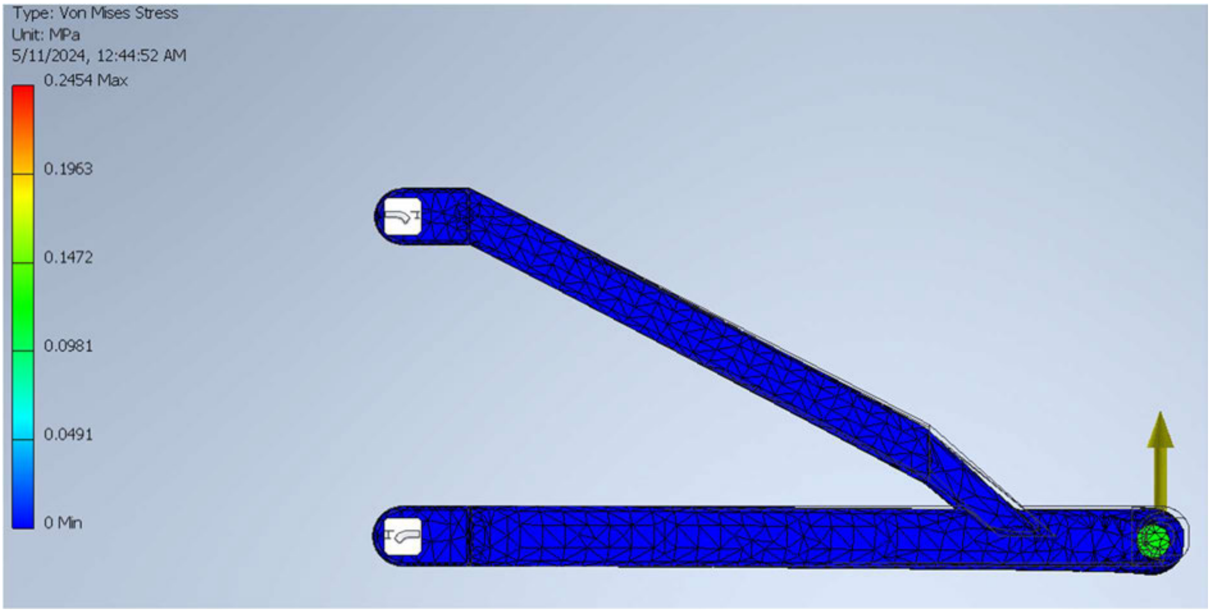


Figure 46: VM Stress of Rear Forks (Side View)

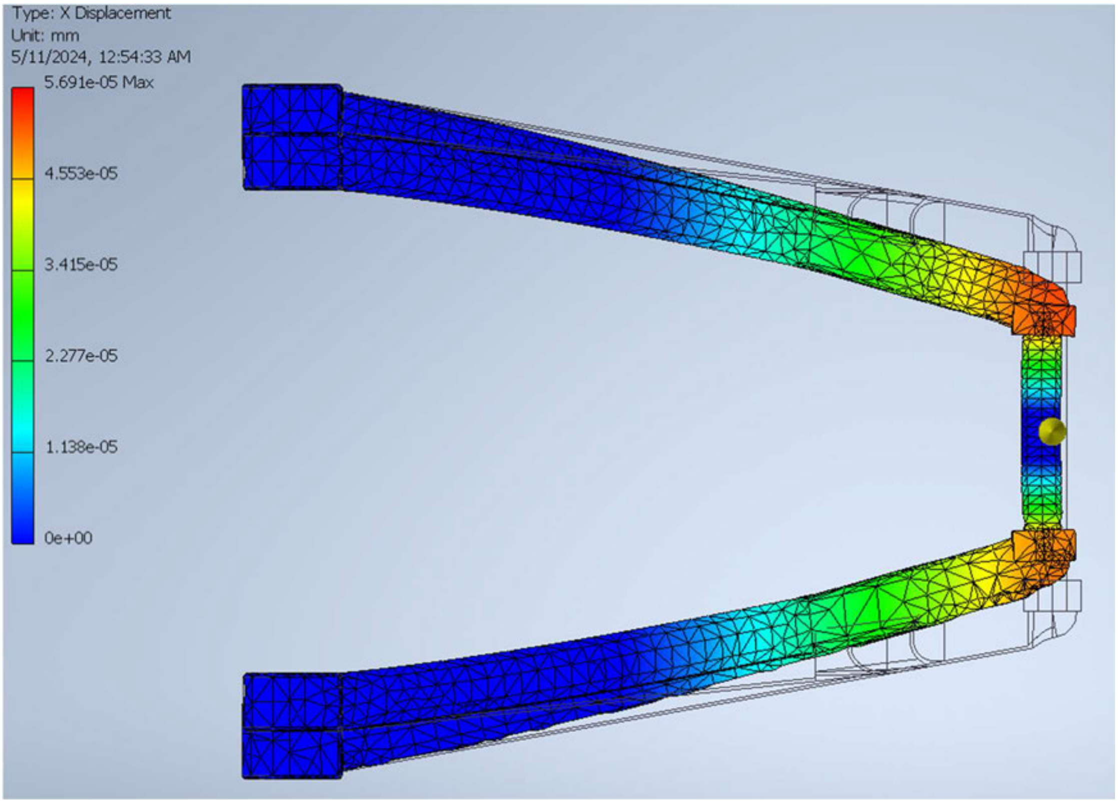


Figure 47: Displacement of Rear Forks (Horizontal Direction) (Top View)

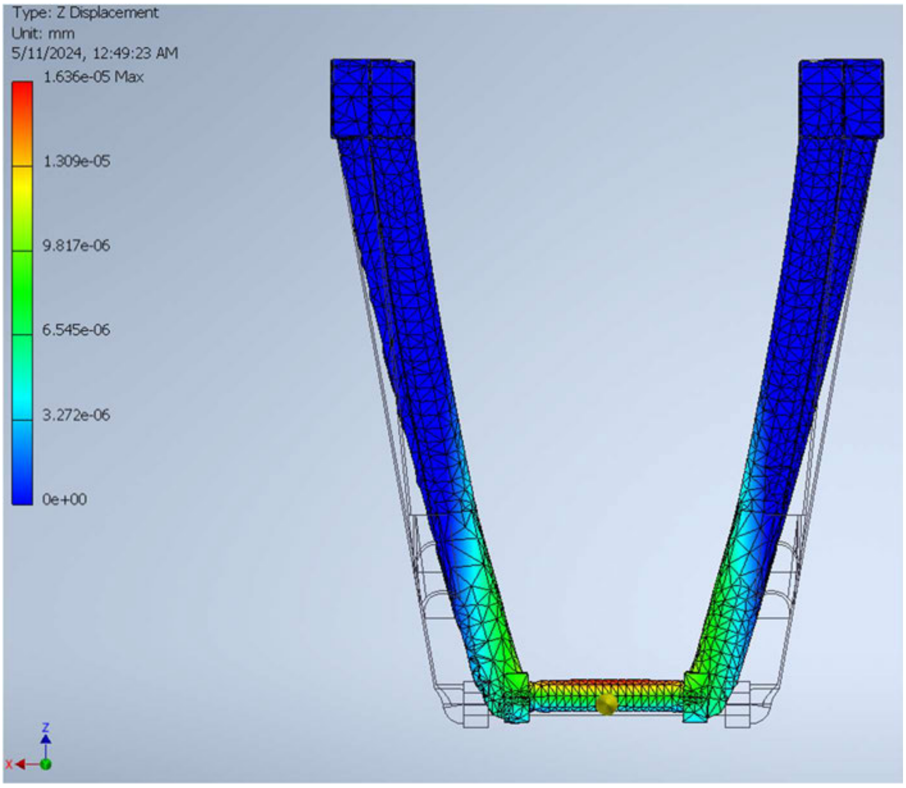


Figure 48: Displacement of Rear Forks (Forward Direction) (Top View)

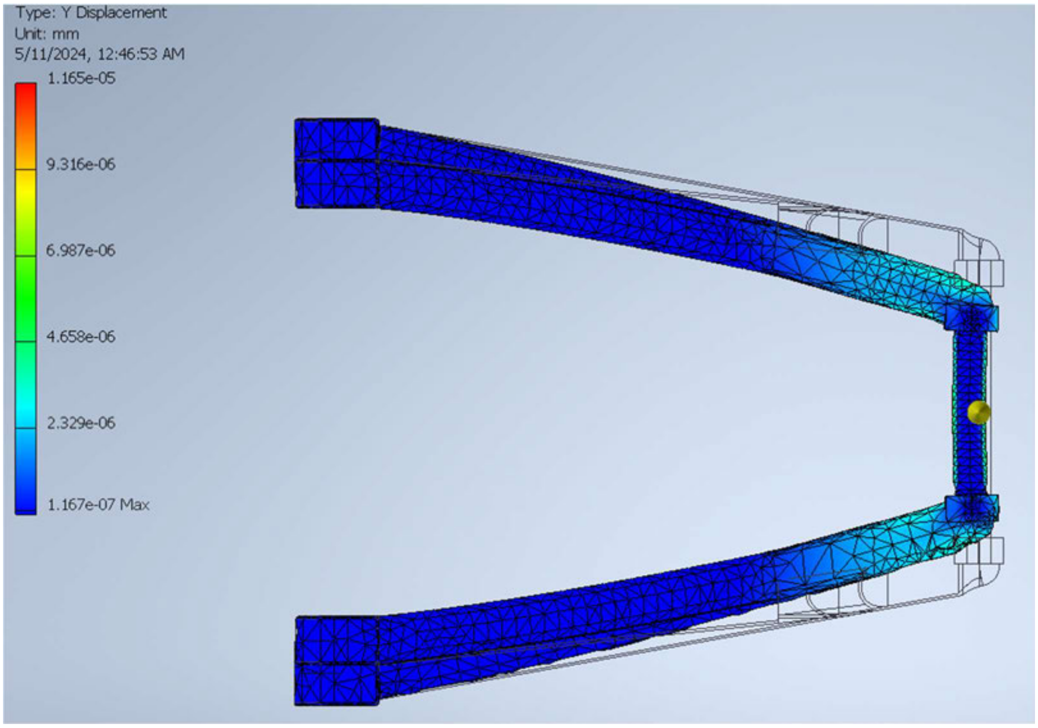


Figure 49: Displacement of Rear Forks (Vertical Direction) (Top View)

As seen in the Figures above for VM Stress and Displacement in Forward, Horizontal and Vertical Directions, the stress is mainly only seen on the fastener itself, as opposed to acting on the forks. This is reflected in the displacement Figures, as the displacement difference with that force applied can be described as insignificant and minuscule. In saying this, as it is Aluminium this like the control arms has less rigidity and therefore distributes the force more evenly as the Aluminium has more ductility or 'flex' so to speak. With that force applied the analysis shows that the componentry tested in Aluminium will be sufficient.

FEA of Rear Forks – Steel 440C

An identical process was done for Steel, with the only change in the analysis being the material tested. The results are shown below:

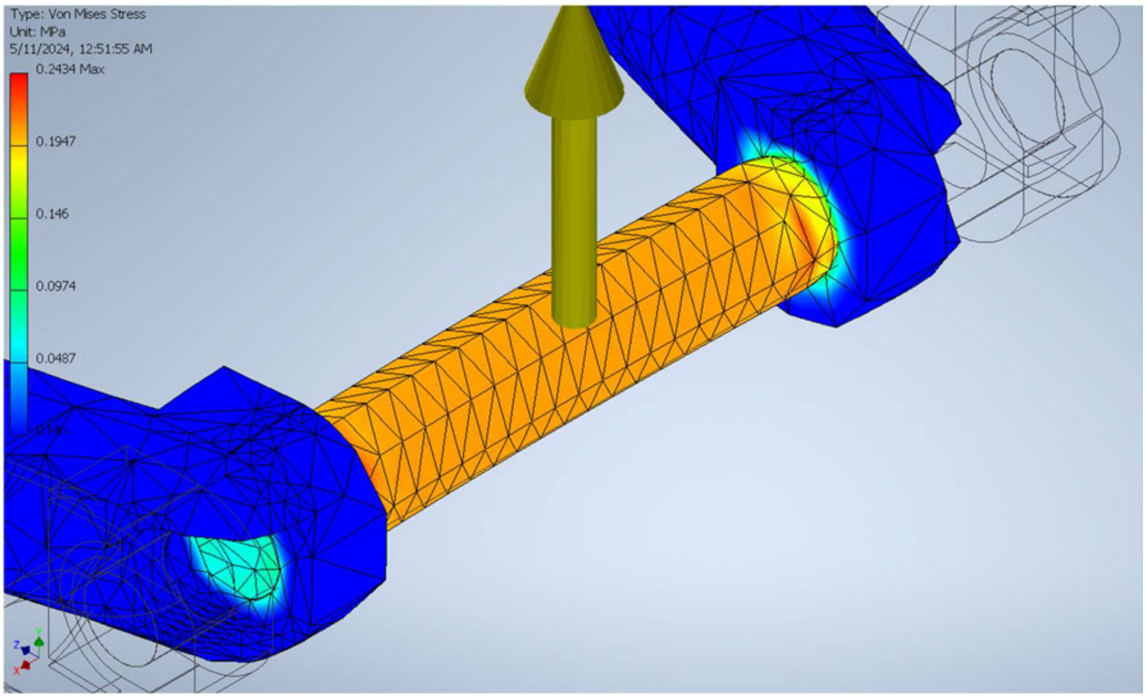


Figure 50: VM Stress Throughout Rear Forks (Angled View of Focus Point)

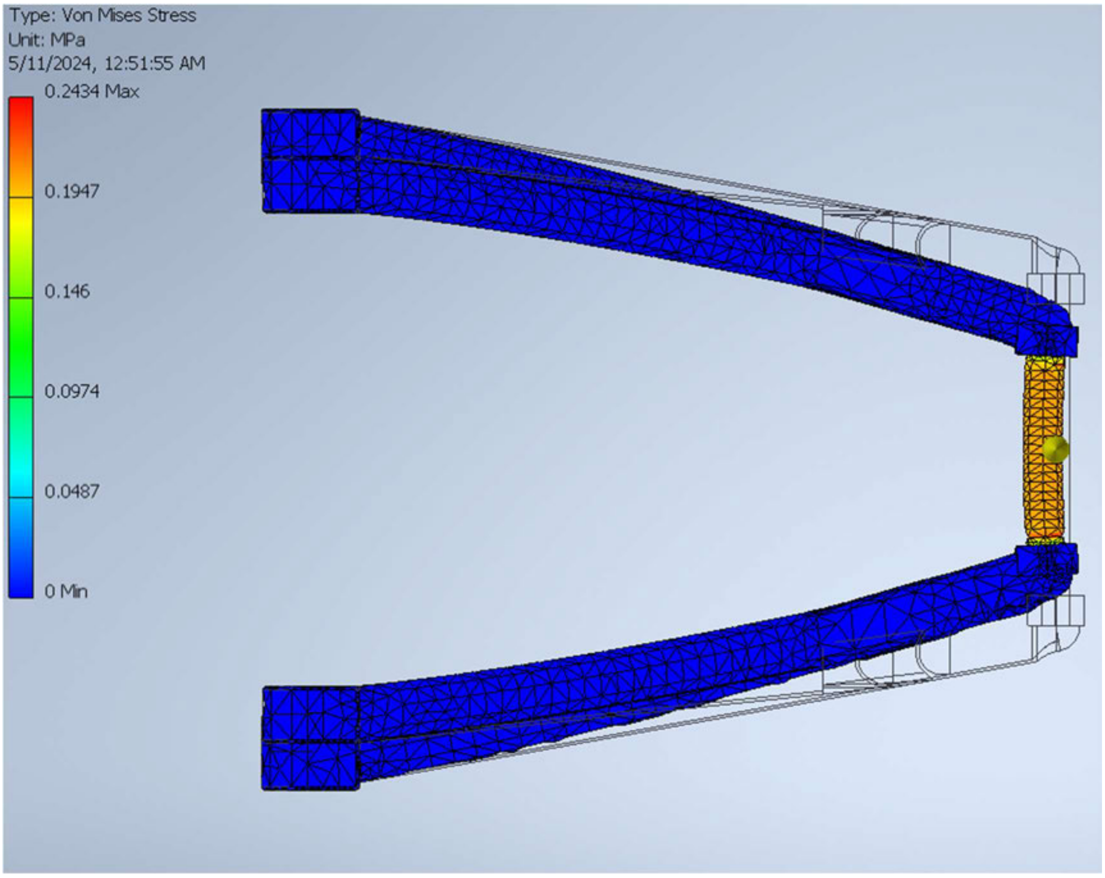


Figure 51: VM Stress Throughout Rear Forks (Top View)

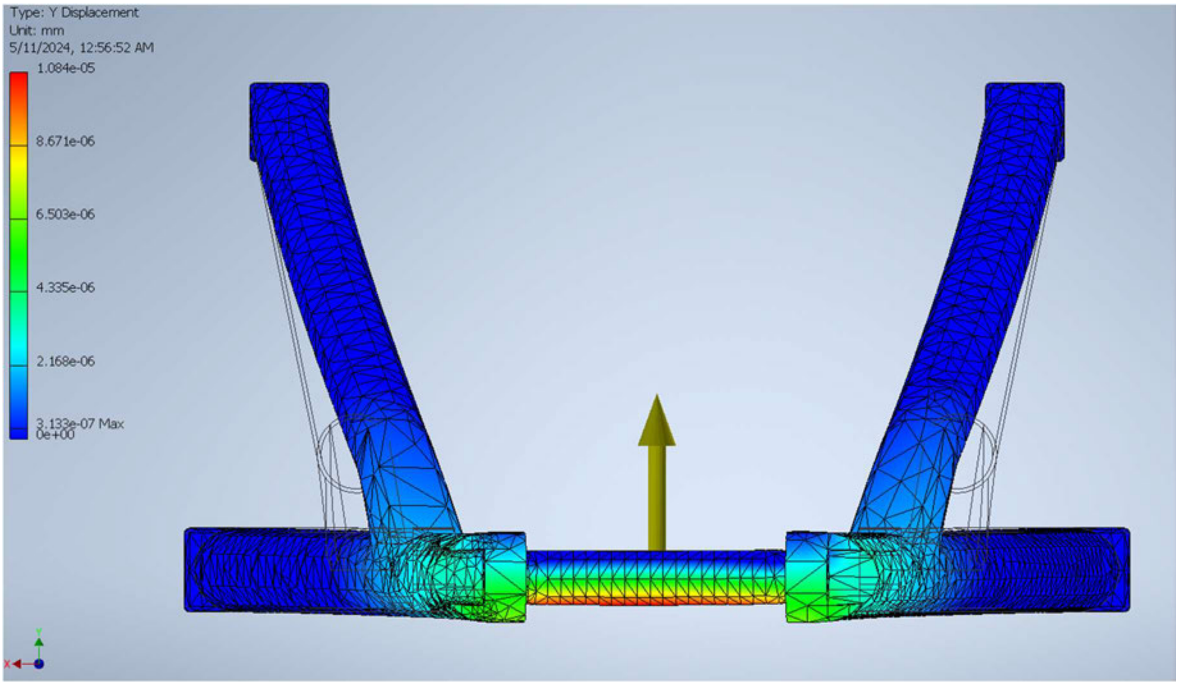


Figure 52: Vertical Displacement Throughout Rear Forks (Back View)

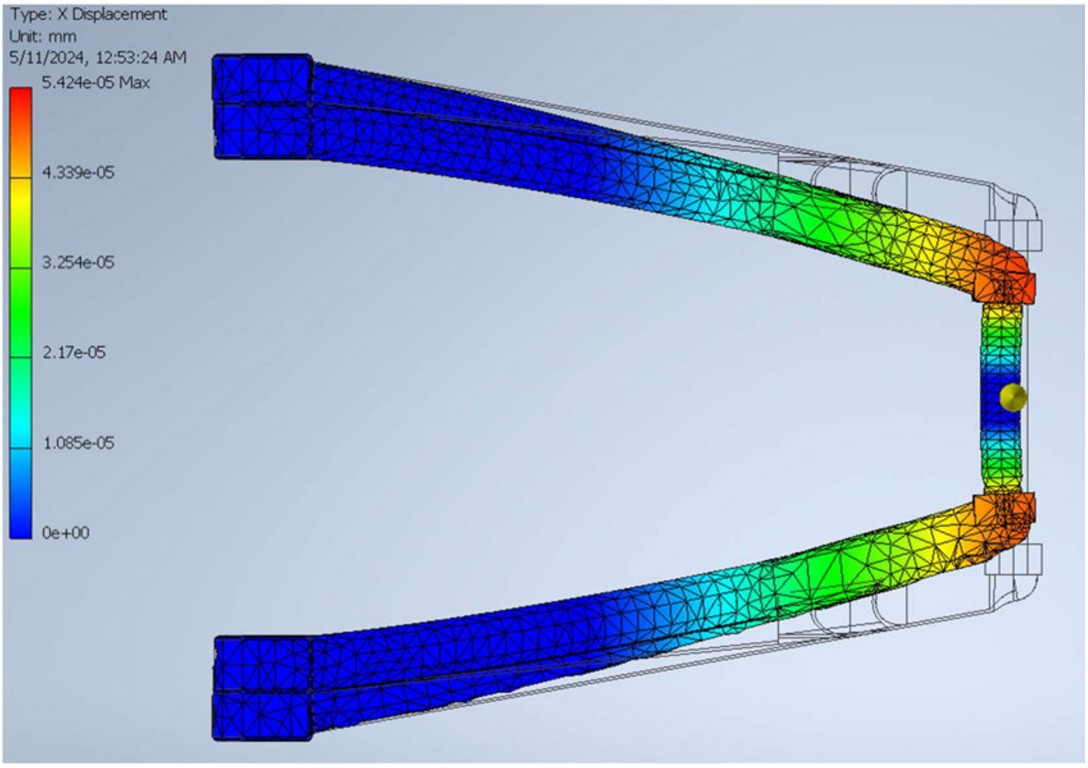


Figure 53: Horizontal Displacement Throughout Rear Forks (Top View)

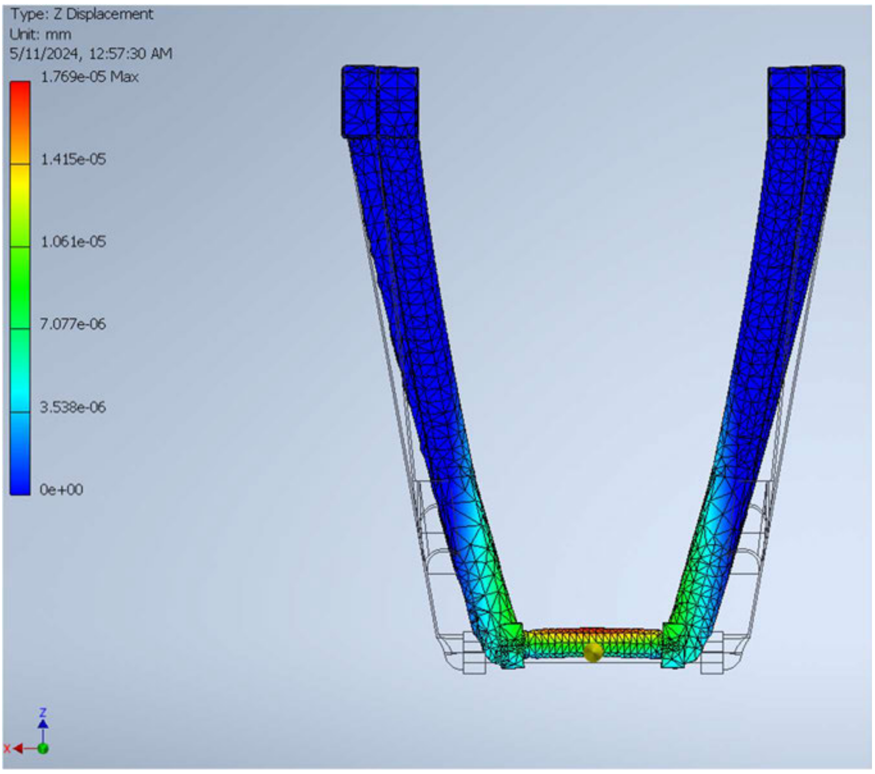


Figure 54: Forward Displacement Throughout Rear Forks (Top View)

Using Steel, it can be observed that the displacement in all directions is still minimal, with values very similar to what was seen with Aluminium, however, Figure 50 highlights a new focus point of stress, this being on the mounting point for the fastener. This makes sense, as Steel is a much more rigid metal than Aluminium, and therefore the stress will not be distributed as easily. In this sense, it creates a focussed amount of stress in this area, which from a practical point of view says that the fastener is likely to wear down the mounting point between the rear forks and the wheel until failure rather than distributing the force evenly.

FEA of Rear Forks – Titanium

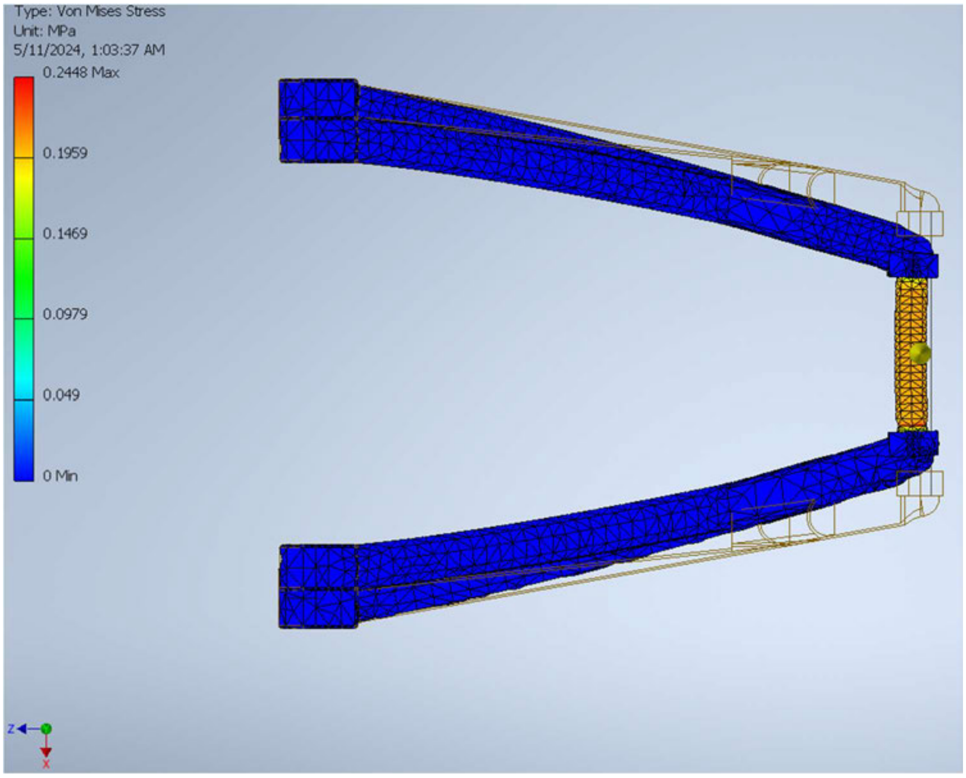


Figure 55: VM Stress Throughout Rear Forks (Top View)

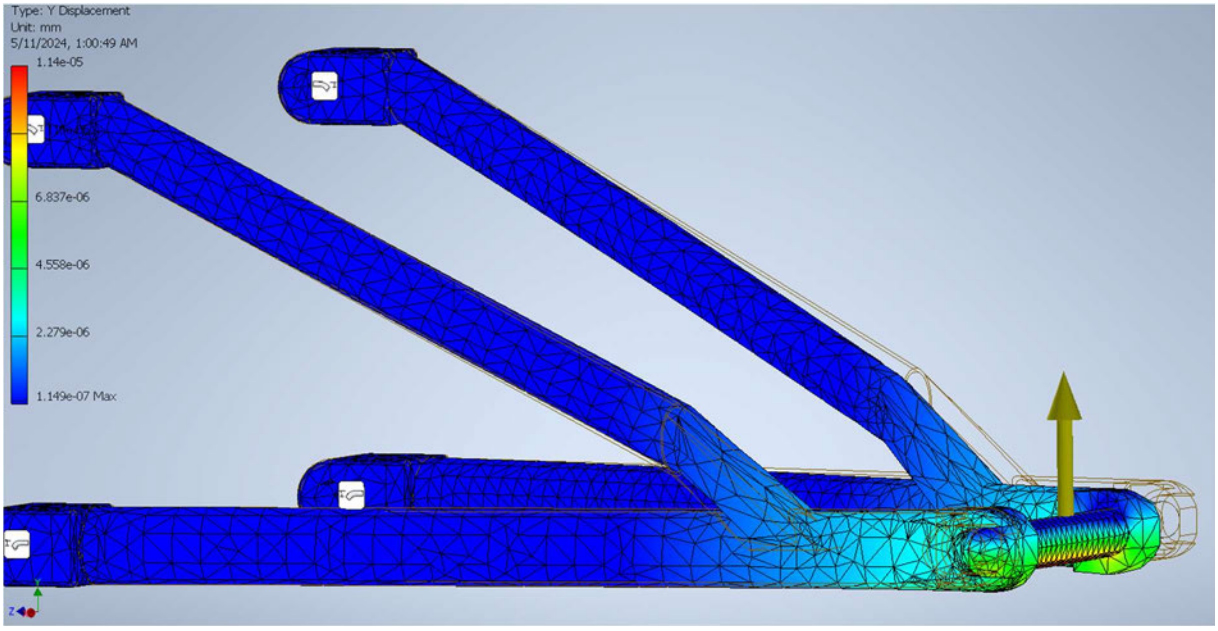


Figure 56: Vertical Displacement Throughout Rear Forks (Angled View)

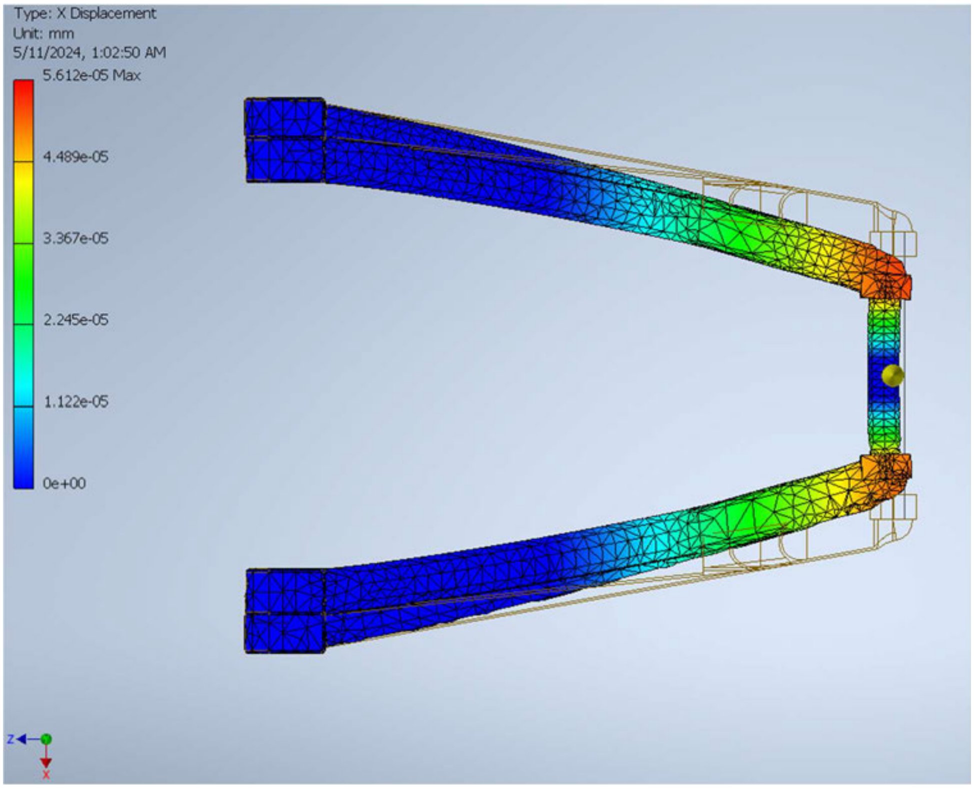


Figure 57: Horizontal Displacement Throughout Rear Forks (Top View)

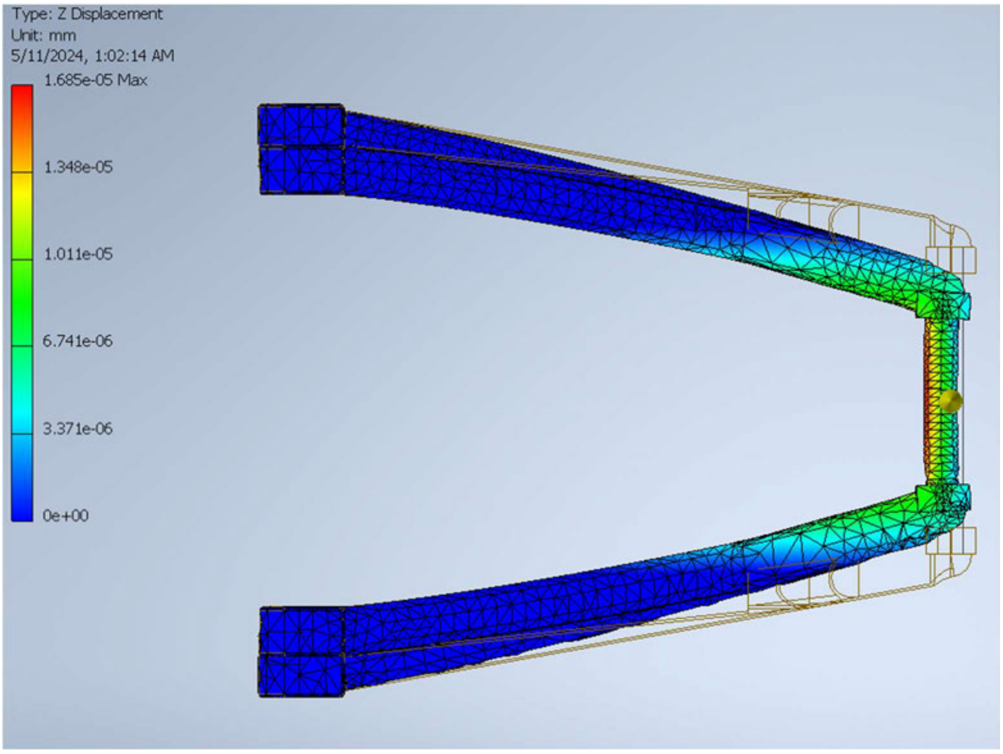


Figure 58: Forward Displacement Throughout Rear Forks (Top View)

As seen in the above figures, in terms of stress there is no extreme focus point like seen for Steel. In this sense, it can be said that the force is more evenly distributed throughout the forks. Much of the stress that is experienced is through the fastener rather than the forks themselves, indicating that this will be the highest stress component in this system. This material has a similar Horizontal displacement to what is seen in Aluminium. As the forces and displacements are both seemingly insignificant, it can be said then that any of these materials will work sufficiently for the rear forks.

3.5.3. Analysis of Main Frame and Suspension Box

Due to errors encountered during FEA, accurate analysis of the Main Frame and Suspension box was not possible. Albeit previous analysis on differing components with multiple variations of materials shows promising results, without proper analysis of the Main Frame and Suspension box it proves difficult to assess the validity of the design. In saying this, prior research can confirm the validity of materials used within the model, and as such the analysis will be conducted based upon prior research.

Analysis of Aluminium on Main Frame and Suspension Box

A study conducted confirms that for Mountain Bikes, Aluminium is widely used however with varying thicknesses, with higher stress points requiring larger diameter and thicker tubing or 'butting' which thickens the tubing to allow for added stresses. (Forrest Dwyer, 2012)The following table (shown after the bike tube example) is taken from the said study, which has measured an already on-the-market Mountain Bike frame and analysed the width and thickness of the down tube as it increases in distance from the head tube of the Mountain Bike. Figure 59 shows a diagram of a top tube and a down tube.

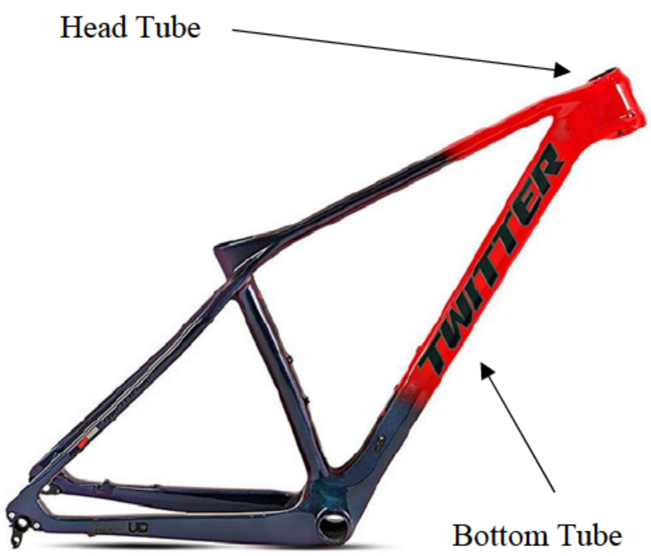


Figure 59: Example of Mountain Bike Frame showing both Head and Bottom Tubes, Source: (*Amazon*, 2024)

Table 6: Measurements for Aluminium with varying cross-sections, Source: (Forrest Dwyer, 2012)

Distance from Head Tube (cm)	Thickness (cm)	Overall Height (cm)	Max. Width (cm)
0	.29	5.08	4.06
10.2	.29	4.75	4.25
20.3	.15	4.75	4.25
45.7	.15	4.01	5.74
64.9	.10	4.01	5.74

From this data, it can be observed that as the distance between the head and bottom tube increases, the thickness decreases alongside the overall height of the bottom tube. In saying this, the width of the bottom tube increases as the distance increases. In terms of measurements, it can be noted that the thickness at the area of high stress (where the head and bottom tubes meet) is less than 3mm thick. In saying this, it has an overall height of approx. 51mm and width of 41mm. In this sense, as the modelled frame and suspension box are 32mm in diameter for the tubing, this means that either an increase in diameter may be needed to withstand necessary forces, or a substantial increase in thickness, however in terms of material availability, an increase in material diameter would prove more beneficial, as the tubing used on the model is 32mm, or approximately 1-1/4 inches. Increasing the diameter to 1-1/2 inches or approximately 38mm would bring the frame and suspension box in line with the data shown above and therefore will prove to be sufficient when working under the given conditions. In its current size however, the components will prove insufficient as it cannot be proven to work through analysis under the conditions given.

Analysis of Steel on Main Frame and Suspension Box

The main chassis and suspension box are arguably the most important components when looking at the final design, as the rider is seated and is supported using both these components, therefore a failure in these areas would prove extremely catastrophic for the user. In a theoretical sense, 440C Stainless Steel for the other components is proven to be sufficient through the FEA already conducted. Upon further research however, it is noted that 440C does not have adequate corrosion-resistive properties and is an extremely hard metal compared to other grades(*440C Stainless Steel*, 2024), such as 4130 Chromoly or 300 Series Stainless Steels. This therefore reduces the ductility of the material and reduces its lifespan if applied to the concept due to being more susceptible to corrosion. Although this metal will work from a theoretical point of view, practically again, it will not work due to its extreme rigidity. An example of this is shown in Figure 50 where FEA is undertaken on the rear forks. The stress is focused on where the fastener meets the mounting point on the rear forks. This as previously stated shows that the stress is not distributed throughout the material adequately and therefore is much more prone to breakages. This is counter-intuitive to what is required. In this sense, albeit in theory the material is hypothesised to work for the specific purpose, no research can be found that supports this hypothesis, and this material cannot be found as being used within any concepts for Mountain Bikes or Adaptive Mountain Bikes currently on the market. As there is no evidence to suggest this material will work it is deemed as insufficient for use with this concept from the analysis undertaken.

It can be said that Aluminium 6061 (with an increase in size) and Grade 9 Titanium can both be used as there is evidence of both materials being used previously in concepts on the market. Although this metal will work from a theoretical point of view, practically it will not work due to its extreme rigidity. An example of this is shown in section 3.5.2. where FEA is undertaken on the rear forks. It can be seen in Figure 50 that the stress is focused on where the fastener meets the mounting point on the rear forks. This as previously stated shows that the stress is not distributed throughout the material adequately and therefore is much more prone to breakages.

Analysis of Titanium on Main Frame and Suspension Box

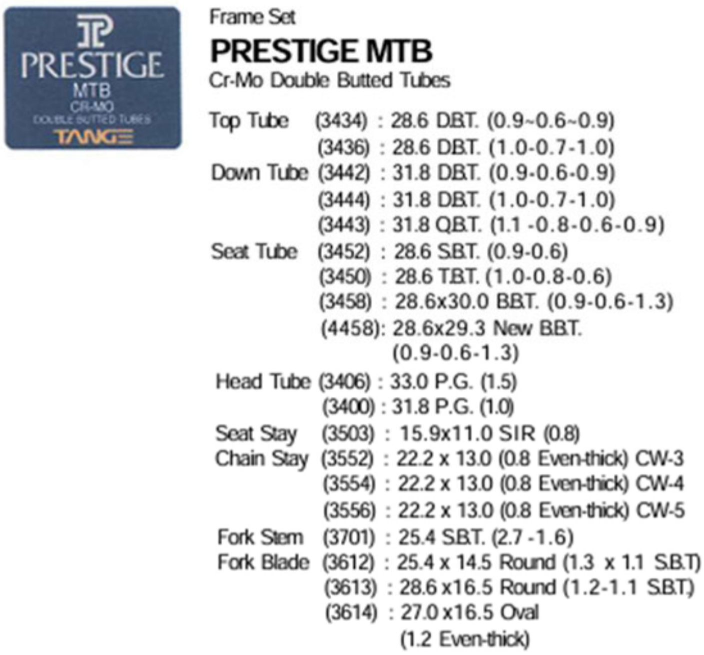
For Titanium, there are currently many options on the market, these being both Adaptive Mountain Bikes and Mountain Bikes in general. However, in saying this, a great example is that of the 'Moots Mountaineer YBB,' as similarly to the design modelled, it utilises tube sizing very close to 32mm. (*Mountaineer*, 2024)As this size is used for the seat tube, it can be said that the tube size can then withstand the weight of the rider alongside any forces the frame would undergo when doing jumps or other riding activities. In saying this, the thickness for the tube size on this concept is not available, however, it is said that the thickness of Titanium tubes ranges from 0.9mm to 1.5mm for most concepts on the market, with it being stated that '[the] 31.6 mm seat tube, is the most commonly installed diameter at the moment.' (*Tube diameter titanium standard tubes*, 2024)In this sense then, as the tubing used throughout modelling is double the thickness said to be commonly used on performance-orientated Mountain Bikes, it can be said that using Grade 9 Titanium will prove sufficient for the application on the concept.

3.6. Summary of FEA Findings

3.6.1. Chassis and Suspension Box

It can be said that Aluminium 6061 (with an increase in size) and Grade 9 Titanium can both be used for the Chassis and Suspension Box as there is evidence of both materials being used previously in concepts on the market. On this topic, Aluminium if the size were to be increased would work however it is still quite expensive. Grade 9 Titanium will work with the current size specifications however it is proven to be extremely expensive, as outlined in the previous cost analysis (Section 3.4.1.). In this sense then, although there are options for using two out of the three metals put under analysis, it begs the question of if they are entirely sufficient. The idea behind the concept is that external parts will fail before the main frame and suspension box, which gives the rider added safety as external components, these being the control arms and rear forks, will fail before the Main Chassis and Suspension Box do. In saying this, if all the concept's componentry is to be made from aluminium, the argument can be made that although load transfer would improve due to increased material ductility, failure points would have a higher chance of occurring in the Main Chassis and Suspension Box. If it were to be made all from Titanium, it would be extremely strong but extremely expensive compared to its counterparts. Therefore, a material is needed that is harder than aluminium but still has enough ductility to flex sufficiently while in use.

In this case, 4130 Chromoly Steel can be said to be suitable, as it is already used on many concepts on the market, with an example being the 'Tange Prestige MTB' frames using 4130 Chromoly in the size modelled, this being approximately 32mm however with a maximum thickness of 1mm, this is shown in an excerpt (Figure 60) taken from their specification sheet for their range of frames(*Presige MTB Frame Set*, 2024).


Frame Set
PRESTIGE MTB
Cr-Mo Double Butted Tubes

Top Tube (3434) : 28.6 D.B.T. (0.9~0.6~0.9)
(3436) : 28.6 D.B.T. (1.0-0.7-1.0)
Down Tube (3442) : 31.8 D.B.T. (0.9-0.6-0.9)
(3444) : 31.8 D.B.T. (1.0-0.7-1.0)
(3443) : 31.8 Q.B.T. (1.1 -0.8-0.6-0.9)
Seat Tube (3452) : 28.6 S.B.T. (0.9-0.6)
(3450) : 28.6 T.B.T. (1.0-0.8-0.6)
(3458) : 28.6x30.0 B.B.T. (0.9-0.6-1.3)
(4458): 28.6x29.3 New B.B.T. (0.9-0.6-1.3)
Head Tube (3406) : 33.0 P.G. (1.5)
(3400) : 31.8 P.G. (1.0)
Seat Stay (3503) : 15.9x11.0 SIR (0.8)
Chain Stay (3552) : 22.2 x 13.0 (0.8 Even-thick) CW-3
(3554) : 22.2 x 13.0 (0.8 Even-thick) CW-4
(3556) : 22.2 x 13.0 (0.8 Even-thick) CW-5
Fork Stem (3701) : 25.4 S.B.T. (2.7 -1.6)
Fork Blade (3612) : 25.4 x 14.5 Round (1.3 x 1.1 S.B.T.)
(3613) : 28.6 x16.5 Round (1.2-1.1 S.B.T.)
(3614) : 27.0 x16.5 Oval (1.2 Even-thick)

Figure 60: Excerpt of Specification Sheet for 'Prestige MTB' Frame Set by Tange, Source: (*Presige MTB Frame Set*, 2024)

Figure 60 shows the diameter of each tube with thicknesses ranging from 0.6 to 1.3mm on this frame. Notably, the modelled concept does not have any butting, however, as the frame is 3mm thick in its entirety it can be said to be sufficient. As it is also harder than Aluminium 6061, this means that in theory, the external componentry will fail before the main componentry, this being the Suspension Box and Main Frame.

3.6.2. Control Arms and Rear Forks

In terms of the Control Arms and Rear Forks, it can be said that all three materials will work in theory, however from a practical sense as stated previously 440C Stainless Steel will not prove sufficient due to its material properties, specifically rigidity and lack of corrosion resistance. As such, this gives the options of Aluminium 6061, 4130 Chromoly and Grade 9 Titanium. As these parts are meant to preferably bend before the Main Frame and Suspension Box for safety reasons, these must be softer and more ductile than the materials used for the two main components.

3.6.3. Cost Analysis on 4130 Chromoly

If 4130 Chrome Moly is to be used on the concept, a cost analysis must be done to determine the cost per kg of the material, such that it can be compared to the materials previously compared. It is said that 1m of 4130 Chrome Moly in the specific size is approx. 27 AUD, with a weight of 2.2kg.(*Chrome Moly Tubing 1-1/4" x .120" (31.75mm x 3.04mm).* 2024) Dividing the price by the weight, like what has been done previously, this equates to 12.27 AUD per kg.

3.7. Sustainability Considerations

In terms of sustainability, cycling in a general sense is regarded as reasonably sustainable as it does not rely upon fossil fuels or finite sources, aside from oil used in the shock absorbers and the production of brake dust from the braking system. In saying this, most of the materials used aside from the brake pads can be recycled. Metals have an almost infinite life span, and once broken or bent can be recycled accordingly and re-purposed, this is the same with the wheels, tyres, and almost every component said to be on the concept. In saying this, brake dust resulting from the use of a hydraulic braking system using brake pads is said to contribute '20% of fine particulate matter pollution, compared to just 7% contributed by exhaust fumes.' (*How brake dust from your vehicle can impact your health*, 2024)However, braking systems that reduce brake dust such as Carbon Ceramic brakes are said to produce marginal amounts of brake dust compared to normal braking systems but are extremely expensive and require extremely high temperatures to work efficiently compared to that of normal hydraulic braking systems. (*What Are Carbon-Ceramic Brakes?*, 2024)As such implementing such a system would not prove effective or efficient for the concept.

3.8. Chapter Summary

From research, multiple concepts were considered to get a basic understanding of what would be required from a design standpoint such that the concept delivers equally or better to concepts currently on the market. To begin two initial sub-system combinations were made, these being a mixture of motors, wheels, braking systems and other components that would be switched or replaced to reduce costs. Calculations were undertaken to determine what would be required of a motor and braking system, as well as what is required from suspension componentry and other componentry relating to concept performance, safety, user-friendliness, cost-effectiveness and sustainability. FEA was undertaken through Autodesk Inventor to determine the validity of self-designed chassis and suspension components allowing an articulating front suspension system capable of transversing larger obstacles than what is seen on most aMTBs. The analysis paired with in-depth research on concepts currently on the market and materials led to many design decisions that led to the final design paired with the materials required for the concept to work sufficiently. Cost analysis was also undertaken to gain insight into the cost versus performance capabilities which then assist in making the design decisions for the final concept, with the chosen sub-syst

CHAPTER 4 RESULTS AND DISCUSSIONS

In terms of results, there are multiple factors that through analysis were chosen and analysed such that the best possible final concept could be made. These will be outlined in the sections below explaining the final design choices part by part.

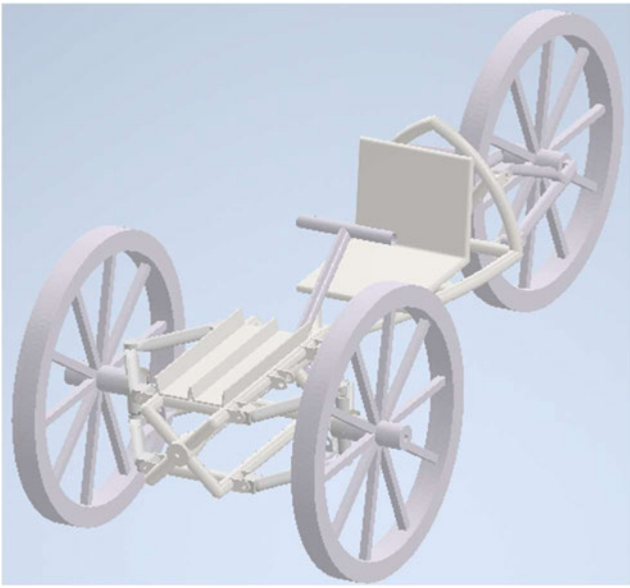


Figure 61: Final Concept Design

4.1. Chassis and Componentry Material Selection

The following section will outline the materials selected for use on parts previously analysed in Chapter 3 Section 5. This will include materials selection for the Main Chassis, Suspension Box, Control Arms (Upper and Lower), and Rear Forks, alongside the Steering.

4.1.1. Main Chassis and Suspension Box

The material decided upon for use in the Main Chassis and Suspension Box is 4130 Chrome Moly. This material, paired with the softer materials to be used on the Control Arms and Rear Forks will prove to be sufficient, while retaining adequate strength such that the external componentry fails before the two main components, these being Main Frame and Suspension Box. Analysis undertaken previously in Chapter 3 proves that this material will be sufficient, and as such will be used for the Main Chassis and Suspension Box.

4.1.2. Control Arms

For the Control Arms, this being Lower and Upper, the decision was made to use Aluminium 6061. As this metal is softer than 4130 Chromoly, it allows in the event of a failure, each control arm to bend or break before the main componentry fails. This adds a level of safety to the design, and as proven by FEA using Aluminium 6061 is sufficient in withstanding the necessary forces and transferring said forces efficiently.

As such, this material will be used for these components as it meets all requirements. These will be connected to the knuckles connecting to the wheels using ball joints, an example of the type of ball joint to be used is seen in Figure 62 below.

Figure 62: Example of Ball Joint used to connect Control Arms and Knuckles, Source: (*Single Replacement Ball Joint for Front Upper Fixed Offset Control Arm TRC6590*, 2024)

4.1.3. Rear Forks

Like the Control Arms, the Rear Forks also were decided to be made from Aluminium 6061. The FEA Analysis shows promising results in terms of force transfer as well as the ability to withstand the forces required within itself. Again, as the Aluminium in question is not as hard as the materials the Main Frame and Suspension box are to be made from, this allows the componentry to bend rather than break, giving the rider added safety and, in this instance, if this component were to bend it would be noticeable by the rider, hopefully, therefore, preventing a catastrophic occurrence while the concept is in use.

4.1.4. Steering

In terms of steering, it is thought that similarly to the frame, Aluminium 6061 will be used. A harder material in this instance can be said to be unnecessary as there is no need for extra rigidity, and Aluminium in 32mm and 3mm thick configurations is widely available as shown through research in Chapter 3. The steering arm itself is designed to be held in with a fastener like what is seen when connecting MTB forks to the frame. In terms of linkages, it is thought that adjustable tie rods with ball joint-style ends will be used, as seen in Figure 63. This will be paired with ball joints which will connect the steering linkage to the knuckle. These systems are not shown through modelling, however, examples of both are shown below.

Figure 63: Example of Ball Joint to be used in Steering, Source: (*RS PRO Steel M5 Ball and Socket Joint, 28.5mm x 25mm*, 2024)

Figure 64: Example of Adjustable Tie Rods used on the Final Concept, Source: (*Motoforti 2pcs 238mm Length 8mm Hole Diamete Adjustable Steering Tie Rod Ball Joint for 49cc Electric ATV Go Kart Accessory Steering Column Steering Suspension Silver Tone*, 2024)

4.2. Off-the-Shelf Products Used – Sub-system Selection

Adequate products were analysed earlier within the project, these being the two initial sub-system combinations, with the first being performance-orientated and the second being cost-orientated. In terms of what is to be used, a mixture of both is being used to provide the best value for money from a sub-system perspective. This is in a bid to reduce costs compared to other concepts already on the market. When both sub-system combinations are compared, it is noticeable that the main price difference is the wheels and the motor. Slight variations can be seen between the brake rotors; however, this can be deemed as insignificant in comparison. A finalised list of sub-system components can be found in Table 7 below. Notably, Labour is a generalised cost and may vary depending on various factors including pay rate, and time taken to manufacture.

Table 7: Final Combination of Sub-Systems

Final Combination Cost	
Part	**Cost (AUD)**
7kW Brushless Motor	256.54
27.5 Inch Wheel	300
Tyre	270
Drivetrain	200
Brake Rotors (220mm)	271.5
Brake Calipers	278.97
Brake Lever/Lines	180
Suspension	2400
Seating	300
Battery	1350
Labour	4000
Total	9807.01

In terms of reasoning behind this combination, the larger 7kW motor allows a more reasonable gear ratio to be achieved as outlined in Chapter 3, which makes drivetrain components more easily accessible and available for the user. The tyres and braking system are taken from the performance sub-system as the difference in price is marginal compared to the performance characteristics gained.

In terms of ergonomics, it is assumed that off-the-shelf slip-over hand grips will be used and that cushioning for the rider on the leg rests and the seat is for the judgement of the rider, however, the cost for this is 200 AUD, and will be included in the final concept cost analysis.

4.3. Fasteners and Mounts Used for each Component

4.3.1. Mounts used on Final Concept

In terms of mounts, all mounts were designed to be in double shear, these being mounts for the suspension control arms to the suspension box, as well as the mounting of the rear forks to the main chassis. This helps evenly distribute the load on said mounts to prevent catastrophic failure. All these mounts were also designed as 5mm thick. The reasoning behind this is that through research, engine mounts for many automotive high horsepower applications which are subject to much greater forces than what is experienced within this concept are made from 5mm thick mild steel. (*Engine Mounts for LS*, 2024)In saying this, 4130 Chrome Moly is known for having higher strength and being more durable than mild steel(*What is Chromoly?*, 2024), and as such this size was deemed sufficient to handle the forces required.

4.3.2. Fasteners used on Final Concept

The fasteners used in the concept are all assumed to be of a high tensile nature, these being made from carbon or alloy steels, with variations in sizing depending on the application. The rear forks and front knuckles are designed such that a 15mm diameter fastener can be used on the rear axle, as most of the weight is put on the rear axle, and there is only one rear wheel, a larger size fastener was deemed necessary, and this is also in-line with standard sizes for axle bolts.(*Burgtec Rockshox Boost Fork - 15x110mm*, 2024) The front knuckle is designed such that a standard 12mm diameter fastener will attach the front wheels, this is also in line with standard sizing. (*Rear Thru Axle, 148mm x 12mm Spacing, 172mm Length, 12mm Through Type*, 2024)The suspension connections are all designed to use a fastener 10mm in diameter, however, it is assumed that bushings made from Elastomers are used in conjunction, and as such a smaller fastener can be used. Suspension control arm bolts for cars, specifically the Holden Commodore are sized at M12(*Bolt - Suspension Control Arm*

M12 X 125mm 92139183 for GM Holden Commodore VE VF, 2024), with a weight of approx. 1.8 tonnes. (Florin Profir, 2024)As such, for this application being that the weight of the system even when under load is nowhere near this weight, the size for the connecting fasteners in question was considered adequate. The mounts for the suspension were designed to accommodate a 15mm diameter fastener or equivalent with bushing. The fasteners used to fasten the suspension box to the main body and the steering arm are designed as a 15mm fastener, providing adequate strength as per prior research.

4.4. Final Cost and Performance Analysis

4.4.1. Cost Analysis

In terms of final cost, the concept must be weighed with each component in their respective material such that an accurate cost for the chassis can be obtained. This can then be added to the cost breakdown of the final sub-system combination giving an approximate total price. In terms of weights of the concept, using Autodesk Inventor the weights equated to:

Table 8: Weights of each set of Components

Component	Weight (kg)
Main Frame and Suspension Box (4130 Chromoly)	14.013
Steering Arms, Control Arms, Rear Forks (6061 Aluminium)	4.889

Using these weights, alongside the prices previously found for 4130 Chromoly and 6061 Aluminium, a rough estimate can be made on the price of materials needed for the chassis and componentry. This is shown below:

$$Cost_{Frame} = (14.013 * 12.27) + (4.886 * \ 25.62)$$
$$Cost_{Frame} = (171.94) + (125.18)$$
$$Cost_{Frame} = 297.12\ AUD$$

If 300 AUD is then added for the cost of bushings, fasteners, and ball joints, this then equates to 597.12 AUD. Notably, this price does not include the pricing to manufacture, however, this price will be factored into the final cost.

Using the cost of the materials for the frame can be added to the sub-system breakdown to give an approximate price for the complete system. This is shown in Table 9 below.

Table 9: Final Cost Approximation

Final Cost Approximation	
Part	**Cost (AUD)**
7kW Brushless Motor	256.54
27.5 Inch Wheel	300
Tyre	270
Drivetrain	200
Brake Rotors (220mm)	271.5
Brake Calipers	278.97
Brake Lever/Lines	180
Suspension	2400
Seating	300
Grips, Cushioning	200
Material Cost	297.12
Battery	1350
Labour	6000
Total	12304.13

It is noted that the added Labour costs reflect the price of fabrication as well as manufacturing. For an accurate cost estimate for manufacturing this product further research would be needed which can be said to be out of the scope of this project, as there are many variables, and being that the concept is conceptual.

In terms of the total cost price, this can be seen in Table 9 as just above 12,000 AUD, if a profit margin is then added to the cost, for example, 25%, this cost price becomes approximately 15,300 AUD. It is highly important to keep in mind that the products used throughout the subsystem are off-the-shelf products with retail pricing, and as such the price will further be reduced if wholesale pricing is to be obtained on said items. The total price including profit margin is substantially cheaper than other concepts on the market with similar specifications, for example, the Bowhead Read Adventure-E Bike, with its starting price of 15,999 USD which is approximately 24,000 AUD. (*BOWHEAD REACH™ ADVENTURE-E BIKE*, 2024)

4.4.2. Performance Analysis

In terms of performance characteristics, as shown in Chapter 3, the maximum speed of the concept is 30 km/h, which it can accelerate to and maintain on a 40-degree incline. It is also designed such that the concept can stop on a 40-degree decline within a reasonable distance, this is all provided the terrain allows for the necessary amount of traction. In terms of clearance, the concept is designed such that it has at least 7 inches of clearance between the terrain and the lowest part of the chassis while allowing 110mm of suspension travel, which is more travel in the front than what is seen on the Bowhead Reach(*BOWHEAD REACH™ ADVENTURE-E BIKE*, 2024), which this concept was inspired by. This is then further benefitted by the pin-unlocked articulating front end, which allows the concept's front suspension box as mentioned in Chapter 3 to further articulate for larger obstacles. All of this paired with the 7-kW motor enables the concept to be on par in terms of performance with other concepts on the market while only being a fraction of the cost. The weight of the final concept with all sub-systems attached can be said to be at or less than 45kg after obtaining the chassis weights. Therefore, all calculations are correct and sufficient.

4.5. Standards of the Design

In terms of standards followed in design, it was deemed as out of the scope of the project being an undergraduate project to design according to every code on aMTBs. In saying this, the concept is proven to be able to withstand twice the necessary forces sufficiently, this being 2G's or 2 times its overall weight, this being system and rider. As the concept is designed for recreational use, and that the concept is designed to withstand the forces required, it can then be said that the concept is sufficient and safe for use. The maximum width of the concept was also designed such that it would fit on normal MTB trails, with a recommended minimum trail width of 38 inches (*Adaptive Mountain Bike Trail Guidelines*, 2024) which is said to be just over 950mm.

4.6. Chapter Summary

From the methodology, a final concept could be designed, with a mixture of both initial concepts, these being both performance orientated, and cost orientated to give a resulting product that had the capability of both areas. This led to a final product that was on par with concepts currently on the market, while only being a fraction of the price. Albeit testing of the main two components was unsuccessful, the materials used can be backed via research and as such is sufficient. This was paired with off-the-market products that were used and underwent a final cost analysis to determine the final approximate price of the concept, however, it is worth noting that this final price is an approximation, and a physical version once manufactured and built may be less or more expensive depending on several variables. The overall weight of the concept can also be said to be at or under the 45kg assumed. Therefore, this makes all calculations accurate and proves that the chassis with the sub-system combination will work sufficiently. A lot of information throughout this process was learnt about the ductility of metals and the different structural components that can improve safety within vehicles.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The project overall can be deemed successful, as a performance-orientated concept was designed, while also satisfying the main research question of 'Can a cost-effective yet high-performance application be achieved through concept design changes?' Compared to other concepts on the market, the concept is a substantial amount cheaper while still theoretically providing an on-par or improved product from a performance and usability perspective. As all the parts used in the concept are off-the-shelf products, this means that the consumer can source said parts locally, reducing ongoing running costs compared to having to order highly specialised and expensive parts. This adds to being user-friendly and cost-effective, and as previously stated the concept in theory will provide a similar experience to the disabled, specifically the paraplegic as what an able-bodied person would experience when participating in recreational mountain biking. In saying this, the theoretical concept was designed to meet all categories, this being performance, user-friendliness and safety, cost-effectiveness, and sustainability, and in theory, has proven to be sufficient in all categories mentioned.

5.2. Recommendations and Future Work

In terms of recommendations, it is recommended that the Finite Element Analysis be re-analysed such that adequate results can be obtained like what was seen when FEA was undertaken for the rear forks and front control arms. As the current design is based upon research and not analysis, doing further analysis on these components would further prove the safety and sufficiency of the material used for said componentry. It is also recommended that from a structural standpoint, once further FEA is undertaken 'butting' is implemented on the system, as this would reduce the cost of the concept while also reducing its weight. On top of this, it is also recommended that Fatigue Analysis be done on the concept, such that its performance over a longer period can be analysed and the design adjusted accordingly. This analysis was deemed out of the scope of this project however is highly recommended if looking to implement the design. Leading on from this, it is also recommended that a prototype of the design be built and evaluated. Computer-Aided-Design can only replicate real-world scenarios and often does not have the same number of variables as what a real-life concept would have. In this instance, it is recommended that a prototype be built and evaluated for feedback such that the design can be further improved based upon these results.

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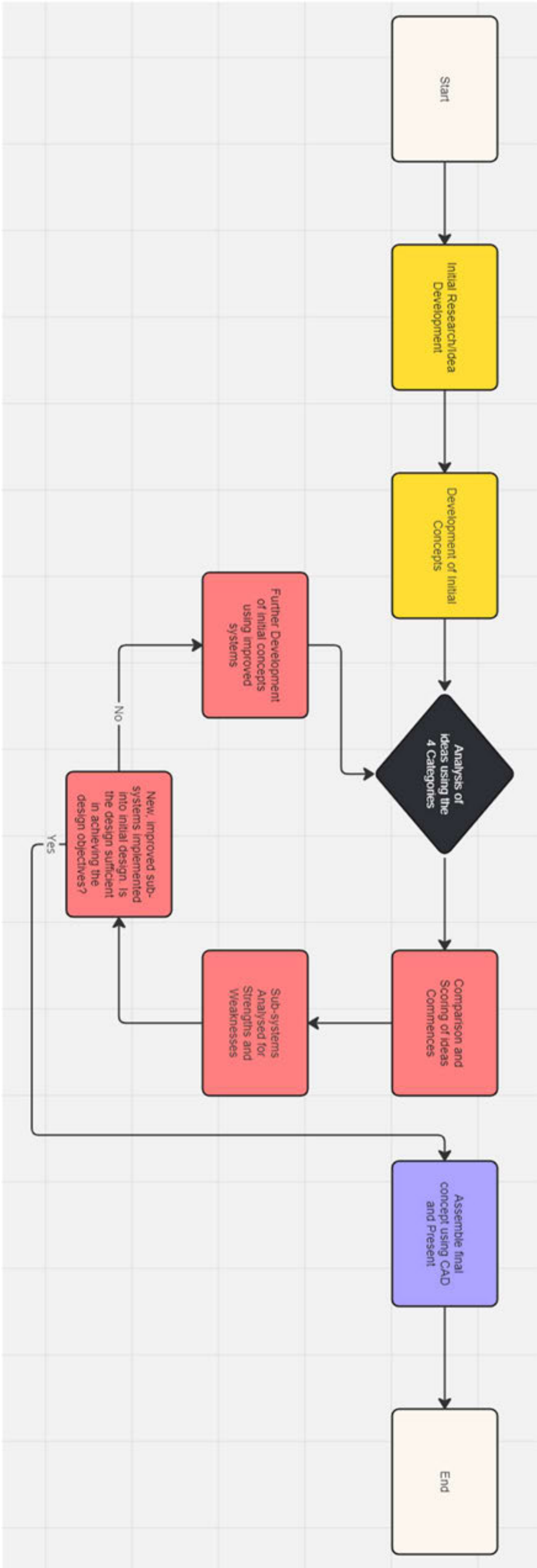
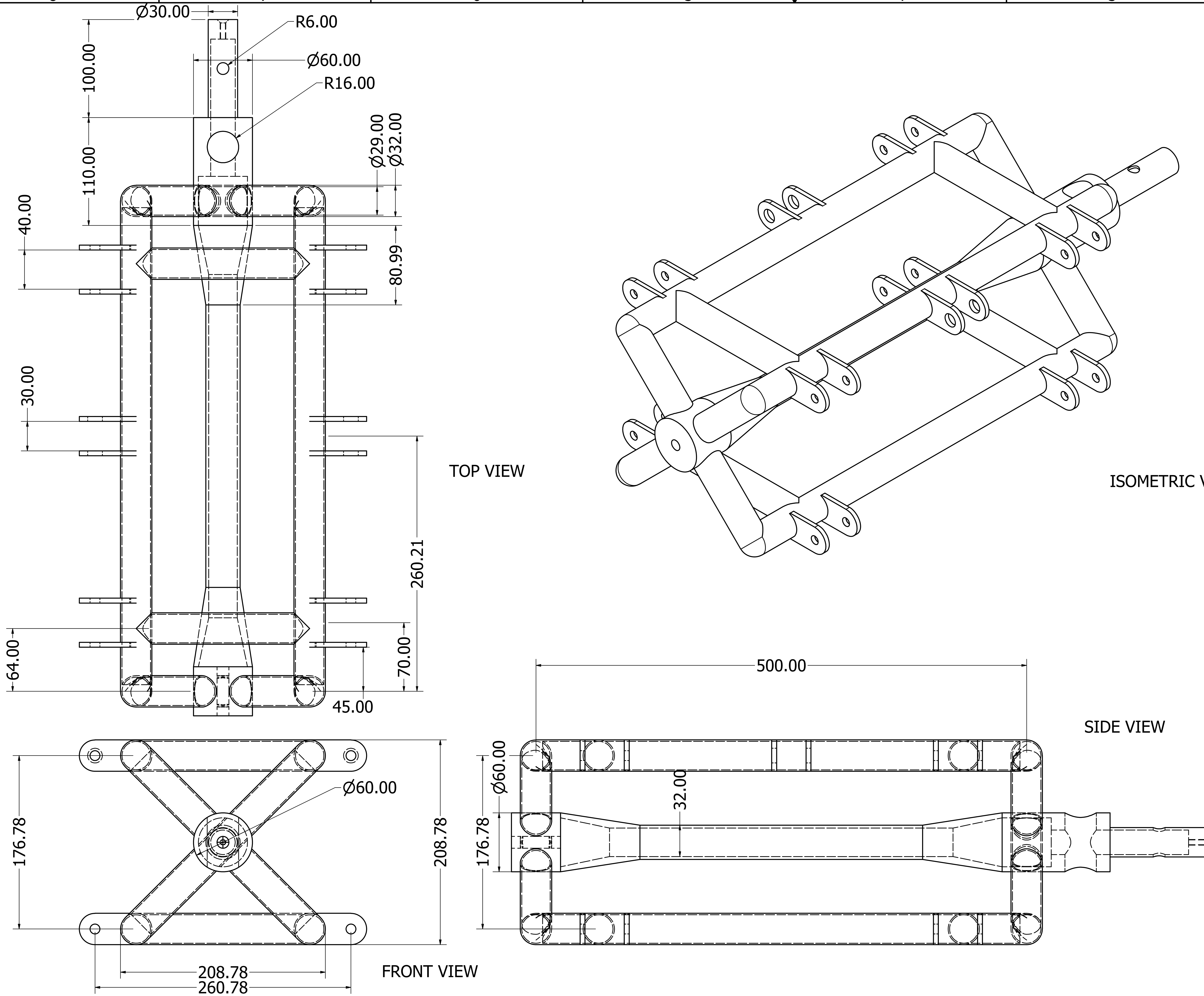
CHAPTER 7 APPENDICES

APPENDIX A

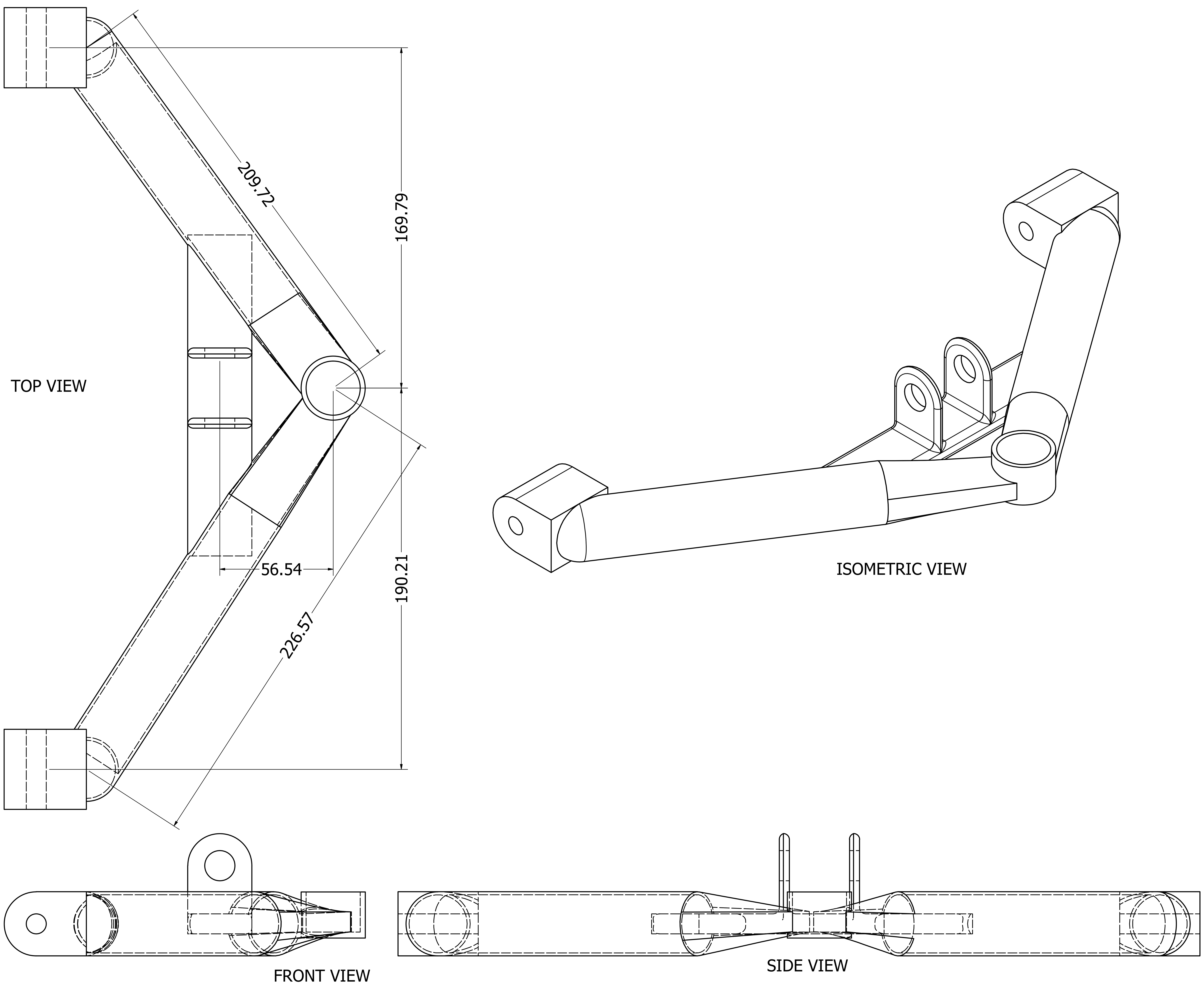


APPENDIX B



ALL TOLERANCES
+/- 0.1MM
UNLESS
OTHERWISE
SPECIFIED

DRAWN foxy2	9/11/2024	
CHECKED		TITLE
QA		SUSPENSION BOX
MFG		
APPROVED		SIZE D / DWG NO / REV
		SCALE 1 / 2 / SHEET 1 OF 1

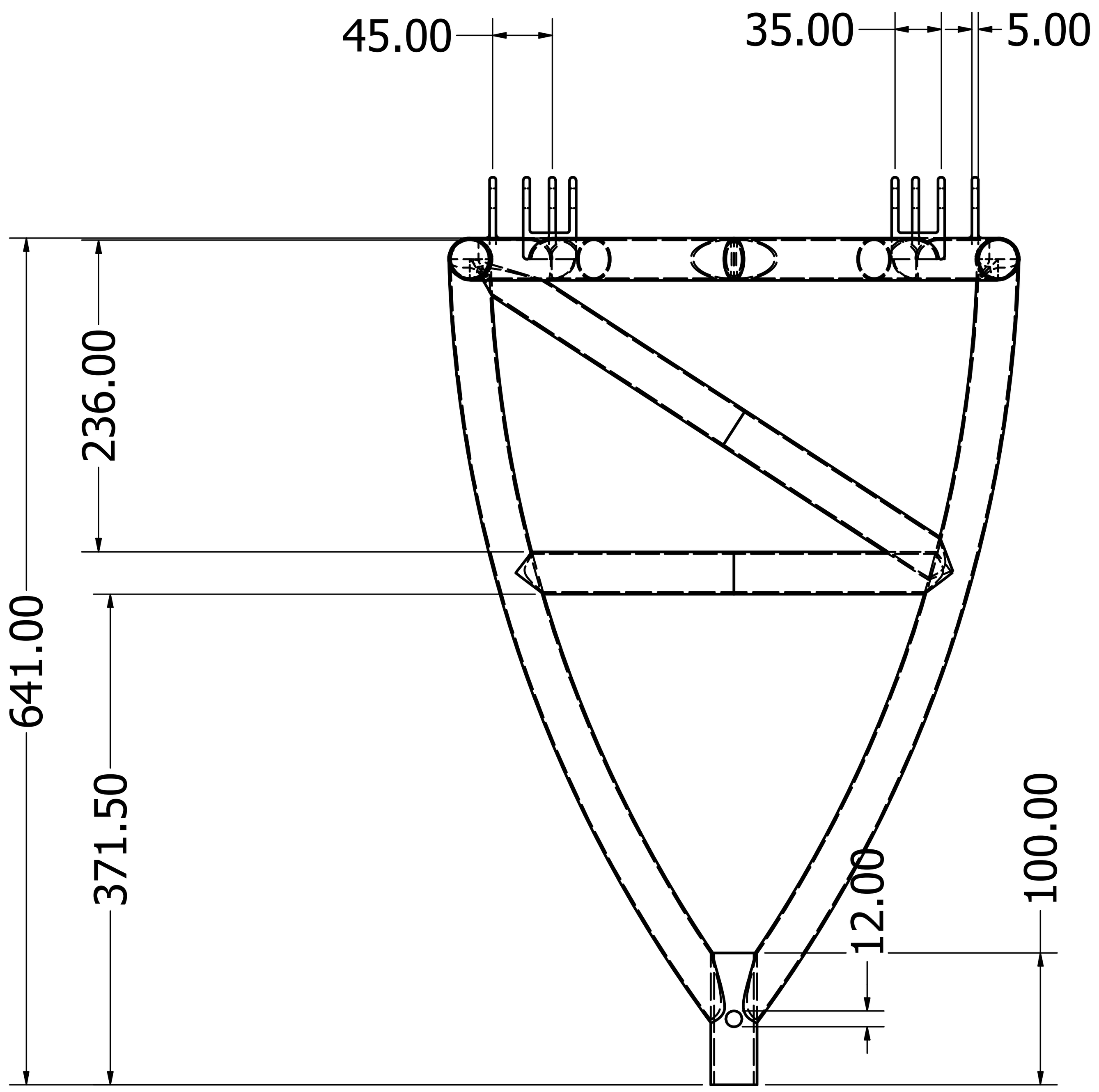


LH IS MIRROR OF RH, ONLY DIFFERENCE IS BALLJOINT POSITIONING

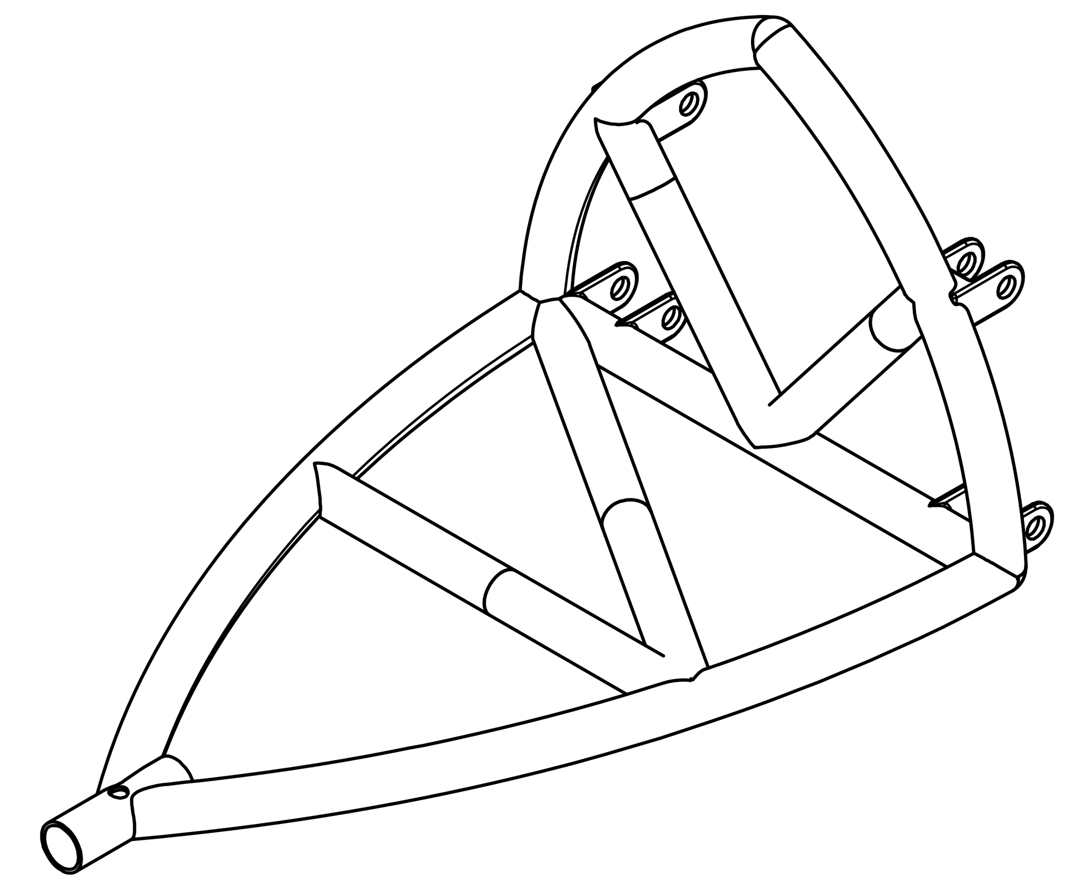
ALL TOLERANCES +/- 0.1mm UNLESS OTHERWISE SPECIFIED

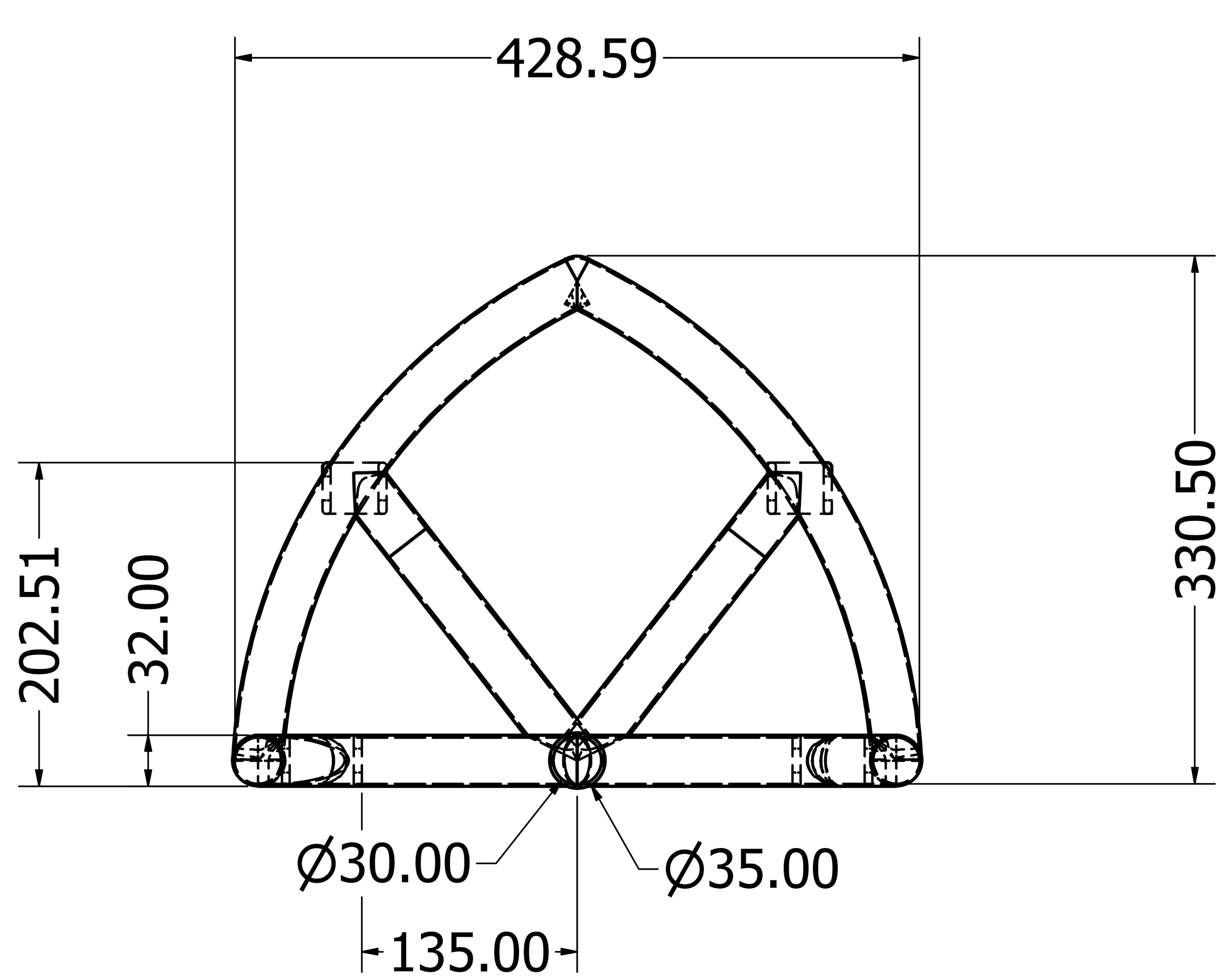
DRAWN foxy2	9/11/2024	
CHECKED		TITLE
QA		LH LOWER CONTROL ARM
MFG		
APPROVED		SIZE D · DWG NO · REV
		SCALE 1 : 1 · SHEET 1 OF 1


8
7
6
5
4
3
2
1
D
C
B
A
209.72
169.79
Ø32.00
Ø27.00
23.84
190.21
226.57
TOP VIEW
ISOMETRIC VIEW
Ø32.00
Ø27.00
23.00
32.00
20.00
Ø10.00
FRONT VIEW
SIDE VIEW
ALL TOLERANCES +/- 0.1MM
UNLESS OTHERWISE
SPECIFIED
DRAWN
foxy2
9/11/2024
CHECKED
QA
MFG
APPROVED
TITLE
LH UPPER CONTROL ARM
SIZE
D
DWG NO
REV
SCALE 1 : 1
SHEET 1 OF 1

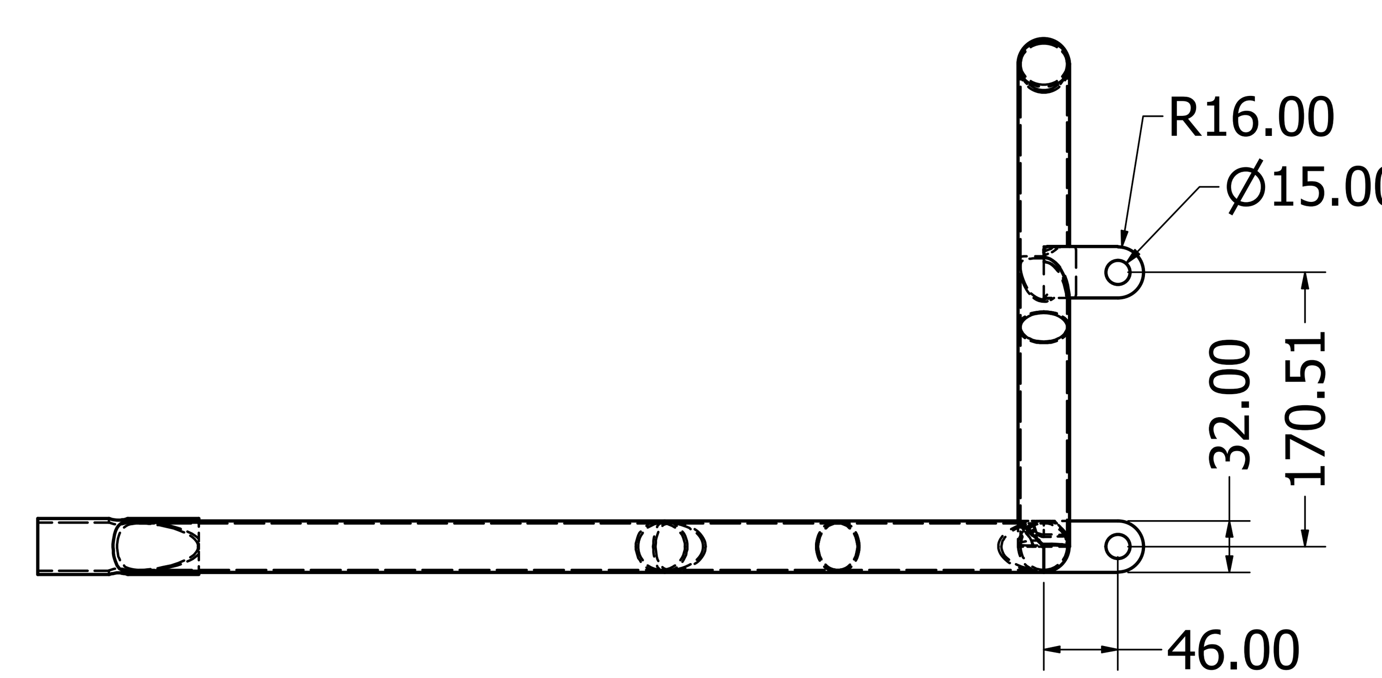


TOP VIEW


ISOMETRIC VIEW



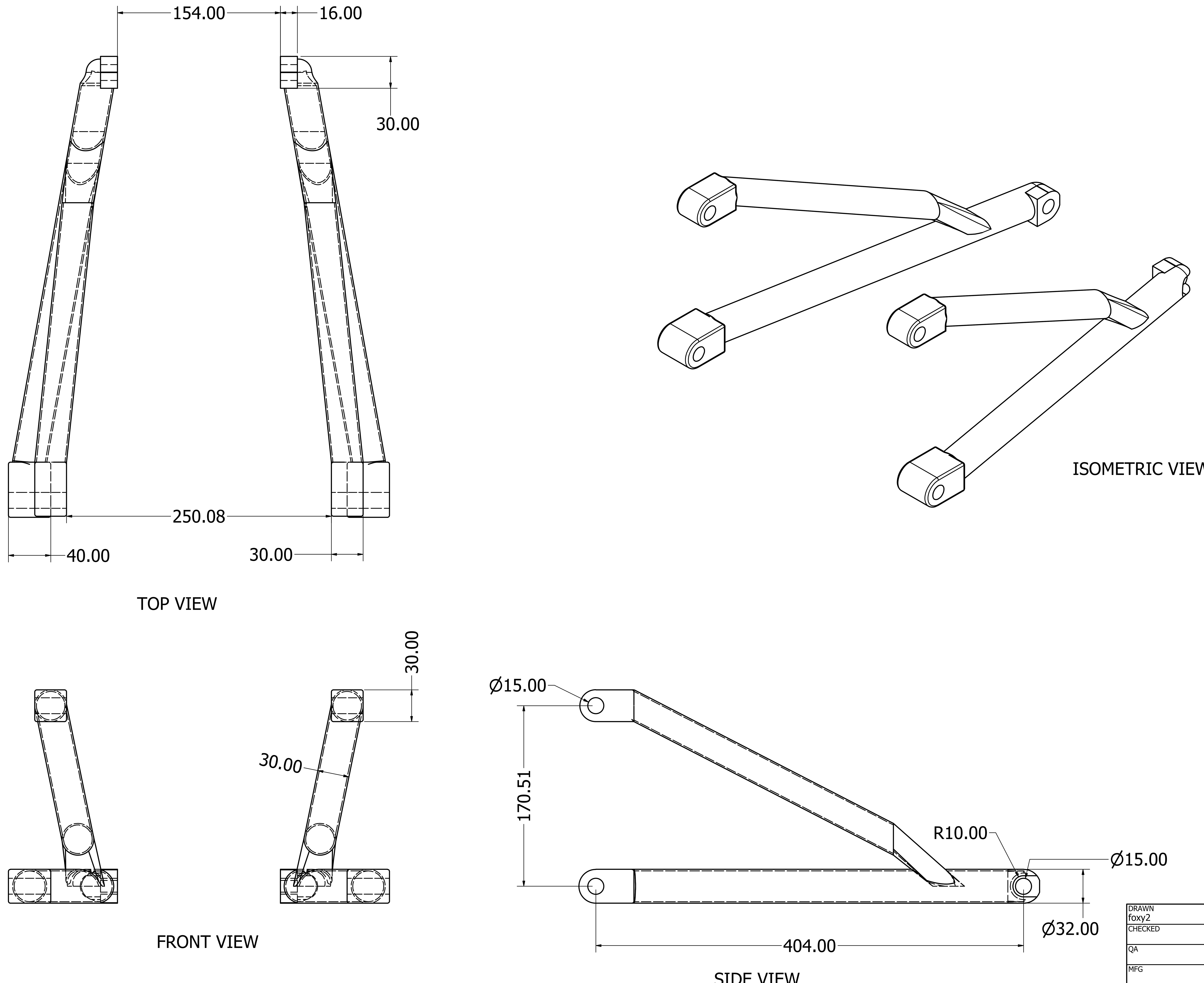
FRONT VIEW



SIDE VIEW

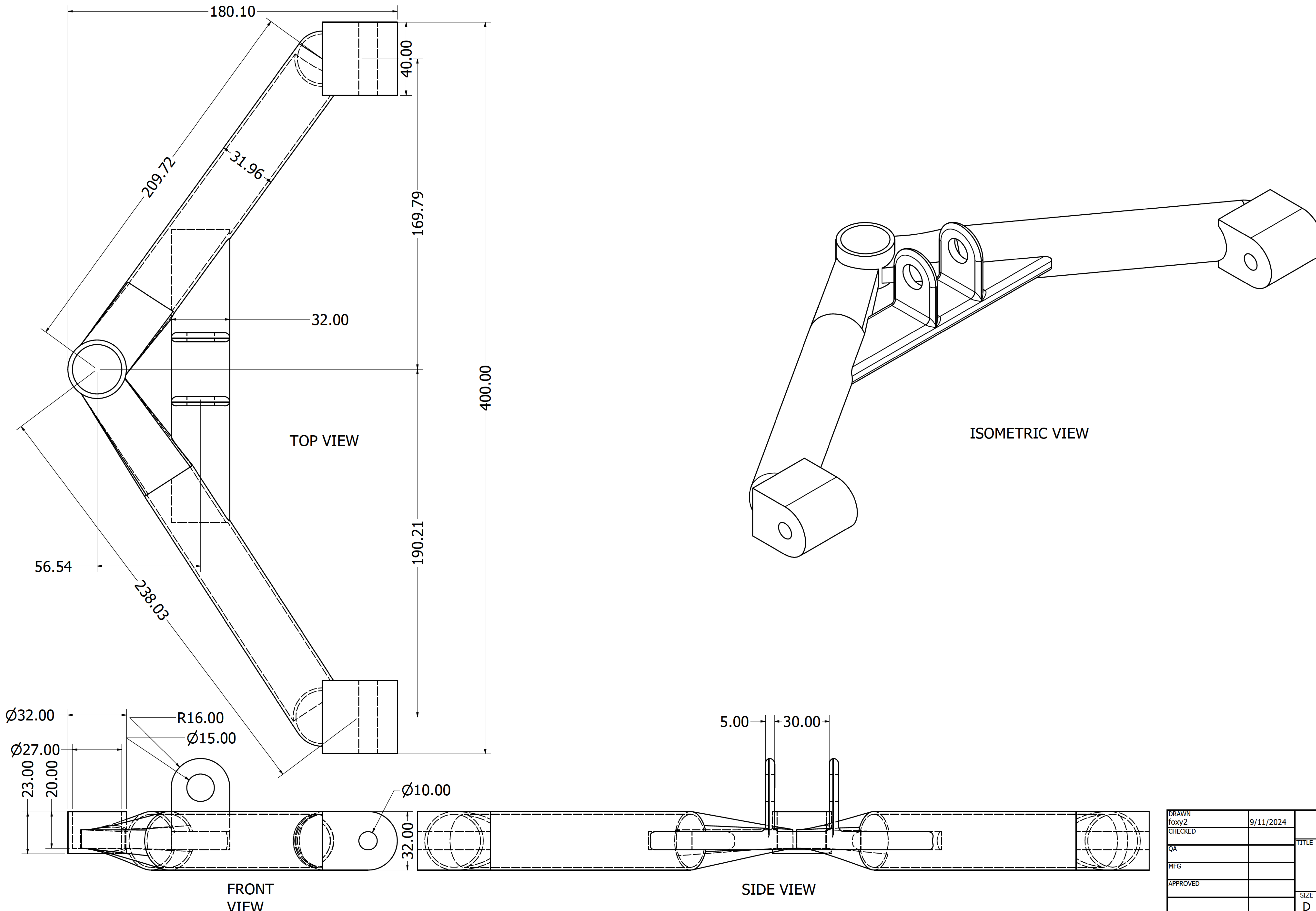
ALL TOLERANCES +/- 0.1MM
UNLESS OTHERWISE
SPECIFIED

DRAWN foxy2	9/11/2024	
CHECKED		TITLE Main Frame
QA		
MFG		
APPROVED		SIZE D — DWG NO — REV
		SCALE 1 / 4 — SHEET 1 OF 1



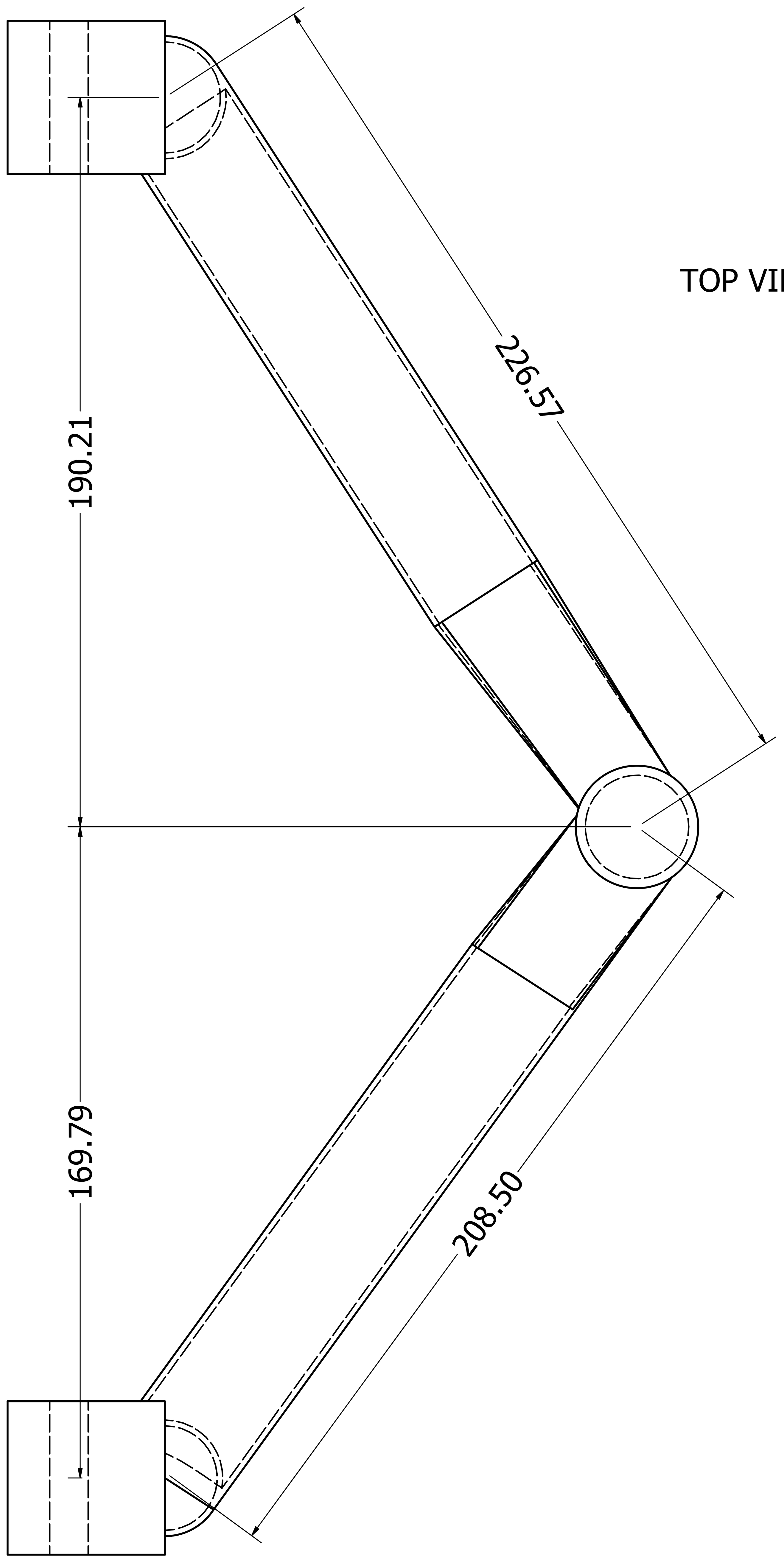
ALL TOLERANCES +/- 0.1MM
UNLESS OTHERWISE
SPECIFIED

DRAWN foxy2	9/11/2024	
CHECKED		TITLE
QA		REAR FORKS
MFG		
APPROVED		SIZE D · DWG NO · REV
		SCALE 1 / 2 · SHEET 1 OF 1

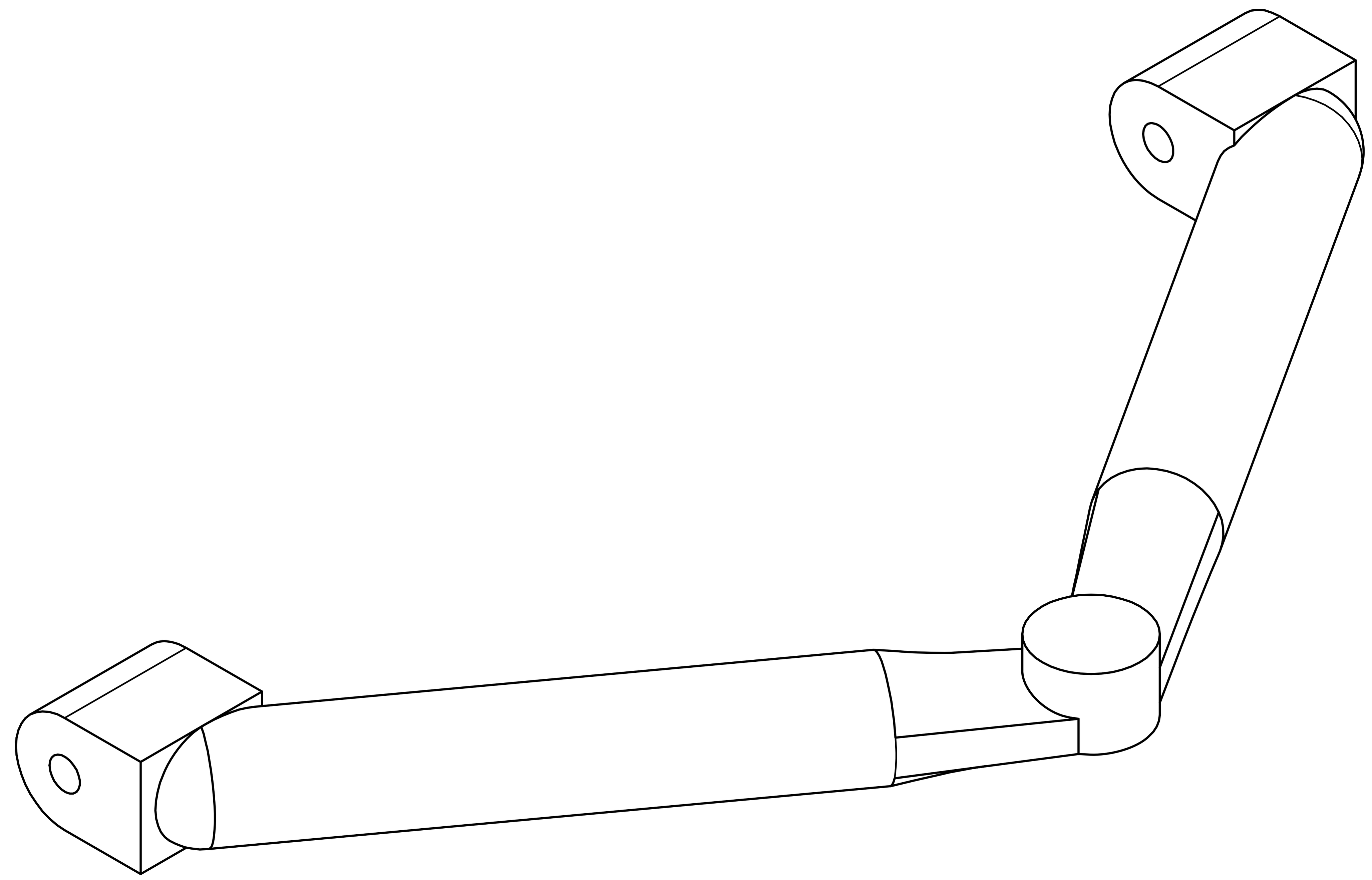


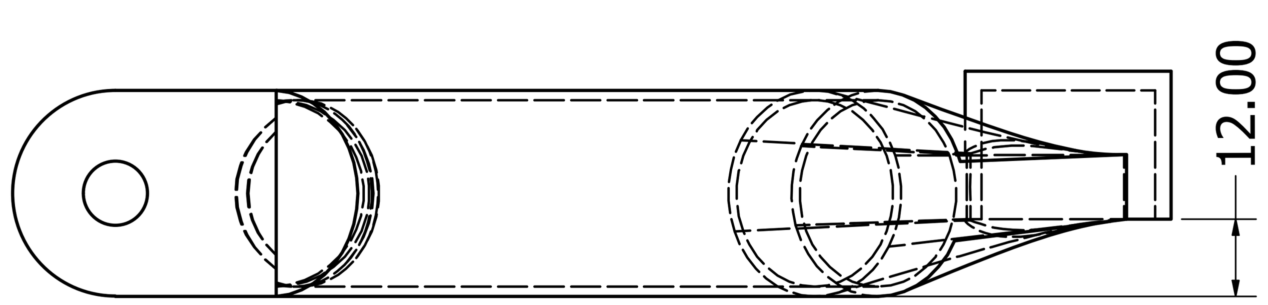
ALL TOLERANCES
+/- 0.1MM UNLESS
OTHERWISE SPECIFIED

DRAWN foxy2	9/11/2024	TITLE RH LOWER CONTROL ARM
CHECKED		
QA		
MFG		SIZE D · DWG NO · REV
APPROVED		SCALE 1 : 1 · SHEET 1 OF 1

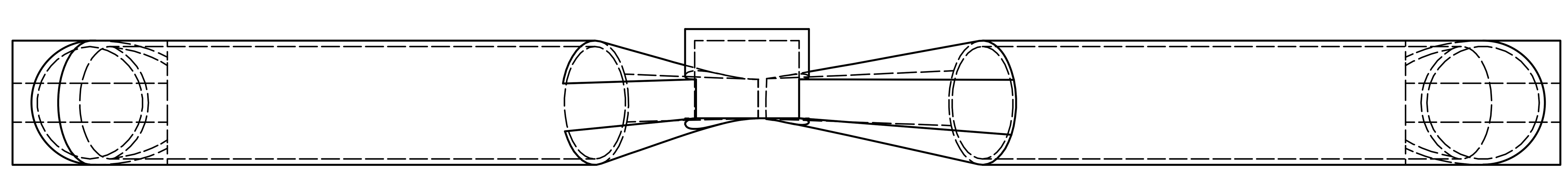


TOP VIEW


ISOMETRIC VIEW



FRONT VIEW


SIDE VIEW

ALL DIMENSIONS BUT POSITIONING OF BALL JOINT IDENTICAL TO LH UPPER CONTROL ARM

ALL TOLERANCES +/- 0.1MM UNLESS OTHERWISE SPECIFIED

DRAWN foxy2	9/11/2024	TITLE RH UPPER CONTROL ARM
CHECKED		
QA		
MFG		
APPROVED		SIZE D / DWG NO / REV
		SCALE 1 : 1 / SHEET 1 OF 1