Portfolio: Mountain Bike Component Design

Author: JingTian Zhang
UWCSEA, Singapore

Summary:

This portfolio documents my learning and thinking journey in designing a steering stabilizer for physically disadvantaged mountain bikers. I began this project from a finger injury that underscored accessibility challenges in mountain biking. I studied linkages in Professor Alexander Slocum's Fundamentals of Design course, learned about inertia tensor and matrices, read papers on load analysis on mountain bike frames. I created CNC prototypes with two factories in China, and engaged with multiple clients.

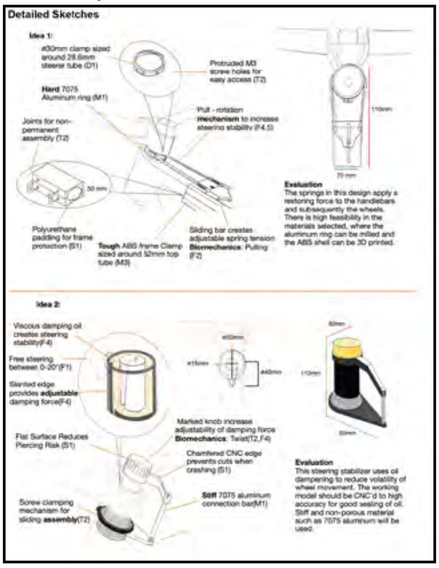
Notes:

- I centered initial designs around children for immediate testing feedback; however, I'm expanding it to include the elderly, injured, and those with mobility disabilities.
- Further changes will be made to the portfolio. I am connecting with a disabled rider in China to schedule testing, and I plan to apply for a design patent.
- This portfolio is long - feel free to scroll through, or skip to sections using the legend.

Legend

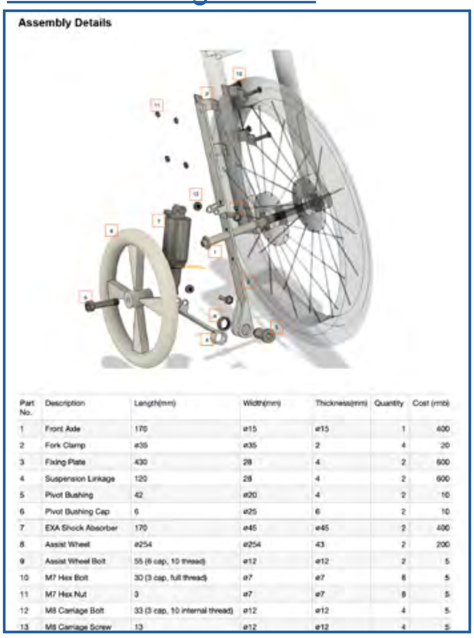
Design Problem

Concept Sketches



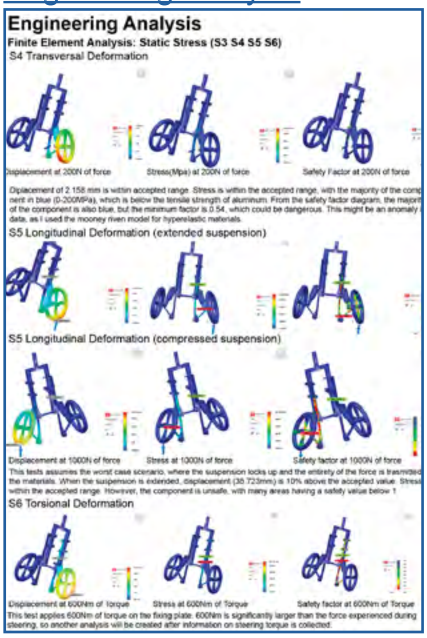
Concept Modelling

Manufacturing Details



User Testing

Engineering Analysis



Appendix I: Technical Drawings

References

Design Problem

Fig 1: Child Crashing

Mountain biking involves riders jumping, cornering and pumping their bikes through rugged terrain. The strength and balance required in these situations can make mountain biking dangerous to children, elderly, and those with mobility disabilities. The goal of my design is to reduce risk and increase accessibility of mountain biking.

Clients & Expert Appraisal

Fig 2: Interview with potential user Max (riding since 5)

- Fear of crashing is the main obstacle to progression.
- Nervousness results in less control over the bike
- Many crashes come from instability in the front end.

Fig 3: Interview with potential user Ja (lost his left arm in a work incident)

- Enjoys the feeling of control when riding
- Don't want to be limited from physical barriers
- Crashing is common and unpredictable in his situation.

Fig 4: Interview with Yan(Former coach of chinese national bmx team)

- The biggest problem in coaching is overcoming fear while ensuring safety
- Children can really benefit from a device that aids low speed fundamentals practice.
- The device should be as light as possible to not hinder steering. It should also be able to endure crashes.
- The device should be able convinient to install for the inexperienced.

Market Analysis

Cost and Materials of Substitute Components					
Component	Knockblock headset	Canyon KIS	WP Steering Damper	14-16 inch training wheel	Orange Phase AD3
Photograph					
Cost(USD)	63.99	400	459	14.2	1000
Advantages	Protects rider and bike from oversteering when crashing.	Stabilizes the steering by combating wheel flop	Stabilizes steering by dampening rotational torque.	Provides great stability to entire bike.	Designed Specifically for disabled mountain bikers
Limitations	No prevention and stabilization function.	Affects low speed practice	Only useful to advanced riders.	Low versatility in mountain biking situations and hinders movement.	Expensive and requires intensive technical abilities

Fig 5: Table of existing products

Relevant Physics

Bikes are designed with trail(Fig 6), which helps the bike balance with corrective steering. When the bike is leaned, the force from the ground turns the front wheel to compensate. However, in sharp corners with high g forces(Fig 9), the front wheel can oversteer violently because of the wheel flop effect(Fig 7). Children and those with lower mobility often lose control and crash in this situation.

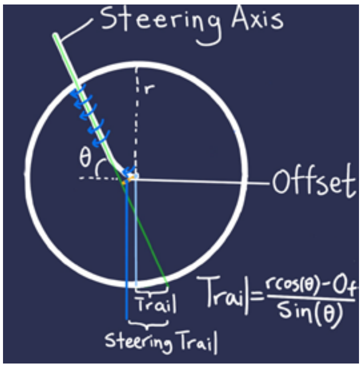


Fig 6

Trail is the leading distance between steering axis and contact line.

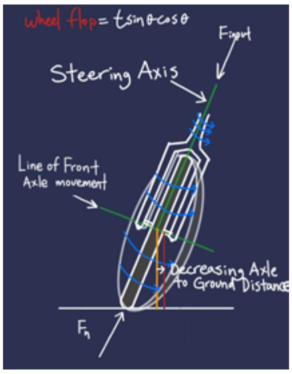


Fig 7

Wheel flop is the decreasing axle to ground distance during steering (as indicated). The compression force from gravity will push the front wheel to rotate further than intended.

Forces					Stress	
Horizontal bump impact on axle(F3)	Front wheel axis static(Fc)	Front wheel axis riding(Fc)	Front wheel axis pedaling(Ffront)	Fmax down 1m slope.	Top Tube Front	Headset
197N	301N	903N	558N	2000N	250MPA	73MPA

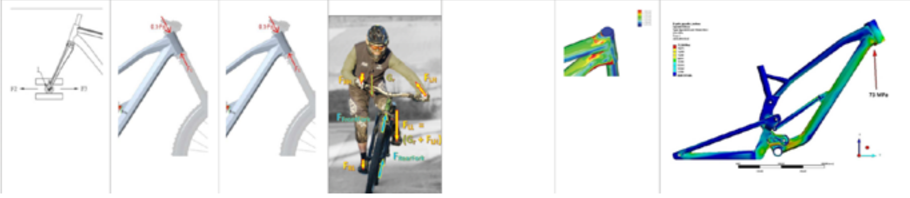
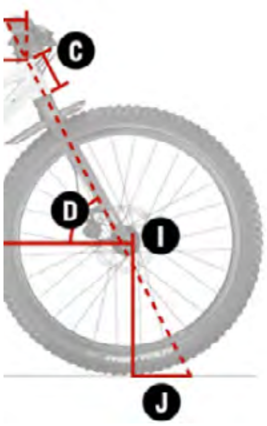


Fig 8: Forces experienced on head tube can reflect strength requirements for forks

Fig 9: Go-pro accelerometer indicate 2G's of force under aggressive cornering.



Wheel Size	16"	20"	24"
Rider Height(cm)	104-122cm	120-130cm	127-142cm
Rider Inseam	40-54cm	52-59cm	57-66cm
Trail(J)	54mm	65mm	81mm
Fork Length(I)	267mm	317mm	367mm
Steering Angle(D)	67.5	67.5	67.5

Fig 10: Kids Mountain Bike Geometry

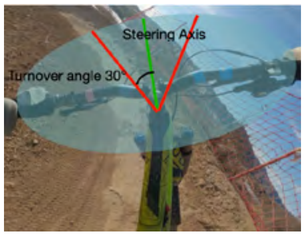
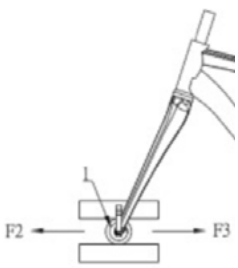


Fig 11: Go-pro attached to chest shot that steering angles does not exceed 20°

Materials Study

Material:	Tensile Strength	Density	Manufacturing process
6061 T6 alloy	290MPA	2.7g/cm³	CNC
7075 aluminum	510MPA	2.81g/cm³	CNC
Steel	767MPA	7.85g/cm³	Electric Arc welding
T800 Carbon Fiber	2000MPA (Brittle under transverse forces)	2.0g/cm³	Layup + heat curing

Fig 12: Table Showing Material Properties



Bicycle type		Mountain bicycles
Forward force, F_2 [N]	Stage 1	1 200
	Stage 2	1 250
Rearward force, F_3 [N]	Stage 1	600
	Stage 2	650
Test cycles, C_1	Stage 1	60 000
	Stage 2	50 000

Fig 13: Cyclic forces applied on a fatigue test before hysteria

Design Brief

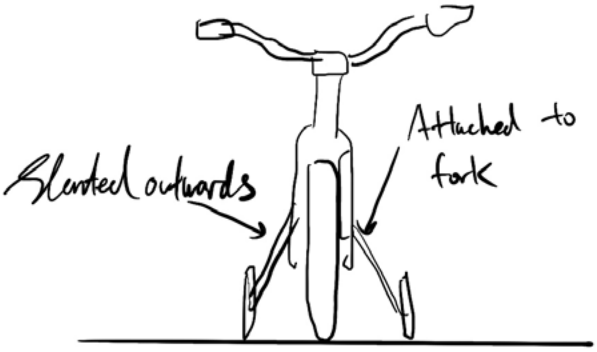
I will design and manufacture a fully functional **prototype** which solves the problem of crashing in mountain biking due to over steering(Fig 1). The **primary audience** is young beginners, **secondary audience** is mountain-biking coaches. The parameters of the product should be designed to fit 16-25 inch bike sizing(Fig 11). The product should be able to reduce risk of user when practicing. The product must be **impact resistant** - consider chromoly, aluminum or high modulus carbon fiber. The product should be **durable** under repeated exposure to dust and mud. **Volumetric requirements** - under 500*500*500mm in collapsed form for **portability**. Performance of will be ensured with low weight. I will adopt a **pioneering strategy** to market the product, focusing on achieving **product development**. My research and development budget, set at 400USD, will cover any required compo-

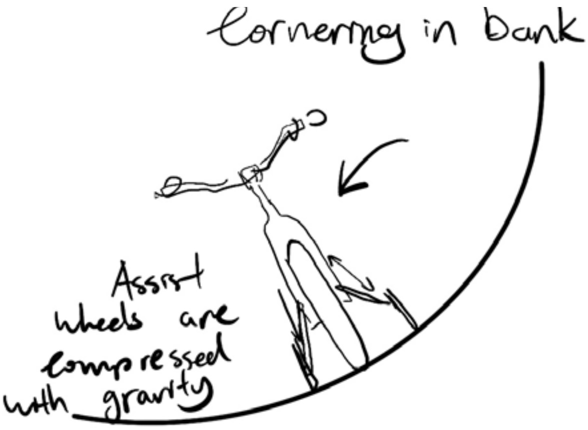
Design Specifications

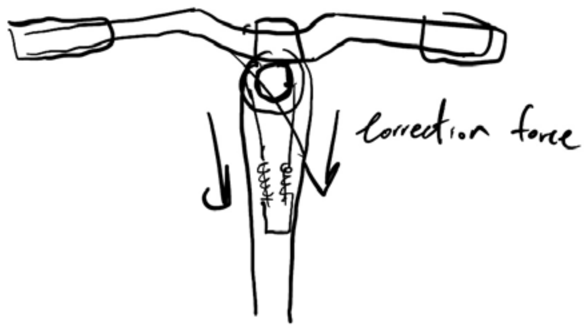
Category(prioritized)	Specification	Justification
Safety 1	No component should prose a safety risk when user crashes.	Fig 1 shows when crashing users groin and torso could collide with component.
Safety 2	No component should cause the user to crash in intended use case	Fig 1 shows that rider is riding on terrain that might jam component.
Safety 3	Product should be able to remain intact under peak loads of 2000N	Fig 8 identifies the force encountered on a bicycle frame when loaded down a 1m ramp.
Safety 4	Product should not deform transverselymore than 5% under horizontal axle impacts up to 200N	Fig 8 identifies the typical horizontal force applied to the front axle.
Safety 5	Product should not compress longitudinal to the steering axis more than 5% under axle loads up to 1000N	Fig 9 shows rider of 50kg can experience 2G of acceleration Fig 8 identifies the vertical force applied to the front axle
Safety 6	Product should not twist torsionally more than 10% under asymmetric pedaling forces up to 600N.	Fig 8 identifies the asymmetric torsional force the bike encounters.
Function 1	Does not inhibit steering mechanics from -45 to +45	Fig 11 indicates the range of steering angles during normal riding circumstances. The component overly interfere
Function 2	Must not damage the bikes intended performance on any situations	Fig 4 Suggests the device should aid rather than affect low speed practice.
Function 3	Should assist in correction of the bike under crashing situations.	Fig 2 shows crashing is based on the front wheel. Fig 4 shows that component must be able to protect the rider from crashes for safety
Function 4	Should reduce the affect of trail and oversteering at low speeds	Fig 7 shows that oversteering can cause unstable riding and potential crashes.
Function 5	Should not significantly alter a bikes geometry	Fig 6 Shows that bikes forks are designed a certain way to fulfill desired handling characteristics. The fork should not interfere negatively with these characteristics

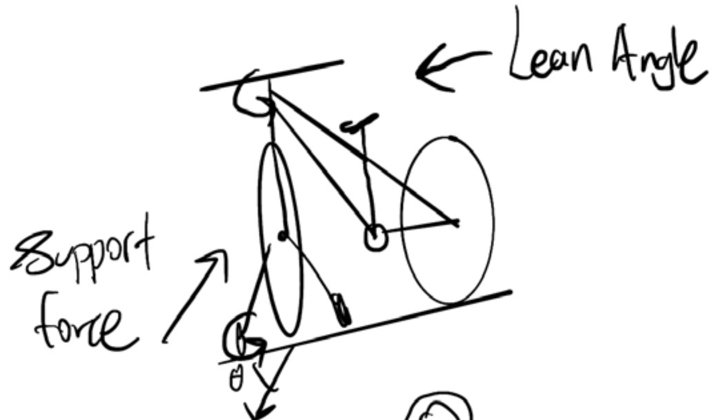
Category(prioritized)	Specification	Justification
Audience 1	Should be designed to fit with 16-24 inch bikes.	Fig 10 shows varying wheel sizes and fork lengths corresponding to users with heigh ranging from 104-142. Component must be designed to accommodate different sizes.
Audience 2	Can be installed and adjusted by coaches/parents under 5 minutes	Design brief states relevant users include coaches and parents. Fig 4 shows some users are inexperienced in technical skills.
Dimension 1	Must be designed to attach to forks with outer leg diameters ranging from 35-45mm	Fig 2 suggest instability is front-wheel based. device could be attached onto fork, which must be compatible with fork standards
Dimension 2	Should be compatible with forks with 100*15 mm or 110*15mm axle standards.	Fig 2 suggest instability is front-wheel based. device could be attached onto fork, which must be compatible with fork standards
Dimension 3	Volume should remain under 500mm*500mm*500mm	Fig shows targeted 16-24 inches bikes. Design should not be larger than the wheel itself to prevent mounting difficulty.
Material Selection 1	Stress bearing material should have a tensile strength greater than 270 MPA.	Fig 5 shows relevant frame areas experiences 250MPA of stress. The material strength must be above this level for safety.
Material Selection 2	Material should be durable under hysteria	Fig 13 shows that cracks will appear after 600N of force is applied for 60000cycles.
Material Selection 3	Material should be impact resistant	Design Brief
Material Selection 4	Complete Design should be lighter than 2.5kgs.	Fig 8 shows a heavy component could hinder steering.
Material Selection 5	Material should be corrosion resistant	Design Brief
Constraints 1	R&D Cost should be lower than 400SGD	Design Brief
Constraints 2	Cost for Manufacturing single commercial Production Model should be under 150SGD	Fig 12 show that highest price is around 400USD. Since product is targeted on children, the expected expenditure further decreases. 150SGD price limit guarantees a 50% profit to cover production when sold average market prices.
Constraints 3	Selling prices should be 25% lower than products with similar function.	Fig 15 shows that similar product sold at 459 USD are already experiencing selling difficulties. A new brand should use lower selling price to attract customers.

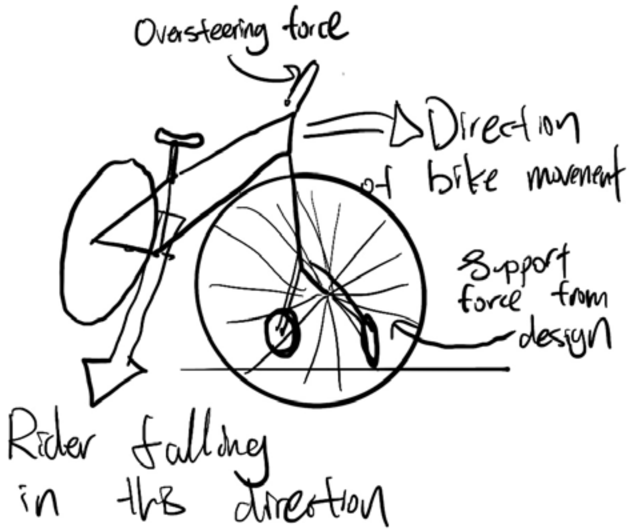
Concept Sketches

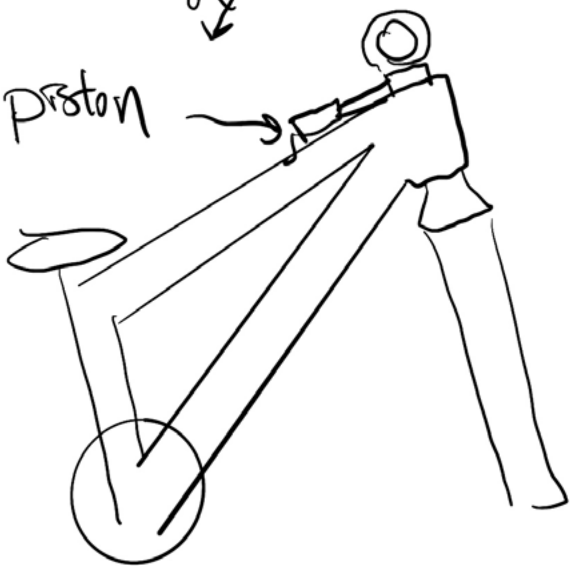


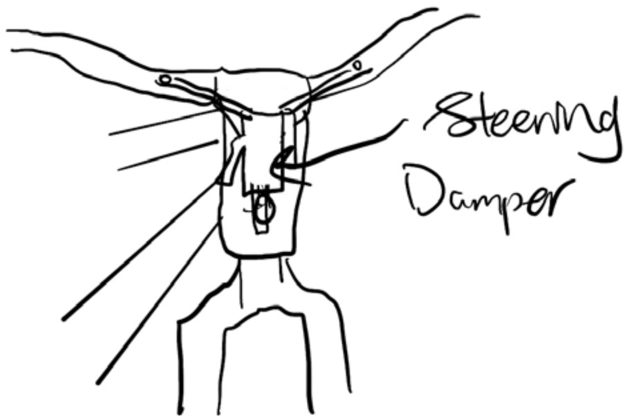






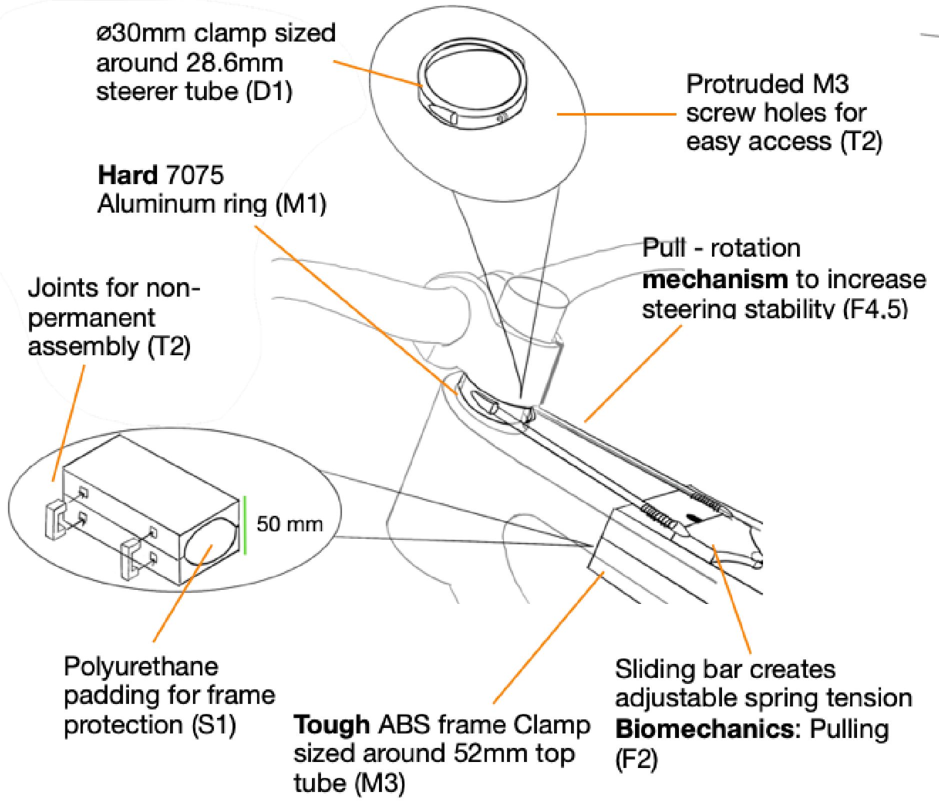


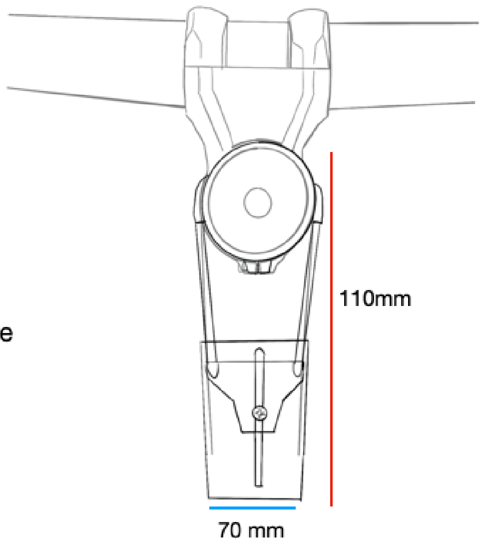




Detailed Sketches

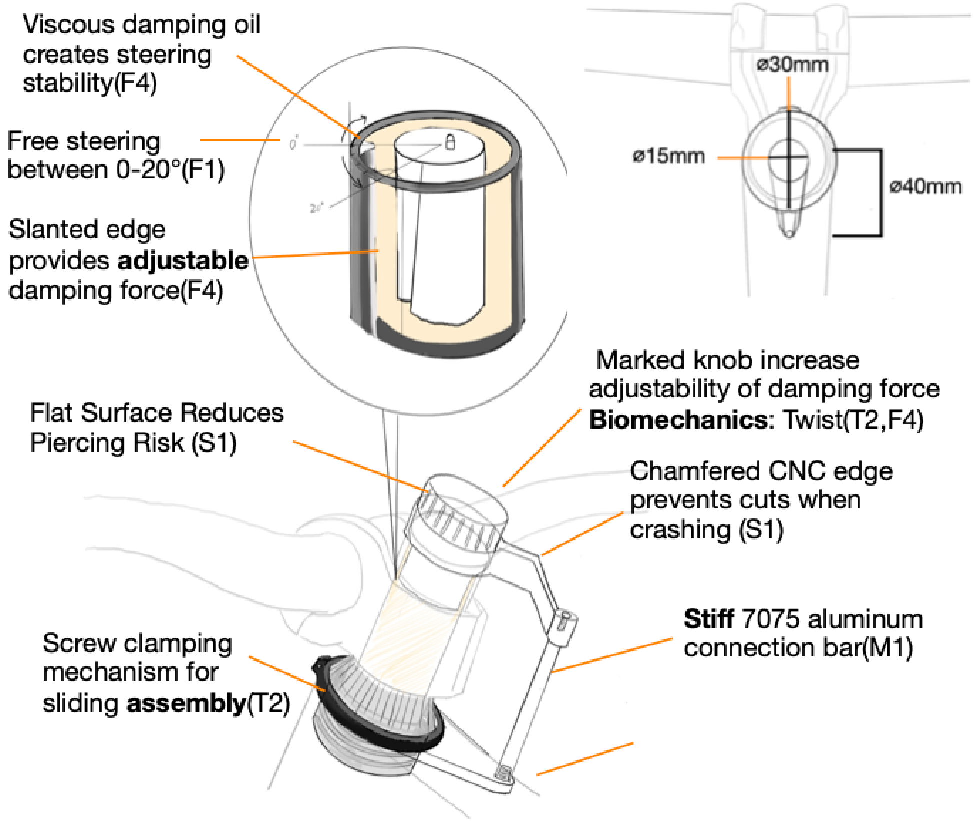
Idea 1:

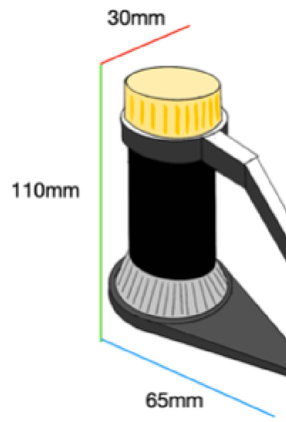




Evaluation
The springs in this design apply a restoring force to the handlebars and subsequently the wheels. There is high feasibility in the materials selected, where the aluminum ring can be milled and the ABS shell can be 3D printed.

Idea 2:





Evaluation
This steering stabilizer uses oil dampening to reduce volatility of wheel movement. The working model should be CNC'd to high accuracy for good sealing of oil. Stiff and non-porous material such as 7075 aluminum will be used.

Idea 3:

Rubber padding on fork clamp adds frame protection(S1)

Temporary screw **assembly** ensures ease of maintenance (A2)

Clamp is **adjustable** for fork diameter between 35-45mm (D1)

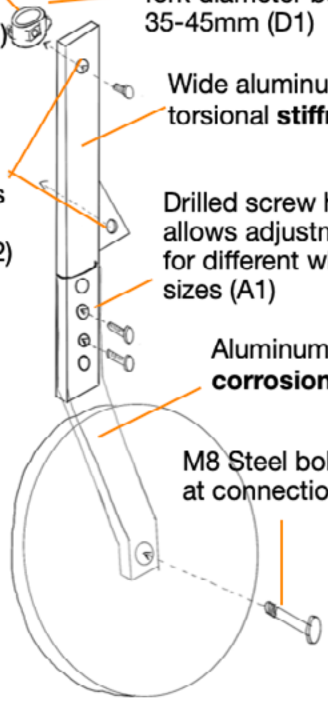
Wide aluminum plate creates torsional **stiffness** (S5)

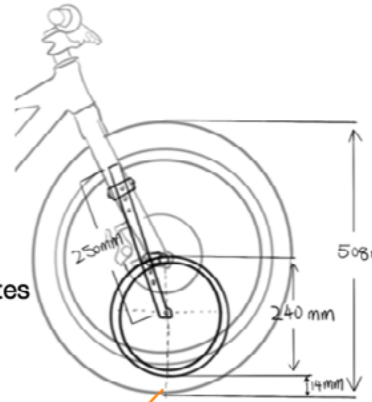
Two points of fixture ensures rigidity of component(S2)

Drilled screw holes allows adjustment for different wheel sizes (A1)

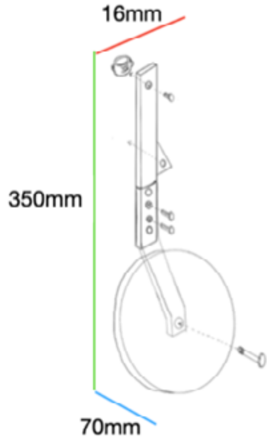
Aluminum material is highly **corrosion resistant**(M5)

M8 Steel bolt ensures strength at connection points.(S2)





14mm **clearance** avoids impacts with trail obstacles(S2)



Evaluation
This design features two extended wheels that float above ground. During turning, the wheel contacts the ground and provides a supporting force. This product can be easily assembled from training wheels, screw and nuts, padded clamps, and a customized metal plate.

Idea 4:

Large fork clamp increases **usability** during assembly(A2)

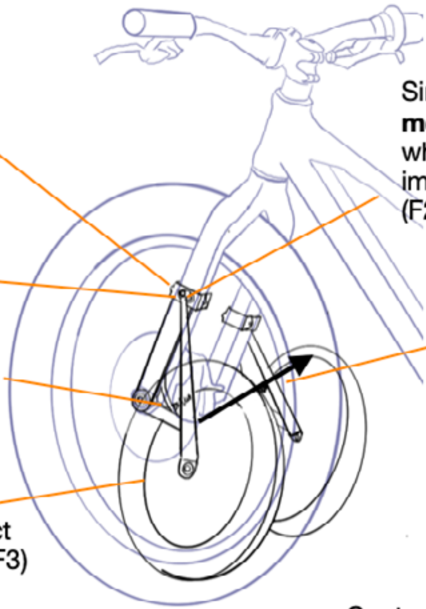
Temporary joint with screws allows for easy disassembly (A2)

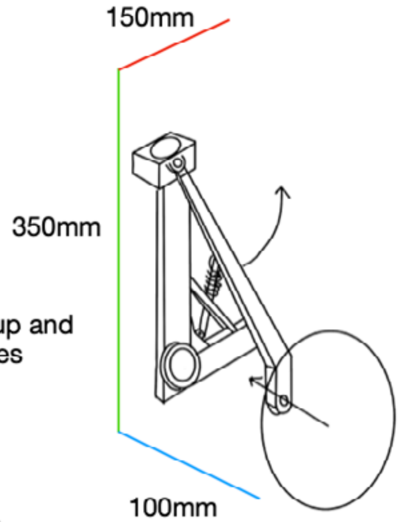
Aluminum reinforcement increases transversal and torsional **stiffness** (S4/5)

Slanted outward to increase ground contact on crashing situations(F3)

Single pivot **mechanism** allows wheel movement on impact with obstacle (F2)

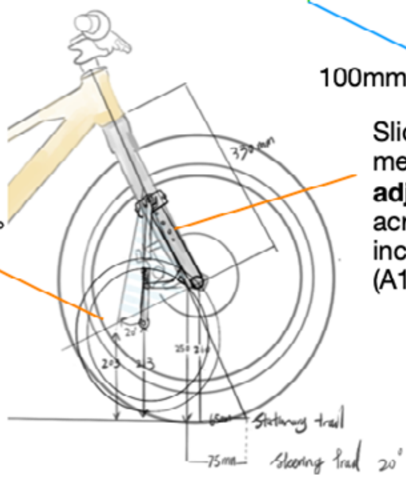
Suspension moves up and back which decreases impact force (F2)





Contact the ground at 20° of steering

Sliding mechanism for **adjustability** across a 16-24 inch wheel sizes. (A1)



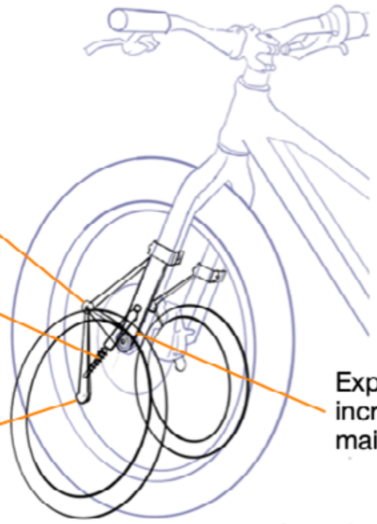
Evaluation
This design builds on idea 3 with suspension. This product can be prototyped with a metal plate, custom suspension arm, and a strong rubber band. For commercial production, the plates will be replaced with shaped metal tubes, and a proprietary shock will be used.

Idea 5:

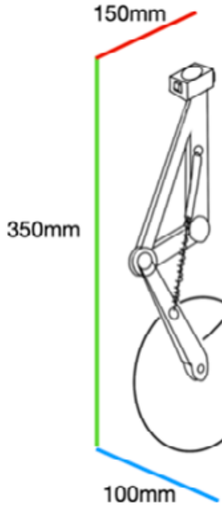
Sealed pivot bearings increase **Corrosion Resistance** to dust and water (M5)

Force is applied through **compression** of the shock absorber (F3)

Design for assembly: Simple axle and bolt mechanism(A2)



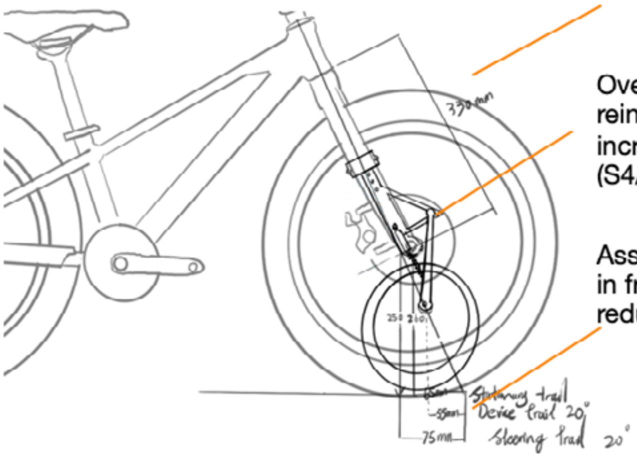
Exposed shock design increases ease of maintenance(A2)



Length sized around 16-24 inch bike trail (A1)

Oversized triangle reinforcement increases **stiffness** (S4/5)

Assist wheels placed in front of main wheel reduces trail (F4)



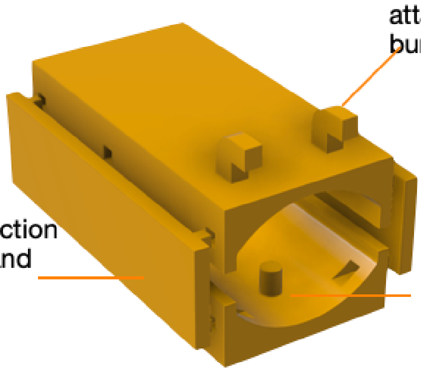
Evaluation
This design is a variation from design 4, which places the wheels in front instead of the back. This reduces the trail of the bike, decreases wheel flop, therefor increase steering control. A compression shock is required for this design. Other Manufacturing processes are similar to design 4.

Review of Ideas

Design	Strengths	Weaknesses
1	• Cost of manufacturing is low with 3D printing • Design will not be subjected to high loads	• Spring system is not consistent over longer periods of use. • Restoring force on handlebars can affect low-speed performance
2	• Design will not be subjected to high loads. • Effective stabilization at both low and high speeds.	• High costs of manufacturing due to low tolerance requirements. • Lacking in assistance for crashing situations
3	• Cost of manufacturing is low with plasma cut steel plates • Low complexity design increases reliability.	• Limits steering on larger turning angles. • Risk of jamming on rough terrain.
4	• Support wheels with suspension prevent a restoring force under crashing situations. • Suspension creates forgiveness on rough terrain and reduces risk of crashing	• Heavy • Moving linkage creates a larger risk of breaking when crashed.
5	• Support wheels with suspension prevent a restoring force under crashing situations. • Suspension creates forgiveness on rough terrain and reduces risk of crashing • Reduced trail and therefor the wheel flop affect at lower speeds.	• Heavy • Moving linkage creates a larger risk of breaking when crashed.

Concept Modelling

Idea 1 (Iteration 1)



Hook for attaching bungee cords

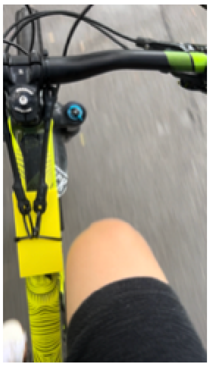
SnapFit Connection Bar for upper and lower part

Cylinders to fix lower component to frame

Bungee cord used as elastic component

Temporary fixture with table ties

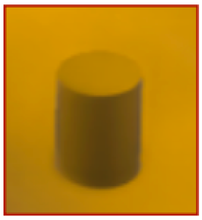
Iteration 1 mounted on bike



Iteration 1 tested during cycling

Errors:

The snap fit resulted in me unable to fit the lower part

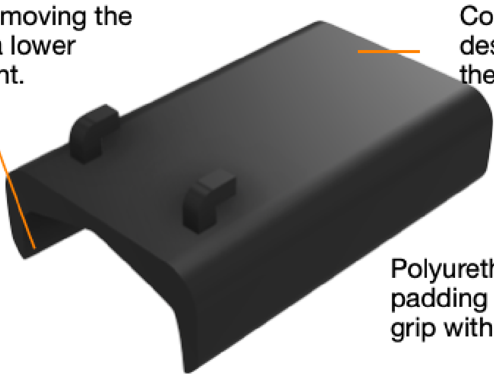


The cylinders provided a loose fit

Temporary solution with table ties causes the spring shift

Iteration 2

Edges are curved inward, removing the need for a lower component.



Contours are designed to fit the bike better

Polyurethane padding increases grip with frame

Top View of Iteration 2

Mounted on Bike

Client Testing:

Paul, a 8 year old rider has 2 years of ride experience. His leaning tourney makes him an suitable client. Paul also rides an 24 inch bike, making him fit within the user range

Client testing the product in riding position

Client Feedback:
- Stabilizes my handlebars when riding fast, and the wheels stay straight even if I let go of the bars.
- I can feel a little bit of resistance under low speeds, making it difficult to turn the bars for balance.
- Even with this product, riding over rough terrain still demands a lot of strength.

Idea 3(Iteration 1)

Modified front axle fits the mounting plate

Mounting plate for wheel and suspension component

Fork Clamp with temporary screw **assembly**

Low fidelity model of Joining Mechanism

1:1 scale front axle installation

Axis Fitment on Bike

Errors:

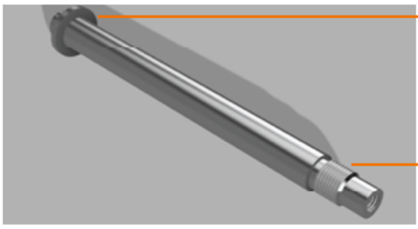
The screw joint causes instability under loads.

The mounting plate has to cross diagonally to reach the fork clamp, making it difficult to assemble

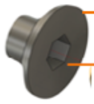
The other end of the front axle is stuck in the treads, so only one side could be used.

Iteration 2

Axle Design



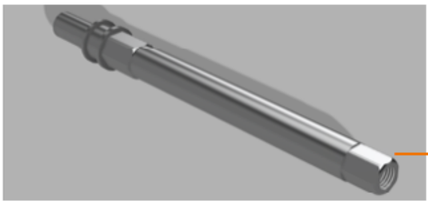
Axle Variant for Quick Release Fork



Large anchor plate increases stability

6mm Hex Socket reduces risk of stripping

Slight indentation for easy insertion over threads



Axle Variant for Hex Lock Fork

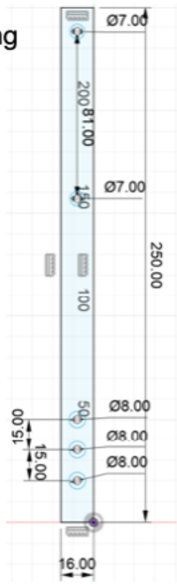
Beveled edges for easy insertion over threads

CNC prototype of 2 axle variants

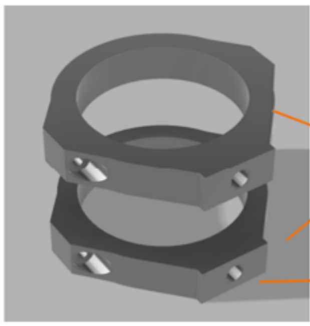
Fixing Plate Design

Straight mounting plate increases ease of manufacture

Three mounting interfaces for adjustability between 16, 20, 24 inch bike



Fork Clamp Design



CAD model for fork clamp

Double clamp design increases stability

Flat mountain surface ensures ease of assembly

Existing market alternative

Rubber Padding for frame protection and grip

Assembly

Front View of Assembled design

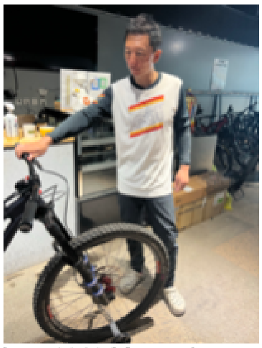
Side View of Assembled design

Wheels contact the ground at approximately 45 degrees of steeri

Paul: 8 year old rider with 2 years of experience

Client Feedback

- The wheels contact the ground and resist turning over 50°
- Provides support but the bike can still fall over when leaned.
- The wheel feels loose when he puts weight on it.



Lee: 2019 Mountain Bike Champion and coach with 10+ years of experience

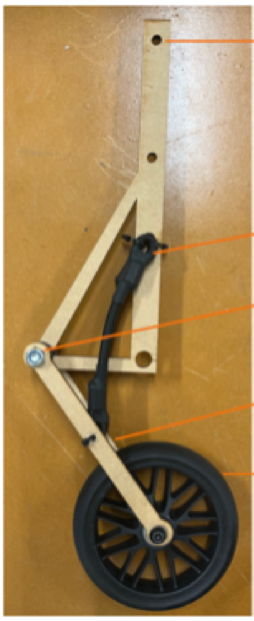
Expert Appraisal

- When turning, the support wheel will take the majority of the load.
- This can lead to reduced traction, which defeats the effect of having this device.
- A good idea is to use a bigger wheel to increase contract area.
- Also use rubber tires to increase traction with the ground

Ideas for Further development

Based on feedback from the client and expert, increasing the grip and load bearing mechanics is the primary objective. Iteration 2 has provided valuable information on how to create a stable connection between the fork and the component. These information will be used in the prototyping of idea 5.

Idea 5(iteration 1)



6mm Laser Cut MDF Mounting Plate

Bungee Cords replace the spring

Partial threaded bolt and wooden spacers make up the pivot

3mm Laser Cut Suspension Linkage Arms

6 inch rubber wheel

Connection with fork clamp

Connection with modified axle

Pushing the model to test suspension dynamics

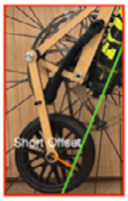
Goals for next iteration:

- Increase Torsional Stiffness
- Calculate offset so the wheel contacts the ground a at a correct steering angle
- Incorporate the use of a shock absorber:

Errors:

The bungee cord bended more than intended, causing a weak pushback force. This means a compression shock has to be used for similar products

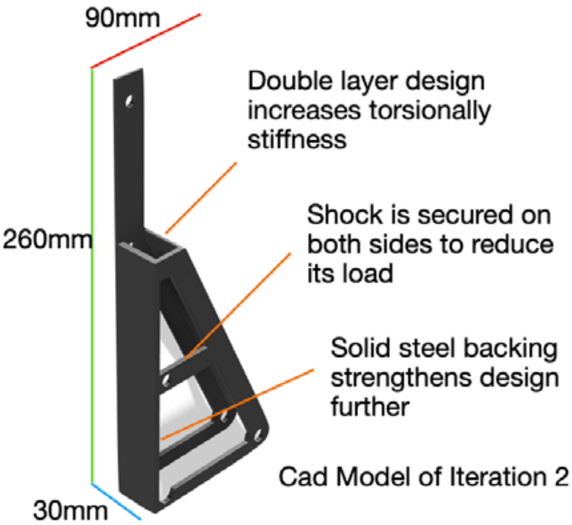
The assist wheels were to small in that they cannot contact the ground even when leaned at a high angle. Measurement shows that a 10-12 inch wheel would be more ideal



The product can only be loaded on the longitudinal axis. There is low torsional stiffness. A sideways impact can damage the bike fork. Even if the final design would be metal, the high loads applied on the pivot and shock will affect durability

The perpendicular offset between the steering axis and the assist wheel is too small. When steering, the lowering of the assist wheel is insufficient.

Iteration 2



Cad Model of Iteration 2

The EXA air shock is chosen because of its lightweight and high adjustability.

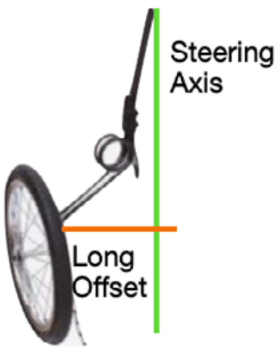
Goals for next iterations:

- Reduce Weight (currently at 300 grams for single frame)
- Reduce thickness (currently at 30mm)

Iteration 3

The two designs below feature a horizontal suspension layout. The are lighter and subjected to less torsion. In this layout, the wheel has to be mounted on a single side. This requires the use of a stub axle.

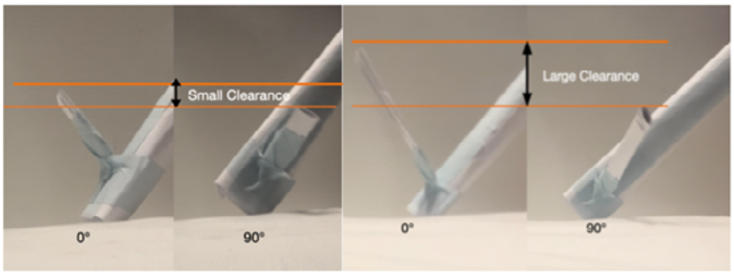
HB fold-up training wheel



Easy Trainer wheel

Stub Axle

Compatible wheel



Experiment with clearance and offset:

The long offset with this design creates a larger clearance due to wheel flop affect, reducing collisions with obstacles.

User feedback on Idea 3 suggested that steering angle should be greater than 45° to not inhibit motion. Using Wheel Flop Formula (Fig 7) and (Fig 13) We can mathematically determine the offset needed to create a suitable clearance. The steering threshold will be set at 50°.

Review Against Specifications

Category	Specification (Simplified)	Idea 1	Idea 3	Idea 5
Safety 1	Low safety risk when crashing			
Safety	Cause Unintended Crashing			
Safety 2	Ultimate load bearing capability			
Safety 3	Transversal Stiffness			
Safety 4	Longitudinal Stiffness			
Safety 5	Torsional Stifness			
Function 1	Doesn't inhibit steering			
Function 2	Doesn't affect bikes intended performance			
Function 3	Correction under crashing situations			
Function 4	Reduce trail/oversteering			
Audience 1	Fits with 16-24 inch bikes.			
Audience 2	Installed and adjusted under 5 minutes			
Dimensions 1	Attach to 35-45mm diameter forks			
Dimensions 2	Compatible with two axle standards			
Dimensions 3	volume remain under 500*500*500mm			
Material Selection 1	Ultimate tensile strength > 270 MPA.			
Material Selection 2	Durable under hysteria			
Material Selection 3	Impact resistant			
Material Selection 4	Lighter than 2.5 kg			
Material Selection 5	Corrosion resistant			
Constraints 1	R&D Cost < 400SGD			
Constraints 2	Manufacturing Cost <150SGD			
Constraints 3	25% lower prince than competition			

Meets Specification | Potential to Improve | Doesn't Meet Specification

Ideas 5 was chosen to be developed further because it has most potential to improve. Although Idea 1 and 3 meets specification in more areas, they have some issues with the specification that could not be resolved.

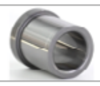
Proposed Design

Design 5 was chosen for manufacturing. Its low mounting position poses minimal risk in crashes, and the large clearance prevents unintended accidents. Straight edges and reinforced plates ensure load-bearing capability, improving stiffness from iteration 1 to iteration 3. Transversal and longitudinal stiffness are achieved through a three-point connection using two clamps and one axle, while torsional stiffness comes from the wide linkage and mounting plate. User testing highlighted the need for appropriate support, leading to the calculation of the offset so that it contacts the ground at the correct steering angle. Performance is maintained with free steering in normal ranges, addressing a problem identified in design 1. The design protects riders from crashes by applying supportive force when the wheel rotates beyond the steering threshold. Adjustable mounting holes accommodate 16, 20, and 24-inch wheels. The design was tested on a fork with a 35mm diameter, and the axle is compatible with both quick-release and hex lock standards. 7075 aluminum was selected and proved effective in manufacturing the modified axle, with a tensile strength of 570 MPa, well above the 270 MPa requirement. Iteration 3 emphasized the importance of load direction for durability, which this design addressed with a horizontal suspension layout aligned with the direction of impact. Large pivots and robust plates enhance toughness. The total system weight is 2.1kg The design is corrosion-resistant with sealed bearings. Manufacturing costs are minimized by using straight plates wherever possible.

Manufacturing Details

Materials

Mechanical Characteristic Aesthetic Characteristic Environmental Considerations Moral Considerations

Component	Image	Material	Justification
Front Axle		7075 Billet Aluminum	- High Tensile Strength (510 MPa) ensures durability under high loads (e.g., forces during crashes). - Low density (2.81 g/cm³) ensures lightweight, critical for maintaining bike maneuverability and not exceeding the 2.5 kg target weight. - Anodized surface allows for a polished, corrosion-resistant, and visually appealing finish. - Aluminum is recyclable, reducing environmental impact compared to non-recyclable materials like some composites. - Its corrosion resistance reduces the need for frequent replacements, minimizing material waste. - Ethical sourcing of raw materials can be ensured by choosing suppliers with sustainable practices. - Reduced failure rates contribute to safety, addressing concerns for user well-being, especially when targeting children and beginner riders.
Fixing Plate			
Suspension Linkage			
Fork Clamp		6061 T6 Plate Aluminum 1mm	- High ductility provides flexibility for snug fit without cracking or failure, essential for securely holding the fork. - Lightweight (density ~2.7 g/cm³) minimizes additional weight, preserving bike performance and handling.
		Silicone Rubber	- High elasticity provides excellent cushioning, absorbing vibrations and preventing damage to the bike frame. - Non-slip properties ensure a secure grip between the clamp and the fork, ensuring safety. - Retains a clean look over time, as silicone rubber is resistant to dirt and UV degradation.
Assist Wheel Bolt		Grade 12.9 Carbon Steel	- High tensile strength(1200Mpa) ensures secure fastening, critical for withstanding vibrations during mountain biking. - Excellent shear resistance prevents failure under transverse loads (S4) - Minimalistic and utilitarian design aligns with the functional purpose of the bolts. - Carbon steel is widely recyclable, reducing the environmental impact.
M7 Hex Bolt			
M7 Hex Nut			
M8 Carriage Bolt			
M8 Carriage Screw			
Pivot Bushing		Quenched No.45 Steel	- Hardness: Quenching enhances wear resistance, reducing friction-induced damage. - Low Thermal expansion coefficient, maintaining optimum tolerances during operation.
Pivot Bushing Cap			
EXA Shock Absorber		Anodized Stainless Steel	- Anodization improves hardness, ensuring scratches and wear don't interfere with tolerance.
Assist Wheel		Butyl Rubber(tire)	- High traction: Ensures grip and stability, crucial for uneven surfaces. - Shock absorption: Damps vibrations, enhance comfort, reduce stress - Natural or synthetic rubber can be recycled into other products. - Ensure ethical sourcing of tire, including safe working conditions.
		ABS Plastic(Frame)	- High strength-to-weight ratio provides structural integrity while keeping the frame lightweight. - ABS plastic is recyclable, reducing environmental impact if disposed of properly.

Manufacturing Techniques

Part Name	Material	Marking Out	Manufacturing	Finishing	Joining
Front Axle	7075 Billet Aluminum	Fusion 360 CAD	CNC Lathe	Anodization - Corrosion Resistance	Screwed with internal thread
Fixing Plate			5-axis CNC Machine	Anodization - Corrosion Resistance	Screwed with nuts and bolts
Suspension Linkage				Polishing of pivot structure for smooth rotation	Press fitting the bearing through the component onto fixing plate

Computer Numeric Control(CNC) Machine

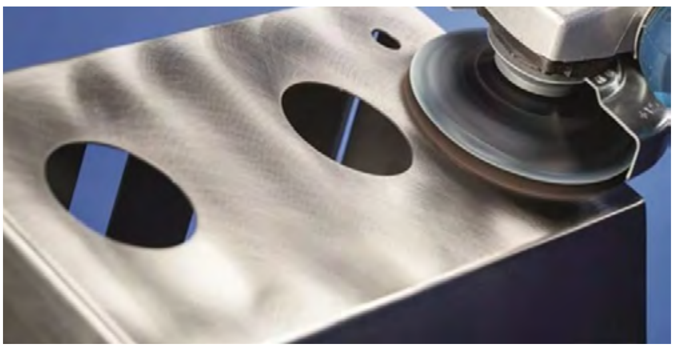
CNC machining, especially with 5-axis, is ideal for one-off prototyping due to its precision, flexibility, and speed. It begins with a CAD model, which is quickly converted into G-code, enabling the creation of complex designs without custom molds. The ability to work across five axes allows CNC machines to produce undercuts, fillets, and high-precision parts in a single setup, reducing production time. CNC machining works well with hard aluminum, like 7075, which cannot be welded or hand cut. This allows prototypes to closely mimic the properties of final production parts. The downside to this process is high energy consumption. Using renewable energy sources for machining can reduce the carbon footprint. Recycling material waste such as metal chips also reduces environmental impact.

Pressfit

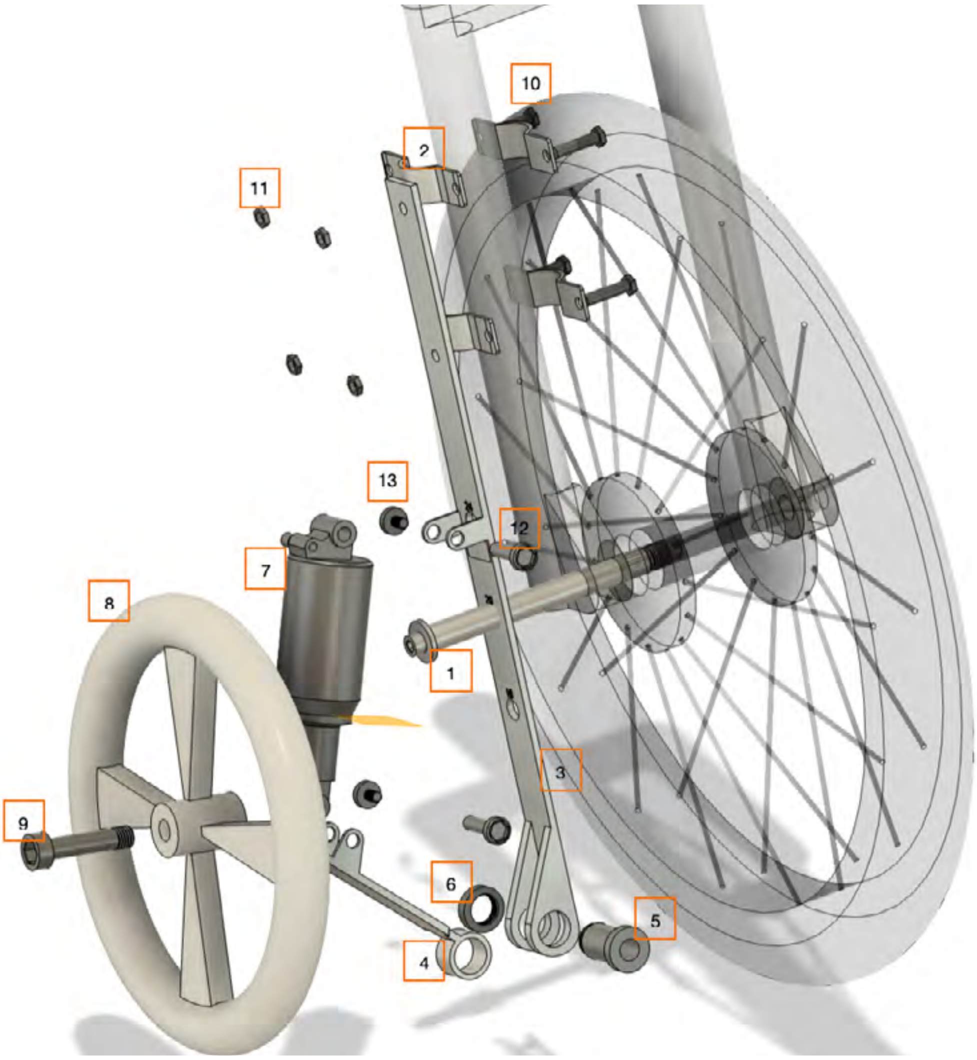
Press-fitting a bearing involves forcing it into a slightly undersized hole in two structures, creating an interference fit. This method is suitable because it ensures a secure, friction-based fit that prevents movement or loosening under loads. In my case, the interference will be applied on the surrounding pivot structure on the fixing plate. No interference will be applied on the Suspension linkage to reduce friction during rotation.

Polishing

Polishing is a finishing process that enhances the surface smoothness and reduces friction. Polishing the internal surface on the hole of the suspension linkage ensures reduced friction during movement and improved wear resistance. Achieving a smooth finish is crucial for components like bushings, as it enhances rotational performance and prolongs part lifespan.

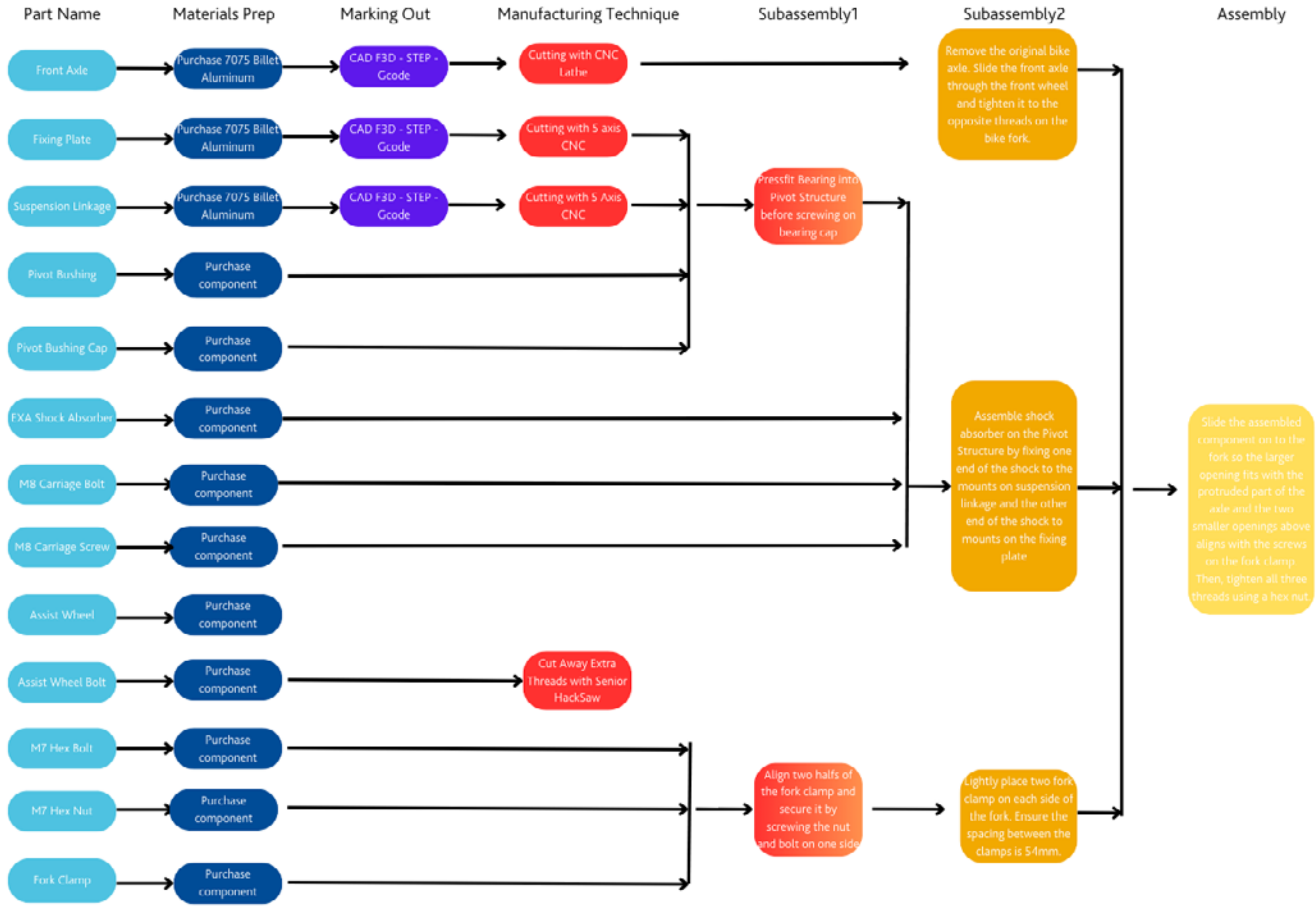


Assembly Details

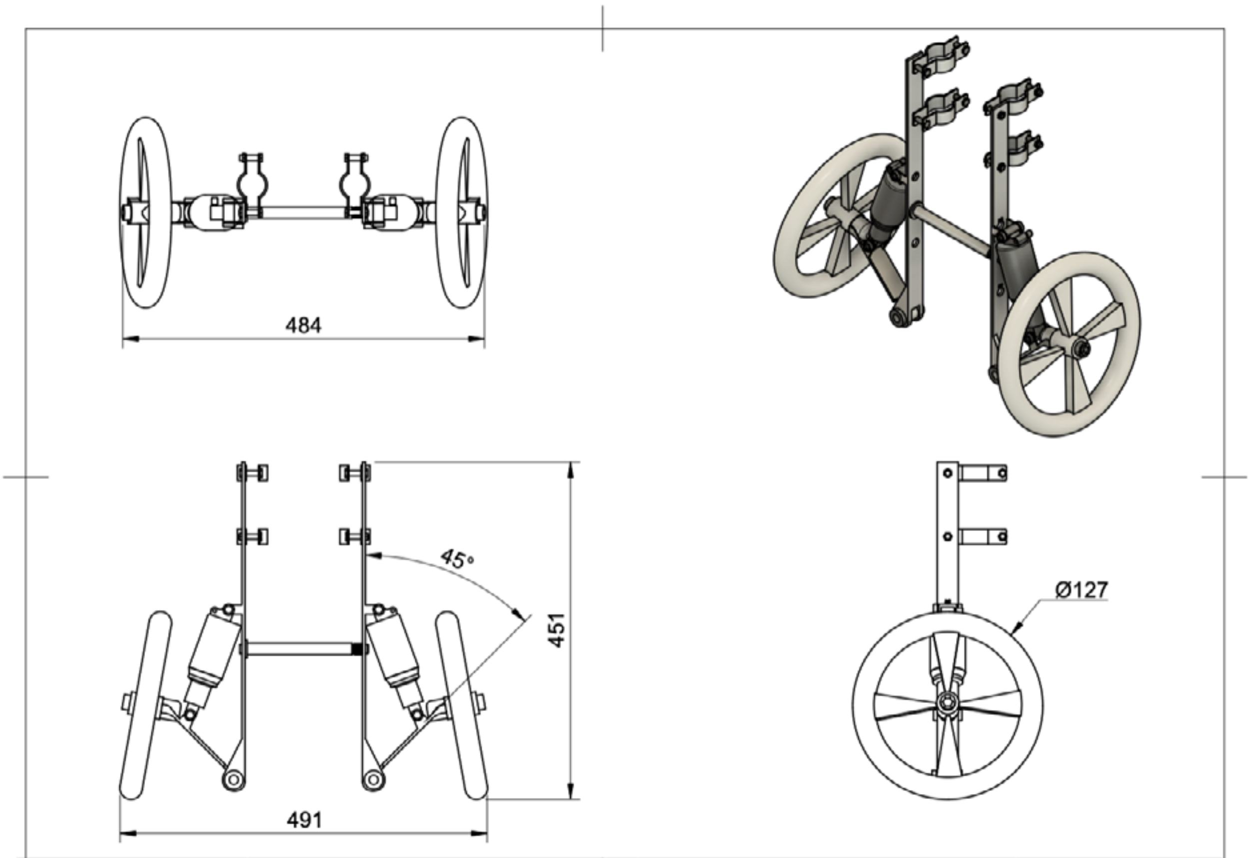


Part No.	Description	Length(mm)	Width(mm)	Thickness(mm)	Quantity	Cost (rmb)
1	Front Axle	170	ø15	ø15	1	400
2	Fork Clamp	ø35	ø35	2	4	20
3	Fixing Plate	430	28	4	2	600
4	Suspension Linkage	120	28	4	2	600
5	Pivot Bushing	42	ø20	4	2	10
6	Pivot Bushing Cap	6	ø25	6	2	10
7	EXA Shock Absorber	170	ø45	ø45	2	400
8	Assist Wheel	ø254	ø254	43	2	200
9	Assist Wheel Bolt	55 (6 cap, 10 thread)	ø12	ø12	2	5
10	M7 Hex Bolt	30 (3 cap, full thread)	ø7	ø7	8	5
11	M7 Hex Nut	3	ø7	ø7	8	5
12	M8 Carriage Bolt	33 (3 cap, 10 internal thread)	ø12	ø12	4	5
13	M8 Carriage Screw	13	ø12	ø12	4	5
Total:					2265 rmb ≈ 400 sgd	

Production Process



Technical Drawings (See Appendix I)



Component Name: Assembly	Materials: Metal, ABS, Rubber	Scale: 1:9
Part No. 0	Quantity: 1	Unit: mm

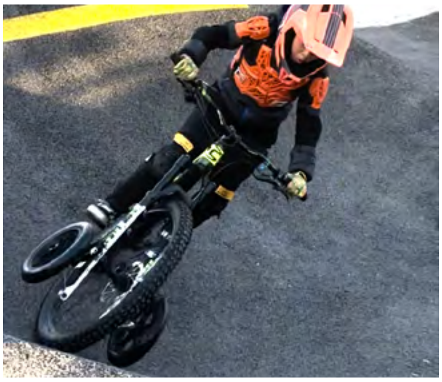
User Testing

Specifications that involves user testing are highlighted orange
Specifications that involves performance test / engineering analysis are highlighted blue
Specification that does not involve testing are removed

Lable	Specification	Test
S1	No component should prose a safety risk when user crashes.	Expert Appraisal: Consult a mountain bike coach on whether the exposed edges can endanger the user.
S2	No component should cause the user to crash in intended use case	User Trail: Ask the user to ride the component on flat ground, banked corners, and uneven terrain.
S3	Product should be able to remain intact under peak loads of 2000N(Fig 5)	Performance Test: Finite Element analysis with static stress.
S4	Product should not deform transversely to steering axis more than 5% under horizontal axle impacts up to 200N	Performance Test: Finite testing analysis with static stress.
S5	Product should not compress longitudinal to the steering axis more than 5% under axle loads up to 1000N	Performance Test: Finite testing analysis with static stress.
S6	Product should not twist torsionally more than 10% under asymmetric pedaling forces up to 600N.	Performance Test: Finite testing analysis with static stress.
F1	Does not inhibit steering mechanics in normal ranges of motion	Performance Test: Steering the bars and measuring the largest free steering angle Performance Test: Use moment of inertia calculation to quantify the added steering difficulty.
F2	Must not damage the bikes intended performance on any situations	User Trail: Ask the user to ride the component on flat ground, banked corners, and uneven terrain.
F3	Should assist in correction of the bike under crashing situations.	Performance Test: Suspension Kinematics Analysis User Trail: Ask the user to ride the component on flat ground, banked corners, and uneven terrain.
F4	Should reduce the affect of trail and oversteering at low speeds	Performance Test: Calculate whether effective trail is reduced with component installed. User Trail: Ask the user to ride the component on flat ground, banked corners, and uneven terrain.
F5	Should not significantly alter a bikes geometry	Performance Test: Compare the steering angle and fork length with the component installed.
A1	Should be designed to fit with 20-26 inch bikes.	User Trail: Assemble the component on 20 inch, 24 inch, and 26 inch bikes.
A2	Can be installed and adjusted by coaches/ parents under 5 minutes	Performance Test/User Trail: Perform a timed trail of coach and parents assembling component.
A3	Must be designed to attach to forks with outer leg diameters ranging from 35-45mm	Performance Test: try installing component on 35mm fork and 45mm fork.
A4	Should be compatible with forks with 100*15 mm or 110*15mm axle standards.	Performance Test: Install component on 100mm axle and 110mm axle
A5	Volume should remain under 500mm*500mm*500mm	Performance Test: Measure the length, width, height of component
M4	Complete Design should be lighter than 2.5kgs.	Performance Test: Weigh the component:

User Trail (S2 F2 F3 F4)

User Testing on Uneven Terrain



User Testing on banked corners

User on flat ground

These tests show the users performance under different circumstances. Using a combination of user interview and observations, I deduced that the component provides support for the user when leaned over a certain angle. However, the user reported that the suspension is too stiff, and aggresive steering can cause lifting of the front wheel.

Expert Appraisal (S1)

Coach of the user examining potential safety hazards.

Coach(Xiang) UCI pump track world cup china champion.

Asking coaches can provide valuable feedback, as they have experience on how a rider progresses, as well as how crashes happen. Specifically, Xiang mentioned that riders are unlikely to impact the component during a crash, as they are attached close the the fork. He also mentioned that the component could be useful in ensuring the safety of practicing jumps, when beginners tend to land sideways.

Assembly Test (A1 A2)

Assembly on a 27.5 inch bike

Assembly on a 24 inch bike

Assembly on 18 inch bike

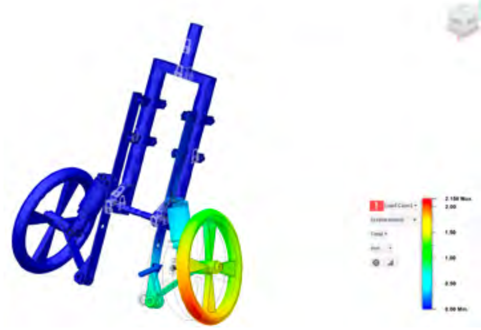
Timed trail of user's father assembling and disassembling component

Timing shows that a totally inexperienced person can assemble the componet in 4:30 and disassemble the component in 2:10. The problem with assembly lies in smaller wheel size bikes, where the axle isn't compatible

Engineering Analysis

Finite Element Analysis: Static Stress (S3 S4 S5 S6)

S4 Transversal Deformation

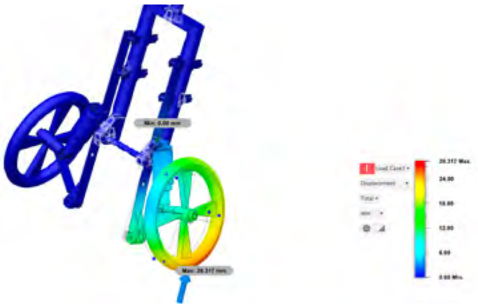

Displacement at 200N of force

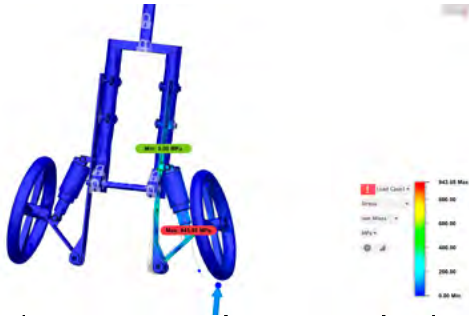

Stress(Mpa) at 200N of force

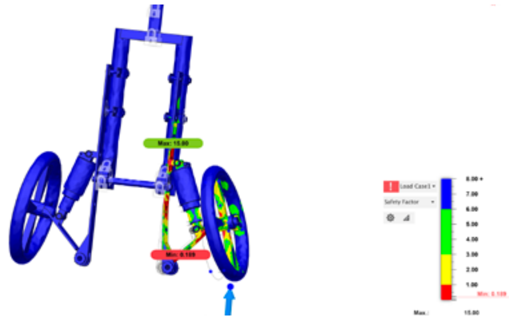

Safety Factor at 200N of force

Diplacement of 2.158 mm is within accepted range. Stress is within the accepted range, with the majority of the component in blue (0-200MPa), which is below the tensile strength of aluminum. From the safety factor diagram, the majority of the component is also blue, but the minimum factor is 0.54, which could be dangerous. This might be an anomaly in data, as I used the mooney riven model for hyperelastic materials.

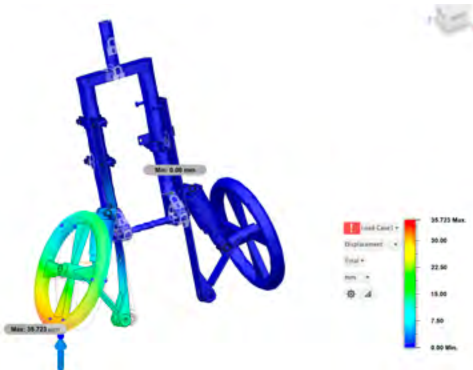
S5 Longitudinal Deformation (extended suspension)

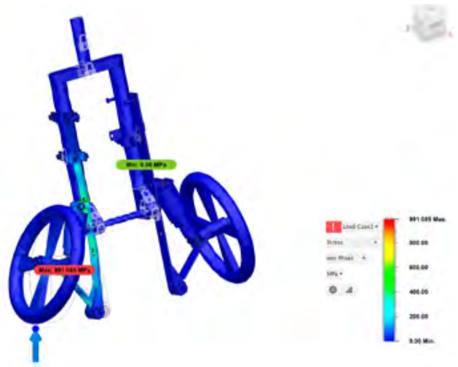


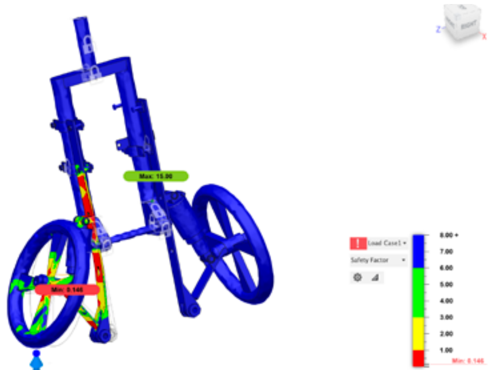




S5 Longitudinal Deformation (compressed suspension)

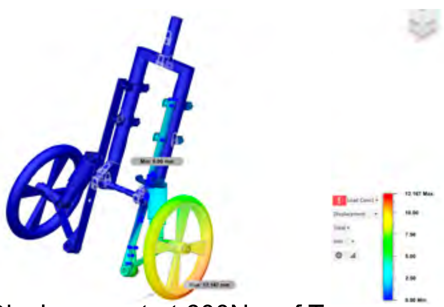

Displacement at 1000N of force

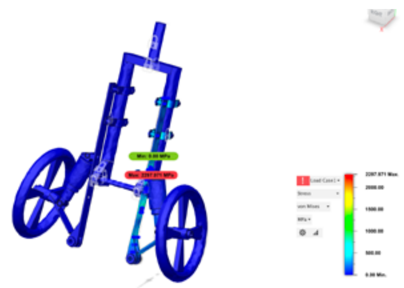

Stress at 1000N of force

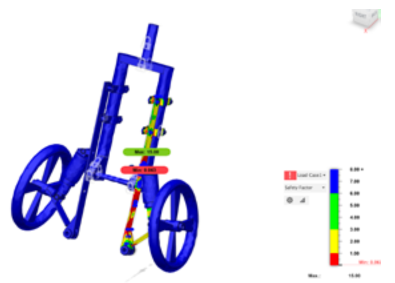

Safety factor at 1000N of force

This tests assumes the worst case scenario, where the suspension locks up and the entirety of the force is trasmitted to the materials. When the suspension is extended, displacement (35.723mm) is 10% above the accepted value. Stress is within the accepted range. However, the component is unsafe, with many areas having a safety value below 1

S6 Torsional Deformation


Displacement at 600Nm of Torque


Stress at 600Nm of Torque

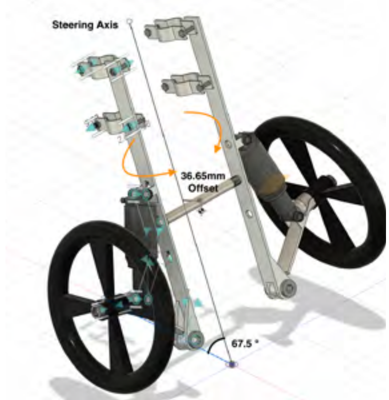

Safety factor at 600Nm of Torque

This test applies 600Nm of torque on the fixing plate. 600Nm is significantly larger than the force experienced during steering, so another analysis will be created after information on steering torque is collected.

Moment of Inertia Study (F1)

Overview

The primary objective of this analysis is to ensure that the assist wheel component does not inhibit the steering mechanics of the bicycle within its normal range of motion. This is quantified using the concept of the moment of inertia (MOI), which measures the resistance of a body to changes in its rotational motion. A reduced MOI ensures responsive steering.

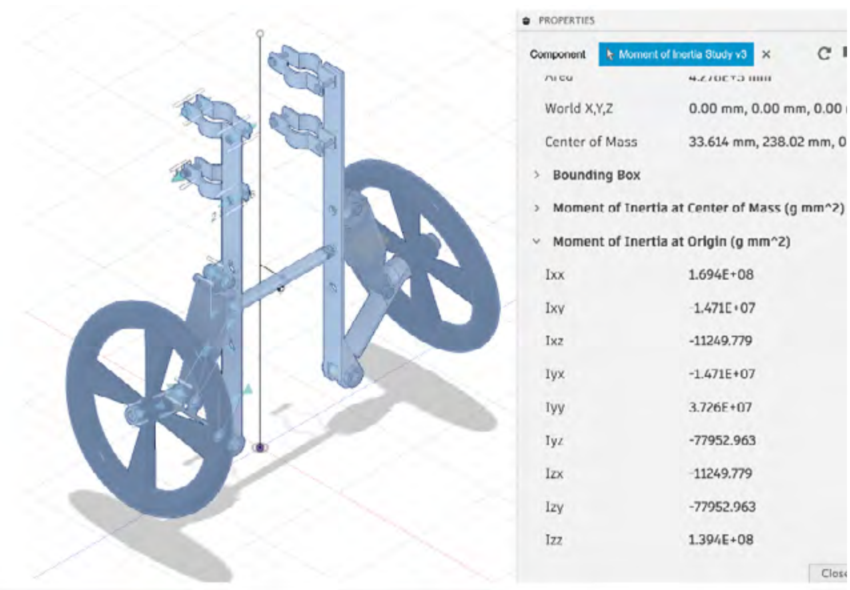


Component aligned with the steering axis in Fusion 360

Calculations with Autodesk Fusion

In Autodesk Fusion 360, we can rotate the entire body of the assist wheel component until the steering axis aligns with the global y-axis. This allows us to use Fusion's built-in CAD feature to calculate the MOI around different axes.

Steering Axis MOI



Aligned MOI Calculated by Fusion

The most relevant axis for steering is I_{yy}, which irepresents the resistance to rotation around the y-axis. The mathematical definition of I_{yy} is:

$$I_{yy} = \int_V \rho \left(x^2 + z^2\right) \, dV = 3.726 \cdot 10^7 \quad (1)$$

where ρ is the density, x and z are the perpendicular distances from the y-axis, and V is the volume of the body. In this equation, the integration represents the sum of all masses multiplied by their distance to the y axis, represented through the pythagorean theorem: $r = \sqrt{x^2 + z^2}$

Strategies to Reduce Axis I_{yy}

The equation for I_{yy} shows that reducing the distance between the steering axis and the component's mass decreases I_{yy}.

To further optimize the design lightweight components could be used and denser materials should be concentrated towards the center of the component

Coupling via I_{xy}

The mathematical definition of I_{xy}, the product of inertia, is:

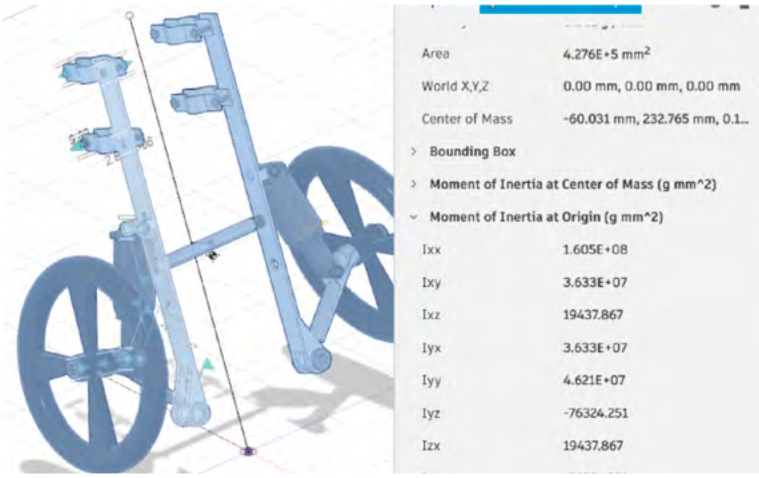
$$I_{xy} = -\int_V \rho \cdot x \cdot y \, dV \qquad (2)$$

I_{xy} introduces coupling between rotations around the x and y-axis. In a symmetrical component, Ixy = 0, indicating no coupling. A nonzero I_{xy} reflects asymmetry, which may affect steering dynamics.

Modeling the Component in a Realistic Tilted Configuration

When the component is installed on the bicycle, the steering axis is tilted. In this case, the MOI must be analyzed relative to the tilted axis

Global MOI in the Tilted Configuration



In the tilted system, the global I_{xx} represents the resistance to rotation about the x-axis, or how the component reacts when the bike is tilted side to side. The I_{xx} shown below is 1.6E+08, which adds considerable resistence to tilt. This is positive since the bike stays more stable when upright.

The steering-related MOI, however, must be calculated about the tilted steering axis. The result in this configuration will help validate the result from the previous configuration.

Calculating MOI about the steering axis

The steering axis can be expressed as an unit vector:

$$\vec{n} = [-\sin(67.5^\circ), \cos(67.5^\circ), 0] \qquad (3)$$

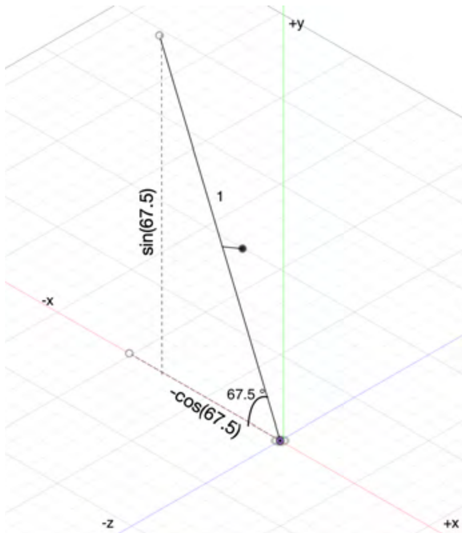
Using the inertia tensor [I] and the unit vector $\vec{n}$, the effective MOI about the steering axis is given by:

$$I_{\text{steering}} = \vec{n}^T [I] \vec{n}. \qquad (4)$$

The general inertia tensor is

$$[I] = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix} \qquad (5)$$

The signs in the tensor are related to coordinate cross-products. However, values in fusion should not be calculated with the signs. This is because the signs are already incorporated. Fusion computes the tensor relative to the origin of the chosen coordinate system, taking into account the positive and negative directions of the axes in the global coordinate system.



Visualization of the Steering Axis Vector

Substituting the calculated values from fusion to the inertia tensor givess:

$$[I] = \begin{bmatrix} 1.605 \times 10^8 & -3.633 \times 10^7 & -1.9437 \times 10^4 \\ -3.633 \times 10^7 & 4.621 \times 10^7 & 7.6324 \times 10^4 \\ -1.9437 \times 10^4 & 7.6324 \times 10^4 & 1.394 \times 10^8 \end{bmatrix} \text{ g mm}^2 \qquad (6)$$

The effective steering moment of inertia can be computed by:

$$I_{\text{steering}} = \begin{pmatrix} -\cos(67.5^\circ) & \sin(67.5^\circ) & 0 \end{pmatrix} \begin{pmatrix} 1.605 \cdot 10^8 & 3.633 \cdot 10^7 & 19438 \\ 3.633 \cdot 10^7 & 4.621 \cdot 10^7 & -76324 \\ 19438 & -76324 & 1.394 \cdot 10^8 \end{pmatrix} \begin{pmatrix} -\cos(67.5^\circ) \\ \sin(67.5^\circ) \\ 0 \end{pmatrix}$$

$$I_{\text{steering}} = 3.726 \cdot 10^7 \text{ g} \cdot \text{mm}^2$$

Results Validation

To validate the results, the component's MOI was calculated in two configurations:

1. Aligned with the y-axis.
2. Tilted to match the real-world steering angle.

Both methods yielded consistent results for Isteering, confirming the validity of the calculations.

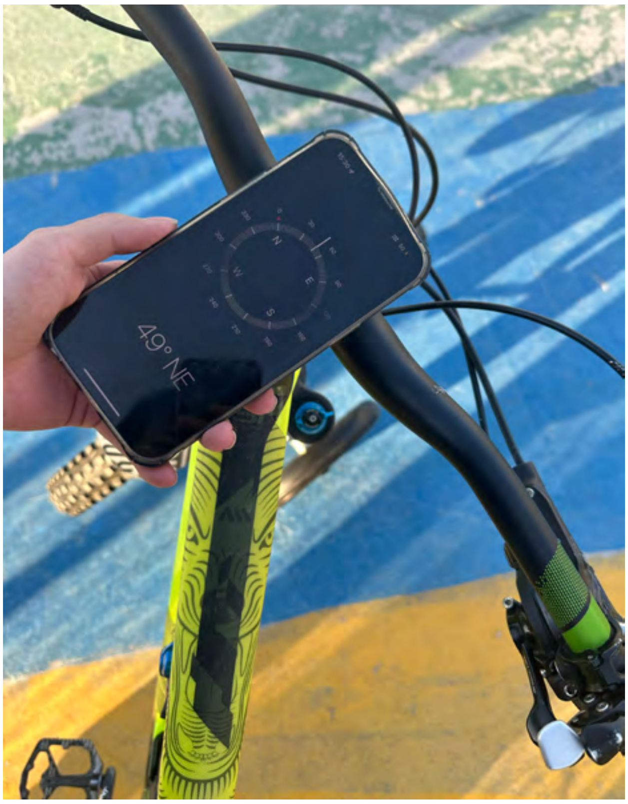
$$I_{\text{steering}} = 3.726 \cdot 10^7 \text{ g} \cdot \text{mm}^2 = 0.03726 \text{ kg} \cdot \text{m}^2$$

A steering moment of inertia of 0.03726 kgm^2 is comparable to the moment of inertia of lightweight bicycle components or small car steering wheels. For context:

- A standard mountain bike front wheel with tire has a typical moment of inertia in the range of 0.05-0.15 kgm^2 depending on the weight distribution and rim/tire size.

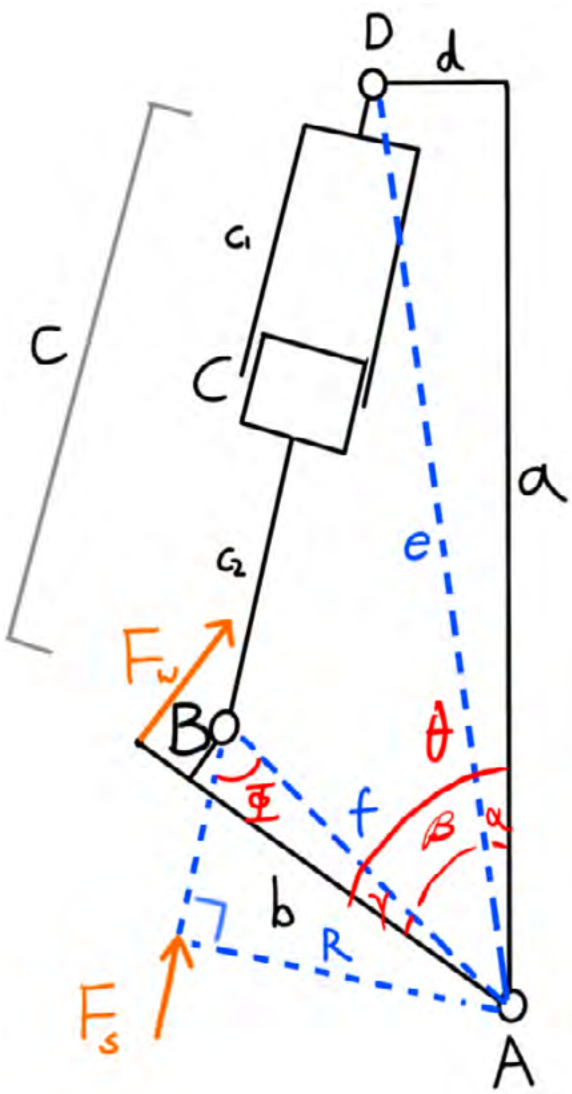
- The calculated value is slightly smaller than the lower end of this range, indicating that the assist wheel component should have minimal interference with the steering dynamics.

Largest Free-Steering Angle (F1)



An Iphone compass could be used to measure the largest free steering angle. The angle here of 49 DEG closely aligns with the 50 DEG spec.

Linkage Analysis (F3)



Simplified Diagram for Kinematic Analysis

Links (L)	Joints(J)
1. a(ground)	1. A(pivot)
2. b(follower)	2. B(pivot)
3. c_1(rocker)	3. C(prismatic)
4. c_2(coupler)	

Degrees of Freedom(Dof)

Gruéblers Equation states:

Dof=3(L-1)-2J
=3(4-1)-2(4)
= 1

This indicates the system requires 1 input motion to control the entire linkage.

Angles & Trigonometry

- $\Phi = \pi - \cos^{-1}\left(\frac{f^2+C^2-e^2}{2fC}\right)$
- $\sin(\Phi) = \sin(180^\circ - \Phi)$
- $\theta = \frac{\pi}{4}$ (variable)
- $\alpha = \arctan\left(\frac{d}{a}\right) = 0.03$
- $\gamma = \arctan\left(\frac{20.6}{62.3}\right) = 0.20$
- $\beta = \theta - \alpha - \gamma = \theta - 0.23$

Lengths

- $a = 227.3$ mm
- $b = 135.7$ mm
- $c = 150$ mm
- $d = 6.8$ mm
- $e = \sqrt{a^2+d^2} = 227.6$ mm
- $f = 104.4$ mm

Definitions

Shock Stroke(Xs): The linear displacement of the shock

Wheel Displacement(Xw): The linear displacment of the wheel

Leverage Ratio (LR): Define as $LR = \frac{F_s}{F_w} = \frac{dX_w}{dX_s}$

Calculating Leverage Ratio

The leverage ratio is the most important parameter in the analysis of suspension systems. Leverage ratio is defined as the ratio of output force(shock) over input force(wheel). This tells us how hard the suspension is to compress. Leverage ratio is also defined as the input displacement(wheel) over the output displacement(shock). This tell us how much the suspension compresses.

The first method to calculate leverage ratio is using forces
To ensure torque equilibrium at the pivot point A:

$$F_s \cdot R = F_w \cdot b.$$

Rearranging this equation gives:

$$LR = \frac{F_s}{F_w} = \frac{b}{R},$$

Where R is the perpendicular distance between the pivot and the line of action of the shock force:

$$R = f\sin(\phi)$$

Using the law of cosines ϕ can be related to the given values of the system.

$$\cos(\pi - \phi) = \frac{f^2+c^2-e^2}{2fc}$$

Using the trigonometric identity that relate sine and cosine, we find:

$$\sin(\pi - \phi) = \sqrt{1 - \left(\frac{f^2 + c^2 - e^2}{2fc}\right)^2}$$

Since $\sin(\pi - \phi) = \sin(\phi)$, R can be written as:

$$R = f\sqrt{1 - \left(\frac{f^2 + c^2 - e^2}{2fc}\right)^2}$$

Substituting the equation for R back into the leverage ratio equation gives:

$$LR = \frac{b}{f\sqrt{1 - \left(\frac{f^2+c^2-e^2}{2fc}\right)^2}}$$

The second method to calculate leverage ratio is using displacement

The leverage ratio (LR) is defined as the ratio of the wheel displacement (X_w) to the shock displacement (X_s), expressed mathematically as:

$$LR = \frac{dX_w}{dX_s}.$$

Using the chain rule, this can be rewritten as:

$$LR = \frac{\frac{dX_w}{d\theta}}{\frac{dX_s}{d\theta}},$$

where θ is the angular displacement of the linkage. The wheel displacement (X_w) is given as the arc length traced by the wheel linkage, with b as the radius:

$$X_w = b \cdot \theta.$$

Differentiating X_w with respect to θ, we find:

$$\frac{dX_w}{d\theta} = b.$$

The shock displacement (X_s) is derived from the geometry of the linkage system, using the law of cosines:

$$X_s = \sqrt{e^2 + f^2 - 2ef\cos(\beta)},$$

where $\beta = \theta - 0.23$. Substituting β directly into the equation, we have:

$$X_s = \sqrt{e^2 + f^2 - 2ef\cos(\theta - 0.23)}.$$

Differentiating X_s with respect to θ, and applying the chain rule:

$$\frac{dX_s}{d\theta} = \frac{1}{2} \cdot \frac{1}{\sqrt{e^2 + f^2 - 2ef\cos(\theta - 0.23)}} \cdot \left(-2ef \cdot \frac{d}{d\theta}\cos(\theta - 0.23)\right).$$

The derivative of $\cos(\theta - 0.23)$ is:

$$\frac{d}{d\theta}\cos(\theta - 0.23) = -\sin(\theta - 0.23),$$

so:

$$\frac{dX_s}{d\theta} = \frac{1}{2} \cdot \frac{1}{\sqrt{e^2 + f^2 - 2ef\cos(\theta - 0.23)}} \cdot (-2ef \cdot (-\sin(\theta - 0.23)))\,.$$

Simplifying:

$$\frac{dX_s}{d\theta} = \frac{ef\sin(\theta - 0.23)}{\sqrt{e^2 + f^2 - 2ef\cos(\theta - 0.23)}}.$$

Substituting $\frac{dX_w}{d\theta} = b$ and $\frac{dX_s}{d\theta}$ into the equation for LR, we find:

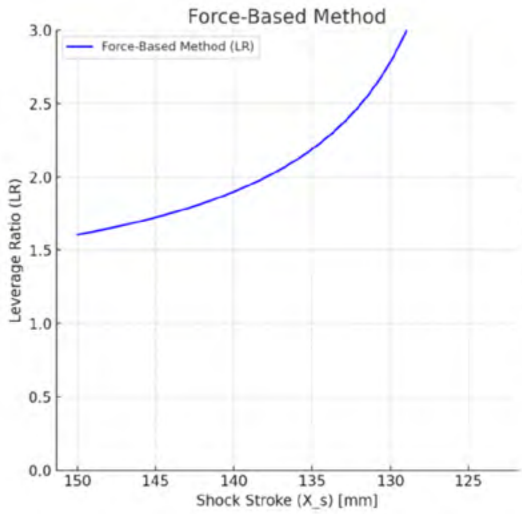
$$LR = \frac{\frac{dX_w}{d\theta}}{\frac{dX_s}{d\theta}} = \frac{b}{\frac{ef\sin(\theta-0.23)}{\sqrt{e^2+f^2-2ef\cos(\theta-0.23)}}}.$$

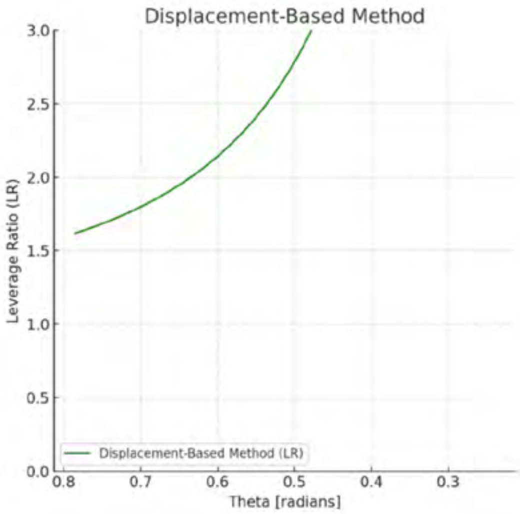
Simplify to get:

$$LR = \frac{b\sqrt{e^2 + f^2 - 2ef\cos(\theta - 0.23)}}{ef\sin(\theta - 0.23)}.$$

The two methods produce expressions of leverage ratio in shock displacement(mm) and pivot rotation(RAD).

Graphing the Leverage Ratio





Sample Calculations

Method 1: $X_s(C) = 150$ **mm**

Using the force-based method:

$$R = f\sqrt{1 - \left(\frac{f^2 + C^2 - e^2}{2fC}\right)^2},$$

and:

$$LR = \frac{b}{R}.$$

Substitute $b = 135.7, e = 227.6, f = 104.4, C = 150$:

$$LR = 1.606.$$

Method 2: $\theta = \frac{\pi}{4}$

Using the displacement-based method:

$$LR = \frac{b\sqrt{e^2 + f^2 - 2ef\cos(\theta - 0.23)}}{ef\sin(\theta - 0.23)}.$$

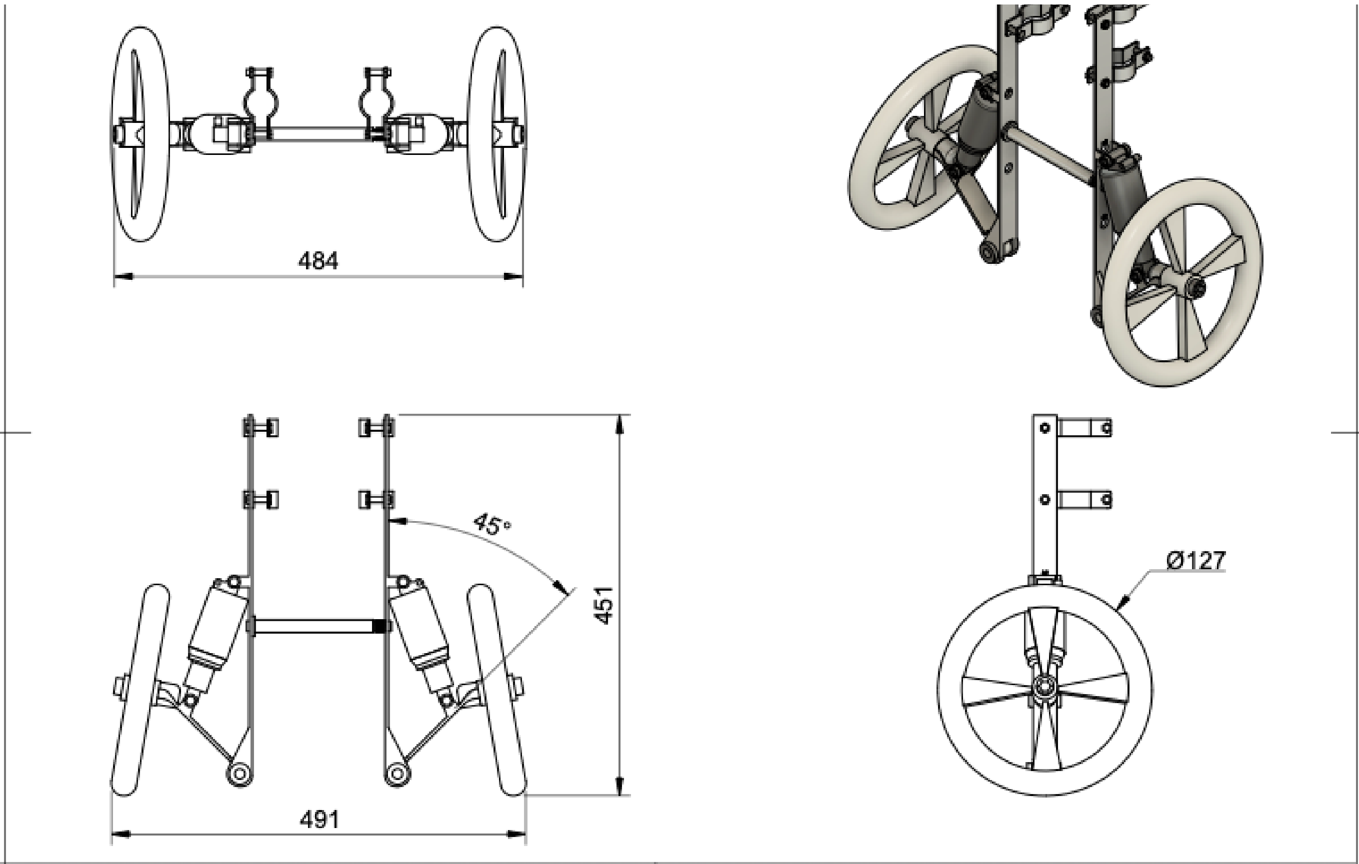
Substitute $b = 135.7, e = 227.6, f = 104.4, \theta = \frac{\pi}{4}$:

$$LR = 1.618.$$

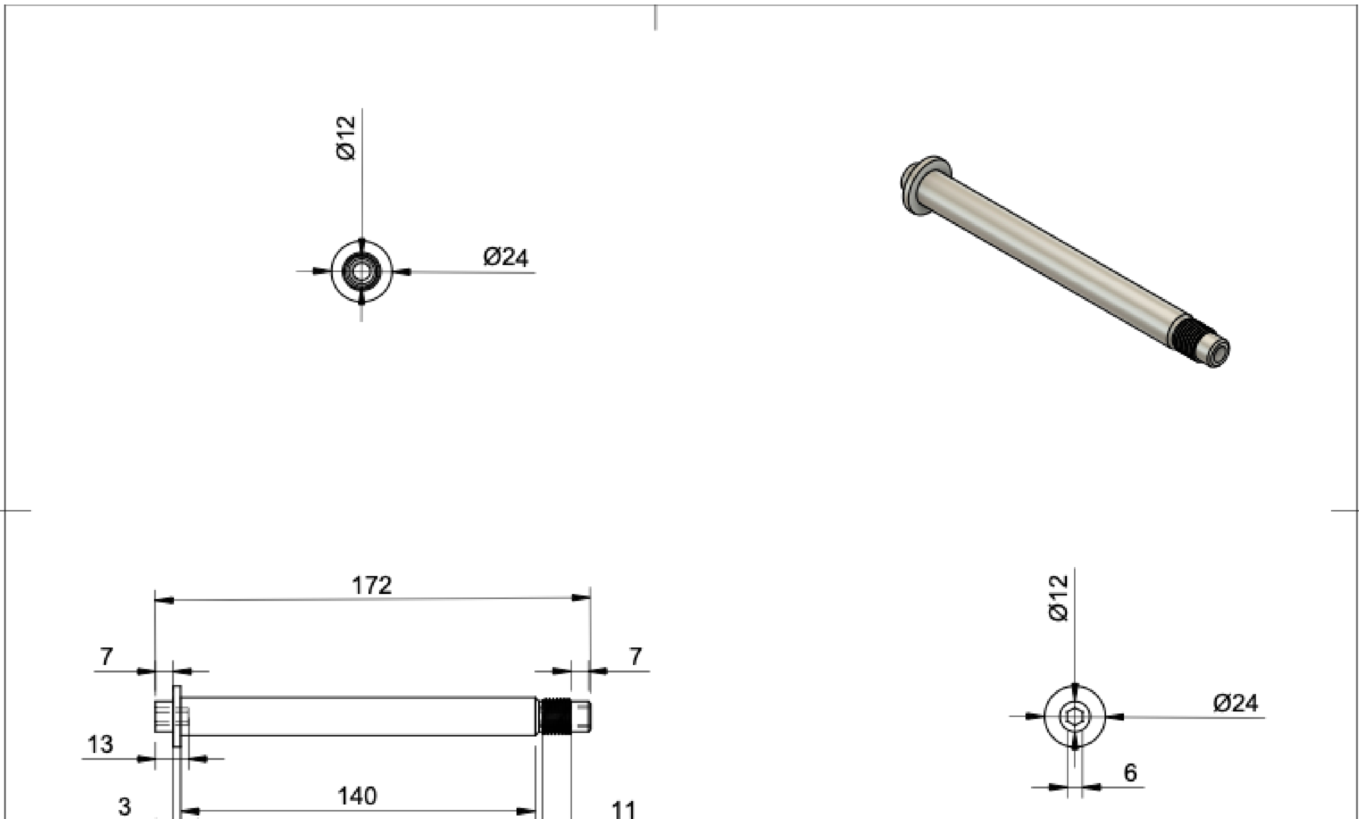
Implications:

The similarities in the trends of two graphs verify the calculation for leverage ratios. An upward trending leverage ratio implies higher mechanical advantage, resulting in amplified wheel displacement for a given shock stroke. For example, when the shock is compressed from 150mm to 135mm, the wheel travels 337.5mm.

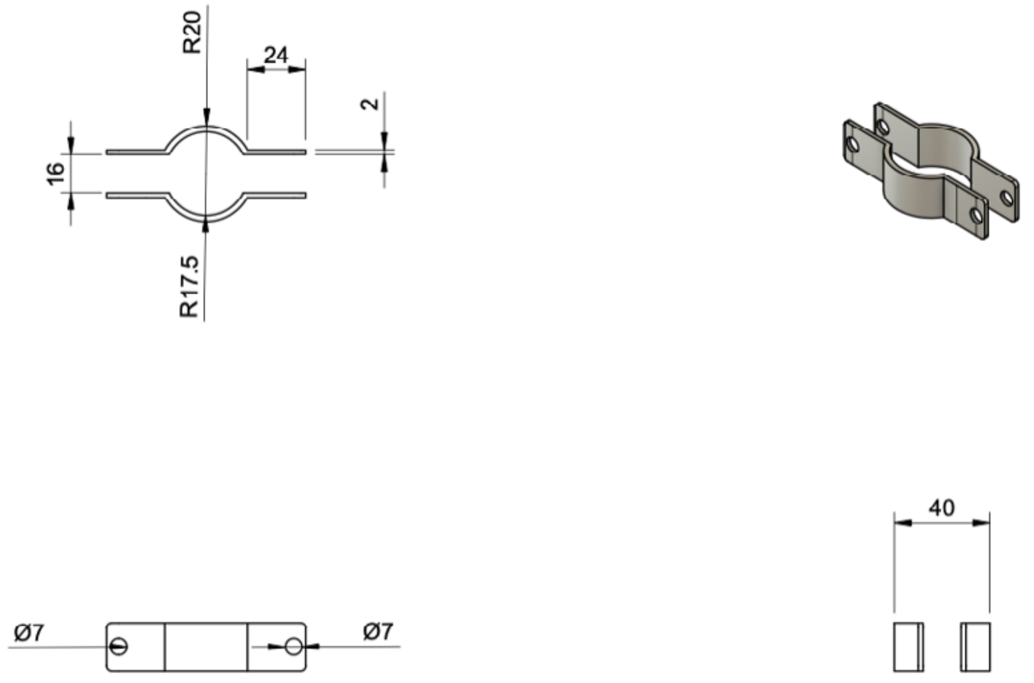
Appendix I: Technical Drawings



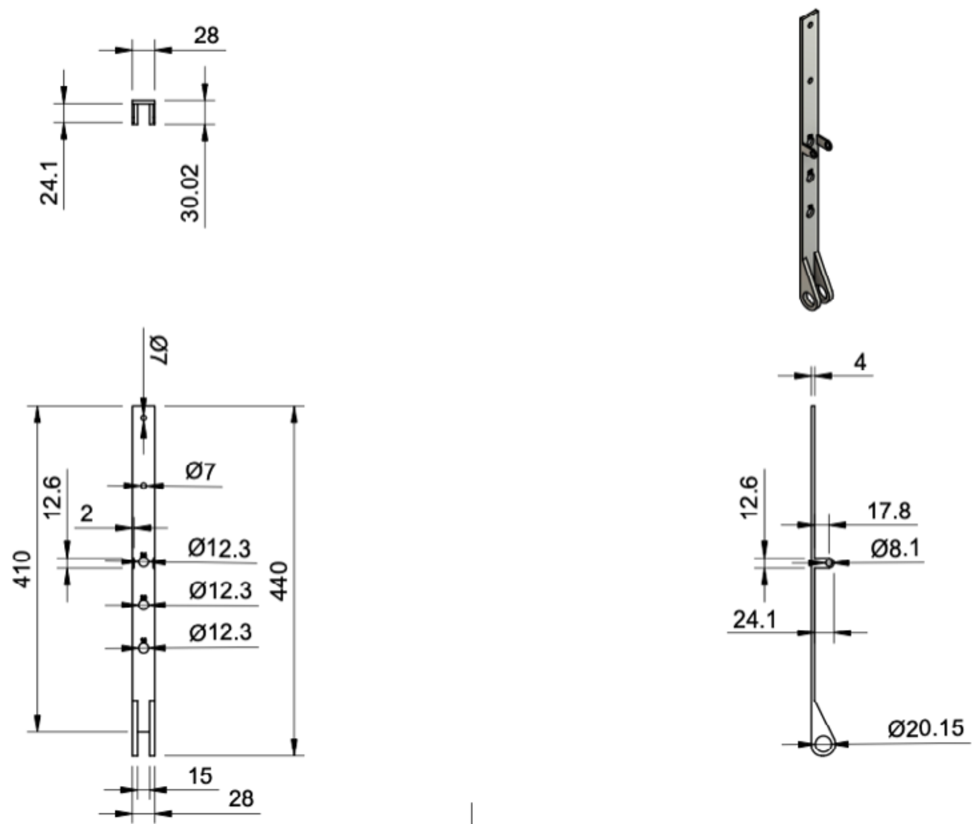
	Component Name: Assembly	Materials: Metal, ABS, Rubber	Scale: 1:9
	Part No. 0	Quantity: 1	Unit: mm



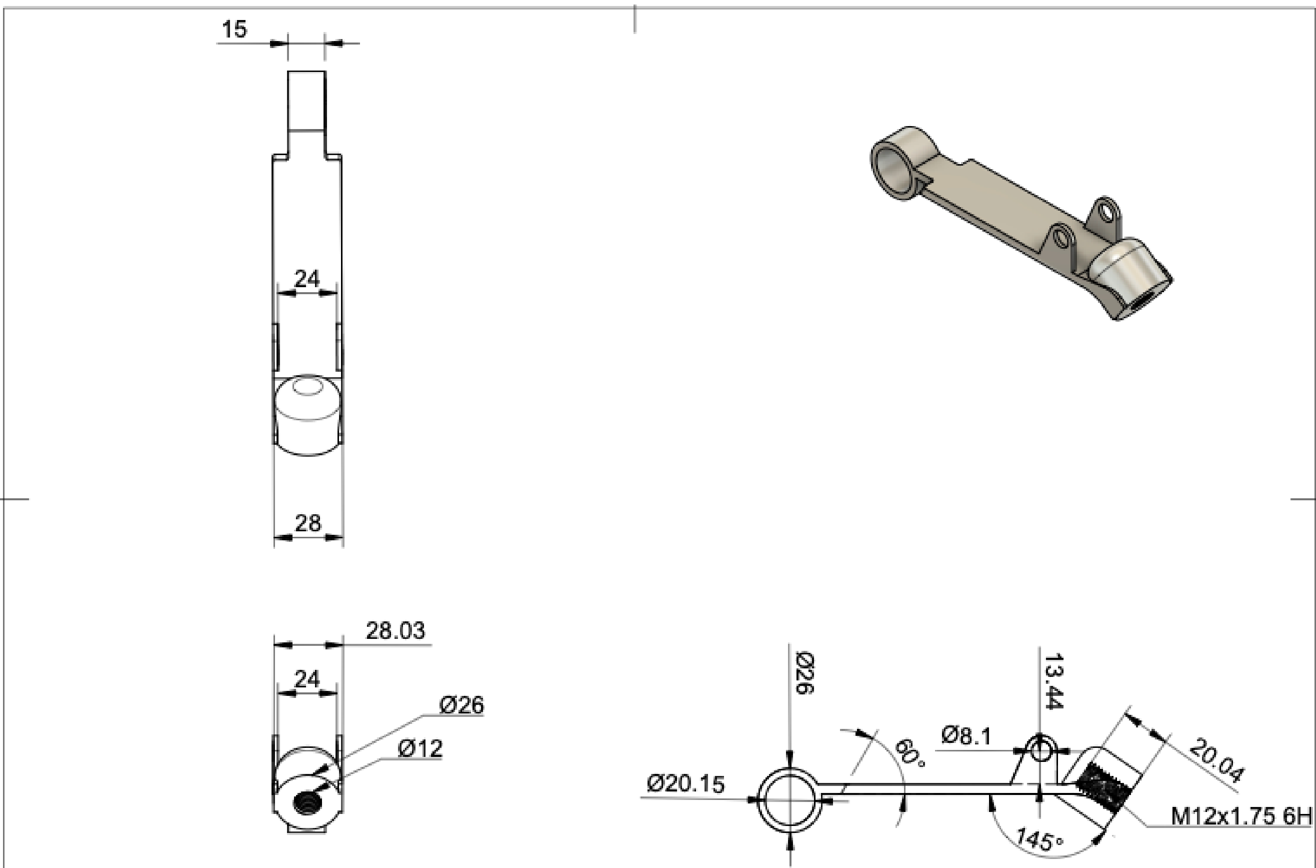
	Component Name: Front Axle	Materials: 7075 Aluminum	Scale: 1:3
	Part No. 1	Quantity: 1	Unit: mm



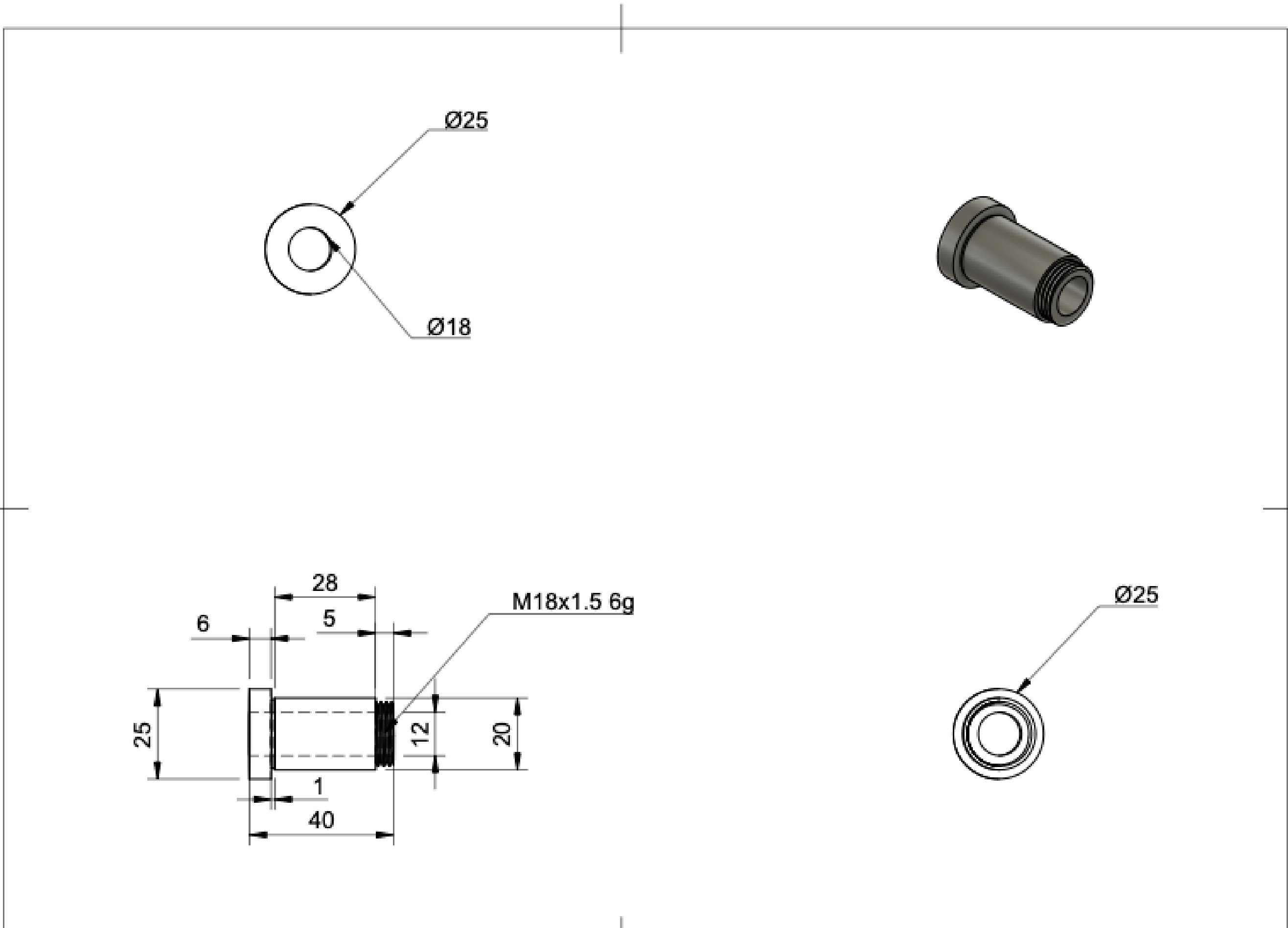
	Component Name: Front Axle	Materials: 6061 Aluminum, Silicone rubber	Scale: 1:3
	Part No. 2	Quantity: 4	Unit: mm



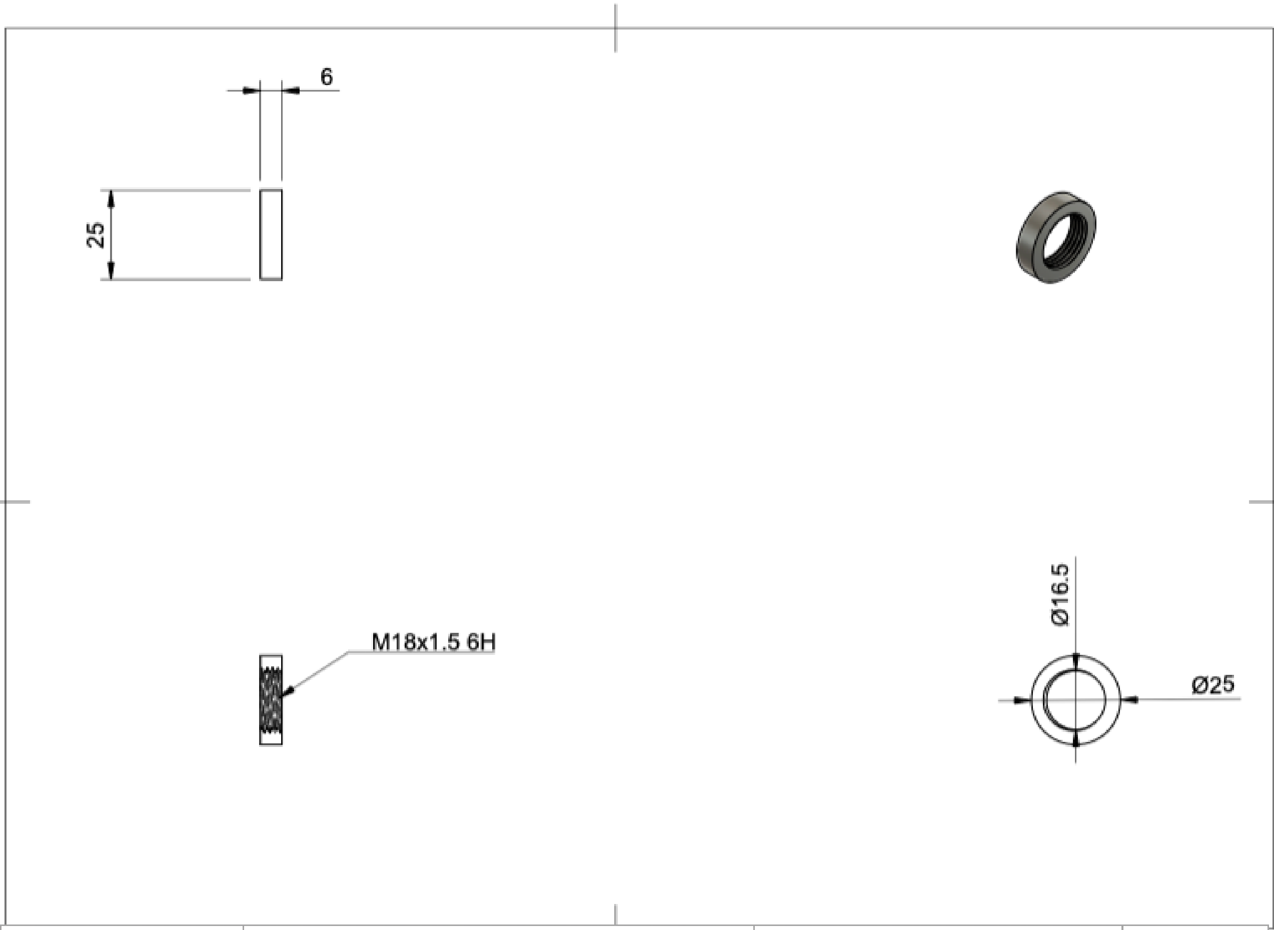
	Component Name: Front Axle	Materials: 7075 Aluminum	Scale: 1:9
	Part No. 3	Quantity: 2	Unit: mm



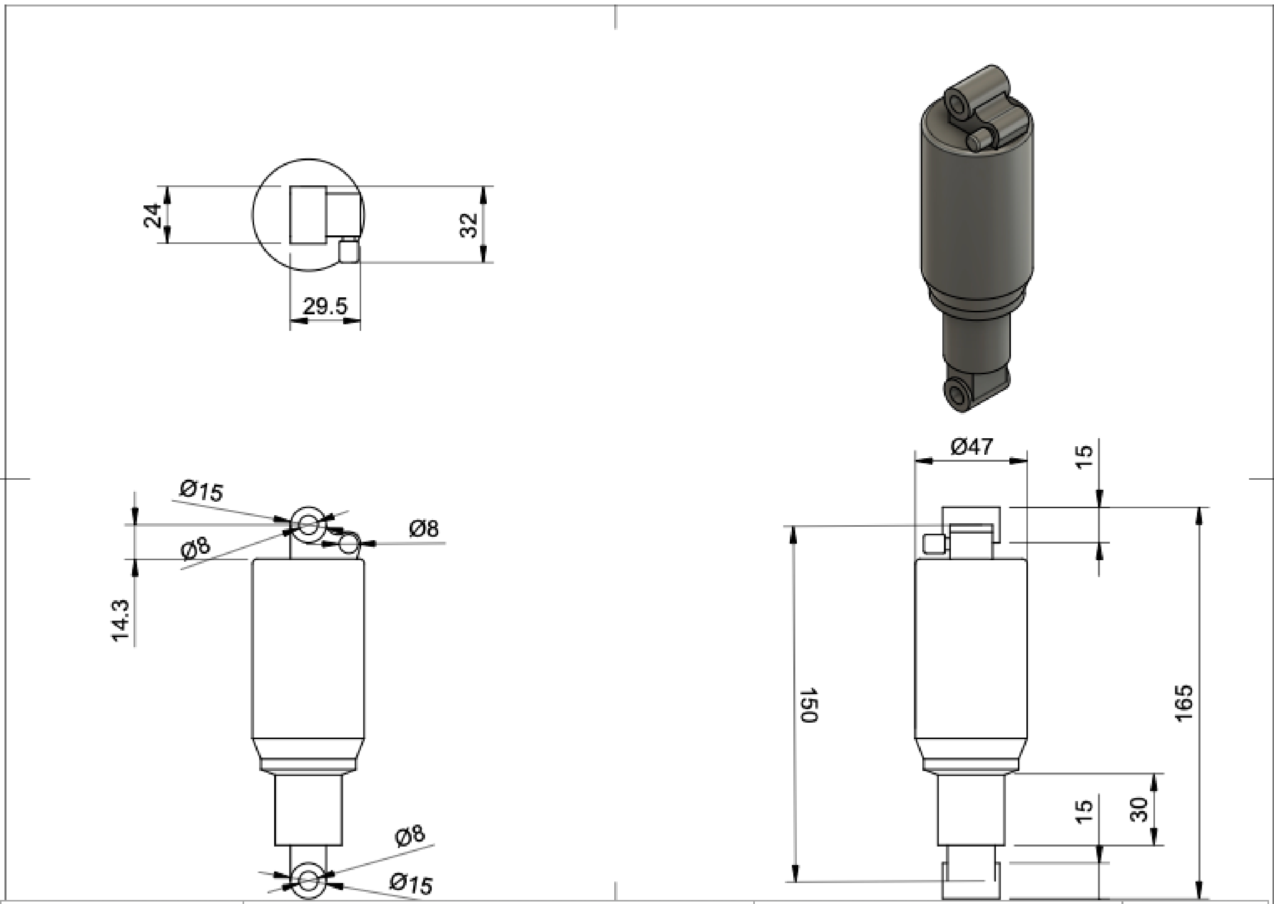
	Component Name: Suspension Linkage	Materials: 7075 Aluminum	Scale: 1:3
	Part No. 4	Quantity: 2	Unit: mm



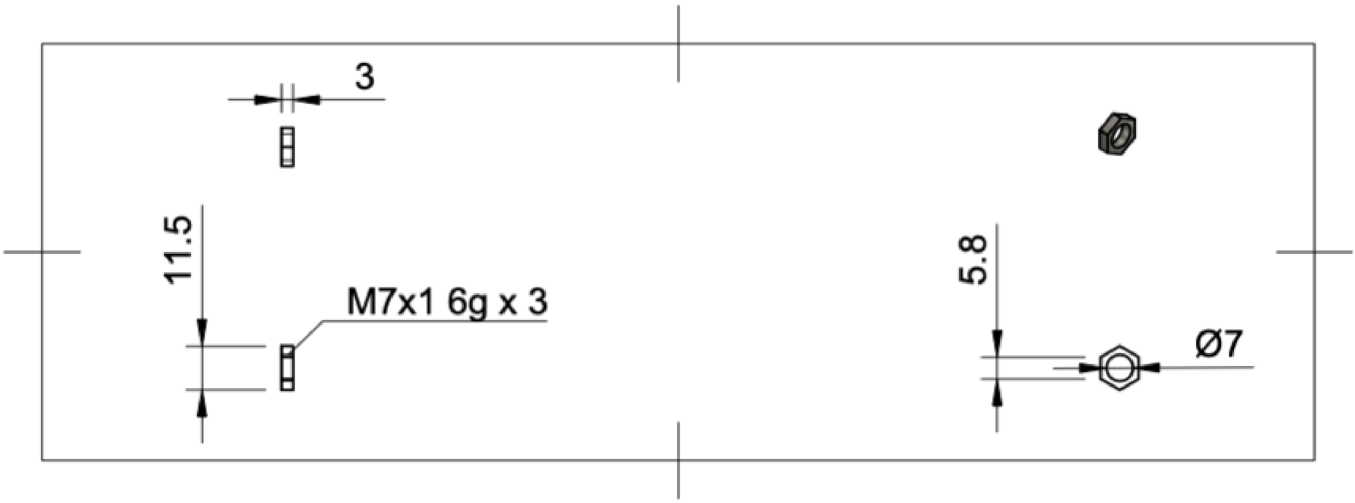
	Component Name: Pivot Bushing	Materials: Steel	Scale: 1:2
	Part No. 5	Quantity: 2	Unit: mm



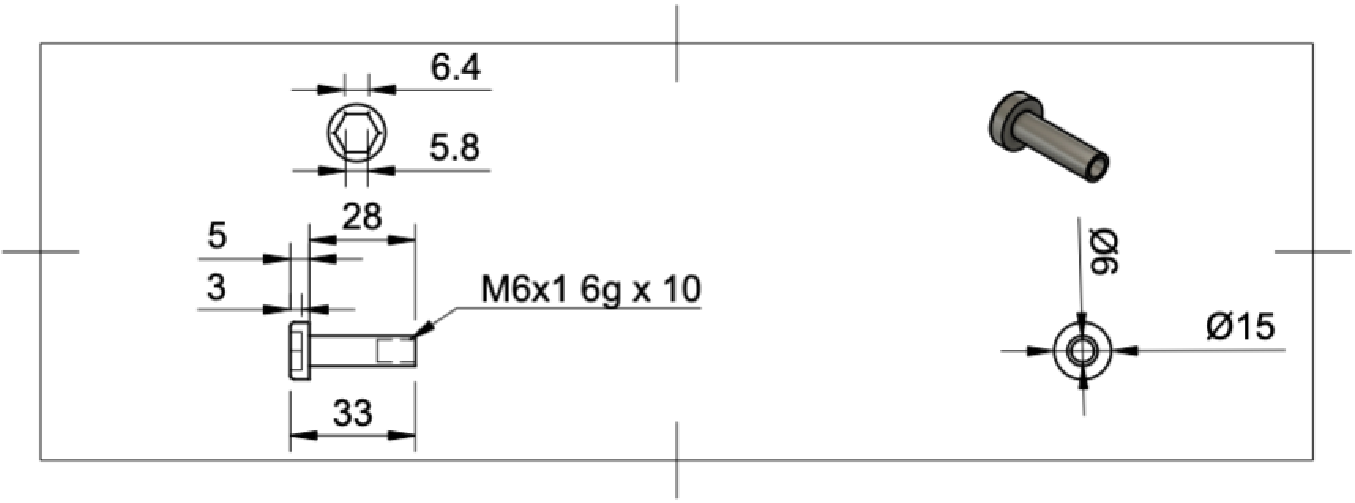
Component Name: Pivot Bushing Cap	Materials: Steel	Scale: 1:2
Part No. 6	Quantity: 2	Unit: mm



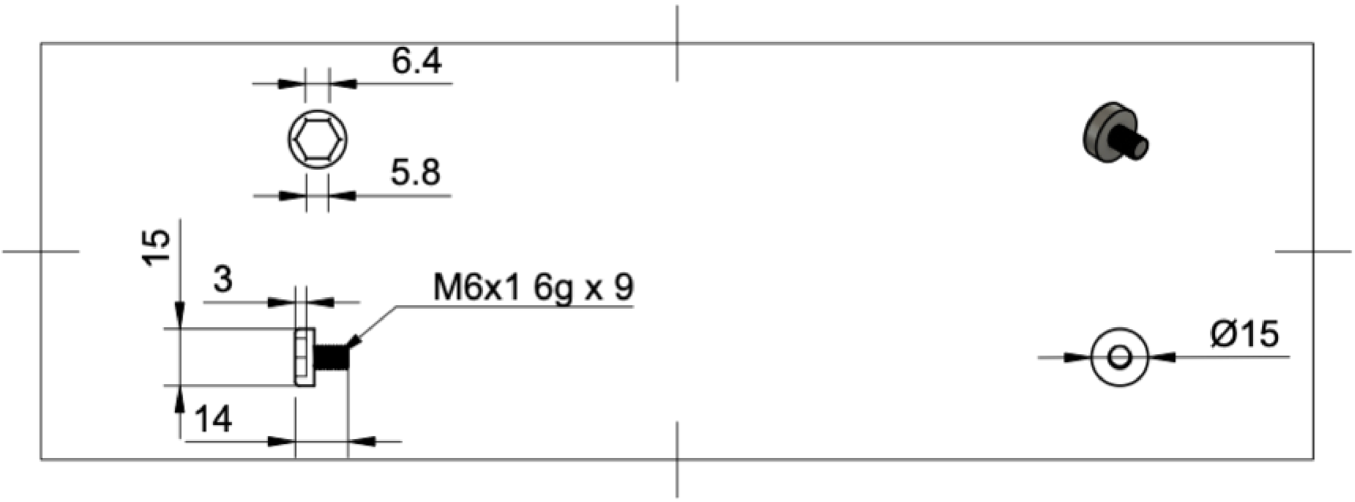
Component Name: EXA Shock Absorber	Materials: Steel	Scale: 1:3
Part No. 7	Quantity: 2	Unit: mm



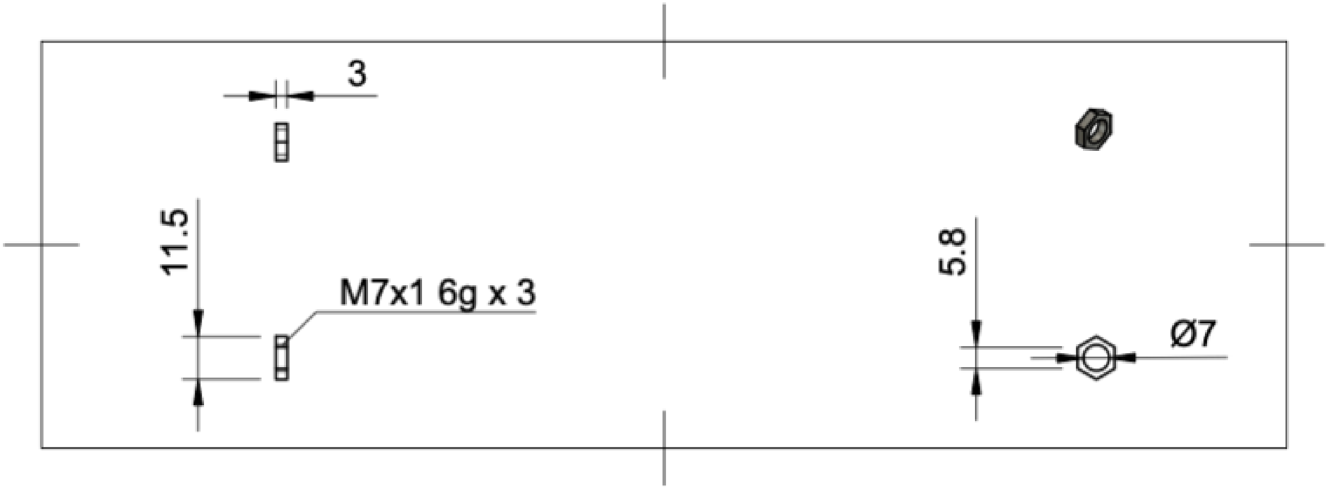
	Component Name: M7 Hex Nut	Materials: Steel	Scale: 1:2
	Part No. 11	Quantity: 8	Unit: mm



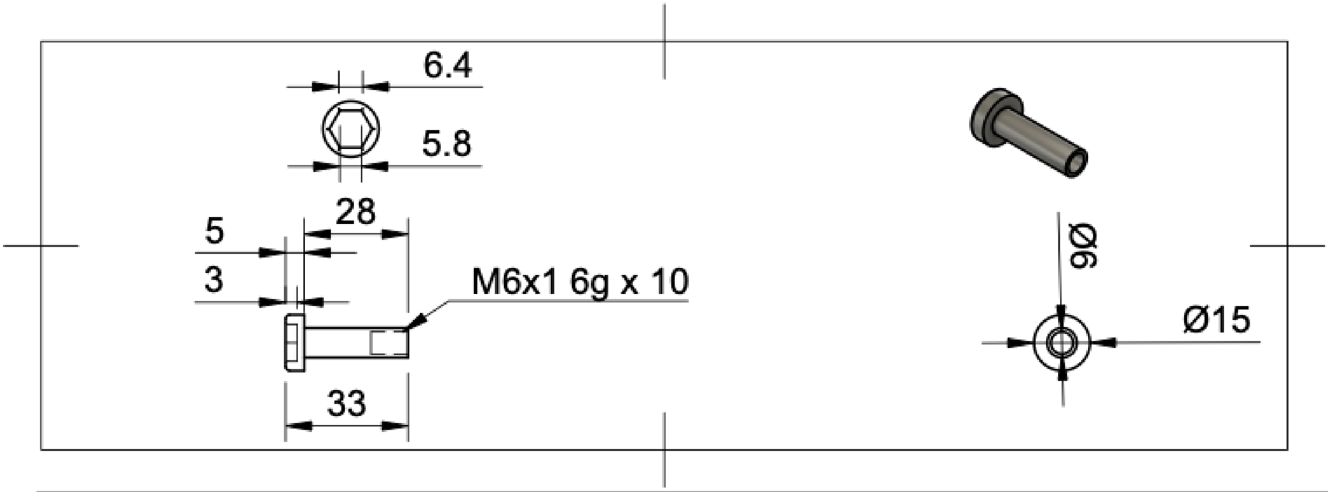
	Component Name: M8 Carriage Bolt	Materials: Steel	Scale: 1:2
	Part No. 11	Quantity: 4	Unit: mm



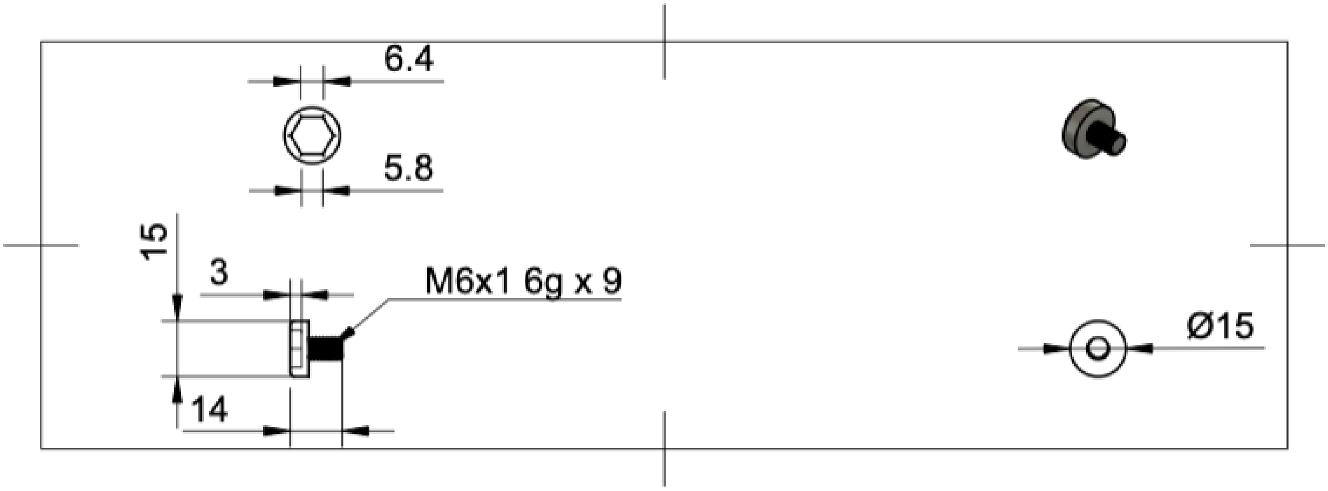
	Component Name: M8 Carriage Screw	Materials: Steel	Scale: 1:2
	Part No. 11	Quantity: 4	Unit: mm



	Component Name: M7 Hex Nut	Materials: Steel	Scale: 1:2
	Part No. 11	Quantity: 8	Unit: mm



	Component Name: M8 Carriage Bolt	Materials: Steel	Scale: 1:2
	Part No. 11	Quantity: 4	Unit: mm



	Component Name: M8 Carriage Screw	Materials: Steel	Scale: 1:2
	Part No. 11	Quantity: 4	Unit: mm

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