



Portfolio: Mountain Bike Component Design

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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

Problem

Mountain biking involves riders jumping, cornering and pumping their bikes through rugged terrain. The strength and balance required to maneuver a bike can be 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

- Interview with potential user (Mark, 50 years old): "The lack of balance is the main obstacle to progression."
 - Nervousness results in less control over the bike
 - Many crashes come from instability in the front end."
- Interview with potential user (Ja, lost his left arm in a work incident):
 - Enjoys the feeling of control
 - Don't want to be limited from physical exercise
 - Crashing is common and unpredictable in his situation
- Interview with Yan (Former coach of Chinese national bmx team):
 - The biggest problem in coaching is overcoming fear while ensuring safety.
 - Solves this by allowing beginners to practice progressively, flat ground to pump track to proper trails.
 - Children can really benefit from a device that aids low speed fundamental practice.
 - The device should be as light as possible to not hinder steering. It should also be able to endure crashes.

Market Analysis

Component	Knockout Heater	Canyon K18	WP Steering Damper	14-16 inch training wheel
Photograph				
Cost (\$D)	63.89	400	450	14.2
Advantages	Protects rider and bike from overheating when crashing.	Stabilizes the steering by dampening wheel torque.	Stabilizes steering by dampening wheel torque.	Provides great stability to entire bike.
Limitations	No prevention and stabilization function.	Affects low speed practice.	Only useful to advanced riders.	Low versatility, in most situations and limited applications.

Concept Sketches

Detailed Sketches

Idea 1: A 60mm clamp sized around 28.6mm steer tube (DT) with a protruded M3 screw holes for easy access (T2). Hard 7075 aluminum ring (M1) joins for non-permanent assembly (T2). This solution increases steering stability (F4.5).

Evaluation: The spring in this design applies a restoring force to the handlebars and subsequently the wheels. Therefore, the stiffness of the materials selected, where the aluminum ring can be 20mm.

Idea 2: Polyurethane padding for frame protection (B1). Tough ABS frame clamping sized around 52mm top tube (M2). Sliding bar creates adjustable spring tension (F2).

Evaluation: The spring in this design applies a restoring force to the handlebars and subsequently the wheels. Therefore, the stiffness of the materials selected, where the aluminum ring can be 20mm.

Concept Modelling

Proposed Design

Evaluation: 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. Transverse and longitudinal supports provide lateral stability. The use of a horizontal suspension layout instead of a vertical one reduces the need for appropriate support, leading to the calculation of the offset so that it contacts the ground at the center of the wheel. The design uses a 7075 aluminum alloy for its structural 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 allow for different wheel sizes. The use of straight plates instead of curved ones provides better rigidity and the axis 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 400 MPa and a yield strength of 250 MPa. The use of a horizontal suspension layout aligned with the direction of impact. Large pivots and robust plates enhance toughness. The total system weighs 2.1 kg. The design is impact-resistant with sealed bearings. Manufacturing costs are minimized by using straight plates whenever possible.

Manufacturing Details

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	ø30	28	4	2	600
4	Suspension Linkage	120	28	4	2	600
5	Pivot Bushing	ø22	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	ø43	2	2	200
9	Assist Wheel Bolt	ø15 (8 cap, 10 thread)	ø12	ø12	2	5
10	M7 Hex Bolt	ø30 (3 cap, full thread)	ø7	ø7	6	5
11	M7 Hex Nut	ø7	ø7	ø7	9	5
12	M3 Carriage Bolt	ø3 (3 cap, 10 internal thread)	ø12	ø12	4	5
13	M3 Carriage Screw	13	ø12	ø12	4	5

User Testing

User Trail SZ F2 F3 F4

User Testing: These tests show the user's 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 aggressive steering can cause lifting of the front wheel.

Expert Appraisal (S1)

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

Assembly Test (A1 A2)

Assembly on a 27.5 inch bike

Assembly on a 24 inch bike

Assembly on an 18 inch bike

Timed trial of rider's faster assembling and disassembling component

Timing shows that a total inexperienced person can assemble the component in a minute or 2. The component also fits in smaller size bikes, where the axle is compatible.

Engineering Analysis

Engineering Analysis

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

S4 Transversal Deformation

S5 Longitudinal Deformation (extended suspension)

S5 Longitudinal Deformation (compressed suspension)

S6 Torsional Deformation

Safety factor at 600Nm of Torque

Engineering Analysis

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

S4 Transversal Deformation

S5 Longitudinal Deformation (extended suspension)

S5 Longitudinal Deformation (compressed suspension)

S6 Torsional Deformation

Safety factor at 600Nm of Torque

Appendix I: Technical Drawings

References

Design Problem

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.



Fig 1: Child Crashing

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 to be convenient 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.

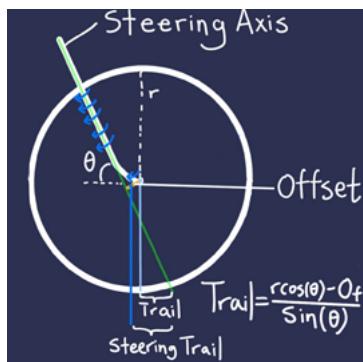


Fig 6

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

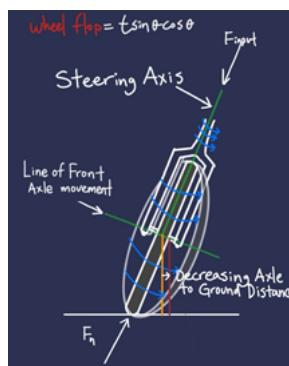


Fig 7

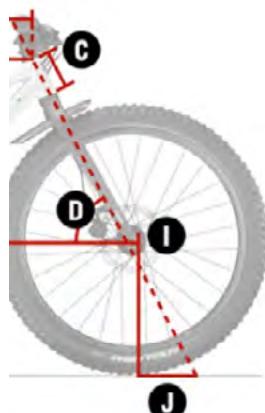
Wheel flop is the decreasing axle to ground distance during steering (as indicated). The compression force from gravity will push the front wheel to rotate further than intended.

Forces			Stress			
Horizontal bump impact on axle(F ₃)	Front wheel axis static(F _c)	Front wheel axis riding(F _c)	Front wheel axis pedaling(F _{fr})	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(l)	267mm	317mm	367mm
Steering Angle(D)	67.5	67.5	67.5

Fig 10: Kids Mountain Bike Geometry

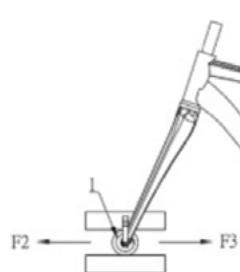


Fig 11: Go-pro attached to chest shot that steering angles does not exceed 20°

Materials Study

Material:	Tensile Strength	Density	Manufacturing process
6061 T6 alloy	290MPA	2.7g/cm ³	CNC
7075 aluminum	510MPA	2.81g/cm ³	CNC
Steel	767MPA	7.85g/cm ³	Electric Arc welding
T800 Carbon Fiber	2000MPA (Brittle under transverse forces)	2.0g/cm ³	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 ₁ [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

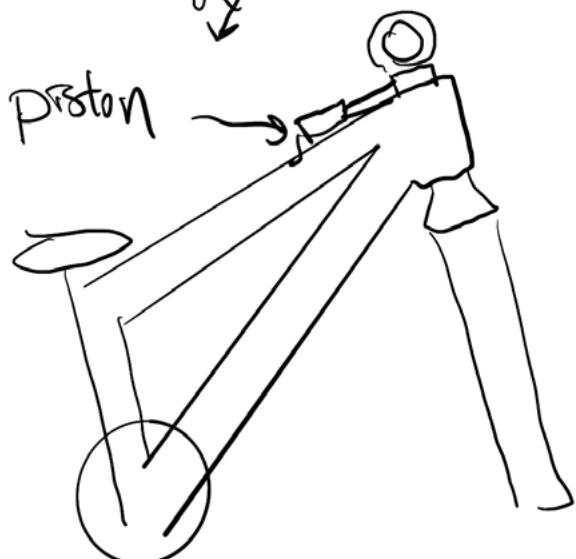
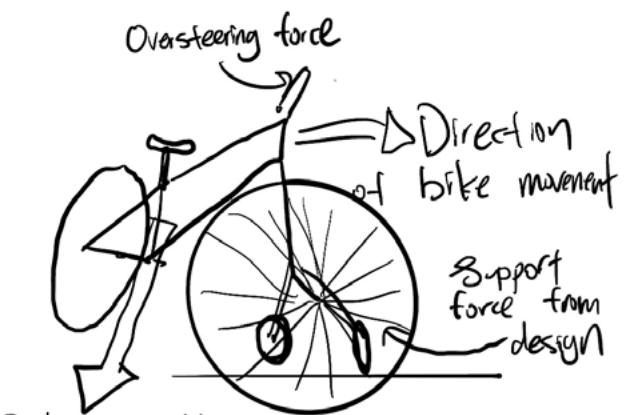
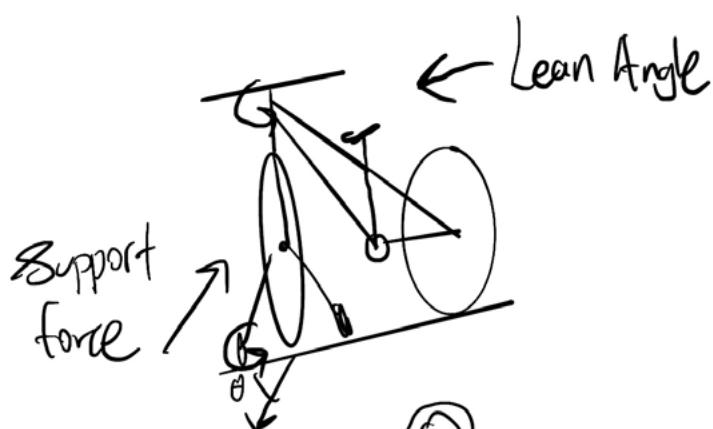
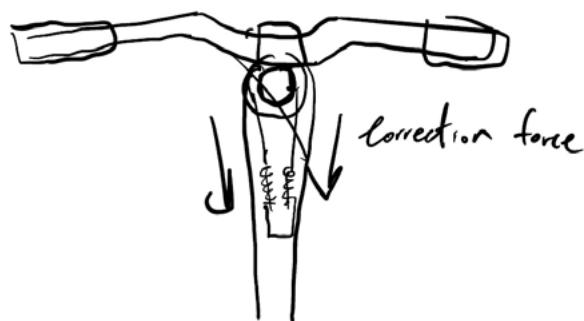
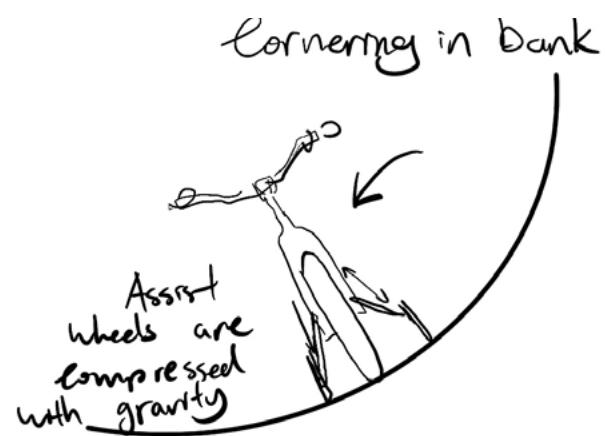
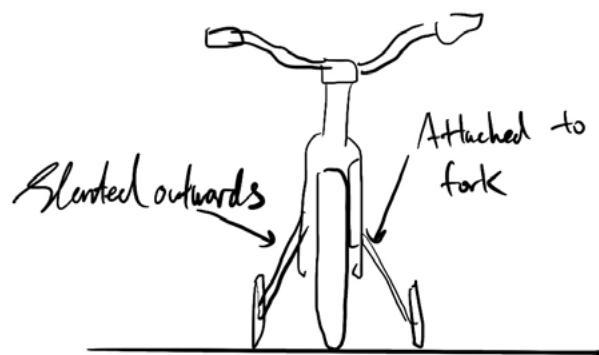
I will design and manufacture a fully functional **prototype** which solves the problem of crashing in mountain biking due to over steering(Fig 1). The **primary audience** is young beginners, **secondary audience** is mountain-biking coaches. The parameters of the product should be designed to fit 16-25 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 pose 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 transversely more 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

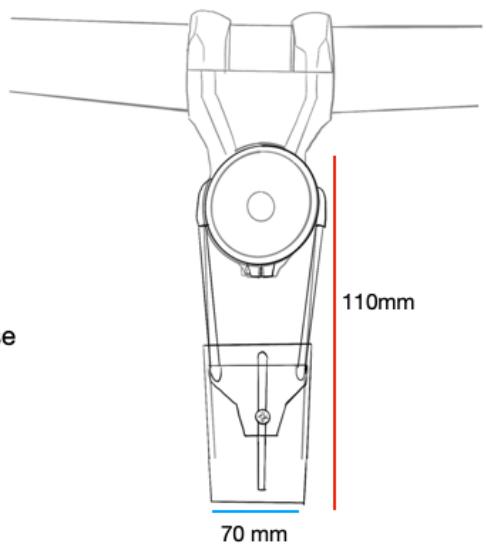
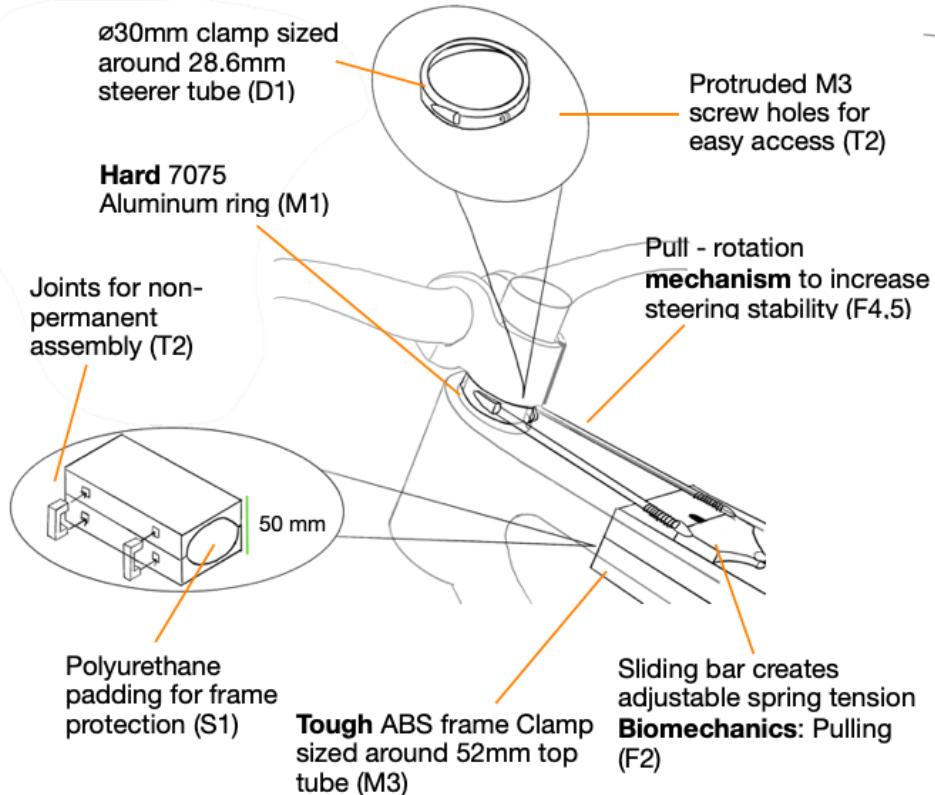
Category(prioritized)	Specification	Justification
Audience 1	Should be designed to fit with 16-24 inch bikes.	Fig 10 shows varying wheel sizes and fork lengths corresponding to users with height ranging from 104-142. Component must be designed to accommodate different sizes.
Audience 2	Can be installed 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

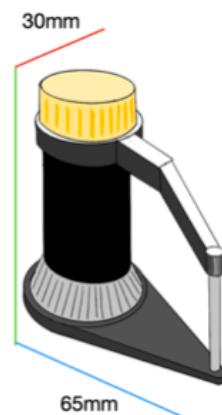
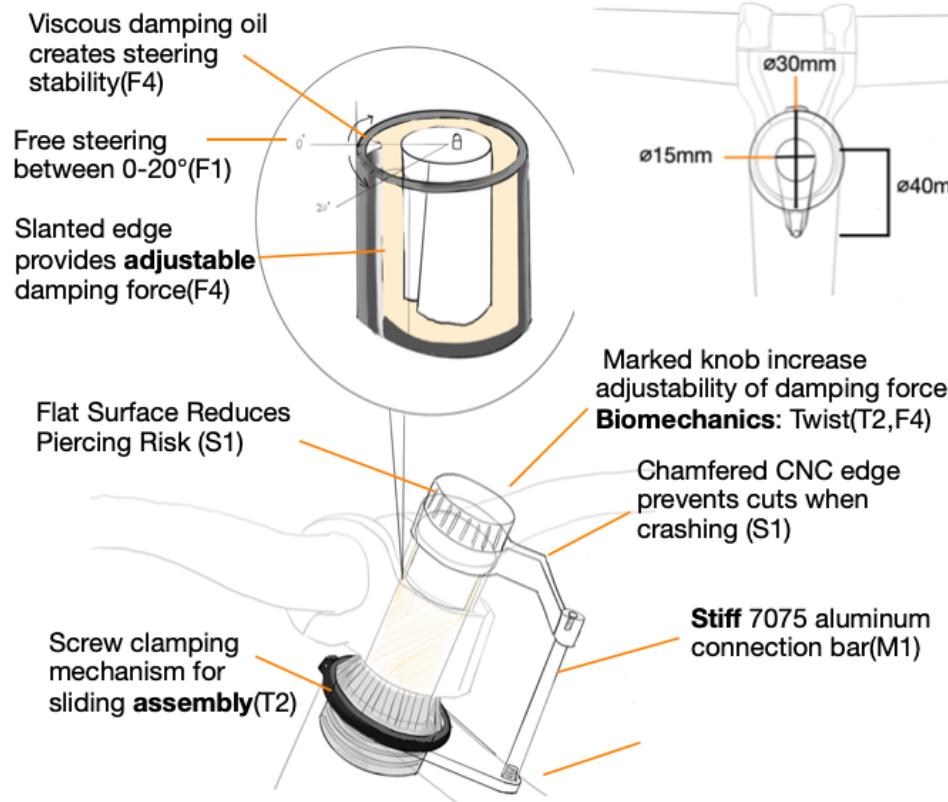
Idea 1:



Evaluation

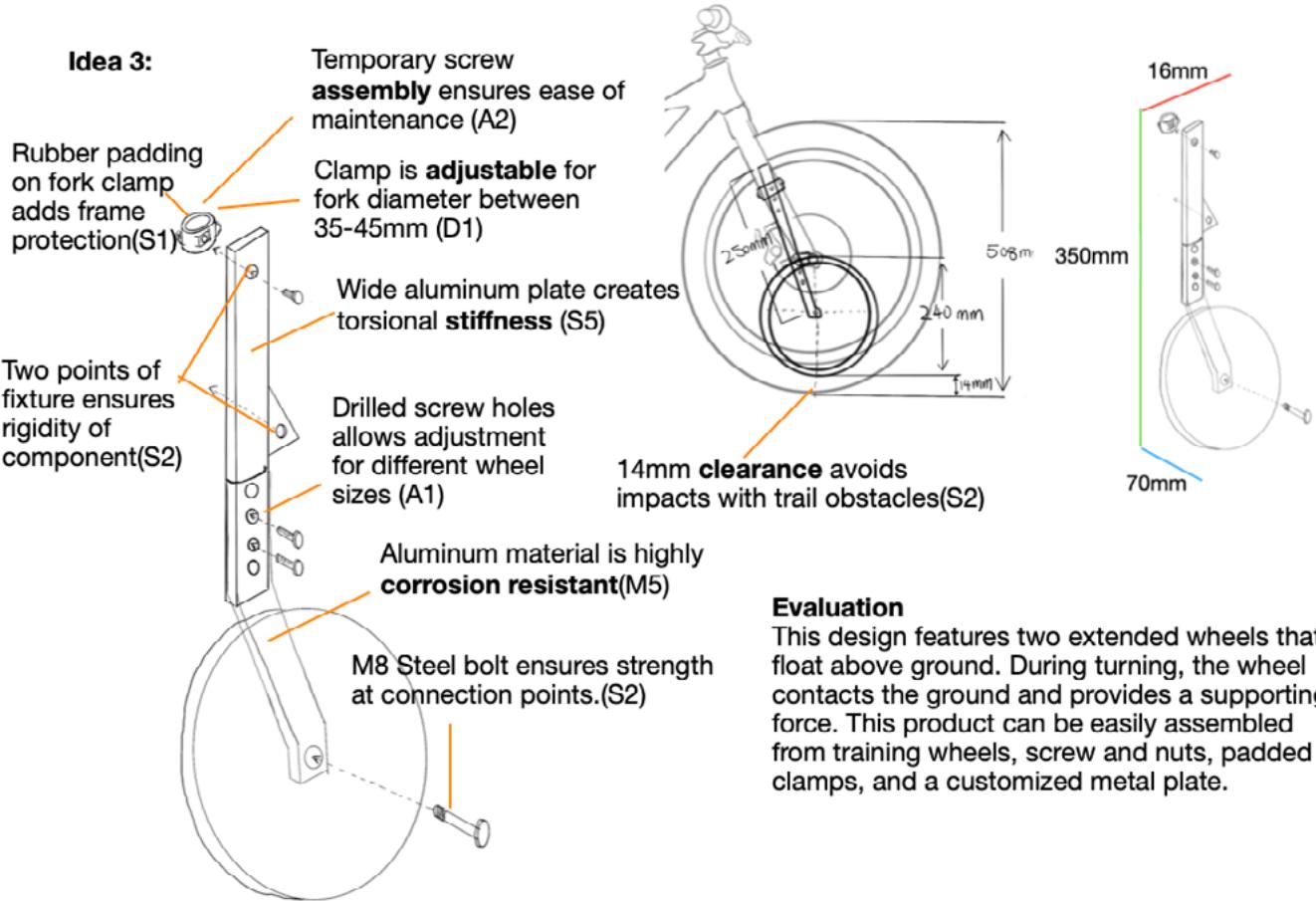
The springs in this design apply a restoring force to the handlebars and subsequently the wheels. There is high feasibility in the materials selected, where the aluminum ring can be milled and the ABS shell can be 3D printed.

Idea 2:

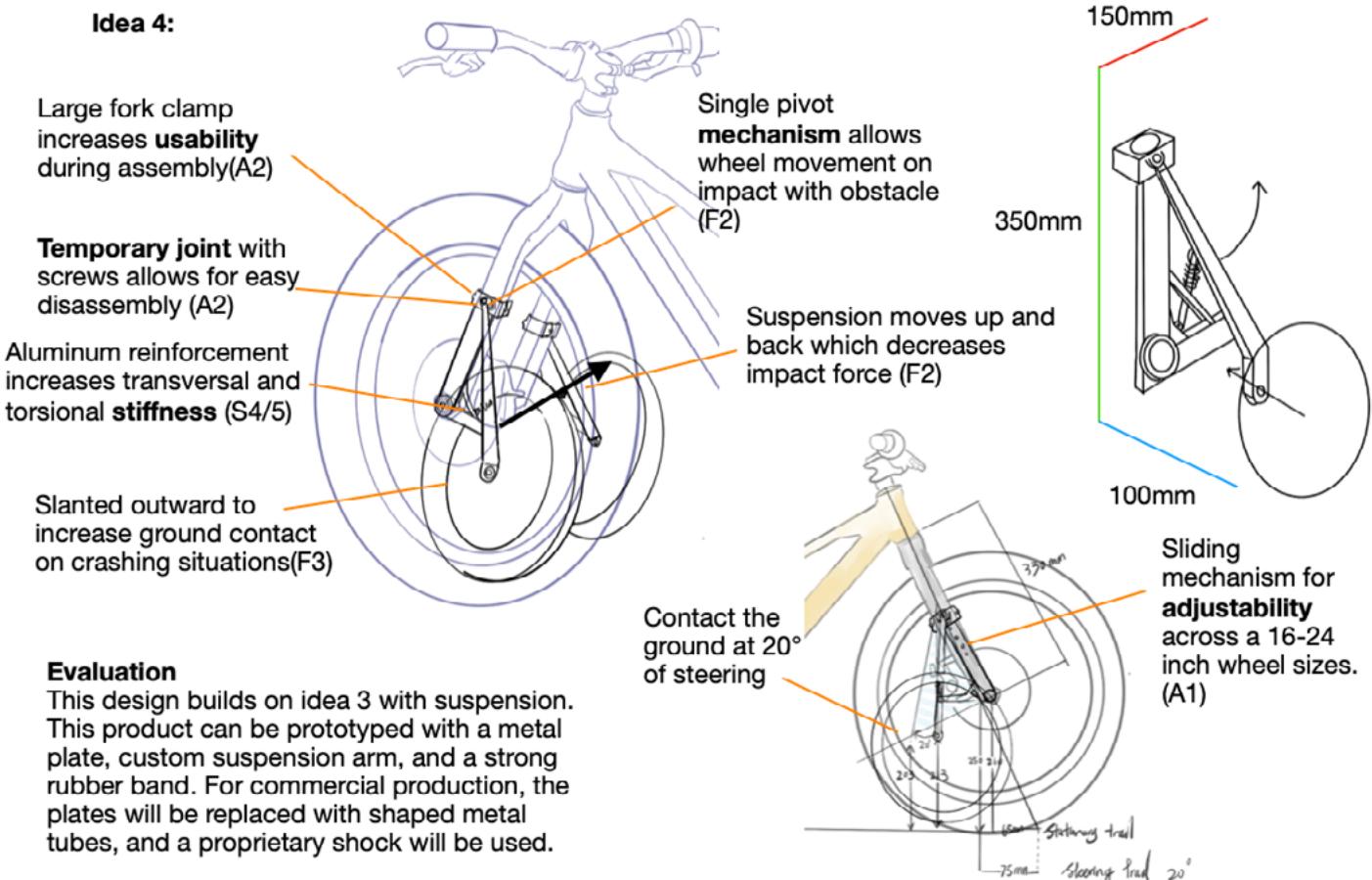


Evaluation

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 4:

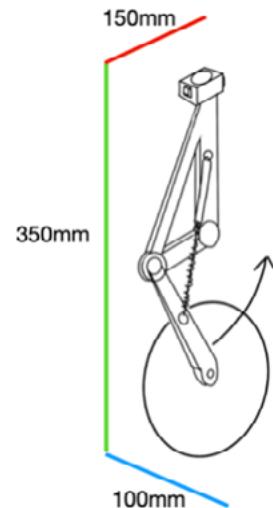
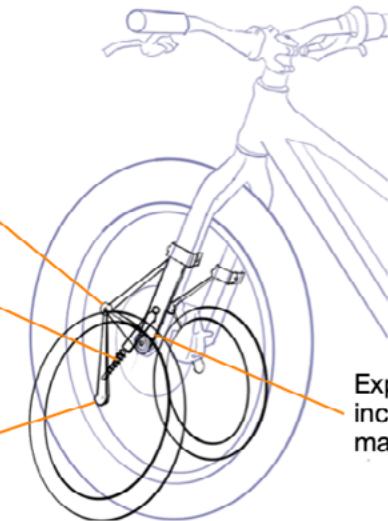


Idea 5:

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

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

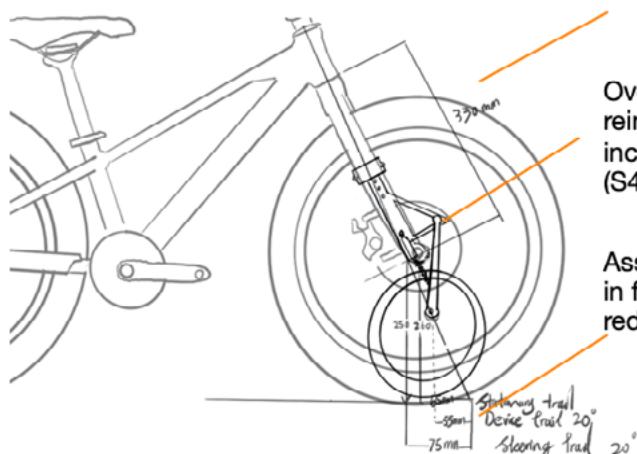
Design for assembly: Simple axle and bolt mechanism(A2)



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

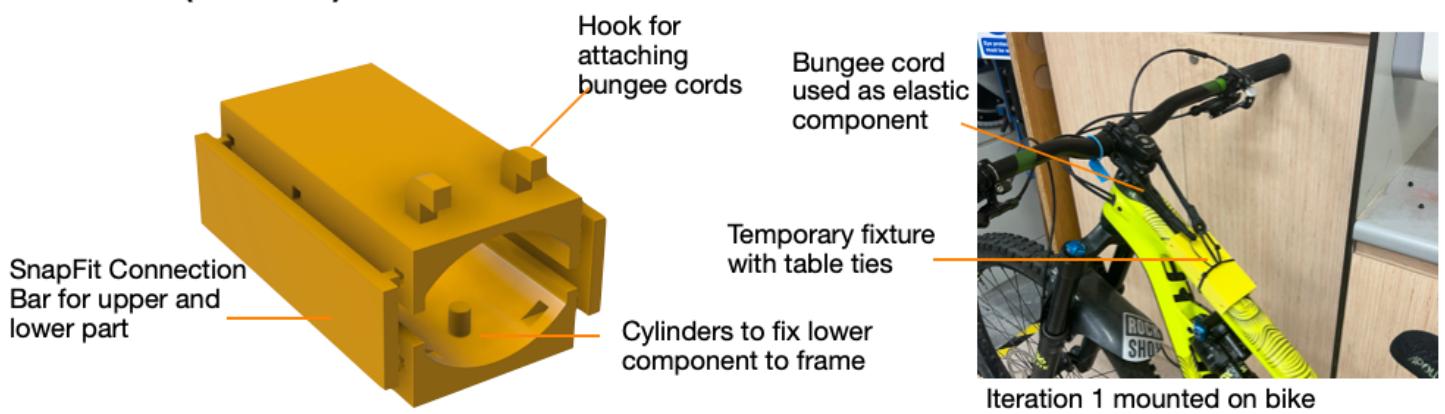
This design is a variation from design 4, which places the wheels in front instead of the back. This reduces the trail of the bike, decreases wheel flop, therefore increase steering control. A compression shock is required for this design. Other Manufacturing processes are similar to design 4.

Review of Ideas

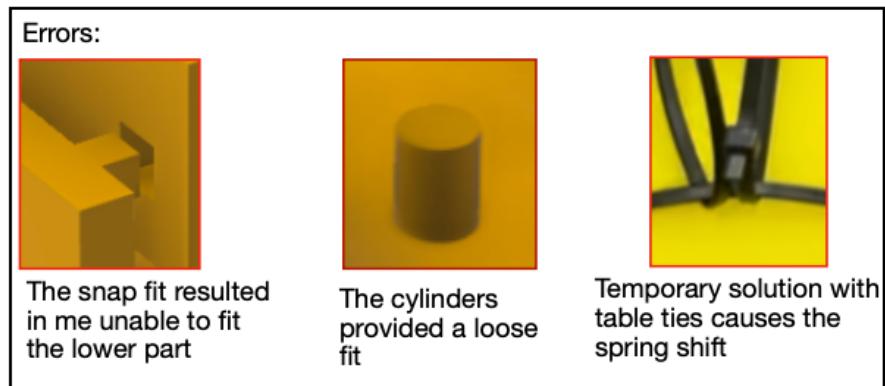
Design	Strengths	Weaknesses
1	<ul style="list-style-type: none"> Cost of manufacturing is low with 3D printing Design will not be subjected to high loads 	<ul style="list-style-type: none"> Spring system is not consistent over longer periods of use. Restoring force on handlebars can affect low-speed performance
2	<ul style="list-style-type: none"> Design will not be subjected to high loads. Effective stabilization at both low and high speeds. 	<ul style="list-style-type: none"> High costs of manufacturing due to low tolerance requirements. Lacking in assistance for crashing situations
3	<ul style="list-style-type: none"> Cost of manufacturing is low with plasma cut steel plates Low complexity design increases reliability. 	<ul style="list-style-type: none"> Limits steering on larger turning angles. Risk of jamming on rough terrain.
4	<ul style="list-style-type: none"> Support wheels with suspension prevent a restoring force under crashing situations. Suspension creates forgiveness on rough terrain and reduces risk of crashing 	<ul style="list-style-type: none"> Heavy Moving linkage creates a larger risk of breaking when crashed.
5	<ul style="list-style-type: none"> 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 therefore the wheel flop affect at lower speeds. 	<ul style="list-style-type: none"> Heavy Moving linkage creates a larger risk of breaking when crashed.

Concept Modelling

Idea 1 (Iteration 1)

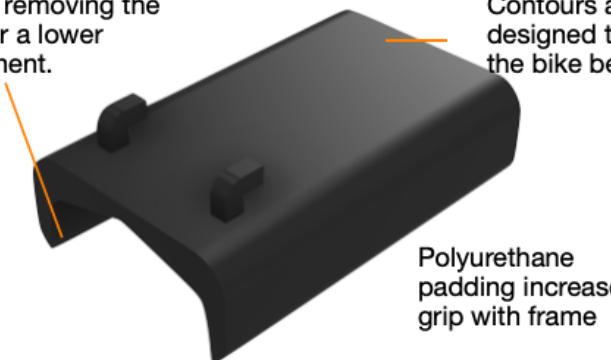


Iteration 1 tested during cycling



Iteration 2

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



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



1:1 scale front axle installation

Mounting plate for wheel and suspension component



Fork Clamp with temporary screw assembly

Low fidelity model of Joining Mechanism

Axis Fitment on Bike

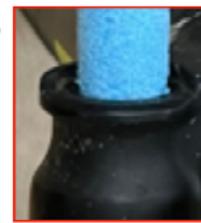
Errors:



The screw joint causes instability under loads.



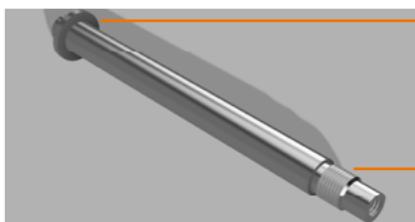
The mounting plate has to cross diagonally to reach the fork clamp, making it difficult to assemble



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

Iteration 2

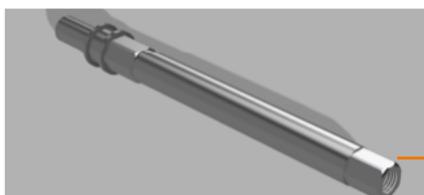
Axle Design



Large anchor plate increases stability
6mm Hex Socket reduces risk of stripping

Slight indentation for easy insertion over threads

Axle Variant for Quick Release Fork



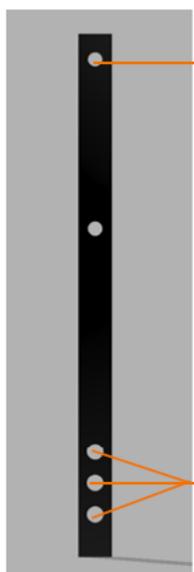
Beveled edges for easy insertion over threads



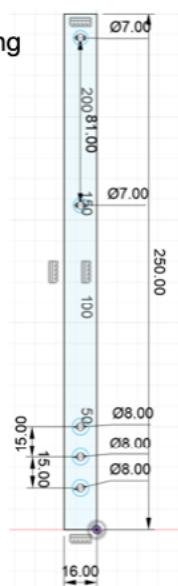
CNC prototype of 2 axle variants

Axle Variant for Hex Lock Fork

Fixing Plate Design

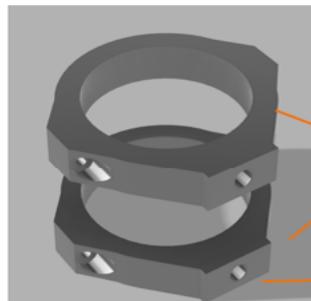


Straight mounting plate increases ease of manufacture



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



Rubber Padding for frame protection and grip

Existing market alternative

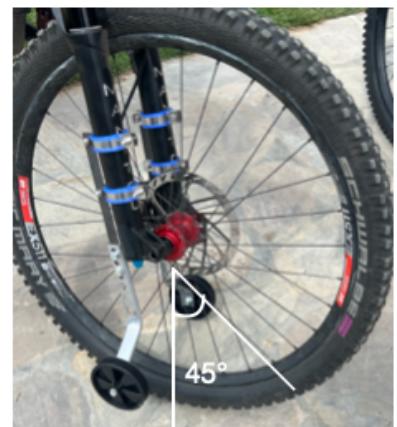
Assembly



Front View of Assembled design



Side View of Assembled design



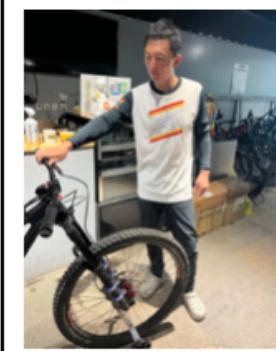
Wheels contact the ground at approximately 45 degrees of steering



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

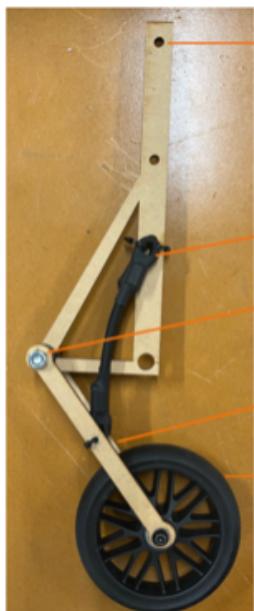
- When turning, the support wheel will take the majority of the load.
- This can lead to reduced traction, which defeats the effect of having this device.
- A good idea is to use a bigger wheel to increase contact area.
- Also use rubber tires to increase traction with the ground



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)





Pushing the model to test suspension dynamics

Goals for next iteration:

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

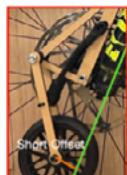
Errors:



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 too 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

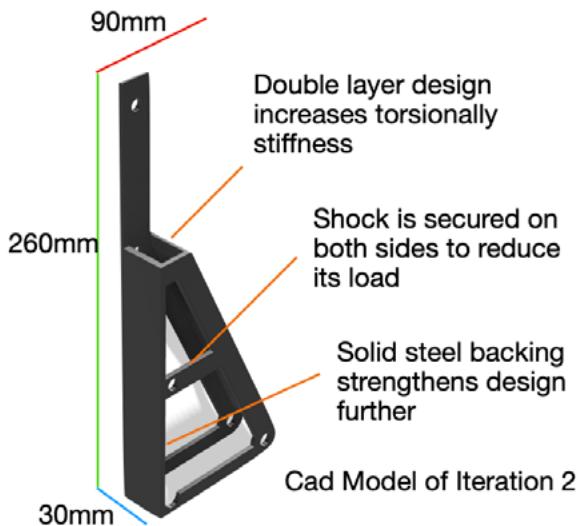


The product can only be loaded on the longitudinal axis. There is low torsional stiffness. A sideways impact can damage the bike fork. Even if the final design would be metal, the high loads applied on the pivot and shock will affect durability



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



Goals for next iterations:

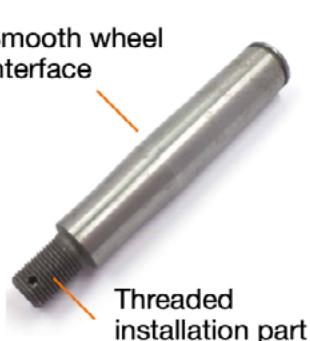
- Reduce Weight (currently at 300 grams for single frame)
- Reduce thickness (currently at 30mm)

Iteration 3

The two designs below feature a horizontal suspension layout. They 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.



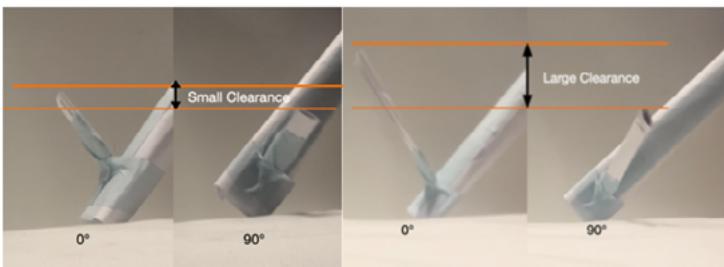
HB fold-up training wheel Easy Trainer wheel



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

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	<ul style="list-style-type: none"> - 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.
Fixing Plate			<ul style="list-style-type: none"> - Anodized surface allows for a polished, corrosion-resistant, and visually appealing finish.
Suspension Linkage			<ul style="list-style-type: none"> - 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.
Fork Clamp		6061 T6 Plate Aluminum 1mm	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - 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.
			<ul style="list-style-type: none"> - Retains a clean look over time, as silicone rubber is resistant to dirt and UV degradation.
Assist Wheel Bolt		Grade 12.9 Carbon Steel	<ul style="list-style-type: none"> - High tensile strength(1200Mpa) ensures secure fastening, critical for withstanding vibrations during mountain biking. - Excellent shear resistance prevents failure under transverse loads (S4)
M7 Hex Bolt			<ul style="list-style-type: none"> - Minimalistic and utilitarian design aligns with the functional purpose of the bolts.
M7 Hex Nut			<ul style="list-style-type: none"> - Carbon steel is widely recyclable, reducing the environmental impact.
M8 Carriage Bolt			
M8 Carriage Screw			
Pivot Bushing		Quenched No.45 Steel	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - Anodization improves hardness, ensuring scratches and wear don't interfere with tolerance.
Assist Wheel		Butyl Rubber(tire)	<ul style="list-style-type: none"> - High traction: Ensures grip and stability, crucial for uneven surfaces. - Shock absorption: Damps vibrations, enhance comfort, reduce stress
			<ul style="list-style-type: none"> - Natural or synthetic rubber can be recycled into other products.
			<ul style="list-style-type: none"> - Ensure ethical sourcing of tire, including safe working conditions.
		ABS Plastic(Frame)	<ul style="list-style-type: none"> - High strength-to-weight ratio provides structural integrity while keeping the frame lightweight.
			<ul style="list-style-type: none"> - 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.



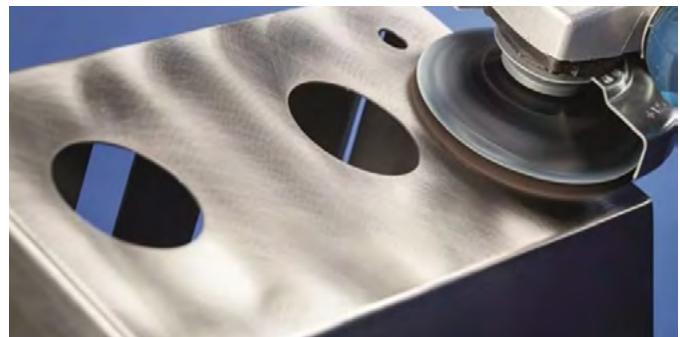
Pressfit

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.

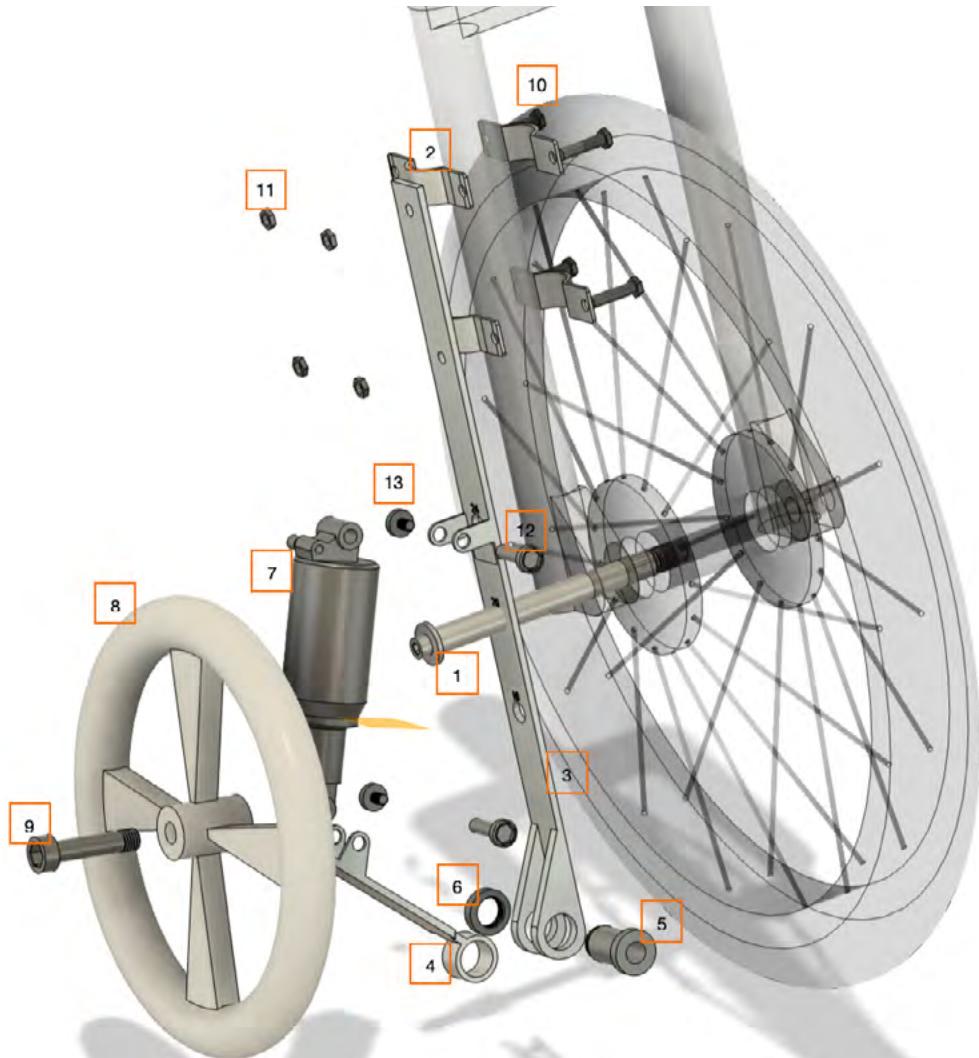


Polishing

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.

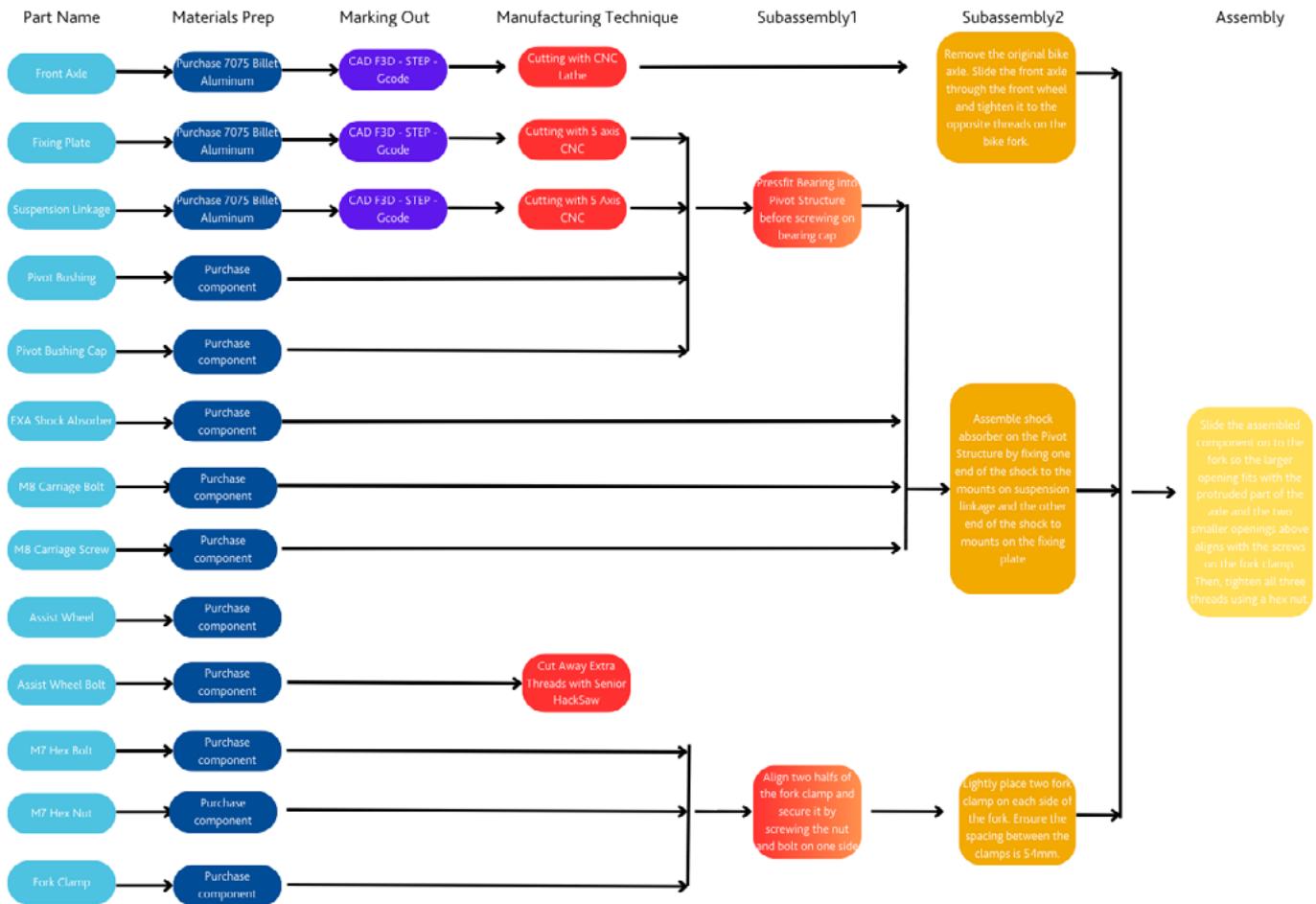


Assembly Details

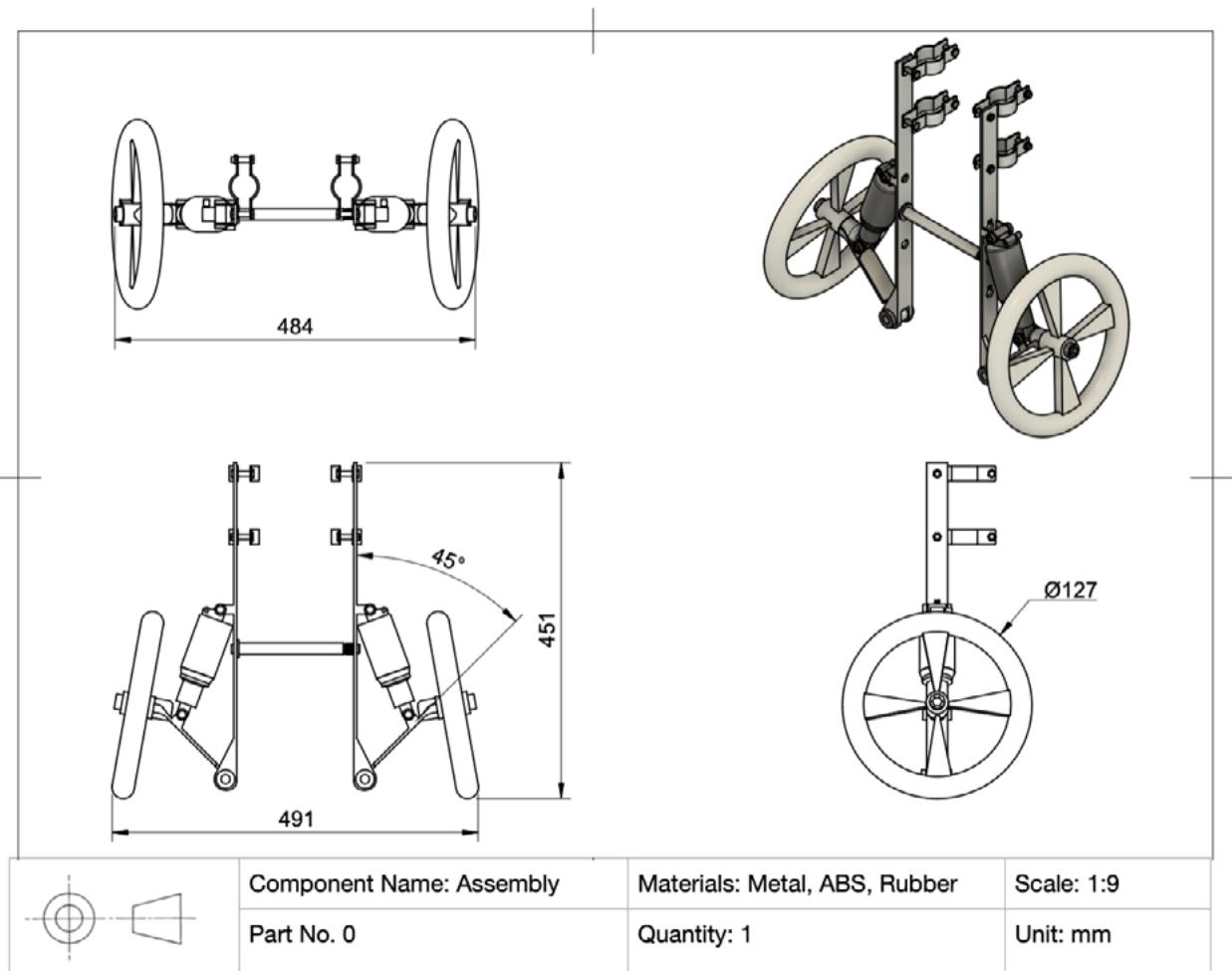


Part No.	Description	Length(mm)	Width(mm)	Thickness(mm)	Quantity	Cost (rmb)
1	Front Axle	170	ø15	ø15	1	400
2	Fork Clamp	ø35	ø35	2	4	20
3	Fixing Plate	430	28	4	2	600
4	Suspension Linkage	120	28	4	2	600
5	Pivot Bushing	42	ø20	4	2	10
6	Pivot Bushing Cap	6	ø25	6	2	10
7	EXA Shock Absorber	170	ø45	ø45	2	400
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](#))



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

Label	Specification	Test
S1	No component should pose 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 trial 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 aggressive 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 to 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 trial of user's father assembling and disassembling component



Timing shows that a totally inexperienced person can assemble the component 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.

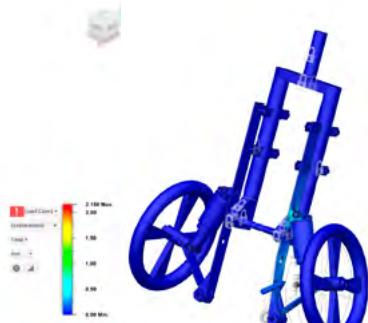
Engineering Analysis

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

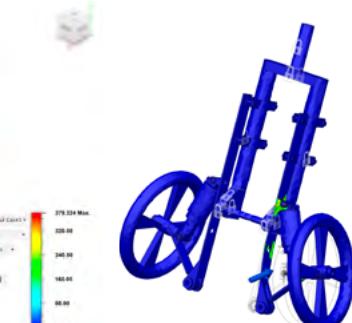
S4 Transversal Deformation



Displacement at 200N of force



Stress(Mpa) at 200N of force



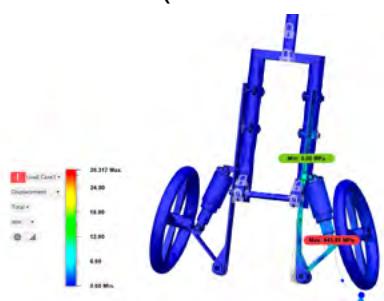
Safety Factor at 200N of force

Displacement 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.

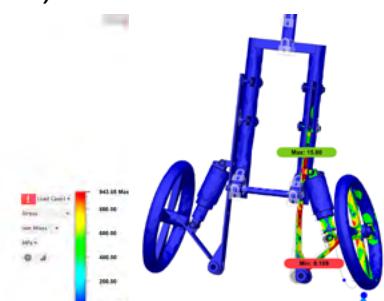
S5 Longitudinal Deformation (extended suspension)



S5 Longitudinal Deformation (compressed suspension)



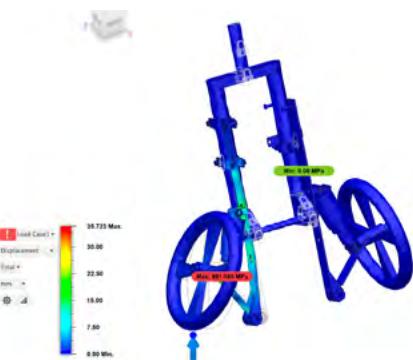
Stress at 1000N of force



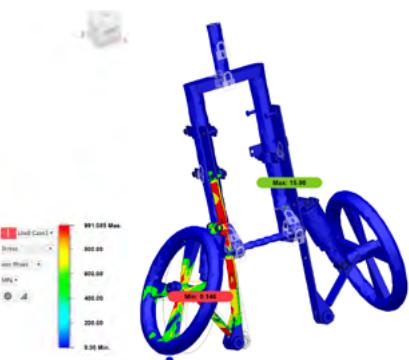
Safety factor at 1000N of force



Displacement at 1000N of force



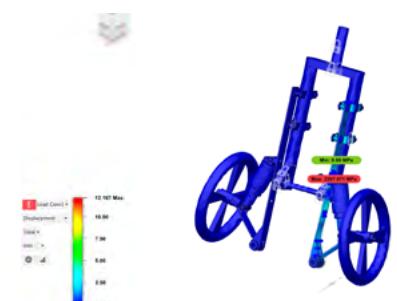
Stress at 1000N of force



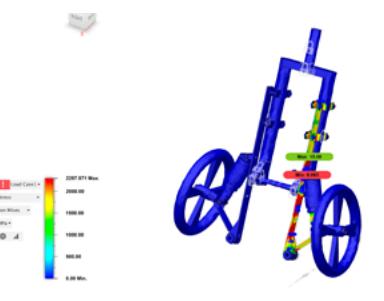
S6 Torsional Deformation



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.

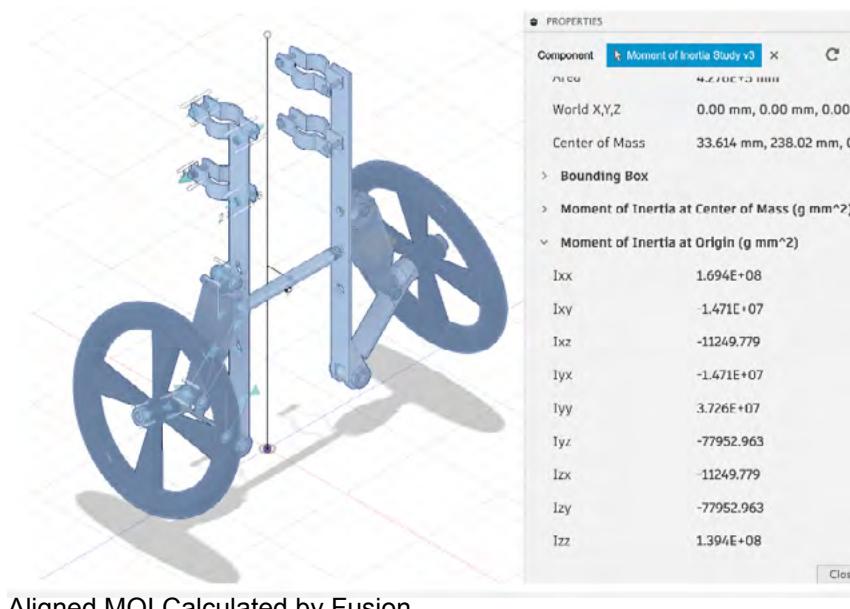


Component aligned with the steering axis in Fusion 360

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 represents the resistance to rotation around the y-axis. The mathematical definition of I_{yy} is:

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

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:

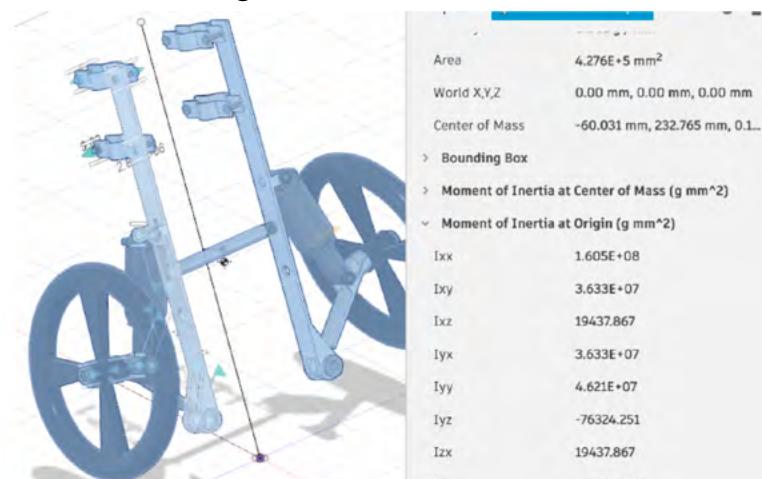
$$I_{xy} = - \int_V \rho \cdot x \cdot y dV \quad (2)$$

I_{xy} introduces coupling between rotations around the x and y-axis. In a symmetrical component, $I_{xy} = 0$, 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 resistance 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:

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

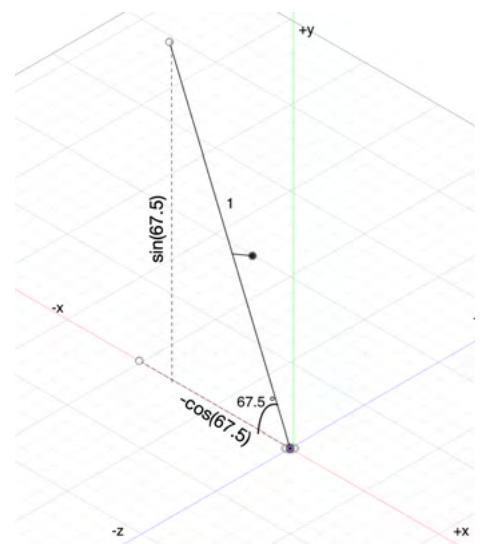
Using the inertia tensor $[I]$ and the unit vector \vec{n} , the effective MOI about the steering axis is given by:

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

The general inertia tensor is

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

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 gives:

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

The effective steering moment of inertia can be computed by:

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

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

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.

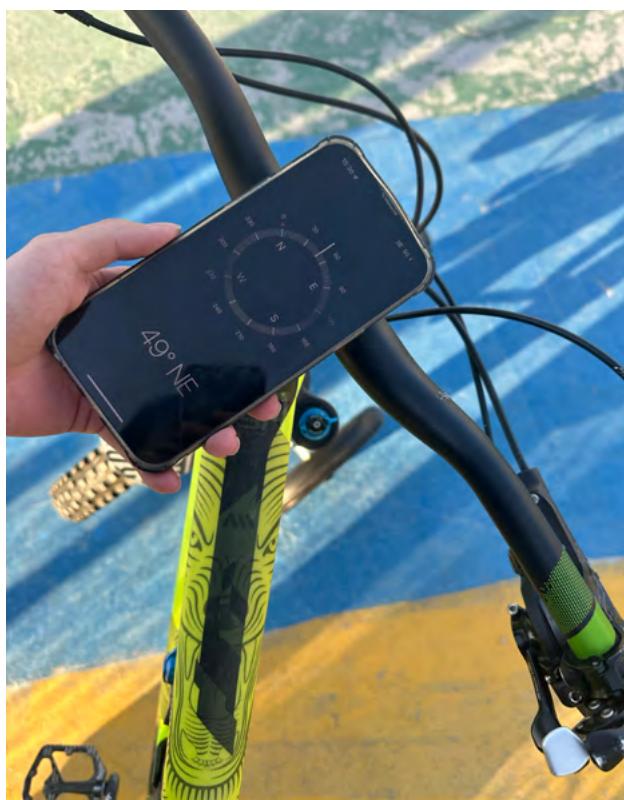
Both methods yielded consistent results for I_{steering} , confirming the validity of the calculations.

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

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:

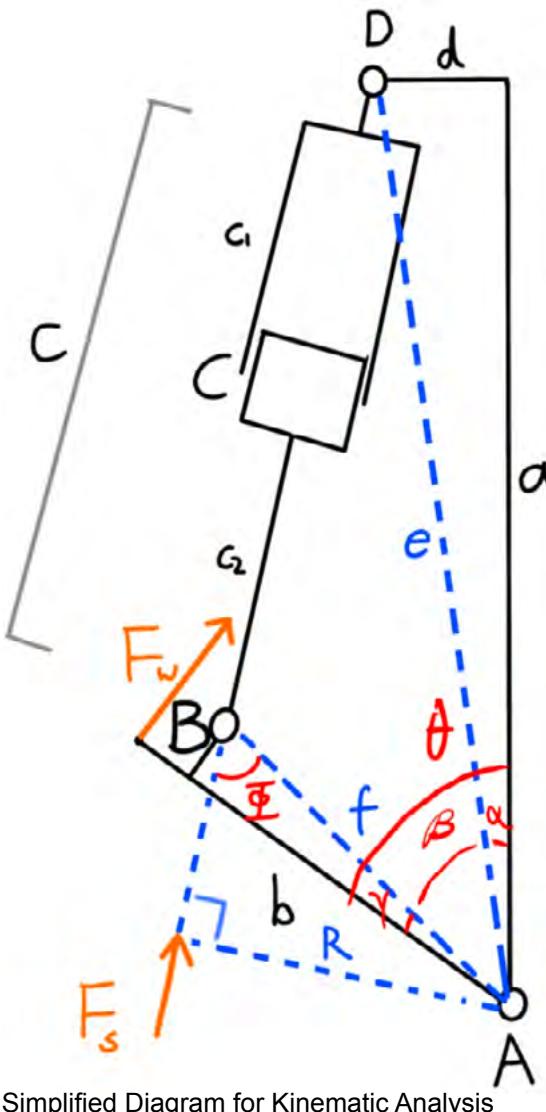
- A standard mountain bike front wheel with tire has a typical moment of inertia in the range of $0.05\text{-}0.15 \text{ kgm}^2$ depending on the weight distribution and rim/tire size.
- The calculated value is slightly smaller than the lower end of this range, indicating that the assist wheel component 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)



Links (L)	Joints(J)	Degrees of Freedom(Dof)
1. a(ground)		Grueblers Equation states:
2. b(follower)	1. A(pivot)	$Dof = 3(L-1)-2J$ $= 3(4-1)-2(4)$ $= 1$
3. c ₁ (rocker)	2. B(pivot)	This indicates the system requires 1 input motion to control the entire linkage.
4. c ₂ (coupler)	3. C(prismatic)	

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

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

Definitions

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

Wheel Displacement(Xw): The linear displacement 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:

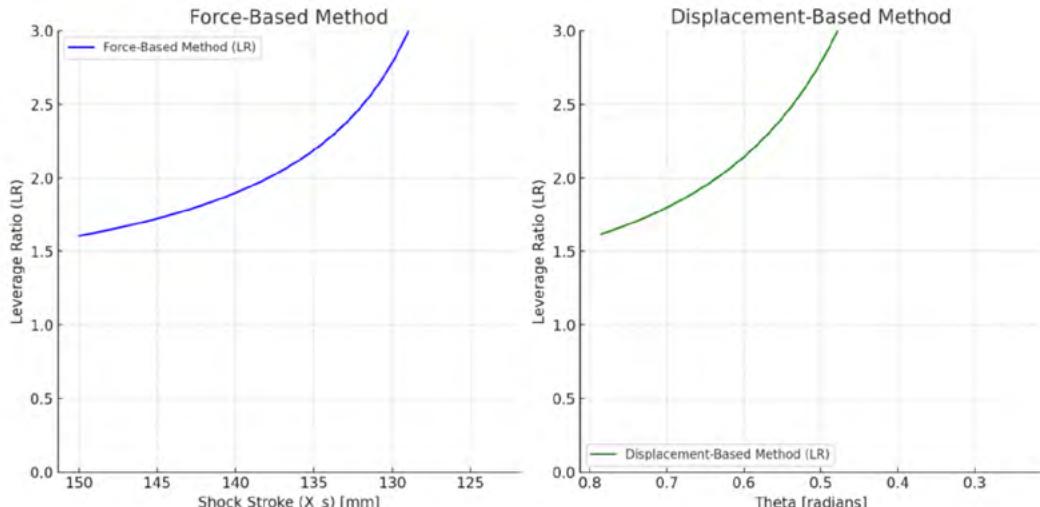
$$LR = \frac{\frac{dX_w}{d\theta}}{\frac{dX_s}{d\theta}} = \frac{b}{\frac{ef \sin(\theta - 0.23)}{\sqrt{e^2 + f^2 - 2ef \cos(\theta - 0.23)}}}.$$

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: $X_s(C) = 150 \text{ mm}$

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.

D3: Suggested Improvements

1

Issue: The air seal on the original shock absorber is too stiff, creating flex in the metal structure.

Solution: Use a thinner coil shock absorber that mitigates the problem of tight air seals.



Shock Locked Up



Original Shock



Original vs New Shock

2

Issue: Axle spacing is designed only to fit 110mm long axles, reducing versatility.

Solution: Design customized axles for forks with different specifications or eliminate its use altogether.



Spacing issue requires washer

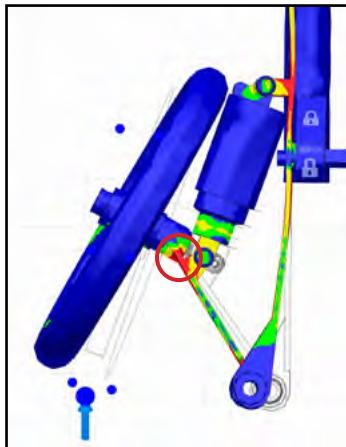


Selectable Axle Standards

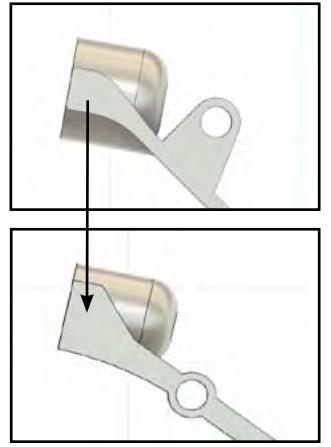
3

Issue: The connection point between the wheel mount and the suspension linkage is too thin, causing flex.

Solution: Reinforce the bending point with additional material



Severe Load at Connection

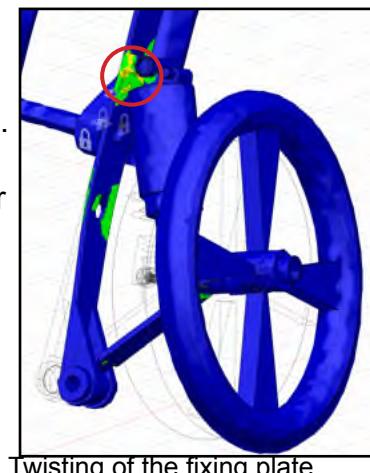


Thickened Connection Point

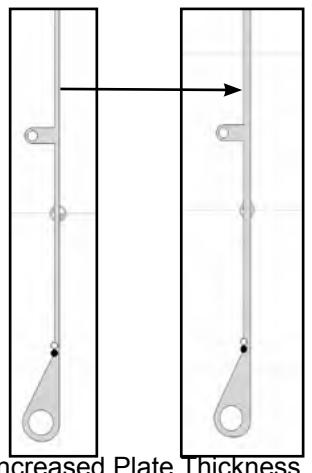
4

Issue: The entire fixing plate twists under torsion.

Solution: Reinforce the backing plate with thicker material



Twisting of the fixing plate



Increased Plate Thickness

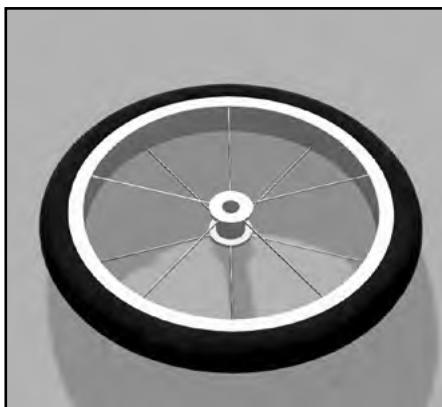
5

Issue: The use of solid tires and plastic rims increases weight, significantly effecting the components moment of inertia, making it harder to steer.

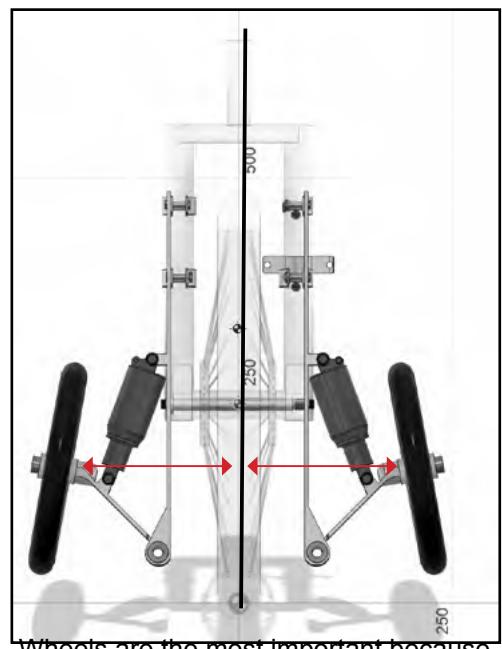
Solution: Use hollow tires with spoked rims to reduce weight



Original Wheel: 467 grams



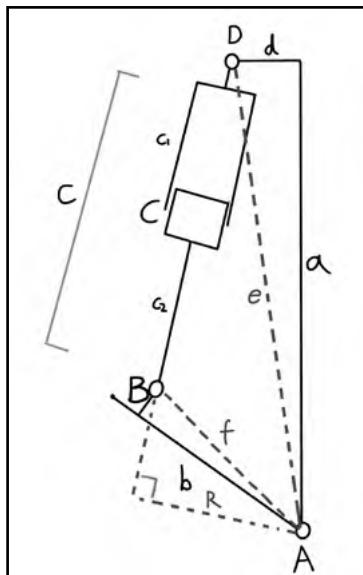
New Wheel: 346 grams



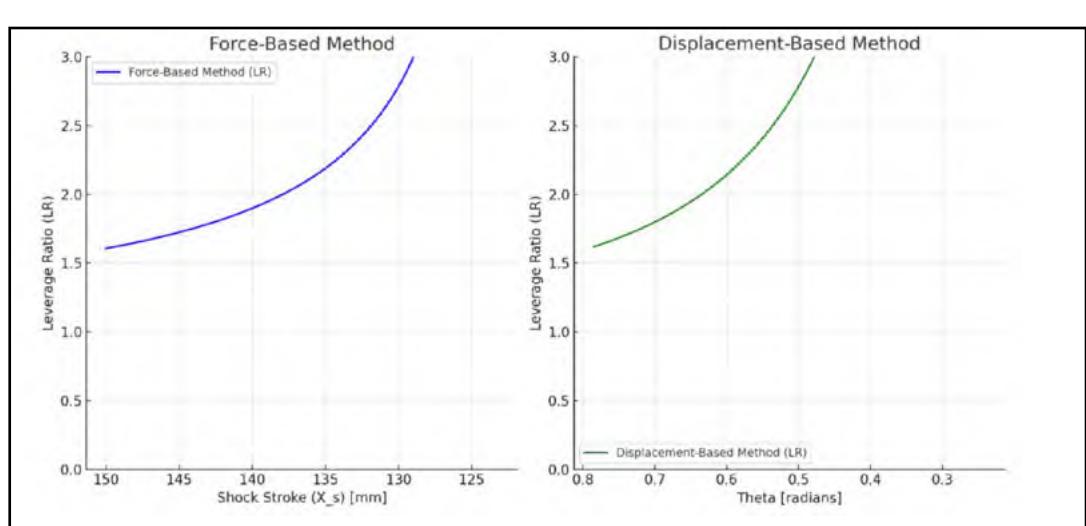
Wheels are the most important because they are furthest away from axis

6

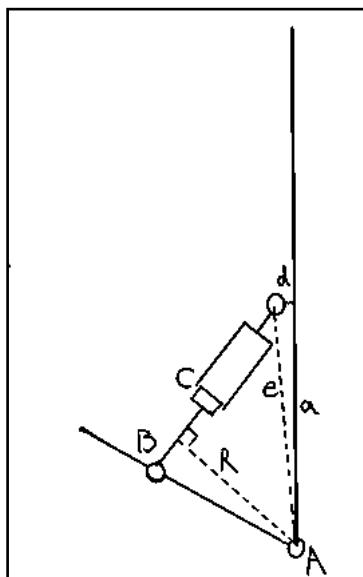
Move the suspension linkage(follower link) below the perpendicular line of action to increase leverage ratios. This makes the suspension less likely to bottom out and uses travel more efficiently.



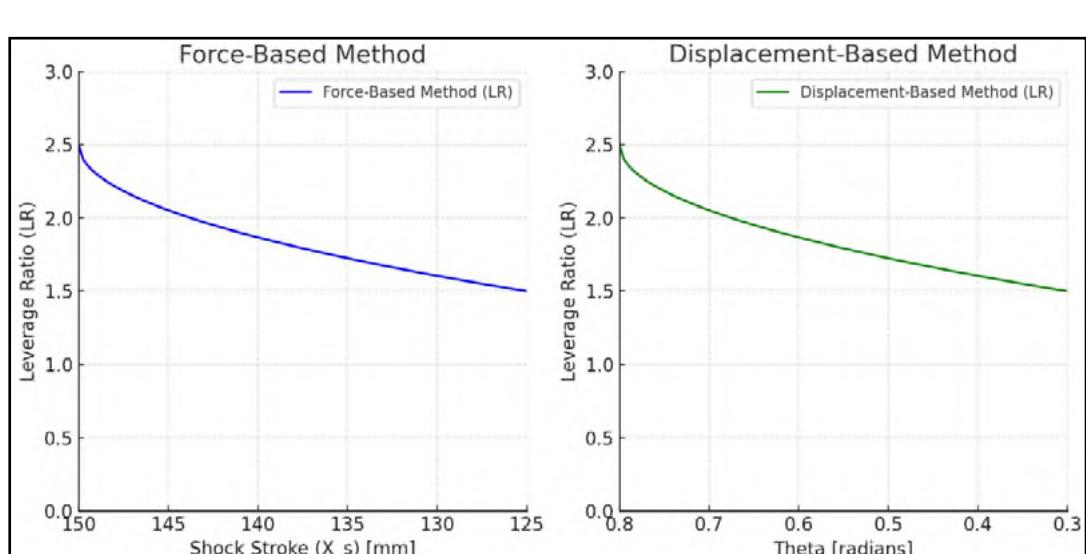
Suspension Before



Previously, the leverage ratio is upward trending, making suspension use inefficient.



Suspension After



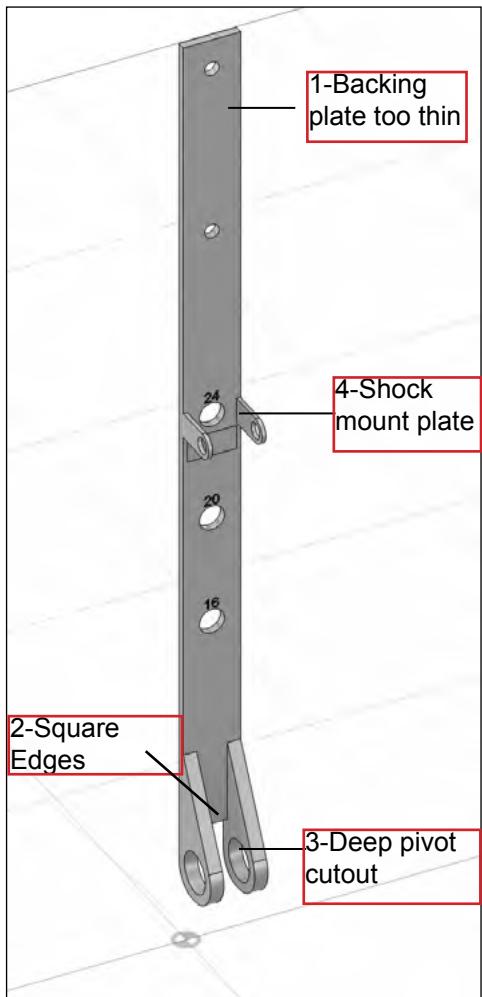
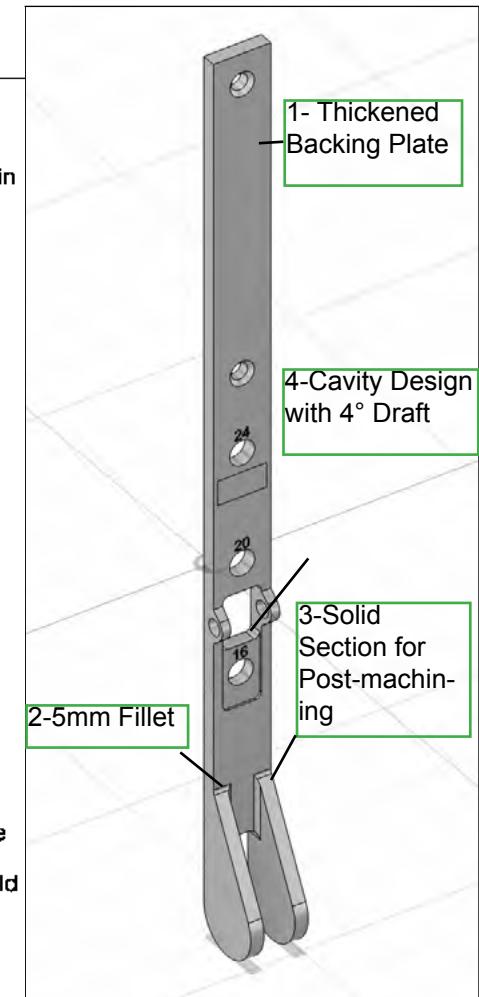
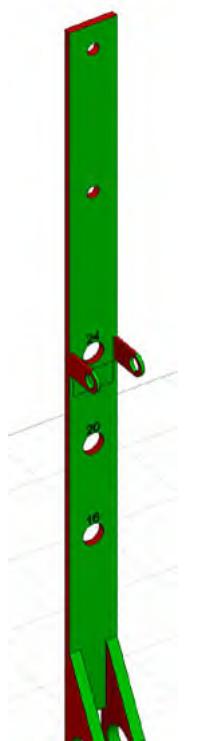
Now, the leverage ratio is downward trending, making suspension use efficient.

E1: Development for Commercial Production

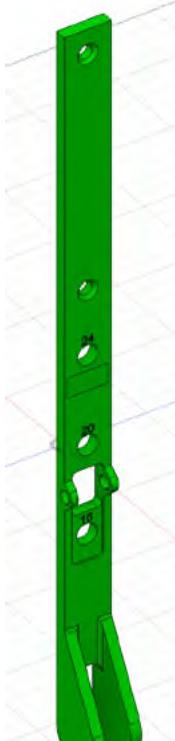
Design for Process

CNC machining (5-axis) is costly and time-intensive for mass production. There is also high material waste. To mitigate this, my design will be optimized for a hybrid (die-casting + CNC) production method.

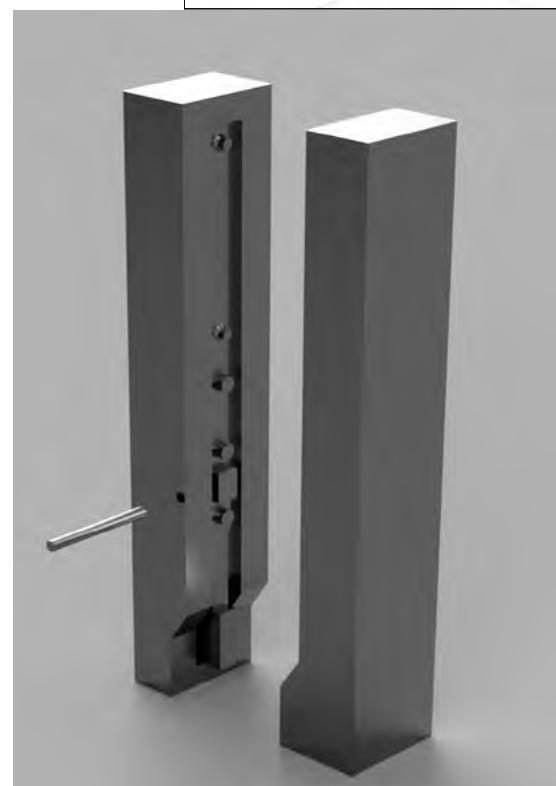
#	Issue	Fix
1	Backing plate too thin	Increase plate thickness to at least 3-5mm to ensure proper material flow in die casting.
2	Square edges on cutouts lead to stress concentrations in high-pressure casting.	Introduce 2-3mm fillets on all internal cutouts and sharp transitions.
3	Deep pivot cutout can create defects and complicate mold	CNC accurate pivot hole post casting instead of casting pivot directly.
4	Thin shock mount requires secondary welding and is prone to warping	Convert to a single-piece cavity structure and use draft angles (3-5°) for smooth mold ejection

Draft Analysis Before (0° Draft)



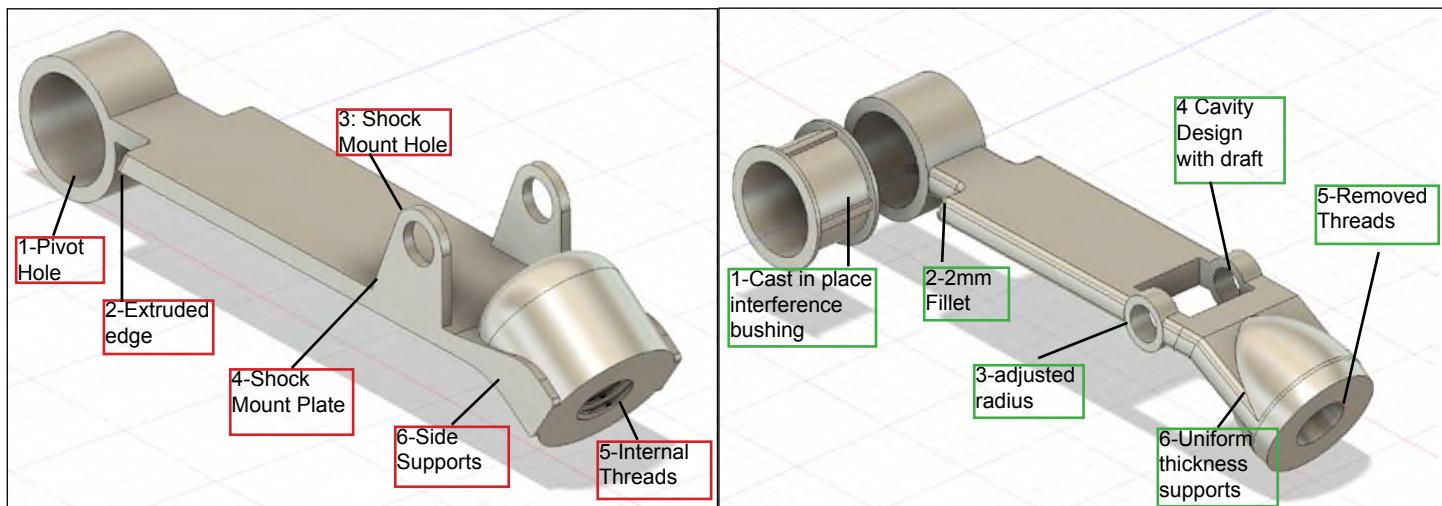
Draft Analysis After (1-4° Draft)



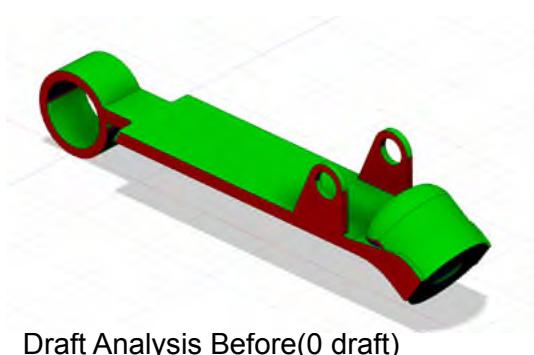
Two part cavity mold with side core insert

Test	Image	Result	Modification
Time to Fill		0.25 s Mounting holes and cavity creates turbulence, increasing fill time.	Adjust gate placement to ensure a smoother metal flow. Redesign cavity cutouts with rounder edges and tapered shapes
Time to Solidus		12.748 s Solidification rate is significantly slower at the wheel mount	Add cooling channels in the mold near the wheel mount.
Shrinkage Porosity		High Porosity between mounting holes where metal flows last.	Place additional gas overflow vents near the shrinkage-prone areas. Increase local thickness for better feed-ability
Pressure Distribution		1000 bar High pressure between the main plate and the wheel mount region. High Pressure near edges of the component	Introduce larger fillets in the wheel mount and edges

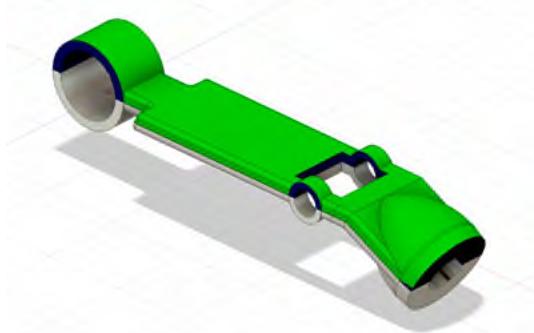
Die Casting Optimization for suspension linkage



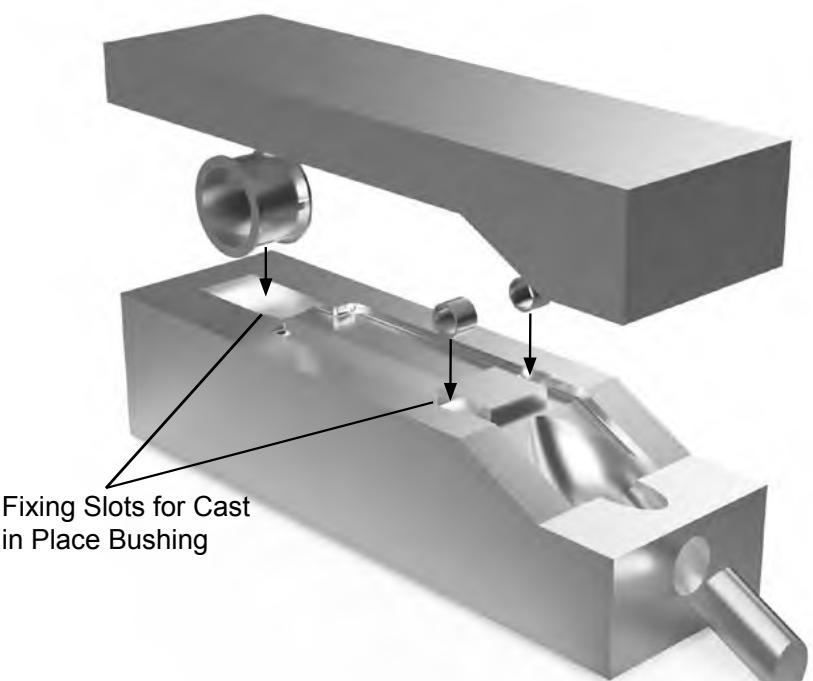
#	Issue	Fix
1	Precision of bearing fitment may not be achieved in casting alone.	Use cast-in-place bushings and adjust mold parting line for better hole alignment.
2	Sharp edges create stress risers, leading to casting defects.	Increase Fillet Radius (2-3mm) for better mold flow and structural integrity.
3	Tolerance may not be precise enough for shock mount fitment.	Adjust radius for secondary machining.
4	Thin sections cannot be casted as one piece and will warp in production.	Change extruded design into cavity design. Ensure 3-5° draft angles for smooth mold release.
5	Threads cannot be cast with precision. High torque loads may strip die-cast threads.	Use CNC post-machining to cut threads for accuracy.
6	Complex Shapes and Uneven Wall thickness causes cooling issues.	Maintain a uniform wall thickness (~3-5mm) for better mold flow.



Draft Analysis Before(0 draft)



Draft Analysis Before(0-2 degree draft)

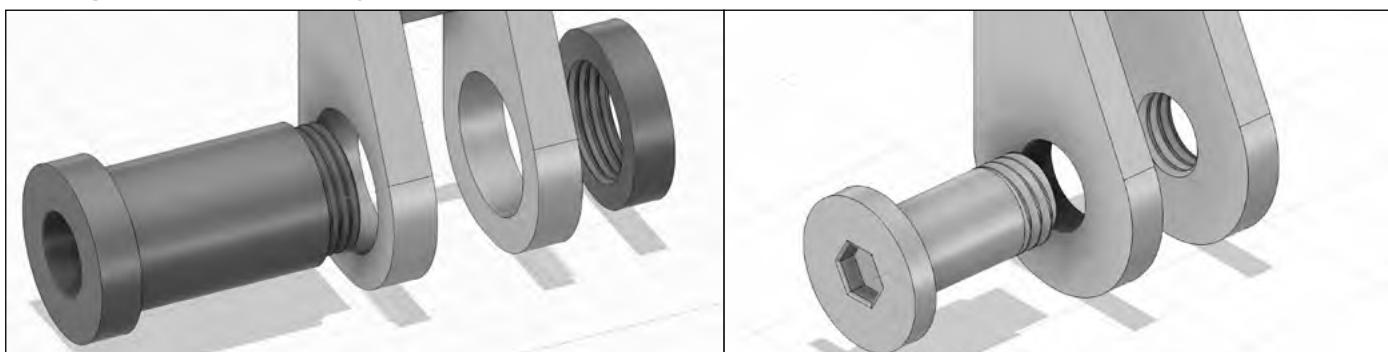


Two part cavity mold with side core insert

Die Casting Simulation with 700 celcius Fill Temperature and 200 celcius mold temperature

Test	Image	Result	Modification
Time to Fill		0.087 s Cavity disrupts metal flow increasing fill time.	Use a fluid-dynamic shape around cavity area
Time to Solidus		29.86 s Solidification rate is significantly slower at the wheel mount	Decrease thickness of wheel mount hole
Shrinkage Porosity		High Porosity near top section and lower pivot section	Implement local cooling and add fillet edges
Pressure Distribution		13.10 bar High pressure near wheel mount	Fillet Sharp Transitional Edges.

Design for Assembly



Issue

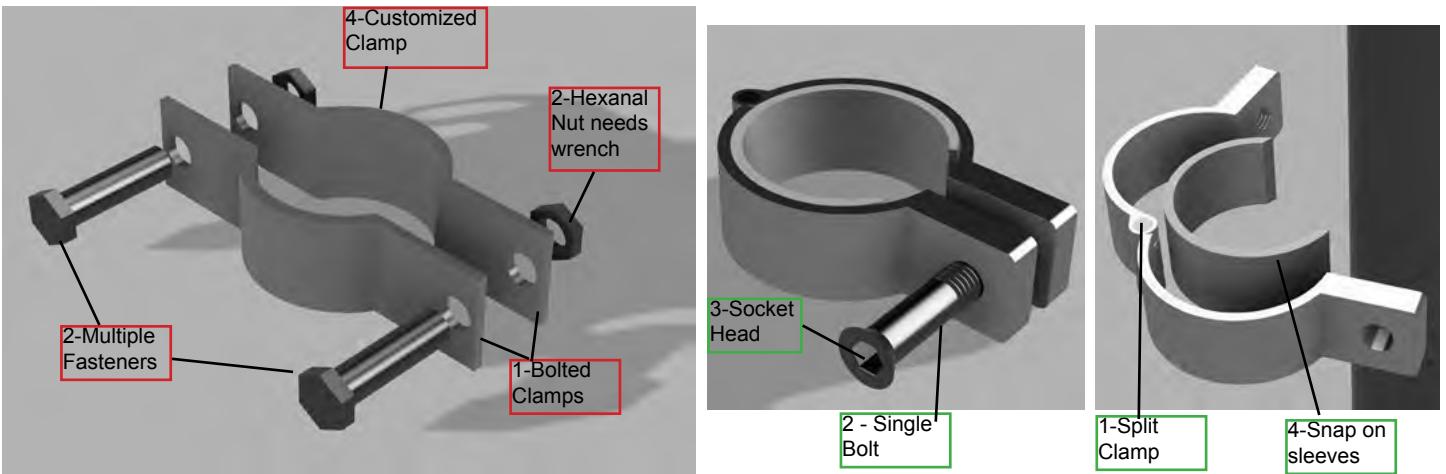
Tight fit requires factory assembly, causing transport and packaging difficulties.

Assembly requires clamps to screw the two halves together.

Fix

Loose fit allows users to assembly the component whenever they wish.

Could be assembled using a standard Allen Key.



#	Issue	Fix
1	Bolted clamps require precise alignment, increasing assembly time	Use a split Clamp Mechanism to increase usability
2	Multiple fasteners increase failure points, and add handling/feeding costs during manufacture.	Use single bolt and internal thread
3	Hexagonal Bolts and Nuts reduce usability.	Use socket head bolts for Allen key adjustment
4	Need for customized clamps for different fork diameters.	Use flexible internal sleeves with snap-on fitment: SKU Reduction & Modular Design

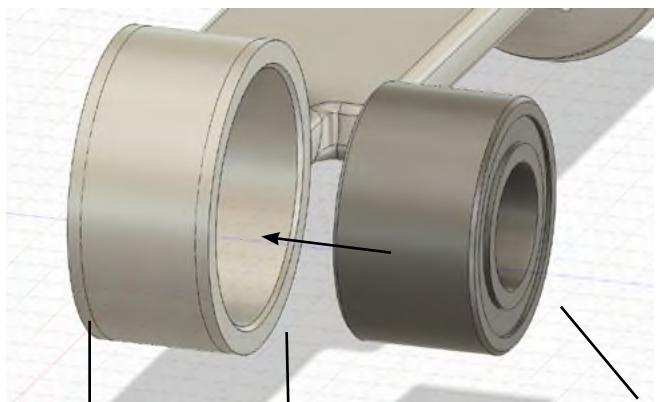
Quality Assurance & Durability



Shouldered Plain Bearing

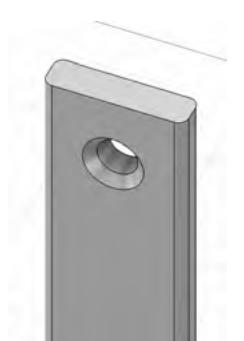


Double Row Deep-Groove Bearing

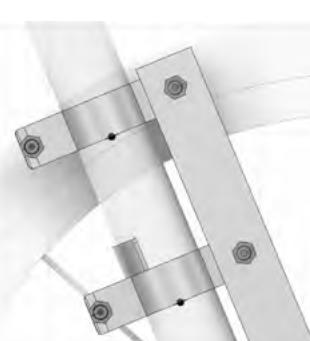


Cast-in-place bushing with tight tolerance
Chamfered edges for pressfit
Slight portusion of internal ring eliminates rubbing

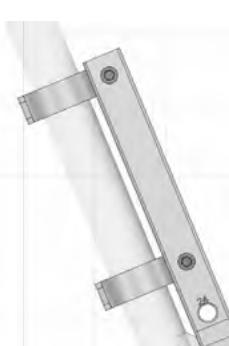
Issue	Fix
Plain bushings cause friction and side loads can wear pivot joints.	Double row bearings are smooth and incredibly resistant to high loads
Press fit requires high precision and tight tolerances	Introduce chamfers on bearing seats to aid alignment and insertion



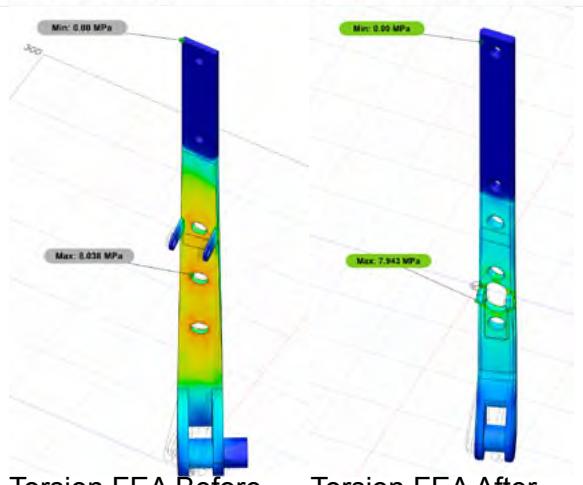
Countersunk holes reduce wear



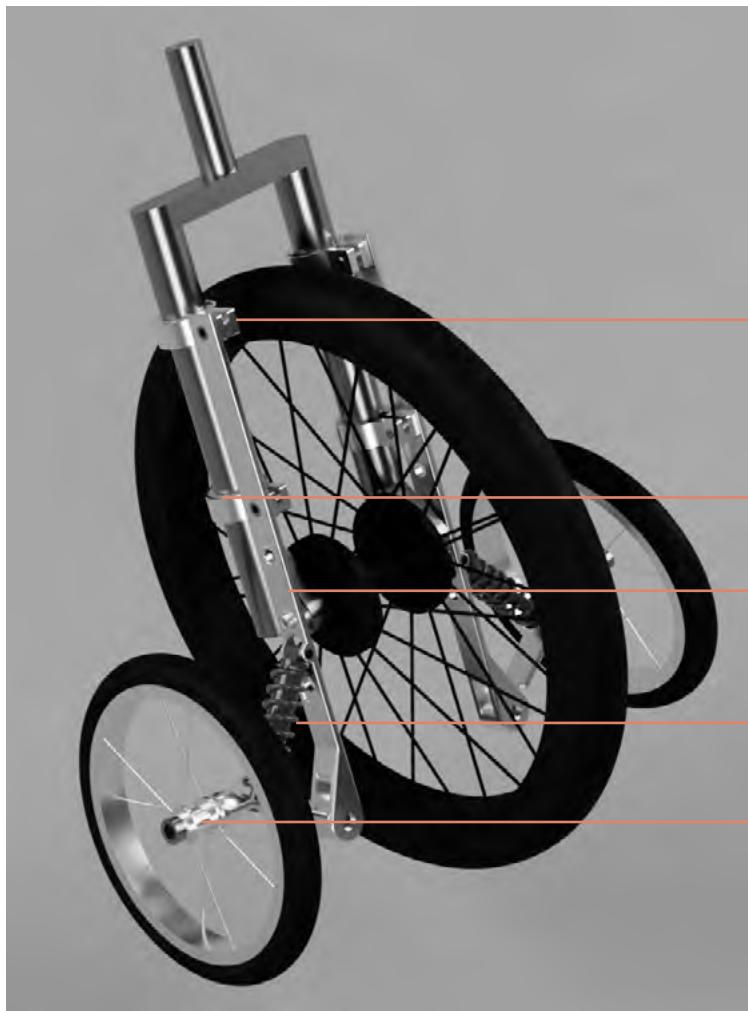
Increased distance between mounting ports for stability, allows for axle free mounting



Torsion FEA Before



E2: Presentation of Final Commercial Product



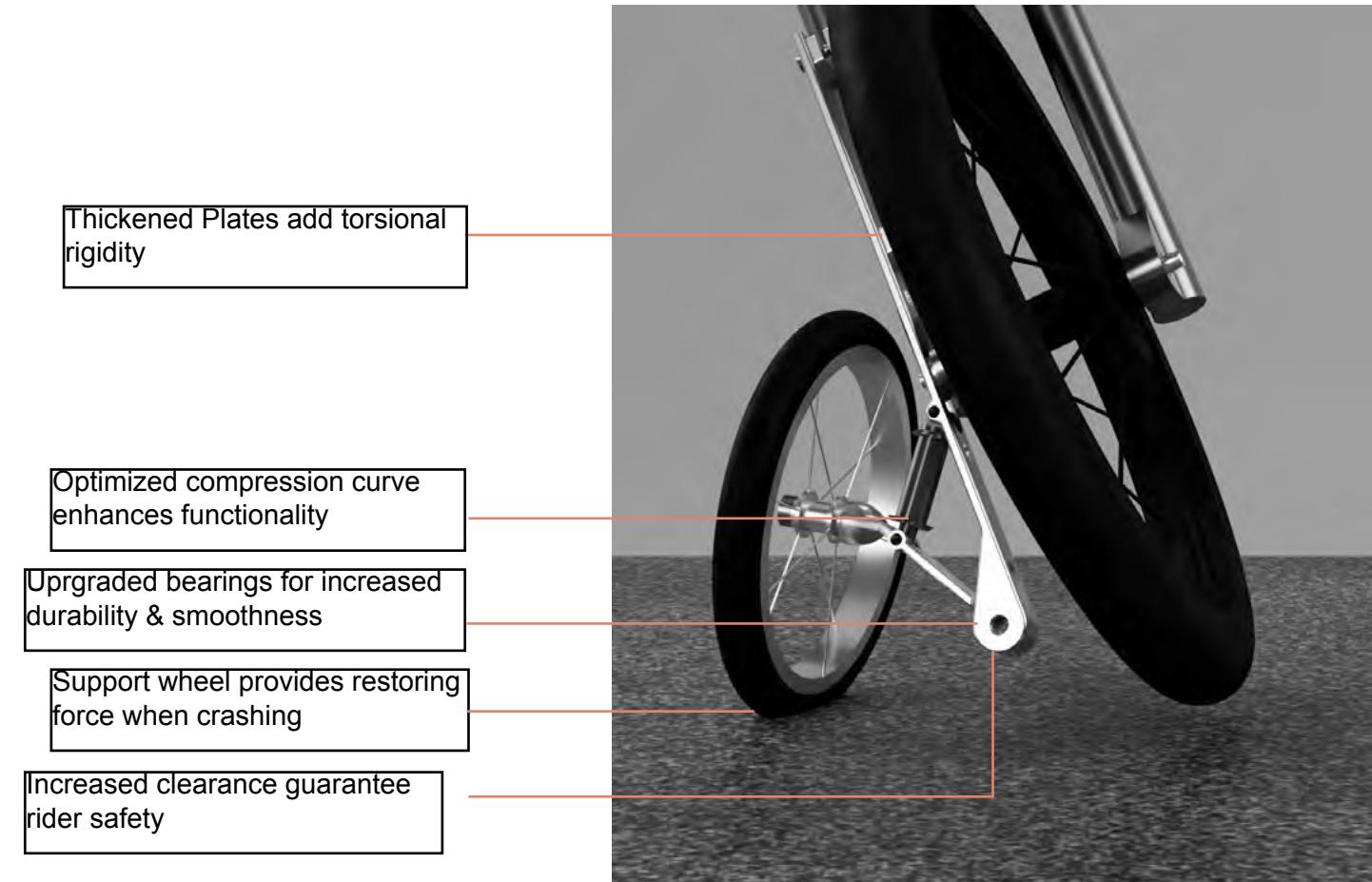
Single Bolt Assembly Cut costs and increase usability

Replaceable plastic sleeves for adjustability across different fork diameters

Rounded edges for die casting and pressure distribution

Customized coil shock reduce weight and friction

Hub & Spoke wheels reduce weight



Thickened Plates add torsional rigidity

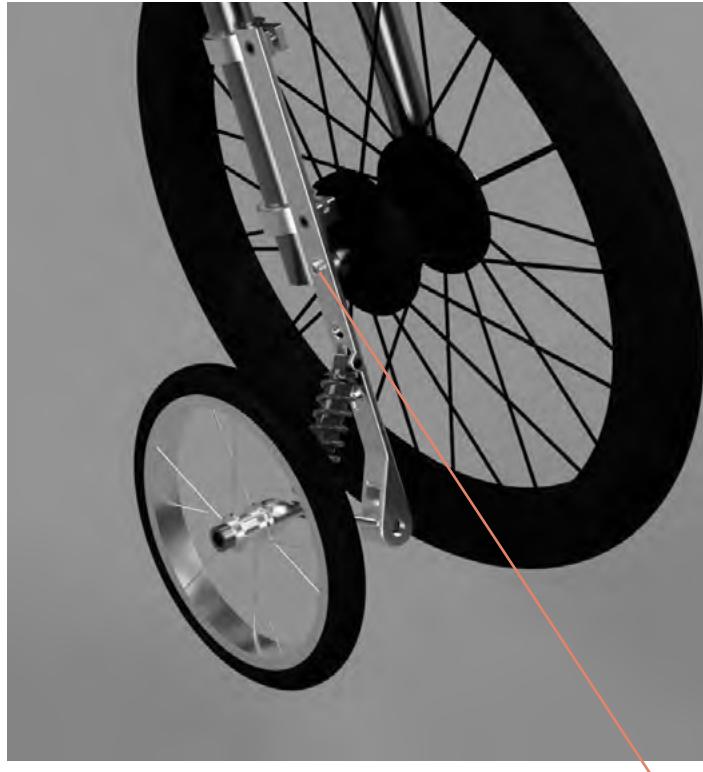
Optimized compression curve enhances functionality

Upgraded bearings for increased durability & smoothness

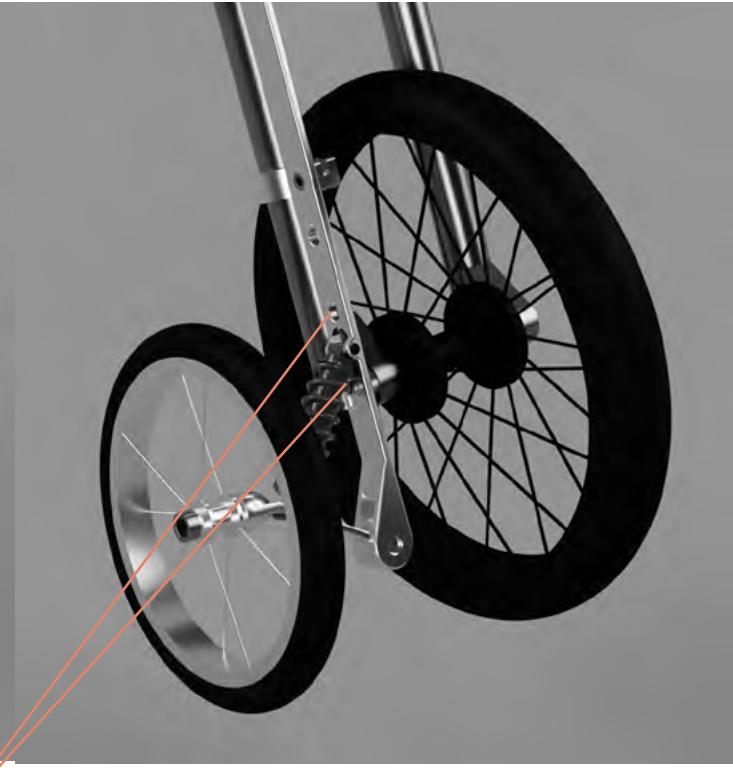
Support wheel provides restoring force when crashing

Increased clearance guarantee rider safety

Assembly on 24 inch wheel bike



Assembly on 16 inch wheel bike



three axle slots create adjustability between 16-24 inch bikes



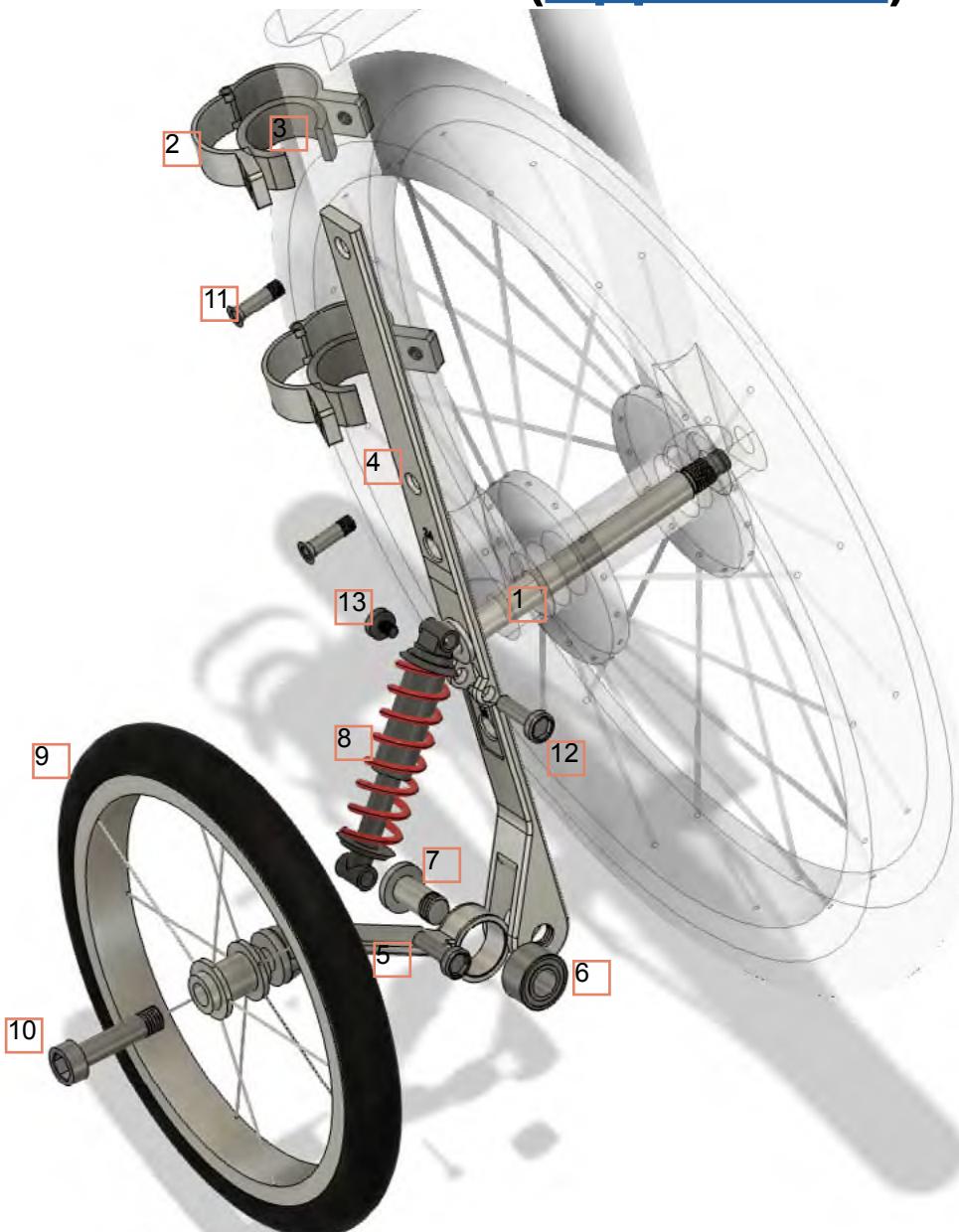
Countersunk bolts reduce wear and enhance aesthetics

Laser engraved labels enhance affordance

1mm fillet to improve metal flow during die casting

Additional supports increase torsional stiffness and guarantee user safety

E3: Manufacture Details ([Appendix II](#))

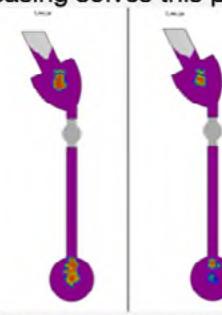


Part No.	Description	Length(mm)	Width(mm)	Thickness(mm)	Quantity	Cost (rmb)
1	Front Axle	170	ø15	ø15	1	50
2	Fork Clamp	20	ø45	3	4	20
3	Adjustment Sleeve	20	ø45(OD)	ø35(ID)	4	2
4	Fixing Plate	415	30	7	2	30
5	Suspension Linkage	120	28	4	2	30
6	Double Row Bearing	16	ø28(OD)	ø14(ID)	2	50
7	Pivot Bolt	32	ø24(OD)	ø14(ID)	2	10
8	Custom Coil Shock	120	ø30(OD)	ø18(Hole)	2	100
9	Assist Wheel	ø254	ø254	35	2	200
10	Assist Wheel Bolt	41 (6 cap, 15 thread)	ø16(OD)	ø12(ID)	2	1
11	M8 Countersink Bolt	30 (3 cap, full thread)	ø12(OD)	ø8(ID)	4	1
12	M8 Carriage Bolt	33 (3 cap, 10 internal thread)	ø15(OD)	ø8(ID)	4	1
13	M8 Carriage Screw	13	ø15(OD)	ø8(ID)	4	1
Total:					992 rmb ≈ 180 SGD	

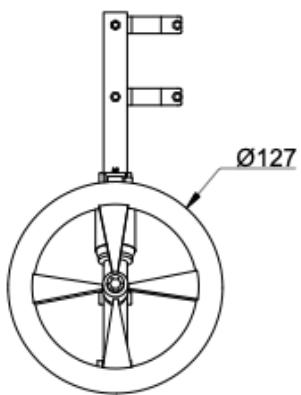
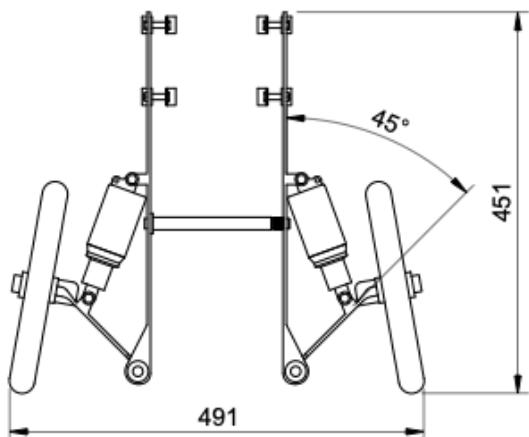
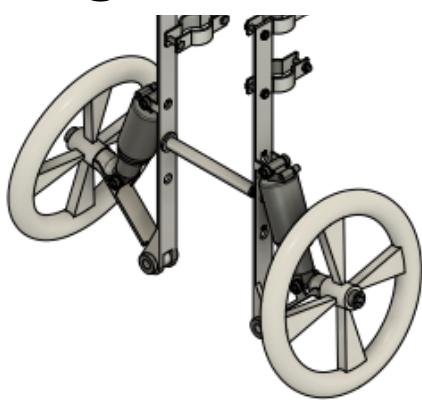
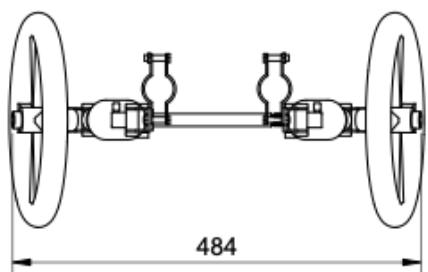
F1: Material + Component Selection

Mechanical Characteristic	Aesthetic Characteristic	Environmental Considerations	Moral Considerations
Component	Image	Material	Justification
Front Axle		7075 Billet Aluminum	<p>Mechanical: High tensile strength(510 MPa)ensures impact resistance; good machinability for precise tolerances.</p> <p>Environmental: Aluminum is fully recyclable, reducing material waste.</p>
Fork Clamp		6061 T6 Aluminum Block (3mm)	<p>Mechanical:(310 MPa): Good ductility prevents cracking during clamping, ensuring repeated use.</p> <p>Aesthetic: Anodized finish provides a corrosion-resistant surface.</p>
Adjustment Sleeve		Thermoplastic Elastomer	<p>Mechanical: High flexibility allows for easy snap fit, preventing vibration-related wear. Relatively soft to prevent damage to bike forks by metal.</p> <p>Environmental: Nylon can be recycled into new plastic products, reducing waste.</p>
Fixing Plate		ADC12 Die-Cast Aluminum	<p>Mechanical: Good fluidity in casting ensures consistent mold filling; high impact resistance (315MPA) reduces failure risk.</p>
Suspension Linkage			<p>Environmental: Die casting minimizes material waste compared to billet machining.</p>
Double Row Bearing		52100 Bearing Steel	<p>Mechanical: High hardness ensures wear resistance, extending service life.</p> <p>Environmental: Steel is widely recycled, reducing environmental impact.</p>
Custom Coil Shock		Anodized Stainless Steel	<p>Mechanical: Corrosion-resistant and wear-resistant, critical for long-term outdoor use.</p> <p>Aesthetic: Anodized surface provides a high-quality, durable finish.</p>
Assist Wheel		Butyl Rubber (Tire) + Aluminum Alloy (Frame & Spokes)	<p>Mechanical: Butyl rubber provides shock absorption and traction. Aluminum frame has high stiffness-to-weight ratio.</p> <p>Environmental: Aluminum frame is reuseable, reducing overall waste.</p>
Assist Wheel Bolt		Grade 12.9 Carbon Steel	<p>Mechanical: Extremely high tensile strength(1200MPA) prevents shear failure; essential for suspension pivots and wheel mounts</p>
Pivot Bolt			<p>Moral: Secure fastening prevents dangerous component failures during riding.</p>
M8 Countersink Bolt		Grade 10.9 Steel	<p>Mechanical: High strength (1040Mpa) and high hardness prevents thread stripping and loosening under stress.</p>
M8 Carriage Bolt			<p>Environmental: Steel is widely recyclable, reducing material waste.</p> <p>Moral: Secure mounting prevents failures in high-vibration environments.</p>
M8 Carriage Screw			

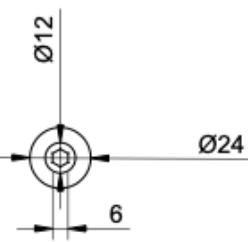
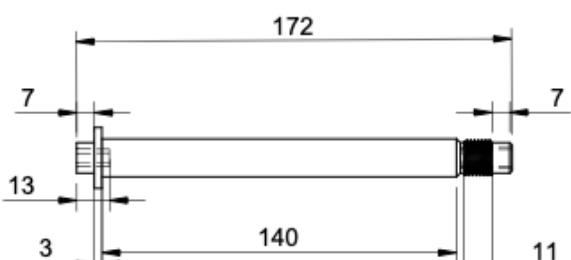
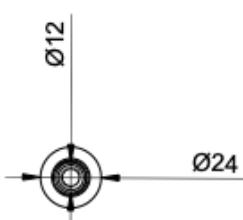
F2: Manufacturing Techniques

Part Name	Manufacturing	Finishing	Justification
Front Axle	CNC turning	Anodization - Corrosion Resistance	<p>Precision: CNC turning ensures tight tolerances critical for bearing fitment and alignment.</p> <p>Strength: 7075 aluminum retains its full mechanical properties since there is no heat-affected zone from casting.</p> <p>Corrosion Resistance: Anodization enhances surface hardness and prevents oxidation in outdoor conditions.</p>
Fixing Plate	Vacuum Assisted High Pressure Die Casting (HPDC)	CNC Lathe(for pivot hole)	<p>Strength: Die casting creates components in one piece, eliminating post-welding processes and heat-induced distortion</p> <p>Material Flow: large component takes time to fill, causing trapped air bubbles. Vacuum assisted casting will remove these bubbles.</p>  <p>Air bubbles concentrated at flatter sections</p> <p>Dimensional Accuracy: CNC machining refines critical features like the pivot bore, which requires precise tolerance control, not achievable by die casting alone.</p>
Suspension Linkage	High Pressure Die Casting(HPDC) with cast-in-place bearings	CNC Lathe (for threads)	<p>Affordability: Die will reduce material waste by ~30% and cut production costs by ~80% at high volumes compared to CNC production</p> <p>Material Flow: there can be high shrinkage porosity and uneven cooling with normal die casting. High pressure die casting solves this problem.</p>  <p>(Shrinkage porosity gravitational die casting vs HPDC)</p> <p>Dimensional Accuracy: undercuts like the shock mount require complex molds that have low accuracy. Cast in bearings solve this issue.</p>
Adjustment Sleeve	Extrusion	None	<p>Material Efficiency: Extrusion produces long sections of precise profiles with minimal material waste.</p> <p>Manufacturing Simplicity: No secondary machining is required, reducing production time and cost.</p>

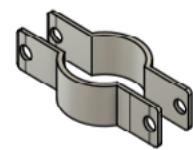
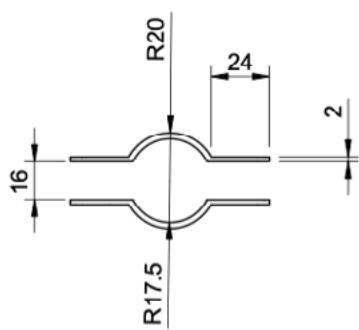
Appendix I: Technical Drawings



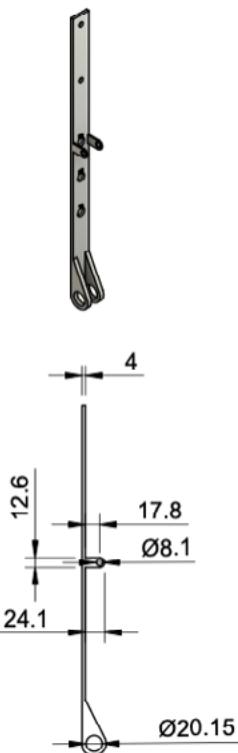
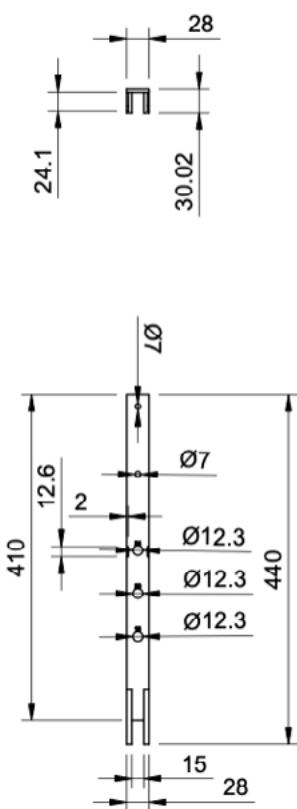
	Component Name: Assembly	Materials: Metal, ABS, Rubber	Scale: 1:9
Part No. 0	Quantity: 1	Unit: mm	



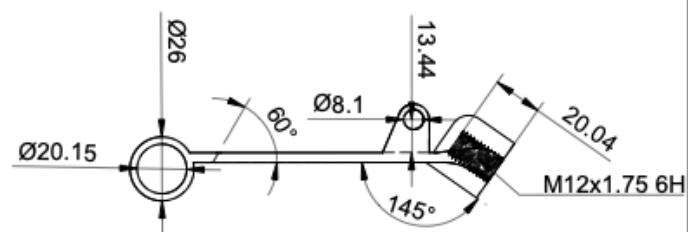
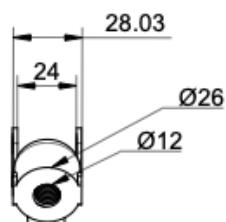
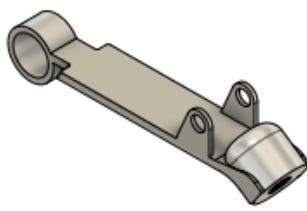
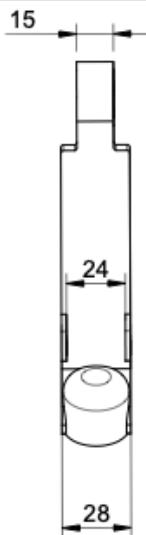
	Component Name: Front Axle	Materials: 7075 Aluminum	Scale: 1:3
Part No. 1	Quantity: 1	Unit: mm	



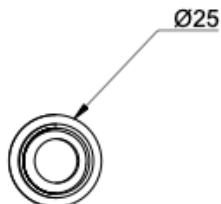
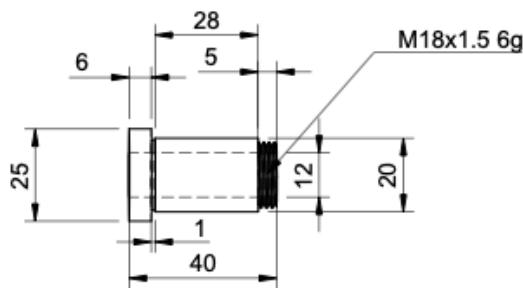
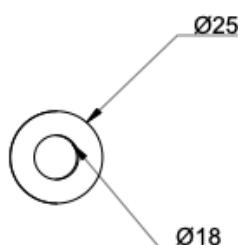
	Component Name: Front Axle	Materials: 6061 Aluminum, Silicone rubber	Scale: 1:3
	Part No. 2	Quantity: 4	Unit: mm



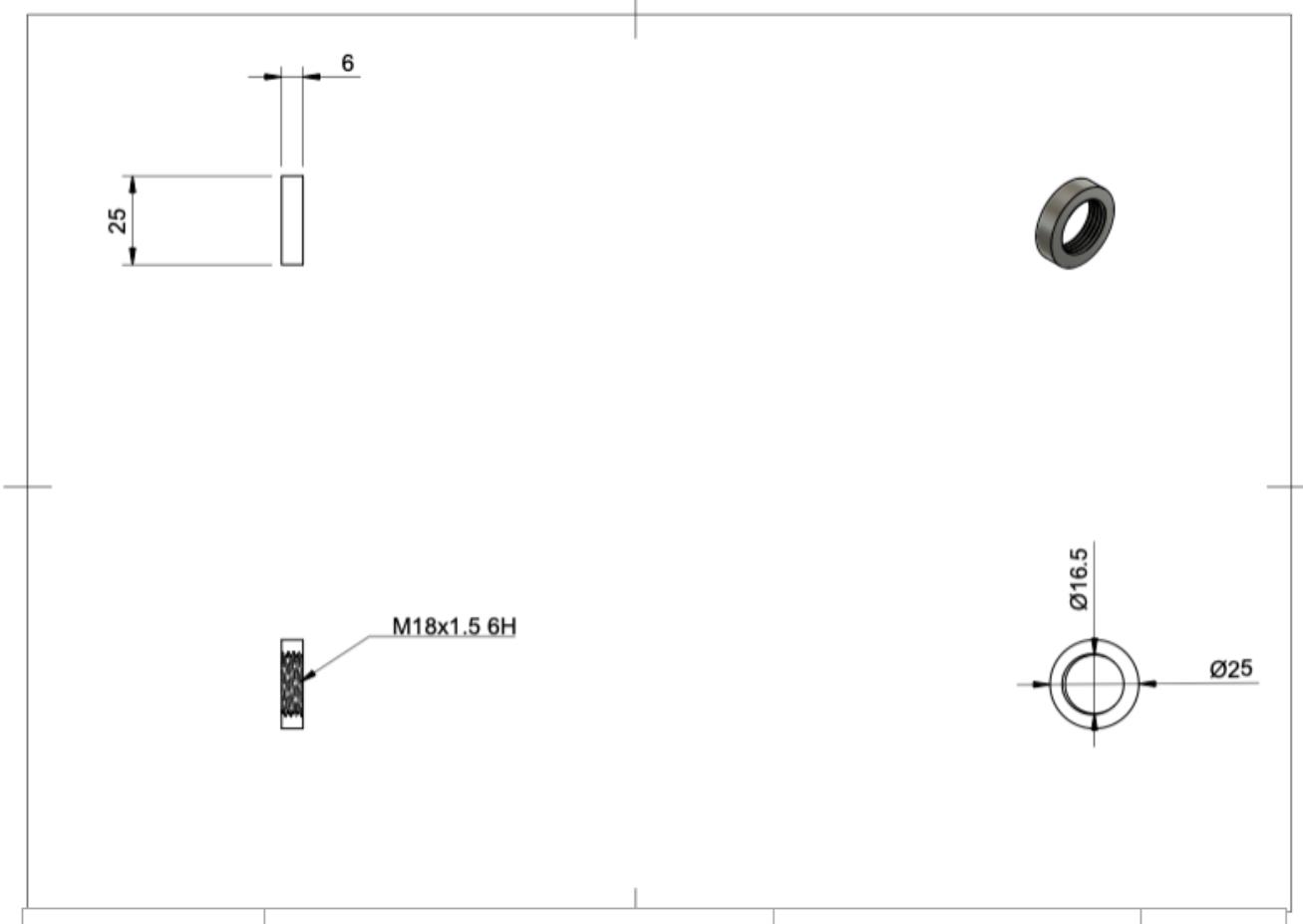
	Component Name: Front Axle	Materials: 7075 Aluminum	Scale: 1:9
	Part No. 3	Quantity: 2	Unit: mm



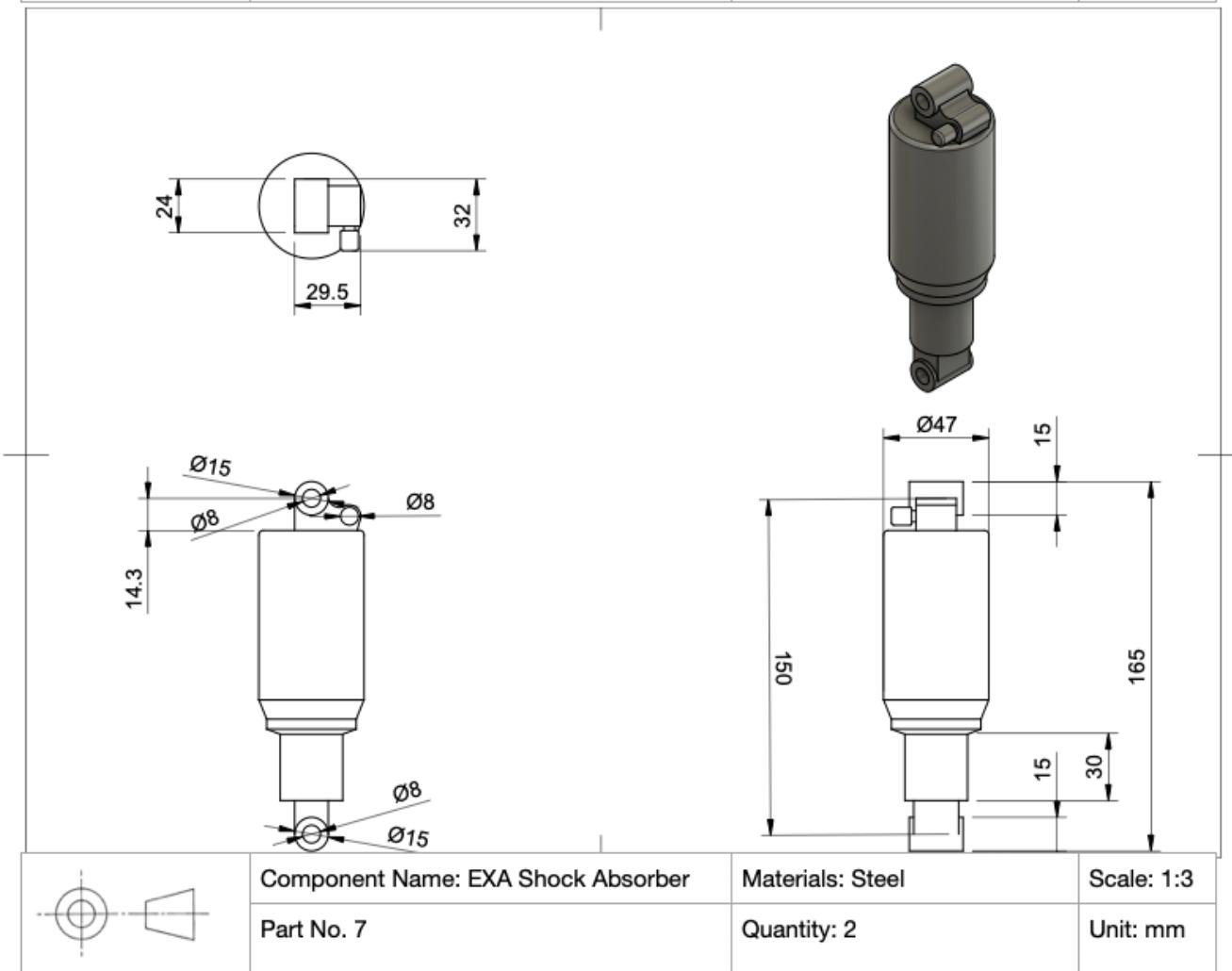
	Component Name: Suspension Linkage Part No. 4	Materials: 7075 Aluminum Quantity: 2	Scale: 1:3 Unit: mm
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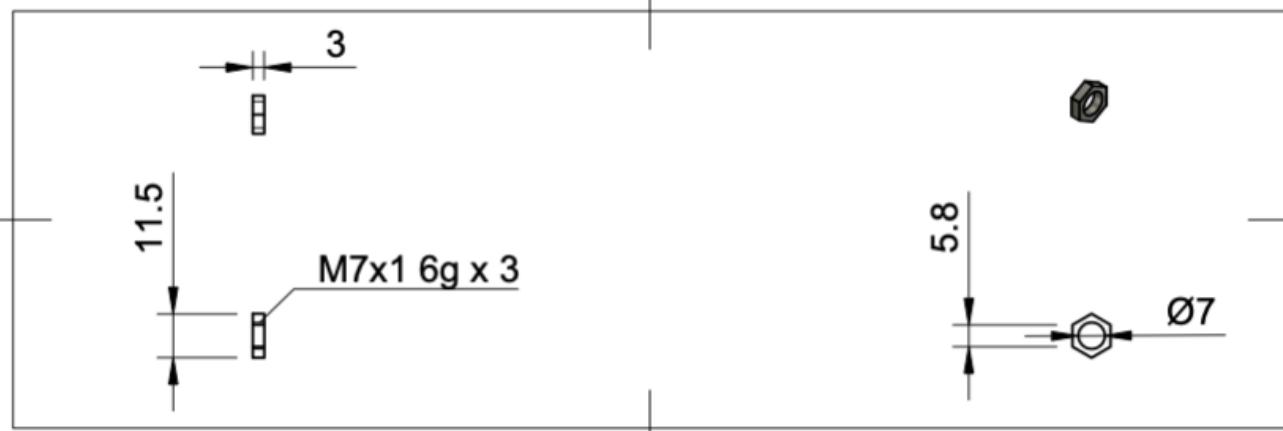
	Component Name: Pivot Bushing Part No. 5	Materials: Steel Quantity: 2	Scale: 1:2 Unit: mm
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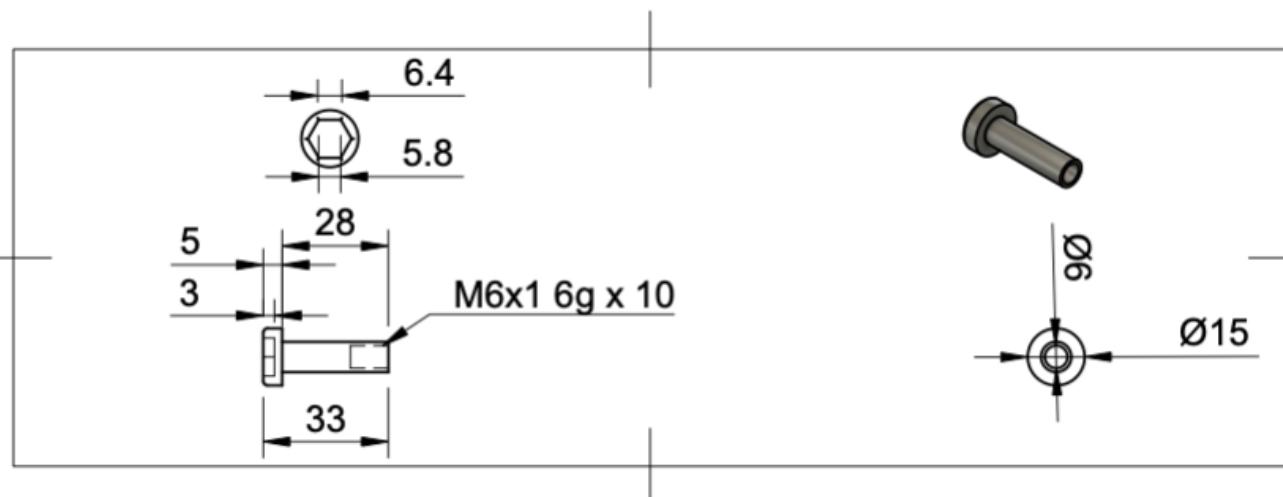
	Component Name: Pivot Bushing Cap	Materials: Steel	Scale: 1:2
	Part No. 6	Quantity: 2	Unit: mm



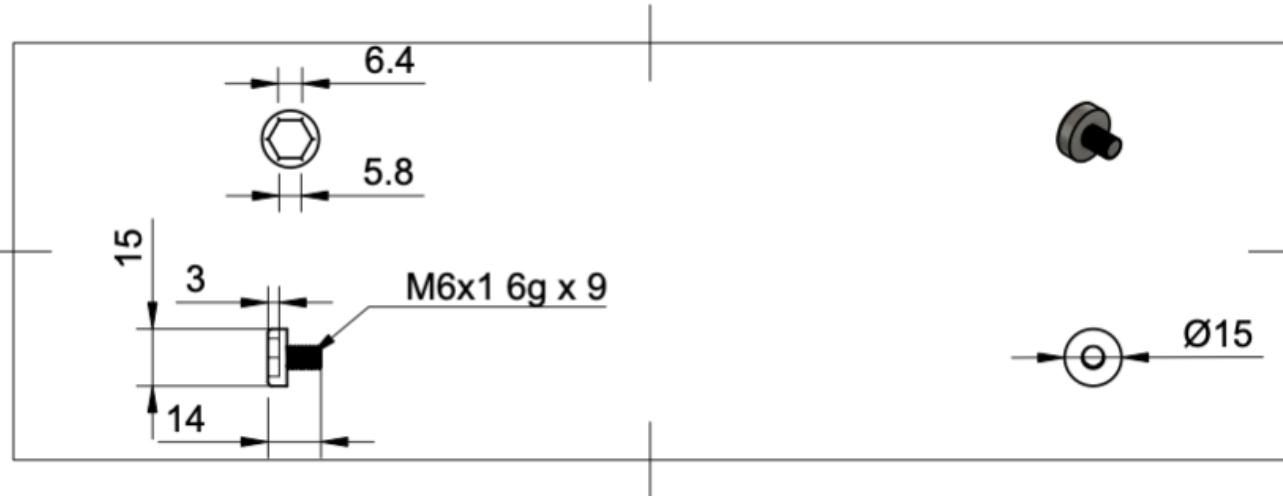
	Component Name: EXA Shock Absorber	Materials: Steel	Scale: 1:3
	Part No. 7	Quantity: 2	Unit: mm



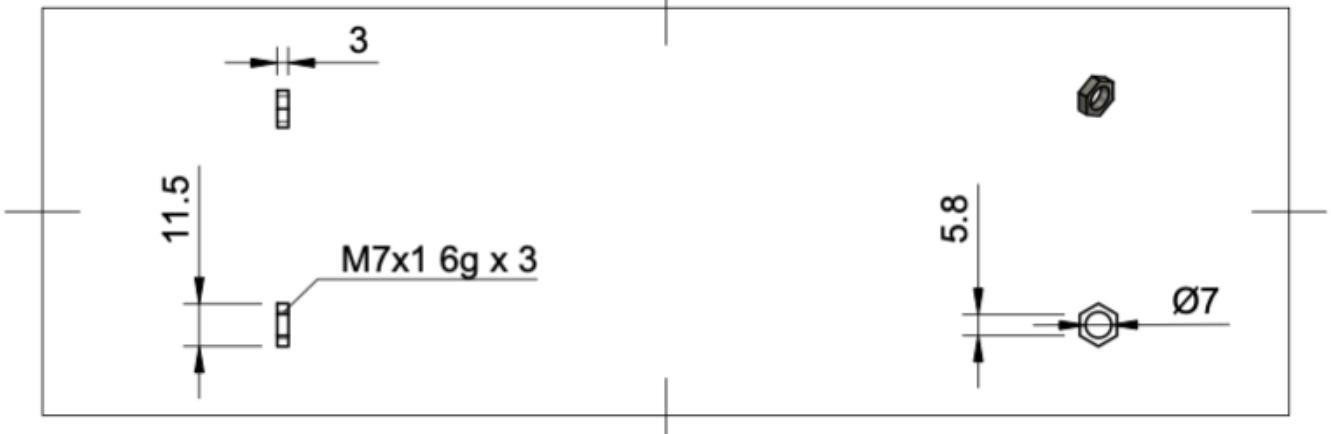
	Component Name: M7 Hex Nut Part No. 11	Materials: Steel	Scale: 1:2
		Quantity: 8	Unit: mm



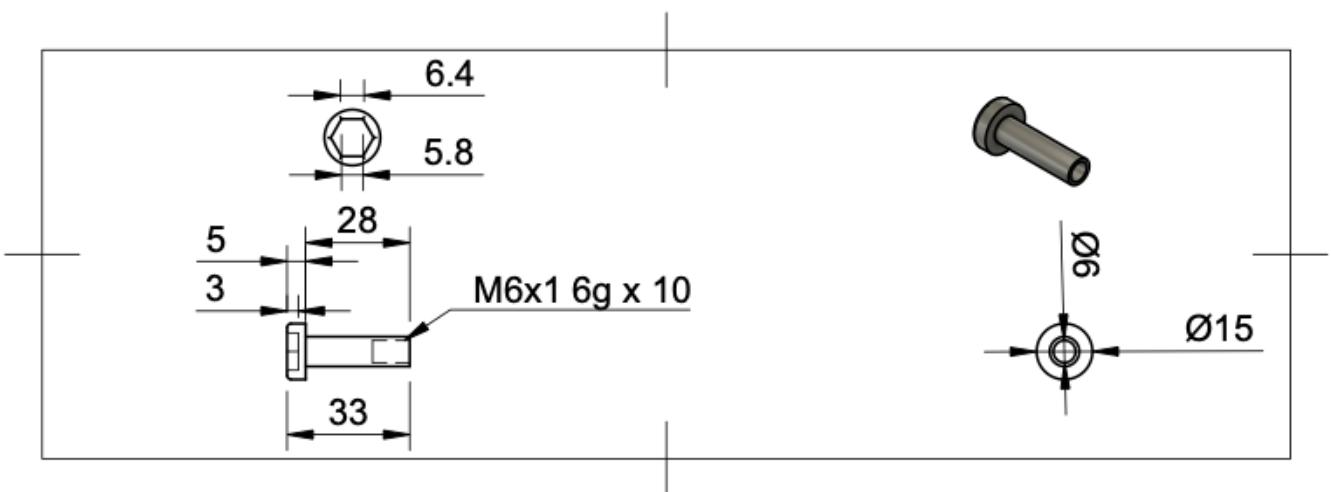
	Component Name: M8 Carriage Bolt Part No. 11	Materials: Steel	Scale: 1:2
		Quantity: 4	Unit: mm



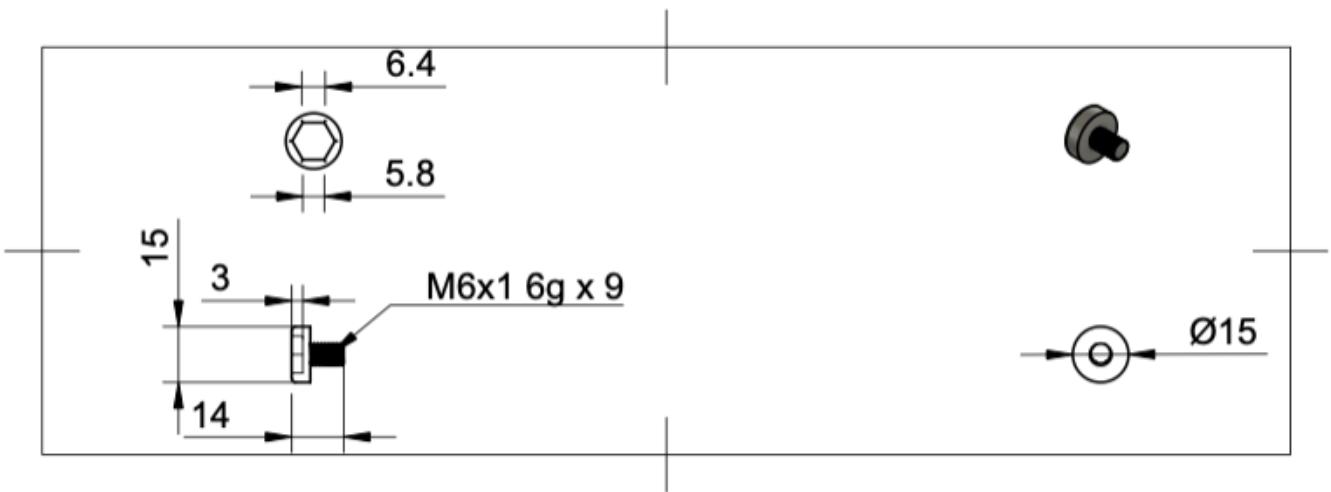
	Component Name: M8 Carriage Screw Part No. 11	Materials: Steel	Scale: 1:2
		Quantity: 4	Unit: mm



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

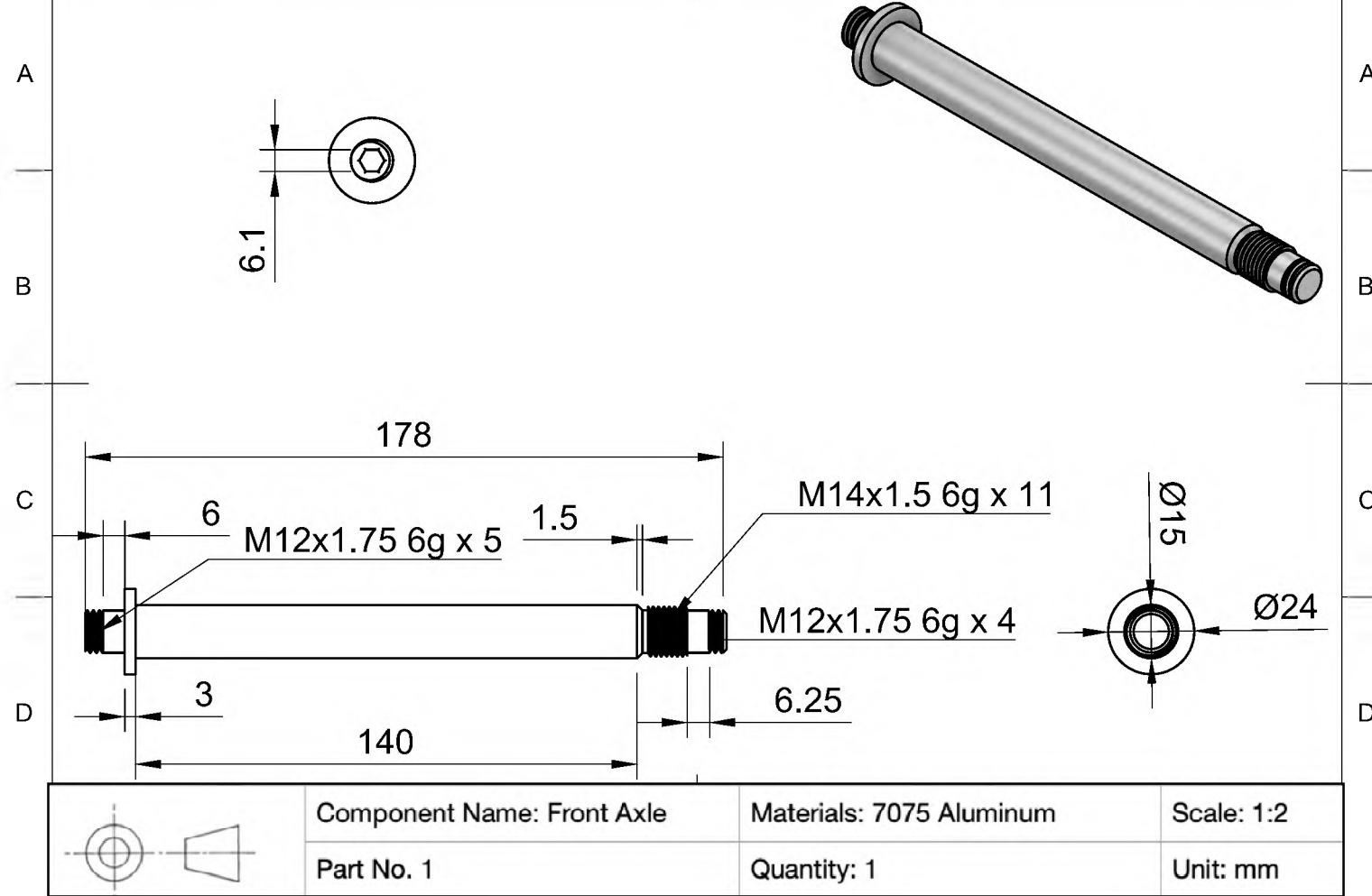
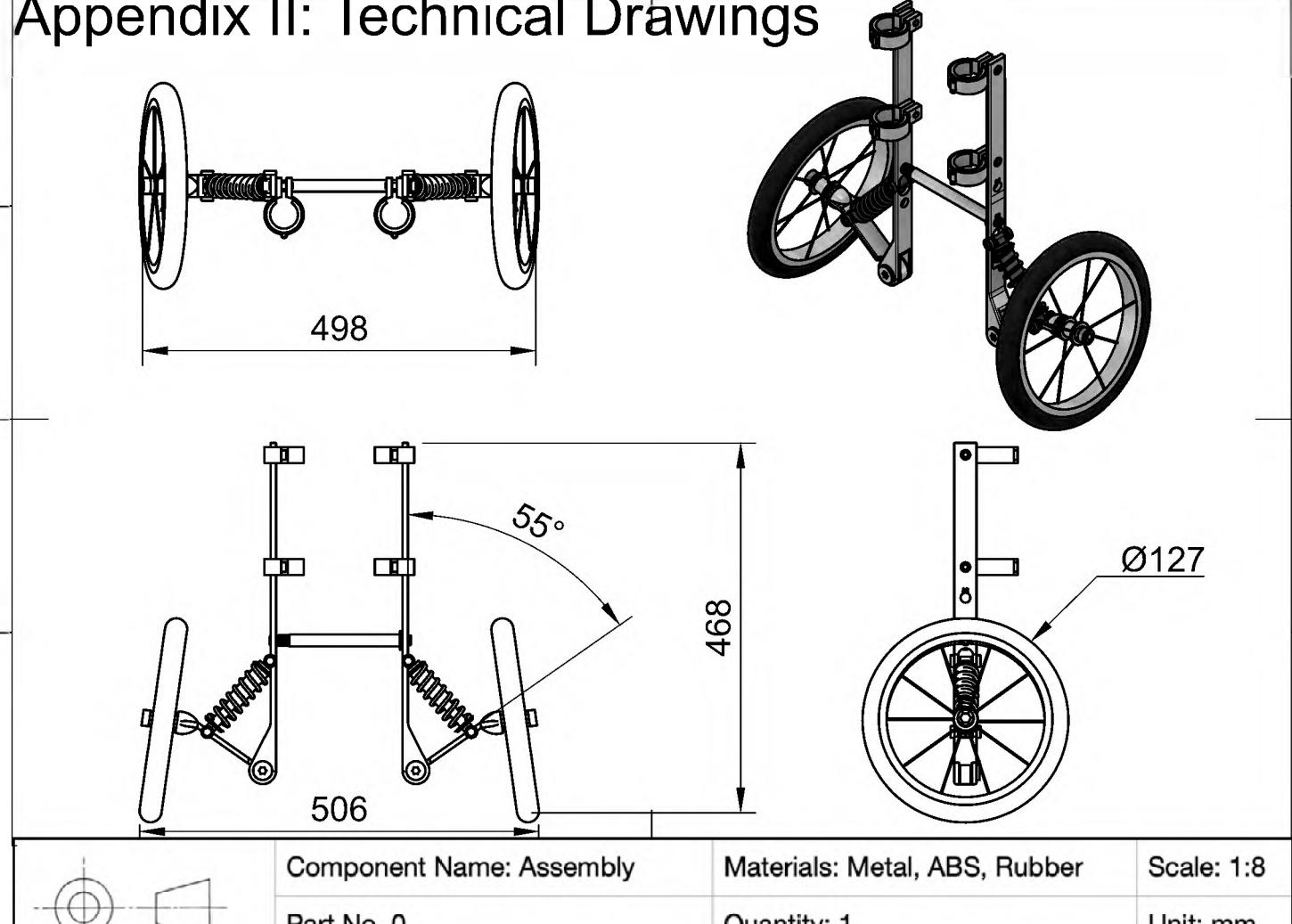


	Component Name: M8 Carriage Bolt Part No. 11	Materials: Steel	Scale: 1:2
		Quantity: 4	Unit: mm

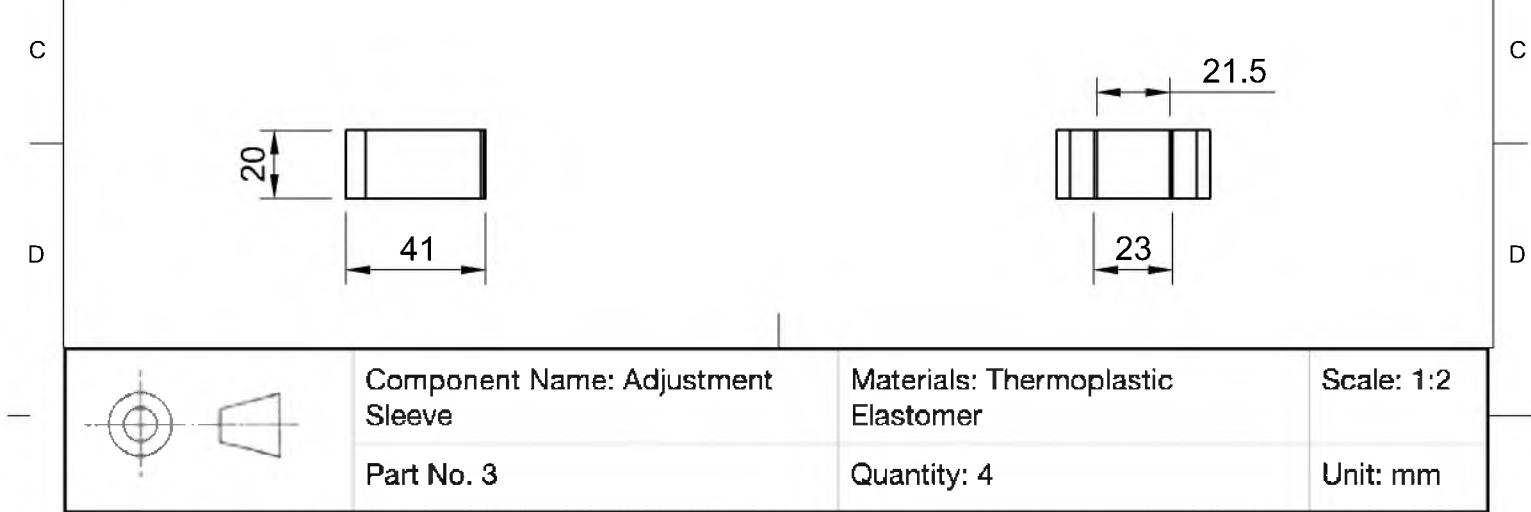
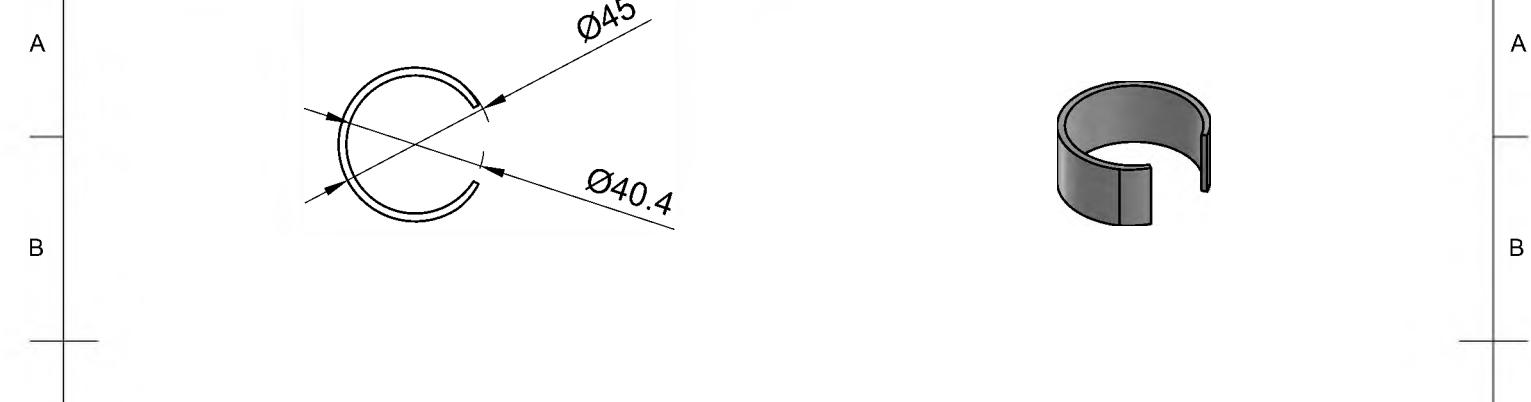
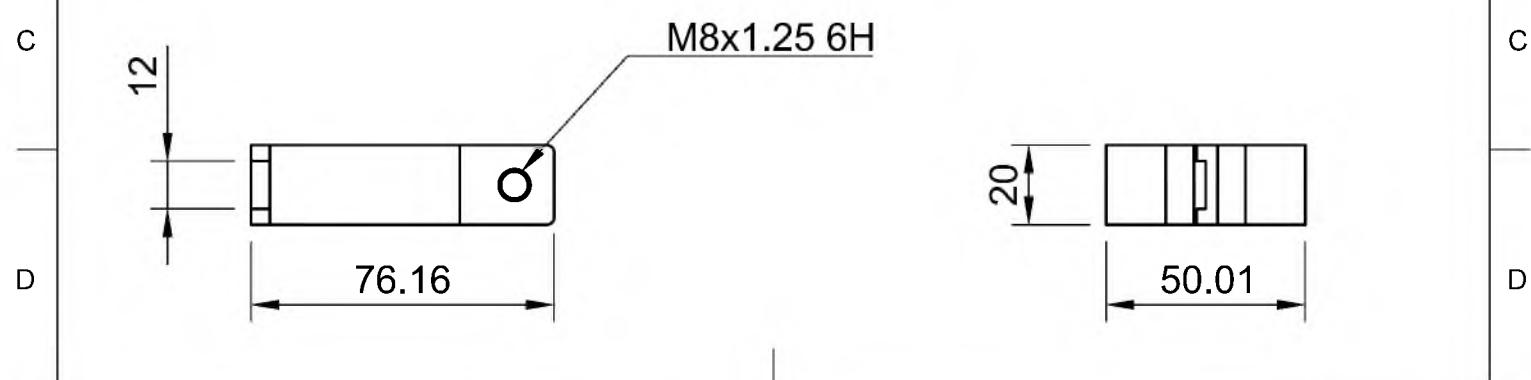
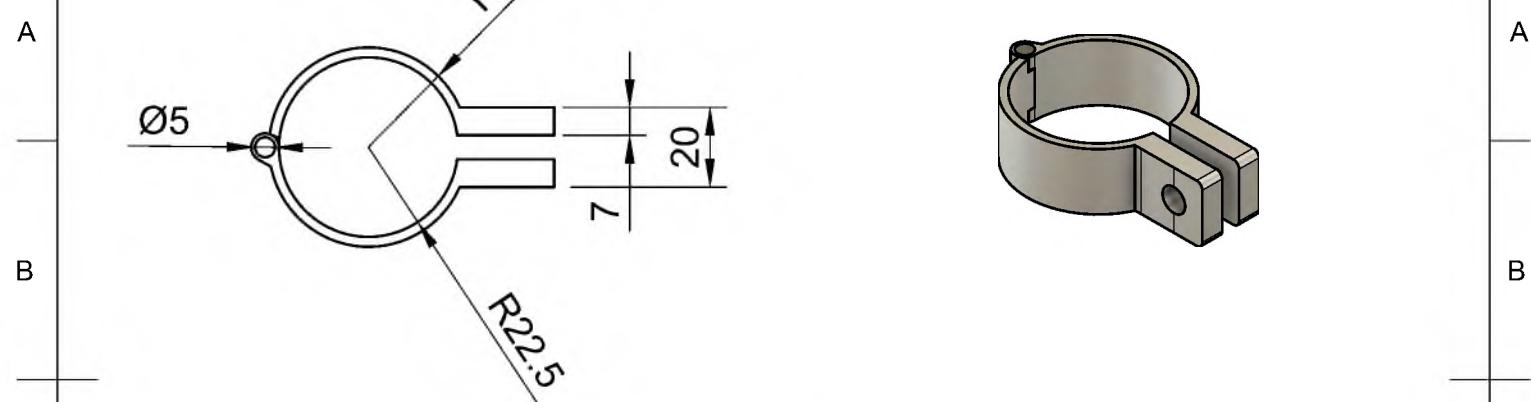


	Component Name: M8 Carriage Screw Part No. 11	Materials: Steel	Scale: 1:2
		Quantity: 4	Unit: mm

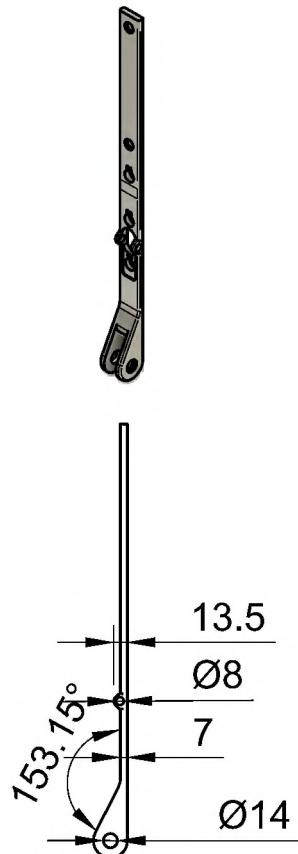
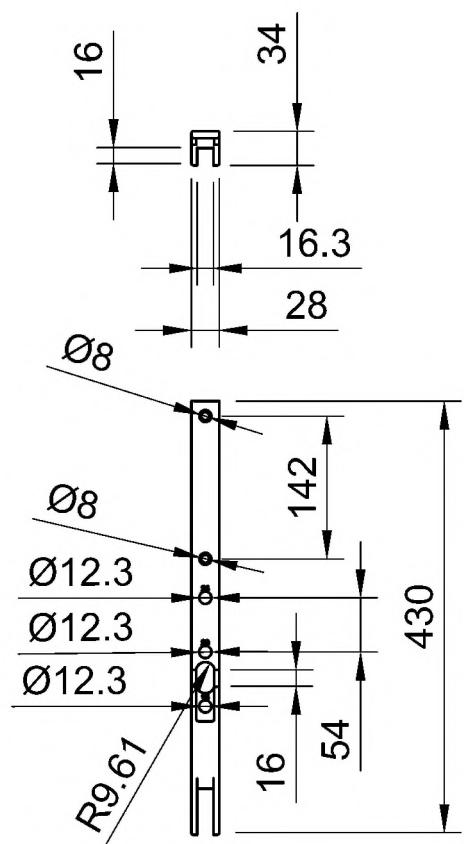
Appendix II: Technical Drawings



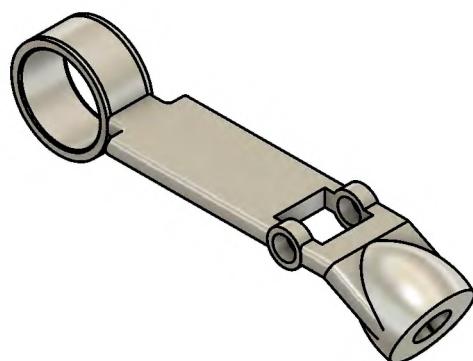
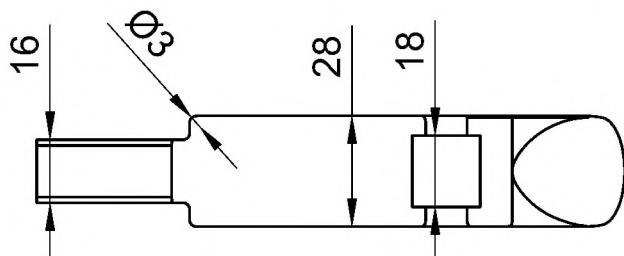
1 2 3 4



1 | 2 | 3 | 4



	Component Name: Fixing Plate	Materials: Aluminum(ADC 12)	Scale: 1:8
	Part No. 4	Quantity: 2	Unit: mm



	Component Name: Suspension Linkage	Materials: Aluminum(ADC 12)	Scale: 1:2
	Part No. 5	Quantity: 2	Unit: mm

1 2 3 4

A

B

C

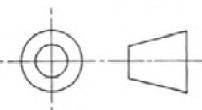
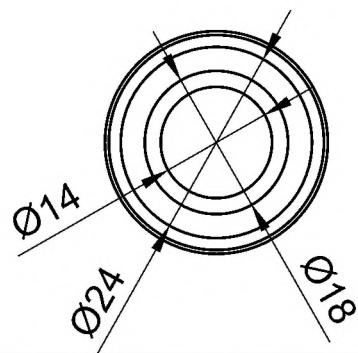
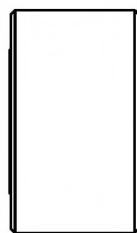
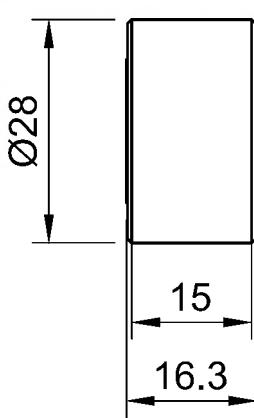
D

A

B

C

D



Component Name: Double Row Bearing

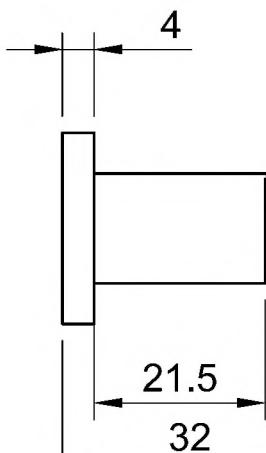
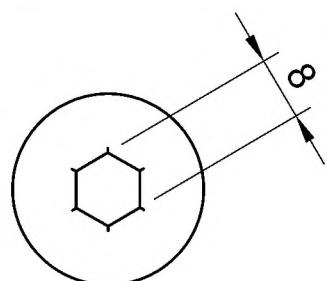
Materials: Steel(52100)

Scale: 1:1

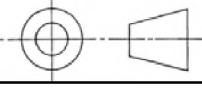
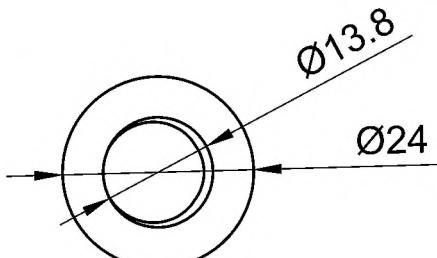
Part No. 6

Quantity: 2

Unit: mm



M14x2 6g x 6.5



Component Name: Pivot Bolt

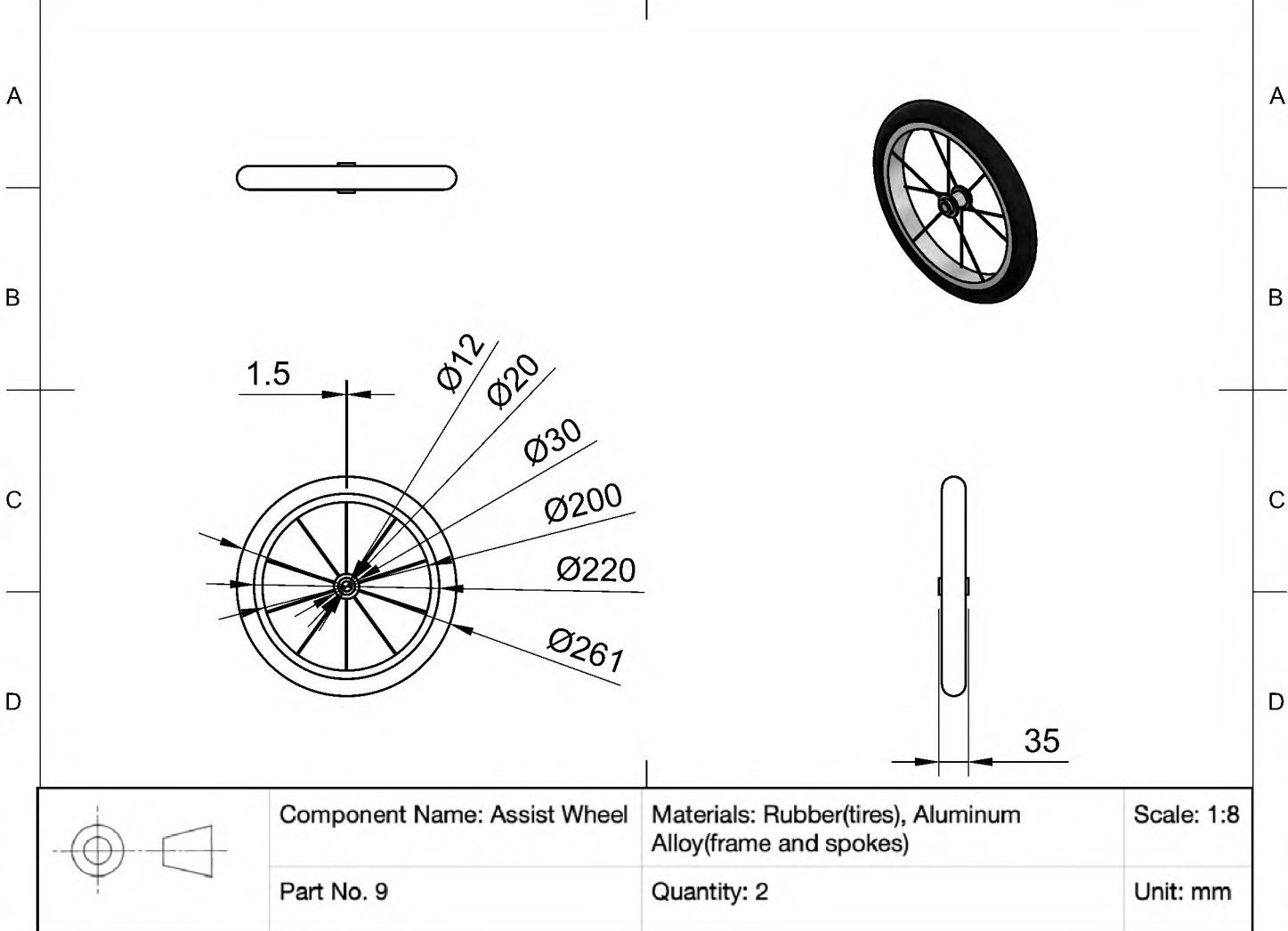
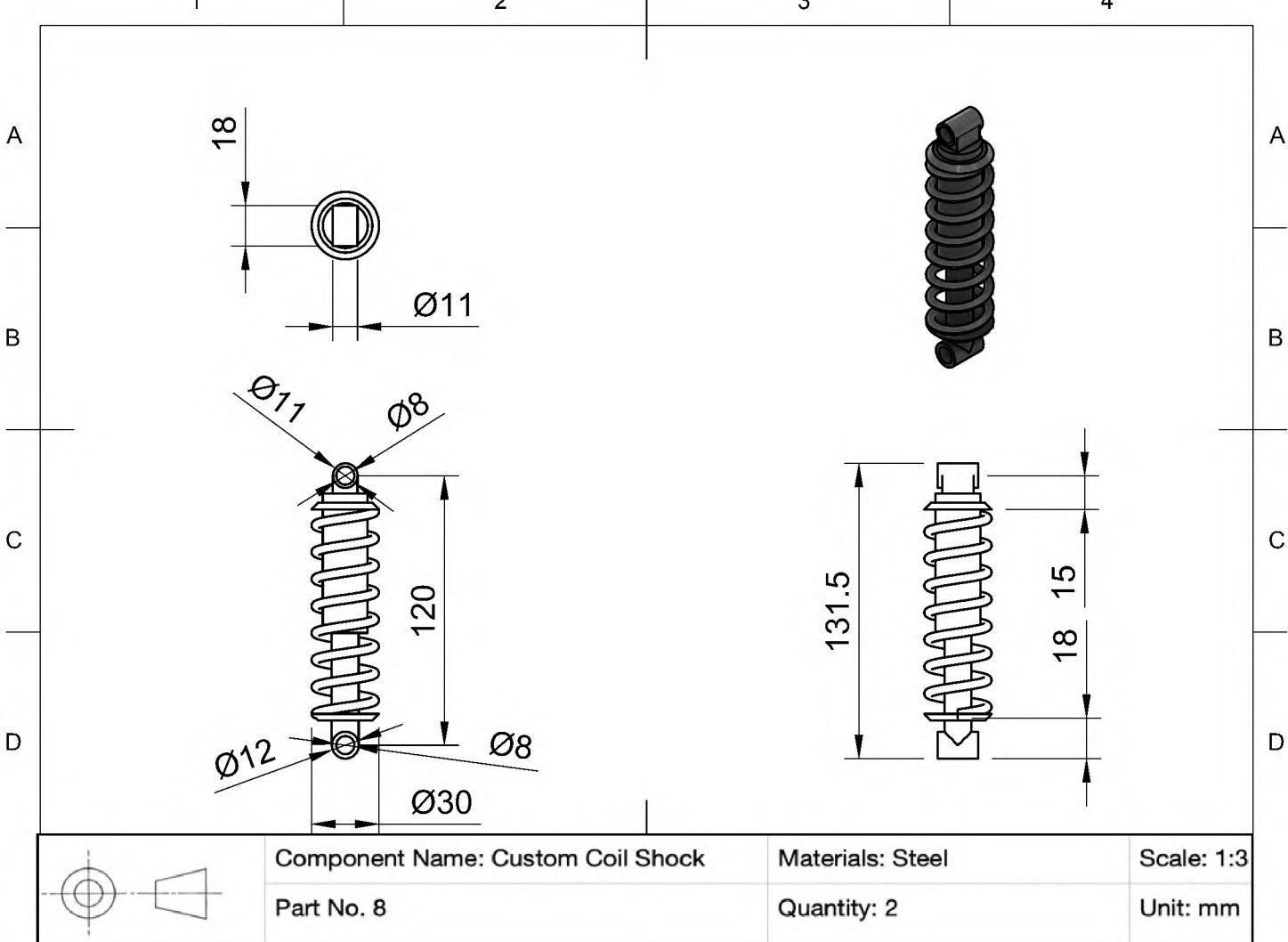
Materials: Steel (Grade 12.9)

Scale: 1:2

Part No. 7

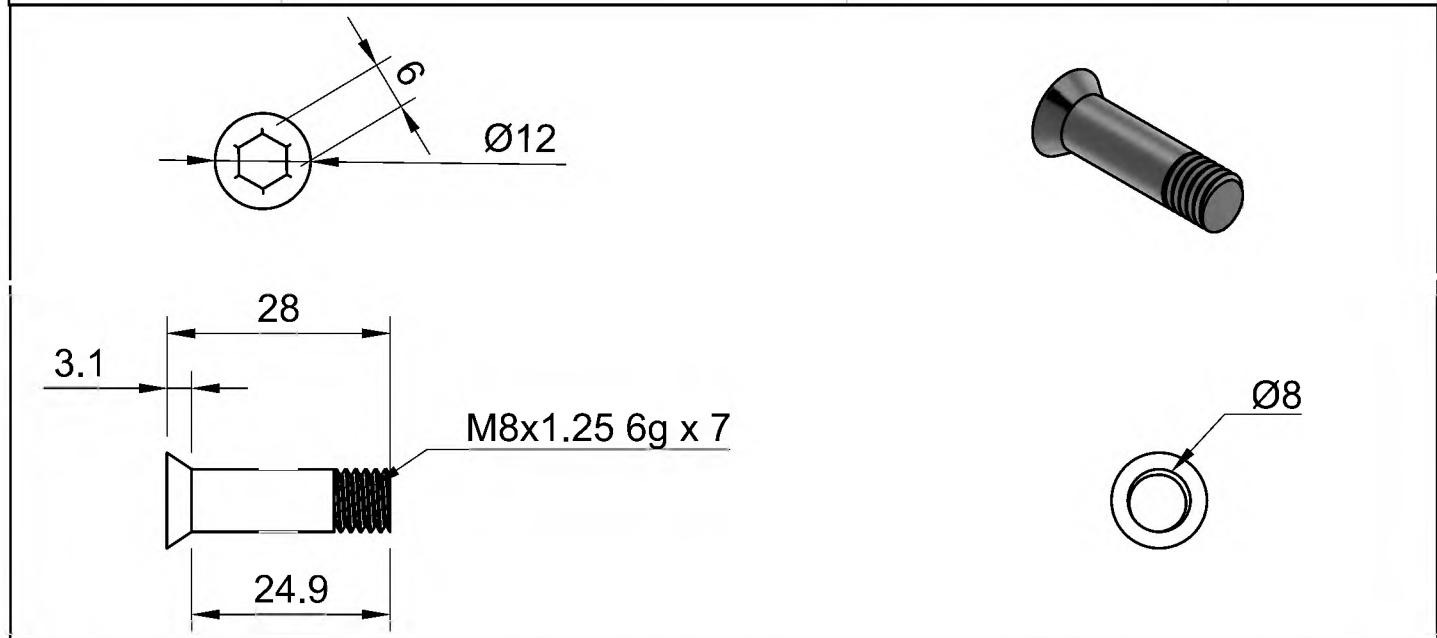
Quantity: 2

Unit: mm

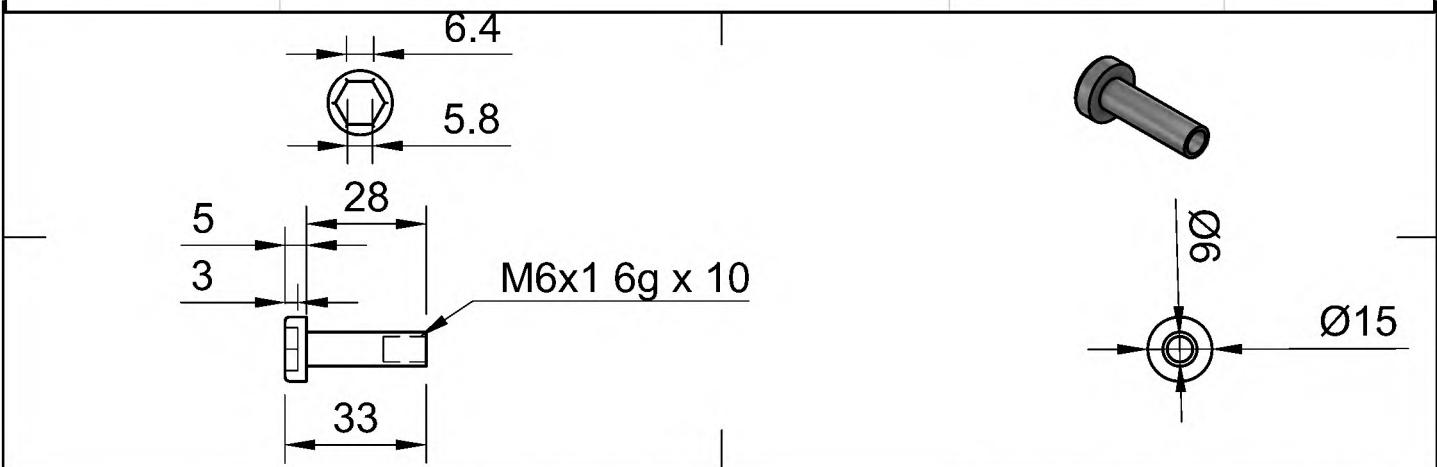




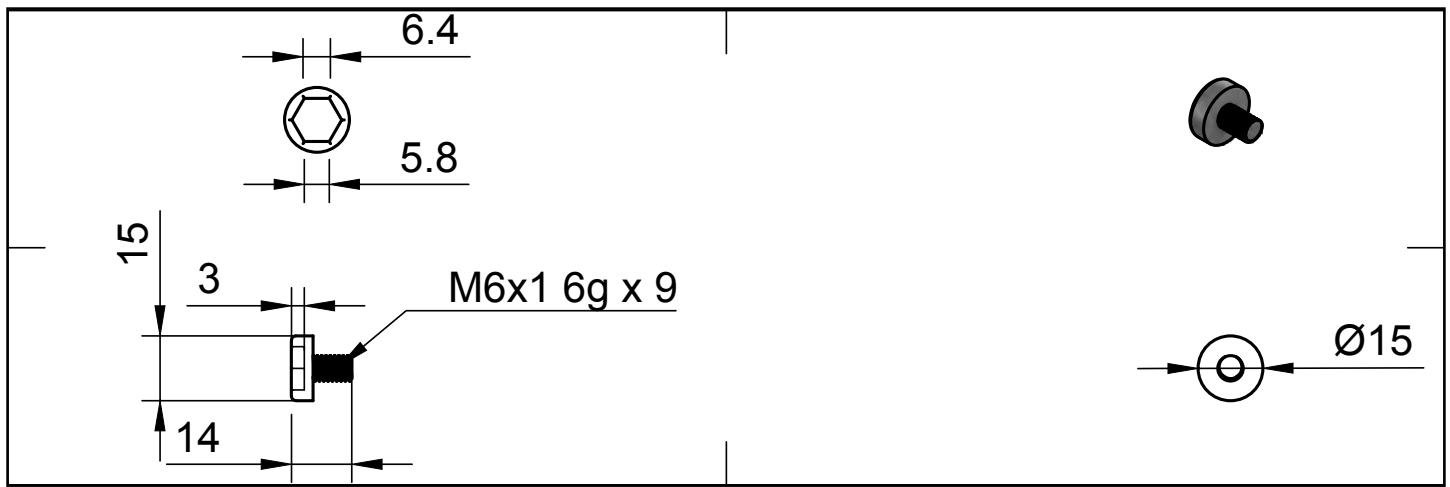
	Component Name: Assist Wheel Bolt	Materials: Steel(Grade 12.9)	Scale: 1:2
	Part No. 10	Quantity: 2	Unit: mm



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



	Component Name: M8 Carriage Bolt	Materials: Steel	Scale: 1:1
	Part No. 12	Quantity: 4	Unit: mm



References and Further Reading

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