

The Development And Design Of Rear Upright For The Garuda UNY UG-23 Urban Car

Muhammad Tafif Fadhlurrahman ^{a,*}, Febrianto Amri Ristadi ^b

^a*Department of Mechanical and Automotive Engineering, Universitas Negeri Yogyakarta, Indonesia*

^b*Department of Mechanical Engineering Education, Universitas Negeri Yogyakarta, Indonesia*

*Corresponding author: muhammadtafif.2021@student.uny.ac.id

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ABSTRACT

The development and design of the rear upright for the Urban Car Garuda UNY UG-23 was carried out to improve the previous design that was no longer compatible due to changes in the car frame. This study aimed to find strong and lightweight materials for the rear upright, and to analyze the structure to get the best design with better performance and lower weight. The development method used an engineering approach based on Computer Aided Engineering (CAE). The design process started by using software for parametric, solid modelling, and numerical analysis with the Finite Element Analysis (FEA) method. FEA was used to measure stress, deformation, and safety factors of the rear upright. The simulation also considered different forces, such as the weight on the upright and the force from the brake calliper. The Ashby Method was used to choose materials based on their properties and the design needs. The analysis results showed that the rear upright made from 7075-T6 aluminum met the strength and efficiency requirements. The analysis showed that the factor of safety was at least 15.62 with a maximum stress of 32.34 MPa. The maximum displacement was 0.08 mm and strain was 0.0 mm. The optimization process reduced the mass from 553.64 grams to 322.73 grams. In the best condition (wheel system), the weight was reduced by 41.7% or about 231.64 grams without significantly reducing the strength.

1 Introduction

Energy-efficient vehicle development requires the integration of lightweight structures, stable chassis systems, reliable braking, and aerodynamic design. In student vehicle competitions such as the Shell Eco-Marathon and Kontes Mobil Hemat Energi (KMHE), reducing vehicle mass is one of the most important strategies for improving fuel efficiency because lower mass reduces the energy required for acceleration and braking [1], [2], [3]. The Garuda UNY Team has developed several types of vehicles, including urban concept vehicles, prototypes, and formula student cars; therefore, continuous component improvement is needed to maintain performance and compatibility with updated vehicle architecture [2].

One of the critical components in the wheel system is the rear upright. The upright supports the wheel bearing, transfers forces from the wheel to the chassis, and provides a mounting point for the brake caliper. In the Garuda UNY UG-23 Urban Car, the previous rear upright design was no longer compatible because the frame construction and ground clearance had changed. The component must therefore be redesigned so that it remains compact, lightweight, manufacturable, and safe under maximum braking conditions.

Computer-Aided Engineering (CAE) and Finite Element Analysis (FEA) are widely used in mechanical component development because they allow the stress, displacement, and safety factor of a structure to be estimated before manufacturing. Previous studies on suspension and upright components show that FEA combined with topology optimization can reduce mass while maintaining structural strength [4], [5], [6], [7]. In addition, material selection must be integrated with structural analysis because strength-to-density ratio, availability, and manufacturability strongly influence the final design [8], [9], [10], [11].

This study focuses on developing a new rear upright design for the Garuda UNY Team UG-23 Urban Car. The novelty of this work lies in combining Ashby-based material selection, maximum-braking load calculation, FEA validation, and topology optimization for a rear upright that is specifically adapted to the UG-23 vehicle geometry and component interfaces. The objective is to obtain a rear upright design that is lighter than the initial model while still satisfying the target minimum factor of safety under maximum braking load.

2 Method

This study used a mechanical design and numerical simulation approach. The design procedure followed a systematic mechanical design process consisting of recognition of need, definition of problem, synthesis, analysis and optimization, evaluation, and presentation [6]. The component was modeled using SolidWorks 2024 Student Edition, and the structural performance was evaluated using static FEA under maximum braking load.

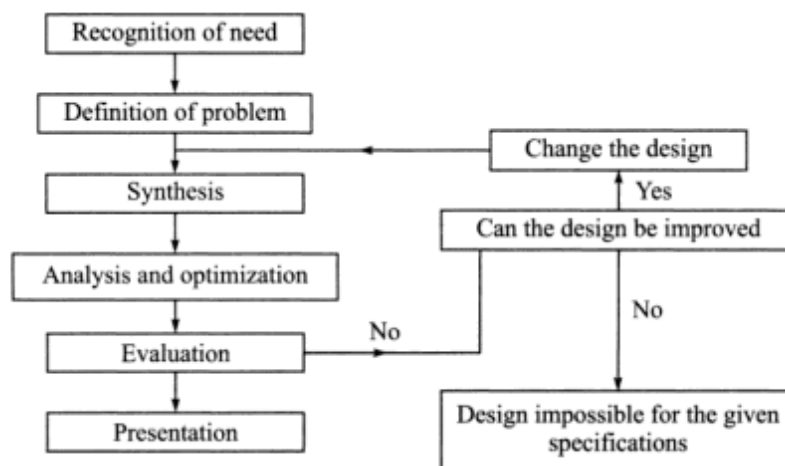


Figure 1. Design process flowchart.

2.1 Design requirements and braking load calculation

The design requirements were established based on the geometry of the Garuda UNY UG-23 Urban Car, the selected brake caliper, the wheel bearing, and the expected braking load. The rear upright was required to have a compact shape, a 25 mm mounting width at the chassis interface, two M10 chassis mounting holes with a spacing of 98 mm, two M8 caliper mounting holes with a spacing of 83.5 mm, and a bearing housing for an SKF 6002 bearing with an outer diameter of 32 mm and width of 9 mm. The component was also required to support the brake caliper and withstand a braking force of 163.96 N.

The main equations used for the preliminary braking calculation are expressed as follows:

$$F = m \cdot a \quad (1)$$

$$N = W = m \cdot g \tag{2}$$

where F is force, m is mass, a is deceleration, N is normal force, W is weight, and g is gravitational acceleration. Additional calculations were used to estimate longitudinal weight transfer, rear wheel load, vertical wheel load, longitudinal brake force, and force components at the bearing housing and caliper bracket [12], [13].

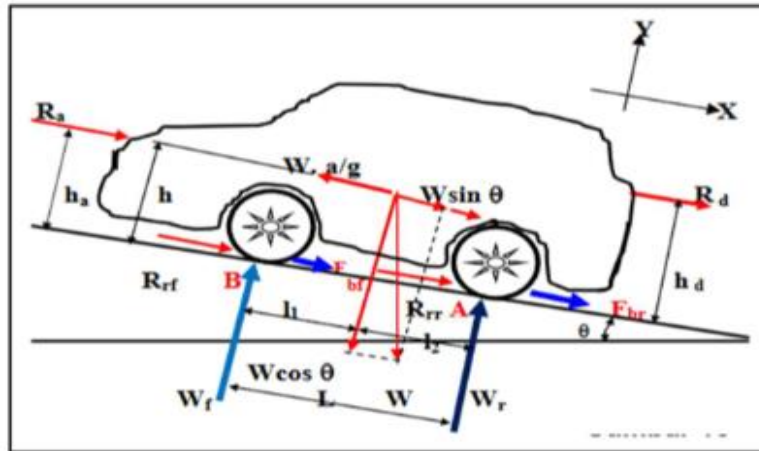


Figure 2. Braking calculation diagram.

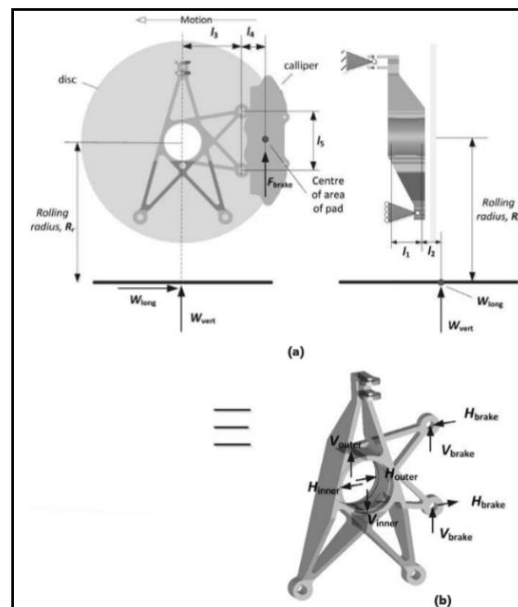


Figure 3. Load direction on the rear upright under maximum braking.

Table 1. Main brake and vehicle parameters for the Garuda UNY UG-23 Urban Car.

Parameter	Symbol	Value	Unit
Vehicle mass	m_vehicle	90	kg
Driver mass	m_driver	70	kg
Vehicle and driver weight	W	1600	N
Wheelbase	L	1.4	m
Distance from front axle to center of gravity	a_f	0.71	m
Distance from rear axle to center of gravity	a_r	0.68	m
Center of gravity height	H	0.42	m
Tire-road adhesion coefficient	mu	0.75	-
Brake pad-disc friction coefficient	mu_b	0.50	-
Rolling resistance coefficient	f_r	0.013	-
Wheel radius	r_w	0.2392	m
Distance from axle to brake pad	r_b	0.09	m

Parameter	Symbol	Value	Unit
Master cylinder area	A_m	0.000198	m ²
Two-piston caliper area	A_c	0.000907	m ²
Pedal ratio	i_p	1.44	-
Initial braking speed	v	13.8	m/s
Aerodynamic coefficient	C_d	0.21	-
Brake reaction delay	t_r	0.1	s
Gravity	g	9.81	m/s ²
Cosine of 11.3 degree road slope	cos theta	0.980	-
Sine of 11.3 degree road slope	sin theta	0.195	-

Table 2. Direction and magnitude of the applied forces on the rear upright.

Indicator	Force direction	Magnitude (N)
A	-X	86.06
A	+Y	180.17
B	+X	86.06
B	+Y	180.17
C1	+Y	466.50
C2	+X	349.87
C3	-Y	221.97
C4	-X	181.48

2.2 Material selection

Material selection was conducted using the Ashby method. The functional requirement was to support maximum braking load and vehicle weight. The constraints were a minimum yield strength of 250 MPa, non-flammable behavior, and metallic material type. The objective was to obtain a lightweight and low-cost material available in Indonesia. The free variable was all metallic materials that satisfied these constraints [10].

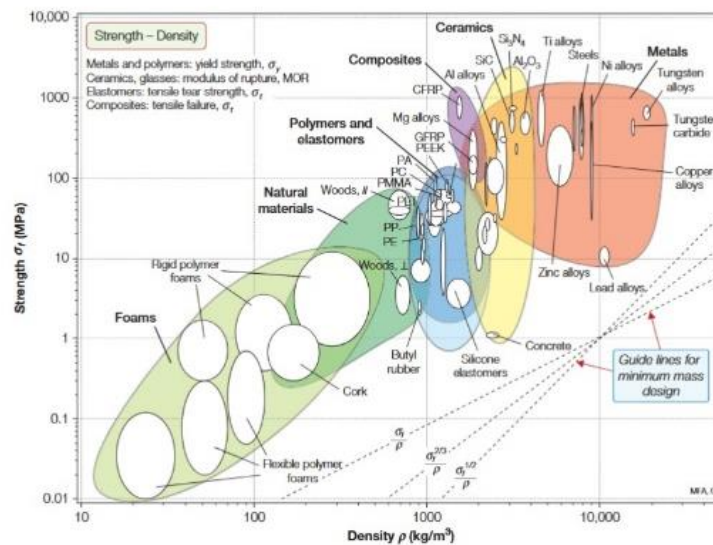


Figure 4. Ashby chart used for preliminary material selection.

Table 3. Material candidates obtained from the Ashby screening process.

Material	Strength (MPa)	Density (kg/m ³)	Typical applications
Aluminium 7075-T6	505	2700	Motor gears, aircraft wing components, automotive parts, wheels
Titanium Ti-6Al-4V	900-1200	4500	Aircraft frames, engine components, turbine blades, missiles
Low-carbon steel	260	7850	Automotive body components and mechanical parts

The selected caliper was a Brembo P2 34 120A44110 with two pistons of 34 mm diameter, CNC aluminium construction, mass of 518 g, and compatibility with DOT 4 brake fluid. The caliper was connected to the rear upright using two ISO 4762 grade 8.8 M8 x 1.25 hex socket head bolts with a length of 25 mm. The bearing used in the design was an SKF 6002 bearing with an outer diameter of 32 mm, inner diameter of 15 mm, and width of 9 mm. The bearing housing was designed to support the wheel shaft and was locked using an internal circlip.



Figure 7. Brembo P2 34 120A44110 caliper.



Figure 8. SKF 6002 bearing used in the rear upright.

3.2 Material selection result

The Ashby-based screening identified Aluminium 7075-T6, Ti-6Al-4V, and low-carbon steel as candidate materials. Aluminium 7075-T6 was selected because it satisfies the minimum yield strength requirement, has the lowest density among the selected candidates, and is relatively available in Indonesia. The material provides a good balance between strength, weight efficiency, and manufacturability for an urban vehicle component.

The SolidWorks engineering database indicated that Aluminium 7075-T6 has a density of approximately 2810 kg/m³, an elastic modulus of 72,000 N/mm², tensile strength of 570 N/mm², yield strength of 505 N/mm², shear modulus of 26,900 N/mm², thermal conductivity of 130 W/(m.K), and thermal expansion coefficient of 2.36×10^{-5} /K. These properties support its application in lightweight automotive components requiring high structural efficiency.

Property	Value	Units
Elastic Modulus	72000	N/mm ²
Poisson's Ratio	0.33	N/A
Shear Modulus	26900	N/mm ²
Mass Density	2810	kg/m ³
Tensile Strength	570	N/mm ²
Compressive Strength		N/mm ²
Yield Strength	505	N/mm ²
Thermal Expansion Coefficient	2.36e-05	/K
Thermal Conductivity	130	W/(m·K)
Specific Heat	960	J/(kg·K)
Material Damping Ratio		N/A

Figure 9. Engineering data of Aluminium 7075-T6 in SolidWorks.

3.3 Geometry and meshing

The model was created as a three-dimensional solid part in SolidWorks. The check entity result confirmed that the geometry was valid and no defective faces or edges were detected. This verification is important because geometric defects can cause meshing failure or inaccurate FEA results.

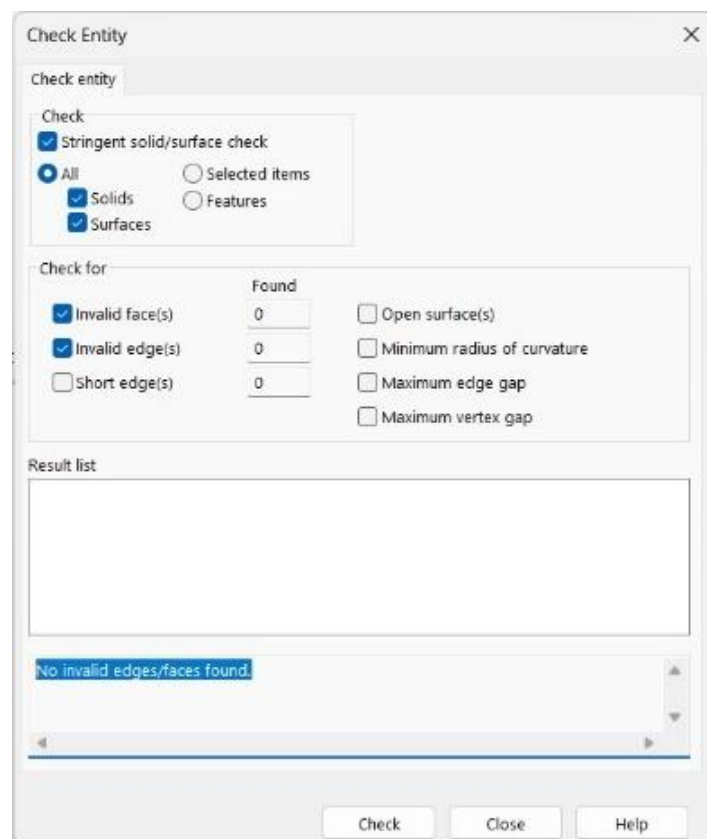


Figure 10. Geometry check result.

The meshing process used a solid mesh with curvature-based meshing. The final mesh had a maximum element size of 8.41484 mm and a minimum element size of 1.3 mm. The model generated 1,825,552 nodes and 1,254,001 elements. The maximum aspect ratio was 10.624, but only 0.0114% of elements had an aspect ratio above 10. Approximately 95.7% of elements had an aspect ratio below 3, and no distorted elements were found. This indicates that the mesh quality was acceptable for static structural analysis.

Mesh Details	
Study name	Rear Upright Static 2 (-Default-)
DetailsMesh type	Solid Mesh
Mesher Used	Curvature-based mesh
Jacobian points for High quality mesh	16 points
Max Element Size	8,14484 mm
Min Element Size	1,3 mm
Mesh quality	High
Total nodes	1829552
Total elements	1254001
Maximum Aspect Ratio	10,624
Percentage of elements with Aspect Ratio < 3	95,7
Percentage of elements with Aspect Ratio > 10	0,0114
Percentage of distorted elements	0
Number of distorted elements	0

Figure 11. Mesh detail data.

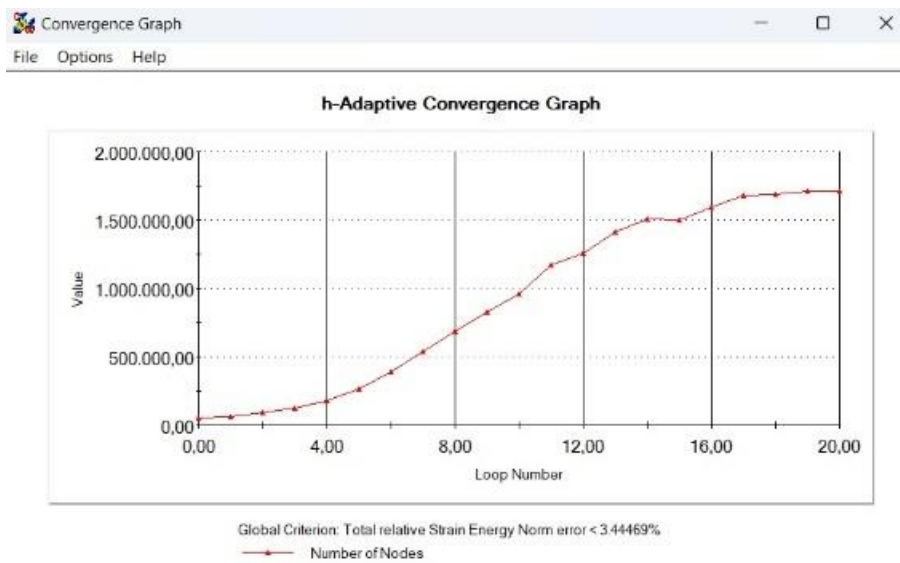


Figure 12. h-adaptive convergence graph.

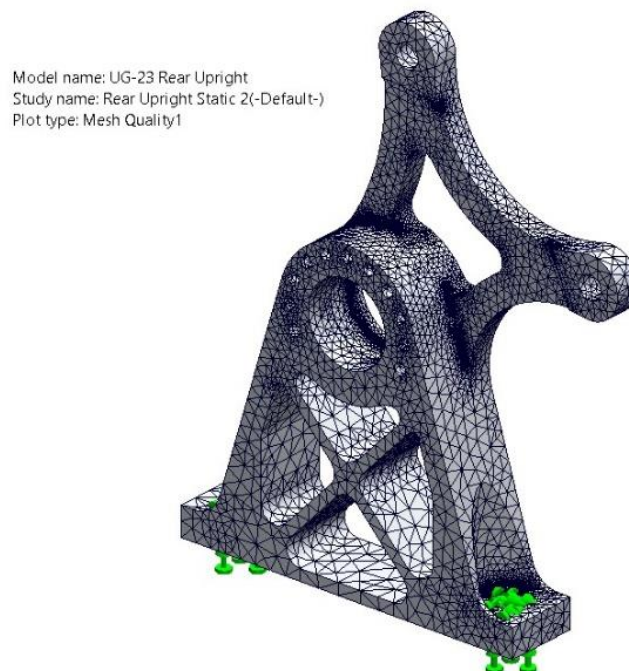


Figure 13. Meshing result on the rear upright component.

3.4 Boundary conditions

The loading condition represented maximum braking. Forces were applied at the bearing housing and caliper bracket based on the calculated braking load. The chassis mounting points were defined as fixed geometry because these surfaces represent the connection between the rear upright and vehicle frame. This assumption prevents translation and rotation at the mounting points during simulation and reflects the actual bolted connection condition.

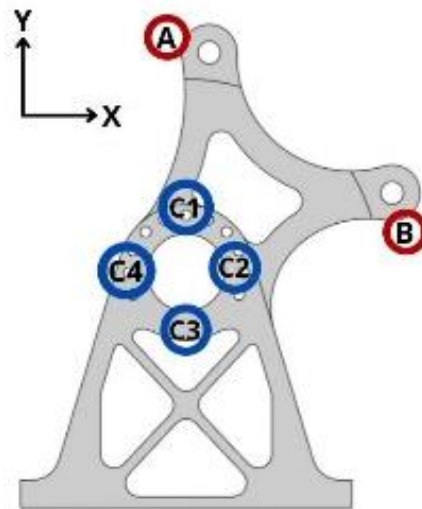


Figure 14. Load locations on the rear upright.

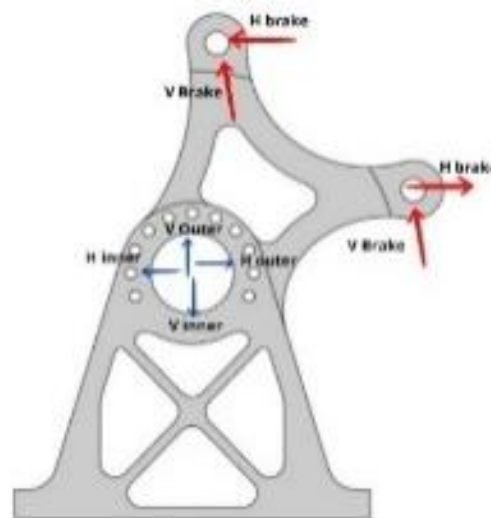


Figure 15. Load type and load direction on the rear upright.

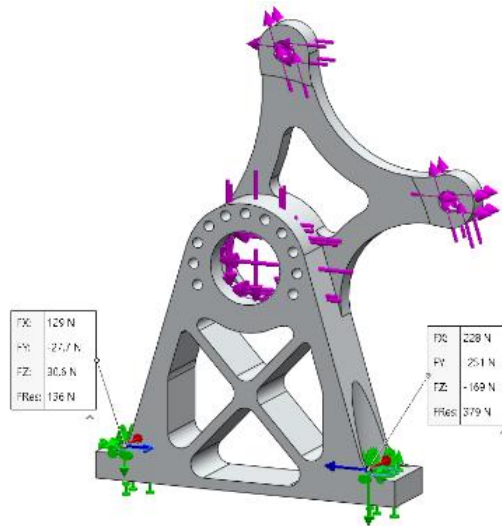


Figure 16. Load and support placement in SolidWorks.

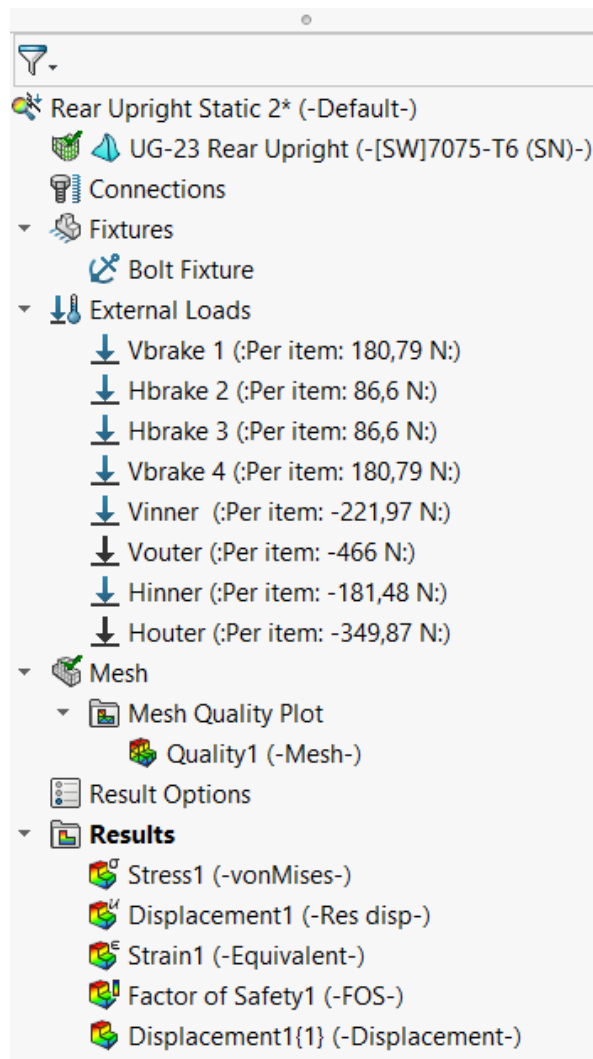


Figure 17. Simulation study tree and load condition summary.

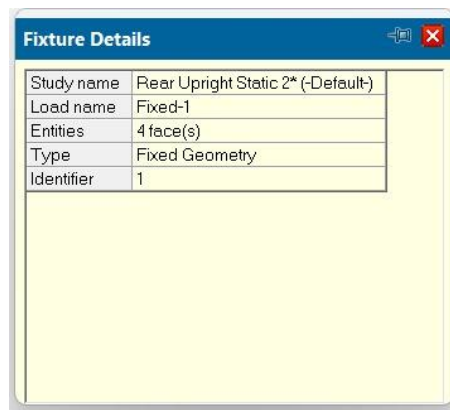


Figure 18. Fixture details.



Figure 19. Fixture location on the rear upright.

3.5 Stress distribution and factor of safety

The static FEA results showed that the critical stress region occurred at the lower radius of the caliper bracket and at the transition between the caliper bracket and the main upright body. The maximum von Mises stress was 32.34 MPa. The stress around the bearing housing was lower, ranging approximately from 3.24 MPa to 9.70 MPa. The stress distribution indicates that the braking moment transferred through the caliper bolts is the dominant source of local stress concentration.

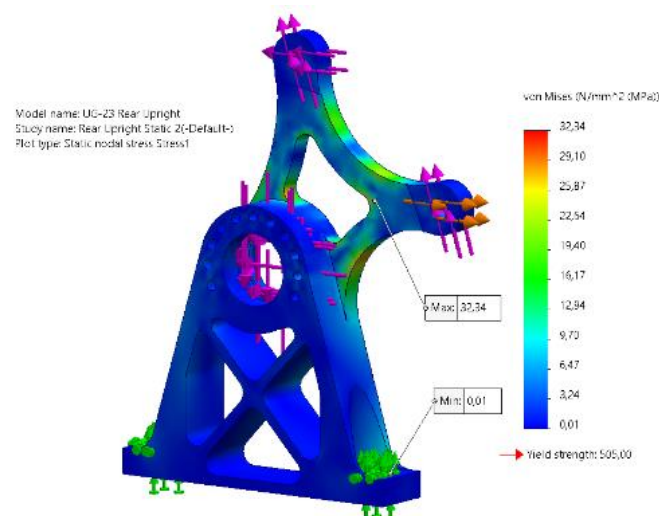


Figure 20. Von Mises stress distribution on the whole rear upright.

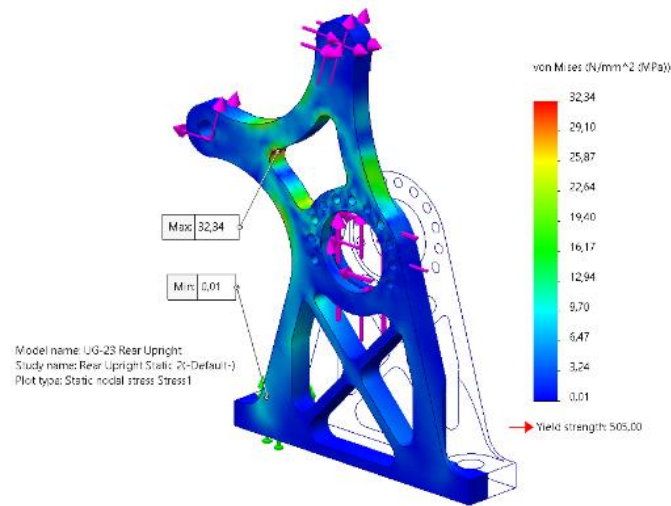


Figure 21. Von Mises stress distribution on the outer side.

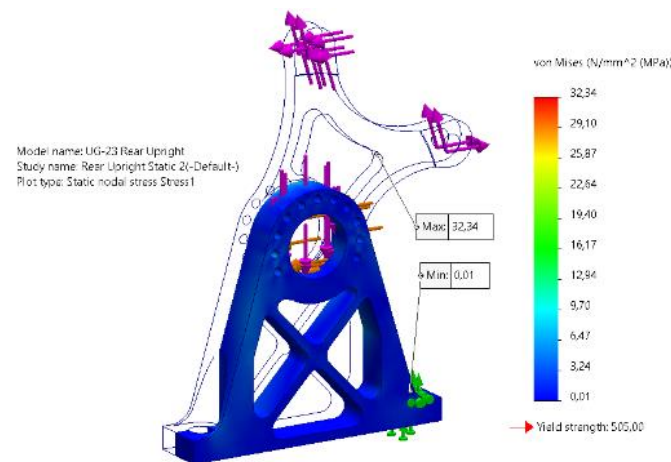


Figure 22. Von Mises stress distribution on the inner side.

The factor of safety was calculated based on the yield strength of Aluminium 7075-T6 divided by the von Mises stress. The minimum factor of safety obtained from the simulation was 15.62 at the bracket-to-body transition area. This value is much higher than the target minimum factor of safety of 4 for the dynamic loading assumption. Therefore, the redesigned rear upright satisfies the strength requirement.

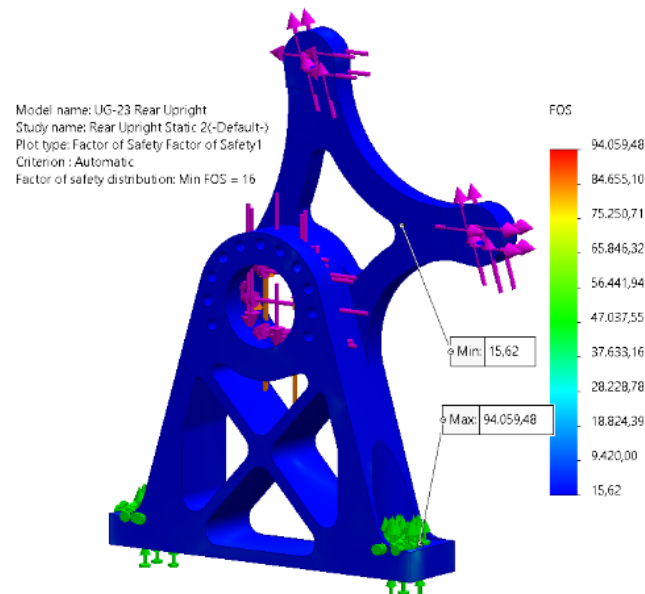


Figure 23. Factor of safety distribution.

Table 4. Factor of safety calculation at critical stress points.

No.	Critical stress point	Von Mises stress (MPa)	Yield strength (MPa)	Factor of safety
1	Caliper bracket area	32.34	505	15.61
2	Bearing housing area	9.70	505	52.06
3	Upright-to-frame mounting bolt area	3.24	505	155.86

3.6 Displacement and strain

The maximum displacement occurred at the outer area of the caliper bracket bolt location. The maximum displacement was 0.08 mm, which is below the target limit of 0.1 mm. This low displacement indicates that the upright remains sufficiently rigid under the simulated maximum braking load. The strain value was negligible, and the visual strain plot confirmed that the most critical region was still located around the caliper bracket.

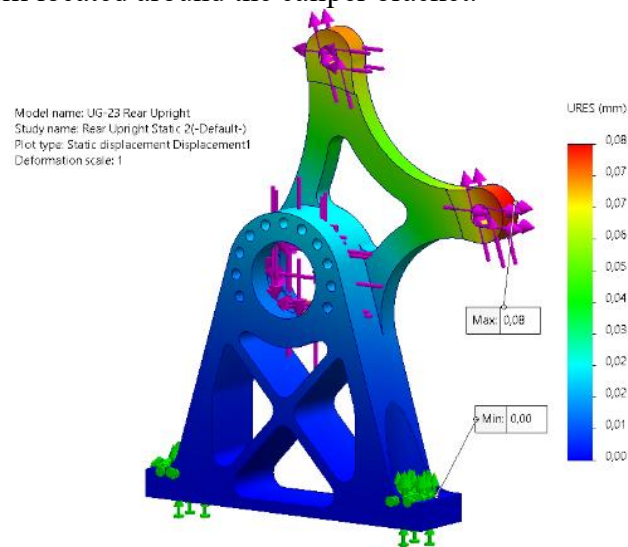
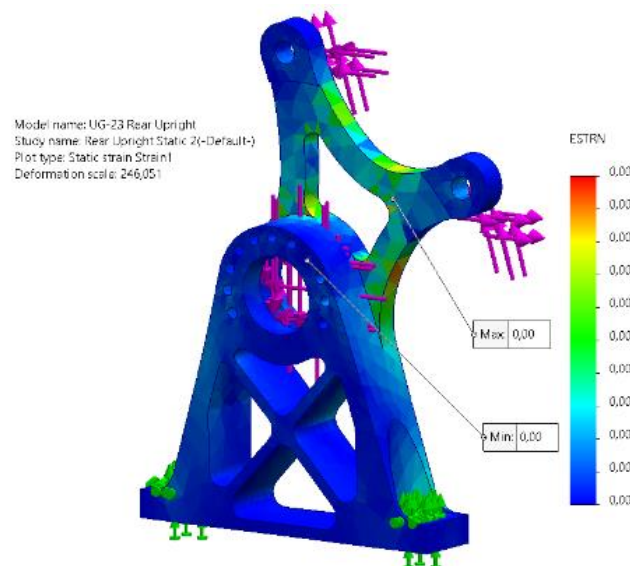
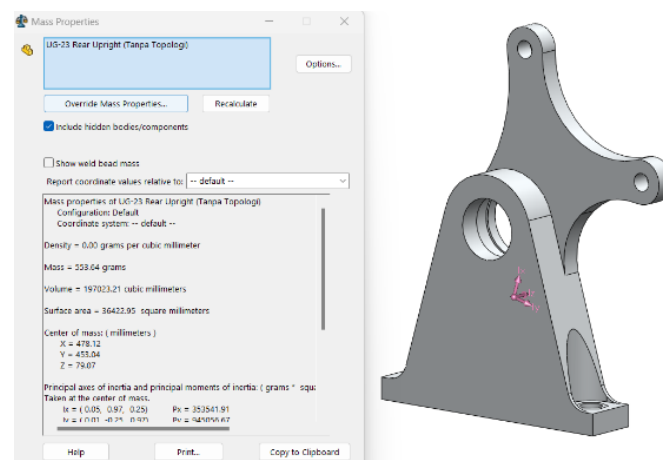
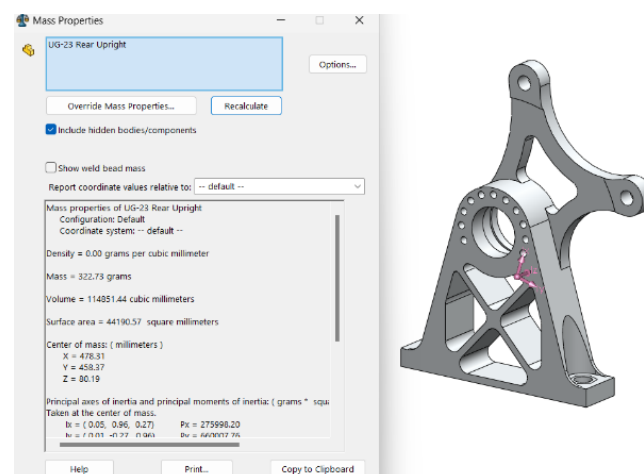
**Figure 24.** Displacement distribution.**Figure 25.** Strain distribution.

Table 5. Evaluation of the FEA results.

No.	Evaluation parameter	Target	Result	Conclusion
1	Design	Rear Upright UG-23	Design successfully developed	Suitable
2	Stress	< 505 MPa	32.34 MPa	Meets target
3	Factor of safety	> 4	15.62	Meets target
4	Displacement	< 0.1 mm	0.08 mm	Meets target

3.7 Topology optimization

Topology optimization was conducted to reduce the mass of the rear upright while maintaining structural integrity. The initial design had a mass of 553.64 g and a total volume of 197,023.21 mm³. After optimization, the mass decreased to 322.73 g and the volume decreased to 114,851.44 mm³. Although the optimized geometry became more complex due to material removal, the FEA results showed that the minimum factor of safety remained above the target value.

**Figure 26.** Rear upright mass before topology optimization.**Figure 27.** Rear upright mass after topology optimization.**Table 6.** Mass reduction after topology optimization.

Condition	Mass (g)	Description
Before topology optimization	553.64	Initial mass
After topology optimization	322.73	Mass after optimization
Mass reduction	230.91	553.64 - 322.73
Mass reduction percentage	41.70%	$(230.91 / 553.64) \times 100\%$

The mass reduction of 230.91 g per component corresponds to 41.70% of the initial mass. Because the vehicle uses four upright-related wheel system components, this reduction is expected to contribute to overall vehicle mass efficiency. The optimized component is therefore

advantageous for an urban vehicle where lower mass can improve energy efficiency and dynamic response.

4 Conclusion

The development and design of the rear upright for the Garuda UNY Team UG-23 Urban Car resulted in a lightweight and structurally safe component. Aluminium 7075-T6 was selected through the Ashby material selection method because it provides a high yield strength of 505 MPa and low density suitable for lightweight automotive structures. The proposed design satisfies the geometric requirements for the caliper, bearing, chassis mounting bolts, and vehicle ground clearance. Static FEA under maximum braking load produced a maximum von Mises stress of 32.34 MPa, a minimum factor of safety of 15.62, a maximum displacement of 0.08 mm, and negligible strain. These values meet the target criteria, including the minimum factor of safety of 4 and the displacement limit of 0.1 mm. Topology optimization reduced the mass from 553.64 g to 322.73 g, equal to a 41.70% reduction, without significantly reducing structural strength. Future work should include manufacturing the component according to the optimized design, applying the specified tolerances and bolt tightening torque during assembly, and conducting field testing to validate the simulation results under real vehicle operating conditions.

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Conflicts of Interest

The authors declare no conflict of interest.

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