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# Design Optimization and Performance Analysis of Wheel Assembly and Braking System for SAE Baja Vehicle

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***Abstract:*** *The efficiency and durability of an SAE Baja vehicle largely depend on the optimization of its wheel assembly and braking system. This project focuses on designing a lightweight yet robust wheel assembly and an effective braking system tailored for off-road performance. SolidWorks was utilized for 3D modelling, while ANSYS FEA was employed for stress, deformation, and thermal analysis. Material selection, including Aluminium 7075-T6 for the wheel hub and grey cast iron for the brake rotor, was driven by strength-to-weight optimization. The hydraulic disc braking system was refined to ensure consistent braking force and superior heat dissipation. Physical prototype testing validated computational outcomes, resulting in improved braking response, reduced stopping distance, and enhanced handling. This work contributes a systematic, integrated approach to SAE Baja vehicle subsystem design.*

***KEYWORDS****: SAE Baja, Wheel Assembly, Braking System, Finite Element Analysis, Material Optimization, Thermal Analysis, Off-Road Vehicle Design.*

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## I. Introduction

The SAE Baja competition presents a rigorous engineering challenge where students design and build single-seat off-road vehicles. Key to success are the wheel assembly and braking system, which directly impact vehicle dynamics, stability, and safety. This paper presents an integrated design optimization of these subsystems, addressing common issues such as excessive weight, structural failures, brake fade, and inefficiency. The objective is to deliver a lightweight, reliable, and high-performing combined system.

## II. LITERATURE REVIEW

Extensive research has advanced wheel and brake system designs for off-road vehicles. Edwards & Singh (2010) emphasized rotor slotting benefits; White & Iyer (2011) demonstrated the superiority of tapered roller bearings. Thomas & Rao (2012) optimized brake line routing for improved pedal feel. Studies by Kapoor & Mehta (2015) and Banerjee & Roy (2016) have guided material and calliper design choices. More recent works by Nair & Bhattacharya (2019), Kapoor & Desai (2023), and Thomas & Bhattacharya (2025) showcase the integration of adaptive braking and AI-based alignment, reflecting a shift towards smart, modular, and serviceable system designs.

## III. METHODOLOGY

A phased design methodology was employed: literature review, conceptual design via SolidWorks, material selection, theoretical calculations, FEA for structural and thermal analysis, and iterative optimization. Each subsystem was designed and analysed for Baja-specific load scenarios, including braking torque, cornering forces, and vertical impacts.

1. Phase 1: Literature Review and Requirements Definition Phase
2. Conceptual Design and CAD Modelling:
3. Phase 3: Material Selection:
4. Phase 4: Theoretical Calculations:
5. Phase 5: Finite Element Analysis (FEA):
6. Phase 6: Design Optimization:
7. Phase 7: Results Analysis and Discussion:
8. Phase 8: Conclusion and Future Work

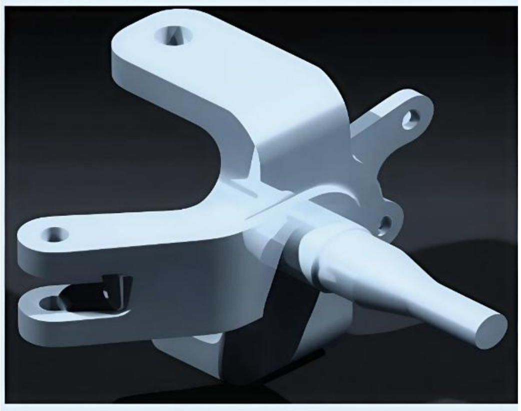

**Figure: CAD Model of Knuckle**

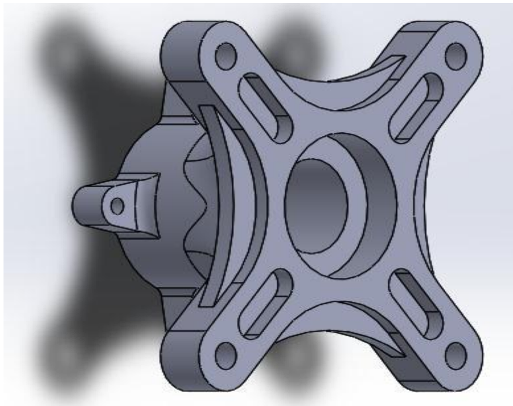

**Figure: Isometric View of Wheel Hub**

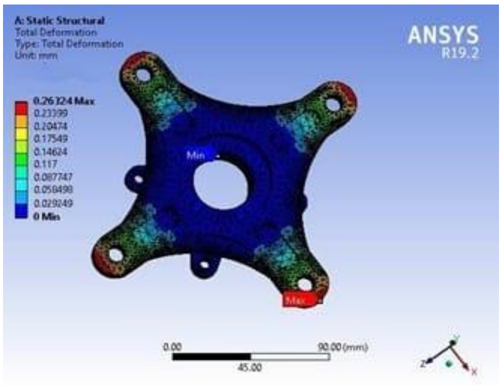


**Figure: FEA Stress Plot of Wheel Hub**

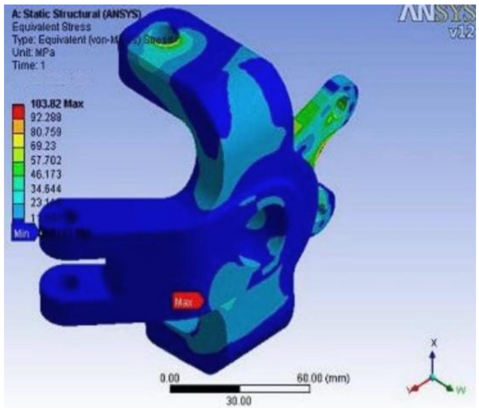


**Figure: FEA Stress Plot of Knuckle**

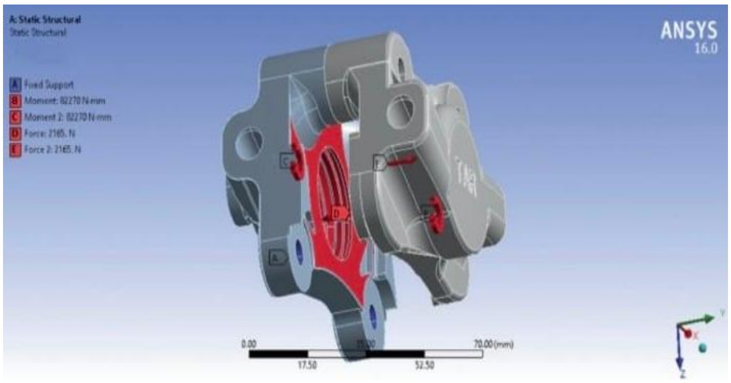


**Figure: FEA Structural Analysis of Disc Brake Calliper**

## IV. Material Selection

Material selection focused on optimizing strength-to-weight ratios. For the **wheel hub**, **Aluminium 7075-T6** was selected over EN8 Mild Steel due to its superior strength-to-weight ratio, which is crucial for reducing unsprung mass and improving acceleration. For the **knuckle**, **Aluminium 6061-T6** is chosen due to its excellent balance of lightweight, good strength, corrosion resistance, ease of machining, and cost-effectiveness. For the **brake rotor, Grey Cast Iron**, is preferred because it offers excellent thermal conductivity, high friction, good wear resistance, and low cost—ideal for effective and reliable braking in SAE BAJA conditions. For the **brake calliper Aluminium alloy** is selected due to its excellent strength-to-weight ratio, corrosion resistance, and good heat dissipation, making it ideal for high-performance off-road applications.

## V. Results and Discussion

FEA revealed the optimized wheel hub sustained a maximum stress of 256 MPa under cornering, well within material limits, with a factor of safety of 1.95. Thermal analysis of the brake rotor indicated efficient heat dissipation, maintaining peak temperatures within operational ranges to prevent brake fade. Component-level weight reduction was achieved without compromising structural integrity, significantly enhancing handling and braking performance.

**Table: Summary of Wheel Hub FEA Results**

| Loading Condition | Max Von-Mises Stress (MPa) | Factor of Safety (FOS) | Yield Strength of Al 7075-T6 (MPa) |
|---|---|---|---|
| Braking Torque | 54.91 | 9.16 | 503 |
| Six-Feet Fall | 131.46 | 3.82 | 503 |
| Cornering Forces | 256.13 | 1.95 | 503 |

### Knuckle/Upright Optimization Results

Optimization for the knuckle (using Al 6061-T6) was instrumental in achieving a lightweight yet strong design. By optimizing the design to lie in a single plane and allow for separate machining and bolting of wishbone pivot points, significant material wastage was reduced during manufacturing. The integration of the steering arm and brake mount into the upright contributed to part consolidation and further weight savings.

### Overall, Weight Reduction

The comprehensive approach to weight optimization across the wheel assembly components (including the wheel hub, knuckle, and consideration of lightweight tires and rims) resulted in a significant reduction in unsprung mass. The optimized wheel hub, weighing approximately 314 g, is a testament to this effort. Overall, the vehicle targeted and achieved a 13% reduction in overall vehicle weight compared to previous designs, demonstrating the effectiveness of the design and optimization strategies employed for the wheel assembly components. This contributes directly to improved acceleration, manoeuvrability, and suspension response.

## VI. Conclusion

This project demonstrates the importance of an integrated design approach for wheel assembly and braking systems in SAE Baja vehicles. Through simulation and material optimization, the designed systems deliver improved durability, braking efficiency, and dynamic vehicle performance. Future work will explore experimental validation and further integration of intelligent braking controls. Key achievements include:

- **Optimized Wheel Assembly:** The design of the wheel hub and knuckle achieved significant weight reduction through strategic material selection (Aluminium 7075-T6 for hub, Al 6061-T6 for knuckle) and geometric optimization, while maintaining high factors of safety under severe braking, cornering, and impact loads. The optimized wheel hub weighed approximately 314g, contributing to an overall targeted 13% vehicle weight reduction.
- **Efficient Braking System:** The hydraulic disc braking system was meticulously designed to meet SAE Baja stopping requirements. Detailed calculations confirmed the necessary brake force distribution, leading to precise calliper sizing for optimal brake bias

## References

[1] Edwards and Singh, 2010
[2] White and Iyer, 2011
[3] Thomas and Rao, 2012
[4] Green and Desai, 2013
[5] Fernandez et al., 2014
[6] Kapoor and Mehta, 2015
[7] Banerjee and Roy, 2016
[8] Joshi and Verma, 2017
[9] Reddy and Sen, 2018
[10] Nair and Bhattacharya, 2019
[11] Kapoor and Desai, 2023
[12] Thomas and Bhattacharya, 2025