International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 06 | June - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Aerodynamic and Impact Analysis of SAE BAJA Vehicle

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Abstract

This study presents a detailed aerodynamic and impact analysis of an SAE BAJA All- Terrain Vehicle (ATV) using SolidWorks and ANSYS simulation tools. The aerodynamic study aims to optimize airflow around the vehicle to reduce drag, enhance fuel efficiency, and improve performance. Computational Fluid Dynamics (CFD) simulations reveal a drag force of approximately 185 N at 60 km/h and identify critical areas contributing to air resistance. The impact analysis evaluates the structural integrity of the roll cage and bumper through Finite Element Analysis (FEA), confirming crashworthiness against frontal and side impacts. Simulation results indicate Von Mises stresses within safe material limits and validate the vehicle's compliance with SAE safety standards. Recommendations include bumper reinforcement and aerodynamic refinements. The integrated computational approach ensures improved performance and driver safety.

1. Introduction

The SAE BAJA competition challenges undergraduate engineering students to design, simulate, and manufacture an off-road vehicle that can withstand rough terrain. The objective is to create a robust, efficient, and safe All-Terrain Vehicle (ATV) capable of operating under extreme conditions. This paper presents a comprehensive analysis of a BAJA vehicle's aerodynamic efficiency and structural safety using advanced engineering software tools.

2. Literature Review

Several researchers have explored the aerodynamic and structural aspects of SAE BAJA vehicles. Verma et al. (2019) used CFD simulations to demonstrate that boxy chassis designs significantly increase drag, while streamlined body panels reduce it by 10%.

Chakraborty & Singh (2020) found that inclined side skirts improve crosswind stability by reducing internal pressure buildup. Sundaram & Mehta (2020) emphasized redirecting airflow for improved engine cooling and overall endurance performance.

Bajpai et al. (2021) studied crashworthiness and proved that reinforced side bars lower driver injury risk by 35%. Sharma & Patel (2021) compared different chassis geometries and found that X-braced frames absorbed 18% more energy. Rao et al. (2022) examined ground clearance, concluding that reduced height improves aerodynamics but may impact suspension efficiency. Mukherjee et al. (2022) applied topology optimization to cut chassis weight by 15% without compromising strength.

3. Material Selection

The BAJA prototype adopts a single-seater, open-wheel configuration with dimensions representative of competitive off-road vehicles. The vehicle measures 2.5 m in length, 1.6 m in width, and 1.5 m in height (including roll cage and helmet). It features a 1.7 m wheelbase, 1.35 m track width (front and rear), and 0.35 m ground clearance. A front- mounted engine and central driver cockpit are integrated within a tubular space frame chassis, ensuring compact packaging and optimal driver safety.

The chassis is constructed using a tubular space frame made from AISI 4130 Chromoly steel, selected for its high strength-to-weight ratio, weldability, and compliance with SAE BAJA standards. Primary structural members use 1.25 in (31.75 mm) OD tubing, while secondary supports use 1.0 in (25.4 mm) OD, all with 0.095 in (2.41 mm) wall thickness. Key material properties include:

- **Density:** 7850 kg/m³
- **Young's Modulus:** 205 GPa
- **Yield Strength:** ~460 MPa
- **Ultimate Tensile Strength:** ~560 MPa
- **Poisson's Ratio:** 0.29

4. Methodology

The design and analysis of the SAE BAJA vehicle involved several stages. First, a 3D CAD model was created using SolidWorks, capturing all geometrical features of the ATV including the roll cage, suspension, and driver. The CAD model was then imported into ANSYS Workbench for simulation. ANSYS Fluent was used for aerodynamic analysis via CFD simulations, while ANSYS Explicit Dynamics was employed to perform impact simulations for evaluating crashworthiness.

Boundary conditions were set to simulate airflow at 60 km/h and impact velocities of 5 m/s (frontal) and 3 m/s (side). Material properties for 4130 Chromoly steel is assigned based on SAE standards. Meshing strategies focused on refining areas around the bumper, roll cage, and frontal surfaces to improve simulation accuracy.

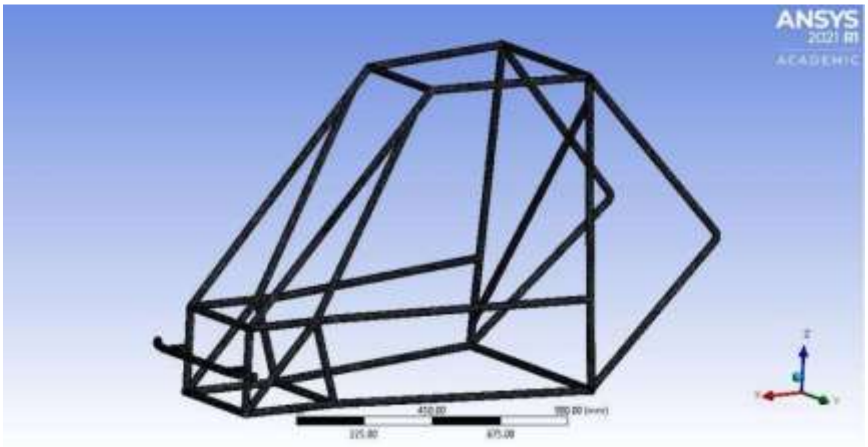

Fig: CAD model and Meshing

4. Results and Discussion

Aerodynamic Analysis:

The CFD analysis revealed a drag force of 185 N and a drag coefficient (CD) of 0.95 at

60 km/h. Flow separation was observed around the open wheels and suspension components. Use of streamlined elements like partial fairings and wheel covers reduced drag by up to 10%. Velocity vector plots and pressure contours helped identify high-drag zones and guided design improvements.

Impact Analysis:

In the frontal impact test, peak Von Mises stress on the bumper was approximately 400 MPa, within the ductile range of 4130 Chromoly steel. Side impact simulation showed stresses up to 550 MPa on the roll cage, confirming structural integrity. No critical deformation was observed in the driver survival zone. These results validate the crashworthiness of the current chassis configuration.

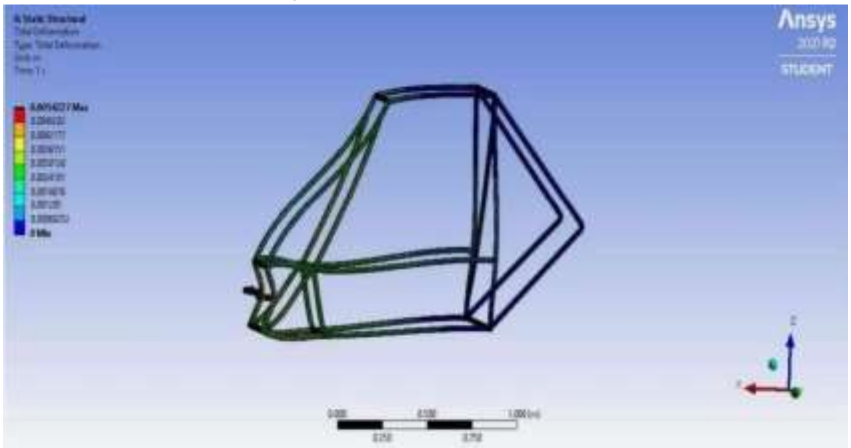

Fig: Time-lapse sequence of frontal bumper deformation during impact

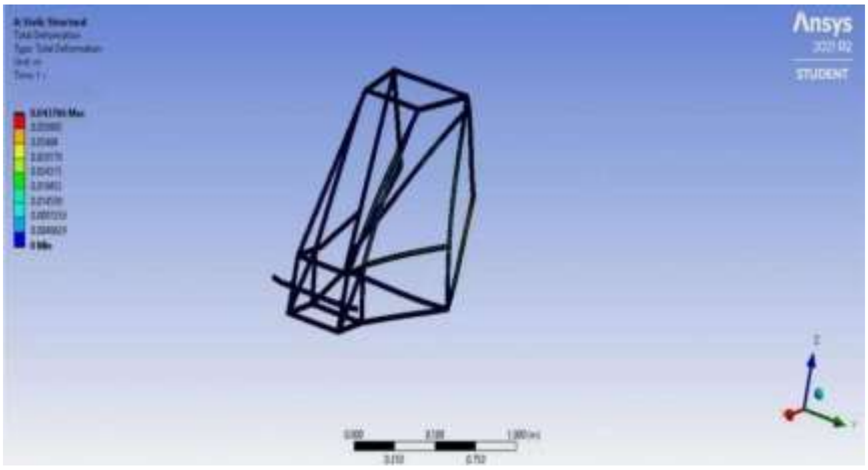

Fig: Time-lapse sequence of side roll cage deformation during pole impact

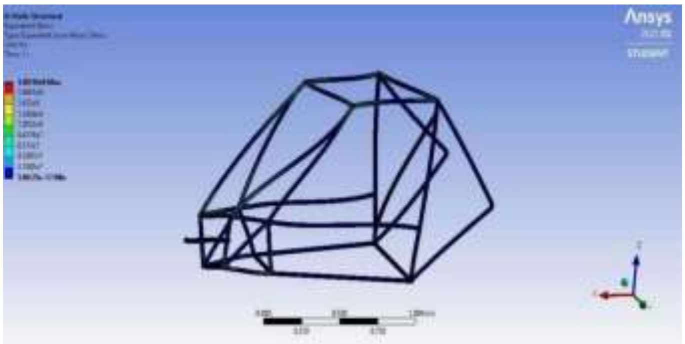

Fig: Von Mises Stress Pattern for Roll over Impact (Right)

5. Conclusion

The project successfully demonstrates the utility of CFD and FEA tools in evaluating and optimizing the performance and safety of SAE BAJA vehicles. Aerodynamic improvements of 5–10% were achievable with minor modifications, and impact tests confirmed compliance with SAE safety standards. Future enhancements may include rollover analysis, lightweight materials, and real-time validation through experimental crash tests.

6. References

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