

Design Improvement and Structural Analysis of the Chassis-Body for a Fuel-Efficient Eco-Vehicle

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ABSTRACT: This paper presents a study on the structural redesign of the chassis-body system for a fuel-efficient eco-vehicle using CATIA software. The objective was to optimize the frame structure to meet key design criteria, including minimal mass and aerodynamic efficiency. As a result, a new configuration was developed that ensures high dimensional accuracy, reduces overall weight, and lowers the vehicle's center of gravity. The proposed structure features a simplified design that maintains essential strength and stiffness characteristics while supporting aerodynamic performance, making it suitable for application in energy-efficient vehicle competitions.

KEYWORDS: Chassis-body structure of the fuel-efficient eco-vehicle; Shell Eco-Marathon; Honda Eco-Mileage Challenge.

I. INTRODUCTION

In fuel-efficient eco-vehicle competitions, key factors determining the success of participating teams are vehicle structure and driving technique. To achieve an optimal structural design, an eco-vehicle must satisfy critical criteria, such as minimum overall weight and the lowest possible aerodynamic drag coefficient.

Among various systems and assemblies of an eco-vehicle, the chassis-body structure typically accounts for the largest proportion of the total mass and has the strongest integration with other vehicle components. In this study, specialized CATIA design software was utilized to enhance the chassis-body structure of a fuel-efficient eco-vehicle. The resulting improvements include ensured dimensional accuracy, lower vehicle center of gravity, reduced frame weight, and simplified structural design, while still meeting the required strength and stiffness conditions.

II. THEORETICAL BASIS

- The chassis-body structure must ensure the overall dimensions of the vehicle comply with all competition regulations.
- The improved chassis-body must achieve the lowest possible structural weight.
- The structural design should remain simple while ensuring adequate strength and stiffness.
- The relative positioning of all vehicle components must be maintained accurately.
- The straight line connecting the centers of the two front wheels must be perpendicular to the vehicle's main axis.
- The height of the center of gravity for both the front steering wheels and the drive wheel must be controlled.
- The center of the rear wheel must be positioned on the perpendicular bisector of the line connecting the centers of the two front wheels.

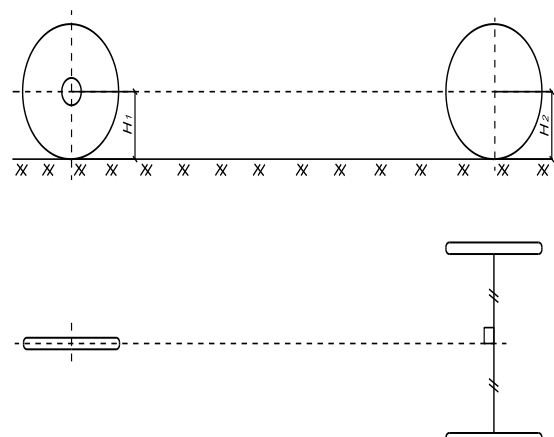


Figure 1: Geometric basis for defining the chassis-body dimensions

III. CALCULATION RESULTS

III.1. DETERMINATION OF OVERALL CHASSIS DIMENSIONS

a) Vehicle dimension regulations for participation in

the Shell Eco-marathon [3]

As a competition that prioritizes vehicle safety, the Shell Eco-marathon imposes strict technical specifications on all participating designs. Among these are detailed limits on the vehicle's dimensions to ensure compliance with both safety and operational standards:

- The total vehicle length must be less than 3500 mm.
- The wheelbase must be greater than 1000 mm.
- The overall vehicle width must be greater than 500 mm and must not exceed 1300 mm.
- The overall vehicle height must not exceed 1250 mm.
- The total vehicle weight must not exceed 140 kg.

b) Determination of overall chassis dimensions

Based on aerodynamic principles, the official dimensional regulations of the competition, the spatial requirements of the installed systems and components, as well as the driver's body size, the overall dimensions of the chassis-body structure were determined as follows:

- Overall length (L): $L = L_1 + L_2 + L_3 = 2550$ mm. In which: L_1 is the wheelbase, determined according to the vehicle's turning radius and stability during motion ($L_1 = 1650$ mm); L_2 is the legroom required for the driver to stretch comfortably ($L_2 = 600$ mm); L_3 is the space for the engine ($L_3 = 300$ mm).
- Overall width (B): $B = B_1 + B_2 = 520$ mm. In which: B_1 is the shoulder width of the driver ($B_1 = 450$ mm); B_2 is the space for additional components and for connecting the body to the frame.
- Overall height (H): $H = 720$ mm. The height was selected to maintain a balanced proportion with the overall length and width. Additionally, it takes into account the mounting position of the fuel tank, ensuring sufficient pressure for fuel delivery to the engine.

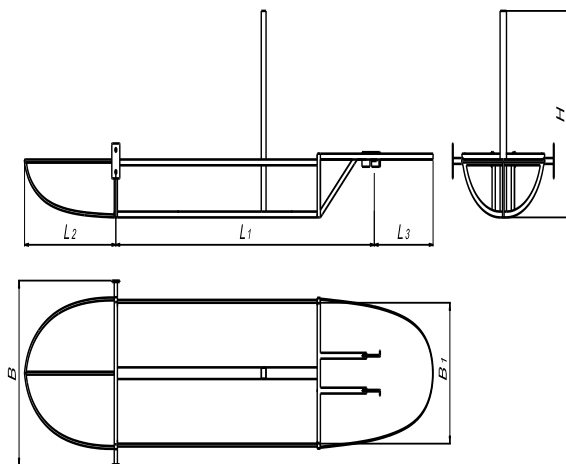


Figure 2: Overall dimensions of the chassis-body

structure.

III.2. STRUCTURAL DESIGN

a) Original chassis-body structure

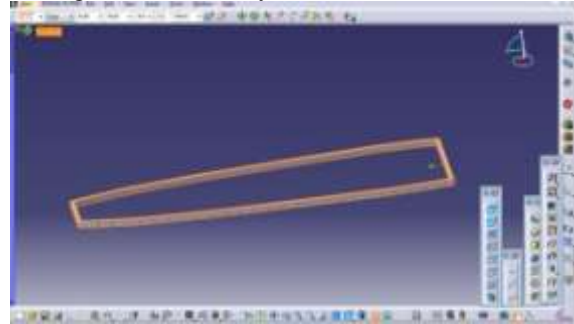


Figure 3: Main chassis profile

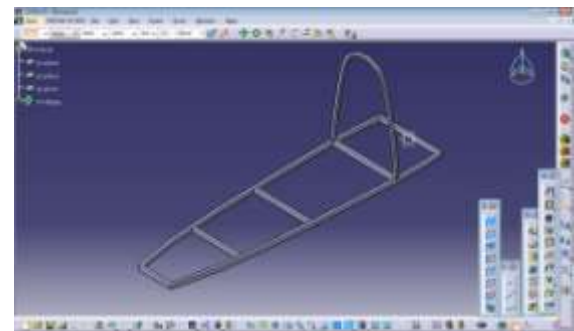


Figure 4: Basic chassis structure

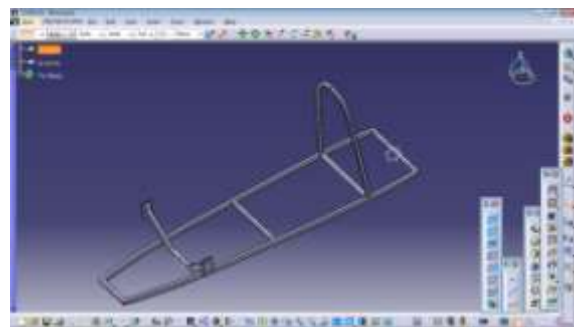


Figure 5: Front wheel mounting structure

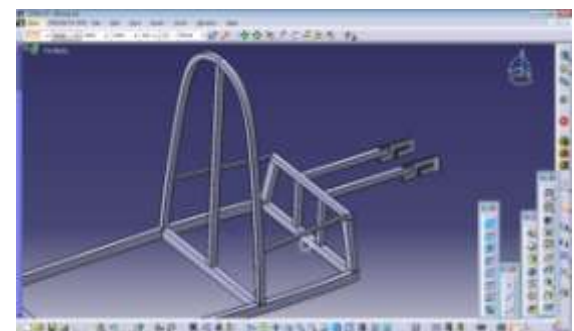


Figure 6: Rear structure and engine compartment

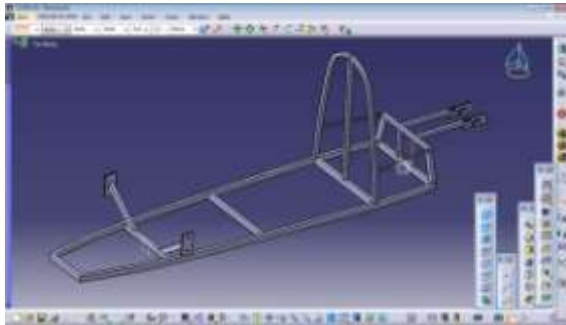


Figure 7: Original chassis-body structure

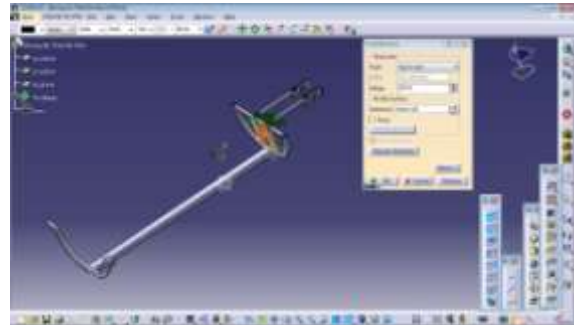


Figure 10: Rear chassis structure

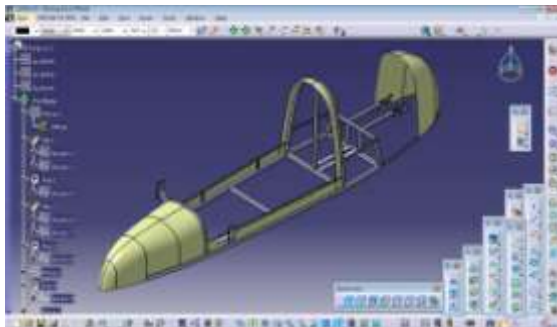


Figure 8: Completed chassis-body assembly



Figure 11: Front wheel mounting assembly

Observations:

- Due to the structural design and materials used, the overall weight of the original chassis was significantly high.
- The original chassis lacked a defined reference surface, resulting in failure to meet two key geometric requirements: The line connecting the centers of the two front wheels must be perpendicular to the vehicle's main axis; The center of the rear wheel must lie on the perpendicular bisector of the line connecting the two front wheel centers.
- The manufacturing process was complex and time-consuming, as the chassis had not been divided into separate modules for individual fabrication.
- The chassis dimensions were relatively large, and the center of gravity remained high.

b) Improved chassis-body structure

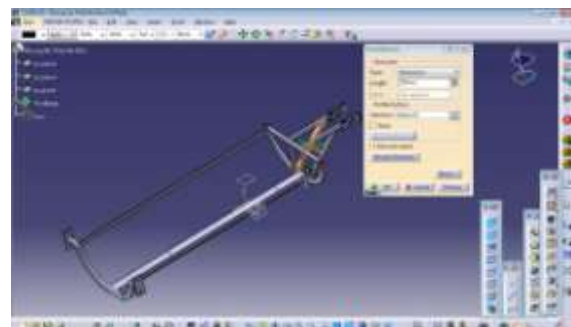


Figure 12: Reinforced rear chassis structure

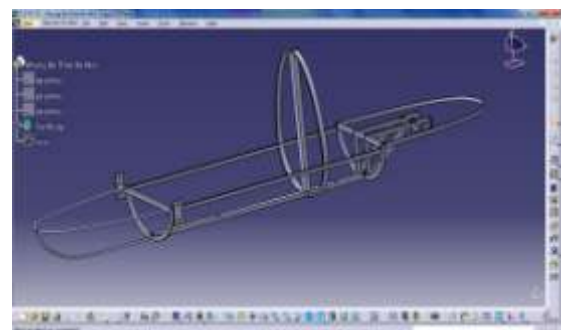


Figure 13: Improved chassis-body structure



Figure 9: Reference surface of the chassis-body structure

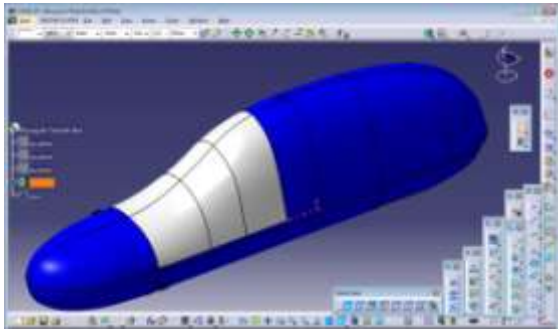


Figure 14: Improved body structure

c) Achieved results after improvement

- The improved chassis-body structure features a simpler design, making it easier to manufacture. A notable advantage of the new design is its modular construction: the front, middle, and rear sections can be fabricated separately and then assembled into a complete structure. This modularity helps reduce both manufacturing time and cost.

- The improved chassis is more compact than the original version (Original: H = 760 mm; B = 540 mm; L = 2600 mm; Improved: H = 720 mm; B = 520 mm; L = 2550 mm). This reduction in size enhances vehicle stability during motion and improves maneuverability, especially during turning.

- The center of gravity of the improved chassis is also lower (Original: 325.235 mm; Improved: 312.5 mm), contributing to better dynamic stability on the track.

- In addition, the improved chassis is significantly lighter, with a total weight of only 9.125 kg compared to 15.515 kg for the original version. As a result, the vehicle with the improved chassis is expected to be more fuel-efficient under the same operating conditions.

III.3. STRENGTH ANALYSIS OF THE IMPROVED CHASSIS-BODY STRUCTURE

The structural strength of the improved chassis was evaluated under two operating conditions: turning and emergency braking [1].

a) Theoretical Background

Emergency braking condition

During emergency braking, the chassis-body structure is subjected to bending due to the inertial forces acting on the vehicle.

$$P_{jk} = \frac{m_k \cdot j_{p\max}}{g}; j_{p\max} = \frac{\varphi \cdot g}{\delta_i}$$

Where:

m_k - Total mass acting on the chassis;

$j_{p\max}$ - Maximum deceleration of the vehicle during braking;

φ - Tire-road adhesion coefficient, $\varphi = 0,7 \div 0,8$;

g - Gravitational acceleration, $g = 10 \text{ m/s}^2$;

δ_i - Coefficient accounting for the effect of rotating masses, $\delta_{i\max} = 1$.

Turning condition

During cornering, the vertical and horizontal members of the chassis-body structure are subjected to lateral and longitudinal inertial forces due to centrifugal acceleration:

$$P_{lt} = \frac{G_k \cdot V^2}{\rho}; \rho = \frac{R_{q\min}}{\cos \alpha}$$

Where:

$R_{q\min}$ - Minimum turning radius of the vehicle;

V - Maximum turning speed.

G_k - Weight of the chassis-body structure;

ρ - Distance from the turning center to the application point of the centrifugal force;

α - Average steering angle of the front wheels.

b) Strength analysis using CATIA software

- Under the emergency braking condition, an inertial force of $P_{jk} = 800 \text{ N}$ was applied, evenly distributed across 10 points on the chassis structure (Figure 15) [2].

- Under the turning condition, the centrifugal force was decomposed into two components: longitudinal centrifugal force (P_{ltd}) and lateral centrifugal force (P_{lmg}). These forces were applied at 15 locations on the chassis structure. The magnitudes of the forces were $P_{ltd} = 140 \text{ N}$, and $P_{lmg} = 433 \text{ N}$, respectively (Figure 18) [2].

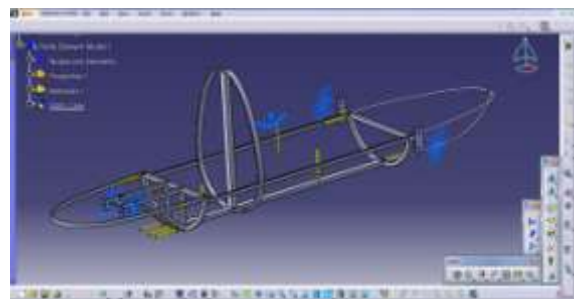


Figure 15: Load application diagram under emergency braking condition

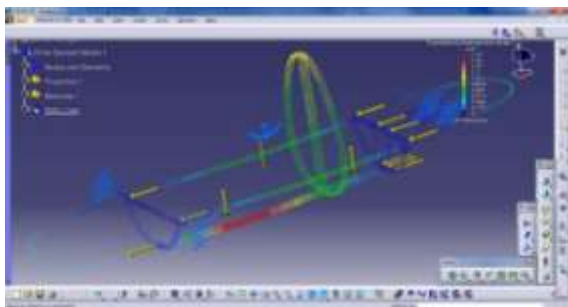


Figure 16:Chassis displacement under emergency braking

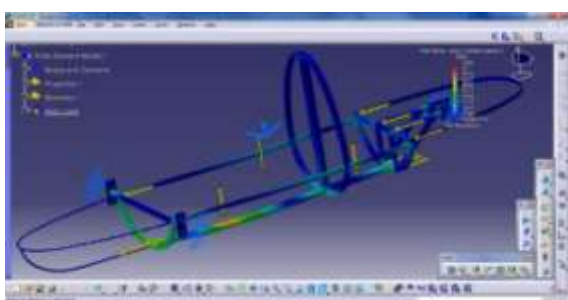


Figure 17: Stress distribution under emergency braking

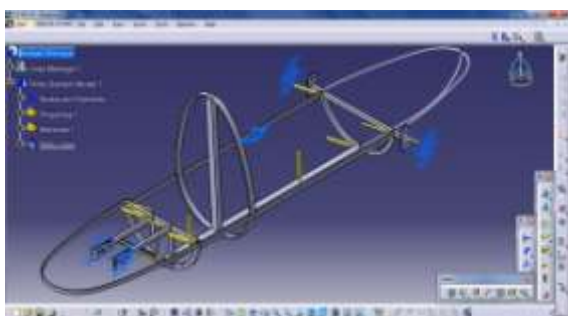


Figure 18: Load application diagram under turning condition

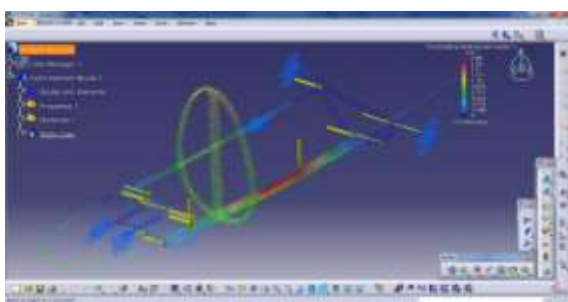


Figure 19: Chassis displacement under turning

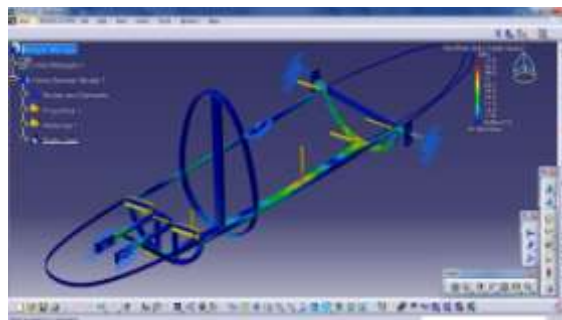


Figure 20: Stress distribution under turning

Table 1: Structural strength analysis results of the chassis-body under two loading

	Maximum Displacement [mm]	Maximum Stress [MPa]
Emergency Braking	1.72	74.4
Turning	1.88	72.9

IV. CONCLUSION

The improved chassis-body structure offers several key advantages: enhanced dimensional accuracy, a lower center of gravity, reduced structural weight, and a simplified design that still ensures sufficient strength, stiffness, and aerodynamic efficiency. These improvements are critical factors contributing to better fuel economy in fuel-efficient eco-vehicle competitions. In addition, the simplified construction of the improved chassis-body helps reduce both manufacturing time and production cost.

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