Optimised Design and Structural Simulation of a Quad Cycle Chassis Using Finite Element Methods

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Abstract. Automotive chassis is the most essential part of an automobile. The chassis serves as a framework for supporting the body and different parts of the quad cycle, so it should be rigid enough to withstand the shock, twist, vibration and other stresses. Manufacturers consider many criteria when designing a chassis structure, including their requirements for its characteristics and established engineering design principles. As a result, strength and stiffness are two essential criteria for the design of the quad-cycle chassis. Also, the weight of the chassis is a critical consideration for chassis design due to its direct relationship with the amount of fuel consumption and the emissions rates emitted to the surrounding atmosphere. This project analyses the structural design of a specific vehicle chassis by using the theory of finite element method (FEM), which is performed by simulating the chassis model into frontal car crash tests using the ANSYS Workbench program. This project aims to achieve analytical results by recommending the following chassis design criteria. The structure's cross-bridges significantly mitigate the collision's effect on the rest of the vehicle's body. The objective of this project is to design and analyse quad-cycle chassis; this will avoid any possibility of structure failure and thus provide enough supporting members to strengthen the region in terms of deformation. Finite element analysis enables the predict the area that tends to fail due to loading. Besides that, there is a need to utilise the feature of CAE software named FEMPRO to get the distribution of stress and strain on the chassis, as well as both component and material costing. The main objective is to study the effect of load on driver weight, the car body and the equipment.

Keywords: Automotive Chassis; Explicit Dynamics Analysis; Finite Element Method; Crash Analysis; Impact test; Computer-Aided Design Software.

INTRODUCTION

Tri-cycles offer a unique combination of features, blending the agility and manoeuvrability of a mini vehicle with the convenience of small motorised vehicles. These vehicles are compact, environmentally friendly, and easily navigable through congested urban areas.

"Quad cycles," also quadricycles, are four-wheeled, smaller, and lighter than traditional cars. They were designed to address various needs and trends, such as urban mobility, fuel efficiency, and cost-effectiveness. Quad cycles often have simpler designs, making them easier to manufacture and maintain while providing basic transportation for short distances. The designers also aim to make them accessible to a broader range of people, including those without a driver's license. The chassis of the quad cycle is the framework that supports and holds all the major components of the quad cycle, including the engine, suspension, steering, and body. The chassis design determines the vehicle's structural integrity, weight distribution, handling characteristics, and overall performance. The quad-cycle chassis should be designed to withstand various loads and forces encountered during regular operation, such as acceleration, braking, cornering, and impacts. It needs to be structurally robust to ensure the safety of the occupants and maintain stability.

In the recent period of industrial history, the automotive industry has faced many challenges due to environmental challenges and international laws, which aim to preserve the environment regarding natural resources that are nearing extinction due to adverse ecological phenomena, such as global warming. Many areas of development in the automotive industry aim to achieve and apply environmental laws.

The main goal is to reduce the use of fossil fuels, obtain a renewable, sustainable, and alternative energy source, and mitigate vehicle emissions. This project aims to study one aspect of the development of the automotive industry by focusing the study on a specific part of the quad cycle. This part is a general development of the automotive industry because it is standard in all vehicles. Researchers will analyse a quad-cycle chassis using scientific simulation and analysis programs, such as ANSYS, to identify its static and dynamic characteristics.

The aim is to demonstrate the feasibility and potential of quad-cycles as a practical mode of transportation. By combining engineering principles, innovative design concepts, and advanced simulation techniques, we aim to create a quad-cycle prototype that fulfils the requirements of urban commuters while emphasising sustainability and performance.

METHODS

Materials. In this work, the researchers used aluminium alloy for the chassis, a material extensively utilised in automotive chassis design. The main reasons for using aluminium alloy are its properties, such as helpful strength, low density, high thermal conductivity, excellent machining behaviour, and good corrosion resistance. For this project, we decided to use aluminium alloy for the chassis. Below are the various mechanical properties of the aluminium alloy:

Table 1 – Aluminium Alloy properties

Properties	Values
Density	2770 kg m^-3
Young modulus	7.1e+010 Pa
Poisson's ratio	0.33
Compressive yield strength	2.8e+008 Pa
Tensile yield strength	2.8e+008 Pa
Ultimate tensile strength	3.1e+008 Pa

Methods. This work used crash and impact analysis with explicit dynamic tools to perform simulations on the model. Explicit Dynamics Analysis is a specialised simulation technique used in engineering to analyse dynamic events involving large deformations, high velocities, and complex interactions.

The geometry model was designed using Solidworks software. Solidworks is a widely used computer-aided design (CAD) software that offers powerful design tools. It provides a comprehensive platform to create and visualise various aspects of the quad cycle's design. The parametric modelling capabilities enabled easy modifications and iterations. By leveraging Solidworks, we were able to streamline the entire design process.

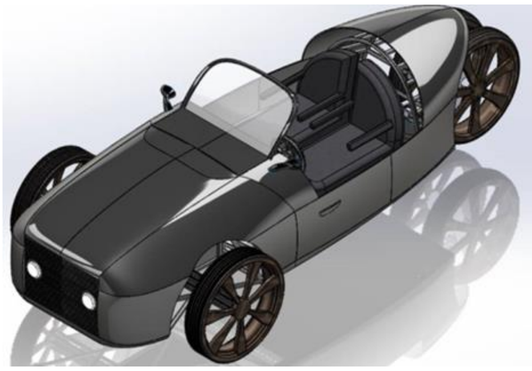

Figure 1 – 3D Model of Quad Cycle

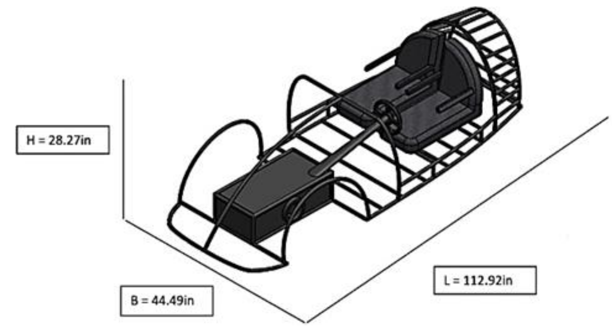

Figure 2 – 3D Model of Quad cycle Chassis with dimensions

Turning radius Design Calculation. Automakers define the turning radius as the radius of the smallest circle a vehicle can make with the steering at full lock. They base it on factors such as the wheelbase, front tyre width, and the steering angle of the front wheels while also considering several other design factors.

A vehicle's turning radius (alternatively, turning diameter or turning circle) defines the minimum dimension (typically the radius or diameter, respectively) of available space required for that vehicle to make a semi-circular U-turn without skidding.

This radius depends on the wheelbase w, which is the distance between the front- and the rear wheel, the angle α of the front wheel.

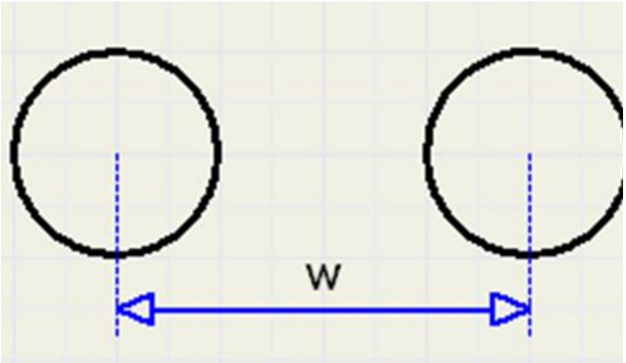

Figure 3 – Side view of wheels

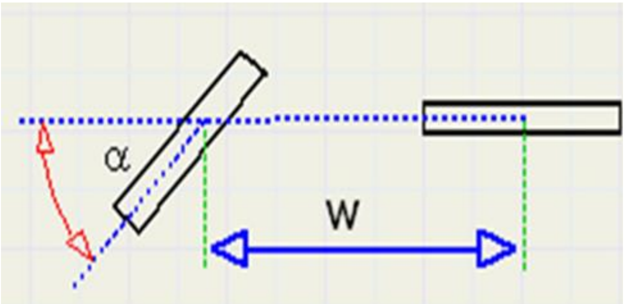

Figure 4 – Top view of wheels

Length = 143.7 inches; Height = 44.9 inches; Width = 68.9 inches; Weight = 1570lbs; Wheel Base= 65 inches; Tire Width= 49 inches.

The steering angle (α) is assumed to be 45º

$$\text{Turning radius} = \frac{\text{wheelbase}}{\text{Sin}\alpha} + \frac{\text{tyre width}}{2}$$

$$\text{Turning radius} = \frac{65}{\text{Sin}(45)} + \frac{49}{2} = 100.8897 \text{ inch} = 2.56 \text{ m}$$

Crash and Impact Analysis. Crash and impact analysis using explicit dynamic tools enables engineers to predict and understand how a model will respond in different collision scenarios. This data-driven approach to design helps optimise safety features, minimise the risk of injuries, and create vehicles that meet stringent safety requirements. The parameters used to accurately simulate and evaluate how the quad cycle responds during collisions help capture the dynamic behaviour and deformation of the quad cycle and its components. The key parameters that are needed for a comprehensive crash and impact analysis of a quad cycle are:

1) Collision Scenario Parameters: Collision type (frontal, side, rear, rollover), Impact conditions (collision speed, angle of impact) and Collision partner (another vehicle, barrier, pedestrian).

2) Material Properties: Material stiffness, elasticity, and strength for each component and Failure criteria for materials (plastic deformation, rupture, etc.).

3) Geometry and Kinematics: Detailed 3D model of the quad cycle's components, Initial velocities, positions, and orientations of the quad cycle and collision partner.

4) Boundary and Contact Conditions: Boundary constraints (fixed parts, movement constraints) and Contact interactions between different parts of the quad cycle and external objects.

5) Time Step and Simulation Duration: Time increment for solving equations of motion and Total simulation time to capture the entire collision event.

6) Material and Failure Models: Material models for different components (linear elastic, nonlinear plastic, composite, etc.) and Failure models to predict component deformation, cracking, or fracturing.

7) Output and Analysis Parameters: Impact forces and loads on different components, Deformation patterns and stress distributions, Intrusion levels into the occupant compartment, Occupant acceleration and deceleration and Potential injury risk assessment (Head Injury Criterion, Neck Injury Criterion, etc.).

8) Simulation Software Settings: Solver settings for explicit dynamics simulation (time step, convergence criteria) and Contact algorithms and interaction models.

These parameters will collectively define the crash scenario's characteristics and the quad cycle's behaviour during impact. Accurate modelling and consideration of these parameters would enable us to conduct realistic crash and impact analyses that provide valuable insights into the quad cycle's safety performance and structural integrity.

Figures 5 to 8 show various views of the quadricycle geometries' basic model, which was used for the design and exported to ANSYS.

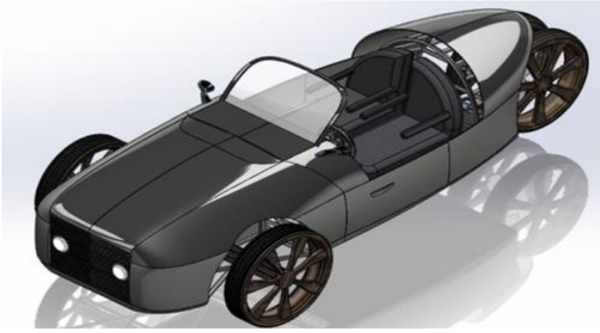

Figure 5 – 3D Model of Quad Cycle

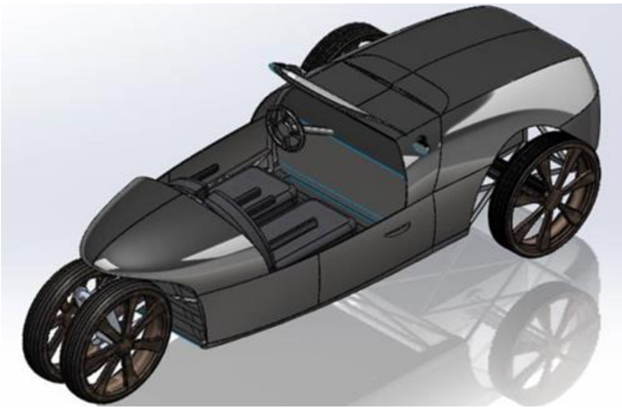

Figure 6 – 3D Model of Quad cycle viewed from the rear

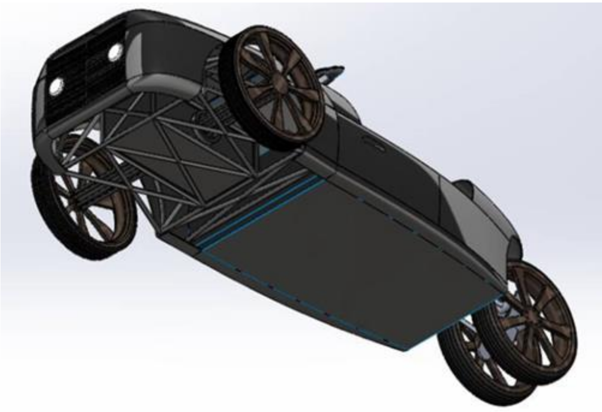

Figure 7 – 3D Model of Quad cycle viewed from beneath

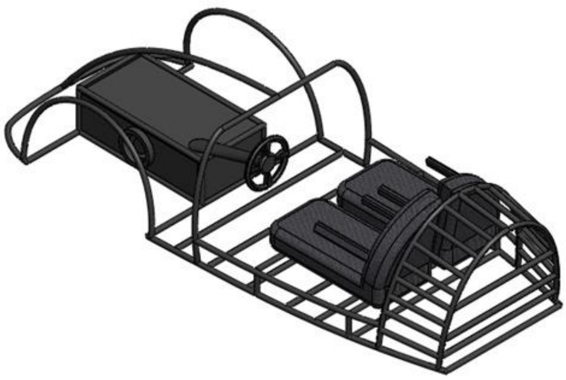

Figure 8 – Rear view of chassis

The surface mesh for the specimen is shown in Figure 9.

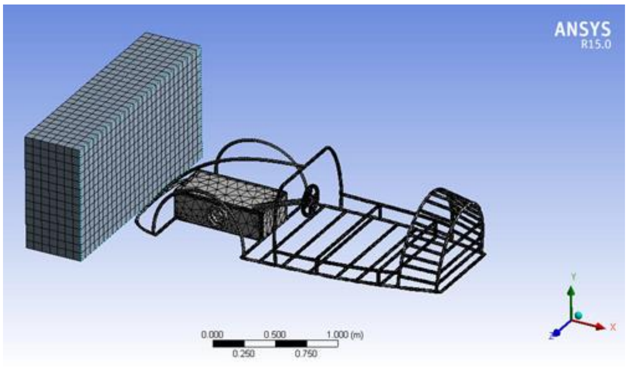

Figure 9 – The surface mesh for the specimen shown [11]

Table 2 – Mesh setting

Span Angle Center	Coarse
Automatic Mesh-Based Defeaturing	On
Defeaturing Tolerance	Default
Use Advanced Size Function	Off
Relevance Center	Medium
Element Size	Default
Initial Size Seed	Active Assembly
Minimum Edge Length	1.7935e-007 m
Smoothing	High
Nodes	21335
Elements	56954

Boundary Conditions. It is critical to describe adequate boundary conditions or limitations to compensate for impacts. Each node inside the structural device has six degrees of freedom: translational, three-square coordinate axes, and three rotating axes around each square axe [12].

Table 3 – Bounding box

Bounding Box		
	Chassis	Wall
	Aluminium Alloy	Structural Steel
LengthX	2.8621 m	0.5 m
LengthY	0.7063 m	1. m
LengthZ	1.1292 m	2. m

Velocity Settings. The velocity of -120 m/s is given to the car body structure to crash into the wall for analysis. The velocity of 120 m/s is shown in the negative X-axis direction.

Table 4 – Velocity setting

X Component	-120 m/s
Y Component	0 m/s
Z Component	0 m/s

RESULTS AND DISCUSSIONS

Explicit Dynamics Test. Explicit Dynamics simulates crash scenarios to evaluate how the quad cycle's structure and components behave during collisions; this helps assess occupant safety and design features to absorb and dissipate impact energy effectively. It is a valuable tool to predict and understand how a quad cycle responds to dynamic events that may be challenging or unsafe to replicate in real-world testing. By performing Explicit Dynamics Analysis, we can fine-tune design to enhance safety, optimise performance, and ensure that it meets regulatory standards and user expectations [13].

From the Explicit Dynamic test, we see graphical representations of Deformations plotted against time, presented in Figures 10 to 14 [14].

Table 5 – Explicit Dynamic Solution

Type	Directional Deformation	Total Deformation	Equivalent Plastic Strain	Equivalent(von-Mises) Stress
Orientation	X Axis			
By	Time			
Display Time	Last			
Coordinate System	Global Coordinate System			
Calculate Time History	Yes			
Identifier				
Suppressed	No			
Results				
Minimum	-1.1968m	0.m	0.m/m	5.0909e+006Pa
Maximum	0.88287m	2.4713m	0.m/m	9.1546e+009Pa
Minimum Occurs On	Chassis	Wall	Chassis	Wall
Maximum Occurs On	Chassis			
Minimum Value Over Time				
Minimum	-1.1968m	0.m	0.m/m	0.Pa
Maximum	0.m		0.m/m	8.7591e+006Pa
Maximum Value Over Time				
Minimum	0.m		0.m/m	0.Pa
Maximum	0.88287m	2.4713m	0.m/m	3.3736e+010Pa
Information				
Time	1.e-002s			
Set	101			
Integration Point Results				
Display Option			Averaged	
Average Across Bodies			No	

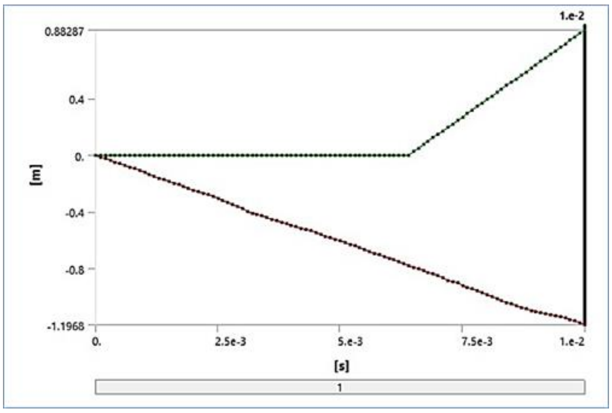

Figure 10 – Directional Deformation

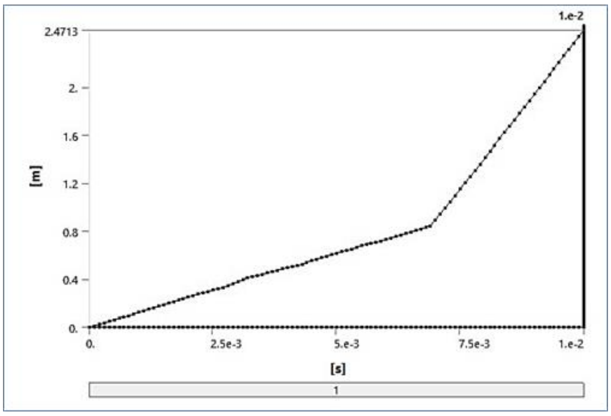

Figure 11 – Total Deformation

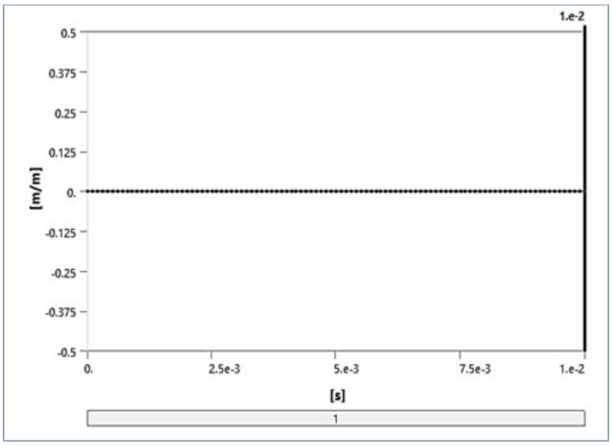

Figure 12 – Equivalent Plastic Strain

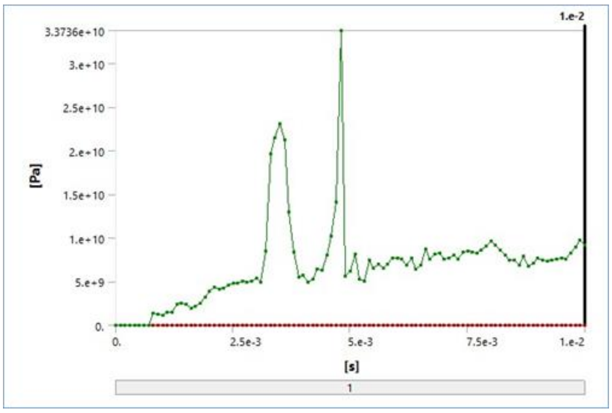

Figure 13 – Equivalent (Von mises) Stress

Assumptions: 1) Neglecting the air drag on the car's body; 2) The wall is assumed to be fixed from the side and bottom faces; 3) The car body is subjected to initial velocity and constant acceleration; 4) No friction at the base of the car body.

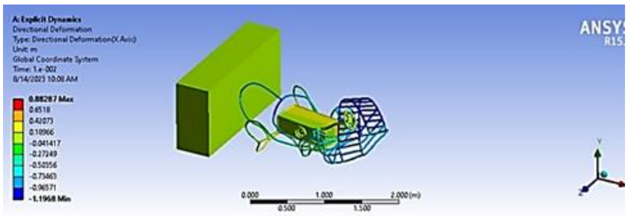

Figure 14 – Deformation after Crash

Results Validation. The author [15] compared the simulated result with their previous work. A similar geometry in his work was modelled using the same material properties (Aluminium alloy). The simulations examined the effect of the collision of the Defender quadricycle chassis. Then, they discussed the crash's impact on the same chassis modified by increased velocities. The total deflection and stress values are taken from the same observation point to compare the results between them under the effect of increasing the chassis speed during the collisions (-120 m/s velocity specifically was the velocity that caused the crash).

Figure 15 compares the three models in terms of maximum total deflection values with increasing chassis collision speeds. It is noticeable from the figure that the deflection values of the chassis structure, the area that collides directly with the concrete wall, began to differ between the three models after exceeding a speed of (100 km/h); the results were almost identical at the lower speeds and then began to vary after this speed.

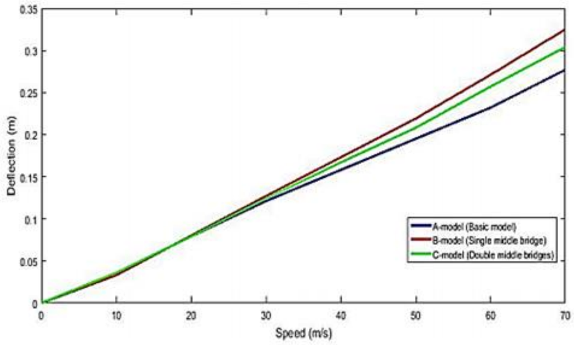

Figure 15 – Deformation against varying speeds

The first model, "A-model", was the model with the least deflection at high speeds, while the second model ", B-model", was the model with the highest deflection values at high speeds. The third model was closer to the second model regarding deflection values at high speeds, but still the lower one; this validates the fact that the deformation is increased with increased speed on the chassis.

CONCLUSIONS

The increasing challenges in urban transportation, such as traffic congestion, limited parking infrastructure, and environmental concerns, call for innovative and sustainable alternatives to conventional vehicles. For short-distance urban commuting, the increase in population density has heightened the need for the critical safety assessment of cars. Given these limitations, a well-designed quad-cycle is needed to combine the advantages of bicycles and small motorised vehicles. Hence, the design of a quad-cycle offers passengers safety and stability.

The quad-cycle chassis structure was simulated in a frontal collision using the ANSYS explicit dynamic method at 120 m/s. Further, the figures illustrate the various degrees of deformation experienced by the quad-cycle chassis. The collision time and deformation are linearly related. Results showed that the maximum and minimum directional deformation of the chassis is 0.88287 m and -1.1968 m, respectively; the maximum and minimum total deformation of the chassis is 2.4713 m and 0 m, respectively; the maximum and minimum equivalent plastic strain of the chassis is zero and the maximum and minimum equivalent (Von-Mises) stress is 9.1546e+009 Pa and 5.0909e+006Pa respectively. The aluminium alloy chassis is observed to have deformed upon contact with the structural steel wall when moving at a velocity of 120 m/s in the negative X direction. It experiences high stress and deformation, which is expected to be the most common scenario in vehicle accidents. From the animation of the simulation, the components that will cause the most harm to the driver would be the steering and the engine box. To achieve vehicle stability and passenger safety, engineers must optimise the design to withstand impact into the wall at the specified velocity. A redesign of the model with more reinforcement should suffice. And, of course, material selection for the chassis can be altered depending on the purpose of the vehicle and the resources available.

The following recommendations are also made for further study and optimisation of the quad cycle:

1) In future studies, different car body structures with other material mixtures should be used to model and analyse the crashworthiness of the quad-cycle chassis.

2) Various velocities should be used to analyse impact and crash.

3) An intricate redesign of the steering and engine box position to ensure driver and passenger safety in the event of a crash.

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