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Lightweight Solar Vehicle Impact Analysis Using ABAQUS/EXPLICIT

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ABSTRAKSI

Makalah ini menggambarkan the Abaqus/Explicit 6.7 simulasi performa kinerja untuk mempelajari dampak kondisi kecelakaan frontal untuk sebuah rancangan dan produksi struktur badan utama kendaraan ringan tenaga surya ringan rumahan. Struktur badan dibuat dari alumunium berongga yang dilas secara bersama – sama. Analisis ini diperlukan untuk menjaga keselamatan pengemudi kendaraan. Respon dinamik dari struktur kendaraan ketika mengalami kondisi benturan frontal adalah simulasi, didasarkan pelatihan terbaik NASA untuk metodologi tes kecelakaan. Kecepatan simulasi yang digunakan didasarkan pada standar NHTSA. Perbandingan analisis dengan Kriteria Cedera Kepala standar (HIC) dan Kriteria Cedera Dada (CIC) mengungkapkan bahwa pengemudi kendaraan yang dirancang tidak akan berisiko karena resultan percepatan ditemukan lebih rendah dari 20 G. Analisis juga membuktikan bahwa komponen struktural mampu melindungi pengemudi saat insiden tabrakan frontal. Namun, untuk memastikan keselamatan pengemudi, dianjurkan tindakan keselamatan pencegahan seperti penggunaan sabuk pengaman dan helm serta mengemudi di bawah batas kecepatan yang dianjurkan.

Kata kunci: simulasi, abaqus, kendaraan ringan, analisa dampak langsung

ABSTRACT

This paper described the Abaqus/Explicit 6.7 simulation work performed to study the frontal crash impact condition for an in-house designed and produced lightweight solar vehicle main structural body. The structural body was fabricated from aluminum hollow pipes welded together. The analysis is needed to safeguard the safety of the vehicle driver. The dynamic response of the vehicle structure when subjected to frontal impact condition was simulated, according to NASA best practice for crash test methodology. The simulated speed used was based on the NHTSA standard. Comparison of the analysis with the standard Head Injury Criteria (HIC) and Chest Injury Criteria (CIC) revealed that the driver of the designed vehicle would not be risk because the acceleration resultant was found to be lower than 20 G. The analysis also proved that structural component was able to protect the driver during any frontal collision incident. However, to ensure the safety of the driver, safety precautions such as the use of seatbelt and helmet as well as driving below the speed limit are recommended.

Keywords: Simulation, Abaqus, Lightweight vehicle, Frontal impact analysis

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1. INTRODUCTION

Global Green Challenges (GGC) or formerly known as World Solar Challenges (WSC) is considered to be a top class green motorsport event of the world. Participants were made to cross the Australian continent from Darwin, in the north, to Adelaide, at the south, at a distance of approximately 3000 km. It is meant to showcase the latest technological advances in different solar, electric, hybrid, and alternative energy low emission vehicle categories [1, 2]. Center for product design and manufacturing (CPDM) of Universiti Malaya fabricated a lightweight solar vehicle to participate in GGC 2009.The vehicle was named MERDEKA 2, with a total weight of 400 kg, shown in figure 1. Vehicles participating in GGC are normally lightweight vehicle. Power to weight ratio is a crucial factor for solar vehicle, because the weight of vehicle will affect the speed and the power consumption. This factor is highly critical due to the limited amount of energy produced by the photovoltaic panels. A good example of a light weight solar vehicles participating in GGC 2009 is the eventual winner, Tokai Challenger solar car with weight below 200 kg, with an average speed exceeding 100 km/h [3]. At that speed and low weight, the safety of the driver is at utmost concern! In is worthy of note that there has been 14 accidents recorded since the inception of the solar race in 2003[4,5]. A crash simulation needs to be conducted to ensure that there will be no harmful effect to the driver during any unforeseen accidents. During a lightweight solar vehicle crashes to rigid wall, the safety viewpoint to be addressed is to ensure that the driver is enclosed within a strong survival cell, surrounded by energy absorbing structures in the front, back and sides. The energy absorbing structures should be defined as the ability of the vehicle structure to provide self protection so that optimum overall safety can be achieved. Apart from that, safety standards need to be maintained, whenever a driver sits in the vehicle, the seatbelt and helmet need to be worn at all times.

Figure 1.. Merdeka 2 Solar vehicle.

Gabaeur and Gabler stated that vehicle crashworthiness injury criteria were measured with 2 criteria, which are the Head Injury Criteria (HIC) and Chest Injury Criteria (CIC) [6]. The HIC calculation is based on time movement of the centre of gravity of the head between T1 and T2 not being greater than 15 msec with the value of HIC being limited to 700 by The National Highway Traffic Safety Administration (NHTSA). For chest acceleration, NHTSA prescribes a maximum of 60 G's [7]. Ideally, a dummy with measuring instruments should be used for crash tests. However for this simulation, in lieu of the use of dummies, reference points were taken at the driver's area and used in determining the corresponding data obtained during the simulation.

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This study aims to simulate a frontal crash of a lightweight solar vehicle front impact structure against a rigid wall using the Finite Element code Abaqus/Explicit 6.7.

2. MERDEKA 2 SOLAR VEHICLE

Merdeka 2 main body structure was fabricated using 38 mm aluminum hollow pipe of 3.14 mm thick. The design concept of the vehicle calls for the adoption off-the-shelf component with the body shell resembling the Box-Fish shape [8]. The examples of off-the-shelf parts are the wheels, spring suspensions, steering and seat [9]. To reduce the weight of the solar vehicle, aluminum alloy 6063 was used for the vehicle framework. Aluminum alloy 6063, a medium strength alloy has good surface finish, resists corrosion highly and can be easily welded using any conventional methods. It is widely used for lots of applications, such as for architectural application, used as windows frame, for road transport, rail transport, and as extreme sports equipment. Aluminum alloy is also commonly used in light vehicles, which had been reported by lots of researchers to possess good energy absorption [10-13]. The aluminum alloy was produced by Kamco Sdn Bhd (Malaysia), purchased locally and for joining, TIG welding machine was used.

3. MODELLING METHODOLOGY

The modeling methodology for lightweight solar vehicle is based on the NASA best practice [14]. The flowchart for the modeling is shown in figure 2. Besides that, there are some other influencing FE modeling factors which are highlighted in Figure 3.

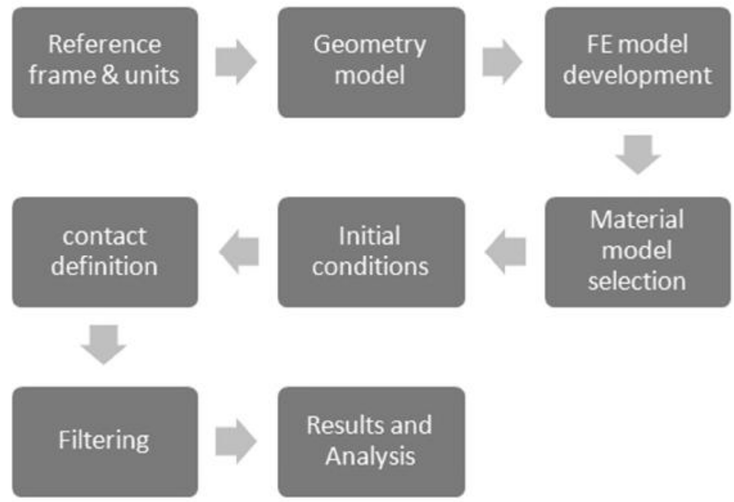

Figure 2.. Finite Element modeling methodology

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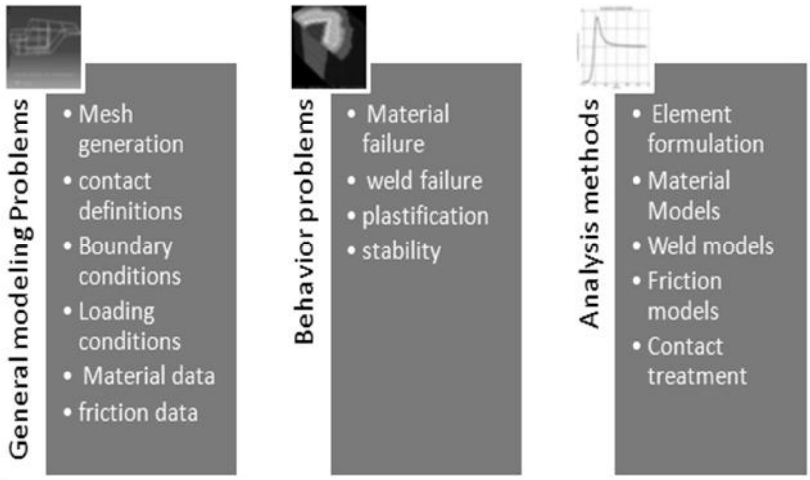

Figure 3. Factors are influencing in FE modeling.

NHTSA recommends the frontal barrier collisions to be investigated at speeds of 25, 30 and 35 mph (FMVSS 208 condition), with the corresponding metric values of 40, 50, and 56 km/h being used for this work. The results from the simulation conducted at all the speeds were analyzed to identify the level of safety for drivers. The results are in the form acceleration, velocity and displacement. To reduce computational time, simplification is made in the form of the vehicle yaw and pitch motions being ignored, with all motion assumed to be on a horizontal plane, and the lateral and longitudinal motions assumed to be independent. During the crash simulation, the friction coefficient for the aluminium-to-rigid wall contact was set as 0.9 [15]. Impact time was set as 0.3 s. Other components of the lightweight solar vehicle such as batteries, motor/engine, spring and tires, were not modeled in this simulation for simplification. Deceleration or nose-dive due to braking was not considered.

4. FE MODEL AND BASIC MATERIAL PROPERTIES

The model of lightweight solar vehicle designed for the GGC 2009 is shown in figure 4. The model was drawn in Abaqus/Explicit 6.7 itself, and not imported from any CAD software, to capitalize the advantage of this software in tackling non-linear, transient dynamics problems (such as crash testing) shown in figure 5, [16, 17]. The model is 4658 mm long, 1400 mm wide, and 1200 mm high (without tires), with the design aspects for the crash test being more focused on the structural frame. The aluminum alloy mechanical and physical properties are shown in table 1.

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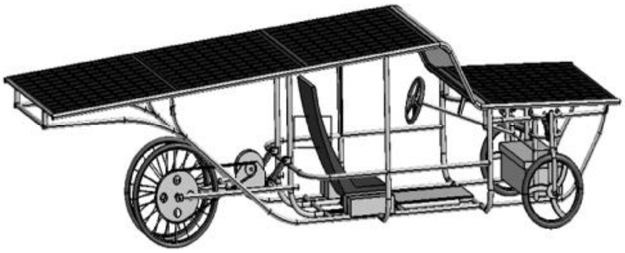

Figure 4. CAD drawing of the vehicle.

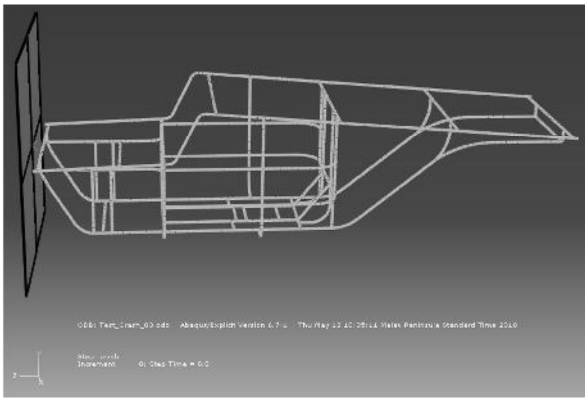

Figure 5. FE model of lightweight solar vehicle

Table 1. Typical mechanical and physical properties for aluminum alloy 6063.

Properties	Value
Density	2.70 g/cc
Tensile strength yield	48.3 MPa
Modulus of elasticity	68.9 GPa
Poisson ratio	0.330
Ultimate tensile strength	89.6 MPa

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5. RESULTS AND DISCUSSION OF FE ANALYSIS

The FE model for the crash simulation was drawn with 1224 nodes. The rigid wall has 8 nodes, with the components weight distributed on the drawing model based on the actual location of the equipment on the vehicle. For example, the photovoltaic panel is located on the roof, the batteries at the front and the seat in the center. The vehicle was crashed against a rigid wall with initial forward speeds of 40, 50 and 56 km/h. An Accelerometer was positioned at the area where the driver sits. It was used as the reference point for the simulation of a driver's movement during a crash, with figure 6 showing its location in the lightweight solar vehicle.

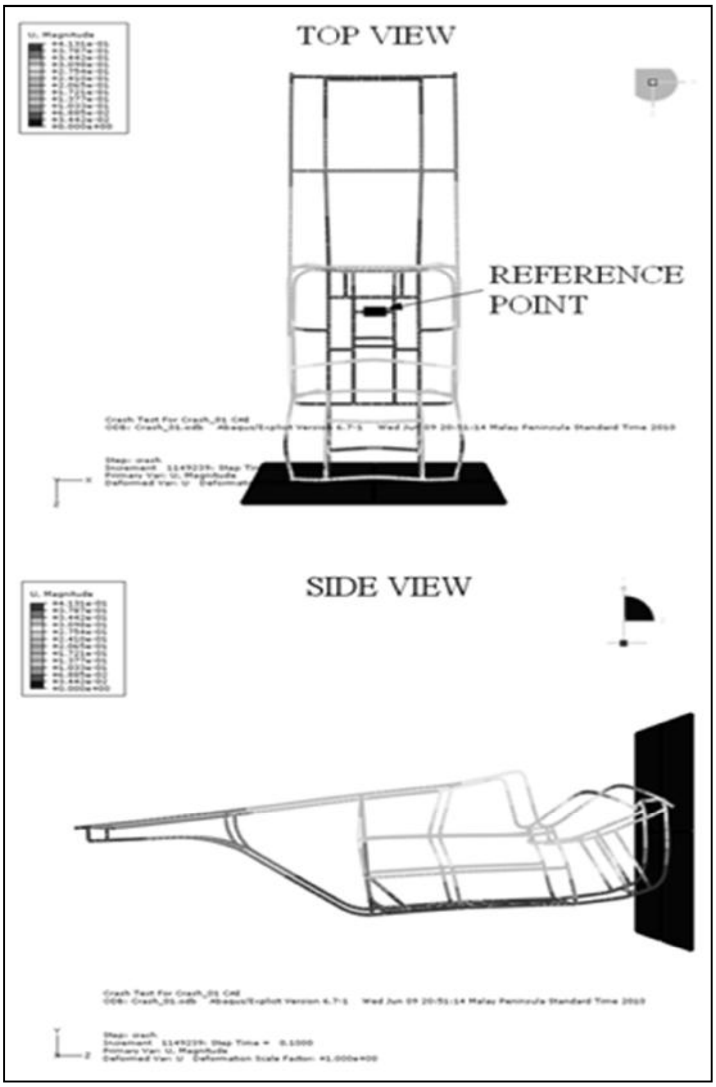

Figure 6. Lightweight solar vehicle accelerometer location

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Using that reference point, data were collected for the X axis. The data, grouped for each speed used are shown in figure 7, figure 8 and figure 9.

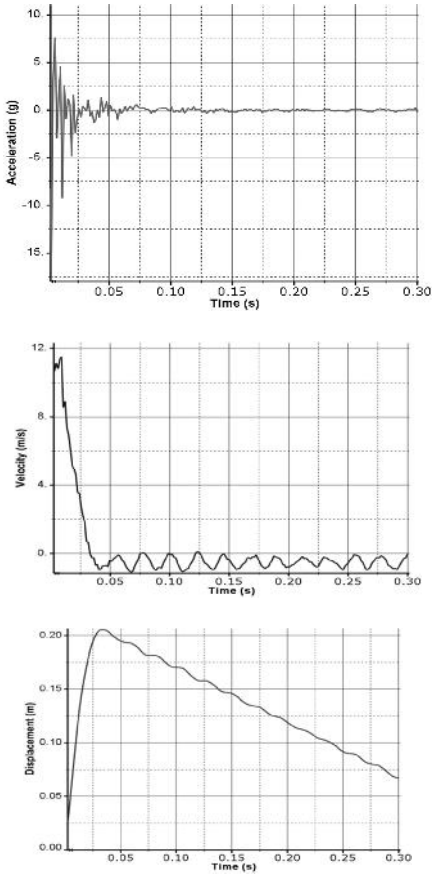
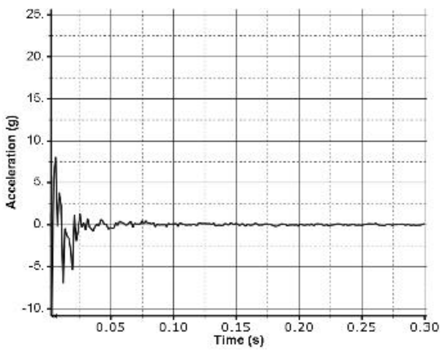


Figure 7. Lightweight solar vehicle-Acceleration, velocity and displacement for speed 40 km/h.



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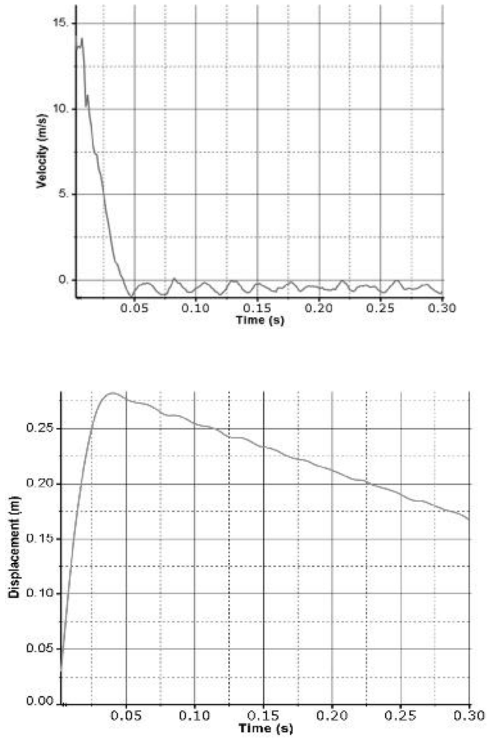
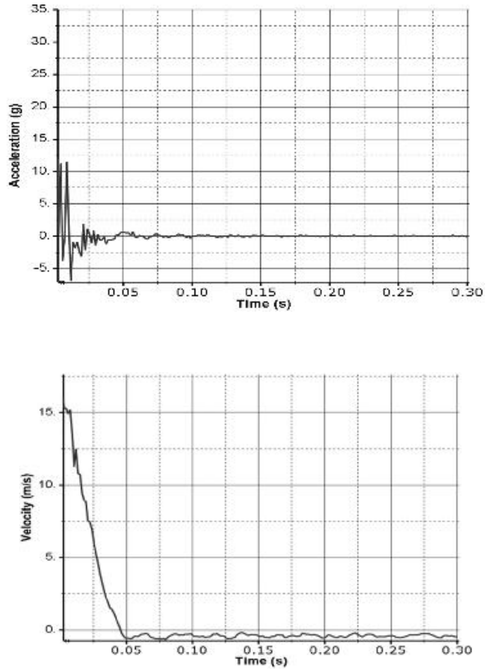


Figure 8. Lightweight solar vehicle-Acceleration, velocity and displacement for speed 50 km/h.



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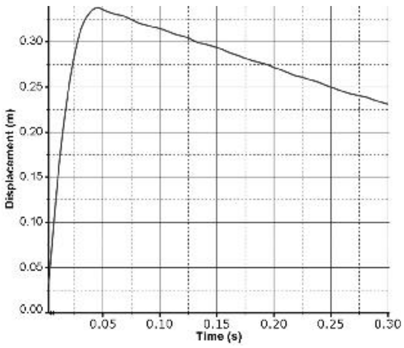

Figure 9. Lightweight solar vehicle-Acceleration, velocity and displacement for speed 56 km/h.

Observations of the displacement chart in Figures 7, 8 and 9 has shown that the impact process reached its peak at 0.3125s, 0.375s and 0.4375s for the speed of 40 km/h, 50 km/h and 56 km/h respectively. The snap-shot for the vehicle deformation shown in figure 10 described deformation conditions at different times. The crash simulation has also shown that at the speed of 56 km/h, the frame was greatly deformed due to the impact of the crash, but not that huge at speeds of 40 km/h and 50 km/h.

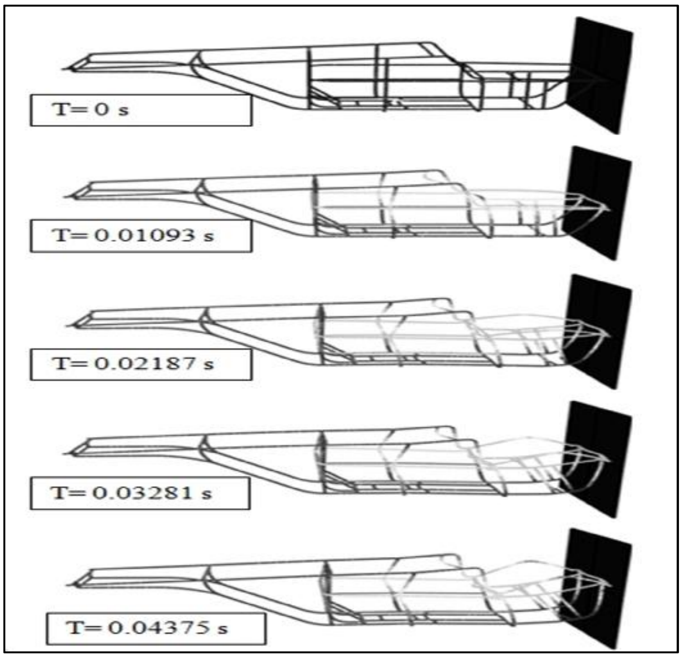

Figure 10. Deformation situations of the numerical results

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Figure 10 revealed that deformation took place at 0.01093s. At that instant, the acceleration graph for that speed showed the value of 11 G. The deformation ended after 0.04375s, with the acceleration found to be below 5 G.

To ensure the safety of drivers, it is important that the compartment collision structure receive the smallest value of impact with an acceleration value within a reasonable limit. The simulation results indicated that the acceleration of the lightweight solar vehicle ranges between 10-20G. This compared favorably with the report by Debs et. al. that the acceleration for the crash impact test for the aluminum base frame vehicle ranges between 30-40 G, to achieve a minimum 3-star rating [12].

6. CONCLUSION

Frontal impact simulations of a lightweight solar vehicle striking a rigid wall have been conducted according to the standards of NASA and NHSTA. An Abaqus/Explicit 6.7 code was used for the simulation due its capability in handling extensive use of contact, able to solve multiple material models and can adapt to a combination of non-traditional elements. Explicit solvers of Abaqus/Explicit 6.7 were found to be more robust and computationally more efficient than the implicit solver. Simulation results showed that the value of acceleration at all speed were below the injury criteria which proved that the aluminum alloy chassis structure used for the vehicle can sufficiently protect the driver from major injuries while driving the lightweight solar vehicle. However the simulation result can be proven by the actual use of an experimental dummy, which will be attempted by the authors soon.

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