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Energy Absorption Efficiency of Crash Box Designs Analysis for NXGV Challenge 2025

M. Z. Mohamed*, M. A. M. Mustafa and M. R. M. Husin

Politeknik Kota Bharu, KM24 Kok Lanas, 16450 Ketereh, Kelantan, Malaysia

*Corresponding author: mzulkafli@pkb.edu.my

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ABSTRACT – *This study aims to develop and compare the effectiveness of two different crash box designs for the NxGV Challenge 2025 vehicle, focusing on enhancing safety and optimizing impact energy absorption. The crash box is a crucial component in electric vehicle (EV) safety systems, designed to absorb collision energy and minimize both driver injuries and structural damage. An efficient crash box reduces the force transmitted to the vehicle's chassis, thereby improving overall crashworthiness. In this research, both crash box designs will be analyzed using HyperMesh for Finite Element Analysis (FEA) to evaluate their structural integrity and impact resistance. Physical impact tests will be conducted to validate simulation results. Both designs will utilize 2mm thick aluminum, selected for its lightweight properties, durability, and high energy absorption efficiency. The impact analysis will simulate a 325kg mass colliding at a velocity of 6.25m/s, representing realistic crash conditions. Performance evaluation will focus on maximum impact force, displacement, and energy absorption efficiency to determine the most effective design. The findings from this study are expected to contribute to the advancement of safer and more efficient crash box designs for lightweight electric race vehicles, with potential applications in real-world automotive safety improvements.*

KEYWORDS: Crash box, design optimization, energy absorption efficiency, Finite Element Analysis, HyperMesh, NxGV challenge

1. INTRODUCTION

Racing vehicles are required to incorporate robust structural safety components capable of effectively absorbing and dissipating collision energy in order to reduce the risk of injury to the driver. One of the key energy-absorbing structures is the crash box, which is positioned at the front end of the chassis. The crash box is specifically engineered to undergo controlled and progressive deformation during a frontal impact (Tan et al., 2021). Through this controlled collapse mechanism, kinetic energy generated during a collision is converted into deformation energy, thereby significantly reducing the magnitude of forces transmitted to the occupant cabin and enhancing overall driver protection.

The NxGV competition places strong emphasis on both vehicle safety and performance, making the optimization of safety-critical components an essential aspect of the design process (Lim & Mansor, 2017; Tan, 2025). Consequently, the crash box must not only comply with regulatory requirements but also achieve optimal functional performance under impact loading (Yusof et al., 2017). This study focuses on the design, analysis, and validation of a crash box using simulation-based methods (Dirgantara et al., 2013). Finite element analysis is carried out using Altair HyperMesh to evaluate structural behavior under frontal impact conditions, with particular attention given to maximizing energy absorption while maintaining peak deceleration (G-force) within acceptable limits. The detailed crash box geometry and dimensional specifications are illustrated in Figure 1.

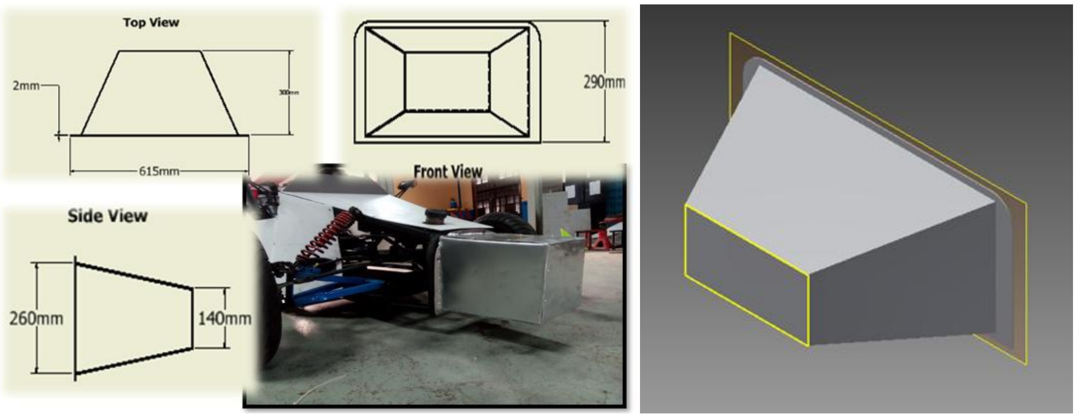


FIGURE 1: Crash box drawing and dimension

2. METHODOLOGY

The crash box was analyzed using the Altair HyperMesh finite element platform (Altair Engineering Inc., 2023). The simulation model involved two configurations:

- **Crash Box 1:** Initial baseline design.
- **Crash Box 2:** Improved version after structural optimization.

The simulation parameters were as follows:

- Vehicle mass: 325 kg
- Impact velocity: 6.25 m/s
- Required average deceleration: ≤ 20 g
- Maximum peak deceleration: ≤ 40 g
- Minimum energy absorption: ≥ 7350 J

The crash box was modelled from 2mm thick steel. The simulation setup involved a frontal collision scenario, and acceleration-time graphs were derived to calculate average and peak decelerations. Energy absorption was measured by the work done by the crash box as it deformed under impact. Crash box simulation conditions are shown in Figure 2.

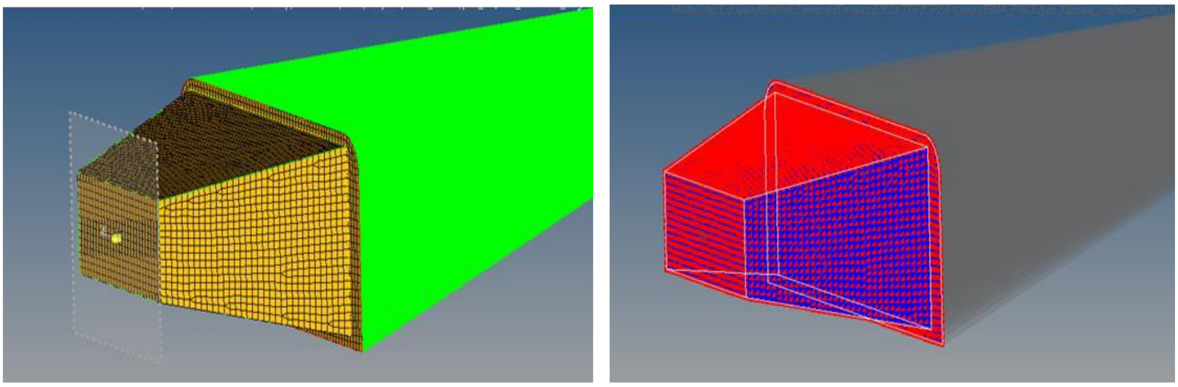


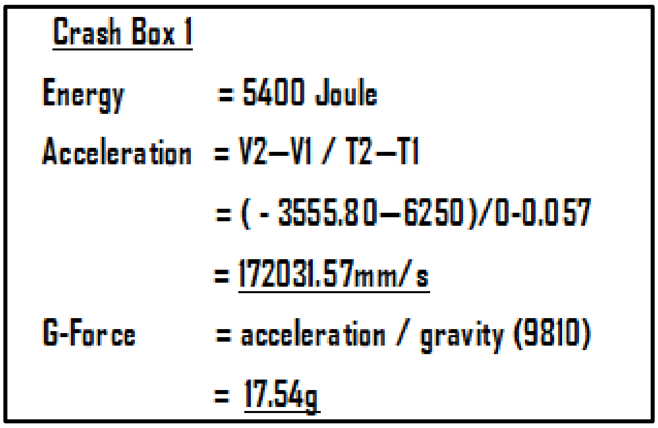
FIGURE 2: Crash box simulation condition setup

3. RESULTS AND DISCUSSION

The crash simulation was conducted on two different crash box configurations: Crash Box 1 (baseline model) and Crash Box 2 (improved model). Both models were constructed using 2mm thick mild steel and tested under identical impact conditions to ensure consistency in result comparison.

3.1 Crash Box 1 Performance

Crash Box 1 absorbed 5400 Joules of impact energy. The deceleration data, obtained from velocity-time plots, revealed an average deceleration calculated as in Figure 3:



Crash Box 1

Energy = 5400 Joule
Acceleration = V2–V1 / T2–T1
= (- 3555.80–6250)/0-0.057
= 172031.57mm/s
G-Force = acceleration / gravity (9810)
= 17.54g

FIGURE 3: Crash Box 1 performance calculation

While the G-force value was within the acceptable safety limits of the NxGV competition (less than 40g), the energy absorption was below the target threshold of 7350 J as specified in the methodology. Visual simulation results (see Figure 3) demonstrated uneven stress distribution across the crash box surface, with stress concentration zones forming near the midsection. This indicates suboptimal deformation behaviour, where energy was not dissipated effectively throughout the structure. Figure 4 shows the conditions of the first crash box after simulation testing.

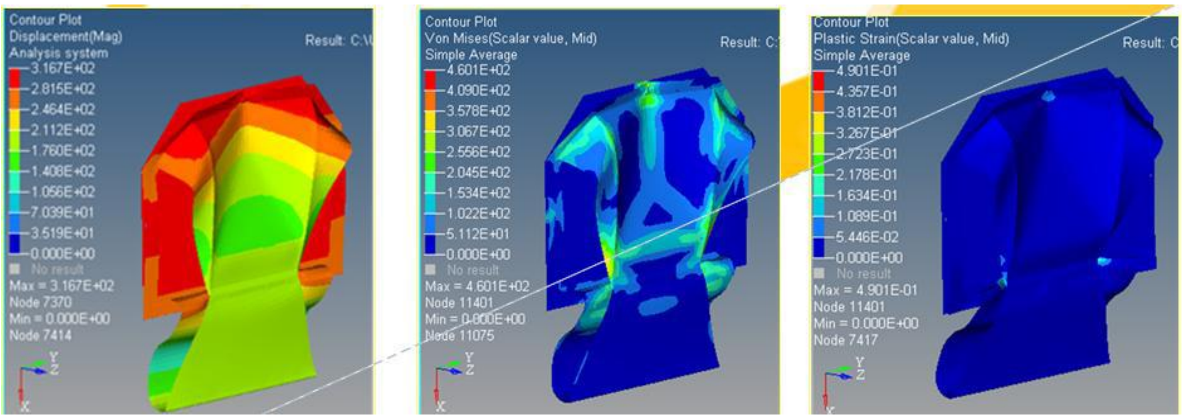


FIGURE 4: Crash Box 1 after simulation testing

Additionally, the force-displacement graph for Crash Box 1 showed a rapid spike followed by a quick drop-off, suggesting that the structure failed abruptly, possibly leading to a sharper impact experience for the driver. From a safety standpoint, such a sudden failure is less desirable such as Figure 5.

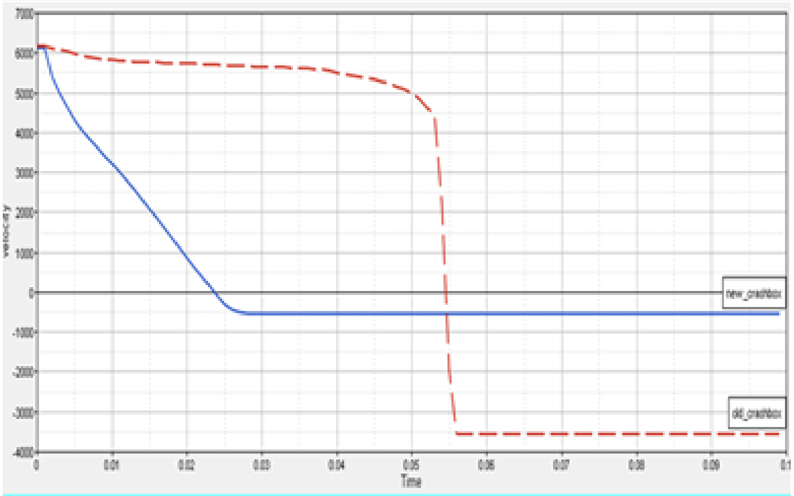
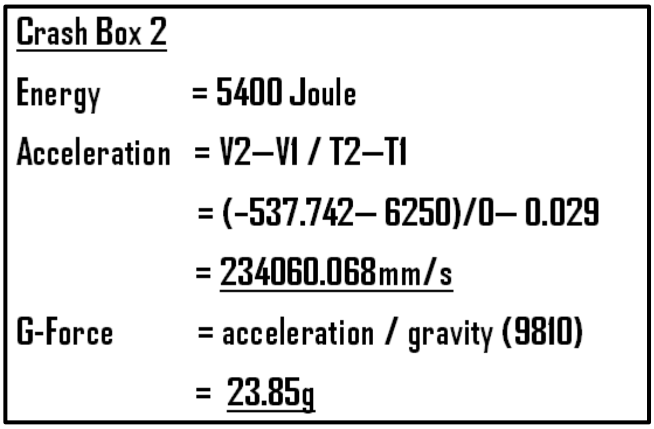


FIGURE 5: Graph for Crash Box 1 force displacement

3.2 Crash Box 2 Performance

Crash Box 2, developed through iterative optimization of geometry and wall stiffness, also absorbed 5400 Joules of energy but did so more effectively over time. The calculated deceleration is as per Figure 6.


Crash Box 2

Energy = 5400 Joule

Acceleration = V2–V1 / T2–T1

= (-537.742– 6250)/0– 0.029

= 234060.068mm/s

G-Force = acceleration / gravity (9810)

= 23.85g

FIGURE 6: Crash Box 2 performance calculation

Although this G-force value was higher than that of Crash Box 1, it still falls within the safe range stipulated by competition guidelines (not exceeding 40g peak). More importantly, simulation visualizations show a more controlled and progressive deformation pattern, with energy distributed more evenly along the entire structure of the crash box.

The force-displacement graph for Crash Box 2 shows a smoother gradient, indicating a more ductile failure behavior. This translates into more predictable crash energy absorption, a key factor in occupant safety.

The higher deceleration observed in Crash Box 2 does not necessarily indicate inferior performance. In fact, the ability to maintain structural engagement over a shorter time interval while still absorbing the same amount of energy suggests greater crashworthiness. The structure deforms in a way that manages the kinetic energy efficiently, reducing the risk of intrusion into the driver's compartment.

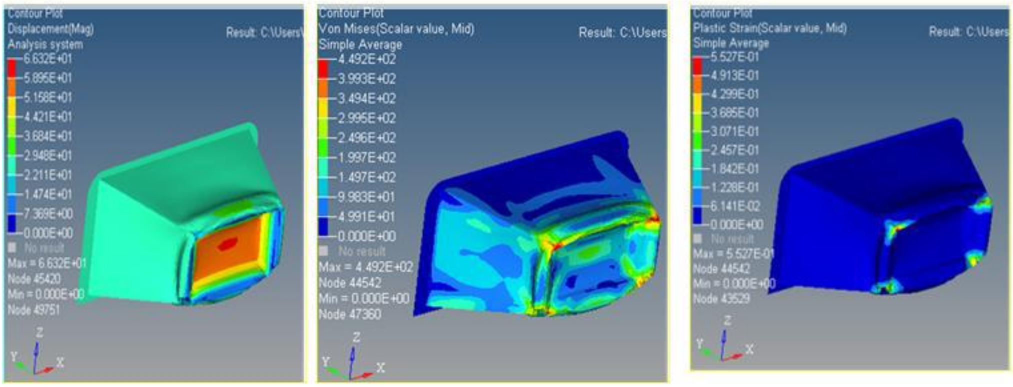


FIGURE 7: Crash Box 2 after simulation testing

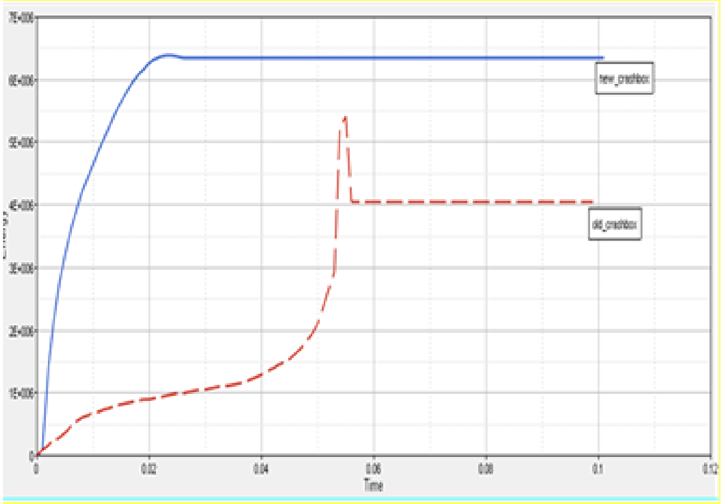


FIGURE 8: Graph for Crash Box 2 force displacement

3.3 Comparative Analysis

From Table 1, it is evident that while both crash boxes absorbed equal energy, Crash Box 2's energy distribution and progressive collapse characteristics make it more suitable for real-world applications. The increase in G-force is a trade-off for better energy dissipation over time.

TABLE 1: Comparative analysis between the two designs

Parameter	Crash Box 1	Crash Box 2
Energy Absorbed (J)	5400	5400
Average Deceleration	17.54 g	23.85 g
Structural Behavior	Brittle	Ductile
Energy Distribution	Localized	Uniform
Simulation Failure Mode	Sudden Buckling	Progressive Folding

4. CONCLUSION

This study successfully evaluated two crash box designs for use in a formula-style racing machine. The findings indicate that Crash Box 2 achieved better energy absorption through optimized deformation characteristics. While the resulting G-force increased compared to Crash Box 1, it remained within safe limits. The improved crash box satisfies the safety criteria of the NxGV competition. Crash Box 2 is thus recommended for future NXGV vehicle integration due to its superior crash energy management.

Future work may include: (i) exploring lightweight composite materials to reduce vehicle mass while maintaining structural integrity; (ii) implementing multi-directional impact simulations (frontal, lateral, and oblique); (iii) investigating thermal behaviour and heat dissipation during impact for high-speed crash scenarios; and studying the integration mechanics between the crash box and vehicle chassis for enhanced energy transfer control.

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REFERENCES

Altair Engineering Inc. (2023). Altair HyperWorks 2023 documentation – Crash simulation and optimization. Retrieved from https://www.altair.com

Dirgantara, T., Gunawan, L., Putra, I. S., Sitompul, S. A., & Jusuf, A. (2013). Numerical and experimental impact analysis of square crash box structure with holes. Applied Mechanics and Materials, 393, 447-452.

Lim, S. J., & Mansor, M. R. A. (2017). Aerodynamic analysis of F1 IN SCHOOLS™ car. Journal of the Society of Automotive Engineers Malaysia, 1(1), 41-54.

Tan, D. (2025). Inaugural NxGV Challenge 2025 by Perodua, MARii and SAEM – tertiary students develop and market an EV. Retrieved from www.paultan.org

Tan, H., He, Z., Li, E., Cheng, A., Chen, T., Tan, X., ... & Xu, B. (2021). Crashworthiness design and multi-objective optimization of a novel auxetic hierarchical honeycomb crash box. Structural and Multidisciplinary Optimization, 64(4), 2009-2024.

Yusof, N. S. B., Sapuan, S. M., Sultan, M. T. H., Jawaid, M., & Maleque, M. A. (2017). Design and materials development of automotive crash box: A review. Ciência & Tecnologia dos Materiais, 29(3), 129-144.