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Design and Analysis of Solar Car Chassis for WSC 2023

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Abstracts: The World Solar Challenger is a biennial global competition that plays a crucial role in testing and advancing the technological limits of solar-powered vehicles, particularly in the context of diverse travel conditions. The competition features three categories: Challenger Class, Cruiser Class, and Adventure Class. In 2023, Siam Technology University participated with the STC-4 model in the Cruiser Class. This research contributed to the vehicle's design, structural integrity, safety, and performance evaluation, essential for passing the scrutineering tests. Researchers were involved in shaping the vehicle's aerodynamics, analyzing structural aspects, and designing safety features compliant with World Solar Challenge 2023 requirements. The goal was to ensure the vehicle's safe participation and successful operation under varied conditions. The designed solar-powered vehicle, STC-4, aimed to address shortcomings from previous competitions. The structural framework, utilizing AISI 4130 steel, met safety standards, with a final weight of 258 kg. Structural testing ensured that the displacement did not exceed 25 mm. Finite Element Analysis confirmed the structural integrity, aligning with the team's objectives. In conclusion, this research significantly contributed to the design and safety aspects of solar-powered vehicles, as demonstrated by the successful participation of STC-4 in the World Solar Challenge 2023 Cruiser Class. The findings highlight advancements in structural design, safety measures, and performance capabilities, emphasizing the importance of continuous innovation in solar vehicle technology.

Keywords: Finite Element Analysis (FEA), Welding, Structural Framework, Solar-Powered.

1. INTRODUCTION

The World Solar Challenge, inaugurated by Bridgestone in 1987, stands as a prestigious competition that has consistently propelled innovation and technological advancements in the realm of solar-powered transportation. Held biennially, this global event attracts teams from high schools and universities worldwide, showcasing their inventive spirit by designing and constructing solar-driven vehicles. The challenging 3,000-kilometer journey from Darwin to Adelaide in 2019 witnessed the participation of 53 teams from 24 countries, capturing the attention of over 1,500 enthusiasts and reaching an extensive viewership exceeding 25 million. This competition operates as a catalyst for transformative innovations across various industries, including energy, automotive, engineering, finance, and material science. It has evolved into a platform where diverse sectors converge to explore educational opportunities and foster collaborations [1].

Aerodynamics, a cornerstone of solar-powered racecar performance, receives substantial investment from racing teams. Employing three standard procedures – road tests, wind tunnel tests, and Computational Fluid Dynamics (CFD) simulations – teams strive for aerodynamic excellence. Despite the popularity of CFD due to its cost-effectiveness and detailed flow field descriptions, race-sanctioning bodies impose restrictions on wind tunnel and CPU hours. This necessitates the development of accurate, reliable, and time-efficient CFD methods [2,3,4].

The classification of CFD methods into Scale-Averaged Simulations (SAS) and Scale-Resolved Simulations (SRS) presents a dilemma. While SRS approaches offer heightened confidence in aerodynamic predictions, their computational cost proves prohibitive for the racing industry. SAS approaches, particularly steady-state Reynolds-Averaged Navier–Stokes (RANS) simulations, retain favor due to their balance between prediction accuracy and reduced computational costs. The critical elements for achieving accurate results lie in the judicious selection of turbulence models and solver parameters [5,6,7]. Beyond the intricacies of aerodynamics, the suspension system emerges as a paramount factor in ensuring passenger safety and comfort. Responsible for dissipating kinetic energy and regulating shocks and vibrations, the suspension system incorporates shock absorbers and springs. This system significantly contributes to vehicle control and ride quality, influencing the overall driving experience [8,9,10].

Within this overarching context, our current research focuses on the “Design and Analysis of the solar car chassis for WSC 2023.” This study presents a comprehensive exploration, encompassing Static Tests, Dynamic Tests, and the meticulous selection of materials tailored to design requirements. Initial structural vulnerabilities identified through analysis are addressed through reinforcement strategies, such as adjusting weld sizes or adding bracing to enhance strength. Subsequent phases involve iterative analysis and design modifications until alignment with WSC specifications is achieved [11,12,13,14]. This research aspires to contribute to the ongoing evolution of solar-powered transportation systems, aligning with the objectives of the World Solar Challenge, and addressing contemporary challenges prevalent in the racing industry.

2. MATERIEL AND METHODS

The Bridgestone World Solar Challenge (2023) competition attracts students from various institutions across different countries. Prior to the competition, solar-powered vehicles undergo performance testing through scrutineering, consisting of static and dynamic tests. Static tests include brake system checks, tilt testing, steering control, and overall vehicle stability assessment, focusing on structural strength. Dynamic tests assess acceleration rates, sliding distances, obstacle navigation, energy consumption rates, and long-term durability. Solar vehicles are expected to be highly efficient, energy-saving, and comply with safety design principles set by the competition organizers each year.

The structural design follows competition regulations, initially constructed based on the competition's rules, with small-scale structural additions in the form of triangular truss framework to enhance strength against compression or tension forces. The design approach ensures ease of production, repair, and maintenance. Research contributions to structural design and material selection aim to provide guidelines for future solar car models. Previous studies, such as [15] on race car chassis design for competition and weight maintenance, and [16] focusing on circular tube structures to withstand racing-induced moments, have influenced and informed the development of the solar car structure.

In the investigation of circular tube structures, testing demonstrated the maximum deformation of 6.67 mm under front-facing forces. Subsequent torsion testing with a torque of 2.314 kN-m per degree resulted in a displacement of 1.12 mm, indicating that the cylindrical tube could withstand the specified force with a displacement within the 25 mm standard [16].

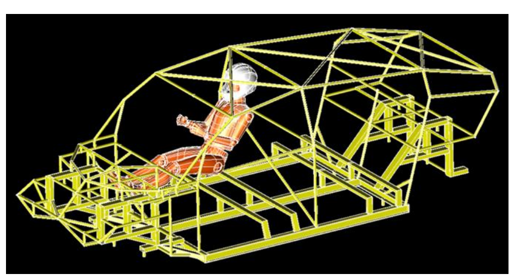

Figure 1. Demonstrate the positioning of the driver to align with the main structure

The static test involves testing and analysis using computer simulation programs to identify initial weak points and vulnerabilities in the structure. Subsequently, reinforcement is implemented by increasing the size of welds, adding structural components, or reinforcing support at identified weak points. The design is then reanalyzed and modified iteratively until it meets the specifications outlined by the World Solar Challenge (WSC) competition guidelines.

2.1. Material Selection

The structure must withstand various forces during the movement of the solar-powered vehicle. The vehicle should maintain its original condition without deformation, endure vibrations, and withstand high-temperature conditions. Therefore, material properties play a crucial role in designing and constructing solar vehicles. Tubular steel, specifically Chromium Molybdenum steel (Chromoly), is chosen for the structure over monocoque structures despite the additional weight. This decision is influenced by lower construction costs, easier accessibility to tools, and simplified repairs in case of damage.

Two main materials utilized in creating the structural framework are Chromium Molybdenum steel (Chromoly) and SAE-AISI 1018. Both materials are analyzed and tested for various parameters. Ultimately, Chromoly steel 4130 is chosen for construction due to several reasons.

Table 1. Material properties [16]

PROPERTIES	SAE AISI 1018	Chromoly 4130 Steel
Density (g/cc)	7.8	7.8
Young's Modulus (GPa)	210	210
Elongation at break (%)	19	19
Brinell Hardness	120	200
Strength to weight ratio at Yield (kN-m/kg)	38	100
Yield Strength (MPa)	360	480
Ultimate Strength (MPa)	420	590
Thermal Conductivity: Ambient (W-m/K)	50	42
Thermal Expansion: 20C to 100C (μm/m-K)	11	12
Specific Heat Capacity Conventional (J/kg-K)	370	370

While SAE-AISI 1018 steel outperforms Chromoly steel 4130 in terms of temperature resistance, it falls short in terms of strength. However, the primary consideration in the design is the safety of the passengers. Therefore, Chromoly steel 4130 is selected for its superior strength and durability, even though it comes at a higher cost compared to SAE-AISI 1018 steel. Table 1 compares the properties of SAE-AISI 1018 steel and Chromoly steel 4130.

2.2. Ergonomics

In the field of ergonomics [17], the study focuses on the collaboration between humans and machinery, a crucial aspect that determines the level of comfort for users interacting with the vehicle. Machinery should be user-friendly, providing convenience and safety for drivers. In the research report [17], valuable information aids in decision-making regarding the driver's position concerning the overall size of the vehicle. Decisions about the driver's position involve considerations such as the distance to the driver's helmet, the position of the elbows, the steering wheel's placement, the driver's foot placement, and more. This information guides decisions about the tilt angle of the driver's seat. Therefore, ergonomics is a critical science in the structural design process, aligning with the regulations of the WSC 2023 competition.

Following ergonomic considerations, the design process proceeds to address other vital components, such as the positioning of the engine, which, in the case of a solar-powered vehicle, corresponds to the battery's location.

Subsequently, the suspension system, control box placement, and solar panel array positions are determined. After finalizing the placement of all components, the next step involves creating various nodes for analysis according to the simulation rules in computer simulation programs. Following the mock-up design, ensuring alignment with WSC 2023 specifications, a thorough design check is performed before initiating computer simulation using the siumulation program.

3. RESULTS AND DISCUSSIONS

The completion of structural strength analysis is achieved through the utilization of the simulation computer program. This analysis is specifically conducted to assess the structure's strength under impact conditions. The process involves creating a 3D mesh on a 3D model of the structure, drawn for testing purposes. Subsequently, the model is subjected to various impact forces in multiple directions to evaluate its performance.

The impact analysis is performed on the solar-powered vehicle structure, considering a diverse range of impact conditions. The 3D model is used to simulate both static and dynamic tests**,** categorized as follows.

3.1. Top Impact (Static Test)

In a hypothetical scenario where the solar-powered car experiences a top impact, assuming the car is overturned and subjected to a force acting from the top towards the bottom with a magnitude of 5g, the design considerations are as follows:

Using the formula F = Mass x Acceleration,

F = 1,500 x (5xg)

F = 73,575 N

This load is uniformly distributed across the top structure of the solar-powered vehicle upon completion, which has an anticipated weight of 1,500 kg.

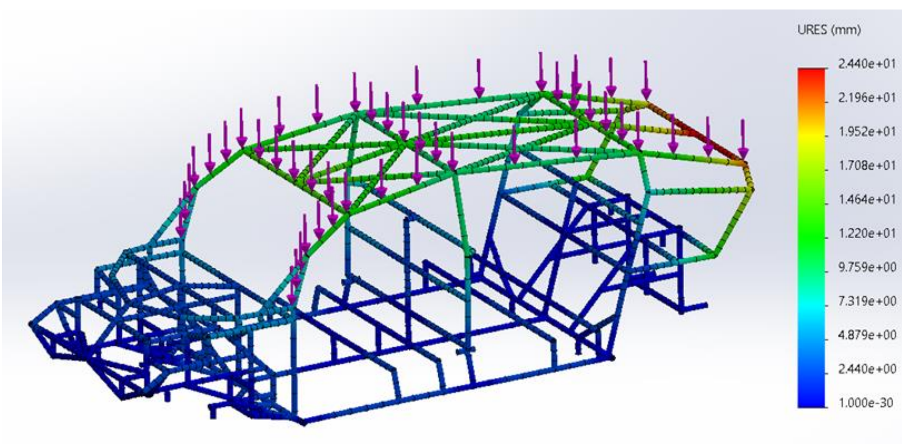

Figure 2. Simulation Results of Top Impact in Static Test

Figure 2 illustrates the movement of the structure during the static test simulation for the top impact scenario. The simulation, conducted using the simulation computer program, indicates a maximum displacement of 24 mm. This value falls below the specified threshold in the regulations set by WSC 2023, demonstrating that the solar-powered vehicle design successfully meets the required standards for top impact conditions.

3.2. Top Impact (Dynamic Test)

In the dynamic test for top impact, the same force as in the static test is applied, but it is done dynamically to determine the crush distance under dynamic conditions.

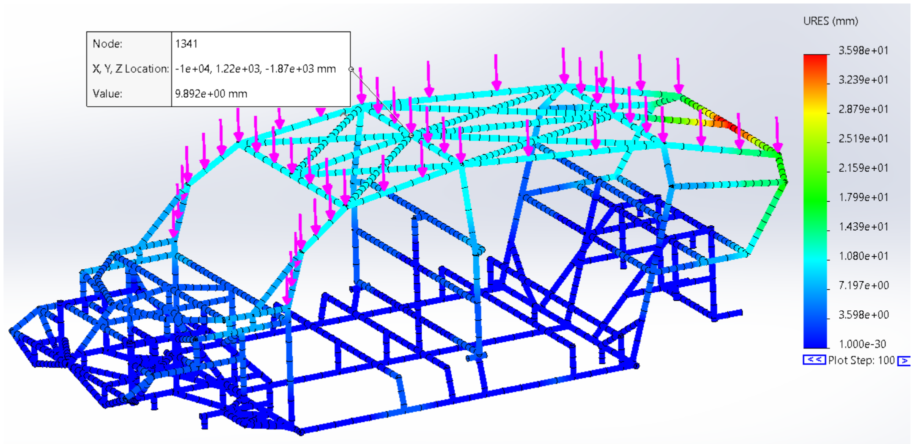

Figure 3. Simulation Results of Top Impact Dynamic Test at Node 1341

As depicted in Figure 3, there is an interval exceeding 25 mm at the rear of the vehicle, outside the passenger compartment, with a value of 36 mm. The team addressed this by constructing additional frame reinforcements to reduce deformation. The simulation focuses on crush distance at Node 1341, a critical area within the passenger compartment. It is observed that the crush distance in this region is 9.89 mm, showcasing the effectiveness of the modifications.

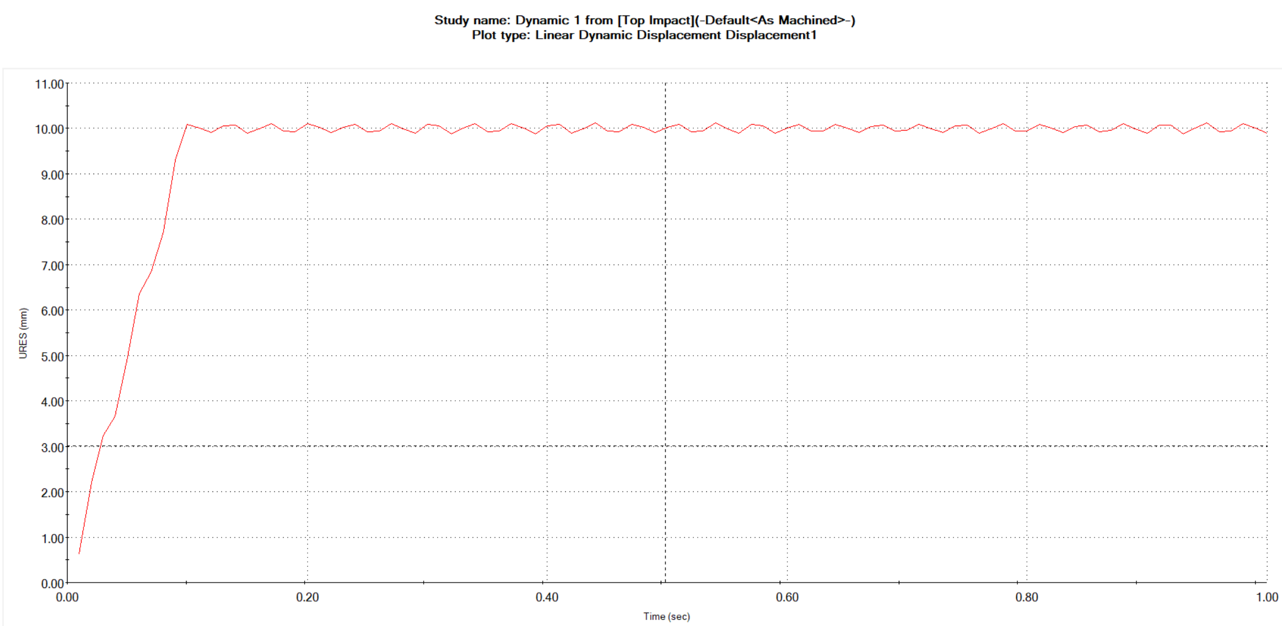

Figure 4. Dynamic Crush Analysis at Node 1341

Figure 4 illustrates the dynamic crush analysis graph at Node 1341, a pivotal point within the passenger compartment considered in Figure 3. The graph initiates from 0 and gradually increases linearly, reaching a value of 10 mm. This dynamic crush analysis provides insights into the deformation behavior under dynamic forces, aiding in the refinement of the vehicle's structural

3.3. Front Impact (Static Test)

In the static test for front impact, it is assumed that the car collides with an obstacle located in front of it. The acceleration for the frontal impact is considered to be 5g.

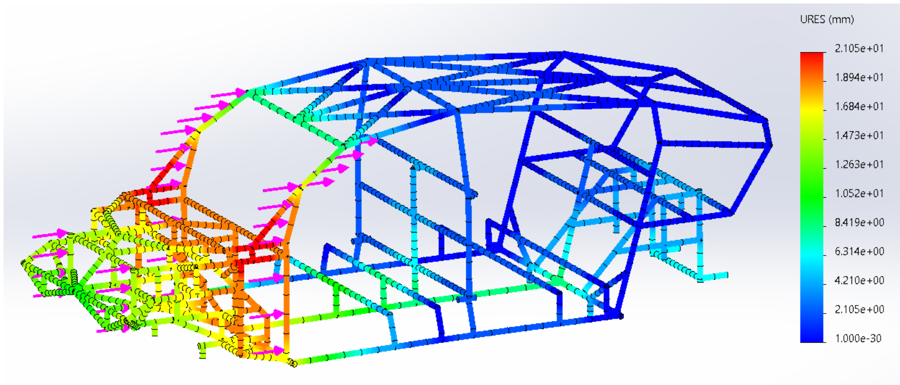

Figure 5. Simulation Results of Front Impact Static Test

Figure 5 illustrates the movement of the vehicle structure based on the static test for front impact. The simulation, conducted using computer simulation software, reveals that the maximum displacement in the static front impact test is 21 mm, which is below the specified value in the WSC 2023 regulations.

3.4. Front Impact (Dynamic Test)

The dynamic test for front impact employs the same force as the static test but is conducted dynamically to determine the dynamic crush distance.

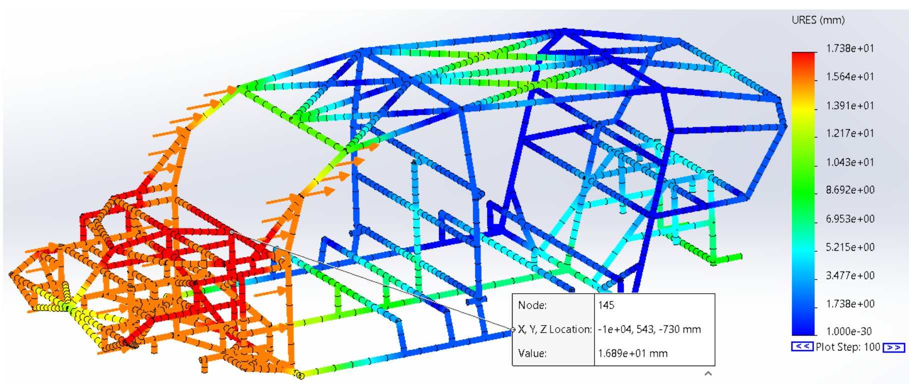

Figure 6. Simulation Results of Front Impact Dynamic Test at Node 145

Figure 6 presents the results of the dynamic test for front impact at Node 145, located in the middle of the structure before reaching the passenger compartment. The maximum crush distance observed is 17 mm, which is below the 25 mm requirement specified in the WSC 2023 regulations. The dynamic crush analysis graph at Node 145 is shown in Figure 7, indicating a gradual increase from 0 to a value of 18 mm.

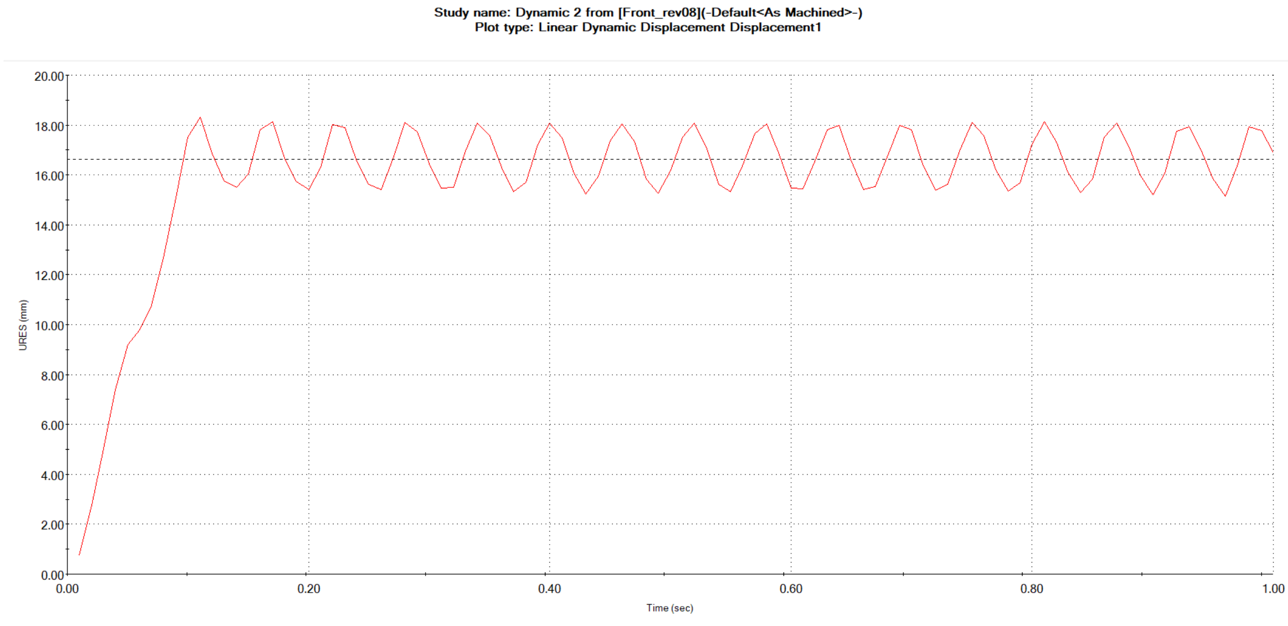

Figure 7. Dynamic Crush Analysis at Node 145

Figure 7 depicts the dynamic crush analysis graph at Node 145, a key point within the passenger compartment considered in Figure 6. The graph initiates from 0 and gradually increases linearly, reaching a value of 18 mm. This dynamic crush analysis provides insights into the deformation behavior under dynamic forces during a frontal impact, aiding in the refinement of the vehicle's structural design.

3.5. Side Impact (Static Test)

In the static test for side impact, it is assumed that the car is struck by another vehicle with the force directed from the right to the left, impacting the driver's side. The acceleration for the side impact is considered to be 5g.

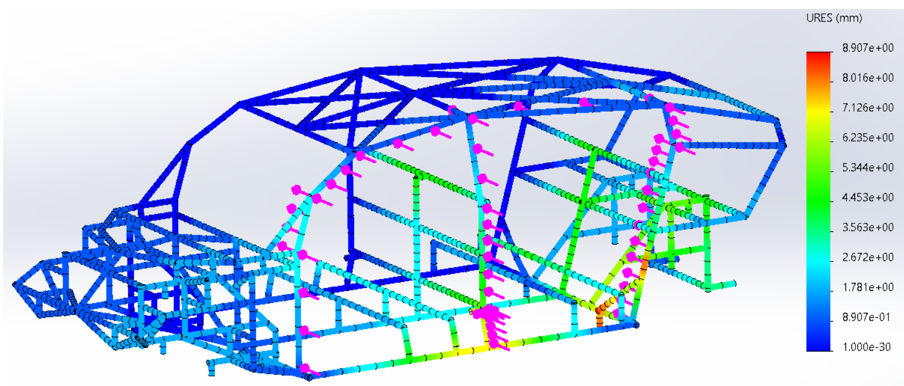

Figure 8. Simulation Results of Side Impact Static Test

Figure 8 depicts the deformation of the vehicle structure based on the static test for side impact. The simulation, conducted using computer simulation software, indicates that the maximum displacement in the static side impact test is 9 mm, which is below the specified value in the WSC 2023 regulations.

3.6. Side Impact (Dynamic Test)

The dynamic test for side impact employs the same force as the static test but is conducted dynamically to determine the dynamic crush distance.

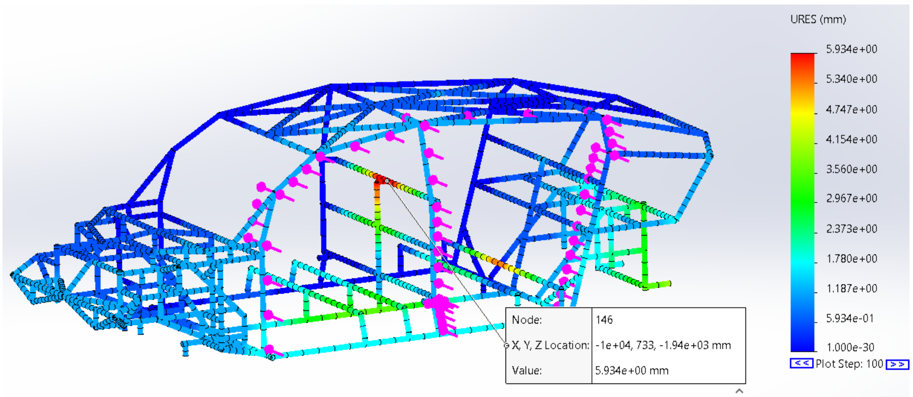

Figure 9. Simulation Results of Side Impact Dynamic Test at Node 146

Figure 9 presents the results of the dynamic test for side impact at Node 146, located in the middle of the structure before reaching the passenger compartment. The maximum crush distance observed is 6 mm, which is below the 25 mm requirement specified in the WSC 2023 regulations. The dynamic crush analysis graph at Node 146 is shown in Figure 10.

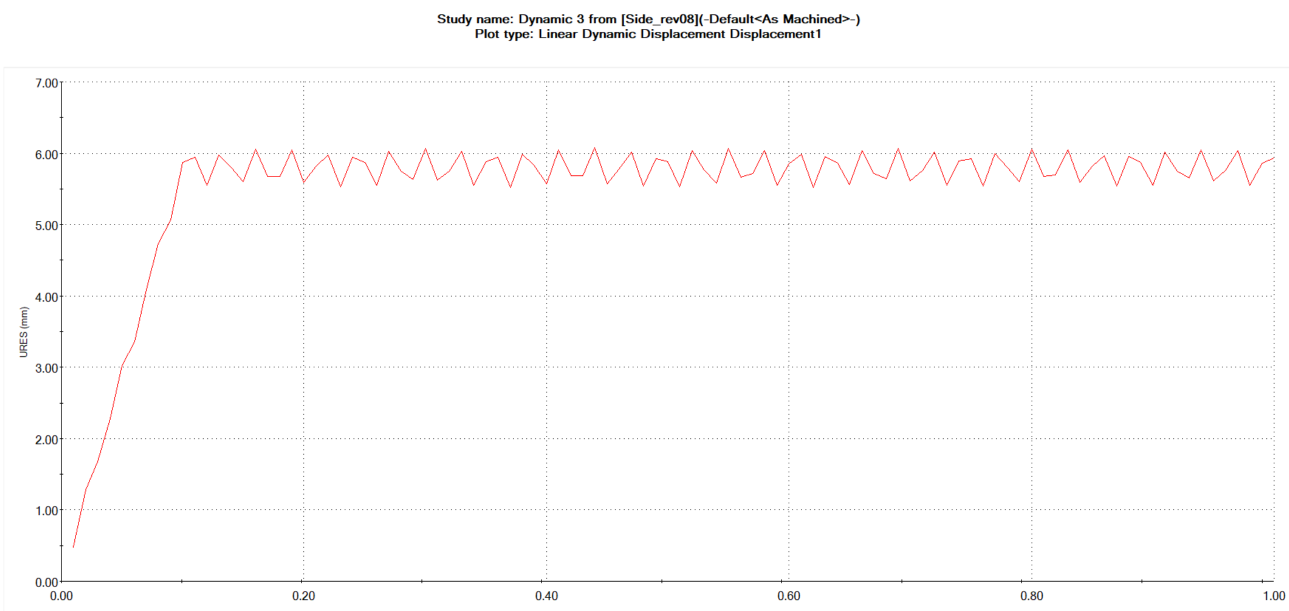

Figure 10. Dynamic Crush Analysis at Node 146

Figure 10 illustrates the dynamic crush analysis graph at Node 146, a key point within the passenger compartment considered in Figure 9. The graph starts from 0 and gradually increases linearly, reaching a value of 6 mm. This dynamic crush analysis provides insights into the deformation behavior under dynamic forces during a side impact, aiding in the refinement of the vehicle's structural design.

The simulation tests were conducted using computer simulation software to assess the vehicle's performance in collisions from all three sides, adhering to the specifications of the World Solar Challenge 2023 competition. The tests were categorized into two types as static tests, considering a specific moment in time, and dynamic tests, spanning from the initiation of impact to a stabilized state.

The results of both static and dynamic tests are illustrated in Figures 2 to 10. Across all tests, it is observed that the deformation values do not exceed 25 mm, aligning with the competition regulations. This outcome underscores the structural safety of the vehicle for both passengers and drivers.

The comprehensive simulation analyses provide valuable insights into the structural integrity and crashworthiness of the solar-powered vehicle. Meeting the stipulated criteria ensures that the vehicle is designed with safety considerations in mind, aligning with the stringent safety standards set by the World Solar Challenge 2023.

CONCLUSIONS

In conclusion, the structural strength analysis of the solar-powered vehicle, conducted through extensive simulations, has provided critical insights into its performance under various impact conditions. The comprehensive evaluation covered both static and dynamic tests, assessing the vehicle's resilience to hypothetical scenarios outlined by the World Solar Challenge 2023 regulations. The top impact simulations, considering both static and dynamic tests, demonstrated that the vehicle design successfully met the stringent standards set by the WSC 2023. The results indicated maximum displacements well below the specified threshold, showcasing the vehicle's robustness in withstanding forces acting from the top. Similarly, the front and side impact simulations, in both static and dynamic contexts, exhibited promising results. The vehicle's structural design consistently yielded deformations below the prescribed limits, affirming its crashworthiness and adherence to safety regulations. The dynamic crush analyses at critical nodes within the passenger compartment further enhanced our understanding of the deformation behavior under dynamic forces. Modifications made, such as additional frame reinforcements, proved effective in mitigating excessive crush distances, ensuring the safety of occupants during collisions. The overall outcome of the research signifies that the solar-powered vehicle has been meticulously designed to prioritize safety, meeting and often surpassing the criteria established by the WSC 2023. These findings not only validate the structural integrity of the vehicle but also provide valuable insights for continuous refinement and optimization in future solar-powered vehicle designs. The successful completion of this structural analysis underscores the commitment to safety and innovation within the realm of solar-powered vehicle development.

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REFERENCES

[1] A.S. Misar, M. Uddin, T. Pandaleon, J. Wilson, “Scale-Resolved and Time-Averaged Simulations of the Flow over a NASCAR Cup Series Racecar,” SAE WCX Technical Paper: 2023-01-0118, SAE: Warrendale, PA, USA, 2023.

[2] C. Fu, M. Uddin, C. Robinson, A. Guzman, D. Bailey, “Turbulence models and model closure coefficients sensitivity of NASCAR Racecar RANS CFD aerodynamic predictions,” SAE Int. J. Passeng.-Cars-Mech. Syst., 2017, 10, 330–345.

[3] A.S. Misar, M. Uddin, “Effects of Solver Parameters and Boundary Conditions on RANS CFD Flow Predictions over a Gen-6 NASCAR Racecar,” SAE WCX Technical Paper: 2022-01-0372, SAE: Warrendale, PA, USA, 2022.

[4] C. Fu, M. Uddin, C. Selent, “The Effect of Inlet Turbulence Specifications on the RANS CFD Predictions of a NASCAR Gen-6 Racecar,” SAE WCX Technical Paper: 2018-01-0736, SAE: Warrendale, PA, USA, 2018.

[5] C. Fu, M. Uddin, C. Zhang, “Computational Analyses of the Effects of Wind Tunnel Ground Simulation and Blockage Ratio on the Aerodynamic Prediction of Flow over a Passenger Vehicle,” Vehicles, 2020, 2, 318–341.

[6] C. Fu, C. Bounds, M. Uddin, C. Selent, “Fine Tuning the SST $k-\omega$ Turbulence Model Closure Coefficients for Improved NASCAR Cup Racecar Aerodynamic Predictions,” SAE Int. J. Adv. Curr. Pract. Mobil., 2019, 1, 1226–1232.

[7] C. Fu, M. Uddin, A.C. Robinson, “Turbulence modeling effects on the CFD predictions of flow over a NASCAR Gen 6 racecar,” J. Wind. Eng. Ind. Aerodyn., 2018, 176, 98–111.

[8] N. Ashton, A. West, S. Lardeau, A. Revell, “Assessment of RANS and DES methods for realistic automotive models,” Comput. Fluids, 2016, 128, 1–15.

[9] A.S. Misar, M. Uddin, A. Robinson, C. Fu, “Numerical Analysis of Flow around an Isolated Rotating Wheel Using a Sliding Mesh Technique,” SAE WCX Technical Paper: 2020-01-0675, SAE: Warrendale, PA, USA, 2020.

[10] C. Zhang, C.P. Bounds, L. Foster, M. Uddin, “Turbulence modeling effects on the CFD predictions of flow over a detailed full-scale sedan vehicle,” Fluids, 2019, 4, 148.

[11] Farooq, A. J., Akhtar, S., Hijazi, S. T., & Khan, M. B. (2010). Impact of advertisement on children behavior: Evidence from pakistan. European Journal of Social Sciences, 12(4), 663-670.

[12] B. Zhang, C.A. Tan, T. Dai, “Ride comfort and energy dissipation of vehicle suspension system under non-stationary random road excitation,” Journal of Sound and Vibration, vol. 511, 2021.

[13] C. Zhang, M. Uddin, L. Foster, “Investigation of the Turbulence Modeling Effects on the CFD Predictions of Passenger Vehicle Underhood Airflow,” SAE WCX Technical Paper: 2018-01-0476, SAE: Warrendale, PA, USA, 2018.

[14] A. Aboazoum, “An overview of the most common vehicle suspension problems,” Brilliance: Research of Artificial Intelligence, vol. 2, pp. 120–124, 2022.

[15] J. Theunissen, A. Tota, P. Gruber, M. Dhaens, A. Sorniotti, “Preview-based techniques for vehicle suspension control: a state-of-the-art review,” Annual Reviews in Control, vol. 51, 2021.

[16] A. J. A. Y. Kashikar, S. H. R. E. Y. A. S. Mhatre, A. Gunpalli, R. A. H. U. L. Chavan, and A. B. H. I. S. H. E. K. Shukla, “Design and Analysis of Formula Car Chassis,” International Journal of Research Publications in Engineering and Technology, pp. 3-3, 2017.

[17] P. Kumar MP and V. Muralidharan, “Design and analysis of a tubular space frame chassis of a high-performance race car,” International Journal of Research in Engineering and Technology, vol. 3, no. 02, 2014.

[18] W. B. Riley and A. R. George, “Design, analysis and testing of a formula SAE car chassis,” SAE Technical Paper 2002-01-3300, 2002.

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