Lightweight Design of Honda Energy-Saving Racing Single-Shell Body based on Carbon Fiber Material

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Abstract. In order to obtain a lightweight Honda energy-saving race car body, the carbon fiber materials and monocoque technology were introduced into the design of the car body. Firstly, a lightweight structural monocoque body geometric model was constructed. Then the design geometric model was subjected to static strength, and the performance simulation analysis of the front collision condition and the rollover condition showed that the designed monocoque body can meet the requirements. Finally, the monocoque body model was processed and manufactured, which was assembled and integrated on the car for physics. The experiment results showed that the designed lightweight body meet the requirements of work performance.

1. Introduction
Honda Energy Contest is a competition held by Honda Automobile Co., Ltd. for Chinese college students and Honda Automobile subsidiaries. The race is divided into college and enterprise groups, and each group is divided into fuel fleet and EV (electric racing). Team [1]. Among them, the fuel car race of the university group requires the development of a small car with more than 3 wheels (including 3 wheels) equipped with a Honda four-stroke 125cc engine as a basic component within one year. An energy-saving competitive event that uses a specified amount of gasoline to run at a speed and within a specified time, and finally calculates how many kilometers a liter of gasoline can run [2]. The energy-saving competition is a social activity of "environmental protection, fun, and challenge", which was launched by Honda in 1981. China introduced the competition in 2007 and currently has over 100 teams.

At present, the international realization of body weight reduction mainly adopts three methods of lightweight structure design, lightweight materials and lightweight processing technology [3]. The single shell technology is a new type of lightweight structural technology, which is different from the traditional skeleton-bearing structure. It is an integrated structure that supports the load through the shell surface [4]. Monolithic shell technology originated in aircraft and ships. The monolithic shell first appeared in the F1 race in 1962. This Lotus car with a metal shell has larger cockpit space, larger torsional rigidity and Lighter and lighter, this successful attempt has also begun to apply monolithic shell technology to automotive product development, such as Jaguar XJ [5]. Because the rigidity and strength of the monocoque body are related to the shell material, major automakers and teams want to find lighter and stronger materials to replace traditional metal materials.

Carbon fiber is a special material composed of carbon elements. Because its graphite microcrystalline structure is preferentially oriented along the fiber axis, it has a very high strength and modulus along the fiber axis direction, and the density of carbon fibers is small, so the specific strength and specific modulus The amounts are very high [6,7]. Since the beginning of the 1990s, high-performance and ultra-high-performance carbon fibers have been introduced, and they have
gradually begun to be used in aircraft and automobiles. In recent years, applications in automobiles have been in a period of rapid development. Tesla Roadster sports car, SLR McLaren supercar, BMW i3 and other car body parts use carbon fiber in large quantities [8]; in domestic such as Zhengzhou Yutong, Suzhou Jinlong, Ankai and other passenger car factory bumper, side panels Car body parts such as trunk door assemblies have begun to use carbon fiber, while carbon fiber materials have been used for front-end parts of car bodies such as Bora, Logo, and Audi A6.

Carbon fiber composite materials with sandwich structure are currently widely used. This structure type uses carbon fiber as the panel, and the sandwich layer uses foam, cotton, honeycomb aluminum and other low density materials [6]. Because hexagonal honeycomb aluminum has high rigidity and energy absorption performance, the sandwich structure made of carbon fiber and hexagonal honeycomb aluminum has high strength and stiffness. The monocoque body with this structural material will have greater torsional stiffness and lighter weight. At present, the single-shell carbon fiber composite material has begun to be used in formula racing cars, but it is rarely used in domestic Honda energy-saving competitions. In view of this, this article uses a combination of these two lightweight approaches to design the body participating in the energy-saving race, and conducts performance research and evaluation of the designed body.

2. Energy-Saving Racing Body Design

2.1. Requirements for the Body of the Race Rules

The 13th Honda China Energy Conservation Competition in 2019 proposed overall requirements for the car body: the participating vehicles with integrated car bodies must have more than 3 wheels (including 3 wheels), and their structure must be more than 3 wheels when stopping or driving (including 3 wheels) structure and can stand on its own, the car is less than 1.8 meters high, the wheelbase is less than 1 meter, the total length is less than 3.5 meters, the track length is less than 0.5 meters, and the full width is less than 1.7 meters. The front end of the helmet is located behind the front wheel axle. In the event of a collision, the body structure needs to avoid direct impact on the head. In the driving posture, the body structure must ensure that the rider's feet will not reach the front of the frame (pedal). The body structure must avoid direct impact from the body.

2.2. Body Shape Design and Geometric Modeling

The body shape is mainly divided into half-package and all-package. Because this competition is an energy-saving competition, according to the experience of multiple energy-saving competitions and statistics, the all-inclusive shape of the car body is adopted. This form has the best effect on reducing wind resistance, which will reduce fuel consumption, so choose All-inclusive body. The external forms of natural creatures such as dolphins and whales not only meet people's aesthetic requirements, but also are streamlined that are conducive to energy saving. Among them, the water drop shape is the currently known shape with the smallest air resistance, so the body shape design mainly mimics the drop shape [9].

Ergonomics is very important for Honda energy-efficient racing. In the race, the driver is the key factor that determines the performance of the race, and whether the driver can achieve the ultimate performance of the car depends on whether the driver can comfortably drive the car, which requires the ergonomic adaptability of the car design. After meeting the requirements of the race rules, the ergonomics of the car needs to be designed. As a good ergonomics, the monocoque racing car body must meet at least three points [9]: 1) the driver must be comfortable in sitting or lying position; 2) the driver's vision must be wide and the safety must be ensured; With enough space, no thugs will appear within the operating range.

According to the requirements of the race, comprehensively consider the influence of the overall layout of the modules such as the frame, power system, starting device, battery, brake and steering, and refer to its water droplet shape and aircraft fuselage cross-section data to determine the basic parameters of the car body. The corresponding Imagine & Shape module of the Catia software shape design module completes the 3D geometric model of the car body. The point and line diagram of the body design project is shown in Figure 1. The resulting initial design geometry of the vehicle body is
shown in Figure 2.

Figure 1. Dotted line drawing of body design engineering  Figure 2. Initial body design geometry

3. Body Shell Structural Performance Analysis
In the Honda Energy Contest, the monocoque body will be subjected to loads from various positions and directions due to the car's running process, and when the car is running to extreme conditions, the load on the monocoque will reach its peak. Therefore, this paper uses finite element analysis software to analyze the performance of the carbon fiber monocoque body under extreme conditions.

3.1. Pre-Processing of Finite Element Analysis of Monocoque Body
The established geometric model of the single shell is imported into the finite element analysis software. Since the quality of the mesh elements affects the calculation speed and accuracy, the geometry is cleaned after the model is imported, and then the material properties of the single shell are defined. It includes carbon fiber cloth and honeycomb aluminum. The density of the carbon fiber cloth is 1.6-2.5g/cm³ and the tensile strength is 2.2Gpa. The properties of the honeycomb aluminum material are shown in the following table [10].

| properties                        | Value   |
|-----------------------------------|---------|
| Young's modulus /GPa              | 72.4    |
| Poisson's ratio                   | 0.33    |
| density (kg/m³)                   | 2780    |
| Yield Strength /MPa               | 39.5    |
| Shear strength /GPa               | 28      |

According to the geometric characteristics of the carbon fiber single shell, the overall mesh size control is set to 25, the local connection and contact area, and the area where the load will cause stress integration is controlled to 5mm. The average average distortion of the mesh after the mesh is set to 0.24. The model after meshing is shown in Figure 3.

Figure 3. Monocoque body mesh model

3.2. Body Static Strength Analysis
The working conditions of energy-saving racing cars at a steady state or on a steady track are the longest working conditions for a monocoque body. This requires ensuring that the monocoque body designed has sufficient strength and stiffness under such conditions. Therefore, the deformation of the
body load of the single shell will not affect the design parameters of the racing chassis. Therefore, the simulation of the stress distribution and deformation of the energy-saving car around the carbon fiber monocoque body is the basic requirement for static strength analysis and evaluation.

The monocoque body mainly bears the gravity from the monocoque itself, the gravity of the rider, and the gravity of the major components connected to the monocoque. In the determination of the load boundary conditions of the static strength condition, the mass of the driver is 40kg, the mass of the entire vehicle excluding the body is 35kg, and the gravity load is added to the position of the wheel surface, and the mass of other components is temporarily ignored here. The results calculated by the finite element are shown in Figure 4. According to the results of the cloud diagram, it can be obtained that the maximum deformation of the single shell occurs at the rear of the car body, and the value is 0.015185mm, which is a slight amount of deformation. This deformation has no effect on the dynamic characteristics of the car, so its bending stiffness meets the design requirements.

3.3. Analysis of Frontal Collision Conditions of Single Shell

According to the rules of Honda fuel-efficient cars, the average speed of the car is 25km / h. However, during a collision, the speed of the car will drop to zero, which indicates that the car will experience a large longitudinal deceleration. In order to ensure the safety of the driver during the collision, combined with the actual road conditions of the energy-saving race track, it is now assumed that the initial speed of the car collision is 45km / h, and the strength analysis of the front part of the monocoque body is performed.

With reference to relevant international automobile crash test standards, it is assumed that the crash time of the energy-saving car is 0.3 seconds and the initial speed of the crash is 45 km / h. According to the physical kinematics formula, $V_t = V_0 - at$ can be obtained, and the acceleration value of the monocoque body without rebound can be calculated. Then the frontal impact force of 3360 Newton is calculated by Newton's second law $F = ma$. The calculated front impact force is applied to the front of the monocoque body, as shown in the finite element analysis model shown in Figure 5, and the strain diagram under the front collision condition is obtained as shown in Figure 6. From the analysis and calculations, it can be known that the ultimate deformation of the single shell when a frontal impact occurs is 0.00035417mm. This amount of deformation is within the safety range, so it can be guaranteed that the legs of the racer will not be damaged by the slight deformation of the body in the event of a collision.

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**Figure 4.** Strain under body static load

**Figure 5.** Front collision force

**Figure 6.** Strain in frontal impact conditions
3.4. Analysis of Single-Shell Rollover Conditions
In Honda's energy-saving competitions, rollovers will directly damage the driver's head. With reference to international automobile crash test standards, it can be known that when the total weight of the racing car is 70kg, a load of 7MPa can be applied to the top position of the monocoque body, thereby establishing a finite element model of the monocoque body rollover condition as shown in the figure 7 is shown.

Figure 7. Stress during rollover  Figure 8. Strain in rollover conditions

According to the calculation and analysis of the established finite element model, a strain cloud diagram as shown in Fig. 8 can be obtained. From the figure, it is shown that during the rollover of the monocoque body, the maximum deformation occurs at a slightly backward position. The value is 0.069478 mm. The amount of deformation is within the safe range, which indicates that when the rollover occurs, the driver is within the protective area of the monocoque body.

4. Processing and Manufacturing of Monocoque Body

4.1. Manufacturing of Body Molds
First, the geometric model of the monocoque body is taken at a certain distance in the longitudinal direction, and then the cross section is taken for each point, and the cross section is printed at a 1:1 ratio. The shape is then arranged in the longitudinal direction and stacked according to the rules of taking points. The layers of foam sections are closely adhered with epoxy resin to form a preliminary body shape. Next, use sandpaper to polish the foam into a car shape close to the design model, as shown in the figure 9 below, which is the ground foam mold.

Then smear the mold with sludge and wait for the sludge mold to dry before scraping the surface with a scraper until it is smooth. After the mold is scraped, spray the release agent, and after the release agent is completely dry, apply two to three layers of release wax. The release wax should be applied evenly, especially at the corners.

Figure 9. Monocoque body mold

4.2. Manufacturing of Body Shells
First, paste the prepared carbon fiber cloth on the surface of the mold, wipe the epoxy resin mixed in a certain proportion onto the mold, and then attach the honeycomb aluminum to the carbon fiber cloth. The selected carbon fiber cloth and honeycomb aluminum are shown in Figure 10. Display, then fix the honeycomb aluminum, then attach two layers of carbon fiber cloth, and then apply epoxy. Vacuum
the surface to a smooth surface, as shown in Figure 11 below. Finally, the windows and the surface are painted as required to complete the final process. Figure 12 shows the finished product.

The processed car body is integrated into an energy-saving car, and the car obtained the entire physical test is shown in Figure 13. In November 2019, he officially participated in the 13th Energy Conservation Competition held at Zhaoqing Circuit. After the race, he returned to the school’s automobile laboratory and then inspected the disassembled car body. No obvious deformation or cracking was found. This shows that the designed lightweight monocoque carbon fiber body meets the requirements of basic performance.

5. Conclusion
(1) Based on the analysis of lightweight carbon fiber materials and monocoque technology, according to the requirements of the Honda China Energy Conservation Competition Rules for bodywork, a carbon fiber monocoque body geometry model was designed.

2) A finite element model for structural performance analysis of a lightweight monocoque body was established, and the vehicle body static strength, collision conditions, and rollover conditions were simulated and analyzed. The results show that the virtual monolithic monocoque body meets the performance requirements.

3) Analyze and design the single-shell body processing technology, and use carbon fiber materials to manufacture the physical samples of the body, and then assemble and integrate it on the car. The physical test of the whole car is verified. The monocoque body meets the basic working requirements. It provides a reference for the lightweight design of the Honda energy-saving racing car body in the future.

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