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Numerical analysis of the rear wing mount of a formula 1 type car for material selection

*Arfan Islam, Arup Kumar Debnath, Md. Shariful Islam and Md. Arifuzzaman**
Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203, BANGLADESH

ABSTRACT
In F1-type racing cars, there is a special type of mounting system for the rear wing and it is the main load-carrying component of the wings that transfer the aerodynamic force to the main structure. This type of mounting is called F1-type rear wing mounting. Wings are mounted on endplates and endplates are connected to the main load-carrying structure. In this analysis, an effort has been given to select proper material with lower weight for the endplates of a formula F1 student vehicle. Aerodynamic forces for longitudinal air flow are considered as the load on the wing and the endplate. Various materials including fiber-reinforced composites are considered for the endplate to identify the proper material for the endplate which would show minimum weight with acceptable deformation and stress. The thickness of the endplate is considered identical for all materials. Aerodynamic forces are also kept constant for all the systems made of different materials. The deformation, weight and equivalent stress of the simple endplates were analyzed. Results show that the Epoxy-Carbon Fiber Unidirectional 395 GPa composite appeared to be the suitable one in terms of weight, deformation and maximum equivalent stress. Using this material, the weight of the endplates can be reduced by 80.38% and 44.41% compared to the steel and aluminum endplates respectively.

Keywords: Rear Wing Mount, Composite Material, Formula F1, Endplate, Weight Reduction.

1. Introduction

Formula One is the highest class of international auto racing for single-seater racing cars sanctioned by the “Fédération Internationale de l'Automobile (FIA).” The F1 car was first designed in 1950 but it was without any external aerodynamic device. In 1968 aerodynamic devices were introduced in F1 by Team Lotus. But due to lack of regulation aerodynamics and related structure became unstable and causes accidents. After these scenarios, FIA makes rules from time to time to make the competition more tight, safe and environment friendly. Many advances were made after it and are still being developed now. Rear wings are one of the developments. However, as rear wings develop, the mounting system issue appears. The rear wing was initially supported by a single mounter rod-style construction. After that the endplate comes for helping in the aerodynamic properties as the upstream wind is noisy for the rear wing. Many cars are also seen using swan neck-type structures for giving extra support to the wing and drag reduction system (DRS) [1].

At present these types of racing environment is highly competitive. Every team wants to reduce even a single gram of weight to take advantage in the race. Aerodynamic devices are also in the race for weight reduction ensuring the highest efficiency of the vehicle. With metal, it is almost impossible to gain advantages. In an F1 car, the rear wing is one of the most important aerodynamic devices and this wing generates a significant amount of down force for the car. As a consequence, strong and efficient mounting is needed for carrying and transferring the load. In F1 vehicle endplate is used as mounting for the rear wing with the diffuser. It is called F1-type mounting. There is also a beam wing to avoid the bending of the endplate due to aerodynamic forces and also for taking advantage of exhaust gas until 2014. Formula Student is a similar type of competition for students and there are different types of rear wing mounts available for formula student vehicles. But all the types have their pros and cons. Under-wing plate mount, under-wing rod mount, swan neck wing mount and F1 style wing mount are some of the mounting types. Like underwing, the mount is easy to manufacture and has good mechanical strength. There is also less drag. But this type of mounting is not appropriate for using the DRS system in the wing. Swan neck type mount also has good strength and manufacturability but it is not always easy to implement this type of mounting in F1-style cars. In the case of an F1-type rear wing mount, there are also some advantages. This mount type has great mechanical strength with good aerodynamic advantages. DRS system can be easily implemented in this type of mounting at a low cost. Most importantly it is easily implementable in the F1 type car though it’s not much easy to manufacture. So, among all other types, the F1 style rear wing mount is better in consideration of mechanical strength, aerodynamics, DRS implementation, manufacturability, sustainability, price and implementation on the car. In the case of the F1-type rear wing mount, the wings are mounted on the endplates. Now the endplates are attached to the chassis or diffuser or any suitable structure. Most of the cases it is attached to the diffuser. It carries all the load of the wings and transfers it to the main structure sometimes for better structural strength a beam wing is attached between two endplates. The endplate is generally designed in such a 3D shape so that it can carry more load in various directions [2]. But before designing this type of mounting it is important to study the amount of force that can exert on the wing and later which is to be sustained by the endplate. These forces can be known from CFD (Computational Fluid Dynamics) simulation in software and later from this force structural simulation can be done to know the behavior of the end plate structure. However,

* Corresponding author. Tel.: +880-1710429727
E-mail addresses: arif48@me.kuet.ac.bd

the validation is needed to accurately find the forces for NACA airfoil.

The National Advisory Committee for Aeronautics has made these things easier [3]. They have tested 78 of their airfoils and published the data in a report [3]. There is data for the angle of attack vs lift coefficient and the ratio of lift to drag. Another graph showed the lift coefficient vs drag coefficient and angle of attack for infinite aspect ratio in the secondary axis. From this report data can be directly implemented in practical work. Airfoils have been tested in a variable density wind tunnel so that the effect of density can also be explored. These data can be directly used in real applications [4]. A. Patil et al. [5] analyzed about front wing plate and came to the conclusion that a vertical plate deflects the air downward by reducing the drag force significantly and also prevents super pressure in the wheel to the extent to multi-element airfoil surfaces by increasing the downward force.

Kieffer et al. [6] analyzed downward forces for different angles of attack and found greater value in 4° than 0° in Mazda formula 1 car. They also discovered that after 8° of the angle of attack, stalling occurs for the rear wing. M. D. Gilchrist [7] used carbon fiber composite in pushrod rather than conventional aluminum or steel rods and found significant weight reduction. He observed a 68% weight reduction due to the change in material from steel rod to carbon fiber.

G. Savage [8] investigated lift and drag forces by using carbon fiber composite material in different sections of the formula one racing car and compared it with the traditional one. This research illustrated different advancements due to the use of composite material in formula one cars. He also investigated the composite engineering in formula one cars and revealed the advantages of using composite material instead of conventional material as the structure of a car. In 2010, G. Savage [9] analyzed the weight reduction as a result of using composite materials and speed gain vs time was also investigated.

For material data, there is a built-in material library in ANSYS. Material data was collected from the library of Ansys mechanical release [10]. After doing the validation and analyzing the reaction for the forces of the endplate with various composite materials can be introduced to see the difference between the stress and deformation chart. Weight can be reduced by using lighter material with greater strength which has lower deformation during the analysis and it is very important for competitive racing cars. If reduction of weight in a racing car can give only 0.1 seconds of advantages in a lap it will be 2 seconds in total after 20 successful laps. For only this reason a car with an average speed of 100 kmph will be 55.55 meters ahead of the car behind with the same configuration excluding the reduction of weight. Moreover, if the weight is reduced below the rules, extra weight can be added to the floor to reduce the center of gravity for better cornering speed and stability. In this work, a simple preliminary rear wing mount is designed for a formula student vehicle. Later it was simulated for different materials including composite and metals for analyzing the deformation and stress in the endplate.

2. Methodology

The methodology of this work can be divided into four parts such as Model validation for the CFD simulation, obtaining pressure distribution from simulation for the main design, structural simulation using various materials using pressure distribution data, and results analysis.

The design of the rear wing of the Formula F1 car is shown in Fig.1. NACA 2415 airfoil is chosen to be used as wing and flat plates with a thickness of 5 mm are used as an endplate. It is required to obtain the pressure distribution on the system for the sake of structural analysis of endplates for various materials. To validate the model a wing with NACA 2415 was simulated and the simulation results were compared with experimental data found in [3]. Boundary conditions used for the simulation were; Reynolds number = 3,060,000, Inlet velocity = 361.4174 m/s, Pressure outlet = 101325 Pa, Wing = No slip wall condition. The polyhedral mesh was used and the mesh dependency is tested for the validation purpose. The results are shown in Fig.2. It is seen that the results for both lift and drag coefficients are consistent for a number of elements = 469956. A comparison of simulated and experimental data [3] is shown in Fig.3. It is observed that the simulated and experimental data are well-matched with insignificant error which is acceptable.

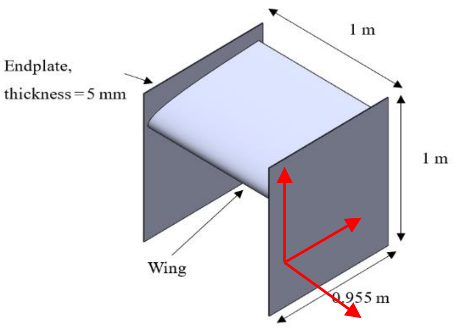

Fig.1 Geometry of the rear wing with endplate for Formula F1 car

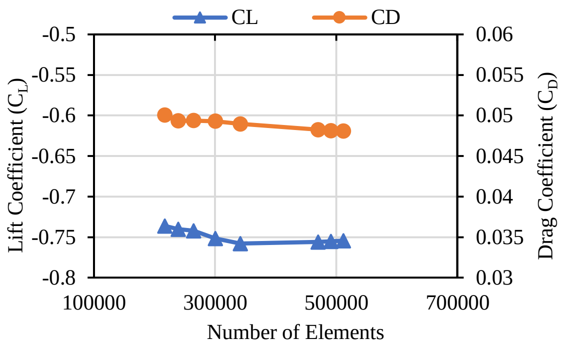

Fig.2 Mesh dependency of lift and drag coefficient for validation

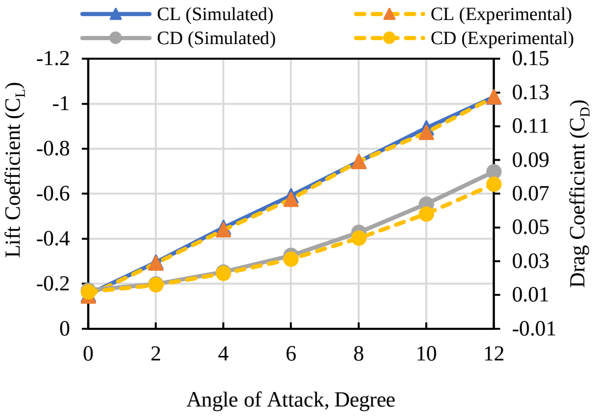

Fig.3 Drag and lift coefficient for simulation and experiment

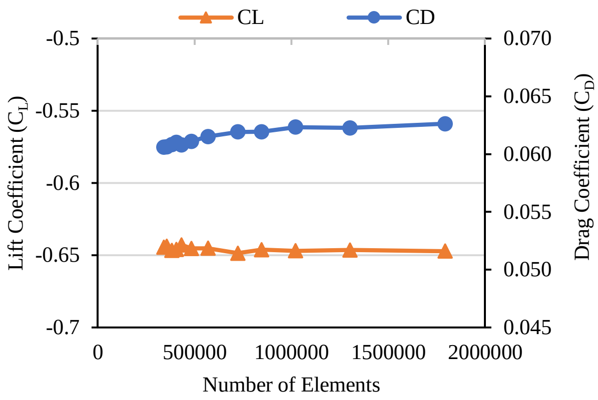

Fig.5 Mesh dependency of lift and drag coefficient for the main design

After validation of the CFD model, the main design (see Fig.1) is simulated for extracting the aerodynamic forces which will exert on the wing and endplates. For the simulation of the main design, the boundary conditions were; Reynolds number = 5248922, Inlet velocity = 83.34 m/s, Pressure outlet = 101325 Pa, Wing = No slip wall condition. The Polyhedral mesh was used for the main design also as shown in Fig. 4. Mesh dependency is tested for the main design also and the results are shown in Fig.5. It is seen that the number of elements for which the lift and drag coefficient become consistent is 1021564. Therefore, the pressure distribution or the aerodynamic forces are extracted from the simulation of the model with the number of elements = 1021564.

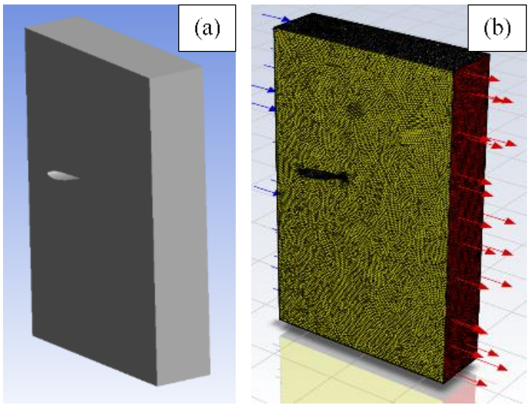

Fig.4 (a) Symmetry enclosure and (b) polyhedra mesh for the main design

To conduct the structural simulation the load/pressure data was imported from Ansys fluent and applied on the wing and endplates. The fluid-solid interaction method was used for simulation. The load was applied as distributed pressure on the surfaces of the wing and the endplates. Symmetry was used for computational efficiency. The applied pressure load is shown in Fig.6(a) and the boundary condition for structural simulation is shown in Fig.6(b). The properties required for the materials used in this study were taken from the Ansys material library.

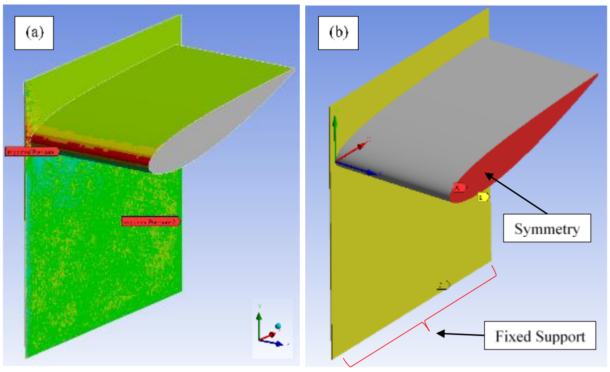

Fig.6 (a) Pressure load on the wing and the endplates and (b) Boundary conditions (the movement of the endplates along the z-axis is restricted).

Boundary conditions for the structural simulation include symmetry on the wing symmetry face, the endplate movement was restricted along the z-axis for simplicity and the bottom face of the endplate was fixed. The mesh dependency concerning deformation was also tested and results are shown in Fig.7. The total deformation was found to be constant for a number of elements of 75700. Therefore, the rest of the analysis was conducted using this mesh size. The simulation was conducted using a 5 mm thickness of endplate for various materials and the results are discussed in the following section.

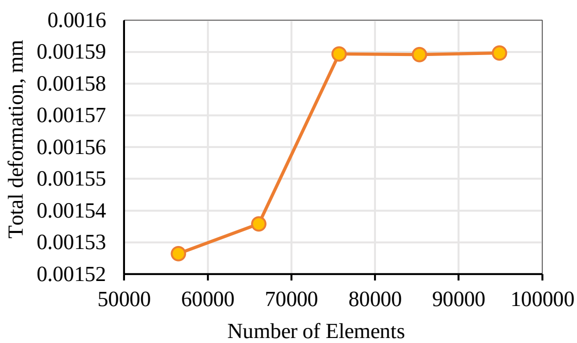

Fig.7 Mesh dependency result for structural analysis

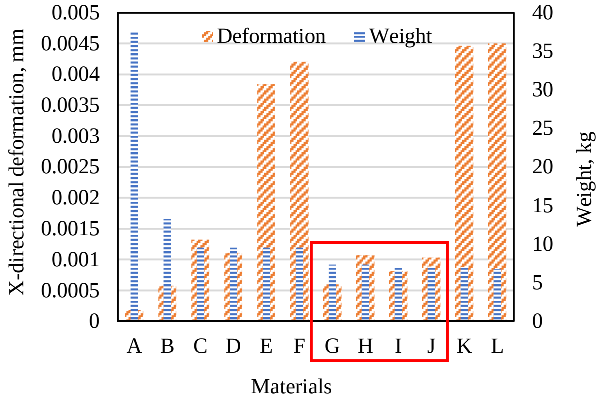

Fig.8 X-directional deformation and weight for various materials (X and Y inside the parentheses indicate the fiber direction of unidirectional composite)

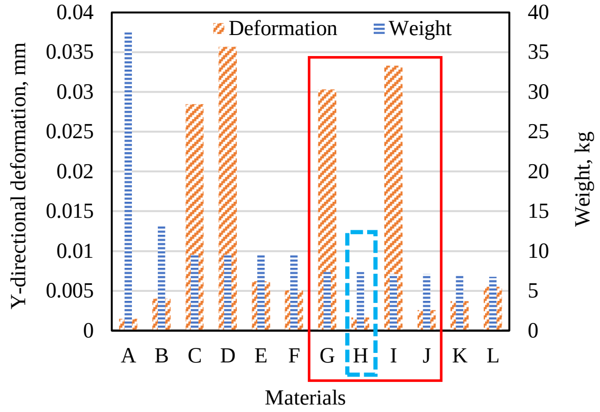

Fig.9 Y-directional deformation and weight for various materials

3. Results and Discussion

The X-directional deformation and the weight of the endplate for various materials are shown together in Fig.8. Table 1 shows the material IDs used in the graph for various materials.

Table 1 Material ID for various materials

ID	Material	ID	Material
A	Structural Steel	G	Epoxy Carbon UD (395 GPa) Prepreg (X) [a]
B	Aluminum Alloy	H	Epoxy Carbon UD (395 GPa) Prepreg (Y) [a]
C	Epoxy E-Glass UD (X) [a]	I	Epoxy Carbon UD (230 GPa) Prepreg (X) [a]
D	Epoxy S-Glass UD (Y) [a]	J	Epoxy Carbon UD (230 GPa) Prepreg (Y) [a]
E	Epoxy E-Glass UD (Y) [a]	K	Epoxy Carbon Woven (395 GPa) Prepreg
F	Epoxy S-Glass UD (Y) [a]	L	Epoxy Carbon Woven (230 GPa) Prepreg

[a]X and Y inside the parentheses indicate the fiber direction of unidirectional composite

The maximum X-directional deformation was seen for the epoxy carbon is woven (230 GPa) prepreg and the minimum deformation is seen in structural steel. On the other hand, the total weight of the endplates is found to be the maximum for structural steel because of its high density and the minimum weight is found for epoxy carbon woven (230 GPa) prepreg which showed the maximum deformation. Since the objective of the work is to make the endplates as light as possible, four carbon fiber-reinforced epoxy composites as indicated by the red rectangle in Fig. 8 may be considered. However, the epoxy carbon UD (395 GPa) prepreg (X) would be the best performing considering the weight and X-directional deformation.

Y-directional deformation and weight of the endplates for various materials are shown in Fig.9. In this case, the structural steel shows the minimum deformation and epoxy S-glass UD (X) displays the maximum deformation. Nonetheless, if the chosen four materials for X-directional deformation are compared for Y-directional deformation, it is seen that the epoxy carbon UD (395 GPa) prepreg (Y) shows the minimum Y-directional deformation as shown by a dashed rectangle in Fig.9. So, if both X and Y-directional deformation is considered together, it is seen that the epoxy carbon UD (395 GPa) prepreg (Y) is best performing in terms of both weight and deformation. The plot for total deformation as shown in Fig.10 also confirms that the epoxy carbon UD (395 GPa) prepreg (Y) is the best-performing material for reducing the weight of the endplates with acceptable total deformation.

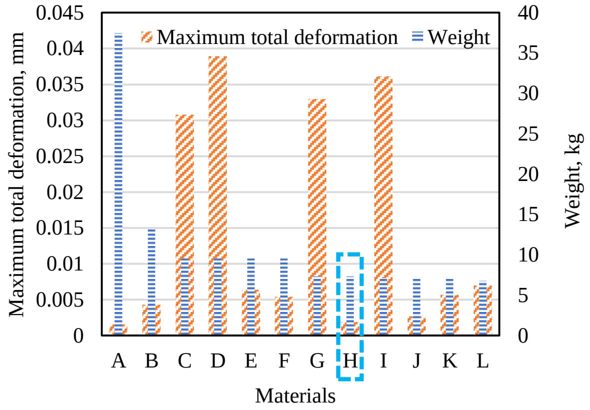

Fig.10 Total deformation and the weight for various materials

The maximum equivalent stress and the weight of the endplates are given in Fig.11. The minimum equivalent stress is developed in epoxy carbon UD (230 GPa) prepreg (Y) and the maximum is found for epoxy E-glass UD (Y). The best performing epoxy carbon UD (395 GPa) prepreg (Y) in terms of deformation and weight shows the second lowest equivalent stress. Therefore, considering both the deformation and equivalent stress it may be said that the epoxy carbon UD (395 GPa) prepreg (Y) among the studied materials can be chosen to be used as endplate material for reducing the weight of the vehicle with considerable deformation and equivalent stress.

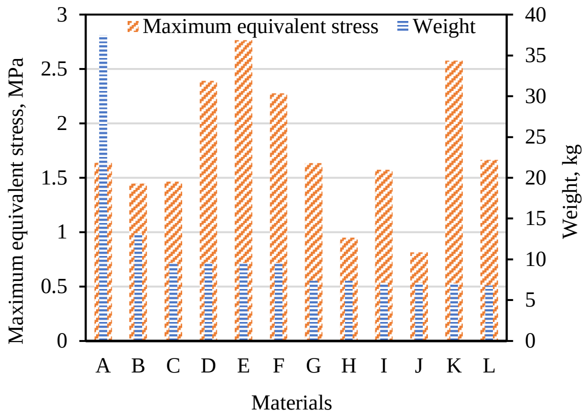

Fig.11 Maximum equivalent stress for various materials

One of the limitations of this study is that the lateral deflection of the endplates was restricted. Further research can be done by considering the lateral deflection using various materials. Also, extensive research needs to be conducted for topology optimization of the endplate to further reduce the weight of the vehicle.

4. Conclusion

In this work, a Formula F1-type car rear wing with endplates was simulated using fluid-solid interaction. The endplates with two metallics and six composite materials were investigated to select the proper material for the endplates with a lower weight. After analysis, it is found that the Epoxy carbon UD (395 GPa) prepreg (Y) with fibers along the vertical axis is the best-performing material which showed the minimum weight, less deformation and comparable equivalent stress among the materials considered in this work. Using Epoxy carbon UD (395 GPa) prepreg (Y), the weight of the endplates can be reduced by 80.38% and 44.41% compared to the steel and aluminum endplates respectively.

5. References

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