



DESIGN AND EXAMINATION OF A REAR SPOILER FOR AN ELECTRIC RACE CAR

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Abstract

The task of the project was the design and CFD simulation of a Toyota MR2 component. The design took into account that the vehicle will be modified for racing purposes. Accordingly, a wing profile was chosen and a 3D CAD model of the profile was created. The wing was designed considering the aerodynamic characteristics of the car, and the brackets to attach the wing to the vehicle were also made. During the testing process, the optimum entry angle of the wing was found.

Keywords: *electric race car, aerodynamics, rear wing, wing profile, CFD simulation.*

1. Introduction

The University of Debrecen, Faculty of Technology has launched new developments in the field of trains for the automotive industry. Artificial intelligence is becoming more and more prevalent in IT and we have started to integrate it into the development and teaching of the Vehicle Engineering Laboratory. The lab has a number of older robot units that are currently undergoing functional upgrades so that they will be able to use AI [1].

A Digital-Twin model of the lab has been created, so it is possible to perform measurements in the virtual lab [2]. Furthermore, it is possible to program virtual 3D robots without actually being in the lab [3]. Measurements in the field of robotics have also been performed in the lab, mainly in the area of singularity measurements [4].

For vehicle navigation, we implemented AGV trajectory planning using augmented reality techniques [5].

Our goal is to develop an Industry 5.0 pattern making system within the lab, where each robot unit can make decisions in workflows based on AI learning from its own dataset. Primarily in sorting tasks and path planning [6].

As the region relies heavily on the automotive industry, a number of simulation models have been designed for forklift trucks [7]. The necessary telemetric data were measured during our previous competitions and analysed later [8].

In keeping with the spirit of the times, sustainability is also a priority in our developments [9]. Innovation is a dominant feature of the engineering profession, which is also present in vehicle development.

Aerodynamic elements are playing an increasingly important role in motor racing, allowing cars to become faster and achieve better lap times. Aerodynamic elements help to efficiently dissipate the air around the car and create downforce, which gives the car more grip, resulting in higher cornering speeds, shorter braking distances and better

acceleration. As well as downforce, these devices also increase drag, so it is important to find the most effective solution for the application, which is the happy medium between downforce and drag. The project aims to design the rear wing of a Toyota MR2 electric race car.

2. Rear wing operation

The rear wings are an aerodynamic element on the vehicle's undercarriage, designed to create more grip and to make the vehicle more stable at high speeds [11].

The wings work by using Bernoulli's principle and Newton's 3rd law to form their lift. On the convex surface of the wing, the Bernoulli principle causes the air to accelerate and its pressure to decrease [12]. The higher pressure of the air on the other side of the wing pushes the wing towards the lower pressure, according to Newton's 3rd law [13].

The efficiency of the wing is influenced by five characteristics: lift and drag coefficients, angle of entry, aspect ratio and airfoil design [14]. These characteristics should be chosen with the airfoil's purpose in mind [15].

The wings mounted on motor vehicles work "quasi" in the same way as the wings on aircraft, the difference being that the rear wings of motor vehicles are upside down so that their lift is in the opposite direction. The force exerted by the wing results in greater traction [16].

It is important to mention the wing tips, which reduce the turbulence on the wing tips that is created when the pressure differences are equalized [17].

The drag of a car is calculated using the following formula:

$$F_D = \frac{1}{2} \cdot \rho \cdot v^2 \cdot C_D \cdot A \quad (1)$$

Turbulence degrades wing efficiency, increasing drag and reducing lift. End flaps minimize these adverse effects, improving the aerodynamic performance of the wing [18]. The lift force on a car can be calculated using the following formula:

$$F_L = \frac{1}{2} \cdot \rho \cdot v^2 \cdot C_L \cdot A \quad (2)$$

3. Designing the rear wing

The vehicle in question, which is owned by the University of Debrecen, Faculty of Engineering, is a Toyota MR2. The official data available were used for the study [19].

The main design considerations for the wing were determined according to the vehicle's aerodynamic sign-plates and the specific needs of slalom racing. The basic criterion for sizing the wing was that it should not exceed the width of the car, which is 1700 mm. This is important because elements protruding from the plane of the bodywork during obstacle avoidance on slalom tracks could hinder maneuvering [20]. Accordingly, the wing span was set at 1700 mm, while the length of the wing profile was set at 300 mm.

A key consideration in the choice of aerodynamic characteristics was to achieve adequate downforce with relatively low drag. On slalom slopes, where lower speeds are generally dominant, higher downforce is of paramount importance as it increases the grip of the vehicle. Minimizing drag was a secondary consideration, but still an advantage for such a high performance vehicle.

When designing the wing, attention was also paid to ensuring adjustability. Slalom races are held on different types of tracks, which have different aerodynamic requirements. The adjustable angle of entry allows the wing to always adapt to the specific needs of the track, thus providing optimum performance.

For the choice of the airfoil, a model with a high forward pitch, a smooth lift and a relatively low drag was chosen based on literature [21]. To design the airfoil, I used an airfoil generator developed by the NACA (National Advisory Committee for Aeronautics) [22] This tool allowed the accurate creation of the desired geometry profile, which is the basis for the aerodynamic performance of the wing.

The NACA generator was used to produce a 5-digit air foil that meets the requirements for high lift. During the generation process, the lift coefficient was set to 1.0, the maximum forward deflection was set at 25% of the air foil length, and the thickness was set to 6% of the chord length. The resulting air foil profile was used as the basis for the design and simulation processes, ensuring optimal performance of the air foil [22]. The air foil profile generator is shown in Figure 1.

Then, from the completed air foil, we designed the 3D CAD model represented in Figure 2.

3.1. Wing rib design

An important aspect in the design of the wing rib was the applicability of additive manufacturing technology. To this end, the rib is 300 mm long, 6 mm thick and designed with a wall thickness of 4 mm, which provides sufficient stiffness to with-

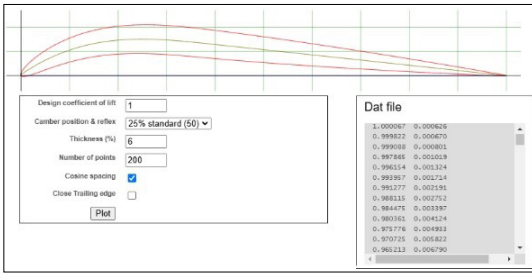


Fig. 1. NACA air foil generator [22]

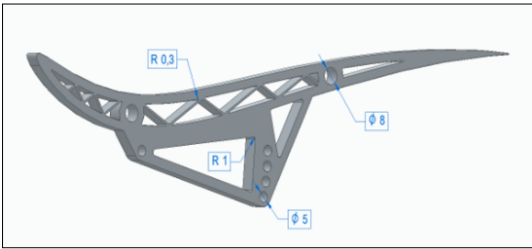


Fig. 2. Air foil 3D CAD model

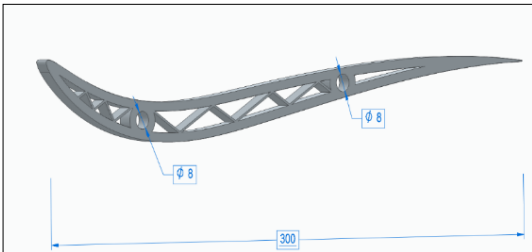


Fig. 3. Wing ribs

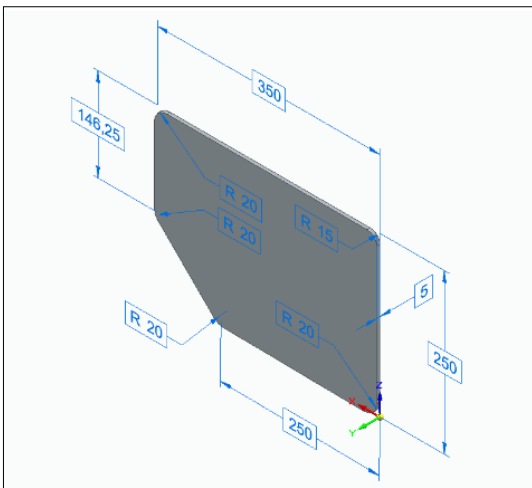


Fig. 4. Windshield

stand the forces applied. The internal stiffeners are 1 mm thick, and there are 0,3 mm rounded edges at the joints. Two 8 mm diameter holes allow easy and stable assembly of the wing frame on aluminium rods. The design is light, rigid and economical to manufacture (Figure 3).

In order to minimise the impact of turbulent air currents on the wing's efficiency, the wing's end plate is designed with a large surface area. 250 millimetres high and 350 millimetres long, the lower side is oriented upwards at an angle of 45 degrees at 250 millimetres. It is 5 millimetres thick.

Various roundings are visible on the model (Figure 4), which are also responsible for improving flow and reducing turbulence.

The purpose of the mounting brackets is to secure the wing structure to the vehicle body in a stable and secure manner, ensuring the correct position and angle of the wing under the effects of acceleration, braking and downforce. It is important that the design and material of the brackets guarantee the deformation resistance and aerodynamic performance of the structure. Solid Edge [23] was used to design the cantilevers. The base was designed to be 250 mm long, 80 mm wide and 10 mm thick. The attachment to the car boot lid is provided by four holes with a diameter of 5 mm located in the four corners of the base (Figure 5).

The wing can be attached to the wing brackets by means of a modified wing rib, which also provides adjustability.

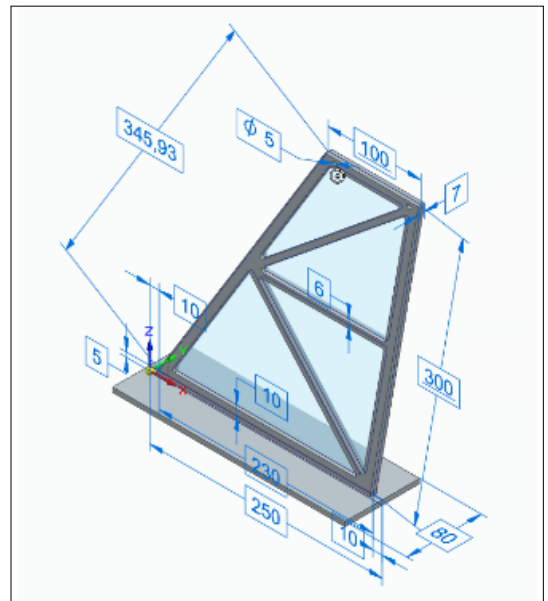


Fig. 5. Fixing bracket.

3.2. Wing assembly

The assembly model was created using Solid Edge Assembly.

On the base, the holes were drilled and the wing brackets were attached to these holes.

The wing ribs were attached to the brackets and fastened together with M5 screws from the Solid Edge model book. The wing model was then glued on and the elements joined.

We also made two types of wing models, one without wing tips and one with wing tips, as shown in **Figure 6**.

4. CFD simulation study

The models were placed into the CFD simulation program Simscale [24] and the current-latency simulations were performed. The program determined the direction and magnitude of the forces acting on the model based on the given current-phase values.

In the simulations, the flow velocity was set to 50 km/h, since our own experience has shown that slalom races do not usually have a bend capable of achieving higher speeds.

Simulations were used to determine the most suitable entry angle for the speed determined (**Figure 7**).

The values obtained from the simulations were sorted into a table and used to select the 10° angle of entry (see **Table 1**).

With this setup, CFD simulations were carried out on both the wing without an endplate and the wing with an endplate.

4.1. Simulation of a wing without wingtip

The results of the CFD simulation show that the assembled model achieves a downforce of 41-42N, which is far below the values of the simple wing model. This performance degradation is not surprising, as the cantilevers significantly break the flow under the wing and induce vortices.

Obviously, the drag of the assembled model is higher than that of the simple wing model. 12-13N is the drag of the complete model.

4.2. Simulation of the air foil wing

The simulation showed that the wing with end plates produced a down-tension force of 52-53N. The end flaps reduced the turbulence on the wing tips, thus increasing the downforce. The drag was also reduced compared to the wing model without wingtips, although not by much, but improved in this aspect as well. It can be clearly

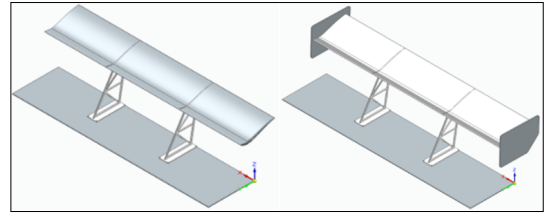


Fig. 6. Assembly models without and with wingtip.

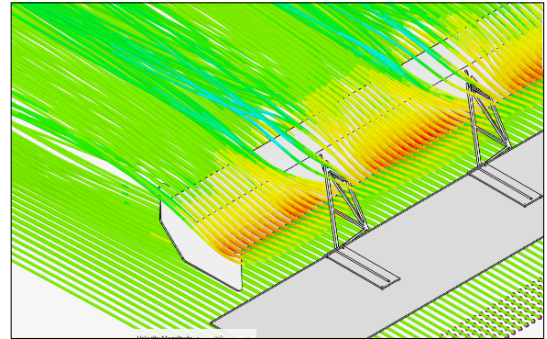


Fig. 7. CFD simulation of a wing model with 10° angle of attack.

Table 1. CFD simulation values for wing profiles

Angle of entry	Downforce	Air resistance
0°	17-20N	3-3.5N
5°	47-49N	4-4.5N
10°	72-73N	5-6.5N
15°	82-85N	14-16N

Table 2. Without wingtip and with wingtip

Considerations	Wing-wing without wing-tip	Wing-fin wing	Difference
Downforce	42N	53N	21%
Air resistance	13N	12N	8%

seen that, thanks to the air foil, lower and higher pressure air cannot create turbulent airflow on the wingtip.

The simulations showed significant differences between the two wings, which are summarised in **Table 2**. Based on the data, the wingtip solution is more efficient and will be the best solution for the race car.

5. Conclusion

The aim of the project was to design and simulation test a rear wing that could improve the driving dynamics of the Toyota MR2 for slalom racing. The design of the wing was based on the literature to determine the optimal wing profile and the geometric parameters required for the simulations. In the analysis of the 3D model created with Solid Edge software, we also investigated the effectiveness of the wing tips in reducing tip vorticity, increasing downforce and reducing drag. CFD simulations at 50 km/h showed that the configuration with wing tips resulted in 21% higher downforce and 8% lower drag than the version without tips. These benefits significantly improve the vehicle's cornering capabilities and acceleration, which is a key priority in competition.

Since we also use DAQ data acquisition systems in the Faculty of Engineering, Vehicle Manufacturing Laboratory [25], we will be able to compare the data with future modifications to the vehicle [26].

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