The Investigation of Optimum Angle of Attack of a Naca Airfoil At Different Velocities and under the Circumstance of High-Speed Braking

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Abstract: In order to further improve the aerodynamic performance of car spoilers, the research team adopted the idea of “movable spoiler”, a rear wing of automobiles whose angle of attack changes with different motion states of the car. Using ANSYS Fluent software to simulate parameters such as lift-to-drag ratio under different conditions, the group did analysis for four conditions: 10 m/s, 30 m/s, 50 m/s and braking, drew the data into charts and got conclusions by observing the graphs. The group also did a shape optimization for an airfoil in NACA database as further investigations.

1. Introduction

With the development of automobiles for several centuries, the performance, and efficiency of vehicles have improved significantly. Therefore, automobile aerodynamics plays a very momentous role in the vehicle design. For instance, rear wings, which is a kind of structure that is usually installed on the trunk, is one of the important car kits. Spoiler first appeared in the 1960s in Formula one, with the purpose of increasing downforce. Then in the far-reaching research, mechanics and researchers found that spoilers had significant influences in the car steering stability and fuel economy by only changing the shapes or the angles of spoilers. With the increase of angle of attack, drag coefficient rises as well. James Reuther’s study showed that different shapes of spoilers could improve downforce and drag force. The study of adjustable rear wings by Yang Yi shows that being at different heights, rear wing can improve the efficiency of braking under different driving conditions. In addition, Bao H studied the relationship between rear wings’ shapes and the cars’ characteristics, as a result, it shows that different shapes of rear wings had various effects, some are positive but some are negative. The purpose of study is to fig. out the relationship between angle of attack and the velocity, then find the best working condition of spoiler under different speed. What’s more, the group has created a new kind of rear wing-moveable rear wing- based on this study.

In our research, the research group used ANSYS Fluent to simulate, and got the data, with these data, the group optimized the angle of attack of the rear wing of automobiles at different velocities, the attack angle which produces the most drag when braking, and found a best shape that suits our purpose. Besides, not only did the best angle of attack is simulated with ANSYS Fluent, but also the research team have used relevant knowledge to ensure the accuracy of our experiment. In the following passage, the group will provide more specific data and graphs to clarify the design, purpose, and the result of simulation.

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2. Validation

The research team simulates the drag coefficient of one of the airfoils in the NACA database, summarizes the results gained, sets up a drag coefficient graph and makes a comparison with that in the NACA database. As a result, the line that represents drag coefficient of the research team has almost the same tendency with the official graph. The tendency of the line in fig. 1 perfectly suits the tendency of the line in fig. 2, which means the research team's simulation has the same result as the official experiment and the accuracy of the results is proven.

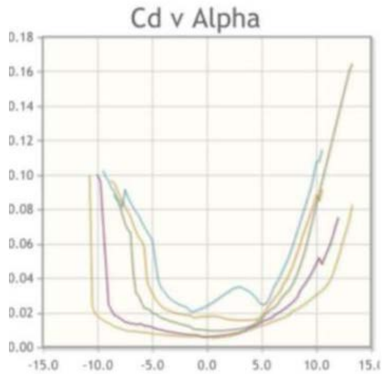

Fig.1 The Drag Coefficient Graph in the Naca Database

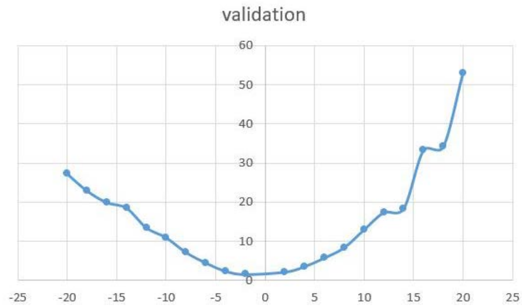

Fig.2 The Drag Coefficient Graph of the Same Airfoil Simulated by the Research Team

3. Problem Statement

The rear spoiler of cars mainly adjusts the surface pressure distribution through the interference of the flow field to reduce the aerodynamic lift. However, the working condition of automobiles changes constantly at different velocities and the fixed spoiler is unable to work efficiently. In order to adapt the same airfoil shape to distinct velocity conditions, the research group comes up the idea of "movable spoiler", whose angle of attack adjusts with change of velocity, so that the spoiler can be in the best working condition under different speeds.

4. Tests

4.1 Modelling

The research group used an airfoil from NACA database. A 3-dimensional rear wing model with a length of 25.4 mm is modeled. According to the size of the aerodynamic field disturbance space caused by the rear wing, the drag and lift of spoiler was calculated in a rectangular space of 6*6*28 cm. Finally, the group prepared the models of the wing at various angles for analysis.

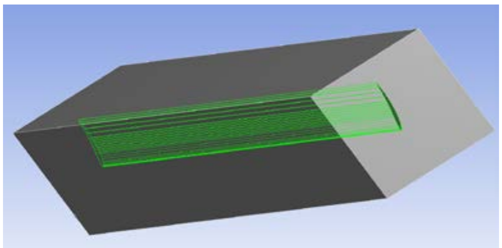

Fig.3 The One of the 3d Models

4.2 Mesh and Setup

The element size of mesh was 1.e-003 m in order to guarantee the precision of calculation. To improve the quality and accuracy of the calculation, the size of the grid field around the body of spoiler is reduced automatically because the airflow is more complicated at that location.

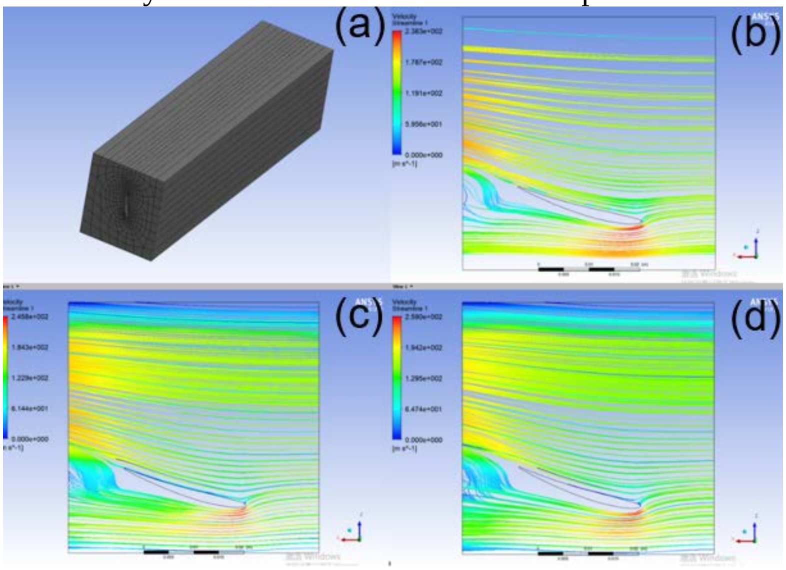

Fig.4 : (a) Mesh Demonstration; (B) 15 Degrees Attack angle’s Streamlines; (C) 16 Degrees Attack angle’s Streamlines; (d) 17 Degrees Attack angle’s Streamlines.

An unsteady model is used in the software. Since the model is 5 times smaller than the size of a rear spoiler, the velocity of input is 5 times larger (50 m/s) and all the other settings are default. In the calculation, the iteration is up to 100 so that the outcomes are relatively precise.

4.3 Optimize Angle of Attack At Different Velocities

The group researched the attack angle of four velocities: 10 m/s, 30 m/s and 50 m/s, calculated the lift to drag ratio as well as the drag coefficient of airfoils of angle of attack of every degrees’ airfoil from 0 to 30 degrees and finally drew a chart to look for the optimum angle for each velocity.

4.4 Optimize Angle of Attack for Braking

The group chose 10 m/s for analyzes, firstly come up with the maximum range of angles and then analyze every degree’s drag conditions in the interval. To determine the range of attack angle that creates maximum resistance, the research group selected 80, 90, 100, 110, 120 and 130 degrees as samples and calculated the drag coefficient and drag force at these angles.

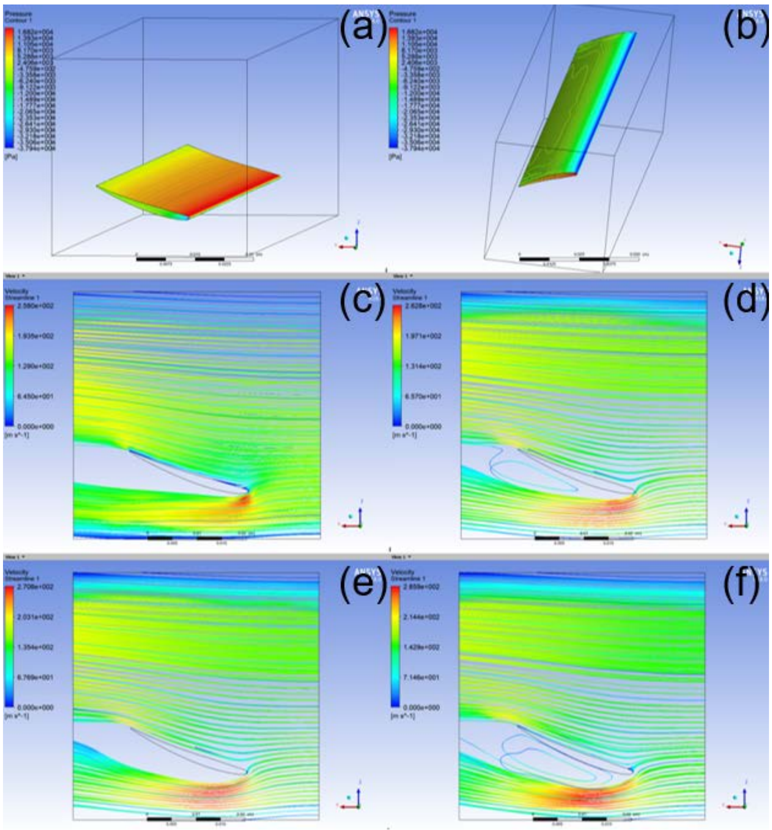

Figure 5: (a)18 degrees attack angle's pressure field; (b)18 degrees attack angle's pressure field; (c)18 degrees attack angle's streamlines; (d)19 degrees attack angle's streamlines; (e) 20 degrees attack angle's streamlines; (f) 21 degrees attack angle's streamlines

5. Results

5.1 Optimize Angle of Attack at Different Velocities

The result is composed of two components: the change in lift to drag ratio and the change in drag coefficient. The formula to calculate the turbulence intensity is shown below:

$$I = 0.16 * Re^{-\frac{1}{8}}$$

$$I \approx 0.024$$

In the range of 0 to 20 degrees, the value of lift fluctuates while the value of resistance increases with a stable slope. While ensuring the lift-to-drag ratio, there should be less resistance. With the increase of angle of attack of the rear spoiler, the lift coefficient decreases and the drag coefficient increases. Selecting an appropriate angle of attack can greatly reduce the lift coefficient but make sure the drag force increases less. Also, considering the high strength of material needed to face the great drag, selecting the values in 0 to 20 degrees interval as final answer turns out to be more appropriate. As a result, at the velocity of 10 m/s and 30 m/s, the optimum angle of attack is 16 degrees. At 50 m/s, the optimum is 9 degrees.

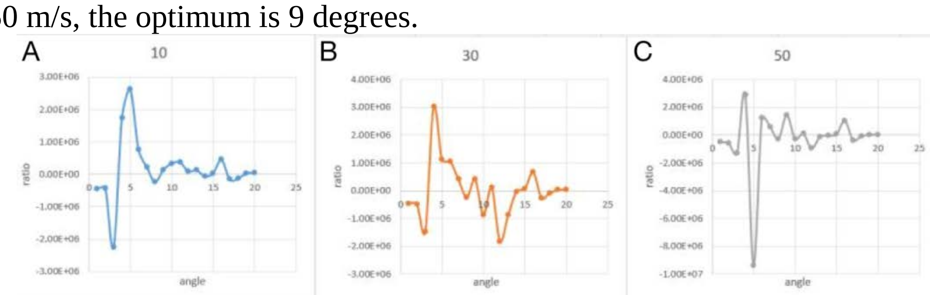

Fig.6 The Graph of Lift to Drag Ratio At Different Attack Angles for Three Velocities

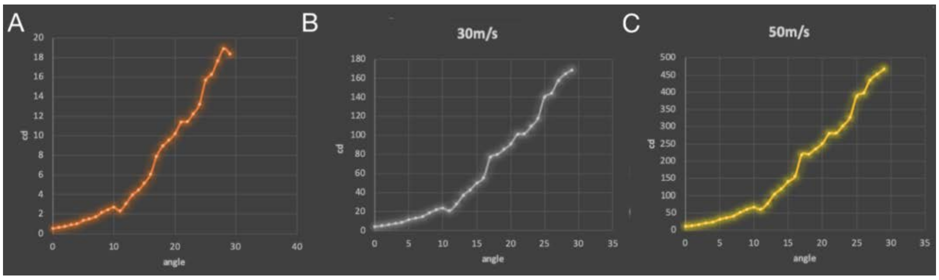

Fig.7 The Graphs of Drag Coefficient At Different Attack Angles for Three Velocities

5.2 Optimize Angle of Attack for Braking

The group discovered that the angle of attack with maximum drag is in the interval of 80 to 100 degrees. To obtain a specific answer, the group simulated the drag coefficient and force of every one degree's attack angle in the 80 to 100 degrees range.

The highest value for both drag coefficient and drag force appears at the angle of 88 degrees, which is the angle of attack that generates the greatest drag and the most suitable angle when braking.

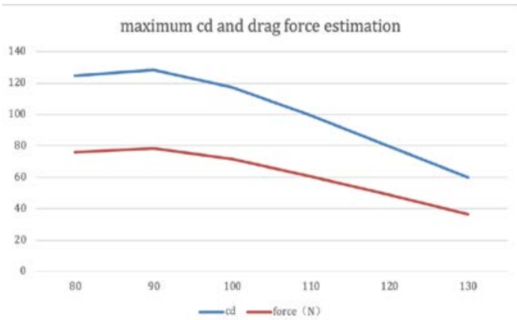

Fig.8 Graph Helps Determine the Range in Where an Optimum Angle Exists

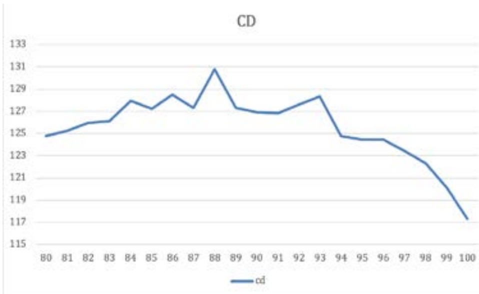

Fig.9 Drag Coefficient of Different Angles of Attack

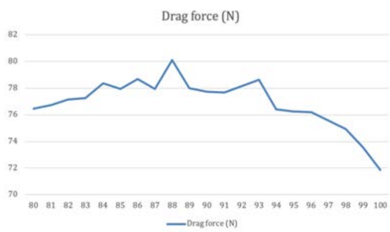

Fig.10 Drag Force of Different Angles of Attack

6. Further Investigations

6.1 Plan a

The research team did the shape optimization of airfoil. In plan A, five arcs with radius 1.5 mm were added underneath the original airfoil, so that the distance for air to travel is extended. According to Bernoulli's principle, higher the velocity of fluid, lower the pressure. As a result, the downforce of the rear wing increases and the lift decreases, which increases the ratio of drag and lift. However, this design also increases the cross-section area. To find out whether this change has influenced the performance of airfoil, the group came up with the plan B.

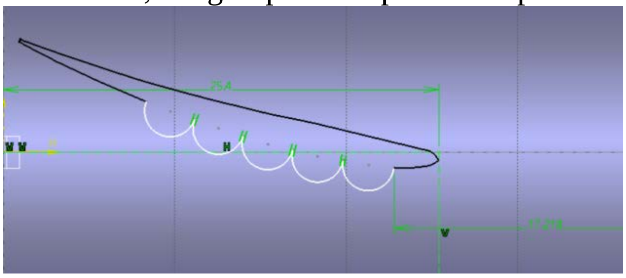

Fig.11 Plan a of Shape Optimization

6.2 Plan B

In plan B, the radius of each arc changes to 3.75 mm, ensuring the perimeters of two airfoils are almost the same.

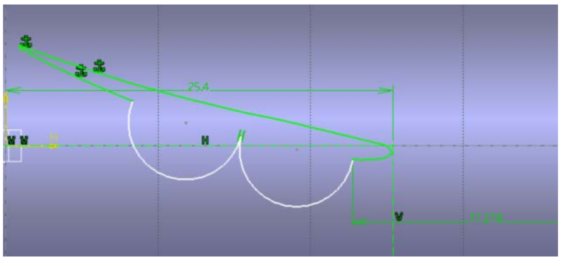

Fig.12 Plan B of Shape Optimization

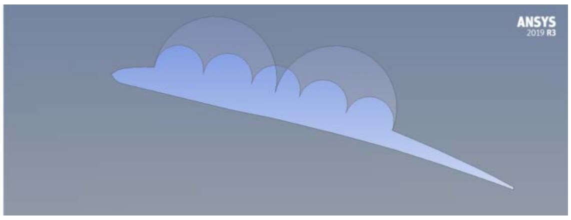

Fig.13 a Comparison of Plan a and B

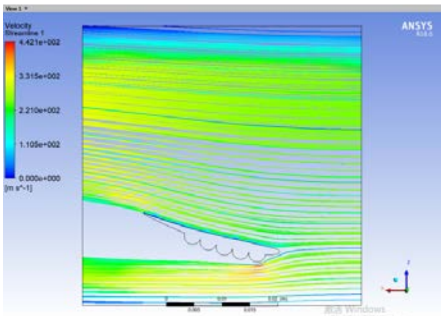

Fig.14 Streamline of Plan a

6.3 Results

The lift to drag ratio of airfoil in plan B is much better than that in plan A, which proves that the lift to drag ratio improves as the length of underneath of airfoil increases. However, if the length is too high, it will become difficult to choose an appropriate material for it. Also, if a local width is much larger than the chord length of the wing, the performance may also be affected. A simulation of optimum length of bottom of wing is needed.

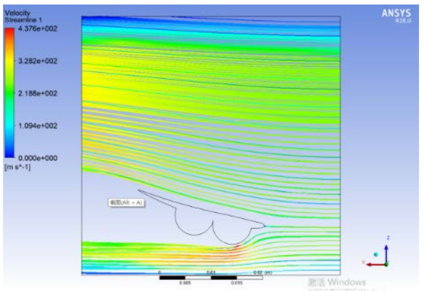

Fig.15 Streamline of Plan B

7. Conclusions

In conclusion, based on the above analysis, the following conclusions obtained. Firstly, the idea of “movable spoiler” gives rise to the performance of race cars. Secondly, for the optimized attack angle at different velocities, 16°, 16° and 9°are optimum values at 10 m/s, 30 m/s and 50 m/s. Then, for braking, an angle of attack of 88°generates maximum drag and is the most appropriate. After that, for shape optimization, within a certain limit, the greater length of the bottom of wing, the better lift to drag ratio it can generate. Since the team only analyzed two plans, which is not comprehensive enough. Further investigations are needed. Finally, in the research, the group only did convergence tests for one specific type of spoilers, so that the conclusion cannot be used for all rear wings and more relevant tests are needed in further investigations.

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