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A Research on Electric Car Styling Design and Low Aerodynamic Drag

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A Research on Electric Car Styling Design and Low Aerodynamic Drag

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Abstract: With the development of the market and the automotive industry, the styling and aerodynamic performance of a car take a more and more important role. This paper takes a research on electric car styling design which focuses on low aerodynamic drag. The design starts with an ideal low-drag shape, and then develops the shape into a car styling. With the method of Computational Fluid Dynamics, and after several times of iterations between design refinement and aerodynamic optimization, the Coefficient of Drag (C_D) finally resulted in 0.19, which is quite low for electric cars for saving energy and further the running range.

1. Introduction

With the development of the automotive industry, electric car is going to take a leading role in the future. The purpose of car styling is not only to get a good look, but also to express other engineering features, especially the aerodynamic drag. According to the fluid dynamic Equation (1), lower Coefficient of Drag (C_D) means lower drag force, hence less energy consumption, less environment pollution, and longer running range as well.

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

where,
F_D is the air drag force,
ρ is the density of the air
v is the speed of the car relative to the air
A is the frontal area of the car
C_D is the coefficient of drag, a dimensionless number

Thanks to the technology, an electric car could have a much flexible architecture, this is very helpful to get a much free shape, which might also very helpful to lower the drag. Since the C_D is proportional to the aerodynamic drag force (drag for shot), how to make the C_D lower through design will be the key point of the research.

The design of Low-drag car has a long history. As early as 1921, the Rumpler Tropfenwagen, also called 'tear drop car', gets a C_D of 0.28, which is much lower than the average level of 0.6 at that time[1].

Quite a few companies launches low-drag cars thereafter, for example the Tatra 77 Type in 1934 from Czechoslovakia was the first mass production car, has a C_D of 0.2455[1] [3]; the Audi 100 C3 in 1982 has a C_D of only 0.30, much lower than the average C_D of that time, the aerodynamic body gives the Audi 100 higher top speed than other cars of similar engine size.

For electric cars, the GM EV1 in 1996 has a C_D of 0.19[4]. In recent years, the Volkswagen's XL1 has a low C_D of only 0.186[5]. Although the C_D of these cars are quite low, but their body size are very small and have only 2 seats, which is not practical enough for local market.

In recent China, electric cars boom up very quickly. However, many of the designs are directly from traditional engined cars. Even cars from the so called "New Manufacture Force" are also quite similar to the traditional car types, especially similar to SUV cars (Figure 1), which usually has a large, tall, boxy body and relatively higher C_D than a common passenger car.

So how to make an electric car practicable, and also make it a low-drag will be a challenge.

Figure 1. The NIO ES8 electric SUV.

2.   Material and Methods

2.1   Research of Ideal Basic Shape

Accord to the aerodynamic studies, 'Half-car-body' and Jaray Type are typical low-drag forms[4]. So the design starts with half-car body P1 (the "P1" stands for the 1st stage of the Proposal, shown as Figure 2). The size is set as 4380×1900×1500 (L×W×H, mm), which is close to a common C-segment car. With Computational Fluid Dynamics (CFD for short), the P1 comes out with a quite low C_D of 0.06.
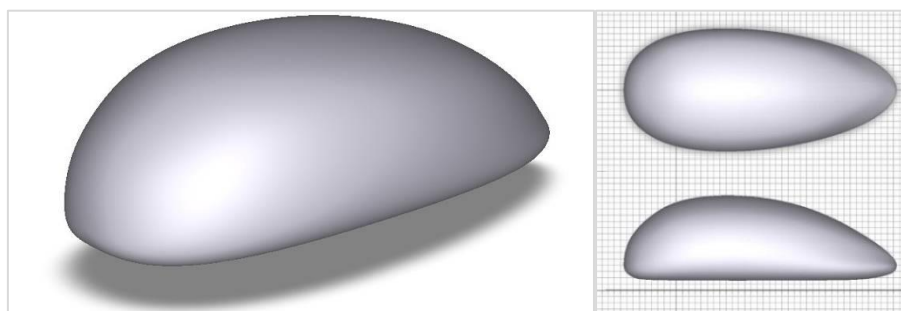

Figure 2. The P1: "Half-car-body".

In order to get aware of how much do the wheels influence the aerodynamic drag, a 'half-car-body' 3D model with wheels is built (the P2, shown as Figure 3), and keep the same ground clearance with P1. The C_D of P2 increases sharply to 0.135.
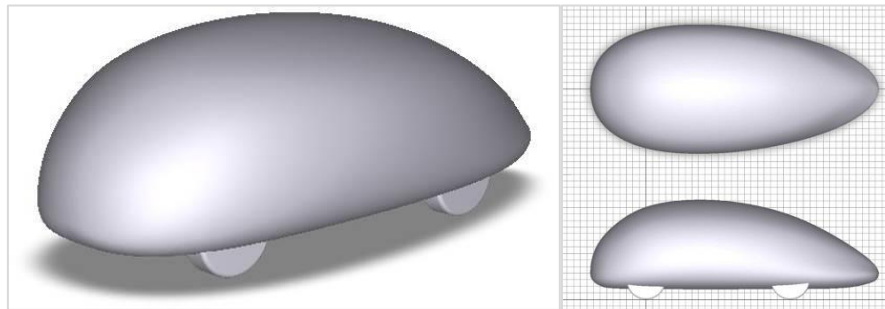
Figure 3. The P2: "Half-car-body" with 4 wheels.

2.2 Early Concept

Since the air flow is greatly affected by the wheels, which have a tight relationship between the body, it is important to lower the C_D by optimizing the shape that around the wheels.

Based on the ideal shape, the early sketches mainly concern on how to get a form from 'half-car-body' in order to get a base of good aerodynamics. The side surfaces are quite smooth to avoid bumps. In order to reduce the flow interference of the wheels, the rear wheels are covered, while the front wheels keep open for steering function (the P3, Figure 4), and the size is set as 4670×1700×1447 (L×W×H, mm).
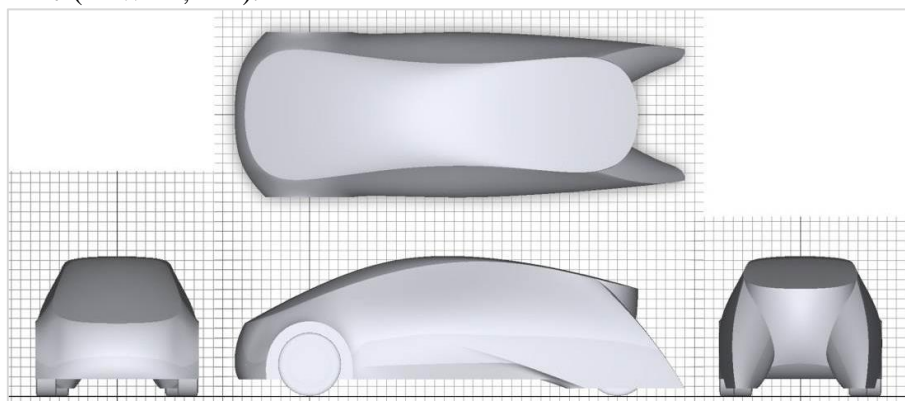

Figure 4. The P3: design with rear wheels covered.

The C_D result in 0.35, which is too high for an early stage. There are two reasons. One is that the center of rear end contract too much (shown in the top view in Figure 4), which leads to premature separation at tail. Another reason is only the separation of vertical direction is considered, while the horizontal separation is ignored.

Then a new design is made to solve the problem. The center of rear end is extended to fill out the concave, hence it decreases the flow separation and then reduces the air drag (Figure 5). The size is 4100×1700×1225 (L×W×H, mm). Notice that the length is reduced by cutting down the rear fender, the concave of the tail becomes to a convex shape, while the interior space keeps the same. The C_D comes out as 0.25, which is a very quick drop from the P3.
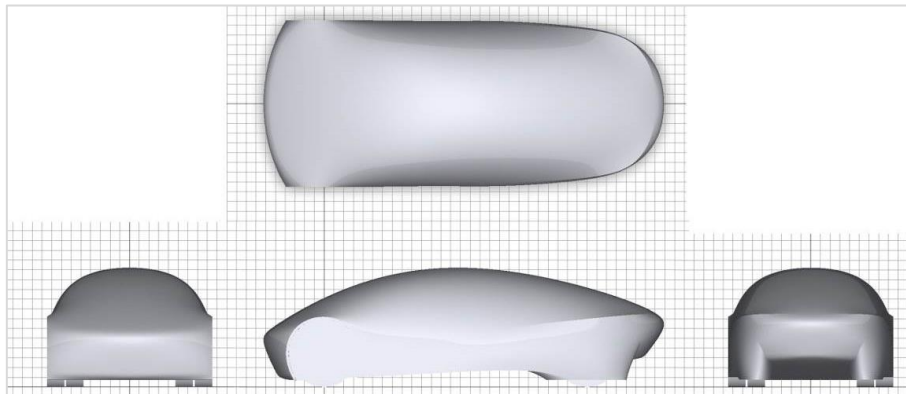
Figure 5. The P4: 3-D model of redesigned tail shape.

Since the front overhang of P4 design is a very short, the front end is quite flat from top view (Figure 5). The airflow concentrates on the front end and result in a large high-pressure zone (Figure 6), which leads to a relatively higher drag.
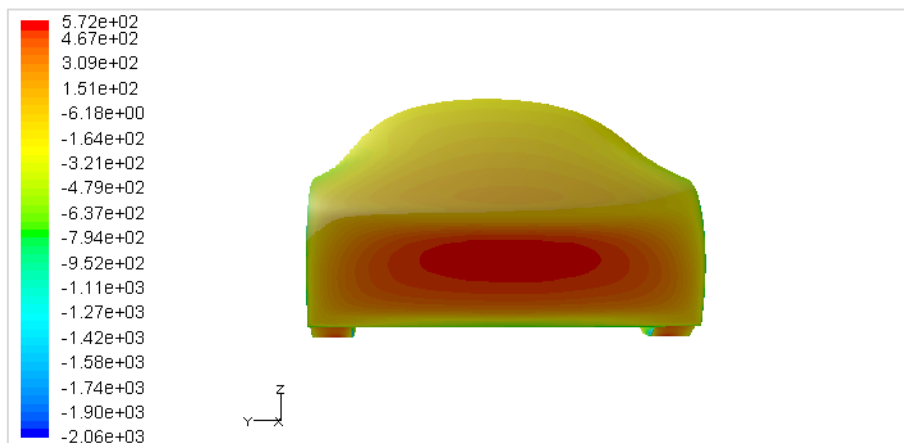

Figure 6. The P4: large high-pressure zone of the front end.

In order to solve this problem, the front overhang is extended forward for a rounder front end to reduce the high-pressure zone. The size is set as 4205×1700×1225 (L×W×H, mm), a little bit longer than P4 by adding length to the front overhang (Figure 7 B). Comparing P5 (Figure 7 B) with P4 (Figure 7 A) , the P5 has a much smoother transition from the front end to the side body, which also result in much smoother airflow, and leads to an obvious reduction of airflow separation and drag (Figure 8). The C_D comes out to be 0.21.
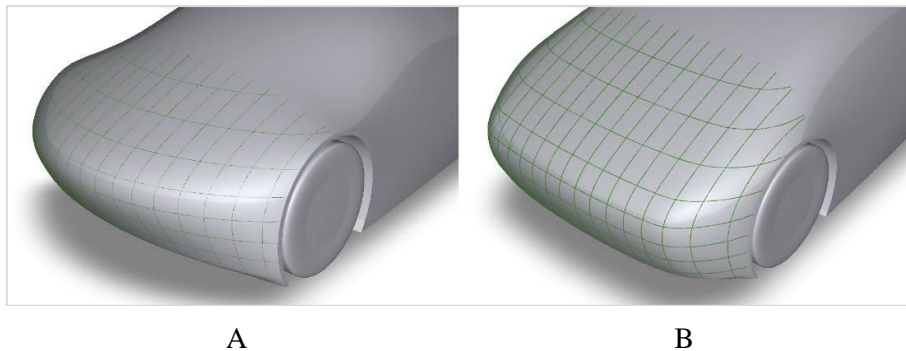

A   B
Figure 7. Front ends comparison of P4 (left) and P5 (right).
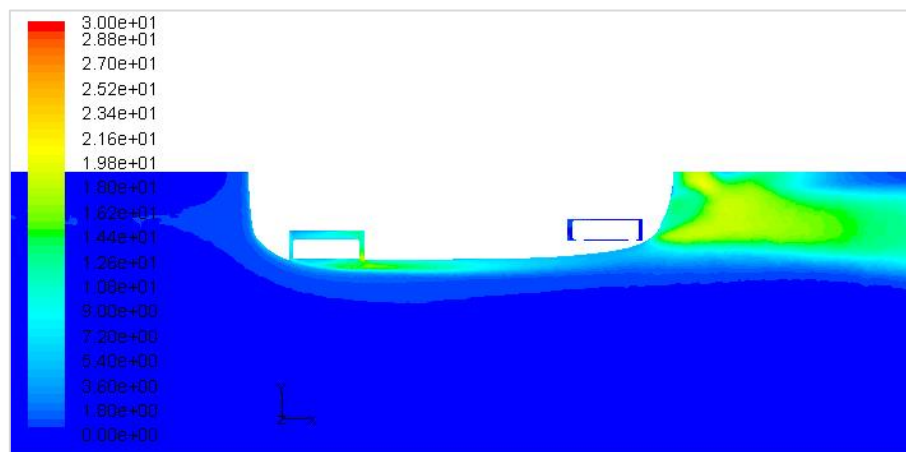
Figure 8. Turbulence intensity distribution of airflow at the height of 500mm for P5

2.3 Design refinements

With the aerodynamic performance improves obviously, the totally shape, however, gradually breaks away from the original design during the iteration. P6 (Figure 9) shows the new sketch where the cabin, roof, pillars and other details are re-designed, and Kamm-tail is also used to lower the drag.

Keeping the main features and aerodynamic achievements of P5, the design refinements are: the body side is designed as flush as possible in order to remain the low drag feature; some subtle feature lines are added on the side to avoid being boring; the shoulder line goes across the front wheel arch and runs into the front end to give a sleek look. The size is 4425×1800×1270 (L×W×H, mm), and the interior is a 2+2 layout, with 95% manikin in the front and 50% at rear, this makes the design more practical (Figure 10).
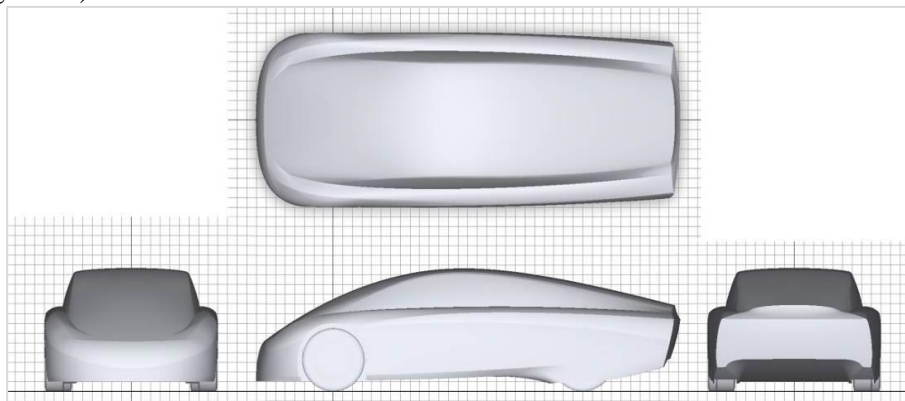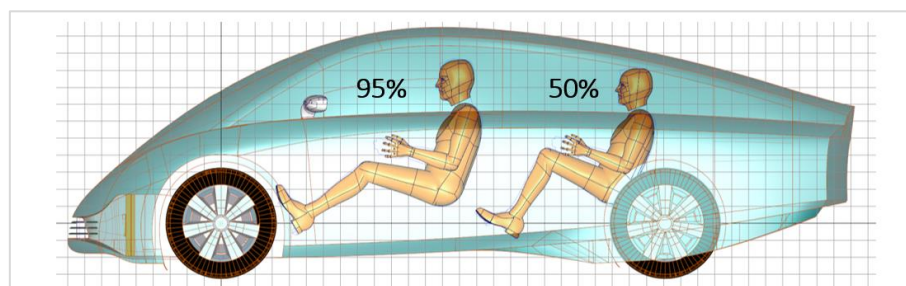

Figure 9. The P6: design refinements.

Figure 10. The P6: 2+2 lay out

The CFD of P6 result in the same C_D 0.21. Comparing with P5 in Figure 11 A, the airflow separation on tail of P6 (Figure 11 B) decreases on both intensity and area. Analysis shows that there

are two reasons for this: firstly, the 'Kamm-back' design of P6 helps to decrease the separation intensity at tail; secondly, the chin of P6 is risen about 30mm from P5, which allows more airflow to run from the under clearance of the car, and then reduces the separation zone at tail.
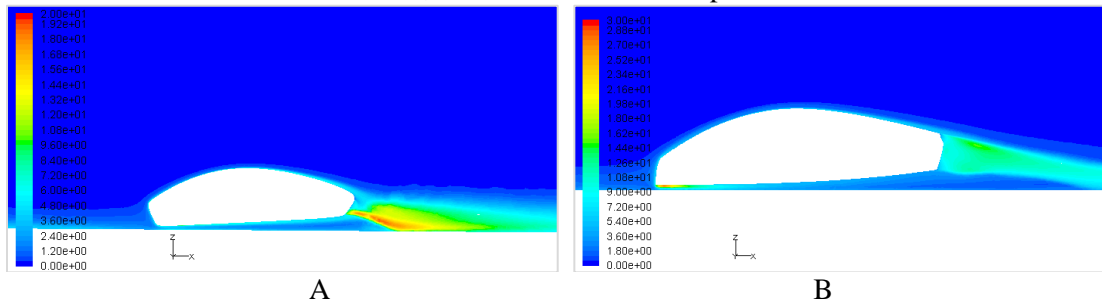

Figure 11. The turbulence intensity distribution of airflow on Y0 of P5 (left) and P6 (right).

According to the research of P6, the front chin rises again and reaches to a new height of 200mm, which is the new design P7 (Figure 12. A). Figure 12. B shows that the separation at tail is reduced greatly, this leads to an apparent decrease of C_D, which comes out to be 0.19.
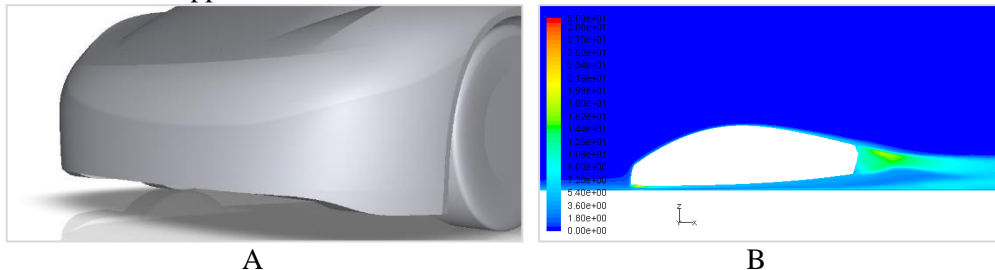

Figure 12. The P7: the chin rises to 200mm from the ground

Based on the P7, the front styling is refined again according to the original design, the main refinement is adding feature lines at the front corner to make the shape more dynamic and less boring (Figure 13). Since the changes of surfaces near the feature lines are so subtle that they rarely affect the airflow. Thus the C_D remains 0.19 by CFD.
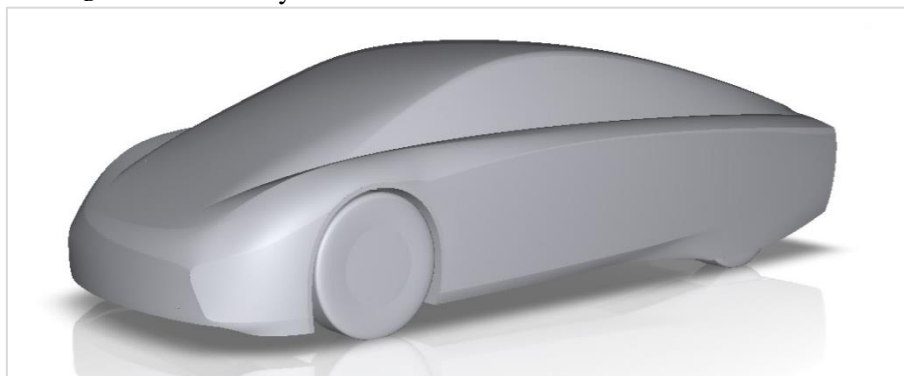

Figure 13. The P8: final design

3.   Results

1) The wheels play an important role of the whole C_D. The C_D of 'half-car-body' is only 0.06, while the C_D of 'half-car-body' with wheels increase sharply to 0.135.

2)   The shape of tail has a great effect on flow separation at the rear end, a concave tail concept with C_D of 0.35, while a redesigned tail decreases it to 0.25.

3)   A rounder nose of car will give a better transition from the front end to side body, which makes the air flow much smoother, and leads to a lower C_D of 0.21.

4)   The height of chin also has obvious effects on the flow separation at the rear end. Higher chin allows more air runing through the ground clearance, and result in lower C_D to 0.19.

5)   Subtle styling design refinements have very few effect on air drag, which keeps the C_D as 0.19.

4.   Discussion

1) Covering the rear wheel leads to a lower drag. If the front wheel could also be covered, the C_D should decrease either. In order to meet the steering function, the front track could be reduced to give the front wheel a turning space under the cover.

2)   The shape of tail has a great effect on flow separation at the rear end. A convex shape is much better than a concave one. However, a too convex shaped tail maybe unpractical because it will waste too much of length. Hence the cut-tail design is a better choice for both low drag and efficiency of tail length.

3)   The height of chin also affects the flow separation at the rear end. Usually a lower chin could reduce the air flow that runs through the underbody and result in smaller friction and irregular flow. In this case because the underbody is set to flat to fit the battery of an electric car, the result is different.

5.   Conclusions

1) For the better commercialization of electric cars in the future, styling design will be an essential element of low aerodynamic drag, which will be helpful for energy saving, and also be helpful to extend the driving range as well.

2)   Iteration between design refinement and CFD optimization is an effective way to research low-drag styling. Usually, starts with a low-drag shape and then develops it into a low-drag car is easier than starts with a car and then tries to make it low drag.

3)   Although styling has a tight relationship with aerodynamics, subtle styling design refinements, however, have very few effect on air drag. This is quite useful when designs a car from early low-drag concept, and then adds detail features to a final styling without too much increase of C_D.

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