Influence of Different Diffuser Angle on Sedan’s Aerodynamic Characteristics

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Abstract

The aerodynamic characteristics have a great influence on the fuel economics and the steering stability of a high speed vehicle. The underbody rear diffuser is one of important aerodynamic add-on devices. The parameters of the diffuser, including the diffuser angle, the number and the shape of separators, the shape of the end plate and etc, will affect the underbody flow and the wake. Here, just the influence of the diffuser angle was investigated without separator and the end plate. The method of Computational Fluid Dynamics was adopted to study the aerodynamic characteristics of a simplified sedan with a different diffuser angle respectively. The diffuser angle was set to 0°, 3°, 6°, 9.8° and 12° respectively. The diffuser angle of the original model is 9.8°. The conclusions were drawn that when the diffuser angle increases, the underbody flow and especially the wake change greatly and the pressure change correspondingly; as a result, the total aerodynamic drag coefficients of car first decrease and then increases, while the total aerodynamic lift coefficients decrease.

Keywords: Computational fluid dynamics; sedan; diffuser angle; aerodynamic characteristics

1. Introduction

Diffuser is one of the most important aerodynamic devices often found on F1 [1]. It is often used to reduce lift for race cars. In recent years, diffuser has also been widely used in ordinary cars. The diffuser can work to both reduce drag and increase downforce for driving car [2], which can improve fuel economy and operation stability of vehicle[3]. It has been shown in studies published by Cederlund and Lasse Christoffersen, that the wake structures of the rear wheels and rear wing for sports car can have a
significant effect on the air flow through the diffuser[4, 5]. It has also been shown in studies published by YE Hui that the diffuser angle and ground clearance played an important role in the function of diffuser [6].

This paper aims to study the influence of different diffuser angles on sedan's aerodynamic characteristics at the modeling design stage. The sedan used for study is a new developed model, and the model's ground clearance is fixed during the study. The paper was performed as a numerical study merely. The result of the study was used to provide for the scheme selection judgment basis.

2. Geometrical Model

The vehicle researched here is a new developed sedan. Fig.1 shows the complete CAD representation of it. In order to reduce computation time, the sedan was simplified. The rearview mirror, front grille and bottom transmission of the sedan were omitted. The simplified sedan's length, width and height are 4829mm, 1888mm and 1458mm respectively, while the ground clearance is 210mm. Five different cases including original model were designed. The diffuser angle was set to 0°, 3°, 6°, 9.8° and 12° respectively for each case while the diffuser angle of the original model is 9.8°. The rear views of automobiles for different cases were shown in Fig.2.

![Fig.1. Geometric model of original model](image1)

![Fig.2. Rear part configurations of automobile for various diffuser angles](image2)
3. Numerical simulation

Because the models studied are symmetrical geometries and numerical simulation without side wind effects can be considered as symmetrical flow-field [7,8,9], a half model was used in the simulation in order to allow quicker solution of the model with a more refined mesh. For the numerical studies an idealized computational domain with a constant rectangular cross-section was used. As shown in Figure 3, the computational domain's L × W × H is 53119mm × 5664mm × 5832mm. In other words, the domain extended around four times the vehicle length to the front and six times to the rear.

Fig.3. Overall dimensions of computational domain (unit: mm)

The geometric models were used for meshing such as the mesh in Fig.4. For all cases the domain consisted of tetrahedral mesh and prismatic mesh. Prismatic mesh was used for meshing the domain around the body and wheel. It can accurately capture surface forces of the vehicle, and improve the accuracy of calculation. Other domain in the computational domain was meshed by tetrahedral grid. Mesh around the vehicle was meshed with a smaller size to get a moderate mesh.

The numerical simulation was done in the commercial code FLUENT. Due to its stability and ease of convergence the k-epsilon model was the chosen turbulence model [9,10]. Both first order upwind discretization schemes and second order upwind discretization schemes were used for the momentum, turbulent kinetic energy and turbulent dissipation. SIMPLE scheme was set as the iterative algorithm; the residual value was set to 0.0001. The boundary conditions used for the study were shown in Table 1.

Table 1. Boundary conditions used for the study
Region | Boundary conditions
---|---
Inlet | velocity inlet, \(v = 30\text{m/s}\), turbulence intensity=0.5%
Outlet | Pressure outlet, reference pressure=0Pa
Symmetry plane | Symmetry
Top and side wall | wall
Ground | wall

4. Results and Discussions

Total drag and lift coefficient for various diffuser angle of the sedan was shown in Table 2. Fig.5 has shown the change curve of total drag and lift coefficient versus diffuser angle. From Table 2 and Fig.5, we can found when the diffuser angle varied from 0° to 12°, the total aerodynamic drag coefficients of car first decrease and then increases, while the total aerodynamic lift coefficients decrease. There is a diffuser angle at which the sedan can obtain the minimum drag coefficient.

Table 2. Total drag coefficients and lift coefficients for various diffuser angles

<table>
<thead>
<tr>
<th>Case name</th>
<th>Diffuser angle</th>
<th>(C_d)</th>
<th>(C_l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case one</td>
<td>0°</td>
<td>0.2841</td>
<td>0.3350</td>
</tr>
<tr>
<td>Case two</td>
<td>3°</td>
<td>0.2718</td>
<td>0.2791</td>
</tr>
<tr>
<td>Case three</td>
<td>6°</td>
<td>0.2487</td>
<td>0.2656</td>
</tr>
<tr>
<td>Case four (original model)</td>
<td>9.8°</td>
<td>0.2673</td>
<td>0.2633</td>
</tr>
<tr>
<td>Case five</td>
<td>12°</td>
<td>0.2822</td>
<td>0.2586</td>
</tr>
</tbody>
</table>

Fig.5. Total drag and lift coefficient versus diffuser angle.

Figures from 6 to 8 were the pressure contours derived from the numerical simulation. From the calculation results, we can find when the diffuser angle varied from 0° to 12°, pressure distributing on the top of body and the front of body changed little. As seen in Fig.6 and Fig.7, with the increase of diffuser angle, the distribution area of positive pressure on the rear of the body first increases and then decrease. The distribution area of positive pressure reach peak at diffuser angle of 6°. Difference of positive pressure distribution on the rear of the body lead to differential pressure of the body surface varies from case to case, which results in the total aerodynamic drag coefficients of car first decreasing and then increasing while diffuser angle changes. From Fig.8 it can be seen that with the increase of diffuser angle
negative pressure is generated at the underbody interface and the region of the negative pressure become larger and larger. At the same time, the positive pressure generated at the edge of underbody decrease. When diffuser angle is changed to 9.8 degree, there is not any positive pressure distributing at the edge of underbody. The increase of negative pressure distribution and the decrease of the positive pressure distribution on the underbody lead to increase in differential pressure of the body surface, which results in decreasing of total aerodynamic lift coefficients. From Fig.8, we can also found the negative pressure peak at the start of the diffuser.

![Fig.6. Pressure contour in rear of automobile for various diffuser angle](image)

![Fig.7. Pressure contour in centre plane of automobile for various diffuser angle](image)
In Fig. 9, the streamline behind the vehicle can be seen for diffuser angles from 0 to 12 degrees. From the streamline and pressure contour of the sedan, it can be found when the diffuser angles varies from 0 degree to 12 degrees, the flow field after the sedan has an obvious change. It can be seen obviously the wake structures after the car of all cases are different.
5. Conclusions

The aerodynamic characteristics of a simplified sedan with different diffuser angles were studied by using numerical simulation in the paper. The study was done at the situation that ground clearance of the sedan was fixed. From the study, it was observed that the change of diffuser angle has a great influence on wake and the underbody flow behind the rear wheels. The total aerodynamic drag coefficients of sedan are first increasing then decreasing with increasing diffuser angle and the total aerodynamic lift coefficients is decreasing as the diffuser angle is increasing. There is an appropriate diffuser angle at which the total aerodynamic drag coefficient of sedan has a minimum value.

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