Research on the Reduction of the Aerodynamic Drag and Noise of EMU6 Air Conditioner

Xiaofang Li, Zhigang Yang and Dan Zhou

ABSTRACT

With 1/8 th Scale of the Electric Multiple Units (EMU) 6 as model, the effects of air conditioner height and guiding angle on the aero-acoustic performance of EMU6 are studied, based on the 3D incompressible Lilly LES+FW-H method. The results show that the aerodynamic drag and noise of EMU6 are smaller when the air conditioner height is 190mm and the diversion angle is 30 degrees. The intensity of the dipole sound source near the air conditioner is larger. The A-weighted sound pressure level reaches the maximum at the frequency slightly lower than 1000Hz. The frequency band for the aerodynamic noise is wide, and the acoustic energy concentrates at the frequency around 1000Hz and decays with the increase and decrease of frequency. The sound pressure level is high at the streamline of the head coach and decreases gradually with the increase of distance from the tail coach.

1 INTRODUCTION

In recent years, China's high-speed train technology has developed rapidly. High-speed train has achieved operating speed of 300km/h. Furthermore, the

Key Laboratory of Traffic Safety on Track, Ministry of Education, School of Traffic & Transportation Engineering, Central South University, Changsha 410075, Hunan, China
design speed of high-speed train can reach 380km/h and the maximum test speed is over 450km/h. With the increase of speed, the aerodynamic effect of high-speed train is rapidly increasing. Therefore, the aero-acoustic performance of high-speed train becomes an important factor that restricts the development of high-speed train. Aerodynamic drag and noise are the main criteria for the aero-acoustic performance of high-speed train. Moreover, when the high-speed train runs at speeds in excess of 300km/h, the aerodynamic drag of high-speed train accounts for about 80% of the total drag. At the same time, since the fact that aerodynamic noise is proportional to the 8th power of speed, the aerodynamic noise becomes the primary noise source in high-speed train\cite{1}. The sharp rise of air drag and aerodynamic noise has a negative influence on the energy consumption, occupant comfort and resident life along the railway.

Numerical simulation and experimental studies are the classical methods for aerodynamic noise research of high speed trains. Frid and Fremion studied the local aerodynamic noise control method of high speed train by using low-noise wind tunnel\cite{2,3}. Sun simulated the pressure fluctuation distributed outside the car, and analysed acoustic field of the external car theoretical\cite{4}. The problem of drag reduction and noise reduction of high speed train is deeply studied by scholars at here and abroad. It is clear that the aerodynamic noise sources of high-speed train are focused on the pantograph and the shroud, the head and tail coach of the train, the connecting parts of the vehicle and other uneven parts. Combined with practical experience and theoretical analysis, Tom proposed a design scheme to improve the aerodynamic noise of the pantograph\cite{5}. Takeshi KURITA had compared the flow field and sound field characteristics of the different pantograph by using acoustic array technique\cite{6}. T. Takaishi had carried on the geometry optimization research for the aerodynamic noise of pantograph by wind tunnel model experiment and the simulation method\cite{7}. Xiao Yougang et al. simulated the far field aerodynamic noise from the streamlined head of high speed train and the aerodynamic noise in the driver's cabin by applying large eddy simulation method and acoustic analogy theory to and studied some near field characteristics of aerodynamic noise\cite{8-10}. Liu Jiali and Zhang Yadong studied the aerodynamic noise of the head coach and bogie of a high speed train by numerical method\cite{11,12}. Sassa simulated the aerodynamic noise of the concave and convex sides of the door of the high speed train\cite{13}. Jiang Changying carried on the noise test of the light rail vehicle, pointed out that the noise mainly distributes on the air conditioning department and under the pantograph\cite{14}.

The concept of smooth-going design can significantly improve the aero-acoustic performance of high speed trains. Streamlined head coach, all
wrapped windshield, pantograph shroud and other techniques have been applied in high speed trains maturely. In order to improve the aero-acoustic performance of the train, the local key areas on the surface of the train, such as air conditioners, doors and windows, antennas and cowcatchers, should be taken into account. The effects of geometric irregularities on the aero-acoustic performance of the whole train and the local region should be studied primarily. In order to achieve consistency of overall and local, coordination of aerodynamic performance and acoustic performance of shape optimization design of the high speed train.

In this paper, the aerodynamic drag and noise of air conditioner of high speed train were studied by numerical simulation. The improved schemes were put forward, the corresponding lower aerodynamic noise shapes were obtained. It is hoped that the aero-acoustic performance of the train will be improved by optimizing the local area of the air conditioner.

2 NUMERICAL SIMULATION

2.1 Models and Cases

In this study, EMU6 was employed as the model for numerical simulations, which is illustrated in Figure 1. Based on the shape of the CRH380A air conditioner, the effects of air conditioner height and guiding angle on the aero-acoustic performance of high-speed train were investigated without changing the basic dimensions of the length and width of the air conditioner. In this study, the number of cases considered was twelve; these are presented in Table I. The schematic diagram of air conditioner height (h) and guiding angle (θ) are shown in Figure 2.

Figure 1. Computational model.
TABLE I. COMPUTATIONAL CASES.

<table>
<thead>
<tr>
<th>cases</th>
<th>A-1</th>
<th>A-2</th>
<th>A-3</th>
<th>A-4</th>
<th>B-1</th>
<th>B-2</th>
<th>B-3</th>
<th>B-4</th>
<th>C-1</th>
<th>C-2</th>
<th>C-3</th>
<th>C-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>h(mm)</td>
<td>190</td>
<td>190</td>
<td>190</td>
<td>190</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>350</td>
<td>350</td>
<td>350</td>
<td>350</td>
</tr>
<tr>
<td>θ(°)</td>
<td>30</td>
<td>45</td>
<td>60</td>
<td>90</td>
<td>30</td>
<td>45</td>
<td>60</td>
<td>90</td>
<td>30</td>
<td>45</td>
<td>60</td>
<td>90</td>
</tr>
</tbody>
</table>

2.2 Grid generation

When the train runs at high speed, the area around the train body is very turbulent in velocity and pressure, and there are vortexes at the rear of the train. Therefore, these areas should be properly encrypted in the discrete grid process. In order to describe the surface dipole aerodynamic noise source accurately, 15 prism layers were added to the boundary layer of the train, and the thickness of the first prism layer close to the train surface was approximately 0.1mm, and the $y^+$ is less than 1. Finally, 60 million meshes were employed to construct the computational domain in this study, which is illustrated in Figure 3.

2.3 Boundary conditions

As shown in Figure 4, the size of the computational domain is 400m×30m×20m. The surface ABCD of the computational domain in front of the train is defined as the velocity inlet boundary condition, which is set as 350km/h. The surface EFGH of computational domain behind the train is defined as the pressure outlet boundary condition, and the reference pressure is 0 Pa. In order to ensure the full development of the flow field and eliminate the influence of the wall on the flow field, the top surface and two side surfaces of computational domain are defined as symmetry boundary condition. The bottom surface ABFE of
computational domain is defined as the moving wall boundary condition, and the velocity in the X direction is the same as that at the inlet of computational domain, and the two directions of Y and Z are both 0. The surface of the train model is set as a frictional no slip boundary condition, and the velocity of three directions of X, Y and Z are all 0.

![Figure 4. Computational domain in simulation.](image)

2.4 Numerical method

In this study, the numerical simulation of the whole flow field was divided into steady and unsteady calculation. The steady calculation was investigated based on Realizable $\kappa-\omega$ turbulence model. SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) algorithm was employed to solve the pressure and velocity coupling equations. For the momentum equation and $\kappa-\omega$ equations, the second-order upwind scheme were employed. As for the unsteady calculation, the steady calculation was used as the initial flow field. And the unsteady calculation was studied based on LES model. PISO (Pressure Implicit with Splitting of Operator) algorithm was employed to solve the pressure and velocity coupling equations. Furthermore, the each time step for the unsteady calculation was set as $5e^{-5}s$, and a total of 10000 time steps had been calculated.

3 ALGORITHM VALIDATION

In order to verify the correctness and accuracy of the simulation algorithm, it was used to calculate the aerodynamic noise of a train pantograph, and the results were compared with the wind tunnel test results. The simulation and experiment results are listed in Table II. It can be found that the accuracy of aero-acoustic simulation technique used in this paper is reliable.
TABLE II. COMPARISON OF EXPERIMENTAL AND SIMULATION RESULTS ON THE AERODYNAMIC NOISE AT THE PANTOGRAPH.

<table>
<thead>
<tr>
<th>Cases</th>
<th>Test point number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>#1</td>
</tr>
<tr>
<td>Experimental</td>
<td>79.7</td>
</tr>
<tr>
<td>Simulation</td>
<td>80.2</td>
</tr>
<tr>
<td>Difference (%)</td>
<td>0.63</td>
</tr>
</tbody>
</table>

4 RESULTS AND DISCUSSION

4.1 Analysis of flow field structure

The pressure distribution on the train surface is compared transversely and longitudinally. The influence of air conditioner parameters on aerodynamic characteristics of high speed train is investigated, which is shown in Figure 5. It reveals that with the increase of air conditioner height and guiding angle, the positive pressure area of the windward side of air conditioner is increasing gradually.

![Figure 5. Pressure distribution on the train surface: (a)A-1, (b)A-2, (c)A-3, (d)A-4, (e)B-1, (f)B-2, (g)B-3, (h)B-4, (i)C-1, (j)C-2, (k)C-3, (l)C-4.]

Similarly, as illustrated in Figure 6, the vorticity distribution of the y=0 cross sections are compared transversely and longitudinally. It shows that the vorticity at the surface of the bogie and near the nose of the tail coach are larger.
The average aerodynamic drag coefficient ($C_d$) of the whole train for different cases are presented in TABLE III. It is obvious that the case of A-1 has the smallest drag coefficient.

TABLE III. AVERAGE AERODYNAMIC DRAG COEFFICIENTS FOR DIFFERENT CASES.

<table>
<thead>
<tr>
<th>cases</th>
<th>A-1</th>
<th>A-2</th>
<th>A-3</th>
<th>A-4</th>
<th>B-1</th>
<th>B-2</th>
<th>B-3</th>
<th>B-4</th>
<th>C-1</th>
<th>C-2</th>
<th>C-3</th>
<th>C-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>h(mm)</td>
<td>190</td>
<td>190</td>
<td>190</td>
<td>190</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>350</td>
<td>350</td>
<td>350</td>
<td>350</td>
</tr>
<tr>
<td>$C_d$(total)</td>
<td>0.31</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.33</td>
<td>0.33</td>
<td>0.34</td>
<td>0.34</td>
<td>0.34</td>
</tr>
</tbody>
</table>

4.2 Analysis of acoustic performance

Time gradient distribution of pulsating pressure is used to characterize the intensity of the dipole sound source. After the completion of LES unsteady calculation, the equivalent sound power of the surface of the train ($p$) can be obtained by the following formulas.

As illustrated in Figure 7, the intensity of the acoustic source in the leeward area of the air conditioner increases with the increase of air conditioner height and guiding angle. This implies that the case of A-1 is the best scheme.

$$p' = \frac{dp}{dt}, \quad p'_{rms} = \sqrt{\frac{\int_{t_1}^{t_2} (p')^2 dt}{t_2 - t_1}}, \quad F' = \int p'_{rms} ds, \quad P \propto (F')^2$$
Figure 7. Time gradient distribution of pulsating pressure on the train surface: (a)A-1, (b)A-2, (c)A-3, (d)A-4, (e)B-1, (f)B-2, (g)B-3, (h)B-4, (i)C-1, (j)C-2, (k)C-3, (l)C-4.

In order to observe the radiated noise of the train, the acoustic receivers are arranged at 25 meters from the axis of the train and 3.5 meters from the ground. The acoustic receivers are 20 meters ahead of the nose cone of head coach and 50 meters behind the nose cone of tail coach, as shown in Figure 8. There are 16 acoustic receivers and the original position is at the nose cone of the head coach. X coordinates of the acoustic receivers are from -20 to 130, and separated by 10 meters. The train is located between the acoustic receiver number 3 to number 11.

Figure 8. Schematic diagram of acoustic receivers.

Figure 9 illustrates the A-weighted sound pressure spectrum of 1/3 octave at the acoustic receiver number 7. It is clear that the sound pressure level (SPL) shows the trend of rising first and then decreasing with the increase of frequency and reaches the maximum at the frequency slightly lower than 1000Hz. The frequency band for the aerodynamic noise is wide, and the acoustic energy concentrates at the frequency around 1000Hz and decays with the increase and decrease of frequency. A weighted total sound pressure level distribution of the all cases is illustrated in Figure 10. The sound pressure level is high at the streamline of the head coach and decreases gradually with the increase of distance from the tail coach. The streamline of the head coach is the biggest source of aerodynamic noise and the radiated noise of A-1 is minimum.
5 CONCLUSION

Based on the 3D incompressible Lilly LES+FW-H method, the radiated aerodynamic noise is calculated and high-precision simulation of high speed train is realized. Furthermore, the effects of the geometric irregularities of the air conditioner on the aero-acoustic performance of high-speed train are investigated and the corresponding lower aerodynamic noise shapes is reached. The main conclusions can be drawn as follows:

(1) With the increase of air conditioner height and guiding angle, the positive pressure area of the windward side of air conditioner is increasing gradually. The vorticity at the surface of the bogie and near the nose of the tail coach are larger.

(2) The aerodynamic drag and noise of EMU6 are smaller when the air conditioner height is 190mm and the guiding angle is 30 degrees. The intensity of the dipole sound source near the air conditioner is larger.

(3) The A-weighted sound pressure level reaches the maximum at the frequency slightly lower than 1000Hz. The frequency band for the aerodynamic noise is wide, and the acoustic energy concentrates at the frequency around 1000Hz and decays with the increase and decrease of frequency.

(4) The sound pressure level is high at the streamline of the head coach and
decreases gradually with the increase of distance from the tail coach.

References