When the railway vehicle is stationary or running at a low speed, the noise of Air-Condition outlet is large, which has a significant effect on the interior noise. How to load it into the simulation model of vehicle reasonably and predict the interior noise level accurately becomes the key technology of vehicle noise simulation. In this paper, based on the structure of the air outlet of air-condition in the passenger compartment of a certain type of EMU, the noise source characteristics are studied, and the noise test method of the air outlet and the equivalent calculation formula of the sound source are studied and proposed. Then, the equivalent noise source is used to simulate the vehicle noise, which is in good agreement with the test results. It is concluded that it is reliable to equal the air outlet noise source to the “single point sound source”, and the method of loading into the vehicle simulation model is also the most reasonable.

Key Word: SEA, Noise prediction, Air-Outlet Noise, Air-Conditioning,
necessary to study the noise characteristics of the air outlet according to the outlet structure and the air conditioning duct to provide reasonable airflow noise source for simulation based on SEA. In this paper, the noise source characteristics of the air-conditioning air outlet of a certain type of EMU are studied, and the source is analysed as the sound source of the vehicle for interior noise simulation.

![Image](https://example.com/image1.jpg)

Figure 1 The air outlet of the EMU (left) The air outlet of the subway (right)

2. Test method of the air outlet noise

2.1 Sound intensity method

There are two advantages to using sound intensity technology to measure the sound power: 1) There has no effect by acoustic environment such as free field or reverberant field. 2) In a sound field with multiple sources, the radiation power of different sources can be distinguished.

The sound intensity method can be divided into “fixed-point measurement” and “scanning method”.

1) Fixed-point measurement

The fixed-point measurement is performed by testing the normal sound intensity values of multiple measurement units on the closed surface surrounding the sound source, and the local sound power $W_i$ of each unit can be obtained, then the sound power level is obtained from the local sound power of all the measurement units. Radiated sound power level as follows:

$$L_W = 10 \lg \left( \sum_{i=1}^{N} \frac{W_i}{W_0} \right)$$

The accuracy of the test depends on the number of test points and the error of the sound intensity measurement. In the case where the measurement error is constant, the more measurement points, the higher accuracy of the result should be.

2) Scanning method

The scanning method measures the sound power by using a sound intensity probe to scan each unit of the envelope surface covering the noise source in a continuous path, then obtains the local sound power $W_i$ of each unit on the measuring surface, as shown in Figure 2.

![Image](https://example.com/image2.jpg)

Figure 2 Scanning method to measure the sound power of the air outlet

Calculate the total sound power from the sound power of each unit:

$$W = \sum_{i=1}^{N} W_i = \sum_{i=1}^{N} \bar{I}_{ni} S_i$$

Where $\bar{I}_{ni}$ is the average normal sound intensity value measured on the unit i; $S_i$ is the area of the unit i. The data acquired by the sound intensity probe moving on the small surface of unit i can estimate $\bar{I}_{ni}$, which is the average result of time and space.

2.2 Sound pressure method

The sound pressure method is a test method for converting the measured sound pressure value to obtain sound power, which is a common method for sound source power measurement. The test environ-
ment is usually divided into a free field and a reverberant field. The sound field in the EMU is more complicated and cannot be simply equivalent to a free field or a reverberant field. In actual tests, the sound pressure is considered to be the combined effect of the source radiation and the boundary reflection. The sound power level $L_{WI}$ of each measuring point can be calculated by the following formula:

$$L_{WI} = L_{Pi} + 10 \log \left( \theta * L_i * L_i \right) - L_{Pr,i}$$

Where $L_{Pi}$ is the sound pressure level at a distance $L_i$ from the sound source; $\theta$ is the incident angle of the line sound source; $L$ is the length of the line sound source; $L_i$ is the distance between the test point and the sound source; $L_{Pr,i}$ is the reflected sound pressure level of the source, which can be estimated by the following formula:

$$L_{Pr,i} = 10 \log \frac{R^4}{\pi}$$

Where $R$ is a constant for the receiving room and can be calculated by $R=(S\alpha^*)/(1-\alpha^*)$. Where $\alpha^*=\alpha+4mV/S$; $m=a/10\lg e$. Where, $\alpha$ is the average sound absorption coefficient in the car, which can be calculated by the reverberation time in the car; $a$ is the atmospheric sound absorption attenuation coefficient, which is related to temperature and humidity.

In the actual measurement, multiple points need to be tested, and the average value is calculated as the actual test sound power level.

### 2.3 Testing on the EMU

Applying the above-mentioned sound pressure method, the air outlet noise is tested in a certain type of EMU. The vehicle is in a static state, and all the equipment except the air conditioner is closed. The test frequency range is from 31.5Hz to 8000Hz. And the microphone is arranged at 20cm, 30cm directly below the air outlet, which is 45° angle to the air outlet, as shown in Figure 3 (left). Each test point was tested 3 times, and the average value of the three tests was taken as the actual measured value.

![Figure 3](image)

Figure 3 The sound pressure test of air outlet (left) The test data of air outlet noise (right)

The measured data is shown in Figure 3 (right). The sound pressure level (green line) in the “free field” at 30cm from the air outlet is approximately equal to the tested sound pressure level (blue line) in EMU minus the influence of roof boundary and reverberation in EMU (about 6dB).

### 3. Analysis of sound characteristics of air outlet noise

The air outlets of the air conditioners in EMU are large and arranged uniformly along the longitudinal direction of the vehicle. In the normal simulation model, the size of the acoustic cavity of the passenger compartment is larger than that of the air outlet, which can cover multiple air outlets. So as to ensure the test data tested in EMU can be reasonably loaded into the vehicle simulation model to accurately predict the noise level inside the vehicle, it is necessary to study the noise characteristics of the air outlet to find the most reasonable loading method. According to the structure and arrangement of the air outlets, they can be equivalent to “single point sources”, “multiple point sources” or “line source” respectively. The following is an in-depth study of the equivalent sound source loading methods of these three hypotheses. Through theoretical calculation and simulation analysis, the correct loading method of the air outlet source is determined.
3.1 Hypothesis 1: Equivalent to "single point source"

Multiple air outlet noise sources are equivalent to a single “Loud Outlet” point source, as shown in Figure 4:

The equivalent "single point source"

Then, the sound power of the point source is $W_m$, as follows. Where $W_m$ is the test sound power.

$$W_m = \frac{p^2(r)4\pi r^2}{\rho_0 c_0 Q}$$

Then the sound power level loaded into the acoustic cavity in simulation model is:

$$L_W^{\text{cavity}} = L_p(r) + 10 \log\left(\frac{4\pi r^2}{Q}\right)$$

Where $L_W^{\text{cavity}}$ is the sound power level of the air outlet that is loaded into the acoustic cavity; $L_p(r)$ is the sound pressure level of the test air outlet in EMU.

3.2 Hypothesis 2: Equivalent to "multiple point sources"

The noise of multiple air outlets is equivalent to a few point sources, that is, each air outlet is equivalent to a point sound source, and considering the size of the acoustic cavity of the simulation model, multiple point sources are superimposed and calculated, as shown in Figure 5. As shown, dx is the outlet spacing.

The sound power of a single point source is known as:

$$W_0 = \frac{p^2(r)4\pi r^2}{\rho_0 c_0 Q}$$

Where $W_0$ is the tested sound power of the single outlet; then the sound power that loaded into the cavity is:

$$W_{\text{cavity}} = W_0 \frac{L_W^{\text{cavity}}}{dx}$$

Where $L_{\text{cavity}}$ is the length of the cavity of the passenger compartment along the longitudinal train; then the sound power that loaded into the cavity is:

$$L_W^{\text{cavity}} = L_p(r) + 10 \log\left(\frac{4\pi r^2}{Q}\right) + 10 \log\left(\frac{L_{\text{cavity}}}{dx}\right)$$

3.3 Hypothesis 3: Equivalent to "line source"

Similar to the “multi-point sound source”, the noise of multiple air outlets is equivalent to one line source. With the length of cavity been taken into consideration, the same size line source is intercepted for calculation, as shown in Figure 6.
The air outlets of the EMUs are evenly arranged along the longitudinal direction of the vehicle body, and the spacing is much smaller than the length of the vehicle, as shown in Figure 7.

Then, for a line source in an ideal state, the mean square sound pressure at the distance $r$ is:

$$p^2(r) = \frac{Q \rho c}{4\pi r} \left( \frac{W' dx}{4\pi(r^2 + x^2)} \right)_{-L/2}^{L/2} = \frac{Q \rho c W'}{4\pi r} \left[ \arctan\left( \frac{x}{r} \right) \right]_{-L/2}^{L/2} = \frac{Q \rho c W'}{4\pi r} \left[ \arctan\left( \frac{L}{2r} \right) - \arctan\left( \frac{-L}{2r} \right) \right]$$

Where $W'$ is the sound power of a single air outlet, the unit is W/m; $L$ is the total length of the air duct, the unit is m. For the EMU, we know $r \ll L$, so:

$$p^2(r) = \frac{Q \rho c W'}{4\pi r} \left[ \frac{\pi}{2} + \frac{\pi}{2} \right] = \frac{Q \rho c W'}{4r}$$

So the sound power of a single air outlet is:

$$W' = \frac{p^2(r)4r}{Q \rho c}$$

In the simulation model, the radiated sound power of the air conditioning outlet of the passenger compartment with $L_{cavity}$ length is:

$$W_{cavity} = W'L_{cavity} = \frac{p^2(r)4rL_{cavity}}{Q \rho c}$$

Therefore, according to the sound pressure level $p(r)$ or the sound power $W'$ of the air outlet, the sound power loading into the SEA cavity corresponding to the air outlet in the simulation model can be obtained.

At present, the arrangement of the air conditioning outlets of most EMUs is arranged uniformly along the longitudinal direction of the vehicle, and the spacing is relatively small with respect to the length of the vehicle. According to the theoretical calculation formulas of the three equivalent sound sources mentioned above, combined with the actual test data, calculate the above three equivalent sound sources as shown in Figure 8:
It’s difficult to determine which method is the most reasonable with separate analysis of the three equivalent sound source calculated in the above figure. So the following simulation model will be established for predictive analysis.

4. Simulation analysis

Based on the principle of statistical energy analysis, the vehicle simulation model is built in VAone software, as shown in Figure 9 (left). The three equivalent sound sources calculated above are respectively loaded into the simulation model, and the noise level of the passenger compartment is calculated, as shown in Figure 9 (right).

The noise result calculated in passenger compartment which is seen from the figure above, in high frequency above 1000Hz, the simulation result of loading the equivalent “multi-point source” or “line source” separately is higher than the experimental data without loading other noise sources into the simulation model. So it is unreasonable. But when loading the equivalent “single point source” into the model, the simulation result is less than the test data in full frequency, and the noise curve trend is consistent with the test data. So the result should be reasonable. Therefore, compared with the other equivalent hypothesis, it is the most reasonable to equal the air outlet noise to a “single point source” and load into the simulation model.

In order to further verify the reasonable accuracy of the equivalent "single point sound source" loading, all other noise sources of the simulation model are loaded into the model to calculate the noise level of the passenger compartment. The simulation model is shown in Figure 10 (left). The comparison between simulation and test results is shown in Figure 10 (right).
It can be seen from the figure that after all the sound sources are loaded, the noise simulation and test results of the passenger room are in good agreement from the spectrum curve and the total noise value, indicating that the sound source of the air outlet is equivalent to a "single point source" loaded into the simulation model. Medium is reasonable.

5. Conclusion

In this paper, through the research on the noise source characteristics of the air conditioning outlet of the EMU passenger room, the difference between the sound intensity method and the sound pressure method is analysed, and tested on the train. At the same time, the theoretical and simulation studies on how to load the test data of the air outlet test into the vehicle simulation model are carried out. The conclusion is that it is most reasonable to equalize the noise source of the air outlet to a "single point sound source". And the passenger compartment noise calculated after loading all the sound sources into the model agrees well with the test data on the train.

Acknowledgement. This research has been conducted with the support of the National Key R&D Program of China (2016YFB1200503). This support is gratefully acknowledged.

REFERENCES

