Correlation Between Aerodynamic Noise and Flow Around a Rearview Mirror

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Keywords: Aerodynamic Noise, Correlation Measurement, Bluff Body, Rearview Mirror

Abstract: The purpose of this investigation is to understand the mechanism of aerodynamic noise from rearview mirrors. In order to clarify velocity fluctuation and radiated noise, velocity fluctuation and aerodynamic sound were measured in the low-noise wind tunnel. The fundamental flow around rearview mirrors was simulated with a half-cylindrical model that was proposed by German researchers. The pure-tone was observed in the case of a bump with rearview mirrors. The instability wave was introduced in the approaching boundary layer by the small bump. The sinusoidal wave was observed both of energy and sound spectra. The coherence function in terms of velocity fluctuation and noise was high level from the bump to the edge of the mirror. Strong aerodynamic noise was generated when the thickness of the bump was almost equal to half height of the boundary layer. The noise was not generated when the bump was placed in the turbulent or separated boundary layer. Therefore, laminar boundary layers and sinusoidal waves are the dominant noise source of pure-tone of the rearview mirrors. It reveals that the bump on the rearview mirror is extremely important to generate aerodynamic noise from the rearview mirrors.

The noise from the rearview mirrors is one of the dominant noise sources of the road vehicles. In order to clarify the relationship between aerodynamic noise and velocity fluctuation around a rearview mirror of road vehicles, correlation measurements were carried out in a low-noise wind tunnel that has an open test section with a square cross section of 300 mm by 300 mm. The background noise level of the wind tunnel is 54 dB at 30 m/s. This wind tunnel has an intensity of turbulence of less than 2 % and a nonuniformity of the velocity distribution about 1 % or less at a velocity of 30 m/s.

The rearview model is composed of a quarter-part sphere with diameter of 100 mm, mounted on the top of a half-circular cylinder as shown in Figure 1. The model placed on a flat plate. Siegert et al. (1999) and Höld et al. (1999) showed this model was expected to reproduce important features of the flow around an actual rearview mirror. However, this model cannot simulate the pure-tone noise that is observed from the actual rearview mirrors. In our previous investigation, the pure-tone is generated by the gap or bump on the surface of the actual rearview mirrors. In order to clarify the generation mechanism of aerodynamic noise from the bump attached on the surface of the model, aerodynamic noise and flow field were measured at various cases of the bump width, height and location.

Figure 2 shows aerodynamic sound spectra radiated from the model with bump. The noise levels depended on the position of the bump. In the case of the bump near the trailing edge, no pure-tone noise was observed. On the other hand, the discrete noise was observed at frequency of 5 kHz in the cases of bump was located at $L = 10 \text{ mm}$ and $20 \text{ mm}$.

Figure 3 shows oil-flow patterns of the rearview mirror. The boundary layer was separated near the trailing edge of the mirror. The solid and dot lines correspond to the position of the bump at $L = 20 \text{ mm}$ and $5 \text{ mm}$, respectively. In the case of the bump in the separated flow (dot line), pure-tone noise disappeared. On the other hand, when the bump was placed at the laminar boundary layer, strong noise was caused by the bump.

The noise levels of the peak-tone also depend on the thickness of the bump as shown in Figure 4. When the thickness of the bump becomes too small or too large compared to the boundary layer thickness of $\delta$. In this case the discrete noise didn’t radiate and noise levels were almost the same as that of model without the bump. One of the authors calculated the flow around the rearview mirror without the bump by using Large Eddy simulation. The result showed the thickness of the boundary layer around the bump was 0.75 mm. As a result, strong aerodynamic noise was generated when the thickness of the bump was almost equal to half height of the boundary layer.

As the results, the discrete noise is exerted by the small disturbances introduced laminar boundary layers. The small disturbances rapidly disappeared in the separated, turbulent boundary layers and they didn’t grow up near the outer region of the boundary layer, because intermittent flows of the outer boundary destroy the small disturbances. When the small disturbances introduced in the laminar boundary layer, they grew up and traveled to the trailing edge of the
mirror. The sinusoidal fluctuation of the flow velocity generates strong aerodynamic noise near the trailing edge such as the edge tone. However, it is not clear that the small disturbances are not destroyed through the separated boundary layer. The sinusoidal fluctuations, origins from the laminar boundary layer, keep their properties even in the separated boundary layers. It seems that the feedback loop of the small disturbances and noise retain the sinusoidal fluctuations. Figure 5 shows the coherence function in terms of aerodynamic noise and flow around a rearview mirror. The coherence between the noise and velocity fluctuation near the bump (position 1) indicated relatively high level. The coherence kept also high value near the trailing edge (position 2). On the other hand, no coherence can be confirmed in the wake of the rearview mirror (position 3). The intensities of the velocity fluctuations at position 1 and 2 are not so large in comparison with that of position 3. However, the pure-tone is generated by the small fluctuations near the bump. It reveals that the small disturbances from the bump in the laminar boundary layer on the surface of the rearview mirror are extremely important to generate discrete noise and the noise levels depend on the thickness of the bump and boundary layers.

Figure 1  Fundamental model for aerodynamic test of a rearview mirror

$L$: distance between the bump and trailing edge
$h$: height of bump

Figure 2  Aerodynamic noise spectra from rearview mirrors with bump ($U_0 = 30$ m/s)

Figure 3  Effects on the noise generation of height of Bump ($U_0 = 30$ m/s)

Figure 4  Oil-flow images of rearview mirror

dot line: peak tone is not observed
solid line: peak tone is observed

Figure 5  Coherence functions of velocity fluctuation and aerodynamic noise radiated form a rearview mirror at $U_0=30$ m/s
