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Study on the sunroof buffeting suppression with a notched flat deflector

He, Yansong[a)]
Zhang, Quanzhou[b)]
Xu, Zhongming[c)]
Zhang, Zhifei[d)]
School of Automotive Engineering
Chongqing University
No.174 Shazhengjie, Shapingba
Chongqing, China 400044

ABSTRACT

Buffeting is a wind noise of low frequency but high level, which makes against the comfort and safety ability of the vehicle. A simulation method of sunroof buffeting was presented and validated by the road test. The simulation method was then employed to investigate the sunroof buffeting characteristics of the vehicle with a castled deflector with the vehicle speed ranging from 30kph to 90 kph. The results showed that the highest sunroof buffeting level occurred at 70kph, with a value of 135.9 dB. To suppress the sunroof buffeting, a notched flat deflector was designed to replace the castled deflector. In particular, the influence of the deflector gap on sunroof buffeting was studied. The results revealed that the deflector had a great influence on sunroof buffeting and the optimal parameters, gap and a, were determined. With the new designed notched flat deflector, the sunroof buffeting of the vehicle was reduced to 97.9 dB. In other words, the sunroof buffeting was completely eliminated.

Keywords: Sunroof buffeting, CFD simulation, buffeting suppression, deflector gap
I-INCE Classification of Subject Number: 30

1. INTRODUCTION

Buffeting is a wind noise perceived inside a moving vehicle when the sunroof or side window open. Due to its characteristics of low frequency (about 20 Hz) but high level (>100 dB), it may make the passengers impatient and tired, which makes against the comfort and safety ability of the vehicle. Therefore, it is necessary to take measures to

a) hys68@cqu.edu.cn
b) zqz2016@cqu.edu.cn
c) xuzm@cqu.edu.cn
d) z.zhang@cqu.edu.cn

suppress the buffeting.

For the past few years, many efforts for suppressing the sunroof buffeting have been attempted. An and Singh [1] installed a dividing bar on the sunroof to suppress the sunroof buffeting. By optimizing the shape and position of the dividing bar,the sunroof buffeting was completely suppressed. Rao's research [2] indicated that the bent in the rear edge facilitated the vortices passing downstream without much solid obstruction. As a result, the sunroof buffeting was suppressed by 5 dB. Wang and Zhuang [3] investigated the effectiveness of the serrated sunroof trailing edge on the sunroof buffeting reduction. The results showed that the SPL was reduced by 10-15 dB for the buffeting frequency. But, it should be mentioned that the dividing bar and the modification of the sunroof tailing edge were difficult to apply on the real vehicle for the arrangement and styling. Karbon [4] and An [5] proved the positive effects of the comfort glass position on sunroof buffeting reduction. When the glass position changed, the vehicle speed at which the highest buffeting SPL arose changed accordingly. But the previous research of Karbon and An were carried out at a certain vehicle speed, there were unreasonable. Up to now, the most practical and reliable measure to suppress the sunroof buffeting is the deflector located near the leading edge of the sunroof. There are different types of deflectors, such as castled type, tubular type, mesh type and flat type. The tubular deflectors can suppress the sunroof buffeting to some extent, but the reduction is not significant [6-8]. The mesh type deflectors can suppress, even eliminate the low-frequency sunroof buffeting, but a high-frequency wind rush noise will be introduced [9]. Karbon [4] and An [5] investigated the flat type deflectors, the optimized flat deflector with a tall height could suppress the sunroof buffeting successfully. But, the dimensions of the deflector are limited by installation.

In this study, a simulation method of sunroof buffeting was presented and its validity was proved by the road test. The simulation method was then employed to investigate the sunroof buffeting characteristics of a vehicle with a castled deflector. To suppress the sunroof buffeting of the vehicle, a notched flat deflector was designed. In particular, the influence of the deflector gap on sunroof buffeting suppression was studied.

2. SIMULATION METHODOLOGY

A sport utility vehicle was chosen to expound the simulation method of sunroof buffeting. The computational procedure is shown in Fig. 1. Firstly, the vehicle with the exterior and interior geometries was placed in the wind tunnel to form the computational domain. The CFD mesh of the computational domain was established, as shown in Fig. 2. Secondly, the flow field simulation was conducted using the The commercial CFD software STAR CCM+. The simulation began with solving the steady flow field using the standard k-ε turbulence model. Then the steady flow acted as the initial field of the transient flow and the LES turbulence model was activated for the transient simulation. The pressure fluctuations at the monitors were obtained by the transient simulation. Finally, the sound pressure levels were obtained by converting the time history of pressure fluctuations using a standard fast Fourier transform (FFT) routine.

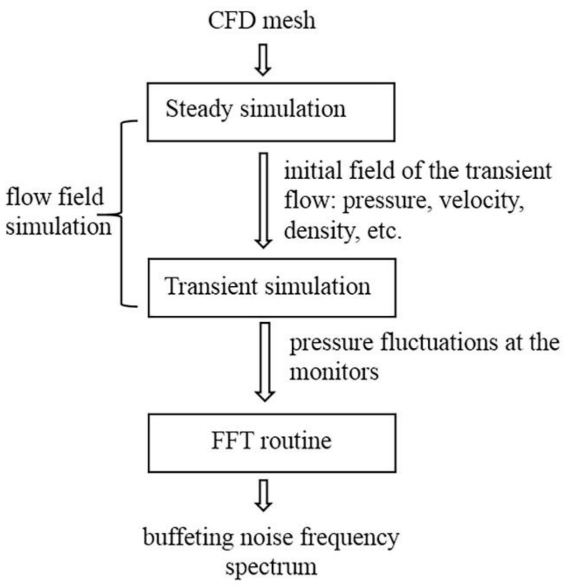

Fig. 1 - Computational procedure of the numerical simulation.

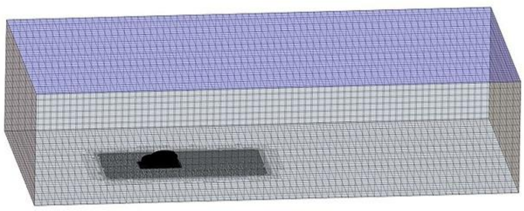

Fig. 2 - Computational domain of numerical simulation.

To validate the simulation method of sunroof buffeting, the road test was carried out on a paved road, with the outdoor temperature of 22 ℃, the wind speed less than 2 m/s, and the ambient noise less than 50 dB. In Fig. 3, the processed experimental data and simulation data at the right ear of driver in frequency domain are displayed. The simulation data are in a good agreement with the experimental data, which proves the validity of the simulation method.

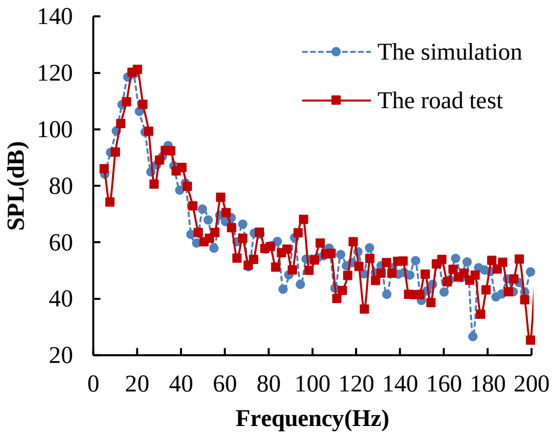

Fig. 3 - Comparison of sound pressure levels for the simulation and experiment.

3. CHARACTERISTICS OF THE SUNROOF BUFFETING

A vehicle in design process, with a castled deflector and a fully open sunroof is shown in Fig. 4. The simulation method detailed in section 2 was then employed to investigate the sunroof buffeting characteristics of the vehicle, with the vehicle speeds ranging from 30kph to 90kph.

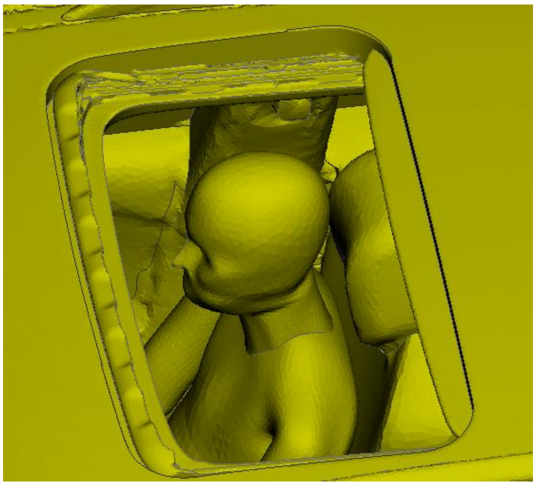

Fig - 4. Geometry model of the vehicle.

Fig. 5(a) shows the peak SPL and the dominant frequency of the sunroof buffeting at the driver's right ear at various vehicle speeds. The peak SPL rise and then fall with the rise of the vehicle speed and the maximum of the peak SPL occurs at 70 kph. The SPL spectrum at 70 kph is shown in Fig. 5(b), with a significant peak SPL, 135.9 dB, at the dominant frequency of 20.1 Hz. The buffeting SPL is much higher than 100 dB. Therefore, it is necessary to take measures to suppress the sunroof buffeting.

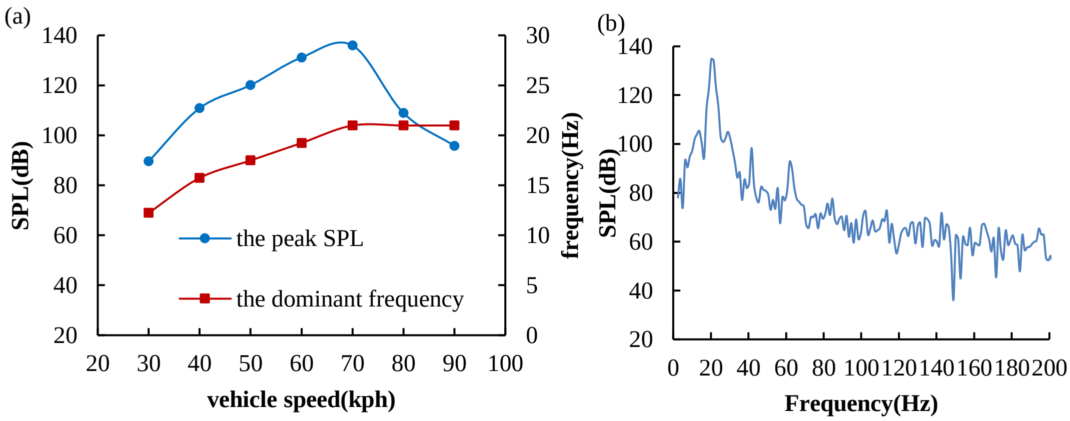

Fig. 5 - (a) The peak SPL and the dominant frequency at various vehicle speeds; (b) The SPL spectrum at 70 kph.

4. SUNROOF BUFFETING SUPPRESSION WITH A NOTCHED FLAT DEFLECTOR

In order to suppress the sunroof buffeting of the vehicle, a notched flat deflector is designed to replace the castled deflector. As shown in Fig. 6(a), the notched flat deflector is held in the channel space of the A-frame when the sunroof is closed, and the deflector pops up near the leading edge of the sunroof through a spring restoration action as the sunroof opens. The shape of the notched flat deflector is determined by the shape parameters a, b, W and D. Here, the parameters a and b represent the deflector length below and above the leading edge of the sunroof opening, respectively. The parameters W and D represent the width and depth of the notch, respectively. The position of the deflector is determined by the position parameters gap and ϕ. The parameter gap represents the horizontal distance between the leading edge of the sunroof and the lower edge of the deflector. The parameter ϕ represents dip angle of the deflector.

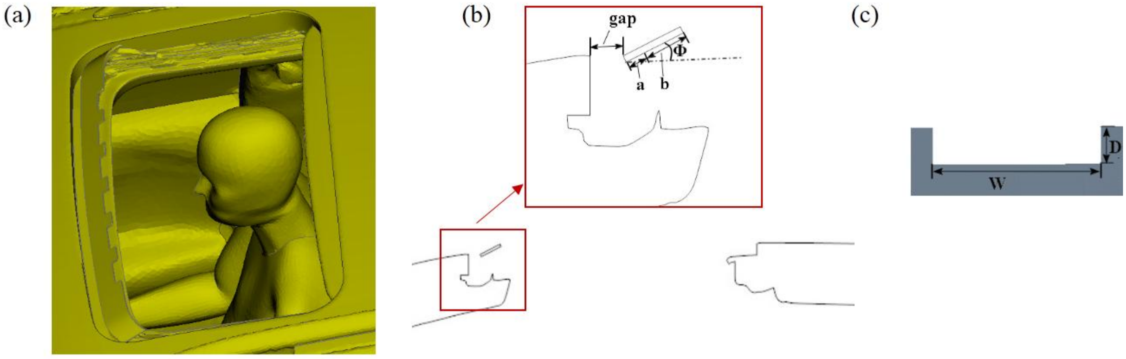

Fig. 6 - (a) Shape and position of the new deflector; (b) shape and poisition parameters of the new deflector; (c) shape of the notch.

An has conducted a research for a flat deflector to investigate the effects of the deflector angle and deflector height on the sunroof buffeting [5]. The results showed that the deflector angle of 40 ° was optimal to minimize buffeting when the deflector angle ranged from 0 ° to 60 °, and the buffeting level was almost unchanged when the deflector height changed from 43mm to 65mm. The new deflector is derived from the flat deflector. Therefore, the angle ϕ, which is the complementary angle of the deflector angle in An's research, was determined as 50 °. The parameter, b, corresponding to the deflector height in An's research was determined as 43mm for a high deflector is disadvantageous to reduce the wind drag. Referring to the castled deflector, the width and depth of the notch were determined as 60mm and 15mm, respectively.

However, very little research has addressed the influence of the deflector gap on sunroof buffeting suppression. There is no reference for the determination of the deflector gap. Here, the deflector gap is determined by the position parameter, gap, and the shape parameter, a. To determine the parameters, gap and a, the influence analyses of the parameters on the sunroof buffeting were conducted. Firstly, various gaps, 10, 15, 20mm, were simulated to investigate the influence of the parameter, gap, on the sunroof buffeting, with a=10mm. As shown in Fig. 7(a), when the gap increases from 10mm to 20mm, the peak buffeting level decreases from 115.1 dB to 105.5 dB. Hence, the parameter, gap, was determined as 20mm. Then, with gap=20mm, various parameter a, 5, 10, 15mm were simulated to investigate the influence of the parameter, a, on the sunroof buffeting. As shown in Fig. 7(b), in the range of the gap 5~15mm, the peak buffeting level increases from 97.9 dB to 105.5 dB, and then keeps almost unchanged. Hence, the parameter a is determined as 5mm. Through the influence analyses, it is found that the deflector gap has a great influence on the sunroof buffeting. With the optimal parameters, gap=20mm and a=5mm, the lowest sunroof buffeting, 97.9 dB, was achieved, which decreased by 17.2dB compared with the parameters, gap=10mm, a=10mm.

As a result, with the parameters, gap=20mm, a=5mm, b=43mm, ϕ=50 °, W=60mm, D=15mm, the sunroof buffeting decreases from 135.9 dB to 97.9 dB compared with the castled deflector, as shown in Fig.8. The sunroof buffeting of the vehicle was completely eliminated by the new designed notched flat deflector.

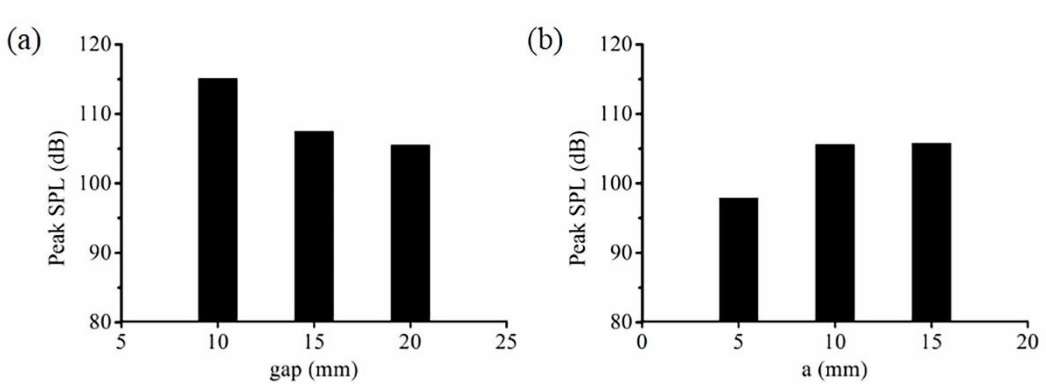

Fig. 7 - Influence analyses of the parameters, gap and a.

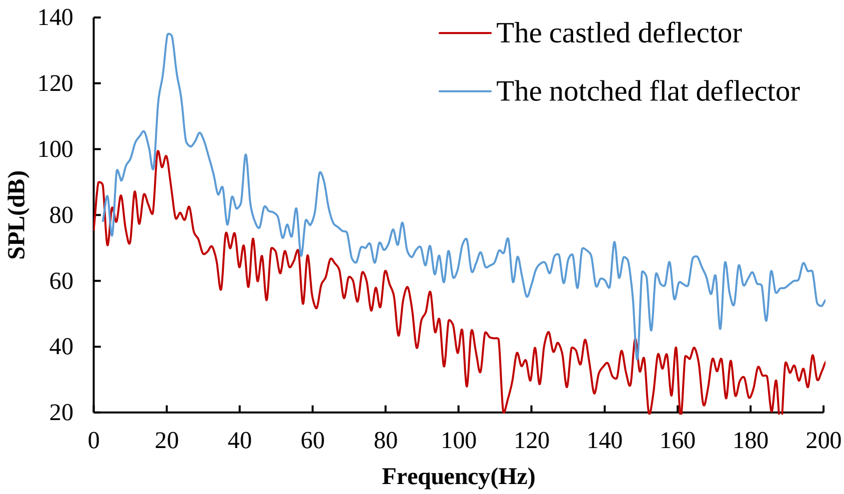

Fig. 8 - Buffeting level curves of the castled deflector and the notched flat deflector.

5. CONCLUSION

In this study, a simulation method of sunroof buffeting was presented and its validity was proved by the road test. Based on the simulation method, the highest sunroof buffeting level of the vehicle with castled deflector was found out, occurring at at 70kph, with a value of 135.9 dB. Moreover, to suppress the sunroof buffeting, a notched flat deflector was designed to replace the castled deflector. In particular, the influence of the deflector gap on sunroof buffeting was studied. The results revealed that the deflector had a great influence on sunroof buffeting and the optimal parameters, gap and a, were determined. With the new designed notched flat deflector, the sunroof buffeting of the vehicle was completely eliminated, achieving a low buffeting level of 97.9 dB.

6. ACKNOWLEDGMENTS

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