Reduction of Flow Fluctuation with Vortex Generating System

Ju Yeol You*, Hyung-il Kwon, Sunghyun Jeon, Jungsik Cho and Yong Su Shin

Aerodynamic Development Team
Hyundai Motor Group
150, Hyundaiyeonguso-ro, Namyang-eup
18280, Hwaseong-si, Gyeonggi-do, Korea
aerodoctor@hyundai.com
hyungil.kwon@hyundai.com
Sunghyun0906@hyundai.com
Jungsik.Cho@hyundai.com
Shin.yongsu@hyundai.com

Abstract: The retractable vortex generating system has been employed in HAWT(Hyundai Aero-acoustic Wind Tunnel) to reduce the data fluctuation. Due to the high fluctuation of the aerodynamic data, large data measurement time has been required. Several experiments have been conducted to investigate the physical cause of the data fluctuation. The experimental results showed that the reflected shear layer from the collector flap caused the data fluctuation. The vortex generating system on the nozzle lip was proposed by FKFS. The plenum pressure and drag force were compared to illustrate the improvement in the data quality. The vortex generating system reduced the data measurement time by more than 50%. As a result, the data recording time was reduced from 200 seconds to less than 100 seconds. However, the axial static pressure distribution in the plenum changed and the drag coefficient increased. In addition, the aerodynamic contribution of each part of a vehicle also changed. Further research will be conducted to compensate for the increase of the drag coefficient.

1 Introduction

Flow uniformity and stability are very important features in open-jet wind tunnels. In order to obtain uniform and stable flow in the test section, it is very important to minimize pressure pulsation in the plenum. For a long time, a lot of studies have been conducted to find out the mechanism of pressure fluctuation [1-7]. The Hyundai Aero-acoustic Wind Tunnel(HAWT) was built in 1999. It had static pressure fluctuation at that time. In addition, the level of fluctuation at certain wind speed was larger than acceptable value. The vortex generator attached to the nozzle lip had been investigated to reduce the pressure fluctuation in the test section. However, due to the increase of aero-acoustic noise and negative static pressure gradient, the use of the vortex generators was considered unacceptable. The edge-tone feedback was found to be the main source of the pressure fluctuation and a slot between the trailing edge of the collector and the entrance of the test section diffuser was proposed [5]. As a result, location of the collector was modified to make a slot between the collector end and entrance of the test section diffuser. Although the structural modifications were made in 2001, there is still aerodynamic data fluctuation and it takes relatively long time to obtain the averaged value. In this study, in cooperation with FKFS, the source of the data fluctuation and the way to increase the quality of the measurement were investigated. Plenum pressure and drag force were analysed to explain the data quality improvement.

2 Experimental Analysis

Fig. 1 shows the wind tunnel test result of a mini-van recorded at 1Hz for 400 seconds at 140km/h. Because the drag coefficient is fluctuating more than 10 counts, a relatively large number of data is required at least 200 to obtain the averaged value.

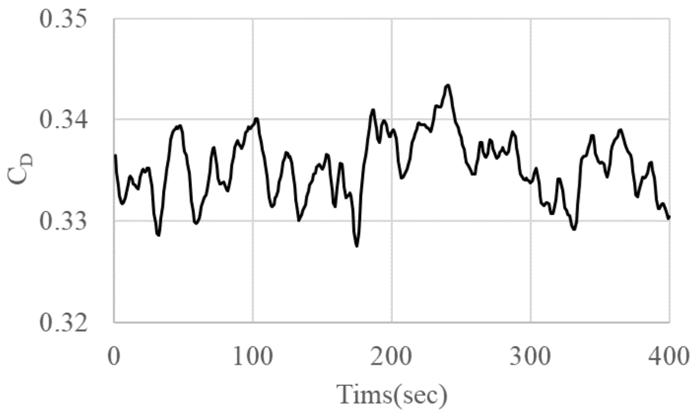

Figure 1. Drag coeffiecient of a mini-van

In order to determine the source of the data fluctuation, several experiments were conducted. A Pitot tube was installed 1.2m above the center of the turntable to compare the pressure fluctuation at 140km/h(reference wind speed) as shown in Fig. 2. The pressure data were recorded at 5Hz for 15 minutes after the wind speed achieved.

Figure 2. Pitot tube set-up

Fig. 3 and Fig. 4 show total and static pressure distributions according to time and their frequencies respectively. The edge-tone feedback loop frequencies are shown in Tab. 1. The frequency of the edge-tone feedback loop is[5]:

$$f_e = \frac{1}{\left(\frac{1}{m}\right)\frac{L_{jet}}{0.65U} + \frac{L_{jet}}{c - U}}$$

For the HAWT, L_{jet} = 14.47m and U=38.9m/s.

The dominant frequencies of pressure pulsations were observed near 1.5Hz and 2.5Hz. In Tab. 1, the edge-tone feedback frequencies are similar to the dominant frequencies of pressure fluctuations. In particular, at m=2, the edge-tone feedback frequency is equal to the dominant frequency of the static pressure fluctuation. It means that the reflected shear layer from the collector can be a source of the aerodynamic data fluctuation.

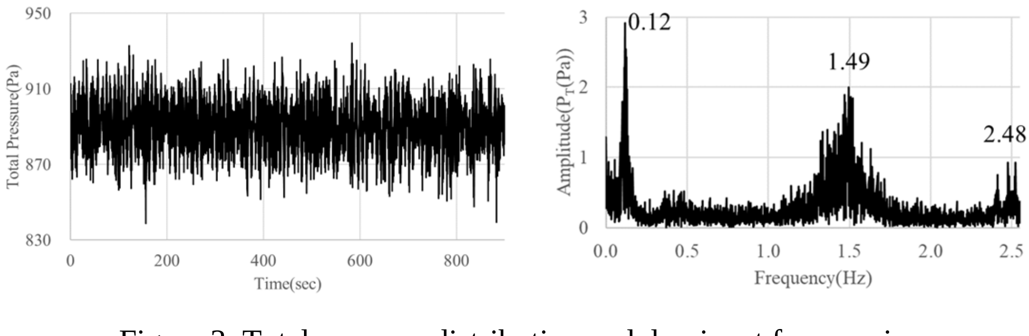

Figure 3. Total pressure distribution and dominant frequencies

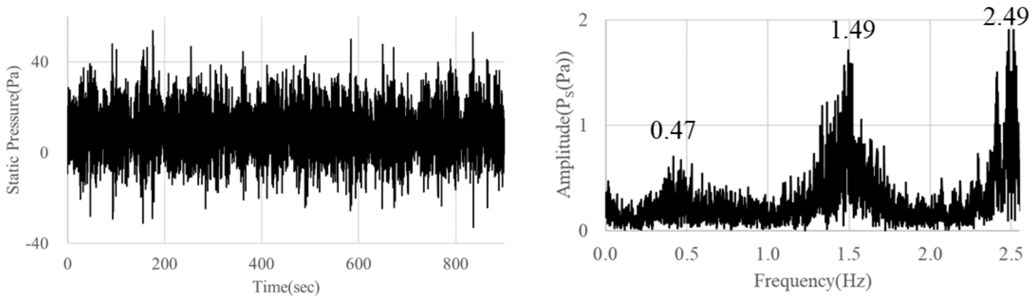

Figure 4. Static pressure distribution and dominant frequencies

Mode(m)	$F_{edge\text{-}tone}$
1	1.336 Hz
2	2.482 HZ
3	3.475 Hz

Table 1 Edge-tone feedback loop frequencies

A simple experiment was conducted to see if the reflected shear layer caused the fluctuation in aerodynamic data. Since HAWT has a traversing system with a large structure near the height of the jet shear layer, so it was assumed that the traversing system might lessen the shear layer reflection and the reduce pressure fluctuation. The traversing system was moved to the collector to prove the assumption as shown in Fig. 5. Fig. 6, Fig. 7 and Fig 8 show the changes in total and static pressure distributions, their frequencies and drag coefficient according to the location of the traversing system respectively. Tab. 2 shows the change in the standard deviation of pressure and drag coefficient of a mini-van. The results show that the data fluctuation reduces when the traversing system is above the end of the turntable. Although the movement of the traversing system is not a permanent solution, it shows that the reflected flow from the collector is manipulating the flow fields around a vehicle.

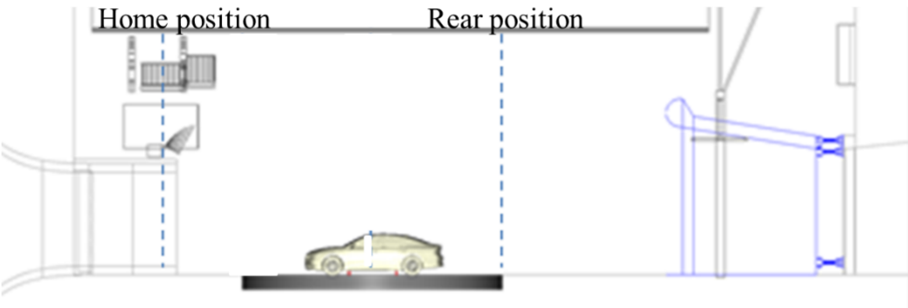

Figure 5. Position of traversing system

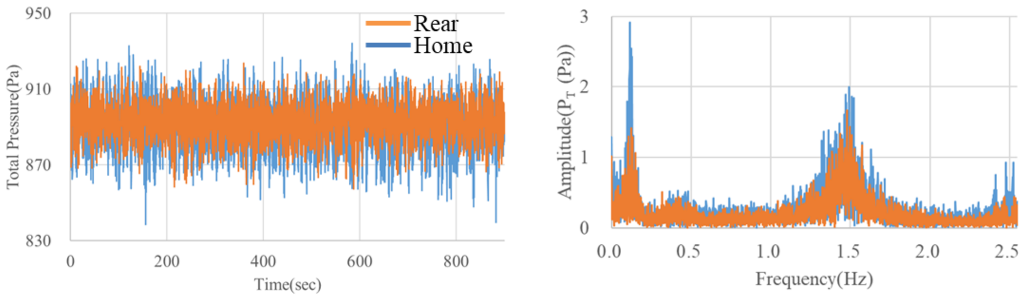

Figure 6. Change in total pressure distribution and frequencies

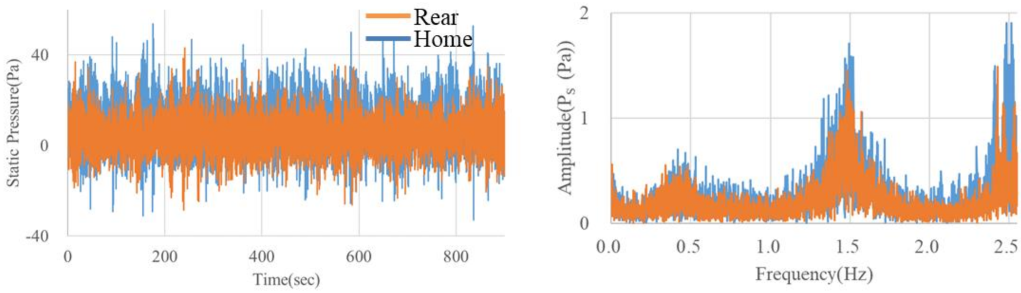

Figure 7. Change in static pressure distribution and frequencies

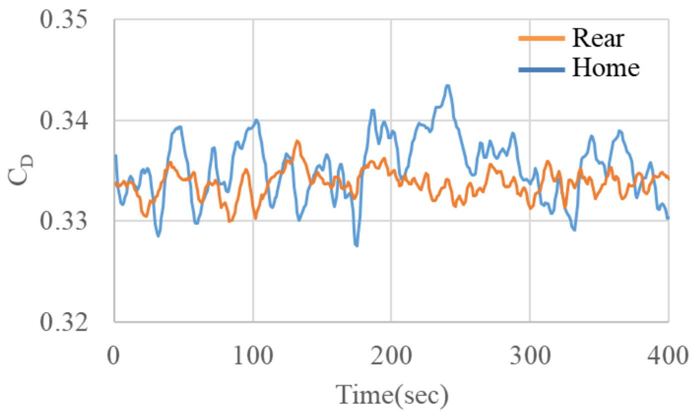

Figure 8. Change in drag coefficient of a mini-van

	Traverse Home	Traverse Rear
STDEV of P_T	13.0	9.6(26% ↓)
STDEV of P_S	11.5	8.6(25% ↓)
STDEV of C_D	0.0031	0.0013(57% ↓)

Table 2. Standard deviation of data

3 Application of Vortex Generators on Nozzle Lip

FKFS suggested vortex generators on the nozzle lip to prevent the formation of the coherent shear layer vortices and reduce the aerodynamic data fluctuation. Previous researches [6,7] applied vortex generators on the upper edge of the nozzle. In this study, vortex generators were also applied on the side edges of the nozzle to increase the stability of the flow. The vortex generator was designed to be retractable considering the aero-acoustic side effects as shown in Fig. 9. The length of the vortex generator is 100mm and the width is set to be placed equally spaced. The angle of flap is 10 degrees towards the nozzle outlet.

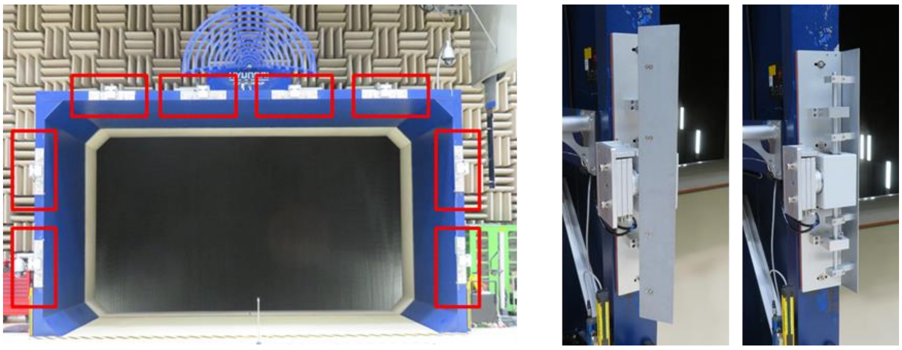

Figure 9. Retractable vortex generators on the nozzle lip

The static pressure at the center of the turntable was measured according to the wind speed. Fig. 10 shows the dominant frequencies of the static pressure fluctuation are depending on the state of the vortex generators. It is observed that all dominant peaks reduce for all wind speeds when the vortex generators are deployed. Especially, the reduction of the magnitude of dominant frequencies at 140km/h is noticeable. The axial static pressure was also measured along the longitudinal direction at 140km/h, and the dominant frequencies are shown in Fig. 11. The peaks of dominant frequencies reduce at all locations with the vortex generators on.

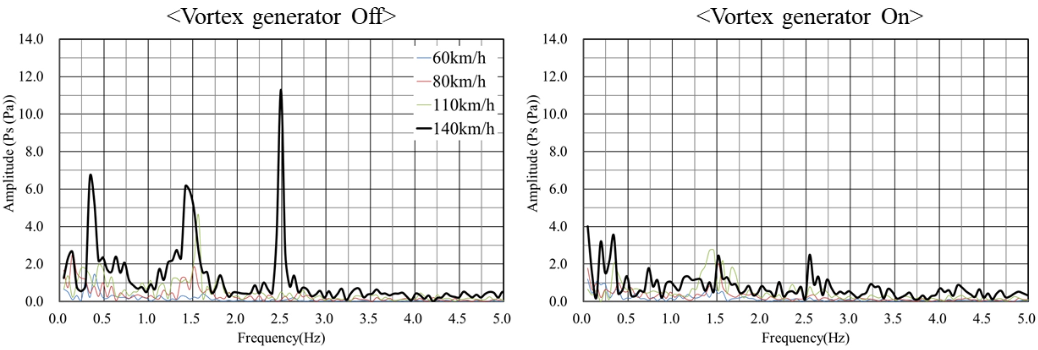

Figure 10. FFT of static pressure accoriding to wind speed

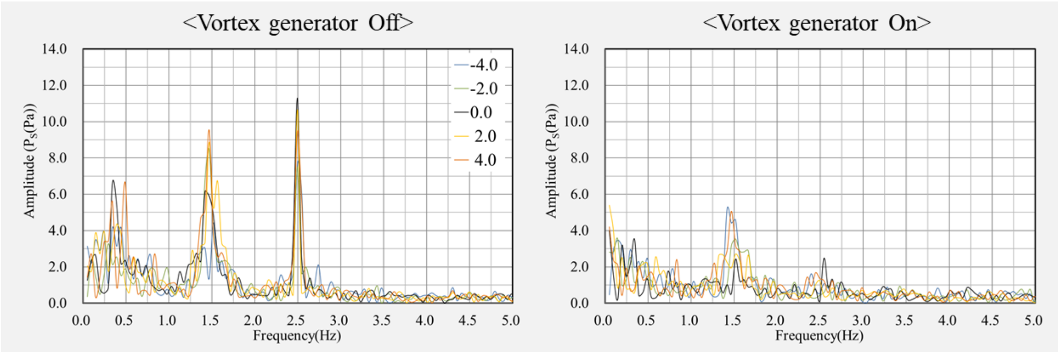

Figure 11. FFT of static pressure accoriding to axial position

The plenum axial static pressure gradient is shown in Fig. 12. The slope of the data varies according to the state of the vortex generators. When the vortex generators are deployed, the difference in static pressure data between fore-body and rear-body of a vehicle increases. It contributes to increasing the horizontal buoyancy effect and increasing the drag coefficient of a vehicle.

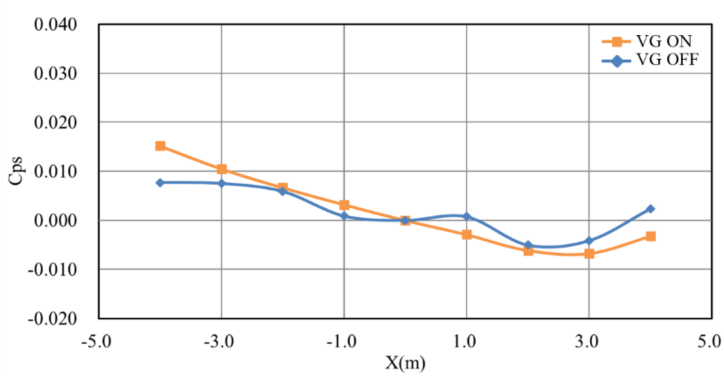

Figure 12. Axial static pressure gradient in plenum

The wind tunnel test of DrivAer notchback model was conducted. Fig. 13 shows the change in the drag coefficient. The standard deviation of the data is reduced by 67% and averaging time can be reduced to less than 100 seconds when the vortex generators are deployed. However, the averaged drag coefficient shows increase as explained in the axial static pressure gradient in Fig. 12. In Fig. 14, the difference in the static pressure along the 0L line shows the same tendency as the difference in axial static pressure gradient in Fig. 12. At the front of the model, the static pressure with vortex generators on is greater than one with vortex generators off, and it appears in reverse at the back of the model. Fig. 15 shows the variation of the drag coefficient according to the wind speed. When the vortex generators are opened, the values of the drag coefficient increase and the tendency of the variation changes similarly to the result of FKFS wind tunnel.

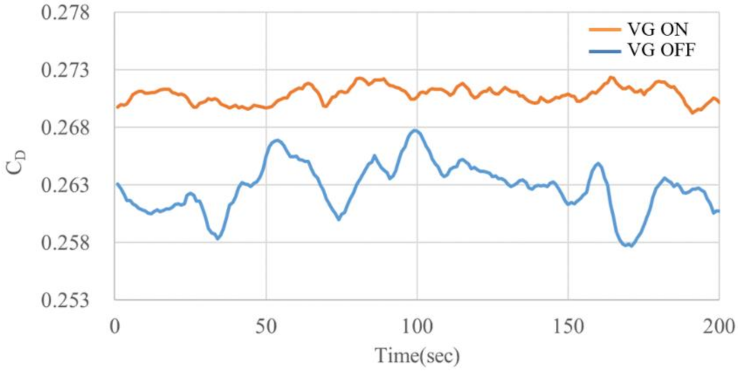

Figure 13. Drag coefficient of DrivAer notchback model

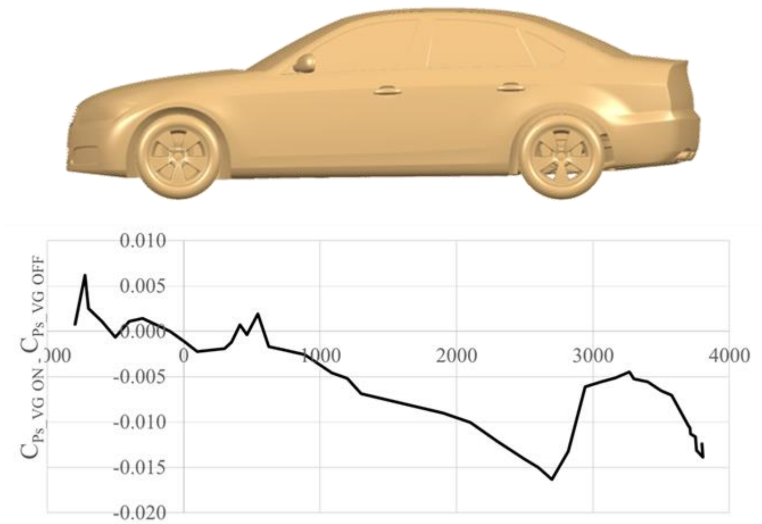

Figure 14. Static pressure distribution on upper body(0L)

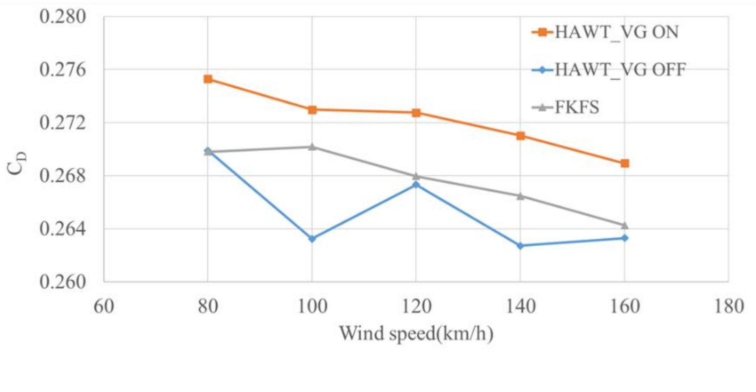

Figure 15. Variation of drag coefficient according to wind speed

Fig. 16 shows changes in the aerodynamic properties of each part of a vehicle, indicating the aerodynamic contributions of wheel, cooling, undercover and posture of a vehicle vary depending on the state of vortex generators.

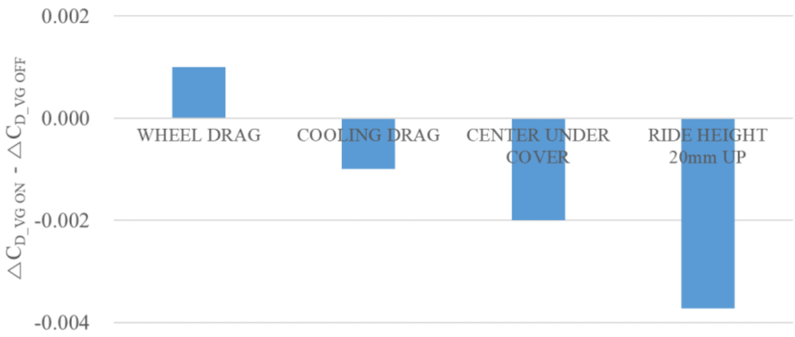

Figure 16. Change in aerodynamic contribution of each part

4 Conclusions

In this study, several experiments were conducted to reduce the fluctuation in the aerodynamic data, and improve the quality of measurement. The reflected shear layer from the collector has been found to be a source of the data fluctuation. Finally, the retractable vortex generators were installed on the nozzle lip not only to solve the problem but also to minimize the aero-acoustic side effect. The fluctuations of the plenum pressure and drag coefficient reduced dramatically when the retractable vortex generators were deployed. However, the vortex generators changed axial static pressure gradient in the plenum and increased the drag coefficient. In addition, the aerodynamic contribution of each part of a vehicle also changed. More researches will be conducted on the various types and positions of vehicles to find out how to compensate for the changes in the aerodynamic forces, and aero-acoustic tests with vortex generators will be conducted as well.

5 Bibliography

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