Journal of Wind Engineering & Industrial Aerodynamics 170 (2017) 46–55

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia

Transient aerodynamic characteristics of vans overtaking in crosswinds

Lining Liu [a,b], Yumei Sun [b], Xuefeng Chi [b], Guangsheng Du [a,*], Meng Wang [c]

[a] School of Energy and Power Engineering, Shandong University, Jinan 250061, Shandong, China
[b] Yantai Nanshan University, Yantai 265713, Shandong, China
[c] Department of Structural Engineering, UC San Diego, 9500 Gilman Drive, La Jolla, CA 92093, USA

ARTICLE INFO

Keywords:
Unsteady aerodynamics
Transient aerodynamic characteristics
Crosswind
Overtaking process

ABSTRACT

Crosswinds affect the aerodynamic characteristics of vehicles involved in overtaking. To investigate such effects, we performed simulations on two identical vans during the overtaking process under different crosswind conditions. The yaw angle between the resultant velocity and the centerline of the overtaken model was varied from 0° to 30°. The results show that the crosswind affects the aerodynamic forces on the two vans significantly, especially on the overtaken van. As the yaw angle increases, the aerodynamic coefficients of the overtaking van increase, but the coefficients of the overtaken van present special patterns at different stages. The pressure fields and flow streamlines for yaw angles $\beta = 0°$ and 20° were presented to illustrate the potential influence of crosswinds on the two vans. It is obvious that the flow field becomes more complicated under crosswinds, and the varying band of pressure field is expanded. When the front end of the overtaking van exceeds the rear of the overtaken van by a quarter of its body length, the aerodynamic force coefficients of the two vans are considerably large, and the handling stabilities of them decrease greatly. The drivers should pay more attention to safety when driving in crosswinds during the overtaking process.

1. Introduction

Overtaking is a common phenomenon on motorways with the number of motor vehicles increasing. During the overtaking process, the external flow field around two vehicles generates strong interference and forms additional transient aerodynamic forces acting on the vehicles, which affects the vehicles' handling stability. Natural crosswind exists universally in daily driving. If a vehicle is affected by a strong crosswind while moving in a high speed, the aerodynamic forces will change significantly, causing variation of the vehicle's movement characteristics and deviation of moving directions. As a consequence, the chance of traffic accidents increases during an overtaking process.

In the literature, there are many existing studies focused on the effect of crosswinds on the vehicles both experimentally and numerically. For instance, Suzuki et al. (2003) and Cheli et al.(2011a, 2011b) carried out wind tunnel tests on different vehicles under crosswind conditions, respectively. Their results indicated that the aerodynamic characteristics of vehicles depend on not only the shapes of the vehicles but also the infrastructures. Guilmineau and Chometon (2009) performed simulations on the Willy square-back model using RANS equations, revealed the physics of steady three-dimensional separated flows, and verified them by experiments. The results laid a foundation for further studies of unsteady flows. Tsubokura et al.(2009, 2010), and Krajnović and Sarmast (2010) used large eddy simulation (LES), Guilmineau et al. (2013) used detached eddy simulation (DES) to investigate the crosswind effects on a single model, their results showed that these two methods provided precious aerodynamic data that was difficult for conventional wind tunnel tests or RANS simulation to provide. However, it should be noted that both LES and DES require large computing resources for high Reynolds number flows, so it is difficult for them to be applied in more complex overtaking process simulations.

In addition, the above studies were not extensive. They only explored the effect of crosswinds on the transient aerodynamic characteristics of a single vehicle, but did not cover the effect of crosswinds on vehicles in complex driving conditions, such as overtaking and passing.

Some scholars studied the overtaking process by experiments and numerical simulations. Noger et al. (2005) used dynamic tests to conduct transient experiments on the overtaking process between two 1/5-scale Ahmed bluff-bodies in a wind tunnel. Their study showed that besides the longitudinal and transverse spacing, the relative velocity and crosswind strength also influenced the aerodynamic characteristics of vehicles. But in the case of a smaller yaw angle, the influence was trivial. Corin et al. (2008) did numerical simulation about the overtaking process between two simple two-dimensional (2D) models. They found out how the

* Corresponding author.
E-mail address: du@sdu.edu.cn (G. Du).

http://dx.doi.org/10.1016/j.jweia.2017.07.014
Received 29 September 2016; Received in revised form 20 July 2017; Accepted 22 July 2017

relative velocity and crosswinds impact the aerodynamic forces of both the overtaking and overtaken vehicles. However, their research deviated from the actual three-dimensional overtaking process due to the limitation of models that they used. The venturi effect between the 2D models was increased and the forces on the vehicles were overestimated. In order to reveal the three-dimensional overtaking process, Noger and Greveynyghe (2011), and Howell et al. (2014) carried out experiments on 3D models in wind tunnels, and Gilliéron (2003), Hu et al. (2012) and Uystepruyst and Krajnović (2013) performed three-dimensional numerical simulations based on RANS approach. They mainly analyzed the variation in drag force, side force and yawing moment coefficients of vehicles caused by the overtaking process. The lift force and rolling moment coefficients as well as the impact of crosswinds were discussed in a paper by Howell et al. (2014). In addition, Bruzelius et al. (2013) presented a simplified real time model that would capture the main features of the side force and yawing moment acting on the overtaking vehicle. Kremheller (2015) described the experimental method to measure the surface pressure and motion of a vehicle when it is overtaking and passing another vehicle on a proving ground. Most of the above studies mainly concerned about the interaction of two vehicles in the overtaking process, but did not pay sufficient attention to the effect of crosswinds.

In order to further investigate the transient aerodynamic characteristics of vehicles during the overtaking process under the influence of crosswinds, we adopted the dynamic mesh and sliding interface to perform three-dimensional numerical simulations. Through the simulation, we showed how crosswinds influence the transient aerodynamic characteristics of overtaking and overtaken vehicles. Through the analysis of the flow field at specific overtaking positions, the major reason causing the variation of vehicles' aerodynamic forces was identified. Our research can provide a reference for comprehensive understanding of the overtaking process under crosswinds.

2. Experimental study

The overtaking process without crosswind was conducted in the wind tunnel of Shandong University with two simplified 1/10-scale van models. This wind tunnel has a cross section of $1 \times 1.2\ m^2$, and the length of the test section is 2 m. The maximum speed of wind in the tunnel is approximately 45 m/s. Details of this tunnel can be found in Li (2010). Due to the limited experimental conditions, we performed the tests with a steady method. The overtaken van model was fixed on the floor, and the overtaking van model was set at several specific positions to implement the whole overtaking process. The aerodynamic forces of overtaken van were measured with a six-component balance. In the experiment, the Reynolds number is 5.2×10^5 based on the width of van model, with a test speed of 35 m/s.

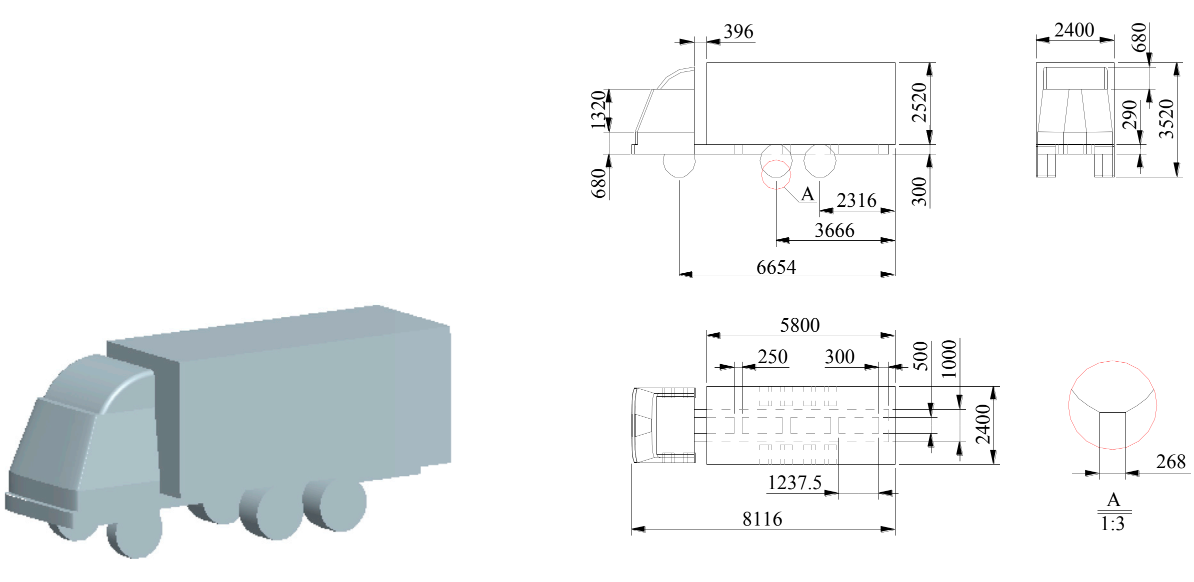
3. Numerical simulation

3.1. Geometry model

In this study, two full-scale vans were simulated as the research models. The length of the model was $L = 8{,}116$ mm, the width was $W = 2{,}400$ mm, and the maximum height was $H = 3{,}520$ mm. The surface reference was the maximum cross section $A = 8{,}448{,}000\ mm^2$. The wheel diameter was $\varnothing = 1{,}000$ mm, and the front cabin top radius was $R = 1{,}297.5$ mm. Other dimensions were shown in Fig. 1. The Reynolds number based on the width of model was $Re = 2.68 \times 10^6$, for a velocity of 20 m/s. To simplify the model body while keeping the calculation accurate, we ignored the side-view mirrors, door handles as well as the under-body small parts. We also assumed the tread of the tire to be flat as shown in Fig. 1 A.

3.2. Computational domain and mesh method

The computational domain periphery was a cuboid, with total length 16.5L, total width 15.5W, and total height 5H. As is shown in Fig. 2, we used Van1 to represent the overtaking vehicle, and Van2 to represent the overtaken one. The crosswind inlet boundary was 3W to the left side of Van1 and outlet boundary was 10W to the right side of Van2. Without discussing the effect of the transverse spacing, the lateral distance between Van1 and Van2 was set to 0.5W. X axis was set along the direction opposite to the moving direction of the models. Y axis was set horizontally from the left to the right side of the vehicles. Z axis was set vertically upwards.



(a) Van model (b) Dimensions of van model

Fig. 1. Van model (dimensions in mm).