The Aerodynamic Characteristics of Vehicle under Lateral Wind Action for the Process of Two Vehicles Passing Each Other

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Abstract. Research the aerodynamic characteristics of vehicle under lateral wind action for the process of two vehicles passing each other based on the CFD (Computational Fluid Dynamics) numerical simulation of the dynamic grid technology. Analysis the change rule of aerodynamic characteristics of vehicles in the process of vehicles passing each other and discuss the influence of wind speed, driving speed and the different bridge transverse driving locations upon aerodynamic characteristics of vehicles. The results show that, it has large mutation for the aerodynamic force coefficients of the windward vehicle and leeward vehicle. The overturn moment coefficient, lift force coefficient, lateral fore coefficient both reduce with increasing driving speed and both increase with increasing lateral wind speed.

1. Introduction
In recent years, the engineering network has been developing very fast. Among them, the proportion of long-span bridges are increasing. The larger spans and higher bridge above the ground, the greater influence of lateral wind load on vehicles running on bridge. The present studies of aerodynamic characteristics for vehicles running on the bridge have some valuable research. Currently, there are two methods for research on this, wind tunnel test and numerical simulation.

At present, the research situation of mutation wind load on running vehicle mainly have following several kinds, vehicle running on the bridge passing the bridge tower, vehicles running on bridge passing each other, vehicles passing out of the tunnel. The wind-vehicle-bridge system are investigated mostly with the numerical simulation method.

The study model of aerodynamic characteristics of vehicle mainly taking vehicle stationary on bridge. This article does the research on the change rule of aerodynamic characteristics using numerical method of CFD technique to simulate the process of vehicles passing each other under the lateral wind action. In the meantime, the moving grid has been applied and the three-dimensional dynamic numerical wind tunnel model has been established.
2. Calculation model

2.1. Model of vehicle and bridge

Study the change of aerodynamic characteristics of vehicles under the lateral wind action in the process of passing each other, select the bus as research object model shown in figure 1 and select the steel box girder as research object model shown in figure 2. The influence of ancillary facilities such as railing on bridge is not considered in the numerical model and the model dimensions are modeled in 1:1 in the numerical modeling.

![Fig.1 Vehicle model (Unit: m)](image1)

![Fig.2 Cross section of bridge (Unit: mm)](image2)

Established numerical model for numerical simulating the process of vehicle passing each other. The outer surface of the two vehicles is 3.5 meters in the numerical model. In the numerical tunnel model, the windward boundary condition is velocity inlet, the leeward boundary condition is pressure outlet, both rest sides conditions are symmetry. Determine the size of the numerical model for fluid computation with the considering of clogging effect to make the windward area of model and numerical wind tunnel cross section area ratio is less than 5%. A local mesh encryption method is presented on the fluid mesh to make the wall y+ function value \( y^+ = y\sqrt{\frac{\rho \tau_w}{\mu}} \) between 30~300 at the vehicle and bridge boundaries. Where \( y \) is the distance from the unit center to the wall, \( \mu \) is aerodynamic viscosity, \( \rho \) is air density, \( \tau_w \) is wall shear stress. The tetrahedral prism is adapted for numerical analysis model of fluid flow and use a varied grade of cell to make the mesh could control the changes of elements size around the vehicle and bridge areas.

2.2. Aerodynamic coefficients

Vehicle under the wind load will be acted on by aerodynamic six-component force, which includes resistance of \( F_z \), lateral force \( F_x \), vertical lift \( F_y \), overturning moment \( M_z \), torque moment \( M_y \) and pitching moment \( M_x \). If the vehicle travels speed is \( V_t \) and acted on by the lateral wind whose speed is \( V_w \) then the aerodynamic three component coefficient can be defined as Eq.1.

\[
C_x = \frac{F_x}{\frac{1}{2} \rho V^2 HL} \quad C_y = \frac{F_y}{\frac{1}{2} \rho V^2 BL} \quad C_{Mz} = \frac{M_z}{\frac{1}{2} \rho V^2 B^2 L}
\] (1)

In Eq 1, \( C_x \), \( C_y \), and \( C_{Mz} \) respective is lateral coefficient, lift coefficient and overturning moment coefficient, besides that \( \rho \) is the air density and \( V \) is the synthesis of positive wind generated by vehicle
traveling and the natural wind. Moreover, H, B, L respectively represents the height, width and length of vehicle.

3. **Wind pressure characteristics of vehicle without lateral wind action**

Firstly, study the change rule of aerodynamic characteristics of vehicle while vehicle passing each other at 80km/h speed. The change rule of aerodynamic force coefficients is shown in figure 3 while vehicle passing each other.

![Figure 3](image)

The overturning moment coefficients and lateral force coefficients of vehicles both come to about 0 when the vehicle before and after passing each other without lateral wind effect. That is because vehicle only subjects the positive wind loads due to vehicle driving when vehicle running on bridge without lateral wind action. Then, the positive surface pressure on vehicle body is larger and the lateral surface pressure on vehicle body is smaller. So, it is accord with the actual that the overturning moment coefficients and lateral force coefficients come to about 0 and it also demonstrate the correct feasibility of numerical simulation in this paper.

The aerodynamic coefficients of windward and leeward vehicles both have a larger mutation in the process of vehicle passing each other without lateral wind action. The change rule of overturning moment coefficients and lateral force coefficients is identical for windward vehicle, which start from zero to decrease and increase to final stable. The overturning moment coefficient and lateral force coefficients of vehicle decrease to negative. That phenomenon can show that the thrust force generates on the windward vehicle deviate from the leeward vehicle because that the air surrounding vehicles met due to the vehicle passing each other. The overturning moment coefficients and lateral force coefficients of vehicle increase to positive. That phenomenon can show that pull force generates on the windward vehicle close to leeward vehicle due to the space pressure becoming smaller between vehicles. The aerodynamic force coefficients come to about zero after the vehicles passing each other.

For the windward and leeward vehicles, it is in contrast for the change rule of overturning moment coefficient and lateral force coefficients but it is same for the change rule of lift force coefficients which increase to positive and decrease to negative stable in the process of vehicle passing each other.

4. **The influence of wind speed and driving speed on aerodynamic characteristics**

Establish the analysis model of vehicle driving respectively at 80km/h and 100km/h speed under the lateral 8m/s or 15m/s wind action to study the change rule of aerodynamic force coefficients while
vehicle passing each other. The temporal change rule of aerodynamic fore coefficients of windward and leeward vehicle are shown in figure 5–6 while vehicle passing each other.

![Aerodynamic coefficients of windward vehicle](image1)

![Aerodynamic force coefficients of leeward vehicle](image2)

**Fig 4.** Aerodynamic coefficients of windward vehicle

**Fig.5** Aerodynamic force coefficients of leeward vehicle

The leeward vehicle has certain influence on the aerodynamic coefficients of windward vehicle in the process of vehicle passing each other. The overturning moment coefficient and lateral force coefficient of windward vehicle both decrease to a certain degree in the process of vehicle passing each other.
each other, but begin to return to normal after the process of vehicle passing each other. The aerodynamic force coefficients have begun to change before the process of vehicle passing each other. The overturning moment coefficients, lateral force coefficients and lift force coefficients of windward vehicle both decrease with increasing vehicle driving speed and both increasing with increasing lateral wind speed.

The windward vehicle has certain influence on the aerodynamic coefficients of leeward vehicle in the process of vehicle passing each other. The overturning moment coefficient and lateral force coefficient of leeward vehicle both have a great change, but begin to return to normal after the process of vehicle passing each other. The overturning moment coefficients, lateral force coefficients and lift force coefficients of leeward vehicle both decrease with increasing vehicle driving speed and both increasing with increasing lateral wind speed.

5. Conclusion
It has large mutation for the aerodynamic force coefficients of the windward vehicle and leeward vehicle. The change region of aerodynamic force coefficients of leeward vehicle is larger than that of windward vehicle due to the windward vehicle blocking when the vehicles pass each other. The overturn moment coefficient, lift force coefficient, lateral force coefficient both reduce with increasing driving speed and both increase with increasing lateral wind speed.

Acknowledgments
The authors gratefully acknowledge the financial supported by the Jilin province department of education science and technology research projects (JJKH20180305KJ), the Jilin province 13th five-year plan important project of educational science: Practical training course construction of civil engineering specialty in applied undergraduate colleges (ZD17122). This work is partially supported by the Chang’an University.

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