Aerodynamic Performance of a Sedan under Wind-Bridge-Tunnel Road Condition

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Abstract. Due to the complexity of the wind environment around bridge-tunnel section in canyon, the flow field around vehicle is complex and changeable. In this paper, the processes of a sedan pulling out of a two-way four-lane tunnel and passing through the pylon area under canyon wind condition are simulated numerically using the dynamic mesh technique and RNG k-ε turbulence model. The results showed that canyon wind and the terrain topography have a significant effect on the aerodynamic performance of the vehicle.
Keywords: Unsteady aerodynamic; Canyon wind; Bridge-Tunnel Section.

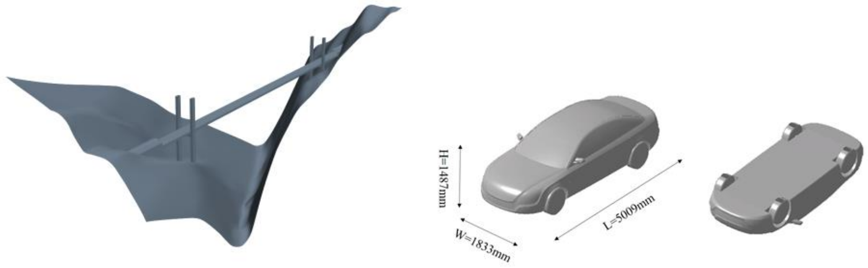
1 Introduction

With the development of economic and city traffic, a great deal of bridges and tunnels are constructed in mountainous highways [1]. Due to the unique topography, geology, climate, altitude and other factors in mountain areas, the strong unsteady crosswind, often called canyon wind, has a great impact on vehicle's performance and driving safety [2-4]. Here, the focus was put on the aerodynamic performance of a sedan pulling out of a two-way four-lane tunnel and passing through the pylon area, thus providing theoretical guidance for improving the crosswind stability of vehicles.

2 Numerical method

2.1 Geometric model

A typical bridge-tunnel connection section in western China is selected as a subject for study. The terrain and geomorphology are constructed by extracting the contour map from the geographic information system (GIS) with its area 1425m*404m. The bridge used in current research is a twin tower three-span cable-stayed bridge. And a common two-way four-lane straight tunnel is chosen, ignoring the wind turbine and other equipment inside the tunnel(see Fig.1a). The sedan, is a simplified passenger car, which located inside the tunnel, 3.2m away from the side wall and 29.09m away from the exit of the tunnel. (See Fig.1b).



a) Mountain-bridge-tunnel model b) Passenger car model

Fig. 1. Mountain-bridge-tunnel-sedan model

2.2 Governing Equation

The flow field induced by a car under wind-bridge-tunnel road condition is three-dimensional, non-stationary, turbulent and incompressible. And RNG k-ε two-equation turbulent model is utilized in this study [5].

Reynolds Average Continuity equation:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

Reynolds Average Navier-Stokes (RANS) equations:

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{1}{\rho}\frac{\partial}{\partial x_j}\left(\mu \frac{\partial u_i}{\partial x_j} - \overline{u_i' u_j'}\right) \tag{2}$$

The turbulence eddy viscosity could be computed as a function of turbulence kinetic energy k and turbulence dissipation rate ε:

$$\frac{\partial k}{\partial t} + u_j \frac{\partial k}{\partial x_j} = \frac{\partial}{\partial x_i}\left[\alpha_k \left(\nu + C_\mu \frac{k^2}{\varepsilon}\right)\frac{\partial k}{\partial x_j}\right] + \frac{G_k}{\rho} - \varepsilon \tag{3}$$

$$\frac{\partial \varepsilon}{\partial t} + u_j \frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_i}\left[\alpha_\varepsilon \left(\nu + C_\mu \frac{k^2}{\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \frac{1}{\rho} C_{1\varepsilon}\frac{\varepsilon}{k} G_k - C_{2\varepsilon}^{*}\frac{\varepsilon^2}{k} \tag{4}$$

Where α_k=α_ε=1.39 is the turbulent Prandtl number in the k equation and the ε equation, C_μ=0.0845, $C_{1\varepsilon}$=1.42, $C_{2\varepsilon}$=1.68, η_0=4.38, β=0.012.

3 Computational Sets

A simplified computational domain is established to enclose the canyon-bridge-tunnel model. The dimensions of the computational domain are as follows: the length of 1257.9 m, the width of 288 m and the height of 540.695 m. The outline features of the real canyon terrain are retained as the bottom of the computational domain (See Fig.2).

The inlet and outlet boundaries are set to pressure outlet (relative pressure p= 0). The speed of the sedan is 30m/s, and the crosswind was perpendicular to the moving direction of the sedan.

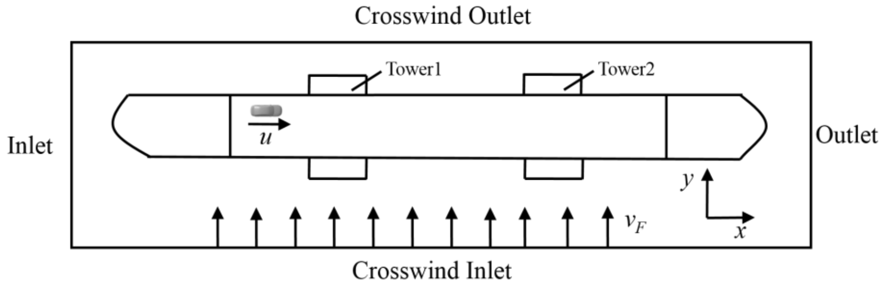
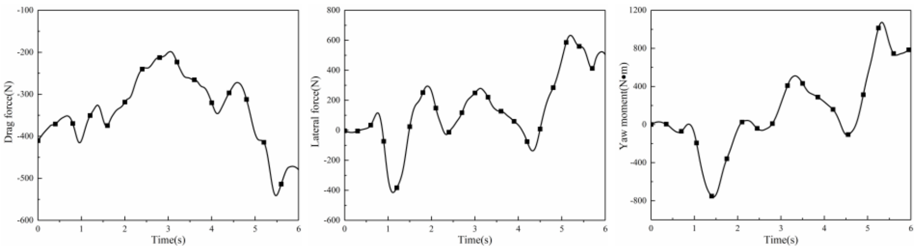


Fig. 2. Boundary condition of computational domain

4 Results and Discussions

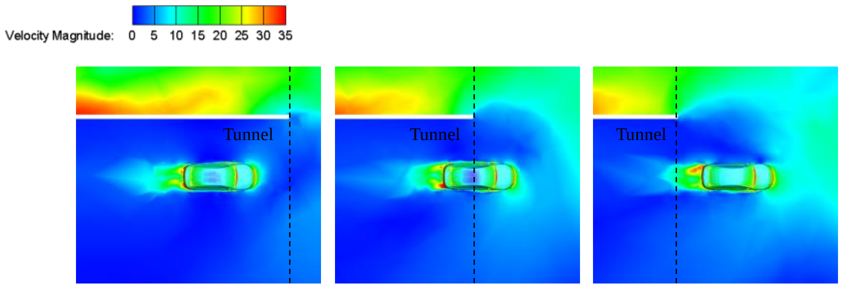
As shown in Fig. 3, the aerodynamic loads of the sedan in the process of pulling out of the tunnel and passing through the bridge tower are plotted. It can be seen from Fig.3a that when a sedan runs out of tunnel, the drag force increases sharply near the exit the tunnel. And then, it generally maintained a downward trend until t=3s, in spite of some fluctuations. When the sedan comes to the pylon area, the drag force fluctuates greatly because of complex canyon wind and topography. In Fig.3b, the variation of lateral force and yaw moment is similar and followed the same trend, which increase significantly in the crosswind and decrease greatly due to the shielding effect of the bridge tower.



a) Drag force b)Lateral force c)Yaw moment

Fig. 3. Aerodynamic Forces and Moment

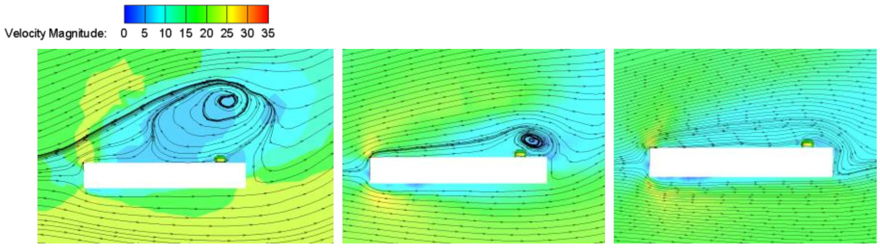
Fig.4 displayed the instantaneous velocity distributions at the x-y section(z=0.6m), which capture the change of the flow field of the sedan pulling out of the tunnel and enters in the crosswind. It can be noted that the flow field changes from symmetry to asymmetry as the car moves out of the tunnel.



a) t=0.8s b)t=0.975s c)t=1.1s

Fig. 4. Snapshot of velocity magnitude (Z=0.6m)

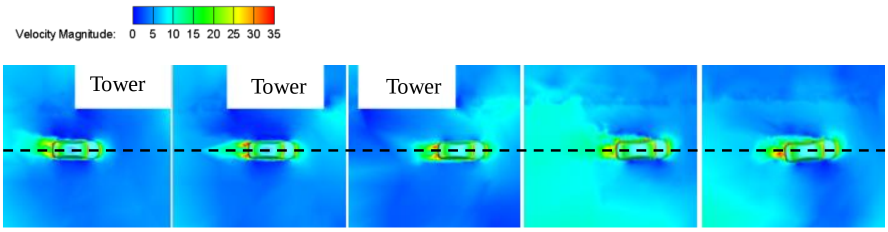
Fig. 5 shows the effect of terrain on the flow field around the vehicle. The complex canyon wind produced a huge eddy near the tunnel exit, acting on the left side of the car body and made the negative lateral force and yaw moment. As the sedan moves far away from the tunnel, the influence of the vortex on the vehicle is reduced.



a) t=1.1s b)t=1.5s c)t=2s

Fig. 5. Snapshot of streamlines

Fig. 6 shows the instantaneous displacement and the velocity distributions of the sedan in the process of driving into and out of the bridge tower area. At 4.2s, half of the sedan is sheltered from bridge tower. The flow field in the front of the sedan is symmetrical, while the velocity distribution in the rear of the car is still asymmetrical. The opposite trend can be found in the process of driving out of the pylon area at t=4.55s. At 4.35s when the sedan is completely shielded from the crosswind by the bridge pylon, the velocity distribution around the sedan is almost symmetric again. It also can be seen that the car has a significant sideslip in the crosswind.



a) t=4.2s b)t=4.35s c)t=4.55s d)t=5.5s e)t=6s

Fig. 6. Snapshot of velocity magnitude at x-y section (Z=0.6m)

5 Conclusions

The aerodynamic performance of a sedan driving in the canyon-bridge-tunnel section is revealed by computational fluid dynamic model. The drag force, lateral force and yaw moment of the sedan increased obviously when it comes out of the tunnel in the crosswind. When the sedan passing by the pylon area, the aerodynamic loads also changed sharply due to the shielding effects of the tower and the complex topography. In this complex road condition, the sedan deviates from the original path. It is worth mentioning that the road condition has a great impact on the vehicle's crosswind sensitivity and driving stability.

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