Numerical Simulation of the flow Past a Passenger Cable Car

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Abstract. In this paper, a numerical calculation method based on CFD is proposed to calculate the force and analyze the flow field of the cable car in static state. When the wind attack angle and the wind deflection angle are both 0°and the wind speed is 10m/s, the drag coefficient of the cable car is calculated by numerical simulation to be 0.77, which is consistent with the experimental results. Vortices with different sizes and intensities were observed on the lateral, upper and lower sides, and behind the cable car. The positions of the vortices correspond to the positions of the negative pressure zone.

1. Introduction

The so-called passenger ropeway transportation system is to hang the cable car from a suspended rope, because it can resist steep slopes, and the length between two adjacent spans can be set longer. Therefore, it is widely used in passenger transport operations in mountainous areas and other complex terrains, and is expected to be used in intra-city transportation in the future [1].

There are currently more than 800 passenger ropeways have been built or under construction in China, and they are increasing at a rate of 10% per year. It is essential to ensure the safe operation of each ropeway [2]. The operation of the ropeway is easily affected by the wind. When the wind speed exceeds 15m/s, the ropeway system cannot work because the system is vulnerable to wind excitation. How to reduce the wind-induced problem of the ropeway has attracted widespread attention [3].

This paper proposes a CFD-based numerical calculation method for passenger cable cars to analyze the flow field structure and force of the cable car under wind. The results show that the CFD numerical calculation results are in good agreement with the experiment, which lays a foundation for the following research on cable car dynamics and installation of aerodynamic accessories on cable car.

2. Numerical calculation method

2.1. Cable car model

In this paper, the scaled model of passenger cable car used by Sato Hisao [4] for wind tunnel test is selected, and the model are shown in Figure 1. The detailed structure of the cable car is properly simplified (such as the grip and hanger), because it will not have a significant impact on the calculation results.
2.2. Computational domain

The computational domain model is shown in Figure 2. The entire model includes two computational domains, and the interface of the computational domain is coupled with Interface boundary condition. Place the cable car at a distance of 2,000 mm from the upstream entrance and 5,800 mm from the downstream exit.

Unstructured grids and structured grids were generated in DOMAIN1 in DOMAIN2 respectively. Grid independence test was performed to exclude the influence of grid density on CFD calculation results, as shown in Table 1.

Table 1. Grid independence verification

| NUM | Number of grids | Drag coefficient |
|-----|-----------------|------------------|
| 1   | 2998262         | 0.77             |
| 2   | 4756852         | 0.79             |
| 3   | 5857201         | 0.78             |

2.3. Boundary conditions

For the CFD simulation of the cable car model, the inlet velocity is 10m/s, the wind attack angle and the wind deflection angle are both 0°, and the outlet adopts pressure outlet. With reference to previous research on automobile aerodynamic performance, the surface of the cable car is regarded as a Wall. According to the characteristic length of the cable car model of 310mm and the free flow wind speed of 10m/s, the Reynolds number $Re=1.87\times10^5$ is calculated. Table 2 lists the boundary conditions for numerical analysis.
Table 2. Boundary condition for CFD analysis

| Region          | Boundary condition                   |
|-----------------|--------------------------------------|
| Inlet           | Velocity inlet, \( V = 10 \text{m/s} \) |
| Outlet          | Pressure outlet, reference pressure=0\( \text{Pa} \) |
| Cable Car       | Wall                                 |
| Wall            | Symmetry                             |
| Turbulent model | \( \text{k-}\omega \text{ SST} \)       |

2.4. Numerical methods
The second-order upwind discrete scheme is used to solve the Navier-Stokes equation, and the pressure-velocity coupling equation is SIMPLEC. In this paper, the \( \text{k-}\omega \text{ SST} \) turbulence model is used, which additionally calculates the turbulent shear stress transport equation [5].

3. Simulation results and analysis
The calculation results are basically agreed well with Sato Hisao’s wind tunnel test. Therefore, the numerical simulation results are reliable, and the calculation formula used in this paper is as follows.

\[ C_d = \frac{F_d}{0.5 \rho U^2 A} \] (1)

\[ C_p = \frac{P - P_{\infty}}{0.5 \rho U^2} \] (2)

Where \( C_d \): drag coefficient, \( C_p \): pressure coefficient, \( F_d \): drag force, \( P \): wind pressure at the measuring point, \( \rho \): air density, \( U \): wind speed, \( A \): projected area of the windward surface of the cable car, \( P_{\infty} \): reference static pressure.

The contour plots of the surface pressure coefficient of the cable car is shown in Figure 3. Figures 3(a) and 3(b) show that the surface wind pressure is the largest at the center of the cable car on the windward side, and the surface wind pressure gradually decreases from the center of the cable car to the surroundings. The extreme value of the average wind pressure coefficient is 0.92, which is located at the center of the windward surface of the cable car, which is the same as the stagnation point. The wind pressure on the leeward surface of the cable car is negative, and at the edge of the cable car the surface wind pressure is minimum, and increases gradually from the outside to the inside. In Figure 3(c) and Figure 3(d), when the wind deflection Angle and wind attack Angle are both 0°, the wind pressure on the side surface of the cable car presents symmetrical distribution and both are negative wind pressure. In Figure 3(e) and Figure 3(F), there is a large pressure difference on the upper and lower surfaces of the cable car, and the surface pressure difference is the main reasons for the lift.
Figure 3. Contour plots of surface pressure coefficient of cable car

Figure 4 shows the streamline diagrams of different cross-sections of the cable car in the flow field. From Figure 4(a), it can be found that there is a pair of vortices with opposite rotating directions and basically the same size at 0.5L behind the cable car (L is the characteristic length of the cable car). The position of the vortex core is the same height as the upper and lower surfaces of the cable car. And observe a vortex of different scales under the cable car, the left side of the upper bracket, and the lower right of the rope holder. It can be clearly seen from Figure 4(b) that there are a pair of vortices with the same size and opposite rotation directions on the leeward and side surfaces of the cable car. The lateral vortex appears near the cable car door, and the vortex core position is less than 0.1L from the edge of the cable car. Also, at the back of the cable car, two vortices with the same size and opposite directions were also observed. The vortex core position is in a straight line with the side edge of the cable car, and the distance from the edge of the cable car in the Z direction is 0.5L.
Figure 5. Contour plots of the pressure coefficient of the flow field around the cable car (a: $y=0.2H$, b: $y=0.5H$, c: $y=0.8H$, d: $0.5L$)

Figure 5 shows the pressure coefficient distribution of the flow field in different cross-sections of the cable car. In Figures 5(a) and 5(c), the contour of pressure coefficient of the flow field around the cable car are basically the same at the heights of 0.2H and 0.8H, which shows that when the wind deflection angle and wind attack angle are both 0°, the suspension bar above the cable car has little influence on the flow field structure around the cable car, which can be almost ignored. From Figure 5(b), at the height of 0.5h, two pairs of negative pressure areas are observed behind and on the side of the cable car. The position of the negative pressure area corresponds to the vortex position in Figure 4(b), and the position of the negative pressure area on the side of the cable car corresponds to the position of the door of the cable car. The position of the negative pressure zone in Figure 5(d) corresponds to the vortex position shown in Figure 4(a).

4. Conclusions

CFD numerical simulation was used to reproduce the cable car wind tunnel test under the condition of crosswinds. By analyzing the aerodynamic characteristics and flow field structure of the cable car, the following conclusions are drawn: The surface wind pressure is the largest at the center of the cable car on the windward side, and the average wind pressure coefficient extreme value is 0.92; Vortexes of different scales were observed on the side, leeward, and upper and lower sides of the cable car. When the wind attack angle and the wind deflection angle are both 0°, the size of the vortexes on the leeward side and the side of the cable car are similar with each other; The position of the negative pressure zone on the side of the cable car corresponds to the position of the door. So, it is suggested to reinforce the cable car door properly to prevent the abnormal opening of the door due to the difference of...
pressure between inside and outside of the cable car during the operation, which will greatly increase the potential safety hazard.

Acknowledgments
This paper is one of the phased achievements of the Heilongjiang Natural Science Foundation general project "Wind shock flow Control of Cableway system based on Micro Vortex Generator" (LH2020E010), gratefully acknowledged.

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