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Investigation on aerodynamic characteristics and running safety of high-speed trains under downburst

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SUMMARY:
A series of physical simulation tests were conducted on a train car model using a downburst simulator to determine the effects of the line type and the angle of jet tilt of the downburst on the aerodynamic characteristics of high-speed trains. The running safety evaluation of high-speed trains was performed based on the physical simulation results and the safe operation speed domain of high-speed trains based on different evaluation indexes for different line types and angles of jet tilt was obtained. The results show that the line type has a certain influence on the mean wind pressure distribution and the extreme value of overall force coefficients, while the angle of jet tilt has a small effect on the extremes of C_{FX} and C_{MY}, but has an effect on the relative positions at which the extremes occurred. Moreover, the safe operation speed domain for trains on viaducts is much lower than that on embankments and ground, indicating that trains are most dangerous when operating on viaducts.

Keywords: aerodynamic characteristics, running safety, high-speed train

1. INSTRUCTIONS

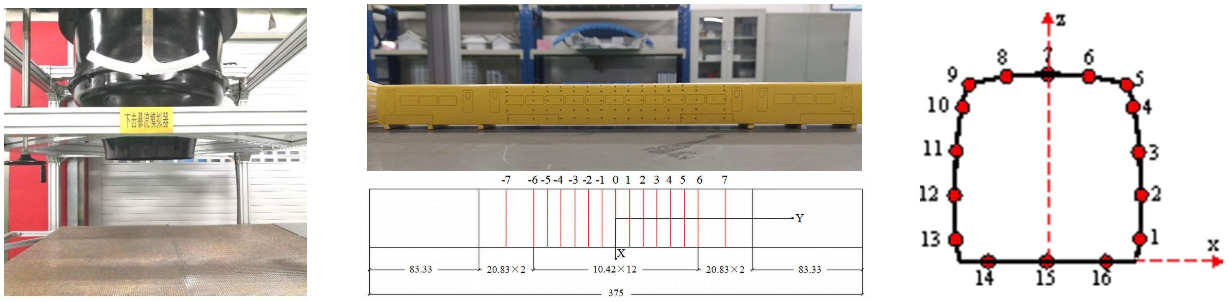
Downbursts are transient, highly localized extreme wind events that can cause severe damage to people's lives and property. Over the past few years, many researchers have carried out extensive research into the wind field characteristics of downbursts and the aerodynamic loading characteristics they generate on structures such as bridges, high-rise buildings and transmission line systems through field measurements, physical simulations and numerical simulations (Hjelmfelt, 1988; Vicroy, 1991; Holmes and Oliver, 2000; Wood et al., 2001; Xu et al., 2009; Li, 2019; Hao and Wu, 2018; Zhang et al., 2014; Abd-Elaal et al., 2018). However, there are few studies on aerodynamic load and safety evaluation of trains under downburst (Li et al., 2021). As the increasing density of railway lines, the shortening of the train departure intervals and the increasing frequency of downbursts, the probability of high-speed trains being hit by downbursts increases, so it is necessary to investigate the aerodynamic load characteristics of trains under the action of downbursts.

In this paper, the aerodynamic characteristics of high-speed trains under the action of downbursts were obtained using a physical simulator, Moreover, the safe operating speed domain of trains was obtained, and the running safety of train operation was assessed.

2. EXPERIMENTAL SETUP

2.1. Downburst Simulator and Physical Train Model

Fig. 1a depicts the picture of the downburst simulator at Beijing Jiaotong university, which is a movable downburst simulator built according to low-speed wind tunnel design specifications and the theory of impinging jets. The simulator has a jet diameter (D_{jet}) of 600 mm. Considering the layout of the measuring points and the limited space underneath the simulator, the geometric scale ratio of the car model was selected as 1:120. The train car model was 375 mm long, 31.25 mm wide, and 31.87 mm high. Fifteen sections (the red lines of Fig. 1b) of pressure taps were installed on the central part of the model, and sixteen pressure taps were distributed across each section, so there were 240 pressure taps in total. The arrangement of the pressure taps is presented in Fig. 1b and Fig. 1c.

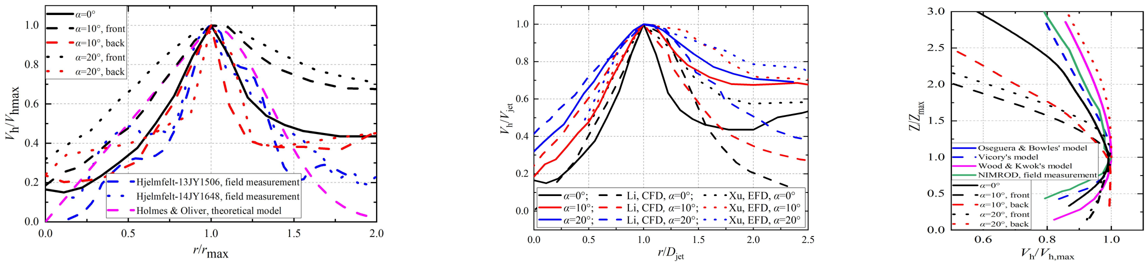


(a) The downburst simulator (b) Physical train model. (c) Pressure tap installation.

Figure 1. Experimental setup and rigid model of train car (unit: mm).

2.2. Downburst Flow Characteristics

Fig. 2 shows the results of the comparison of the experimental results with the measured results of the real downburst and the theoretical results. It is clear that both the radial wind profiles and the vertical wind profiles of horizontal velocity generated by the downburst simulator were consistent with the overall trend of the empirical model and the measured values. This confirmed the validity of the simulation's performance using the downburst simulator at Beijing Jiaotong University. Thus, it was considered appropriate for conducting the following studies.

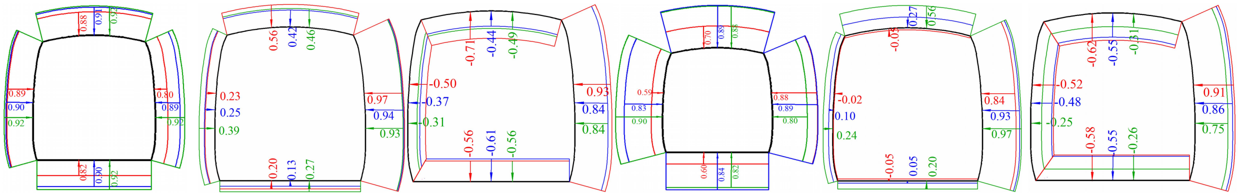


(a) Radial profiles (b) Vertical profiles

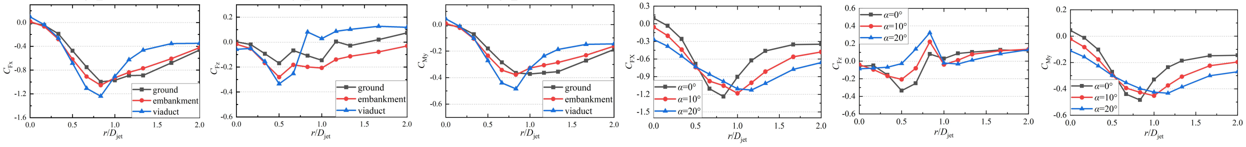
Figure 2. Comparison of the experimental results with the measured results and the theoretical results.

3. AERODYNAMIC CHARACTERISTICS OF HIGH-SPEED TRAIN

Fig. 3 shows the mean wind pressure coefficients and overall force coefficients of train car under different line types (types of train operation routes) and angles of jet tilt when the train car is on the front side of the downburst. The red, blue and green outlines represent viaduct (α=20°), embankment (α=10°) and ground (α=0°) conditions, respectively. It is obvious that the type of line affects the aerodynamic characteristics, with the extreme values of overall force coefficients being greater when the train is on embankments and viaducts than when the train is on the ground (Fig. 3(g-i)). The angle of jet tilt has a small effect on the extremes of C_{FX} and C_{MY} but affects the relative positions at which the extremes occurred. Moreover, in the presence of the angle of jet tilt, C_{FZ} exhibits a positive peak, which increases with increasing the angle of jet tilt (Fig. 3(j-l)).



(a) r/D_{jet}=0, line types (b) r/D_{jet}=0.5, line types (c) r/D_{jet}=1.0, line types (d) r/D_{jet}=0, jet tilt (e) r/D_{jet}=0.5, jet tilt (f) r/D_{jet}=1.0, jet tilt

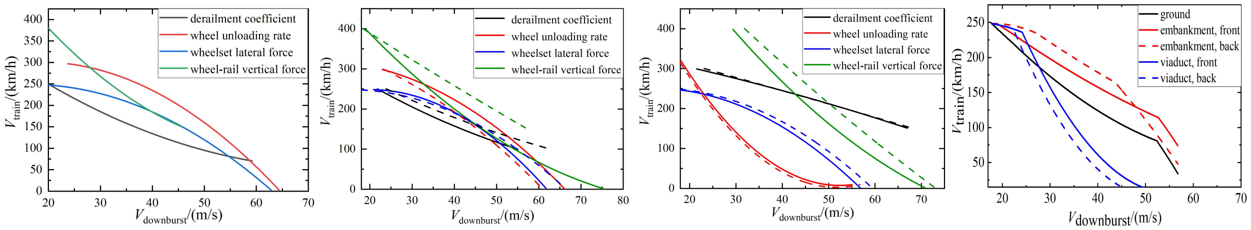


(g) C_{FX} (h) C_{FZ} (i) C_{MY} (j) C_{FX} (k) C_{FZ} (l) C_{MY}

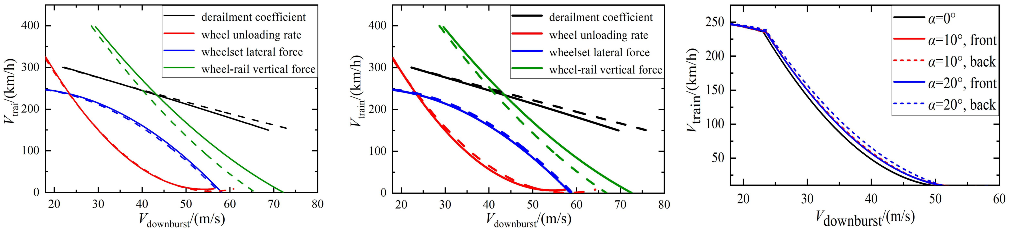
Figure 3. Effect of different line types and angles of jet tilt on the mean wind pressure coefficients and overall force coefficients.

4. RUNNING SAFETY ASSESSMENT

Fig. 4 depicts the safe operation speed domain of high-speed trains based on different evaluation indexes for different line types (types of train operation routes) and angles of jet tilt. The index for determining the safe operation speed domain is different for different line types and angles of jet tilt. The safe operation speed domain for trains on viaducts is much lower than that on embankments and ground, indicating that trains are most dangerous when operating on viaducts. Moreover, the influence of the angle of jet tilt on the safe operating speed domain is very small, the allowable running speed on the back side of the downburst flow is higher than that on the front side.



(a) ground (b) embankment (c) viaduct (d) Comparison



(e) *α*=10° (f) *α*=20° (g) Comparison

Figure 4. Comparison of safe operation speed range of high-speed trains under downburst.

5. CONCLUSIONS

1. Both the radial and vertical profiles of the horizontal wind speed of the downburst generated by the physical simulator are similar to the real downburst, the theoretical model and the numerical simulation results.
2. The line type has a certain influence on the mean wind pressure distribution and the extreme value of overall force coefficients while the angle of jet tilt has a small effect on the extremes of C_{FX} and C_{MY}, but affects the relative positions at which the extremes occurred.
3. The safe operation speed domain for trains on viaducts is much lower than that on embankments and ground. The presence of the jet tilt angle makes the train's allowable running speed increase under the same wind speed, and the allowable running speed on the back side of the downburst flow is higher than that on the front side.

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