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# Numerical Study of Snow Accumulation on Bogies for Long Marshalling High-Speed Trains

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## Abstract

Current numerical research on snow accumulation on bogies often simplifies train models as 1.5 cars or 3 cars, and there is less research on long marshalling trains with real bogies. In this paper, based on the Euler–Lagrange method, the airflow structure and snow accumulation characteristics in the bogie area of an 8-car high-speed train (HST) are studied by numerical simulation. The results show that the airflow velocity and snow distribution concentration inside the bogie cabin vary along the flow direction. The downstream bogie cabin has a lower airflow speed, spatial snow particle concentration, and components snow accumulation. Because of the bogie cabin cover structure, the main airflow direction above the first and second bogie cabin is different, resulting in higher snow concentration and range on the windward side of the first bogie. There is a significant difference in snow accumulation characteristics between powered and nonpowered bogies. The powered bogie gearbox is directly affected by the airflow carrying snow particles, leading to severe snow accumulation on the windward side. This study provides a research foundation and engineering guidance for the snow protection strategy of HST bogies and is important for improving the comfort and safety of HSTs on snow-covered rails.

**Keywords:** numerical simulation, bogie, long marshalling high-speed train, Euler–Lagrange method, computational fluid dynamics, snow accumulation

# 1 Introduction

When HSTs travel in areas with abundant snowfall and low temperature, the snow will be stirred up by the airflow at the bottom of the train and move with it. The potential hazards caused by extensive snow accumulation in the bogie area include blocked brake calipers due to icing, resulting in brake failure; or an increased load on the transmission shaft (Cao et al., 2015). Therefore, to ensure the safety and comfort of HSTs on snowy ballast beds, it is necessary to conduct in-depth research on the characteristics of snow accumulation and the corresponding prevention measures.

CFD numerical simulation can obtain snow particle distribution information in the train bogie area. Research has shown that the two-phase flow method is suitable for describing the motion process of particles under the action of airflow (Tominaga, 2018; Wang et al., 2018; Wang et al., 2023). To reduce computational complexity and shorten computational time, a simplified single-bogie, 1.5-car, or 3-car model has been widely adopted by most numerical studies based on the DPM. However, the simplified method cannot analyze the snow particle movement and concentration distribution in the bogie area of each car in a long marshalling train. It is also difficult to reveal the differences in snow characteristics for different types of bogies. To investigate the distribution and adhesion of snow on the bogies of each carriage of a long marshalling train, this study focuses on a high-fidelity 8-car HST model to study the snow accumulation characteristics of the bogies.

# 2 Methods

### 2.1 Geometry

The 8-car marshalling HST model used in this study is shown in Figure 1 (a). The model includes one head car, one tail car, and six middle cars. The bogies are numbered according to their positions. For example, Bogie 2-1 represents the first bogie at the second car, and so on. Each car is equipped with 2 bogies, which are referred to as the “first bogie” and “second bogie” in this study. The bogie types of the train model include powered bogies and nonpowered bogies. In addition, to accurately simulate the flow field at the bottom of the train, a single-track ballast and rail (STBR) is used. The train model has a total length of 200.5 m and a height (H) of 3.62 m.

### 2.2 Computational domain and grid

As shown in Figure 2, the HST model is arranged in the rectangular calculation domain, and the size of the calculation domain is dimensionless by the height H. The velocity inlet is 10 H away from the nose of the head car, and the pressure outlet is 30 H away from the nose of the tail car to ensure sufficient wake development. The computational domain is 10 H high and 20 H wide. The velocity inlet inflow velocity is 55.56 m/s, consistent with the typical operating speed of the HST in winter. The static pressure at the pressure outlet is 0 Pa. The ground and STBR are set as moving walls, and their moving velocity and direction are consistent with the incoming flow. The top and both sides of the computational domain are set as symmetric (Wang et al., 2023). Snow particles are released on a rectangular plane below the front of the head car. As previously mentioned, the diameter and density of snow particles are 0.15 mm and 250 kg/m$^3$, respectively. When snow particles collide and contact the bogie cabin or bogie components, it is considered that the snow particles are trapped by the corresponding wall. The wheels and car body are set as the reflection boundary, and others are the escape boundary (Wang et al., 2018).

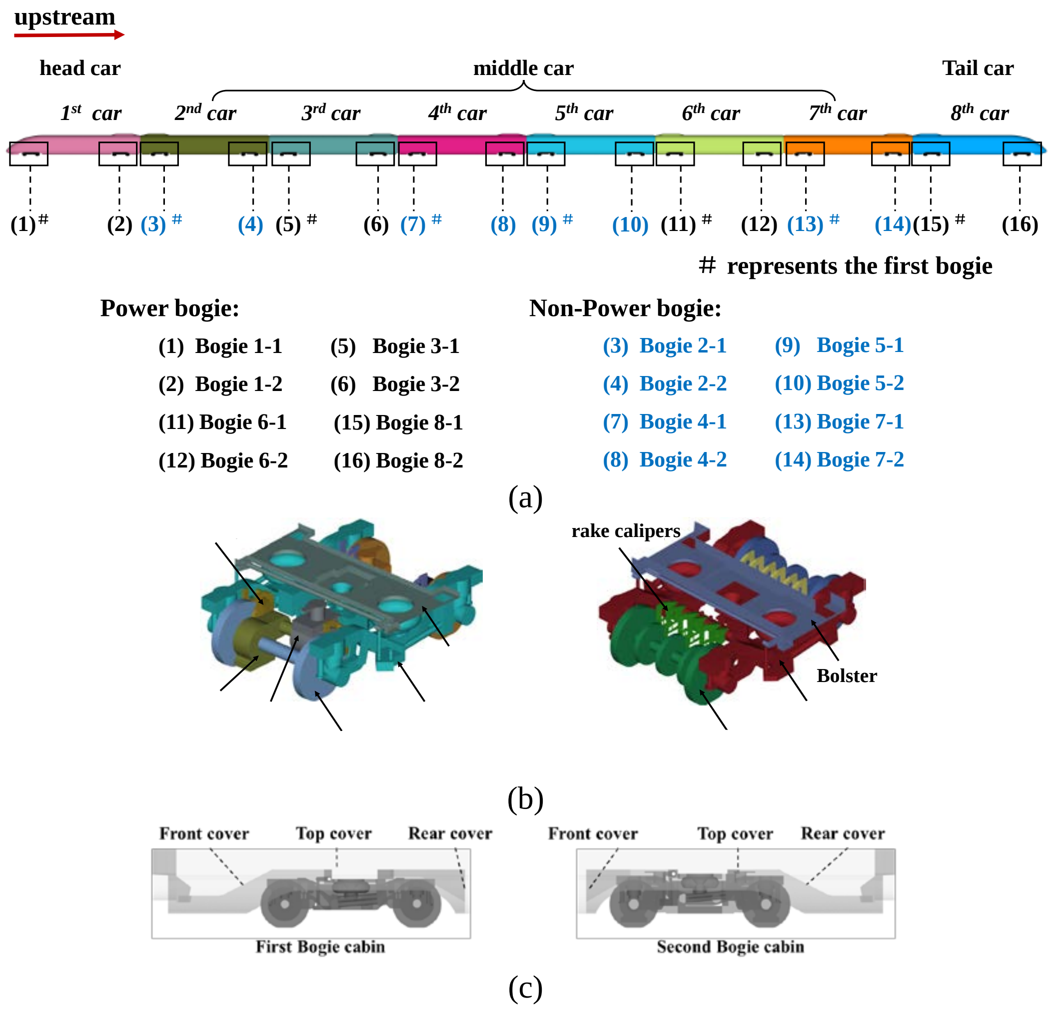


Figure 1: Geometry: (a) Bogie arrangement; (b) The components of the power and non-power bogie; (c) The cover outline of the first and second bogie.

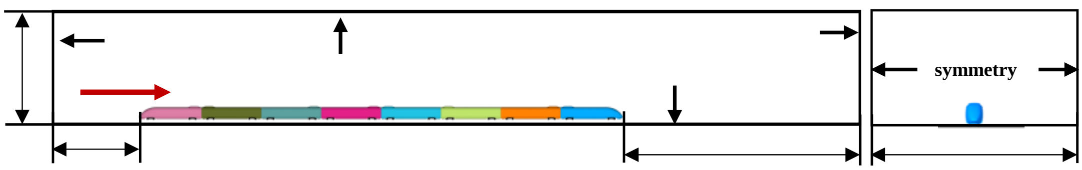


Figure 2: Setting of calculation domain and boundary conditions.

As shown in Figure 3, a PolyHexcore mesh based on FLUENT meshing software is used for computational domain discretization. The maximum dimensions of the poly mesh of the train body and bogie areas are 80 mm and 20 mm, respectively, to ensure that the geometry is accurately represented. Ten-layer prisms are arranged on the surface of the train and bogies. The results show that the values of *y* plus for the train body and the bogies are between 30–70. The meshes around the bogie and body of the train are locally refined. The sizes of the fine area, middle area and coarse area are 160 mm, 320 mm and 640 mm, respectively. The total number of calculation grids is 76 million.

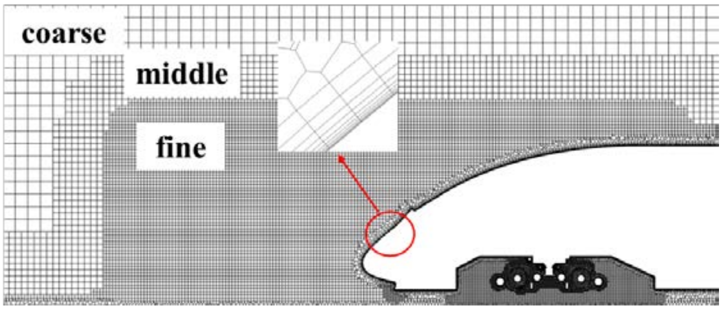


Figure 3: Computational Grid.

**2.3 Simulation settings**

ANSYS FLUENT code based on the finite volume method is used to solve the flow field and snow particle movement. The pressure-based solution is adopted in this study. A realizable $k$-$\varepsilon$ model is used to simulate the turbulence, and the SIMPLEC algorithm is used to couple the pressure and velocity. The standard format is employed for pressure term spatial discretization. A second-order upwind scheme is used for spatial discretization of the momentum, turbulent kinetic energy, and turbulent dissipation rate equations. The DPM is enabled to simulate snow particle movement. The bidirectional coupling between snow particles and the flow field is considered.

## 3 Results

**3.1 Flow field structure of the bogie cabin**

As mentioned earlier, the bogies of the *1st*, *3rd*, *6th*, and *8th* cars are powered bogies, and components such as motors and gearboxes are included to drive the train. To study the flow characteristics of the powered bogie areas, the slice flow field of the gearboxes and the center position of the bogie are analyzed. Figure 4 (a) shows that, except for the first bogie of the head car and the second bogie of the tail car, the configuration of the first and second bogie cabins of other cars is correspondingly consistent, and the overall trend of airflow is also similar. The front cover of the first powered bogie cabin is inclined to the bottom of the car for transition, and the rear cover is vertical to the bottom of the car. When the incoming flow from the bottom of the train just enters the bogie cabin, the airflow can smoothly develop to the upper part of the bogie cabin due to the inclined transition structure and sufficient space. The main flow above the bogie cabin moves in the same direction as the incoming flow at the bottom. When the airflows out of the bogie cabin, the flow sectional area is suddenly reduced. Therefore, some recirculation vortexes are formed near the rear cover of the bogie cabin, making part of the airflow rise. However, the influence range of these vortices is relatively small and limited to the bogie components on the leeward side.

The gearbox is an important component of a powered bogie, and its cavity structure at the bottom is lower than that at the bottom edge of the HST, which is also one of the important structural differences between a powered bogie and a nonpowered bogie. According to the flow field in Figure 4, the high-velocity flow at the bottom of the HST directly impacts the surface of the gearbox cavity. This phenomenon can significantly increase the snowpack at the corresponding location. In addition, gearbox 1 arranged on the windward side of the bogie can divert the bottom incoming flow. Therefore, the airflow in the local area is attached to the gearbox 1 shell and moves above the bogie cabin. The front edge of the bolster is impacted by this airflow (shown by the black dashed arrow at Bogie 8-2). There is also a risk of additional snow accumulation at the front edge of the bolster or the corresponding position of the frame.

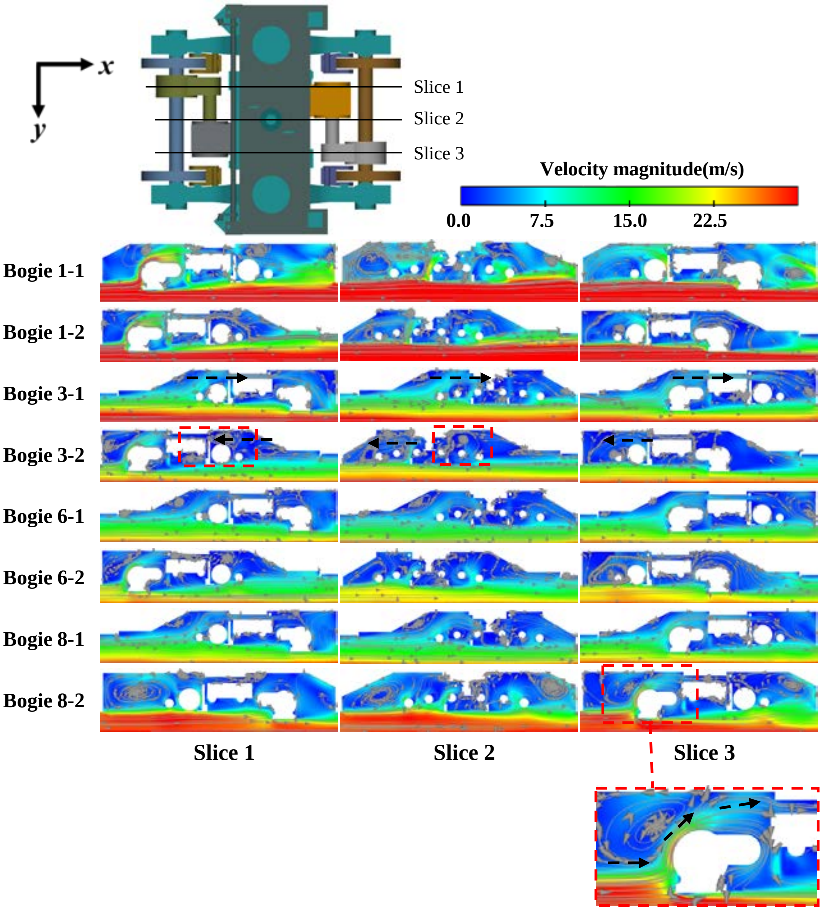


Figure 4: Flow field structure of longitudinal slice of the power bogie.

As previously mentioned, the nonpowered bogies are arranged in the *2nd*, *4th*, *5th*, and *7th* cars. Unlike the powered bogie, the nonpowered bogie does not bear the dynamic load of the HST, and its structure is relatively simple, with fewer components and a more symmetrical distribution. Figure 5 shows the velocity contours of longitudinal slices in the nonpowered bogie area. The geometric shape of the front and rear covers of the first and second bogie cabins of the cars with nonpowered bogies is correspondingly consistent with that of the powered bogie. It can be seen in the velocity contours that the main flow structure and direction of the first and second nonpowered bogies are similar to those of the powered bogies. The airflow velocity in the bogie cabin decreases along the flow direction. The main flow direction above the first bogie cabin is the same as the underfloor flow of the car and has fewer vortices. The main flow direction above the second bogie cabin is opposite to the underfloor flow of the car, and there are more complex vortices in the bogie clearance. The nonpowered bogie has no components below the bottom edge of the HST except the wheels. In general, the complexity of the flow field in the nonpowered bogie cabin is also lower than that of the powered bogie, and the flow field in the same position bogie cabin of different cars is similar. Therefore, the components at the same position nonpowered bogie cabins of different cars may have similar snow accumulation characteristics.

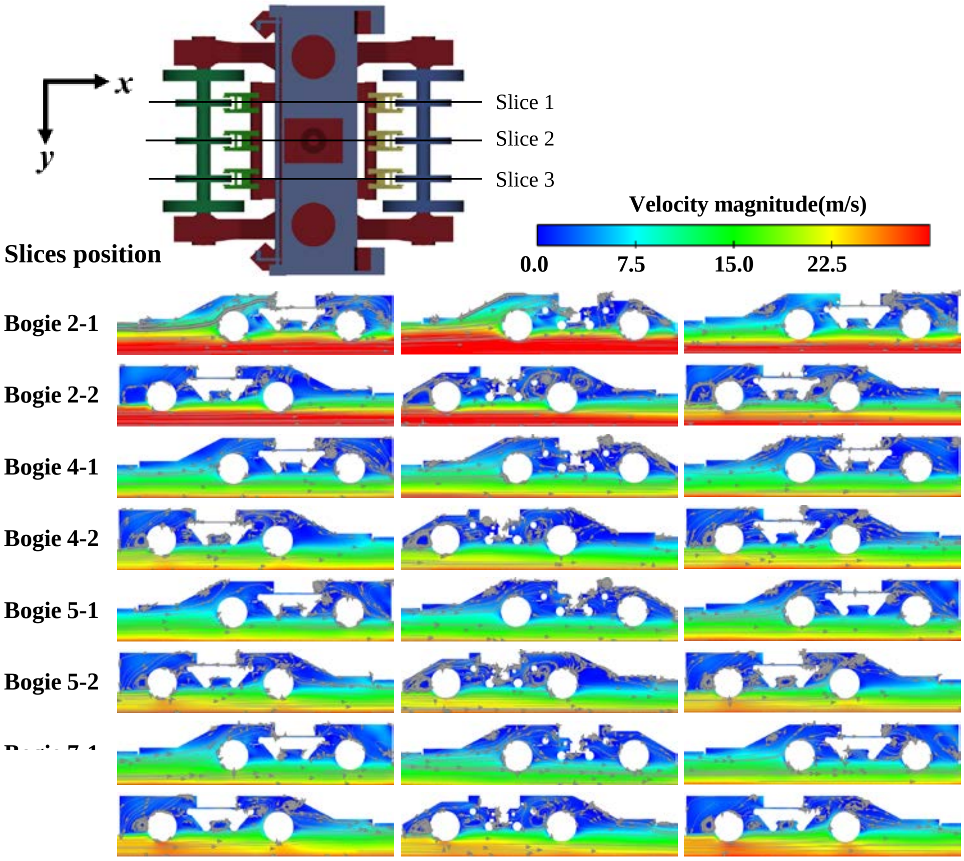


Figure 5: Flow field structure of longitudinal slice of the non-power bogie.

### 3.2 Movement process and characteristics of snow particles

Figure 6 shows the distribution and diffusion range of snow particles around the HST model at $t$=5.5 s. The snow particles released under the front of the head car move downstream under the action of the airflow around the HST. According to the spanwise airflow velocity distribution of each bogie area, snow particles spread to the outside of the HST near the first bogie of the head car. The spreading width of snow particles in the spanwise direction increases continuously along the flow direction. In addition, the vertical movement height of snow particles also increases along the flow direction. From the *6$^{th}$* car, the distribution height of snow particles is almost the same as the car height, and the tail car has been completely submerged by snow particles.

A length of the wake zone exists at the tail of the HST, where snow particles continue to move downstream under the wake and show a certain swing in the spanwise direction. Compared with the research of Wang et al. (2018), the vertical height of snow distribution near the tail car of an 8-car marshalling is higher, and the spanwise width is wider. Therefore, it may be difficult to accurately reflect the snow particle distribution and accumulation characteristics of the downstream bogie by using only a 3-car marshalling model. In addition, when the HST crosses a platform, a large area of lifted snow particles has an adverse impact on the surrounding environment and platform personnel (Tian, 2019). Therefore, the velocity of the HST entering the station should be suppressed to reduce the surrounding scope of snow particles when the road area is snowy.

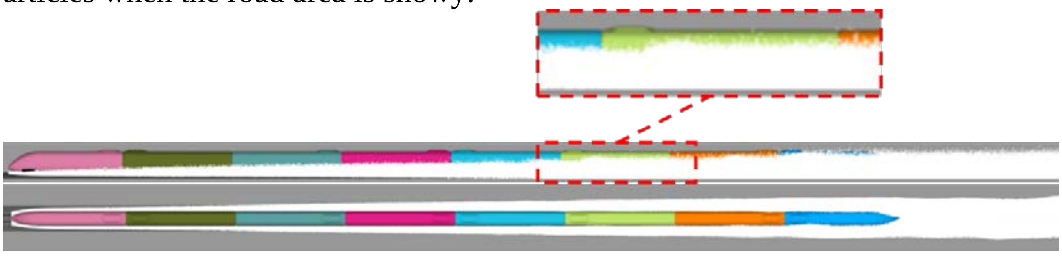

Figure 6: Distribution of snow particles around the HST at *t*=5.5 s.

### 3.3 Snow accumulation characteristics of bogies

To quantify the accumulation of snow particles on bogies, the total amount of snow particles accumulated on each bogie at *t*=5.5 s is plotted in Figure 7. As predicted in 3.2, the components of Bogie 1-1 are virtually snow free due to cowcatcher suppression. After Bogie1-1, a large amount of snow particles are raised and attached to the surface of Bogie 1-2, so Bogie 1-2 has the highest amount of snow accumulation among the 16 bogies. The accumulation amount of snow particles in Bogie 2-1 drops sharply, accounting for only 32.4% of the total amount in Bogie 1-2. The amount of snow accumulation on Bogie 2-2 to Bogie 6-2 is relatively stable and shows a slow downward trend. After Bogie 7-1, the amount of snow accumulation on the bogies decreases to a lower level, below 5% in comparison to Bogie 1-2. Overall, starting from Bogie 1-2, the amount of snow accumulation on the bogie decreases along the flow direction.

Notably, although the bogies located downstream of the HST have a small proportion of snow accumulation in this simulation, for a real HST running on a snowy ballast bed at a speed of 200 km/h for a long time, snow on important components of the downstream bogies could still seriously affect the stability and safety of HST operation (for example, an HST from Harbin to Beijing takes up to 8 hours to travel). Therefore, the snow accumulation characteristics of each bogie should be analyzed to develop a targeted snow protection design. Due to different structural shapes, the snow accumulation characteristics of the powered and nonpowered bogies are described in the following studies.

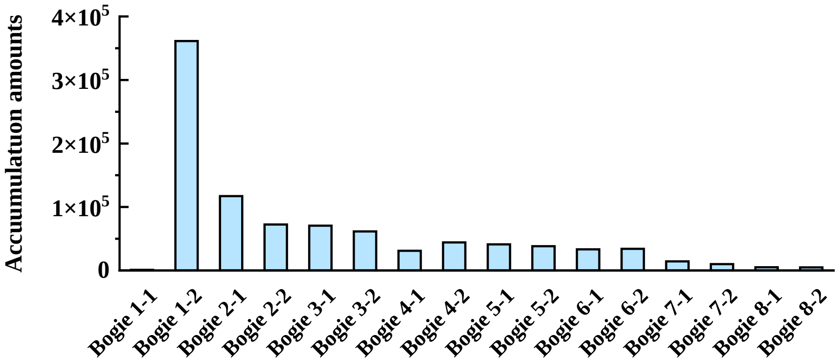

Figure 7: Amount of snow particles accumulated on each bogie.

# 4 Conclusions and Contributions

Based on the Euler–Lagrange method, this paper used a discrete phase model to study snow accumulation characteristics in the bogie area of the 8-car marshalling HST. The research conclusions are as follows:

(1) The airflow velocity and spatial concentration of snow particles in each bogie cabin are generally reduced along the flow direction. Influenced by the structure of the bogie cabin cover, the direction of the main flow in the upper area varies between different bogies.

(2) For the same car, the main flow in the first bogie is identical to the bottom airflow, whereas the second bogie exhibits the opposite tendency. This results in a higher snow concentration on the windward side of the first bogie. For the second bogie, snow particles concentrate more on its leeward side.

(3) The total snow accumulation of the bogie reaches its peak at Bogie 1-2 and decreases sharply at Bogie 2-1. The amount of snow particles accumulated on the bogies of the *3rd* to *6th* cars remained relatively stable, and starting from the *7th* car, the amount decreased to less than 5% of that on Bogies 1-2.


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# References


[1] Y. Cao, J. Huang, J. Yin., "Numerical Simulation of Three-dimensional Ice Accretion on An Aircraft Wing", International Journal of Heat and Mass Transfer, 92, 34−64, 2016.

[2] Y. Tominaga, "Computational Fluid Dynamics Simulation of Snowdrift Around Buildings: Past Achievements and Future Perspectives", Cold Regions Science and Technology, 150, 2-14, 2018.

[3] J. Wang, G. Gao, M. Liu, et al., "Numerical Study of Snow Accumulation on the Bogies of a High-speed Train Using URANS Coupled with Discrete Phase

Model", Journal of Wind Engineering and Industrial Aerodynamics, 183, 295−314, 2018.
[4] Y. Wang, T. Wang, C. Jiang, et al., "Numerical Study on Slipstream-induced Snow Drifting and Accumulation in the Bogie Region of a High-speed Train Passing the Snowy Ballast Bed", Journal of Wind Engineering and Industrial Aerodynamics, 232, 105269, 2023.
[5] H. Tian, "Review of Research on High-speed Railway Aerodynamics in China", Transportation Safety and Environment, 1(1), 1−21, 2019.