The recent progress and state-of-art techniques for high-speed railway

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Abstract. Contemporarily, high-speed railway serves as an extremely important role in human beings' daily in normal life. It possesses the features of cheap, fast and safer for citizens to travel by high-speed train, which can carry more people compared with airplane. In this paper, the recent progress and the state-of-art techniques for high-speed railway will be demonstrated. Especially, the crucial aerodynamic problems are evaluated analytically, e.g., the wind across the train or the shape of the head train. These results shed light on guiding further exploration of high-speed railway.

Keywords: high-speed railwal, aerodynamics, Computational fluid dynamic.

1. Introduction

The history of railway dates back to two thousand years ago in ancient Greek which is the first country to have railway [1-6]. They used horse to carry the cargoes in fixed pathway. Back to 1804, Richard Trevithick invented actually the first steam locomotive and successfully working on the pathway in Welsh. However, it broke up at last while working. Ten years later, "the father of railway" George Stephenson decided to use the steam engine in transportation. He built a steam locomotive which can really be used. In 1863, the first subway system started running. At that time, the subway had to use steam as their power since electricity wasn't widespread. In 1937, Robert Davidson from Scotland invented the first pony haulage motor. After five years he made his second haulage motor and can travelled in 6.4km/h. In 1866, Robert Davidson invented direct-current generator and in 1879, he invented the first electric locomotive. In 1893, Rudolf Diesel invented the first Diesel-powered compression combustion engine and can reach the thermal efficiency of 26%. In 1923, the railway called Flying Scotsman from London and North East Railway Company can reach a speed of 160km/h. In 1937, THE ETR200 electric express produced by AnsaldoBreda S.P.A and has a maximum speed of 201km/h. In 1938, LNER's Mallard "Mallard" steam locomotive set a steam locomotive speed record of 202.58km/h. In 1954, French CC7212 electric locomotive came out, and set a new speed record of 243km/h. On March 28, 1955, CC7107 locomotive designed and manufactured by French ALSTOM company refreshed the speed record of the world electric locomotive again, reaching 326km/h [7].

In 1964, Japan started the first passenger railway line called Shinkansen from Tokyo to Osaka. The total length is 515 kilometer and the average speed is 210km/h. One of the reasons of why it can reach such a high velocity is that they designed the headstock according to aerodynamics. it can not only increase the speed but also but also protect the car from flying upward. The shape of it looks like a duckbill [8]. After that, China designed a headstock similar to the one with the Japan's, which is called "bullet". At the beginning of 1990, Shanghai began to build its first subway and the work was done in the year of 1993. It had become the largest underground system in the world until 2017.

Contemporarily, railway has become an indispensable transportation in our normal lives. Millions of passengers use it and travel to other places. Countries are also competing with each other to see whose railway is faster and safer. It seems to become a war of technology through the whole world. In order to reduce the resistance of the air to the railway, scholars all around the world had designed different but similar headstock. The rest part of the paper is organized as follows. The section 2 will

talk about some basic description of the formula when calculating. The section 3 will talk about the simulation of several parts of the aerodynamic theory in railway. Eventually, a brief summary will be given in Sec. 4.

2. Basic description

When the railway is developing, one of the most important points is the speed. The designers designed several shapes of the headstock to decrease the air resistance acting on the train. As a result, according to F=ma, when the resistance force decrease, the resultant force will increase, so the acceleration of the train increase, so that the train is able to travel in a larger speed [9]. When a strong crosswind passes through the high-speed train, but may case danger. As a result, we have to find how to avoid this problem. The equations be used in calculation is

$$C_y = \frac{2F_y}{\rho U^2 S} = \frac{2F_y}{\rho S(v_t^2+v_w^2)} \tag{1}$$

where C_y is the side force coefficient of the head car; F_y is the side force; p is the density of air which is 1.225kg/m²; U is the relative speed of the train speed V_t; V_w is the crosswind speed and S is the reference area [10]. Additionally, from the model designed by the group of Navarro-Medina, we can notice that wind may affect the ground and capacity of the ballast bed to resist the effect of the air flow or the "erodibility". Therefore, BTE can produce aerodynamic to spin the stone, and the erodibility is related to the opposing stabilizing moment generated by the gravity. The ability of BTE is measured by the pressure coefficient which is

$$C_{pAB} = \frac{2(p_A-p_B)}{\rho_a U_T^2} \tag{2}$$

Here, p_A and p_B denote the pressure in the windward and leeward side of the ballast stone, respectively; ρ_a is the air density and U_t is the train circulation speed [11]. In the way the find the speed of the wind, we have to use the fluid dynamic equation:

$$\frac{\partial(\rho j)}{\partial t} + \nabla \cdot (\rho u j) = \nabla \cdot (f \nabla \mathrm{j}) + s_j \tag{3}$$

In this equation, ρ is the density of air, t is time taken, v is the resultant velocity of the moving train and the flow field around the train. ϕ is flow flux.

3. Simulation

The aerodynamic of the high-speed train when a strong crosswind pass through it. When the train is travelling under a crosswind, we must consider the safety of the railway in order not to let it roll over. This can be affected by the shape of the train, the bridges, the terrain nearby the railway, etc. Under the condition of strong wind area, it is pretty important to add a windbreak. Avila-Sanchez et al. use scale models of trains to study the effect on windbreak. They found that adding a second windbreak can retrain the location of the separation bubble to the bridge deck. Here's an example of a test, where a sketch is given in Fig .1 [9]. As presented in the left panel of Fig. 2, when in the test, the width direction of the terrain seems to become uniform landform beyond 150m. The distance from side ABFE and DCGH to the vertical centre of the train is 54H. In order to get a stable flow field and an initial train aerodynamic shown in right panel of Fig. 2.

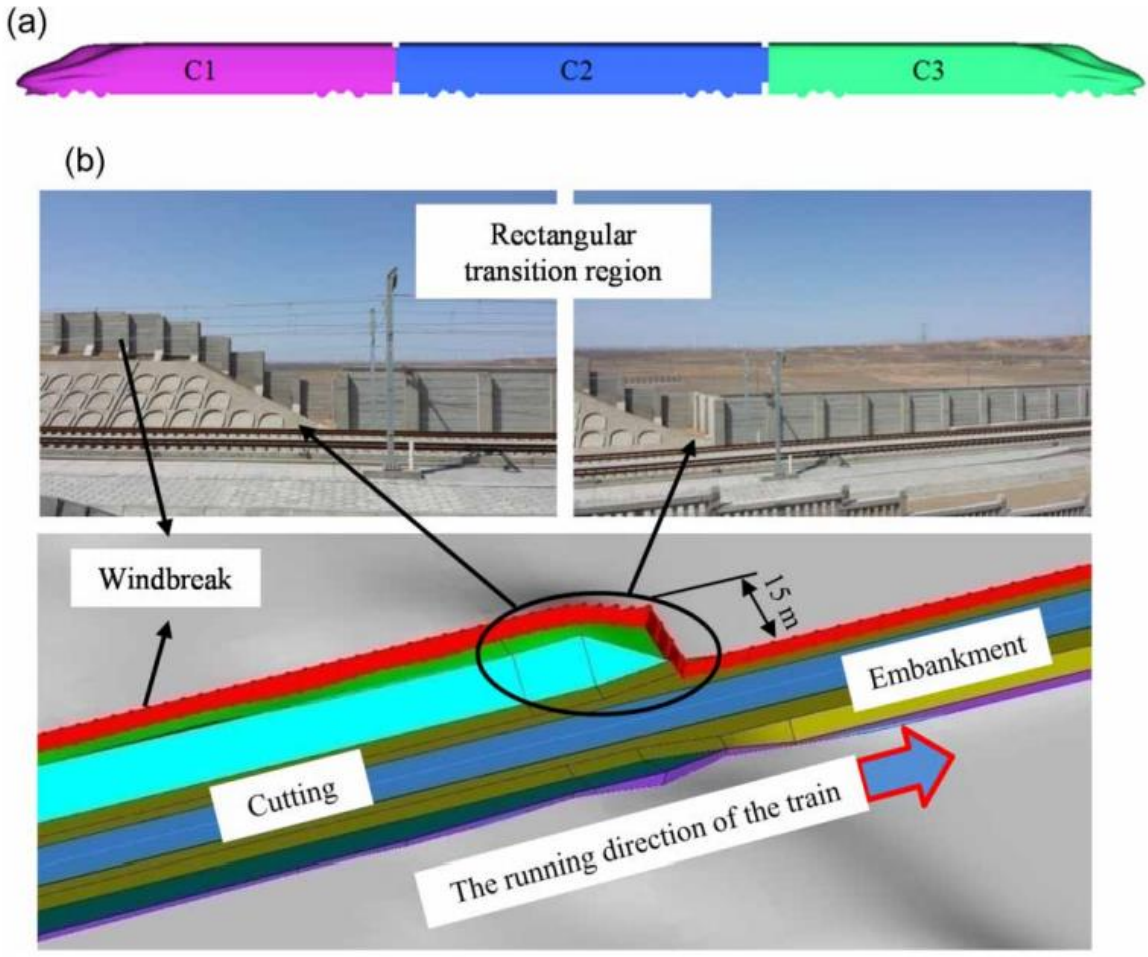


Figure 1. The sketch of the simulation [9].

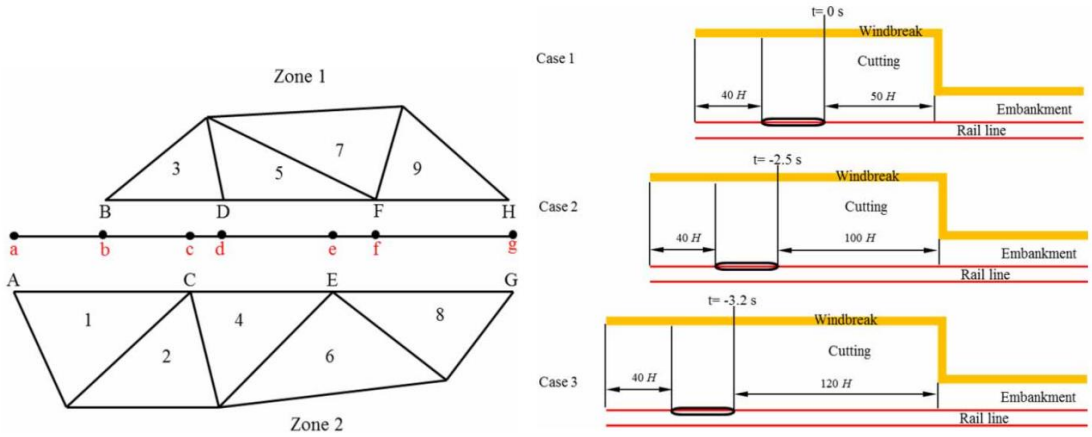


Figure 2. Information transfer among different sliding grids [9].

The distance from the end of the train to the boundary is 40H, the cutting has increased its length when the distance from the headstock to the rectangular transition at 50H, 100H, 120H. The side force coefficient of the head car is used to compare with the results. Seen from Fig. 3, the side force coefficient is 0.1 and 0.3. A shorter cutting length will cause the unstable character, and when the cutting length increase, the side force coefficient will become more stable. As illustrated in Figure 4, it shows the side force coefficient of each carriage and response the total pressure difference. It seems to be steady when the wind act on it although there's still some fluctuate on it.

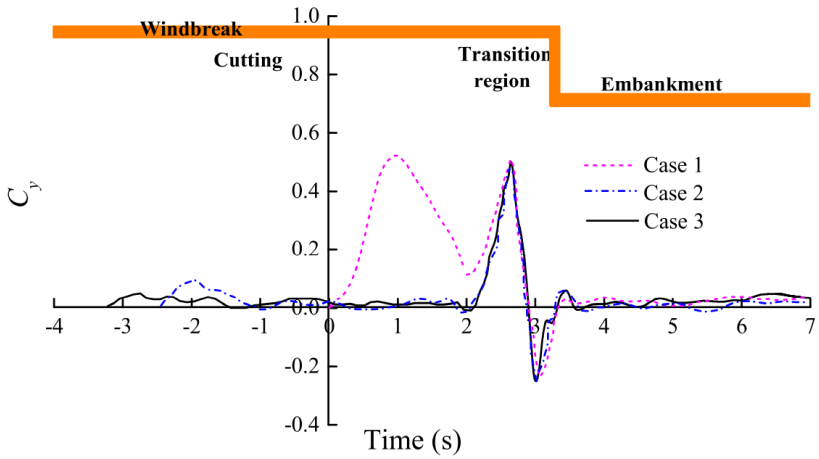


Figure 3. Pressure coefficient curves with different mesh resolutions.

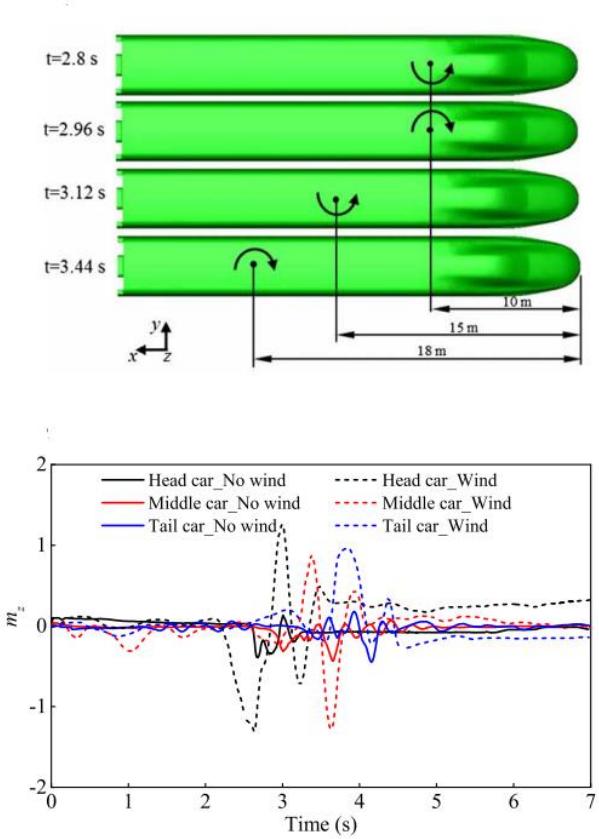


Figure 4. Evolution of the side force coefficients of the head car, middle car, and tail car.

In another point, it's a hidden danger that when train pass through rail, the rock may fly out and damage the people and buildings nearby. According to the analysis of Kal tenbach' research in 2008, it's an important factor that the shape of the rail will cause the stream under the train. As it known to all, the main part of the analysis of the flow of the bottom of the railway is derived from its relation to the ballast flight phenomenon. We can explain the aerodynamics in three parts which are particles' initial spinning, rolling jump stage, and final flying process. It can separate into two parts which are the ability of the wind to the ground (BTE) and the capacity of the ballast bed to resist the effect of the air flow. As illustrate in figure 4, from the rough plane, we choose some maximum point caused by the ballast stone to determine the ability of BTE. The change in the windmill and the side of the stone's static pressure difference shows the instability of the ballast bed when train passed.

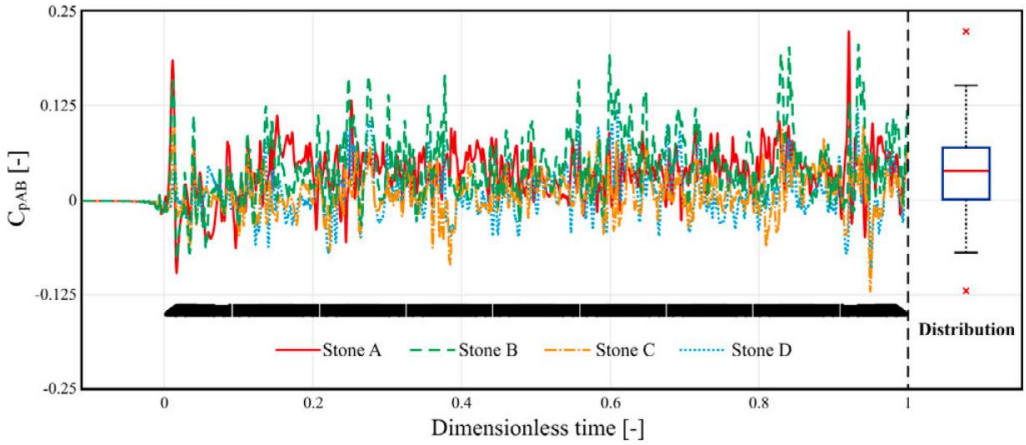


Figure 5. Evolution of the pressure coefficient Cpab between the wind and the lee side of several standard ballast stones [11].

4. Limitation & Future prospect

CFD is now proven to be able to examine in detail the flow characteristics found in experimental studies. Field experiments on high-speed trains are too expensive and difficult to perform, requiring tracks with sufficient length but low curvature, as well as being susceptible to weather conditions and the difficulty of placing measurement instruments close to the train surface to collect data. Simulation of the train in proportion to the scale, and repeated simulation using different calculation methods before experimental demonstration, is a more cost-effective and easier alternative.

The large amount of data from the current study can indicate that CFD is indeed a relatively reliable method and will be used more often for simulations in the future. There are still many improvements needed, such as increasing the porosity and surface roughness of the porous probe to simulate the dispersion of fluid energy at the orbital boundary, which can provide more details for data collection. Additionally, to reduce the impact of ballast on experimental studies, the type of bogie can be controlled as one of the variables to change the air flow under the train.

In addition to the above research methods, further research is needed on the state of the train in the face of crosswinds in order to increase the stability and safety of the train movement. The first is the unstable crosswind caused by the breakage of the windbreak. Some studies have shown that when facing a crosswind, the wheel set on the windward side of the train has a probability of reaching the allowable value. The amplitude of the running part of the train will increase in the face of this crosswind, which will lead to an increase in the lateral displacement of the car and affect the correct operation of the channel at the same time. Therefore, further studies are needed to test the vibration patterns of the car body, bogies and wheel sets under unsteady crosswinds in the field. The aerodynamic model of high-speed trains needs to be enriched and refined, taking into account the bogies and the surrounding terrain, as well as the wind speed fluctuations.

Trains with different undercarriage characteristics should also be further simulated, because the shape of the undercarriage affects the airflow velocity near the undercarriage to the ground. The airflow under a rough train is more complicated because it affects the turbulence between the undercarriage and the track sleepers, and small turbulences will occur more frequently on rough surfaces. Additionally, differences in track geometry need to be taken into account, as well as the flight effect of the track ballast affected by turbulence. The inclusion of the above simulations to evaluate the train performance can reduce the risk during the actual experimental motion.

The effect of porous shelters on aerodynamic force and moment coefficient needs to be continued in the future. This is a factor that affects the dynamic behaviour of the train on a two-lane track. The usage of LBM for CFD simulations reduces the amount of model pre-processing required by engineers. However, the computational cost is much higher, making the lead time usually less, but

the results are more accurate. With LES, many details of the simulation such as separation and transient flow states can be accounted for, so the average particle velocity and retention velocity fluctuations are also accounted for, again ensuring accuracy.

5. Conclusions

In conclusion, this article discusses the application of hydrodynamic studies to high-speed railroads. First of all, the development history of the railway is introduced, and then a brief introduction of three equations is introduced, namely lateral force calculation, BTE pressure coefficient, and NS equation. We present three formulations of hydrodynamics, and the application of the formulations, and describe the application of each formulation variable. Subsequently, we also introduce some simulation data results. Besides, the simulations of CFD are discussed for each component of the train under unstable crosswind conditions due to windbreak and extreme weather conditions. Then, we demonstrate the limitations of the current high-speed railway development and the possible future directions. In the future, CFD will be used more often as a preview before the actual experiment and more methods will be added. In addition, more fluid influences are taken into account in the simulation, instead of a single train. For example, ballast, e.g., the different chassis of the train, such as the natural wind changes also need to be taken into account. The significance of this study will provide a scientific basis for calculating the stability of future high-speed train operations and reduce safety risks. Overall, these results offer a guideline for the research direction of the future development of high-speed railway.

References

[1] M. D. Esposito, (Ed.).. A World History of Railway Cultures, 1830-1930: Volume IV. Routledge 2020.

[2] C. Divall, and G. Revill, Cultures of transport: representation, practice and technology. The Journal of Transport History, 26(1), (2005), 99-111.

[3] U. C. Zitzlsperger, Reading Across Cultures: Global Narratives, Hotels and Railway Stations. Fudan Journal of the Humanities and Social Sciences, 9(2), (2016), 193-211.

[4] I. Tsuji, Railway as the Media for Imagination: Historical Changes of Boys Cultures and Rail-fans in Japan, 2017.

[5] M. T. Berger, After the Third World? History, destiny and the fate of Third Worldism. Third world quarterly, 25(1), (2004), 9-39.

[6] K. L. ryant Jr, and F. W. Frailey, istory of the Atchison, Topeka and Santa Fe Railway. U of Nebraska Press, 2020.

[7] T. Takatsu, The history and future of high-speed railways in Japan. Japan Railway & Transport Review, 48, (2007), 6-21.

[8] B. Yan, et al., Recent development of design and construction of short span high-speed railway bridges in China. Engineering Structures, 100, (2015), 7-717.

[9] T. Liu, et al., A CFD analysis of the aerodynamics of a high-speed train passing through a windbreak transition under crosswind. Engineering Applications of Computational Fluid Mechanics, 12(1), (2018), 137-151.

[10] C. Paz, E. Suárez, C. Gil, and A. Cabarcos, Effect of realistic ballasted track in the underbody flow of a high-speed train via CFD simulations. Journal of Wind Engineering and Industrial Aerodynamics, 184, (2019), 1-9.

[11] Z. Sun, et al., Dynamic performance of high-speed train passing windbreak breach under unsteady crosswind. Vehicle system dynamics, 57(3), (2019), 408-424.