Recent Studies on Aerodynamic Characteristics of Railway Vehicles

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Aerodynamic phenomena concerning railway vehicles relate to various issues on railways. The improvement of aerodynamic characteristics of railway vehicles could enhance the value of railway from the view point of safety, convenience, comfort, harmony with the environment, cost reduction, etc. This paper describes the outlines of recent studies on the aerodynamic characteristics of railway vehicles conducted by the Railway Technical Research Institute such as stability against cross wind, air resistance, lateral motion in tunnels and aerodynamic noise.

Keywords: aerodynamics, cross wind, air resistance, car body vibration, aerodynamic noise

1. Introduction

As railway vehicles run through the air, the resultant interaction between the vehicles and the surrounding air produces the following effects: aerodynamic force acting on the vehicles while at the same time aerodynamic phenomena occurring along the wayside. More specifically, possible effects on vehicles include overturning due to cross winds, air resistance, car body vibration caused by unsteady aerodynamic forces and aerodynamic upward force variation of pantographs; while possible wayside phenomena include aerodynamic noise (including low-frequency noise), micro-pressure waves radiated from tunnel portals and other environmental concerns, pressure variation caused by passing trains, flying ballast, accretion of ice and snow, train draft pressure, etc. Railway vehicle aerodynamics affect many essential railway related areas such as safety, convenience, comfort, harmony with the environment and cost reduction, therefore, resolving these issues should help enhance the value of railways.

Among the issues concerning the aerodynamic characteristics of vehicles, this paper discusses aerodynamic characteristics of vehicles exposed to cross winds, air resistance, car body vibration in tunnels and aerodynamic/low-frequency noise in open sections, and outlines some recent major undertakings on these subjects.

2. Aerodynamic characteristics of vehicles in cross wind

In Japan, there have been more than 30 recorded accidents involving vehicles overturned by cross winds [1]. To prevent overturning, physical measures such as installation of wind barriers or altering vehicle specifications may be taken, as well as operational measures such as train operation control. To minimize the risk of vehicles overturning through an appropriate mix of these measures, it is necessary to clarify the characteristics of natural winds affecting lines, the dynamic characteristics of vehicles and aerodynamic characteristics of vehicles in cross winds, and combine them for a comprehensive evaluation of safety.

Aerodynamic forces acting on vehicles in cross winds are evaluated primarily by means of wind tunnel tests. Wind tunnel tests used to be conducted in a uniform-flow field. Following transitional steps including the measurement of natural winds and aerodynamic forces taken in Shimamaki, Hokkaido, using full-size vehicle and viaduct models, wind tunnel tests today are conducted in flow fields (turbulent boundary layers) simulating the mean velocity and turbulent intensity profiles of natural wind [1]. Based on the application of turbulent boundary layers, wind tests were conducted using five types of vehicle geometry and seven types of track structure geometry, all of which are samples of what is typically seen on conventional lines, to obtain and summarize aerodynamic force coefficients in a set of tables [2]. With these tables, it became possible to calculate approximately the critical wind speeds that can lead to overturning, as a measure of vehicle resistance against cross winds. More recently, RTRI has been actively pursuing studies on aerodynamic force coefficients of vehicles when passing over structures, which have not generally been covered in past studies, such as half-bank, half-cut sections typically found in coastal areas and structures with sound barriers [3], as well as studies conducted in conditions more closely reflecting the actual conditions such as wind tunnel tests using a moving model rig [4].

However, as it is difficult to clarify with only wind tunnel tests all the essential factors underlying aerodynamic force coefficients of vehicles, therefore efforts are also being made to develop numerical simulation methods capable of reproducing the results of wind tunnel tests. Simulation of wind tunnel tests involves computation of an extensive space that includes a turbulent boundary layer generator, which generates a heavy computation load. It was found, however, that computation time can be shortened by dividing computation first dealing with the turbulent boundary layer and then focusing on space around the vehicle (Fig. 1) [5]. Simulation of a vehicle on a viaduct and on an embankment using an approach developed by RTRI found that the method was capable of reproducing the aerodynamic force coefficients from wind tunnel tests with a maximum error of only around 20%. The simulation method will be utilized as a tool to narrow down test conditions etc. to increase the efficiency of wind tunnel tests.
3. Air resistance of vehicles

For high-speed trains such as the Shinkansen, running resistance is therefore vital to save energy. As Shinkansen trains sets are long with a streamlined nose and tail, air resistance comes mainly from the intermediate cars. Wind tunnel tests were conducted on intermediate cars (Fig. 2) and the results were collated with those of past tests on actual cars to estimate air resistance for various areas of a car. It was found that, with today’s highly-smoothed Shinkansen cars, around 50% of air resistance comes from the frictional drag of car surfaces, slightly less than 20% from the pressure drag of the bogie space and just under 30% from the pressure drag of the car ends. In addition, as possible measures to reduce air resistance, bogie bottom covers (Fig. 3) [6] and bellows on the ends of the vehicles extended downwards to cover the gap between the cars (all-around bellows) (Fig. 4) were proposed and put through wind tunnel tests to examine their performance. It was found that larger bogie bottom covers were more effective in reducing air resistance, that covering around 25% of the bogie bottom reduced air resistance of intermediate cars by around 10% and that downward-extended bellows reduced air resistance of intermediate cars by more than 20%.

In an effort to further reduce air resistance, quantitative evaluations are underway to assess the impact on air resistance of smaller unevenness on the underfloor covering, side windows, side sliding doors, etc.

4. Flow-induced vibration of car body in tunnels

Unsteady airflows are generated around running vehicles. When vehicles are subjected to resultant unsteady aerodynamic forces, the car body vibrates to the extent that ride comfort can be diminished. Car body vibrations are greater at higher running speeds, and greater in tunnels than in open sections. To reduce car body vibrations in tunnels and ensure ride comfort, studies have been conducted to clarify the phenomenon and develop mitigation measures.

On-site tests revealed the characteristics of unsteady aerodynamic forces acting on vehicles running in tunnels [7] while experiments using a moving model rig and wind tunnels helped further clarify the forces on running vehicles through measurement of pressure on the car body sides. Numerical simulations were conducted to determine flow fields around vehicles that are difficult to clarify in experiments. It was found that vortices were generated close to the underside of the car body floor which interfered with the tunnel wall and then spread over the entire car body sides whilst moving rearward. Based on the findings, it was hypothesized that, as the vortices move rearward, unsteady aerodynamic forces would be generated and act on the vehicle [7].

Recently introduced large-scale CFD analysis using supercomputer advanced numerical simulation, making it possible to observe more detailed flow fields than those offered by the previous simulation with which the above hypothesis was proposed. It was shown by large-scale CFD analysis that laterally meandering flows were generated beneath the floor of vehicles running in open sections, and that in tunnels those meandering flows under the floor spread to the car body side near the tunnel wall causing pressure variation (Fig. 5). Those meandering flows beneath the floor of vehicles that were shown by CFD analysis were later verified in wind tunnel tests using a moving ground belt.
5. Aerodynamic/low-frequency noise in open sections

Environmental quality standards govern the noise produced by Shinkansen super-express trains, and efforts are being made to ensure compliance with these requirements. Shinkansen noise measured along the wayside primarily consists of rolling noise, bridge noise and aerodynamic noise. Recent studies show that 50% of the noise emitted from cars running at 300 km/h or faster is aerodynamic noise which is primarily generated by bogies and other components located beneath the vehicle, followed by the current collecting system [8]. Studies are underway on these noise sources, especially on how the noise is generated and to devise mitigation measures.

In wind tunnel tests simulating flows beneath actual vehicles, a method was developed for quantitatively evaluating aerodynamic noise from bogies. Results from tests using this method helped clarify the contribution to aerodynamic noise of bogie components (Fig. 6) [9, 10]. Findings from this work are being applied to develop measures to mitigate aerodynamic noise from bogies. With a view to reducing aerodynamic noise from current collection systems, studies are underway to improve the shape of pantograph head-support joints and pantograph head-horn joints, and also to examine the use of porous materials for components that cannot be easily modified for improvement, and new techniques based on flow control technology, etc. [11, 12, 13]. The aim of this research is to combine these component technologies and further improve the mix to develop noise mitigation measures applicable to vehicles on commercial lines.

As for noise with frequencies below the audible range of above 20 Hz, to which quality standards do not apply, rattling of building furniture can be caused for different reasons depending on circumstances, and therefore, mitigation measures are still needed. A past study showed that low-frequency sound can be divided into components: those generated by aerodynamic phenomena and emitted from vehicles and those generated by structural vibration; and that aerodynamic components consist of pressure variation induced by pressure fields at the nose and tail of a train and that continuously sent out from intermediate cars (Fig. 7) [14]. However, sources and mechanisms of the latter were not sufficiently detailed, which is largely due to the following reasons: pressure variation from intermediate cars is difficult to distinguish from structural sound measured in on-site tests; long-wavelength sources of low-frequency sound are difficult to locate; and it is difficult to produce an average for long sound wave cycles given the speed of passing trains.

With the above in mind, on-site tests were conducted in a non-elevated section free of bridge noise using a 28-meter-long linear microphone array to clarify sources and mechanisms of pressure variation emitted continuously from intermediate cars. Using this method, it was found that sound sources can be separated and at the same time...
located more accurately by averaging data from a reasonable number of trains [15]. It was also found that sources of low-frequency aerodynamic noise are concentrated at and around bogies (Fig. 8). With this insight, further efforts will be made to mitigate low-frequency aerodynamic noise.

6. Conclusions

In the railways, aerodynamic phenomena affect a wide range of areas, with growing impact as trains run faster. Offering faster rail services in future means that solving aerodynamic-related issues will become increasingly important. At RTRI, research and development activities are underway using actual vehicle tests, laboratory tests, numerical simulation and other techniques to clarify and predict/evaluate the mechanism of these phenomena and come up with mitigation measures. It is hoped that this work will continue to benefit from the support and cooperation of other parties involved in this field of research.

References


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