RTRI's Large-scale Low-noise Wind Tunnel and Wind Tunnel Tests

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Four years have passed since the RTRI's Large-scale Low-noise Wind Tunnel was completed at Maibara in 1996. This wind tunnel was built to study aerodynamic noise and aerodynamic phenomena for high-speed trains and develop their reducing measures. This wind tunnel has two excellent features: one is the extremely low background noise which makes it possible to measure the noise generated from a model precisely and the other is a large and high-speed moving belt ground plane which enables the simulation of the flow between the model and the ground. This review reports the specifications of this wind tunnel and an outline of the tests performed over four years.

Keywords *: wind tunnel, aerodynamic noise, aerodynamic drag, aerodynamic characteristics of vehicles under cross winds*

1. Introduction

The Railway Technical Research Institute (RTRI) decided to build the Large-scale Low-noise Wind Tunnel at Maibara (the Maibara Wind Tunnel) in 1992 to study the aerodynamic noise and aerodynamic phenomena of high-speed railways such as Shinkansen. The specifications of the wind tunnel were planned by the technical committee which consisted of RTRI's members and outside specialists such as professors of universities. The construction of the wind tunnel was started in 1994 June and completed in 1996 June.

This wind tunnel has two excellent features: one is the extremely low background noise which makes it possible to measure the noise generated from a model precisely and the other is a large and high-speed moving belt ground plane which enables the simulation of the flow between the model and the ground.

Here the specifications of this wind tunnel and an outline of the tests performed over four years are reported.

Fig. 1 Large-scale Low-noise Wind Tunnel

2. Specifications of the Large-scale Low-noise Wind Tunnel

Figure 1 shows a general view of the Large-scale Low-noise Wind Tunnel at Maibara (the Maibara Wind Tunnel). The specifications of this wind tunnel are shown in Table 1. This wind tunnel is a single return wind tunnel.

Table 1 Specifications of Large-scale Low-noise Wind Tunnel

Item	Specifications	
Tunnel	Single return wind tunnel	
Test sections (Width & Height) (Length)	Open type 3.0m×2.5m 8m	Closed type 5.0m×3.0m 20m
Maximum wind velocity	400km/h	300km/h
Contraction ratio	16:1	8:1
Uniformity of wind velocity	Under ±0.7% at 324km/h	Under ±0.4% at 288km/h
Turbulence intencity	Under 0.2% at 360km/h	Under 0.2% at 198km/h
Background noise level	75dB(A) at 300km/h	
Main instruments	Sound level meters, Linear array Microphones, Parabola microphones	6-Component balance with turn table, 6-Component wire balance, Pressure transducers
Main accessories	Anechoic room 20m×22m×13m Traversing gear	Moving belt ground plane 2.7m×6.0m Maximum speed 216km/h, Boundary layer Suction systems, Traversing gear
	Flow visualization system (Smoke generator,Lightning system, Video monitoring system)	
Fan	Diameter:5m Rotation:550rpm(maximum) Three phase induction motor:7MW	
Overall dimensions	Length:94m,Width:42m,Height:10m Total path length 228m	

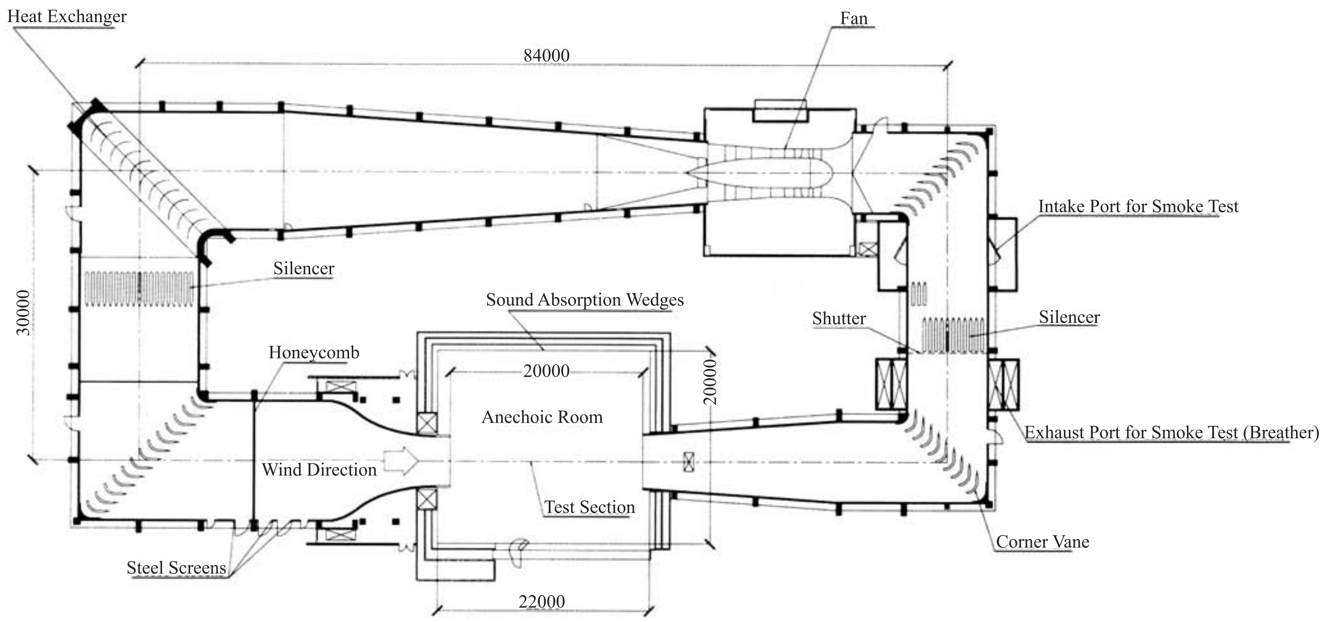

Fig. 2 Wind tunnel circuit

Fig. 3 Open type test section

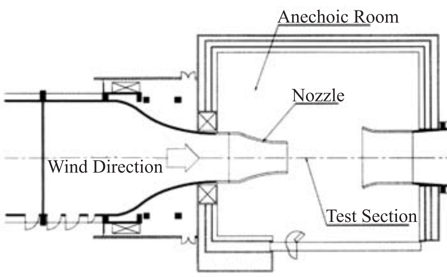

Fig. 4 Ground plan of open type test section

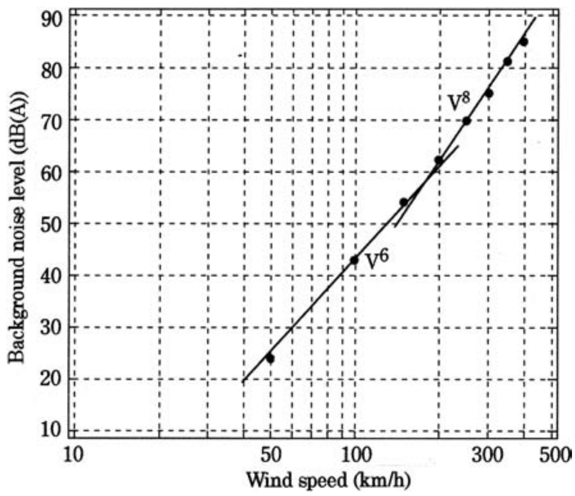

Fig. 5 Background noise level

Figure 2 shows the wind tunnel circuit. This has two types of test sections: one is an open type test section surrounded by an anechoic chamber and the other is a closed type test section.

The open type test section is used for aeroacoustic tests. Figure 3 and 4 show the open type test section and its ground plan, respectively. The cross-section of the open type test section is 3 m wide × 2.5 m high and its length is 8 m. The volume of the anechoic room is 20 m wide × 22 m long × 13 m high. The maximum wind speed is 400 km/h. The background noise is extremely low, which makes it possible to measure the noise generated from a model precisely. Figure 5 shows the relation between the wind speed and the background noise level measured at a point 3 m leeward from the center of the nozzle and 4.5 m distant horizontally from the centerline of the nozzle. The background noise level is 75.6 dB(A) at 300 km/h. Various measures for reducing background noise are taken, such as sound absorbing porous concrete walls along the wind circuit, splitter type silencers in the wind circuit and fiber on the surfaces of nozzle and collector. A traversing gear is installed in the anechoic room. Main instruments for aeroacoustic measurements are sound level meters, linear array microphones, paraboloidal and ellipsoidal mirror microphones.

The closed type test section is used for aerodynamic tests. Figure 6 and 7 show the closed type test section

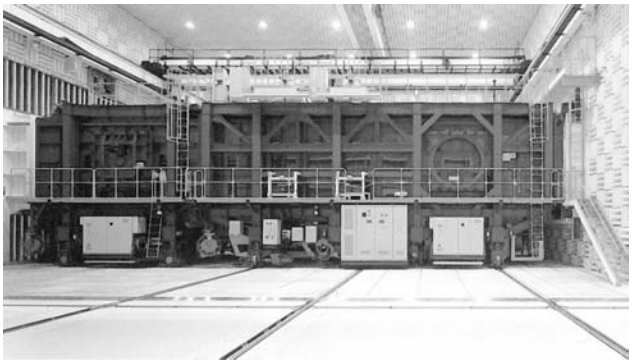

Fig. 6 Closed type test section

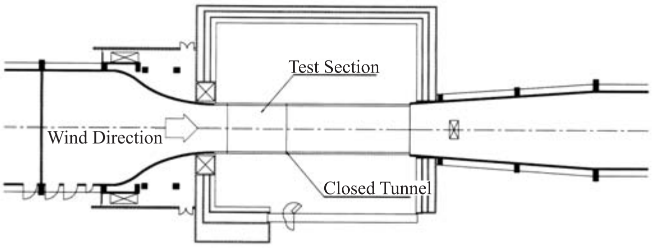

Fig. 7 Ground plan of closed type test section

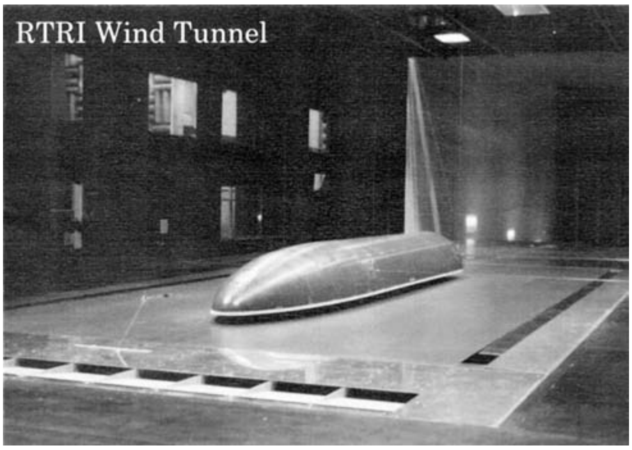

Fig. 8 6-component wire balance above moving ground plane

and its ground plan, respectively. The cross-section of the closed type test section is 5 m wide × 3 m high and its length is 20 m. On the floor of the closed test section, the first boundary layer suction system, a front turntable, the second boundary layer suction system, a large and high-speed moving belt ground plane and a rear turntable are installed in the direction of the wind. The boundary layer suction systems and the large and high-speed moving belt ground plane enable the simulation of the flow between the model and the ground. The size of the moving belt ground plane is 2.7 m wide × 6 m long and its maximum speed is 216 km/h. Two vertical turntables are installed face to face on the front side walls and these can be moved to the rear side walls. A traversing gear is also installed in the closed test section. Main instruments for aerodynamic measurements are a 6-component pyramidal balance installed at the front turntable, a 6-componet wire balance on the ceiling above the moving belt ground plane, pressure transducers and hot wire anemometers. Fig.8 shows a model hung with the 6-component wire balance above the moving belt ground plane. For flow visualization, a smoke generator, a laser lighting system and a video monitoring system are set up.

Basic performance tests have proved that specifications shown in Table 1 are satisfied. These results will be described in Chapter 3.1.

The Maibara Wind Tunnel is now being used for researches by RTRI and contract researches by Japan Railway Group and other companies throughout the year except at periodic inspections.

3. Outline of wind tunnel tests

3.1 Basic performance tests on flow quality

After completion of the Maibara Wind Tunnel, its basic performance was investigated in detail. For the open test section, the background noise level, the flow

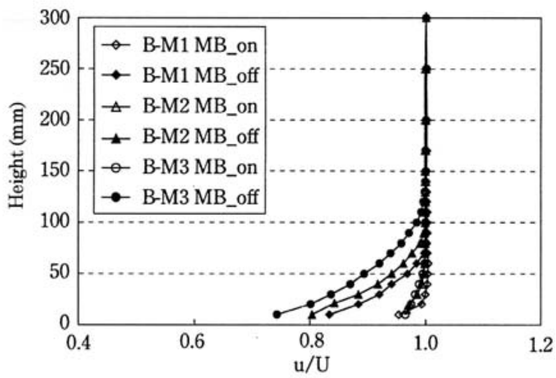

Fig. 9 Boundary layer distribution on moving ground plane

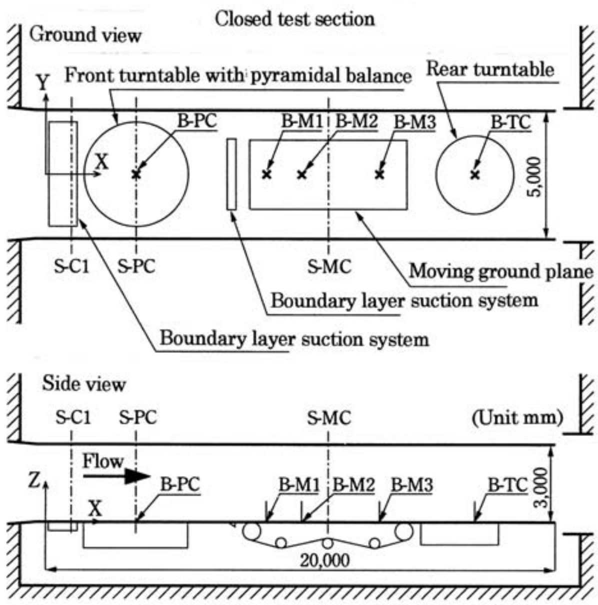

Fig. 10 Measured positions for boundary layer distribution

velocity distribution, the turbulent intensity, the static pressure distribution and the flow temperature distribution were measured above the platform whose level is the same as the bottom of the nozzle of the open test section. For the closed test section, the flow velocity distribution, the turbulent intensity, the boundary layer distribution on the floor including the moving belt ground plane, the static pressure distribution and the flow temperature distribution were measured. These basic data are needed to make various types of wind tunnel tests.

As a result of basic performance tests, the flow velocity distribution in the inner region of the flow of the open test section is uniform with accuracy at ±0.7 % and the turbulent intensity is less than 0.2 %. The flow velocity distribution of the closed test section is uniform with accuracy at ±0.4 % and turbulent intensity is less than 0.2 %. Figure 9 shows the boundary layer distribution on the moving belt ground plane. In Fig.9, MB_on and MB_off denote that the ground plane is moving and stopped, respectively. Figure 10 shows the measured positions on the moving belt ground plane. The moving ground plane is effective in simulating the flow between the model and the ground. For further details, refer to the literature [1].

3.2 Basic performance tests on a 6-component wire balance

The 6-component wire balance is installed on the ceiling of the closed test section above the moving belt ground plane. The wire balance has five vertical wires from the ceiling and four horizontal wires from side walls to the model that is supported close to the moving belt ground plane (Fig.8). The aerodynamic drag measured with the wire balance is the total aerodynamic drag of the model and wires. Accordingly, in order to evaluate the aerodynamic drag of the model, it is necessary to evaluate the aerodynamic drag of wires and subtract it from the total aerodynamic drag. Here three methods were applied in order to evaluate the aerodynamic drag of wires. The first method is to measure the aerodynamic drag of a piece of wire used for the wire balance directly according to the flow velocity and then to calculate the aerodynamic drag of wires of the wire balance. The second method is to measure the total aerodynamic drag of wires and a rod frame hung with wires with the wire balance and the aerodynamic drag of the rod frame by the pyramidal balance on the front turntable and then to calculate the aerodynamic drag of wires by subtraction of the aerodynamic drag of the rod frame from the total aerodynamic drag. The third method is to measure the total aerodynamic drag of wires and the rod frame hung with wires with the wire balance and the total drag of wires and two rod frames hung with wires with the wire balance and then to calculate the drag of wires in a similar way. A comparison of these methods indicates that the first method is convenient and the wire balance guarantees the accuracy of 2 digits to the aerodynamic drag coefficient of a model the ratio of whose cross-sectional area to that of the closed test section is about 1 %. In the future, it will be necessary to reduce the aerodynamic drag of wires and improve the accuracy of the wire balance further. For further details, refer to the literature [2].

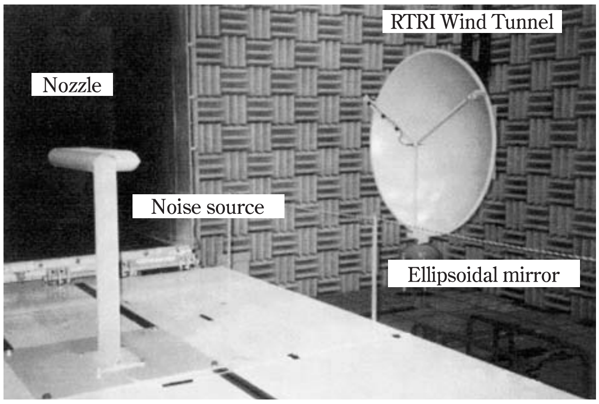

Fig. 11 Directional microphone with ellipsoidal mirror

3.3 Wind tunnel tests for aeroacoustics

3. 3. 1 Wind tunnel tests on the method of analyzing aerodynamic noise with directional microphone systems

In field tests, railway noise has been measured with a directional microphone with a paraboloidal mirror (diameter 1 m) which is designed on the assumption that incident waves are plane waves. In wind tunnel tests, as the microphone in wind tunnel tests is installed near the model, incident waves to the microphone can not be assumed to be plane waves. Accordingly a directional microphone with an ellipsoidal mirror (diameter 1.7 m) was developed for aeroacoustic wind tunnel tests. Figure 11 shows the directional microphone with the ellipsoidal mirror. The microphone is located at a focal point of the ellipsoid near the mirror and the noise source is supposed to be located at the other focal point of the ellipsoid. Wind tunnel tests on the characteristics of this directional microphone were performed at the Maibara wind tunnel. As a result of tests, it has become clear that the characteristics of the microphone with the ellipsoidal mirror are superior to those with the paraboloidal mirror for the acoustic wind tunnel tests. The microphone with the ellipsoidal mirror has higher spatial resolution than that with the paraboloidal mirror for point noise sources. The correction for the convection and the diffraction of the sound wave by the flow has also been confirmed experimentally. Finally, the method for estimating the contributions of the localized noise sources to the far field noise level has been proposed on the basis of the wind tunnel test data measured with the directional microphone with the ellipsoidal mirror. For further details, refer to the literature [3] published in this Quarterly Report.

3. 3. 2 Wind tunnel tests on the aerodynamic noise generated from simplified models

Wind tunnel tests on aerodynamic noise generated from a circular cylinder were executed under the cooperative study with Prof. Fujita of Nihon University. Refer to the literature [4]. Wind tunnel tests on aerodynamic noise generated from simplified models such as a hemisphere, half hemisphere, an elongated hemisphere and half spheroid on a flat base were also conducted. For further details, refer to the literature [5] published in this Quarterly Report.

3. 3. 3 Wind tunnel tests on the aerodynamic noise generated from a pantograph

The cross-section of the open test section is 3 m wide 2.5 m high so that it is possible to make wind tunnel tests by using a real pantograph. Various wind tunnel tests have been made to develop low noise and aerodynamically stable pantographs. One is the wind tunnel test for the PEGASUS pantograph developed by RTRI. This pantograph has a variable attack angle mechanism of panhead. Figure 12 shows the prototype model of the low noise pantograph PEGASUS. Refer to the literature [6].

3. 3. 4 Wind tunnel tests on aerodynamic noise from a Shinkansen train

First, wind tunnel tests were made by using a 1/5-scaled Shinkansen train model on the platform in the open test section. As a result of the tests, it was proved that aerodynamic noise from the bottom of the nose, the pantograph and the pantograph shield was dominant. Next, wind tunnel tests on the aerodynamic noise from the lower part of the Shinkansen train were made because it was confirmed from field tests that the aerodynamic noise from the lower part of the Shinkansen train became dominant as measures had be taken against aerodynamic noise from the pantograph, the pantograph shield and instruments on the roof. In these wind tunnel tests, it is necessary to simulate the flow under the train body correctly, namely the effect of the ground that moves relative to the train. Though the moving belt ground plane is installed on the floor of the closed test section, it generates noise and cannot be used for aeroacoustic tests. Accordingly, in order to simulate the flow under the train body, a pair of mirror image models was installed in the open test section. The symmetrical plane between the mirror image models was assumed to be the ground. In these wind tunnel tests, the sound levels generated by several combinations of front shapes, bogie conditions and inter-car gaps were measured with the directional microphone with the paraboloidal mirror and the properties of the flow under the train were also measured. As a result, it has become clear that the aerodynamic noise from the bogie is mainly generated by the vortices that are separated at the leading edge of the bogie section, travel leeward at the convective flow speed and then impinge upon the trailing edge of the bogie section. For further details, refer to the literature [7] published in this Quarterly Report.

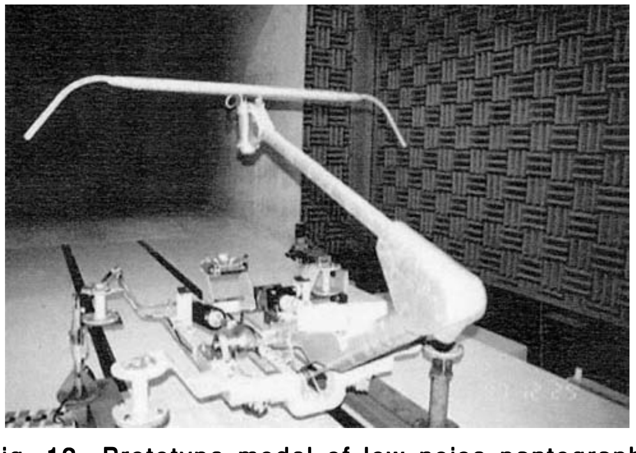

Fig. 12 Prototype model of low noise pantograph PEGASUS

3.4 Wind tunnel tests for aerodynamics

3. 4. 1 Wind tunnel tests on the aerodynamic drag of a Shinkansen train

The aerodynamic drag of a train is proportional to the square of the train speed. Accordingly, it is important to reduce the aerodynamic drag of high-speed trains for speed-up and energy-saving. Wind tunnel tests were made on the aerodynamic drag of the Shinkansen train by using 1/7 scaled models consisting of three cars: a head car, intermediate car and tail car on the moving belt ground plane of the closed test section. The aerodynamic drag and the pressure distribution of the intermediate car were measured for several under-floor configurations of cars because the aerodynamic drag of the long train-set such as Shinkansen trains is mainly generated by the intermediate cars. As a result of the wind tunnel tests, it has become clear that the aerodynamic drag of the intermediate car is caused by the pressure drag around the bogies and the gaps of the car and that smoothing of the under-floor configuration reduces the aerodynamic drag. For further details, refer to the literature [8] published in this Quarterly Report.

3. 4. 2 Wind tunnel tests on the aerodynamic characteristics of train/vehicles under cross winds

In Japan, nearly thirty wind-induced accidents have happened since the opening of railway operation in 1872. The speed of a wind which can overturn a vehicle depends on the wind force caused by cross winds, vehicle weight, track gauge, cant of a bank and train speed. In order to establish a safe and effective regulation method under cross winds, it is necessary to study the aerodynamic characteristics of vehicles as well as the characteristics of strong winds. The aerodynamic characteristics of a vehicle under cross winds depend on not only the shape of the vehicle but also those of infrastructures such as bridges and embankments. Accordingly, wind tunnel tests in the closed test section were made to evaluate the aerodynamic characteristics of typical configurations of vehicles on typical configurations of infrastructures. In the wind tunnel tests for embankments, the aerodynamic characteristics were measured on the rear turntable where the boundary layer naturally developed along the floor of the long closed test section became similar to the real boundary layer. For further details, refer to the literature [9].

3.5 Other wind tunnel tests

Wind tunnel tests were performed on basic studies of the flow at a high Reynolds number of fluid dynamics under the cooperative studies with other institutes, namely on the transition of a boundary layer with Dr. Takagi and Dr. Tokugawa of the National Aerospace Laboratory and on the structure of the intermittent region in a turbulent boundary layer with Dr. Sato and Prof. Fukunishi of Tohoku University.

4. Conclusions

The RTRI's Large-scale Low-noise Wind Tunnel (the Maibara Wind Tunnel) was built to study aeroacoustic and aerodynamic phenomena for high-speed trains and develop their reducing measures. This wind tunnel has two excellent features: one is the extremely low background noise which makes it possible to measure the noise generated from a model precisely and the other is a large and high-speed moving belt ground plane which enables the simulation of a flow between the model and the ground. Various kinds of tests have been made since the completion of this wind tunnel in 1996. This wind tunnel makes it possible to locate the noise sources generated from train and pantograph with a directional microphone with a ellipsoidal mirror because of the extremely low background noise. It is possible to make wind tunnel tests on aerodynamic noise and aerodynamic stability of the pantograph by using a real pantograph owing to the large open test section. It is possible to evaluate the aerodynamic drag by using the moving belt ground plane installed at the closed test section. The long closed test section enables the simulation of the boundary layer developed on the ground, which is needed for the study of the aerodynamic characteristics of vehicles under cross winds. This large and high-speed wind tunnel can be used for the basic study of the flow at a high Reynolds number of fluid dynamics. In the future, it will be necessary to improve the accuracy of the measurements for aeroacoustics and aerodynamics further. It will be also necessary to compare the results of the wind tunnel tests with the results of field tests and establish the methods of wind tunnel tests for evaluating the results of actual conditions.

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