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EXPERIMENTAL STUDY ON SIMILARITY OF AERODYNAMIC NOISE MEASURED IN WIND TUNNEL TESTS

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ABSTRACT

This paper describes the similarity of aerodynamic noise between scaled models of high-speed trains for wind tunnel tests. Through several tests, we have reached a conclusion that the following factors cause the non-similarity between models: i) Large difference of Reynolds Number that causes different flow patterns such as a flow separation with a turbulent flow and that with a laminar flow; ii) Two different types of aerodynamic sound components that obey 6th and 8th power laws of airflow velocity, which are recognized in aerodynamic sound generated from sufficiently smoothed test models; iii) Certain acoustic effects on radiated aerodynamic sound, which are related to a certain fixed frequency regardless of Strouhal number.

1 - INTRODUCTION

This report presents acoustic characteristics of aerodynamic sounds radiated from simplified models on a flat base. The simplified models consist of a hemisphere, a spheroid, a half hemisphere and an elongated hemisphere with an inserted half cylinder as an intermediate part to the hemisphere. An important purpose of these test models is to provide acoustic data which can be used to survey aerodynamic noises from the upper parts of train front. The other purpose is to provide acoustic data which can be compared with the results of simulation including CFD. The installation which is called the Maibara wind tunnel was used for experimental tests.

2 - TEST EQUIPMENT AND MODELS

The Maibara wind tunnel that belongs to RTRI was completed in June 1996. The installation has an open test section and a closed test section. Tests to measure aerodynamic sounds are usually performed at the open test section. The main specifications of the Maibara wind tunnel are described in Table 1. Three-dimensional models shown in Fig. 1 were selected as the simplified models. The representative size was set at 0.6 m, which was decided to be as large as possible under the condition to make the blockage rate less than 10%.

1. A hemisphere (marked by Hemisphere)
2. A half hemisphere (marked by Half Hemisphere)
3. An elongated hemisphere (marked by Elongated Model)
4. A half spheroid (marked by Half Spheroid)

Item	Specifications	
Tunnel	Gottingen Type, Single Return Wind Tunnel	
Test Sections	Open Type	Closed Type
Width & Height	3.0 m ×2.5 m	5.0 m ×3.0 m
Length	8 m	20 m
Maximum Wind Velocity	400 km/h	300 km/h
Contraction Ratio	16:1	8:1
Uniformity of Wind Velocity	under ±0.7% at 300 km/h	under ±0.7% at 200 km/h
Turbulence Intensity	under 0.3% at 300 km/h	under 0.3% at 200 km/h
Background Noise Level	75 dB(A) at 300 km/h	
Overall Dimensions	Length 94 m, Width 42 m, Height 10 m, Total path length 228 m	

Table 1: Specifications of Maibara wind tunnel.

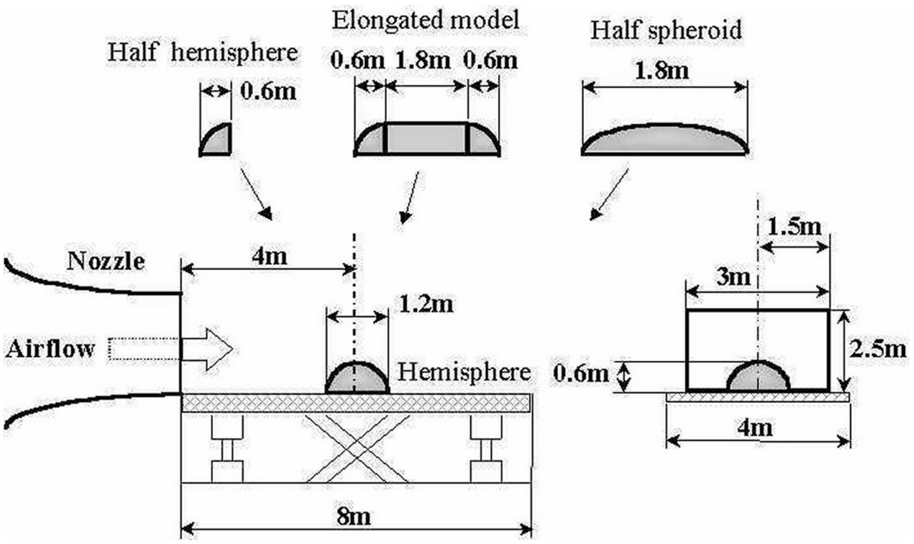

Figure 1: Schematic setup of three models.

Dimensionless parameters under test conditions are as follow:

- Mach Number: 0.12-0.29 (airflow velocity: 150-350 km/h)
- Reynolds Number: 1.7-3.9 $\times 10^6$ (representative length: 0.6 m)
- Acoustic frequency parameter: 1.11-222 (frequency: 100 Hz - 20 kHz)
- Strouhal Number: 0.62-288

3 - MEASUREMENT RESULTS

Sound pressure is measured at points that are 6 m distant from the center of a flat base. And spectra of the sound pressure are analyzed. As the outlines of the spectra have simple shapes, we analyzed mainly the 1/3 octave band spectra instead of analyzing detailed power spectra. The 1/3 octave band spectra of the sounds from the three-dimensional models are compared with each other in Fig. 2 except those of the sounds from the spheroid, which are considered too weak to be distinguished from the background noise. In Fig. 2, black symbols represent data from relatively small models (1/10 size) measured in another small wind tunnel. Large difference between data of two different scaled models suggests that different flow patterns such as a flow separation with a laminar flow and that with a turbulent flow are caused by large difference of Reynolds Number. Under sufficiently large Reynolds Number, large differences among the sounds from the three models which have spherical front surfaces do not seem to be found. The sound spectrum corresponding to the half spheroid could not be displayed because the strength of the sound turned out to be extremely weak.

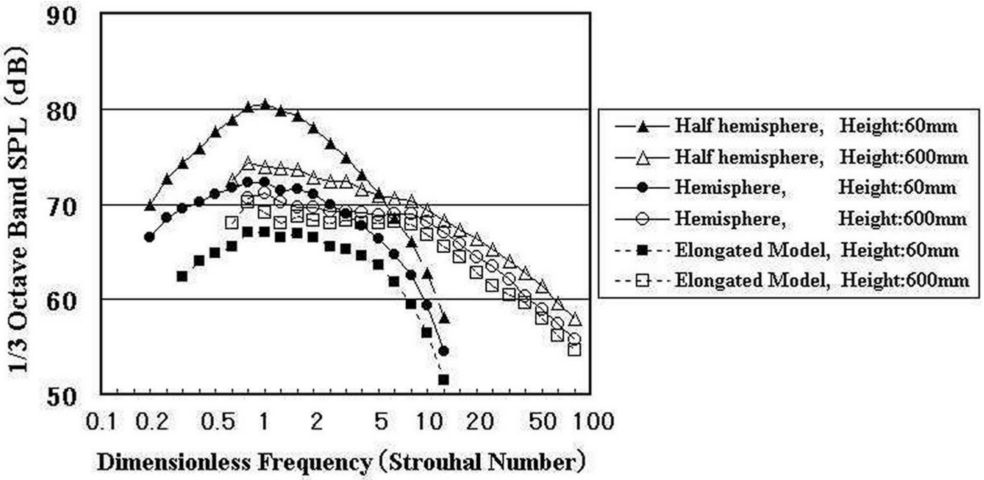

Figure 2: Sound spectra of two scaled models at side point of 12.5 ℓ distance (under 300 km/h airflow, ℓ: height).

Concerning the sounds from the three models which have spherical front surfaces, A-weighted sound pressure levels almost follow the 8th power law of airflow velocity (Fig. 3), despite that the empirical law deduced from high-speed railway cars usually suggests the 6th power law. On the other hand, it is confirmed that the overall sound pressure levels follow the 6th power law of airflow velocity. These facts suggest that two different types of aerodynamic sound components that obey 6th and 8th power laws of airflow velocity are recognized in aerodynamic sound generated from sufficiently smoothed test models.

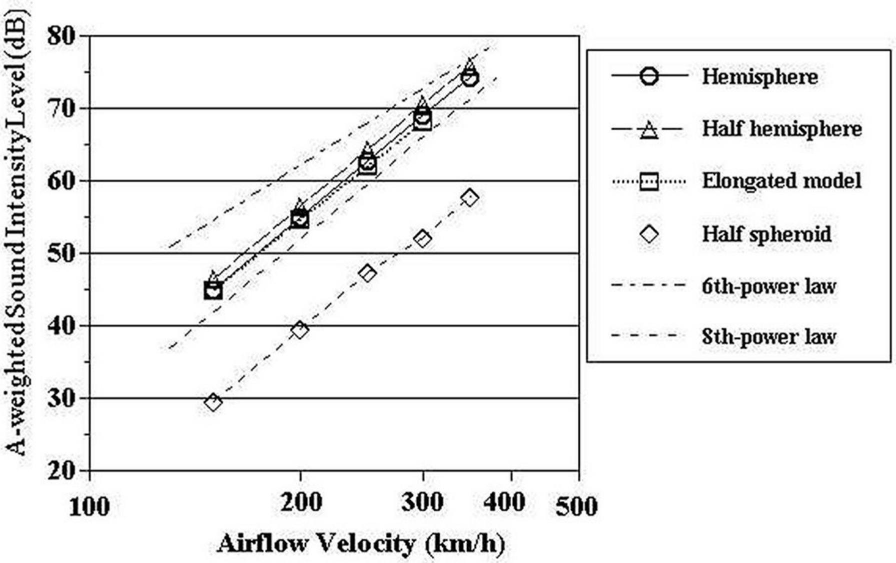

Figure 3: Dependence of averaged sound intensity levels of measured sounds on airflow velocity (estimated at a point of 25 m distance).

Finally, certain acoustic effects on radiated aerodynamic sound that are related to a certain fixed frequency regardless of Strouhal number are guessed though the precise interpretation of the effect can not be provided for the present (Fig. 4).

4 - CONCLUSIONS

1. Large difference of sound spectrum patterns between data of two different scaled models suggests that different flow patterns such as a flow separation with a laminar flow and that with a turbulent flow are possibly caused by large difference of Reynolds Number.

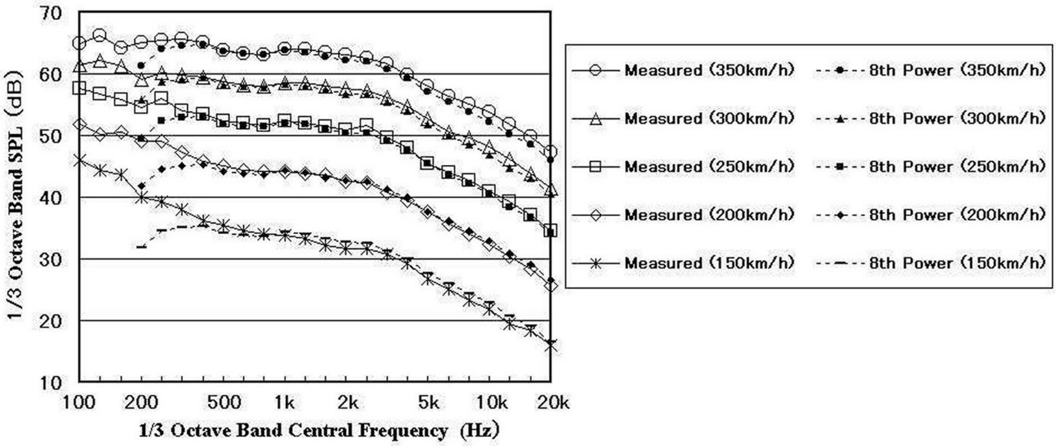

Figure 4: Measured sound spectra of hemisphere model (estimated at a point of 25 m distance).

2. Two different types of aerodynamic sound components that obey 6th and 8th power laws of airflow velocity are recognized in aerodynamic sound generated from sufficiently smoothed test models.
3. Certain acoustic effects on radiated aerodynamic sound that are related to a certain fixed frequency regardless of Strouhal number are recognized.

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