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Component-based model to predict aerodynamic noise from high-speed train pantographs

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ABSTRACT

At typical speeds of modern high-speed trains the aerodynamic noise produced by the airflow over the pantograph is a significant source of noise. Although numerical models can be used to predict this they are still very computationally intensive. A semi-empirical component-based prediction model is proposed to predict the aerodynamic noise from train pantographs. The pantograph is approximated as an assembly of cylinders and bars with particular cross-sections. An empirical database is used to obtain the coefficients of the model to account for various factors: incident flow speed, diameter, cross-sectional shape, yaw angle, rounded edges, length-to-width ratio, incoming turbulence and directivity. The overall noise from the pantograph is obtained as the incoherent sum of the predicted noise from the different pantograph struts. The model is validated using available wind tunnel noise measurements of two full-size pantographs. The results show the potential of the semi-empirical model to be used as a rapid tool to predict aerodynamic noise from train pantographs.

1. Introduction

At speeds typical of conventional railways the rolling noise is the main source of noise. However, the aerodynamic noise becomes significant at speeds between about 300 and 320 km/h and dominant above around 350 km/h [1]. Taking into account that high-speed trains exceeding 300 km/h are being introduced in several countries, aerodynamic noise becomes an important source of railway noise. Different aerodynamic sources of noise are found in a high-speed train, including the bogies, train nose, inter-coach gaps and pantographs (current collector). Although it is only one of many sources contributing to the overall noise of the train, the pantograph is particularly important as it is located on the train roof and is therefore not so effectively shielded by noise barriers as other sources.

From data acquired using a microphone array during passage of a Train à Grande Vitesse (TGV) Duplex at different train speeds, Mellet et al. [1] found that the pantograph can be identified as a significant noise source at a train speed of 350 km/h. Aerodynamic noise could be identified with two different mechanisms: vortex shedding noise due to the flow-cylinder interaction generated by the struts that compose the main pantograph body and head and broadband noise from the turbulence generated in the pantograph recess [1].

Kitagawa and Nagakura [2] showed that noise barriers are less efficient in reducing the noise from the pantograph

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compared with other railway noise sources. They measured the time history of the A-weighted sound pressure level (SPL) when two types of Shinkansen train were passing with speeds of 235 km/h and 312 km/h over a viaduct with 2 m high noise barriers installed on both sides. Prominent peaks in the time-history were seen due to the pantographs, showing that they have a significant contribution to the overall noise radiated by the trains. More examples of acoustic array measurements performed during the passage of different high-speed trains are given in [3–7].

Wind tunnel tests present an alternative method of assessing the aerodynamic noise from train components. Lölgen performed noise tests in the Large-scale Low-noise wind tunnel at Maibara (Japan) using an isolated full-scale pantograph at flow speeds up to 400 km/h [8]. He found strong peaks in the noise spectrum due to the vortex shedding from contact strips, horns and stroke-limiting cage. From wind tunnel noise tests on a full-scale pantograph Barsikow and King [5] similarly found the noise from the pantograph head to be significant and governed by distinct peaks due to vortex shedding noise from struts. Lauterbach et al. [9] carried out noise tests in an aeroacoustic wind tunnel using a 1/25 scale ICE3 model and a microphone array. They found the noise generated from the pantograph to be tonal and to dominate the noise spectrum for measured frequencies above 5 kHz (200 Hz at full scale).

Due to the importance of the inflow conditions during wind tunnel tests, Brick et al. [10] used spires upstream of a pantograph mounted on a section of train roof to develop an inflow turbulent boundary layer similar to that present on the train roof. Using a microphone array they concluded that the noise emitted by the pantograph decreased due to the effect of the spires reducing the incident flow speed. Takaishi and Ikeda [11] used a similar approach placing spires upstream of a full-scale pantograph. The spires were optimized to reduce the noise they generated themselves and a noise barrier was placed between the spires and the microphone array.

Anechoic wind tunnel noise tests have also been carried out to assess the effect of noise counter-measures applied to train pantographs. For instance, Sueki et al. [12] assessed the effect of porous materials wrapped around the pantograph components to avoid vortex shedding and to reduce the noise radiation, and Ikeda et al. [13] evaluated the variation in the noise radiation due to modifications of the panhead shape.

Prediction models are gaining importance due to the convenience of addressing the problem at early stages of the design process. Predictions of the aerodynamic noise generation can be made, in principle, by means of Computational Fluid Dynamics (CFD) and Computational AeroAcoustics (CAA) numerical methods. However, in the case of high-speed train components, the large spatial domain and complex geometric configurations required make the current numerical prediction techniques very computationally-intensive.

Computational methods have been applied recently to predict the noise radiated by high-speed pantographs. For example, Sato et al. [14] investigated the noise produced by the knee region of the pantograph. They measured experimentally the noise radiated by different tapered cylinders connected by the knee region and used CFD analysis ($\kappa - \epsilon$ turbulence model) in order to investigate the flow behaviour around the knee models. Other examples are found in the application by Yu et al. [15] of a hybrid method of Non-Linear Acoustic Solver (NLAS) and Ffowcs Williams-Hawkings (FW-H) acoustic analogy to predict the aerodynamic noise produced by a simplified pantograph type DSA350 for an incident flow speed of 350 km/h, and in the numerical methods applied by Lei et al. [16] to predict the noise radiated by the pantograph struts, dividing the calculation into an unsteady incompressible flow analysis using the Finite Element Method (FEM) and an acoustic analysis using the Boundary Element Method (BEM).

An option to simplify the numerical simulations is to use a component-based approach, as for example in the physics-based model used by Peers [17] to predict the noise radiated by an aircraft landing gear. In this case the flow field and noise are calculated for isolated components reducing the size and complexity of the geometry. An example of application of this approach for high-speed train pantographs is the numerical study carried out by Liu et al. [18] using Delayed Detached Eddy Simulations (DDES) and FW-H acoustic analogy to predict the noise from a circular cylinder yawed by different angles, approximating the main strut of a train pantograph.

Measurements of noise from cylinders were carried out by Hutcheson and Brooks [19]. Similar tests have been performed by King and Pfizenmaier [20] assessing the effect of the cylinder aspect ratio on the noise radiation for different cylinder cross-sections. Moreau and Doolan [21] assessed experimentally the dependence of the noise on the aspect ratio of a wall-mounted cylinder with a free end. Latorre Iglesias et al. [22] performed anechoic wind tunnel tests studying the dependence of the aerodynamic noise from cylinders on the yaw angle, flow speed, cross-sectional shape, angle of attack and radiation angle (directivity). The results of these experiments can be applied to the study of the aerodynamic noise radiated by a train pantograph.

The use of semi-empirical models based on measured data from individual components can reduce dramatically the computational costs compared with full CFD and CAA simulations. Behr et al. [23] developed a semi-empirical component-based model to assess the noise from a train pantograph based on wind tunnel noise tests with single cylinders. Smith and Chow [24] and Guo [25] developed semi-empirical models to predict the noise from aircraft landing gears based on the noise radiated by its different components.

Thompson et al. [26] presented a preliminary adaptation of Guo's model for the aerodynamic noise radiated by different parts of a train such as pantograph, bogie and nose, using the empirical factors from Guo [25]. Latorre Iglesias et al. [27] compared predictions obtained following this approach with available wind tunnel noise tests using a full-size pantograph. It was shown that the model, with modified coefficients, was able to provide fairly good predictions of the overall noise radiated by the pantograph but there were significant differences in the spectral shape. The measured noise spectrum was found to be governed by individual peaks due to the vortex shedding generated by individual struts that are not predicted in