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AN INVESTIGATION OF THE AERODYNAMIC ADMITTANCES AND AERODYNAMIC WEIGHTING FUNCTIONS OF TRAINS

M Sterling[*], C J Baker[*], A Bouferrouk[*], H O'Neil[†], S Wood[†], W Pearce[††] and E Crosbie[††]

[*]Department of Civil Engineering, School of Engineering
The University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK
e-mail: m.sterling@bham.ac.uk

[†] Interfleet Technology Ltd, Interfleet House, Pride Parkway, Debry, DE24 8HX, UK
[††]RWDI Anemos Ltd., Unit 4, Lawrence Industrial Estate, Dunstable, Bedforshire, LU6 1BD, UK

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1 INTRODUCTION

The stability of passenger trains and the dewirement of pantographs from overhead power cables are just two instances where the effect of cross winds can be of paramount importance. In order to examine either of these two problems in detail, a knowledge concerning the behaviour of the approaching wind and the induced response of the train is required. However, the complex nature of the wind in the lower part of the atmospheric boundary layer (ABL) and its interaction with the train can lead to the creation of addition flow structures which in turn can complicate the issue of predicting the wind induced forces. Nevertheless given sufficient information concerning the characteristics of the wind it is possible to begin to formulate a response to address these issues. Conceptually, there are essentially two approaches which can be used to relate fluctuations in the wind to those on a vehicle. Such calculations are usually either performed in the frequency domain or the time domain. In frequency domain it can be shown that:

$$S_{CFCF}(n) = 4C_F^2 \frac{S_{uu}(n)}{U^2} |X_F(n)|^2 \tag{1}$$

where $S_{CFCF}(n)$ is the power spectral density of the force coefficient, n is the frequency, C_F is the force coefficient, $S_{uu}(n)$ is the power spectral density of the streamwise component of the approaching wind, U is the mean velocity corresponding to the streamwise component of the wind and $|X_F(n)|^2$ is the aerodynamic admittance function. In the time domain the quasi steady effects are usually incorporated through a convolution of the fluctuating streamwise velocity (u'(t)) and a weighting function $h_F(\tau)$:

$$f'(t) = \frac{1}{2} C_F \rho A \int_0^\infty h_F(\tau) u'^2(t-\tau) d\tau \tag{2}$$

where f'(t) is the fluctuating force on the train and A is the side area. The full paper will examine the variation of both of these functions with respect to train type and yaw angle. Section 2 of the abstract outlines the background to the experimental work, while section 3 discusses the results of previous and current work in terms of the admittance function. Section 4 introduces a possible expression which will later be shown is sufficient to express the aerodynamic admittance in terms of three constants. Further work which will be presented in the full paper is outlined in section 5.

2 THE MEASUREMENTS

Unfortunately there is sparse data available in the public domain relating to this topic. Early model scale experiments undertaken in wind tunnels provided the main source of data prior to 2000. Three sources of data prior to 2000 will be investigated in this paper: Advanced Passenger Train (APT); a magnetically levitated vehicle (Mag-lev), [1]; and an idealised train (IT), [2]. All of the experiments were undertaken at model-scales of 1:50, 1:25 and 1:50 respectively. Further details relating to the simulations will be given in the full paper with experimental data available from [3].

In order to investigate the stability of the Class 390 "Pendolino" train in cross winds and to compare the data to that of a perceived "safe" vehicle (i.e. a Mark 3 coach), a series of full-scale experiments were undertaken at a coastal site at Eskmeals in Cumbria in the north west of England during the winters of 2001/02 and 2002/03, (see [4] and [5] for further details). Further details relating to the experimental site will be given in the full paper.

In the light of recent developments in the wind loading Codes of Practice in the UK, Europe and elsewhere, a perceived problem with respect to potential pantograph de-wirement between the pantograph arm and overhead cable arose. Hence, the Railway Safety and Standards Board (RSSB) funded a series of wind tunnel experiments on a Class 365 EMU. The experiments were undertaken in an open return wind tunnel. Full details of the project can be found in [6] with an in depth analysis of the supporting data given in [7].

3 EXPERIMENTAL RESULTS

3.1 Pre-2000 measurements

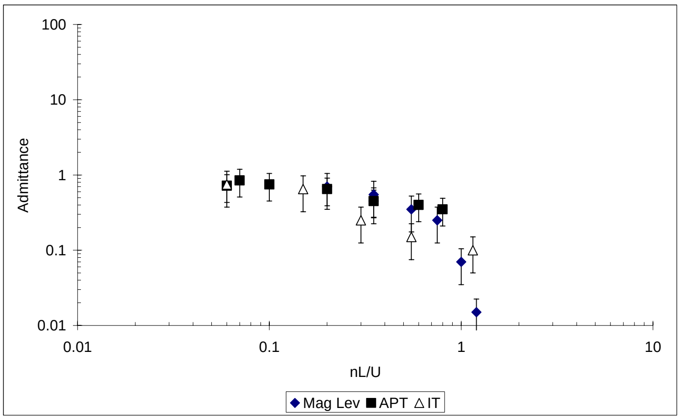

Fig. 1. Side force admittance data for the Mag-lev, APT and IT vehicles.

In what follows the data presented relate to the wind induced side forces only, and correspond to a limited set of yaw angles. These yaw angles are 76^o, 90^o and 90^o for the Mag-lev, APT and IT respectively. Fig. 1 illustrates the aerodynamic admittance function for the Mag-Lev, APT and IT. The vertical axis in figure represents the admittance function as defined by Eqn. (1), while the horizontal axis represents the reduced frequency (actual frequency x length of train / mean streamwise velocity). This format will be adopted throughout the paper. It should be noted that these data represent the mean values only and in all cases have a large degree of scatter, e.g. [8] states that the associated standard error (standard deviation/mean) is of the order of 38%. All of the data in Fig. 1 follow the same trend and indicate that as the reduced frequency tends to zero, the admittance tends towards unity, i.e. the large scale (low frequency) variations in the wind directly affect the forces measured on the trains. As the reduced frequency increases (turbulent scales reduce), the admittance rapidly decreases and takes into account the filtering that the inertia of the vehicle has on the flow.

3.2 Mark 3 coach full scale measurements

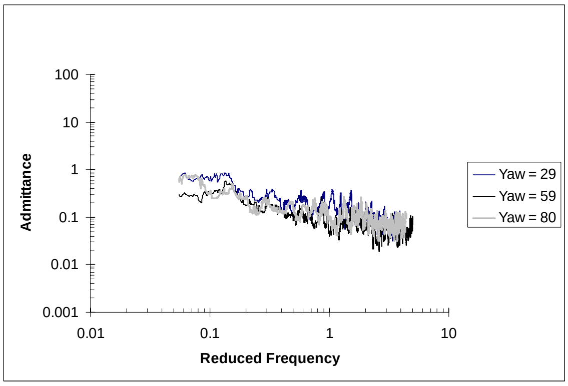

Fig. 2. Side force aerodynamic admittances for the Mark 3 coach

Fig. 2 illustrates the side force aerodynamic admittances corresponding to the Mark 3 coach. It is evident that all curves appear to collapse onto a single line, albeit with a significant amount of fluctuations. The rate of change of the side force admittance with respect to reduced frequency appears to be greater than that of the corresponding lift force admittance (not shown in the abstract). The effect of this will be examined in detail in the full paper.

3.3 Class 390 full-scale measurements

Fig. 3 illustrate the aerodynamic admittance corresponding to the side force for the Class 390. In order to ease the interpretation of the aerodynamic effects, the effect of any vehicle induced response has been removed. This removal of data is manifested as gaps in the admittance functions, although in reality these gaps would not be present. For the two yaw angles examined the admittances behaves as expected, i.e. they tend towards a constant value at low reduced frequencies and decrease with increasing values of reduced frequency.

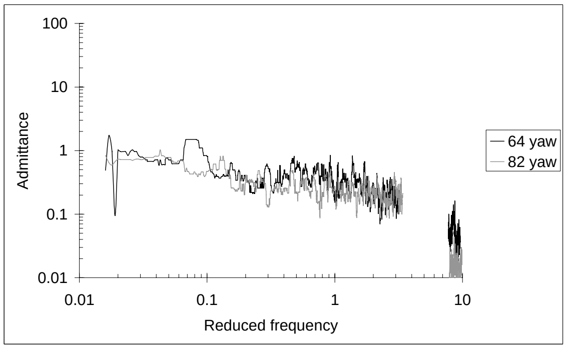

Fig. 3. Side force aerodynamic admittances for the Class 390

3.4 Class 365 wind tunnel tests

Due to space limitations details of the admittance data relating to the Class 365 data are not presented in the abstract. However, the full paper will examine the variation of lift and side force admittance with respect to yaw. Appropriate conclusions will be drawn.

4 FITTED AERODYNAMIC ADMITTANCES AND CORRESPONDING WEIGHTING FUNCTIONS

In the full paper it will be demonstrated that a curve of the following form can be fitted to all of the aerodynamic admittances irrespective of train type and yaw angle:

$$|X_F(n)|^2 = \frac{1/k}{\left\{\left[1-\left(\frac{\bar{n}}{\bar{n}'}\right)^2\right]^2 + \left[2\xi\frac{\bar{n}}{\bar{n}'}\right]^2\right\}^{1/2}} \tag{3}$$

where $\bar{n}$ is the reduced frequency and k, ξ and $\bar{n}'$ are constants. The benefit of fitting an equation of the type shown in Eqn. (3) is that it that is has a corresponding an analytical form in the time domain. The corresponding weighting function will be developed further in the full paper. In order to fit Eqn. (3) to the experimental data, the following assumptions are made:

- The value of k corresponding to each admittance function was considered to be given by the average value of the admittance for reduced frequencies of 0.1 and below.
- The parameters ξ and $\overline{n'}$ were varied and the corresponding values of admittance given by Eqn. (3) over the reduced frequency range were calculated.
- In order to evaluate the correct combination of ξ and $\overline{n'}$, the sum of the square of the difference between the measured data and that obtained from the fitted curve will be evaluated for reduced frequencies greater than 1.0. The correct combination of ξ and $\overline{n'}$ will be assumed to be given by the minimum value of this parameter. In what follows this parameter is termed the 'error'.
- ξ and $\overline{n'}$ will be varied over a large range in order to evaluate the behaviour of the '$\overline{n'}$-ξ-error' surface.

5 FURTHER WORK

In the full paper the results outlined above will be expanded to include the lift forces and considered in more detail. The importance of the three constants in Eqn. (3) will be examined along with the implications for the corresponding weighting functions. The choice of parameter values for k, ξ and $\overline{n'}$ will be examined in detailed and argument for keeping both k and $\overline{n'}$ constant will be presented. Furthermore, an in depth analysis will be undertaken in order to evaluate the height of the most significant streamline. Such heights are typically assumed to occur at 3m. However, the full paper will demonstrate that this is not the case and is highly dependent on train type.

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