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FULL-SCALE AERODYNAMIC MEASUREMENTS UNDERNEATH A HIGH SPEED TRAIN

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1 INTRODUCTION

Damage to the rail running surface, known in the industry as the railhead, has long been known to occur and is a major maintenance cost on any rail network [1]. Various forms of railhead damage have been indentified including rail breakage, traffic initiated wear and fatigue initiated cracks. Collectively these are now referred to as Rolling Contact Fatigue (RCF) and mitigation measures which have been introduced to control these issues include railhead surface grinding and lubrication [2, 3]. With the development of high-speed rail (HSR) systems another form of railhead damage, known as “ballast pitting”, has become apparent and is illustrated in Fig. (1).

This form of damage is thought to be due to small particles of ballast being crushed between the railhead and the wheels of rail vehicles. This form of damage becomes more apparent on HSR networks because of the speed and energy of the vehicle which is thought to generate an explosive crushing of the ballast particle which damages the railhead. The effect is also more significant on HSR networks because the forces involved are large enough to cause permanent deformation of the rail, which in turn leads to “voiding”, the formation of hollow areas in the ballast between and under the sleepers, which affects the track geometry and stability. Rail industry experience in several countries suggests that such voids reoccur if the underlying rail deformation is not corrected and that a series of such voids can form “downstream” of an uncorrected deformation. It is assumed that both aerodynamic and mechanical factors play a role in this issue but the detailed mechanisms for void generation and the initial ballast pitting are not clearly understood.

As an initial investigation into these issues this paper describes a series of observations and measurements made on the Network Rail Channel Tunnel Rail Link (CTRL), the first dedicated HSR track in the UK, as part of an MSc dissertation project. The CTRL is the first purpose built HSR track in the UK and is capable of vehicle speeds up to around 85 ms^{-1} (300 km/h). These observations sought to qualitatively and quantitatively establish the properties of the flow underneath HSR vehicles in order to establish whether they are potentially capable of depositing ballast particles on the railhead thereby initiating the ballast pitting and voiding process.

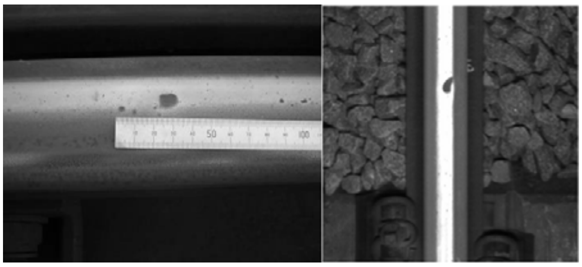

Figure 1 - Ballast pitting damage observed on a HSR railhead (left) and from a train mounted sensor (right)

Previous studies [4, 5, 6] have looked at the aerodynamic features around the sides and roof of high-speed vehicles at both model and full-scale but no measurements of the conditions occurring underneath vehicles, particularly rail vehicles, seem to have been made. Such conditions may be significantly different from those around the vehicle sides and roof because of the presence of the ground as a containing surface on the flow.

2 METHODOLOGY

The site chosen for this study was on the CTRL near Maidstone, Kent. This location was selected because it was on a generally straight and level section of track with good access. As such the HSR vehicles, all of which are Eurostar (Class 373) vehicles on this section, are able to pass the location at near maximum speed. The location is also one of the timing locations for the CTRL and therefore the likely schedule of vehicles was well known. The location also houses signalling control gear and therefore power and shelter for the experimental equipment was available. All the observations and measurements were conducted during normal operation of the CTRL and were conducted in full accordance with normal CTRL track operational safety procedures. The equipment used was fully certified for use on the CTRL rail network prior to the measurements taking place.

Figure 2 - Photograph of initial observations showing lightweight tapes during a Eurostar pass

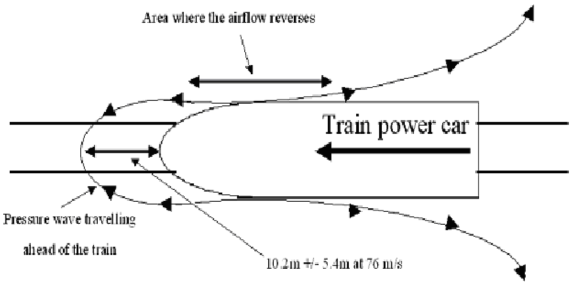

Figure 3 - Illustration of airflow pattern from Phase 1 results. Note that the details represented are limited by the time resolution of the video data to around ± 6m

An initial observation phase was conducted in which lightweight plastic tape strips were fixed to the rail, and on the ballast “shoulder” as shown in Fig. (2), and filmed during vehicle passes. These video recordings were analysed frame by frame to give an air direction and rate of change of direction. This analysis showed that very rapid direction changes were linked to the initial nose region of the flow and to the passing of individual wheel sets. These observations were repeated on sections of canted track (i.e. on curved sections), sections with different surroundings and sections with various widths of ballast “shoulder”. All these observations produced results similar to Fig. (3) and therefore it was concluded that the observed effects were entirely due to the passing vehicle and therefore measurements at a single location would be sufficient for the next phase.

In phase 2 the objective was to measure the magnitudes of the pressure and air speed and improve the time resolution of the data. To achieve this 5 pressure transducers [Honeywell 160PC] connected to static pressure probes [7], 4 load cells [Tedea-Huntleigh model 355] and a Cobra Probe [Turbulent Flow Instrumentation Pty Ltd] were mounted on a modified gauge bar which could fixed under the running rails as shown in Fig. (4). These instruments gave static pressure, load on a representitive piece of ballast (three different sizes of which were used) and air speed respectively. The Cobra Probe was moved to 4 positions across the track during the course of the measurements whereas the pressure probes and load cells remained at fixed positions. An additional 2 pressure probes and transducers, mounted at the side of the track equidistant up and down of the instrumented bar, gave an independent measure of vehicle speed.

The data from the pressure transducers and load cells was collected via an analogue-to-digital converter card [Measurement Computing PC-DAS16/16] at 1000 samples per second using purpose written software on a laptop computer. The data from the Cobra Probe was collected at 1250 samples per second using proprietary software supplied by the instrument manufacturer on a second laptop computer. It was found that some of the data collected from the pressure probes and load cells was contaminated with a 50Hz electrical interference from the overhead catenaries supplying power to the vehicles. Frequency analysis showed that the vehicle signal was entirely below this frequency and therefore all this data was double-filtered using a 40Hz 10-pole low-pass Butterworth filter before further processing.

Pressure and load cell data from 42 vehicle passes were successfully collected over a 2 day measuring period with 29 of those also being recorded with the Cobra Probe in one of the four positions. The data from each vehicle pass was extracted and the time base synchronised [5, 6] and non-dimensionalised by the speed / length of the vehicle. The data were then also non-dimensionalised by the dynamic pressure or vehicle speed as appropriate and an ensemble formed from data in each instrument position.

3 RESULTS AND DISCUSSION

Fig. (5) shows a typical pressure coefficient trace obtained from these measurements. The basic form of the trace fits well with the results for other vehicle shapes and speeds [5] and is particularly interesting because of the clear peak of pressure at the vehicle trailing end which has not previously been reported at full-scale. Analysis of the ensemble shows that this feature is repeatable and occurs in the ensemble average as well as the ensemble standard deviation (SD), the latter only having been previously reported [5]. The air speed measurements show

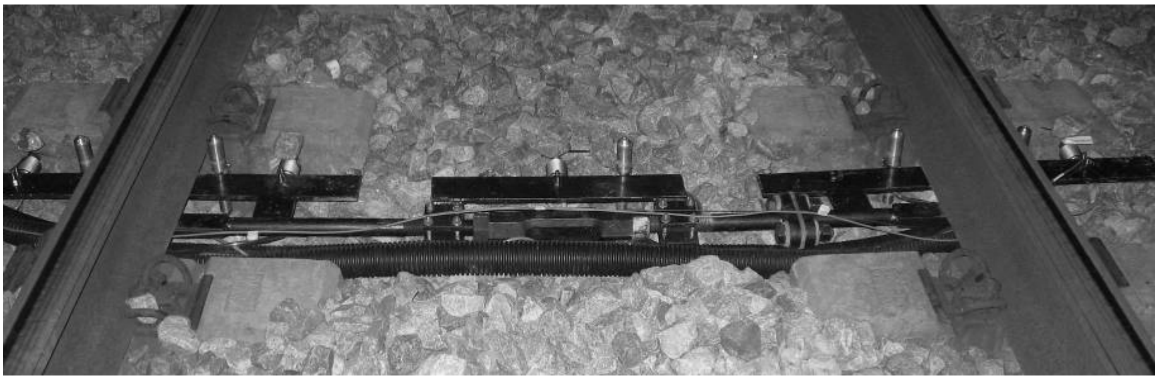

Figure 4 - Photograph of instrumented gauge bar installed on track

relatively little variation with track position which may suggest the under body flow has less sensitivity to position than the free side / roof flow field [4, 5]. The general form of the ensemble follows the five flow field regions identified in previous studies [6] and appears generally to scale with vehicle speed as expected. However the coefficient of velocity was higher than expected with the stream-wise component typically being in the range 0.3 to 0.4 approximately 50 mm above the ballast surface.

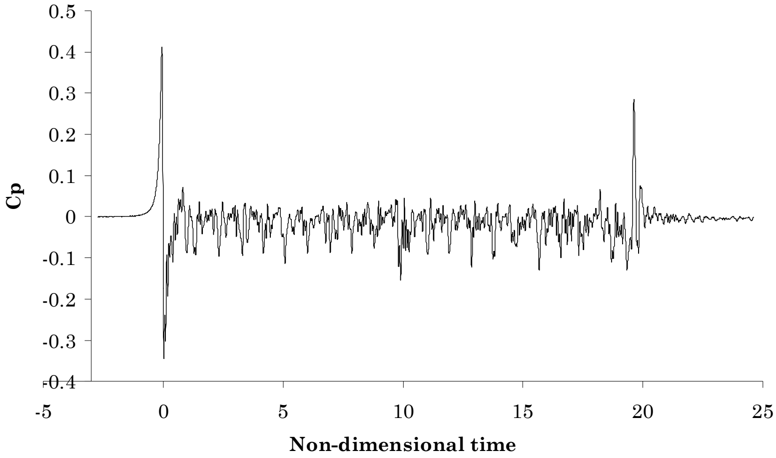

Figure 5 - Typical pressure coefficient trace from the central track position (Run A001A T3)

In all cases the detail of the results relates well to the known geometry of the vehicle with peaks, both positive and negative, associated with bogie / wheel positions and larger peaks in the central and power-car coupling positions. Further work is currently underway to assess the effect of these forces on the ballast and to couple these data with geotechnical data on the mechanical (vibration) generated by the same vehicle.

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