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Experimental investigation of the slipstream development around a container freight train using a moving model facility

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ABSTRACT

Increases in the volume of trade within the UK rail freight industry have led to proposed increases in freight train speeds. There is a concern that the unsteady slipstream created around a moving freight train could have implications on efficiency and the safety of passengers waiting on platforms or trackside workers. This paper describes a series of moving model-scale experiments conducted at the University of Birmingham's TRAIN rig facility. Experiments were undertaken to assess the slipstream development of a container freight train and draw conclusions on flow characteristics. In this paper the term 'freight train' refers to a series of flatbed wagons loaded with ISO standard shipping containers hauled by a Class 66 locomotive. In-depth analysis of slipstream velocity and static pressure ensemble average results at train side and above the roof identified a series of key flow regions. Results within the boundary layer region exhibit an influence from container loading configuration. Slipstream magnitudes are larger than typical high speed passenger train results, which it is suggested is related to the vehicle shape. The effect of train length and train speed was also considered. A detailed analysis of the nature of slipstream velocity components in specific flow regions is investigated, and conclusions drawn on characteristic patterns and factors influencing possible safety issues. The analysis highlighted differences created through decreased container loading efficiencies, creating increased boundary layer growth with a larger displacement thickness with higher turbulence intensities. Integral time and length scales calculated through autocorrelation indicate that proposed limits of human instability are exceeded for the container freight train with a lower loading efficiency. Overall the results from this paper offer for the first time a definitive experimental study on container freight slipstream characteristics, allowing the nature of the flow field around freight trains to be understood in far greater detail than before.

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1. Introduction

The UK rail freight industry is a growing sector with increasing volumes of international trade coupled with a gradual transfer from road to rail transportation. The UK government has set aims to double the volume of rail freight cargo on the UK rail network by 2030 (Department for Transport DfT. Delivering a Sustainable Railway, 2007). Efficiency studies into increased volumes of freight trains within an already overstretched network, primarily focused on passenger transportation, recommend building new and reopening closed railway lines, while developing faster and longer trains (Woodburn, 2008). However, infrastructure developments are expensive and would take several years to complete. Capacity could be increased by lengthening freight trains; however, this may lead to slower trains, due to locomotive power, thus creating further congestion within the rail network (Frost et al., 2012). The final option to increase freight operational speeds would be simpler to implement and lead to increased route capacity. This however has implications on efficiency and safety, as the movement of a vehicle causes deformation in the surrounding air, creating transient aerodynamic effects.

The airflow around a moving vehicle is called a slipstream, characterised by a highly turbulent non-stationary region of air (Baker et al., 2001). Induced slipstream forces can interact with trackside objects, potentially destabilising such objects and people. In the last forty years there have been twenty six train slipstream incidents on the UK rail network, the majority caused by freight trains. In one incident a braked pushchair was drawn by the slipstream 3 m towards a freight train, hitting the moving train and thrown across the platform into two passengers (Temple and Johnson, 2008). Knowledge of slipstream velocity and pressure magnitudes is therefore important in the authorisation of increased train speeds and development of new trains (Baker et al., 2013).

Concerns over the possibility of slipstream induced incidents have led to a number of studies into the effects of slipstreams,

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Notation

C_p	coefficient of pressure
N	number of independent runs undertaken to create the ensemble average
R	gas constant (J/kg K)
T_{room}	room temperature (K)
U	ensemble longitudinal component of slipstream velocity, normalised by train speed
V	ensemble lateral component of slipstream velocity, normalised by train speed
V_{train}	train speed (m/s)
W	ensemble vertical component of slipstream velocity, normalised by train speed
p_0	ambient pressure (Pa)
u	ensemble longitudinal component of slipstream velocity (m/s)
v	ensemble lateral component of slipstream velocity (m/s)
w	ensemble vertical component of slipstream velocity (m/s)
x	distance along the track measured from vehicle front (m)
y	distance normal to the track measured from the centre of the track (m)
z	distance in the vertical direction measured from the top of the rail (m)
ν	kinematic viscosity (m^2/s)
ρ	density of air (kg/m^3)

mainly for high speed passenger trains (Baker et al., 2001, 2013; Pope, 2006; Sterling et al., 2008). Results show the flow can be divided into a number of regions along the train – the upstream/nose region characterised by a velocity peak; the boundary layer region characterised by a boundary layer growth along the length of the train; a tail/near wake region shown to be highly turbulent with a series of shear layer separations or periodic longitudinal vortices and a far wake region exhibiting gradual decay of slipstream velocities. Individual results were shown to be highly variable, as the flow is dominated by large scale turbulent structures, thus the technique of ensemble averaging is required when studying train slipstreams (Sterling et al., 2008). Results from these and other studies have led to the development of the Technical Specifications for Interoperability (TSI); a series of laws on train aerodynamics giving limiting values for slipstream velocities, allowing for interoperability of trains across national boundaries in Europe (Technical Specifications for Interoperability. Commission, 2008). Although some freight research has been included in these studies, a thorough study of freight slipstream development and appropriate guidelines written in relation to rail freight is yet to be undertaken.

This paper will present and analyse the results of a series of experiments to assess slipstream development of a container freight train that were carried out as part of the first author's doctoral study (Soper, 2014). Results from a series of open air moving model-scale experiments undertaken at the University of Birmingham's TRAIN (TRansient Aerodynamic INvestigation) rig facility in Derby are presented and analysed. The experiment facility and model are described in Section 2.1. The adopted coordinate system and experiment methodology are discussed in Section 2.2. Section 2.3 introduces the measuring instrumentation and method of ensemble analysis. The experimental results and analysis are presented in Section 3 for coefficient of pressure (Section 3.1), normalised ensemble longitudinal component of velocity U (Section 3.2) and normalised ensemble lateral and vertical components of velocity V and W (Section 3.3). Section 4 presents a discussion of the various analysis techniques previously employed in high speed passenger train studies and the results when these methods were applied for freight slipstreams. Finally, Section 5 presents conclusions drawn in this model-scale study.

2. Experimental methodology

2.1. TRAIN rig and experiment model

The TRAIN rig is a purpose built testing facility for examining the transient aerodynamics of moving vehicles (Baker et al., 2001). It consists of three 150 m long tracks along which reduced scale vehicles can be propelled at speeds up to 75 m/s. The TRAIN rig offers the possibility to measure slipstream velocities, static pressure pulses and pressures acting on the train or trackside structures in a 12 m long open air test section (Baker et al., 2014). The effects of crosswinds at various yaw angles and ground simulations can also be modelled using a purpose built 6.35 m long crosswind generator (Dorigatti, 2013; Soper et al., 2014). A 23 m long tunnel is also installed for the measurement of vehicle aerodynamics in tunnel confines. The advantage of using a moving model rig over a typical stationary wind tunnel is the ability to correctly simulate relative motion between the vehicle and the ground/structures or crosswind simulation.

Models are accelerated using a pre-tensioned elastic bungee cord system, ensuring the rate of acceleration occurs very rapidly; thus the model is travelling at the specified testing speed within a 50 m firing section. Once in motion the model is free from any propulsion devices, allowing free motion with minimal constraints on model design. However, due to aerodynamic drag and friction, a small decrease in vehicle speed is created between the firing and braking section. For the models tested in this experimental campaign, an average speed decrease of 1 m/s^2 has been estimated for an average train speed of 20 m/s through the open air testing section. Following the 50 m test section, the model is decelerated using a friction device in a 50 m braking section. The firing, open air testing and brake zones are shown in Fig. 1.

A 1/25th scale moving model was developed to simulate container loading configurations seen at full-scale. Unlike focusing on a specific high speed passenger train, the term 'freight train' applies to many different train types (e.g. containers, tankers, mineral wagons etc.). For this study the term 'freight train' refers to a series of flatbed wagons loaded with International Shipping Organisation (ISO) standard shipping containers hauled by a Class 66 locomotive. Container freight is one of the largest sectors of freight transported in the UK and the choice for this study offers relative ease for modelling purposes. An existing Class 66 model was modified to include a long flat plate to simulate four/eight FEA type B flatbed wagons, with bogies modelled using balsa wood, shown in Fig. 2. The model is mounted on a specially designed chassis and trailing wheel system, designed to spread model weight out evenly, providing stability and a structure by which to fire/brake the model. The Class 66 model is mounted onto the chassis (Fig. 2a)), while four/eight (depending on model length) sets of trailing wheels are attached at varying distances along the flat plate (Fig. 2b)). The chassis and trailing wheels axle plate, onto which the wheel is mounted, extends below the radius of the wheel and the head of the rail to an L-shaped skid plate (Fig. 2b)),

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