Detached-eddy simulation of the slipstream of an operational freight train

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Abstract

With increasing train speeds the subsequent increase in slipstream velocities can have a detrimental effect on the safety of persons within a close proximity to the vehicle. The highly turbulent non-stationary slipstream of a model-scale Class 66 locomotive is investigated using delayed detached-eddy simulation (DES). Good agreement was seen between the present work and model-scale physical experiments. Slipstream velocities along the train side were investigated with the bogie region producing the highest slipstream velocities.

1 Introduction

The UK government aims to double the volume of cargo transported by freight trains on the UK rail network by 2030 (DFT, 2007). The increase in traffic volume on the network can be supported in several ways: building new lines, re-opening old lines, increasing train length or train speed. The first two options are expensive would take several years to complete. Route capacity could be increased by lengthening freight trains, although this could lead to slower moving trains congesting the already full lines. The final option of increasing the operational speed of freight trains would be a much simpler option to increase route capacity; though there are associated aerodynamic consequences.

When a train moves through the air it generates a slipstream that is characterised by a high-turbulent non-stationary region of air. To a static observer the slipstream appears as gradually-building gust punctuated with pulses of higher speed air. These air pulses are caused by gaps in the geometry of the vehicle and are generally much larger for freight trains than for passenger trains, therefore causing much larger pressure and velocity transients.

Slipstreams are recognised as posing a risk to the stability of persons and being capable of moving objects on platforms: an assessment of the risks posed by the slipstreams of freight and passenger trains was conducted by RSSB (Pope, 2006). The project collated previously collected slipstream data although due to a great deal of scatter in the data the drawing of solid conclusions was prevented.

The present work uses the open-source software, OpenFOAM (Open Foundation, 2012) to conduct a delayed detached-eddy simulation (DDES) in order to investigate the flow properties and behaviour of the slipstream of a 1/25th scale model freight train. The simulation is validated against the physical experiments of Soper et al., (2013) in order to elucidate the nature of the flow field around the freight train.

2 Model description

The freight train used in the present work is a 1/25th scale Class 66 locomotive with 4 fully-loaded FEA type B container wagons in tow; rails are also included in the simulation.

Figure 1: Comparison between train models used in the numerical and physical experiments

3 Computational domain and boundary conditions

The computational domain used in the present work is shown in Figure 2. The simulation replicates the relative movement between the train and the ground by specifying a no-slip moving-wall boundary condition for the ground plane and rails with the same velocity as the inlet. By holding the train in a fixed reference frame, the correct relative movement between the train and the ground is achieved without the need for complex methods such as sliding meshes.

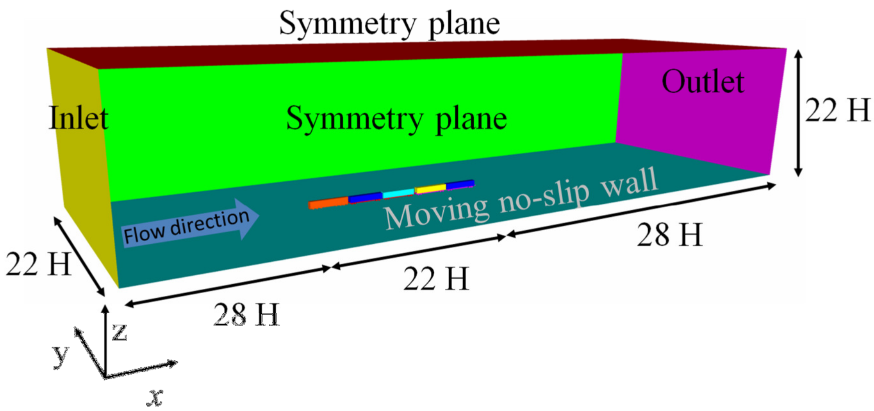

Figure 2: Computational domain and boundary conditions

4 Numerical schemes

The convection terms were discretised using a blended central differencing scheme with 5% upwinding to aid stability. Time integration was conducted using a second order backward implicit scheme and time steps were kept at $\Delta t = 3\text{x}10^{-6}$ s in order to prevent the maximum Courant number from exceeding 2. The high computational cost associated with such small time steps is compensated by the resolution of the high frequency/small-scale structures in the flow.

5 Computational mesh

The computational mesh used in the present work is an unstructured hexahedral grid. The entire computational mesh consisted of 38 million cells: 400,000 cells on each container wagon and 600,000 cells on the locomotive. The mesh is dominated by hexahedral cells but other polyhedral elements are also present due to the complexity of the geometry (Figure 3). The quality of the mesh was verified using mesh metrics within OpenFOAM and it was ensured that the maximum skewness of every cell was below 4 and maximum non-orthogonality was less than 60.

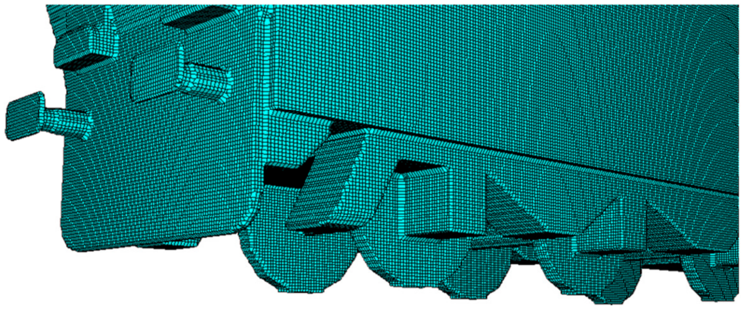

Figure 3: Surface mesh on the complex geometry of the Class 66 locomotive

6 Results

To ensure the validity of the numerical results a comparison was made to the experimental data. Comparison between the pressure and velocity for the physical and numerical experiments is seen in Figure 4, there is a good agreement with the experimental work. The poorest agreement for the slipstream velocity occurs in the latter half of the slipstream (x=60-100 m). It is unclear why the there is such a large discrepancy for x > 60 m, it is possible that it is due to minor differences in experimental procedures for the physical and numerical cases.

Upstream of the train (x<0 m) noise in the experimental velocity and pressure signals is observed. It is likely that this noise is a result of vibration in the experimental equipment.

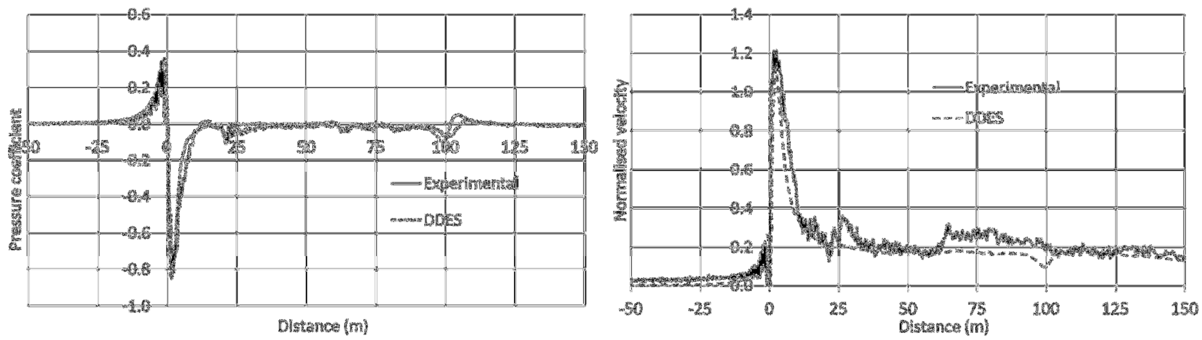

Figure 4 Time and ensemble-averaged pressure coefficients and u components of velocity at probe position 2 for the numerical and experimental results, respectively.

Figure 5 shows the variation of slipstream velocity magnitude at the side of the train. The maximum velocities in the slipstream are always observed near the train nose, x≈0 m. The blunt front of the Class 66 locomotive causes the flow to shear around the sharp corners and accelerate in much the same way that it would around any cuboid. The highest peak velocity is observed at z=2.0 m (i.e. at approximately mid-height of the locomotive) and is likely to be a consequence of the rear-sloped front of the locomotive causing the air to accelerate upwards thus increasing the vertical component of velocity.

The velocity transients in the slipstream are due to the presence of inter-wagon spacings. The spacing between the second and third wagon is the largest and hence it is responsible for the greatest velocity peaks (x=60 m) in the slipstream, after the nose peak. Similar, but smaller, peaks are observed at x=21 m, x=40 m and x=80 m and are due to inter-wagon gaps that are 1/3[rd] of the largest inter-wagon spacing.

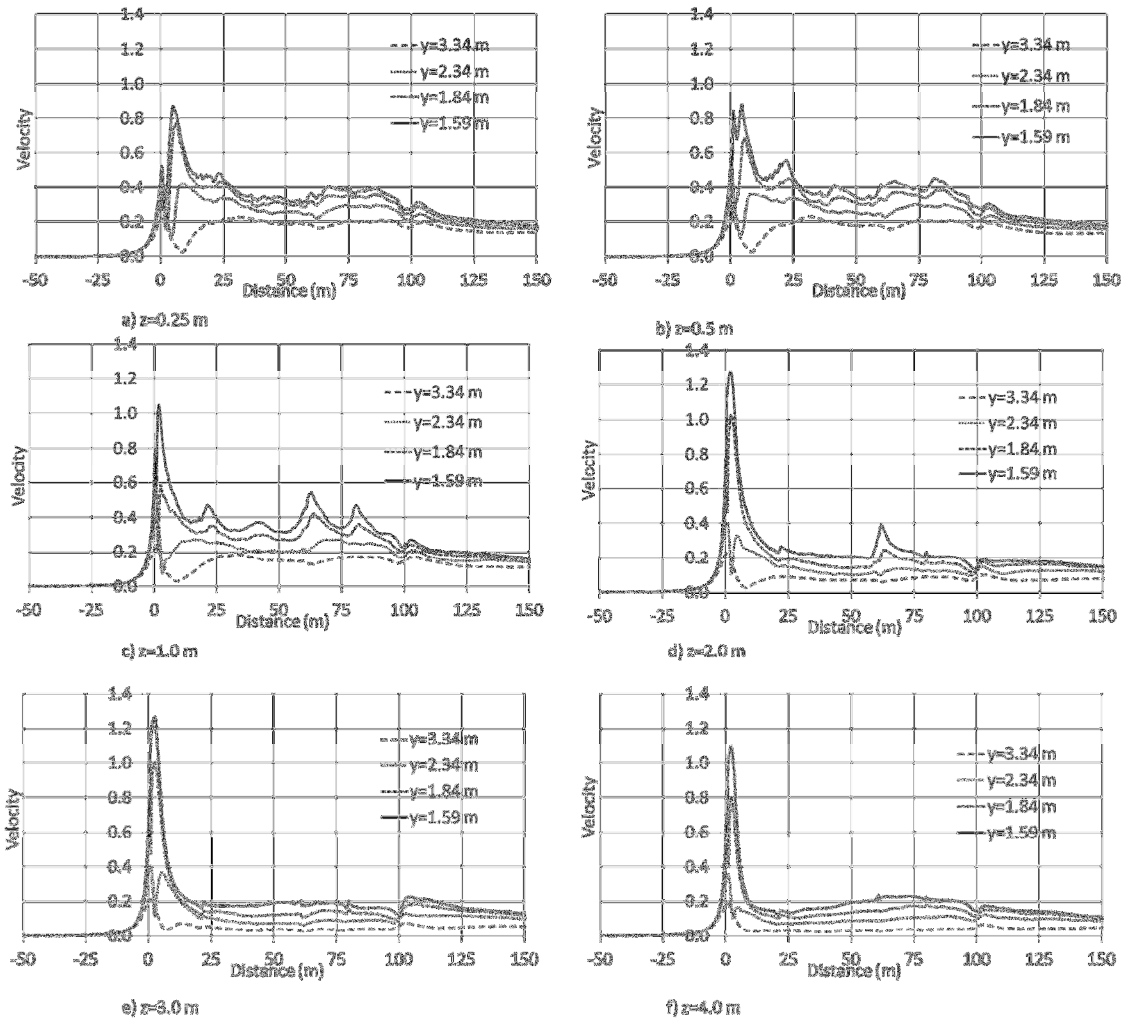

Figure 5: Normalised slipstream velocity magnitude at distances from the centre of track and at varying distances above top of rail (TOR) (a) z=0.25 m,(b) z=0.5 m, (c) z=1.0 m, (d) z=2.0 m, (e) z=3.0 m and (f) z=4.0 m.

An increase in slipstream velocity is observed at the top of the container wagons (Figure 5f). The increase in velocity is associated with a growth of the slipstream which has been shown to occur at full-scale (Sterling et al., 2008), although the present train is too small to determine how long it would continue to grow for.

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