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The aerodynamic characteristics of a tanker wagon

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Abstract

Aerodynamic flows associated with freight trains are highly turbulent and can have large pressure and velocity magnitudes. This potentially creates a risk to the public on platforms and trackside workers. This study presents results of an in-depth study conducted in collaboration with VTG Rail UK Ltd to understand the aerodynamic characteristics of a JPA type tanker wagon within a typical train formation. The aim of the project was to explore the aerodynamic characteristics of the tanker wagon with a view to considering potential design alterations to support the aerodynamic improvements in light of decarbonisation and safety requirements. The study utilised computational simulations and physical modelling, using the interplay between techniques to offer for the first time an in-depth characterisation of a tanker wagon. Results indicated that the slipstream boundary layer development is similar in growth and magnitude to a fully loaded container freight. The drag force on the tanker wagon exhibited a range of values depending on the wagon location in the train in relation to the lead locomotive. It was observed that the blunt Class 66 locomotive effectively shielded the first two wagons in the train from an aerodynamic perspective. The Class 66 locomotive has a very high drag coefficient in relation to wagons in the train formation; however, the addition of more wagons makes the overall influence of wagon design in the train formation important when considering drag effects. Through visualisation of flow features using the CFD results it was observed that the inter-wagon regions and bogies were the main sources of drag around the wagon.

Keywords: aerodynamics, freight train, drag, slipstream.

1 Introduction

Developments in the capabilities of rail freight, including increased freight speeds and larger, better connected rail networks, will enable greater competition between rail and road markets while having many environmental benefits. The British Government have recently set strategic aims to double the volume of cargo carried by rail by 2030, to which Network Rail have invested in detailed studies with a view to assessing opportunities to enable continued sector growth to 2043 and beyond. There is also an important requirement by law for the UK to decarbonise by 2050. Opportunities exist within the rail freight sector to make large strides toward achieving this goal.

Such potential has however been overshadowed by a series of high profile "near miss" incidents related to freight train aerodynamic flows as trains passed through stations – such as at Twyford where a wheelchair containing a disabled passenger was drawn into the side of a freight train, before rebounding leaving the passenger with only minor injuries. It is also becoming clear from recent experience that freight trains passing close to trackside infrastructure can cause significant pressure transient loading, resulting in fatigue failure. Aerodynamic flows associated with freight trains are highly turbulent and can have large pressure and velocity magnitudes. This potentially creates a risk to the public on platforms and trackside workers. Concern over these risks has led to fundamental studies to analyse flow development around different freight train configurations [1,2,3]. To date these studies have primarily focused on intermodal container freight trains, as typically these are the most common wagon type internationally. However, previous full-scale studies[4] have indicated that other wagon types, such as tanker wagons, hoppers or car-carrying wagons, may also cause highly turbulent boundary flows with velocity magnitudes that could potentially cause similar aerodynamics risks as observed for container freight.

This study presents the results of an in-depth study conducted in collaboration with VTG Rail UK Ltd to understand the aerodynamic characteristics of a JPA type tanker wagon within a typical train formation. The aim of the project was to explore the aerodynamic characteristics of the tanker wagon with a view to considering potential design alterations to support the aerodynamic improvement of this wagon in light of decarbonisation and safety requirements. The study utilised computational simulations and physical modelling, using the interplay between techniques to offer for the first time an in-depth characterisation of a tanker wagon.

2 Methods

This study utilised computational simulations to visualise the aerodynamic flow, as well as physical modelling experiments for thorough validation and detailed insight to flow patterns for slipstream and surface pressures.

Experiments were conducted at the University of Birmingham TRAIN rig, a purpose built testing facility for examining transient aerodynamics of moving vehicles[2]. 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 ground. A 1/25th scale Class 66 model was modified to include a long flat plate, simulating eight tanker wagons, onto which the bodies of the tanker, underbody sumps and bogies were mounted. All models were 3D printed using PLA from the CAD model utilised in the CFD, to enable small components to be modelled precisely. Figure 1 shows the experimental and CAD models. Slipstream velocities were measured using multi-hole pressure probes at a range of fundamental positions, as well as TSI equivalent positions. The 3rd and 6th wagons following the locomotive were fitted with onboard pressure monitoring systems to measure the surface pressure on these wagons at 106 positions per wagon.

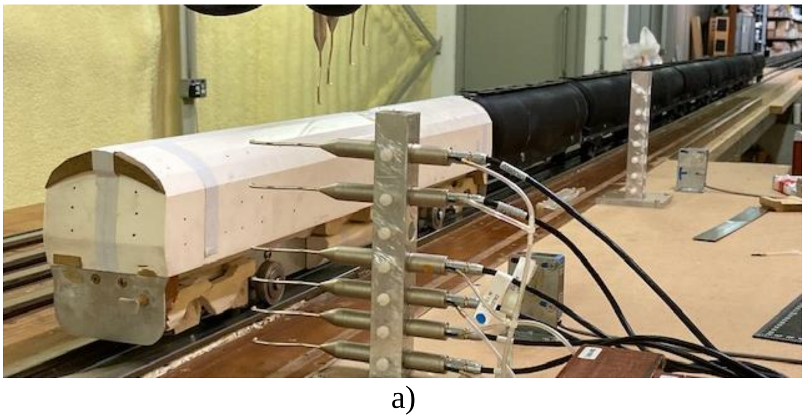
Computational Fluid Dynamics (CFD) simulations were conducted using RANS k-ω SST and DES techniques. The computational domain used in this work is sized as (28H+train length)×13H×7H in length, width and height respectively, where H = 0.156m, is the height of the train. The domain consisted of a velocity inlet placed at 8H upstream of the train nose while the zero-pressure outlet was placed 20H downstream of the train tail. A slip-wall boundary condition was set at the domain sides and the roof while a no-slip boundary condition is applied to the train surfaces. To replicate the relative movement between the train and the ground, a moving wall boundary condition was set for the ground as well as the rails, with the same velocity as the inlet flow (33.5 m/s). Coarse and fine meshes were created which consisted of 36 million and 43 million cells, respectively. A mesh sensitivity analysis was conducted to determine the effects of mesh density on the solution. Probe positions in the experimental study were replicated in the numerical simulations as well to determine overall forces. All results were aligned with the train nose passing at the origin, indicated by the point at which pressure crosses the x-axis between peaks created about the train nose. Aligned data was normalised with respect to train speed u_{train},

$$c_u(x) = \frac{u(x)}{u_{train}}, \qquad c_p(x) = \frac{p(x)-p_0}{0.5\rho u_{train}^2(x)} \tag{1}$$

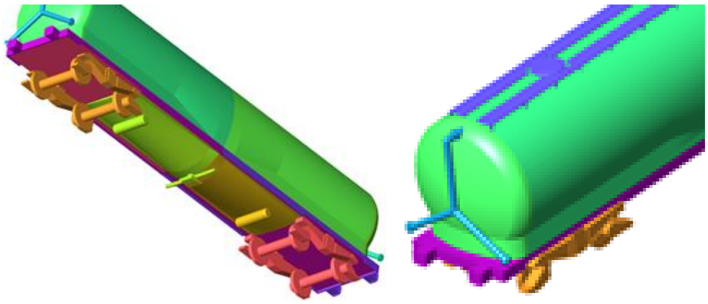
where p_0 denotes ambient pressure. Ensemble averages for normalised velocities and coefficient of pressure are created,

$$\bar{c}(x_k) = \frac{1}{n}\sum_{i=1}^{n} c_i(x_k) \tag{2}$$

where n denotes the ensemble size per x-position.



a)

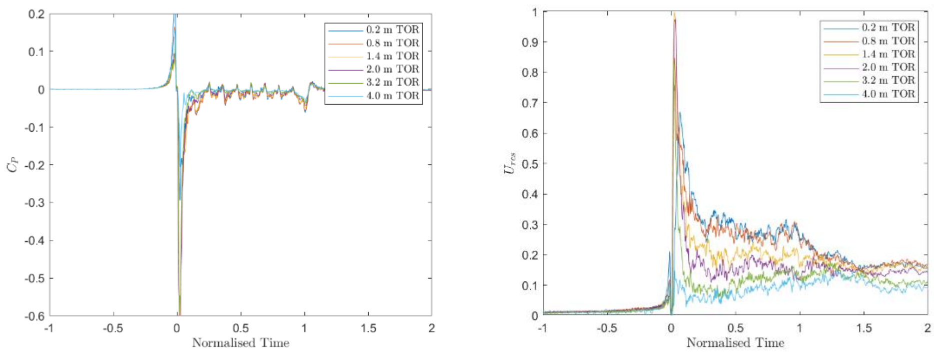


b)

Figure 1: The experimental and CAD models adopted. The complete train is a Class 66 locomotive and 8 JPA tanker wagons.

3 Results

The results focused on characterising the aerodynamic flow development around the tanker wagon, as well as assessing the surface pressure and forces on the wagon itself. Figure 2 illustrates ensemble total horizontal slipstream velocities and the coefficient of pressure measured for increasing heights above top of rail for a position of 2 m from the centre of track. As observed in previous studies, the flow can be broken into a number of characteristic regions about the train nose, boundary layer, tail and wake[4]. When compared to previous freight studies it can be seen that this type of flow development is similar to a fully loaded container freight train, although peak magnitudes are higher due to larger inter-wagon gaps[2].



a) b)

Figure 2: Ensemble coefficient of pressure (a) and total horizontal slipstream velocities (b) measured for increasing heights above top of rail for a position of 2 m from the centre of track.

Values of turbulence intensity are highest in the bogie and underbody regions, due to the unshielded nature of these features, whereas the relatively aerodynamically shaped tankers induce a less turbulent boundary layer, as shown in figure 3.

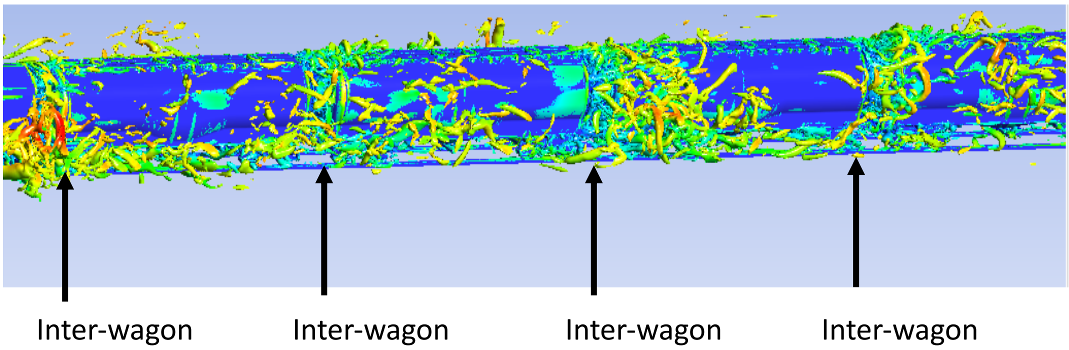


Figure 3: Iso-surfaces of the second invariant of the velocity gradient, Q = 200,000, showing locations of vortex generation, coloured by velocity.

The surface pressures were used to validate the CFD simulations, which in turn were able to provide an understanding of drag coefficients associated to this wagon design, as shown in table 1. Firstly, the locomotive has a very high drag value, associated with the highly bluff nature of this vehicle. The drag values for the wagons are initially very low, before increasing to a stable value towards the rear of the train, with the final wagon having the highest value. It is clear that the bluff locomotive is aerodynamically shielding the first 2 or 3 wagons, before the true drag value for the wagon in a train consist is realised. The final wagon has a higher drag value due to flow separation from the unshielded end of the train. This highlights the importance of correctly modelling a sufficiently long train to enable a full aerodynamic characterisation. From the simulations it was seen that pressure drag is dominant over viscous drag and that visualisation of the flow structures indicated the inter-wagon regions and bogies were the main sources of drag around the wagon.

Table 1: A table of drag coefficients for the Class 66 hauled JPA tanker wagon train.

Part	Drag Force Coefficient
Total train	1.883
Locomotive	0.678
1st Wagon	0.055
2nd Wagon	0.114
3rd Wagon	0.127
4th Wagon	0.159
5th Wagon	0.171
6th Wagon	0.154
7th Wagon	0.168
8th Wagon	0.257

4 Conclusions and Contributions

This study has for the first time, through the synergy of experimental and computational techniques, provided a detailed characterisation of the aerodynamic properties associated to freight tanker wagons. The following important conclusions can be drawn on the results from this research:

- The slipstream boundary layer development is similar in growth and magnitude to that of a fully loaded container freight as previously observed.
- The drag force on the tanker wagon exhibited a range of values depending on the wagon location in the train in relation to the lead locomotive.
- The blunt Class 66 locomotive effectively shielded the first two wagons in the train from an aerodynamic perspective.
- The Class 66 has a very high drag coefficient in relation to wagons in the train formation; however, the addition of more wagons makes the overall influence of wagon design in the train formation important when considering drag effects.
- Pressure drag is dominant over viscous drag for the simulations conducted.
- Drag values and visualisation of the flow structures indicated the inter-wagon regions and bogies were the main sources of drag around the wagon.

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