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Effect of separation bubbles around the head of a freight train on pressure waves inside tunnels using 1d and 3d numerical methods

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Abstract

The bluff nature of freight train will influence the pressure wave pattern generated by it passing through a tunnel. This paper aims to investigate the effect of separation bubble induced by the blunted head of a freight train on pressure waves, and model it into a redeveloped 1-d code. Firstly 3d simulations have been done to and assess the capability of RANS to predict the development of the separation bubble. The results shows that SST k-ω RANS gives a reasonable predication of the shape and height the of separation bubble. Then this model is adopted to conduct a simulation of a freight train enter into a tunnel, from which the result is used as the input of the 1d code. Besides, the 1-d code is redeveloped to consider the effect of gradual cross-sectional area change of the train body. The result shows that the traditional 1d code failed to predict the maximum initial pressure rise caused by the separation bubble. After modification, this issue is greatly improved.

Keywords: freight train, tunnel, train aerodynamics, pressure wave.

1 Introduction

The UK government aim to double the volume of rail freight cargo on the UK rail network by 2030. Opportunities highlighted to achieve this aim include the introduction of dedicated high speed freight, however, increasing train speed causes a series of aerodynamic problems. For example, the amplitude of the pressure change increases approximately proportional to square of train speed. Furthermore aerodynamic problems are more obvious when the train is running in confined space, such as a tunnel. Though numerous studies have been conducted to consider the aerodynamics of trains in tunnels, the majority have purely focused on passenger trains due to the speed at which these vehicles travel. There are however aerodynamic issues that need to be considered for freight trains passing through a tunnel due to the bluff nature of these vehicles.

As the train head enters into a tunnel, the nose of the train pushes the air ahead of it and generates a compression wave that propagates to the tunnel exit with the speed of sound. This compression wave leads to a sudden pressure rise where it passes. For a freight train, the separation bubble induced by the blunted head will increase the effective blockage ratio, and further notably increase the magnitude of initial pressure rise[1]. This has lasting impact on the subsequent pressure changes as the pressure wave propagates inside tunnel.

With the improvement of computing ability, massive simulations can be undertaken using commercial software to achieve a better knowledge of the flow field when trains pass through tunnels [2]. However, the simulation of a moving train is very computationally expensive and time consuming. Since the length of tunnel is much larger than the diameter of tunnel section, the pressure fluctuation over a certain cross section of the tunnel could be neglected compared to its variation with time [3]. Therefore many researchers have developed 1d programmes to calculate a quick solution of the pressure variation in tunnel [4][5][6]. Compared to 3d simulations, that can take days/months to simulate a train passing through a tunnel, it may only take seconds or minutes for a 1d code to obtain a fairly accurate result of the pressure variations, which is very useful for the initial design of new trains and/or tunnels. However, the pressure change caused by the separation bubble at the train head is not able to be predicted in traditional 1d methods. To overcome these problems, we aim to build an improved 1d flow model that is capable of predicting the pressure wave generated by freight trains passing through a tunnel.

2 Methods

The pressure wave pattern induced by a freight train entering a tunnel is numerically studied using 3d and 1d methods. The commercial software Fluent is used to solve the flow field around the freight train. Since the prediction of the separation bubble is very sensitive to mesh, and the subsequently the development of the numerical model chosen, the whole computational domain is divided by structured mesh to increase the mesh quality with an estimated $y+\approx 5$. In this work both LES and SST k- ω RANS models are adopted to visualize the flow field and assess the capability of RANS to predict the development of the separation bubble. A sliding mesh method is used to simulate the relative motion between the train and the tunnel. Using this method, the whole computational domain is composed by a stationary region that contains the tunnel and a sliding mesh region that contains the freight train and moves in the longitudinal direction with train speed. The computational domain and boundary conditions are illustrated in Figure 1.

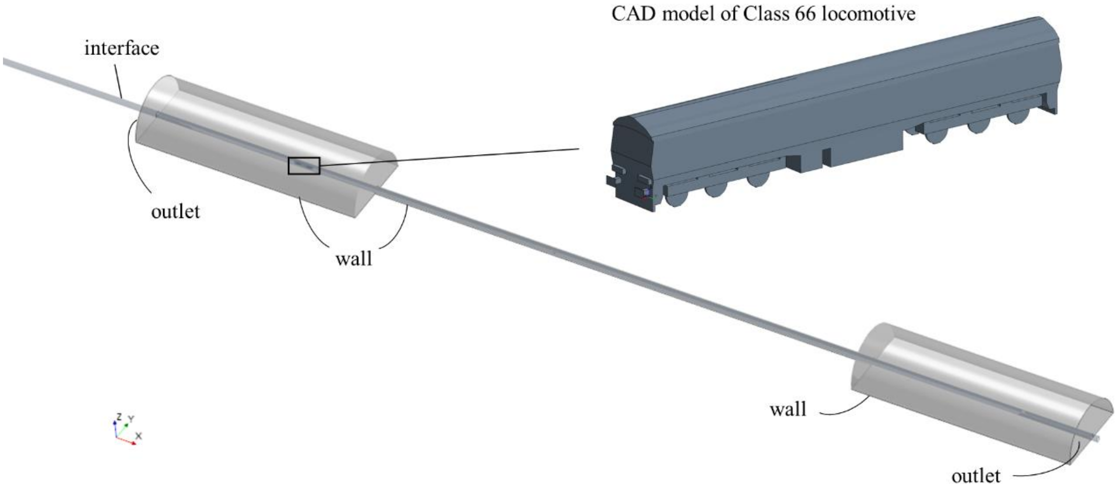


Figure 1 Computational domain and boundary conditions

The 1d method is developed from an in-house code, which adopts an unsteady, compressible, non-homentropic flow model solved by MOC method. This method is validated by previous research with full-scale experiment data, suggesting that the numerical method can predict temperature, velocity and pressure variations accurately, and therefore be commonly adopted by researchers to build into computer programs[3][7]. In this model, the heat transfer and friction effect between air and train/tunnel walls are considered, and the air inside tunnel is modelled as ideal-gas. More details of solving the characteristic variables using MOC method are introduced in Benson & Whitehouse. A mesh is divided into several separated ducts by train ends and tunnel portals. The whole process of train entering the tunnel is composed by three phases due to the different expanding and contracting mesh in each phases. The boundaries at tunnel portals and moving train ends need to be calculated separately by flow equations in conjunction with the characteristic equation. These equations are solved using Newton-Raphson method.

3 Results

The result obtained from LES and RANS is shown in Figure 2. The streamline in Figure 2 (a) is calculated using mean *u* and *w* and the surface of the train is coloured by mean x-wall shear stress, which reflect the separation and reattachment points. It can be seen that RANS is capable of simulate the height of the separation bubble but tends to overpredict the length of the bubble. Overall SST k-ω RANS gives a reasonable predication of the shape of separation bubble therefore is adopted to simulate the freight train passing through a tunnel.

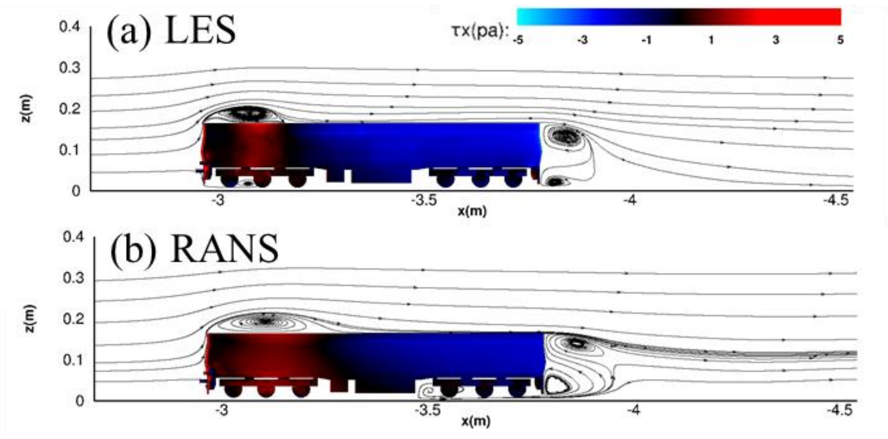


Figure 2 Comparison of the separation bubble at top of the freight train predicted by LES and RANS

Figure 3(a) shows the streamline around the blunted train head at different contours when the freight train is inside the tunnel. The result obtained from the simulation is used to describe the shape of separation bubble in the 1d code. The shape of the bubble is simplified as sin functions as illustrated in Figure 3(b). E' is the effective cross sectional area = E_{train} + E_{bubble}. Therefore after extract the E'_{max} from the simulation, the radius of separation bubble r_b could be obtained from $E'_{max}=\pi(r_t+r_b)^2$. $l_b/2$ is the x-coordinate of the maximum effective cross sectional area. In order to consider the effect of gradual cross-sectional area change of the train body in the 1d code, an additional term $\frac{\rho u}{E'}\frac{dE'}{dx}$ is added in the continuity equation.

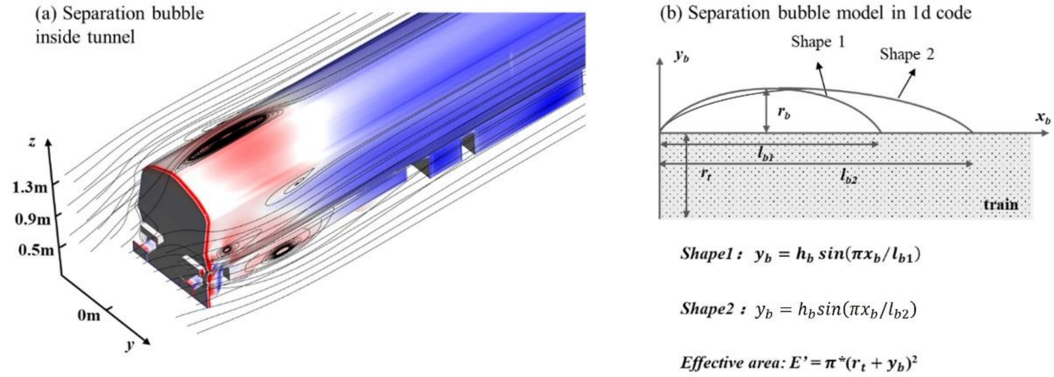
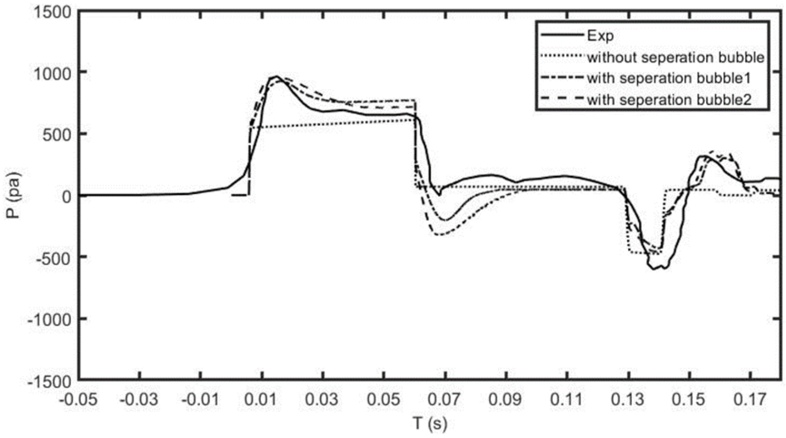
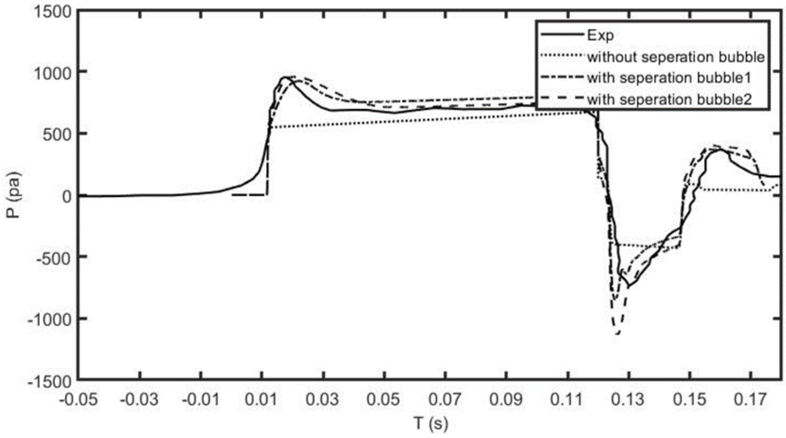


Figure 3 Separation bubble at blunted train head inside tunnel

The pressure variation at different measuring points inside tunnel predicted by with and without consideration of the separation bubble in the 1d code, and is compared with experimental results of a full-length freight train entering the tunnel. It can be seen that the maximum pressure rise calculated by the 1d code without considering the separation bubble is 528 pa, resulting in an error of 45% comparing to that obtained from the experiment. By adding the influence of separation bubble, the error is reduced to 4%. Furthermore, the subsequent pressure change caused by the pressure wave propagation is also well predicted.



(a) 2m to tunnel portal



(b) 4m to tunnel portal

Fig4 Comparison of pressure history curve obtained from 1-d result and experiment

4 Conclusions and Contributions

As a freight train enters into a tunnel, the separation bubble induced by the blunted head of freight train will increase the effective blockage ratio, and further influence the initial pressure rise. This phenomenon is numerically studied in this paper, and then modelled in a redeveloped 1d code. Firstly, 3d numerical simulations are carried out to visualize the flow separation around the blunted train nose. The result obtained from the simulation is adopted to calculate the input for the 1d code. A model is built to describe the shape of the separation bubble and enable the 1d code to accurately simulate the gradually changing cross-sectional area of the train body.
The development of pressure waves calculated before and after modification on the code is compared with experiment results in previous work. Results indicate that the traditional 1d code failed to predict the maximum initial pressure rise. This issue is greatly improved after considering the influence of the separation bubble. For next step the 1d code is going to be further developed to consider the influence of loading configurations of a freight train on pressure waves.

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References

[1] lliadis, P., Hemida, H. & Soper, D., 2019. Numerical simulations of the separated flow around a freight train passing through a tunnel using the sliding mesh technique. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit,* 237(8), pp. 857-868

[2] Ogawa, T., & Fujii, K., 1997. Numerical investigation of three-dimensional compressible flows induced by a train moving into a tunnel. *Computers & Fluids*, *26*(6), 565-585.;

[3] Woods, W. & Pope, C., 1981. A generalised flow prediction method for the unsteady flow generated by a train in a single-track tunnel. *Journal of Wind Engineering and Industrial Aerodynamics*, 7(3), pp. 331-360.L

[4] William-Louis, . M. & Grégoire, . R., 2002. 1-D calculations of pressure fluctuations outside and inside a pressure sealed high-speed trainset travelling through tunnels. *In: TRANSAERO—A European Initiative on Transient Aerodynamics for Railway System Optimisation*. Berlin, Heidelberg: Springer, pp. 342-357.L

[5] Vardy, A. & Reinke, P., 1999. Estimation of train resistance coefficients in tunnels from measurements during routine operation. Proceedings of the Institution of Mechanical. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit,* 213(2), pp. 71-87L

[6] Fox, J. & Henson, D., 1971. THE PREDICTION OF THE MAGNITUDES OF PRESSURE TRANSIENTS GENERATED BY A TRAIN ENTERING A SINGLE TUNNEL. *Proceedings of the Institution of Civil Engineers,* 49(1), pp. 53-69.

[7] Mei, Y., 2013. A generalized numerical simulation method for pressure waves generated by high-speed trains passing through tunnels. *Advances in Structural Engineering,* 16(8), pp. 1427-1436.