Study on the Influence of Blocking Ratio on Slipstream in Tunnel

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ABSTRACT

When a train moves through air, it generates a turbulent flow around it called a slipstream. The slipstream is associated with high air velocities and rapidly-changing pressure fields. The air velocity, pressure variation and direction of the flow inside tunnels are different than the slipstream in open air. These differences depend on the size of the tunnel and length of the tunnel and the shape and speed and length of the train.

In the present paper, the effect of tunnel length on the velocity flow and pressure inside is investigated. The investigation uses computational fluid dynamics techniques (CFD), in which a model of the CRH380A train is used. Two tunnel lengths are also investigated; one is 200m called case 1 and the other is 400m called case 2. The sliding mesh technique is employed to simulate the movement of the train in the tunnel. The simulation uses unsteady RANS and applies the Shear Stress Transport (SST) turbulence model. The effect of tunnel length on both pressure and velocity fields is discussed.

Keywords: slipstream; tunnel length; high-speed train; SST

1. INTRODUCTION

Flow around high speed trains has received considerable attention from researchers in the last three decades[1][4]. Investigations have been performed using
different experimental and computational techniques, including full-scale\textsuperscript{[6]}, physical modelling \textsuperscript{[6][7]} and numerical simulations\textsuperscript{[2][3][5][9]}. With the increasing speed of the train, the aerodynamics of train has become a big issue for both train operators and train manufacturers. When a train is running at high speed, it will generate several regions of highly turbulent flow due to the viscosity of air around the train known as slipstream\textsuperscript{[8][10]}. Slipstream is often accompanied by drastic changes in velocity speed and direction and pressure.

Velocity, pressure variation and direction of the flow inside tunnels are different than those around a train in open air\textsuperscript{[11][12][13]}. These differences can be related to the cross section and the length of the tunnel. Therefore, the focus of this thesis is to investigate the effect of the blocking ratio on the pressure variation and the velocity around a high-speed train in a single-track tunnel.

2. NUMERICAL MODELING

2.1 Train and tunnel geometries

The main train model used in this study is the CRH380A train. The length and cross sectional dimensions of the idealized CRH380A train model are shown in Figure 1. The tunnel used in the CRH380A train simulations is of rectangular cross section with no portal at the entrance or exit. Figure 2 shows the shape of the tunnel section in the numerical simulation. Simultaneously, Table 1 shows the calculating conditions of different tunnel lengths.

![Figure 1. Geometrical illustration of the train.](image1.png)

![Figure 2. Geometrical illustration of the single-line tunnel.](image2.png)
2.2 Mesh and numerical details

The commercial software STAR-CCM+ has created all the meshes in this work. Polyhedral meshes were used in all the domains; moving and stationary. The same mesh strategy has been used for all the meshes, in which the mesh is concentrated around the train and in the wake region. However, the stretching ratio kept less than 1.2 everywhere. Figure 3 shows the mesh distribution around the train and tunnel portal. The governing equations of unsteady, compressible flow are mass conservation equation and Reynolds-averaged Navier–Stokes equations. The Shear Stress Transport (SST) turbulence model is used for turbulence closure: the model is based on the Boussinesq hypothesis with transport equations for turbulent kinetic energy and its dissipation rate.

Convection terms are discretized using the second-order accurate upwind scheme, whilst the diffusion terms are discretized using the second-order accurate central differencing scheme. For unsteady flow calculations, time derivative terms are discretized using the fully implicit backward scheme. The velocity–pressure coupling and overall solution procedure are based on SIMPLEC algorithm.

The methodology adopted here consists in subdividing the domain into two (non-overlapping) sub-domains. The first one (sliding domain part) contains the train and can be set in motion whose speed is the train speed \( V_{\text{train}} \), as shown on Figure 4. The second domain encapsulates the first one. It contains walls of the tunnel and the external domain. With this approach, there is no need to the mesh and the length of the sliding domain can be kept constant. The grid generator relies directly on an octree structure. The boundary cells are truncated and a merging procedure allows one to avoid the convergence problem caused by small cells. Both sub-domains are connected to each other at common interfaces where a reconstruction of the cells faces is made on each side to preserve the conservative properties of the numerical scheme.

![Figure 3. Surface mesh distributions on the train model and tunnel portal.](image-url)
3. RESULTS AND DISCUSSION

Figure 5 and Figure 6 show the positions of the monitoring points.

![Figure 5](image1.png)

(a) Tunnel length 200m  
(b) Tunnel length 400m  
Figure 5. The positions of monitoring points along the tunnel.

![Figure 6](image2.png)

Figure 6. The positions of p2, p3, p4, p5, p6 and p7 monitoring points.

Figure 7 shows the Cd history of the train, Fx1, Fx2, Fx3 is the drag of head car, middle car and tail car respectively. As can be seen from the Figure 7, the drag of head car and middle car increases instantaneously when the train runs into the tunnel and decreases instantaneously when the train runs out of the tunnel. And the change of drag of the tail is reverse. When the train runs in open air, the coefficient of drag of
the head car, middle car and tail car is respectively 0.14, 0.10 and 0.10 which are consistent with the wind tunnel experimental.

![Figure 7. The Cd history of train.](image)

### 3.1 Slipstreams in the tunnel

Figure 8 shows the histories of the velocity magnitude and three velocity components at points P5, P6 and P7, shown in Figure 5 and Figure 6. When the train approaches the point’s velocity magnitude and velocity component are measured, the velocity magnitude is about 14% of the train velocity when the head of the train arrives at the section of the monitoring points. The maximum velocity magnitude always occurs near the wake. It can be seen also from Figure 8 that in the wake flow, point P7 has the maximum velocity followed by point P5 and then P6. This is because P7 is close to the ground and in this region the flow is affected by the underbody complexities. Also P5 is close to the train surface and is influenced by the train. We can get that the location of the maximum velocity magnitude is different at different monitoring points, the maximum velocity magnitude of P6 and P7 occurs 8H behind the train tail, while P5 occurs 5H behind the train tail. It is also concluded that the velocity magnitude of the same point in case 1 is larger than that in case 2, because the smaller blocking ratio can compress air and result in larger slipstreams. Figure 8(b) shows that the longitudinal velocity component is negative at the three points and the point P6 is the closest to the train surface, the velocity is affected by the boundary layer region of the train slipstream and thus has less reversed flow than the other two furthest points. In the near wake region, the maximum velocity magnitude and the longitudinal velocity component have the same trend and value. Figure 8(c) and Figure 8(d) show the history of the span-wise and vertical velocity components at the three points. It can be seen that these two components have zero velocity before the train head approaches the section of the monitoring points. There are some changes in these two components when the train head and tail passes but the magnitude of these components is very small in comparison to the longitudinal velocity component. When the train nose arrives at the measuring point, the span-wise velocity direction is away from the track, when the train tail arrives at the measuring point, the span-wise velocity direction of P7 is away the track while the span-wise velocity direction of P5 and P6 is toward the track.
Figure 8. Velocity histories at the monitoring points P5, P6 and P7 in side.

Figure 9 shows the histories of the velocity magnitude and three velocity components at points P2, P3 and P4, shown in Figure 5 and Figure 6. As can be seen that the tunnel length only influences the velocity in the space in front of the train in the tunnel and the annular space between the train and the tunnel, has little effect on the velocity in the space behind the train tail because of the space is the same.

In front of the train, the velocity magnitude and the longitudinal velocity component in case 1 are larger than that of the case 2, meanwhile the direction of the velocity magnitude and the longitudinal velocity component is the same as the direction of the train. In the annular space between the train and the tunnel, the velocity magnitude and the longitudinal velocity component in case 1 are smaller than that of the case 2, meanwhile the direction of the velocity magnitude is the same as the direction of the train while the direction of the longitudinal velocity component is opposite to the direction of the train. More obvious phenomenon is that the longitudinal velocity component of P2 changes from negative to positive because P2 is submerged in the boundary layer with the train running.
Figure 9. Velocity histories at the monitoring points P5, P6 and P7 in top.

Figure 11 shows the profiles of the velocity component in the direction of travel at the sections shown in Figure 10. In section 1, it can be seen that the longitudinal velocity component in case 1 is 0.08 relative the train velocity while it is 0.04 relative the train velocity in case 2. The air around the train at sections 2, 3 and 4 has negative velocity components except the small slipstream region and the negative velocity components in case 1 about is 0.1 relative to the train speed while 0.15 relative to the train in case 2.

Figure 10. Showing the distance of five sections from the tunnel entrance, symmetry plane coloured by the velocity component.
3.2 Pressure in the tunnel

The static pressure inside the tunnel was monitored during the simulation at different points. The location of the specific monitoring points as shown Figure 5 and Figure 6. Figure 12 shows the history of the static pressures as a function of the distance between the train nose and the tunnel entrance. The point in tunnel entrance experiences a sudden increase when the train nose enters tunnel and a sudden decrease when the train tail enters tunnel. The point in tunnel exit experiences a sudden decrease when the train nose leaves tunnel and a sudden increase when the train tail leaves tunnel. We can get that the tunnel length have almost no influence on the pressure change on points in tunnel entrance and exit.
In general, there is a sudden increase in the pressure in the tunnel when the train enters and when the train nose leaves the tunnel. A sudden decrease in the tunnel pressure occurs when the tail of the train enters the tunnel and when the train nose passes. The monitoring points located in the same distance from the tunnel entrance in different tunnel length experience the same change trend but different specific value. When the train noses enters tunnel, the point in longer tunnel have higher pressure than in shorter tunnel, when the train noses leaves the tunnel, the point in longer tunnel have lower pressure than in shorter tunnel.

4. CONCLUSION

Simulations of a train moving through short and long tunnels are conducted to study the influence of tunnel length on slipstream in tunnel, the sliding technique method is enough to simulate the relative motion between the train and the tunnel.

- The drag of head car and middle car increases instantaneously when the train run into the tunnel and decreases instantaneously when the train run out of the tunnel. And the change of drag of the tail is reverse.
- Tunnel length mainly influence the velocity in the space in front of the train in the tunnel and the annular space between the train and the tunnel, has little effect on the velocity in the space behind the train tail Lower velocities are observed ahead of the train in longer tunnels and the revered flow also has higher velocity.
- We can get that the tunnel length have almost no influence on the pressure change on points in tunnel entrance and exit.
- In general, there is a sudden increase in the pressure in the tunnel when the train enters and when the train nose leaves the tunnel. A sudden decrease in the tunnel pressure occurs when the tail of the train enters the tunnel and when the train nose passes.
- Similar flow structures have been obtained in the wake flow in both the short and long tunnels.
REFERENCES