QUALITATIVE INVESTIGATION OF THE MAIN FLOW FEATURES OVER A TGV

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Abstract: In this paper, we present the results of a preliminary investigation of the flow features encountered over a TGV. As a matter of fact, it is the first step in a more detailed analysis which is necessary in the perspective of future flow control experiments. The experimental investigation has been carried out in a low-speed hydrodynamic channel with a small-scale model. The consequence is that the Reynolds number based on the length $L$ of the model is relatively low ($Re_L = 1.26 \times 10^5$) compared to the full-scale aerodynamic Reynolds number ($Re_L = 10^9$) so that the results can only be used as qualitative tools to illustrate the main features encountered in the flow over a TGV. Particle Image Velocimetry (PIV) and Laser Induced Fluorescence (LIF) visualizations were carried out in most of the critical regions over a TGV: the front nose, the pantograph cavity, the spacings between the coaches and the rear part of the model.

Clearly some common features can be found with the flow over a road vehicle. For instance, both LIF and PIV show the strong vortex shedding, the large recirculation bubble and the large counter-rotating vortices created over the rear part of the model, very similar to a Ahmed body with a $25^\circ$ rear slant. The flow over the flat panels of the coaches constituting the TVG is also more complex than expected because of the perturbations induced by the pantograph cavities and the deep cavity between the coaches. Finally, a synthesis is proposed pointing out the most critical areas in a perspective of flow control for drag reduction.
1 INTRODUCTION

The flow around a high speed train is a challenge to the fluid mechanics community. While the use of experimental techniques on an operating vehicle only gives partial information on the flow, both reduced-model and numerical based investigations are confronted with the problems of the high Reynolds and Mach numbers. A full length and fully detailed numerical simulation of the unsteady flow at a Reynolds number around $10^8$ stays out of reach or at a prohibitive cost. The reduced model studies seems to have found a good compromise with a few coaches at $1:7$ scale ratio in a wind tunnel at $40m.s^{-1}$ [5]. Nevertheless the cost of the studies in a wind tunnel large enough to allow this kind of model with the ability to simulate the moving ground and the boundary layer is still heavy. In this study we present qualitative results obtained on a $1:127$ small-scale model in a hydrodynamic channel. The Reynolds number reached based on the model length $L$ is $Re_L = 1.26 \times 10^5$.

2 EXPERIMENTAL SET-UP

2.1 THE HYDRODYNAMIC TUNNEL

The experiments have been carried in the PMMH low-speed hydrodynamic tunnel. The flow inside the hydrodynamic tunnel used (Fig. 1) is gravity driven thanks to a reservoir whose water level is kept constant. The height between the reservoir and the point of return to ambient pressure is three meters. The tunnel can be used either in open flow for ink visualisation or closed flow for PIV measurements. A steady laminar incoming flow is obtained through the combinaison of a slow diverging section followed by two honeycombs and a short converging section. The test area is a rectangular section of $150 \times 100mm^2$ over a length of $800mm$. Note that the channel is fully plexyglas which allows optical access from all side, especially in the axis of flow from downstream. Below the test zone is a submerged area used to install the dye injection lines other equipment. The speed of the flow in the configuration used is $15cm.s^{-1}$. 

![Figure 1: Scheme of the hydrodynamic tunnel with the model placed in the test section.](image)
2.2 THE SMALL-SCALE MODEL

The model is a toy in 1 : 127 scale made up of two nose or tail coaches and two middle coaches of a TGV-PSE (see Fig. 2). The model has a total length of $L = 630\text{mm}$ for a height of $h = 31\text{mm}$ and a width of $l = 23\text{mm}$. The intercoach space are $2\text{mm}$ long. The model is positioned on rails which themselves are set on a plate for $900\text{mm}$ long plate. This boundary layer plate is a flat plate at both ends bevelled and placed at a $20\text{mm}$ to cut the previous boundary layer of the channel with a thickness around ten millimeters. Thus, a new boundary layer is at the leading edge of the boundary layer plate which results in a boundary layer thickness as low as possible. An engine coach was hollowed, equipped with a mouthpiece for the admission of dye and holes of $0.5\text{mm}$ have been placed on the hull. Thus it is possible to fill the coach with dye have the near wall area of the train seeded. In addition the intercoach spaces are equipped with dye injectors. It is possible to reverse the model in order to have either the front or rear coach equipped with wall injection of dye. The Reynolds number for a velocity of $U_\infty = 15\text{cm.s}^{-1}$ and a total length of $L = 630\text{mm}$ is $1.26 \times 10^5$. The pantographs could only be kept in lowered position.

2.3 LIF AND PIV EQUIPPEMENT

The visualisation have been obtained through Laser Induced Fluorescence. The fluorescent dyes used are the rhodamine-B or fluorescein. The volume visualisations are obtained either with ambient light or a UV punctual source. The plane visualisations are achieved with plane laser sheets issued from argon or YaG continuous lasers. Image acquisition is achieved with a numeric reflex camera or a numeric camcorder. Two PIV set-ups are available. The first one is made of a $2 \times 15\text{mJ}$ pulsed laser and a double framed camera with a $1600 \times 1200$ resolution.
and can achieve a $15\,Hz$ acquisition rate. The second one is a homemade time resolved PIV system made of a $2\,W$ YaG continuous laser and a high-speed Phantom Camera which allows an acquisition rate up to $1\,KHz$. Both these configurations allow the measurement of the two velocities component in the plane defined by the laser sheet and the object focus plane of the camera.

3 FLOW VISUALISATIONS AND PIV

This configuration is quite far away from the canons of the reduced model high-speed train tests [5]. In particular there is a $10^3$ factor on the Reynolds number, the flow can be considered as incompressible, the incoming boundary layer is hardly simulated and the wall is not moving. Despite these facts we managed to identify some of the known salient features of the flow around a high-speed train.

3.1 Front coach and longitudinal structures

On the visualisations is observed that the dye wraps around the side edges of the front engine coach (Fig. 3a) and show vortical structures that raise to the roof. Downstream we find their traces in the laser cross section (Fig. 3b). As the position of the laser cross section is moved further downstream the flow has to deal with pantograph cavities and intercoach spaces and more streamwise vortical strucures are present with a strong unsteady behaviour. The mean

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**Figure 3**: Photographs of the flow around the front coach of the model. The swirl of the dye lines shows the existence of pillar vortices on the nose coach edges (a). The cross section plane at the end of the first coach shows the existence of longitudinal vortices on the roof (b), (c) (d)
velocity field in the symmetry plane of the front coach (Fig. 3c) shows a deceleration of the flow at the nose and an acceleration at the beginning of the roof. Numerical simulations with RANS modelisation of the turbulence[4] shows the same qualitative behavior (Fig. 3d).

3.2 Pantograph cavity

As it was not possible to raise the pantograph on the model, the flow downstream the rear coach is very different from the case of a high-speed TGV. However, the visualisations showed in Fig. 4 allow to see the reverse flow that occurs in these cavities. We can also observe the separation experienced by the flow on the roof downstream the cavity.

3.3 Wake

At the exception of the recirculation bubble that is attached to the wall, all the structures expected in the wake of a high speed train are shown in Fig. 5. We can clearly observe the instable shear layer due to boundary layer separation at the roof end on Fig. 5a and c. Due to the absence of reproduction of the moving ground the recirculation bubble observed on the Fig. 5c is attached to the ground while it should be attached to the train. Fig. 5b shows the existence of quasi-longitudinal vortices detached from the rear coach as has been observed in operating tests or numerical simulations[2]. We can notice that these kind of structures are the same that the one obtained in the wake of an Ahmed body[1]. The time resolved PIV measurement shown at Fig. 5d shows the alternate vortex shedding due to the separation of the boundary layers on the side of the end coach as has already been reported on smoke visualisations [3]. The vortex shedding exhibits a Strouhal number of 0.2 like in the case of the bidimensional cylinder.

4 CONCLUSIONS

While being far away from the ideal conditions to perform accurate measurements on high speed trains we show that the flow around a small-scale model with a moderate Reynolds number has already experienced enough transitions to have the essential features of the flow around a high-speed train. At the exception of the near wall flow we reproduce the qualitative behavior of the flow. While it is impossible to obtain quantitative results in agreement with measures on operating material it is predictable that a study driven on this kind of model should give the correct sensibility of the real flow. The methodology possesses the advantages of being much cheaper than a 1 : 7, full-scale experiment and numerical simulations depending on the accu-
Figure 5: Life visualisation in the symmetry plane of the rear coach (a). Volume visualisation of the wake (b). PIV measurement of the mean velocity modulus in the symmetry plane of the wake (c). Time resolved PIV obtained velocity amplitude cartography in a plane parallel to the ground at the altitude of the nose with the mean flow subtracted (d).

Moreover it is well adapted to parametric studies and full flow investigation in a reduced time, actually the results presented have been obtained in two days. In the scope of flow control these preliminary results bring the confirmation that the flow behavior and sensibility can be qualitatively predicted from this kind of methodology. The parametric testing of different flow control strategy can be greatly helped and fastened by reducing the number of strategies to test before wind tunnel, numerical or full scale tests, leading to more solution efficiently tested at a reduced cost.

Références


