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Experimental analysis of train slipstream in confined spaces

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Abstract: The train slipstream, i.e. the air velocities induced by the train, is one of the most important aerodynamic effects connected to railway vehicles because it has a direct impact on the safety of passengers on the platform and track workers along the railway line. In recent years, a lot of studies were performed to understand the development of this phenomenon in the open field and specific EU standards, the EN 14067-4 and the TSI (Technical Specifications for Interoperability) were issued. On the other hand, only few studies have been carried out to analyze the train passages in confined spaces (as tunnels, line sections with acoustic barriers, etc.), even if the first results of these analyses have shown that the confinement of the air causes more severe conditions regarding the speed of the air flow. This work aims at studying, through a full-scale experimental campaign, the effects of the flow confinement on the air speed caused by the train passage. In particular, the effects of different parameters, linked to the train i.e. the train type and length, the train speed and the measurement position, and linked to the infrastructure i.e. variations in the local infrastructure geometry, were analyzed.

Keywords: Aerodynamics, trains, slipstream, tunnel, experimental, full-scale measurements.

1 Introduction

The train slipstream, i.e. the air velocities induced by the train, is one of the most important aerodynamic effects connected to railway vehicles because it has a direct impact on the safety of passengers on the platform and track workers along the railway line. Because of that, in the past many analyses were done by different research groups in open field but only few of them focused on the development of this phenomenon in confined spaces. Moreover, the study of the slipstream effect in confined space has been mainly developed on scaled models (e.g. Gilbert et al. [3]), by using moving model rig or wind tunnel, or by CFD numerical simulations (e.g. Fu et al. [2]). This work aims to analyse the main characteristics of this phenomenon generated within a tunnel and to identify the most significant parameters by using a full-scale measurements data set. A full-scale experimental campaign (Sec. 2) has been carried out in the Turin Rebaudengo underground station. Thanks to the data set acquired during the campaign, the main parameters that influence the air flow development inside the tunnels are identified and their effects described in Sec. 3. Finally, in Sec. 4, the main conclusions are summarized.

2 Experimental Setup And Post Processing Analysis

Figure 1 shows the experimental setup adopted at the Rebaudengo Fossata underground station in Turin, where different train types regularly pass i.e. conventional passenger trains, high-speed trains and freight trains. For the air velocity measurement, four 3-Axis ultrasonic anemometers were placed along the line, 1.2 m high from the platform and at 2.5 m (the closest allowed position for the passengers) and 3 m (according to the TSI standard) from the track center. Other instruments were used for the train characterization, such as photocells to estimate the train speed and length, a camera for the train type recognition and accelerometers to trigger the acquisition system. In the next sections, the slipstream phenomenon will be analyzed by plotting the ensemble averages of the wind velocity acquisitions (Baker et al.[1]) for many passages of the same train types.

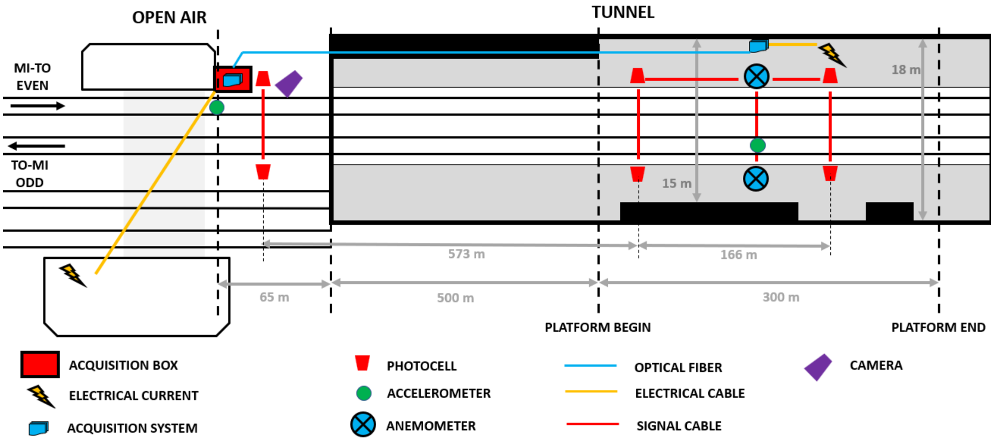

Figure 1. Sensor's setup scheme: measurement stations for the even and odd track directions.

3 Analysis of Experimental Data

In Fig. 2(a) a group of slipstream profiles obtained from high-speed train passages, superposed in the same graph, is reported. By considering this figure it is possible to notice that the air flow inside the tunnel is perturbed by the train even before the train nose arrives at the measurement position. Hence, to describe the slipstream in a confined field, it is chosen to split the analysis considering at first the air variation before the train arrival at the measurement location, in Sec. 3.1, then the slipstream behavior during and after the train passage, in Sec. 3.2.

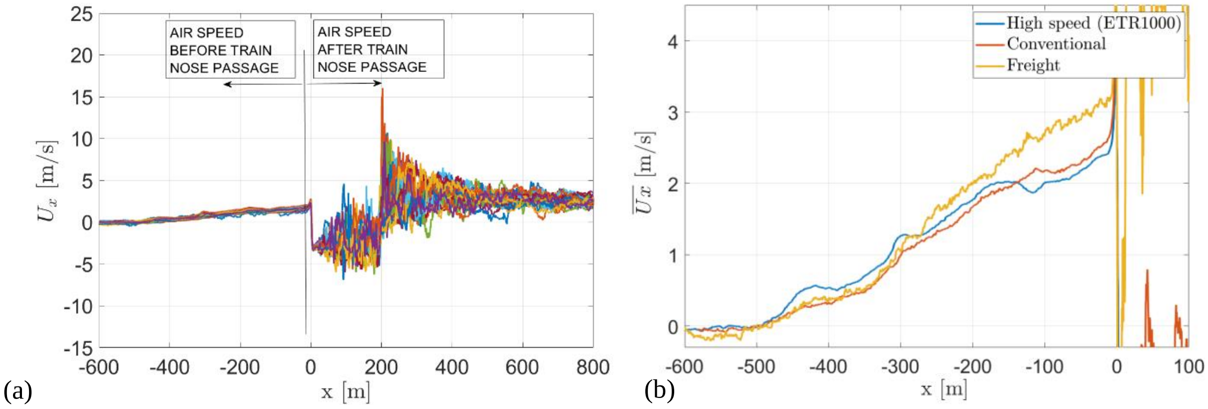

Figure 2. (a) Superposition of longitudinal air flow velocity profiles in tunnel, before and after the train nose passage. (b) Piston effect, different train types. On x axis: train nose position from anemometers, on y axis: ensemble mean of longitudinal air speed.

3.1 Air flow behaviour before train arrival

When the train enters a tunnel, the air starts to move even ahead of the train itself, mainly because of a

pushing effect (the so called "piston effect") generated by the train. Depending on the volume occupied by the train and on its geometry, this effect causes an air speed up which develops in the longitudinal direction. To better understand the phenomenon, the flow velocity measured before the train nose passage in front of the measurement position is studied for three train categories, high-speed trains (ETR1000), conventional passenger trains and freight trains, and for different lengths of the same train type. In Fig. 2(b), the ensemble mean profiles of the slipstream velocity for the different train types are shown, considering the passages on the even track direction.
A re-scaling of the train velocities is performed, considering specific reference values (V_{ref}) for each train type: 160 km/h for high-speed trains, 145 km/h for conventional trains and 120 km/h for freight trains. The re-scaling of the air speed (U_x) is described in Equation 1, where U_{air} is the measured air speed and V_{train} corresponds to the train traveling speed.

$$U_x = \frac{U_{air}}{V_{train}} * \mathrm{V_{ref}} \tag{1}$$

The results shown in Fig. 2(b) show that the flow speed up caused by the piston effect depends on the train geometry: all the trains entering in the tunnel cause an increase of the air speed before the train passing, with maximum speeds of about 3/4 m=s for longer trains with a less aerodynamic shape. In the following sections, considering the results shown in Fig.3, the air speed value reached because of the piston effect before the train arrival will be subtracted from the slipstream profiles, to study the effects of the different parameters separately.

3.2 Air Flow Behaviour After Train Arrival

Considering the air flux development after the train nose passage in front of the anemometers, the main dependency parameters related to the train and to the infrastructure are analyzed. In this abstract, for synthesis reasons, only the train length and type influence are described.

3.2.1. Train type effect

Considering the air development after the train nose passage in front of the anemometers, the first effect to be analyzed is the train type influence, comparing different train types for the same length of about 200 m. The ensemble mean profiles for the train types, plotted in Fig. 3(a), show that the behaviour of high-speed and the conventional passenger trains is similar, noting that the maximum air speed is reached in the near wake zone. However, higher flow speeds are generated by the conventional trains, due to their less aerodynamically-optimized shape. For freight trains, the slipstream profile is different from the other two types: the configuration of freight trains does not allow the formation of a persistent back flow after the train nose region. For this train type the highest speed peaks are generated, independently from the transit speeds, in the nose and boundary layer regions. Moreover, analyzing also the ensemble standard deviation results, here not shown, these trains are characterized by highest variability for freight trains in all the slipstream zones, particularly in the boundary layer zone.

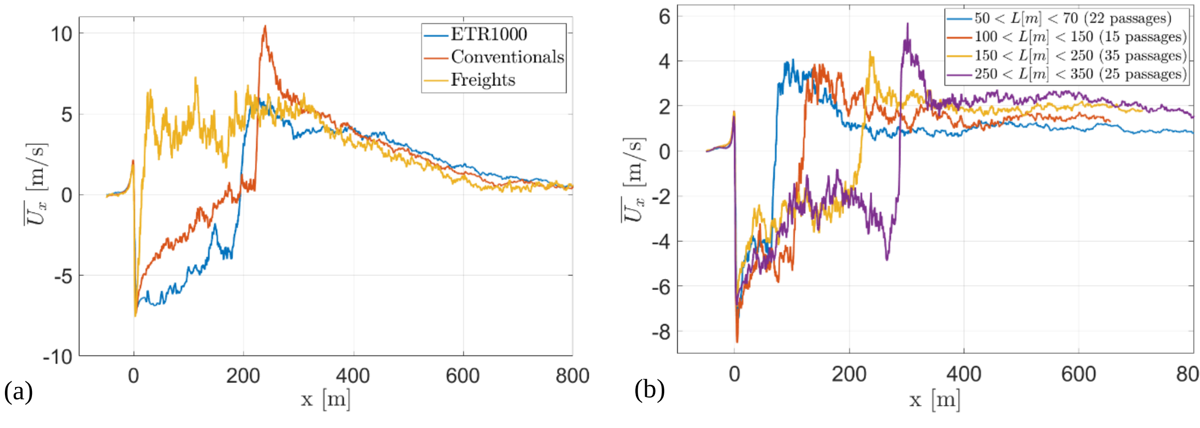

Figure 3. (a) Train type comparison (Length=200m), odd track direction. (b) Length effect, conventional trains, even direction. On x axis: train nose position from anemometer, on y axis: ensemble mean of longitudinal air speed.

3.2.2. Train length effect

The piston effect is not the only effect on the slipstream that could be generated by the train length variations, so a specific analysis is now performed on the conventional passenger and the freight trains, which could have different lengths depending on each configuration. Starting from the ensemble mean results for the conventional trains (Fig. 3(b)), two main peculiarities have been noted: for shorter trains, the boundary layer is not able to reach a stability condition, which is reached after a specific length for each train type. Moreover, longer trains show higher velocity peaks in the tail region, with respect to shorter ones.

4 Conclusions

Referring to the analyses carried out in the previous sections, the following conclusions can be drawn.

- The piston effect is only acting inside confined spaces and is dependent on the train length and geometry, considering the same environment.
- The slipstream phenomenon generated by high-speed and the conventional passenger trains in tunnel is similar, showing maximum peaks in the wake region. For freight trains, the slipstream is totally different from the other two types because of the discontinuous boundary layer growth.
- As train length increases, higher speed peaks are generated within the tunnel; moreover, for shorter trains the boundary layer is not able to reach a stability condition.

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