BBAA VI International Colloquium on:
Bluff Bodies Aerodynamics & Applications
Milano, Italy, July, 20-24 2008

PRESSURE MEASUREMENTS ON REAL HIGH-SPEED TRAINS TRAVELLING THROUGH TUNNELS

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Keywords: train, pressure distribution, tunnel.

1 EXTENDED ABSTRACT

In the last years a deep transformation of the Spanish railway transportation system is being produced due to the large increase of high-speed railway lines, which has given rise to a flourishing period of innovation in both high-speed infrastructure and vehicle technology. In this frame of vehicles travelling at speeds as high as 300 km/h, or even larger, aerodynamic effects play a role in the vehicle operation, so that aerodynamic problems have focused the attention of many scientist.

Research efforts have been significantly directed to the design of high-speed trains running through tunnels because of the need to travel at high velocity notwithstanding the presence of environmental obstacles, such as mountains or rivers. Issues related to the aerodynamics in open spaces become even more involved when the vehicle runs through a gallery, since compression and expansion waves are generated when the train passes an opening or encounters a change in the tunnel cross-section. These waves produce discomfort for the passengers and give rise to further complications such as the possible damage of the vehicle and the release of spherical micro-pressure waves from the tunnel apertures, which causes environmental disturbance.

The aerodynamic problems occurring when train travels at high speed in a tunnel are more complicated than the ones arising in the open air travelling. The aerodynamic drag and pressure loads on the train are strongly dependent on the pressure waves in the tunnel. The aerodynamic drag on a train travelling in a tunnel can significantly increase, compared with that in the open air. When a high-speed train enters a tunnel, a compression wave is formed ahead of the train which propagates along the tunnel at nearly sonic speed (in the same way, an expansion wave is formed at the train end). When these finite amplitude pressure waves reach the tunnel exit, the compression wave is partly reflected back into the tunnel, forming an expansion wave, and is partly emitted outside as a micro-wave. A complex wave interaction occurs inside the tunnel due to successive reflections of the pressure waves at the exit from and the entry to the tunnel. So the train meets the waves several times during its passage in the tunnel.

When combined, the waves can cause relevant aerodynamic loads on the vehicle and tunnel structure, and can also affect the passenger comfort, when the train air-tightness is not enough to attenuate the transmission of the pressure waves into the vehicles.

A large amount of papers dealing with such phenomenon can be found in the literature, the problem being extensively studied both theoretical and experimentally. From the theoretical point of view the aerodynamics of a train travelling inside a tunnel (the aerodynamics of train/tunnel systems) is governed by a three-dimensional, unsteady, turbulent, compressible flow. However some attempts have been made to develop simple one-dimensional models which in many cases provide sufficiently accurate explanations of experimental data. In the experimental side, many laboratory tests have been performed to analyse the influence of a wide range of parameters on the waves appearing inside the tunnel (most of these parameters being concerned with the tunnel entrance geometry). However measurements in real trains, although they have been done, are scarce, probably because of the economic cost associated with experimentation with real train vehicles.

At the end of 2006 and during the first half of 2007, several tests to measure the pressure at selected points of seven different commercial high-speed train models were performed in the high-speed line Madrid-Barcelona (Spain). The train speed ranged from 230 km/h to 310 km/h. Typically, trains were composed of a head, a number of intermediate coaches and a rear unit of the same geometry as the head.

Since one of the goals of the tests was to validate the air conditioning systems, there were three pressure sensors located inside the coaches, plus another three placed outside, all of them on the same side of the trains. In each train, one of the outer pressure taps was located in the middle section, whereas the other two were placed approximately 10 meters away from the ends of the train, one at the head unit and the second at the rear one. Inner pressure sensors were located in the same sections than outer pressure taps.

The test field covers 100 km of the high speed line, and there are sixteen tunnels in the path, with lengths ranging from 126 meters to 4784 meters. Measurements started a few kilometres before the tunnel entrance and they continued until at least 30 s after the train reached the tunnel exit.

In this communication, details on the used instrumentation, measurement procedure and data analysis are described, the results being compared with theoretical predictions obtained from a one-dimensional model already used by other authors (Ref. [1, 2]). Some preliminary results are shown in figure 1, where the variation with time of the dimensionless pressure measured on the head coaches of the trains, on the middle coach and in the rear coaches has been represented. The results correspond to the longest tunnel (4784 m). As can be observed, when dimensionless variables are used, there is an almost self-similar solution for the pressure measured on the trains; at least before the first reflected expansion wave is reached. Note that pressure conditions are different from the tunnel entrance to the tunnel exit, due to a difference of altitude of nearly 35 m between both tunnel sections.

The variation of the pressure along the train is shown in figure 2, where the pressure variations at the head, middle and rear coach pressure taps are represented. These results correspond to a Siemens train with a mean speed of 87 m/s.

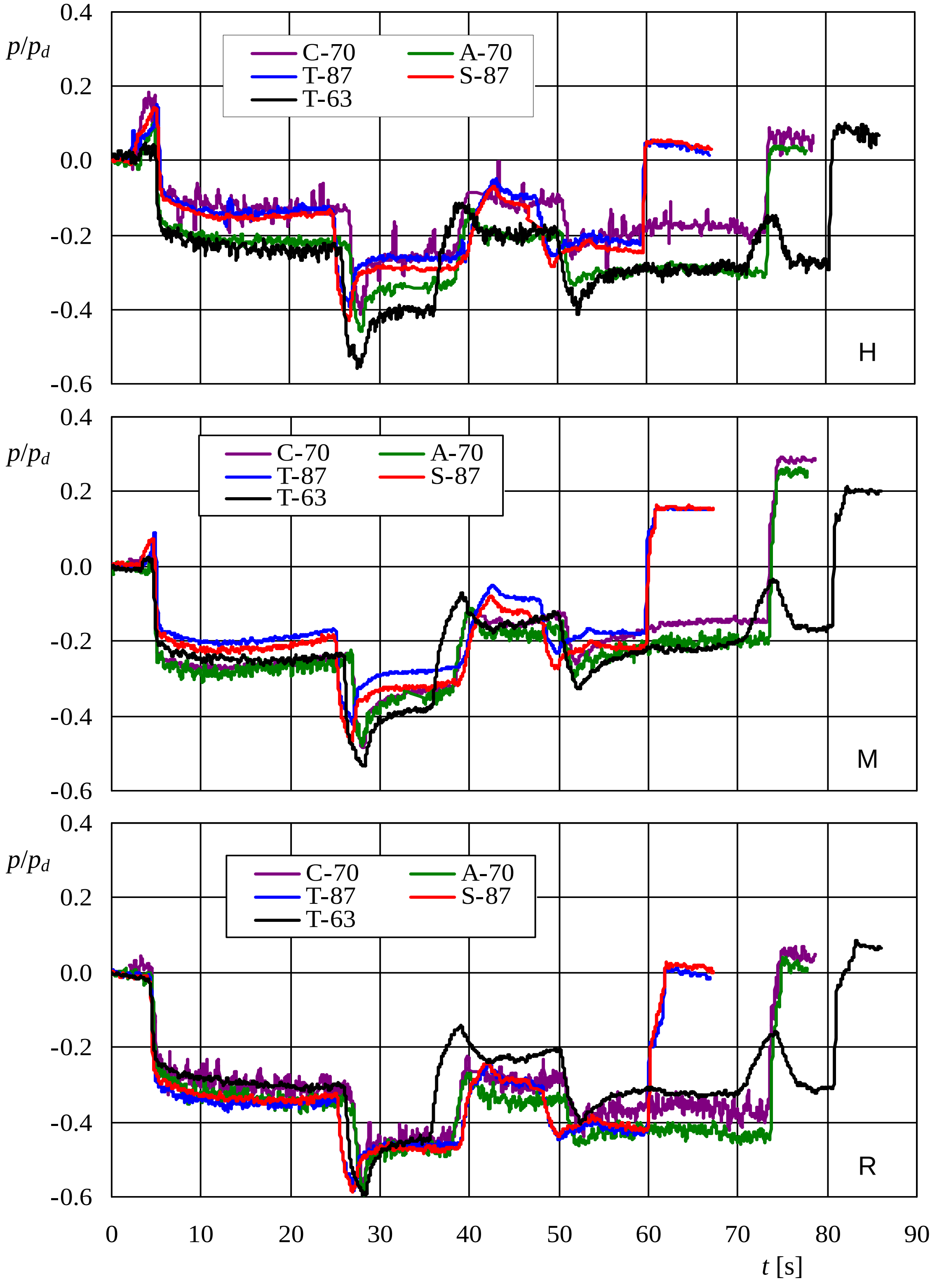

Figure 1. Variation with time, t (the time origin being 3 s before the entrance of the train in the tunnel), of the ratio, p/p_d, where p stands for the pressure measured on the pressure tap of the train coach (head, H, middle, M, and rear, R) and p_d for the dynamic pressure associated to the train speed, $p_d = \rho U^2/2$, ρ being the air density and U the train velocity. The results correspond to measurements made in the same tunnel (4784 m length) with different trains (C: CAF, A: Alstom, T: Talgo, and S: Siemens) and different velocities (the mean velocities in m/s are given by figures in the inserts).

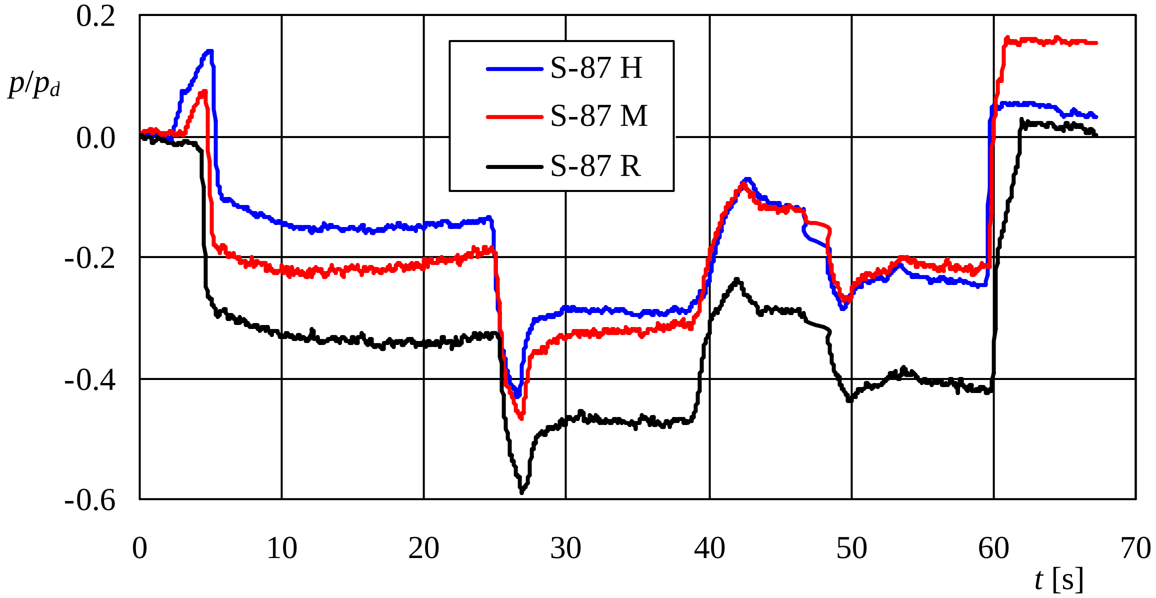

Figure 2. Variation with time, t (the time origin being 3 s before the entrance of the train in the tunnel), of the ratio, p/p_d, where p stands for the pressure measured on the pressure tap of the train coach (head, H, middle, M, and rear, R) and p_d for the dynamic pressure associated to the train speed, $p_d = \rho U^2/2$, ρ being the air density and U the train velocity. The results correspond to measurements made in the 4784 m length tunnel with a Siemens train with a mean velocity of 87 m/s.

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