Measurement of the aerodynamic features of the ETR1000-V300Zefiro high-speed train

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Abstract

New generation high speed trains are designed to have better performances, retain the safety of the rolling stock at higher speed and guarantee the passengers comfort. Design features are verified during the homologation and the commissioning of the train. The opportunity to perform some measurements on the train allows to define the characteristics of the rolling stock and to assess the reliability of design procedures and numerical codes used to predict the train performances. As part of the homologation process one of the ETR1000-V300Zefiro high speed trains has been equipped for the assessment of the aerodynamic features of the rolling stock. Besides the standard homologation tests, supported by numerical tools, additional measurements have been performed for investigation purposes to assess the aerodynamic performances of the train. This testing is very important for the definition of the aerodynamic loads acting on the train, on the infrastructure and on people on board and along the track. More than 100 sensors have been installed and distributed along the train, inside and outside, including leading and trailing car, pantograph area, undercar body, bogie skirts and train lateral and top surfaces. All the instruments have been installed in a manner that does not affect the aerodynamic performance of a typical fully finished rolling stock, in particular the pressure tightness. All measurements have been taken simultaneously in order to have a general overview of the aerodynamic actions on the train. The data acquisition system was distributed along the train while only one data collection and storage unit was used. The tests were performed to assess the impact of the train aerodynamics on passengers, in particular to define the pressure tightness performance of the train when running in tunnels. Some tests were performed correlating the measurements on board with data acquired on the ground, in order to achieve a larger perspective on the aerodynamic phenomenon of the train. Dedicated test runs have been performed to characterize the slipstream and the wake of the train and its interference with the pantograph area and with the tail of the train; the definition of the train resistance to motion has been performed in both open air and tunnel. These data are very important to verify the reliability of numerical prediction tools that are used for the assessment of the rolling stock performances and to design increasingly safer, more efficient and comfortable trains.

1. Introduction

The ETR1000-V300Zefiro with 360 km/h design speed pushes the boundaries for existing European high speeds trains. Most aerodynamic aspects increase with train speed squared, i.e. by a factor 1.44 compared with a 300 km/h train. Therefore aerodynamics has been highly in focus during the design, e.g. an optimized front shape, an outer complete fairing of the inter car gaps, a recess for the pantograph with a pantograph designed to have a very low height when folded, the high voltage equipment in a covered box, a flush design of roof equipment and underframe creating smooth aligned surfaces, bogie covers on the leading bogies, design of the bogies that minimize intrusion of air into the bogie cut out and equipment exhausts to the track having very low speed to minimize the aerodynamic load on track. Not so obvious to see but more apparent to passenger is the very high level of pressure tightness, achieved through a careful process with high attention to detail, extending from the start of the design through to the production. The design builds on experiences from previous high speed trains as ICE 3 and CRH380D that have been further developed. The design process relied heavily on numerical simulations, complemented with analytical analysis and empirical based estimations, why it is of interest to verify the on-track performance. This is done in several tests required for homologation and customer acceptance, during which additional data has been collected, and in some cases by extending the tests. For authorization to place into service, the Technical Specifications for Interoperability (TSI) have requirements on head pressure pulse, slipstream effects and maximum pressure variations in tunnels (train-tunnel pressure signature), that have been proven in full scale tests. These are all measurements at the at the track side, not on the train. TSI also require the cross wind performance to be determined, however, that has been done through model scale wind tunnel tests combined with vehicle dynamic simulations. National requirements relate to a minimum pressure comfort, which has been verified by measuring the internal pressure variation at tunnel passage. During the tunnel passage measurements, additional pressure sensors have been used; on the exterior of the carbody to be able to judge the load and derive the dynamic pressure tightness, reported in [1] (the dynamic tightness can later be used to estimate the pressure comfort at different scenarios than tested as for example higher train speed, other tunnels and train encounters); at various positions on the front, underframe and roof differential and absolute pressure sensors to determine the aerodynamic loads. National requirements also concern the aerodynamic load on the track ("ballast projection"), not reported here. The performance was shown to be very good at 300 km/h, but higher speeds on ballasted tracks is fairly unexplored and the split between train and track still needs to be determined. In agreement with the customer the aerodynamic resistance is determined in coasting tests, which were extended to also include tests in a tunnel to judge the additional resistance, i.e. tunnel factor. Pressure sensors on the head/tail and on the roof around the pantograph region serve the purpose of verifying simulation predictions. In this paper the experimental setup for measuring the aerodynamic features will be presented.

2. Train experimental setup

The ETR1000-V300/Zefiro test train #4 has been equipped on almost every coach in order to provide data for the characterization of the aerodynamic features of the train. The total length of the train (202m) and the location of the sensors required a distributed data acquisition setup.

2.1 Data acquisition system

The data acquisition system is quite complex and the setup can be seen in Figure 1. Sensors distributed inside, on the sides and on the undercar body of car 1 and 2 are connected to the data acquisition chassis located in car1; sensors positioned on the roof of car 2 are connected to chassis 4 and chassis 5 located in car 2; sensors located inside and on the sides and the undercar body of car 3 and car 4 are connected to chassis 6, while the sensors positioned on the roof of car 4 are connected to chassis 2; sensors located inside and outside of car 8 are connected to chassis 3. Data acquisition PC is located in car 6: all connection between the data acquisition pc and the chassis is performed through Ethernet connection. Sensors positioned on the roof of the train are treated differently from the others, since they must be electrically isolated from the inside of the train. This is achieved by positioning the data acquisition card and all the equipment necessary for measuring data in an electrically isolated area, while the data transmission to the data acquisition PC is performed through a conversion of Ethernet signal to Optic Fiber signal in order to guarantee electrical insulation from the train roof. Data acquisition synchronization is guaranteed by dedicated Ethernet synchronization cables that connect different chassis.

2.2 Sensors and wiring

The majority of sensors are pressure sensors, for the measurement of the pressure around atmospheric pressure values. Several differential pressure sensors are placed in some particular locations in order to measure net pressure loads on surfaces, some temperature and moisture sensors are used for assessing ambient conditions. All data acquisition cards are located in the interior of the train, therefore all signals must be driven inside the train cars; also the power is provided from the inside of the car. Several tests have been conducted on the train, but one of the main goals of the measuring setup of the test train #4 was the assessment of the pressure tightness performance of the train: this particular test requires that the openings from the inside to the outside of the train must be the same of the commercial trains. This requirement did not allowed to use the same cable passage generally used for the preparation of common test trains, but all cable passages (generally closed with pressure tight manholes) needed the installation of pressure tight cable screw glands.

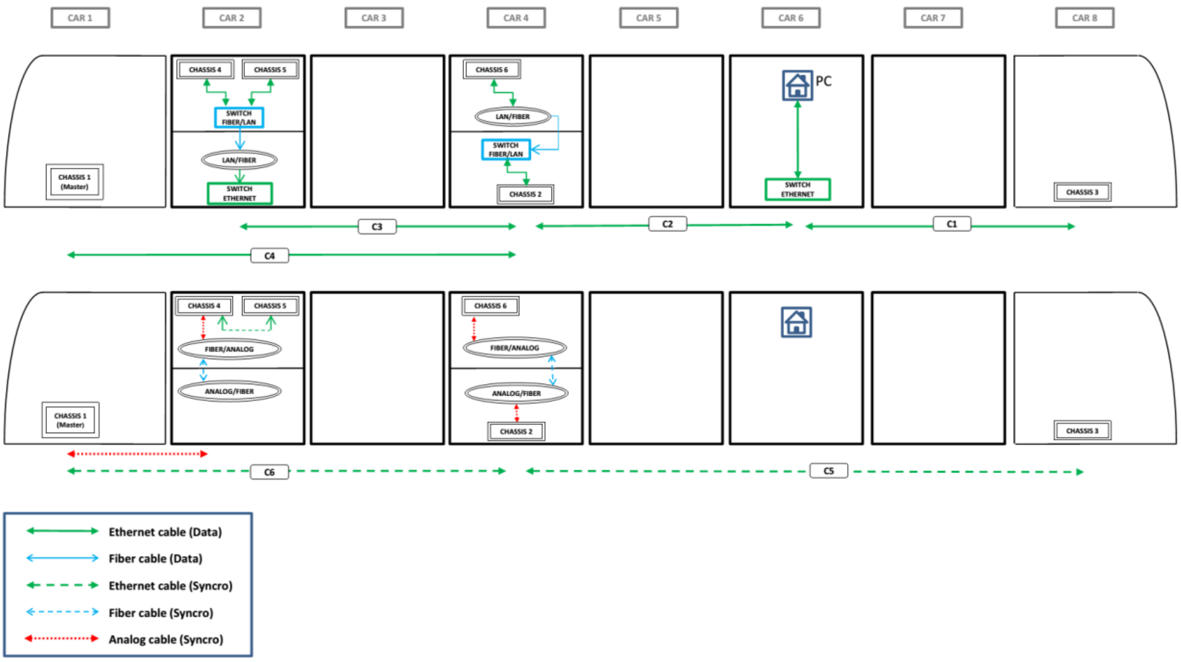

Figure 1 – Data acquisition system distributed across the train

Pressure sensors in the exterior of the train were installed according to Figure 2: due to the fact that it is not possible to drill a hole on the train surface and the pressure measurement has to be performed on the train surface the displayed solution has been adopted in order to avoid pressure disturbances related to the presence of the train. Two fairings have been planned in order to solve this issue: one is used to house the tube that brings the pressure from the train surface to the pressure transducer (about 8mm in height), the other is used to house the pressure transducer (about 25mm in height). The idea is that the lower housing has lower interference with the undisturbed flow over the train surface and is therefore a good solution to get the static pressure on the train surface, while the higher one should not affect the flow over the lower one in any direction of motion of the train. Both fairings are held in position using sailing boat adhesive tissue in order to avoid unwanted detachments and guarantee a good durability with sun and wind pressure. The pressure sensors are already conditioned, therefore the electric output could directly be delivered to the data acquisition card. Pressure sensors positioned in the inside of the train were placed directly in the ambient where the pressure needed to be measured without the need of any fairing. Pressure sensors positioned on the roof fairings, on the bogie-skirts and on the train undercar were installed by drilling the plates and installing the sensors in a shielded position. Temperature and moisture sensors were installed inside and outside the train in order to have the information about ambient conditions, since the air density information is quite important for the tests. Speed of the train is gathered by means of a wheel speed system, which gives access also to the train position along the track. The information on the air conditioning system operating condition was inferred from the HVAC actuation system.

Figure 2 – Picture of the pressure sensors installed on the train side.

2.3 Testing procedure

The testing procedure for the assessment of the pressure comfort requires that before the start of every test the pressure sensors are calibrated and checked against the HVAC system: the opening and closing of the train doors generates a pressure gradient, showing higher pressure in the inside of the train. Pressure sensors on the outside of the train need to be acquired with the train standing still in order to verify eventual derivation on the pressure signal. Pressure comfort is evaluated, when travelling across tunnels, on the basis of the measured internal pressure value, verifying the pressure variations in determined time intervals. Pressure tightness of the train is evaluated by comparing the pressure time histories inside the train with the pressure time histories measured outside: pressure tightness is evaluated with different internal configurations of the train (train in normal operating condition, train with all internal doors open, train with sealed cars) and with different HVAC system configurations. The analysis of pressure distribution on the train surface for the support of numerical design models for the aerodynamic optimization of the train shape need a different treatment of the data, since the pressure value measured on the train surface is not affected only by the train shape, but also by train speed and track height: a pressure correction on the basis of track height and air density is therefore performed for defining the pressure coefficient on the surface of the train, in particular on the head of the train and on the pantograph area.

Figure 3 – Picture of the pressure sensors installed on the train head

3. Results

Several analysis can be conducted analyzing pressure data measured on the ETR1000-V300Zefiro train, depending on the objective of interest. Raw measured data are influenced by air temperature (can be seen as density), by track height (atmospheric pressure) and by train speed. Different type of analysis need to perform different data treatment. The analysis of pressure loads on the train, the evaluation of pressure variation inside the train and the pressure tightness does not need any correction, but only the need to equalize internal and external pressure when the train stands still with the doors open. Fundamental for the correct evaluation of the pressure tightness is that the HVAC system works correctly when entering the tunnels. The definition of pressure distributions on the train surface needs a more complex data treatment, since it is necessary to take into account the train passage in tunnels, to considering track height and train speed, in order to be able to define pressure coefficients for the validation of numerical models for the prediction of the train aerodynamic performance.

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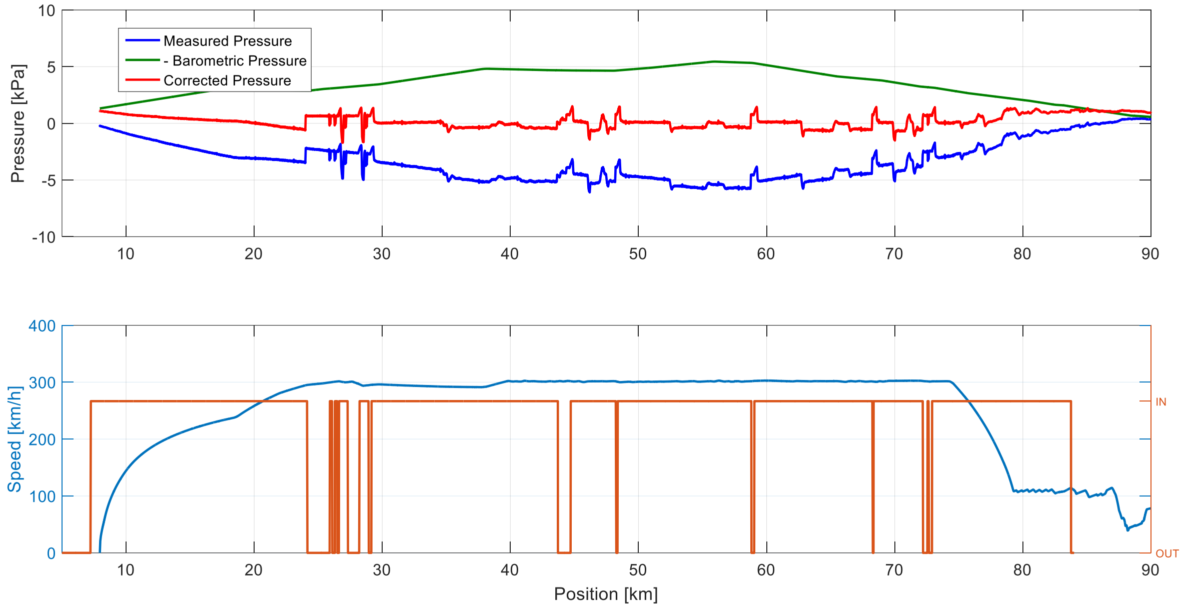

Figure 4 it is possible to see the time history of pressure on the outer surface of the train together with the speed of the train and the track height. On the upper graph it is possible to see that the measured pressure can be corrected with the Barometric pressure to eliminate the pressure variations due to height. On the lower graph it is possible to have the information about the train speed and the position of tunnels on the Firenze-Bologna line. Also on the pressure time history it is possible to detect the entrance of the train in the tunnel.

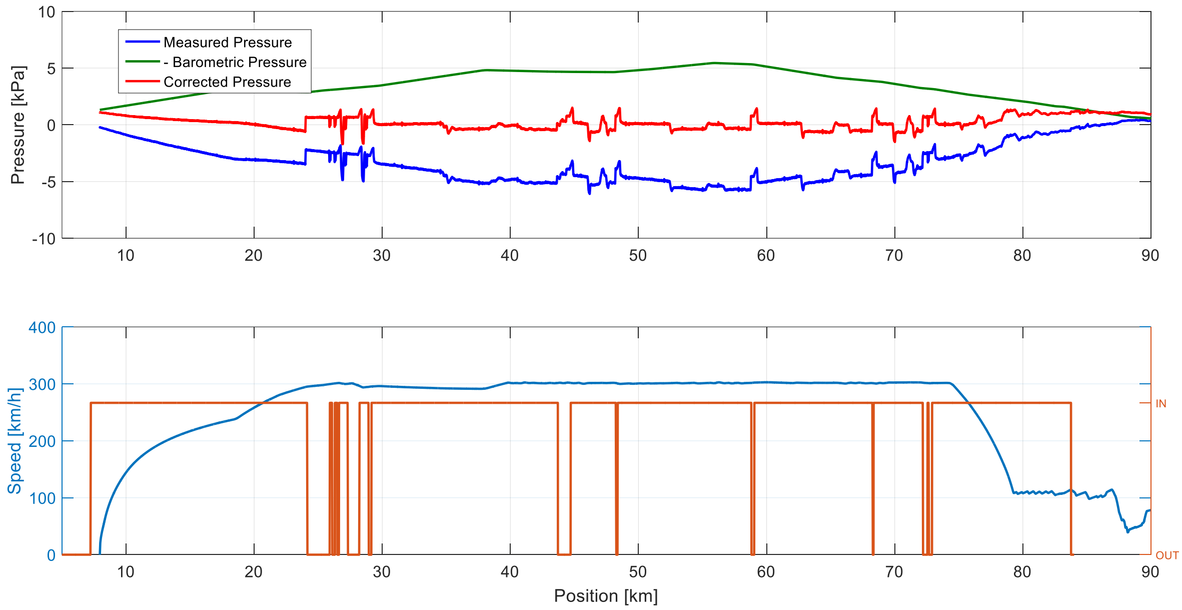

Figure 4 – Pressure time history on train surface during a run between Firenze and Bologna.

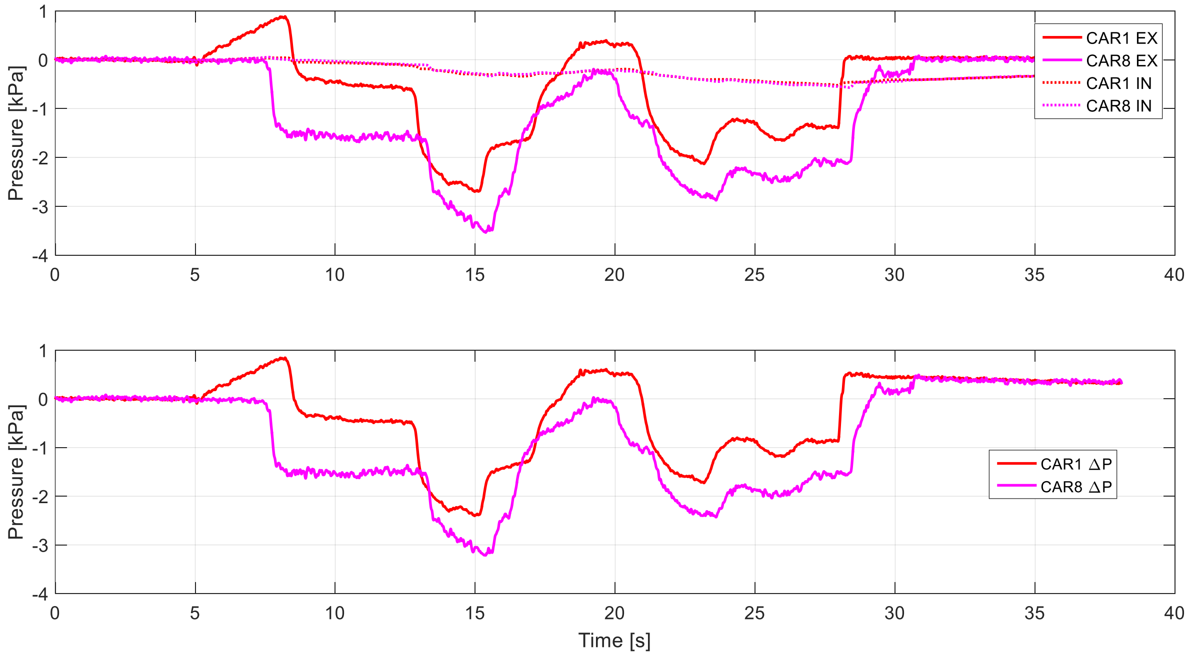

Figure 5 reports the pressure time histories inside and outside the train during the passage in a tunnel. In the upper graph it is possible to see that CAR1 is at the front of the train and CAR8 is at the train tail: the pressure time histories when entering the tunnel are quite different; the internal pressure sensors show the same pressure time history, with minor differences between the first and the last car. These time histories can be used to assess the pressure tightness of the train. The lower graph in

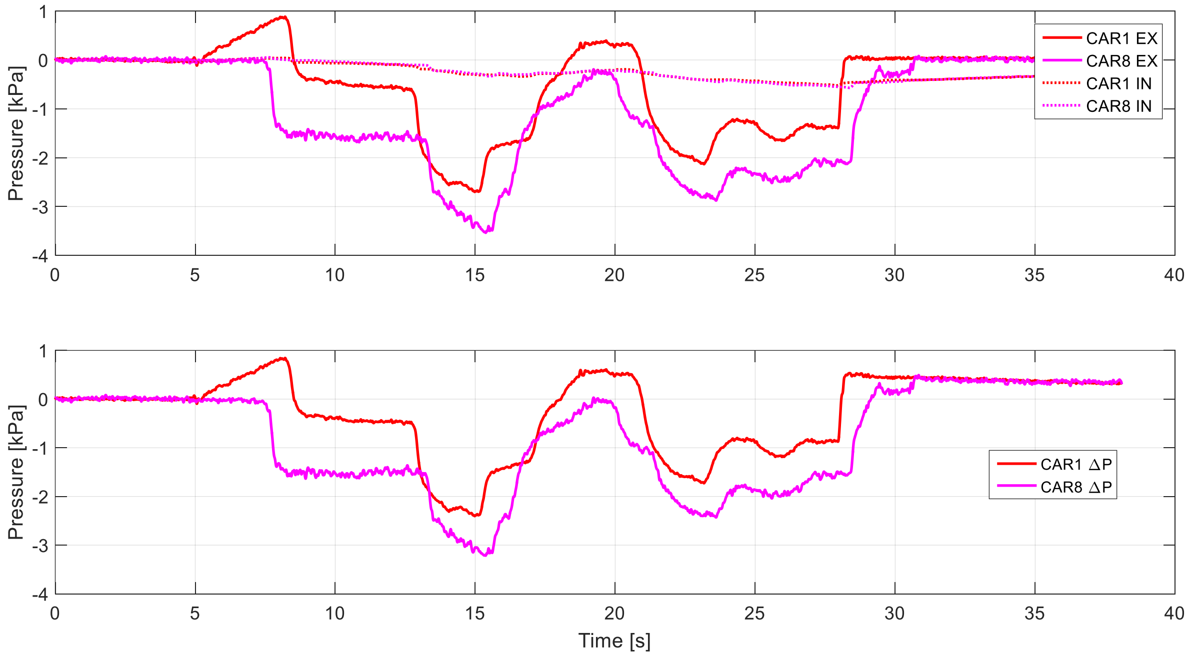

Figure 5 reports the difference between the internal and the external pressure in CAR1 and CAR8: this refers to the pressure loads on the train structure.

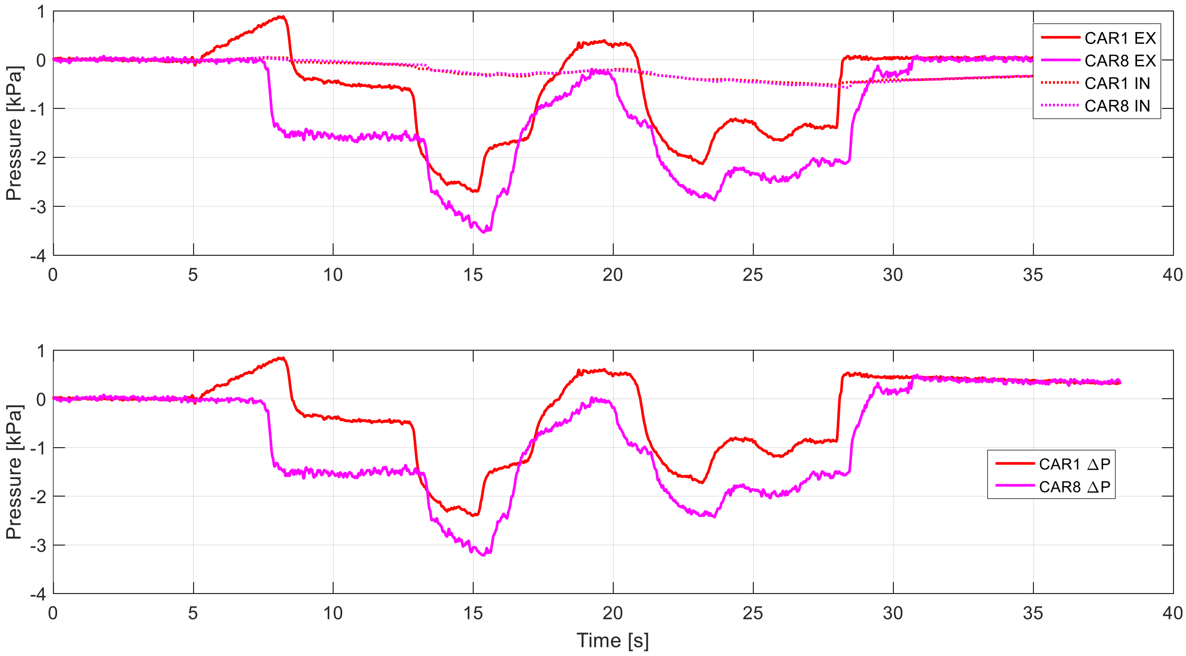

Figure 5 – Pressure time histories outside and inside the train during the passage in a tunnel

4. Conclusion

An ETR1000-V300Zefiro train has been successfully instrumented with all sensors needed for the definition of the aerodynamic features of the train. The setup allowed to define the pressure tightness of an operating train, the aerodynamic loads on the car structure, on the roof fairings and on the bottom of the train. The tests allowed also to compute the pressure distribution on the train surface in order to obtain pressure coefficients for the validation of numerical codes that are used for the definition of the aerodynamic features of high speed trains.

5. References

[1] Sima M., Barbone L., Galeazzo G. and Gölz P., 2016. Dynamic Pressure Tightness of Very High Speed Train ETR1000/V300ZEFIRO. In *Proc. Of the 11th World Congress on Railway Research,* May 29 – June 2, 2016, Milano, Italy.
[2] CEN, EN 14067-2: Railway applications - Aerodynamics - Part 2: Aerodynamics on open track, 2003
[3] CEN, EN 14067-3: Railway applications - Aerodynamics - Part 3: Aerodynamics in tunnels, 2003
[4] CEN, EN 14067-4: Railway applications - Aerodynamics - Part 4: Requirements and test procedures for aerodynamics on open track, 2009
[5] CEN, EN 14067-5: Railway applications - Aerodynamics - Part 5: Requirements and test procedures for aerodynamics in tunnels, 2010