Vibroacustic Problems in High SpeedmTrains

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Abstract

Passengers' comfort in terms of acoustic noise levels is a key train design parameter, especially relevant in high speed trains, where the aerodynamic noise is dominant.

The aim of this work is to progress in the understanding of the flow field around high speed trains in open field, which is a subject of interest for many researchers with direct industrial applications, but also the critical configuration of the train inside a tunnel is studied in order to evaluate the external loads due to noise sources of the train.

The airborne noise coming from the wheels (wheel-rail interaction), which is the dominant source at a certain range of frequencies, is also investigated from the numerical and experimental points of view.

The numerical prediction of the noise in the interior of the train is a very complex problem, involving many different parameters: complex geometries and materials, different noise sources, complex interactions among those sources, broad range of frequencies where the phenomenon is important, etc.

During the last years a research plan has being developed at IDR/UPM (Instituto de Microgravedad "Ignacio Da Riva", Universidad Politécnica de Madrid) involving both numerical simulations, wind tunnel and full-scale tests to address this problem. Comparison of numerical simulations with experimental data is a key factor in this process.

Keywords: high speed train, vibro-acoustics, airborne noise, noise prediction.

1 Introduction

In modern high speed trains the aerodynamic noise becomes dominant at around 300 km/h over wheel-rail noise, engine, gearbox, air conditioning, etc.. The characterization of the airborne noise generated by the flow around the train becomes an important step in the design process. It is used to validate numerical simulations, for near-field propagation and the integration of these aeroacoustic sources within algorithms for far-field propagation [1].

The prediction of the noise inside the train with vibro-acoustics models before the final train configuration is frozen is used in the design of the noise control treatments (NCT), [2].

A summary of the methods to evaluate the acoustic performance of a rail vehicle at the design state are given in [3].

In this paper a full-scale test is reported and the results obtained have been used to correlate turbulent boundary layer models used in the vibro-acoustic models in order to obtain a more accurate prediction.

2 Experimental set-up

The microphones used to characterize the airborne excitation where located at the front (at 7, 20.5 and 25 m from the tip of the train) and the rear of the train (at 193, 179.5 and 175 m from the tip of the train). The accelerometers were located at 40 and 16 m from the nose of the train. The microphones M1 and M2 are at the lateral side of the train flushed to the surface, and microphone M3 is in the bogie cavity. To characterize the behavior of the junctions between the structure and the NCT once they are mounted in the train, the acceleration of different points at both parts of the junctions were measured.

The microphones used in the test were Roga Instruments MI-17, the acquisition card NI9233 in a hi-speed usb carrier NI USB-9162, the sampled time was 2 sec at 25 kHz.

The accelerometers used are presented in table 1, the constant current supplied to the accelerometers was ICP AC 0.7 Hz, and the time sampled was 1.7 sec at 12 kHz. The acquisition card used for the accelerometers was a LSD Dactron Focus II model, and the software use RT Pro Focus.

Accelerometer	Sensitivity [mV/g]	Channel
KISTLER 8702B25	203.07	1
KS77C.100	103.99	2
KS77C.100	103.99	3
KS77C.100	103.00	4
4513B-001	103.10	5
4513B-001	102.30	6
PCB 353 B01	22.10	7
PCB 353 B01	21.22	8

Table 1: Accelerometers used in test campaign.

3 Test results

The experimental sound pressure level (SPL) measurement can be used to validate the aerodynamic noise spectra from the turbulent boundary layer (TBL) model used in vibro-acoustics, and the acceleration in the structure to be used as a point constrain in the model. The transmisibility through the junctions between the structure and the NCT can be modified by changing the coupling loss factor (CLF) calculated from the experimental test.

3.1 Aerodynamic noise characterization

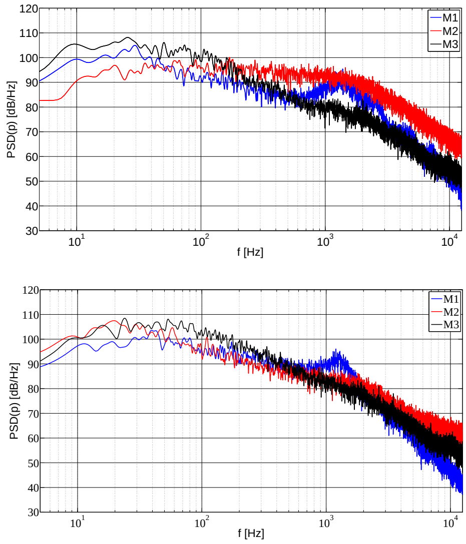
In this part the aerodynamic noise generated by the turbulent boundary layer in the nose of the train, in the gap between the cars, and in the bogie is characterized with microphones measurements. The expression (1) used to evaluate the sound pressure level, where the pressure reference is $p_{ref} = 20 \cdot 10^{-6}\mathrm{Pa}$,

$$\mathrm{SPL(dB)} = 20 \log_{10} \left(\frac{p_{rms}}{p_{ref}} \right) \quad . \tag{1}$$

The SPL measured can be introduce in the vibro-acoustic model as a user defined TBL or has a constrain in pressure inside an acoustic cavity.

3.1.1 SPL in open field

In Figure 1 the power spectral densities in narrow band (frequency bandwidth is 0.5 Hz) of the microphones at 300 km/h are presented.



a) b)

Figure 1: SPL (dB) in the microphones at 300 km/h in open field: a) at the head; b) at the tail.

As it can be appreciated in figure 1 the spectra in the bogie cavity (microphone M3) at the tail or at the head does not vary significantly except for a constant level. In the other microphones it can be seen the energy flow from middle turbulent structures to smaller once as the position in the closer to the tail of the train, but also the existence of new big turbulent structures. There is a resonant frequency at approximately 1250 Hz in the microphone M2. The characteristic size of the source that generates that tonal noise could be sized with the Strouhal number ($\mathrm{St} = fL_c/U$), using $\mathrm{St} \sim 0.2$ the length obtained is 0.13 m.

In the table 2 the sound pressure level overall (SPLOA) at 300 km/h is presented.

Microphone location [m]	SPLOA (dB)
7	123.0
20.5	127.1
25	125.2
175	127.1
179.5	124.1
193	124.3

Table 2: SPLOA (dB) in open field at 300 km/h.

3.1.2 SPL inside the tunnel

The noise during the pass through different tunnels was measured, and in the figure 2 a tonal resonant mode can be appreciate at around 10 kHz, probably due to the noise generated in the bogie, which is reflected in the tunnel walls.

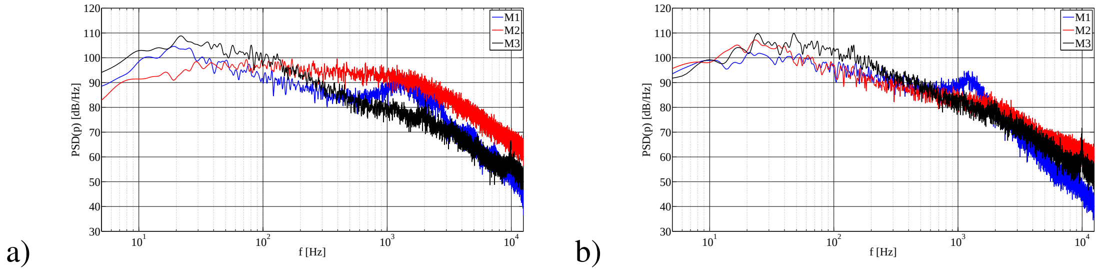


Figure 2: SPL (dB) in the microphones a) at the head b) at the tail at 300 km/h inside a tunnel.

Microphone location [m]	SPLOA (dB)
7	122.8
20.5	127.1
25	125.0
175	127.0
179.5	123.4
193	123.7

Table 3: SPLOA (dB) inside the tunnel at 300 km/h.

3.2 Junction characterization between the structure and the noise control treatments

The transmissibility through the junction is evaluated with the ratio between the acceleration power spectral densities in the structure and the NCT. The expression used to evaluate the transmissibility through the junctions is the ratio between the acceleration spectral densities in the structure asd_s and in the coating ([4]). The odd accelerometers were attached to the structure and even to the coating, at the other side of the junction.

$$H2(f) = \sqrt{\frac{asd_c(f)}{asd_s(f)}} \tag{2}$$

The accelerations at the structure can be considered as the load and can be applied as a constrain in the node of the vibro-acoustic model.

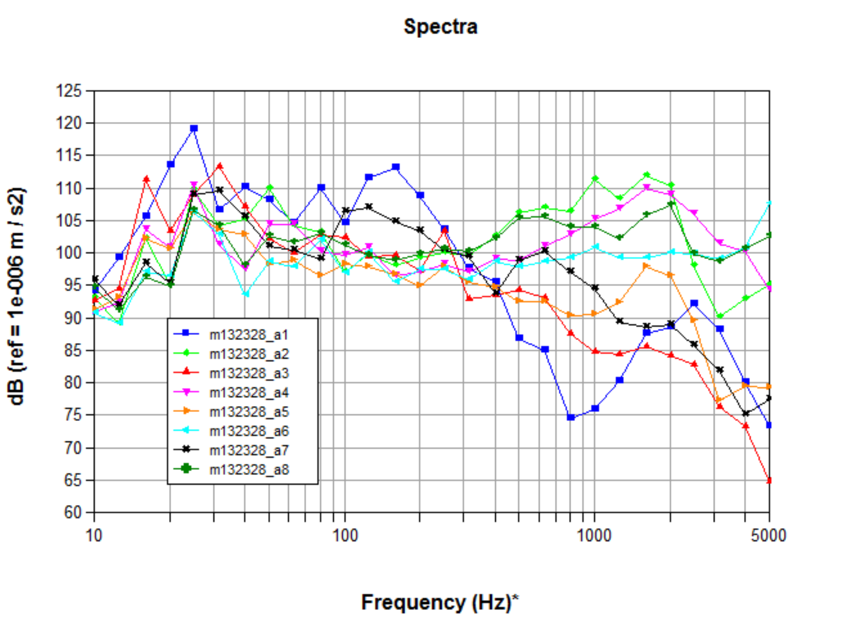


Figure 3: Acceleration spectral density in the junction at 300 km/h.

The transmissibility can be used to impose the behavior of the junction in the vibro-acoustic model.

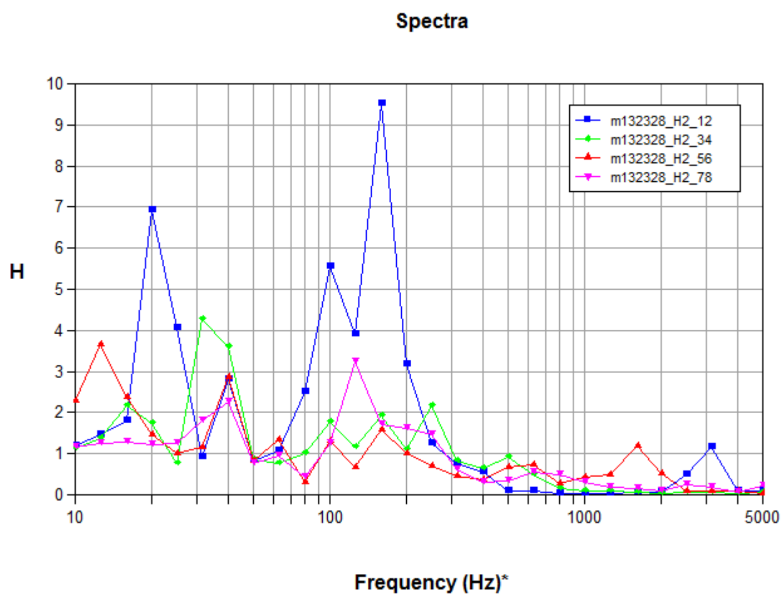


Figure 4: Transmissibility obtained from the accelerometers at 301 km/h.

4 Interior noise prediction

4.1 Vibro-acoustic model

The model was generated based on typical high speed train structure, with extruded (truss-like cores) and ribbed panels, derived from the examples found in the bibliography. The model is separated in parts with similar structural properties; a modal analysis was done to identify the subsystem partitions for statistical energy analysis (SEA) modeling. The truss-like cores that compose the structural box were separated in external, core and internal subsystems to facilitate the separation of interior and exterior domains and to make easier the connection to the exterior air. The SEA model is valid for frequencies larger than 315 Hz, frequency at which the subsystems have more than 3 modes per frequency band in 1/3 of octave. The SEA model requires much less computational time than the FE model, and this allow us to study the influence of the in input parameters faster.

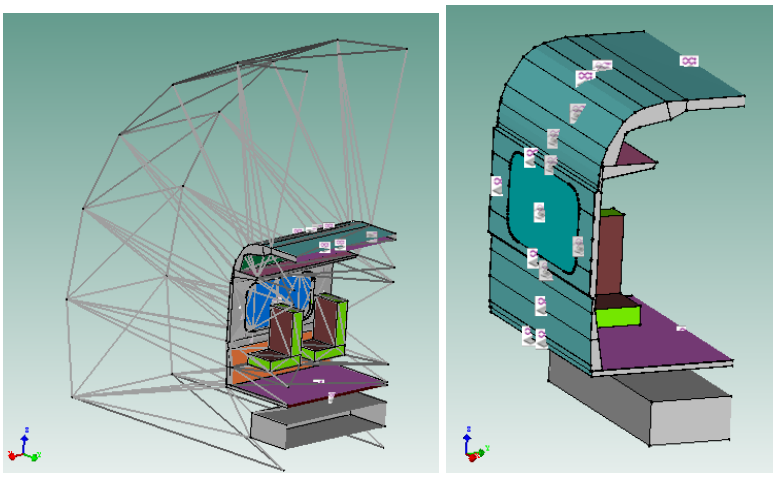


Figure 5: Vibro-acoustic SEA model for high frequency range.

4.2 Loads

The loads considered in the vibro-acoustic model are the airborne noise due to the turbulent boundary layer, for this microphone signals are used to substitute the TBL VAOne models in the regions where we had information from measurements (microphone M2); and the airborne noise generated by the interaction between the wheel and the rail in the bogie cavity (microphone M3). As it can be appreciated in figure 6 the pressure signal of microphone M2 is between the attached and the separated model of VAOne for the TBL. The SPL of the microphone M2 has been applied to the SEA plates at both sides of the train and for the rest the TBL attached.

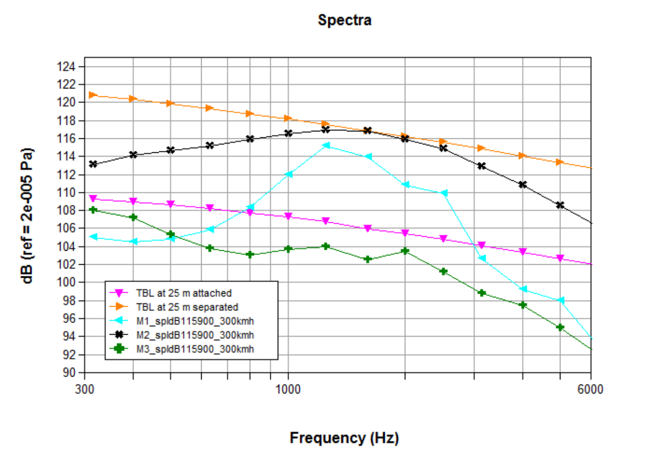
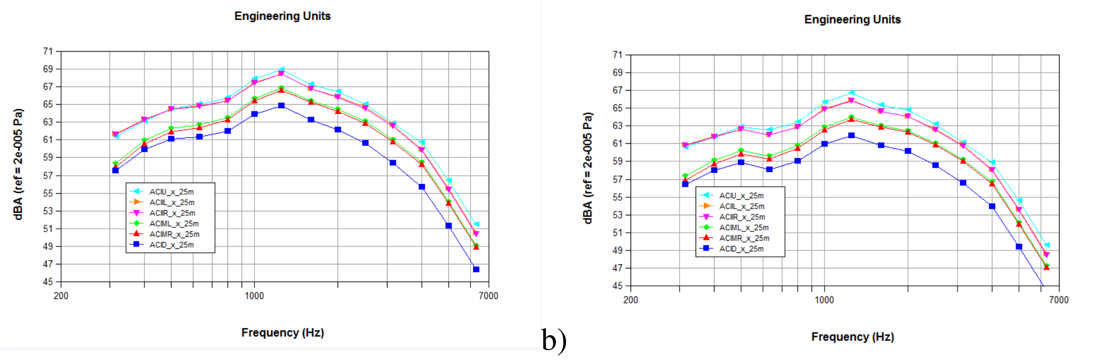


Figure 6: Pressure spectra considered in the vibro-acoustic model.

4.3 SPL model prediction

Using the characteristic train section in which we have impose the pressure measurement in the bogie cavity and the acceleration in junction of the structure with the NCT, we have obtained the SPL shown in presented in 1/3 of octave in the figure 7.



a) b)

Figure 7: SPL (dB) predicted inside the train at 300 km/h in a section at 25 m from the nose: a) analytic expression for CLF in point junction b) point junction CLF obtained from experimental test.

The SPL predicted are in accordance with expectations extracted from bibliography [5].

5 Conclusions

In this paper a experimental set-up to characterization of the airborne noise have been created and the experimental results used to correlated TBL model and also the junctions behavior. The prediction obtained is inside the SPL expected levels. The importance of the characterization of the airborne excitation and the junction behavior is shown.

Acknowledgments

The authors want to thank to Prof. Marcos Chimeno Manguán and Prof. Pablo García Fogeda from UPM for their support during the test campaign.

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