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COMPARISON OF WIND TUNNEL TESTS RESULTS ON THE ATM TRAIN

Daniele Rocchi[†], Martin Schober[*], Federico Cheli[†], Alexander Orellano[*] and Gisella Tomasini[†]

[*] Centre of Competence for aerodynamics and thermodynamics Bombardier
Am Rathenaupark, 16761 - Hennigsdorf - Germany
e-mail: Martin.Schober@de.transport.bombardier.com, Alexander.orellano@de.transport.bombardier.com

[†] Mechanical Department – Politecnico di Milano
Campus Bovisa, Via La Masa 1, 20158 Milano, Italy
e-mails: Federico.Cheli@polimi.it, Daniele.Rocchi@polimi.it, Gisella.Tomasini@polimi.it

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Abstract. *The paper presents a comparison of the results obtained by experimental campaigns, performed in different wind tunnel plants on the same train model. The comparison will be presented in terms of global forces and pressure distribution on the first vehicle of the train model. Tests have been performed on a flat ground configuration and allow to investigate the effects related to the Reynolds number on the different components of the global aerodynamic force, to the blockage ratio, and to the adoption of open or closed wind tunnel test section. The sharing of the same scaled model and the availability of detailed data regarding the pressure distribution in the different test conditions allow a good insight in the modeling of the train aerodynamics in wind tunnel..*

1 INTRODUCTION

One of the not yet answered questions on the assessment of the aerodynamic behavior of trains concerns the reliability of the aerodynamic coefficients measured in wind tunnel with respect to the full scale behavior. Wind tunnel tests are commonly performed in different experimental laboratories with different flow qualities, different performances, different equipments and different techniques using scaled models and scaled representation of the ground scenarios. These differences may insert uncertainties in the definition of the aero-dynamic performances of trains and a deeper understanding of the physics of the flow around the vehicle should be reached to assess the importance of each single term on the experimental result. In this paper a comparison of the results obtained by three experimental campaigns, performed in the 2 test sections of the Politecnico di Milano wind tunnel (PMWT) and at the wind tunnel T103 of the Central Aerodynamic Institute TsAGI (TsAGI) on the same train model is provided. The model is a 1:10 power car and it represents a reference train built by Bombardier, called “Aerodynamic Train Model ” (ATM) for comparison purposes [1]. The model shape is similar to an ICE2 train and it shows all the interesting aerodynamic features of high speed trains. The tests have been performed using, not only the same model of the power car but also the same end car. The model allows to measure the global forces using both internal and external force balances and it is also equipped by pressure taps to measure the pressure distribution on the carbody. Tests have been performed on a flat ground configuration trying to reproduce the same boundary condition by means of splitter planes. The different characteristics of the used wind tunnel plants allows to investigate the effects related to the Reynolds number on the different components of the global aerodynamic force, to the blockage ratio, and to the adoption of open or closed wind tunnel test section. The sharing of the same scaled model and the availability of detailed data regarding the pressure distribution in the different test conditions allow a good insight in the modeling of the train aerodynamics in wind tunnel.

2 THE ATM TRAIN MODEL

The ATM train model is a 1:10 simplified version of an ICE2 train shape (see Figure 1a), that is used by Bombardier for research and benchmark purposes. It is made by an instrumented locomotive vehicle and by an endcar model with the same nose geometry of the leeding car that is used for the boundary condition reproduction. A gap of 5mm is left between the leading car and the end car to grant that they are mechanically disconnected.

The basic dimensions of the wind tunnel model are: length=3.557m, width=0.299m and height=0.385m. The model can be equipped with bogies and with a spoiler under the train head, in the present research the model without bogies and without spoiler is considered. In this version the bogie cavities are closed by covers (Figure 1b). The model has an internal aluminum frame allowing for the connection with the supporting system in the central part.

The model is also instrumented with 91 pressure taps distributed along 8 transversal sections along the train axis (Figure 1c). The position of the instrumented sections is reported in the following table while an example of pressure taps distribution in the section is reported in Figure 1c for section 6:

Section n.	1	2	3	4	5	6	7	8
Distance from the train head [mm]	100	175	250	500	700	1500	2000	2500

Table 1: position of the instrumented sections along the train.

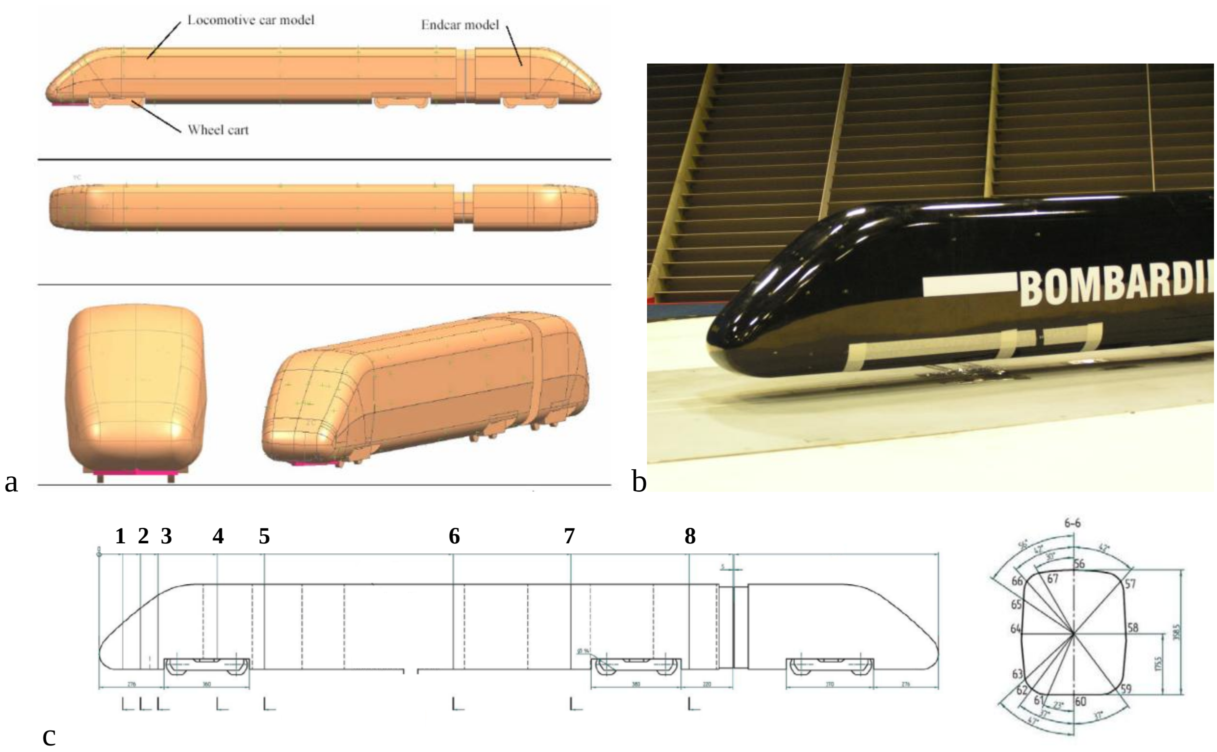


Figure 1: ATM model geometry (a); ATM model without bogies and without spoiler in the PMWT (b); position, along the train axis, of the sections instrumented with pressure taps (c)

3 WIND TUNNEL TESTS

The results of three wind tunnel campaigns will be compared in this papers, two of them was performed at the Politecnico di Milano Wind Tunnel (PMWT) and another one at the TsAGI T103 wind tunnel (TsAGI). Wind tunnel tests have been performed on a true flat ground scenario (flat plate without rails). A splitter plate was used in all the considered wind tunnel campaigns in order to grant similar incoming flow conditions on the model.

Aerodynamic forces were measured by external force balances while the pressure distribution was measured through pressure scanners positioned inside the train model.

3.1 TsAGI wind tunnel tests

TsAGI T103 wind tunnel tests were performed in an open test section with a wind speed range between 30 and 70m/s, which corresponds to Re-numbers of $Re_l = 0.6{\sim}1.4{\cdot}10^6$. Tests were performed at different yaw angles between 0 and 60 deg. The blockage ratio varies between 4% and 8% for yaw angles between 10° and 30°.

A sketch of the wind tunnel plant is reported in Figure 2a. The flat ground consists of an elliptical shaped floor which contains a turntable (Figure 2b).

The model is fixed on the turntable which can be automatically rotated during the wind tunnel measurements. Figure 2b shows the whole set up of the experiment including the ATM model and the elliptic splitter plate. An external six-component force balance was used to measure the aerodynamic forces and moments on the leading car. Data averaging was performed over 4s for each angle with a sampling frequency of 100Hz.

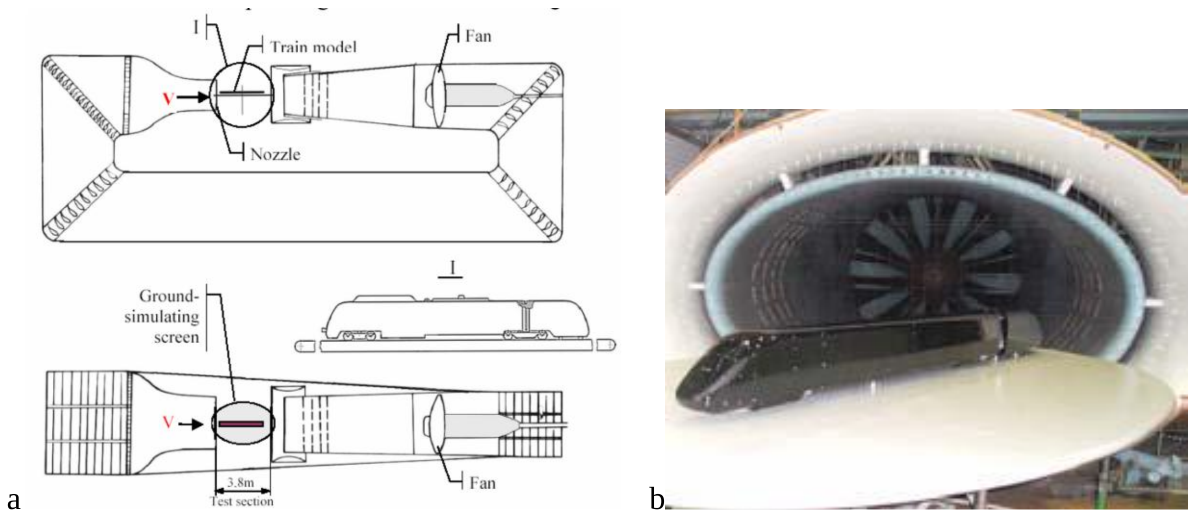


Figure 2: TsAGI wind tunnel plant scheme (a), ATM model in the TsAGI test section (b)

3.2 PMWT wind tunnel tests

The PMWT plant is a closed circuit wind tunnel with two test sections: a larger one (14m x 4m) where tests can be carried on with a wind speed up to 15 m/s (PMWT LS tests section) and a nominal turbulence intensity IT<2% and a smaller one (4m x 4m) where tests can be carried on with a wind speed up to 50 m/s (PMWT HS tests section) and a nominal turbulence intensity IT<0.2%. A sketch of the wind tunnel plant is reported in Figure 3.

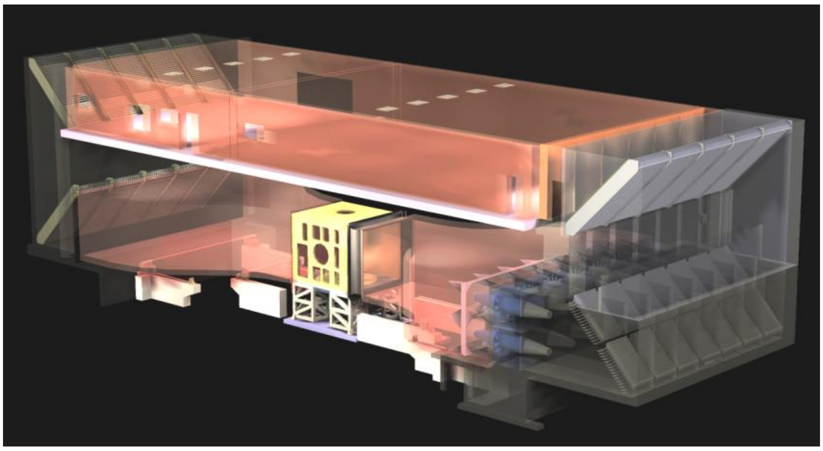


Figure 3: PMWT wind tunnel plant scheme

Tests on the ATM model were performed in both the test sections using a RUAG 6 components external force balance. Tests in the PMWT LS test section were performed in a wind speed range between 7 and 15m/s, which corresponds to Re-numbers of $Re_l = 1.4 \cdot 10^5 \sim 3.0 \cdot 10^5$, with a blockage ratio that varies between 0.9% and 4.7% for the considered yaw angles between 5° and 90°. Tests in the PMWT HS test section were performed in closed arrangement at a wind speed range between 7 and 50m/s ($Re_l = 1.4 \cdot 10^5 \sim 1.0 \cdot 10^6$), with a blockage ratio that varies between 3% and 10% for the considered yaw angles between 5° and 30°.

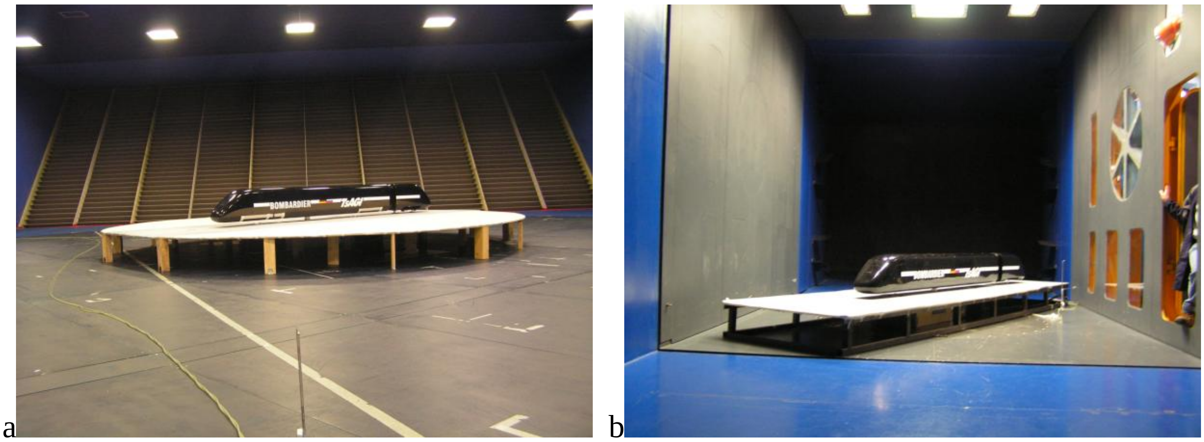


Figure 4: ATM model in the PMWT LS test section (a) and in the PMWT HS test section (b)

Pressure measurements have only been recorded at 14 m/s during the PMWT LS tests session using a PSI high frequency pressure scanner system.

4 WIND TUNNEL RESULTS

The dependence of the aerodynamic coefficients on the yaw angle will be compared in the following paragraphs. Coefficients are computed according to the sign convention reported in Figure 5 and to the following formulation:

$$C_{Fi} = \frac{F_i}{\frac{1}{2}\rho \overline{U}^2 S} \qquad C_{Mi} = \frac{M_i}{\frac{1}{2}\rho \overline{U}^2 Sh} \qquad C_p = \frac{\Delta p}{\frac{1}{2}\rho \overline{U}^2} \tag{1}$$

where F_i (i = x,y,z) are the aerodynamic force components in the train's reference system (Figure 5), M_i (i = x,y,z) are the corresponding moments and Δp is the differential pressure measured on the generic pressure tap. In equation (1), ρ is the air density, U is wind speed, h is equal to 3m (full scale), and S is a standard reference surface which is equal to 10m^2(full scale).

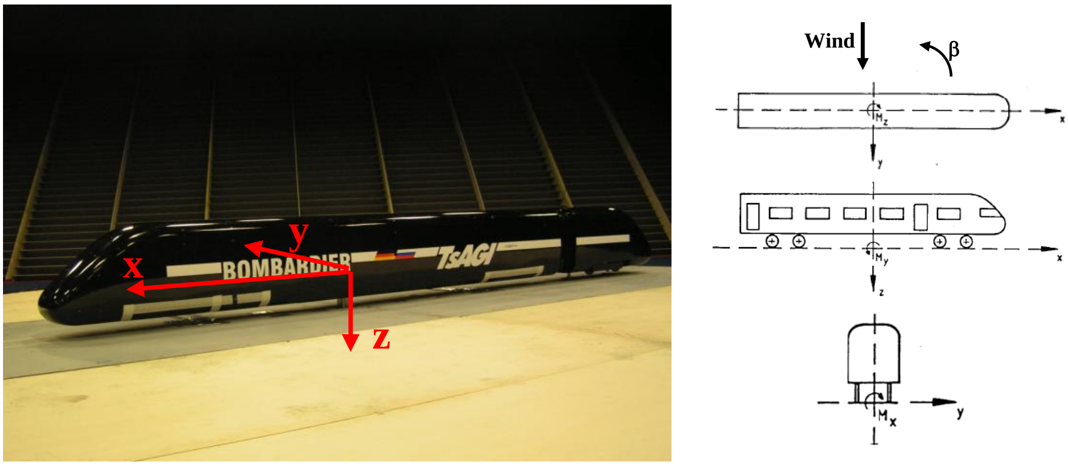
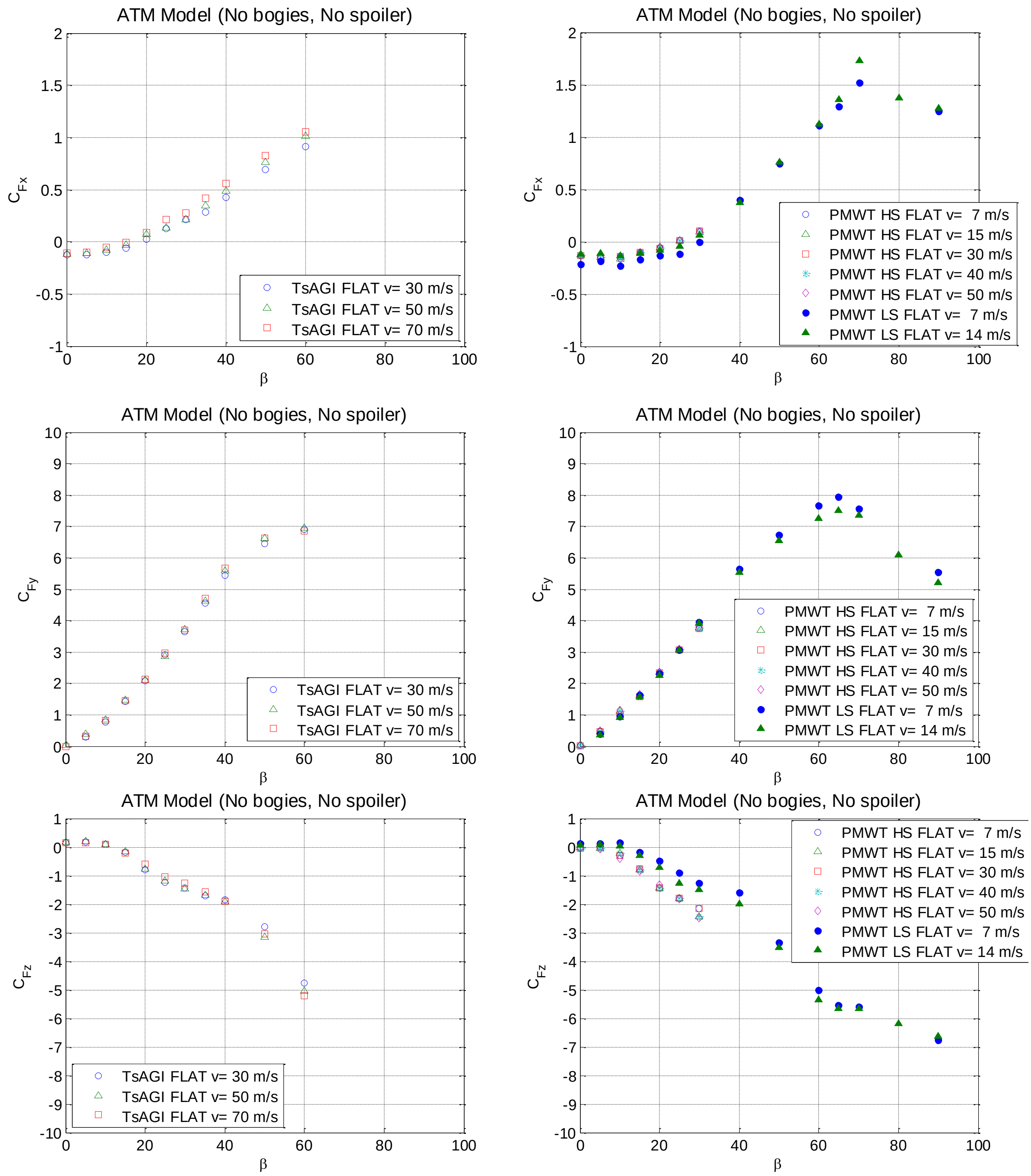


Figure 5: Aerodynamic coefficients' sign convention

4.1 Aerodynamic coefficients

In the following figure a comparison between the aerodynamic coefficients measured at TsAGI and PMWT is reported for different mean wind speeds and different yaw angles β (expressed in deg). Results obtained at PMWT in the high speed (HS) test section and in the low speed (LS) one are overlapped in the figures on the right.

Furthermore a comparison in terms of $C_{Mx,lee}$ coefficient is reported in Figure 7.



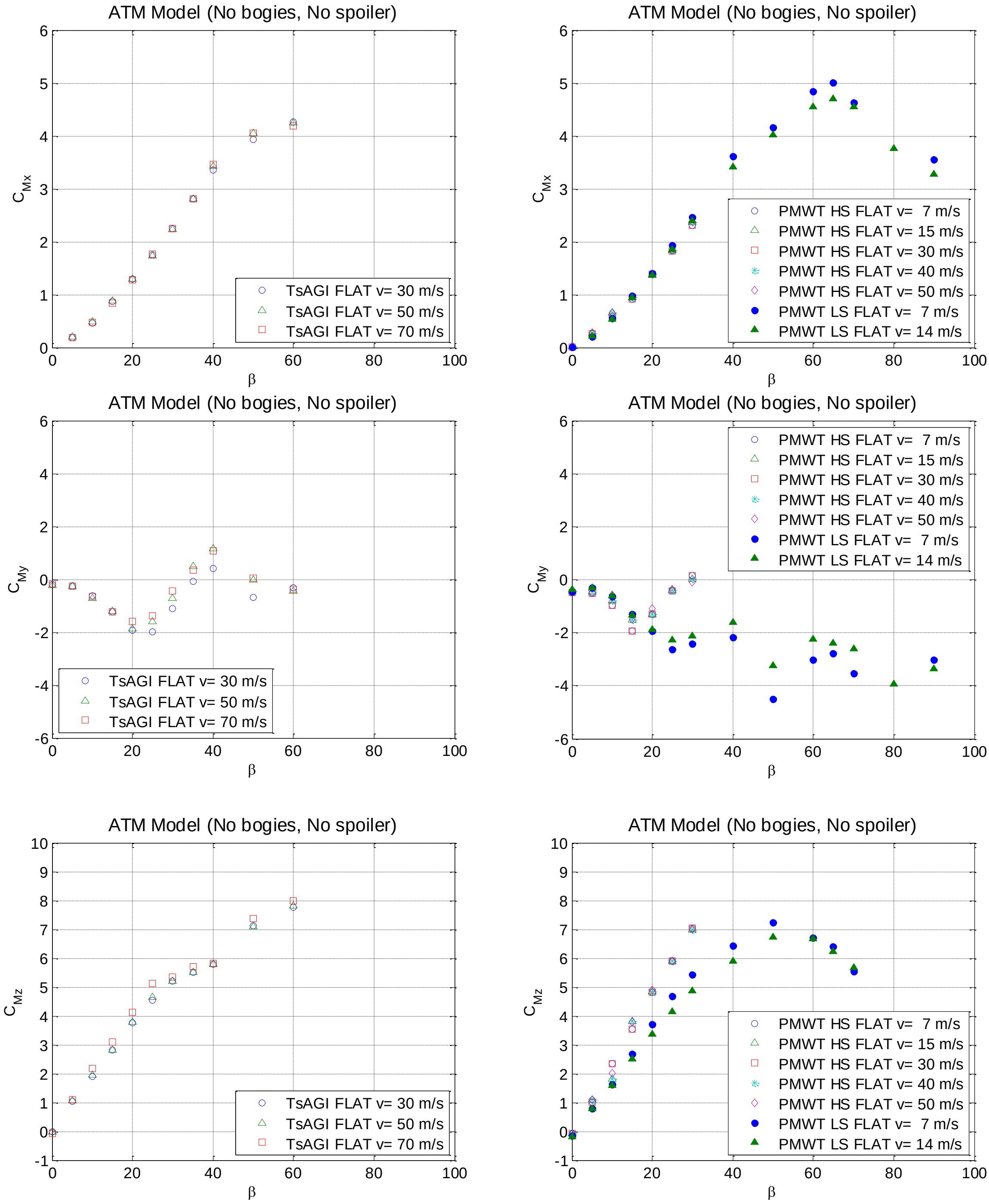


Figure 6: Aerodynamic coefficients vs yaw angle

A very good agreement is visible by the comparison of the TsAGI and the PMWT LS results for all the aerodynamic coefficients apart from C_{My}.where a similar trend is visible only up to 20 deg. For higher yaw angles, the TsAGI results show a double sign change from negative to positive C_{My} values at 35 deg and from positive to negative values at 50 deg, while PMWT LS results show the same slope changes, they never reach positive C_{My} values.

A C_{My} trend closer to the TsAGi results is highlighted by the PMWT HS data even if they seem to anticipate the minimum (β=15 deg) and the crossing of the x-axis (β=30 deg) to lower yaw angles.

PMWT HS results differ significantly from the PMWT LS results for the C_{Fz} and C_{Mz} coefficients where HS data overestimate the consistent values of the PMWT LS and TsAGI results.

Differences in the C_{Fz} and C_{My} coefficients indicate, for the PMWT HS data, a higher vertical lifting force positioned in the forepart of the train. It is difficult to explain this experimental evidence starting from the global force measurement, since, even if the model and the measurement system are the same, tests are performed with different turbulence intensity levels and different splitter plates. Similar considerations hold also for the C_{Mz} coefficient.

TsAGI results show a small Reynolds number dependency for the C_{Fx} coefficient that increases the slope at yaw angles higher than 20 if the wind speed is increased. The same aerodynamic coefficient seems to be not affected by Reynold number effect in the PMWT data where only the 7 m/s LS coefficient shows some differences from 0 to 30 deg.

C_{Fy} and C_{Mx} coefficients don't have any Reynolds number dependency both for TsAGI and PMWT results up to 60 deg. A different maximum value is reached by the PMWT LS data, being the lower wind speed the more conservative.

Reynolds number effects are negligible also comparing the TsAGI and the PMWT HS results for the C_{Fz} and C_{Mz} coefficients even if the best agreement is shown between the TsAGI and the PMWT LS data for these coefficients.

Another discrepancy between TsAGI and PMWT LS results is present at β=60 deg that represents the largest yaw angle tested at TsAGI due to the test section/model dimensions. C_{Fy} and C_{Mx} seem to change the slope passing from 50 to 60 deg in the TsAGI results while they continue with a different trend in the PMWT LS results. Also looking at the comparison on the C_{Fx} and C_{Mz} coefficients a difference appears at 60 deg while a very good agreement is present on the other yaw angles. This could be explained considering that, at 60 deg, the model in the TsAGI open tests section is too close to the boundaries of the flow while in the large PMWT LS test section results are less affected by the boundary conditions and wind tunnel tests may be extended up to 90 deg.

Figure 7 reports the comparison between TsAGI and PMWT data in terms of $C_{Mx,\ lee}$ representing the overturning moment computed around the leeward rail axis that is a key parameter for the evaluation of the overturning effects induced by cross-wind. From the comparison it is visible the complete agreement up to 50 deg and the negligibility of the Reynolds number effects on this coefficient.

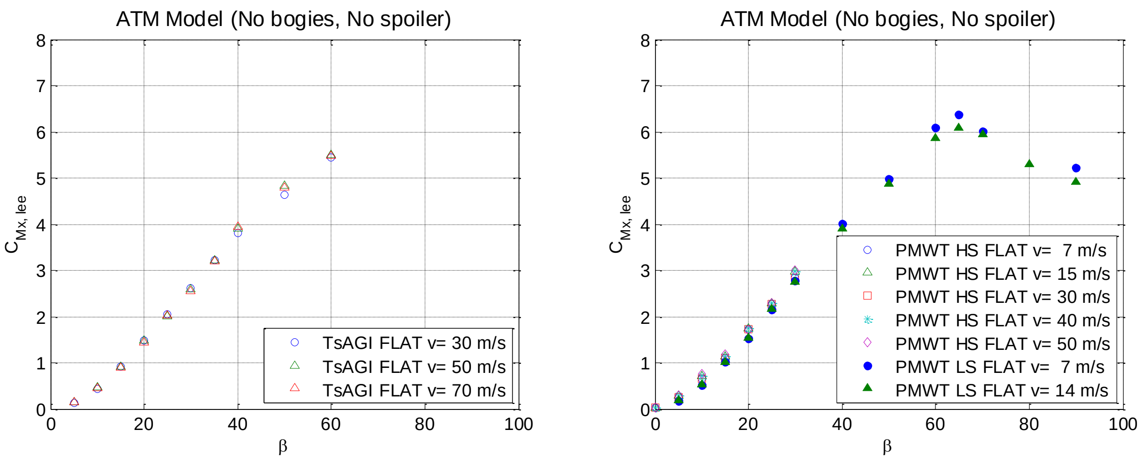


Figure 7: Comparison of $C_{Mx,lee}$ coefficient vs yaw angle

4.2 Pressure distribution

The comparison of the pressure distribution on all the 8 sections measured at TsAGI and at PMWT LS is reported in Figure 8 for the yaw angle β=30 deg in terms of pressure coefficients C_p. Arrows and points inside the section boundary represent positive values.

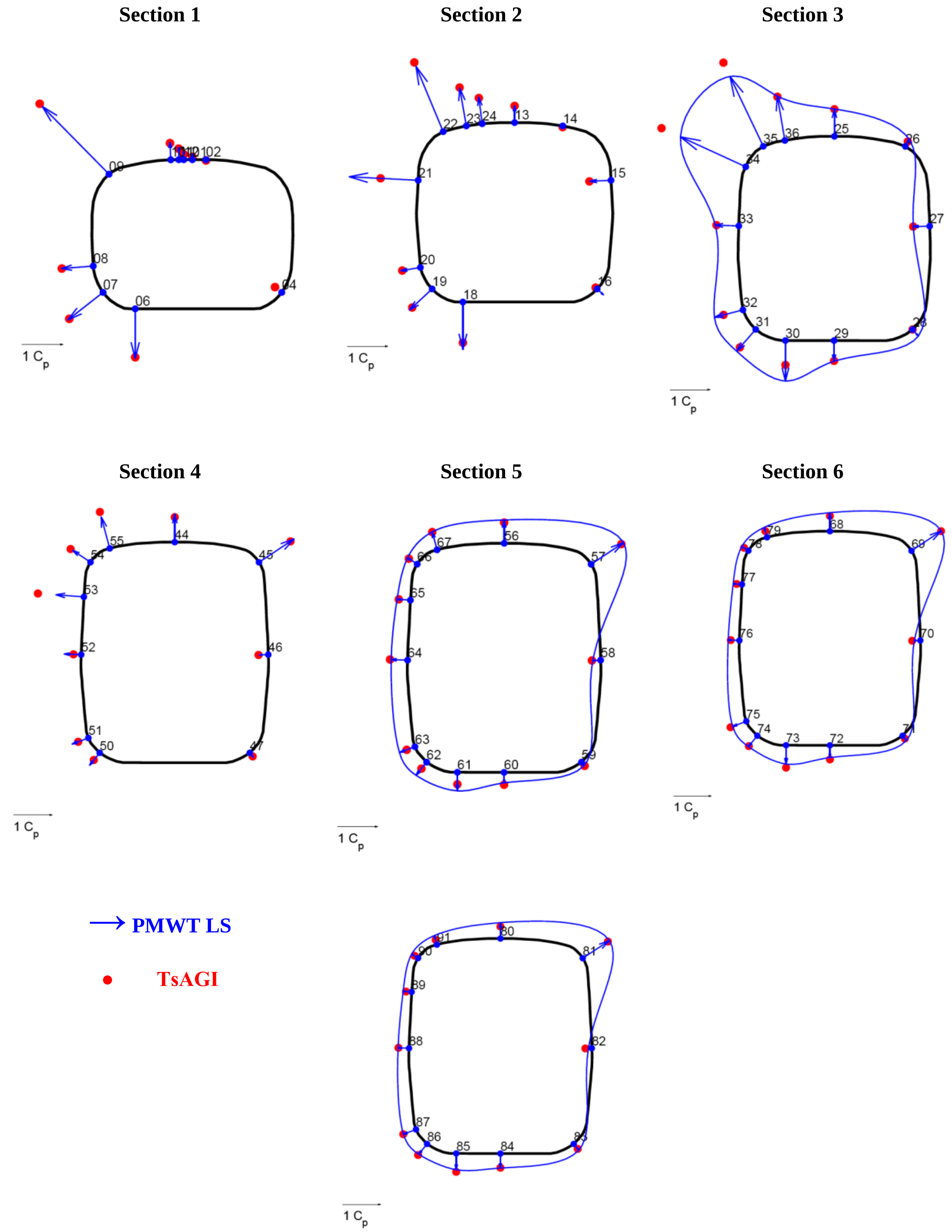


Figure 8: Pressure coefficient distribution at β=30 deg (blue arrows: PMWT; red points: TsAGI)

A very good agreement is visible on all the 8 sections at the different pressure taps positions. TsAGI values show a slightly higher suction zone in the upper leeward part of section 3 and section 4. This difference confined in the forepart of the train model could explain the negative value of the PMWT LS C_{My} coefficient compared to the almost null value of the TsAGI being the C_{Fz} coefficients equal for both the cases.

Smaller discrepancies are visible in the lower leeward part of sections 3 and 5 where PMWT LS results present a higher suction.

Similar differences appears also in the comparison between the TsAGI results and CFD results presented in [2] and PMWT results seem to be closer to the numerical simulation data.

5 CONCLUSIONS

- Good agreement is reached by the comparison of wind tunnel results performed at different wind tunnel plants on the same 1:10 scaled train model.
- Results showed negligible Reynolds number effects especially for those coefficients involved in the cross wind analysis (C_{Fy} and C_{Mx})
- Differences in the results are present in C_{Fz}, C_{My} and C_{Mz} coefficients between PMWT HS and PMWT LS data while TsAGI (open section) and PMWT LS (large closed test section) data are in good agreement on all the coefficients apart from C_{My} for yaw angles higher than 20 deg.
- Differences between PMWT HS and PMWT LS data may be due to different wind tunnel test conditions as turbulence intensity levels and splitter plate geometry being the model and the measurement set-up the same in both the wind tunnel campaigns.
- The different C_{My} behavior, for yaw angles higher than 20 deg, between TsAGI and PMWT LS data, can be explained by analyzing the pressure distribution measured on the train model especially in the upper and lower leeward parts of the train in the forepart.

Benchmark tests and benchmark vehicles represent a good tool to compare and validate data and wind tunnel procedures that is also included in standards [3]. Among all the parameters affecting the wind tunnel results analyzed in the present work, Reynolds number seems to be not critical for cross wind analysis while other parameters as turbulence intensity and boundary layer treatment affect only some aerodynamic coefficients.

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