CFD ANALYSIS OF THE UNDER CARBODY FLOW OF AN ETR500 HIGH SPEED TRAIN

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1 INTRODUCTION

To study the ballast projection problem, consisting in the aerodynamic effects induced by the train passing that causes the lifting and dragging of the stones lying between rails, a research project was coordinated among European train constructors and line managers. The project, named AOA (Aerodynamic in Open Air), facing also other topics, developed different numerical and experimental approaches to investigate the problems. The aim is to define what is the mechanism that generates the phenomenon of the fly stones “ballast projection”, and how it is correlated to the flow condition, present underneath the train during the operating conditions. The study of the flow conditions have been performed using CFD (Computational Fluid Dynamics) simulations and experimental tests in wind tunnel and in full scale. The under-carbody region of a train is a very complicated region, due to the presence of the bogies, of cavities with complex geometry as the inter-car gap. Furthermore the geometry characteristics of this region, that is confined between the railway and the bottom of the train, may vary also if different high speed trains are considered since different constructive schemes are used: distributed or concentrated power distribution, different bogie architectures, different auxiliary parts geometries.

The CFD analysis presented in this paper gives a contribution in the definition of what are the flow patterns in the under carbody region for an ETR500 PLT high speed italian train.

The study took advantage from other preliminary studies performed by other partners inside the same AOA project whose major results are: the choice of the most appropriate and the most cost effective turbulence model obtained after specific numerical-experimental comparison [1]; the definition of an equivalent roughness to take into account the ballast friction effects [2]; the specifications of the more appropriate grid parameters and boundary conditions. One of the aim of the project was, in fact, the synthesis of a procedure to perform simulations in the under floor region using CFD approaches. The present work represents the final
step of the project consisting in a validation of the whole procedure, with a final comparison between the numerical results and some experimental results that were obtained during an experimental campaign on an Italian railway line [3] on ETR500 PLT trains.

The procedure validation was split in the following parts:
1) geometry reconstruction
2) domain decomposition
3) mesh generation
4) simulation
5) post processing and comparison with experimental data

The most relevant results for each of the over mentioned activities will be presented in the paper.

2 CFD PROCEDURE

2.1 Geometry reconstruction

The geometry of a motor car and of a trailer car of the ETR500 PLT high speed train were completely redrawn paying attention to simplify all the geometrical details that are considered not significant from a fluid dynamic point of view and that could produce too much effort in the mesh generation. The part of the train that required the greater simplifications were the bogies where the large number of components, connections, cables and so on were replaced with simpler geometries. An example of the motor bogie simplified geometry is reported in Figure 1 in comparison with a 3D drawing of the real geometries.

![Figure 1: Geometry simplified reconstruction of the motor bogie.](image)

The ETR500 PLT uses a lumped power distribution with 2 motor bogies under the motor car and trailer bogies under the trailer cars. The bogie regions are similar for the trailer bogies but are different for the two motor bogies. Another region that required particular attention was the inter-car gap region where the more complex geometries have been substituted by other smoother geometries.

2.2 Domain decomposition

A marching technique was adopted to perform the CFD computation in order to better exploit the computational resources. The marching technique consists in splitting the computational domain along the train axial direction in order to perform sequential simulations of short parts of the train using the output flow of the previous simulation as input for the following one.
The method applicability requires that the solution on the output of the single simulation was stable and symmetric. This consideration was taken into account during the choice of the splitting planes and was verified during the application of the procedure. The splitting planes also answer the request of modularity and the full train geometry can be rebuilt using only the three modules reported in Figure 2.

2.3 Mesh generation

The mesh generation procedure was performed separately for the more challenging bogie regions that include also the inter car gap regions (red volumes in Figure 2) and for the less demanding external domain. Non conformal interfaces was used at the boundary planes between the sub-volumes. Special care was paid to put the surfaces of the non conformal meshes in not critical zones for the flow solution. Mesh refinements are provided close to all the walls of the domain using boundary layers of hexahedral cells granting that the cell dimension are suitable for the near wall treatment used for the different rough surfaces. Outside the boundary layer a tetrahedral mesh is adopted. Table 1 reports the grid dimensions of the 3 domain used in the marching technique.

<table>
<thead>
<tr>
<th>Module</th>
<th>n. elements bogie regions</th>
<th>n. elements external regions</th>
<th>Total n. elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.08 e^6</td>
<td>2.68 e^6</td>
<td>7.77 e^6</td>
</tr>
<tr>
<td>2</td>
<td>9.62 e^6</td>
<td>1.54 e^6</td>
<td>11.16 e^6</td>
</tr>
<tr>
<td>3</td>
<td>8.30 e^6</td>
<td>1.48 e^6</td>
<td>9.78 e^6</td>
</tr>
</tbody>
</table>

Table 1: Example of a table.

2.4 Simulations set-up

Three steps of the marching technique were performed. Symmetry boundary conditions are used for the lateral and top surfaces of the domain, while at the output a pressure condition is prescribed. A pressure condition was also used for the inlet condition of the first step of the marching technique while, for the other steps the inlet condition is taken from the result of the previous step at the outlet surface. The wall belonging to the train are moving walls at a speed equal to 77.8 m/s. The bottom wall inside the rails are considered rough and the adopted parameter of the roughness corresponds to what was computed in [2].

The realizable k-ε model was used with a second order scheme for momentum, pressure, k and ε equations. Static simulations have been performed and a verification that the solution was not time dependent was performed.

3 RESULTS

The flow development in the region under the train is reported in Figure 3 where a contour plot of the non dimensional x-velocity \( C_u \) is reported for the 3 steps of the marching technique.
The analysis of the pressure and of the velocity gradients in the flow field allows to estimate the effect on the ballast bed. In Figure 4, the vertical profiles of $C_u$ in the middle vertical plane are reported, on the left, for different positions along the train axis that are highlighted on the right with vertical lines.

A deeper investigation of the flow patterns will be presented in the full paper together with the comparison with what was experimentally measured on the line.

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REFERENCES

