CFD assessment of the effect of windblown sand on a high-speed train

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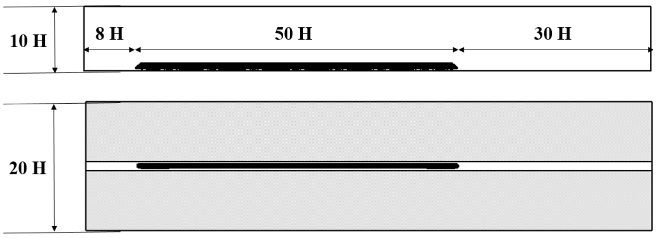
Abstract

Aerodynamic effects have long been a matter of concern in the design of high-speed trains [1]. Issues resulting from the increased velocity, including crosswinds [2] and ballast flying [3], have recently arisen as important fields of research. In contrast, the purpose of this paper is to study a less researched phenomenon: windblown sand. The response of high-speed trains to demanding environments such as deserts is still relatively unknown, although a few works have been reported in this field [4]. For this reason, this paper aims to assess the consequences of train motion in a particulate matter atmosphere using computational fluid dynamics (CFD) simulations while focusing on the forces acting on the body and the wear of the materials.



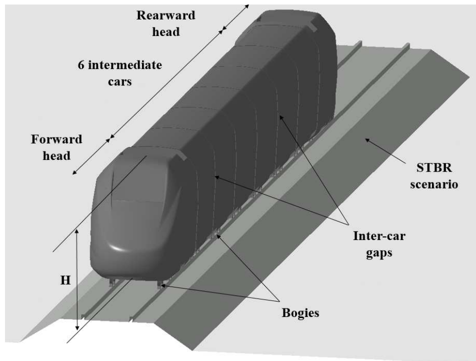


Figure 1: Geometry model (left) and computational domain (right).

The geometry selected for this study is a simplified full-scale model of the ETR500, with a total length of 200 m. This model is employed in a single-track ballast and rail (STBR) scenario. The computational domain is extended 8 H beyond the nose of the forward head and 30 H from the rearward head to the outlet. The height and width of the outer box, which limit the domain, are 10 H and 20 H, respectively [2] (shown in Figure 1). Two different meshes were created to evaluate the mesh convergence. In addition, the geometry model was validated with experimental data taken from previous works. In Figure 2, a good agreement between the meshes is shown, with the results falling between the limits of the experimental and simulation results of Rocchi et al. [5].

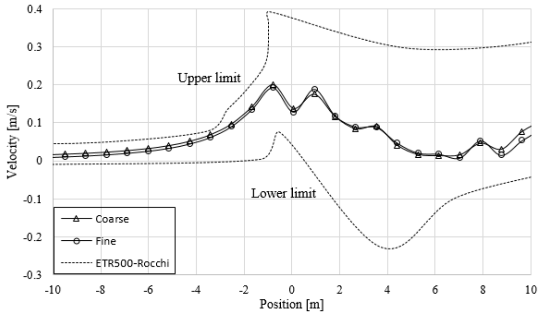


Figure 2: Non-dimensional velocity profile along a line 0.2 m from the track centre and 0.025 m under the top of the rail.

The simulations were performed on the commercial software Ansys Fluent, using the k-epsilon viscous model for the fluid phase [6]. In contrast with other references [4], a Eulerian-Lagrangian approach was chosen, using the Discrete Phase Model (DPM) of Fluent. In this case, the sand was treated as a collection of individual particles with no interaction with the continuous phase, due to the size and concentration criteria. These particles were injected from a vertical plane parallel to the inlet of the domain, representing the stratified particulate matter in the air, and from the track, representing the lying sand and allowing the slipstream of the train to influence these particles. The implementation of a User-Defined Function (UDF) allows for a representation based on contours of the distribution of impacts on the train surface, thus indicating the areas with greater wear, the angle of these impacts in relation to the walls and the velocity of the particles when impacting the model. These factors allow for a determination of the forces on the train produced by the windblown sand.

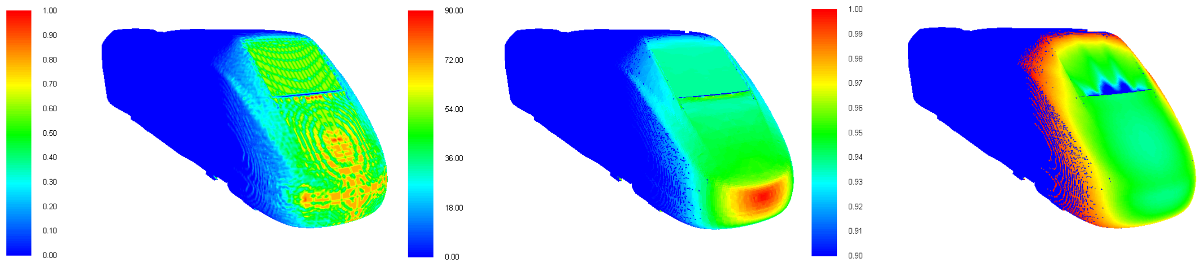


Figure 3: Contours of the impact distribution (left), angle (middle) and velocity (right).

The results indicate a large number of impacts with low velocities in the nose, whereas the sides of the head are subjected to fewer impacts with higher speeds. The remaining regions of the power head and the first intermediate cars are well protected against particles. However, the tail of the train, especially the roof, suffers from collisions with sand grains that were displaced after impacting the forward head. For the particles lying on the track, only the roughness of the bogies contributes to their upward motion due to the small gap between the cars; no sleepers or ballasts are considered. The distribution of impacts in the bogies region represents a matter of concern because several moving elements are located in this area. Regarding the forces acting on the train, the ETR500 model moving inside a sand-laden flow exhibits drag increases of up to 15% of the aerodynamic resistance. Lateral and lift forces are negligible in the case of a still atmosphere, but not in the presence of crosswinds. Furthermore, by accounting for the properties of the materials in this model, it is possible to predict the duty life of pieces exposed to severe wear, such as windscreens or headlamp shields.

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