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Multi-scales gap bridging for windblown sand as basis of CFD simulation of trains in a sand and dust environment

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SUMMARY:
In 2022, Siemens Mobility won a contract for a modern, safe and integrated rail system in Egypt supplying trains based on its proven Velaro, Desiro HC and Vectron product platforms. Since then, special efforts were made to improve their design to operate in sand and dust conditions.
To assess the impact of the sand and dust phenomenon, Computational Wind Engineering (CWE) is increasingly used during the various design stages. However, due to the sparsity of the geomorphology, arid or semi-arid in Egypt, the weather conditions, or the rapidly evolving typology of the cross-sections over the full length of an alignment, the derivation of appropriate boundary conditions to be adopted during the CWE design phases remains a challenge. A framework methodology is proposed to model the gap between macro and micro scales involved in windblown sand (WbS), allowing to perform the required CWE computations and the CFD simulations for the vehicles. The latter ones were carried out to better understand the interaction of the train with sand and dust, to determine the expected sand and dust loads, and to design measures to reduce these loads.

Keywords: Regional & High-Speed Train, Windblown sand, Computational Wind Engineering, multiscale modelling

1. INTRODUCTION

In 2022, Siemens Mobility signed a contract for a 2,000-kilometer modern, safe, and integrated rail system that will connect 60 cities across Egypt for people and goods with trains that can travel up to 230 kilometres per hour. By shifting to rail, the fully electrified network will reduce carbon emissions by 70 percent compared to current car or bus transportation, further supporting Egypt's efforts to transform its mobility to a more sustainable one (Siemens, 2022).

To equip the entire rail network, consisting of three lines, Siemens Mobility will deliver trains based on its proven product platforms. These include 41 eight-car Velaro high-speed trains, 94 four-car Desiro high-capacity regional trains, and 41 Vectron freight locomotives (Siemens, 2022). However, these product platforms were mainly designed to operate in European conditions and not in the sand and dust conditions found in Egypt. Therefore, special efforts were made to improve the design to cope with sand and dust loads.

The first step in designing a train for such conditions is to know the exact environmental conditions along the tracks. To this end, a cooperation between Siemens Mobility GmbH, Optiflow and WSMM was established to investigate the mechanisms of sand and dust particle transport and to determine, among other things, the sand particle distribution and concentration (on the ground and in the air) as well as representative wind and temperature conditions.

1. CONDITIONS OF SAND AND DUST ALONG THE TRACKS

Windblown sand affects civil structures and infrastructure in sandy desert environments (Bruno et al. 2018). Railway infrastructure is particularly affected due to the specific sensitivity of infrastructure components to windblown sand and the increasing number of projects currently underway and planned in sandy regions in North Africa, the Middle East, and Southeast Asia.

Windblown sand interacts with man-made surface obstacles of all types, causing sand erosion, transport and sedimentation around them. This can lead to detrimental effects (Bruno et al. 2018). However, the rigorous assessment of wind-blown sand risk is still in its infancy in the scientific literature and engineering practice.

CWE is increasingly used in the different design stages. However, the derivation of appropriate boundary conditions remains a challenge, especially along large railway megaprojects (Raffaele and Bruno 2020).

In the present study, the authors propose an innovative approach aimed at bridging the gap between the macro and micro scales involved in WbS transportation (see Fig. 1). Indeed, WbS processes range from macroscale geomorphological features, such as dune fields and sand plains, to meso- and microscale windblown sand transport features, i.e. windblown sand transport around the railway body and specific infrastructure components.

Macro geomorphic features affecting windblown sand transport are identified through systematic field observations from virtual land scans of time series of satellite imagery and supplemented by systematic site visits. Macroscale open field windblown sand transport is then quantified using a probabilistic approach that couples wind phase and sand phase inherent uncertainties.

CWE simulations are performed using the macroscale results as inlet boundary conditions to elucidate the wind flow pattern around the rail body and to identify sand erosion and deposition zones. At the same time, the CWE results form the initial condition for the multiphase Erosion Transport Deposition - Avalanching (ETD-A) simulation (Lo Giudice et al., 2019).

Finally, ETD-A results are implemented as boundary conditions for multiphase Lagrangian Sand Grain (SG) simulation of sand particle transport around specific infrastructure components.

Specifically, this study takes advantage of (i) CWE and ETD-A simulations to assess the amount of sand sedimentation over the top ballast of a railroad embankment and induce ballast contamination, and (ii) Lagrangian SG simulations of windblown dust.

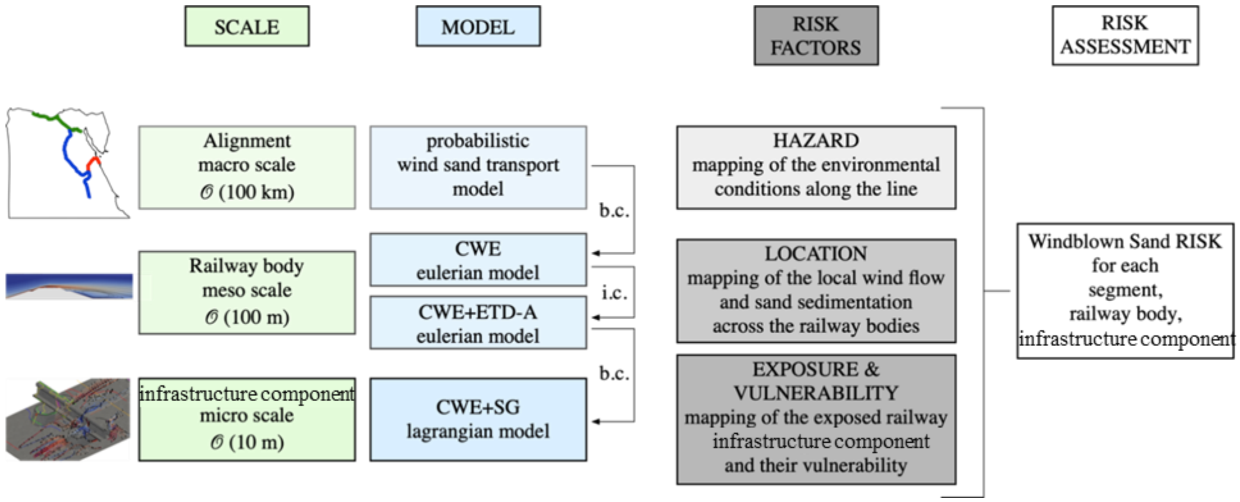

Figure 1. Framework of the study

2. CHALLENGES WITH SAND AND DUST FOR TRAINS

Sand and dust loads are a challenge for both the track and the vehicle. Generally, the track alignment shall consider suitable measures to avoid excessive sand and dust loads, however the vehicle also must meet special requirements to allow operation in such an environment. For this reason, extensive studies of not only the track but also the vehicle are important.

For numerical investigations the boundary conditions for the sand particles on the ground as well as in the air were tested with different approaches. For sand particles in the air, the relationship between air velocity and particle size has to be considered, which allows the distribution of the particles in the air to be derived. Investigations were carried out to determine how sand and dust on the track interacts with the different types of rail vehicles.

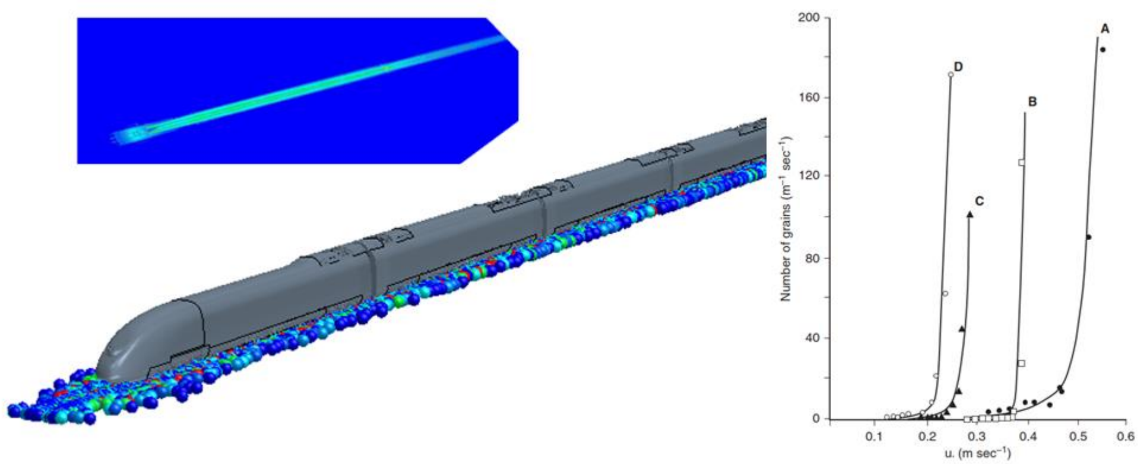

Figure 2. Numerical Boundary Conditions for the Lagrangian multi-phase (LMP) simulation [left]; shear velocity approach according to Nickling (Nickling, 2009) [right]

Due to its complexity, the mechanism of sand particle lifting is nearly impossible to be considered in a simulation of an entire train. As a workaround, Nickling's model (Nickling, 2009) was used, which describes the relationship between particle diameter and shear stress velocity on the edge of saltation. Depending on the particle size, it was possible to identify surfaces to be used as injector surfaces for the subsequent simulation. As can be seen in Figure 2, the induced shear stress on the ground is highly concentrated in the close vicinity of the rails, so these are the relevant areas from which sand and dust are influenced by the train induced airflow.

The identified and defined boundary conditions were used as input for extensive train CFD simulations. After the creation and meshing of highly detailed models of the Desiro HC and Velaro, considering even small gaps, several investigations were carried out in order to set up a suitable model for the simulation of sand and dust injected from the air and from the ground (particle model, restitution coefficient, injector planes, etc.). The aim of these simulations was not only to investigate and show how a passing train interacts with the sand and dust (see Fig. 3), but also to derive a parameter specification, to classify the train areas according to the sand and dust load, and to derive suitable modifications to reduce the sand and dust load.

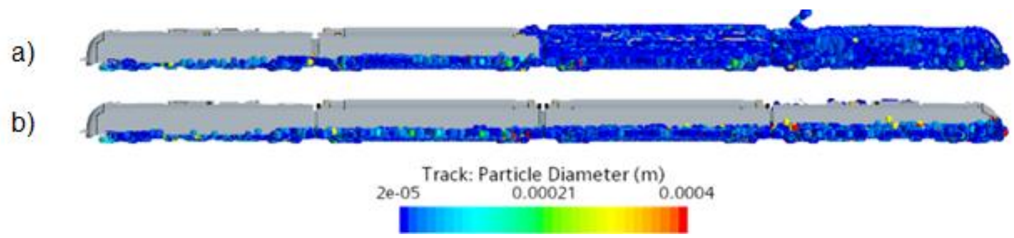

Figure 3. Sand raising before (a) and after (b) modification on a Desiro HC

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