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Experimental validation of a railway multibody model on a scaled track

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Abstract

This paper presents the experimental validation of a computational multibody model of a scaled railway vehicle. Several test have been carried out using an instrumented 1:10 scaled vehicle running on a 5-inch-gauge scaled track. The computational model proposed assumes a weakly couple lateral and vertical dynamics. The obtained results show a good agreement between experiments and simulation. It has been concluded that the computational model satisfactory reproduces the scaled vehicle dynamics.

Keywords: Multibody railways dynamics, Scaled railway vehicle, Scaled track, Efficient multibody formulation, Weakly coupled dynamics.

1 Introduction

In the field of railroad dynamics, multibody models used for on-board state observation, parameter identification and track geometry measurement must ensure a high computational efficiency, particularly when real-time simulations are required. In this regards, a simplified model based on the assumption of weakly coupled lateral and vertical dynamics was previously proposed by the authors [1] which considers arbitrary-geometry tracks including rail center-line irregularities.

Evidently, in order to test the performance and robustness of any numerical model, experimental validation seems essential. It is important to note that, one remarkable inadequacy of many works in literature is the lack of rigor in the validation of numerical models: most of them are validated through the use of "virtual experiment", obtained by more complex numerical models. Even though numerical tools to obtain "virtual experiment" can be an useful way for validation purposes, this should be only considered a first step in the validation process and, consequently, any numerical model must be finally validated through real experiments. Regarding the experimental validation, the use of scaled vehicles seems to be a useful tool for validation purposes, with a reduced operational costs. Some interesting examples of scaling design applied to the railroad field can be found in [2-4]. It must be noted that, the use of scaled vehicles comprises inconveniences related to the geometry scaling and causes design problems that should be given due consideration.

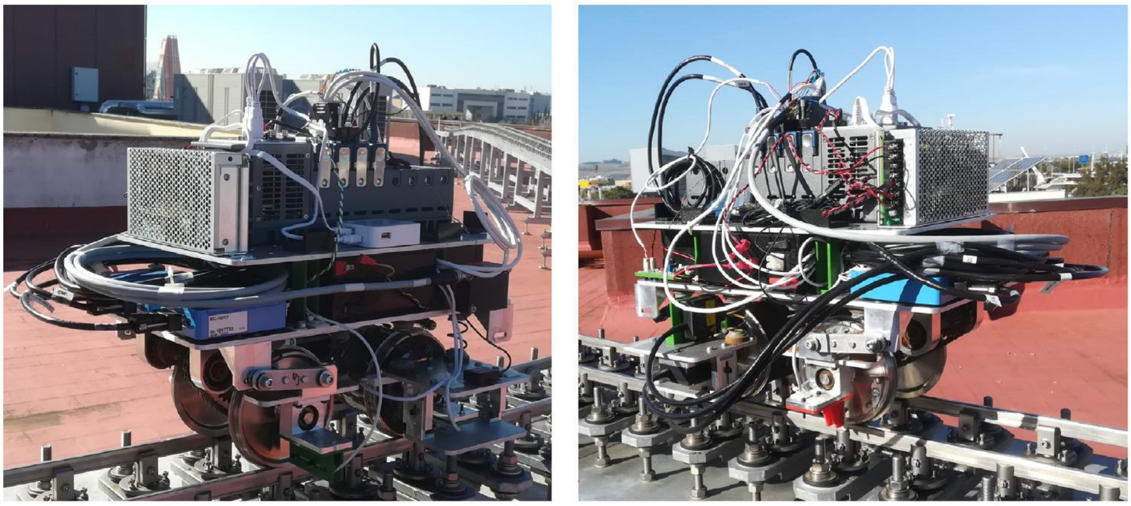
Taking into account the complexity of carrying out experiments on real railroad vehicles or railways facilities, the railways research group of the University of Seville has built a 1:10 scaled track facilities, comprising a 90 m long scaled track and an instrumented scaled vehicle [5]. The use of scaled track facilities is just a first step to validate the estimation methodology proposed by the authors, not being the results presented in this paper directly extendible to a full-scaled system.

The main goal of this work is the experimental validation of the numerical model proposed by the authors in [1]. Several experiments have been carried out on the experimental scaled track at different velocities in order to evaluate the numerical model performance under variable working conditions.

2 Methods

The computational model proposed in [1] is a linearized model of a railway vehicle that assumes that vertical and lateral dynamics are weakly couple. That means, both set of equation of motion (vertical and lateral) can be solved separately improving in that way the computational efficiency of the model. The model formulation is based on the use of Vehicle Track Frame (VTF) coordinates.

As mentioned before the main goal of this work is the experimental validation of the mentioned computational model. Figures 1a and 1b shows the instrumented 1:10 scaled vehicle used during the experiments [6]. As it can be observed is a single bogie including two wheelsets and a bogie frame connected through the primary suspension. The vehicle has been instrumented with several sensors whose measurements are used for the model validation process.

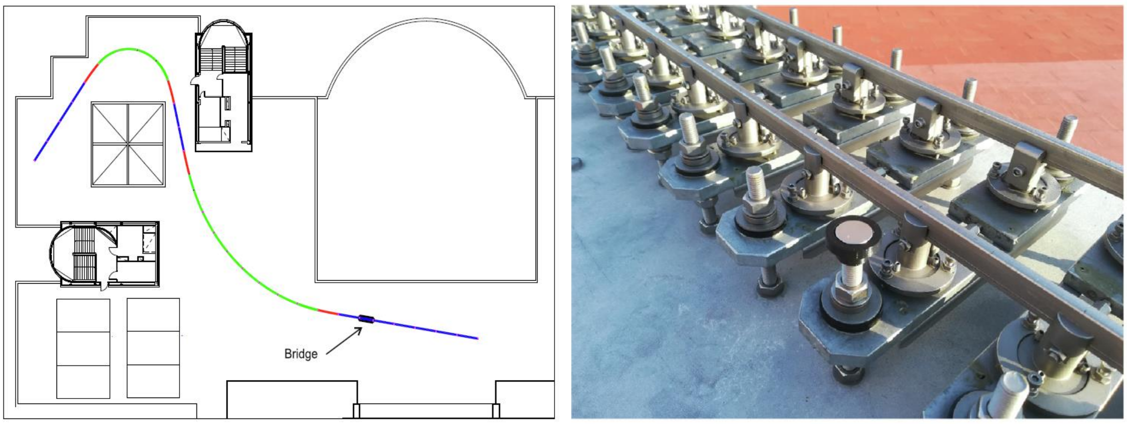


(a) (b)

Figure 1. Instrumented scaled vehicle on the track

The most important sensors installed on the vehicle are a couple of Inertial Measurements Units (IMU). One is located at the right bearing box of the front wheelset and the second one is installed at the center of gravity of the bogie frame. The inertial measurement of these sensors must be compared with the simulated acceleration and angular velocities drawn from the computational model. In addition, the vehicle has two high precision encoders, one on each wheelset that allow the calculation of the forward velocity and travelled distance.

The scaled track used in the experiments is a 90m long and 5-inch-gauge. Figure 2a shows the top view of the scaled track. As it can be observed it has a tangent section and two constant curvature section (24 and 6 meters of radius respectively) connected by transition sections. The rails are installed on a set of mechanisms (simulating the sleepers) that allow the manual generation of track irregularities. Using different bolts and nuts the track gauge, cant angle and relative height between rails can be modified. Figure 2b shows the scaled track and its mechanisms.



(a) (b)

Figure 2a. Scaled track geometry. 2b Scaled track assembly

3 Results

In this section, the measurement obtained from several experiment on the track are going to be presented. A total of six experiments have been carried out. They can be divided in two groups of three experiments each. The first group are the experiments where the vehicle moves forward on the track, and, the second group are the experiments where the vehicles moves backwards. Both set of experiment have been carried out at 1.7, 2 and 2.5 m/s. The goal was to analyse the vehicle's performance under different working conditions. For the sake of simplicity, only the most relevant results obtained during the experimental campaign are going to be presented in this manuscript.

Figure 3 shows the velocity profile during one of the experiments when the vehicles moves in the forward direction. As it can be observed the vehicles reaches a maximum speed of 2.5 m/s. The initial fluctuations of the graph are due to the PID action control on the vehicle's motor. This velocity profile together with the ideal track geometry and its irregularities have been introduced as inputs in the computational model.

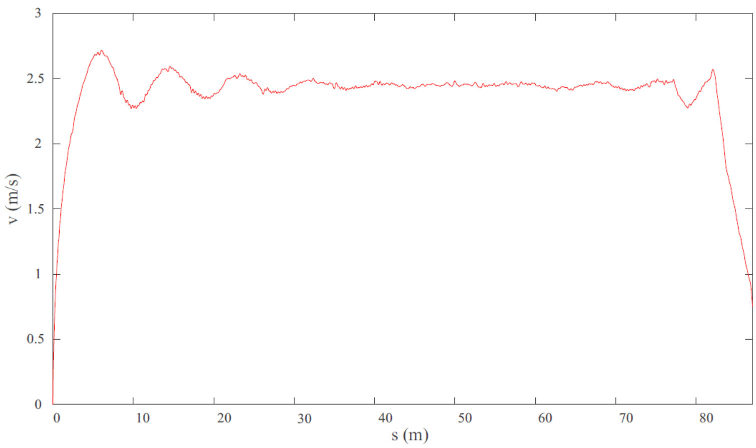


Figure 3. Experimental velocity profile

The following graphs show a comparison between the simulated and experimental data obtained during the experiment. Figure 4 shows a comparison between numerical and experimental data of the longitudinal and lateral accelerations and yaw angular velocity measured by the IMU installed on the front wheelset. Experimental results are coloured in blue and simulated results are coloured in red. As it can be observed there is a good agreement between both set of data.

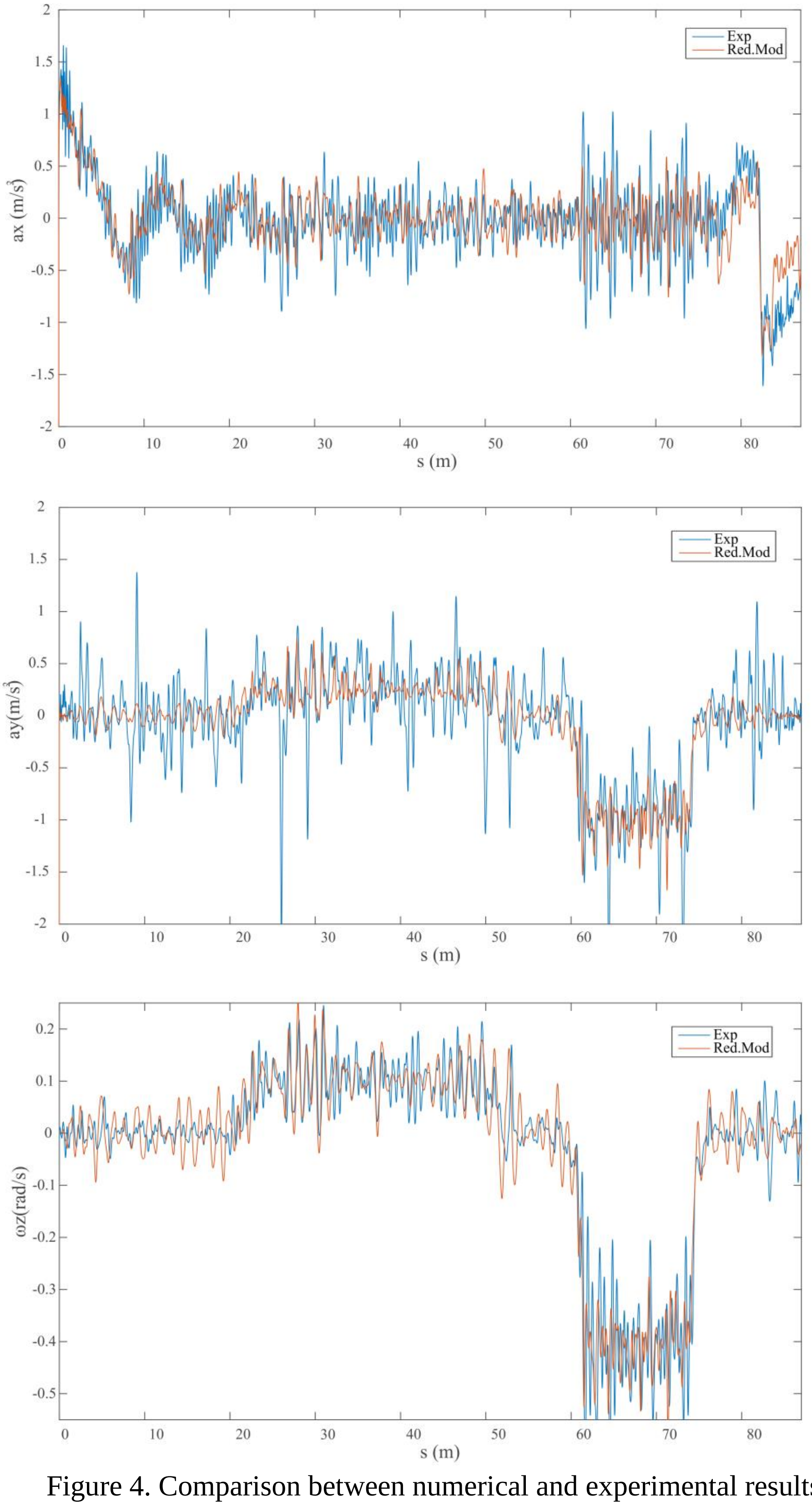


Figure 4. Comparison between numerical and experimental results

4 Conclusions and Contributions

In this work a computational multibody model of a railway vehicle has been experimentally validated using an instrumented scaled vehicle running on a scaled track. The vehicle is instrumented with inertial sensors whose measurements have been compared with the numerical data drawn from the simulation model. In view of the obtained results it can be said that the proposed railway model [1] satisfactory reproduces the dynamics of the scaled vehicle.

Having a precise, robust and efficient computational models is fundamental for the railways industry. In countries like USA, Korea or Japan, there are modern standards that allow computational simulations for vehicle approval. That represent a great advance for the railways industry, reducing the number of expensive field experiments and saving millions in cost. However, achieving a reliable computational model is a complex task that requires a lot of effort and experimentation. In addition, if real time simulation is required, for instance during online estimation of wheel-rail contact force, the computational model must be computationally very efficient. In this regard, the model proposed in this work assumes that vertical and lateral dynamics are weakly couple and they can be solved separately. That significantly simplifies the computational cost making the model real-time capable.

As a future line of work, this research work is currently working on the C++ implementation on the weakly couple lateral and vertical dynamics multibody model.

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