

Analogue Models of Rocking Suitcases and Snaking Trailers

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Abstract. The stability of towed vehicles is investigated with special attention to the analogy between the rocking suitcase and snaking trailer problems. A common mechanical model is constructed for the suitcase and the trailer. Governing equations for the different motion states (the left or the right wheel on the ground, two wheels on the ground, none of the wheels on the ground) are determined. The non-smooth system is implemented in computer code and simulations are run for different initial conditions and parameter values in order to identify the stability properties. The model is partly validated via experiments on the suitcase problem.

Introduction

Instability of towed vehicles (trailers, semi-trailers) is a relevant safety risk in road transport. Under certain conditions (the trailer is badly loaded, high velocities, etc.), the so-called snaking motion (see [1]) may appear, namely the towed vehicle rocks from one of its wheels to the other. Similar phenomenon appears in case of a towed two-wheeled suitcase (see [2, 3, 4, 5]), moreover, similar mechanical models can be composed for the investigations of the stability behaviour. The analogies of the problems and the mechanical models are illustrated in Fig. 1.

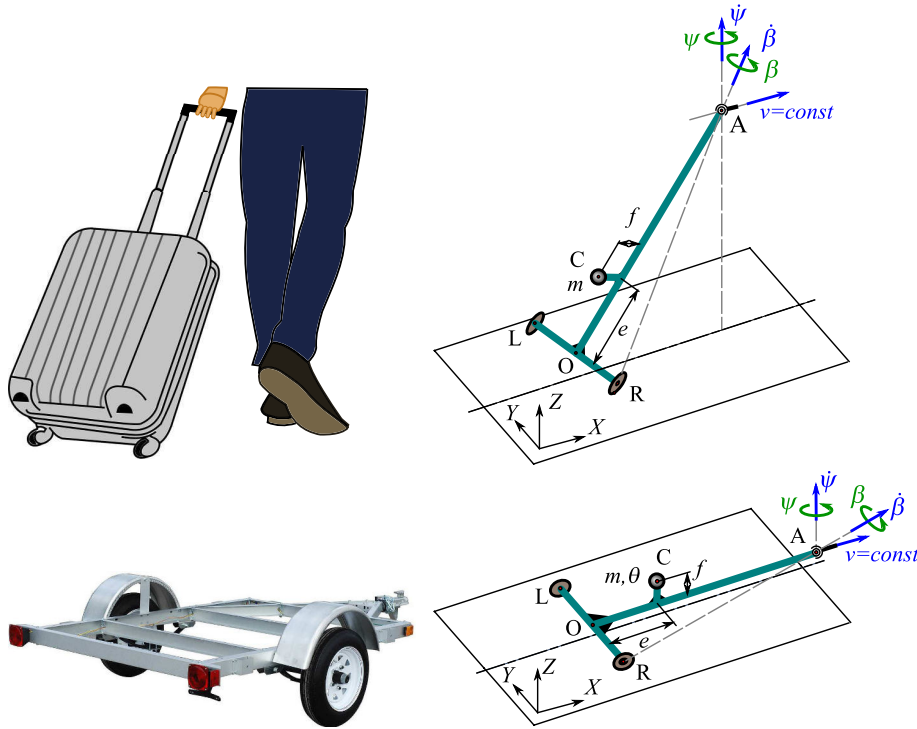


Figure 1: The analogy between rocking suitcases and snaking trailers. The two phenomena can be seen on the left panels of the figure, while their mechanical models are on the right panels.

Common property of the rocking suitcase and the snaking trailer problems is that the dynamics is strongly effected by non-linearities. The presence of unstable limit cycles makes the phenomena mystic in point of view of practical observations. There are bistable parameter domains where the desired stable rectilinear motion and large amplitude oscillations (or rocking motion) coexist. The analytical exploration of these domains is complicate due to the fact that the existence of the different motion states (the left or the right wheel are on the ground, both wheels are on the ground, none of the wheels is on the ground) makes the system non-smooth. The mathematical handling of the transitions between the motion states is a complex task. In our study, the non-linear analysis of the problems are carried out by means of numerical simulations and experiments.

Mechanical model

The mechanical models of the towed two-wheeled suitcase and the trailer can be seen in Fig. 1. The suitcase/trailer is pulled with constant speed v at point A. The ground is assumed to be horizontal and rigid. The inertial properties of the body of the suitcase/trailer is considered. The location of the center of gravity is parametrized by the distances e and f . In the analysis, both the single contact point concept and the creep force

idea (see [6]) are used and compared. In addition, elastic behaviour of the system is considered by spring and damper elements at the wheel suspensions.

Four motion states (the left or the right wheel are on the ground, both wheels are on the ground, none of the wheels is on the ground) can be differentiated. When rigid wheel-ground contacts are considered, the different states correspond to mechanical models with 1, 3 and 6 dimensional state spaces, respectively.

Numerical simulations, experimental investigation

The equations of motion are implemented in computer code. Numerical simulations were run for different initial conditions and parameter values (e.g. towing velocity v , initial tilting angle, etc.) and the domain of attraction of the rectilinear motion is depicted. The dangerous parameter ranges can be discovered, where large amplitude vibrations leading to roll-over can emerge for large enough perturbations.

Experiments were also carried out on the rocking suitcase problem in order to validate the numerical simulations, i.e. an experimental rig was constructed and placed on a treadmill. The suitcase was perturbed by obstacles that were temporarily located to the treadmill at the left wheel. The motion of the body was recorded by an OptiTrack measurement system. The trajectories of the left and the right wheels, the center of mass and the towing point are shown in the left panel of Fig. 2. A measurement result can be seen in the right panel of Fig. 2, where d_0 refer to the diameter of the obstacle, which is assumed to be proportional to the initial condition. The dots refer to the practically detected boundary between the attracting and repelling domains.

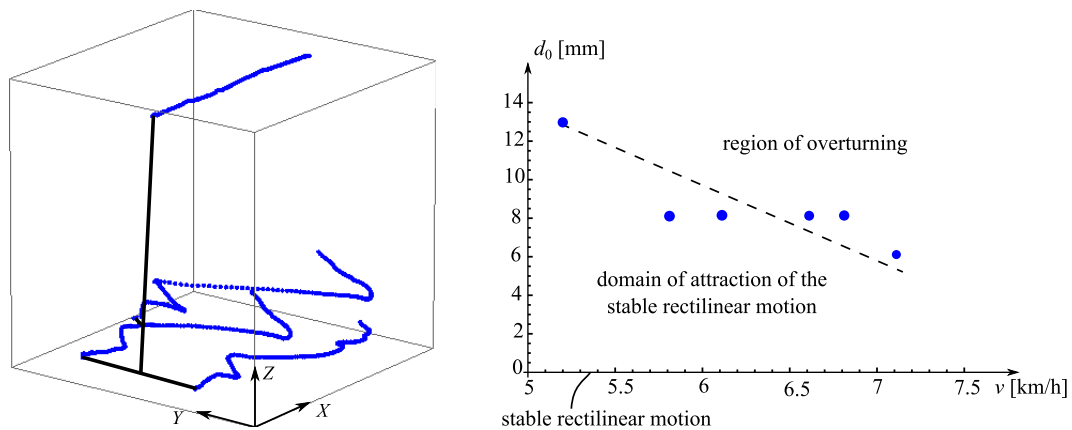


Figure 2: Measurement result. The trajectories of the left and the right wheels, the center of mass and the towing point can be seen in the left panel. The domain of attraction of the rectilinear motion is identified in the right panel.

Conclusions

Based on the analogy of the rocking suitcase and the snaking trailers problems, a common model is constructed for the numerical investigation of the stability behaviour of the systems. Both the simulations and the experiments confirm that all possible motion states can appear and there exist such parameter domains that represent relevant safety risks in practice.

Acknowledgement

This research was founded by the National Research, Development and Innovation Office under grant no. NKFI-128422. The publication of the work reported herein has been supported by ETDB at BME. The authors thank Laszlo Bencsik for his contribution in the use of the OptiTrack measurement system.

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