

Abstract

The stability of suitcases is an important and irritating problem of everyday life as two-wheeled suitcases are often used for travelling. As known, a suitcase can start to rock if large enough perturbation occurs, and in crucial cases the suitcase overturns. The topic is so significant that it is researched in high quality scientific journals even nowadays, see [1, 2]. The interest of researchers is supported by the fact that similar stability problem of trailers exists in vehicle dynamics. In this study, we analyse the system through numerical and experimental methods.

1. Introduction

In mechanical point of view, the analysis of the rocking suitcase problem is very fascinating. On the one hand, the system is non-smooth as different equations describe the different motion states. On the other hand, in case of contacting wheel, the spatial motion of the suitcase is influenced by the kinematic constraints, which makes the derivation of the equation of motion more complicated.

2. Mechanical model

The simplified mechanical model is depicted in Fig.1. The suitcase is pulled with constant speed v by the ball-joint at A. The body of the suitcase is assumed to be rigid and it is modelled by means of massless rods and by a lumped mass m at its center of mass C. One can describe the position of the mass with parameters e and f . The length and the width of the suitcase are described with the parameters l and $2b$, respectively, while h is the distance between the towing point A and the ground. The radius of the wheel (r) is assumed to be zero, which is a suitable approximation in our simplified model.

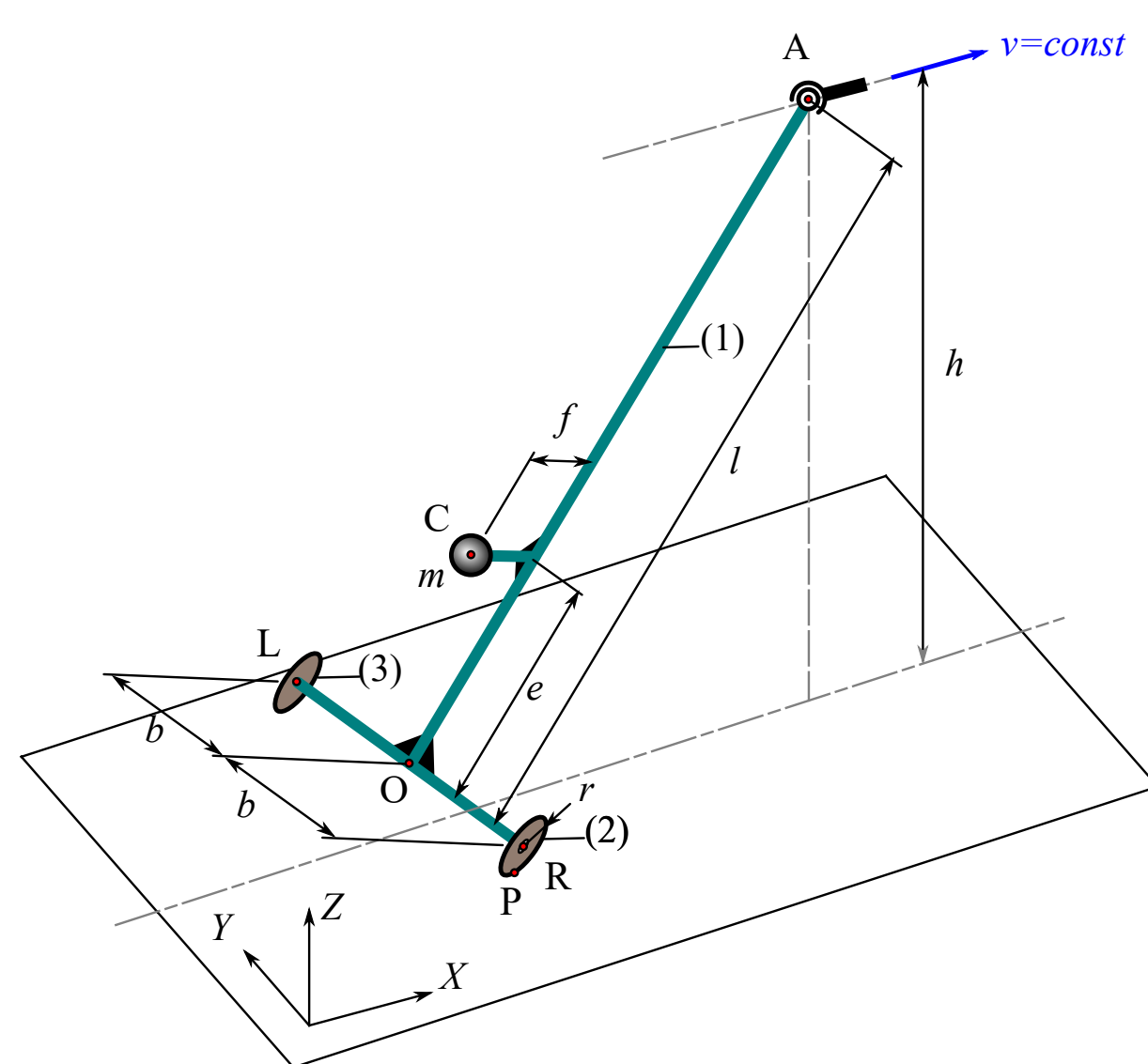


Figure 1: The simplified mechanical model of a towed suitcase.

3. Equations of motion

There are four different motion states: both wheels contacting the ground, one wheel (right or left wheel) on the ground, none of the wheels on the ground, see Fig. 2. The different states correspond to 1, 3 and 6 degrees-of-freedom mechanical models, respectively. The equations of motion can be derived from the Routh-Voss-equation. When both wheels are on the ground, the suitcase makes in-plane motion and the equations of motion can be easily derived. Having only one wheel on the ground is the most intricate case, since the motion is spatial, while the kinematic constraint of rolling has to be considered. If none of the wheels have contact with the ground, the motion is spatial but the system simplifies to a spatial mathematical pendulum. Also, the forces acting on the body have to be taken into consideration.

To make switches between the motion states, a complex impact model is sufficient since classical rigid body impact models could not be used to describe the practically observed transitions between the different states of motion. To do so, a spring and a damping is placed to the impacting wheel. Since the dynamic of the impact is much faster than the change in the body's position, the simulations of the impact can be carried out in another time scale. This method is an established custom for such multi-scale systems. The different impact models (impact on the left or the right or on both wheels) correspond to 2, 2 and 4 degrees-of-freedom mechanical models, respectively.

4. Simulations

The governing equations and the impact model were implemented in computer code. As all motion states had different number of degrees of freedom, the coupling between them is extremely difficult to deal with. The motion states and the possible ways to couple between them can be seen in Fig. 2.

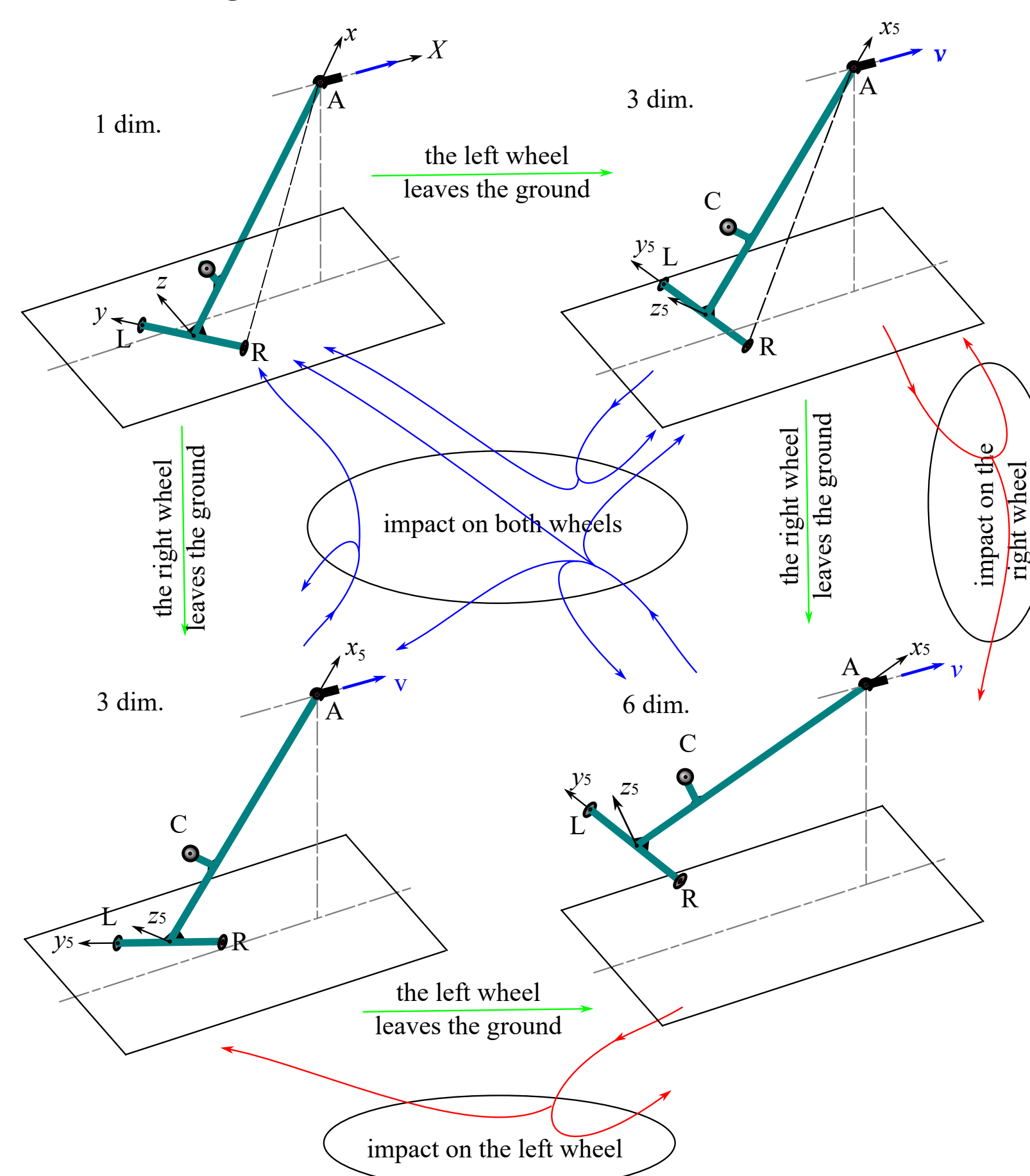


Figure 2: The motion states and the possible ways to couple between them.

Because of the difficulties in the coupling between the motion states, we consider a motion to be stable, if it results in the state in which both wheels are on the ground. Otherwise, we are talking about an unstable motion. Simulations were run for different initial conditions (different β values, where β is the rotational angle around the axis between points A and the centre point of a wheel) and parameters (e.g. towing velocity v). One can draw the basis of attraction of the rectilinear motion by means of these simulations. In Fig. 3, the results of a simplified mechanical model are shown, where the fourth motion state (no wheels on ground) was not considered.

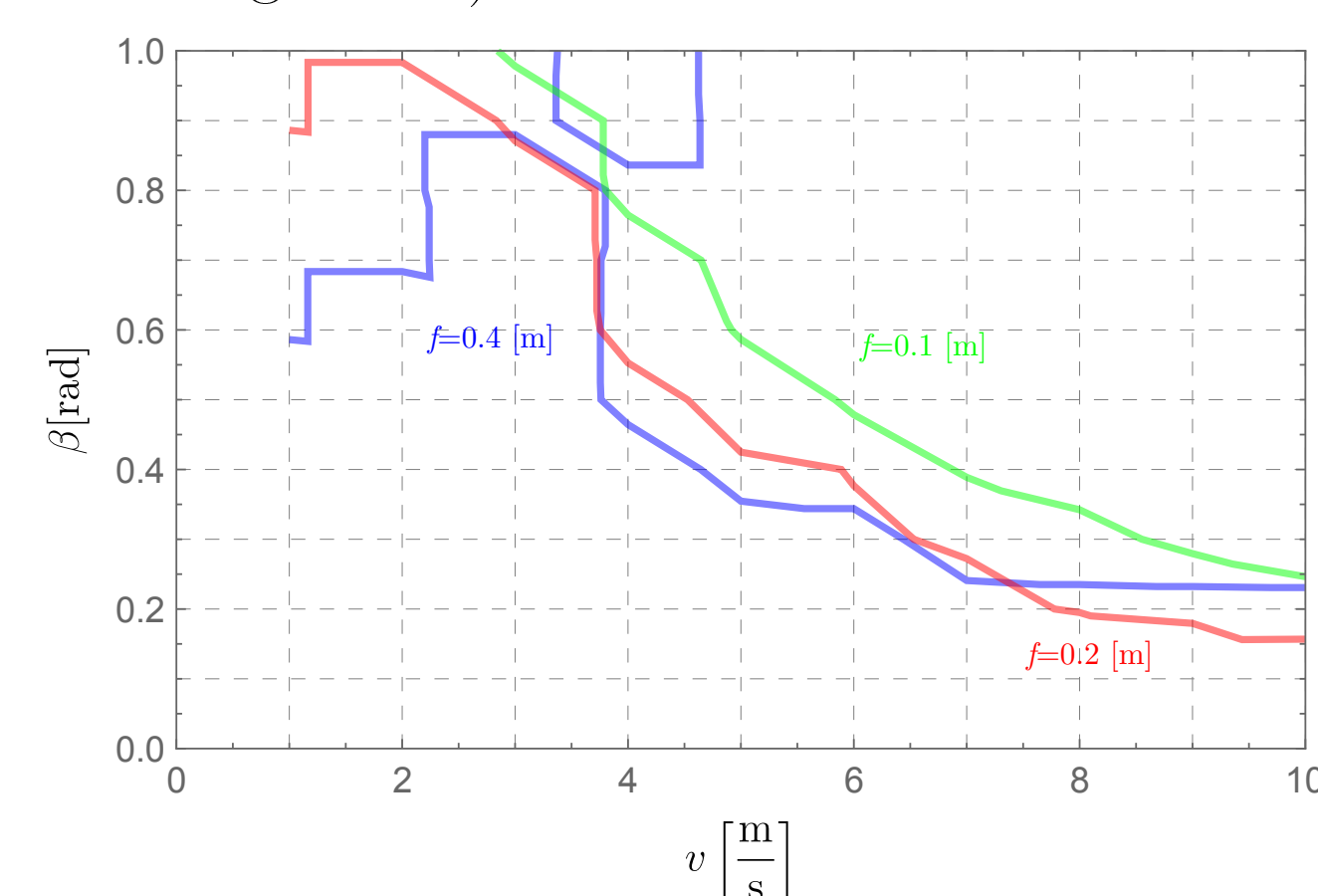


Figure 3: The basis of attraction in such a mechanical model, where the fourth motion state (no wheels on the ground) is not considered. The parameter values are the following: $l = 1$ m, $h = 0.6$ m, $b = 0.3$ m, $m = 10$ kg. Different colours represent different basis of attraction considering different f values.

One can observe the attractive and the repelling regions, i.e. below and above a specific line, respectively. Other figures could be depicted considering different e , b , h or l values. If the value of b or l is increased, the attractive region grows as well. In case of increasing e , f or h , the repelling region grows. As a curiosity, it is worth mentioning that while varying the value of f , there exists such velocities that for specific initial rotational angles, the motion tends to the straight rolling, then while in-

creasing the angle, the motion becomes unstable, then again stable. Such behaviour was observed during the measurements, as well. One can see a snapshot of the simulation in the left panel of Fig. 4.

5. Measurements

Two types of measurement were carried out in order to validate the numerical simulations. While „classical” measurements, the body was placed on a treadmill, so it was towed with its A point fixed with a ball-joint. Since we could not perturb the system identically with every measurement, we could only determine the stability on statistical basis. The measurement setup can be seen in the right panel of Fig. 4.

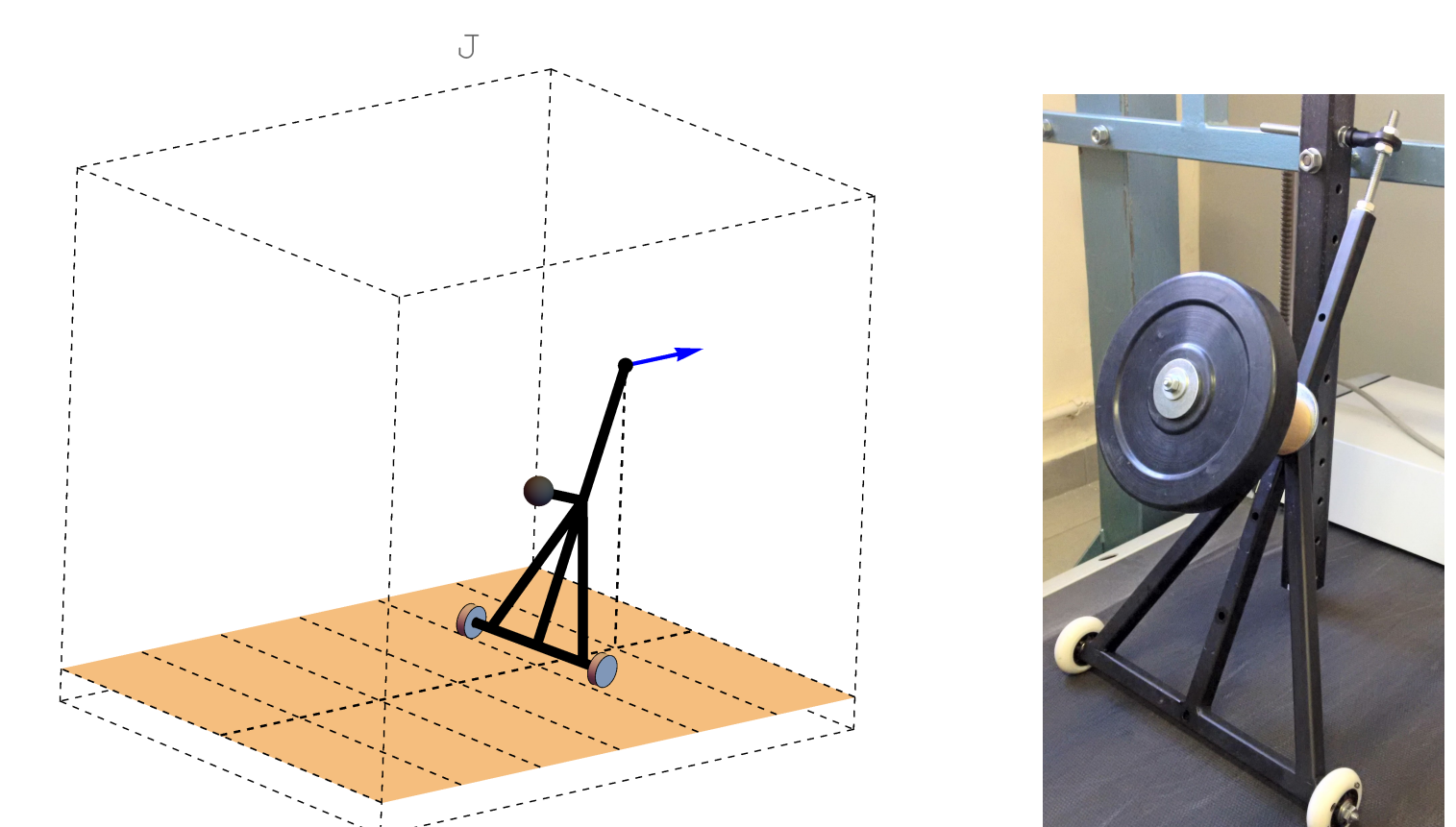


Figure 4: A snapshot of the simulation (left) and the measurement setup (right).

Motion capturing algorithm was also applied in the measurements with 4 markers on the body (on points A, C, R and L). Snapshots about the measurement is shown in Fig. 5, where the rocking motion can be also observed. Evaluating these measurements, we can gain important information about the level of perturbations. Therefore, a more sophisticated identification of the basis of attraction can be carried out.

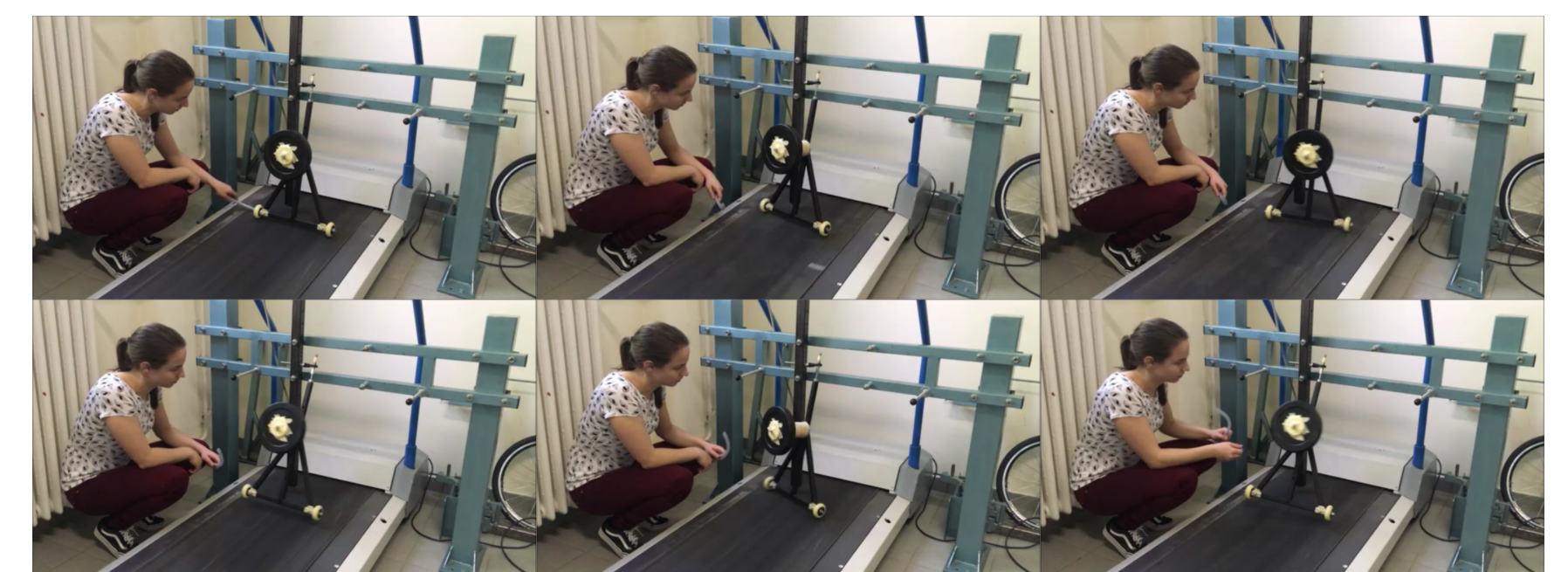


Figure 5: Example from a „motion capturing” measurement - unstable motion.

6. Conclusions

A simplified mechanical model of rocking suitcases was constructed and the equations and motion of the different motion states were derived. The numerical investigation of these equation can result important information about the non-linear behaviour of the suitcase. Experimental rig is also ready to validate these results and provide basic rules that can help the design of suitcases having better stability properties.

Acknowledgements

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