

Multibody Mechanical Model and Simulation of Rocking Suitcases

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Summary. The stability and the rocking motion of two-wheeled suitcases are analysed in this study through numerical investigations and measurements. A simplified mechanical model is presented, the governing equations are derived for all the motion states of the suitcase and an impact model is also defined to realize switching between these states.

Introduction

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 [1–3]. The interest of researchers is supported by the fact that similar stability problem of trailers exists in vehicle dynamics.

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 (i.e., rolling on two wheels, rolling on one of the wheels or non of the wheels having contact with the ground). 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. In this study, we analyse the system through numerical and experimental methods.

The simplified 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.

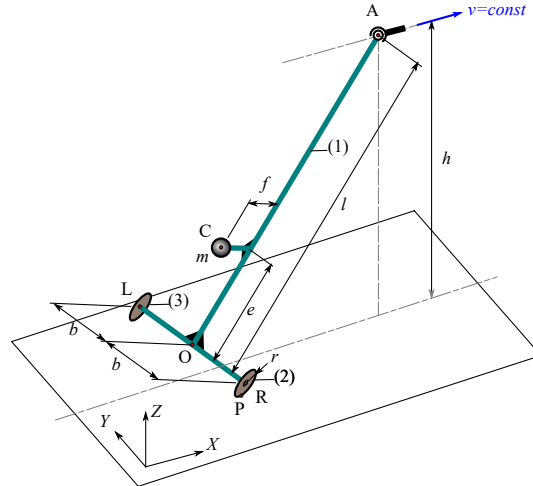


Figure 1: The simplified mechanical model of a towed suitcase.

There are four different motion states: both wheels contacting the ground, one wheel (right or left wheel) is on the ground, none of the wheels is on the ground. The different states corresponds to 1, 3 or 6 degrees-of-freedom mechanical models.

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, 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. 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.

Measurements

Measurements were carried out to investigate the motion of the suitcase. A simplified construction of the suitcase was designed and built and was towed on a conveyor belt, see Fig. 2. We analysed the effect of the initial conditions and parameters e , f and h on the stability meanwhile the speed was changed in small proportions from 0.5 km/h to 18 km/h.



Figure 2: The experimental rig.

The measurements showed that all the four motion states could be detected and the effect of the parameters f and h are relevant. The stable speed range is larger if these parameters are chosen to be smaller.

Numerical investigation

The governing equations and the impact model were implemented in computer code, in additional, simulations were run for different initial conditions and parameters. As all the motion states had different number of degrees of freedom, the coupling between them is a difficult problem. By means of the numerical investigation, the domain of attraction of the rectilinear motion can be identified.

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 nonlinear 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.

References

- [1] Facchini, G., Sekimoto, K., Courrech du Pont, S.: The rolling suitcase instability: a coupling between translation and rotation. In: Royal Society, 473(2202). 2017.
- [2] Plaut, R. H. : Rocking instability of a pulled suitcase with two wheels. In: Acta Mechanica 117. 1996. 165-179. p.
- [3] Suherman, S., Plaut, R.H., Watson, L.T., Thompson, S.: Effect of Human Response Time on Rocking Instability of a Two-wheeled Suitcase. In: Journal of Sound and Vibration, 207 (5). 1997. 617-625. p. Computers and Information in Engineering Conference, Long Beach, California, USA, September 24-28, 2005. Paper No. DETC2005-84574. 1-12. p.