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Electrodynamic magnetic levitation for high-speed trains

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Aim

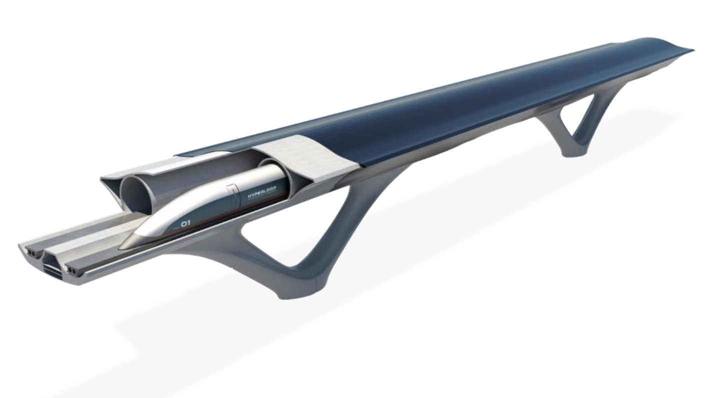
My PhD focuses on the study of the Hyperloop levitation system by addressing the following steps:

- Modeling
- Stabilization
- Performance assessment
- Experimental validation

This research is supporting the activities at the Hyperloop TT center in Toulouse (FR).

Research Background

- MAGLEV trains are the new frontier of very-high speed ground transportation systems. Passenger routes are operative in China (450 km/h), Japan (100 km/h) and South Korea (110 km/h). Air drag represents a limit to the achievement of higher speed.
- **Hyperloop** idea is to enclose the track in a low-pressure tube thus enabling cruising speed up to 1200 km/h. The train is magnetically levitated through the **Inductrack** technology that is based on the electrodynamic principle and is featured by:



+ Fully passive
+ Hardware reduction
+ Large airgap
+ Increasing lift vs speed
+ Decreasing drag vs speed

− Intrinsically unstable above a threshold speed
− No lift at low speed (wheels required)

Future Work

- Design and manufacturing of a mini-scale prototype in order to carry out the experimental validation of the developed models
- Apply the developed numerical approach to a full-scale Hyperloop system

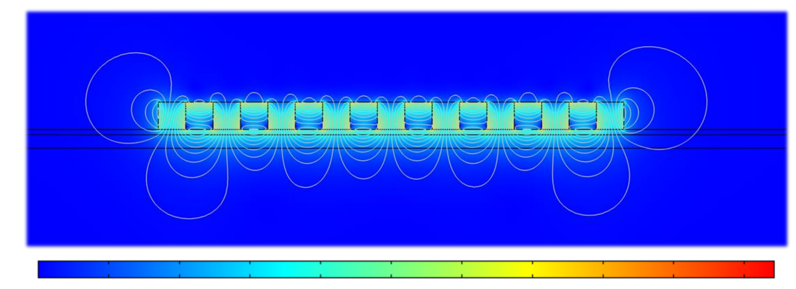
Publications

- Circosta, S., Bonfitto, A., Lusty, C., Keogh, P., Amati, N. and Tonoli, A., 2018, December. Analysis of a Shaftless Semi-Hard Magnetic Material Flywheel on Radial Hysteresis Self-Bearing Drives. In Actuators (Vol. 7, No. 4, p. 87). Multidisciplinary Digital Publishing Institute.
- Circosta, S., Galluzzi, R., Bonfitto, A., Castellanos, L., Amati, N. and Tonoli, A., 2018, December. Modeling and Validation of the Radial Force Capability of Bearingless Hysteresis Drives. In Actuators (Vol. 7, No. 4, p. 69). Multidisciplinary Digital Publishing Institute.
- Circosta, S., Galluzzi, R., Amati, N., Bonfitto, A., Molina, L.M.C. and Tonoli, A., 2019, May. Improved 1-D Model for Semi-Hard Magnetic Material-Based Electromagnets. In 2019 IEEE International Electric Machines & Drives Conference (IEMDC) (pp. 870-874). IEEE.
- Galluzzi, R., Circosta, S., Amati, N. and Tonoli, A., 2018. Design and characterization of rotary regenerative shock absorbers for automotive applications. Applied energy **(Under review)**

Workflow and Results

1. **Finite element model of a single electrodynamic pad**

↳ Understand lift and drag forces produced by the electrodynamic levitation

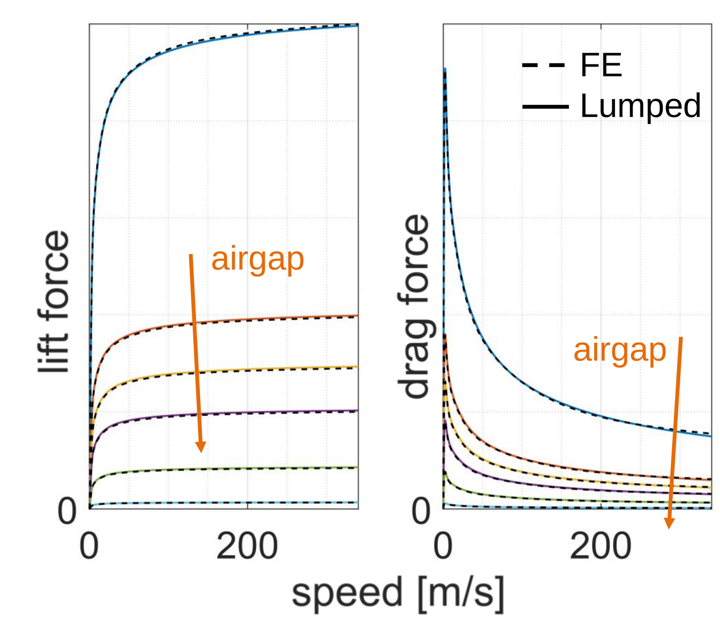


Surface: Magnetic flux density norm
Contour: magnetic vector potential, z component

2. **Lumped parameter model of a single electrodynamic pad**

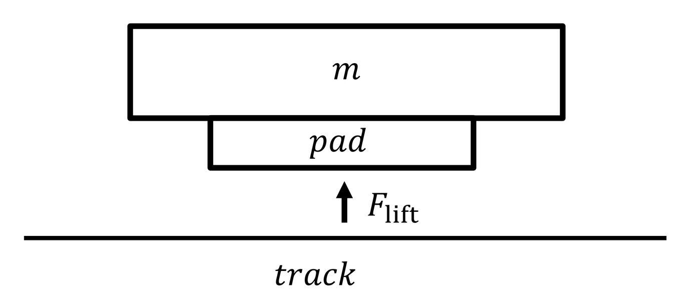
↳ Track parameters are identified from the FE results

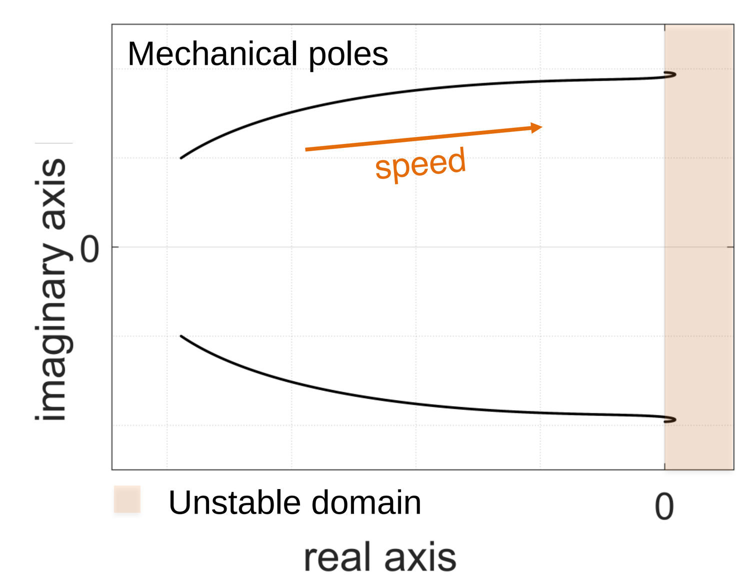
↳ Reduced computational load still capturing the essential features of the electrodynamic levitation



3. **Vertical dynamics of a single body equipped with an electrodynamic pad**

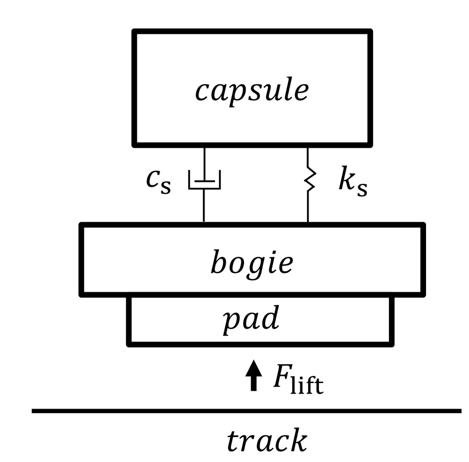
↳ The system is demonstrated to be unstable above a threshold speed

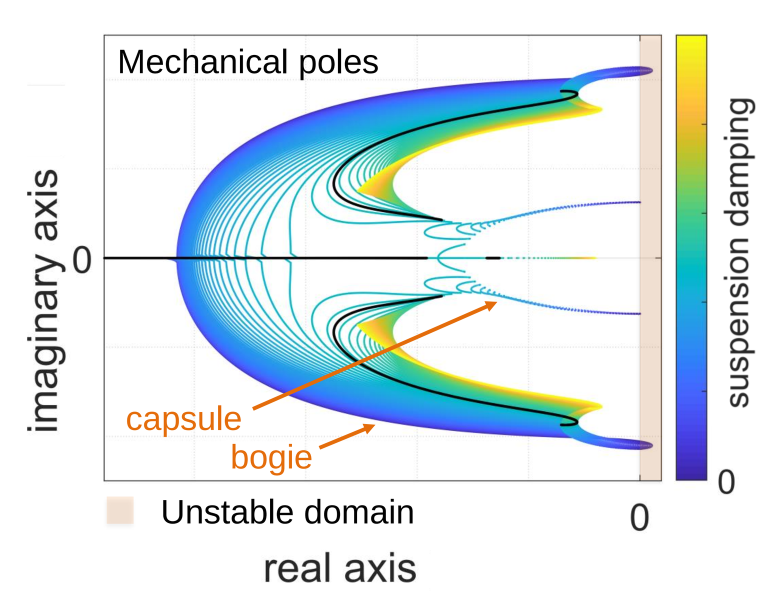




4. **Quarter car model equipped with an electrodynamic pad**

↳ The secondary suspension introduces the damping needed to achieve system stability





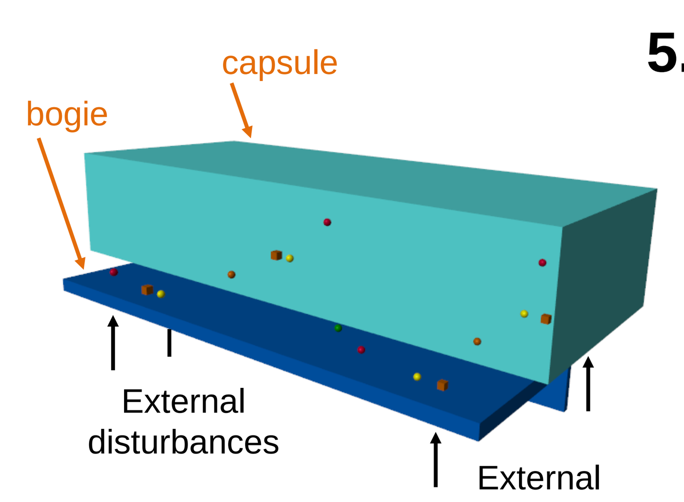
↳ The methodology to find the parameters of the secondary suspension is defined. It is based on stability and comfort criteria

5. **Half car models equipped with electrodynamic pads and linear PM synchronous motor**

Heave-pitch, sway-yaw, heave-sway-roll half car models

↳ The destabilizing effect of the motor imposes some constraints on the lateral electrodynamic pads thus influencing total drag

↳ Vertical and lateral secondary suspensions are designed by means of the developed methodology



5. **Simscape bogie-capsule full model**

4-lateral and 4-vertical electromagnetic pads

↳ Frequency domain analysis of the linearized model to address system stability and comfort

↳ Study of the vehicle performance when running through realistic track profiles