# Experimental and numerical study of wingtip vortices

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## WHAT ARE WINGTIP VORTICES?

One of the main concerns in modern aeronautics is the existence of wingtip vortices, which are an undesired byproduct of finite-span lifting wings. These persistent and highly rotating axial flows remain for a long time over airport runways during landing and takeoff operations, constituting a potential hazard on **flight safety** and dictating operational restrictions in **air traffic management**. For these reasons, efficient control of the wake behind the wing is crucial, not only to minimize the time interval between operations at airports, but also to enhance the **safe maneuvering of trailing UAVs in flight formation** and **reducing fuel consumption**.

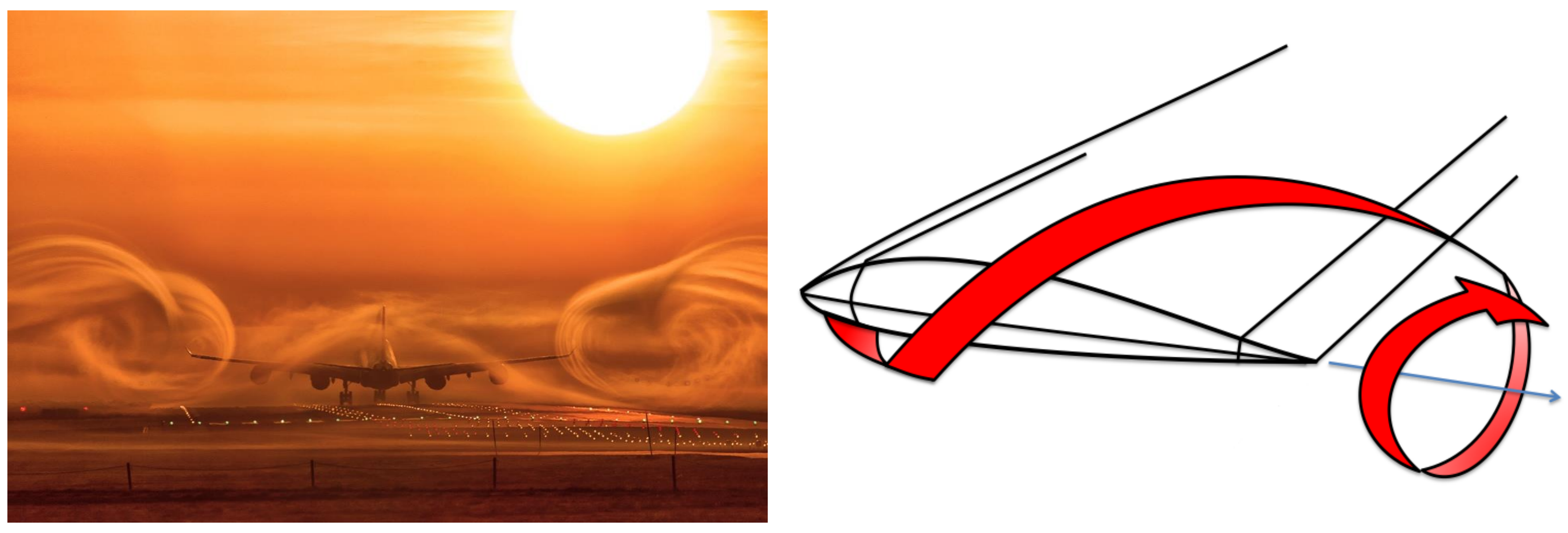

**Fig. 1**: Pair of trailing vortices formed during a landing operation (left) and schematic of the roll-up process of a wingtip vortex (right).

## ACTIVE FLOW CONTROL

A potential approach to mitigate wingtip vortices involves employing an effective vorticity reduction method utilizing **active control devices**. The objective of active control devices is to diminish the strength of vortices by intentionally triggering the intrinsic vortex instabilities prematurely and/or amplifying the growth rate of the vortex core through the injection of added mass and turbulence. Active control methods employing single-pulse fluidic actuation or forced transverse gusts present promising solutions for reducing vortex strength. Adopting zero net mass flux devices, such as synthetic jets, has gained widespread attention in flow control research. In this work, we focus on an **off-centered single punctual injection (SPI)** in the streamwise direction, which is capable of exciting multiple azimuthal modes. This in-house experimental device is currently pending patent [1].

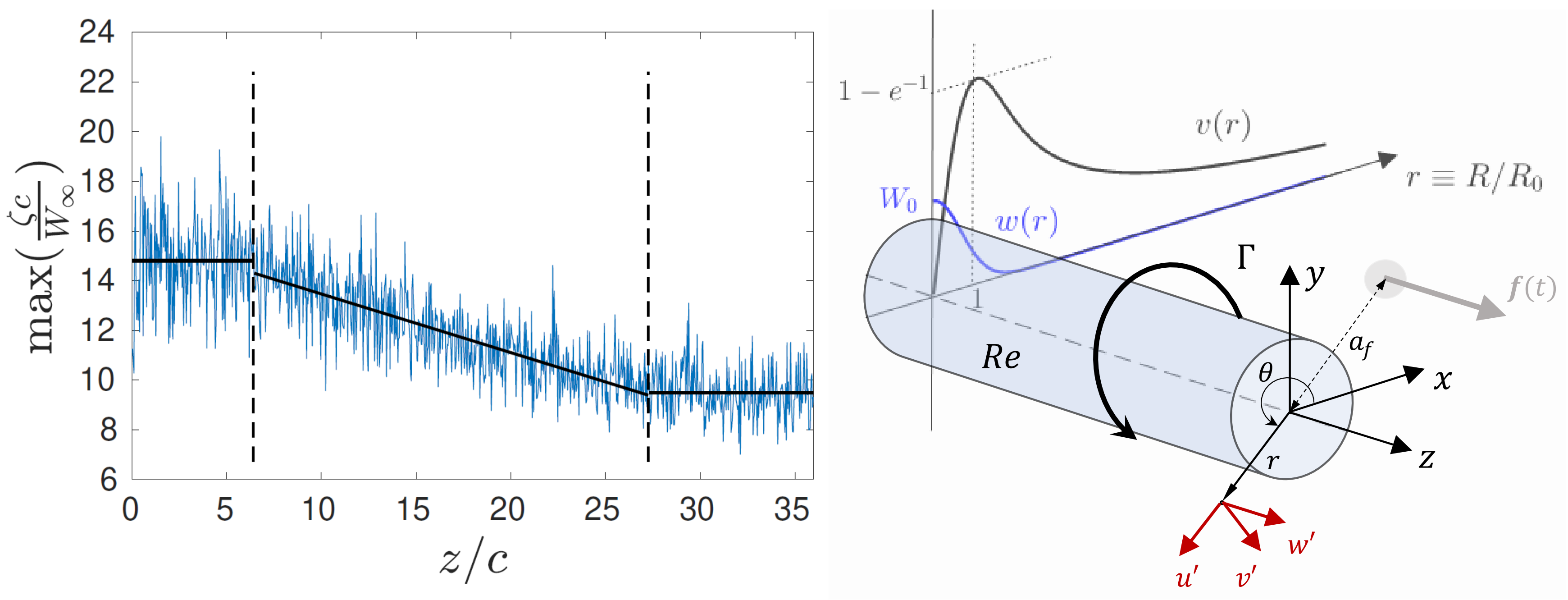

**Fig. 2**: Streamwise evolution of the maximum axial vorticity of an experimental vortex (left) and schematics of a vortex model forced with a pulsating SPI forcing $f(t)$ (right).

## EXPERIMENTAL SETUP

With the objective of testing experimentally the effectiveness of this device, we employ a **towing tank**. A fixed NACA0012 wing model (either straight or with an imposed spanwise deformation to simulate flight loading conditions [2]) is moved from right to left at a constant velocity, generating a wingtip vortex in its wake. During its translation, the SPI device generates a **pulsating jet waveform velocity profile** near the wingtip in order to promote vortex alleviation. The induced velocity fields can be measured thanks to the **2D3C-PIV technique**, which allows us to quantify the effect of the active control for diverse experimental conditions. Additionally, the post-processing of these results via **modal decomposition techniques**, such as *Proper Orthogonal Decomposition* (POD) or *Higher Order Dynamic Mode Decomposition* (HODMD), provides further insight into the intrinsic instabilities from both an energetic and dynamic perspective [3].

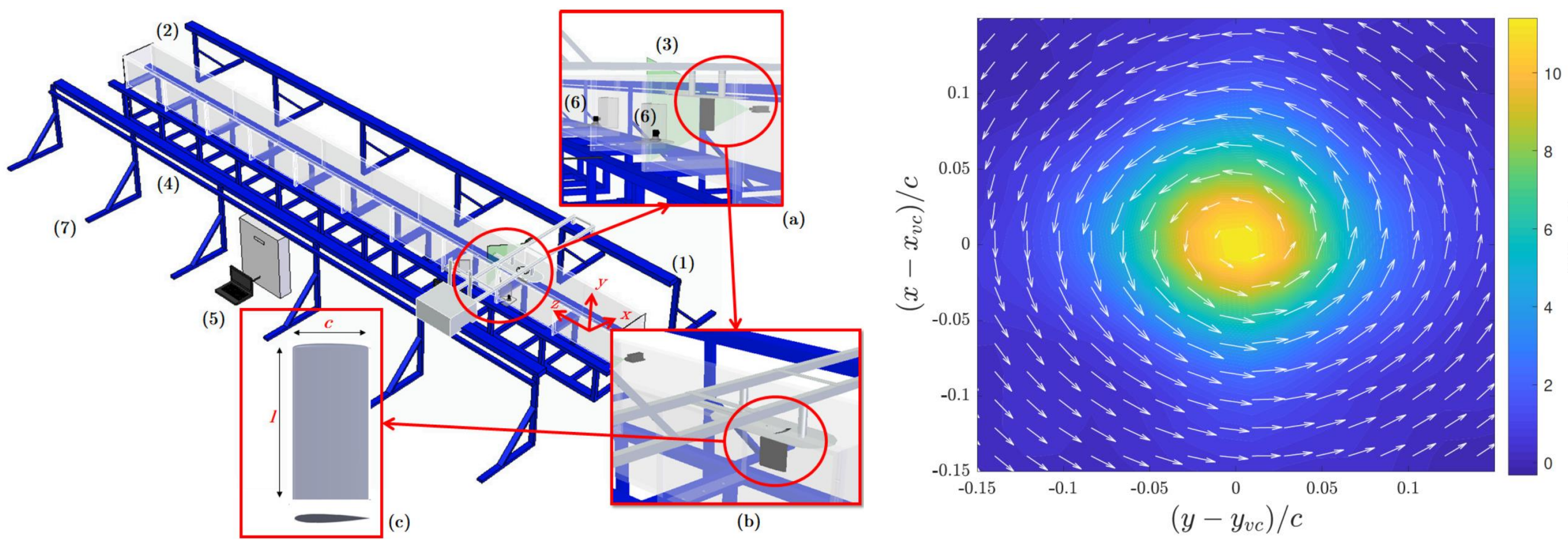

**Fig.3**: 3D schematic of the towing tank and the 2D3C-PIV system (left), and a wingtip vortex vorticity contour with its corresponding velocity vector field (right).

## NUMERICAL METHODOLOGY

However, the **precise tuning** of the experimental parameters governing the SPI active control is critical. In particular, the intensity, blowing frequency and radial location of the jet application strongly determines its efficiency. **Frequency response analysis** arises as a cost-efficient complementary method to study these dependencies [4]. This numerical method allows to simulate in time the 2D linearized Navier-Stokes equations with a custom forcing term. A parameter analysis has been carried out on the axial wavenumber $k$, the forcing frequency $\omega_f$ and the radial distance $a_f$ of the SPI forcing.

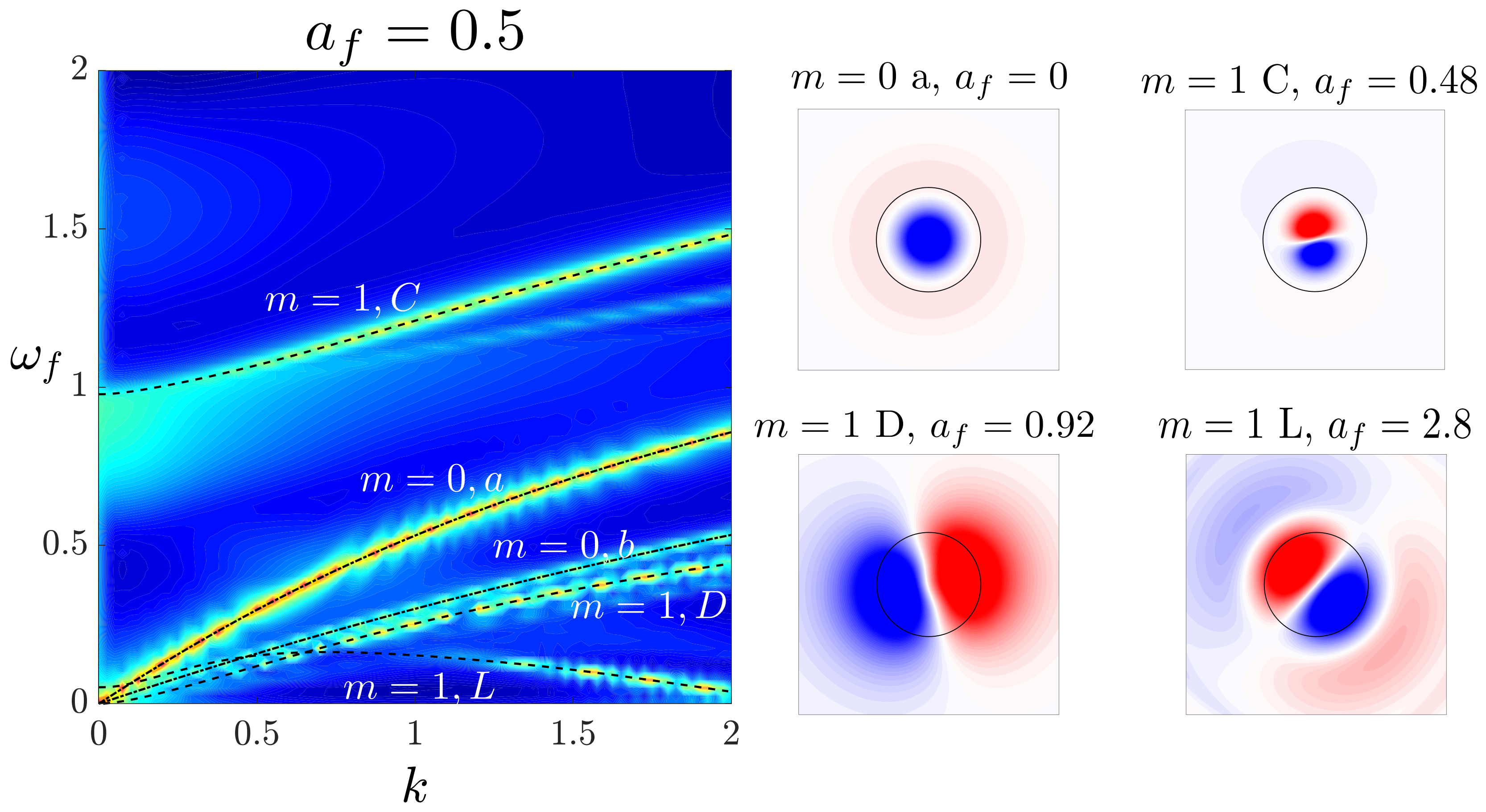

**Fig.4**: Contour map of the frequency response gain (logarithmic scale) with linear stability resonance branches (left), and contours of the most amplified axial velocity perturbations for $k = 1.55$ (right).

## CONCLUSIONS

Most high gain regions correspond to resonance branches obtained from a linear stability analysis. The most amplified perturbations correspond to **axisymmetric and helical modes**. These results from the numerical research will serve as a basis for the optimization of the experimental parameters that define **potential technological candidates** for the active control of wingtip vortices.

## REFERENCES

[1] Patente bajo revisión y presentada a nivel nacional: "*Dispositivo para atenuar vórtices turbulentos en estelas provenientes de perfiles aerodinámicos*", ID P202330823 (2023).

[2] P. Solis, **M. Garrido-Martin**, E. Duran, P. Gutierrez-Castillo, and C. del Pino, "*On the influence of spanwise deformation on lift coefficient and trailing vortices properties at low Reynolds number*", Physics of Fluids **36** (2024).

[3] P. Gutierrez-Castillo, **M. Garrido-Martin**, T. Bölle, J. H. García-Ortiz, J. Aguilar-Cabello and C. del Pino, "Higher order dynamic mode decomposition of an experimental trailing vortex", Physics of Fluids **34** (2022).

[4] **M. Garrido-Martin**, P. Gutierrez-Castillo, F.J. Blanco-Rodríguez, T. Bölle and C. del Pino, "*Frequency response analysis of jet-vortex interaction for variable relative spacing*", Submitted.

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