Master 2 Internship + PhD Thesis

Interaction between a vortex and a fluid interface

Hosting laboratory: **IRPHE – CNRS / Aix-Marseille Université / Centrale Méditerranée**
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Description

Fluid vortices in environmental and engineering flows exist over a large range of scales, from huge tornadoes, through tip vortices in the wake of turbines, to the smallest eddies in turbulent regions at dissipation scale. Many situations involve vortical flows in which several immiscible fluids are present. They include floating bodies or bodies immersed at small depth which shed vortices under the water surface, or propellers and foils in the wake of which tip vortices may cavitate or simply trap atmospheric air into their core. In these instances, the presence of a liquid/gas interface located either in the vicinity of the vortex or within its core, significantly modifies its dynamics. Fundamental studies on the interplay between vorticity and interfaces are rare. The work proposed here will investigate the interaction of a single fluid vortex and a liquid/gas interface in various configurations, through water channel experiments and theoretical/numerical modelling.

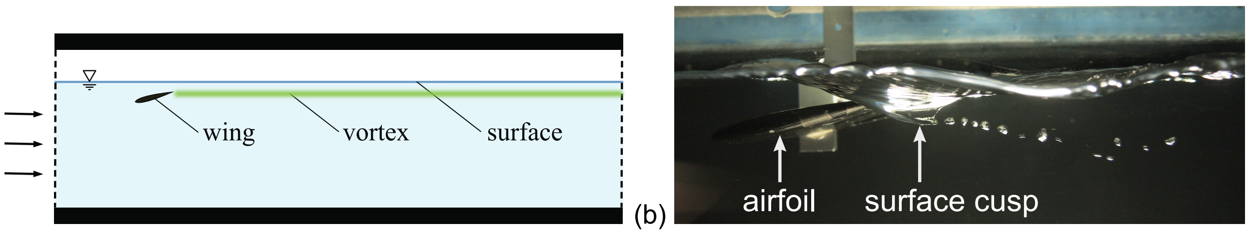


Figure 1. (a) Schematic of a wing tip vortex near the free surface of the IRPHE water channel.
(b) Deformation of the free surface by a wing tip vortex, with stripping of air bubbles.

In the experimental study, the interaction of a streamwise vortex with an air/water interface parallel to the vortex axis will be analysed in a recirculating free-surface water channel. The vortex is generated by an airfoil, whose tip is placed near the water surface. The strength (circulation) of the vortex is varied by changing the angle of attack of the airfoil and/or the free-stream velocity in the channel; the tip vortex core size can be varied by choosing different wing chords. An important parameter is the distance between wing tip and surface. The vortex structure will be characterized using high-resolution 3-component Particle Image Velocimetry (PIV), yielding radial profiles of swirl and axial velocities, as well as vorticity. Surface deformations will be determined using optical methods (scanning of the surface with a vertical laser sheet). The objective of these measurements is to document the vortex evolution in the presence of a nearby interface and the surface deformations induced by the vortex, as well as the detection and characterization of possible long- and short-wave vortex instabilities in this configuration. The Master internship will be dedicated to a first experimental exploration of the vortex-surface interaction.

In the second part of this project, the experiments will be complemented by a theoretical analysis where two-dimensional quasi-steady solutions describing a vortex placed below and parallel to a free surface will be de-rived. Both the deformations of the surface and their effects on the velocity field in the core of the vortex will be evaluated for common vortex models without axial velocity component (Rankine vortex, Lamb-Oseen vortex) or with axial flow (Batchelor vortex). In addition, both the long-wavelength instability (Crow instability) and short-wavelength instability (elliptic instability), which are expected to be present, will be analysed theoretically. The objective is to quantify the variations of the properties of these two instabilities with respect to the problem parameters (vortex strength, surface distance). The results of these analyses will be compared to the experimental findings.

Extensions of this work include configurations where a liquid/gas interface exists inside the vortex core. These can be obtained by injecting air into the vortex, either through the wingtip or further downstream, or by having the wing pierce the surface from above, in which case air can be sucked into the tip vortex from the surface along the wing's trailing edge. Preliminary experiments have shown the existence of interesting features such as vortex breakdown when air is injected into a strong wing tip vortex.

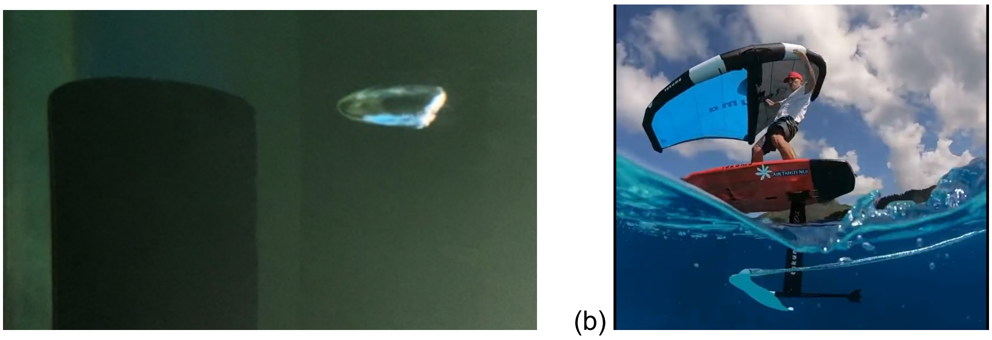
(a) (b)


Figure 2. (a) Vortex breakdown triggered by air injection into a wing tip vortex in water.
(b) Gaseous core of a foil tip vortex.

Candidate profile

The candidate should have a solid background in fluid mechanics, with particular knowledge in the field of vortex dynamics. He/she will have a strong taste for experimentation, as well as an interest in numerical simulation and theoretical analysis. Good oral and written communication skills in English (delivering presentations, writing scientific articles) are desired.

Publications on the topic

Archer, P. J., Thomas, T. G., Coleman, G. N. 2010 The instability of a vortex ring impinging on a free surface. *J. Fluid Mech.* **642**, 79. https://doi.org/10.1017/S0022112009991753

Brøns, M., Thompson, M. C., Leweke, T., Hourigan, K. 2014 Vorticity generation and conservation for two-dimensional interfaces and boundaries. *J. Fluid Mech.* **758**, 63. https://doi.org/10.1017/jfm.2014.520

Leweke, T., Le Dizès, S., Williamson, C. H. K. 2016 Dynamics and instabilities of vortex pairs. *Annu. Rev. Fluid Mech.* **48**, 507. https://doi.org/10.1146/annurev-fluid-122414-034558

Lundgren, T. Koumoutsakos, P. 1999 On the generation of vorticity at a free surface. *J. Fluid Mech.* **382**, 351. https://doi.org/10.1017/S0022112098003978

Willert, C. E., Gharib, M. 1997 The interaction of spatially modulated vortex pairs with free surfaces. *J. Fluid Mech.* **345**, 227. https://doi.org/10.1017/S002211209700626

Applications (motivation letter, CV, grade transcripts, references) should be sent to the supervisors by e-mail.