Internship/PhD proposal – The Physics of Paragliding

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Introduction

Paragliding is a young adventure sport (early 80's) consisting in flying lightweight, free-flying, foot-launched glider aircrafts with no rigid primary structure (see Fig.1). For a physicist, it truly is a bottomless drawer of fascinating unexplored phenomena, combining a variety of fields covering fluid mechanics, fluid-structure interactions, flight Mechanics, materials science, micrometeorology, and even game theory in the context of understanding exploration-exploitation optima in paragliding competitions.

Figure 1: Paragliding in the mountains.

Mechanics of unsteady phases

Since the first prototypes, paraglider wings haven't ceased to evolve, both in terms of performance and security. While most of the research done by paragliding manufacturers (see e.g. [1, 2]) has focused on optimising wings for steady flight phases, unsteady regimes have only received limited attention [3, 4].

In particular, many questions remain unsolved when it comes to the dynamics of stalls or wing collapses combined with the aircraft specific pendulum-motion. In a preliminary study [5], we have addressed the physics of the launching phase: How does a seemingly simple rag inflate in response to a slight breeze to become a rather stable aircraft in just a matter of seconds? In particular, we designed, built and ran a reduced-scale model experiment to study the paragliding inflation and launching phase at given traction force. We found that the the launch trajectory is universal (see Fig. 2), and as a result the distance required for the glider to reach its "ready to launch" vertical position is independent of the strength of the exerted force.

This study revealed a number of other exciting questions, such as the differences between regular and single skin wings during unsteady phases, or the optimal folding of the wing for a comfortable launch in strong wind conditions. As a first step, we shall therefore continue systematically this series of experiments to rigorously explore the space of parameters (different wings, initial conditions, etc.). The intricate question is that of the two simultaneous phases: (i) the phase during which the chambers fill with air to give the aircraft its wing shape ensuring lift, and (ii) the dynamics where the "inflated" wing rises from the horizontal to the vertical position. To unravel their roles we shall use rigid wings printed in 3D, or cut with a hot wire in polystyrene, in order to understand how the characteristic times of each isolated phase interact. We shall also conduct wind tunnel experiments in the laboratory, to explore the effects of turbulence on the wing (stall or wing collapse). Due to the limitations of the model experience (difficult to scale to the stiffness of the materials), we shall continue to interact with our colleagues at Puy de Dome, filming in the field with the high speed cameras. Our results are

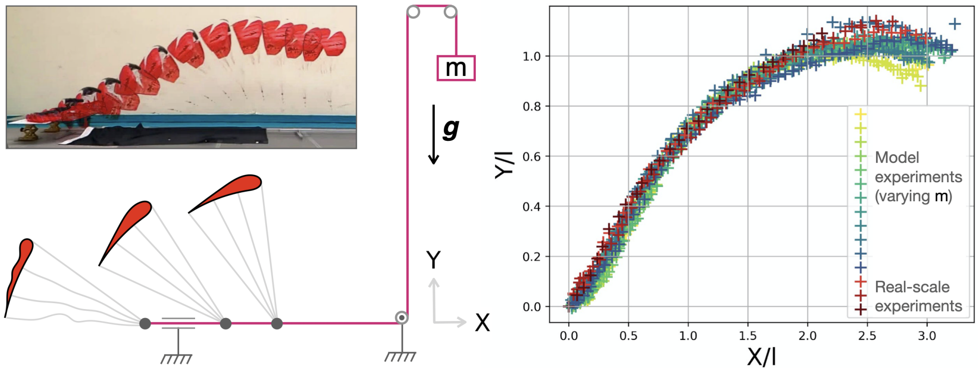

Figure 2: Model experiment and universal launch dynamics.

susceptible to provide quantitative elements for improving the safety of modern sails, the approval of which is now based exclusively on the feeling of test pilots.

Micrometeorology and optimal exploitation of thermals using 3D track data

To gain altitude in the atmosphere, birds, paragliders and sailplane pilots exploit thermal updrafts or *thermals* [6–9]. These are cyclic columns of rising air resulting from the uneven solar heating of the ground surface, which in turn warms the air directly above it, and initiates atmospheric convection. The first experiments and models in the 1960s [10–13] made it possible to outline the basic structure, periodicity, flow nature and vorticity of thermals (Fig. 3a). Later on, on-board measurements on the one hand [14, 15], and numerical simulations on the other hand [16], allowed to refine their physical characteristics (for example their size or the exchanges by shear with the surrounding air [17–19]) and integrate thermal convection into weather models [20, 21].

Yet, due to the lack of probes, many questions remain. How far are these columns from each other? How regular is their spatiotemporal structure? What is the influence of the season, the time of day, the cloudiness or the topography and nature of the soil that gives rise to them? The idea is to use light aircrafts (paragliders and hang-gliders) as smart atmospheric probes to answer such question, and build a statistical model of the multi-thermal spatiotemporal structure. Indeed, modern pilots carry on-board-instruments called *altivario GPS* providing the 3D GPS coordinate (see Fig. 3b) as well as the associated velocities and accelerations, for hundreds of thousands of flights around the world. Most of these large databases are freely accessible online. Coupling such data with satellite data on the nature of the soil, weather data and ground topography constitutes an exceptional playground to tackle the above mentioned questions.

Once the data has been mastered, another part of this project will use it to study the optimal exploration-exploitation strategies of thermal convection. Optimal cross-country flying theory stipulates *climbs in discrete thermals, separated by glides through stationary air (...) the relative duration of which depends on the performance of the glider or bird and the rate of climb in thermals* [22]. On the biomimetic level, thermal exploitation strategies of birds and paragliders have been compared [23, 24]. Climbing strategies within individual thermals have been optimised using modern tools such as machine learning) [25] in order to improve the performance of glider autopilots [26]. But the literature does not report quantitative results on competitive cross country strategies. Race pilots seeking to cover the greatest possible distance must find the right balance between (i) the individualistic strategy based on one's knowledge (topography and color of the ground, cumuliform clouds, etc.) to find the next nascent thermal, with the risk of missing out, and (ii) the collective strategy consisting in following other pilots that materialise where the thermals are located, with the risk of getting there too late.[1] But is this picture confirmed in reality? What is the optimal rank to make sure one does not land before the final transition to the finish line? And if everyone seeks the same rank, how do you get out of it?

[1] Common saying among pilots: "alone one goes faster, together we go further".

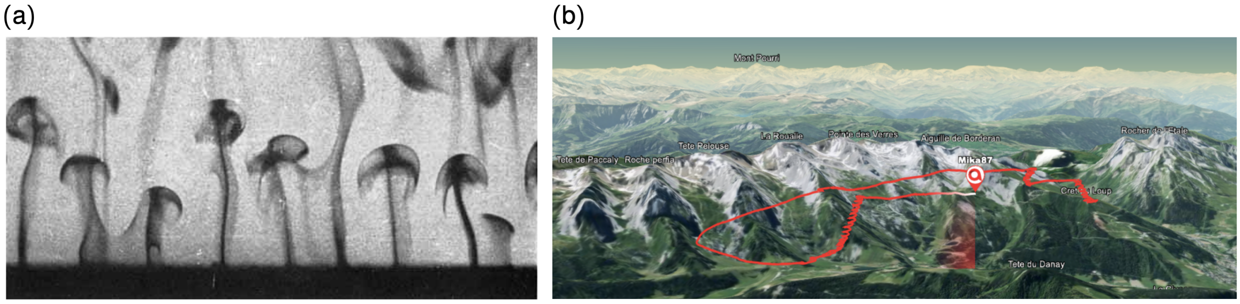

Figure 3: (a) Visualisation of thermals above a heating plate [13]. (b) 3D GPS track of a paraglider (begining of MB's flight on June 12 2021, *chaîne des Aravis*, French Alps).

So many questions that we should be able to answer with the aforementioned databases, coupled with elements of game theory.

PhD specifics

The present PhD will be devoted to exploring the questions presented above, among others, combining reduced-scale model experiments with real scale observations (field trips and opportunities to fly), numerical simulations and data analysis. Depending on the profile and taste of the PhD candidate, more weight shall be given to one project or the other.

The PhD candidate will be hosted at the Laboratoire d'Hydrodynamique de l'X in close connection with our collaborators in the south of France to confront our findings and learn from their experience. Good experimental and numerical skills are advised.

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