Internship proposal – Micrometeorology and optimal exploitation of thermals using 3D track data

Laboratory name: Laboratoire d'Hydrodynamique, LadHyX
CNRS identification code: UMR CNRS 7646
Internship location: Ecole Polytechnique, Palaiseau.

Supervision: Michael Benzaquen
Email: michael.benzaquen@polytechnique.edu

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.

Subject

To gain altitude in the atmosphere, birds, paragliders and sailplane pilots exploit thermal updrafts or *thermals* [1–4]. 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 [5–8] made it possible to outline the basic structure, periodicity, flow nature and vorticity of thermals (Fig. 2a). Later on, on-board measurements on the one hand [9, 10], and numerical simulations on the other hand [11], allowed to refine their physical characteristics (for example their size or the exchanges by shear with the surrounding air [12–14]) and integrate thermal convection into weather models [15, 16].

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. 2b) 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* [17]. On the

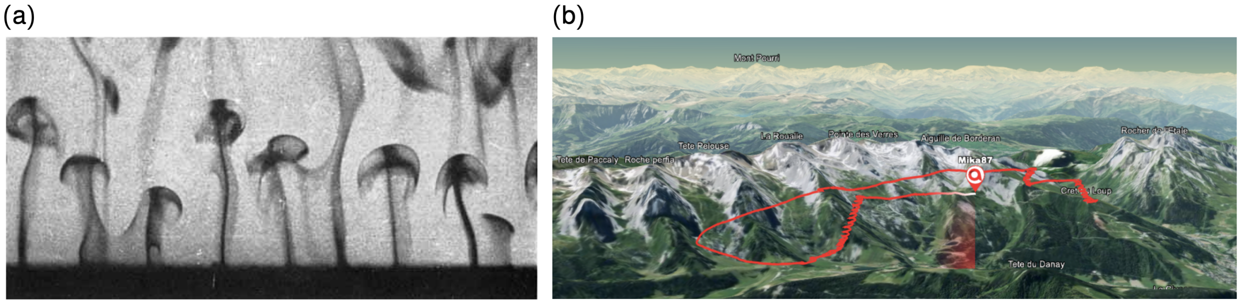

Figure 2: (a) Visualisation of thermals above a heating plate [8]. (b) 3D GPS track of a paraglider (begining of MB's flight on June 12 2021, *chaîne des Aravis*, French Alps).

biomimetic level, thermal exploitation strategies of birds and paragliders have been compared [18, 19]. Climbing strategies within individual thermals have been optimised using modern tools such as machine learning) [20] in order to improve the performance of glider autopilots [21]. 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? So many questions that we should be able to answer with the aforementioned databases, coupled with elements of game theory.

References

[1] H. Weimerskirch, O. Chastel, C. Barbraud, and O. Tostain, Nature **421**, 333 (2003).
[2] H. J. Williams, E. Shepard, M. D. Holton, P. Alarcón, and R. Wilson, PNAS **117**, 17884 (2020).
[3] Y. Leshem and Y. Yom-Tov, Ibis **138**, 667 (1996).
[4] H. Weimerskirch, C. Bishop, T. Jeanniard-du Dot, A. Prudor, and G. Sachs, Science **353**, 74 (2016).
[5] B. Woodward, Quarterly Journal of the Royal Meteorological Society **85**, 144 (1959).
[6] A. Townsend, Journal of Fluid Mechanics **3**, 361 (1958).
[7] J. Turner, Annual Review of Fluid Mechanics **1**, 29 (1969).
[8] E. Sparrow, R. Husar, and R. Goldstein, Journal of Fluid Mechanics **41**, 793 (1970).
[9] D. Konovalov, Technical Soaring **29**, 121 (1970).
[10] D. Lenschow and P. Stephens, Boundary-Layer Meteorology **19**, 509 (1980).
[11] A. M. Blyth, S. G. Lasher-Trapp, and W. A. Cooper, J. of the Royal Meteorological Society **131**, 1171 (2005).
[12] D. Hernandez-Deckers and S. C. Sherwood, Journal of the Atmospheric Sciences **73**, 4117 (2016).
[13] D. Lecoanet and N. Jeevanjee, Journal of the Atmospheric Sciences **76**, 3785 (2019).
[14] J. M. Peters, W. Hannah, and H. Morrison, Journal of the Atmospheric Sciences **76**, 1645 (2019).
[15] J. Pergaud, V. Masson, S. Malardel, and F. Couvreux, Boundary-layer meteorology **132**, 83 (2009).
[16] S. C. Sherwood, D. Hernández-Deckers, M. Colin, and F. Robinson, J. of Atm. Sciences **70**, 2426 (2013).
[17] C. J. Pennycuick, Journal of Avian Biology **29**, 33 (1998).
[18] Z. Akos, M. Nagy, and T. Vicsek, Proceedings of the National Academy of Sciences **105**, 4139 (2008).
[19] Z. Ákos, M. Nagy, S. Leven, and T. Vicsek, Bioinspiration & biomimetics **5**, 045003 (2010).
[20] I. Guilliard, R. Rogahn, J. Piavis, and A. Kolobov, arXiv preprint 1805.09875 (2018).
[21] G. Reddy, J. Wong-Ng, A. Celani, T. J. Sejnowski, and M. Vergassola, Nature **562**, 236 (2018).

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