Anomalous Transport in Soaring Flights: Collective Strategies and Intermittent Search Models

Laboratory name: EconophysiX Lab
Internship location: EconophysiX Lab, CFM (Paris)
Supervision: Michael Benzaquen, Damien Challet, Alexandre Darmon
Email: michael.benzaquen@polytechnique.edu

Motivation and Background

Cross-country soaring flights provide a natural laboratory to study transport processes emerging from the coupling between environmental heterogeneity, individual decision-making, and collective interactions. Trajectories result from an intermittent dynamics alternating between relocation phases (gliding) and localized exploration around atmospheric updrafts (thermals), naturally connecting soaring flight to classical problems in movement ecology and anomalous transport in complex environments [1, 2, 3].

Recent analyses of large GPS datasets suggest non-trivial scaling properties in soaring trajectories, consistent with effective dynamics that go beyond simple transport models [4]. However, several key questions remain open, particularly regarding the precise nature of directional persistence, the influence of flight phases, and the impact of collective behavior. This internship aims to address these issues through a combination of statistical analysis and theoretical modeling.

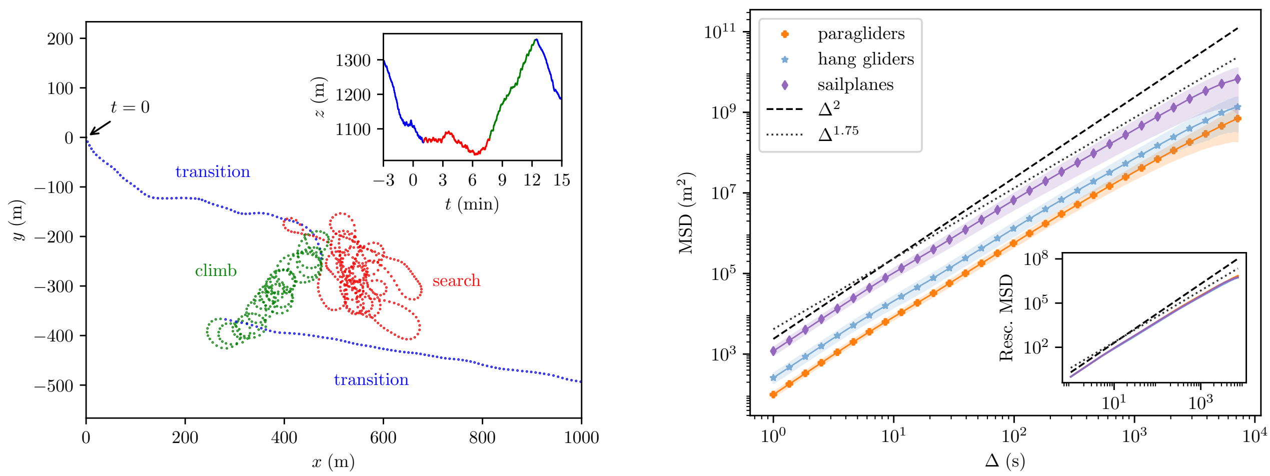

Figure 1: Left: Example of a paraglider trajectory segmented into transition (blue), search (red), and climb (green) phases. Right: Mean square displacement of paragliders, hang gliders, and sailplanes, showing robust and universal sub-ballistic scaling at long times [4].

Objectives and Methodology

Autocorrelation Structure and Discrimination of Movement Models

A central objective of the project is to characterize heading and velocity autocorrelation functions along soaring trajectories. These quantities will be measured both globally and conditionally on flight phase, distinguishing between thermalling (climbing), search, and gliding (relocation) segments. Phase-resolved autocorrelations provide a direct way to discriminate between Lévy-walk-like dynamics and finite-persistence correlated random walks. Lévy walks can arise in intermittent transport processes with heavy-tailed relocation statistics [5], while correlated random walks are characterized by finite correlation times and exponential decorrelation [6]. By quantifying how persistence and correlation times differ between flight phases, this analysis will clarify the effective stochastic description of cross-country soaring.

Effects of Collective Interaction on Transport Properties

Soaring flight is often a collective activity, with pilots implicitly sharing information by exploiting common thermals and observing each other's trajectories. A second component of the project will therefore focus on the role of collective interaction in shaping transport properties. By comparing solo and collective flights, the project will examine how key observables such as displacement statistics, turning angles, and effective persistence are modified in the presence of other gliders. This analysis will address whether collective soaring leads to enhanced exploration efficiency, improved exploitation of thermals, or qualitatively different transport regimes. More generally, collective soaring can be framed as a collective exploration–exploitation problem, in which individual and group-level strategies may not coincide [7, 8].

Theoretical Modeling: Soaring as an Intermittent Foraging Process

In parallel with the data-driven analysis, the project will develop a theoretical framework that casts cross-country soaring as a foraging problem in the spirit of first-passage and intermittent search theories [9, 10]. Within this framework, thermals are modeled as spatially distributed resource patches where pilots gain altitude, while gliding and search phases correspond to relocation and detection events between patches. The alternation between localized exploitation and long-range search naturally leads to intermittent dynamics, allowing connections to established models of search efficiency and anomalous transport in statistical physics and ecology [3]. Analytical predictions for quantities such as displacement scaling and phase durations will be derived where possible and confronted with empirical measurements.

Expected Outcomes and Impact

This internship will provide a principled statistical characterization of soaring flight dynamics, identify appropriate effective transport models, and quantify the influence of collective interactions. By linking empirical observations to theoretical models of intermittent search and foraging, the project will contribute to the broader understanding of anomalous transport and collective motion in complex environments, with potential implications for both fundamental research and soaring flight strategy.

References

[1] Peter Turchin. *Quantitative analysis of movement: measuring and modeling population redistribution in animals and plants*. Sinauer Associates, 1998.

[2] E. A. Codling, M. J. Plank, and S. Benhamou. Random walk models in biology. *Journal of the Royal Society Interface*, 5:813–834, 2008.

[3] R. Metzler and J. Klafter. The random walk's guide to anomalous diffusion: a fractional dynamics approach. *Physics Reports*, 339:1–77, 2000.

[4] Jérémie Vilpellet, Alexandre Darmon, and Michael Benzaquen. From random walks to thermal rides: Universal anomalous transport in soaring flights. *arXiv preprint arXiv:2601.01293*, 2026.

[5] V. Zaburdaev, S. Denisov, and J. Klafter. Lévy walks. *Reviews of Modern Physics*, 87:483–530, 2015.

[6] Peter M. Kareiva and Nanako Shigesada. Analyzing insect movement as a correlated random walk. *Oecologia*, 56(2-3):234–238, 1983.

[7] Iain D Couzin, Jens Krause, Nigel R Franks, and Simon A Levin. Effective leadership and decision-making in animal groups on the move. *Nature*, 433(7025):513–516, 2005.

[8] Andrew M Berdahl, Albert B Kao, Andrea Flack, Peter AH Westley, Edward A Codling, Iain D Couzin, Anthony I Dell, and Dora Biro. Collective animal navigation and migratory culture: from theoretical models to empirical evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 373(1746):20170009, 2018.

[9] Olivier Bénichou, Claude Loverdo, Michel Moreau, and Raphaël Voituriez. Intermittent search strategies. *Reviews of Modern Physics*, 83(1):81–129, 2011.

[10] Sidney Redner. *A Guide to First-Passage Processes*. Cambridge University Press, Cambridge, 2001.