Robust multi-scale optimal trajectory planning for a long-range UAV in a stochastic wind field

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Context

In 2020, ISAE-SUPAERO launched the Mermoz challenge (*Défi Mermoz*). It is about designing a UAV able to **cross the Atlantic** between Dakar and Natal (following air mail pioneer Jean Mermoz) **without en-route CO2 emissions** and **autonomously**. Among the different challenges posed by the mission, the construction of **feasible and optimal trajectories** for the drone is the focus of this PhD.

The Mermoz drone

- **Fixed-wing** UAV
- **4**m wingspan
- **Hydrogen** powered

PhD objectives

- **Large scale** : develop a planning method to compute optimal trajectories which are robust to an uncertain and unsteady wind.
- **Local scale** : develop an adaptive control law for the drone from the observation of the local wind.

The mission

Dakar and Natal are around 3000km apart. The drone will fly at around 200m above sea level at an airspeed of 83km/h.

Challenging features

- **Strong wind regions** : there may be regions in which the wind value can be greater than the drone's airspeed.
- **Time-varying windfield** : the problem is not purely spatial.
- **Spatially uncertain windfield** : the wind measurements are only made on a mesh which resolution can be large.
- **Temporally uncertain windfield** : the wind predictions used to build a model of the windfield in the future are only made up to a certain likelihood degree.

Bidisciplinary work

DAEP (ISAE-SUPAERO):
expert in aerodynamics
→ Physics model

OPTIM (ENAC):
expert in optimization
→ Problem solving

Base model

- We consider that the UAV is a mass point in 2D space with position vector $\underline{X}$, airspeed v_a and we control the heading angle u. The wind $\underline{v_w}$ is a vector field of space. With this model, the problem of reaching some point in space while minimizing a criteria is called a **Zermelo problem**.

$$\frac{\mathrm{d}\underline{X}(t)}{\mathrm{d}t} = v_a\left(\cos u(t) \;\; \sin u(t)\right)^T + \underline{v_w}(\underline{X}(t)) \qquad (1)$$

- Progressively, we will add the dependence of the windfield to **time** and we will make it a **random variable**. Both characteristics will be highly influenced by the atmospheric wind model we plan to use.

First results

- Derivation of properties over the Zermelo problem (1) when the wind is a **potential flow**
- Development of an algorithm similar to Bijlsma's [1]. We use Pontryagin's maximum principle (PMP) to compute trajectories candidate to optimality which are called **extremals**. This is a first step towards the study of the **reachable set** for the drone.
- Study of atmospheric boundary layer windfield models

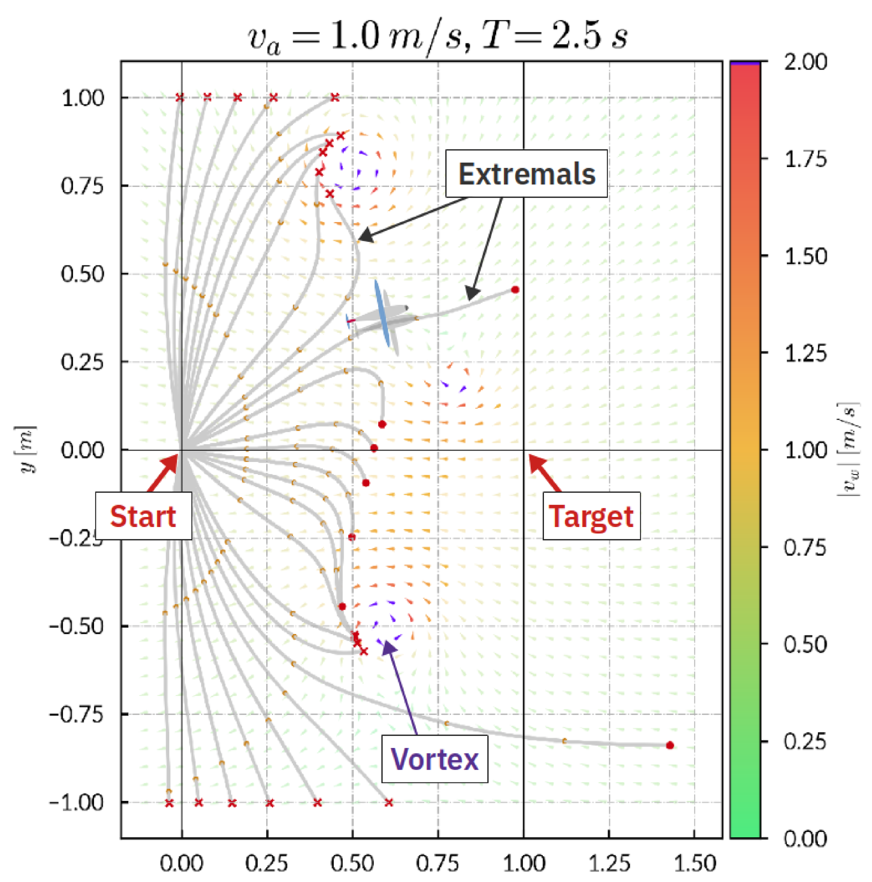

Figure 1: Bijlsma's algorithm

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