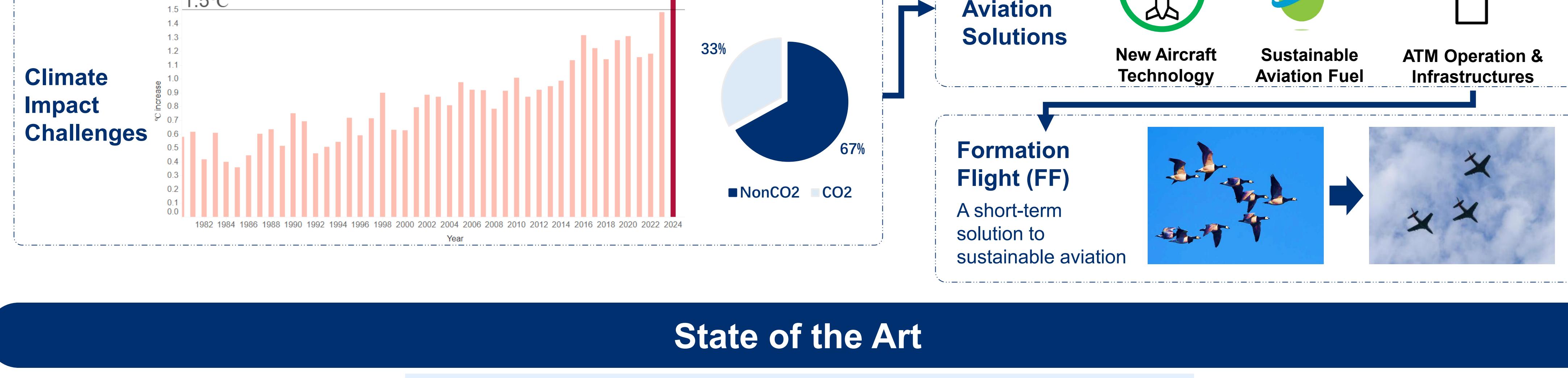# Assessing the Climate Impact of Formation Flight in Commercial Aviation through Network-Level Optimization
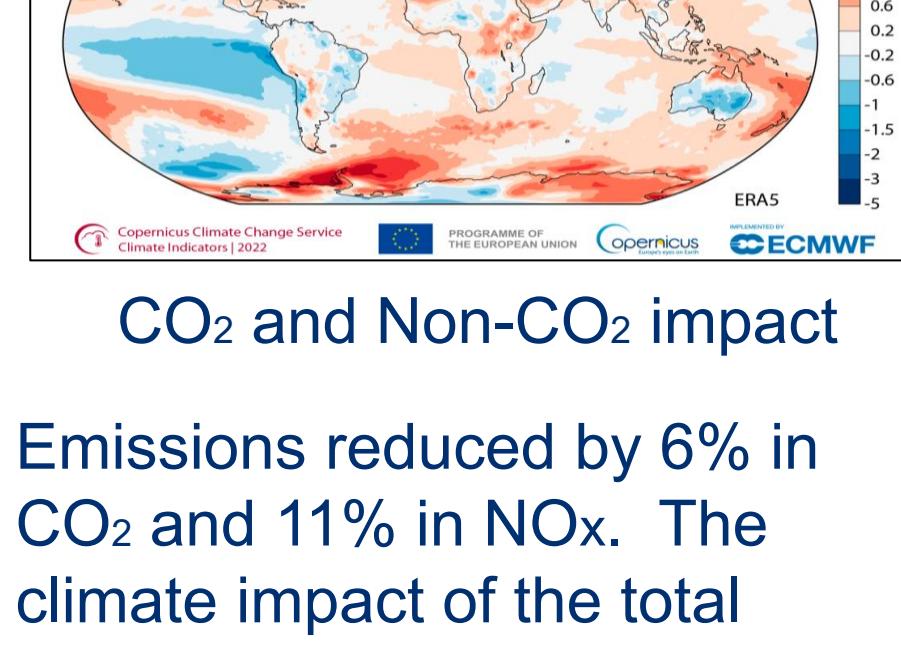
Author: Xiaoqing Deng
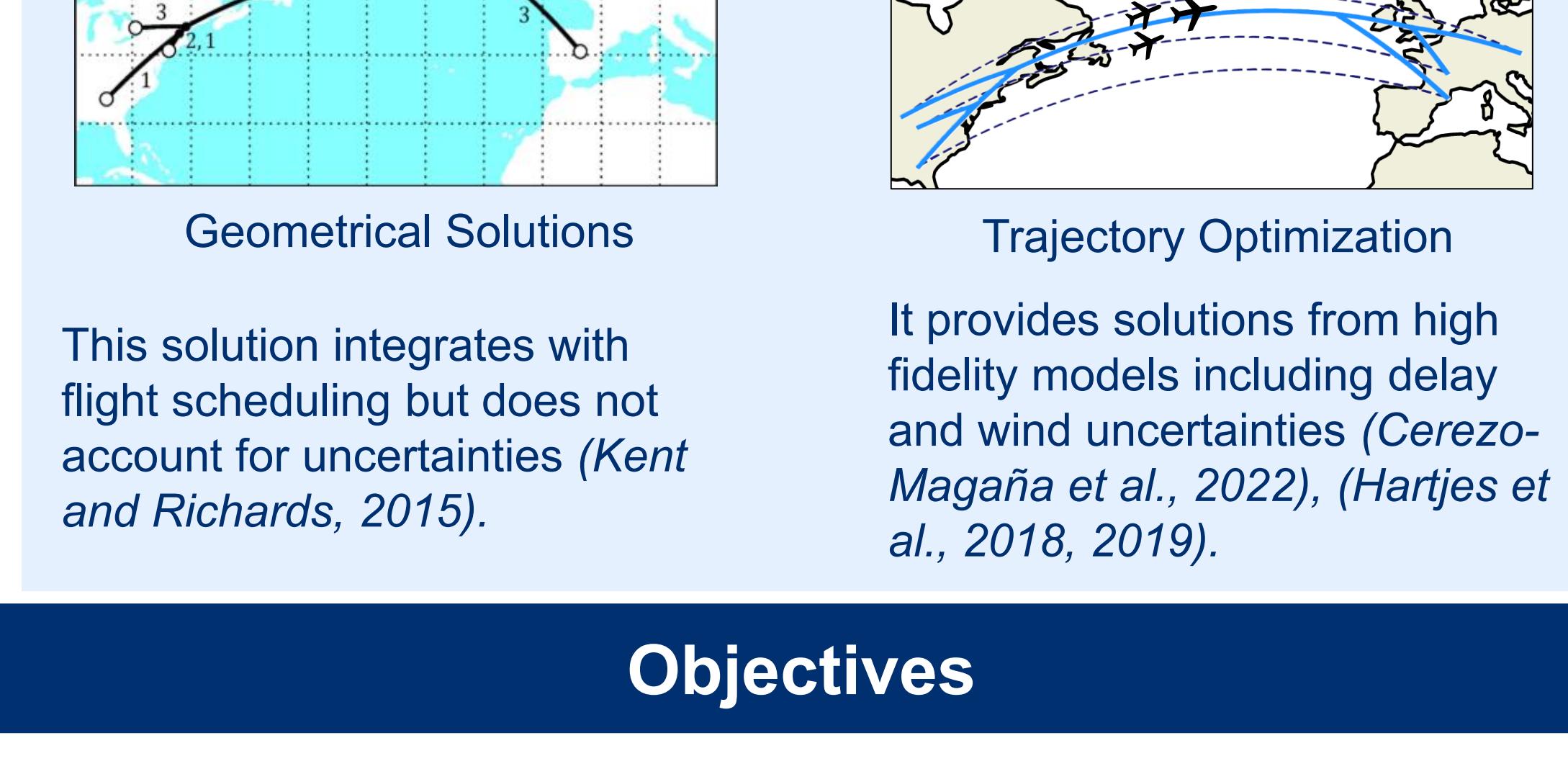Supervisor: María Cerezo Magaña and Ricardo Gázquez

Motivation

To support the **Paris Agreement**, the IPCC has established the objective of limiting the temperature increase to within 1.5 °C above preindustrial levels. However, the Copernicus Climate Change Service confirms **2024** as the **warmest** year and the **first year to exceed 1.5 °C** above the preindustrial level.

Temperature increase above pre-industrial

1.5℃

Climate Impact Challenges

33%
67%
■ NonCO2 ■ CO2

Emerging Aviation Solutions

New Aircraft Technology | Sustainable Aviation Fuel | ATM Operation & Infrastructures

Formation Flight (FF)
A short-term solution to sustainable aviation

State of the Art

Simulation of Climate Impact for FF

CO₂ and Non-CO₂ impact

Emissions reduced by 6% in CO₂ and 11% in NOx. The climate impact of the total formation is reduced by about 23% (Dahlmann et al, 2020).

Modeling of the Formation Flight Problem

Geometrical Solutions

This solution integrates with flight scheduling but does not account for uncertainties *(Kent and Richards, 2015)*.

Trajectory Optimization

It provides solutions from high fidelity models including delay and wind uncertainties *(Cerezo-Magaña et al., 2022), (Hartjes et al., 2018, 2019)*.

Flight Testing for FF

Fello'fly Project / NASA C-17 Flight Test

Flight tests demonstrated 5 – 8% Fuel savings overall (Two Aircraft)

Objectives

The main objective:
Quantify the mitigation of climate impact (CO₂ emission, non-CO₂ impact, and contrails) on a network scale for commercial formation flight to ensure safety, balance operating cost, and operational safety.

O1 - Adopt the **climate impact model** suitable for formation flight
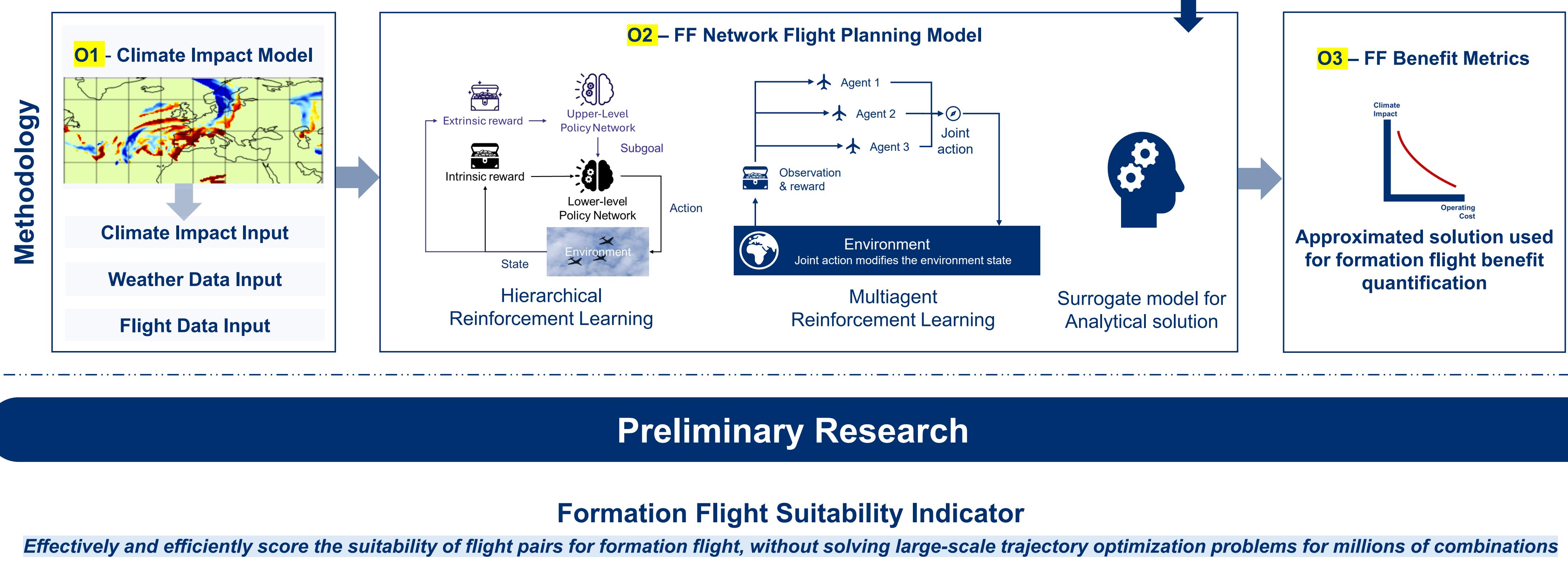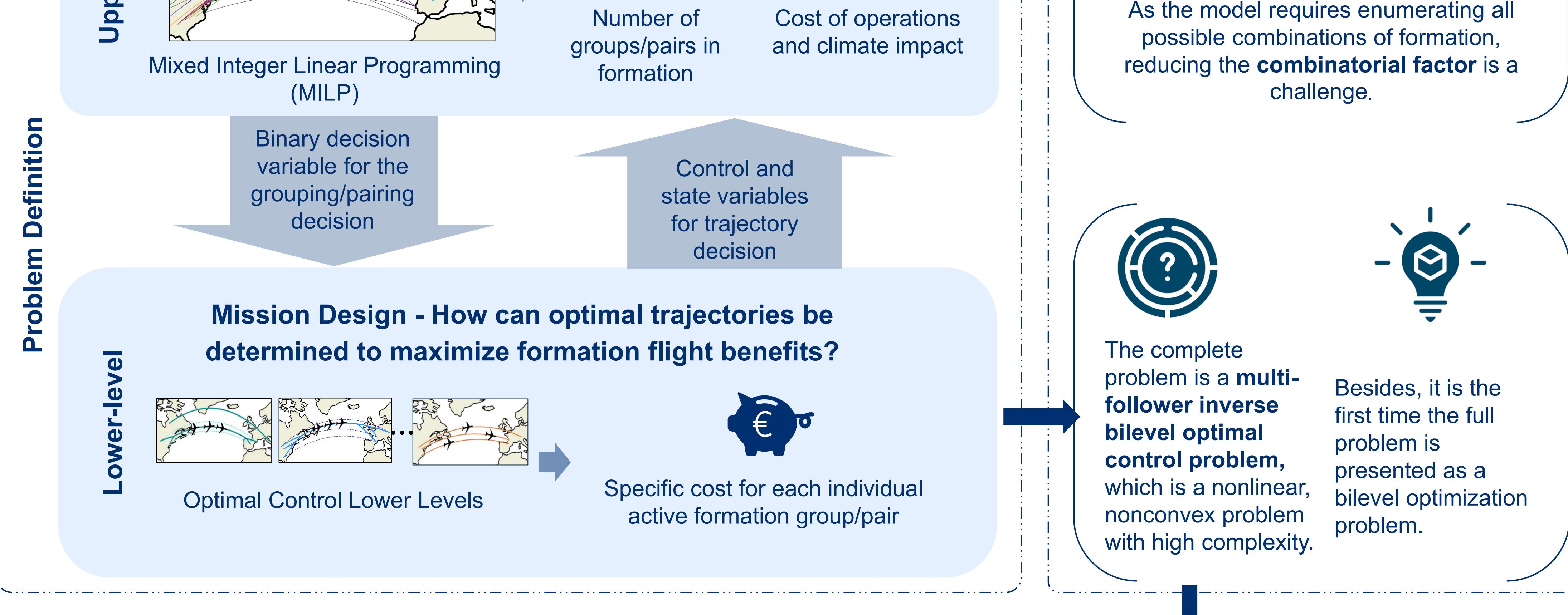
O2 - Develop the most suitable framework to solve the entire real-world **formation problem at the network level**, including **high-fidelity models** and **uncertainties**.

O3 - **Quantify** the **potential and challenges** of commercial formation flight in terms of environmental, economic, and operational impact.

Methodology

Problem Definition

Upper-level

Partner Allocation - How can flights be optimally paired/grouped for formation flight?

Mixed Integer Linear Programming (MILP)

Number of groups/pairs in formation

Cost of operations and climate impact

Binary decision variable for the grouping/pairing decision

Control and state variables for trajectory decision

Lower-level

Mission Design - How can optimal trajectories be determined to maximize formation flight benefits?

Optimal Control Lower Levels

Specific cost for each individual active formation group/pair

Challenges

As the model requires enumerating all possible combinations of formation, reducing the **combinatorial factor** is a challenge.

The complete problem is a **multi-follower inverse bilevel optimal control problem,** which is a nonlinear, nonconvex problem with high complexity.

Besides, it is the first time the full problem is presented as a bilevel optimization problem.

Methodology

O1 - Climate Impact Model

Climate Impact Input
Weather Data Input
Flight Data Input

O2 – FF Network Flight Planning Model

Hierarchical Reinforcement Learning

Multiagent Reinforcement Learning

Surrogate model for Analytical solution

O3 – FF Benefit Metrics

Approximated solution used for formation flight benefit quantification

Preliminary Research
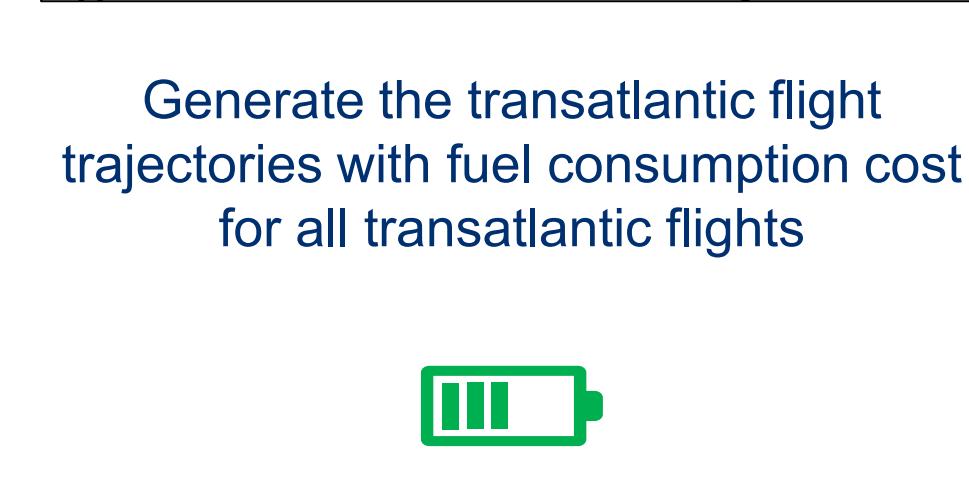
Formation Flight Suitability Indicator
Effectively and efficiently score the suitability of flight pairs for formation flight, without solving large-scale trajectory optimization problems for millions of combinations
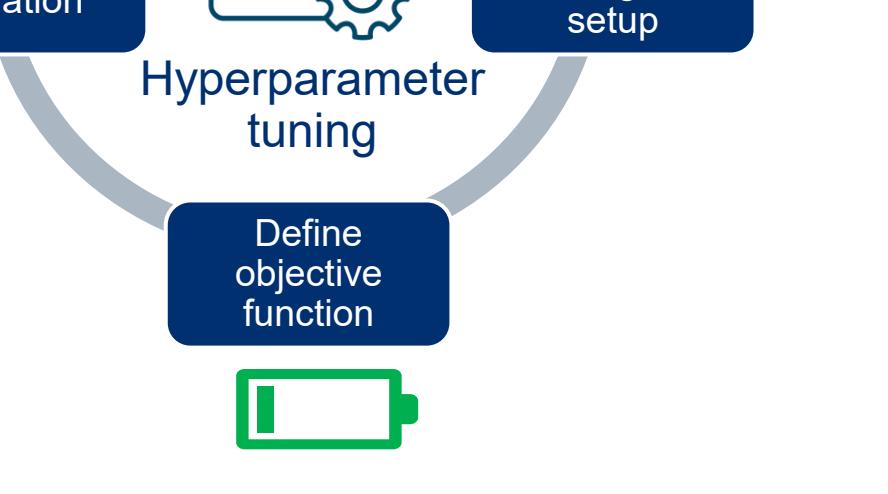
Indicator Formulation

$$Cost = 1 - \omega_1 \frac{\frac{1}{N}\sum_{i=1}^{N} D_i}{max(D_i)} + \omega_2 \frac{(t_2 - t_1)}{(T_2 - T_1)}$$

Distance term | Time term

Calculate the Fuel Consumption Cost

Generate the transatlantic flight trajectories with fuel consumption cost for all transatlantic flights

Hyperparameter Tuning

Data Preparation
Cross-validation
Training/ testing set setup
Hyperparameter tuning
Define objective function

Indicator Validation

Checking with a new scenario for missing good or including bad formation pairs/groups.