

# Assessing the Climate Impact of Formation Flight in Commercial Aviation through Network-Level Path Planning

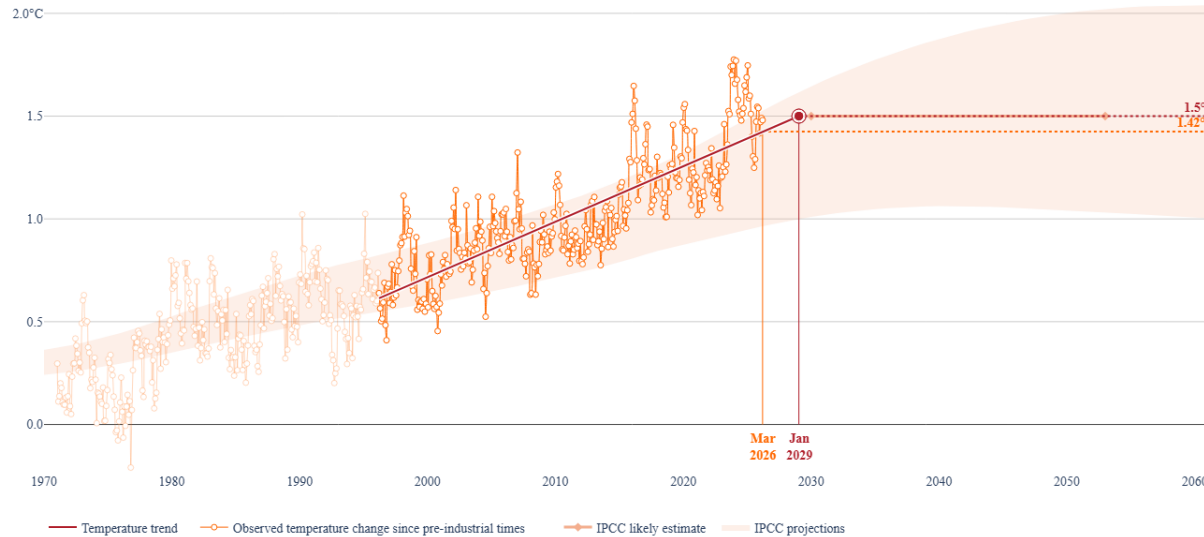
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**PhD Aerospace Engineering UC3M**  
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# Background and Motivation

Global warming reached an estimated **1.42°C** in **March 2026**.

If the 30-year warming trend leading up to then continued, global warming would reach **1.5°C** by **January 2029**.



## Formation Flight



**ATM Operation & Infrastructures**



**New Aircraft Technology**



**Sustainable Aviation Fuel**



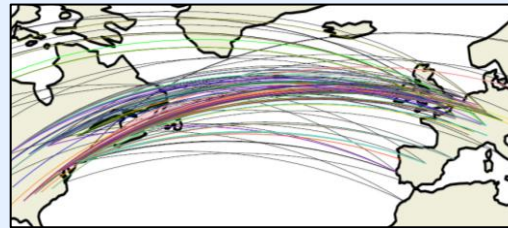


Develop a scalable **formation flight planning framework** to adapt **climate-aware** trajectory planning **for large-scale analysis**.

## Two-Levels Formation Flight Planning Problem

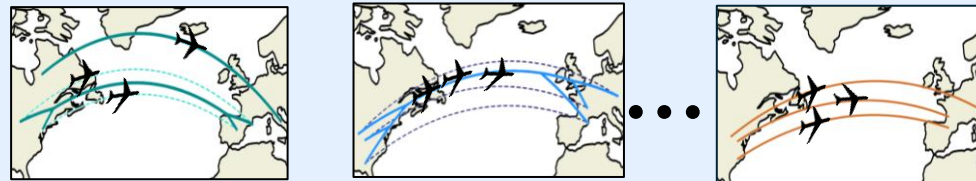
### Partner Allocation

*How can flights be optimally paired/grouped for formation flight?*



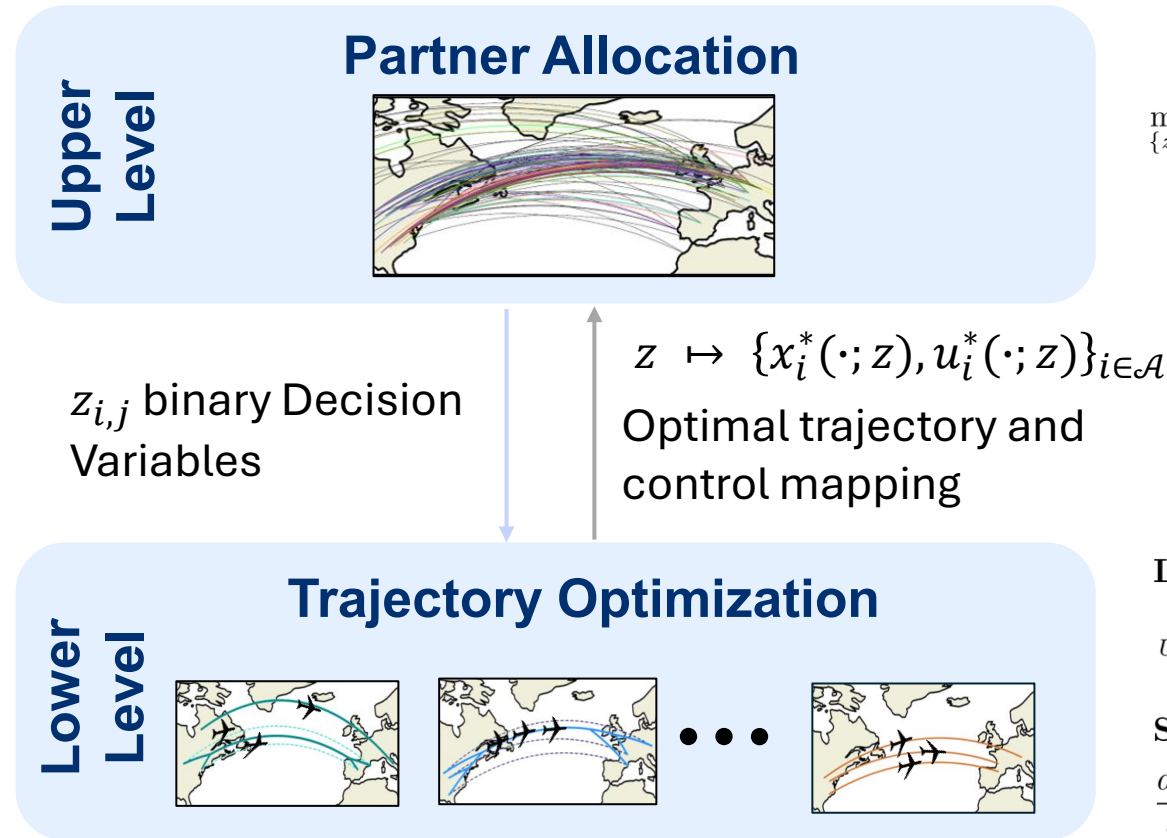
### Trajectory Optimization

*How can optimal trajectories be determined to maximize formation flight benefits?*



- High Dependency
- Combinatorial Factors

## Bilevel Optimal Control Framework



We simplify the problem to model each formation involving **two aircraft** as a pair on a 2D horizontal **plane**.

### Upper Level Partner Allocation Optimization:

$$\max_{\{z_{pq}\}} \sum_{(p,q) \in \mathcal{F}} B_{pq} z_{pq}$$

Total fuel consumptions

$$\text{s.t.} \quad \sum_{p \neq i} z_{pi} + \sum_{q \neq i} z_{iq} \leq 1, \forall i \in \mathcal{A},$$

Leading OR trailing aircraft

$$z_{pq} \in \{0, 1\}, \forall (p, q) \in \mathcal{F}.$$

**Combinatorial Factors**

### Lower Level Trajectory Optimization (Multiple):

$$\min_{U(t), t_f} \mathcal{J} := \Phi(X_f, t_f)$$

Solo/formation fuel consumption

Subject to:

$$\frac{dX}{dt} = F(X, \mathcal{U}(t))$$

Flight Dynamics

$$\mathcal{C}(\mathcal{U}(t)) \leq 0, \quad \mathcal{S}(X, \mathcal{U}(t)) \leq 0$$

Flight Envelopes

$$\phi_0^T(X_0) := (x_0 - x(0), y_0 - y(0), m_0 - m(0), z_0) = \vec{0}$$

$$\phi_f^T(X_f) := (x_f - x(t_f), y_f - y(t_f), 0, 0) = \vec{0}$$

Boundary Conditions

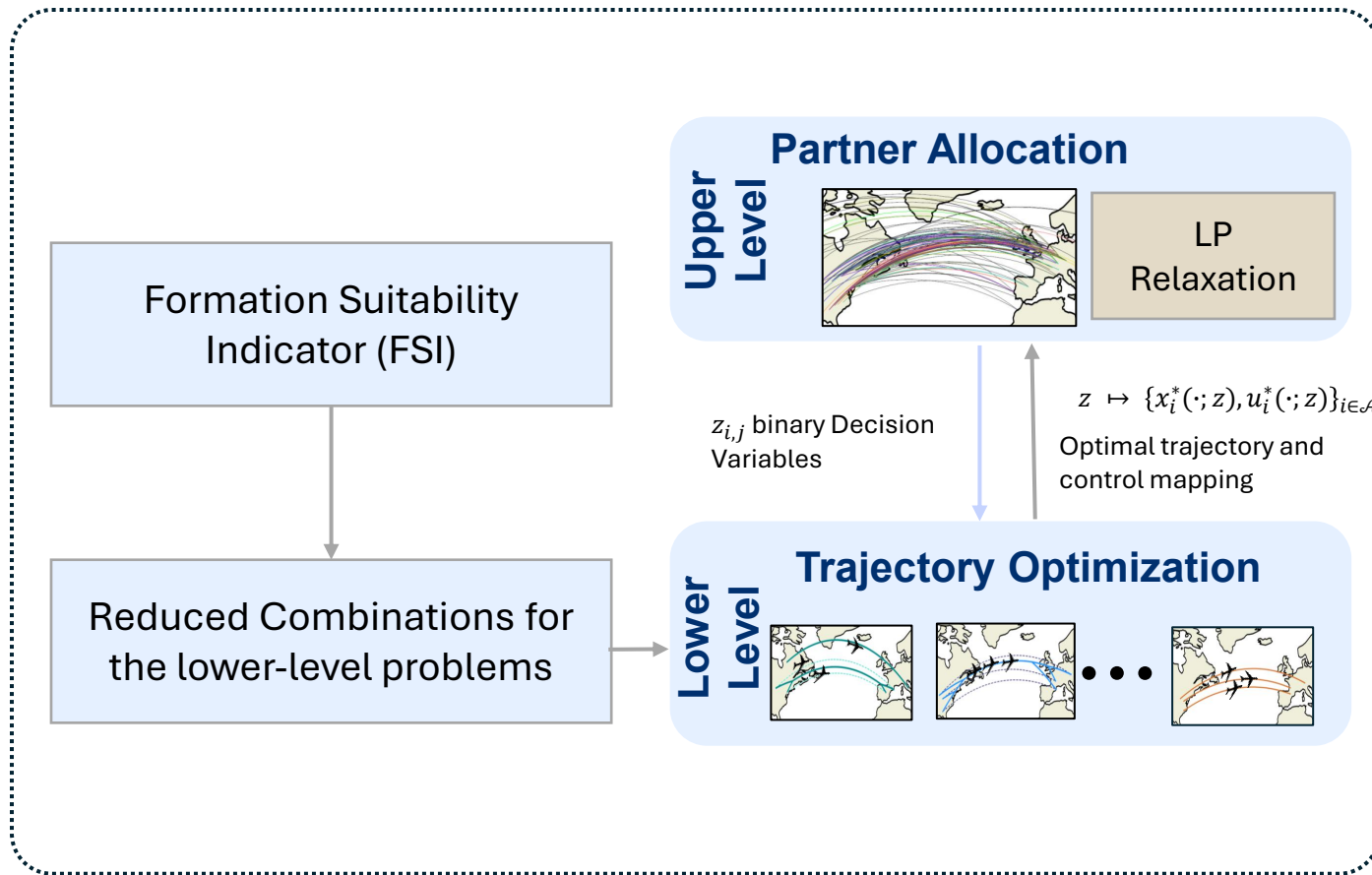
$$10b - M_1(1 - z_{pq}) \leq D_{pq} \leq 20b - M_2(1 - z_{pq})$$

Lateral distance between flight pairs

$$C_D = C_{D0} + kC_L^2(1 - \mathcal{CD}_i)$$

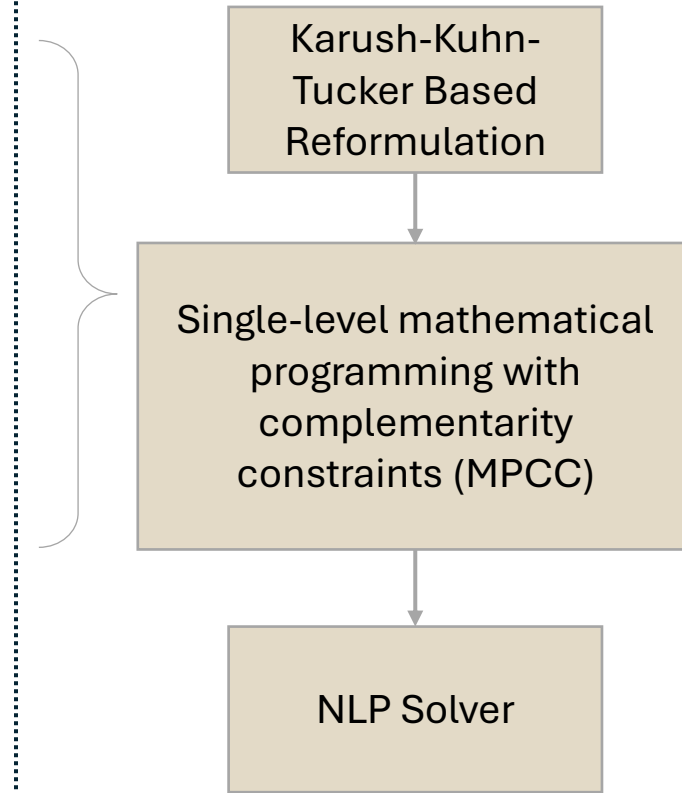
For trailing Aircraft, the Drag coefficient

# Next Work: Bilevel Optimal Control Framework



Current Work in FSI and Formulations

## Future Work in Reformulations and Solutions

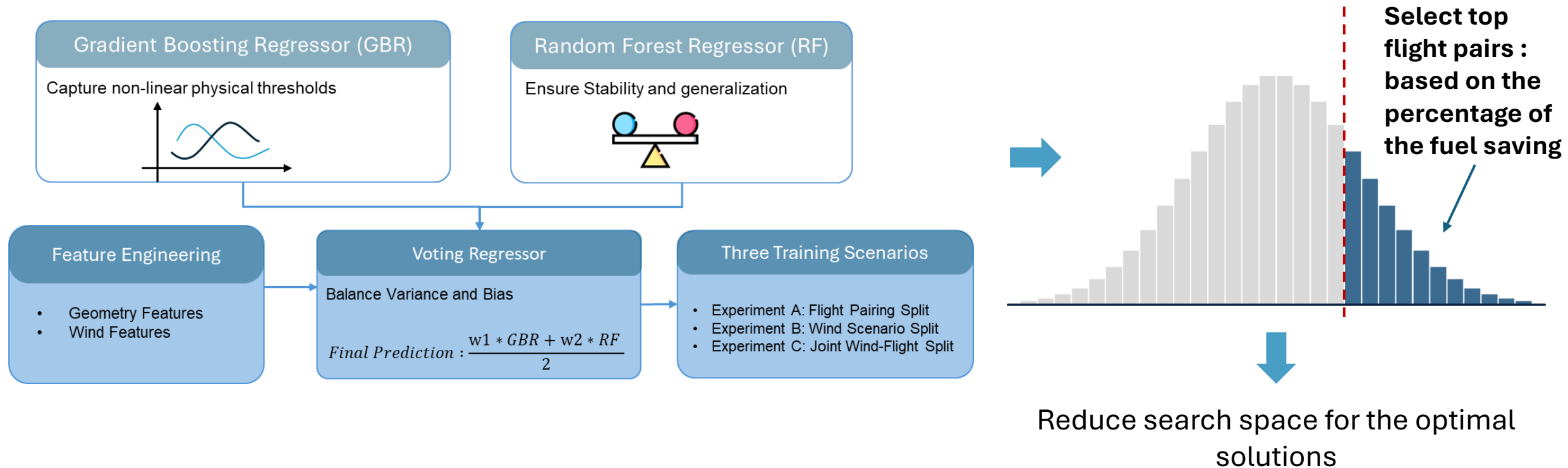


# Formation Suitability Indicator

## ▪ Goal of Formation Suitability Indicator:

Create an indicator based on **formation fuel saving prediction** to quantify the formation's suitability using only **solo flight information**.

## ▪ Method used in Regression for Fuel Savings Predictions:



# Results

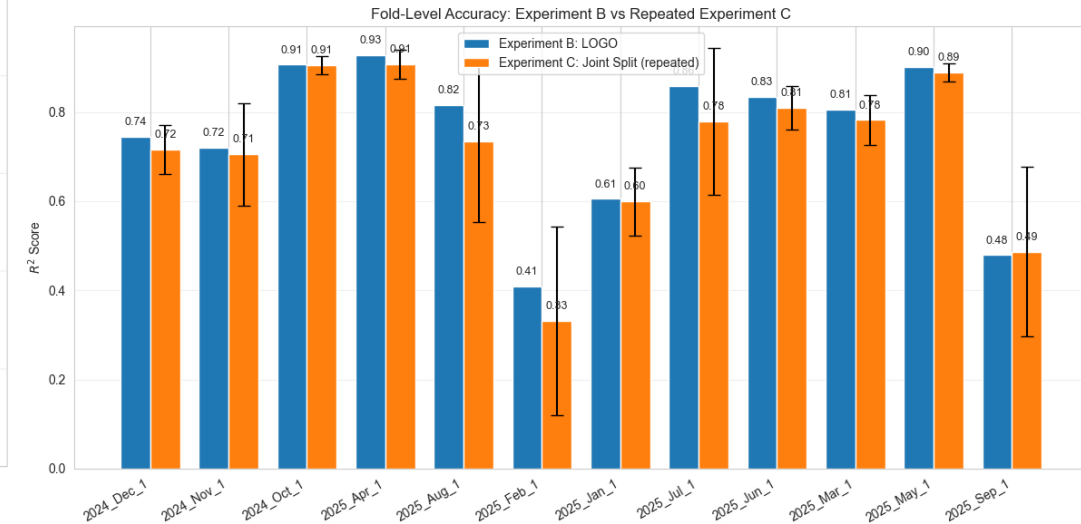
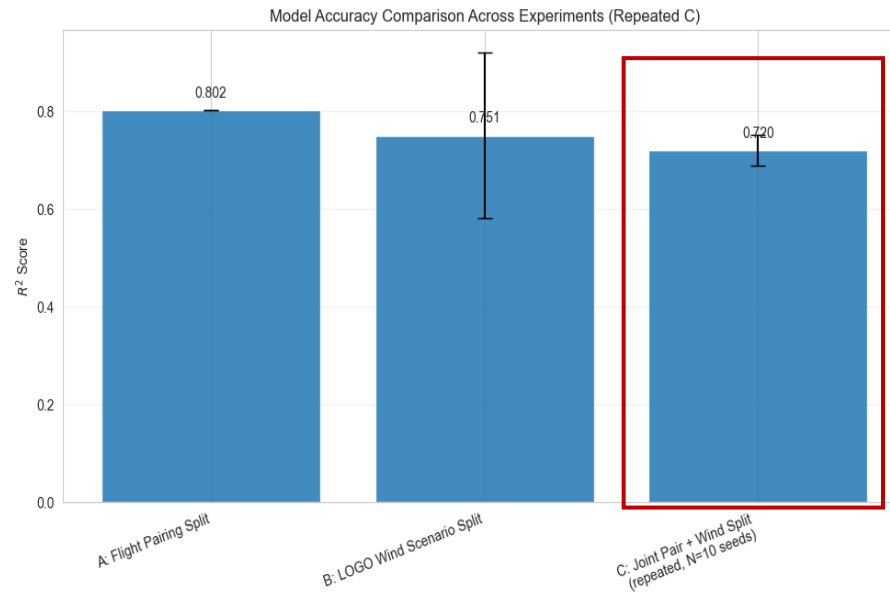
## Case study Data

2025-01-01 Flights  
between 9-11 UTC time

Total flights (solo): 57

Total flight pairs: 383

Total flight pairs for  
prediction: 382 (1 outlier  
detected)



Data Removed Potential: 92%

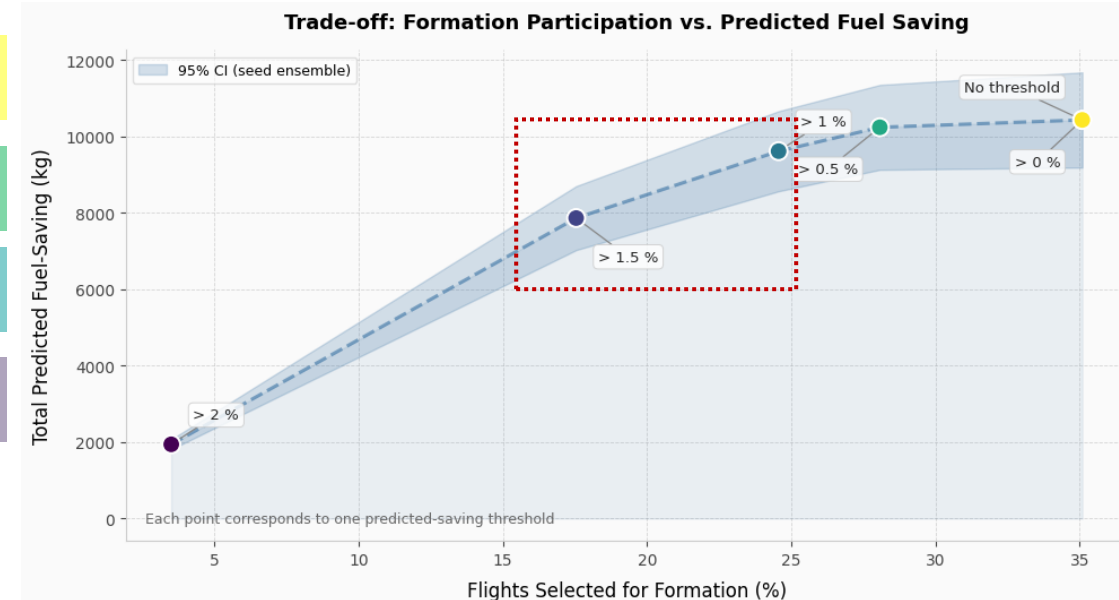
Select positive fuel saving: 8%  
of the total flight selected

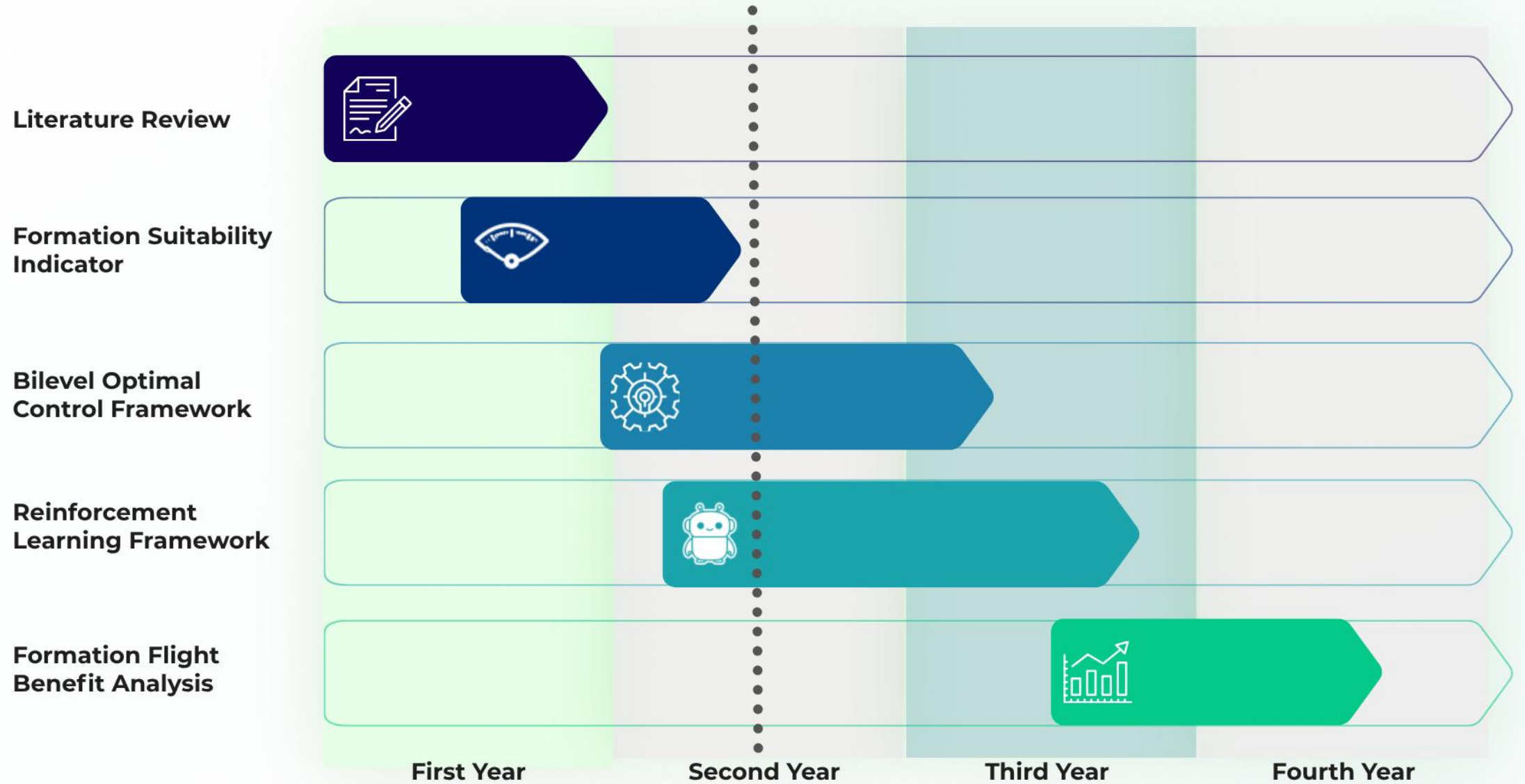
Select 0.5% of fuel saving:  
5.8% flights selected

1% fuel saving: 4.4%  
flights selected

1.5% fuel saving: 3%  
flight selected

2% fuel  
saving 0.3%  
flight selected





- Journal Paper In preparation:
  - A Scalable Formation Flight Suitability Indicator to Enable Network-Level Fuel Savings
- Conference Posters:
  - EASN 2025: *A Scalable Formation Flight Suitability Indicator for Network-Level Fuel Efficiency. Xiaoqing Deng, María Cerezo Magana, Ricardo Gazquez*
  - ECATS 2026: *Data-Informed Identification of Suitable Formation Flight Pairs Under Multi-Scenario Wind Modeling. Xiaoqing Deng, Amin Jafarimoghaddam, Ricardo Gázquez, María Cerezo-Magaña*
- Summer Schools:
  - Engage 2 Summer school 2024 and 2025

Thank you!  
Questions?

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