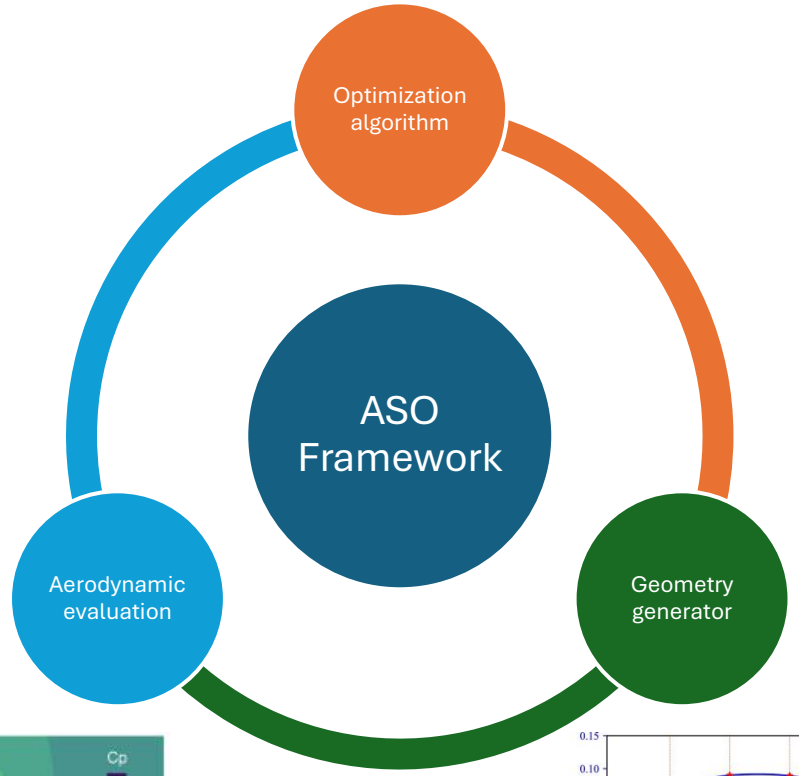
Supported by the Predoctoral scholarship of the
Spanish National Institute for Aerospace Technology

Aerodynamic Shape Optimization *using Reinforcement Learning*

PhD Student: Javier Berrueco-Fernández
Supervisor/s: Rodrigo Castellanos (UC3M),
Esther Andres-Perez (INTA)

PhD Aerospace Engineering UC3M
Doctoral Meetings 2026
2nd and 3rd June 2026

- **Aerodynamic Shape Optimization** is the process of modifying a geometry to minimize aerodynamic drag
- Three core elements: geometry, evaluation and optimization

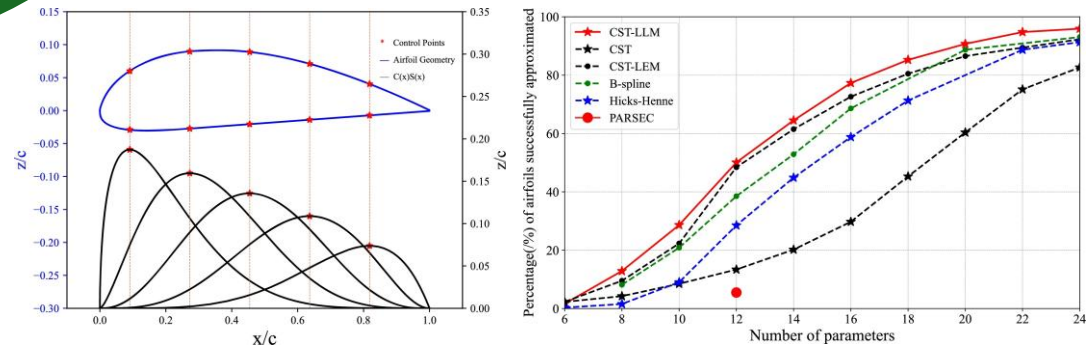


1%

Drag reduction

Translates into billions of dollars in annual fuel savings for the global aviation industry

(Burgess, 2014)

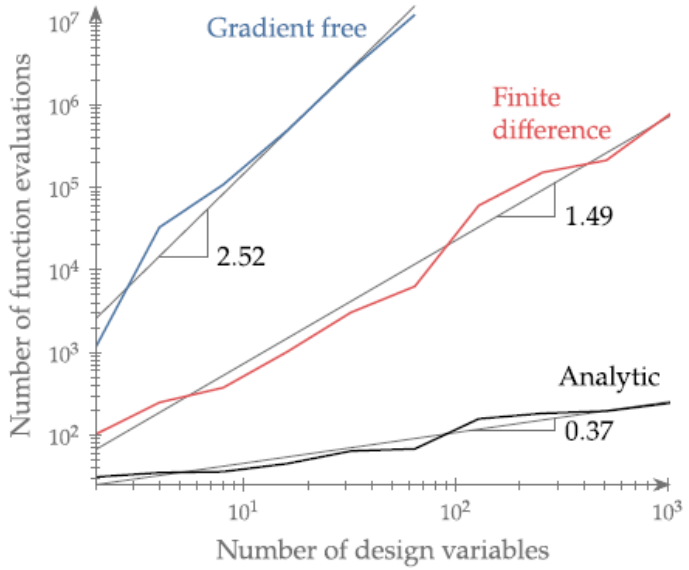


(Zheng et al., 2025)

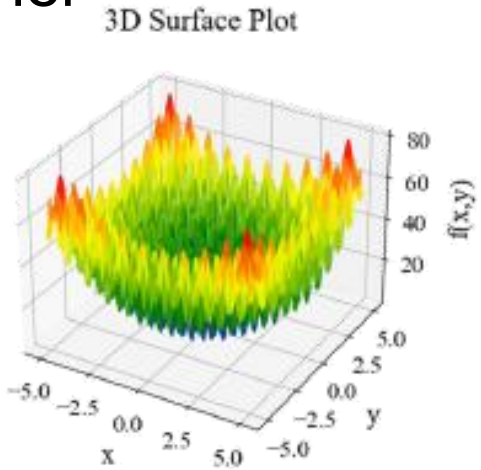
Introduction

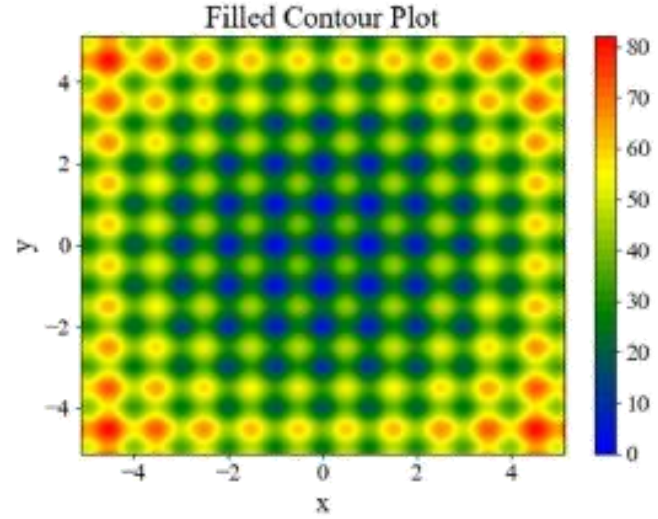
- **SOTA in ASO**:
  - **Bottlenecks/Challenges**:
    - Cost of simulations
    - Multimodality, non convexity
    - Curse of dimensionality
  - **Methodologies**:
    - Adjoint Method + CFD
    - Hybrid Genetic Algorithms (or other heuristic algorithms)
    - **Machine Learning**

(Li et al., 2022)



(Martins, 2022)



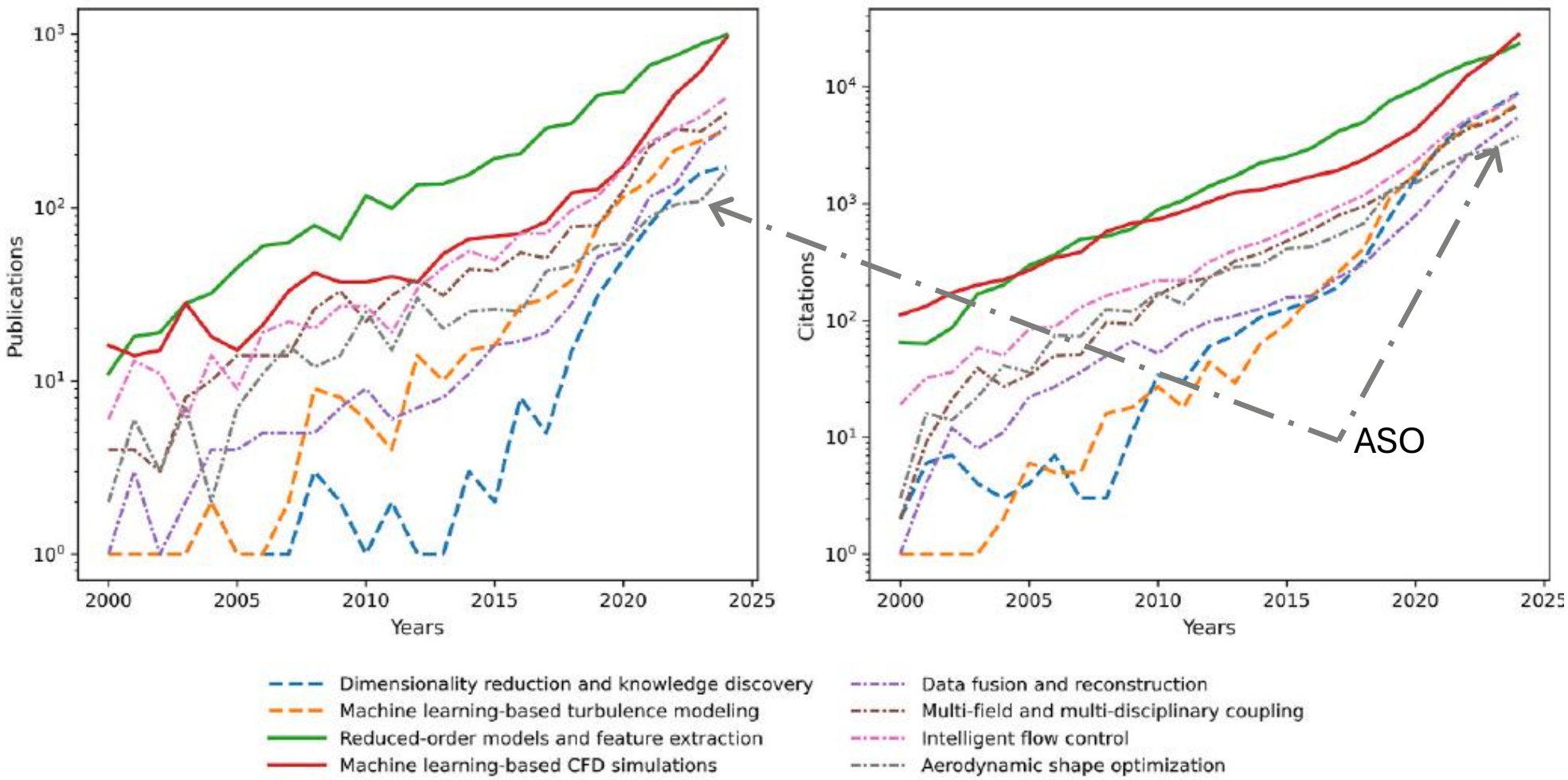


(Wang et al., 2025)

Introduction

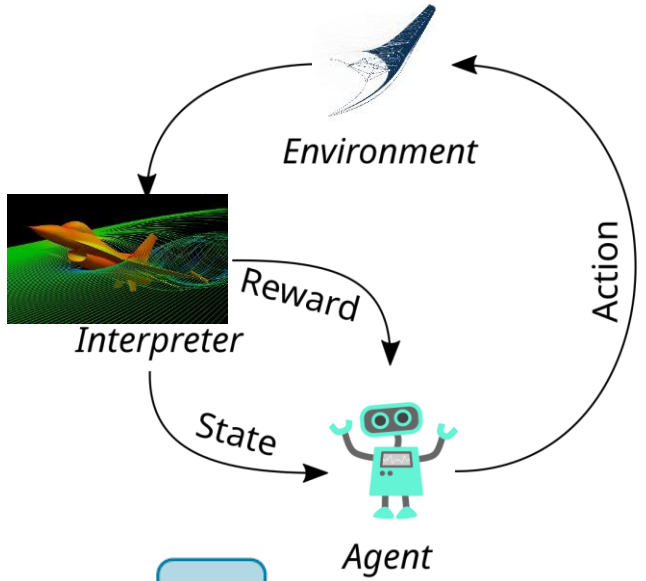
ASO is not the trendiest discipline in Artificial Intelligence for Fluid Mechanics (Zhang et al., 2025)

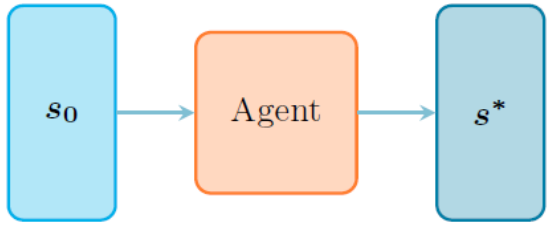
(Zhang et al., 2025)



Reinforcement Learning and ASO

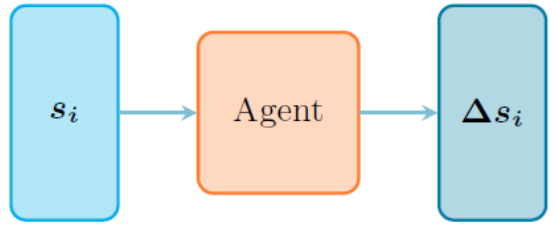
- **DRL** methods like PPO and DDPG **effectively navigate continuous, non-linear aerodynamic design spaces** (Viquerat et al., 2022)
- **Agents optimize** geometry either **incrementally** or in a **single step**, maximizing aerodynamic efficiency rewards (Viquerat et al., 2021; Dussauge et al., 2023; Ramos et al., 2025; Scavella et al., 2025)
- **Transfer Learning** accelerates training by using fast surrogate models before deploying computationally expensive CFD solvers (Yan et al., 2019; Bhola et al., 2023; Ramos et al., 2025)
- Guiding agents with **physical flow features** enables zero-shot generalization to different flight conditions (Wang et al., 2026)





(a) Direct shape optimization.

(Viquerat et al., 2022)



(b) Incremental shape optimization.

Motivation & Research Question

- **ASO is critical** in the transport industry
- **ASO is facing technical bottlenecks** while fresh new aerodynamic designs are emerging
- **DRL offers transformative potential** for ASO
- **DRL lacks generalizability**

"How can a Deep Reinforcement Learning (DRL) framework be developed to enable the creation of aerodynamic shape optimization strategies that generalize to unseen flight conditions (zero-shot) without requiring retraining?"

Thesis Roadmap

2025
- Literature review on ASO
- Built conventional ASO framework
- Propeller Blade Shape Optimization using Hybrid Genetic Optimization (HyGO)

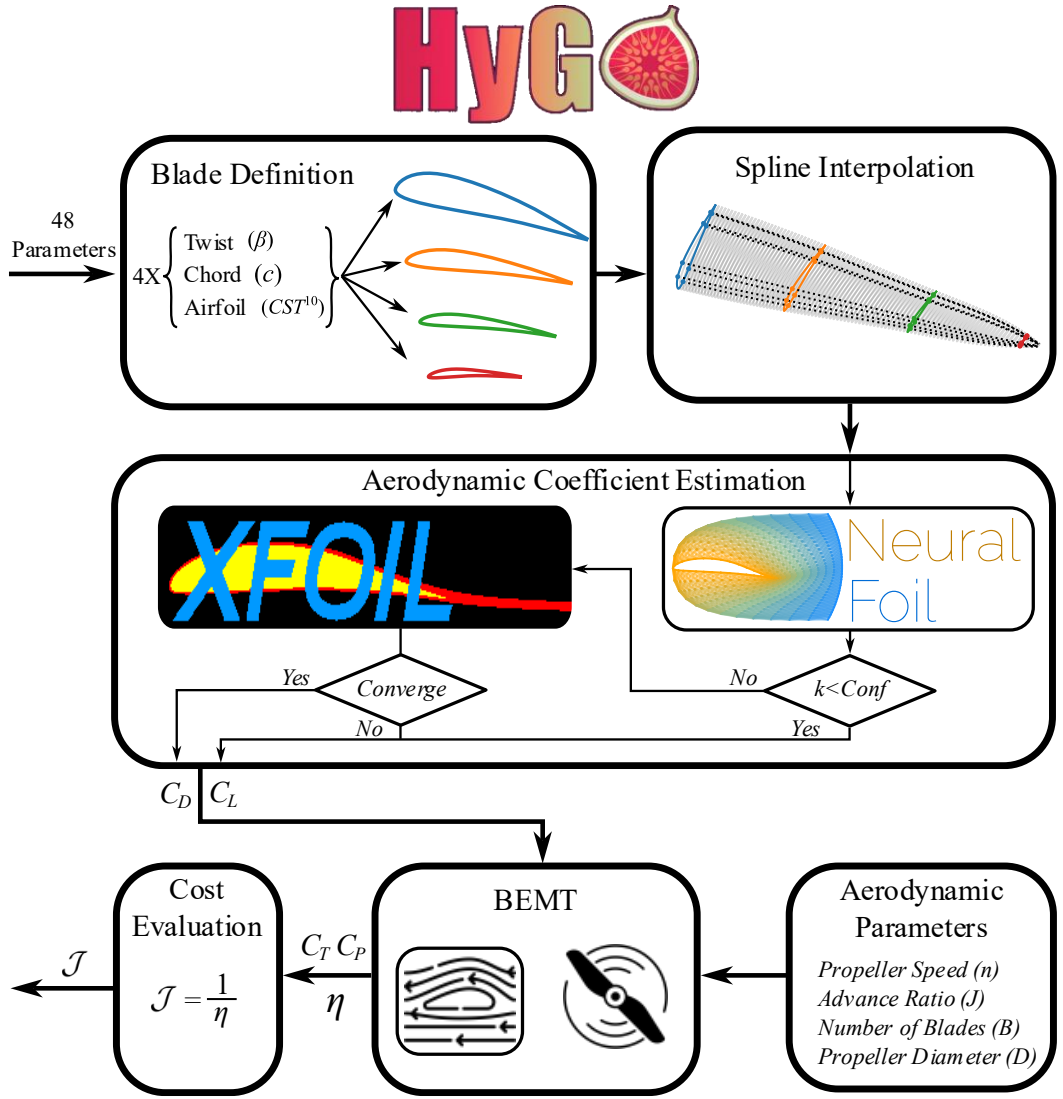
2026
- Literature review in ASO & RL
- Transform original ASO framework to a RL-driven ASO framework
- Airfoil optimization

2027
- To continue testing the scientific hypothesis
- Face different optimization problem (i.e.: PBSO)

2028
- Addressing the conclusion of any remaining open topics
- Focus on structuring and writing the thesis
- PhD defense

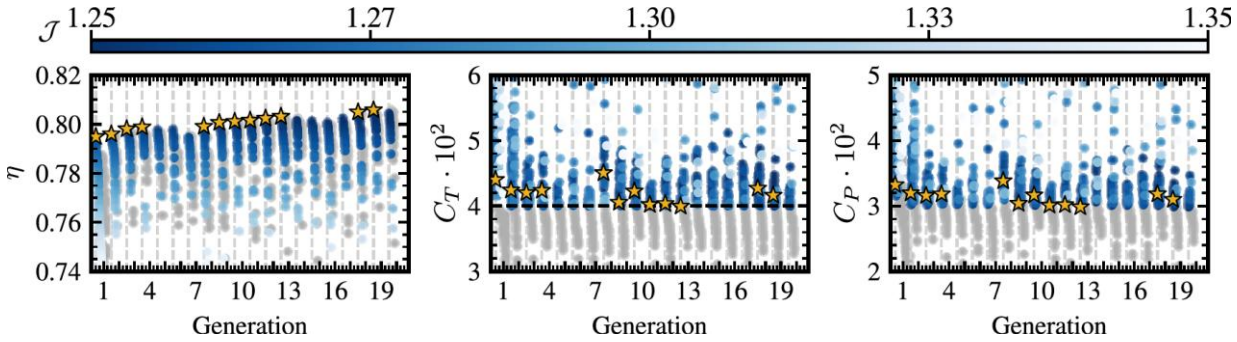
Propeller Blade Shape Optimization

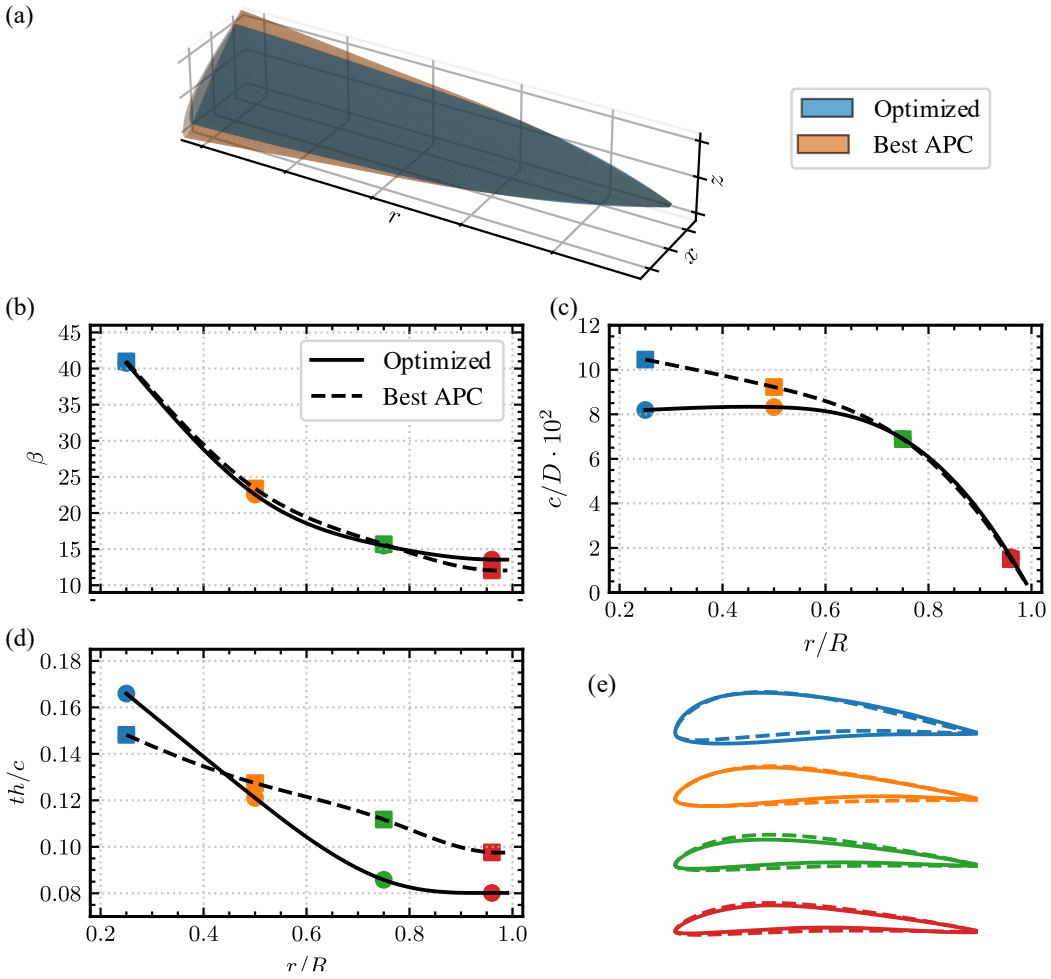
- **Objective**
  - Optimize using low-cost physics, neural surrogate models and hybrid genetic algorithms
- **Why?**
  - Leverage Machine Learning (ML) into the preliminary stages of the aerodynamic design process
- **What?**
  - Optimize small UAV or model aircraft propellers
- **How?**
  - Building a dedicated framework integrating BEMT, NeuralFoil and XFOIL for airfoil analysis and HyGO



Propeller Blade Shape Optimization

- Best optimizations reached the same efficiency
- The optimization tops in terms of efficiency an already high-performance real propellers batch
- Save more than 100x in optimization time in comparison of using only XFOIL (and even more compared to using RANS)





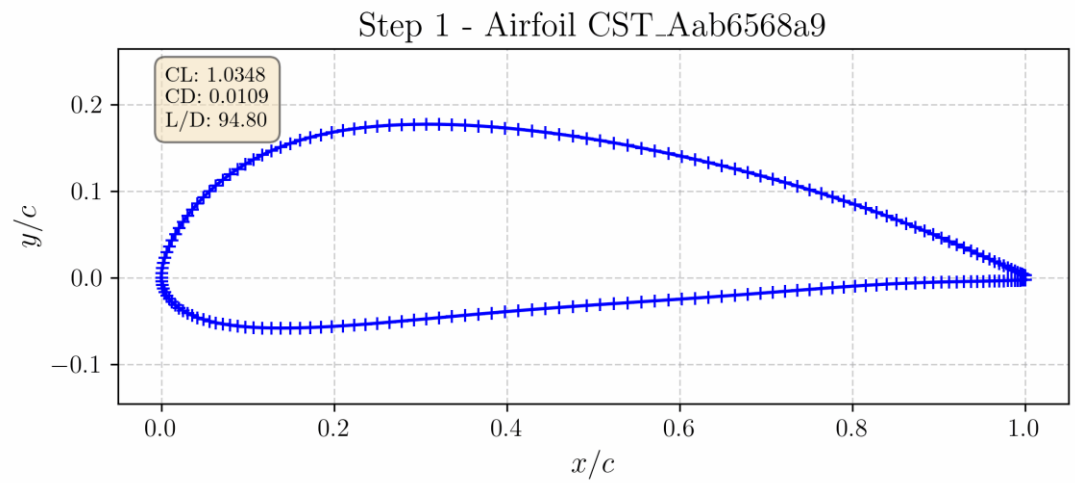
Achievements

- Conference: EUROGEN 2025 - 16th ECCOMAS Thematic Conference on Evolutionary and Deterministic Methods for Design, Optimization and Control Lahti, Finland, 16–18 September, 2025
- Conference proceedings: Berrueco-Fernández, J., Robledo, I., Andres-Perez, E., Castellanos, R. (2026). Propeller Blades Shape Optimization Using Hybrid Genetic Algorithms and Surrogate Models. *Computational Methods in Applied Sciences.* Springer. (Accepted, pending publication)

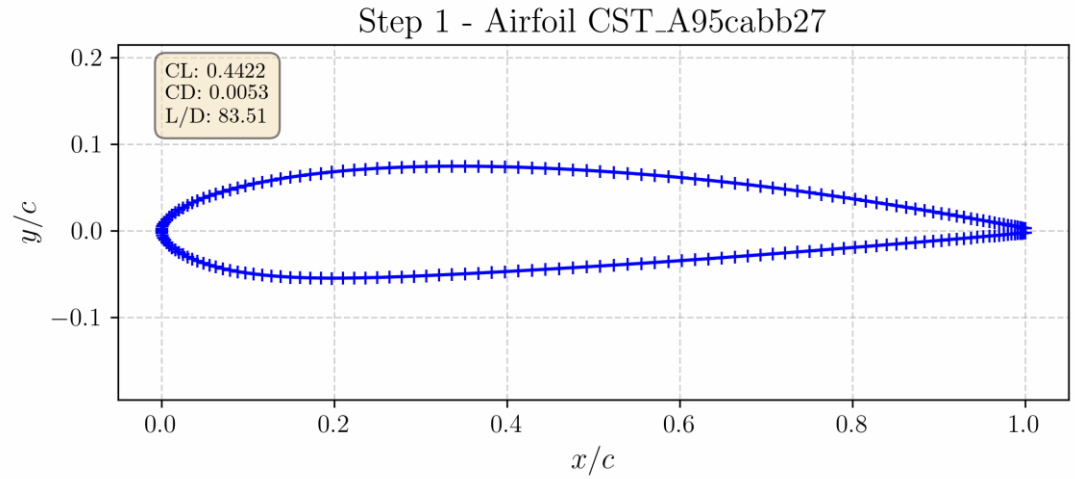
Airfoil Shape Optimization using Reinforcement Learning

- Reproduce an existing methodology (Ramos et al., 2025):
  - PPO using stablebaselines3
  - Incremental action
  - Geometric state variables
  - CST parameters
  - Initialization from existing airfoils
  - Airfoil evaluation using NeuralFoil
- The current objective: **zero-shot!**

Early Training (Episode 100)



After Training (268 episodes)



Other activities

- Course on “Best Scientific Practices” – CSIC foundation
- Mentoring:
  - Researchers Beyond Academia (REBECA) – FECYT
  - Mentoring of the Young Academy of Spain

Supported by the Predoctoral scholarship of the
Spanish National Institute for Aerospace Technology

Thank you!
Questions?

Aerodynamic Shape Optimization *using Reinforcement Learning*

PhD Student: Javier Berrueco-Fernández
Supervisor/s: Rodrigo Castellanos (UC3M), Esther Andres-Perez (INTA)

The author gratefully acknowledges the financial support provided by the Spanish National Institute of Aerospace Technology (INTA) through a predoctoral scholarship, which has made this research possible