Development of a UAV as a Platform for Current and Future Dynamic Soaring Research

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ABSTRACT

We address the final stages in the development of a dynamic soaring (DS) capable unmanned aerial vehicle (UAV). This project has been funded by the Embry-Riddle Office of Undergraduate Research through the Ignite program. Dynamic soaring is a bio-inspired flight maneuver in which energy is extracted by flying through vertical wind velocity gradients such as the wind shear layer. The objective of our project is to design an autonomous dynamic soaring flight controller through simulation, develop a DS capable UAV platform, and perform DS maneuvers in the real world. For simulation, a 6-degrees-of-freedom (6DoF) flight simulation environment in MATLAB and Simulink has been developed. Using computational fluid dynamics (CFD) a variable-fidelity aerodynamic model was obtained. The UAV platform is an FMS Fox Aerobatic Glider, a high aspect-ratio powered glider with a robust sensor suite and autonomous flight control system. Finally, we are developing a reinforcement-learning (RL) trained artificial intelligence (AI) that will optimize the path of the UAV to minimize power consumption. After completion, the UAV will be capable of testing future DS navigation systems. This presentation will discuss current progress as well as address challenges we face in the completion of our goals.

INTRODUCTION

- Dynamic soaring (DS) is a specialized flying maneuver in which energy is extracted from the wind boundary layer by flying through vertical wind gradients
- Vertical wind gradients can be found over flat land, bodies of water, or cliff edges
- In nature sea-fairing birds such as the Albatross use DS to fly for thousands of miles over bodies of water with minimal energy expenditure
- RC hobbyists commonly use DS to gain high speeds using only the gradient of the wind over cliff edges

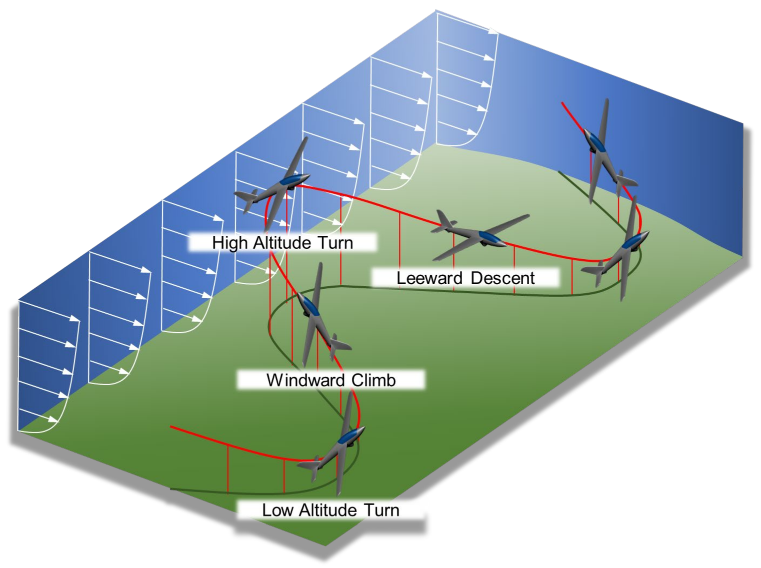

Figure 1. Diagram of the traveling dynamic soaring cycle.

Dynamic Soaring Phases

(1) *Low altitude turn*
- Max kinetic energy

(2) *Windward climb*
- Exchange KE for PE

(3) *High altitude turn*
- Max potential energy

(4) *Leeward descent*
- Exchange PE for KE

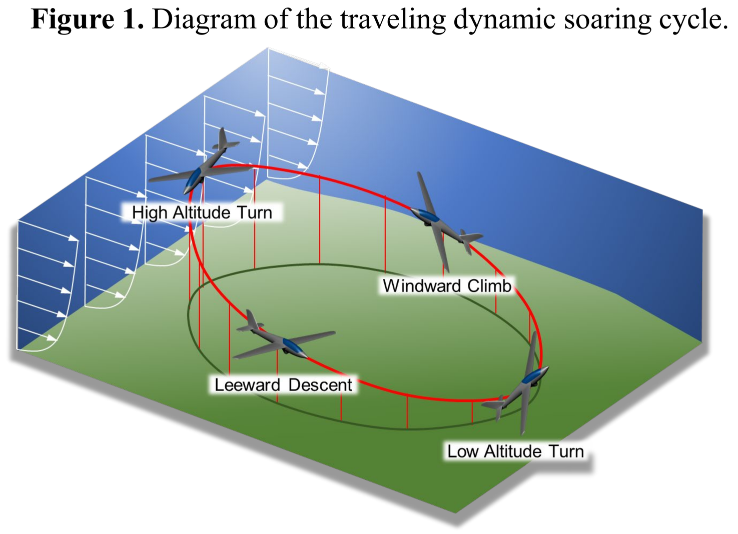

Figure 2. Diagram of the loitering dynamic soaring cycle.

OBJECTIVES

- Our primary objective is to develop an Unmanned Aerial Vehicle (UAV) platform that can perform DS autonomously provided a well-designed autopilot.
- The DS platform consists of:
  a) The physical UAV
  b) Flight simulation environment
- This UAV platform will allow us to:
  (1) Develop and test DS autopilots
  (2) Perform autonomous DS in the real world
  (3) Validate and improve the simulation

Figure 3. UAV platform diagram.

METHODS

UAV Platform

- To perform DS using only the power of the wind:
  - Total energy must be conserved between cycles
  - Requires high lift-to-drag ratio like a glider
  - However, an engine is required to prevent stall in the absence of wind energy
- FMS Fox Aerobatic Glider
  - Cost efficient high-aspect ratio foam RC plane with nose mounted engine
  - Excellent gliding performance balanced with large fuselage for equipment
  - Foam construction provides high durability and easy repairs
- Flight Control and Sensors:
  (1) Pixhawk 4
  - Flight controller
  - Gyroscope
  - Accelerometer
  - Barometer

  (2) Raspberry Pi 4
  - Flight computer

  (3) RTK GNSS
  - GNSS Position
  - Magnetometer

  (4) Data Telemetry
  (5) Airspeed sensor
  (6) AoA Sensor Array

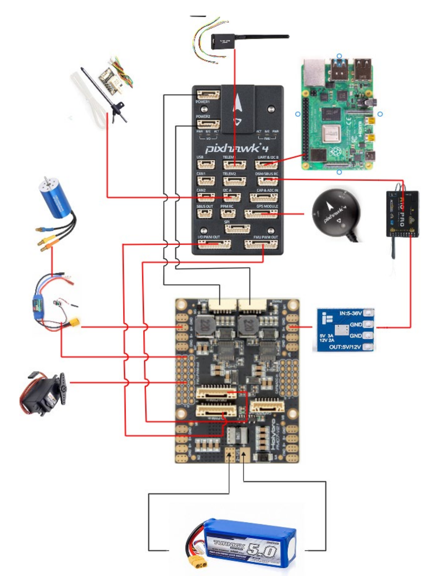

Figure 4. Wiring diagram of the Fox UAV.

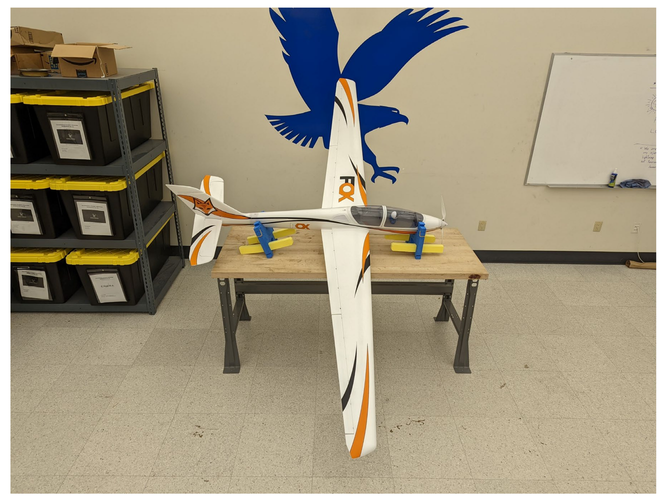

Figure 5. FMS Fox 3000mm aerobatic glider.

Flight Simulation Environment

- The DS simulator is a 6-degree-of-freedom (6DoF) flight simulation environment in MATLAB and Simulink
- Components:
  (1) 6DoF nonlinear equations of motion
  (2) Aerodynamic lookup tables
  (3) DS Autopilot
  (4) Wind shear model
  (5) Power consumption model

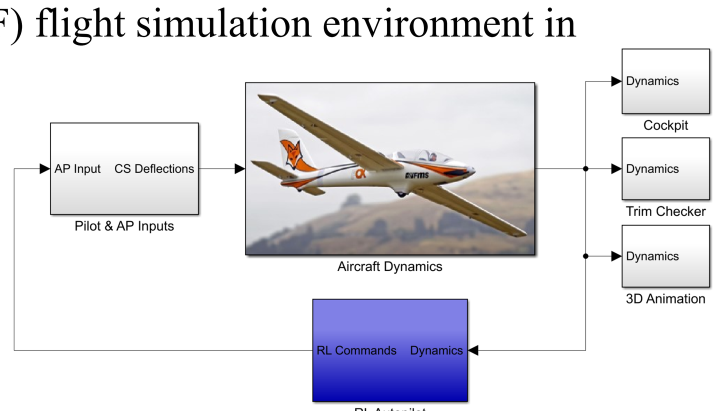

Figure 6. MATLAB & Simulink flight simulation environment.

Computational Fluid Dynamics

- Used to model aerodynamics of UAV
- ANSYS Fluent
  - High-fidelity Navier-Stokes solver
  - Static coefficients
- SURFACES Aircraft Design Software
  - Low-fidelity Vortex-Lattice method
  - Dynamic and Control surface derivatives

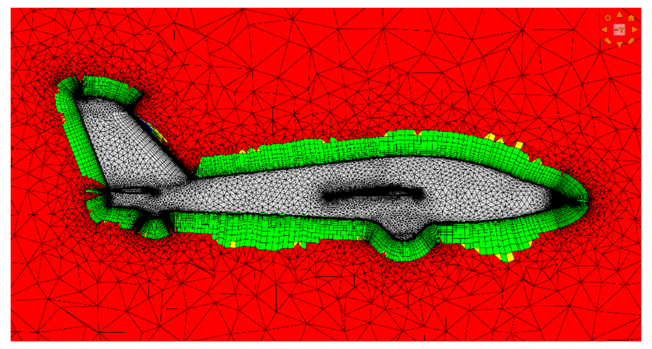

Figure 7. Cross-section of the Fox CFD mesh.

Dynamic Soaring Autopilot

- DS autopilot can be designed using simulation
- Current DS autopilot is a reinforcement learning (RL) trained agent (DSRL)
  - Deep Deterministic Policy Gradient
- The DSRL autopilot consists of two RL agents:
  (1) Path Optimizing Agent
  - Optimizes closed-loop DS flight path

  (2) Path Following Agent
  - Follows the DS path using minimal thrust

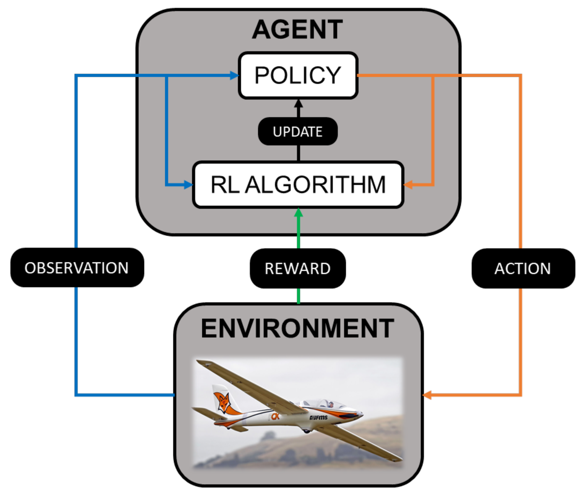

Figure 8. RL flowchart.

RESULTS

Previous Simulation Results

- Demonstrated the feasibility of autonomous DS using a steady, logarithmic wind shear model [1]
- Compared performance of autonomous DS and manually piloted DS
  - Autonomous DS performed consistent but inefficient cycles due to control law limitations
  - Manually piloted DS was less consistent but more efficient cycles since the pilot could dynamically adjust UAV motion in real time
- Results prove that the DS simulator could be used as a tool to design future DS autopilots
- An improved DS autopilot will be developed using reinforcement learning

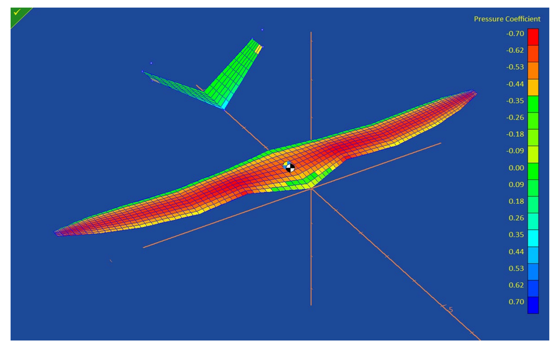

Figure 9. UAV used to perform DS in original DS simulation.

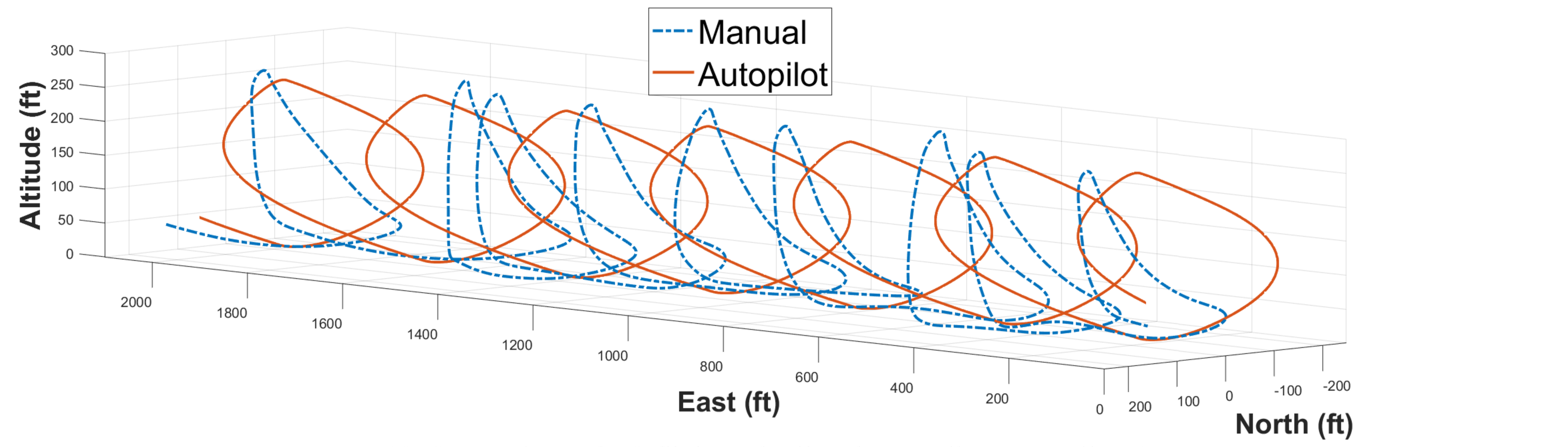

Figure 10. Comparison of DS flight path piloted manually to autopilot [1].

FUTURE WORK

- DS will be performed by integrating the RL path following agent into the Fox UAV
  - Real world results will be compared to simulated results
  - The energy gain from the wind will be quantified by comparing the endurance of a DS cycle with and without wind
- The successful completion of this project will allow for student researchers at ERAU to develop and test future autonomous DS algorithms

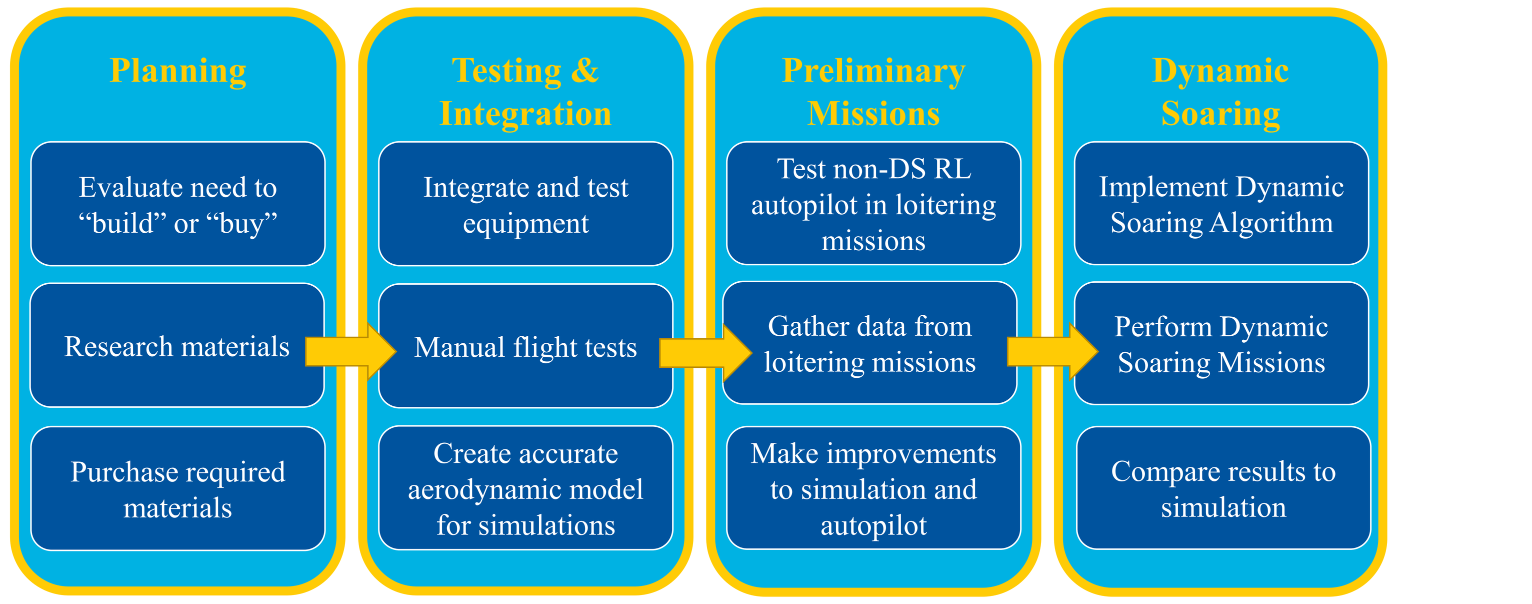

Figure 11. Flowchart of the project phases.

REFERENCES & ACKNOWLEDGEMENTS

[1] Gladston, Joseph, "Design and Flight-Path Simulation of a Dynamic-Soaring UAV," Embry-Riddle Aeronautical University, 2021.

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