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

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ABSTRACT

We address the ongoing development of a dynamic soaring (DS) capable unmanned aerial vehicle (UAV) platform optimized for minimal power consumption. 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 from the wind shear layer by flying through regions of varying wind speed. The objective of our project is to design an autonomous dynamic soaring flight controller and perform DS with a real-world UAV. Development of this project can be divided into three sub-categories: (1) the UAV platform, (2) flight simulations, and (3) the flight controller. The UAV platform is an FMS Fox Aerobatic Glider, a high aspect-ratio glider with a nose-mounted engine. A flight control system has been crafted to allow us to integrate our DS autopilot. In previous works we have created a 6-degree-of-freedom (6DoF) flight simulation environment in MATLAB and Simulink to develop and test DS flight controllers. The simulator can be adapted to integrate our current UAV by building a variable-fidelity aerodynamic model using computational fluid dynamics (CFD). Finally, we are developing a robust reinforcement-learning (RL) trained artificial intelligence (AI) that will optimize the path of the UAV to minimize power consumption. DS will be performed autonomously in the real world and results compared to the simulations.

INTRODUCTION

- Dynamic soaring (DS) is a specialized flying maneuver in which energy is extracted from the wind boundary layer by repeatedly flying through regions of varying wind speed
- Wind gradients are generally found over flat land, bodies of water, or cliff edges
- In nature the Albatross uses DS to fly for thousands of miles over bodies of water with minimal energy expenditure
- RC hobbyists commonly use DS to gain incredible speeds using only the gradient of the wind over cliff edges

The dynamic soaring maneuver consists of four phases:
(1) *Low altitude turn*
(2) *Windward climb*
(3) *High altitude turn*
(4) *Leeward descent*

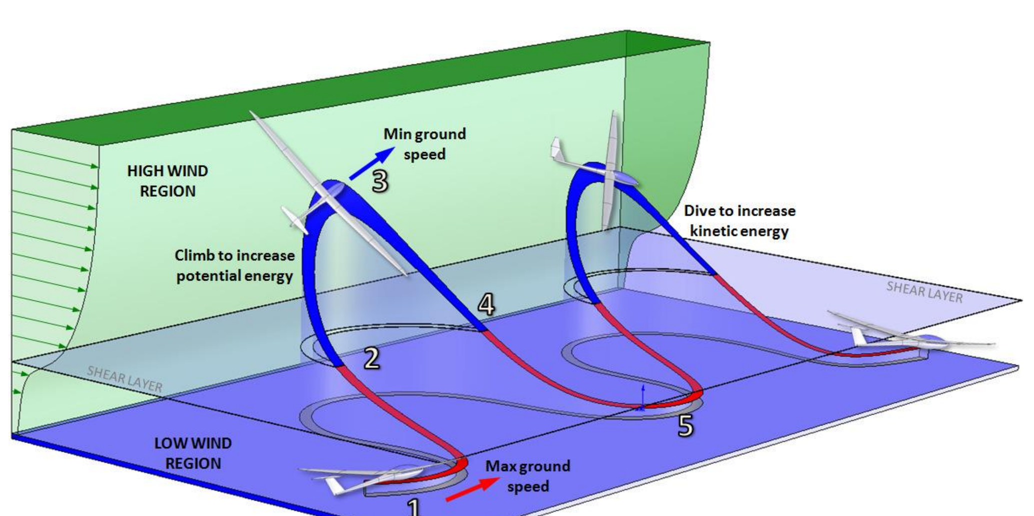

Figure 1. Diagram of the UAV Dynamic Soaring cycle[1].

OBJECTIVES

Our primary objective is to develop an Unmanned Aerial Vehicle (UAV) platform that can perform DS autonomously provided an adequately designed autopilot.

The DS platform consists of:
a) The physical UAV
b) Flight simulation environment

This UAV platform will allow us to:
1. Perform autonomous DS in the real world
2. Validate and improve the simulation
3. Rapidly develop and test future DS autopilots

Figure 2. UAV platform diagram.

METHODS

UAV Platform

- To perform DS using only the power of the wind the UAV must perform like a glider:
  - High lift, low drag
  - Good energy conservation
  - However, an engine is required to maneuver without the presence of wind energy
- FMS Fox Aerobatic Glider
  - Cost efficient high-aspect ratio foam RC plane with nose mounted engine
  - Excellent gliding performance balanced with ample space for equipment
  - Foam construction provides high durability and low weight

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

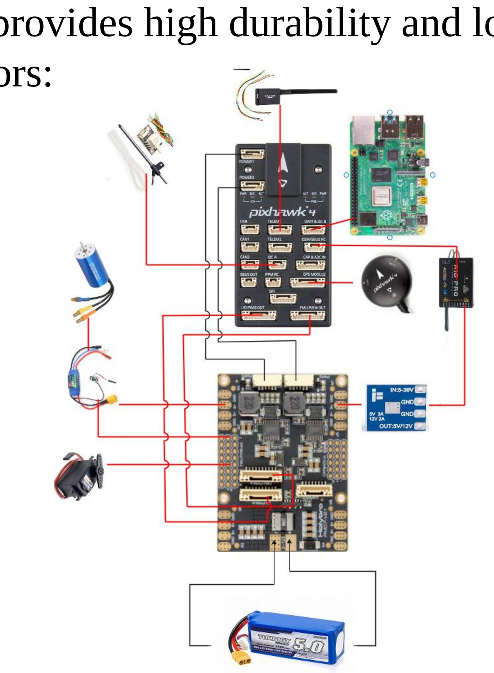

Figure 3. Wiring diagram of the Fox UAV.

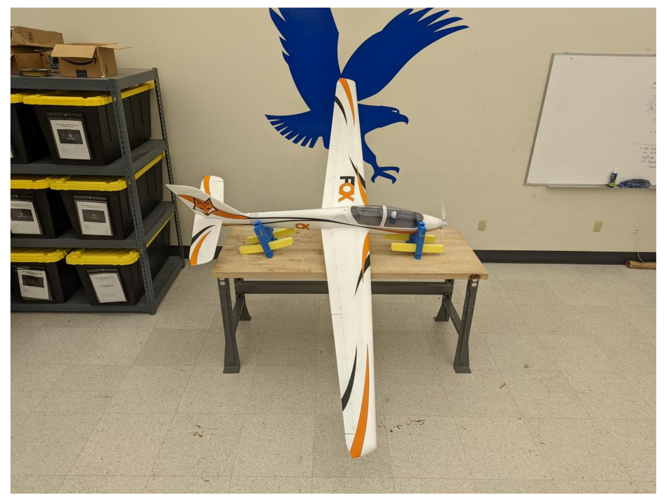

Figure 4. FMS Fox 3000mm aerobatic glider.

Flight Simulation Environment

- The DS simulator is a 6-degree-of-freedom (6DoF) flight simulation environment in MATLAB and Simulink
- Model must accurately represent UAV and wind for an integrable autopilot to be designed
- Components:
  (1) 6DoF Aircraft equations of motion
  (2) Aerodynamic lookup tables
  (3) DS Autopilot
  (4) Wind shear model
  (5) Power consumption model
- Computational Fluid Dynamics (CFD)
  - Need CFD to build accurate aerodynamic model
  - ANSYS Fluent
    - High-fidelity CFD
    - Static coefficients
  - SURFACES Aircraft Design Software
    - Low-fidelity Vortex-Lattice Solver
    - Dynamic and Control surfaces derivatives

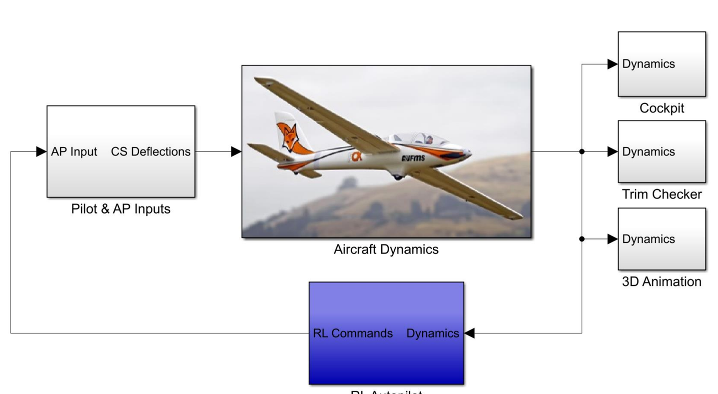

Figure 5. MATLAB & Simulink flight simulation environment.

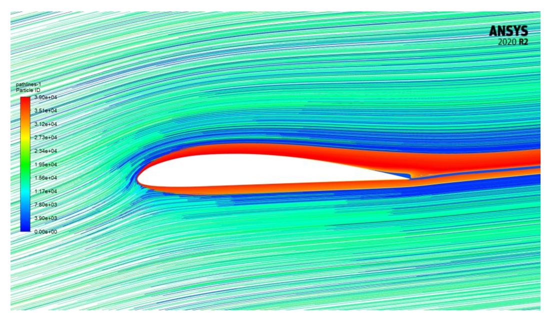

Figure 6. Distribution of streamlines over the Fox airfoil (Clark Y).

Dynamic Soaring Autopilot

- Using the flight simulation environment, an autopilot controller can be designed for DS
- Previously, Gladston Joseph has designed a DS autopilot using an earlier version of the simulator as a component of his master's thesis[2]
- The current DS autopilot is a reinforcement learning (RL) trained controller (DSRL)
- The DSRL autopilot consists of two RL trained agents:
  1. Path Optimizer – creates a closed-loop DS path optimized for an arbitrary wind shear
  2. Path Follower – follows the optimized path with the goal of using minimum engine power
  - Adapts DS path to variable wind shear conditions
  - Performs DS if wind speed is too low by using engine power

RESULTS

- UAV and simulator are still in development, so only preliminary results are shown
- Using a previous version of the Simulink model, DS was performed both autonomously and under human piloted control
- Gladston Joseph assisted by Jacob Adamski, demonstrated the feasibility of autonomous DS using a steady, logarithmic wind shear model[2]
- Autonomous DS performed more consistent yet less efficient maneuvering due to the limitations of the control laws used
- On the other hand, manually piloted DS was less consistent but more efficient since the path could be optimized dynamically from pilot observations
- These results proved that the DS Simulink model could be used as a tool to design future DS autopilots
- An improved DS autopilot must be developed to perform DS in more unsteady wind shear conditions

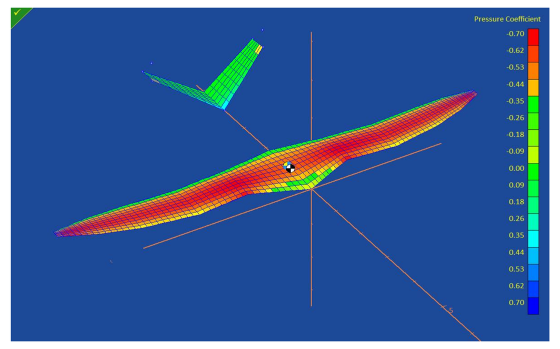

Figure 7. UAV used to perform DS in original DS simulation.

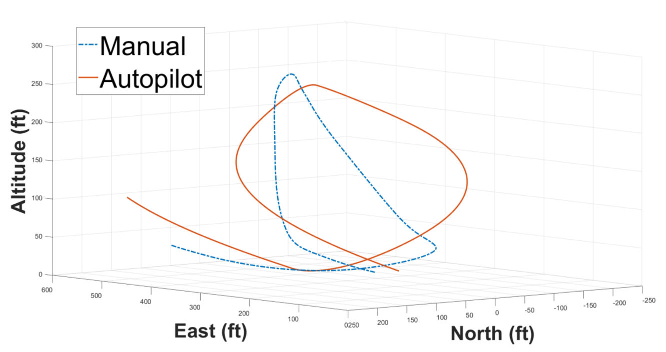

Figure 8. Snapshot of a single DS cycle[2].

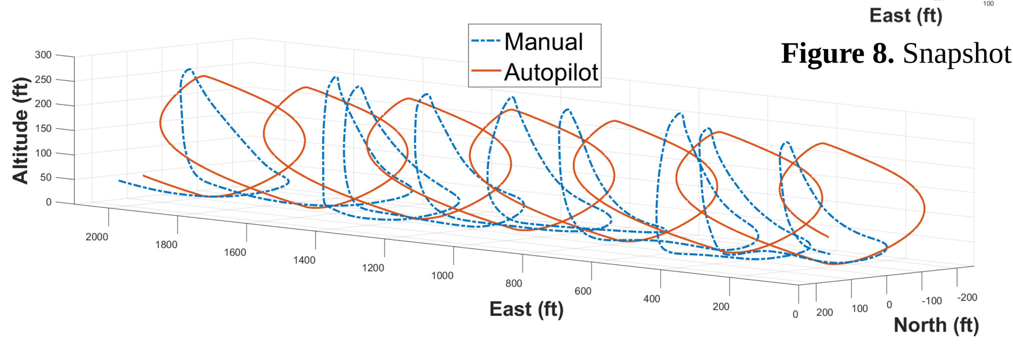

Figure 9. Comparison of DS flight path piloted manually to autopilot[2].

FUTURE WORK

- For the final paper autonomous DS will be performed using 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 loitering with DS and loitering in a non-DS pattern
- The successful completion of this project will allow for future researchers at ERAU to develop and test their own autonomous DS algorithms

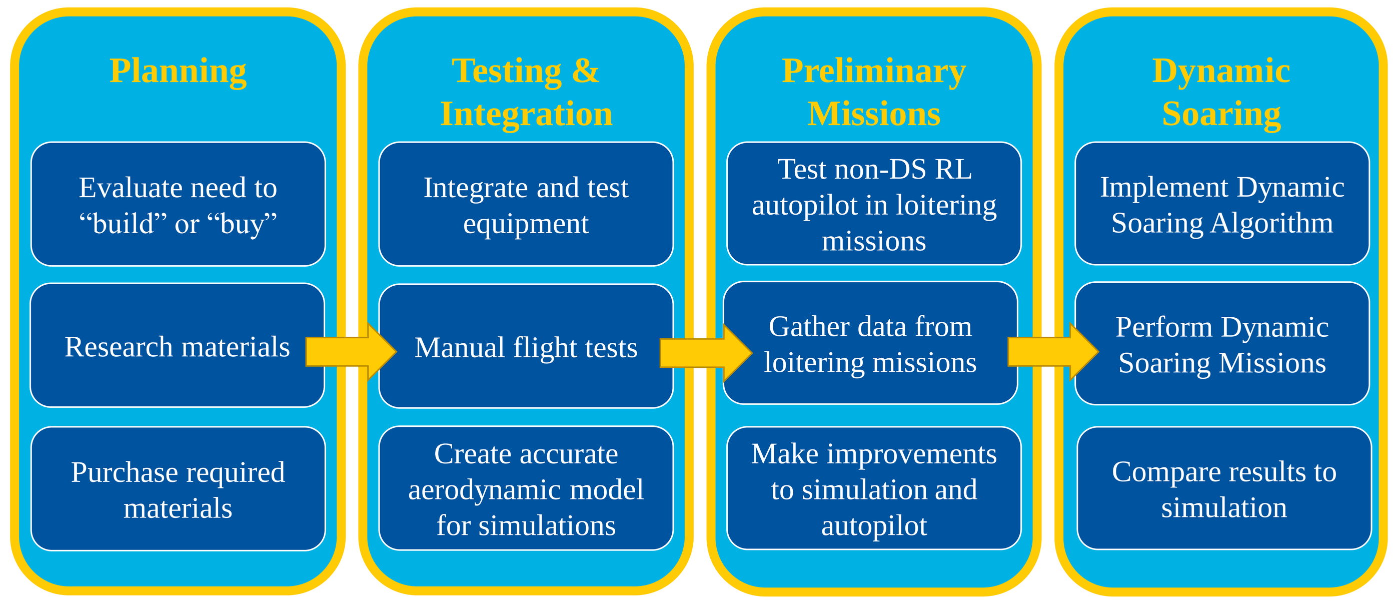

Figure 10. Flowchart of the project phases.

REFERENCES & ACKNOWLEDGEMENTS

[1] Gudmundsson, Snorri, "General Aviation Aircraft Design – Applied Methods and Procedures," Elsevier, 2013.
[2] Gladston, Joseph, "Design and Flight-Path Simulation of a Dynamic-Soaring UAV," Embry-Riddle Aeronautical University, 2021.

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