RAM-Air Parachute Real Time Piloting Simulator

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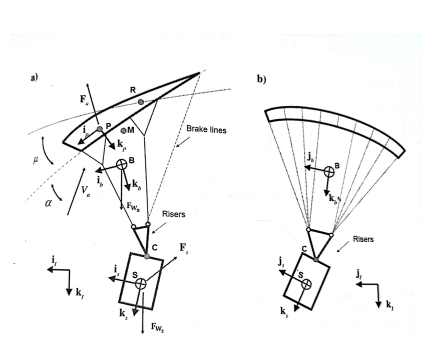
Motivation & Research Goals

RAM Air parachutes are commonly used for military purposes, precision delivery systems, and sports skydiving. RAM Air parachutes can be considered low aspect ratio wings; thus, they are highly maneuverable and very challenging to control. Achieving a high or even adequate skill level in piloting requires an extensive amount of training. However, conventional piloting training can only provide theoretical knowledge, while the required capabilities are acquired from trial and error in the sky.

In a field where safety is of high importance and an error can be fatal, it is beneficial for both piloting students and professionals to have an available simulator for training on the ground. Therefore, the goal of this project is to develop a parafoil piloting real-time simulator to provide a training environment for pilots.

Dynamic Model

- **6-DOF Model:** Assumes the parafoil and pilot form a single rigid body with six degrees of freedom—three translational and three rotational.
- **9-DOF Model:** Includes six degrees of freedom for the parafoil and three additional rotational degrees of freedom for the pilots.



The 9-DOF model is governed by a set of ODEs of the form $\dot{\bar{V}} = A^{-1}\bar{B}$, and is solved in MATLAB using ode45. The state vector $\bar{V}$ is:

$$\bar{V} = \begin{bmatrix} u_c & v_c & w_c & p & q & r & p_s & q_s & r_s & F_{cx} & F_{cy} & F_{cz} \end{bmatrix}^T$$

Here, $\bar{V}_c$ is the connection point velocity, $\bar{\omega}_{body}$ and $\bar{\omega}_s$ are the angular velocities of the canopy and payload, respectively, and $\bar{F}_c$ is the unknown connection force. The system matrix A:

$$A = \begin{bmatrix} m^* I_{3x3} + I'_{a.m} & -I'_{a.m} s(r_{CM}) - m^* s(r_{CB}) & 0 & -I_{3x3} \\ s(r_{BM}) I'_{a.m} & I^* + I'_{a.i} - s(r_{BM}) I'_{a.m} s(r_{CM}) & 0 & S(r_{CB}) \\ m_s R_b^s & 0 & -m_s s(r_{CS}^s) & R_b^s \\ 0 & 0 & I_s & -s(r_{CS}^s) R_b^s \end{bmatrix}$$

Here, m^* is the mass of the system, $I'_{a.m}$ and $I_{a.i}$ are the matrices of apparent mass and apparent inertia, respectively, and I_s is the inertia of the payload. R_b^s is the rotation matrix that transforms from the body to payload frame. r_{CS}^s is the distance vector from the payload's center of mass to the reference point, r_{CM} is the vector from the center of apparent mass to the connection point, and r_{CB} is the vector from the center of mass to the connection point.

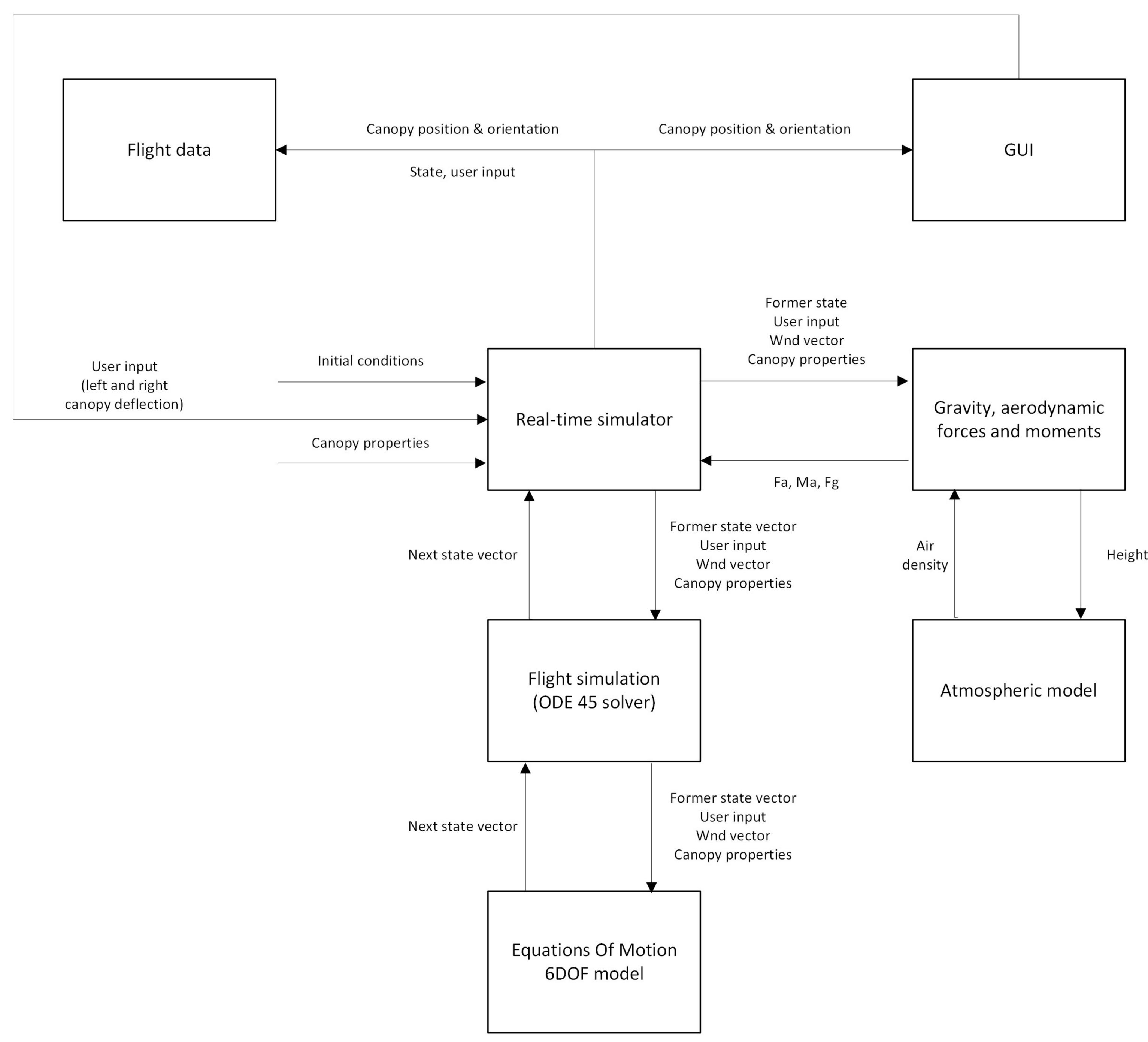
The forcing vector $\bar{B}$ includes aerodynamic and gravitational forces and moments for both canopy and payload. The aerodynamic forces and moments acting on the parafoil are:

$$F_a^* = -\frac{1}{2}\rho V_a^2 S R_w^b \begin{bmatrix} C_{D0} + C_{D\alpha^2}\alpha^2 + C_{D\delta_s}\bar{\delta}_s \\ -C_{Y\beta}\beta \\ C_{L0} + C_{L\alpha}\alpha + C_{L\delta_s}\bar{\delta}_s \end{bmatrix}$$

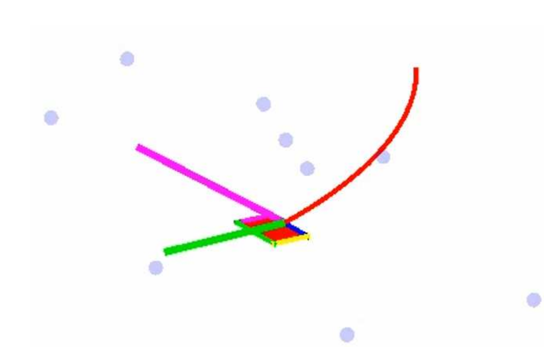
$$M_a^* = \frac{1}{2}\rho V_a^2 S \begin{bmatrix} b(C_{l\beta}\beta + \frac{b}{2V_a}C_{lp}p + \frac{b}{2V_a}C_{lr}r + C_{l\delta_a}\bar{\delta}_a) \\ \bar{c}(C_{m0} + C_{m\alpha}\alpha + \frac{c}{2V_a}C_{mq}q) \\ b(C_{n\beta}\beta + \frac{b}{2V_a}C_{np}p + \frac{b}{2V_a}C_{nr}r + C_{n\delta_a}\bar{\delta}_a) \end{bmatrix}$$

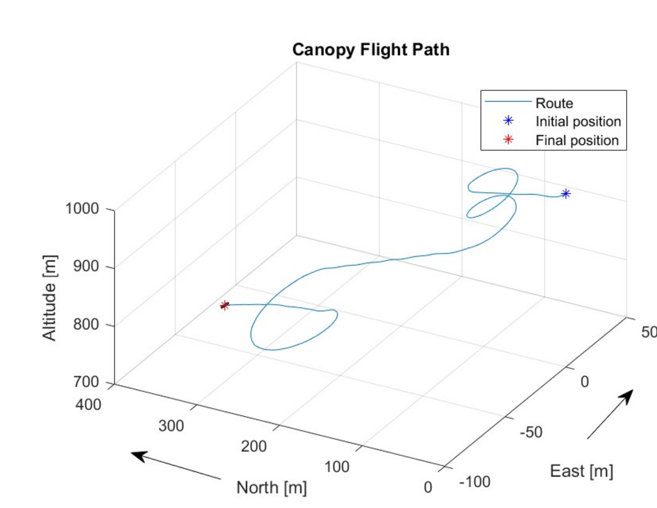
ρ is air density, V_a is the airspeed, S is the parafoil area, b and c are the span and chord, $\bar{\delta}_s$ and $\bar{\delta}_a$ are symmetric/asymmetric inputs, and p, q, r are the angular rates of the canopy in body frame.

Simulator

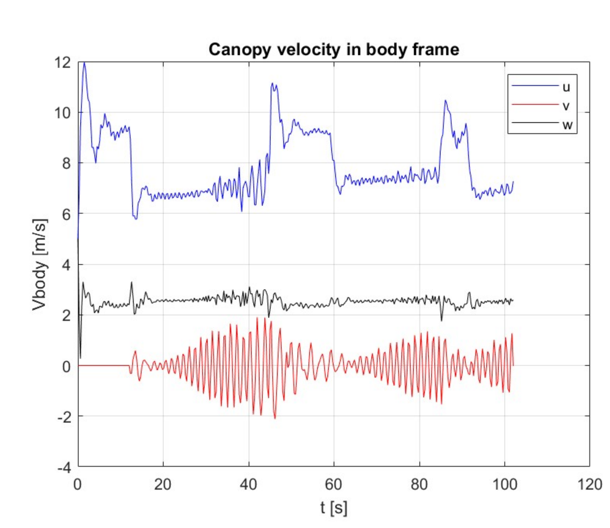


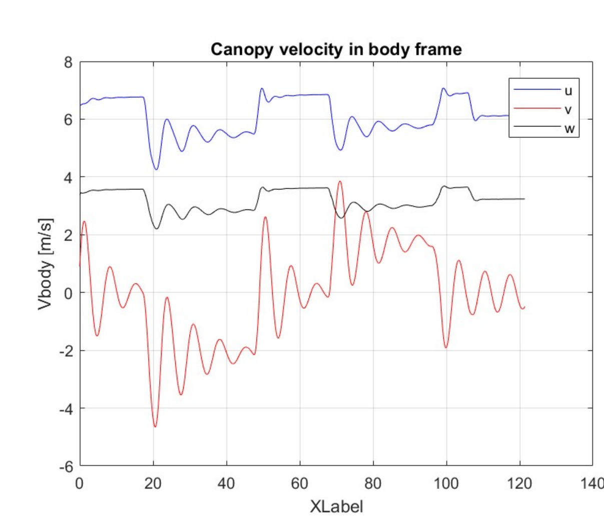
The simulator is a real-time system that receives steering inputs from the user and continuously displays the position and orientation of the canopy. The simulator also records flight data, which can be reviewed after the simulation ends.





The 9-DOF model (left) is more nuanced, and can account for behaviours that can not be seen in the 6-DOF model (right).





Summary & Future Work

- A real-time parafoil piloting simulator was developed using dynamic 6-DOF and 9-DOF models of a RAM Air Parachute.
- Simulated canopy behavior aligns with empirical expectations in terms of position, orientation, velocity, and angular rates.
- The 9-DOF model offers greater fidelity, capturing effects such as coordinated turns and payload rotation.
- Notable differences were observed when simulating the small canopy, especially in pitch dynamics.
- Future work includes further investigating the 6-DOF model to understand deviations from expected full-scale canopy behavior, refining parafoil parameters based on experimental data relevant to human-piloted systems, and validating simulation results against real-world parachuting data.
- In addition, we aim to integrate a physical interface for real-time pilot input, and develop a Virtual Reality interface to visualize the parafoil motion from the pilot's viewpoint.