Landing a Thrust Vector Controlled Rocket after Main Chute Deployment

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1. Background

This research investigates whether a hybrid descent strategy, combining parachute-based deceleration with **TVC** stabilization, can achieve high-precision landings with greater fuel efficiency and safety margins than traditional powered descent guidance. [1]

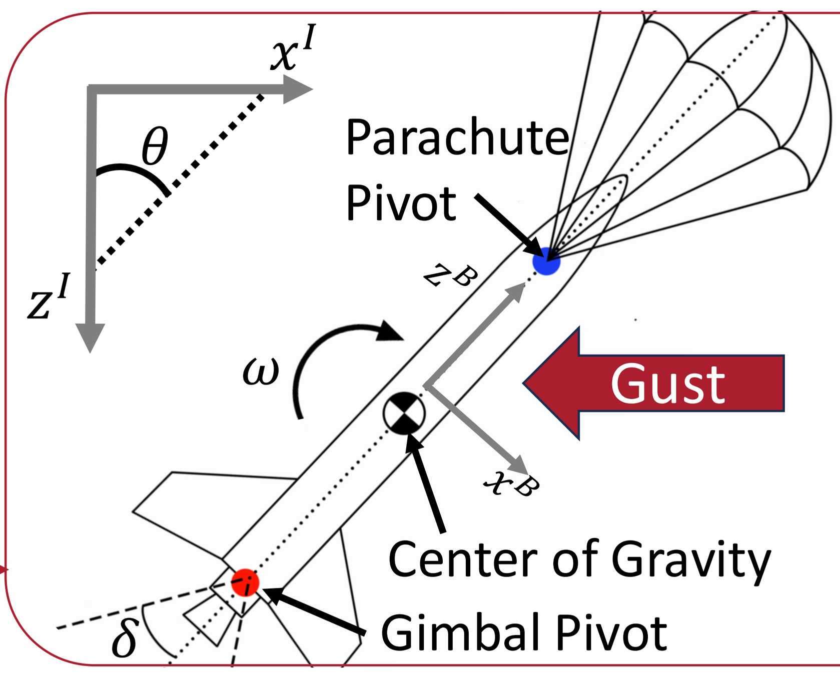

Figure 1: Schematic representation of the rocket airframe defining the reference points for the Thrust Vector Control (TVC) rocket system. Wind turbulence acts as the main destabilizing force while the gimballed engine attempts to counter it.

2. Methods

2.1 Mission Scenario

2.2 Environmental Model

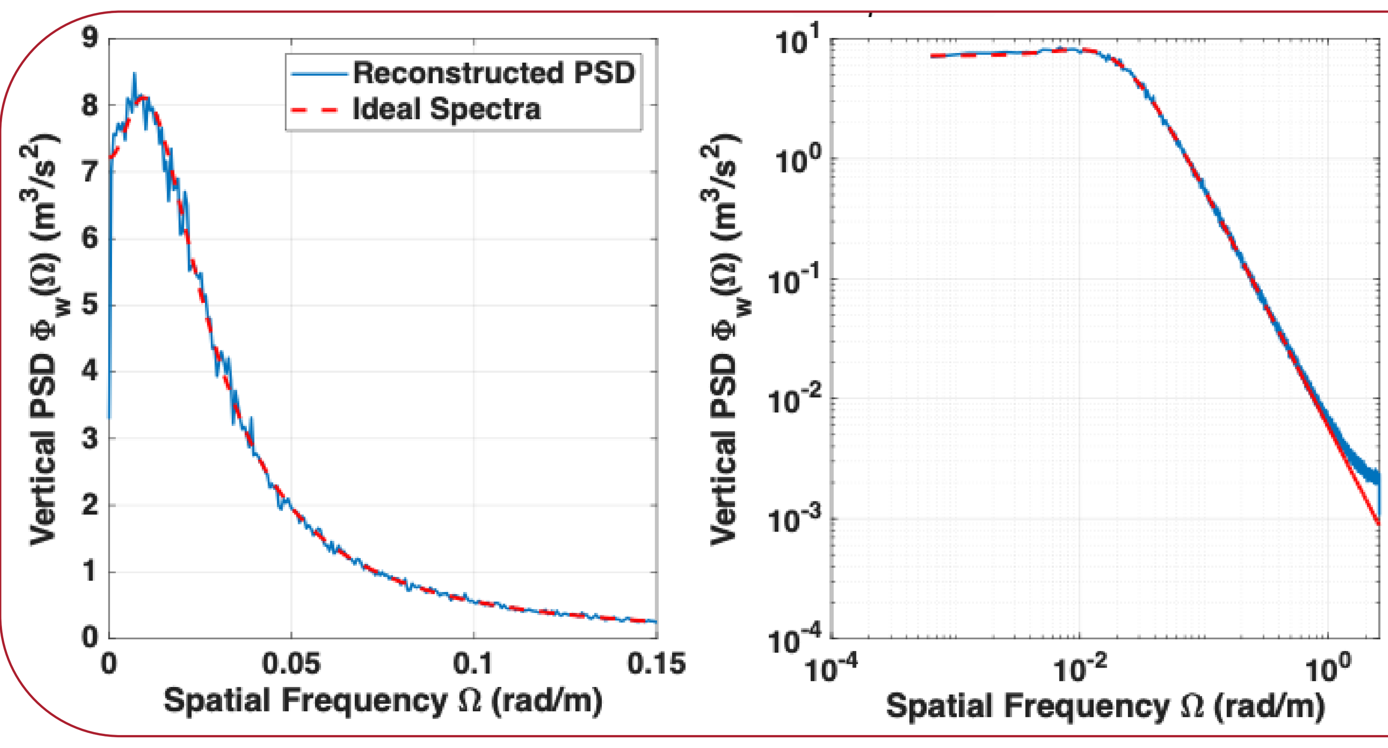

Figure 2: Verification of the simulated vertical turbulence against the ideal NASA Dryden spatial power spectral density (PSD), confirming the accuracy of the discrete-time filter stages in preserving gust energy across low and high spatial frequencies. This ensure the model is experiencing realistic wind gusts. [2]

2.3 Model Architecture

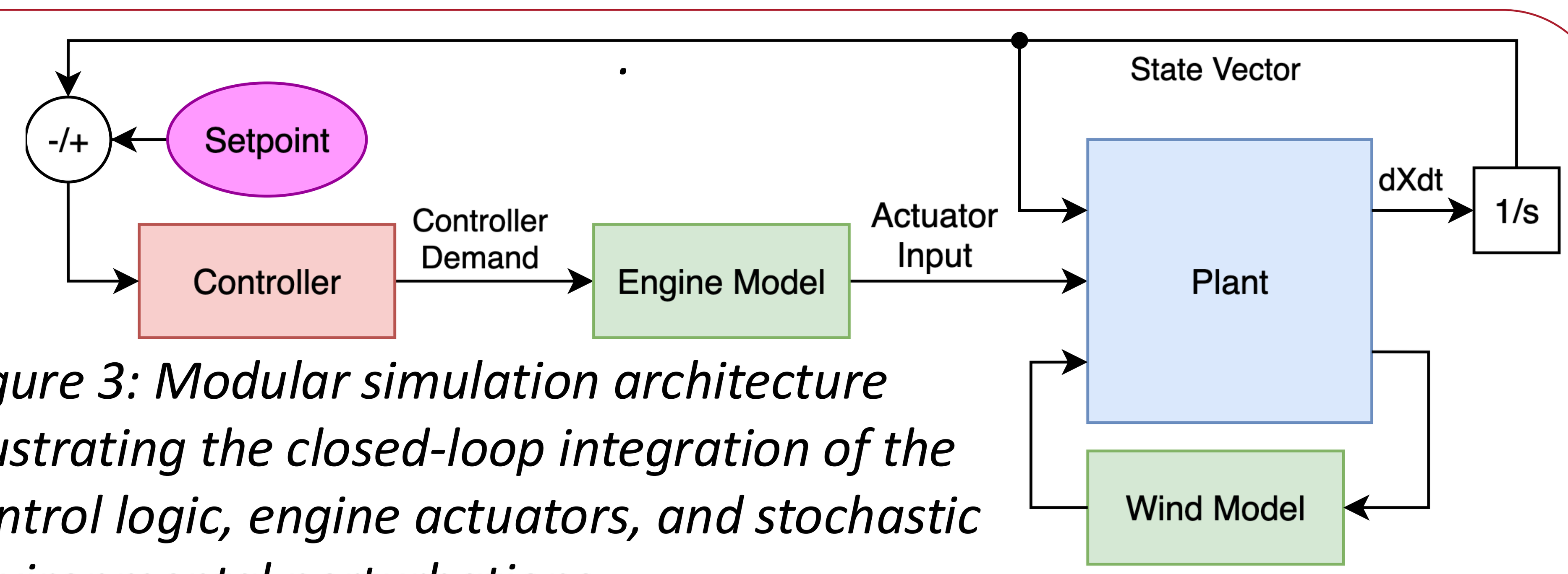

Figure 3: Modular simulation architecture illustrating the closed-loop integration of the control logic, engine actuators, and stochastic environmental perturbations.

2.4 Equations of Motion

The equations of motion resolve the 3DOF coupled system dynamics by summing the forces and moments to determine the state derivatives for numerical integration. [3]

3. Preliminary Results

3.1 Parachute Dynamics Model

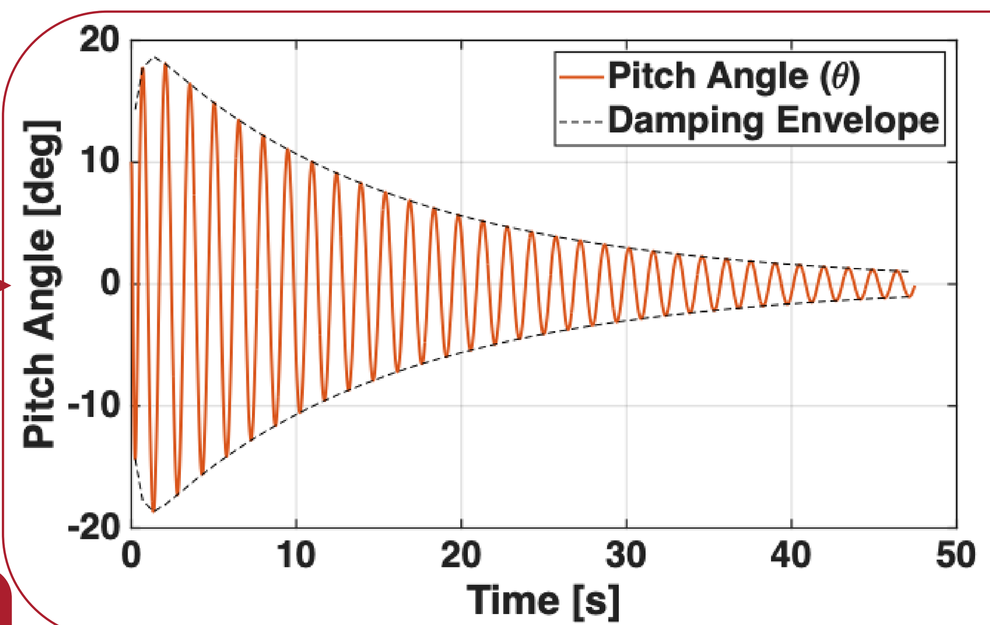

Figure 5, Time-domain response of the pitch angle, illustrating the passive parachute stabilization when undisturbed. [4]

3.2 Wind Coupling Implementation

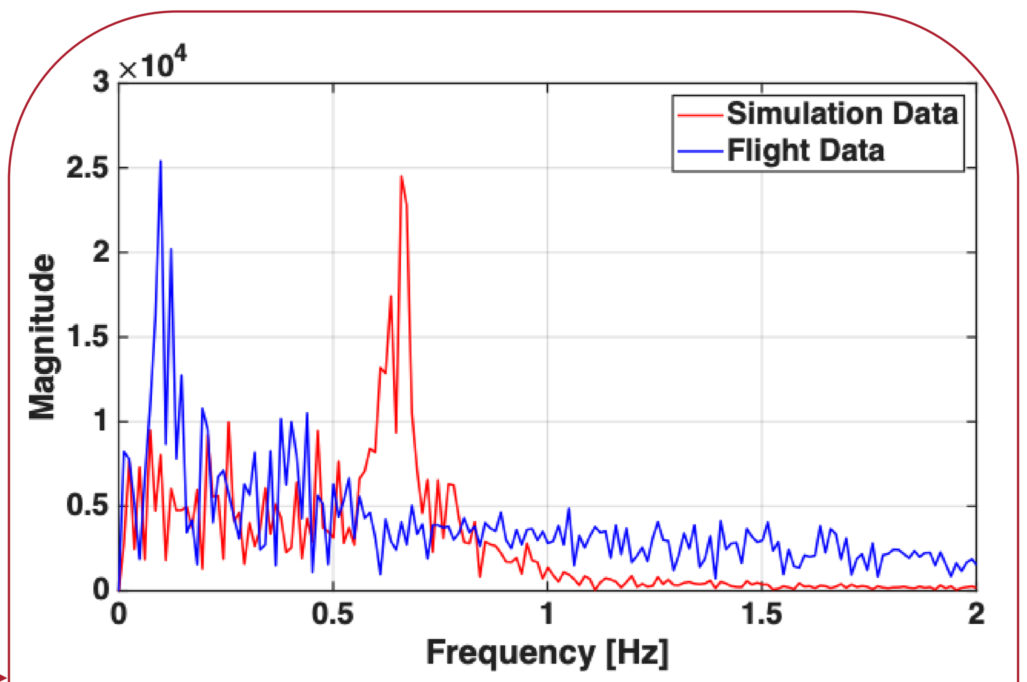

Figure 6: Fast Fourier Transform analysis comparing simulated pitch dynamics against real flight IMU tilt data, validating that the integrated wind coupling and atmospheric models can accurately replicate the vehicle's low-frequency oscillation spectra.

3.3 LQR Controlled Descent

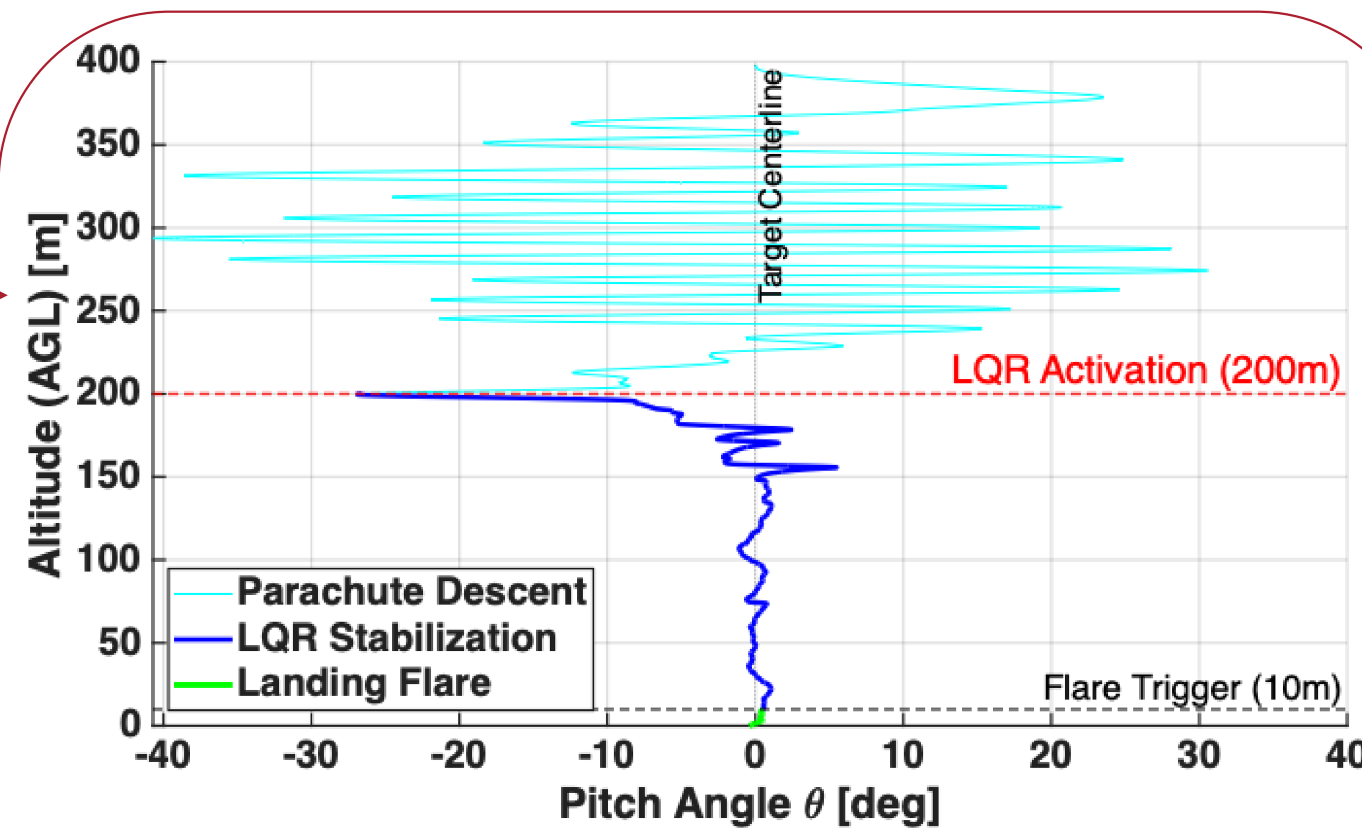

Figure 7: Visualization of the Linear Quadratic Regulator (LQR) controller successfully damping high-magnitude parachute oscillations upon activation at 200m, stabilizing the vehicle into a vertical orientation for the final landing flare.

3.4 Next Steps

- Implement Sensor Noise
- Add first-order actuator lag
- High-swing stability analysis
- Advanced Controller (e.g. MPC)
- Monte Carlo analysis
- Full 6DOF model

4. Conclusions

Initial results shows system is able to combat simulated turbulence and achieve a vertical landing.

Limitations: gimbal saturation, planar dynamics only, zero sensor noise/lag, and rigid parachute physics.

[1] Wang. "A Survey on Convex Optimization for Guidance and Control of Vehicular Systems". 2024. [2] Madden. "Verifying Implementation of the Dryden Turbulence Model" NASA, 2018
[3] Carradori."6-DOF Atmospheric Rocket Landing Guidance Using Meta-Reinforcement Learning". 2024 [4] Dobrokhodov. "6-DOF Model of a Controlled Circular Parachute". 2003

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