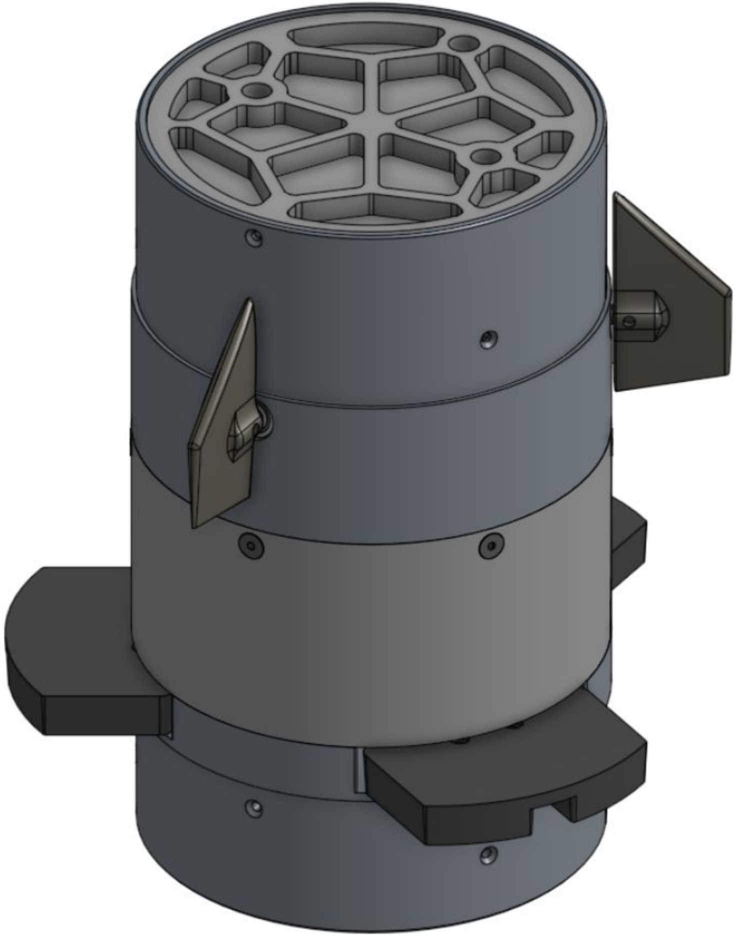
Active Roll Stabilization using Canard Control Surfaces

Prepared for the 2025 IREC

DUKE AERO



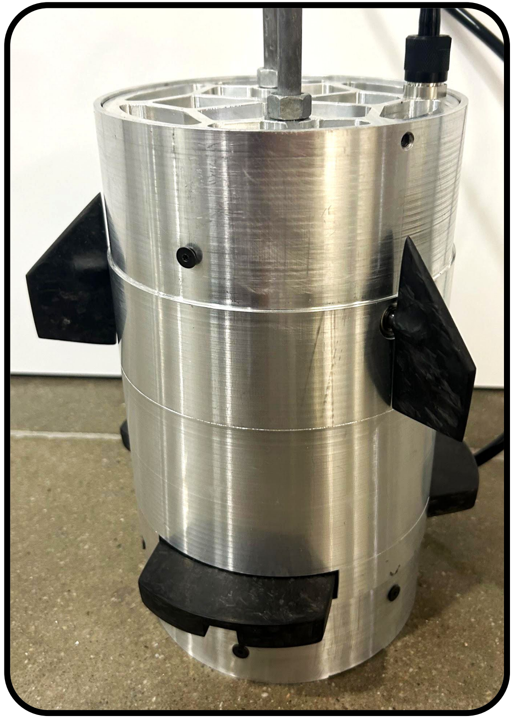
Why Roll Stabilization?

- 3 years of ***Variable Drag Airbrake System***
- Roll detrimental to in-flight performance
- Next step in team goal

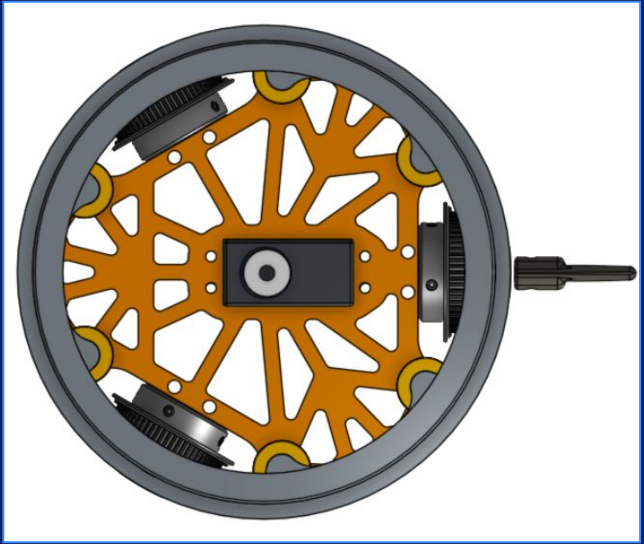
In-Flight Video From Previous Projects

Why Canards?

- Compared **reaction flywheel vs. aerodynamic canard system**
  - Flywheel offered low drag but had high mass, power draw, and integration complexity
  - Required 1.8 kg wheel @ 5100 RPM for 0.0096 N·m² inertia
  - Structural and energy concerns led to rejection
- **Chose canard-based system for simplicity and efficiency**
- Evaluated two mechanical actuation designs:
  - Belt-drive: low backlash, but tension/alignment issues risked desync
  - Hybrid gear + linkage: tolerates misalignment, controlled backlash enables passive neutral return on power loss



Design Selection



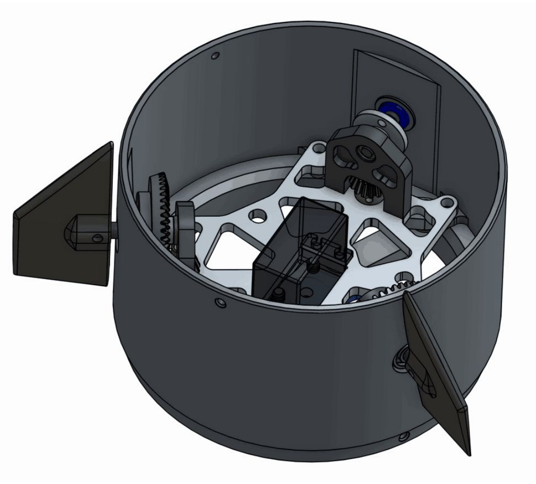
Central Belt Drive

Bevelled Gear/Linkage

Bevel Gear Design

A hybrid 4 bar-linkage, beveled gear approach

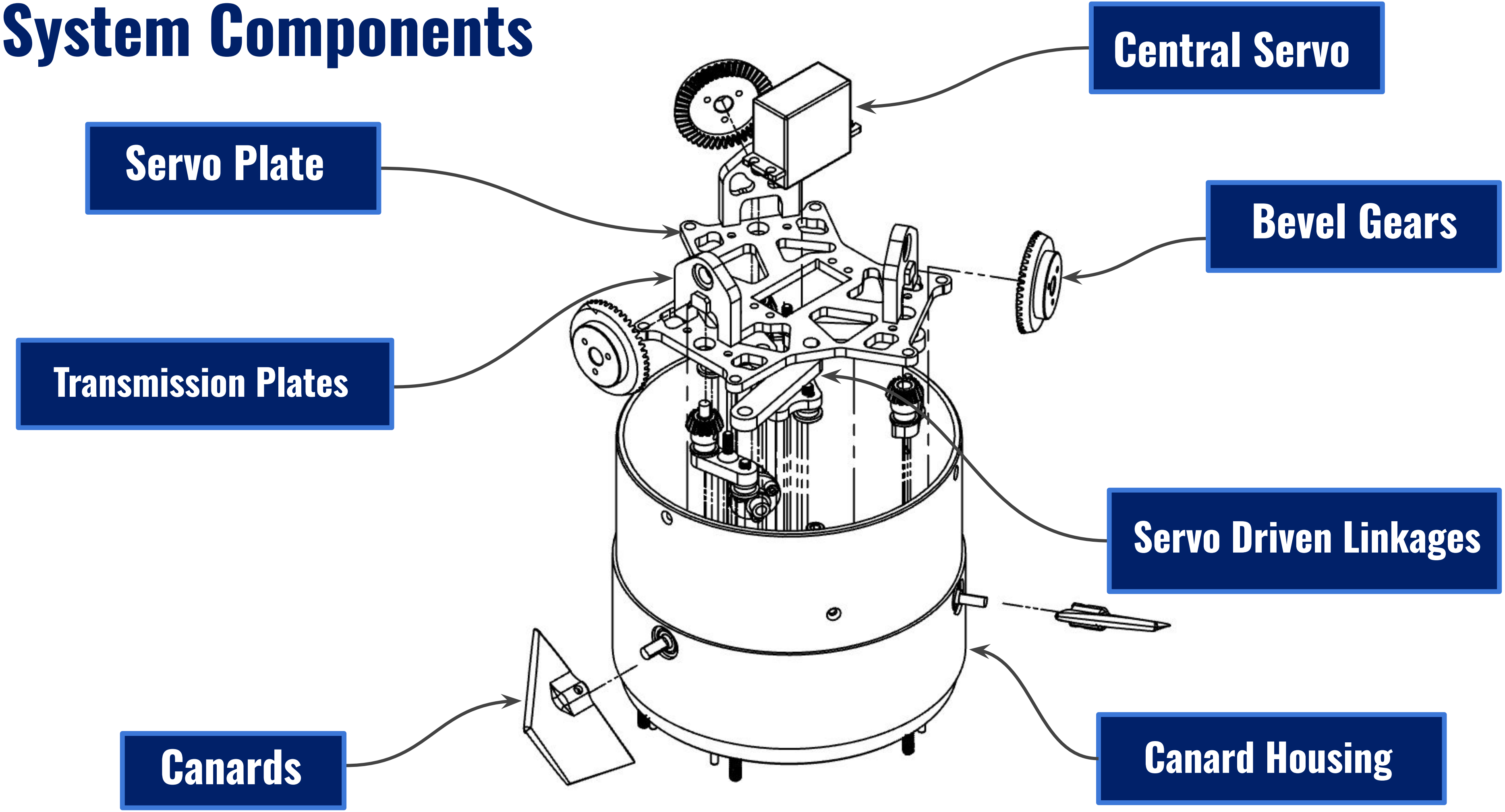
- **Major Design Constraint:** Mechanically synchronized control surfaces to avoid pitching moments
- Shifting rotational actuations from a central servo drives canard rotation
- Fail safe by offsetting pivot point forward of CP



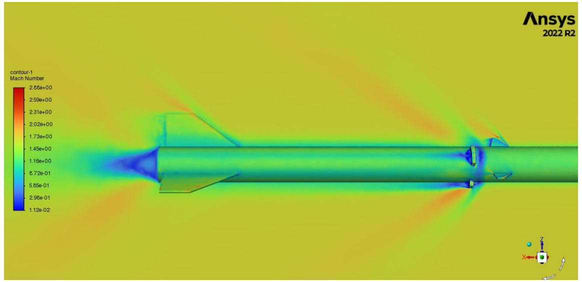
Animation of Canard Mechanism

Top View of Canard System

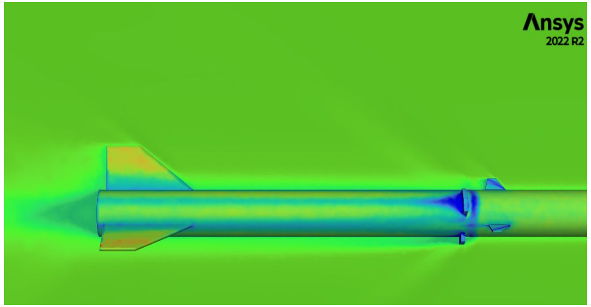
System Components



CFD Simulations



Mach Number Contour of Aft Section



Dynamic Pressure Number Contour of Aft Section

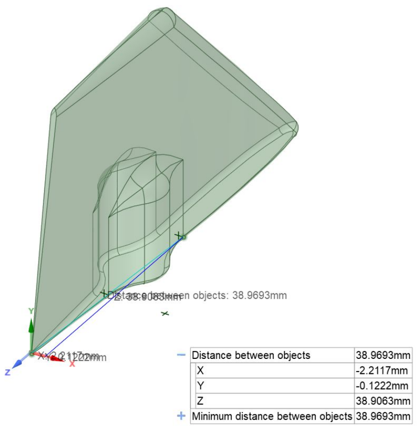
Aerodynamics Problems

1. Downstream effects on fins
2. Loss of overall rocket stability
3. Center of Pressure of Canards

Results

1. Low downstream effects on fins
2. CP of canards for pivot selection
3. Maintained high stability caliber (meeting IREC requirements)

CFD Simulations (cont'd)



Center of Pressure on Canard Blade

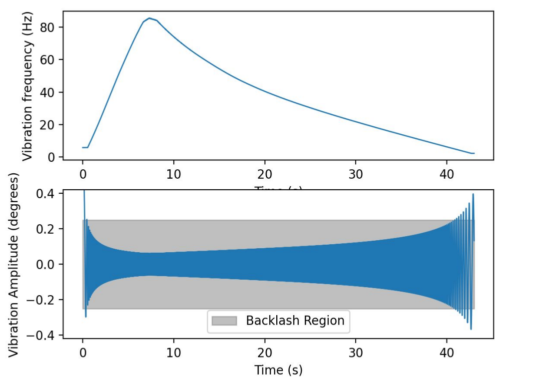
Canard Placement

- 18 test cases based on distance from bottom of rocket and canard angle of attack
- 61-inch placement proven to be most aerodynamic and most drag variance
- Proved minimal downstream effects on air brakes and fins

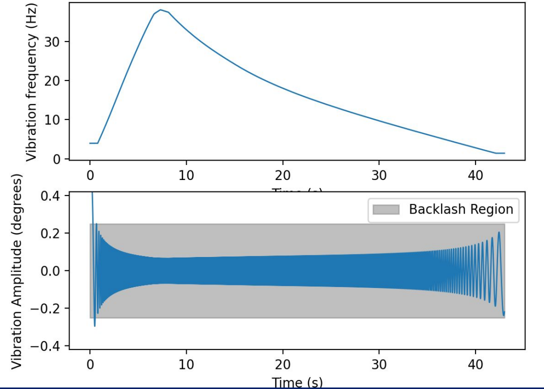
Pivot Placement

- CP @ 39 mm from bottom of canard
- NACA 0006 airfoil
- Pivot above CP for fail safe

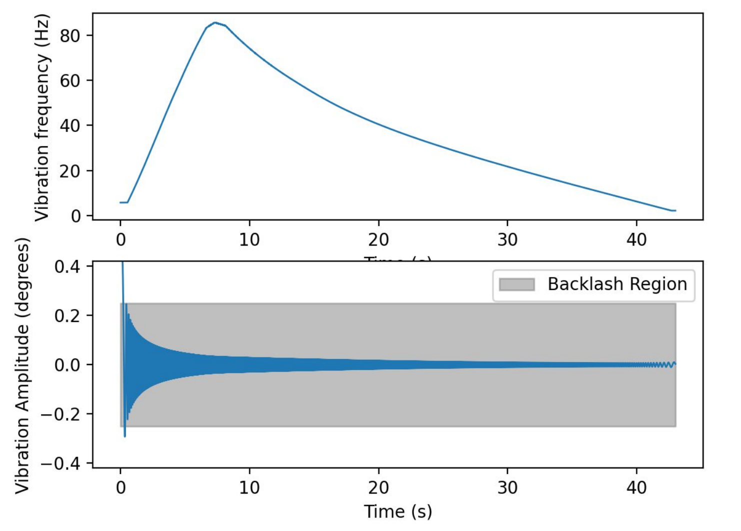
Vibration Analysis



Iteration 1



Iteration 2



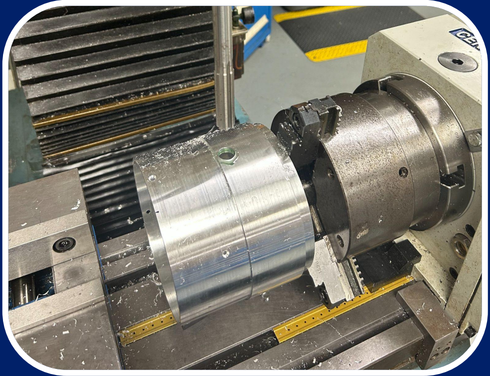
Iteration 3

I1: Initial Fin
I2: CoP, CoM Optimized Pivot
I3: CoP Optimized and Damping Grease

Manufacturing

- Housing milled **in-house** using CNC milling machine
- **6061-T6 aluminum** selected for strength-to-weight and machinability
- Machining operations included: facing, boring, and pocketing
- Other components (servo plate, linkages, shafts, flanges, etc) were manufactured with **waterjet, manual mill,** and **lathe**

Canard Housing in CNC Setup



4th-Axis Milling, Housing

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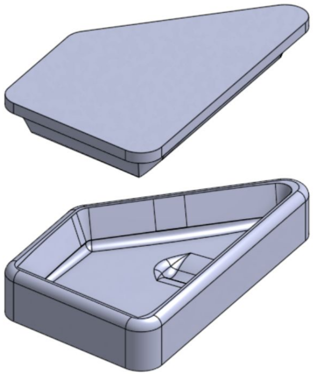
Machining Results

Post-Milling Housing

Lathe-Turned Steel Shafts

Manufacturing (cont'd)

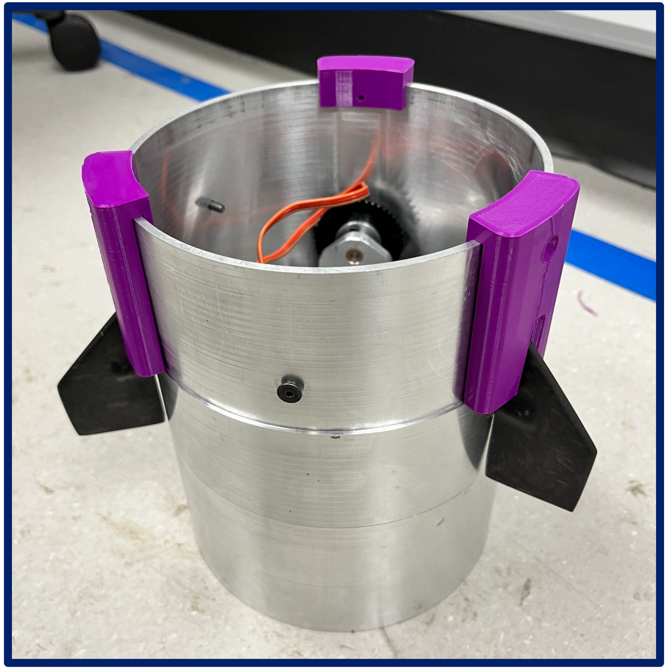
1. 3D Printed PETG molds, sanded smooth
2. Layer in dry, chopped carbon fiber with ambient curing epoxy
3. Bottom out mold in vise over 5-10 minutes, cure under pressure
4. Clean and sand surfaces for smooth finish
5. Drill and tap necessary holes



3D-Printed Vise Mold

Forged Carbon Fiber Canard

Manufacturing (cont'd)



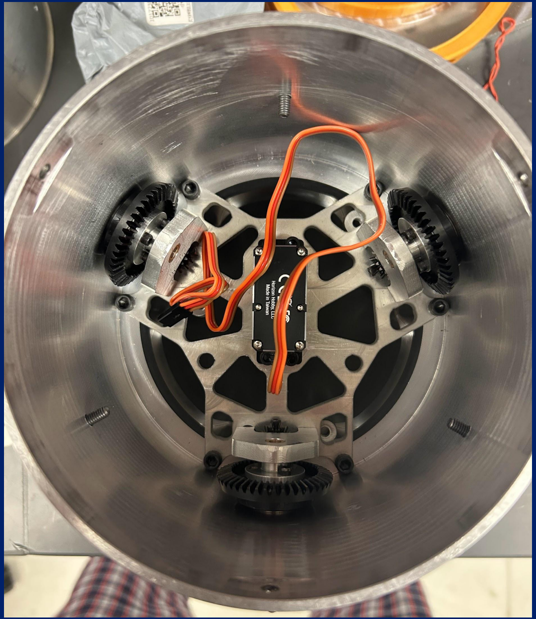
Canard Blade Alignment System

- Linkages & bevel gear subassembly are **individually indexed**
- Each component individually **match-machined** to its mating part, ensuring optimal tolerance, minimizing freeplay
- 3D-printed jig to ensure true alignment of canard positions

Assembly

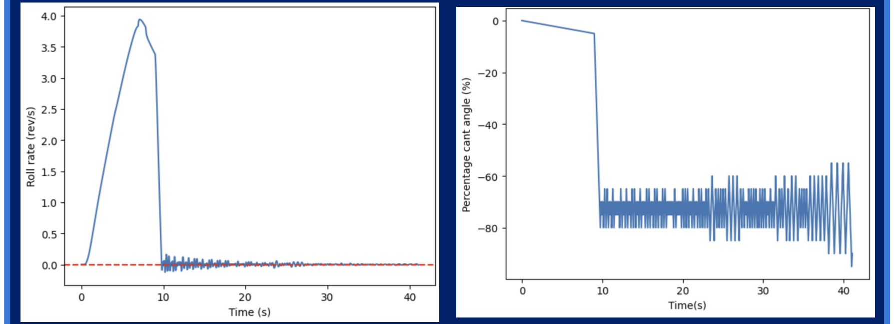
Canard System Assembled

Blade Integration

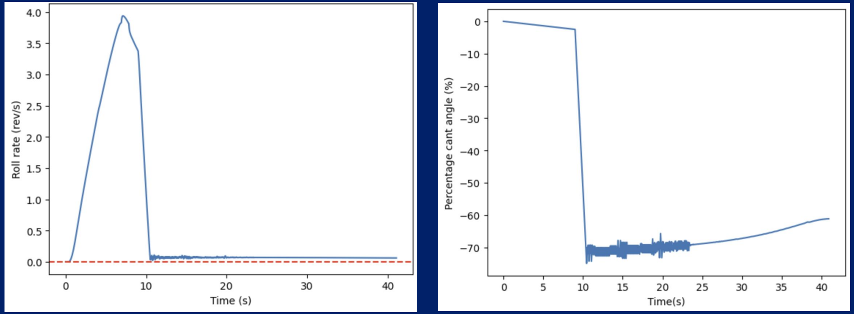


Internal View

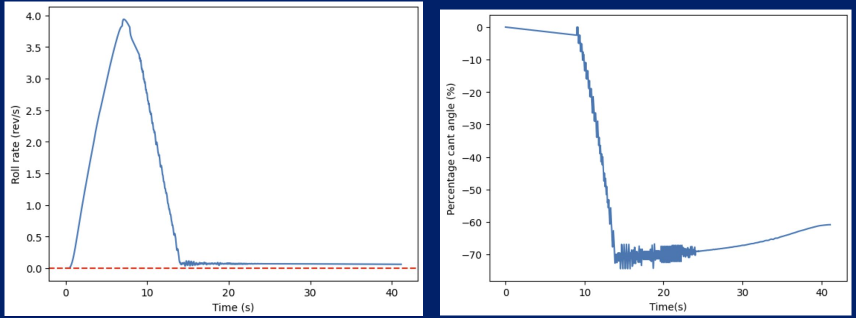
Control Software



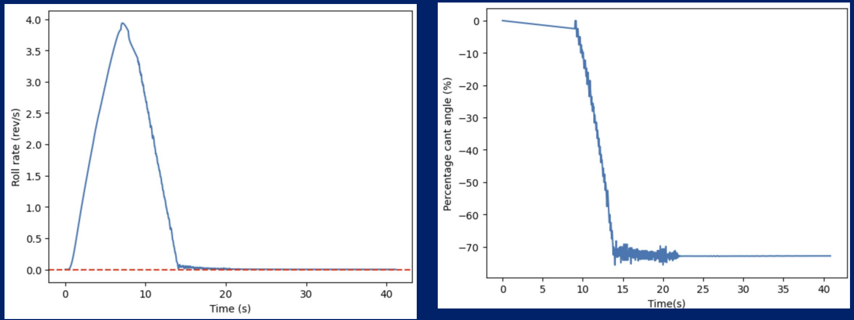
Bang-Bang; Roll Rate (Left), Canard Angle (Right)



Proportional (high kP); Roll Rate (Left), Canard Angle (Right)

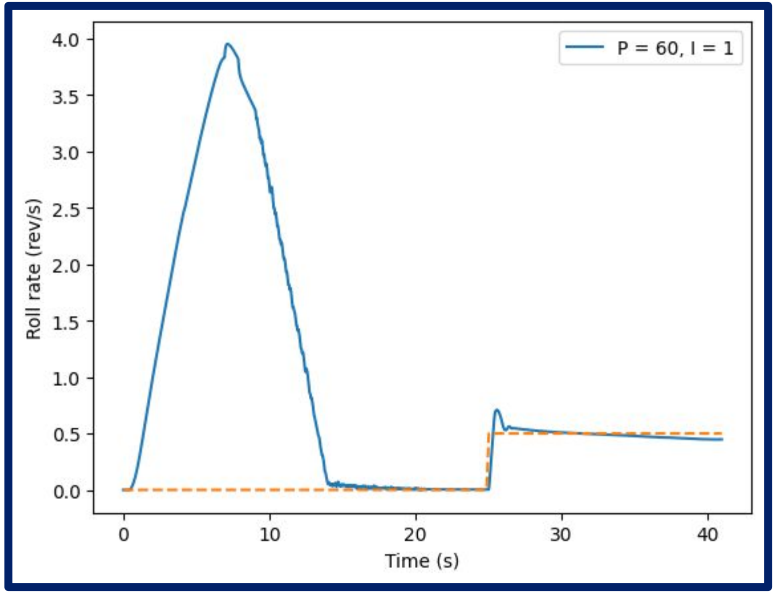


Proportional (medium kP); Roll Rate (Left), Canard Angle (Right)



PI (typical kP & kI); Roll Rate (Left), Canard Angle (Right)

Control Software (cont'd)



Step Response Tune

- Step response test to tune P & I gain values
- kP = 61.4, kI = 0.98
- Stress test with weather & wind gusts in RocketPy
- Good control authority, chosen for flight

THANK YOU

Does anyone have any questions?

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