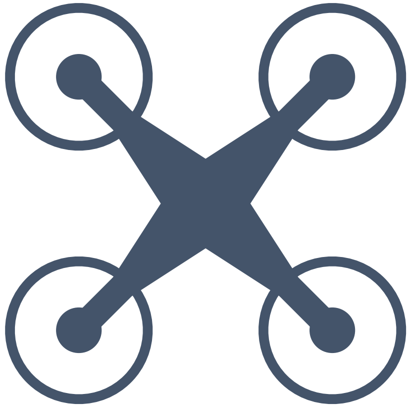
Dragonfly-Inspired Microglider Design

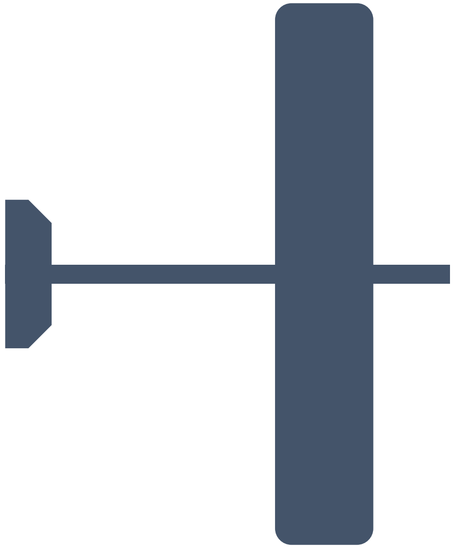
IROP 2025 – Kasper Atkinson

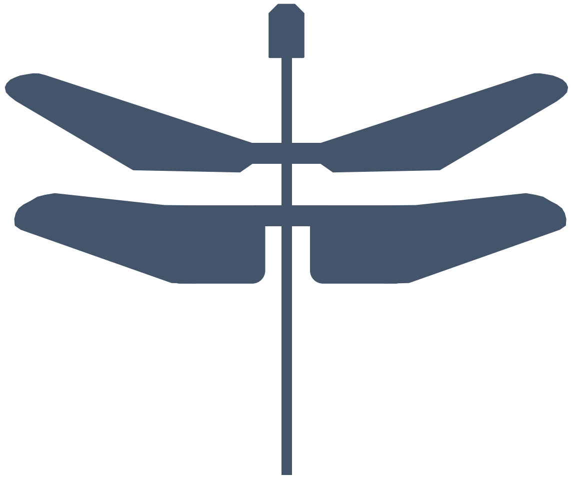
My Background

- Second year student at Cornell
- On exchange in London for the summer
- Spent the last two years building fixed-wing drones for competitions
- Experienced primarily in electrical
- Interests in Aerodynamic modelling, self-taught so far

Why build a Dragonfly Drone?







Quadcopters

- Vertical takeoff
- Maneuverability

Fixed-Wings

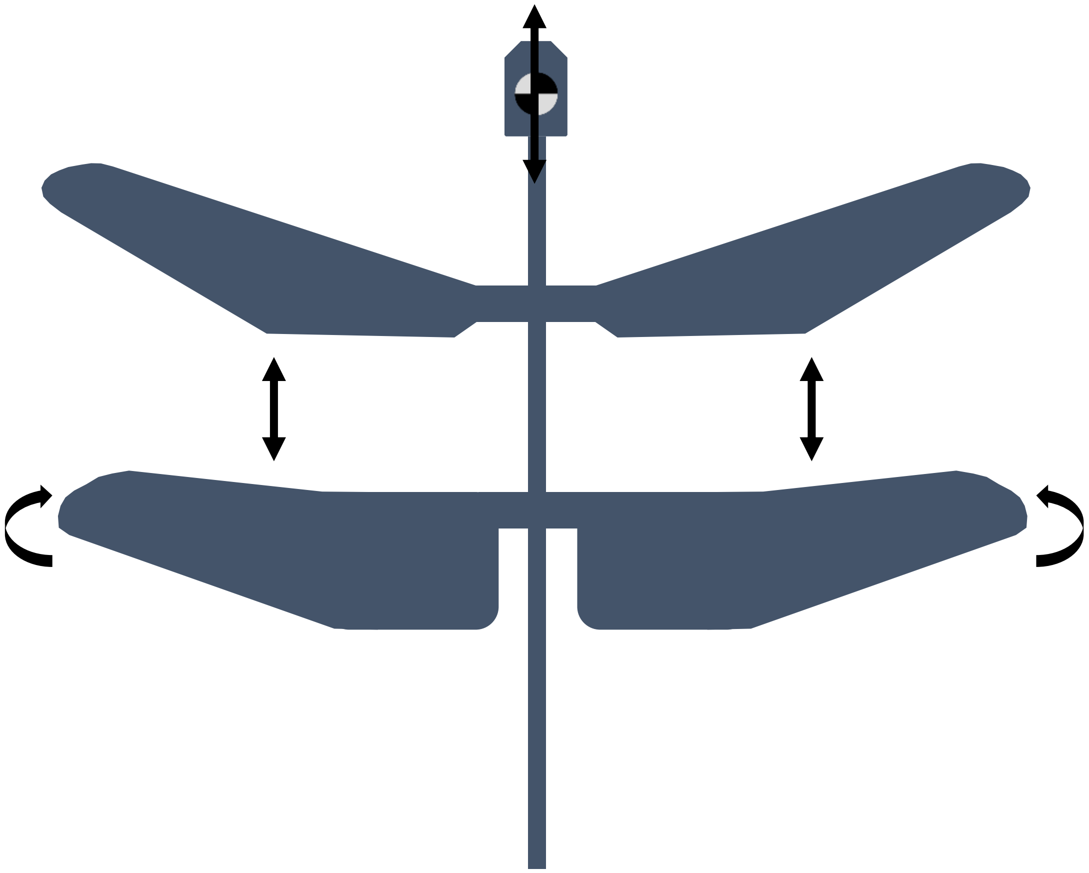
- Efficiency at cruise
- Greater load capacity

Ornithopters

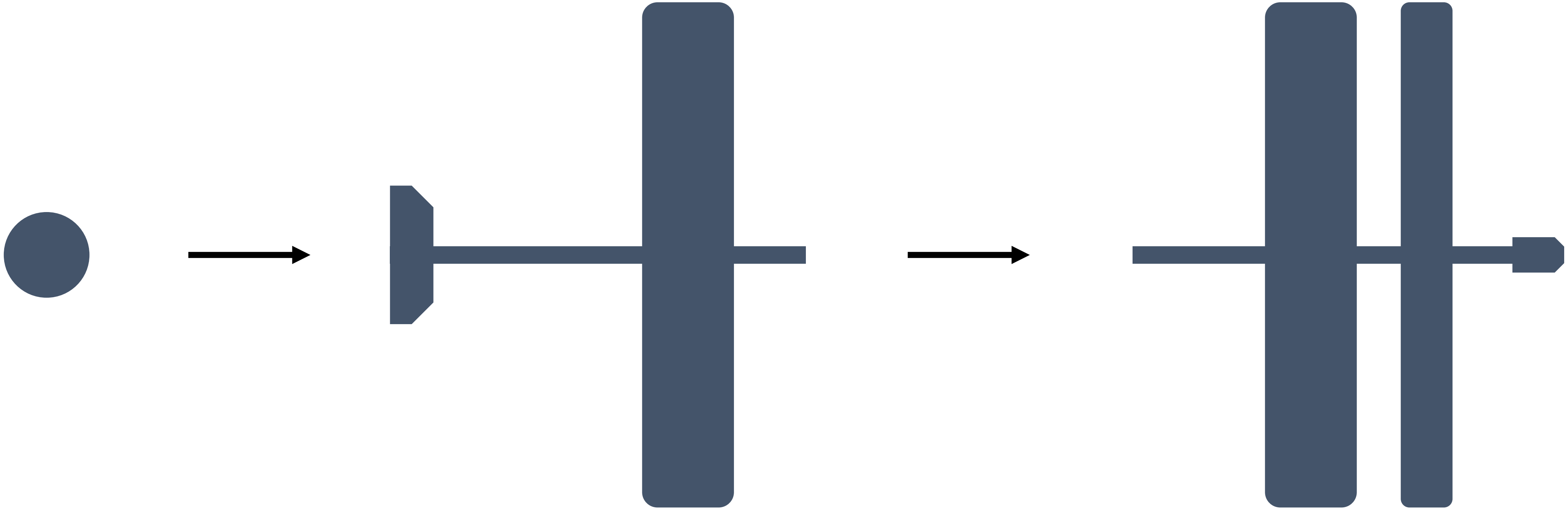
- Efficiency and maneuverability
- Wide range of applications

Leading Questions

- How do aerodynamic variables affect flight?
    - Wing placement
    - Incidence angle and decalage
    - Center of gravity
- Can you control pitch with shifting mass?
    - Movement extrema
- Is there an “optimal” configuration?
    - Best L/D ratio
    - Ideal stability



Building a Model



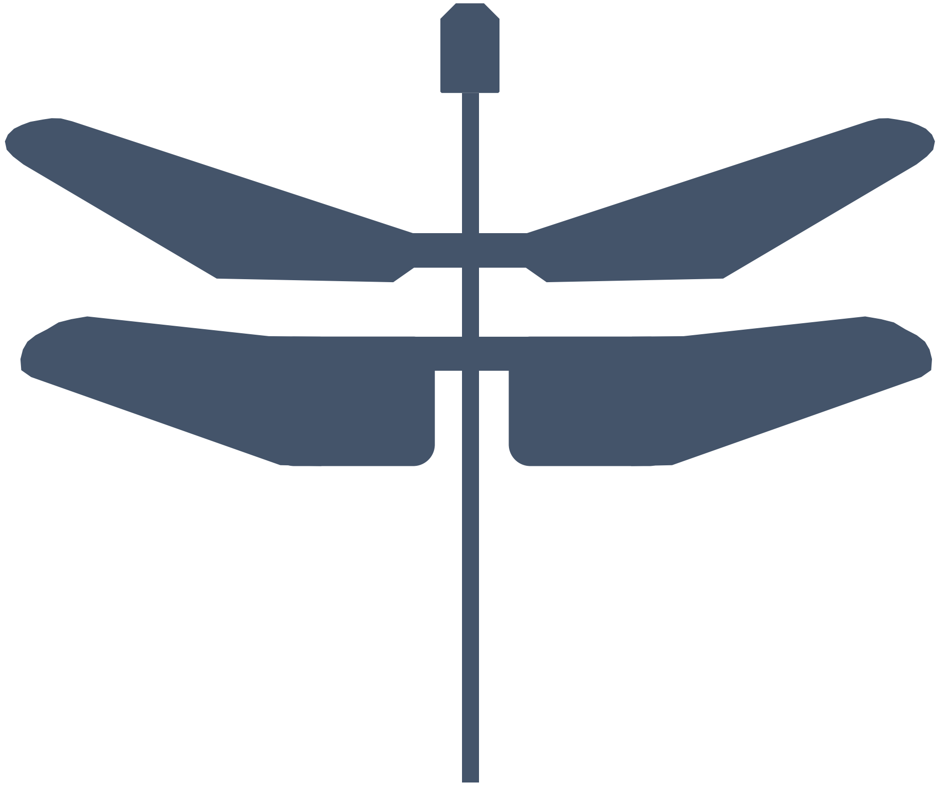
Point Mass

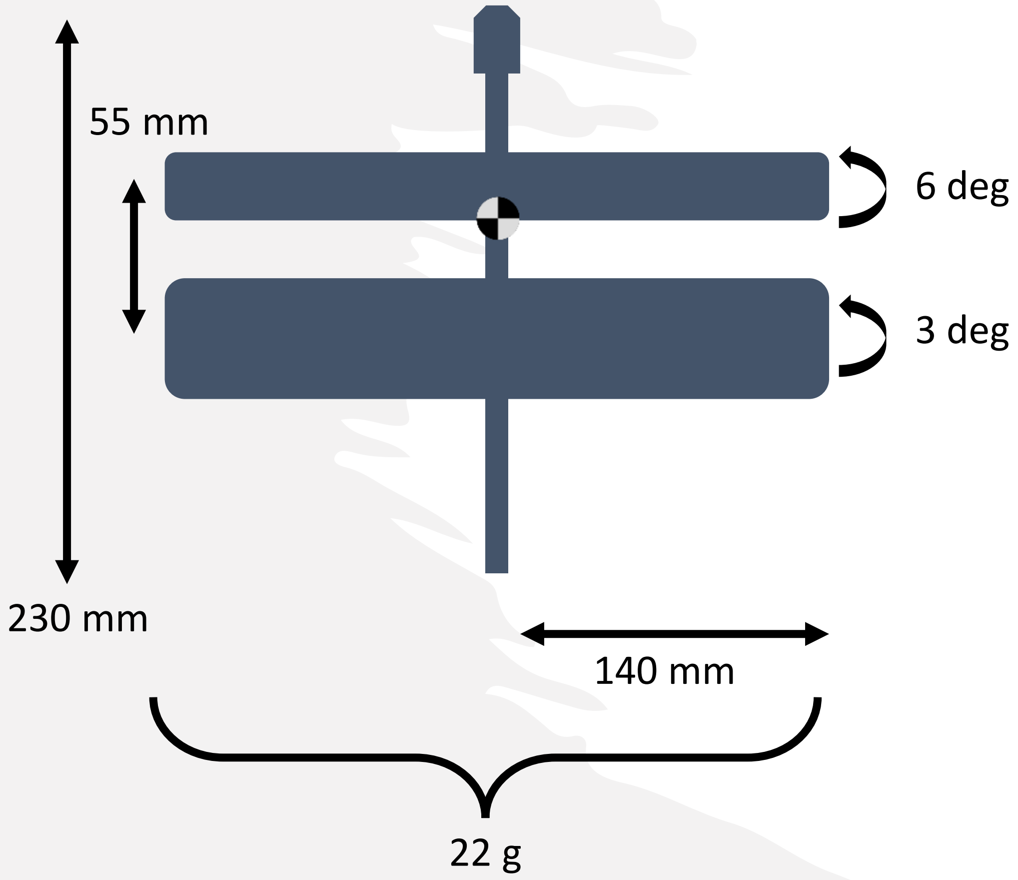
Rigid Body

Tandem Wing

Flight and Control

Simulating Flight
Varying C.G.





Component	Approximation
Aero surfaces	Flat, rectangular, plates
Downwash angle	Constant, distance independent
Wings	Forces act from point
CF fuselage rod	No aerodynamic effects, inertially thin
Movement	Only 2-dimensional, 3 DOF

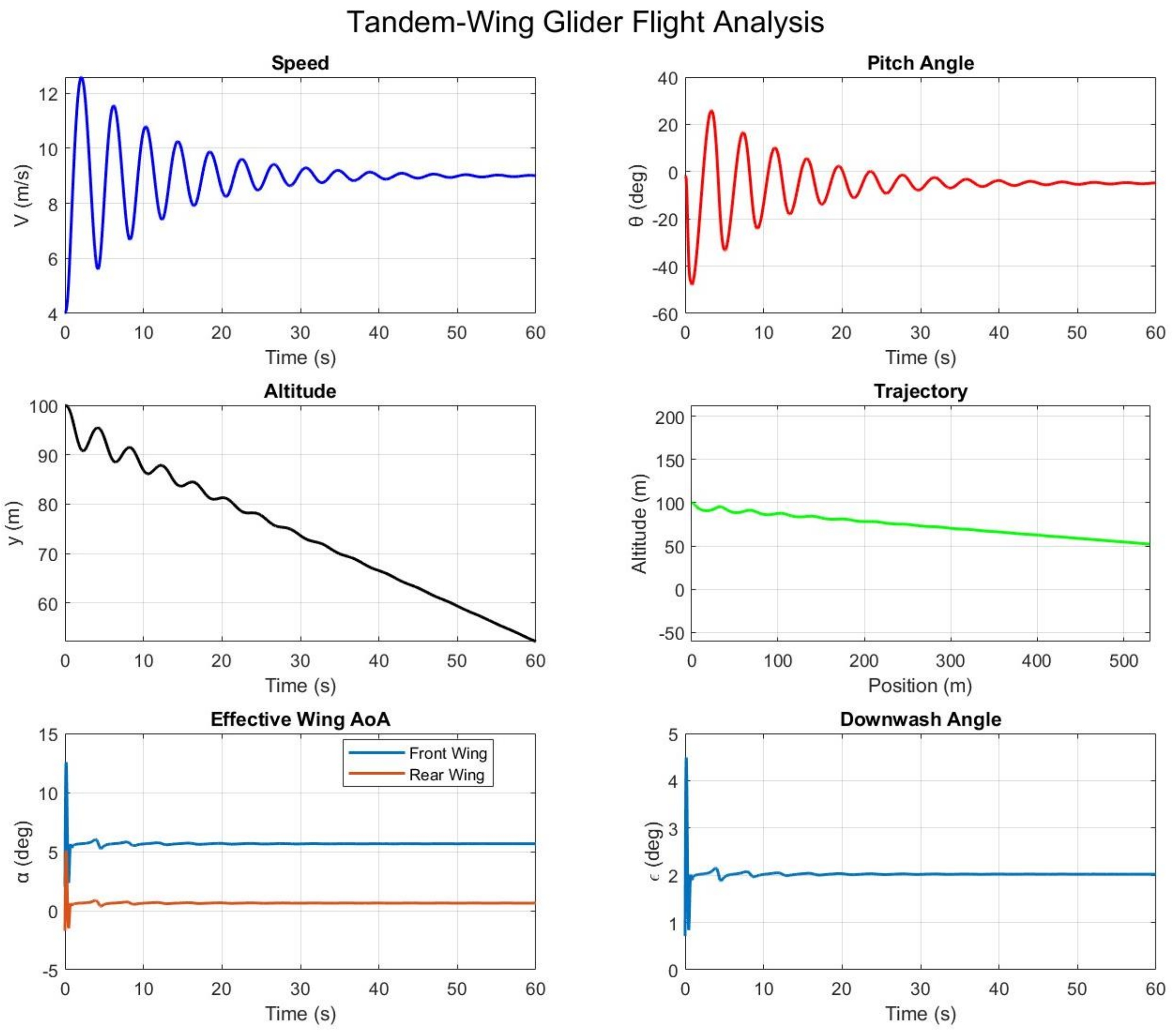
Preliminary Simulation

- Mathematical model:

$$\frac{\partial v}{\partial t} = -g \sin\gamma - \frac{D}{m} \qquad \frac{\partial \theta}{\partial t} = q$$

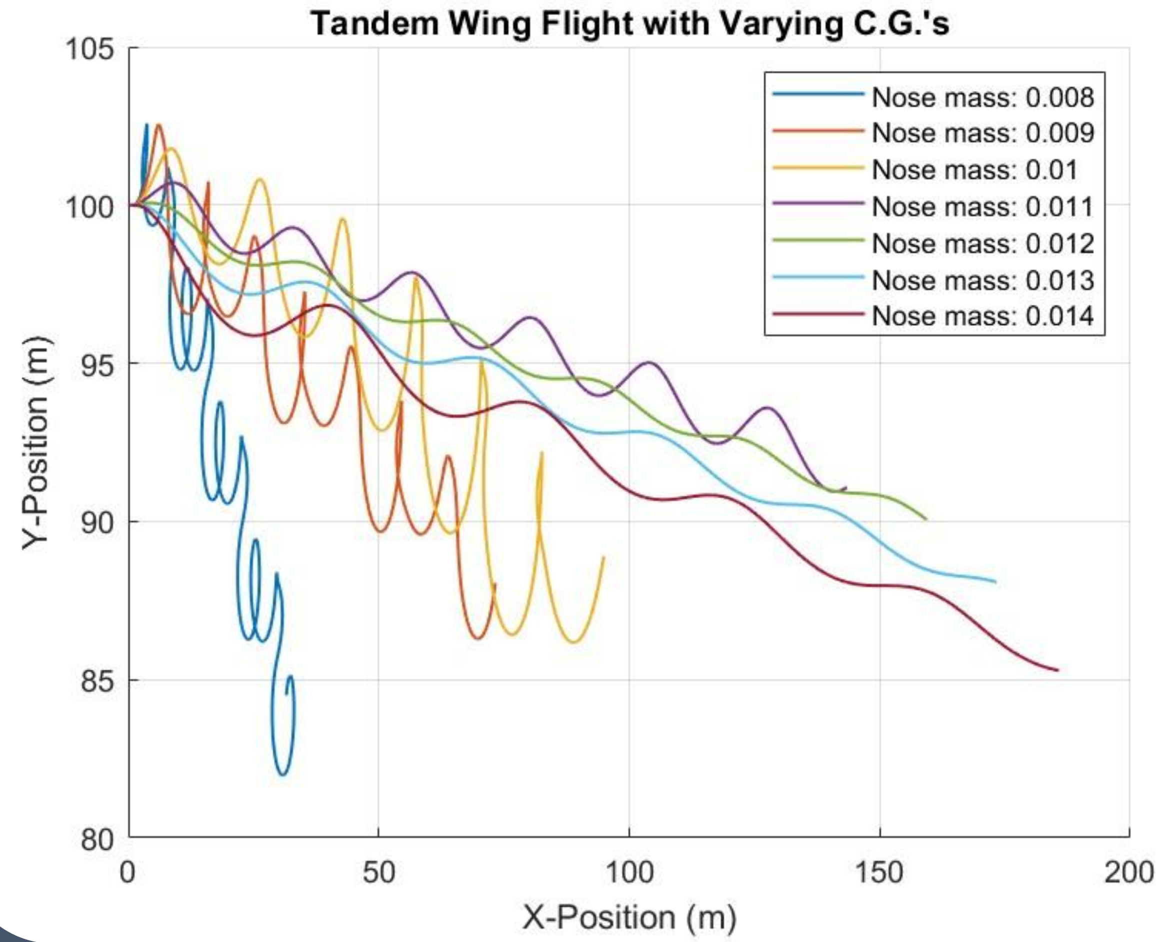
$$\frac{\partial \gamma}{\partial t} = \frac{L}{mv} - \frac{g\cos\gamma}{v} \qquad \frac{\partial q}{\partial t} = \frac{\Sigma M}{I}$$

- Set initial conditions and integrated e.o.m.
- Time-dependent solutions allowed sanity-check
  - Slightly high forward speed, but reasonable descent



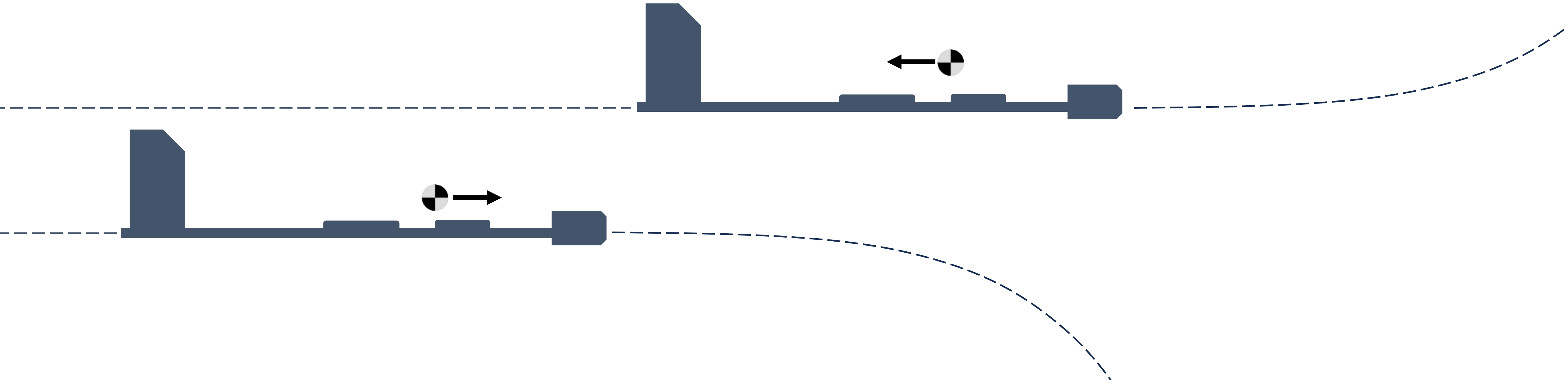
Varying C.G.'s

- Ran simulations with different nose weights
- Tail-heavy created instability immediately noticeable
- Nose-heavy led to faster diving
- "Ideal" 11g corresponded to a C.G. slightly behind the front wing
    - Similar finding on the physical model in the ARL
    - 41% fuselage length



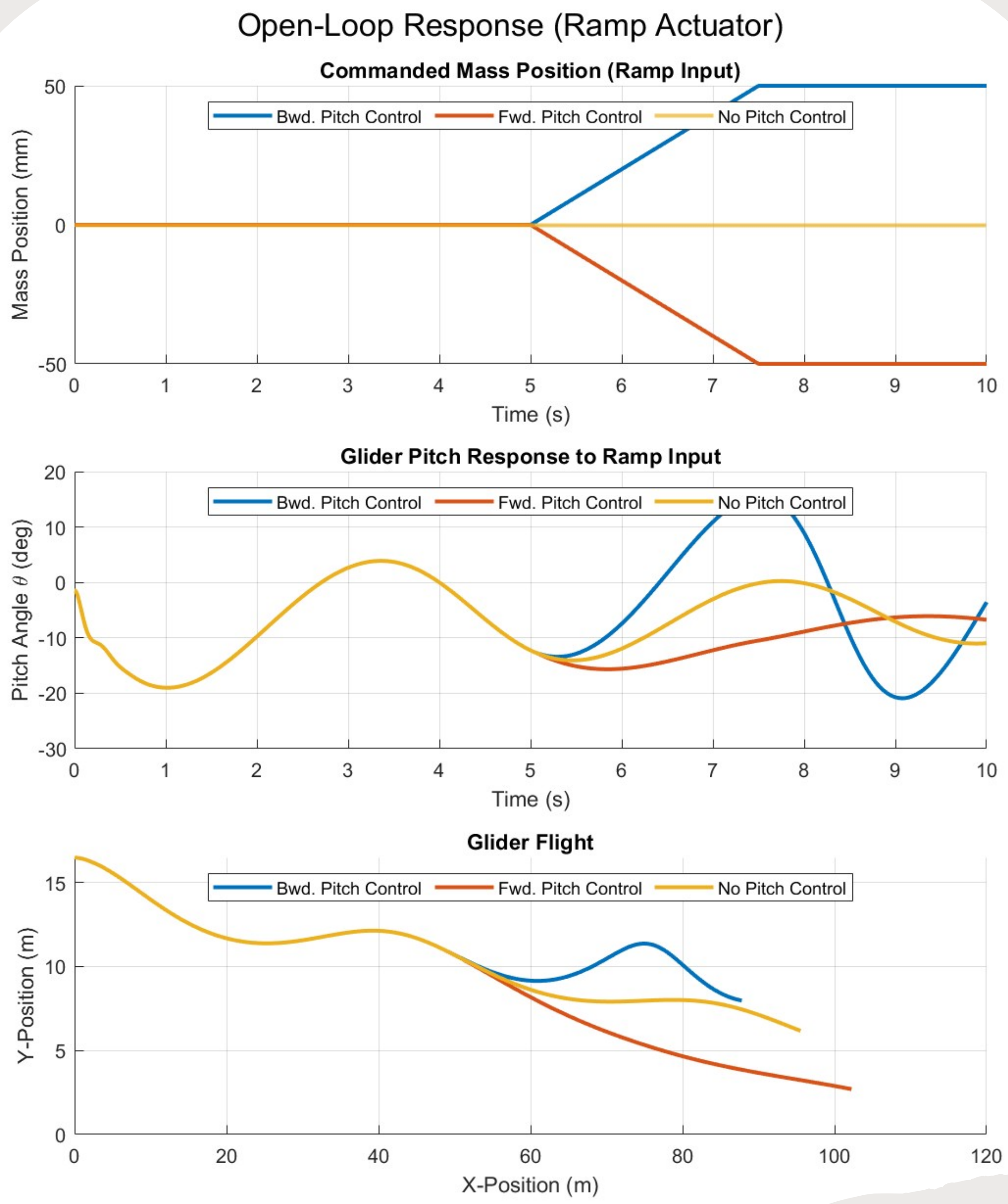
Dynamically Varying C.G.

- Ramping a fictional 4g mass up/down the fuselage to create a pitching moment
- Accounting for change of C.G. and inertia, but not for any internal forces due to movement



Backward Pitch Control

- C.G. shifted away from nose
- Increased oscillatory behavior
- Model pitches up

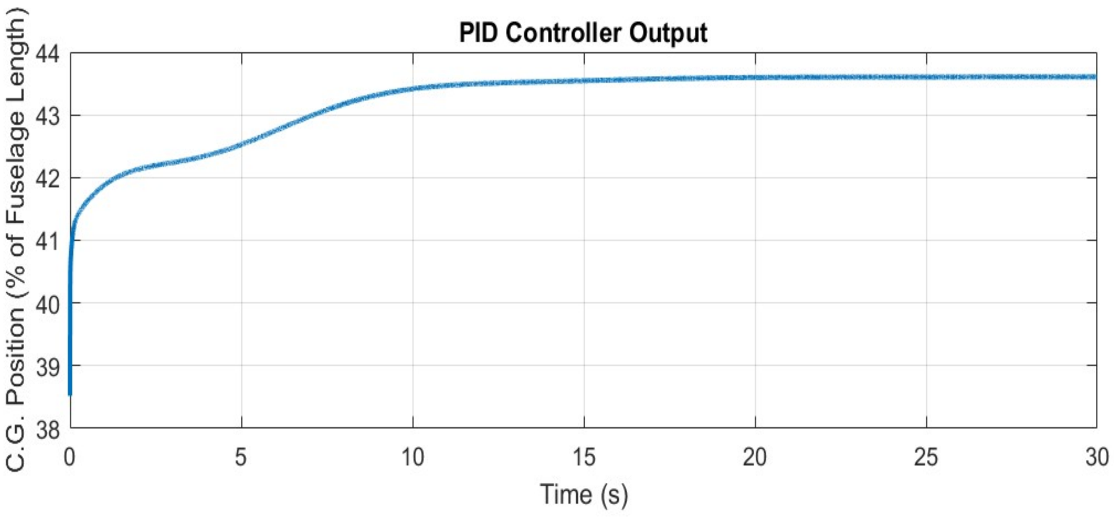


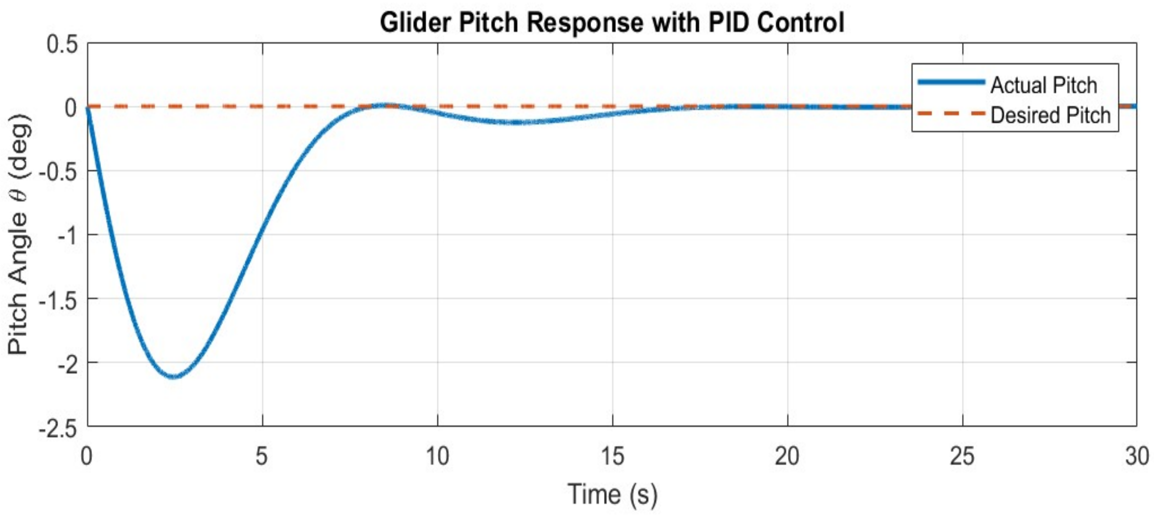
Forward Pitch Control

- C.G. shifted towards nose
- Decreased oscillation
- Down pitch

PID Pitch Controller

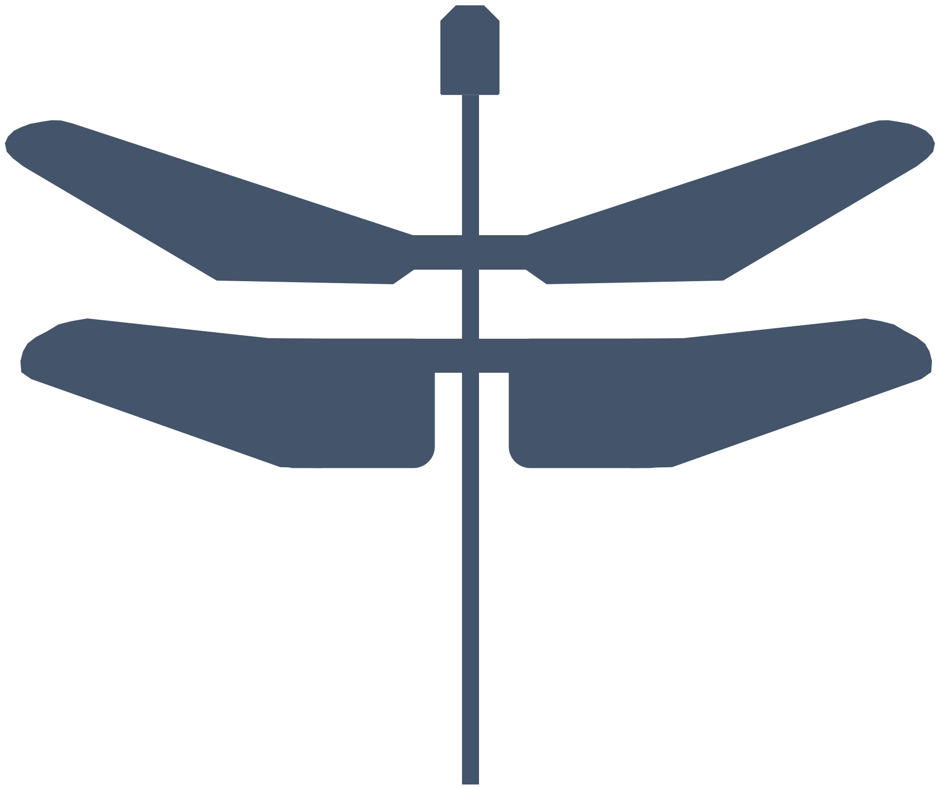
- Simple loop based on current vs. target flight angle
- PID gain values chosen with trial and error, best for a small target angles
- C.G. shift 5% of fuselage length
  - A 70mm shift for a 4g mass





Aerodynamic Analysis

Stability
Mode Examination
Efficiency

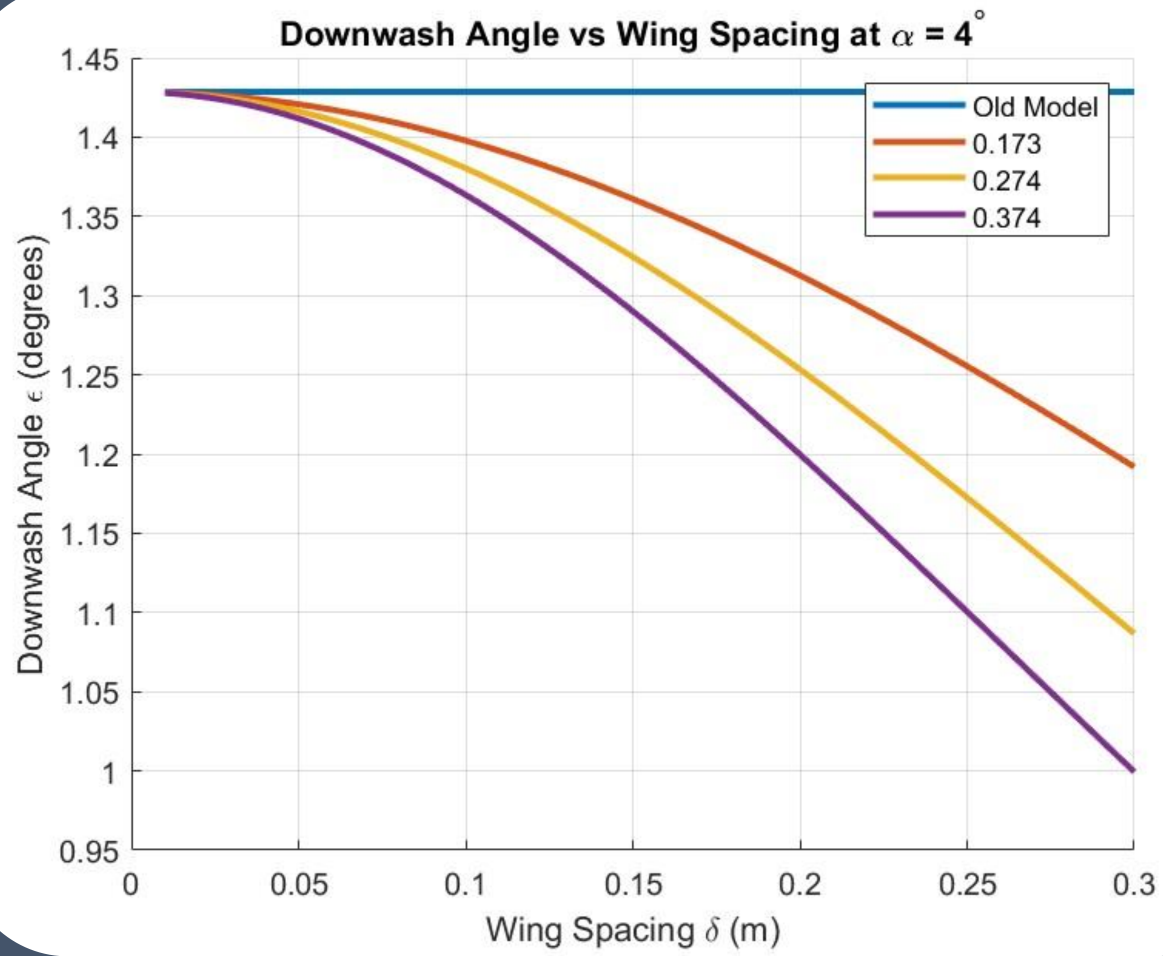


Distance-Dependent Downwash

- Two stabilizing variables:
  - Rear wing moment arm
  - Front wing downwash effect
- Each work best at different wing separations

$$\epsilon = \frac{2C_L}{\pi AR} \times \frac{1}{1 + K\left(\frac{\delta_{wing}}{S}\right)}$$

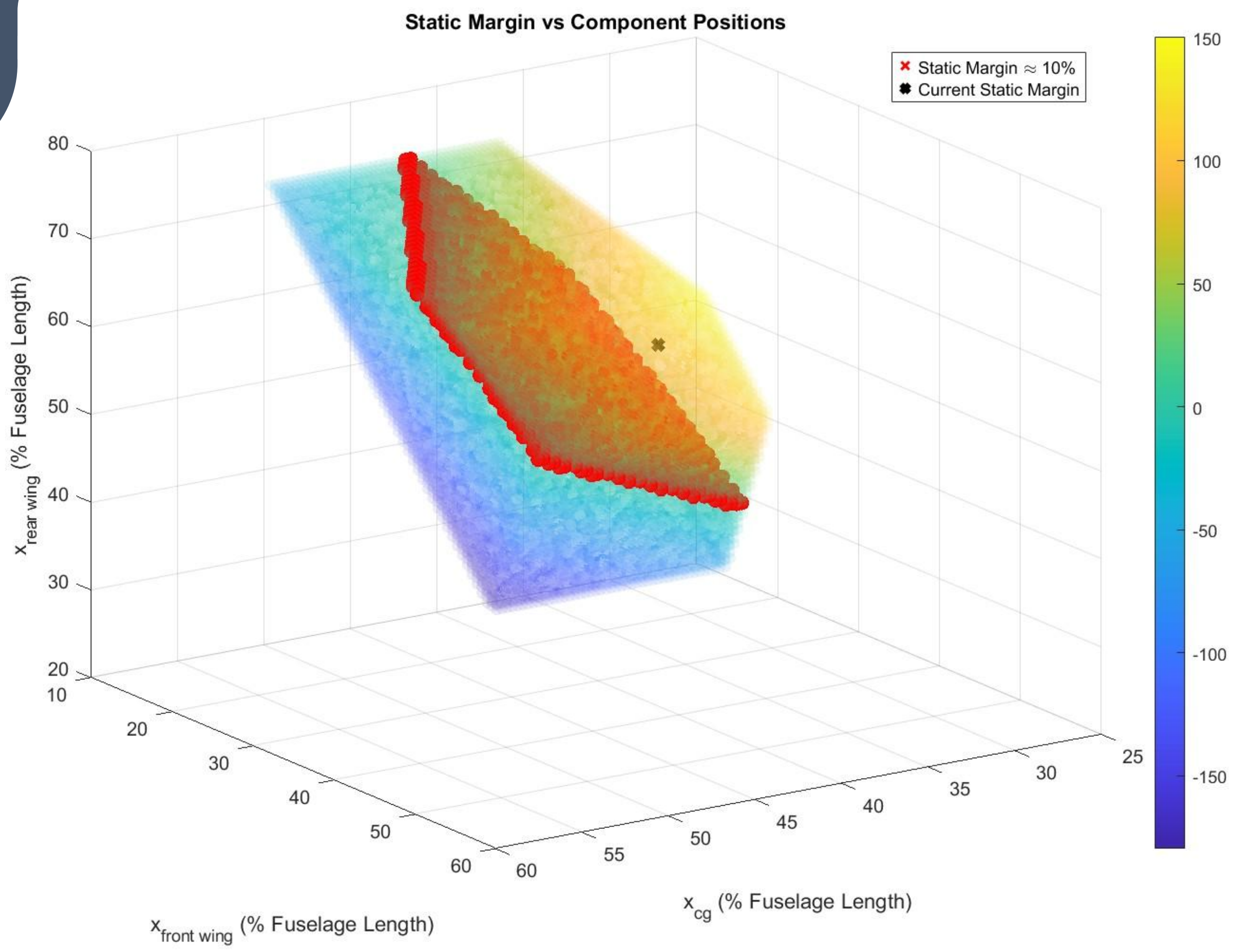
- Tabulated K values based on wing sizes, distances, and vertical offset
- Not a significant difference between possible K values



K-Value Ref: Aerodynamics of Tandem Wing Aircraft, Illia Kryvokhatko

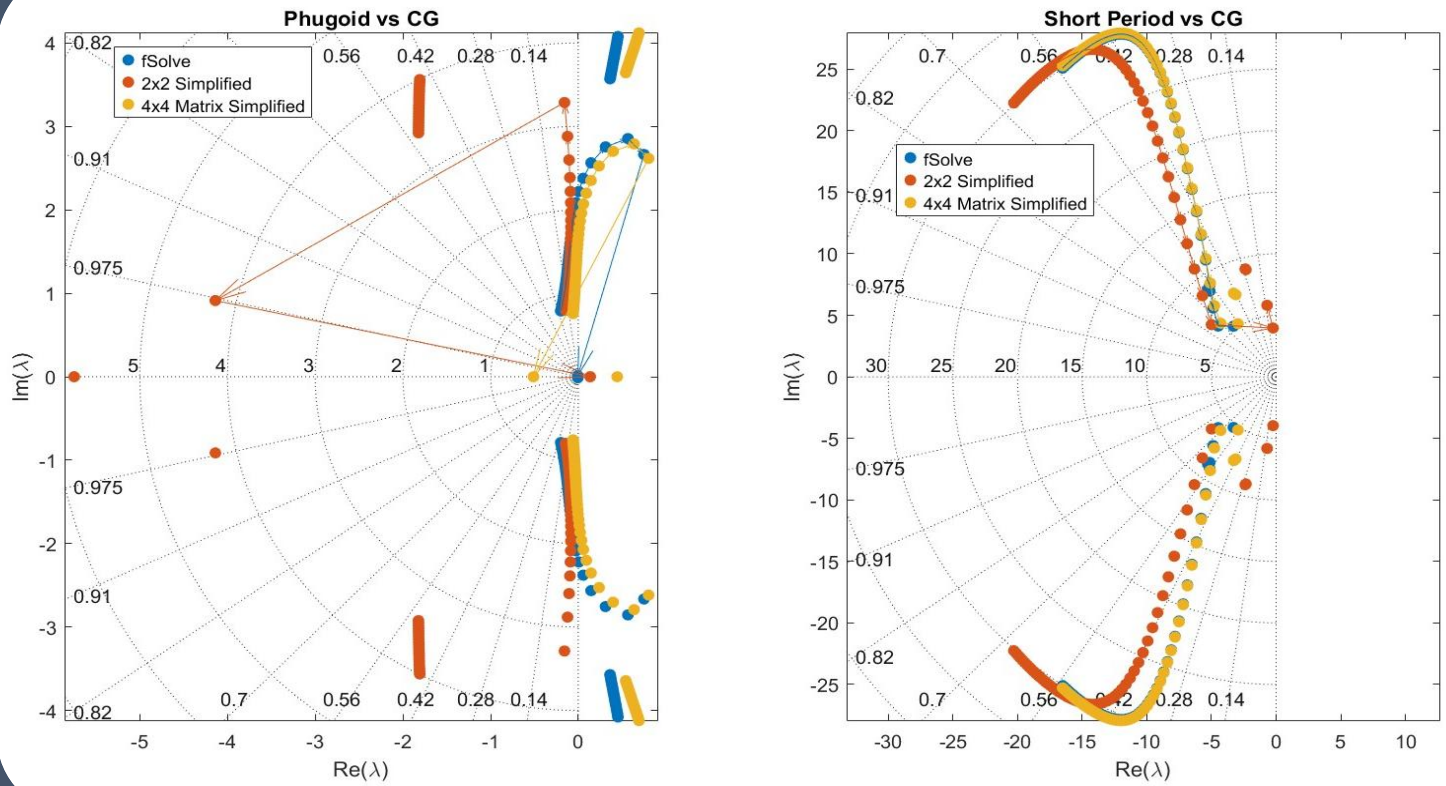
Static Stability

- Expected pattern, high margins have:
  - Forward C.G.
  - Back-set wings
- For a set static margin, there exists a planar relationship between:
  - Wing positions
  - C.G. placements
- Current configuration's margin is calculated at 60%



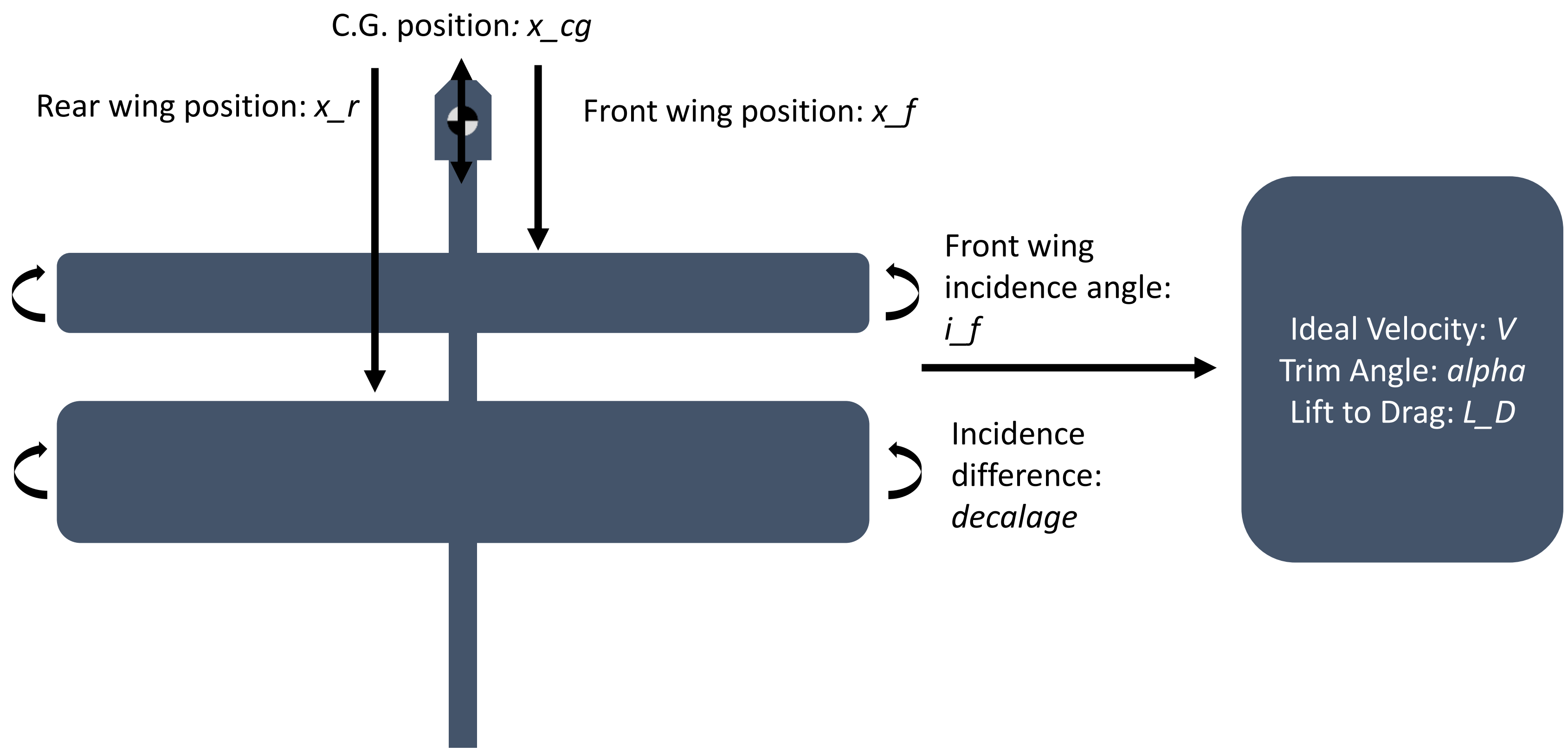
Dynamic Stability

- Set-velocity approaches:
    - Textbook-simplified decoupled 2x2's
    - Full 4x4 state matrix
- Variable-velocity:
    - MATLAB's *fsolve* for full equilibrium
- At same velocities, *fsolve* and the 4x4 proved similar
    - Handled instability better

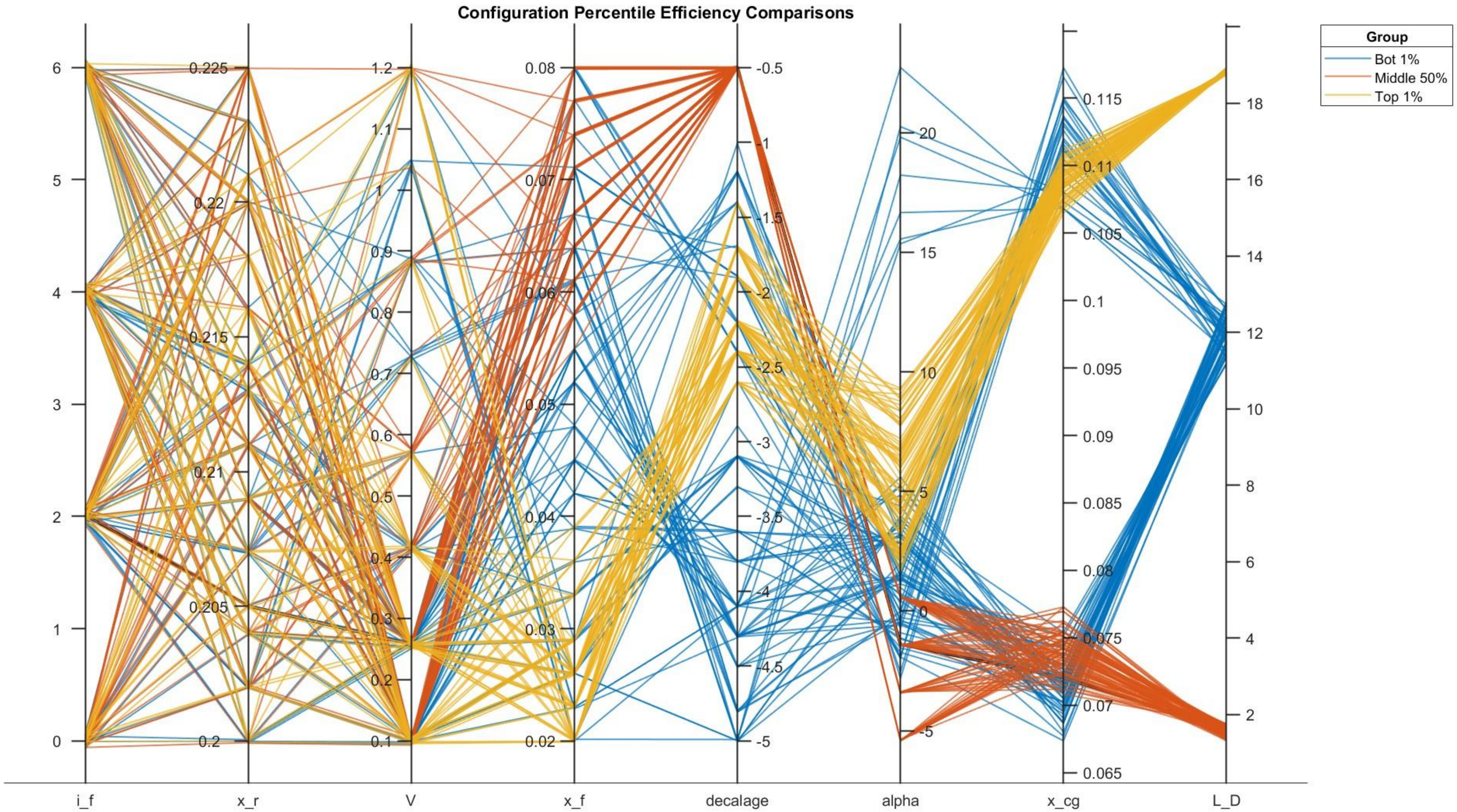


- Became unstable at a C.G. 118mm, or 53% fuselage length
- Equilibrium velocity decreased linearly from 12m/s to 3m/s as C.G. ramped backwards

Configuration Efficiency



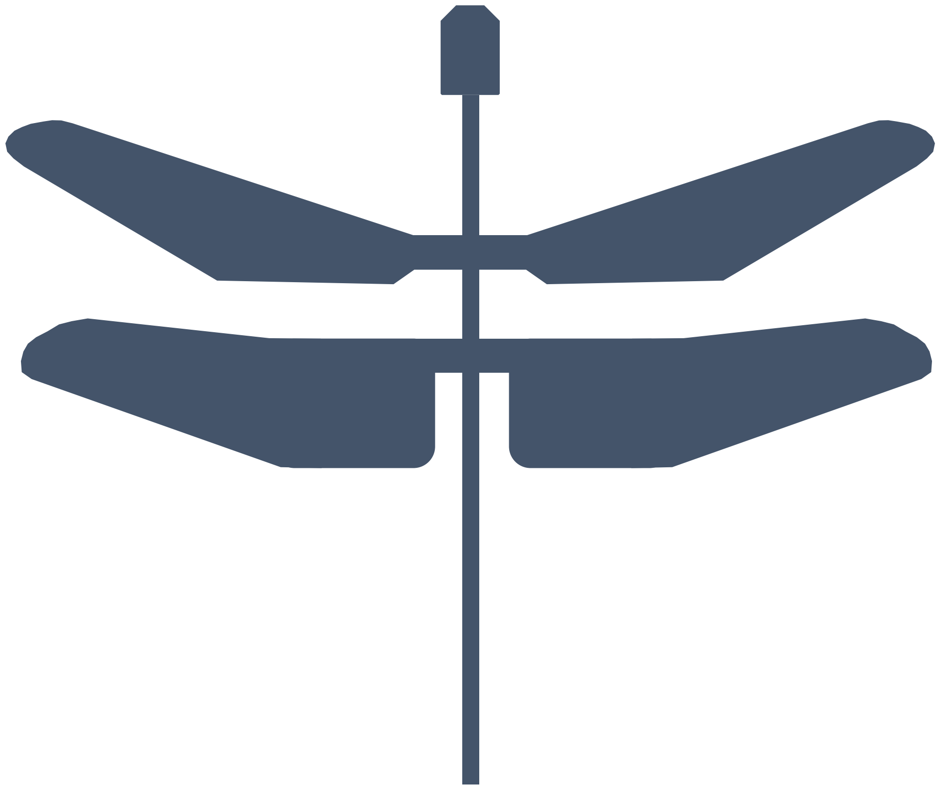
- Wide-net approach
  - Testing all positioning variables
  - Gathering all relevant outputs
- Comparing different configurations with similar efficiencies
  - How do they differ?
- Identifying variables most correlated with efficiency



- Efficient flight has a strong correlation with a 110mm C.G. (48% fuselage length) and 2° of decalage
- Efficiency falls as the front wing moves back and decalage decreases

Project Conclusion

Key Considerations
Future Work



Key Considerations

- Ideal pitch control seemed to ramp C.G. between 40-50% fuselage length
    - 41% for shallow glide
    - 43.5% for level glide
    - 48% for peak efficiency

- Certain factors contribute more heavily to stable, efficient flight
    - C.G.
    - Decalage angle

Future Work

- Deepen pitch control analyses
  - Expand model for further DOF and inertial effects of moving mass
  - Methods of implanting mass ramping on physical model

- Apply same approach to further define the viable design space
  - Compare efficiency with dynamic stability
  - Parallel Coordinates plot with the phugoid mode
  - Ideal placement for electronics