Senior Design EXPO – Long-Range Endurance Platform UAV : Flight Team

Client:

Dr. Allyson Yarbrough representing The Aerospace Corporation

Team Advisors:

Michael Thorburn, Ronald Sobchik, Ray Manning

Team Members:

Miguel Ortega (Team Lead)
Christopher Martinez
Alan Sosa
Muhammad Ghauri
Janice Arteaga
Jerry So
Marisa Munoz
Luis Robles

Agenda

Rendering courtesy of Structure-Design sub-team

Project Objective

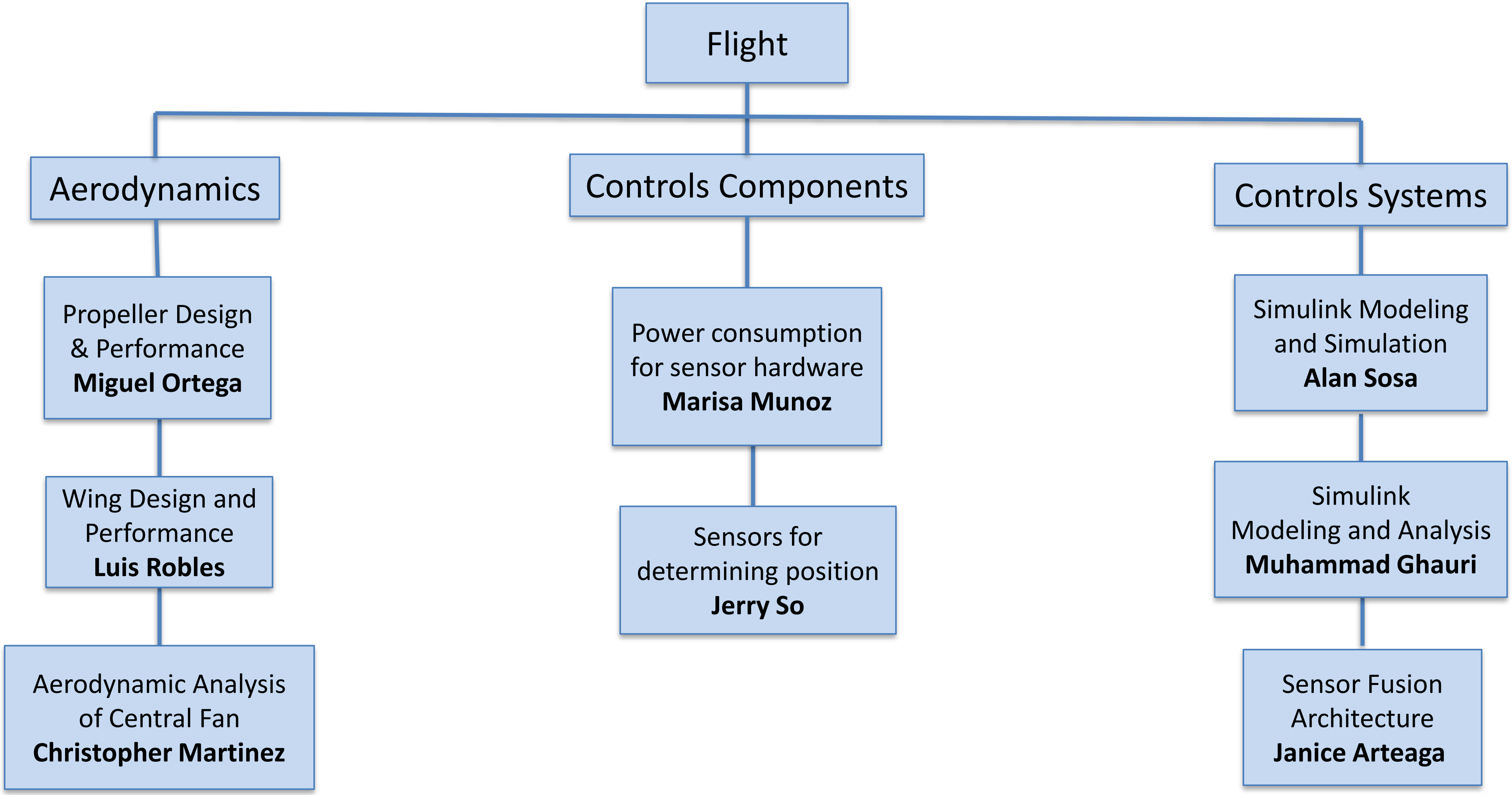
- Hybrid powered UAV
- Long-range capabilities
  - 4-hour flight time
- Monitor emissions from ships at the Port of Long Beach

Photo property of CaliforniaPorts.org

Flight Team Objective

- The Flight Team focuses on the aerodynamics and controls aspect of the UAV design by conducting aerodynamic analysis to verify that the proposed design is achievable. In addition, the sensor components were determined to best fit the necessary flight capabilities and design a controls system model to achieve stable flight.

Work Breakdown

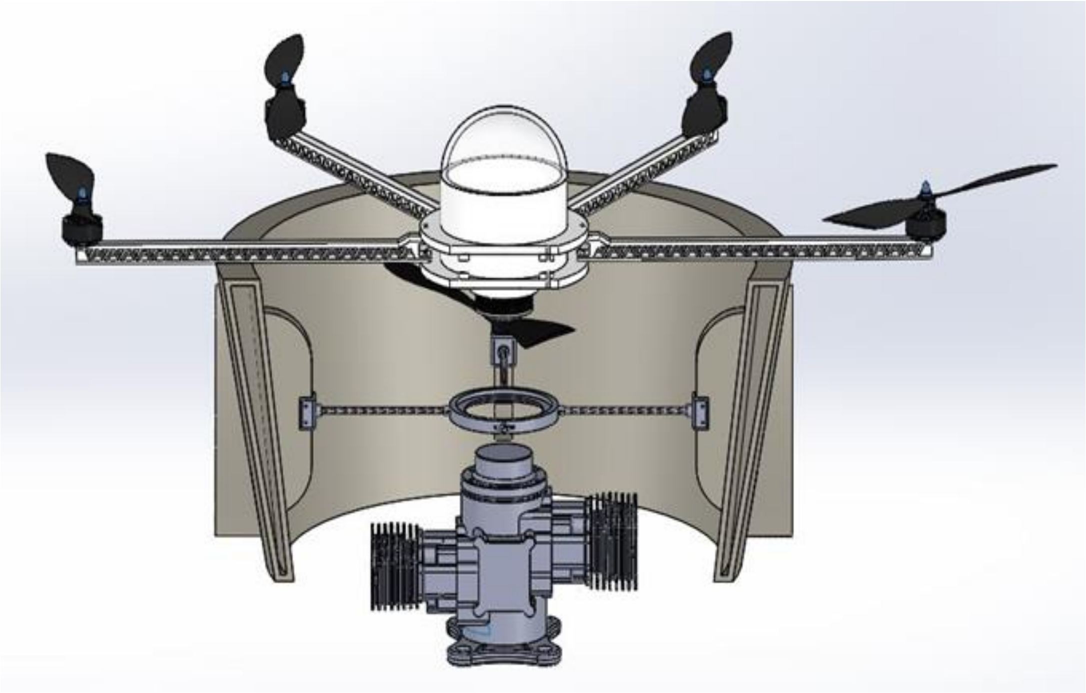


UAV Overview

- Unmanned aerial vehicles (UAVs) are becoming more popular in a wide range of applications. Ex: Aerial photography, mapping, and surveying.

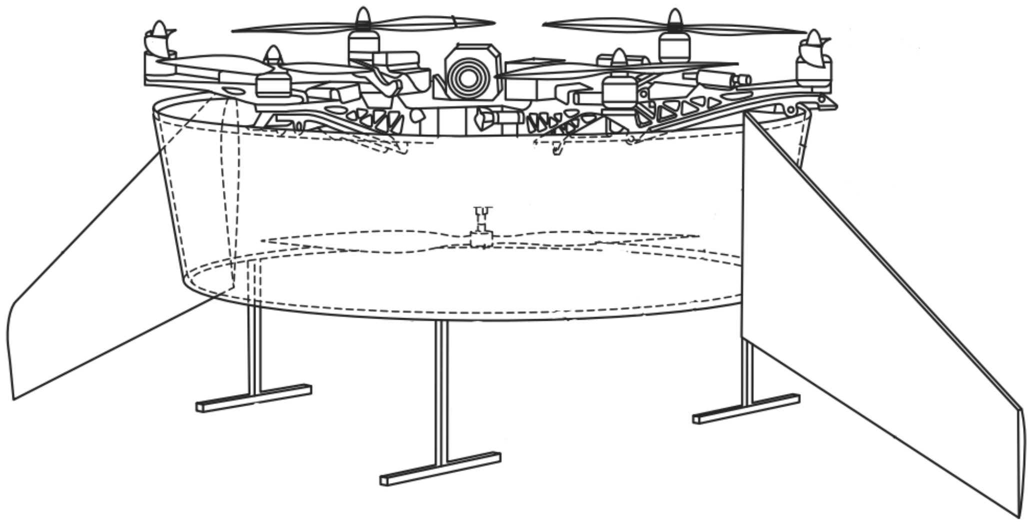
- UAVs are cheaper and smaller than larger aircraft/rotorcraft and can serve the same functions as mentioned above.

- Sensor Assembly, Flight control system, fin & propeller design and performance were investigated.



Proposed Design

- 1 Central Ducted Fan
- Six surrounding micro-propellers
- A set of wings
- Under 55 pounds in weight
- Hybrid powered
- Can fly for at least 4 hours without refueling/recharging



Current Design

- UAV estimated weight = 100 lbs
- 20in central propeller in a 2 ft diameter duct
- Six 24.5 in propellers
- Propellers run on KDE Direct electric motors
- Propeller total weight = 1.2 lbs

Rendering courtesy of Structure-Design sub-team

Propeller Flight Configuration

$$\sum F_x = 0$$

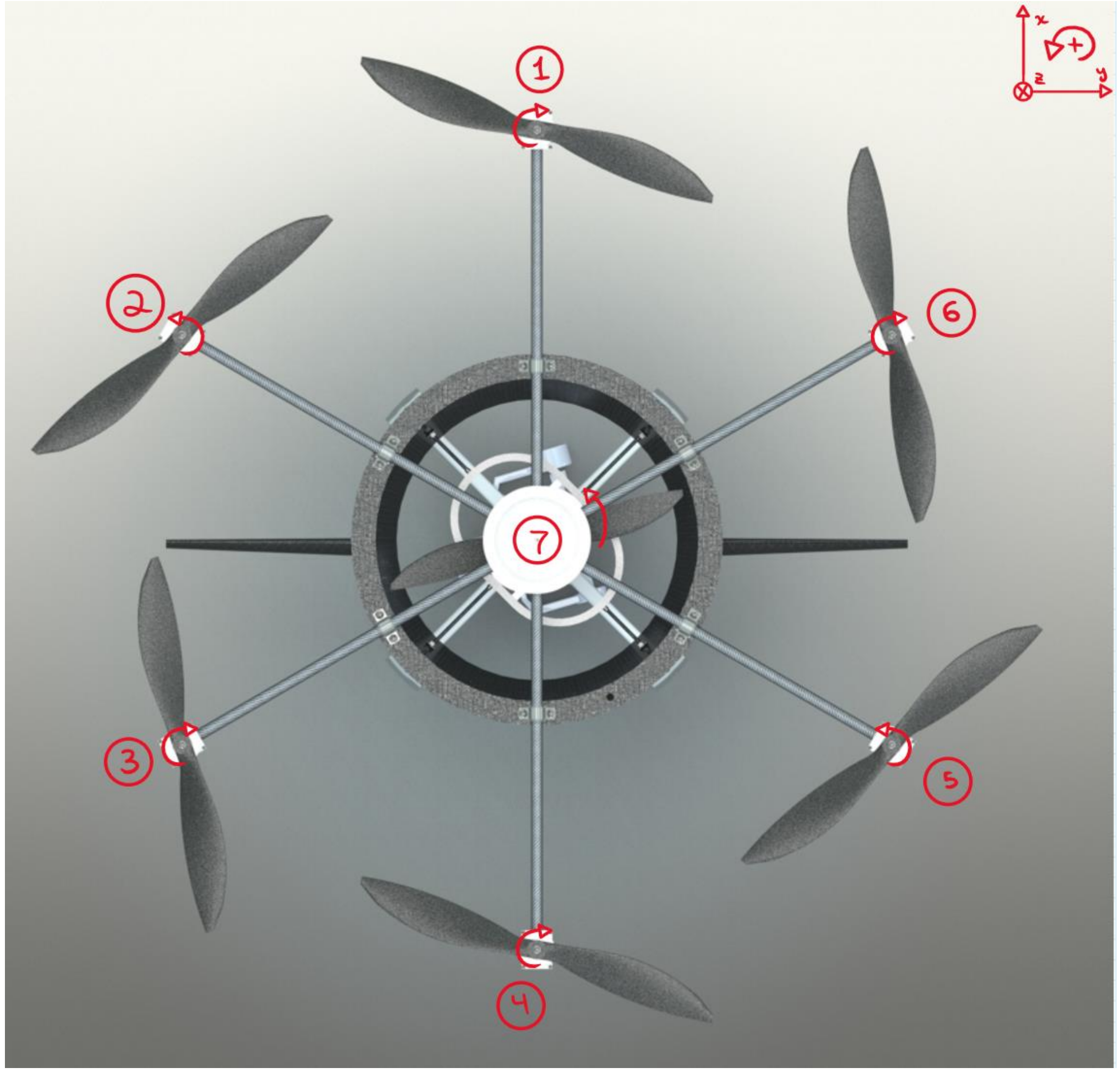
(1) $$(Th_1 + Th_2 + Th_3 + Th_4 + Th_5 + Th_6 + Th_7) \times \sin(\theta_p) - F_d = 0$$

$$\sum F_Z = 0$$

(2) $$(Th_1 + Th_2 + Th_3 + Th_4 + Th_5 + Th_6 + Th_7 - Weight) \times \cos(\theta_p) = 0$$

$$\sum \tau_Z = 0$$

(3) $$-\tau_1 + \tau_2 - \tau_3 - \tau_4 + \tau_5 - \tau_6 + \tau_7 = 0$$



Rendering courtesy of Structure-Design sub-team

Propeller Flight Configuration

$$\sum F_x = 0$$

(1) $$(Th_1 + Th_2 + Th_3 + Th_4 + Th_5 + Th_6 + Th_7) \times \sin(\theta_p) - F_d = 0$$

$$\sum F_Z = 0$$

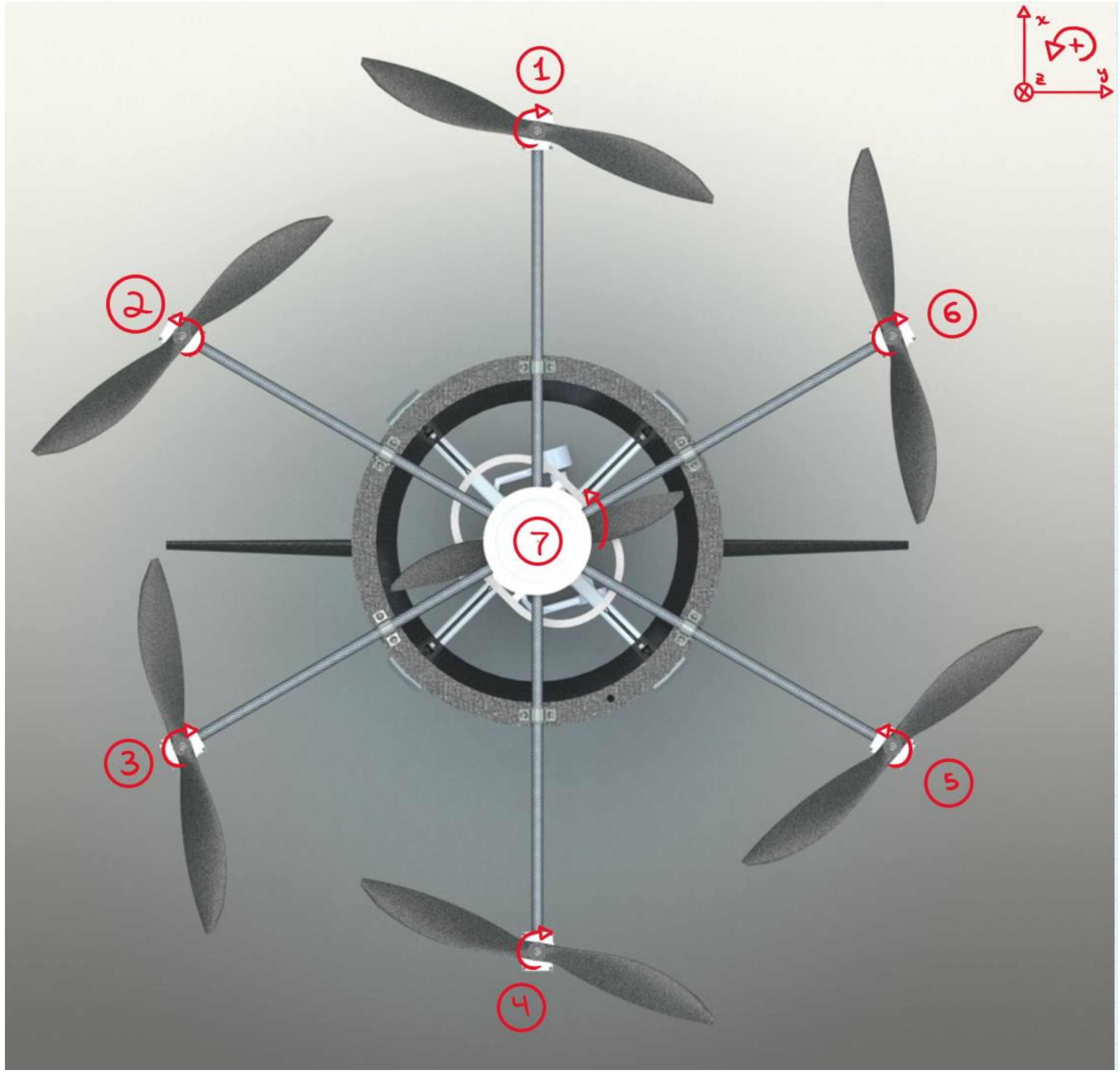
(2) $$(Th_1 + Th_2 + Th_3 + Th_4 + Th_5 + Th_6 + Th_7 - Weight) \times \cos(\theta_p) = 0$$

$$\left(\sum \tau_Z\right)_1 = 0$$

(3) $$-\tau_1 - \tau_4 + \tau_7 = 0$$

$$\left(\sum \tau_Z\right)_2 = 0$$

(4) $$+\tau_2 - \tau_3 + \tau_5 - \tau_6 = 0$$



Rendering courtesy of Structure-Design sub-team

Forward Flight

- KDE Direct provides performance data for electric motor and propeller combination.
  - From 0-100% Throttle
- Logarithmic linearization used to determine equations for Thrust, Torque, and Power.
- These interpolated equations were plugged into the equilibrium equations

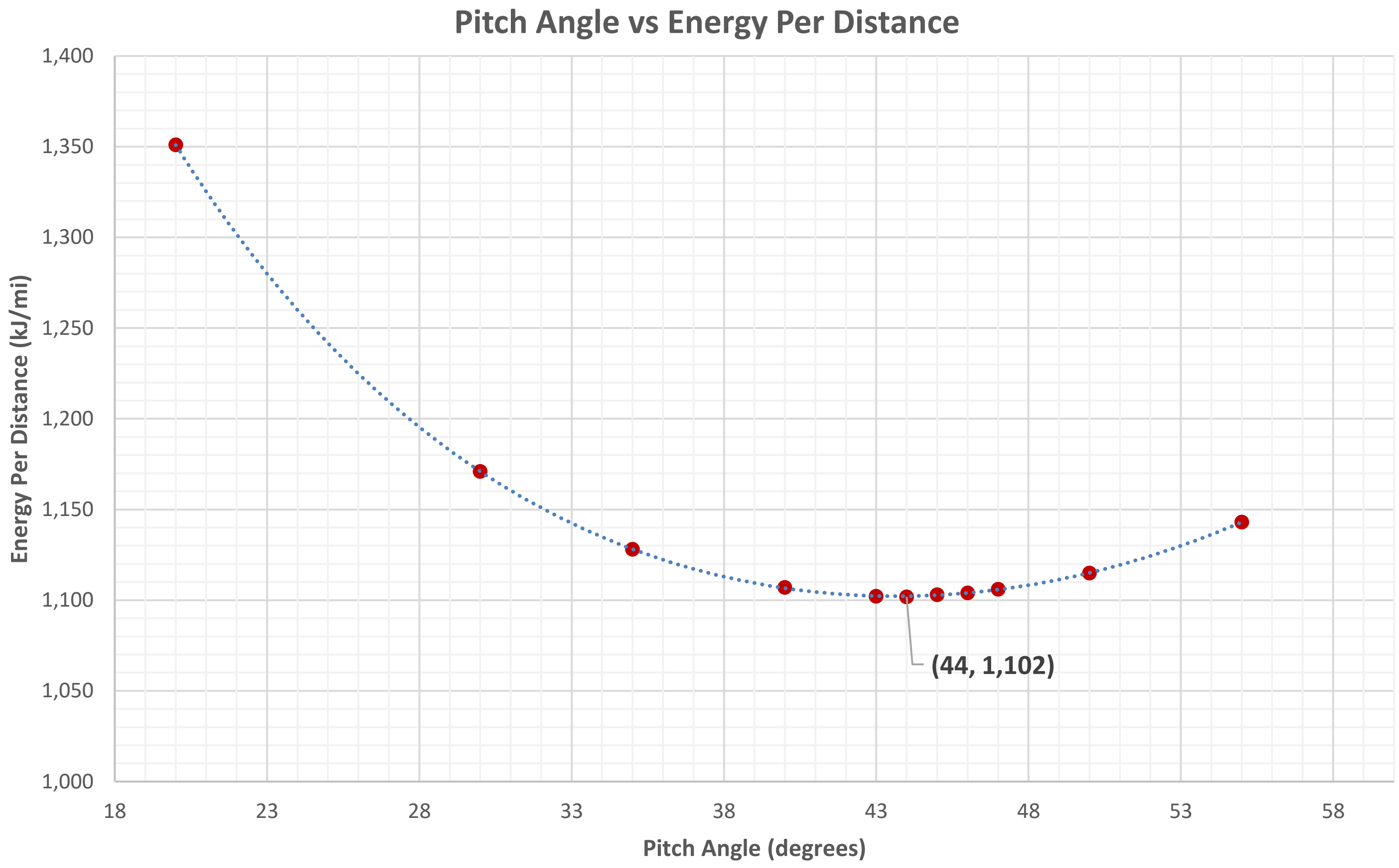
Pitch [degrees]	Thrust [lbs]	Forward Speed [mph]	Power [kW]	Energy Per Distance [kJ/mi]
20	106.4	16	6.03	1351
30	115	21	6.85	1171
35	122	23.8	7.45	1128
40	130.5	27	8.3	1107
43	136.7	29.1	8.92	1102.1
44	139	29.9	9.15	1101.8
45	141.4	30.7	9.39	1103
46	143	31.5	9.65	1104
47	146.6	32.3	9.93	1106
50	155.6	35.1	10.9	1115
55	174	40.7	12.9	1143

Forward Flight

- Energy per distance when forward-flying at varying pitch angles

- Minimum point on curve at pitch angle = 44°

- Forward velocity = 29.9 mph and consumes 1,102 kJ/mi

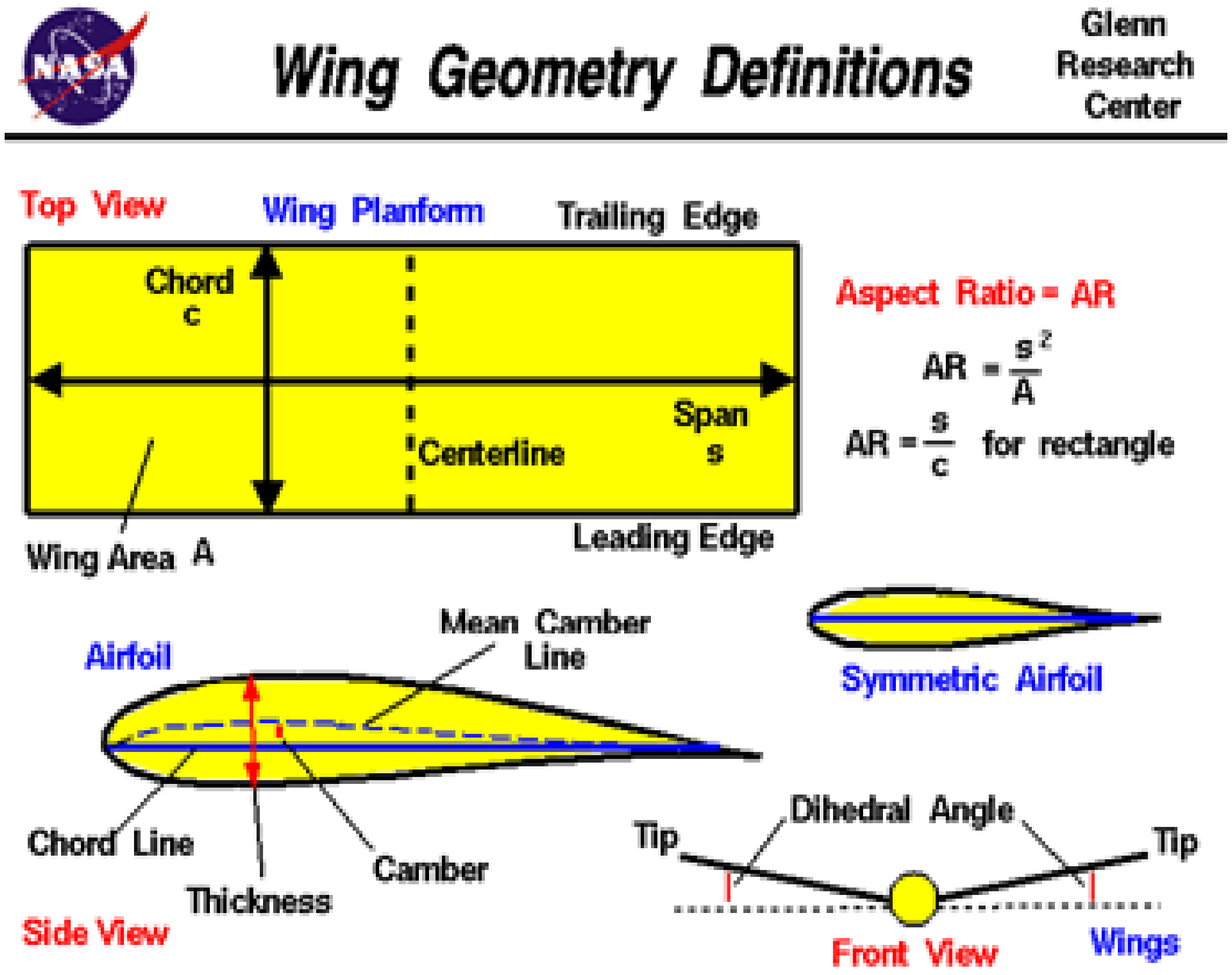


Choosing a fin

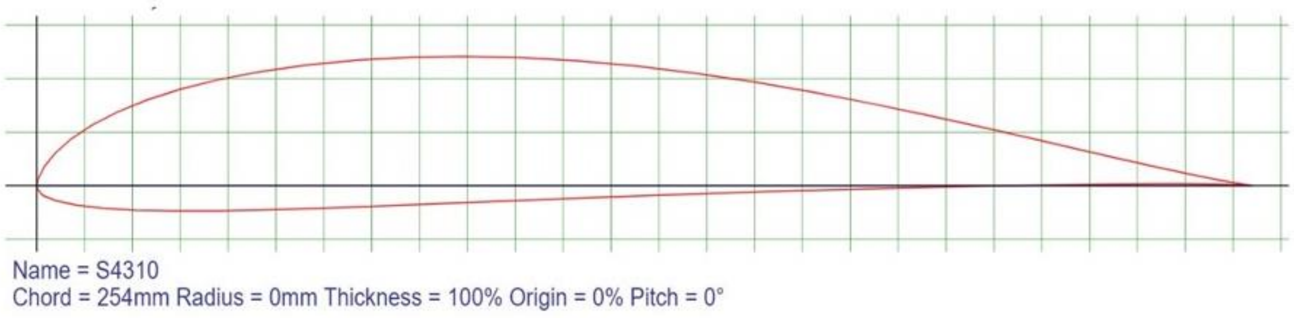
$$Lift = Cl * \frac{\rho * Vel^2}{2} * A$$

$$Re = \frac{\rho v l}{\mu}$$

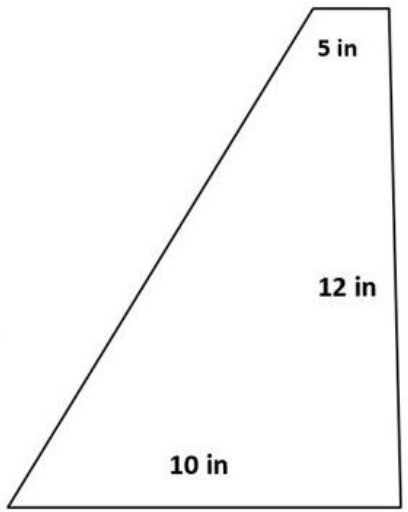
Lift Coefficient of 1.4



Current fin Design



Surface area is 600 in^2
Hollow carbon fiber wings
1mm thick
Current weight is 0.45 lbs each



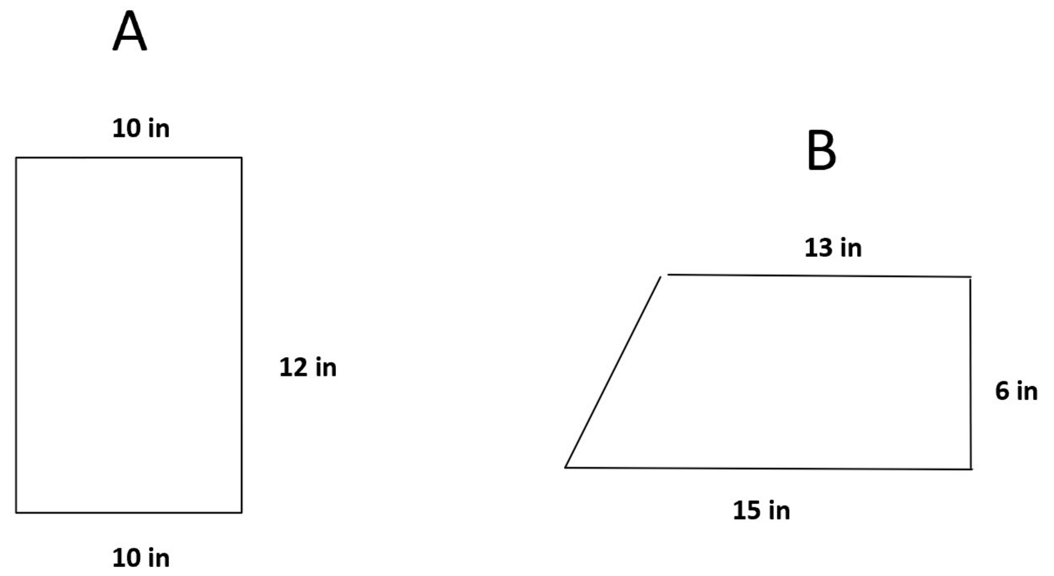
Alternative Designs

- Design A: wing area of 1200 in^2

The tip length was increased to 10 inches while everything else remained constant.

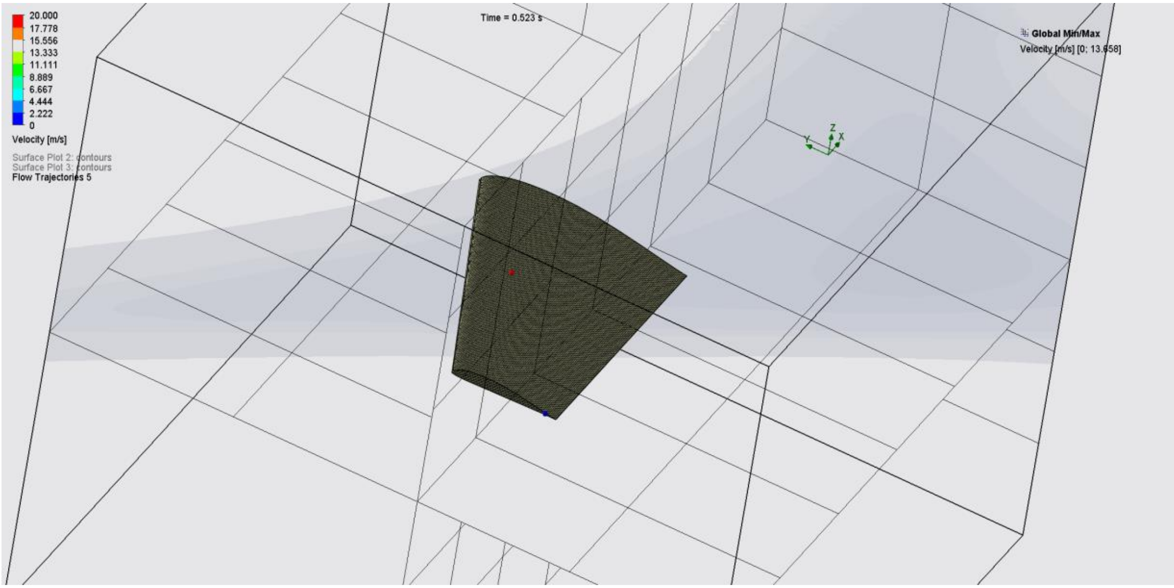
- Design B: wing area of 1170 in^2

The tip length was increased to 13 inches and the span was decreased to 6 inches.



Lift at different velocities

- Lift per wing calculated at different velocities



Flow simulation of current wing design

Velocities	Velocities	
mph	m/s	lift (lbs)
11.91	5.32	2.12
22.75	10.17	7.72
23.36	10.44	8.14
26.05	11.65	10.13
27.58	12.33	11.35
28.41	12.70	12.05
29.27	13.08	12.79
34.39	15.37	17.65
35.6	15.91	18.92
54.22	24.24	43.88

Fin efficiency

- Does the energy change with the addition of the wings?

Forward Speed [mph]	Power [kW]	Energy Per Distance w/o wings [kJ/mi]	Energy Per Distance with wings [kJ/mi]	% Difference
16	6.03	1351	1240	8.22
21	6.85	1171	1005	14.18
23.8	7.45	1128	921	18.35
27	8.3	1107	851	23.13
29.1	8.92	1102.1	810	26.50
29.9	9.15	1101.8	789	28.39
30.7	9.39	1103	769	30.28
31.5	9.65	1104	760	31.16
32.3	9.93	1106	750	32.19
35.1	10.9	1115	688	38.30
40.7	12.9	1143	547	52.14

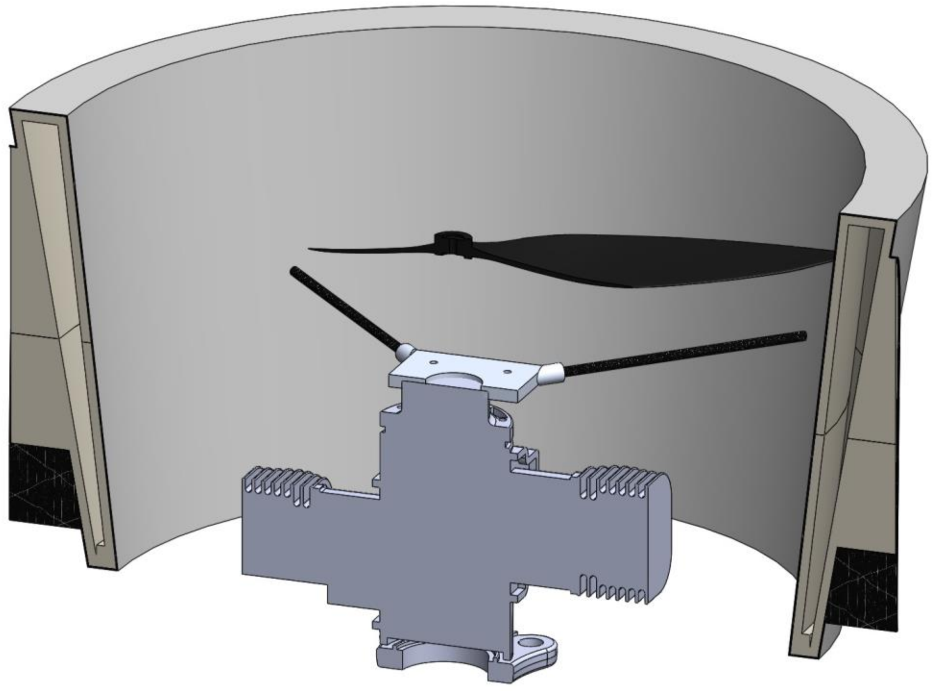
Aerodynamic Analysis of Central Fan

- In order to validate having a central ducted fan, the increase of thrust added by the fan was observed.
    - Including drag and changing pressures inside duct

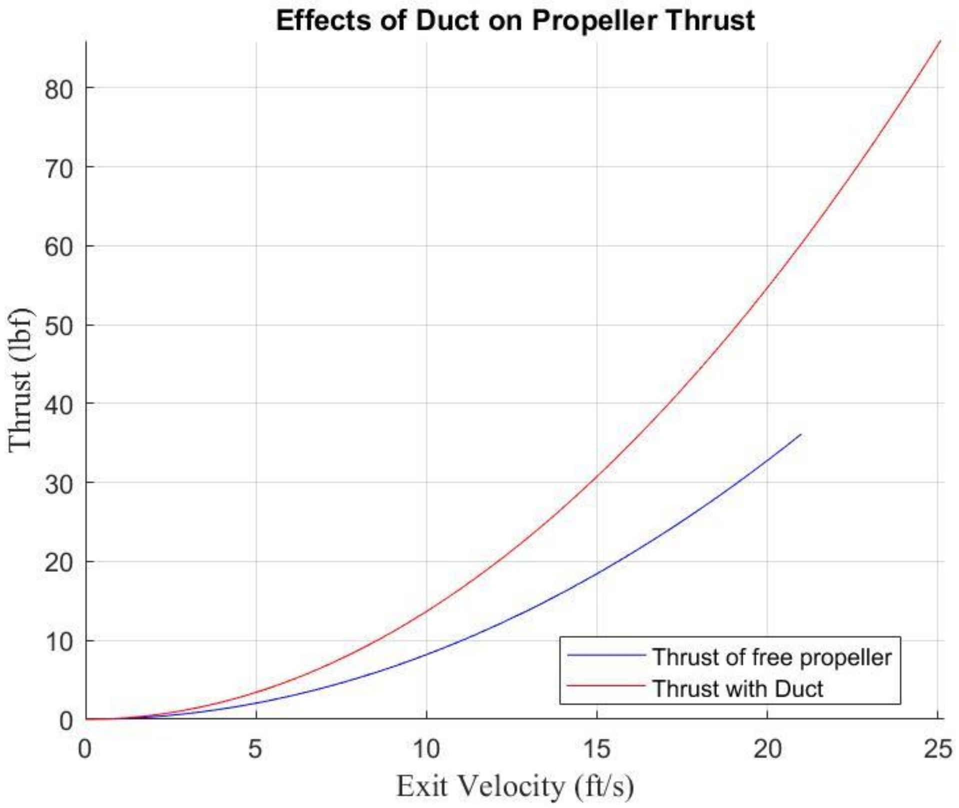
Aerodynamic Analysis of Central Fan

Two aspects observed:

1. Effects that Duct has on thrust
    - Duct is a simple open-ended cone shape
    - Slight Nozzle Effect
2. Drag forces due to Blockage inside duct
    - Engine
    - Engine Mount



Effects of Duct on Thrust

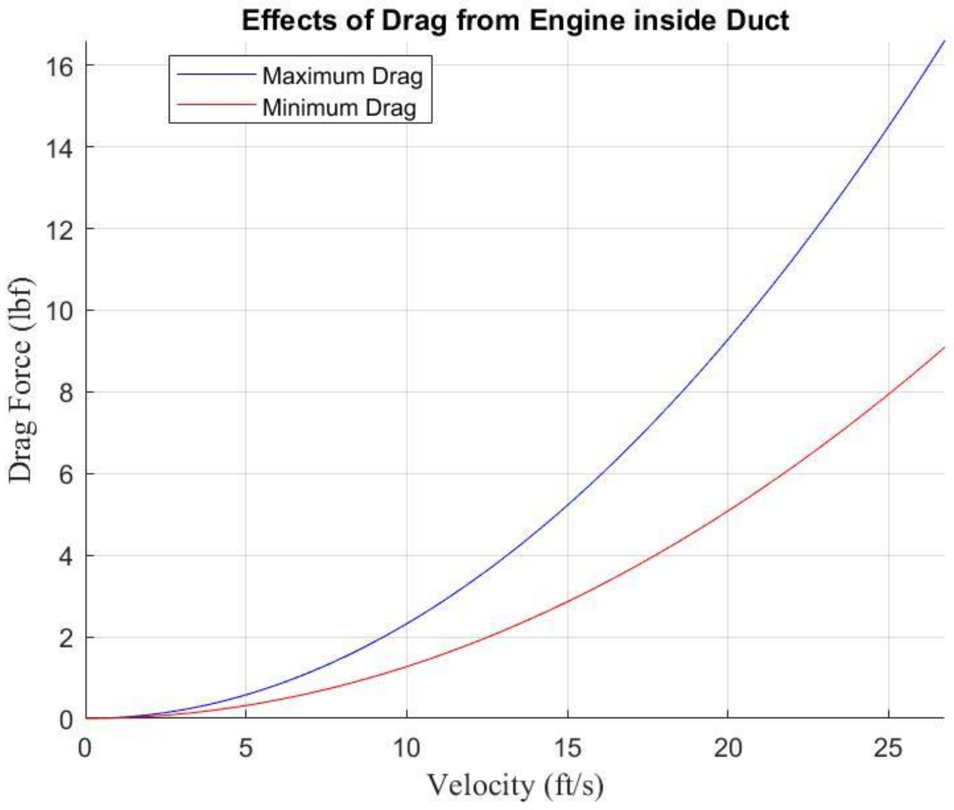


Considering 20 in. diameter propellers

Air velocity increases from nozzle effect

Theoretical thrust has an increase of 139.9%

Drag Forces due to Engine



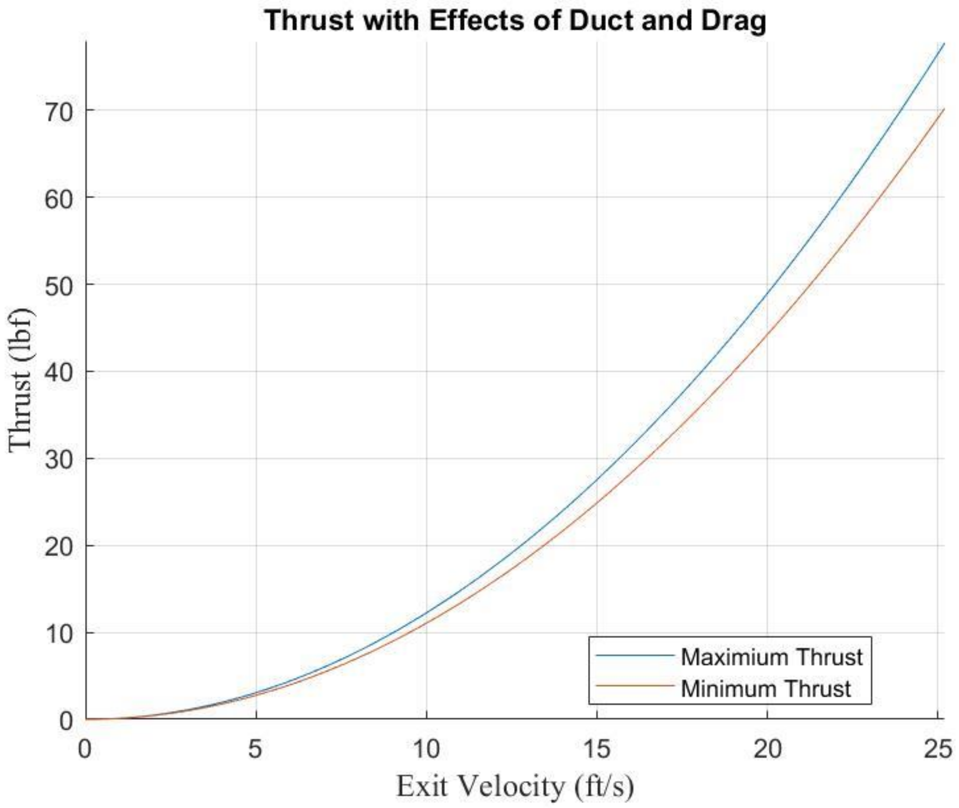
Drag Considerations:

- Engine assumed to be rectangular

Yet to Consider:

- Drag due to other components

Thrust with effects of Duct and Drag



Net Performance:

- Considers Effects of Duct and Drag due to Engine blockage
  - Max Thrust increase of 114%
  - Min Thrust increase of 94%

Power Consumption

Hardware	Power (Watts)	Voltage
ADIS 16500 (IMU)	1.98	3.6V
Kernel-100 (IMU)	0.37	5 V
AP 10.2 **(IMU)**	TBD	27 V
Ellipse-N (INS)	0.6	36 V
FLIR Hadron (Camera)	2.82	5 V

Weight & Cost Budget

Hardware	Weight (lb)	Cost
FLIR Hadron (Camera)	0.09	$3,249
7 Propellers	1.2	TBD
3 Wings	1.35	TBD
AP 10.2 (Control System Unit)	1.11	TBD
Gremsy T3V3 (Gimbal)	2.65	$1,749
Total	6.4	$4,998

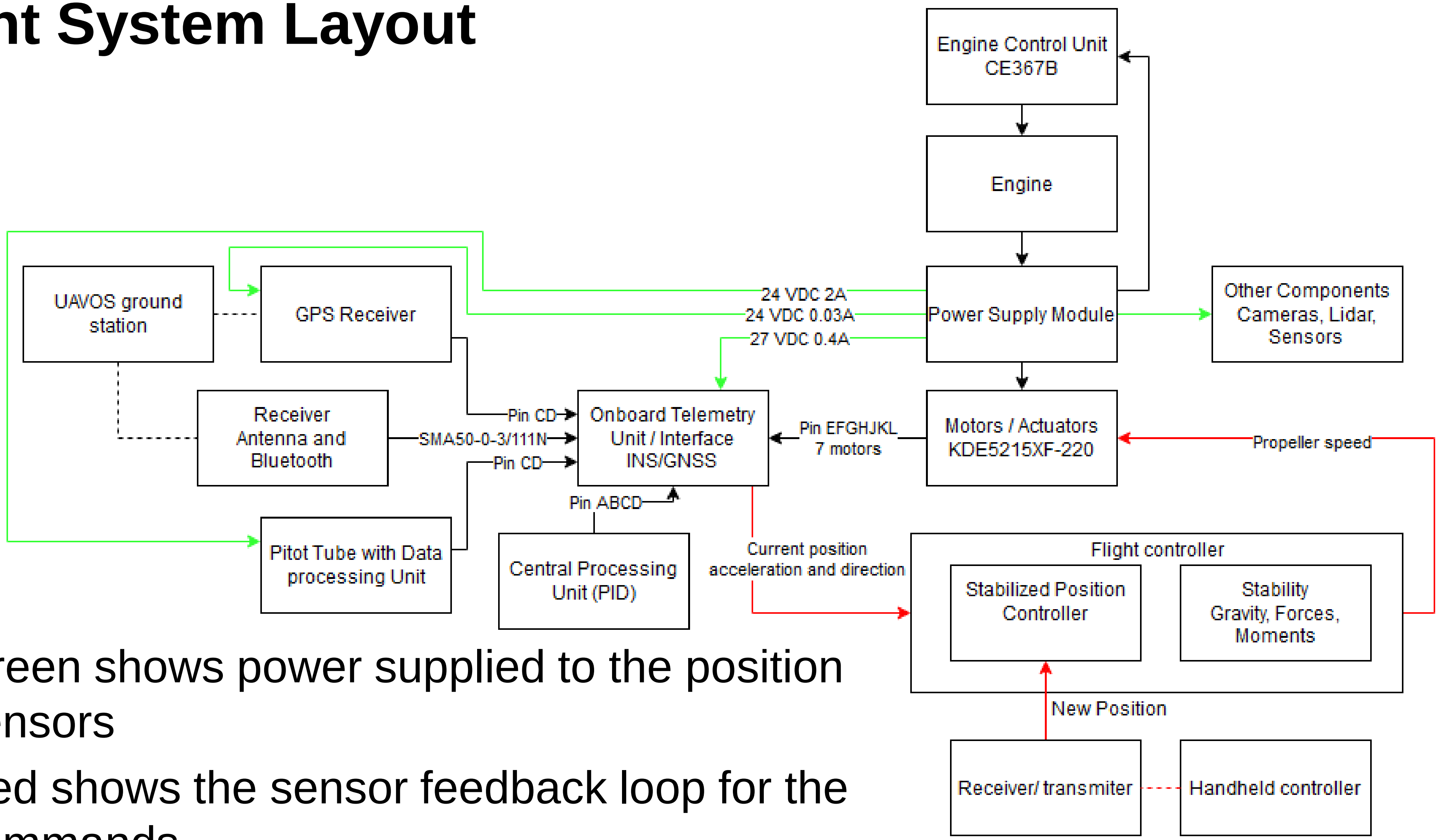
Vision Ground Control Unit

Figure 1: Vision Ground Control Unit

Features include…

- Antennas allow for UAV to fly in ranges up to 8 km
- Allows pilot to fully control UAV along with visual capabilities to intended destination
- Visual display showcases…
  - Altitude, location, UAV battery level
  - DoD (Department of Defense) Grade Security

Flight System Layout

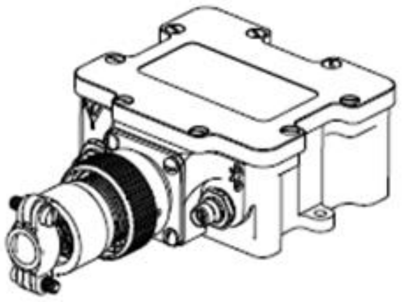


- Green shows power supplied to the position sensors
- Red shows the sensor feedback loop for the commands

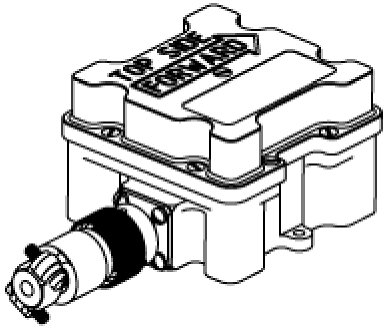
Position Sensor

- UAVOS AP 10.2
    - Telemetry system that has an integrated IMU, GPS, and Altimeter
    - 12 RPM sensor inputs
    - Controller area network
    - Connections to a ground station

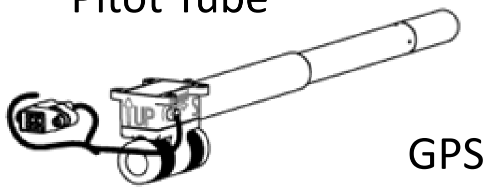
Telemetry Unit



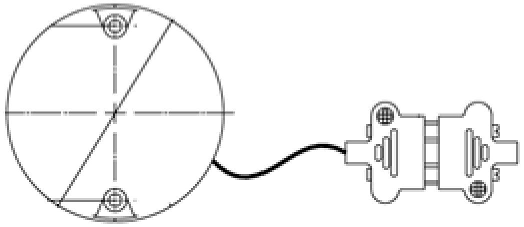
Central Processing Unit



Pitot Tube

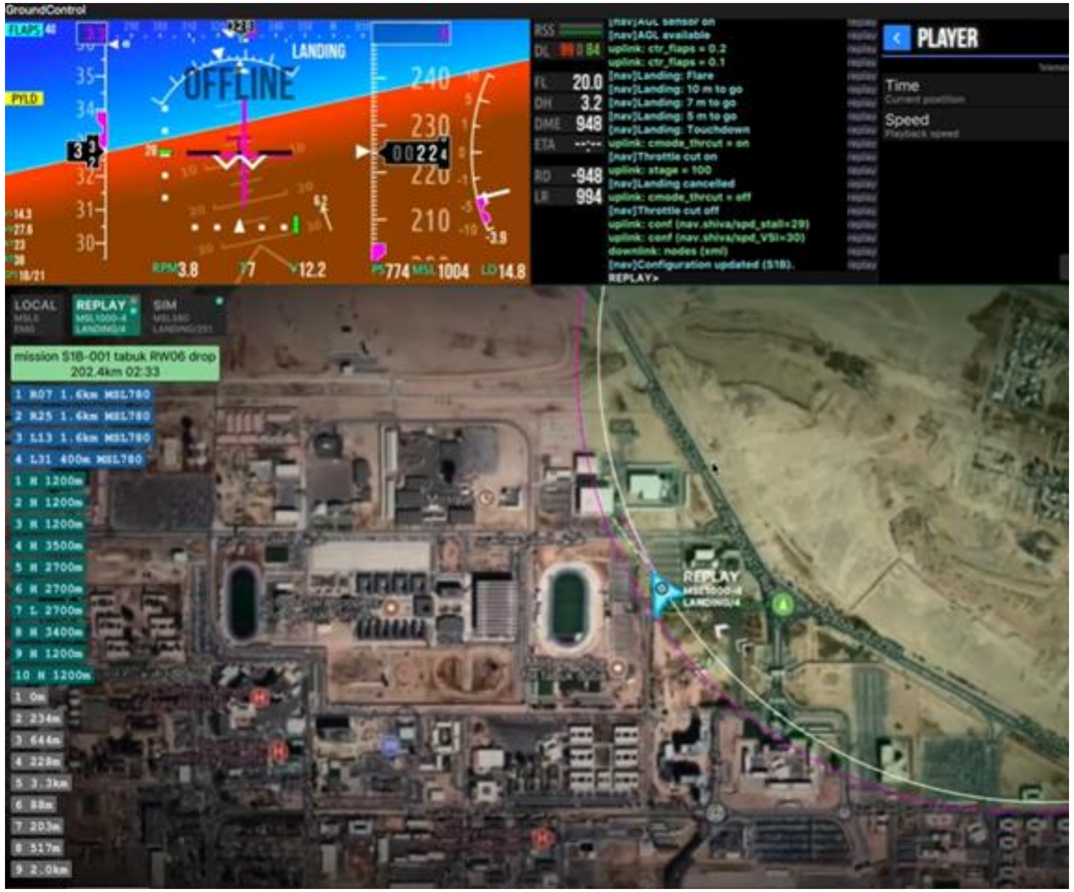


GPS Receiver



APX Ground Monitor

- Is an open-source program that receives data from the UAVOS telemetry unit
- Uses Google Earth to monitor current position and flight path
- Shows real time telemetry data
- Can be used to adjust flight path
- Capable of using data from a flight simulator



Methods

- The flight control sub-team utilized Simulink & MATLAB to create, model, and simulate our UAV control system architecture and flight performance.

- Performed trade studies to determine some of the key components and parameters that needed to be set in order to develop a model for the UAV.

- The knowledge gained was implemented into the Simulink model, and will demonstrate our simulations of hover and controlled flight.

Control System Variables

Variables and parameters we needed to determine for the flight control system include:

- Applied Forces, moments, and inertias.
- Desired and Input commands for : Thrust, Roll, Pitch, Yaw, Altitude.
- Mass of the UAV
- 7 Propellor Locations
- Pitch Angle

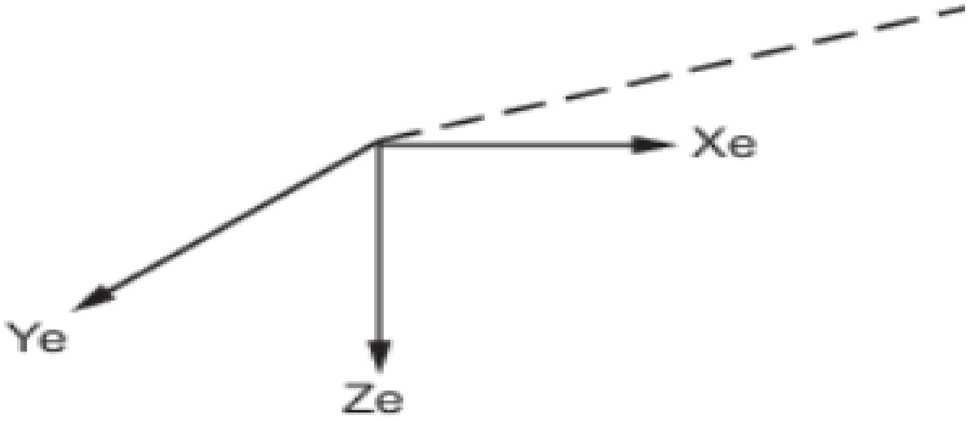
Measured Vehicle Variables

- Angular rates
- Angular Accelerations
- Accelerations in body-fixed axes
- Initial and Real time feedback Velocity
- Initial and Real time feedback Position
- Euler Rotation Angles (roll, pitch, yaw)

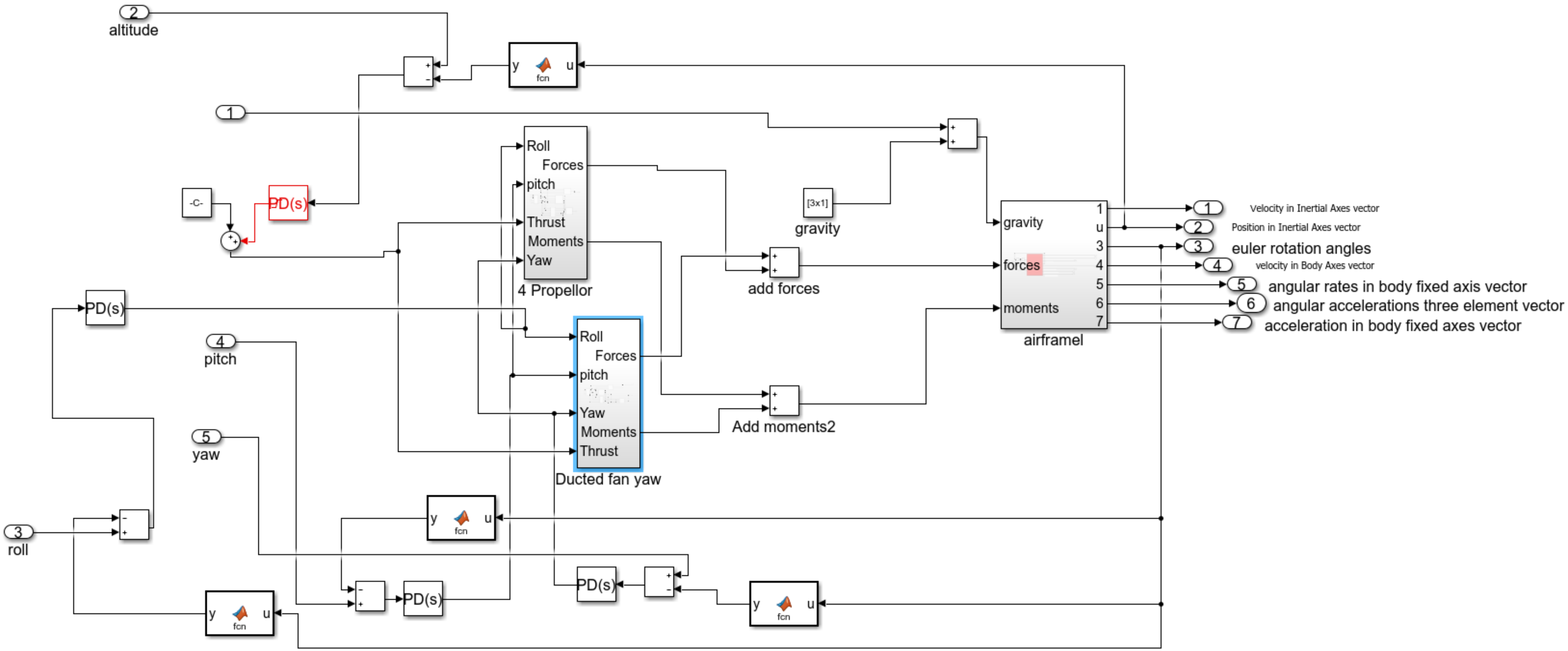
UAV Reference Coordinate System

- The coordinate system of the Control model follows the following convention:

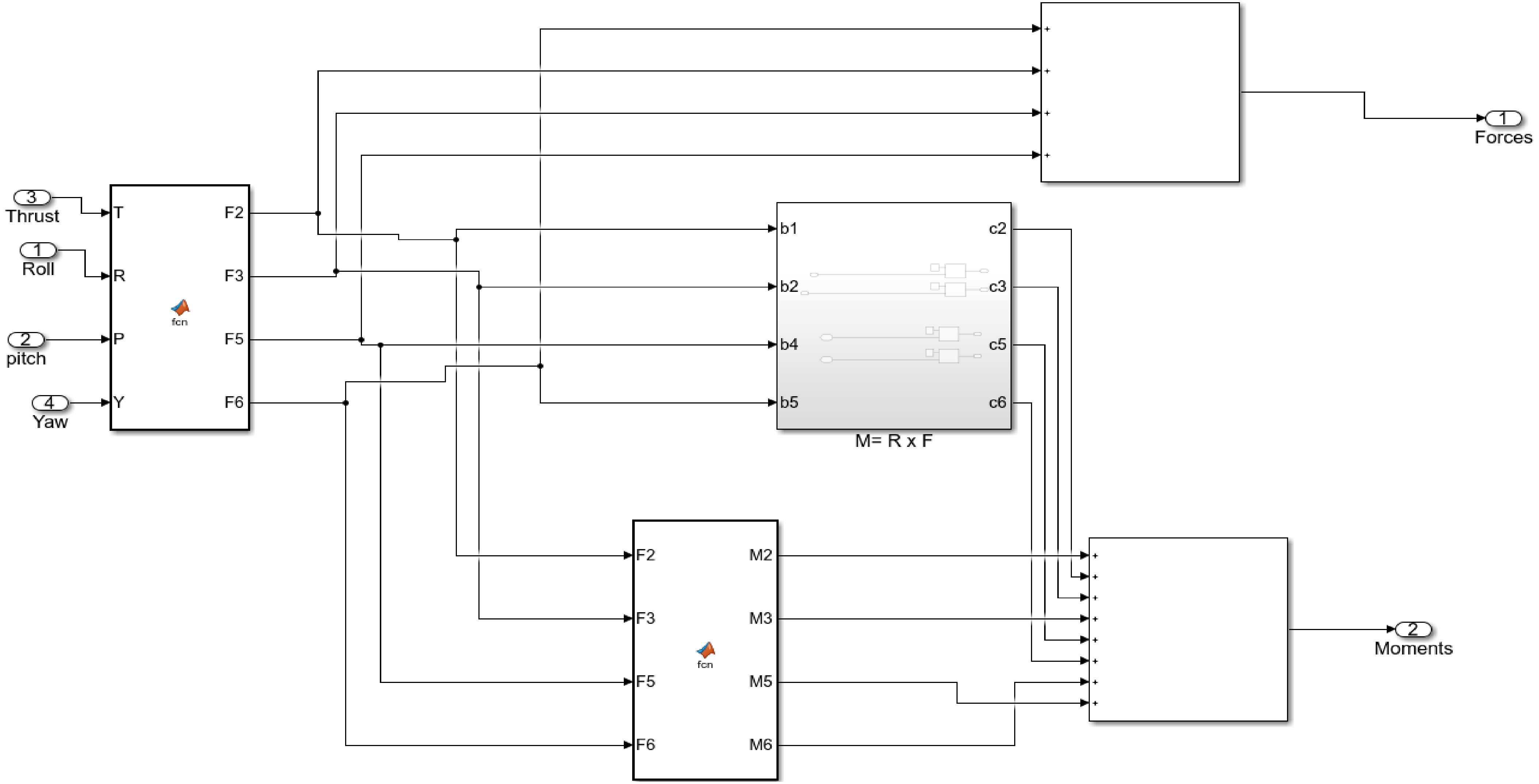
- -Z on the coordinate system is represented as +Z
- So forces in the –Z direction are forces driving the body up.
- Forces in the +Z direction are driving the body down



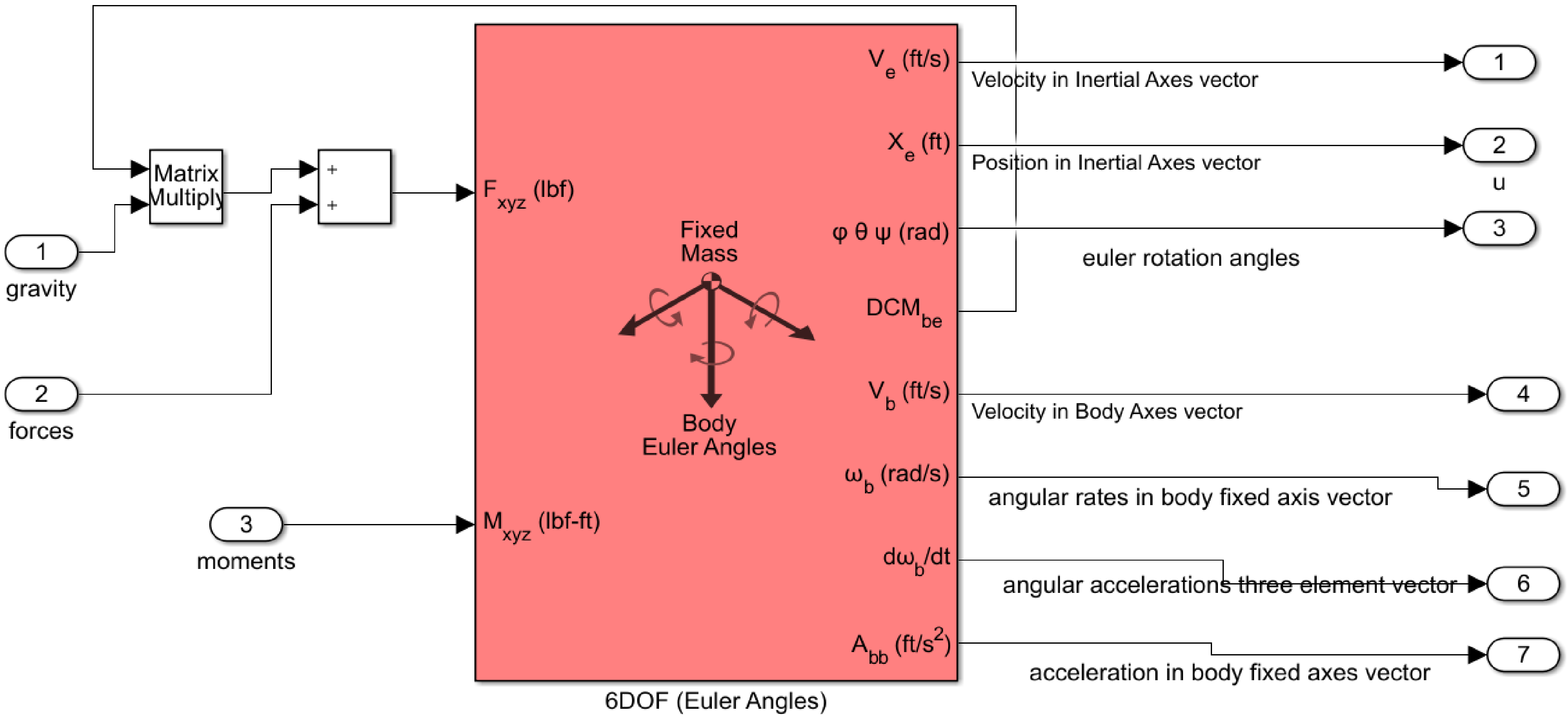
Hover Altitude Control Model



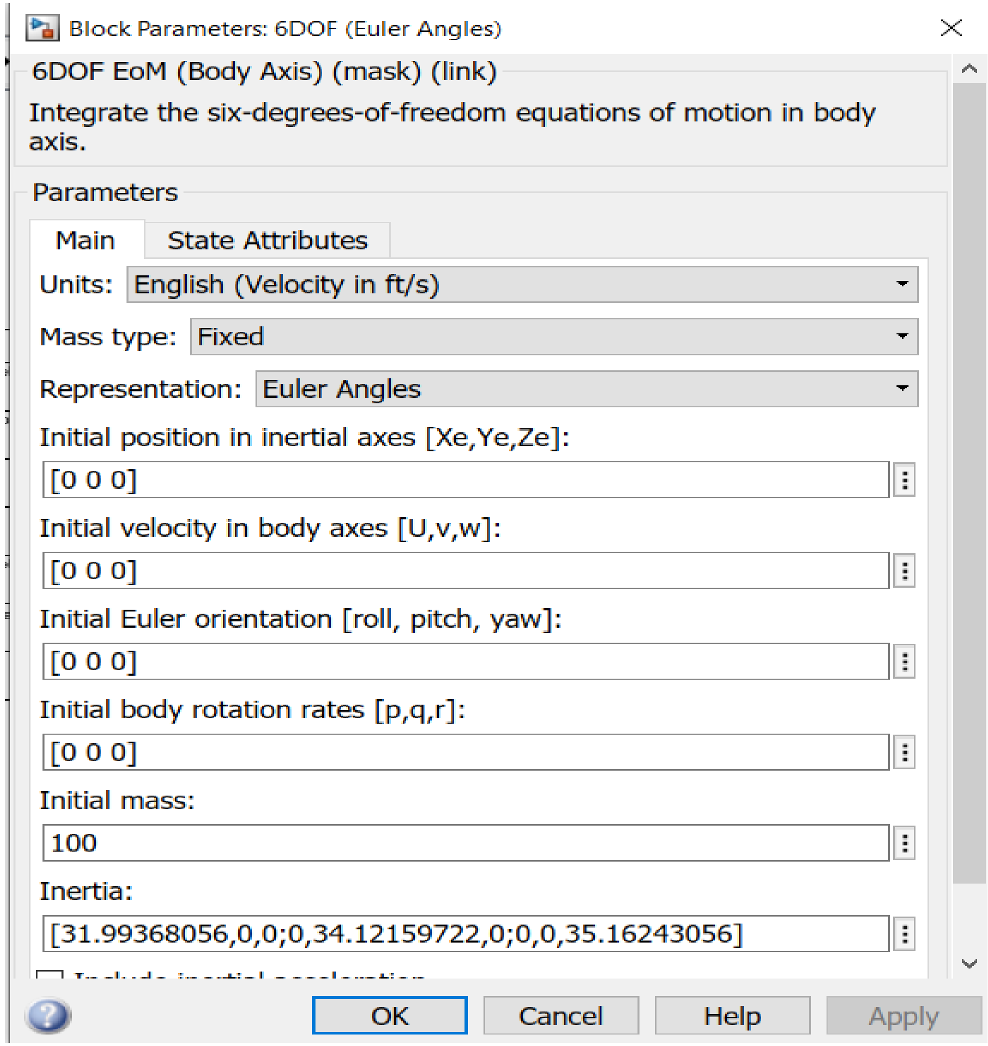
Forces and Moments



UAV Airframe to Model 6DOF

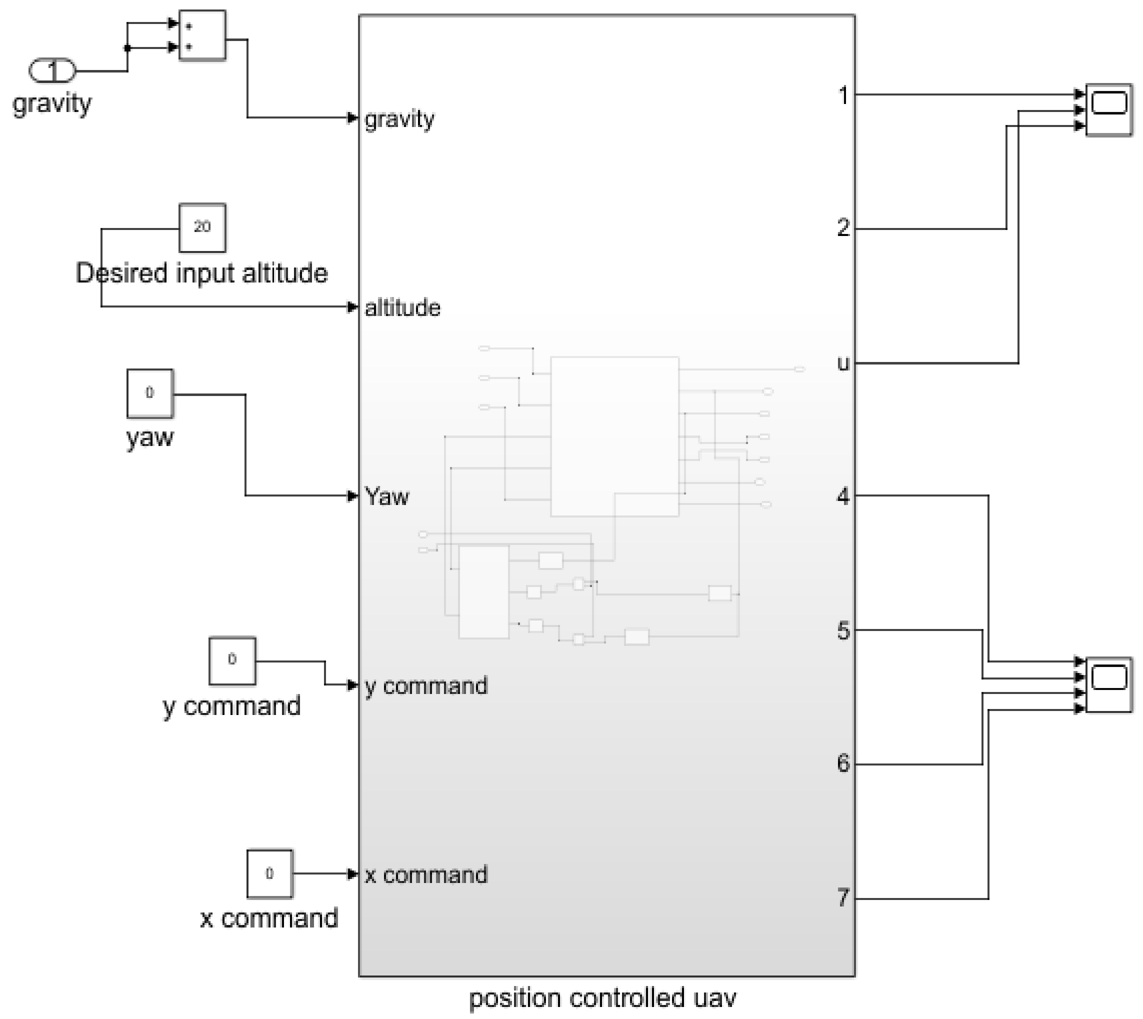


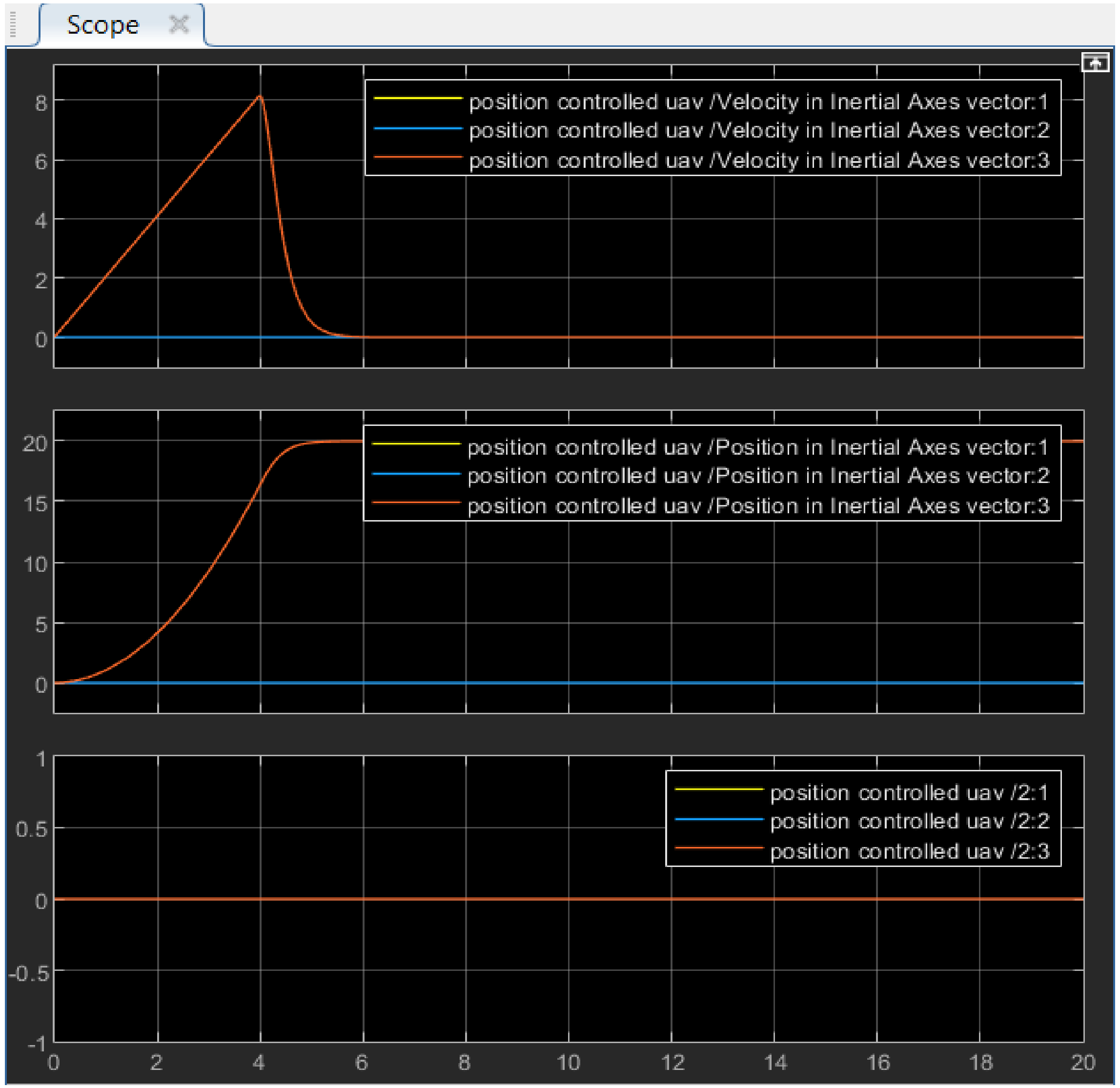
Airframe parameters and Propellor Locations



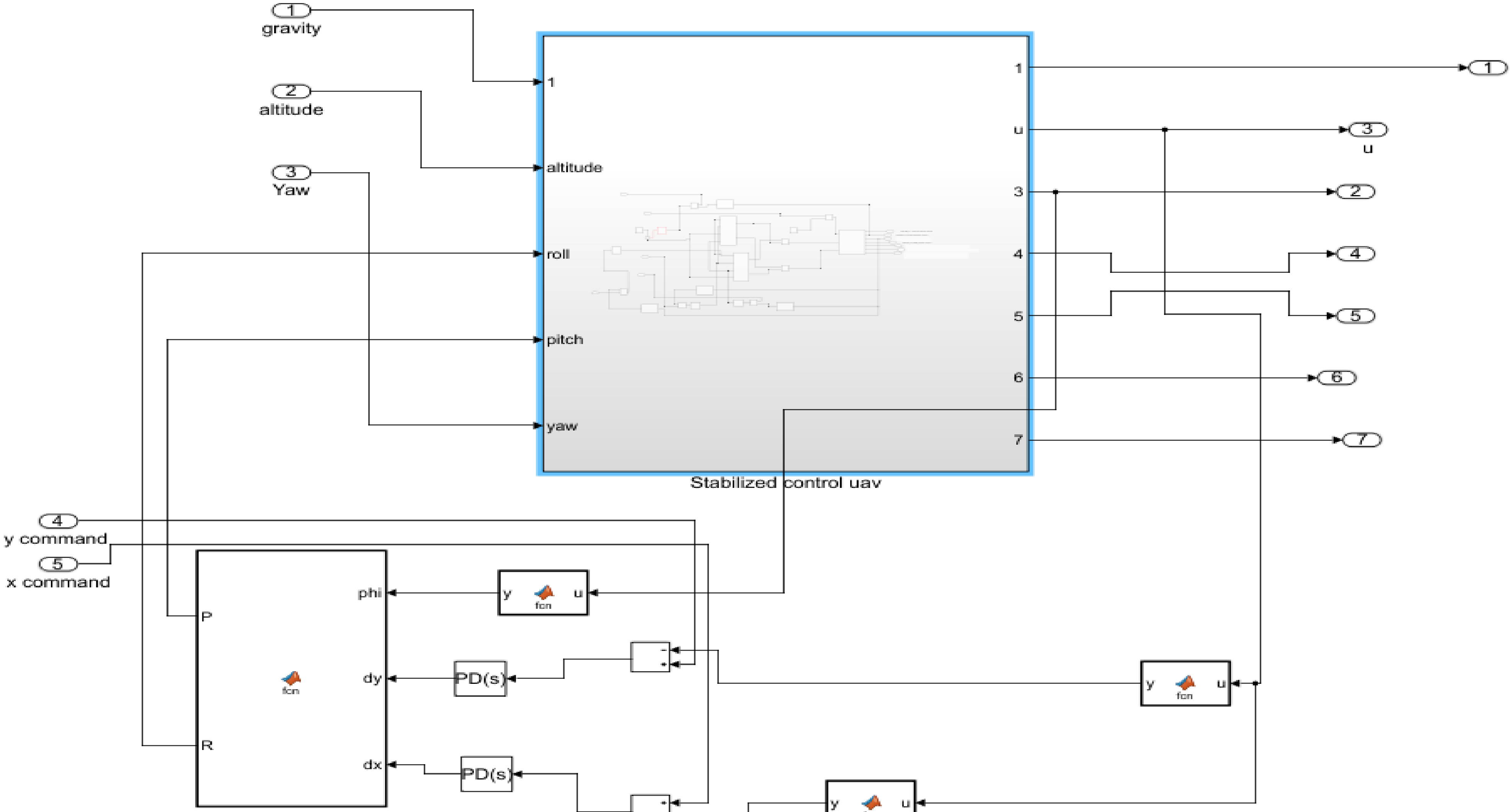
Propellor #	X position(Ft)	Y position(Ft)	Z position(Ft)
1	2.3467	0.0042	-0.8783
2	1.1725	-2.0292	-0.8783
3	-1.1758	-2.0292	-0.8783
4	-2.3467	0.0042	-0.8783
5	-1.1758	2.0375	-0.8783
6	1.1725	2.0375	-0.8783
Ducted Fan	-0.0017	0.0042	-0.4283

Hover Simulation Tuned Response

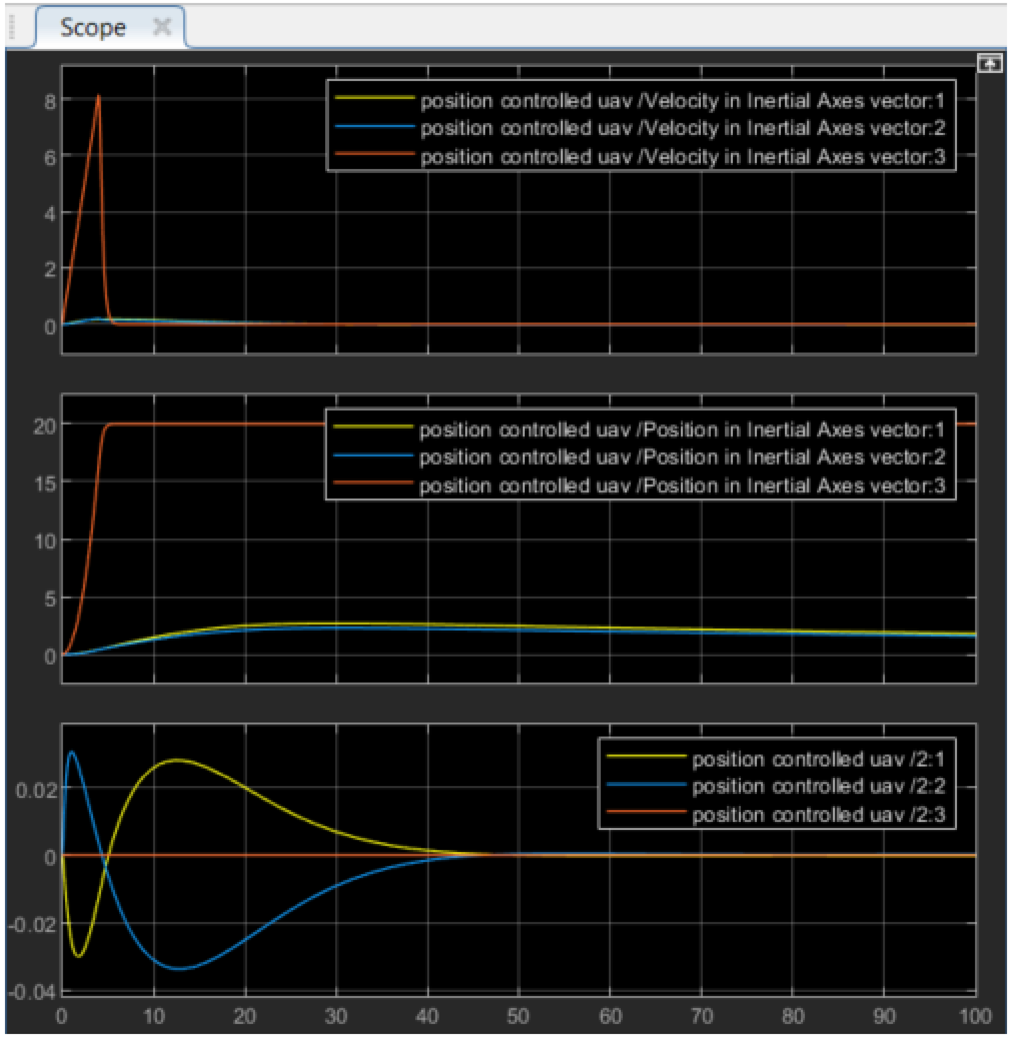


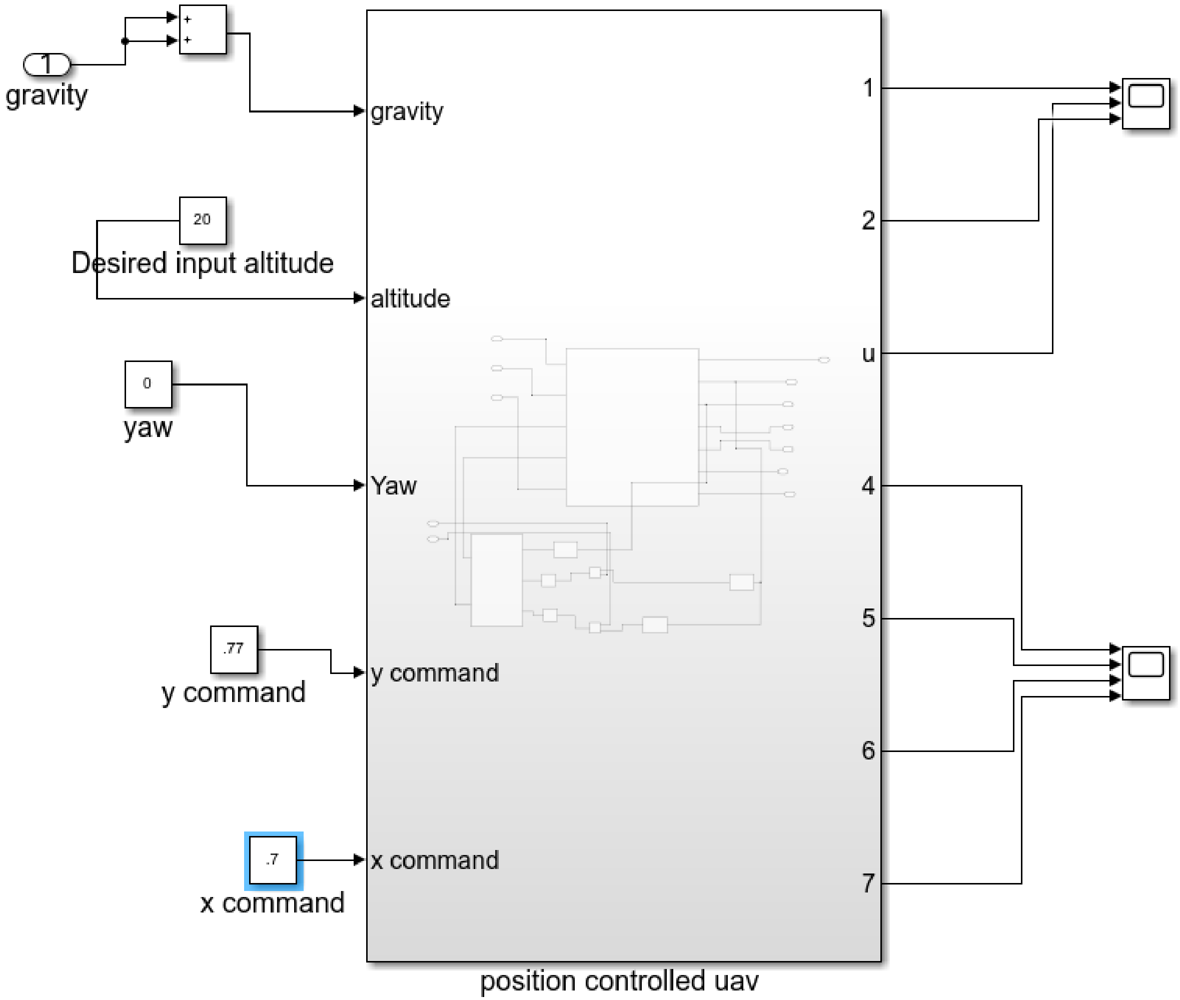


Stabilized Position Control



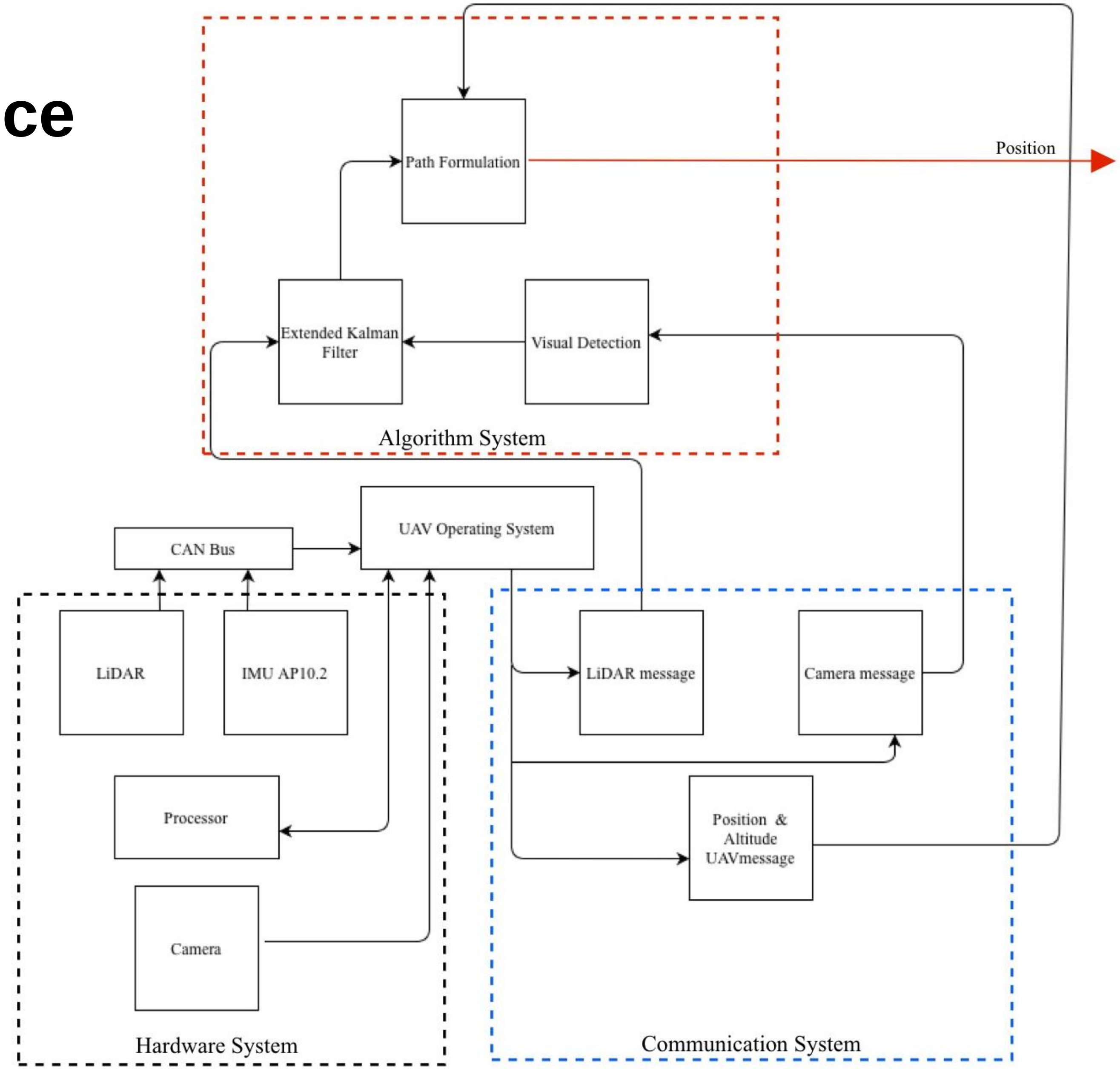
Stabilized Flight Tuned Simulation Response





Collision Avoidance Process

- Hardware System
  - Senses
- Communication System
  - Perceives
- Algorithm System
  - Plans



Summary

- A UAV with a 20-inch central propeller with wings, with a span of 12 inches, and six 24.5-inch propellers was designed, and an aerodynamic analysis was performed on the wings and central ducted fan using MATLAB.
- The current control components are the AP 10.2 telemetry Unit and the FLIR Hadron camera.
- A Simulink Control Model for the design was created, tested through simulation which showed stable and controlled hover/flight stages.
- A collision avoidance process was designed to show the process of an obstacle crossing the UAV's intended path.

Rendering courtesy of Structure-Design sub-team