Final Report

Honeywell Navigation Challenge

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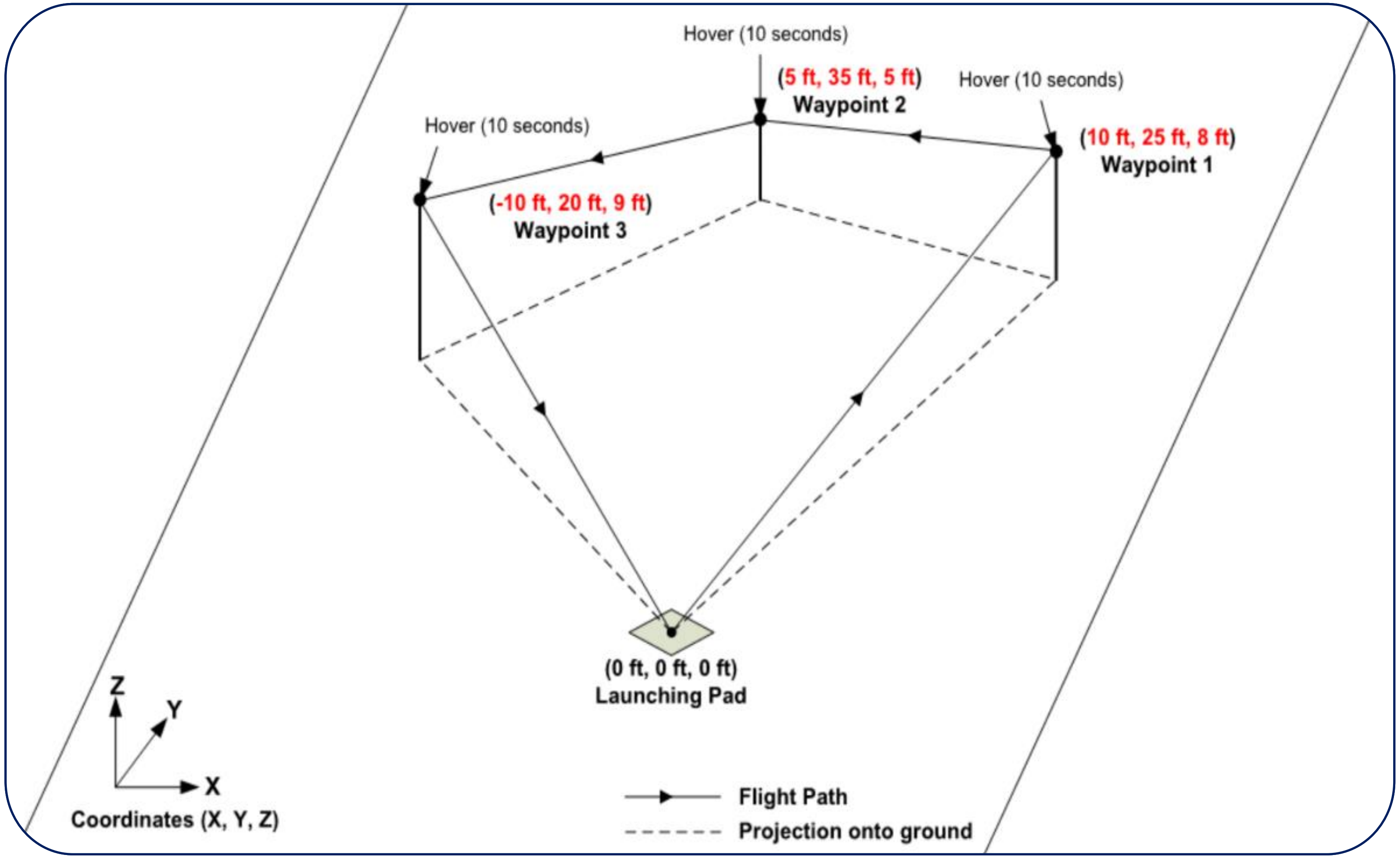
Agenda

- Introduction
- Problem Statement
- UAV Definition
- UAV Design
- Results and final design
- Conclusions

Introduction

- **1906**: Honeywell was founded
- Multinational company dedicated to:
  - Design, develop, and manufacture commercial and consumer products
  - Offer engineering services
- Has various sub-divisions → Honeywell Aerospace
- This sub-division designed the HGuideN580 navigator
- From this design, the Annual Honeywell Navigation Challenge was born in 2018

Problem Statement



- Multidisciplinary project
- Integrate HGuideN580
- Build from scratch
- Design control system through MATLAB/Simulink

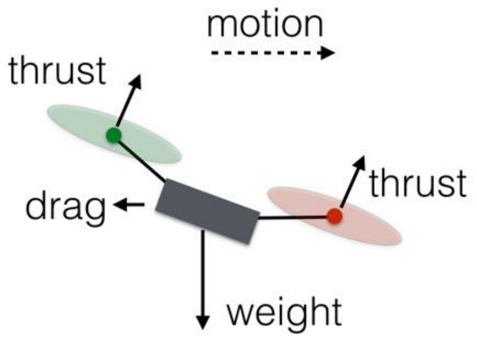
UAV Concepts

What is a UAV?

- A UAV or drone can be defined as an aircraft that does not carry a human pilot or passenger and is fully or partially autonomous
- UAS = UAV + Ground Control Station + Communication Unit

How are they designed?

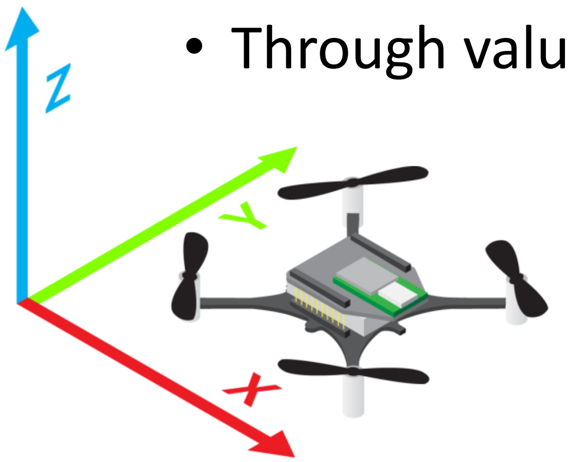
- Design process varies according to desired autonomy
- **Basic factors to be taken into consideration**:
  - Weight
  - Drag
  - Thrust

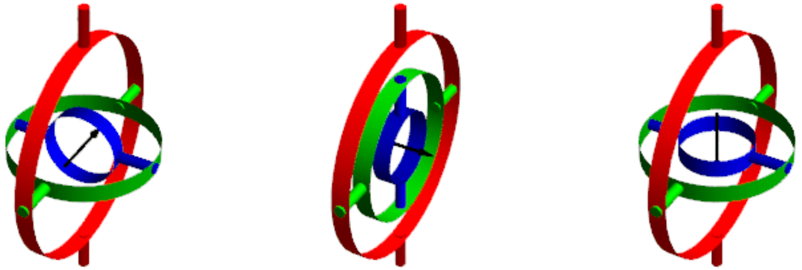


- **Mechanical components**: frame and propellers
- **Electrical components**: motors, electronic speed controllers (ESCs), battery, flight controller, and sensors

How do they work?

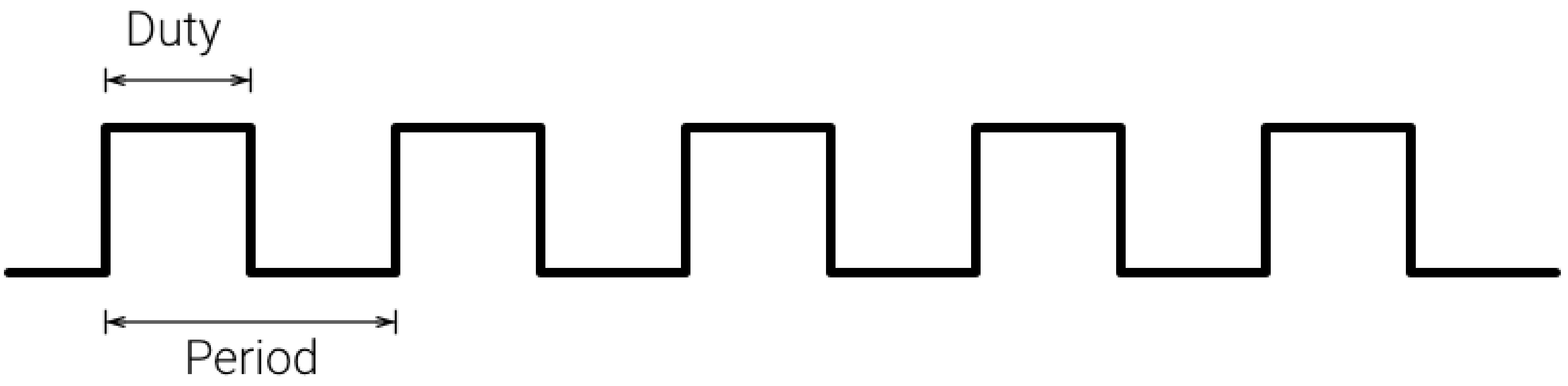
- UAVs mainly due to their flight controllers which are designed to assist UAV flight
- Need information from the user to function (desired state)
- Two ways to receive desired position:
  - Through values for throttle, roll, pitch, and yaw (manual mode)
  - Through values for X, Y, and Z (autonomous mode)





How do they work?

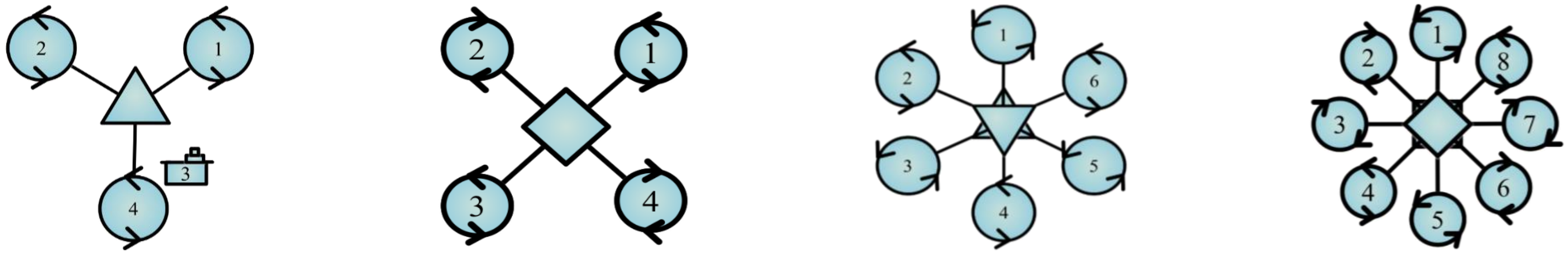
- According to the desired state, the flight controller will estimate its current state from the data given by the navigator and calculate the error
- Through this error, it will determine the necessary pulse width modulation (PWM) signals to send to each of ESC in order to achieve the desired state since the ESCs control the revolutions per minute of the UAV’s motors.



UAV Design

Multirotor technology

- Any rotorcraft containing more than two rotors
- Generally implemented in the design of radio-controlled aircraft and UAVs.
- **Most common**: tricopter, quadcopter, hexacopter, and octocopter.



- No such thing as the best motor configuration.
- Motor configuration is selected according to the aircraft's needs.
- **Number of used motors ↑, Aircraft's lift capacity and redundancy ↑, Aircraft's power efficiency ↓**

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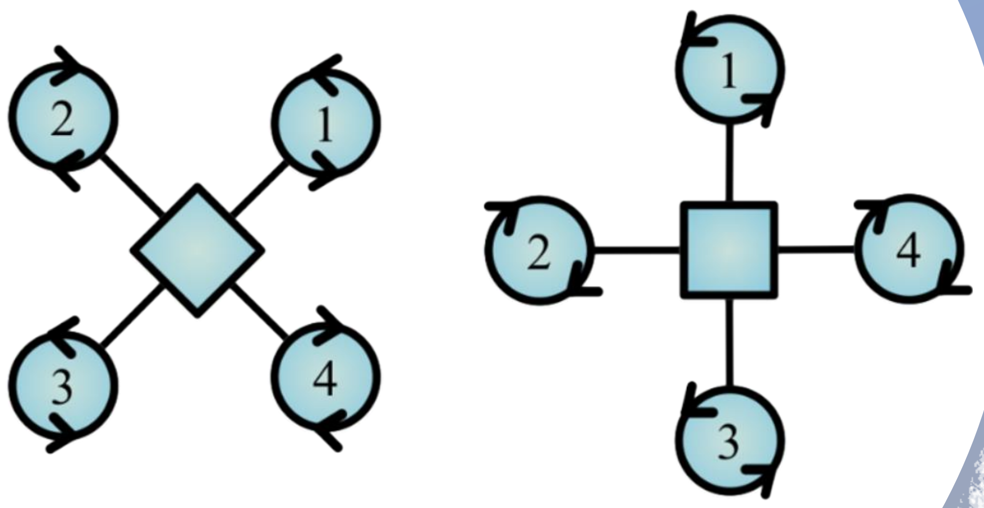
Selected Multirotor: Quadcopter

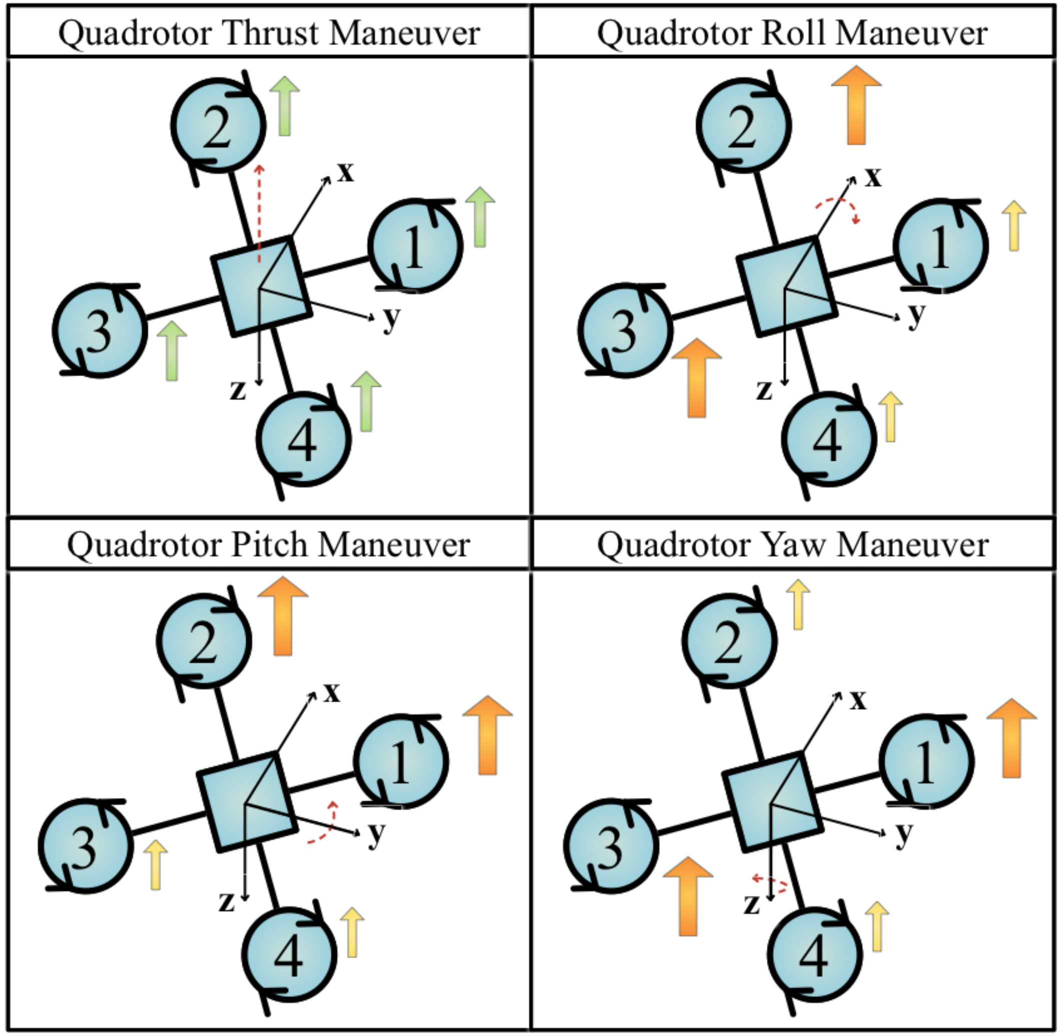
- This type of multirotor is mechanically simple
- Most popular type of multirotor among UAV designers and enthusiasts
- Thus, a greater amount of references may be obtained for our design



Quadcopter Configuration

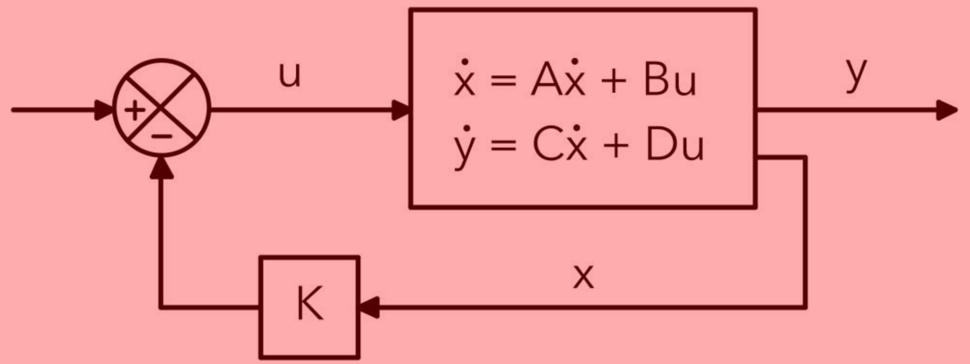
- The quadcopter has two types of configurations: cross-style and plus-style
- **Plus-style**: changes the aircraft’s attitude by varying the speed of two of its motors
- **Cross-style**: changes the aircraft’s attitude by varying the speed of all its motors
- The cross-style has improved maneuverability over the plus-style configuration

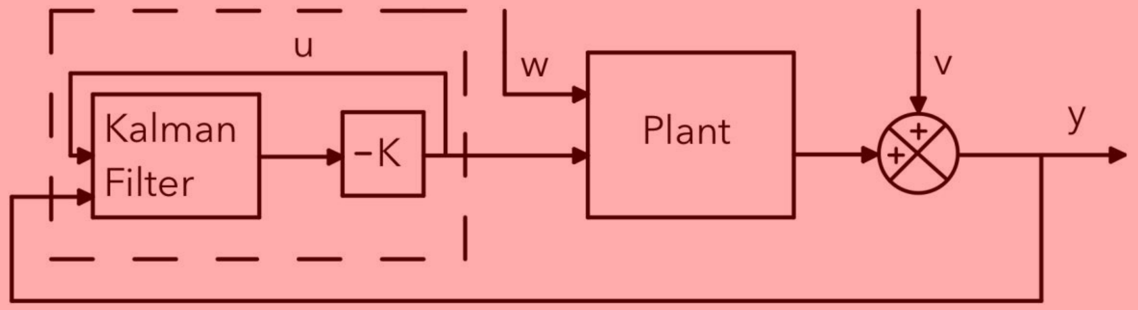
Selected Configuration: Cross-style

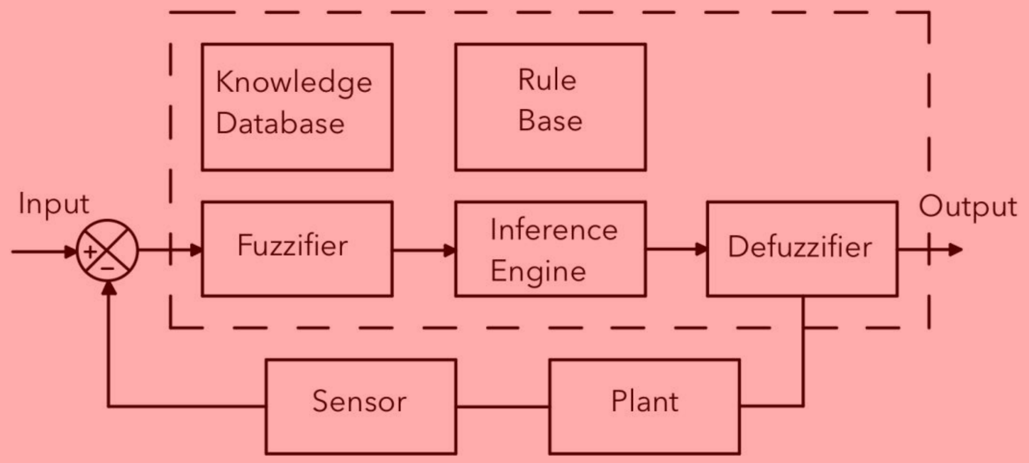


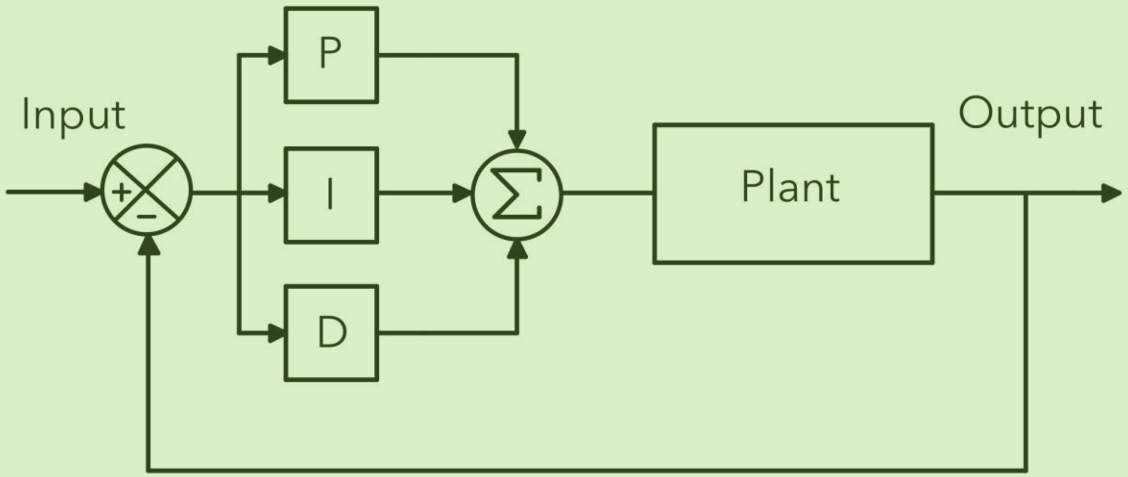
Quadrotor Flight Control Design

Control Techniques









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Quadrotor Flight Control Design

Modeling Technique

- To design the control system for a quadcopter one must be able to properly model the quadcopter.
- There are two ways in which one may pursue the modeling phase:
  - Find the model of a single brushless motor and evaluate the step response of the each PID controller (roll, pitch, and yaw) for a set of brushless motors.
  - Find the model of the complete quadcopter by taking into consideration both motor and rigid body dynamics.

Quadrotor Flight Control Design

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Finding non-linear model of the quadcopter

- Underactuated system (4 motors and 6DOF)
- Directions quadcopter movement divided into 2
- **Translational directions**: up/down, left/right, forward/backward
- **Rotational directions**: roll, pitch, yaw.
- Rotation and thrust is then coupled to accomplish the goal of control over a quadcopter’s movement.

Non-linear model of the quadcopter

$$\begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{z}\end{bmatrix} = \begin{bmatrix}\cos\theta\cos\psi & \cos\psi\sin\theta\sin\phi - \sin\psi\cos\phi & \cos\psi\sin\theta\sin\phi + \sin\psi\cos\phi\\ \sin\psi\cos\theta & \sin\psi\sin\theta\sin\phi + \cos\psi\cos\phi & \sin\psi\sin\theta\cos\phi - \cos\psi\sin\phi\\ -\sin\psi & \cos\theta\sin\phi & \cos\theta\cos\phi\end{bmatrix}\begin{bmatrix}u\\ v\\ w\end{bmatrix}$$

$$\begin{bmatrix}\dot{u}\\ \dot{v}\\ \dot{w}\end{bmatrix} = \begin{bmatrix}rv - qw\\ pw - ru\\ qu - pv\end{bmatrix} + \begin{bmatrix}-g\sin\theta\\ g\cos\theta\sin\phi\\ g\cos\theta\cos\phi\end{bmatrix} + \frac{1}{m}\begin{bmatrix}0\\ 0\\ -F^b\end{bmatrix}$$

$$\begin{bmatrix}\dot{\phi}\\ \dot{\theta}\\ \dot{\psi}\end{bmatrix} = \begin{bmatrix}1 & \sin\phi\tan\theta & \cos\phi\tan\theta\\ 0 & \cos\phi & -\sin\phi\\ 0 & \dfrac{\sin\phi}{\cos\theta} & \dfrac{\cos\phi}{\cos\theta}\end{bmatrix}\begin{bmatrix}p\\ q\\ r\end{bmatrix}$$

$$\begin{bmatrix}\dot{p}\\ \dot{q}\\ \dot{r}\end{bmatrix} = \begin{bmatrix}\dfrac{J_{yy} - J_{zz}}{J_{xx}} qr\\ \dfrac{J_{zz} - J_{xx}}{J_{yy}} pr\\ \dfrac{J_{xx} - J_{yy}}{J_{zz}} pq\end{bmatrix} + \begin{bmatrix}\dfrac{1}{J_{xx}}\tau\phi\\ \dfrac{1}{J_{yy}}\tau\theta\\ \dfrac{1}{J_{zz}}\tau\psi\end{bmatrix}$$

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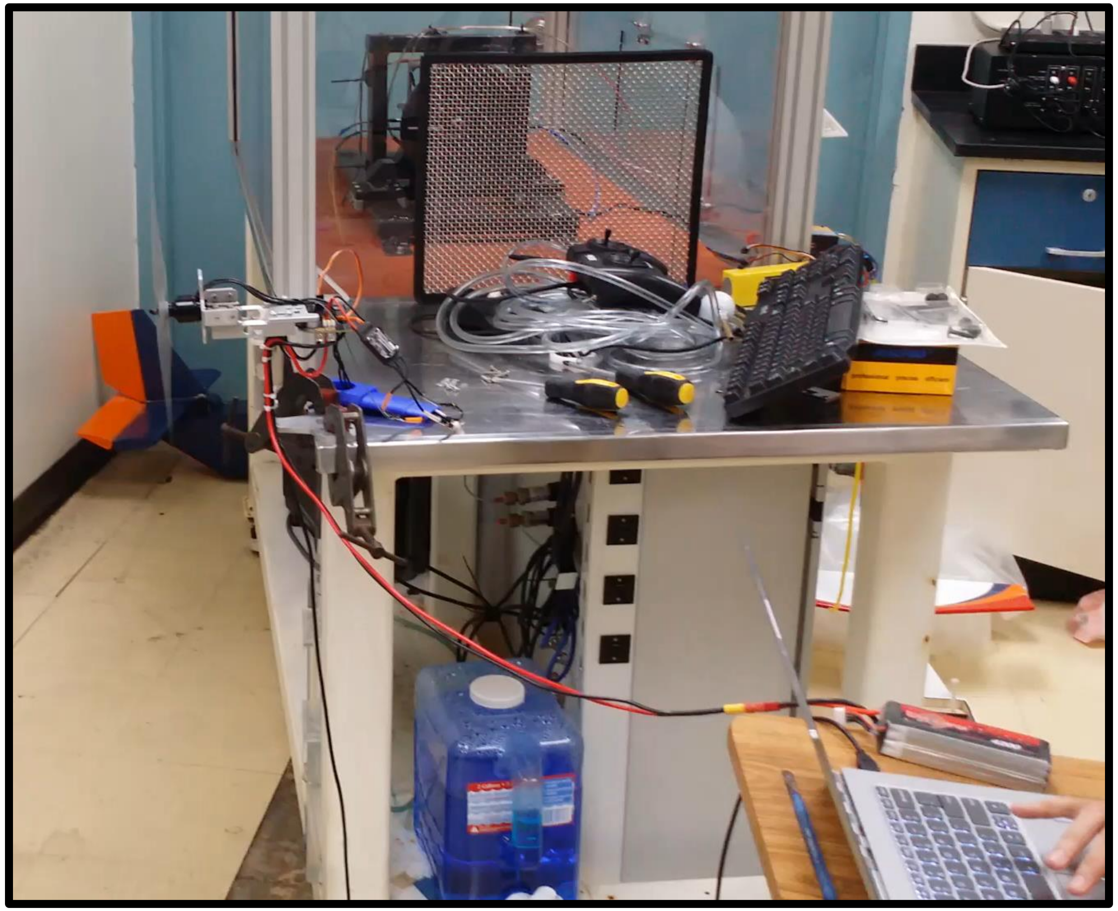
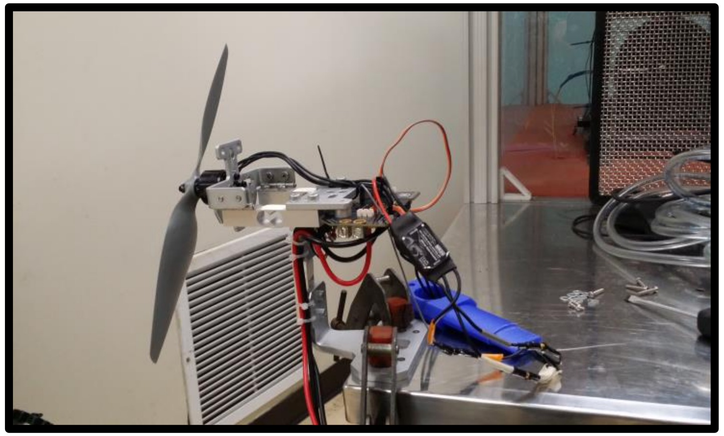
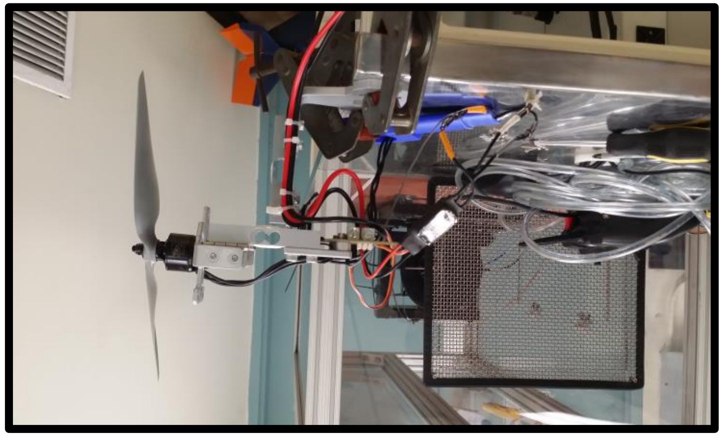
Testing Phase

Dynamometer







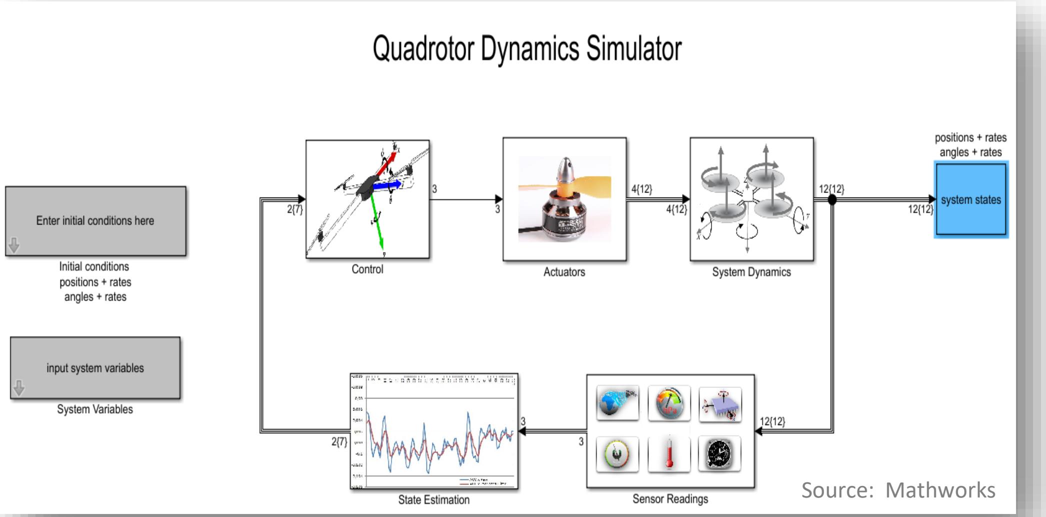
Testing Phase

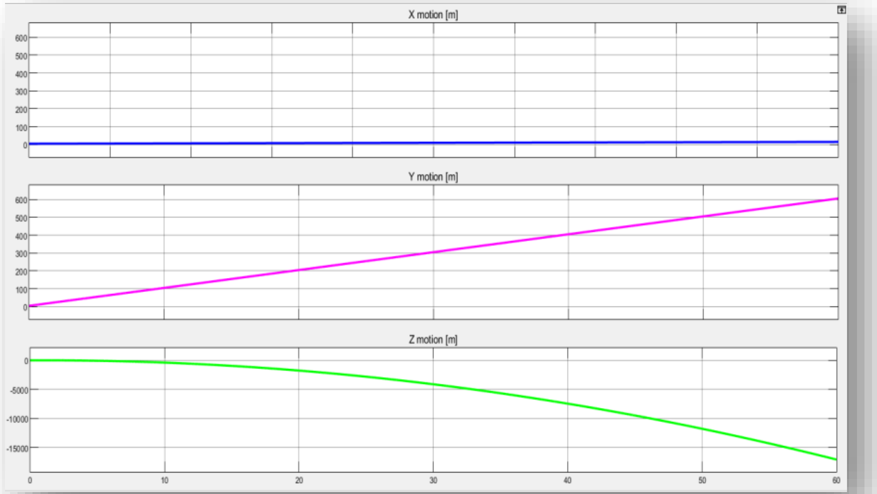
Dynamometer

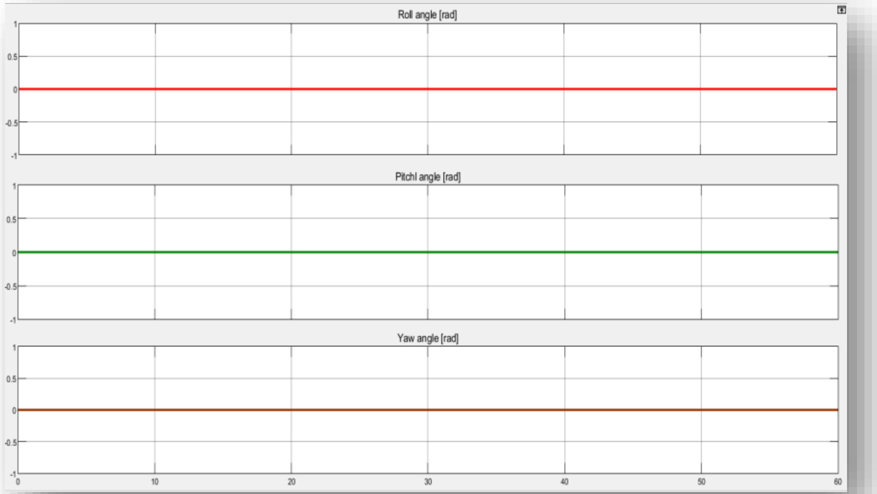
Thrust coefficient (C_t)	Power coefficient (C_p)
0.102	0.0449
Thrust factor (b)	**Drag factor (d)**
1.9366×10^{-5}	3.7909×10^{-7}

Testing Phase

Simulink models

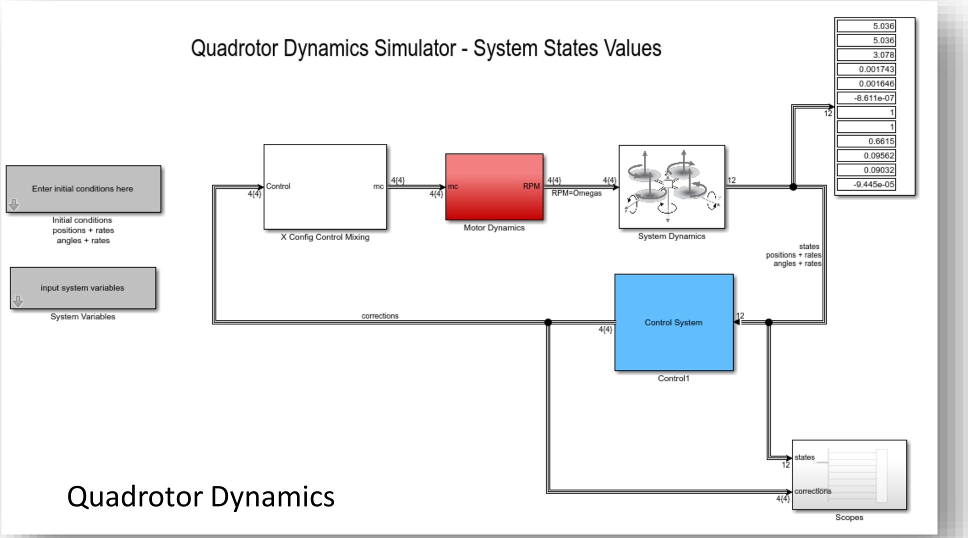


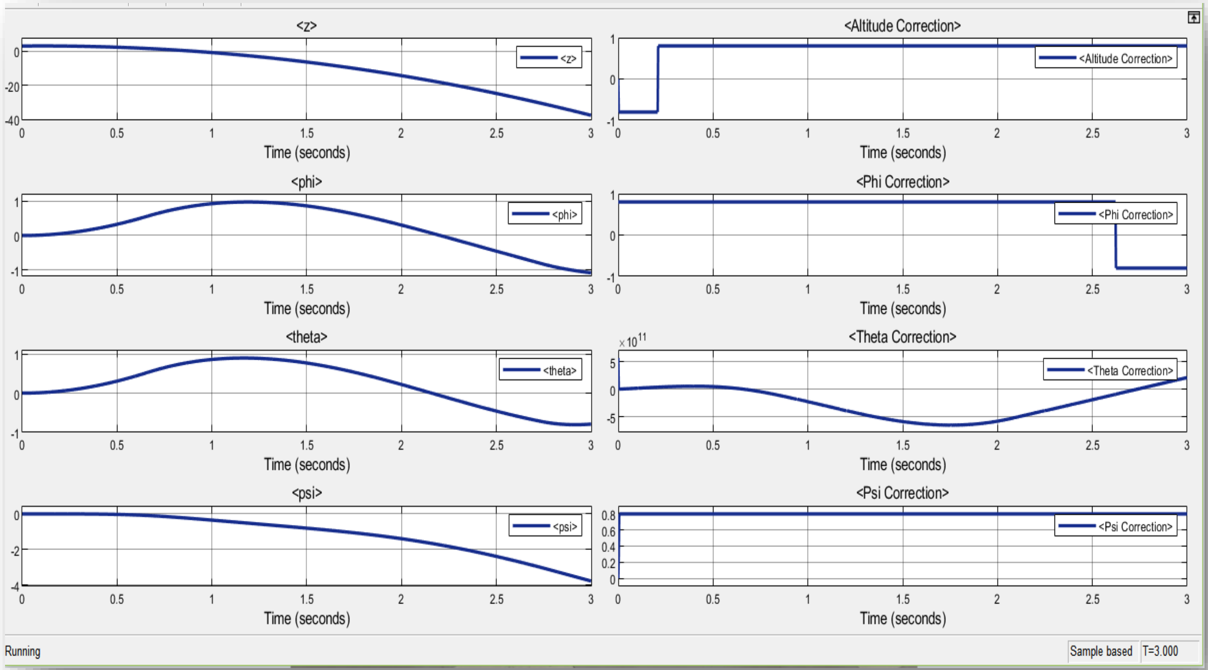




Testing Phase

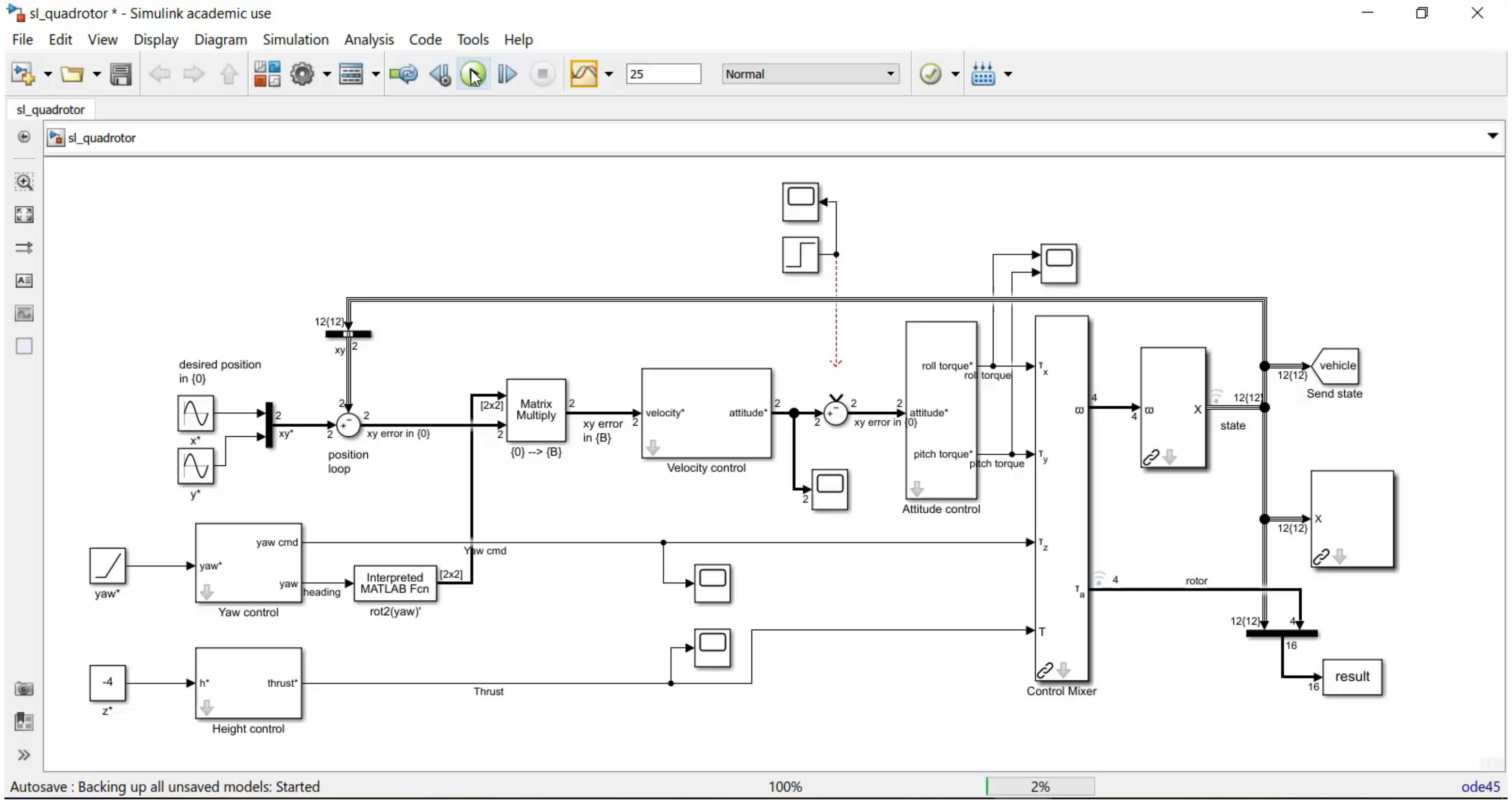
Simulink models

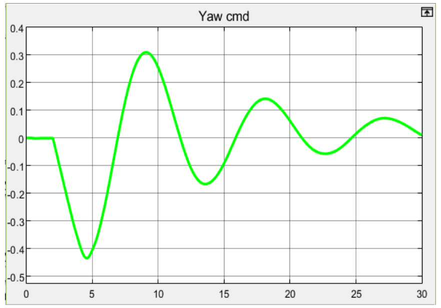


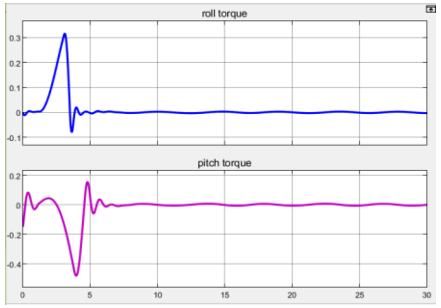


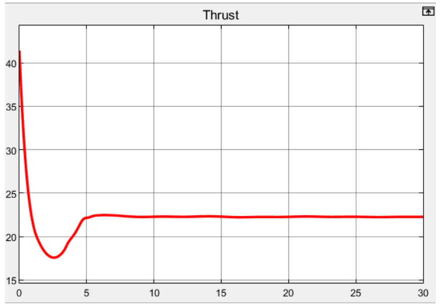
Testing Phase

Simulink models





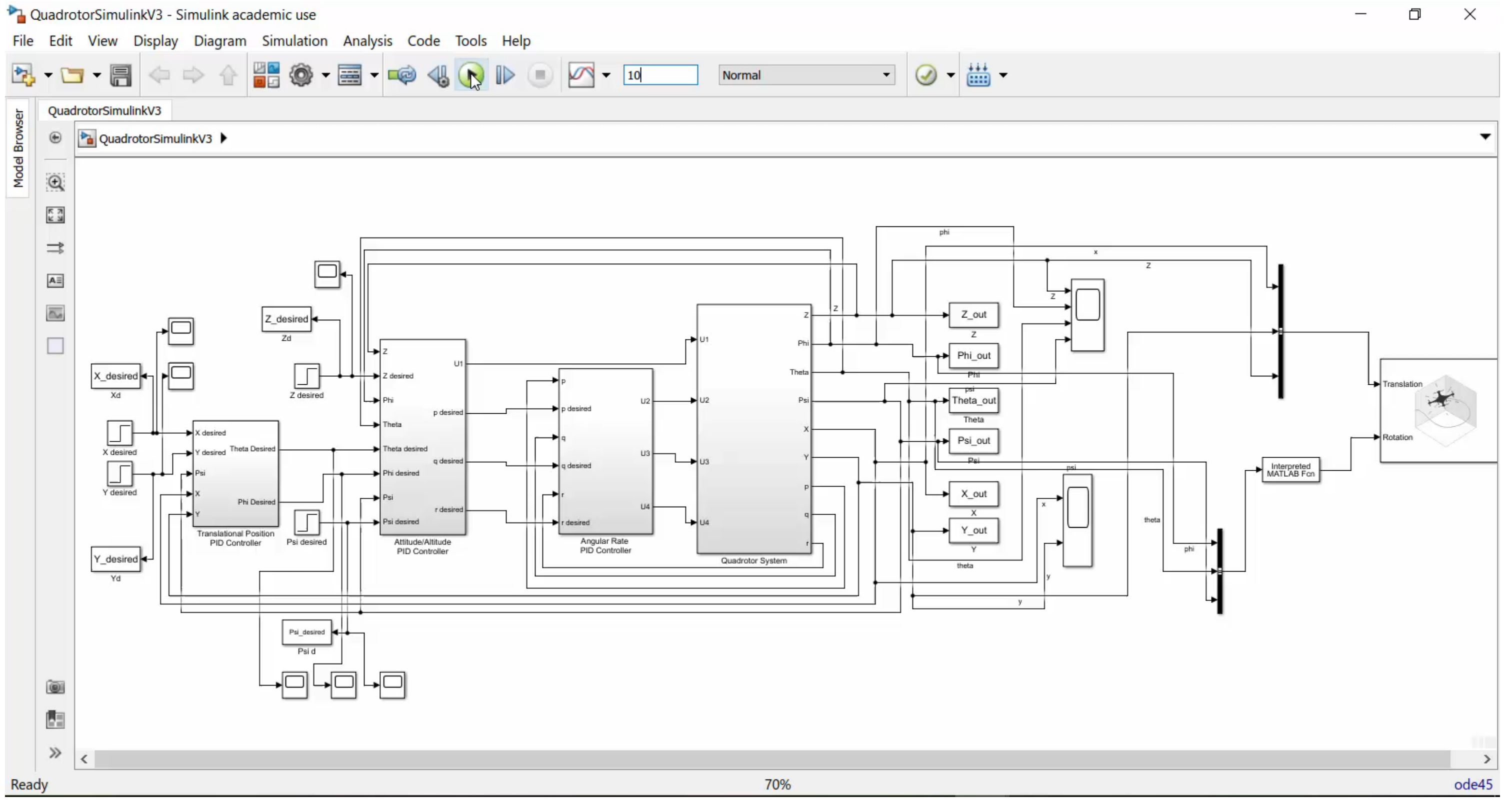




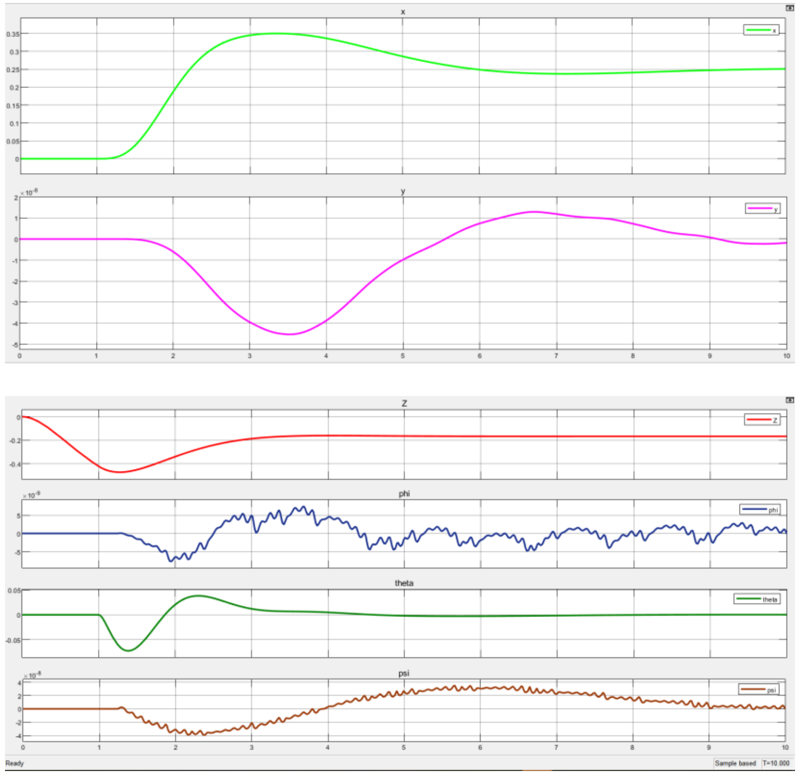
Source: P. Corke

Testing Phase

Simulink models



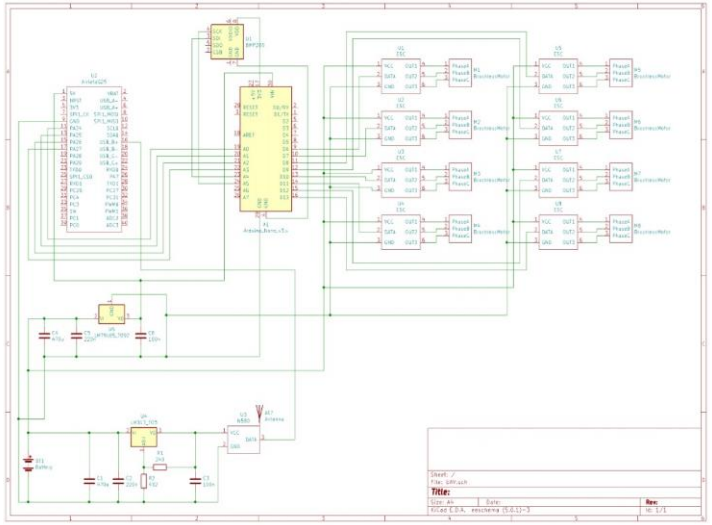
QuadrotorSimulink



Source: W. Selby

Quadcopter Components

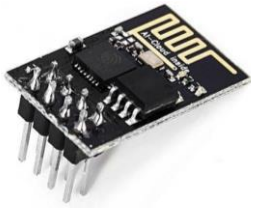
Selection #1

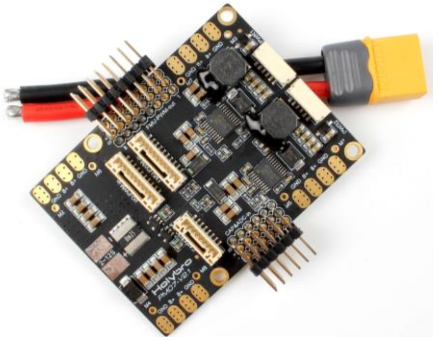


- Quadcopter control board: Arduino Nano + Arrieta G25
- Sensors and additional peripherals:
  - HGuideN580
  - GPS antenna
- Remote control and receiver: Futaba 6J 6-Channel w/S-FHSS Receiver
- Motors: Cobra CM-2216/23 950KV
- Electronic speed controllers: Cobra 20A Multirotor ESC
- Propellers: APC 11x4.5 MR
- Battery: 4S/14.8V/4200mAh/35C LiPo Battery
- Power management board: Substituted by configuration of LM317 voltage regulators, capacitors, and resistors

Selection #2

- Quadcopter control board: **Cube flight controller**
- Sensors and additional peripherals:
  - **Here+ RTK GPS**
  - **Wi-Fi Telemetry Module**
- Remote control and receiver: Futaba T6J w/S-SHH Receiver
- Motors: CM-2216/23 950KV
- Electronic speed controllers: Cobra 20A Multirotor ESC
- Propellers: APC 11x4.5 MR
- Battery: Wild Scorpion 4S/14.8V/4200mAh/35C LiPo Battery
- Power management board: **HolyBro PX4 power management board**





New considerations

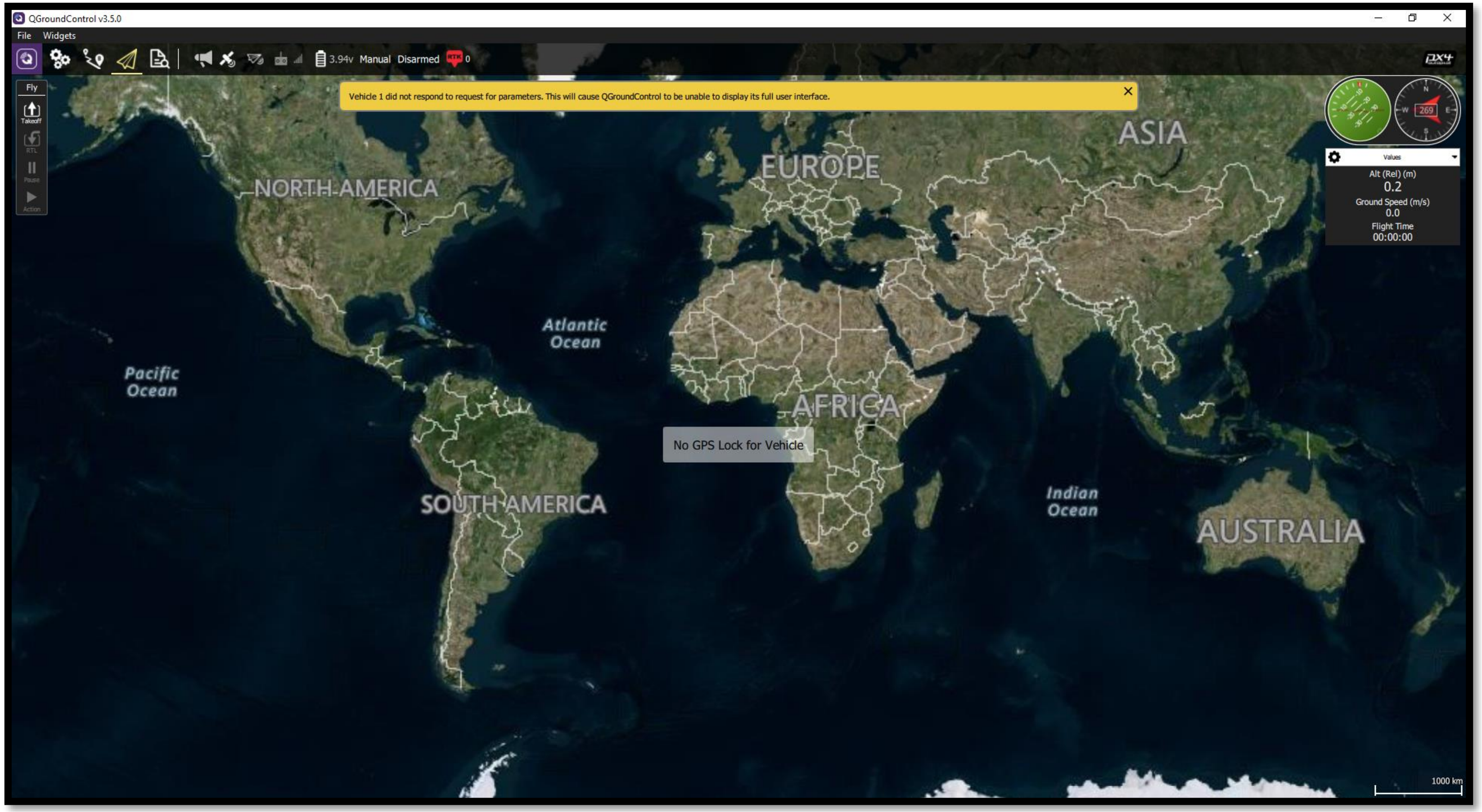
- Flight controllers must run on a firmware to be functional.
- Flight controllers must be calibrated through a ground control station
- Consequentially, one must proceed to select the firmware and the ground control station to be implemented.

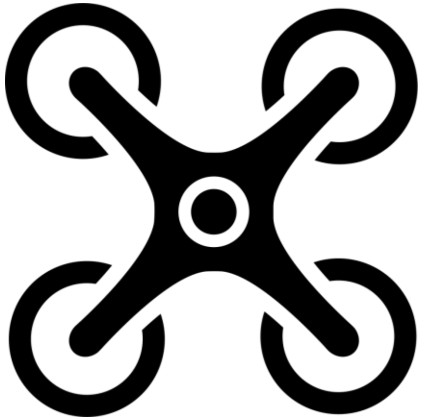
Firmware selection

Ground control station selection

Testing Phase

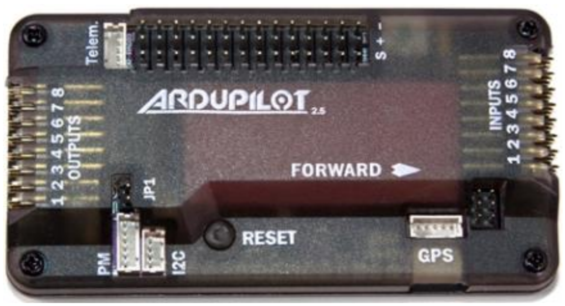
Ground Control Station – Pixhawk Implementation





Selection #3

- Quadcopter control board: **Ardupilot v2.6 flight controller**
- Sensors and additional peripherals:
  - **XT-XINTE GPS**
  - **Radio Telemetry Module**
- Remote control and receiver: Futaba T6J w/S-SHH Receiver
- Motors: CM-2216/23 950KV
- Electronic speed controllers: Cobra 20A Multirotor ESC
- Propellers: APC 11x4.5 MR
- Battery: Wild Scorpion 4200 mAh, 4S, 35C, LiPo
- Power management board: HolyBro PX4 power management board



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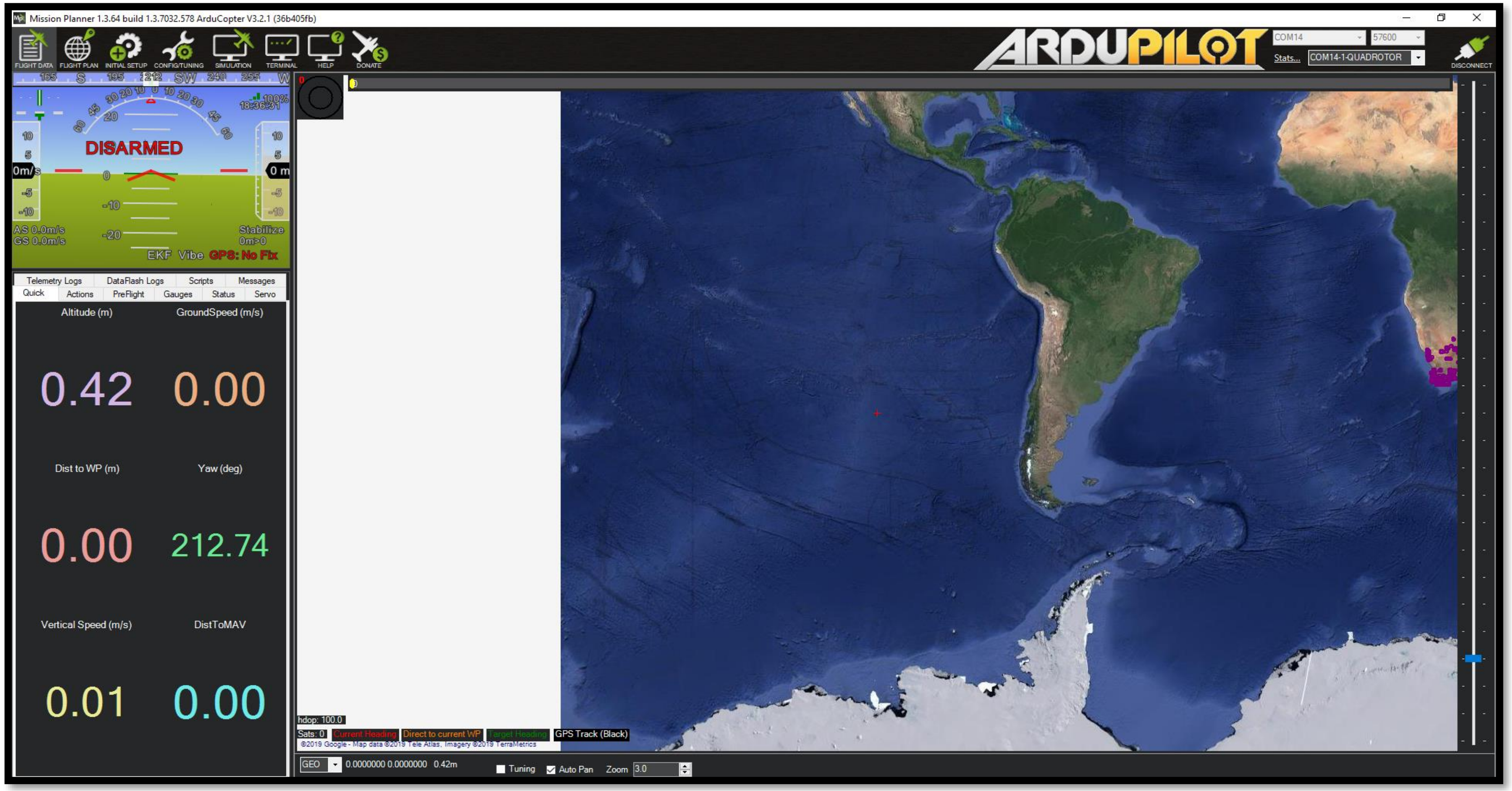
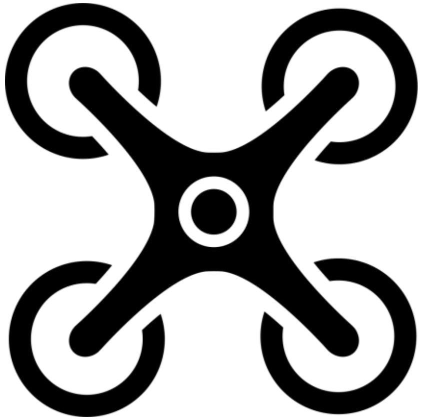
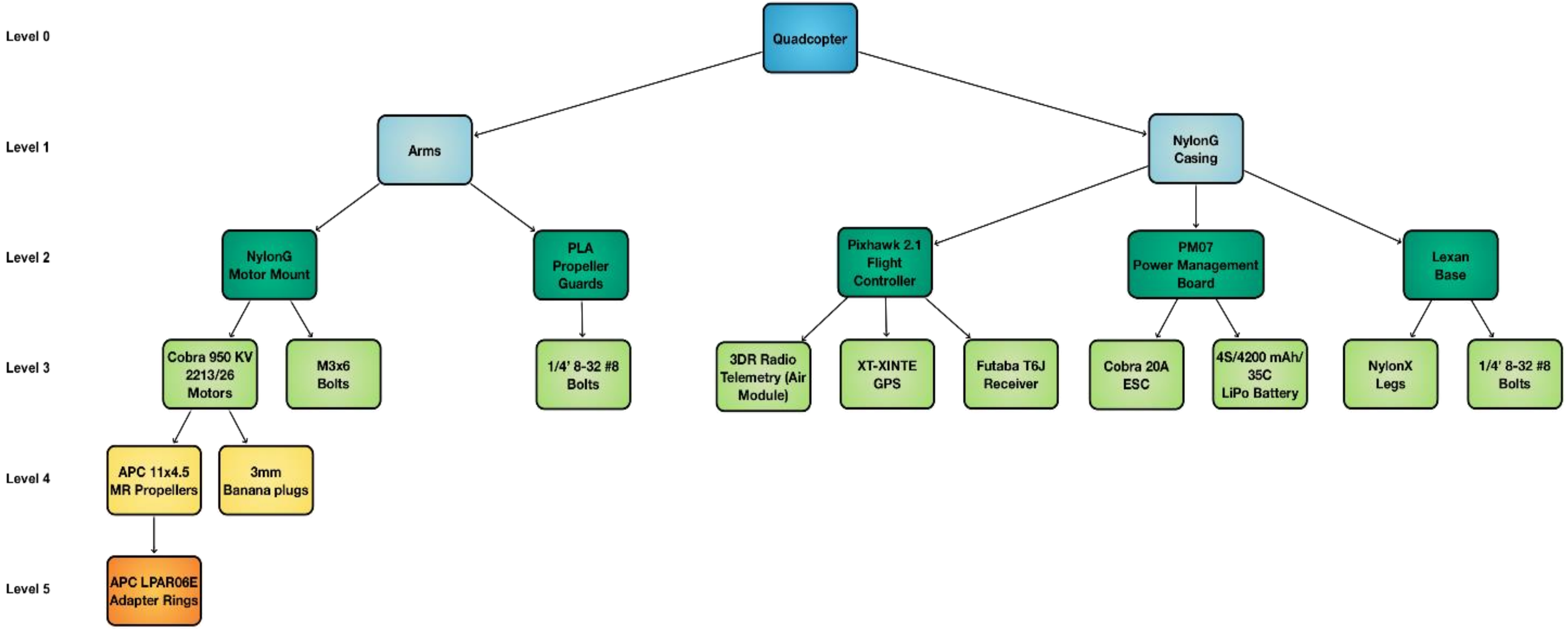
Testing Phase

Ground Control Station – Ardupilot Implementation





Manufacturing Phase



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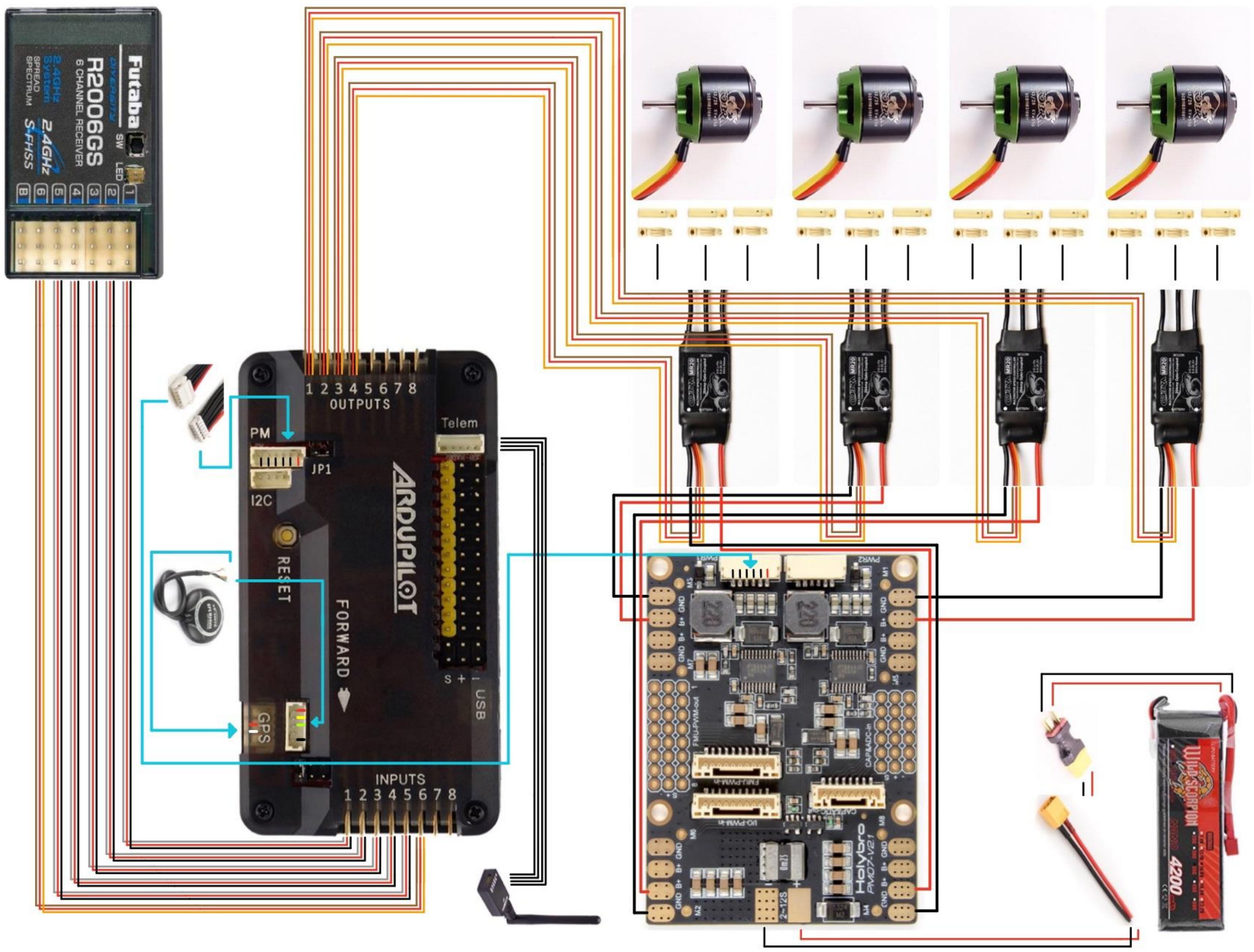
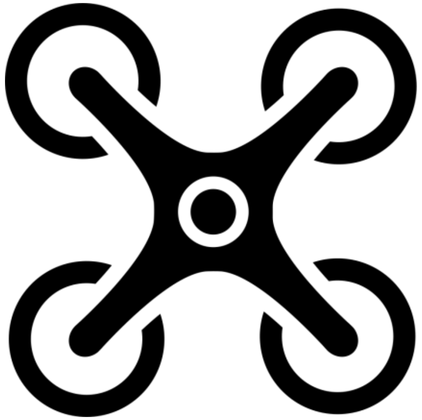
Wiring Phase



Testing Phase

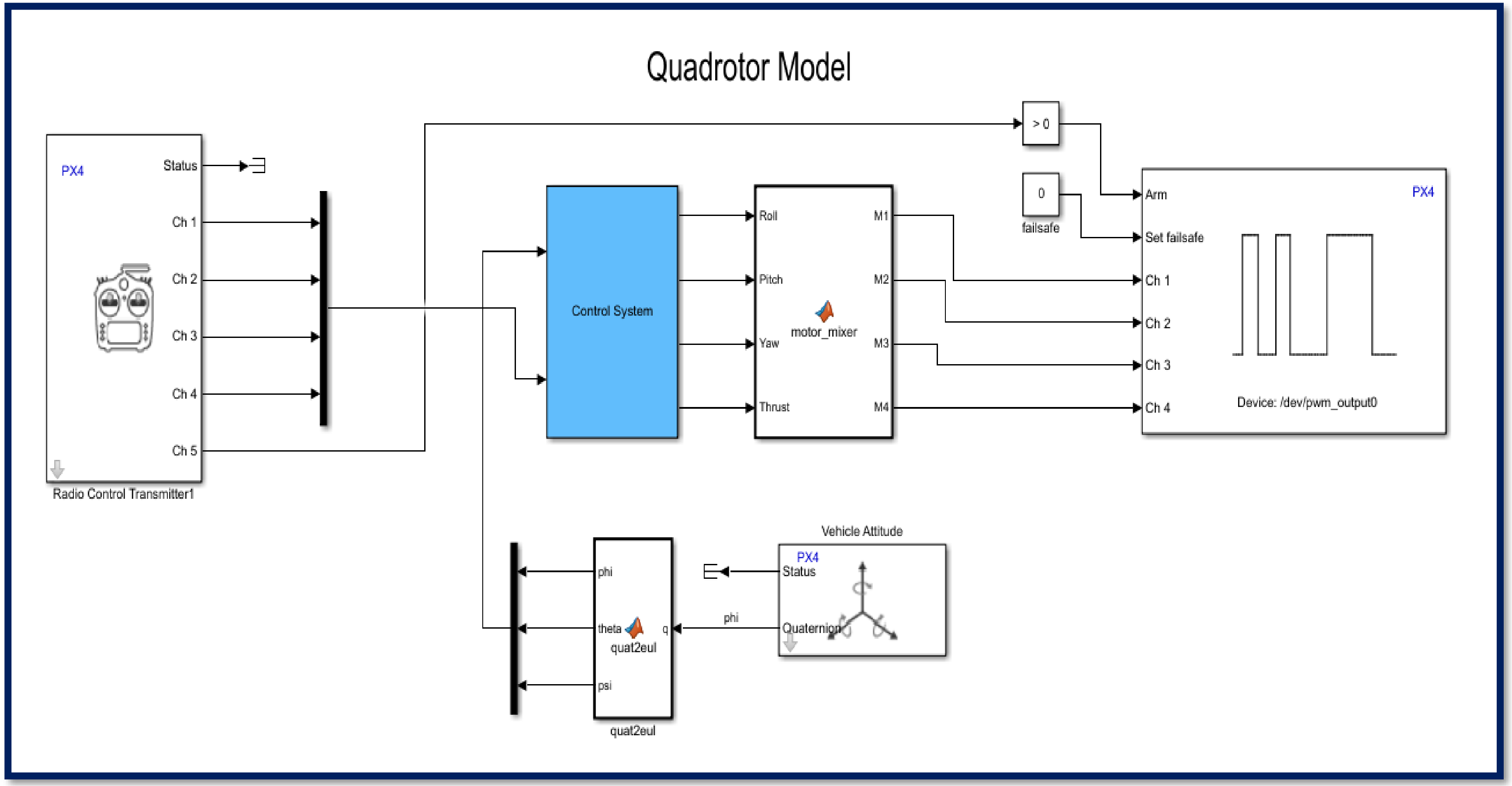
Quadcopter Flight



Results and final design

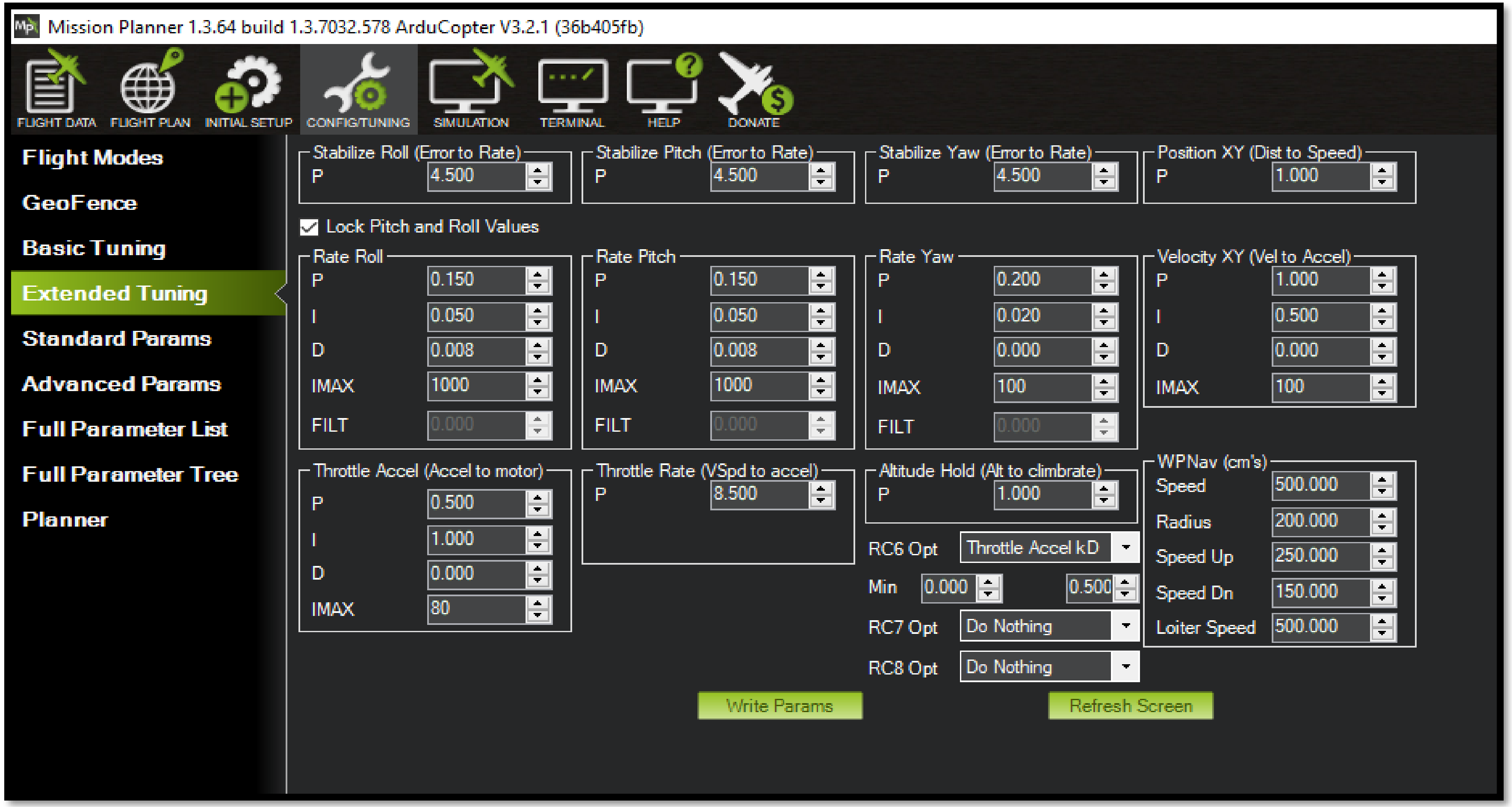
Software

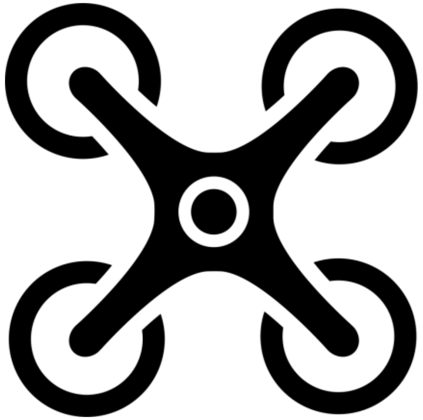
Simulink model to be uploaded to the Cube flight controller



Software

PID parameters in Mission Planner

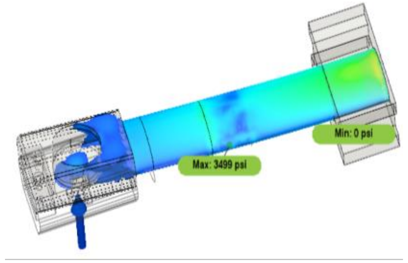


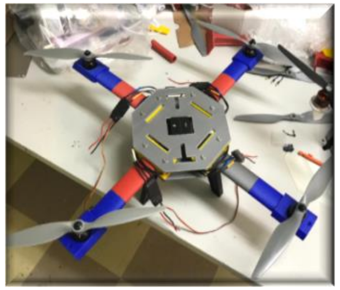


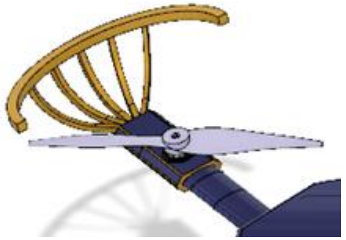
Hardware

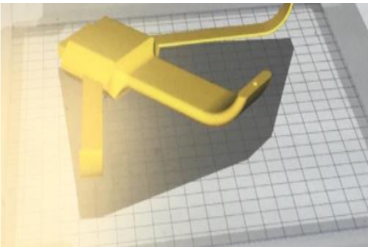
Quality of Design

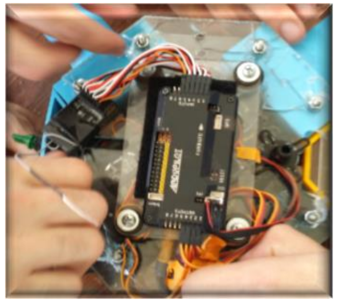
- Nylon G vs PLA
- Arms
    - Initial bending
- Propeller guard
    - Version #1
    - Version #2
- Top/Bottom Base
    - Lexan (shatters easily)











Day of competition

Conclusions

Experiences and lessons learned

- Obtained the opportunity to participate in a multidisciplinary team
- Systems engineering and exposure to real-life industry project workflow
  - Preliminary Design Review (PDR)
  - Critical Design Review (CDR)
  - Flight Readiness Review (FRR)
- Achieved better understanding of the client for future collaborations
- Opened the doors to future projects related to UAV design
- Broadened knowledge concerning engineering concepts applied to UAV design
- Managed unforeseen issues and learned the importance of developing a baseline to handle possible deviations in a project

Findings and recommendations

- Successful quadcopter flight simulation through MATLAB/Simulink
- Simulink-Pixhawk implementation requires further investigation
- Precaution when uploading firmware to telemetry module
- Mission planner enables user to operate designed UAV through in both manual and autonomous modes
- **Alternative**: Program flight controller through Ardupilot using Arduino IDE
- **Recommendation**: Continue executing R&D w/designed UAV

Questions?