Multicopter Design and Control Practice
——A Series Experiments Based on MATLAB and Pixhawk

Lesson 01 Introduction

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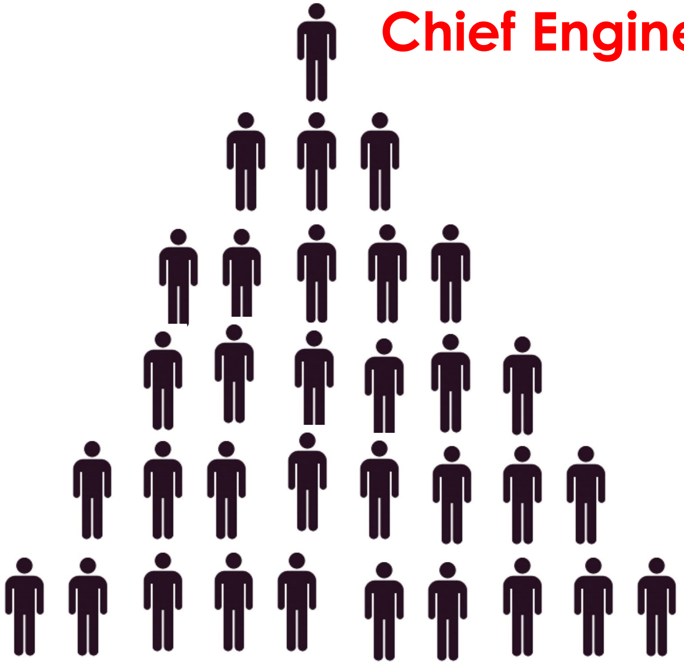
New Requirement

Chief Engineer



No lack of Engineers, Financial support, Experience, Resources

Traditional

- Fewer engineers
- Less experience
- Fewer resources

New

- A full-stack multicopter engineer has a functional knowledge of all techniques, languages and systems engineering concepts required in multicopter development.
- The term "full stack" refers to the technologies and skills needed to complete a project, with each individual component being a stack.

New Requirem

◻ Theory

- Airframe Configuration
- Propulsion System
- Modeling
- Calibration and State Estimate
- Controller Design
- Planning Design
- Failsafe Design
- ……

New Requirement

Theory

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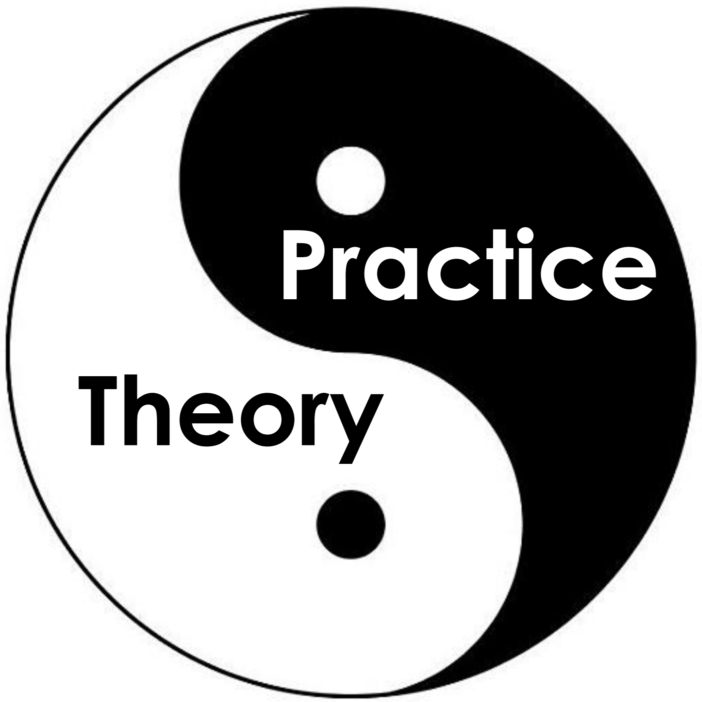
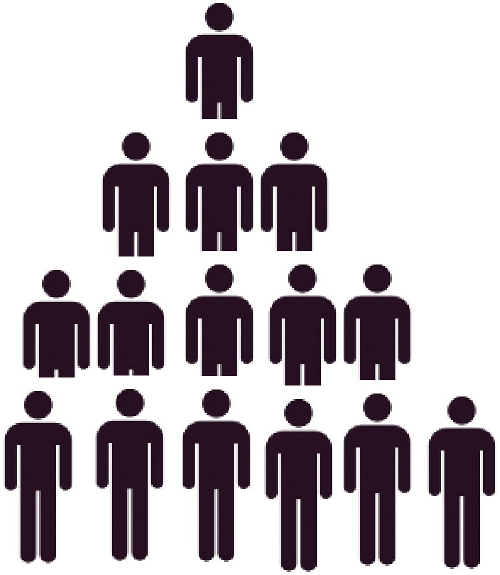


Practice

- Develop Tool
- Operating System
- Coding
- Software Testing
- Flight Testing
- ……

- How we do it? New Tool + New Course

New Requirement



Education

People with Background of
Electronic Engineering

Chief Engineers

- How we do it?   New Tool + New Course

Platform and Process

Pixhawk:

Most Widely-Used

Autopilot Hardware

Matlab:

Most Widely-Used

Language in Engineering

Multicopter:

Most Widely-Used

Small Aircraft

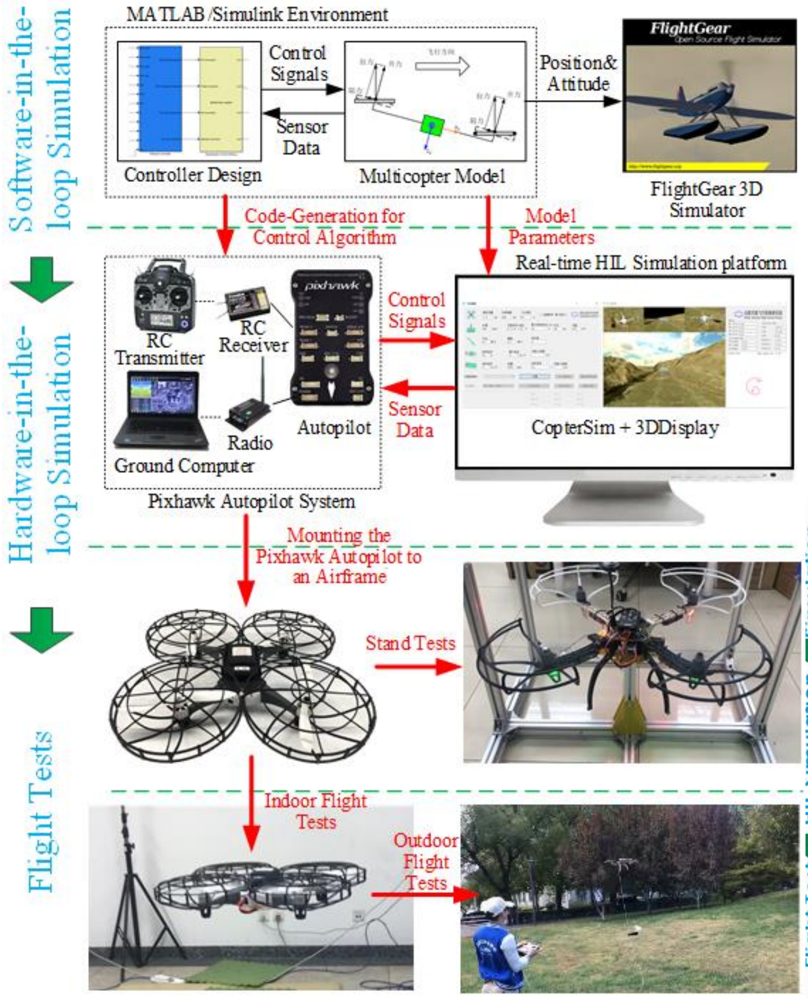
Model-Based Design(基于模型的设计)

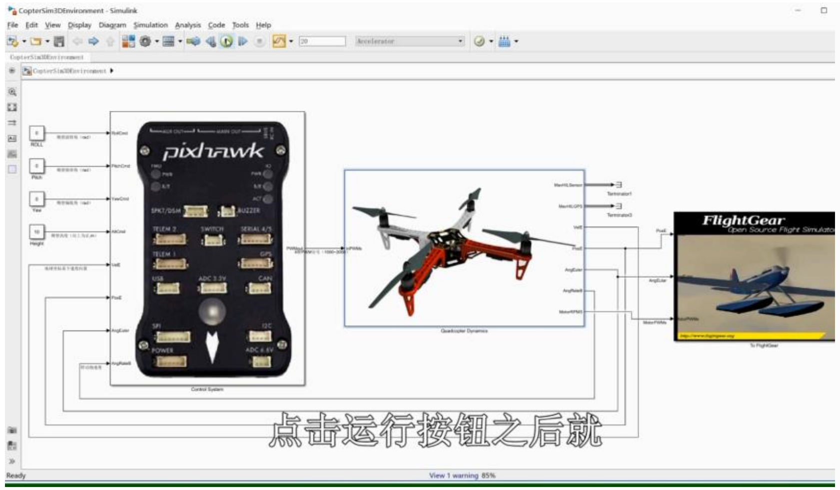
Multicopter Control Algorithm Rapid Development and Teaching Platform based on Model-Based Design with Matlab and PixHawk

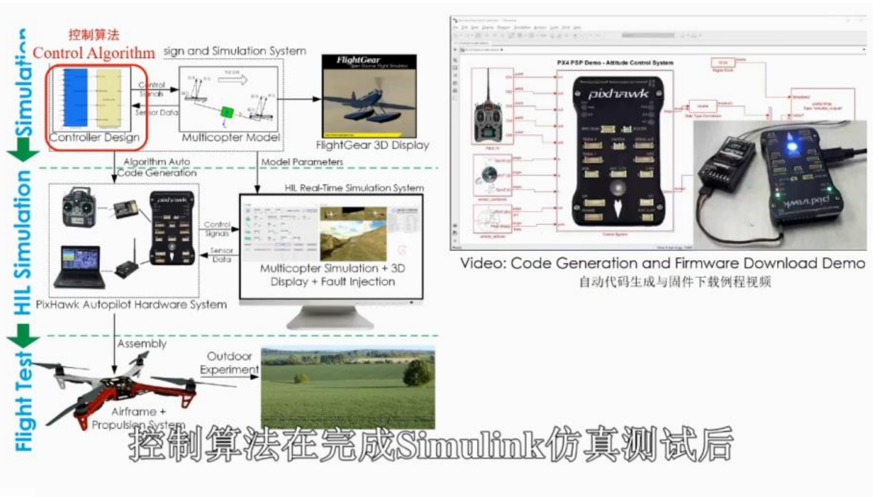
基于模型设计的思想和采用Matlab和PixHawk工具的多旋翼控制算法快速开发与教学平台

北航可靠飞行控制研究组
BUAA Reliable Flight Control Group

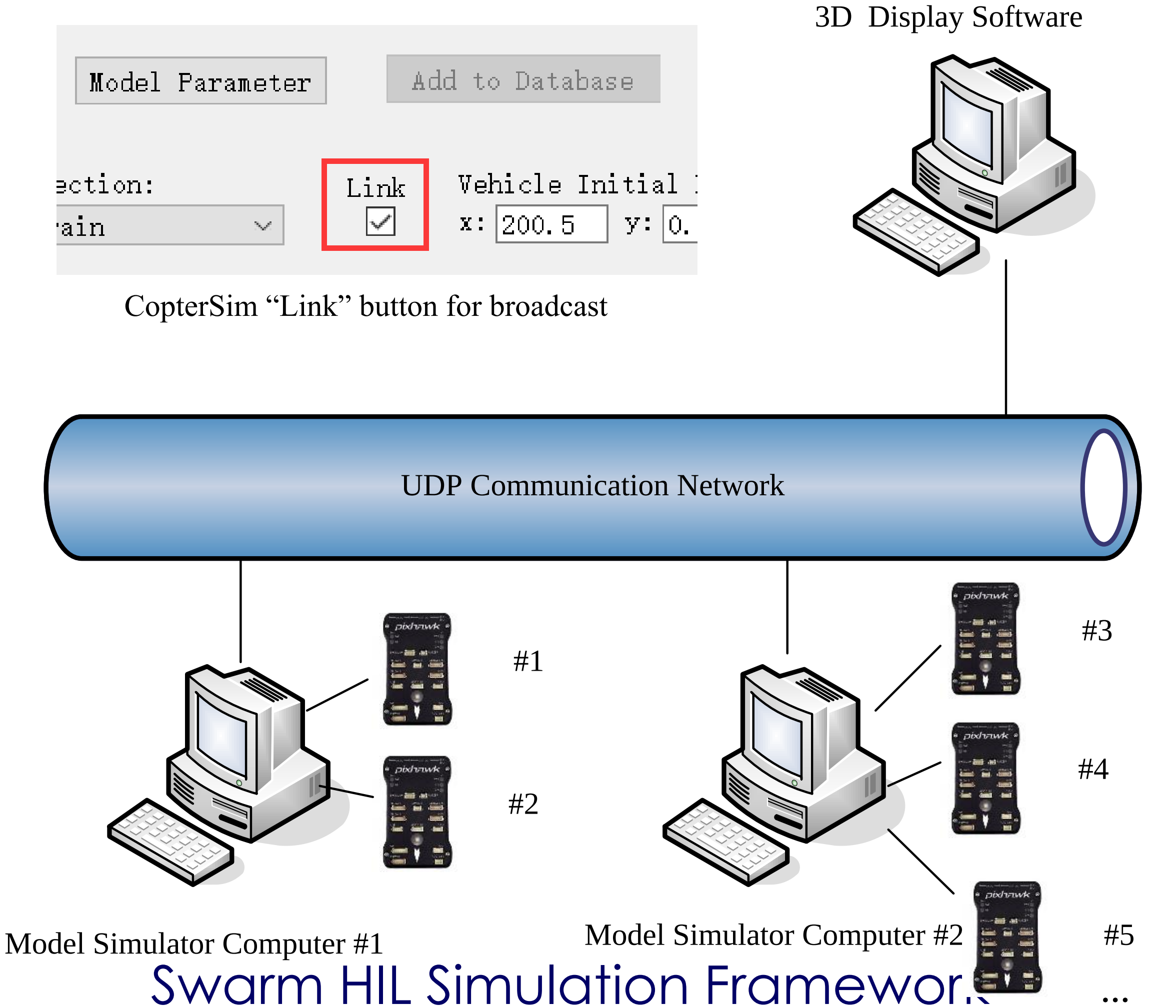
Platform and Process



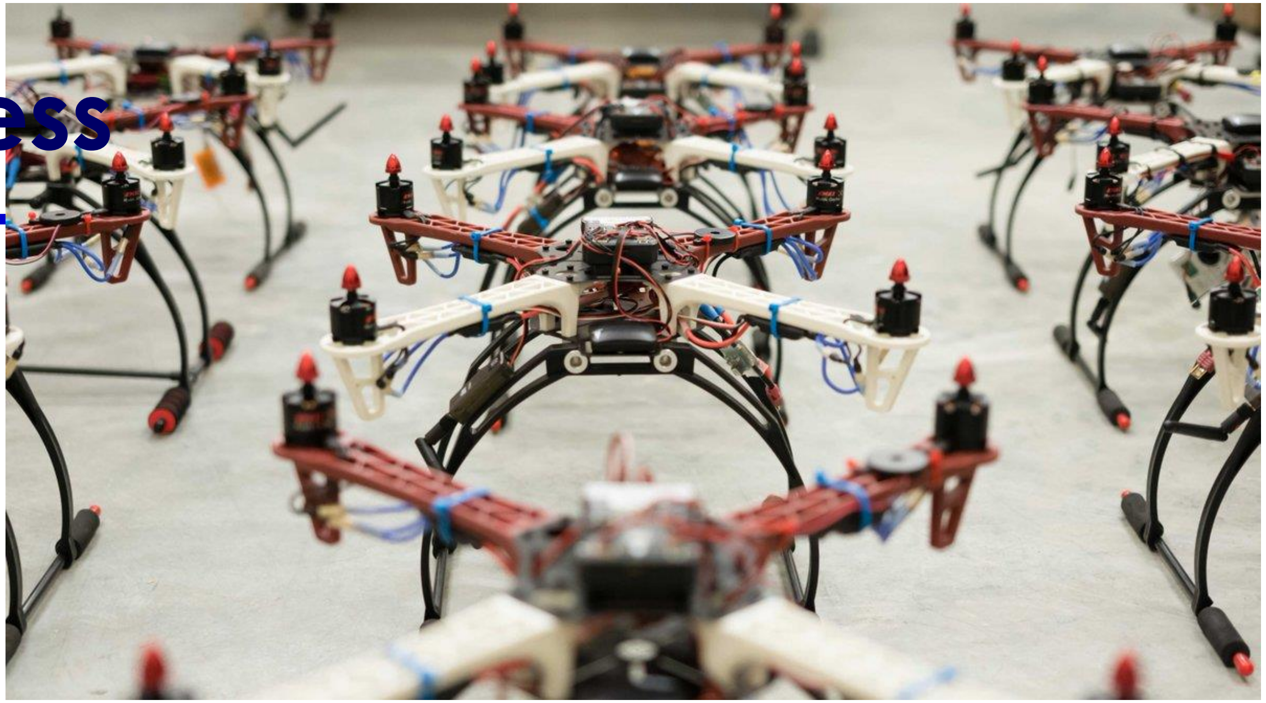


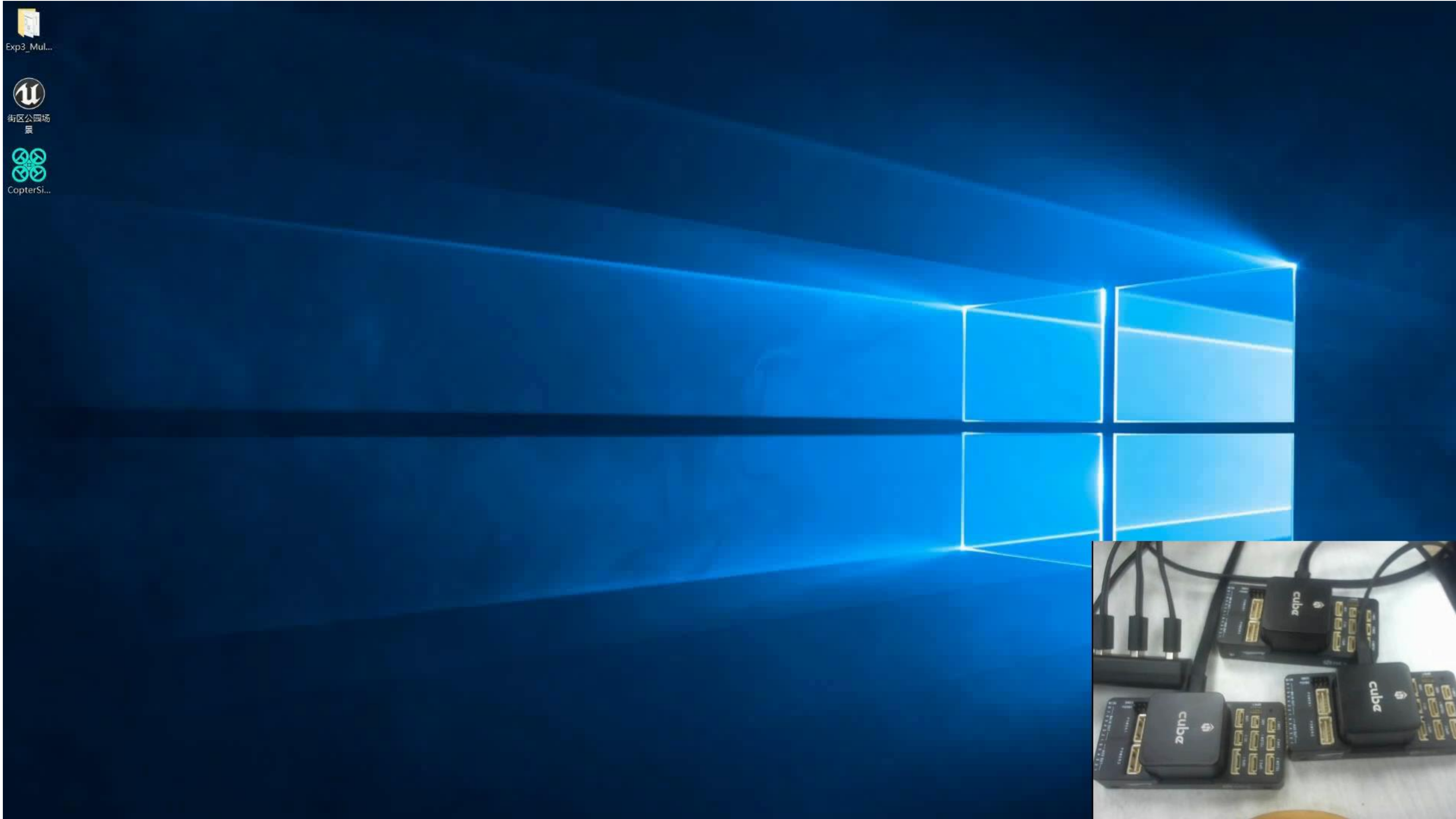


Platform and Process



Swarm HIL Simulation Framework

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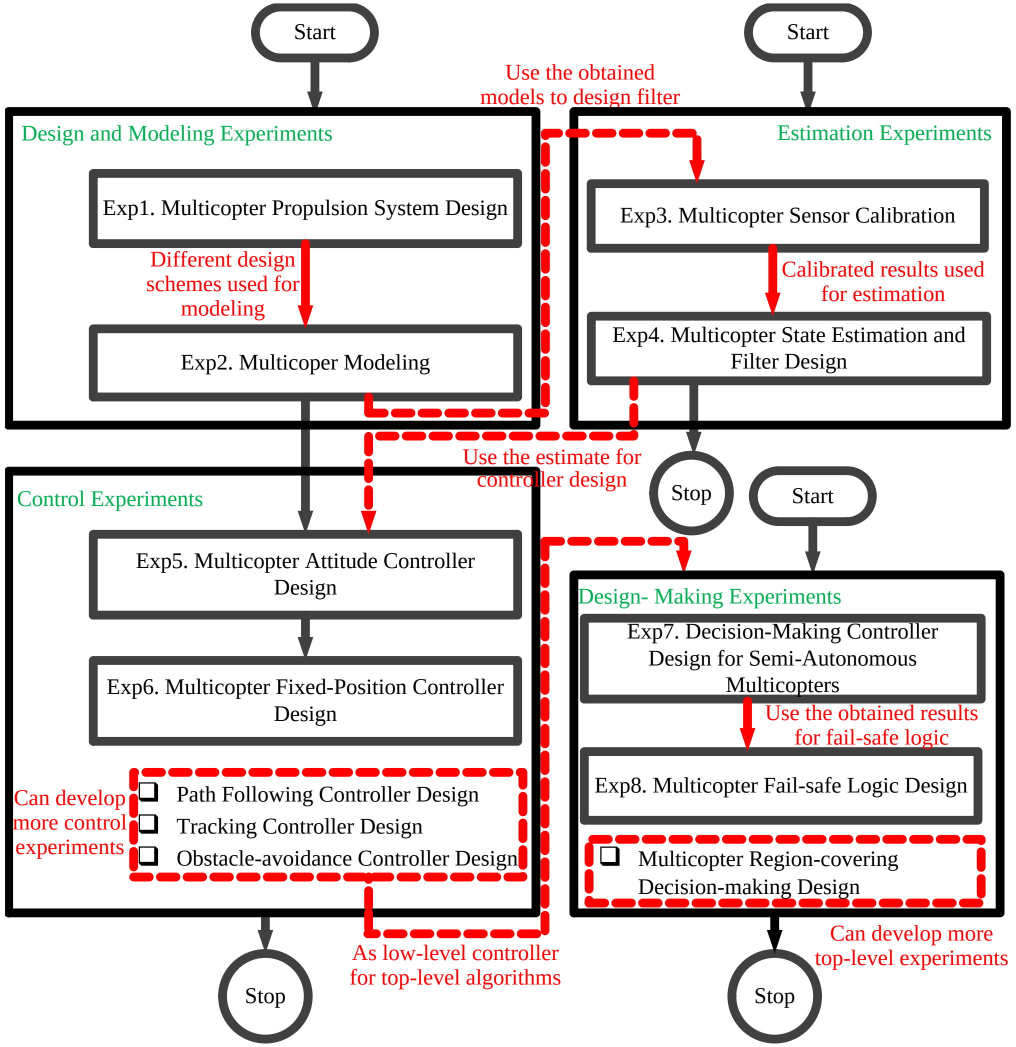
Experiment Course Design

■ Experiment Content and Framework Design

- Propulsion system design
- Dynamical modeling
- Sensor calibration
- State estimation and filter design
- Attitude controller design
- Fixed-position controller design
- Semi-autonomous control design
- Failsafe logic design



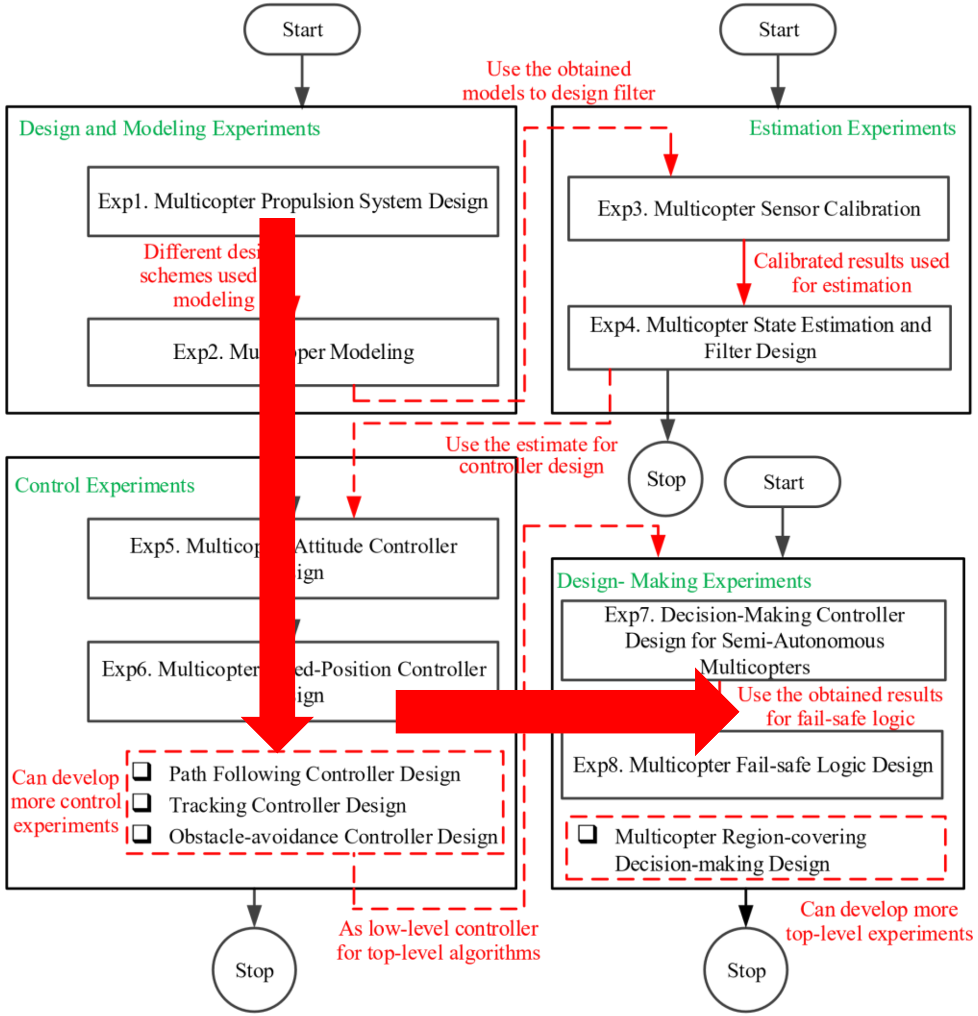
Experiment Course Design

The progressive studying routes are as follows:

(a) Design and modeling experiments → Control experiments

(b) Design and modeling experiments → Control experiments → Decision-making experiments

(c) Design and modeling experiments → Estimation experiments → Control experiments → Decision-making experiments



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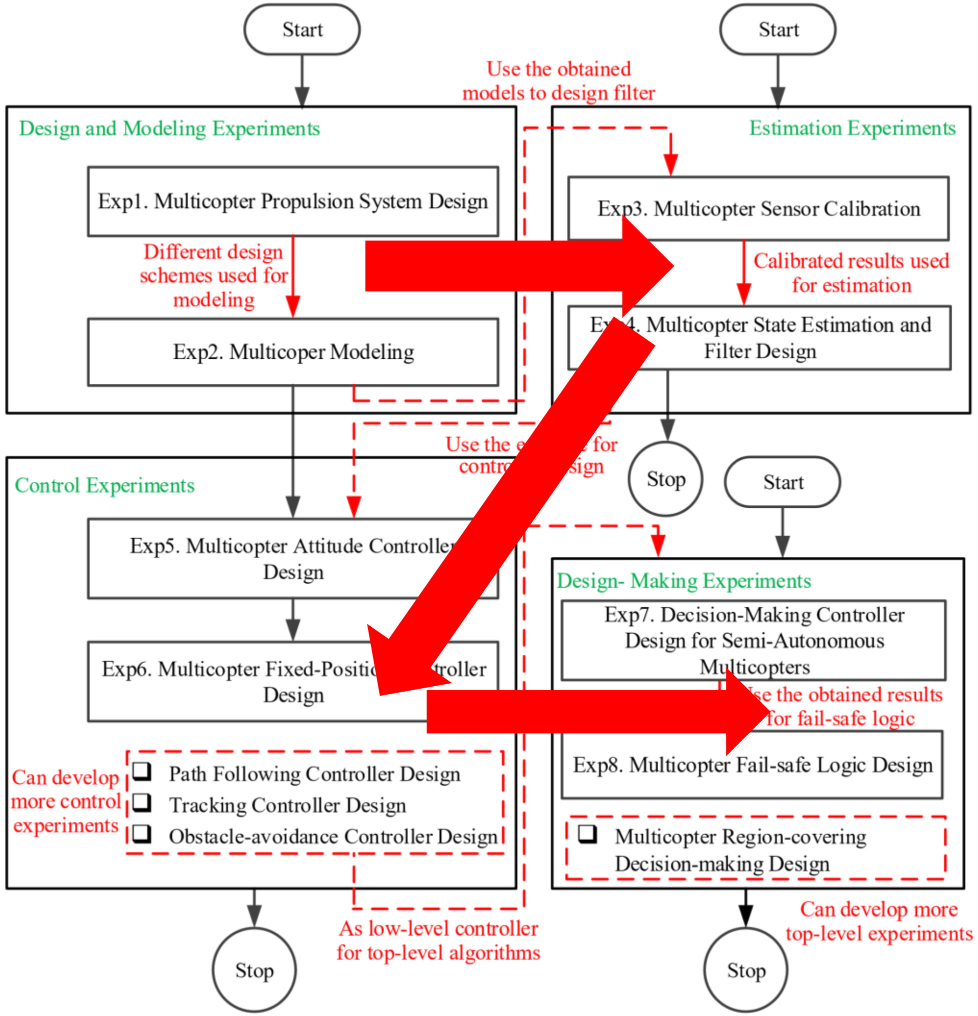

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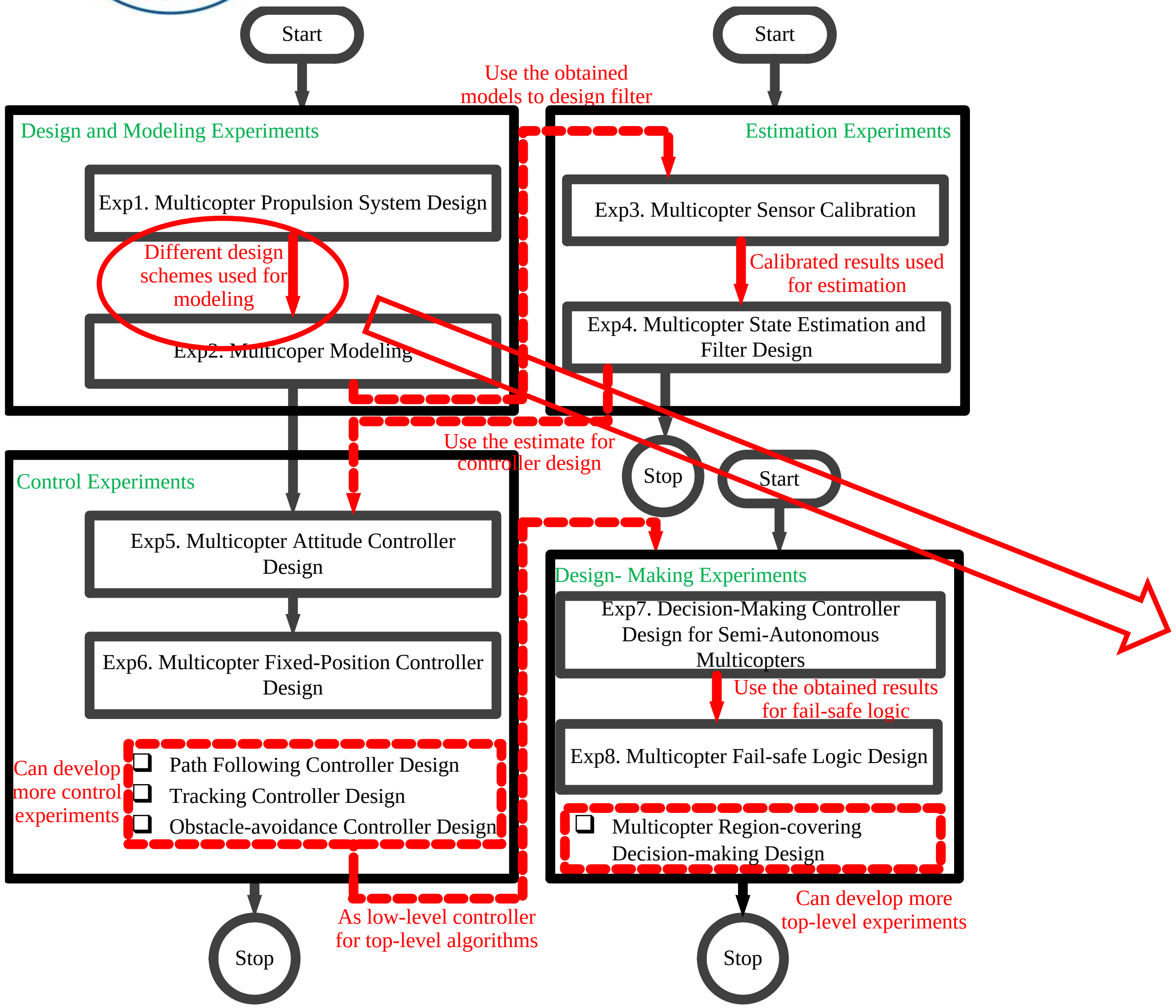
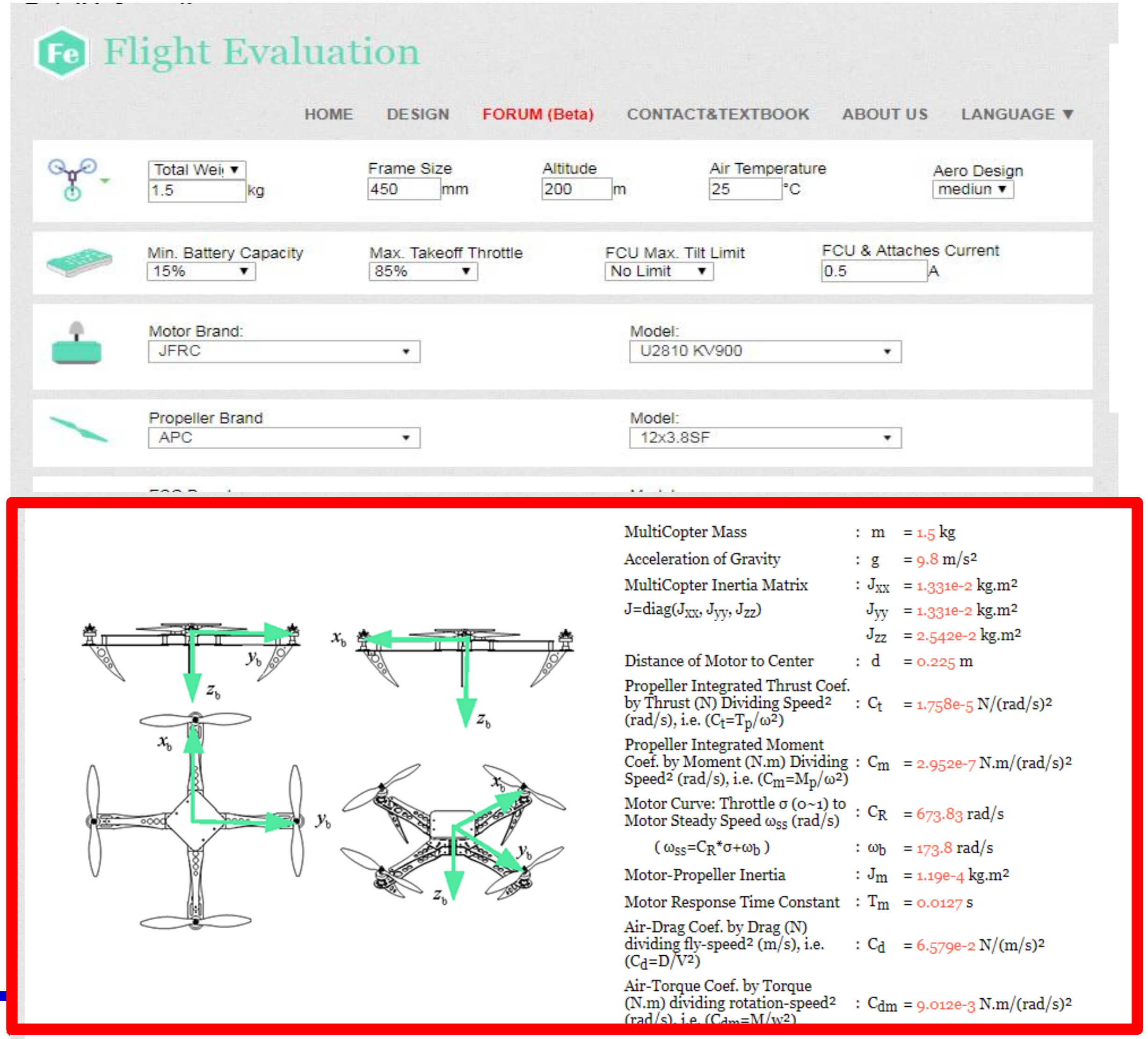
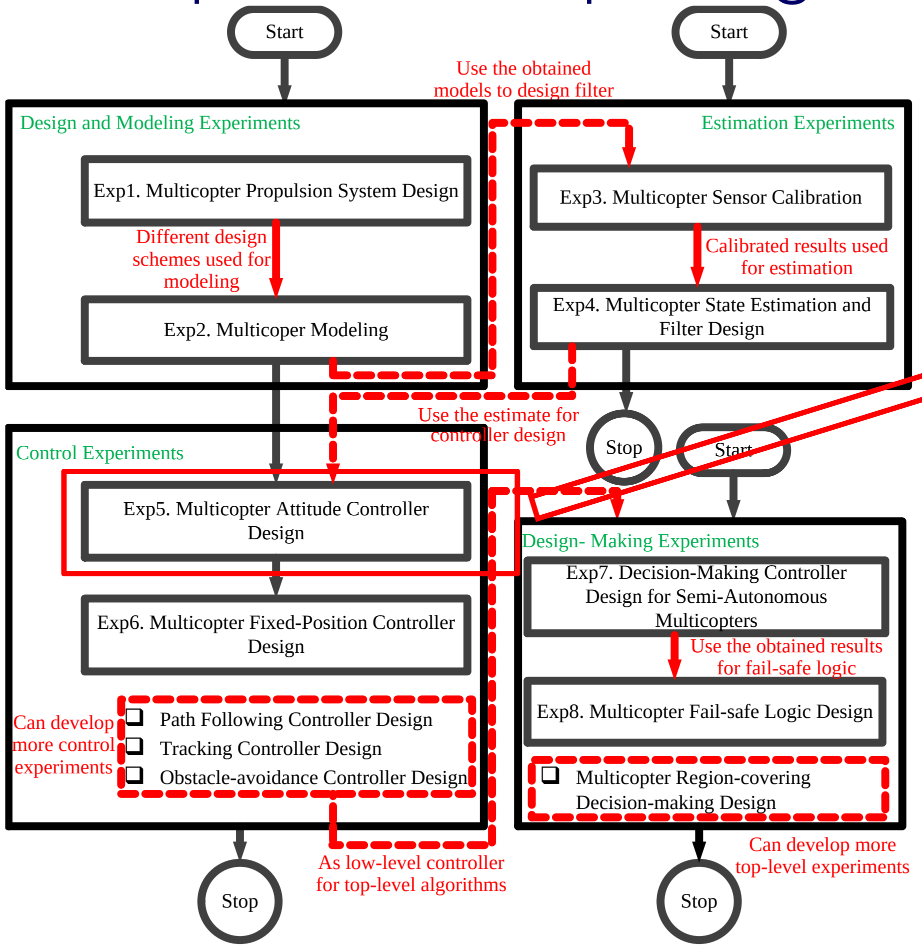
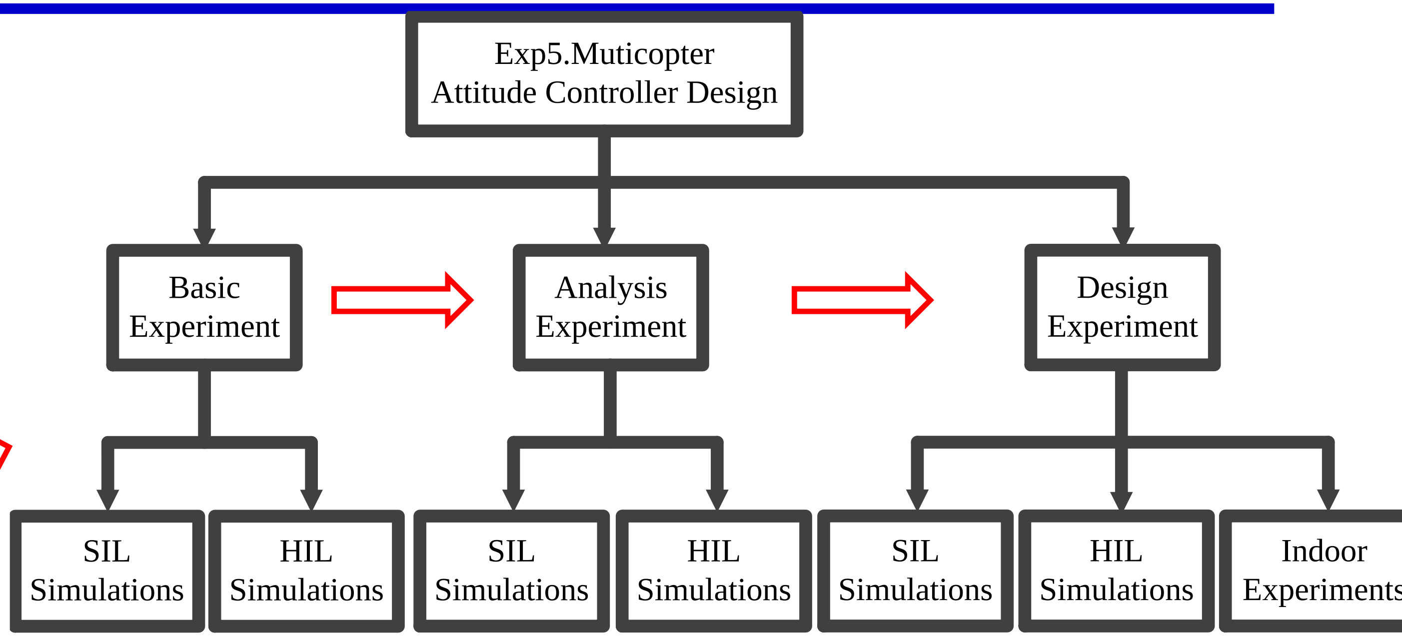


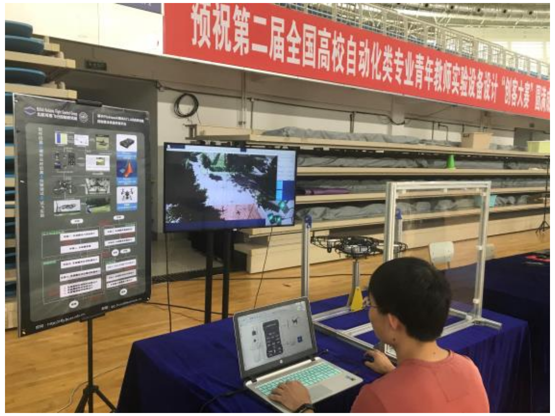


Experiment Course Design

- Experiment Step Design







Experiment Course Design

- Experiment Step Design

Basic Experiment

Open the given code example. Then, read and run its source code directly to observe and record the results.

Analysis Experiment

Modify the given code example. Then, run the modified example program to collect and analyze the data.

Design Experiment

Based on the above two experiments, complete the given design task independently.

Experiment Course Design

- Experiment Step Design • Basic Experiment

9.2.1 Experiment Objectives

(1) Things to prepare

1) Hardware: Multicopter System, Pixhawk Autopilot System;

2) Software: MATLAB 2017b and above, Simulink-based Controller Design and Simulation Platform, HIL(Hardware in the loop) Simulation Platform, Experiment Instruction Package "e5.1" (http://rfly.buaa.edu.cn/course.html → Lesson 11 → Experiment).

(2) Objectives

1) Repeat the Simulink simulation of a quadcopter to analyze the functions of the control allocator;

2) Record the step response of the attitude, and sweep the open-loop attitude control system to obtain the Bode plot and further analyze the stability margin of the closed-loop control system;

3) Perform the HIL simulation.

Experiment Course Design

- Experiment Step Design

- Analysis Experiment

(2)Objectives

1)Adjust the PID controller parameters to improve the control performance, record the overshoot and settling time, and obtain a group of satisfied parameters;

2)Using the satisfied parameters, sweep the system to draw the Bode plot. Observe the system amplitude versus frequency response curve and the phase versus frequency response curve; finally, analyze the stability margin.

- Design Experiment

(2) Objectives

1) Establish the transfer function model of the attitude control loop, and then design a compensator for the attitude angular velocity control loop satisfying the following conditions: steady-state error $e_{rss} \leq 0.01$, phase margin > 65° and cut-off frequency > 10rad/ s. The attitude angle control loop is satisfied when cut-off frequency > 5rad/s, phase margin > 60°;

2) Complete the SIL simulation and HIL simulation experiments with the designed controller;

3) Use the designed controller to perform flight test experiment.

Experiment Course Design

All codes are implemented in real flight tests

Manual Mode Switch

Failsafe

Experiment Course Design

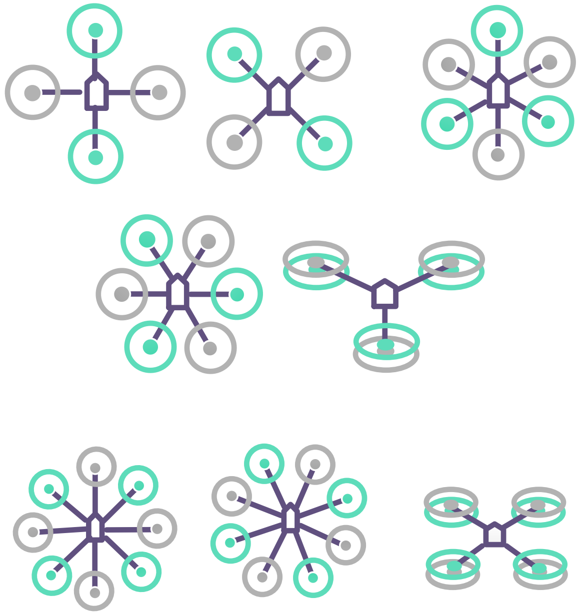
Table. Experimental types, projects and content

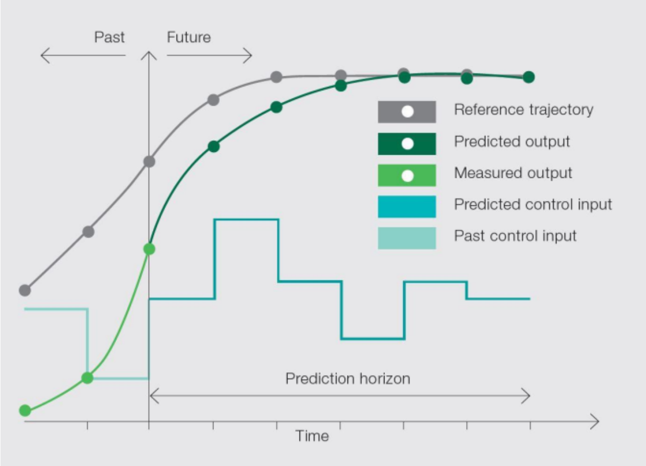
Objective	Basic experiment	Analysis experiment	Design experiment
Development platform	✓	✓	✓
Analysis process	×	✓	✓
Design methods	×	×	✓
SIL simulation	✓	✓	✓
HIL simulation	✓	✓	✓
Flight tests	×	×	✓

Experiment Course Design

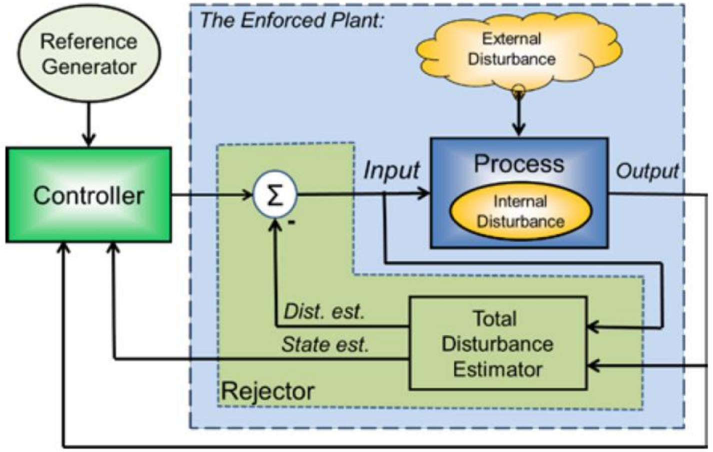
■ Teaching Design

- Modifying the goals in the propulsion system design and modeling experiments
- Different progressive studying routes and opening new experiments





Predictive control



Active disturbance rejection control

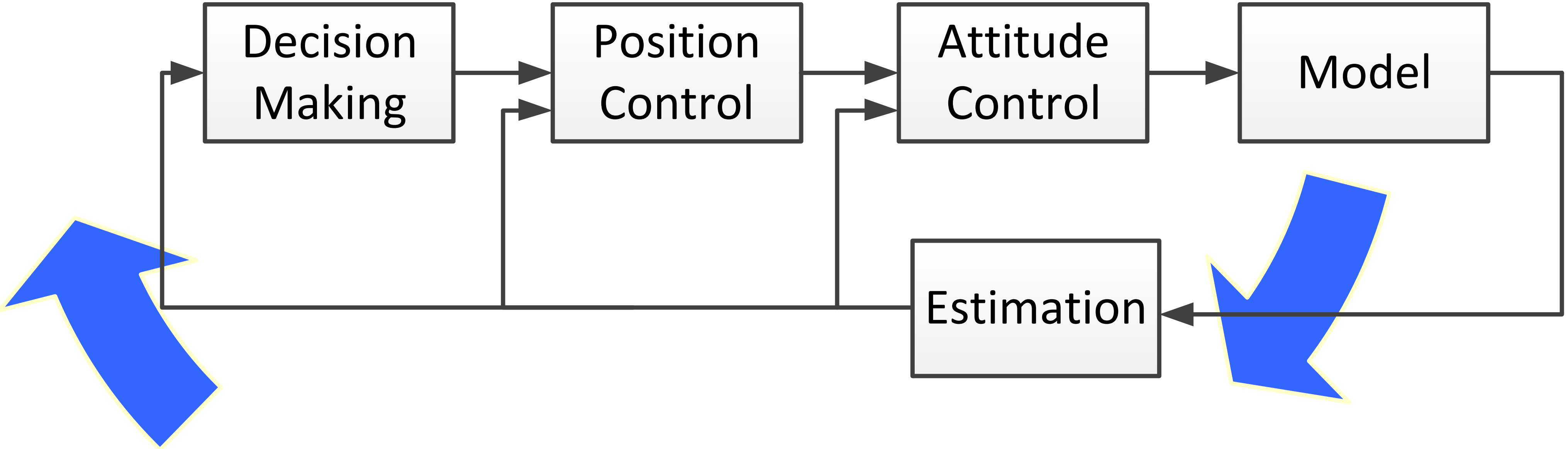
Conclusions

No.	Questions
Q1	Given a payload and flight endurance requirements, how design a multicopter prolusion system?
Q2	Given a Pixhawk autopilot, how calibrate its accelerometer and magnetometer and how design the filter to estimate the state?
Q3	Based on the designed multicopter prolusion system and airframe configuration, how establish a multicopter dynamical model?
Q4	Based on the dynamical model established, how design a motor controller, a control allocator and an attitude controller?
Q5	Based on the designed attitude controller, how design a set-position controller?
Q6	Based on the designed an attitude controller and set-position controller, how design a semi-autonomous controller?
Q7	Based on the semi-autonomous controller, how design a fail-safe logic for the designed multicopter?
Q8	Given a new algorithm, how to realize it by the model-based design?
Q9	How new functions are developed based on the platform, such as health evaluation or vision-based autonomous flight?
Q10	Given a group of engineers, how to organize them effectively?

Conclusions

Flight Test

Software-in-the-loop Simulation



Hardware-in-the-loop Simulation

Thank you!