Safety Testing for PX4 based UAV Flight Control System

Part 1: Brief Introduction of Our Group

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Forewords

- Vision: Reliable Flying Makes Life Easier
- Objective: Develop evaluation and control methods to make flight reliable.
- Logo：

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

BUAA Reliable Flight Control Group

- 网 址: http://rfly.buaa.edu.cn/

Forewords

- How to evaluate the health of aircraft more accurately?
- How to design controllers more robust?
- How to make aircraft safer under failures?
- How to regular the design process to make aircraft reliable?

Forewords

Objective

Reliable Flight Control

Application

- **Flight Control**
  - Autonomous Aerial Fueling
  - Multicopter Design and Control

Theory

- **Evaluation Theory**
  - Controllability
  - Reachability
  - Profust Reliability
- **Control Theory**
  - Additive Decomposition Based Tracking Control
  - Repetitive Control
- **Decision Theory**
  - Failsafe generated automatically.
- **Model-Based Design**

- **How to regular the design process to make aircraft reliable?**

Forewords

Towards a full stack developer

1) Airframe Design
2) Estimation
3) Control
4) Decision

5) Software and Hardware

6) Developing Process

?

Safety Testing for PX4 based UAV Flight Control System

Part 2: UAV Safety Testing and Future Development

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Outline

1. Background and Motivation
2. Introduction of Safety Testing
3. Platform Overview
4. Video Demonstration
5. Outlook

Preface

What is the most important requirement of a successful UAV product?

Functions? Performance? Appearance? Advertisement?

Safety and Reliability!

Background

UAVs are more Dangerous Than Other Vehicles.
Safety Testing is Very Important for Flight Safety!

Unmanned Vehicles: the Future of Human Life --- as the Development of Battery and AI Technologies

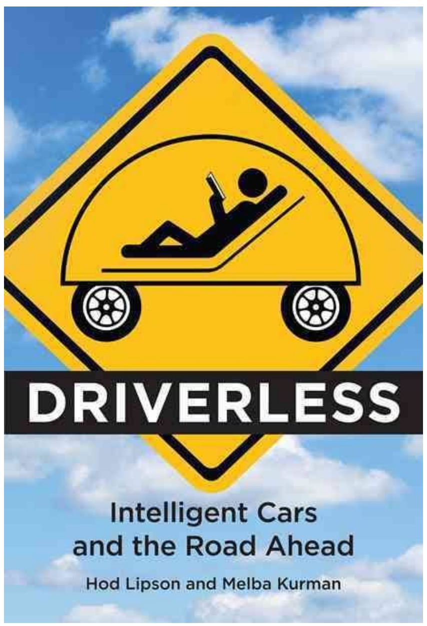

Fig. Famous Book *Driverless*

Top Level: AI

Middle Level: Safety

> 80% work

> 90% work

Low Level: Control

Fig. Autopilot System Structure

Problem 2: Bad Data

- Broad consumer/commercial adoption of Ardupilot = lots of corner cases
- Over 90% of development work is about 'corner cases' relating to bad sensor data including:
  - IMU gyro and accelerometer offsets
  - IMU aliasing due to platform vibration
  - GPS glitches and loss of lock
  - Barometer drift
  - Barometer disturbances due to aerodynamic effects (position error, ground effect, etc)
  - Magnetometer calibration errors and electrical interference
  - Range finder drop-outs and false readings
  - Optical flow dropouts and false readings

Fig. Key Problems of UAV Autopilot System Development

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Test Content

- Reliability : Reduce the Possibility of Fault
- Safety : Reduce the Damage After Fault

- Reliability Testing Safety Testing

	Normal Flight tests	Fault Tests
1	Normal Maneuvering (Attitude Control, Position Control)	Communication Link (Interference, Attack, Disconnect…)
2	Automatic Flight (Auto Take Off, Flight, Land)	Sensors - GPS, Accelerometer,… (Data error, Noise, Discontinuous)
3	Mode Switch (Triggered and Executed Correctly)	Propulsion system (Propeller, Battery Failures)
4	Mission Execution (All functions work as expected)	Model Change (Inertia, Mass) (Weight loss, Weight Center Shift)
5	Endurance Test (Long Time and Many Times)	Wind Interference (Wind Gust, Turbulence, Sheer)
6	…	…

Comparison of testing methods

Experiment Test (实验测试)

- Outdoor
- Flight place, test engineers, time, money…
- Most faults are hard to reappear in experiments
- Test after the completion of system development
- The test results are more accurate and trustworthy

HITL Simulation (硬件在环仿真)

- Indoor
- Only Computers
- Simulate any faults with proper modeling technologies
- Test during the development stage
- Require the modeling techniques

HITL (hardware-in-the-loop) is a simulation mode where the flight controller (hardware) is running with the sensor data generated by a UAV simulator (software) on a computer.

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Platform Components

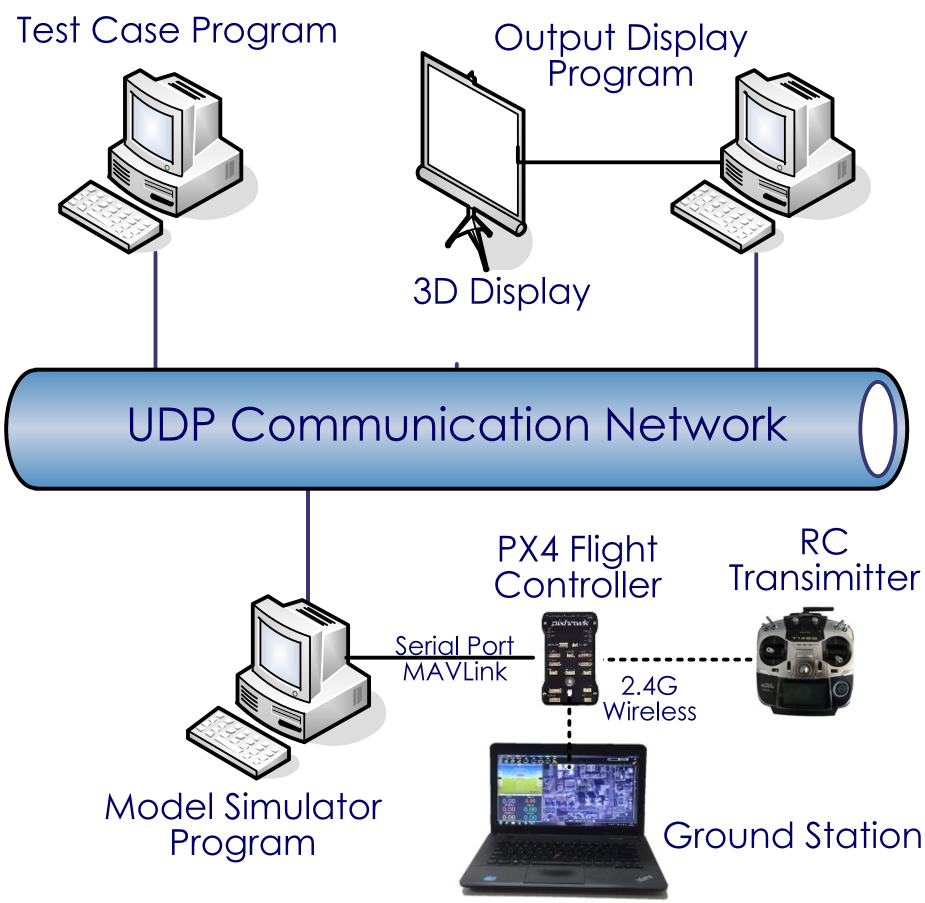


Fig. Structure of HITL safety Testing Platform

1. **Flight Controller (PX4 + RC):** Generate throttle control signals to the model simulator.
2. **Ground Station Program**: Configure the flight controller and send mission commands.
3. **Model Simulator Program**: Configure parameters of UAV, and generate sensor data to flight controller.
4. **Test Case Program**: Generate normal flight and fault injection signal to the model simulator.
5. **Output Display Program**: Evaluate the flight performance and output the test results and reports.

Normal Flight Simulation

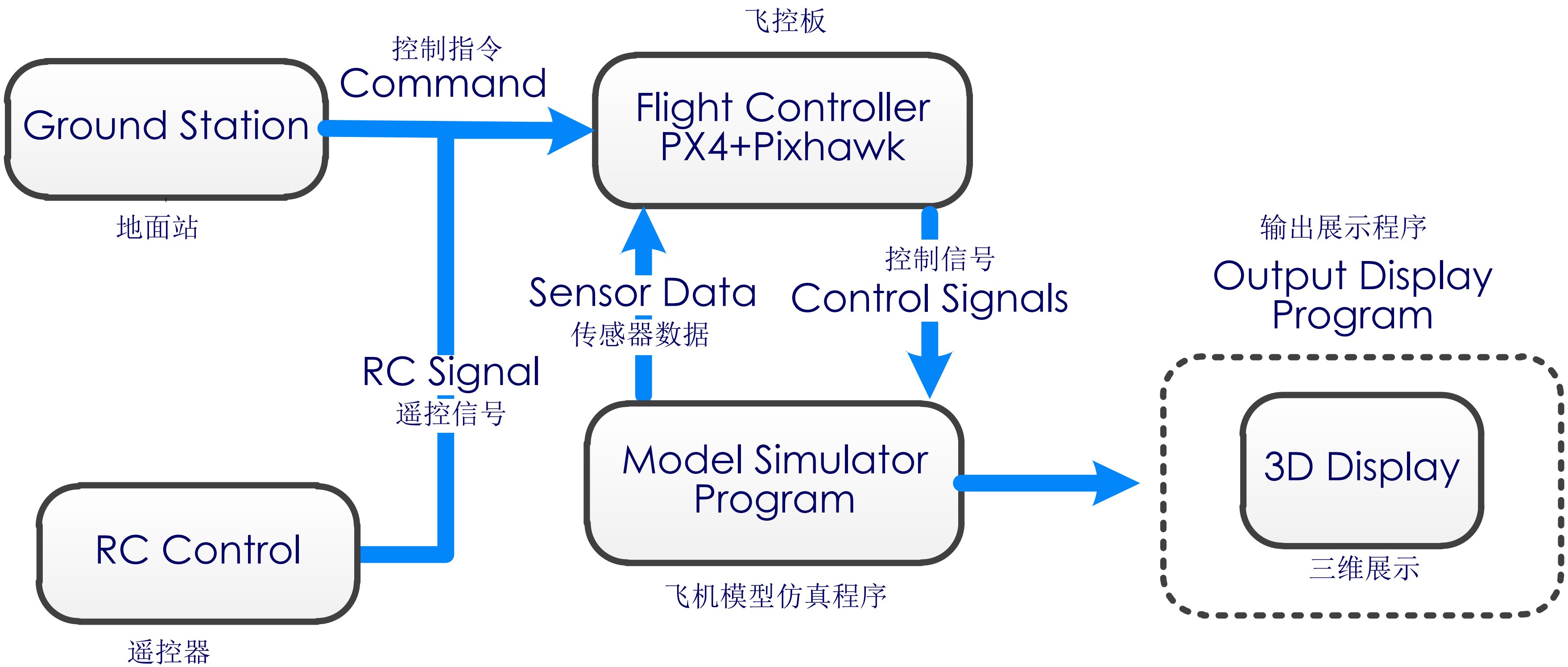


Fig. Flow Diagram of Normal Flight Simulation

Safety Testing Operation

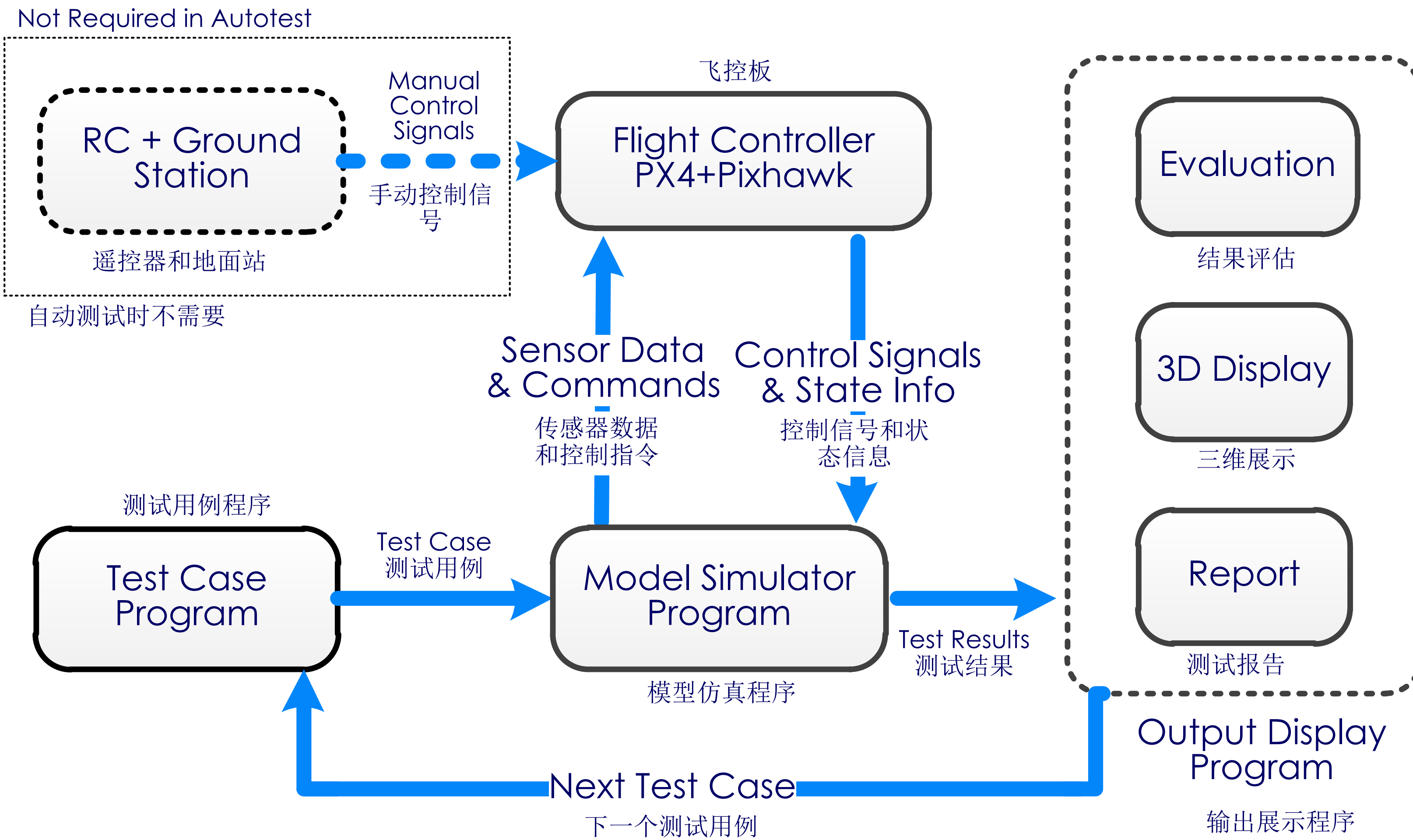
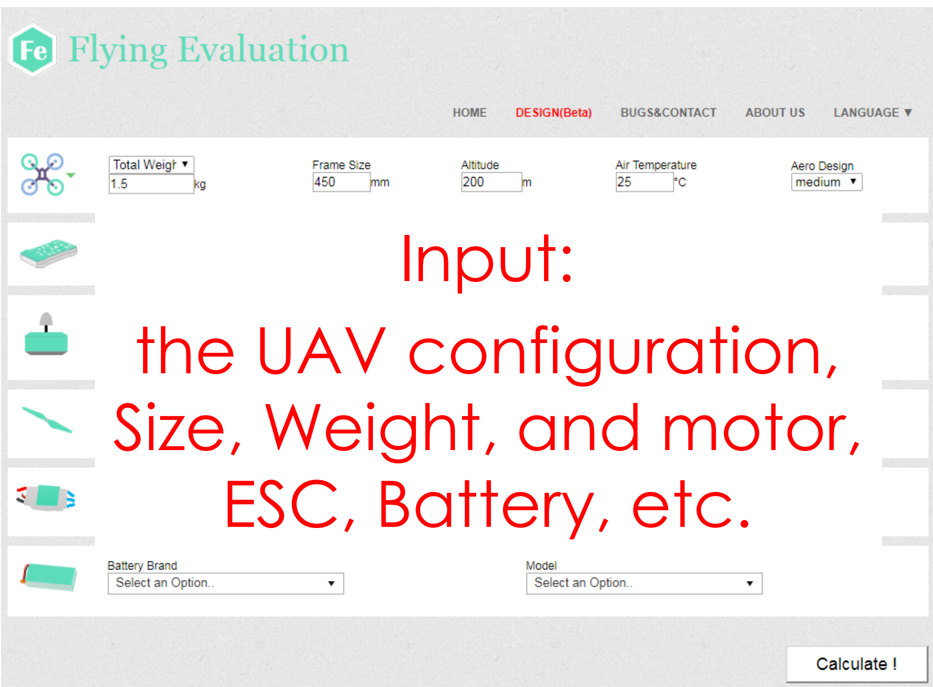
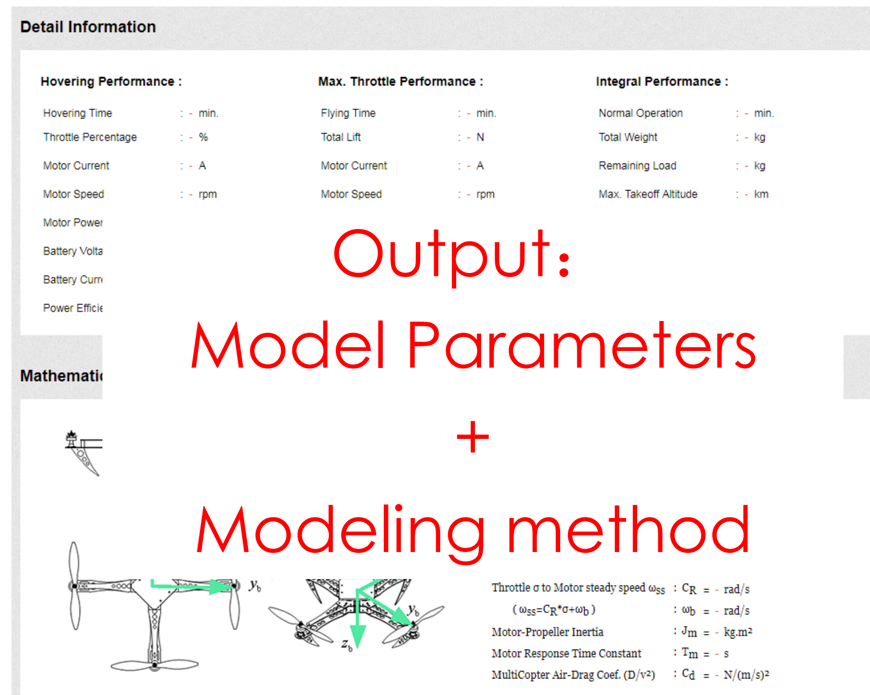


Fig. Flow Diagram of Safety Testing

Key Problems

- The key of the platform is the UAV model simulator
- Other programs for UI, 3D display, interfaces etc.
- **Problem 1**: How to Get Model Parameters
- Visit our website www.flyeval.com





Problem 2: Model Programming

- Matlab/Simulink → Code Generation → C++ Class→ QT project

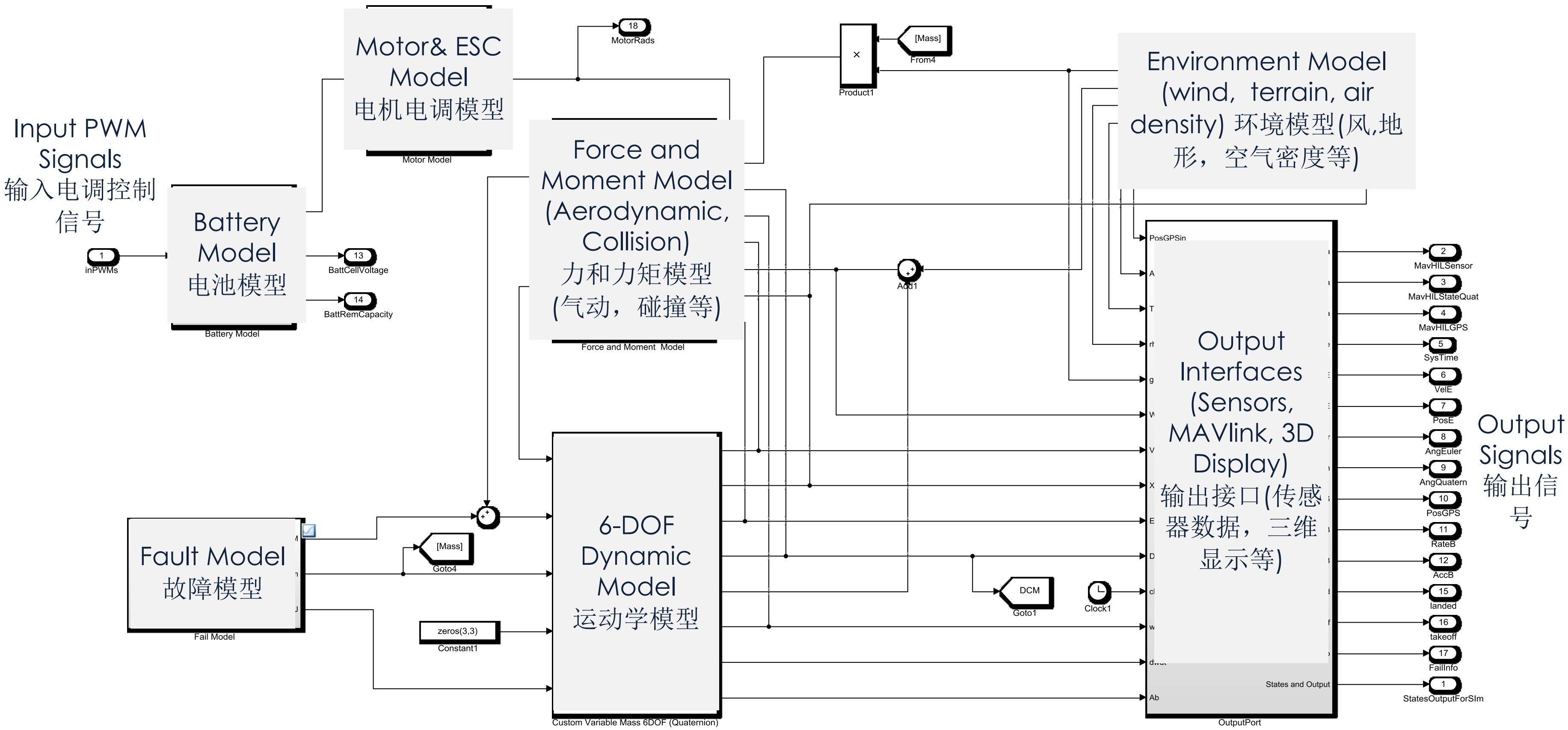


Fig. Structure of UAV Model Simulator in Simulink

Problem 3: HITL Simulation of PX4

Open Source Project Documents:

1. PX4 Document: https://dev.px4.io/
2. Mavlink : https://github.com/mavlink/mavlink
3. QGroundControl :
   https://github.com/mavlink/qgroundcontrol
4. PX4/jMAVSim : https://github.com/PX4/jMAVSim
5. Microsoft/AirSim :
   https://github.com/Microsoft/AirSim

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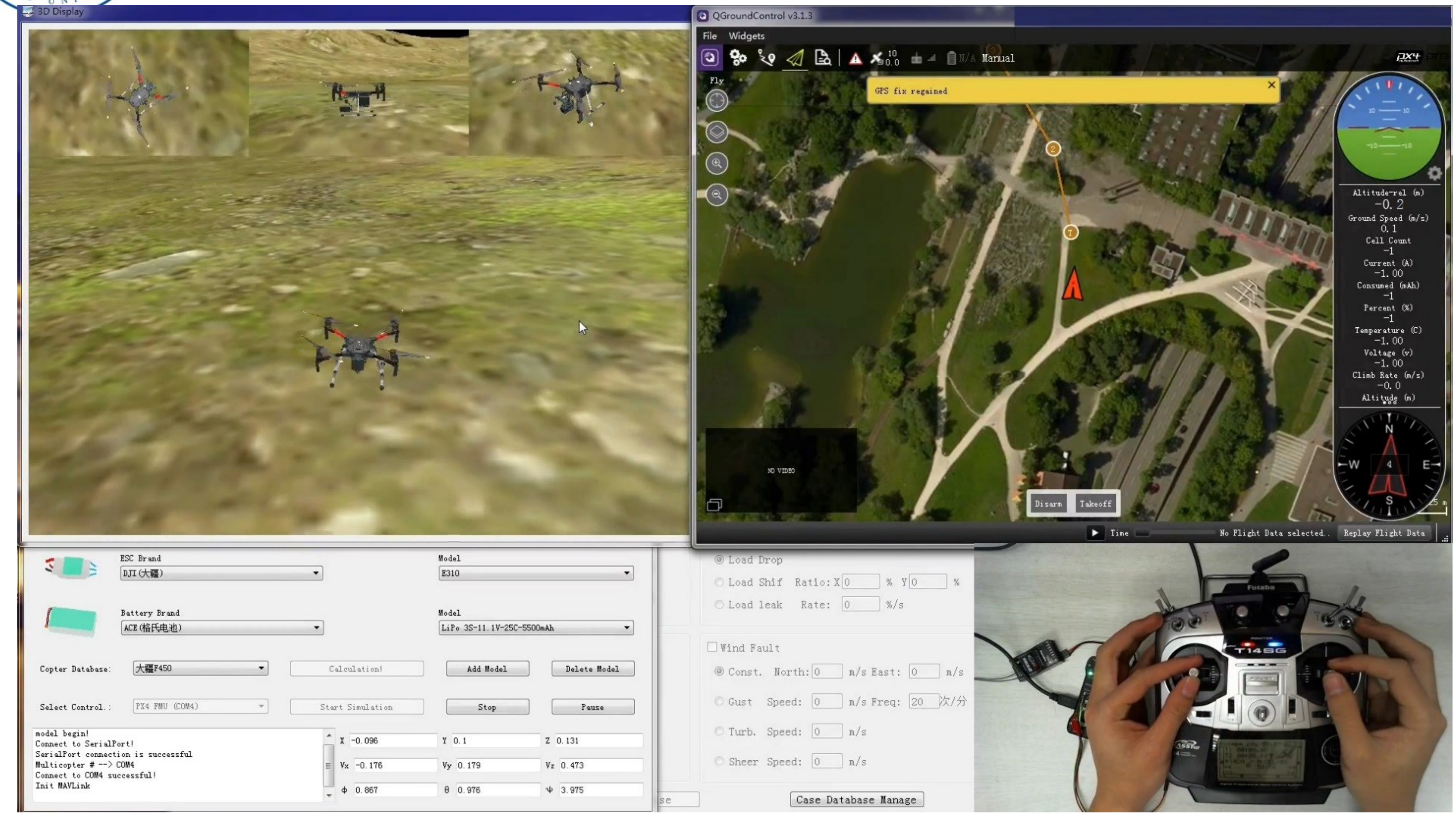
Demo Video



Youku : http://v.youku.com/v_show/id_XMzI0NzA2MTc2MA==.html

Youtube : https://youtu.be/-M9OMHFWO4w

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Traditional Design

Problems:

1. Test at final stage (too late for problems exposure).
   最后才测试，问题暴露时间太晚
2. Control algorithm by Manual coding (inefficient and low-reliability).
   手工编代码，效率低，可靠性低
3. Coupling of Software and hardware (hard to locate problem).
   软硬件耦合，发现问题难以定位错误位置
4. Hard to reuse codes
   代码复用率低，已有成果难继承

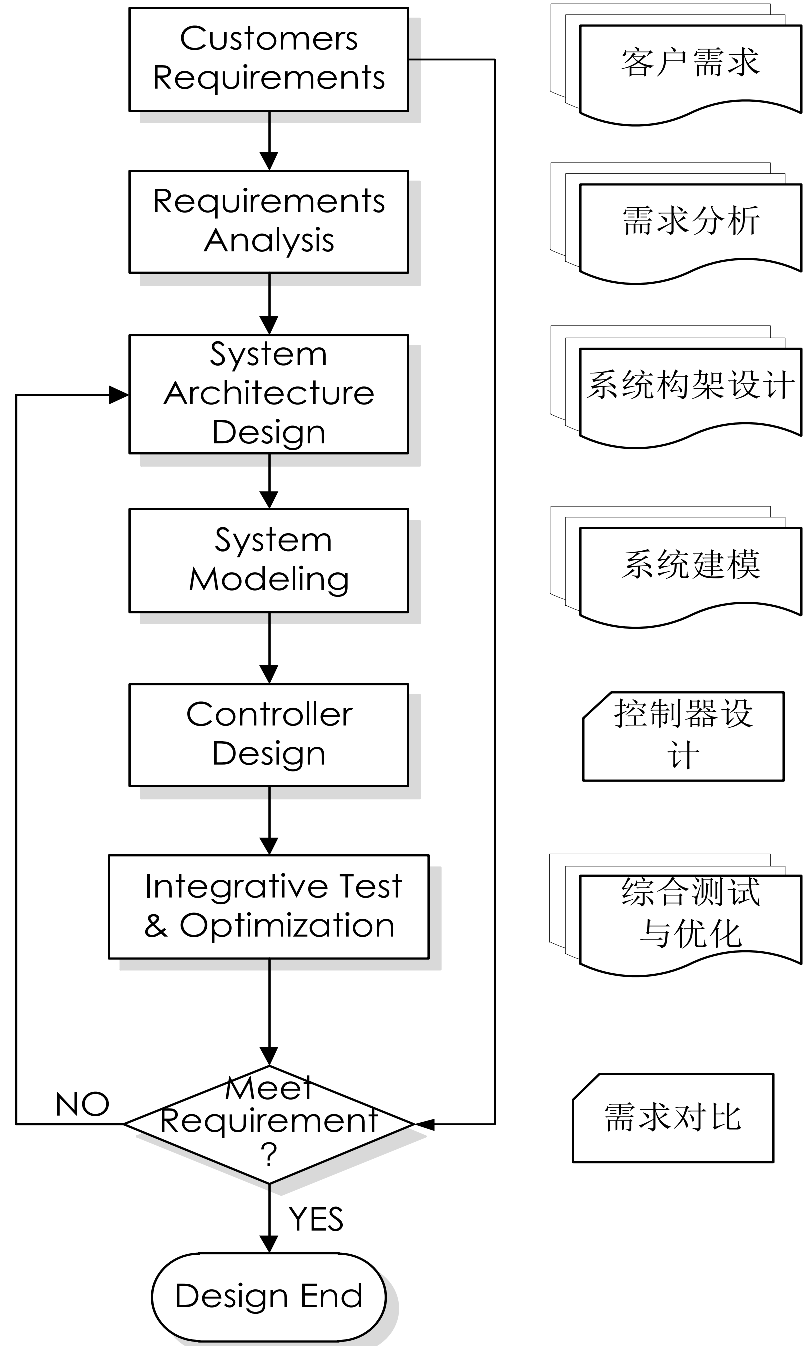

Fig. Flow Diagram of Traditional Design

Future UAV System Model-Based Design

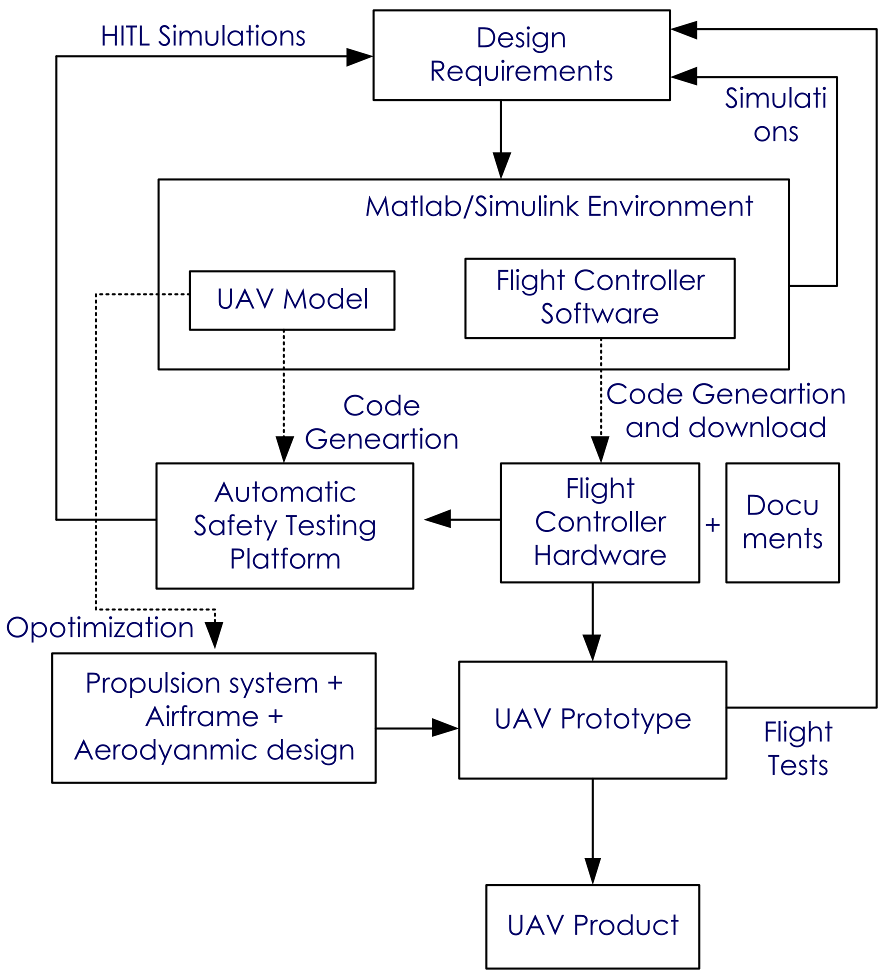

Fig. Structure of Mode-Based Design for UAV

1. Fast development with Matlab Toolboxes(Matlab丰富工具箱开发)
2. Graphical Programming (图形化编程)
3. Standards and Guidelines Compliance (遵循产品标准)
4. Auto-code/document Generation (代码+文档自动生成)
5. Verification and Validation (随时测试与验证)
6. Model Reusability (模型可重用)
7. Retention of Legacy Code (代码传承与维护)
8. Requirement Traceability (需求可追溯)
9. Continuous Integration and Testing (持续整合与测试)

Standards

- After certification standards for light UAV published.
  无人机标准发布后，如何测量无人机飞控功能？

- Test the basic functions of the flight controller on UAV
- Outdoor experiments?

- Inefficient, costly, complicated,…


JARUS

Joint Authorities for Rulemaking of Unmanned Systems
WG-3 Airworthiness

Certification Specification for
Light Unmanned Rotorcraft Systems
(CS-LURS)

Version 1.0
30-10-2013

Fig. JARUS_CS_LURS Light UAV Standard

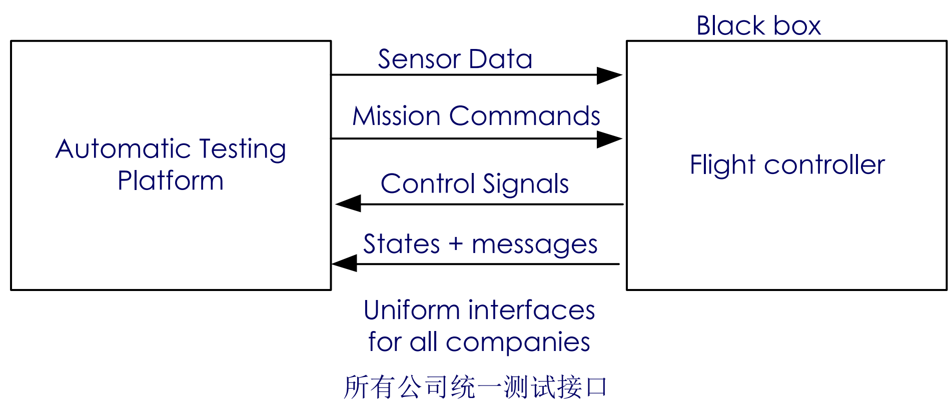

Fig. Structure of Multiple Flight Controllers Simulation

UAV Formation Simulation

- HITL Simulation for UAV Group
- Battery and load change Simulation
  电池与负载变化模型，适用于植保等多机协同仿真
- Algorithm development and verification

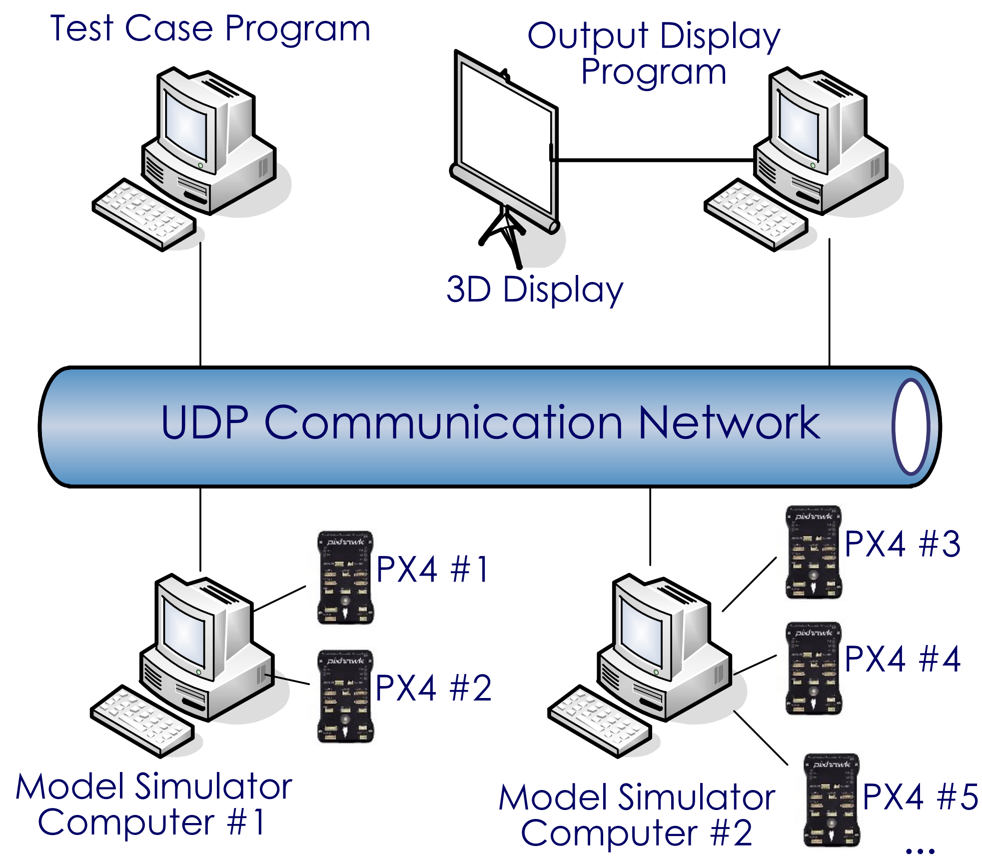

Fig. Structure of Multiple Flight Controllers Simulation

Other Types of UAVs

- HITL Simulation for New Configuration UAVs

Design Optimization with UAV Model

http://flyeval.com/recalc.html

Flying Evaluation

HOME DESIGN(Beta) BUGS&CONTACT ABOUT US LANGUAGE ▼

Frame Type	Total Weight ▼	Hovering Time	Flying Altitude	Design Application	Battery Density (*Optional)
QuadCopter ▼	1.5 kg	15 min.	50 m	Aerial Photography ▼	Wh/kg

Reverse Solution!

Recommended Configurations

Num.	Moter	ESC	Propeller	Battery	Frame Size	Hovering Time	Remaining Load	Weight
1	JFRC U2212 KV750	Hobbywing XRotor 20A	APC 10x4.7	Lipo 3S-11.1V-20C-6000mAh	450mm	26.6min.	0.3kg	1.5kg
2	JFRC U2208 KV1500	Hobbywing XRotor 20A	APC 10x4.7	Lipo 2S-7.4V-20C-9900mAh	450mm	24.7min.	0.3kg	1.5kg
3	JFRC U2206 KV1500	Hobbywing XRotor 20A	Carbon 8x3.8	Lipo 3S-11.1V-20C-7900mAh	360mm	22.6min.	0.3kg	1.5kg
4	EMAX MT2216-810KV	EMAX Simonk 12A	1055 Carbon Fiber	Lipo 3S-11.1V-20C-7100mAh	450mm	23.6min.	0.3kg	1.5kg
5	JFRC U2212 KV980	Hobbywing XRotor 20A	APC 9x4.7	Lipo 3S-11.1V-20C-6600mAh	400mm	23.6min.	0.3kg	1.5kg
6	T-MOTOR MT2208 KV1100	T-MOTOR AIR 15A	T-MOTOR 10*3.3CF	Lipo 3S-11.1V-20C-6900mAh	450mm	23min.	0.3kg	1.5kg
7	EMAX MT2208II-2000KV	EMAX Simonk 25A	HQ 6x4.5	Lipo 3S-11.1V-25C-7900mAh	270mm	20.9min.	0.3kg	1.5kg
8	T-MOTOR MT2212 KV980	T-MOTOR AIR 15A	T-MOTOR 10*3.3CF	Lipo 3S-11.1V-20C-6500mAh	450mm	23.1min.	0.3kg	1.5kg

flyeval.com

1. Input UAV Design Requirements (flight time, range, load capacity, etc.).
   输入设计需求
2. Calculation and Optimization with UAV Model.
   根据模型逆向求解与优化
3. Output Optimization Design Results Of Airframe Size, Weight, Brands and Models of Propeller, ESC, and Motor, etc.
   输出最优的尺寸、重量、电机电池等器件具体选型

Thank you!

Forewords
Vision: Reliable Flying Makes Life Easier
Objective: Develop evaluation and control methods to make flight reliable.
Logo :
北航可靠飞行控制研究室
BUAA Reliable Flight Control Group
网 址:
rfly.buaa.edu.cn

Test Content
Reliability : Reduce the Possibility of Fault
北航