Design of Simulation Test Platform for UAV Flight Control System

Xing Zheng, Chuanmei Bao and Zhongzhu He
Ordnance NCO Academy, Army Engineering University, Lo Yu Dong Road, Wuhan, China.
Email: zhengxcn@foxmail.com

Abstract. According to the analysis on the composition as well as functions of flight control system of unmanned aerial vehicle (UAV), the computer simulation test method of flight control and management based on simulation test platform is introduced, with the focus on fault injection and test method. Thereby putting forward the construction principle and test method for simulation test environment of flight control system. In the end, the follow-up development of the dynamic simulation test of UAV flight control system is pointed out.

1. Introduction
During its flight course, UAV can respond to ground operation and conduct various flight missions. Therefore, its flight control system is much more complicated than that of the general aircraft [1]. Hence, in order to guarantee high reliability, the test of its flight control system requires more than that of the general aircraft.

According to the test methods as well as the completed test items of all sorts of aircraft, it is the method "open-loop+static", which realizes the unit test of discrete components as well as the complete machine comprehensive test after installation of components, that is mainly adopted [2]. However, it cannot verify the dynamic performance during the actual flight course of UAV. Nor can it simulate the environmental disturbance factors like wind during the flight or the flight situation of UAV after the sensor failure. Since it fails to verify the correctness of interactive working between man and machine in data link during the flight course, it goes against carrying out targeted flight control, correction of flight management strategy and so on so forth.

As a result, it is necessary to construct a UAV flight working environment close to the reality with the use of simulation technology, so as to realize the in-depth and in-width close-loop dynamic test on flight control. It is particularly necessary to verify the coordination and correctness of the software and hardware system of the UAV flight control system, and to verify the rationality and adaptability of the flight control and flight management.

2. Composition and Functions of UAV flight Control System

2.1. System Composition
UAV flight control system is usually composed of sensor subsystem, fight control and management computer, servo-actuation subsystem, ground operation and display terminal [3].

Sensor subsystem can contain: (1) aircraft position/ speed sensor; (2) airspeed and height sensor; (3) attitude/ heading sensor; (4) angular rate sensor.

Servo-actuation subsystem includes elevator, rudder, control aileron, the other steering engines which deflect as required, as well as their controllers and engine throttle controller, etc.
As for ground operation and display terminal, they are comprised of mission planning, integrated remote test information display, remote operation, flight state monitoring and so on.

Flight control and management computer (hereinafter referred to as flight control machine) consists of system hardware and integrated control software, mainly responsible for information collection and processing, navigation solution and flight control, mission management and fire control, information monitoring and control output and so on. It plays the core role in UAV flight control system.

2.2. System’s Functions
The functions of UAV flight control system can be divided into flight control, flight management, mission equipment management and fire control.

Flight control is the most basic function of the flight control system. It usually involves: control modes like pitch/ roll/ yaw attitude control and stabilization, height control and stabilization, lateral deviation control and stabilization, speed control and stabilization, climb/ glide control, recovery/ landing control and so on.

And the flight management function generally contains: flight mission management and planning, judgement and treatment of airborne equipment failure, navigation solution, remote control and remote test management, etc.

Mission equipment management mainly controls and manages the mission equipment and monitors its working state.

Fire control is usually the function of UAV that can not only detect but also attack. It mainly consists of the examination and monitoring of carried weapons’ state, target binding, emission control, emergency delivery and so on.

3. Dynamic Simulation and Test Technology of Flight Control Machine
The flight control machine is in the core position in the UAV flight control system. Only by ensuring the reliability of the flight control machine can the UAV be carried out safely and correctly. Therefore, it is necessary to conduct the dynamic simulation test before the installation of the flight control machine. As a prerequisite to dynamic simulation test, the external working environment of flight control machine should be built firstly, based on which the dynamic simulations under the conditions of normal mode and fault injection mode can be carried out.

3.1. Dynamic Simulation and Test System of Flight Control Machine
The dynamic simulation and test system of UAV flight control machine internally integrates all the simulated cells of subsystem models cross-connected with flight control machine, except for the flight control machine itself. These simulated cells remain consistent with the actual subsystem’s hardware interfaces in terms of hardware interface. And a semi-physical simulation environment which specially targets at the dynamic simulation and test of flight control machine is formed. Its working principle is as indicated in figure 1.

3.1.1. System composition. The simulation and test system is mainly composed of two major parts, namely, system hardware and main control software [4]. System hardware, whose major function is to complete the transmission and interaction of signals between the simulation and test system and the flight control machine, is the foundation for the operation of simulation and test system; as the core of the simulation and test system, the main control software can complete functions like resolution of all the subsystem models of UAV, interaction of interface signals, real-time display and storage of simulation test data, control of simulation and test process, etc. It is able to satisfy the simulation and test demands of UAV flight control machine.

3.1.2. Working mode. The simulation and test system mainly contains the following working modes: (1)Mathematical simulation: based on the mathematical model of space flight path, the super real-time mathematical simulations of dynamics model and kinematics model solution as well as control system solution in the ideal state and in the situation where there are disturbances are realized through
computer programming. The result of mathematical simulation can act as one of the criteria for verifying the correctness of the work of simulation and test system.

(2) Physical simulation and test: when the flight control machine is in test, through air-frame dynamics and kinematics model, combined with the function of interface communication simulation, the software and hardware dynamic simulation test under the normal operation process is realized.

(3) Fault injection and test: when the flight control machine is in test, it can set the types and attributes of faults and carry out real-time injection of the faults, so as to achieve the dynamic simulation test of the flight control machine under the abnormal process where there are faults.

(4) Self-inspection of the system: complete the examination of the correctness of simulation test system’s interface operation as well as the examination of all the performance indexes, so as to ensure that the simulation test system is available before the simulation test.

To sum up, simulation test system possesses all the signal cross-link relationships of flight control machine and is able to conduct the real-time simulation of the working process as well as timing sequence of the external environment of the flight control machine. It can not only act as the dynamic debugging environment of the integrated control software and provide effective debugging approaches, but also act as the flight control machine’s comprehensive detection device and realize the dynamic test through simulation method.

**Figure 1.** Schematic diagram of simulation test system

### 3.2. Dynamic Simulation and Test of Flight Control Machine

3.2.1. Routine dynamic simulation test. The routine dynamic simulation test of flight control machine is a testing approach which verifies flight control machine’s functions, such as information collection and treatment, navigation solution and flight control, mission management and fire control, information monitoring and control output and so on, under the normal working process with mission constraint.

The method of implementing dynamic simulation test through the simulation test system is:

(1) Verify the simulation test system’s performance as well as the correctness of interface working through the working mode of system’s self-inspection, so as to ensure that the system is available.
(2) Figure out the standard flight path data with the use of the mathematical simulation mode of simulation test system.

(3) Conduct the physical simulation and test of the physical butt joint between simulation test system and flight control machine. Figure out the flight control machine’s remote test data as well as the real-time flight track calculation result (collectively referred to as real-time simulation and test data) received by the remote test interface of simulation test system.

(4) Through the contrastive analysis on real-time simulation test data and standard flight track data, the issue whether the flight control machine has problems or not can be verified and positioned.

3.2.2. Fault injection and test. In the actual flight of UAV, random faults may occur in every part of the aircraft due to the influence of the external environment. This requires that the flight control machine can respond and deal with it in time so as to reduce the loss to the maximum extent. Therefore, it is not enough to test the reliability of the flight control machine only through the conventional dynamic simulation test. It also needs to inject the fault in the dynamic simulation process to detect the fault handling capacity of the flight control machine.

The fault injection and test working mode of the simulation test system owns the following functions:

(1) Fault setting: it is able to set the types of faults flexibly in accordance with users’ demands. And the optional faults cover as many sorts of common faults as possible [5].

(2) Fault injection: inject faults of the required number to specific fault positions at specific time as demanded by the users, who can control the starting time and ending time of fault injection and also monitor the fault injection situation anytime during the process.

(3) I/O transmission of real-time data: all sorts of signals of injected faults can be delivered to the flight control machine.

(4) Preservation and analysis of experiment results: it is able to preserve the experiment data of fault injection dynamic test in the form of files for the analysis of experiment personnel, so as to judge the flight control machine’s capacity of failure response and treatment.

Under the simulation test system’s working mode of fault injection and testing, hardware failure simulation of the peripheral equipment cross-linked with the flight control machine can be realized through software. Fault injection is flexible and adjustable and easy to be conducted.

Take a certain type of UAV, whose flight control machine owns double-channel back-up airborne interface of measurement and control, as an example. Under normal conditions, a channel receives remote control commands and sends remote measuring data. However, when a channel goes abnormal, the flight control machine may open B channel to conduct the function. In the dynamic simulation test of the flight control machine of the certain type, the failure case lost by the remote control command of the airborne interface of measurement and control, namely, a channel has been set. And the failure model is Data→no Data. Its attribute belongs to RS-422 serial port permanent fault. The fault injection process is as shown in figure 2.

After the dynamic simulation test of simulation test system, it is discovered that the flight control machine can detect faults immediately after fault injection and switch B channel to receive remote control command automatically and also deliver remote measuring data, which insures the correct response to remote control command and fulfills missions like mission equipment management and fire control, etc. Besides, it can download remote measuring data immediately for the experiment personnel to monitor the state, so as to minimize the influence brought by failures.

4. Dynamic Simulation and Test Technology of Flight Control System

4.1. Construction of Flight Control System’s Dynamic Simulation and Test System
The dynamic simulation and test of UAV flight control system is the dynamic simulation and test which involves flight control machine, sensor subsystem, servo-actuation subsystem and so on inside the loop, and is usually called as the semi-physical simulation experiment of flight control system, which can create a dynamic testing environment closer to the actual flight for flight control system’s tested objects, such as flight control machine, all sorts of sensors and servo-actuation systems, etc.
The semi-physical simulation test system of flight control system is composed of simulation software, simulation equipment, and flight control system’s tested objects and so on, which build a semi-physical simulation experiment network through real-time optical fibre communication device.

Apart from the simulation machine responsible for simulation model solution and experiment dispatch and control, as well as the interface computer responsible for signal conversion as well as data communication, the simulation equipment also contains the devices simulating the operating characteristics of various sensors.

The construction of semi-physical simulation test system of flight control system takes the tested objects and experiment aim as the principle. The corresponding semi-physical simulation experiment system is combined in the way of modular block building.

4.2. Dynamic Simulation and Test of Flight Control System

The most significant function of flight control system’s dynamic simulation and test is used in parameter testing of flight control. The original design is adjusted and completed based on the simulation test results. After repeated simulations, the ideal parameter of control system is acquired. Moreover, it can also be applied in the verification of the special handling function (such as combined altitude correcting algorithm, etc.) during the joint operation between the flight control machine and various sensors as well as servo-actuation subsystems.
With the use of all sorts of simulation devices inside the semi-physical simulation experiment system, dynamic simulation and test on the tested objects of the entire flight control system can be realized:

1) Through simulation software, typical interference section dynamic simulations, such as constant wind, gust, turbulent flow disturbance, constant torque disturbance, aerodynamic coefficient deviation and so on, can be realized [6]. Check the adaptability and robustness of flight control system’s control parameters and verify the rationality as well as correctness of flight control scheme and control parameter.

2) In the devices simulating the operating characteristics of various sensors, failure simulation can be carried out by man to check sensors’ capacity of emergency response to abnormal conditions, thereby verifying the fault treatment process of flight control system.

3) Faults can also be injected through interface machine software (the method is similar to simulation test system’s fault injection and test) to test the fault treatment capacity of the entire flight control system and verify the working coordination, security as well as reliability of flight control system’s each software and hardware.

5. Conclusion
The importance of flight control system to UAV is self-evident. Dynamic simulation and test of flight control system has become an indispensable developing and testing approach during the development process of UAV system. An increasing amount of vital equipment in UAV has been participating in the dynamic simulation test loop of flight control system. The follow-up dynamic simulation and test environment of flight control system will develop to be in greater consistence with the real sky and ground.

6. References
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