Ground Test and Evaluation of a Flight Control System for Unmanned Aerial Vehicles

Jinyoung Suk*
Department of Aerospace Engineering, Chungnam National University,
220 Gung-dong, Yuseong-gu, Daejeon 305-764, Republic of Korea

Jinhyung Kim**
Simulation Division, Dodaam Systems, Ltd.,
461-36 Junmin-dong, Yuseong-gu, Daejeon 305-811, Republic of Korea

Abstract

UAV(Unmanned Aerial Vehicle) has become one of the most popular military/commercial aerial robots in the new millennium. In spite of all the advantages that UAVs inherently have, it is not an easy job to develop a UAV because it requires very systematic and complete approaches in full development envelop. The ground test and evaluation phase has the utmost importance in the sense that a well-developed system can be best verified on the ground. In addition, many of the aircraft crashes in the flight tests were resulted from the incomplete development procedure. In this research, a verification procedure of the whole airborne integrated system was conducted including the flight management system. An airborne flight control computer(FCC) senses the external environment from the peripheral devices and sends the control signal to the actuating system using the assigned control logic and flight test strategy. A ground test station controls the mission during the test while the downlink data are transferred from the flight management computer using the serial communication interface. The pilot control box also applies additional manual actuating commands. The whole system was tested/verified on the wind-tunnel system, which gave a good pitch control performance with a pre-specified flight test procedure. The ground test system guarantees the performance of fundamental functions of airborne electronic system for the future flight tests.

Key Word : UAV, Ground Test and Evaluation, Flight Test, Flight Management System, Communication Interface, Pilot Box, Wind-Tunnel, Airborne Electronic System

Introduction

UAV(Unmanned Aerial Vehicle) is defined by a high-performance aerial vehicle that can perform autonomous navigation flight and specific missions on telemetry command from GCS(Ground Control Station). In general, UAV systems are composed of GCS and air vehicle, which is consisted of an airframe, engine and onboard electronic devices. FMS(Flight Management System), power management system, sensors and actuators comprises onboard electronic devices. FMS is the key of airborne electronics: it generates the actuator control command based on various flight information from

* Professor
E-mail : jsuk@cnu.ac.kr, TEL : 042-821-6685, FAX : 042-825-9225
** Research Engineer

AHRS(Attitude and Heading Reference System), air data sensors and uplink data from GCS. It also controls the mission payload and downlinks the necessary flight data to GCS. Since the UAVs have much more risks and loss of aircraft during operation than manned vehicles, the ground test and evaluation stage has become one of the most important phases in UAV development. In a ground test phase, testing in environment that UAVs may encounter in real flight reduces the dangerous factors. An evaluation phase can help aircraft perform successful missions by analyzing ground test data.

Evaluations of the flight control algorithms are achieved in part by PILS (Processor-In-the-Loop Simulation) using onboard FCC or HILS(Hardware-In-The-Loop Simulation) for more advanced evaluation, while true evaluation is performed directly through flight tests[1-4]. Also, extraction of aerodynamic stability derivatives and performance analysis of the designed aircraft can be tested for a limited degree of freedom using wind tunnel or floating the aircraft in the air using magnetic field[5-6].

In this paper, we discussed some practical aspects of ground test and evaluation of UAV including thrust test, wind tunnel test, and on-road test. In wind tunnel test, longitudinal stability of aircraft was identified, and the evaluation of sensors and navigation system were evaluated in on-road test. Remote commands for the autonomous flight are transmitted by pilot control box and test data for evaluation are transferred simultaneously through RS-232 data communication interface between onboard flight control computer and ground control system.

Ground Test and Evaluation

2.1 Flight Control Computer for a UAV

Fig. 1 shows a configuration of a FCC used for the development of a UAV. Navigation system and sensors transmit the real-time position, altitude, and other flight information to FCC and FCC sends out control commands for autonomous flight to actuators. Also, they exchange uplink/ downlink data through a communication system.

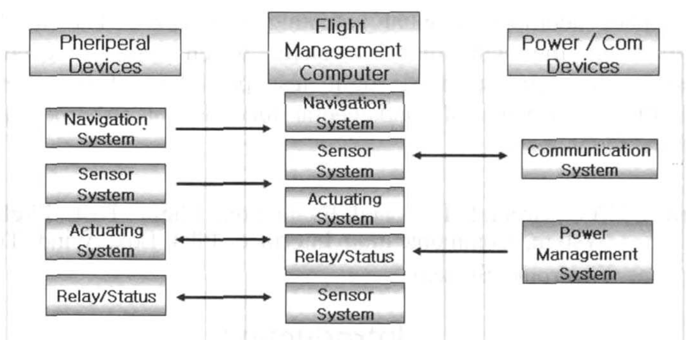


Fig. 1. A Schematic of FCC

The power management system provides stable driving power required for FCC, various sensors and actuators. The hardware of the onboard FCC is a small-sized and lightweight, but high-performance industrial level computer shown in Fig. 2, interfacing with the peripheral devices such as Multi-I/O, PWM(Pulse Width Modulation) device. The sensor and actuating system provide real time flight information to the FCC. Navigation devices are GPS and AHRS system measuring 3-D aircraft position and attitude. Both of them transmit flight information to the FCC through RS-232 data communication. Also, a pitot-static system measures pressure altitude, airspeed, angle of attack, and sideslip angle of the aircraft, respectively. The air data measured from the pitot-static system are directly applied

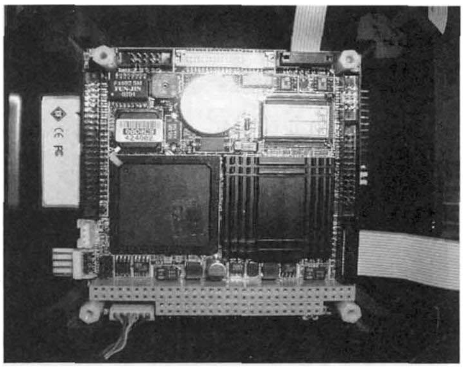


Fig. 2. Flight Control Computer

Table 1. FCC Hardware Specification

Memory	144pin SODIMM 128MB
SSD	Compact Flash Card 256MB
Multi I/O	16CH 12bit A/D 2CH Counter/Timer
Operating Temperature	0 ~ 60℃
Operating Humidity	0 ~ 90%
Size	96mm x 90mm
Weight	1.4 Kg (including Case)

Table 2. Navigation and Sensor System Specification

Navigation System	Data Range > 100Hz Attitude Roll ±180° Pitch ±90° Yaw 0 ~ 360° Resolution 0.1° Temperature -40~+85℃	
Altimeter	Type A	Altitude Range -300 ~ +3,000 m Accuracy 2.1~3.3 m Environment Temperature -55~+71℃ Vibration 10g, 5~2000 Hz Shock 15g, 11ms half sine
	Type B	Pressure Range 20~105kPa Accuracy 1.8% Temperature -40~+125℃ Sensitivity 0.054V/kPa
Airspeed Indicator	Pressure Range 0~3.93kPa Accuracy 1.5% Temperature 0~+85℃ Sensitivity 1.0V/kPa	

to the control algorithm of FCC, so FCC can control flight altitude and airspeed. Channel-wise distributed actuating signals commanded by the PWM device drive the servos, which control throttle, aileron, rudder and elevator. Deflection of each control surface is fed back by the potentiometer mounted at the surface. It is verified by the loaded/unloaded frequency sweep test that the selected control servo provides sufficient bandwidth.

2.2 Thrust Modeling

Propulsion system is the main driving unit for FCC. And it is very important to model the propulsion system in flight control system design via ground thrust test. While most reliablemedium/large-sized propulsion systems have their own performance data and quality control, stable performance are not guaranteed for small, low cost engine-propeller systems. That is why we didprecise thrust tests. Thrust tests were performed on three individual parameters: altitude, airspeed and throttle position. Thrust measurement test with respect to the airspeed is performed using

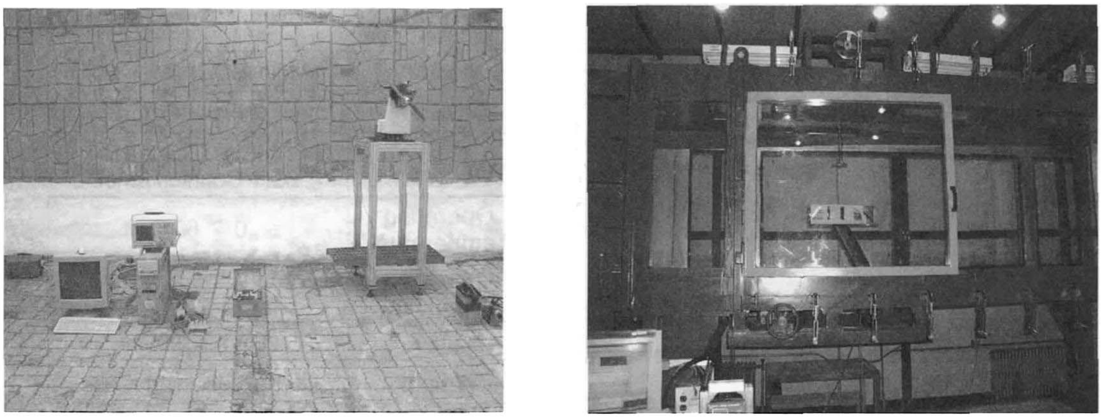


Fig. 3. Ground Thrust Test w.r.t. Altitude and Airspeed

medium-type subsonic wind tunnel. It was difficult to get accurate measurement data in the test because of the severe vibration caused by the propeller and detonation of engine. Also, an electronic noise problem due to a bunch of signal lines was resolved by a D.C. stabilization device and proper grounding. Fig. 4 shows 3-dimensional modeling results with respect to the airspeed, altitude and throttle through ground thrust test. As expected, thrust of the propulsion device reduces as the airspeed increases, and it is inversely proportional to the flight altitude. Also, thrust at an altitude of 1000 meters reduces almost 25% lower than that in sea level. The thrust at low subsonic section is approximately 60 ~ 70 percents of that at zero airspeed, increasing according to the throttle position. Also, the low RPM region is treated as dead-band by the flight control computer because the RPM of the reciprocating engine fluctuates seriously at this region.

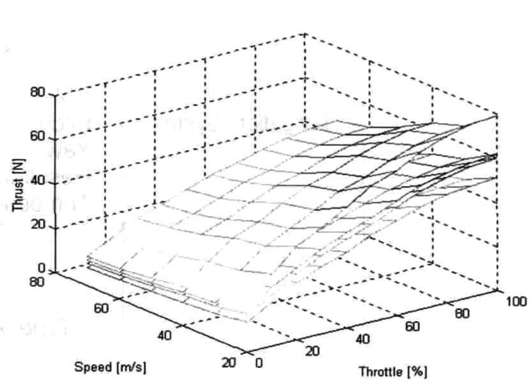


Fig. 4. 3-Dimensional Thrust Modeling

2.3 Wind Tunnel Test and On-Road Test

This section deals with the longitudinal stability test of a complete UAV. We used a medium-sized subsonic wind tunnel whose performance specifications are shown in Table 3. Fig. 5 shows an installed aircraft for wind tunnel test. One end of the pipe is connected to the upper part of the wind tunnel, and the other end is connected to the C.G(center of gravity) of the aircraft. A set of ball bearings is used to provide free pitching motion. Also, GCC(Ground Control Computer) and FCC exchange uplink pitch command and downlink data using a wired serial communication. The stability and command tracking capability of the aircraft were verified with respect to the various airspeed through pitch command itself and flight mode application.

Table 4 shows test flight modes applied in wind tunnel test. The time and amplitude of each input signal are set differently, with respect to the mode change. Whenever the ground control computer applies a specific flight mode flag to the FCC, the FCC sends out the computed actuating commands to the actuator. Fig. 6 shows the response of the servo deflection and the pitch attitude with respect to the pitch command and the flight mode. The figure also shows the response of the actuator when the pitch commands are engaged/disengaged. As shown in the figure, servo response appears a while after the flight mode and servo command are engaged, and we can see that the servo is tracking commands well.

Table 3. Wind Tunnel Performance Factor

Closed Type Wind Tunnel	
Test Section	1.25Wx1.25Hx4.0 L(m)
Max Speed	70 m/s

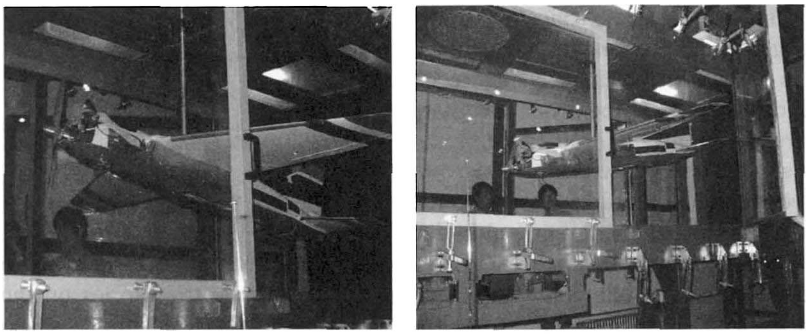
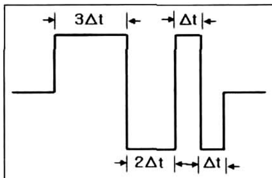


Fig. 5. Wind Tunnel Test

Table 4. Summary of Flight Modes



Mode	Δt	δ_E
1	1.0	2°
2	0.5	2°
3	0.2	3°

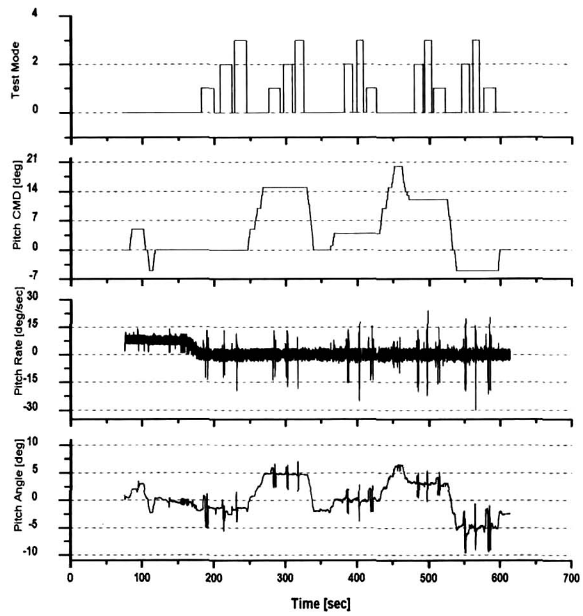


Fig. 6. Responses of the Aircraft with Flight Mode and Pitch Command

The evaluation of navigation and air data sensors that offer important aircraft information was performed in on-road test. In this test, the real aircraft was mounted on the roof of a car and the test data was transferred from FCC of the aircraft to the ground control computer inside the car in real time while the car is moving around. The on-road test is performed as the last evaluation phase of the ground tests in order to calibrate various kinds of sensors. The performance of GPS was tested throughout the whole trajectory from Daejeon to Jangsoo, and the results are shown in Fig. 7. As is shown in the track comparison of departure and return, it can be concluded that the position error is within the acceptance limit. The trajectories of the altitude sensors are shown in Fig. 8. Three individual altitude sensors were equipped in the aircraft: the reference altitude sensor, GPS altitude, and another test altitude sensor. The other altitude sensors were evaluated and calibrated based on the reference altitude sensor. The altitude trajectories on the whole show similar responses with some bias shift. After the calibration of the test altitude sensor, the bottom figure shows only a bias error between the test sensors and GPS altitude. It is because the pressure sensor was not compensated as the absolute sea-level altitude. Also, it can be revealed that the GPS altitude error drift was not that large and bounded within a hundred meters. Airspeed sensor output is shown in Fig. 9, showing irregular fluctuations. These drifts were due to ambient atmospheric disturbance from the wake of the convoy car. There were many cars running in the highway and it was impossible to remove the effect of atmospheric disturbance. The airspeed sensor was calibrated through wind tunnel test earlier and Fig. 9 shows the calibrated sensor output with respect to the wind tunnel airspeed

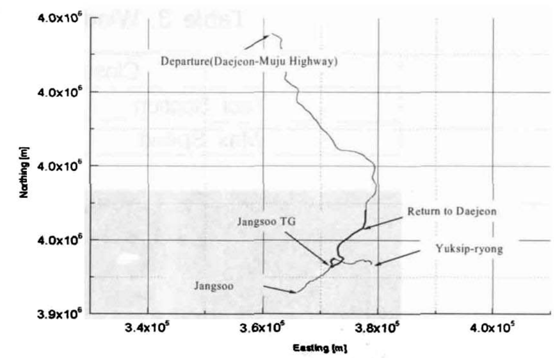


Fig. 7. Trajectory of the Air Vehicle

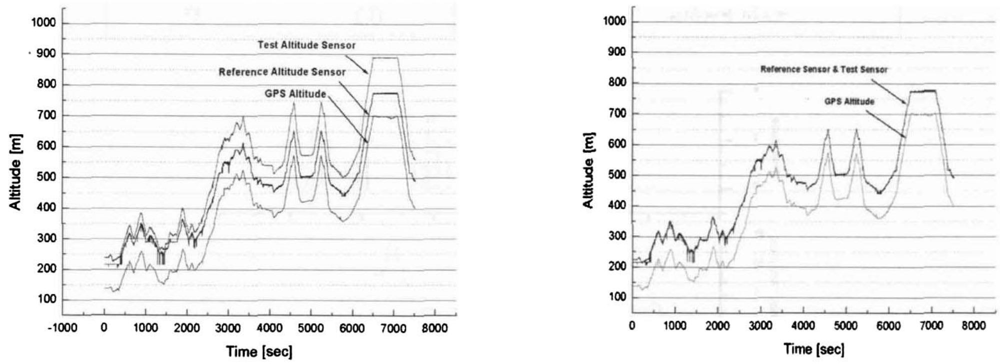


Fig. 8. Altitude Trajectory of the Air Vehicle

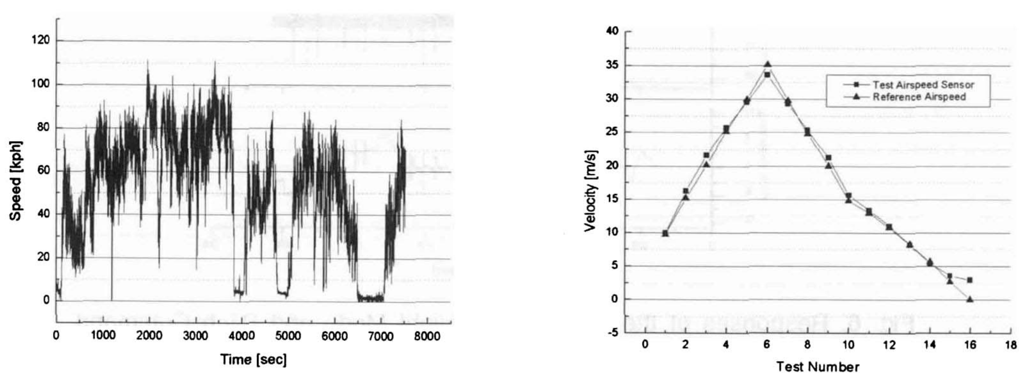


Fig. 9. Results of the Airspeed Sensor

Conclusions

The ground test and evaluation play a very important role in UAV development before the real flight test. It is too much to treat the entire ground test and we briefly described the three main phases of the ground test: the thrust test, the wind tunnel test, and the on-road test. The sensors, actuators, propulsion devices, and FCC of the aircraft are evaluated from various ground tests. The test results showed that the performance of fundamental functions of the flight control system is acceptable for the flight test.

Acknowledgements

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References

1. Y. Nam and J. Ko, Application Technology of the R&D Aircraft Simulator, *ICASE Journal*, Vol. 3, No. 2, 1997, pp.64-77.

2. Y. Kim, M. Tahk, and J. Lee, "A Study on Hardware-in-the-loop Simulations of a Flight Control System," KSASS Journal, Vol. 22, No. 2, 1994, pp.81-92.

3. S. Lee, V. Povstyanoy, K. Noh, J. Park, S. Ko, " A Study on Engineering Software Design for Aircraft Development," Proceedings of the KSAS Annual Conference, 1999, pp.100-104.

4. S. Yoon, "Airplane R&D Simulator," KSASS Journal, Vol. 30, No. 7, 2002, pp.150-162.

5. Jessica A. Woods-Vedeler, Anthony S. Pototzky, and Sherwood T. Hoadley, *Active Load Control During Rolling Maneuvers,* NASA-TP-3455, 1994.

6. Nelson J. Groom, *Simplified Analytical Model of a Six-Degree-of-Freedom Large-Gap Magnetic Suspension System,* NASA-TM-112868, 1997.