

# The Development of Low-Cost Ground Simulator for Aircraft Flight Testing and Performance Evaluation

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**Abstract:** This paper presents the development of a ground simulator for use in aircraft flight testing and performance evaluation during the conceptual design phase of autopilot system. The development of the ground simulator is mainly based on the Visual Basic (VB) software including VB and Global Majic Software (GMS) Active X components, aiming to have features of low cost, high reliability with the aircraft 6-DOF model, and used as a test-bed with visualization environments. The simulator provides a modularization approach to include upload and download data for communications with the other computer having the control law design for the autopilot tests and flight performance evaluation. The entire system is then demonstrated through an unmanned aerial vehicle (UAV) design to ascertain the whole approaches.

**Keywords:** Ground Simulator, Aircraft Performance, Flight Testing, Unmanned Aerial Vehicle

## 1. Introduction

Current trend in unmanned aerial vehicle (UAV) development makes gradually emphasis on autonomous, control-independent and multi-purpose flight system, which usually facilitates flight management system (FMS), autopilot system, flight control system, efficient communication system, and data-collection system [1, 2]. The Remotely Piloted Vehicle and Micro-satellite Research Laboratory (RMRL) in the Institute of Aeronautics and Astronautics, National Cheng Kung University (NCKU) has devoted its resources and efforts for many years in the development of UAV and microsatellites. RMRL's research topics include the design and manufacture of the UAV development, Global Positioning System (GPS) for navigation, application payload system, and real-time trajectory and navigation system. RMRL's recent typical work is mainly to develop a low-cost differential GPS and payload system for unmanned aerial vehicle [3]. In order to achieve the mission of UAV's autonomous flight trajectory planning, a more expensive equipment including on-board computer, sensors and actuators and remote sensing system shall be installed to fulfil this goal. It is the current objective to integrate the whole subsystems with an unmanned vehicle to fly autonomously according to the prescribed trajectory. Therefore, in consideration of the flight testing reliability and equipment protection, all systems including hardware and software on-board the aircraft shall be carefully tested on the ground, especially the catastrophic emergency may occur due to failure of aircraft

flight instability, lost contact from poor signal communications or electromagnetic interference. This paper hence makes emphasis on the development of a ground simulator using existing software in two personal computers to perform the aircraft flight tests and performance evaluation before proceeding the real flight tests. The simulator is also to be used as a handy tool of educational purpose for aerospace engineering students in control law design and stability evaluation of the aircraft.

## 2. UAV's automatic structure on board the computer system

As the unmanned aerial vehicle (UAV) is designed to have the capability of autonomous navigation, the computer system aboard the vehicle containing the hardware and software equipment is important to conduct the stability and control calculation. The UAV's autopilot system is one of the primary systems to be able to perform the stable flight trajectory during the flight course. The on-board computer (OBC) shall govern and monitor all processes during the flight program, which shall include the receiving sensors' data, calculating the aerodynamic control law, sending commands to the actuators, and scheduling the procedures. Fig. 1 schematically describes the whole processes of the OBC for the UAV, which will be used as a real-time platform to receive, calculate, upload, and download the data for each subsequent process monitoring.

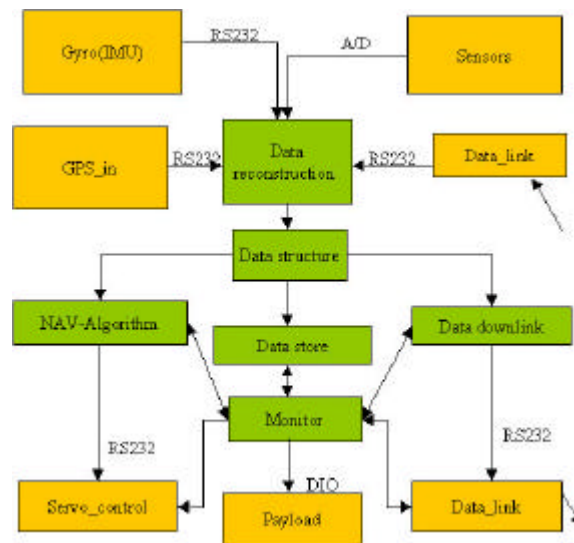


Fig. 1. OBC processing diagram.

## 3. Architecture of the ground simulator system

In order to facilitate the usage of the ground simulator, the relevant software used here is called the Visual Basic (VB). The simulator's primary function is to provide the visualization testing environment of the UAV's automation system and dynamic performance evaluation. The fundamental layout is shown in Fig. 2. On the basis of the ground simulator shown in Fig. 2, the dynamic model in six degrees of freedom (6-DOF) of the airplane's motion should be as accurate as possible to provide the aerodynamic coefficient data, which is also used as the control law design testbed. Fig. 3 describes the operation diagram of the ground simulator for the control law design.

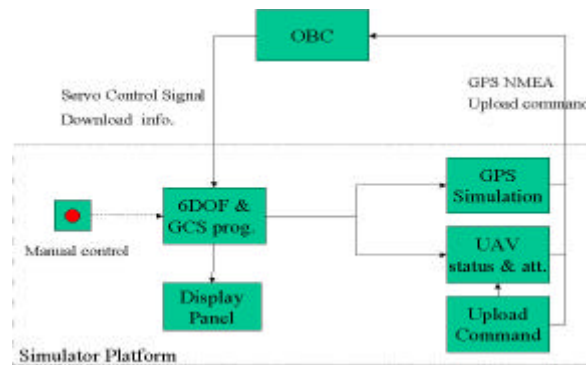


Fig. 2. UAV automation's OBC system and ground simulator

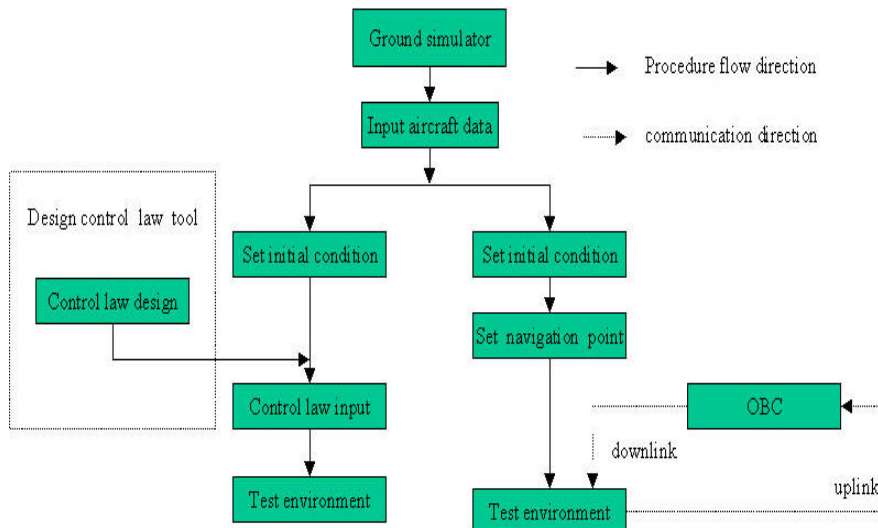


Fig. 3. Ground simulator operation diagram

### 3.1 Input the aircraft data

This ground simulator can provide students or other users with interactive performance and handling qualities for a variety of aircraft types with given aircraft properties including dimensions, aerodynamic coefficients, aerodynamic derivatives, static stability features and propulsion. All of the data above should be provided by students or users through calculation, wind tunnel tests or specifications from the airplane manufactures. The more accurate the data available, the higher accurate model will be. The GMS components have three different kinds of airplanes, which includes Cessna 182RG, F/A18 Hornet and Boeing 747-200. In this way, the students can set their airplane to simulate the dynamic performance of the airplane.

### 3.2 Setting initial condition

After choosing which airplane's model to be studied, the users should input the initial conditions for the airplane. The initial conditions of the simulator including the aircraft coordinates, initial position, speed, altitude and attitude are going to be used in the followings. The system has three different kinds of coordinates, North East Down (NED) flat Earth in feet, Universal Transverse Mercator (UTM) in meters, and Geodetic (Latitude/Longitude) in degrees.

### *3.3 Navigation point*

In this stage, there are two ways to input the navigation points. One way is to enter the navigation points directly; the another way is to enter the navigation points by using a mouse moving on the map. The upper bound is 255 navigation points.

### *3.4 Control law design tool and control law input*

In Fig. 3, the dashed-line box shows the control law design tool. Because the Microsoft Visual Basic doesn't have the control law design's Active X component, the users must design the control law from their own methods. However, the Matlab tool, for example, can help users in deriving the control law gain. In this respect, users can easily try different control-law gains to test and improve their vehicle's dynamic performance in the visualization pseudo environment rather than in actual flight-testing.

Another benefit of this process is that the 6-DOF simulation model of the airplane is closely related to the actual flight model. Since most students usually design their control laws by assuming the linear flight dynamic model of airplane, therefore, the users can quickly distinguish the difference between the linear and non-linear model. For the future development, the control-law design tools for the system can be integrated with the Labview environment to enhance the capability of the ground simulator.

### *3.5 Test environment*

This window displays the flight states including aircraft's position, speed, altitude, attitude and heading of user's desired airplane. It provides the visualization interface between the users and flight conditions. Therefore, one can easily analyze the flight results of the dynamic flight performance.

Since the simulator has two modes, the test environment also has two kinds of windows. One is for the use of the OBC testing environment, the other is the control-law design test environment. When the OBC testing mode is used, the PC installing simulation program has to communicate with the OBC, which is to be placed in the UAV, through the serial ports (COM1 or COM2). Besides selecting which serial ports to send or receive data, the communication protocol also needs to be pre-determined. The simulator provides several kinds of communication Baud rate (bit per second) and parity check modes. In addition, the integration time of the 6-DOF model is limited by the GMS aircraft dynamic Active X component. In order to match the command sent from OBC's navigation commands with the dynamic model integration time, users also need to select the navigation command time interval. The current simulator provides two frequencies, 1 Hz and 10Hz. In our test case, the Baud rate of the GPS data communication is 9600 bps, parity check is N81, and the integration time of the system is 10Hz.

After completed the settings of the communication protocol and the integration time interval in order to test the OBC's other functions, the simulator needs to receive all download commands from the OBC. These commands comprise 5 different packages including navigation point data, control command, payload situation and DGPS data. All of the commands are transferred from binary to ASCII code, so the simulator needs to retransfer. Besides receiving and sending data or commands, one of the primary functions of the simulator is to produce pseudo GPS data in accordance with the high-accuracy 6-DOF dynamic model and the OBC's control-law to be carried out. Above all, the simulator is used to check and correct the OBC's algorithm.

Another mode is the control-law test environment. After applying the control-law gains and initial conditions into this environment, the airplane will follow the 6-DOF model to fly in the map. Users can see the aircraft's altitude, speed, attitude and heading in the PC screen. Besides, the program also records the airplane's data to be analyzed afterwards. If the flight states and path don't satisfy user's requirements, the simulator can redesign the control law. In short, the test environments will provide as the visualization platform to demonstrate all the data which users will be used.

#### **4. Benefits of ground simulator operation in engineering education**

The usage of the low-cost ground simulator in flight tests and dynamic performance evaluation can be widely used in engineering education. Through the on-line visualization and high accuracy 6-DOF model, teachers can use this software as a teaching tool for such courses as flight dynamics and stability analysis to help students in understanding the effect of the control surface, aerodynamic derivatives of the airplane, and control-law design. In addition, the visualization airplane's instruments and its arrangement are similar to the real aircraft and easier to be used. In the UAV autopilot design, we have tested the whole autonomous flight planning in a PC, which indicates that the developed ground simulator is very much beneficial to the aerospace engineering students.

#### **5. Concluding remarks**

This paper describes the development of the ground simulator and the usage of this program for the aircraft dynamic performance and analysis. Based on the concepts of low-cost and causing no physical damages to the aircraft prior to the flight test, users can utilize this ground simulator to develop their whole OBC system or hardware testing, especially for the development of the whole autopilot system in school. In addition, because the environment is also implemented as a visualization interface, the engineering students can be trained easily by operating the simulator. Another benefit of the developed simulator is that one can enhance the simulation capability by adding some Active X components. As results, the ground simulator then plays an important role in education, training, testing, and research.

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