Computational Simulation of flight behavior of Flying Wing UAV

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Abstract – *The aim of this work is to model and simulate a Flying Wing Aircraft and acquire flight data from two different simulations. The framework proposed constitutes of the development of a graphical model as well the use of a mathematical model of the aircraft. In order to simulate realistic flight conditions, we used a commercial flight simulation environment, X-plane 10. We performed the real time flight data collection from the simulator, as well as the software-in-the-loop feedback control through MATLAB/Simulink.*
Key-words: *UAV, Software In the Loop, Hardware In the Loop, X-Plane, Simulink, Flying Wing*

Introduction

In the recent years, computational simulation has been an important tool for data acquisition, and in providing essential information about the behavior of mechanical systems [1]. In the aerospace industry, simulations are used throughout the development of all aircraft, and they evaluate the control algorithm allowing for easy manipulation of the early model. This allows for faster development of the product, as well as minimizing the number of experimental flights. Thus, reducing the number of persons involved and consequently the final cost of the project [2].

Several commercial simulators are available and used as a tool, known as Software-In-the-Loop (SIL), for the implementation of flight dynamics, navigation control, and for validating models in a precise fashion before field tests [2]. Despite simulation-based testing being a very important part of the product development, Hardware-In-the-Loop (HIL) simulation tests should be adopted whenever it is possible in order to validate together both the hardware and the software under realistic conditions [3].

In the specific case of Unmanned Aerial Vehicles (UAV) the mathematical model, as well as the implementation of SIL and HIL were describe by Markin at all (2010) [4]. It not only describes the physics of the system but also the behavior of the low-level autopilot, and the state estimation routines.

UAVs are of high interest for prospective military and civilian applications due to their several advantages such as maneuverability, and lack of need of direct human interaction [5]. The literature shows several works of multirotor aircraft modeling [6, 7]. However, more detailed modeling of flying wings and their integration with SIL and HIL is still a growing field of high interest [8].

The objective of the present work is to, first, graphically and mathematically model the flying wing. Second, to simulate the aircraft dynamics, using the commercial flight simulator X-Plane (Laminar Research©) and the mathematical software MATLAB/Simulink (MathWorks©). Finally, perform tests and acquire flight data.

Materials and methods

The methodology was organized as follows. Section 1 introduces the procedure and the software X-Plane used for the modeling. The next section describes the flight dynamics of a fixed wing UAV and the implementation of its control laws through Simulink. The communication between the X-Plane and MATLAB/Simulink, for the simulation of the UAV flying, is presented in section 3. Section 4 briefly describes the control systems.

Modeling

The flying wing was modeled using the platform Plane-Maker, built into X-Plane 10, which enables the creation of any aircraft. With its graphical interface, the user can have a visual feedback of the in-flight behavior of the aircraft once all the physical characteristics are applied to the model. X-Plane 10 is a realistic flight simulator certified by the Federal Aviation Administration (FAA), and a viable tool due to its aircraft creation environment and its ability to simulate the aircraft dynamics. Through the combination of both these assets, we obtained the graphical model of the UAV.

The UAV chosen for this project was a commercial RC Flying Wing (Figure 1B), and its characteristics are shown below (Table 1). This specific model did not exist in the X-Plane database; therefore, we modeled it from scratch. The dimensioning of the reference model is very important because X-Plane separates the aircraft into small sections to calculate several aerodynamic factors on each, ensuring that the entire aircraft is being computed. This methodology is based on a theory called *Blade Element*, which is explained by [6]. The model was created in the Plane-Maker according to the specifications of the actual model and following the guidelines recommended by the platform's manual [9].

After modeling and adjusting all parameters of the Flying wing in Plane-Maker, following the same dimensions, weight and CG of the real aircraft, we implemented the control laws using the software MATLAB/Simulink, in order to test control algorithms and navigation of the aircraft.

Table 1. Flying Wing characteristics list.

Properties	**Value**	**Units**
Total Mass (payload + batteries)	0.652	$[kg]$
Aerodynamic Reference Area (S)	0.35	$[m^2]$
Wing Sweep Angle (Λ)	31	$[deg]$
Root Aerodynamic Chord ($\bar{c}$)	0.31	$[m]$
Tip Aerodynamic Chord ($\bar{c}$)	0.2	$[m]$
Lateral Reference Length (b)	1.20	$[m]$
Airspeed (V_T)	40	$[m/s]$
Flight path angle (γ)	0	$[deg]$
Altitude (h)	150	$[m]$
Wing Airfoil	MH-45	

Mathematical Modeling

The dynamics for fixed-wing aircraft can be approximately decomposed into longitudinal motion. Aiming to obtain the mathematical model that describes the longitudinal dynamics, a series of considerations are made to obtain the equations, some are described below:

a. The Earth is the inertial reference system;

b. The aircraft is a rigid body and its weight is a constant;

c. Acceleration of gravity does not change with flight altitude;

d. The Sideslip Angle (β) is considered null;

e. The disturbances around the equilibrium are small, with small variations to the pitch angle (θ);

f. The deflection of the elevator does not alter any force, only the moment of pitch.

An aircraft usually has 6 degrees of freedom (6DoF), that can be described by equations of forces and moments acting on it, and presents nonlinear dynamics [13]. Using these nonlinear equations of the longitudinal dynamics, and the calculation of the forces and moments through the stability and control derivatives (obtained from flight test data), we can finally simulate the flight of the UAV. For this, MATLAB/Simulink was used. The simplified steps and calculations for the mathematical modeling of the longitudinal dynamics of a fixed wing UAV are described below [14].

I. Determined the Flight condition for the simulation: cruise flight, velocity and altitude (table 1); as well as the dynamic pressure and Reynolds number;

II. The derivatives of stability and control used were based on the work of Markin at all (2010) [4];

III. And finally, the aerodynamic coefficients (C_L,C_D,C_M); the aerodynamic forces and propulsion; and moments were computed.

Framework Simulation

MATLAB/Simulink is an environment for simulation of dynamic systems. It provides a customizable set of block libraries that enables the user to design, simulate, and test a variety of systems time-varying. This platform presents ready blocks for performing communications with external environments, allowing data exchange. Therefore, a block diagram was created in Simulink aiming to send flight control to the model built in the platform X-Plane. The controls details for the architecture used for this project can be found at [15].

For the communication between the two platforms, X-Plane for simulation and Simulink for control, we configured the UDP blocks for receiving and sending data in both software as explained by [2].

UDP is a transport layer protocol, where each output operation of a process produces exactly one UDP datagram, causing one *Internet Protocol (IP)* datagram to be sent, an in-depth description can be found in [6]. The simulation used constitutes of two computers that use an Ethernet network with IP addresses defined for each, which allows data exchange between MATLAB/Simulink and X-Plane, as illustrated below (Figure 1). Both software were configured for sending packets and data, following the guidance at [2]. The MATLAB PC generates the error signal through a reference signal and feedback data provided by X-Plane. Then, it uses the error signal as input to the control law, thus generating a command signal for the motors that will be sent back to X-Plane. Finally, X-Plane PC receives the command data for the engine, executes the interactions and sends the new data position to the MATLAB PC again [10]. This communication procedure is explained in detail by [11, 12].

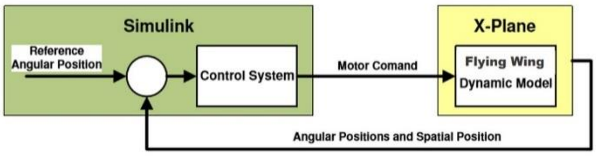

Figure 1. Simulation loop. Source: modified from [10].

Control System

The Flying Wing is a tailless fixed-wing aircraft that has no definite fuselage. Because of it lacks conventional stabilizing surfaces and the associated control surfaces, this type of aircraft suffers from the inherent disadvantages of being unstable and difficult to control. Therefore, a PID (Proportional-Integral-Derivative) Controller system for the pitch and roll was necessary to perform the flight tests for both analytical and graphical methods.

Results

Based on the real RC UAV specifications, the Flying Wing was successfully modeled in Plane-Maker environment, as illustrated below (Figure 2A). Then, flight tests were performed in X-Plane as shown below (Figure 3), using the same flight conditions as on the analytical flight tests.

With the Flying Wing model in flight, it was necessary to adjust the PID Controller, in order to enter the cruise flight phase at a specific velocity and no roll attitude.

Thus, once on a cruise flight, the aerodynamic coefficients, propulsive, and aerodynamic forces were obtained and could be compared directly with those calculated by the analytical method. This comparison is shown below (Table 2). It is important to emphasize that X-Plane considers the wing area as the wing area plus the area of the horizontal stabilizer, differently from the normal way adopted by the aerodynamic concept. Thus, this factor can be one of the reasons of the differences found.

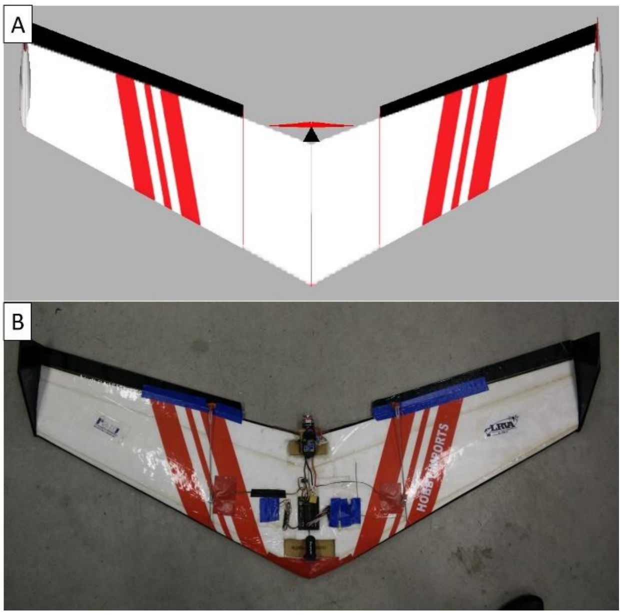

Figure 2. (A) Flying Wing model built in Plane-Maker. (B) RC Flying Wing model used as reference for the project. Source: The author.

Figure 3. Flight test of the Flying Wing in X-Plane. Source: The author.

Table 2. Comparison of forces and aerodynamic coefficients.

Parameter	Analytical Method	X-Plane Simulation
Lift	33.268 lb	33.640 lb
Drag	4.568 lb	4.608 lb
Lift/Drag	7.283 ratio	7.301 ratio
Thrust	1.136 lb	1.205 lb
c_L	0.7958	0.872
c_D	0.0642	0.0535

Discussion

Both platforms used for this project are great tools for simulation of early aircraft models to obtain flight data in different conditions, facilitating a prediction of its behavior and performance during the flight before manufacturing a prototype. The flight simulator X-Plane along with MATLAB/Simulink have shown high confidence level and reliability in modeling and simulating, providing strong expandability for data collection and wide application in aircraft project development.

The model created in Plane-Maker opens up numerous possibilities for applications, enabling in depth studies of Flying Wings Aircraft design, also the testing of several techniques for control and navigation algorithms.

The next development step, which will be tackled in future work, is the Hardware In The Loop (HIL) simulation and other control laws, which in turn, would receive the state variables generated from the simulator and calculate the control signals injected into the simulated plant.

In conclusion, the acquisition of data from the modeling of an aircraft and its flight simulation could lead to a disruptive approach in aircraft design, potentially reducing time and costs necessary to manufacture a final prototype. The results of this work are part of an ongoing undergraduate thesis project.

References

[1] SKIRA, Charles A., Reducing the cost of advanced technology engines, AIAA 97-3156, 33rd Joint Propulsion Conference, Seattle, WA.

[2] BITTAR, A; FIGUEIREDO, H. V; GUIMARAES, P. A; MENDES, A.C. Guidance Software-In-The-Loop simulation using X-Plane and Simulink for UAVS. International Conference on Unmanned Aircraft Systems (ICUAS) May 27-30, 2014. Orlando, FL, USA.

[3] SANTOS, S. R. B; JUNIOR, S. N. G; JUNIOR, C. L. N; BITTAR, A; OLIVEIRA, N. M. F. Modeling of a Hardware-In-The-Loop Simulator for UAV autopilot controllers. 21^{st} Brazilian Congress of Mechanical Engineering October 24-28, 2011, Natal, RN, Brazil.

[4] MARKIN, S. Multiple Simultaneous Specification Attitude Control of a Mini Flying-Wing Unmanned Aerial Vehicle. Thesis for the degree of Master of Applied Science. University of Toronto.

[5] SILVA, W. R. Modelagem, simulação e controle de um veículo aéreo não tripulado (VANT) de asa fixa. Trabalho de conclusão de curso - Engenharia de controle e automação, Universidade Federal De Santa Maria, Santa Maria - RS, dez 2015.

[6] FIGUEIREDO, H. V. Simulation Platform for Quadricopter: Using MATLAB/Simulink and X-Plane. 2012. Dissertação de mestrado — Department of graduate studies of the Aeronautics Institute of Technology, Instituto Tecnológico de Aeronáutica.

[7] HENZ, G. Modelagem e desenvolvimento de controlador de voo de um veículo quadrirotor. Trabalho de conclusão de curso - Engenharia de controle e automação, Universidade Federal de Santa Maria, Santa Maria - RS, dez 2015.

[8] BEARD, R.; MCLAIN, T. Small Unmanned Aircraft: Theory and Practice. [S.L.]: Princeton Univesity Press, 2012. (Princeton University Press).

[9] RESEARCH, L. Plane Maker Manual. 2013.

[10] FIGUEIREDO, H. V; BITTAR, A. Platform for Quadricopter: Analysis and Applications. International Conference on Unmanned Aircraft Systems (ICUAS). Orlando, USA - May, 2014.

[11] L. R. Ribeiro, "Plataforma de testes para sistemas de piloto automático utilizando MATLAB/Simulink e simulador de voo X-Plane," Mestre Em Ciências, Instituto Tecnológico de Aeronáutica, 2011.

[12] A. Bittar, Piloto Automático Para VANT 'S TUTORIAL Comunicação X-Plane Simulink, 2011. [Online]. Available: Https://Pilotoautomaticovant.Wikispaces.Com/Tutorial+Xplane+%26+Simulink

[13] HULL, D. G. Fundamentals of Airplane Flight Mechanics. [S.l.]: Springer, 2007.

[14] SILVA, N. M. Modelagem e Simulacao de Veiculos Aereos Não Tripulados no Simulador de Voo X-Plane. Anais do XXII Encontro de Iniciação Científica e Pós-Graduação do ITA - XXII ENCITA / 2016 Instituto Tecnológico de Aeronáutica, São José dos Campos, SP, Brasil, XXII 14 de outubro de 2016.