Development of Tools and Methods for Autonomous Fixed-wing UAV Research

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Abstract—Development of tools and methods to aid in the research of fixed-wing Unmanned Aerial Vehicles (UAVs) is presented. A Remote-Controlled (RC) model aircraft is used as the target airframe. The flight simulator X-Plane 10 is used for the grey-box modelling and MATLAB/Simulink is used for the white-box modelling. XFLR5 is utilised to obtain crucial aerodynamic data. The process of constructing the flight model on X-Plane 10 via a set of software tools and the development of a 12-state, six-degrees-of-freedom MATLAB/Simulink based simulation are demonstrated. The method presented demonstrates useful applicability.

Keywords—UAV, HITL, GNC, Simulation, Modelling

I. INTRODUCTION

Autonomous systems, like fixed-wing UAVs, employ two major operational modules: high-level Guidance and Navigation algorithms and low-level control laws. Whereas the former module, Guidance and Navigation, is concerned with tasks such as localisation, path-planning, state estimation, etc., the latter module focuses on transcribing these higher level outputs to low-level outputs (for example: deflecting a control surface to alter the flight trajectory). These modules together can be thought of as the Flight Control System (FCS). The field of Guidance Navigation & Control (GNC) is where various disciplines within Robotics and Aerospace Systems converge. The increasing global demand for autonomous flying vehicles with ever increasing applications has highlighted certain shortcomings pertaining to fixed-wing UAVs. While fixed-wing UAVs offer greater operational range, fuel efficiency and payload carrying capabilities, they have yet to benefit from appropriate level of attention from researchers.

There are various challenges a researcher may face with in this complex interdisciplinary area of research. The inability of fixed-wing UAVs to hover or fly at low speeds (relative to rotary wing design) translates to a very unforgiving (high risk of crashing) situation for flight tests. To avoid collisions and crashes of fixed-wing UAVs, the researchers then have to conduct every flight test outdoors, which is not necessary for rotary wing designs. Even with that problem resolved, researchers are left with the challenge of devising autonomous precision landing and take-off from designated airstrips. In the absence of that, whether the UAV carries scientific-research payloads or is being deployed to deliver emergency medical payloads, it remains a high risk endeavour. This calls for greater emphasis to be placed on the need for higher fidelity mathematical modelling and simulation along with means of testing both the software and hardware prior to real flight test [1]. In this paper, the development of a test bench which utilises common software packages, open source codes and hardware, simulation software etc. to aid researchers in the field are presented.

II. TEST BENCH SETUP

A. Target Airframe: FMS SkyTrainer 182

Fig 1: Target RC Airframe

A 1410mm wingspan RC airframe [2] based on the Cessna 182 has been acquired to be used as the target airframe.

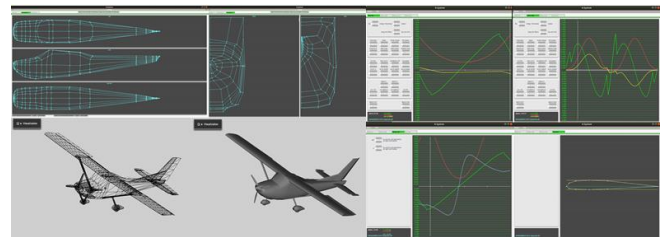### B. X-Plane Modelling and Simulation:

Fig 2: Plane Maker & Airfoil Maker X-Plane modelling

X-Plane 10 is an FAA (Federal Aviation Administration) certified flight simulator which comes with tools such as Plane Maker and Airfoil Maker [3]. Plane Maker enabled the construction of a flight model of the target airframe to be used by the simulator. Airfoil Maker enables generation and/or editing of aerofoil data to enhance the realism of the simulation. X-Plane allows communication over the User Datagram Protocol (UDP), which makes it possible to control the aircraft externally (e.g. with Simulink) and capture the live flight data (simulated).
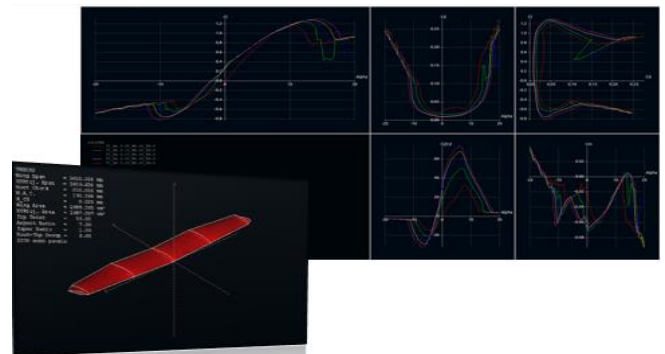
C. XFLR5 Wing Analysis:

Fig 3: Wing Aerodynamics analysis on XFLR5

The aerofoil data in X-Plane is typically applied to high Reynolds' number flows and therefore does not accurately model the behaviour of a small aircraft. XFLR5 (based on XFoil) is a freely available and open source tool that produces reliable aerofoil/wing data for aircrafts in low Reynolds' number regimes (50k to 250k) [4]. Given the specific geometry of the target aerofoil, it generates reliable curves/graphs representing its aerodynamic characteristics (polars). This reliability refers to the consistent polars and plots that match the experimental (wind tunnel) data for the same aerofoil [4]. Therefore, the resulting polars were utilised to generate aerofoil data to be used as inputs to the X-Plane model. The parameters obtained also aid in the construction of the simulation discussed in the following section (section D).
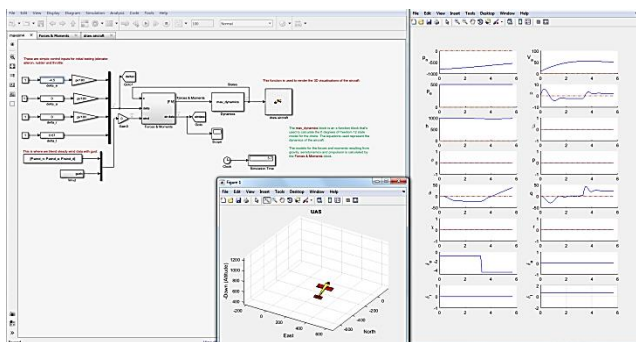
D. MATLAB/Simulink Models and Simulation:

Fig 4: Simulink Simulation of the target airframe

A 12-state, 6 degrees-of-freedom MATLAB/Simulink simulation was developed. The Forces & Moments acting on the UAV and associated Flight Dynamics parameters were modelled with appropriate first order ODE's. S-function blocks [5] were utilised to make custom-blocks for the Forces & Moments and Dynamics. This allows for complete control over the underlying mathematical equations. This model includes the capability to communicate over UDP, a visual output, environmental modelling (e.g. Dryden Gust Model [6]), and interfacing with a flight controller. Beard & McLain (2012) presents much of the general outline of this simulation in the form of skeletal MATLAB and Simulink files. However, the researcher must write appropriate codes based on suitable mathematical models to make these skeletal files functional.
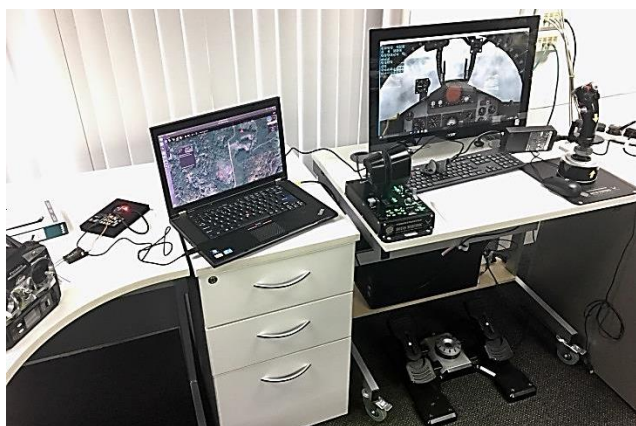
E. HITL Simulation:

Fig 5: Hardware-In-The-Loop (HITL) simulation test

The open-source flight controller Pixhawk and flight control software PX4 has been used alongside QGroundControl (GQC) [7] to establish communication between X-Plane and the controller. By modifying the code of the FCS, it is possible to test the Pulse width modulation (PWM) servo outputs during the Hardware-In-The-Loop (HITL) simulation. It is also possible to develop an FCS on Simulink and deploy that on the Pixhawk through the Pixhawk PSP package [8] for Simulink's Embedded Coder.

III. RESULTS, DISCUSSION & CONCLUSION

The goal was to present a test-bench that addresses many of the problems faced by researchers whilst working with fixed-wing UAVs. The mathematical models were implemented in the form of a Simulink simulation. X-Plane 10's built in modelling tools were utilised to create an X-Plane simulation of the target airframe. One problem with such modelling is the absence of quality aerodynamic data on the aerofoil being used. It was demonstrated that via the use of tools like XFLR5, it is possible to obtain appropriate aerodynamic data and improve the simulation fidelity without the reliance on resource intensive wind tunnel testing or complex Computational Fluid Dynamics modelling.

Finally, a practical application was demonstrated in the form of a HITL simulation. Such simulations allow researchers to test the behaviour and performance of the flight code in a safe context where modelling errors, hardware faults and various other bugs in the overall system can be identified and dealt with without risking damage to the actual UAV and its systems in real flight. Once actual flight tests are conducted and appropriate flight data are recorded, the researcher benefits from important insights from juxtaposition of the flight data against the two simulation's predictions. This allows for fine-tuning of the models and higher simulation fidelity. The overall setup presented here can also be exploited to conduct studies on a range of topics such as Guidance Algorithms, State Estimation, Parameter Identification and Sensor Fusion.

REFERENCES

[1] J.R. Raol, J. Singh, Flight Mechanics Modelling and Analysis, , CRC Press, Boca Rayton Florida, 2009, chapter 6-9

[2] FMS Models, FMS SkyTrainer 182, http://www.fmsmodel.com/fms-1400mm-sky-trainer-182-5ch-at-red-pnp, retrieved on 28/03/2018

[3] FAA Certified X-Plane, https://www.x-plane.com/pro/certified/ retrieved on 28/03/2019

[4] Drela M. XFOIL: an analysis and design system for low Reynolds number airfoils., University of Notre Dame, 1989

[5] Simulink S-Function, Mathworks User Guide, https://uk.mathworks.com/help/simulink/sfg/what-is-an-s-function.html, retrieved on 28/03/2019

[6] Dryden Wind Turbulence Model, Mathworks https://uk.mathworks.com/help/aeroblks/drydenwindturbulencemodel continuous.html retrieved on 28/03/2019

[7] The Pixhawk Project, PX4, QGC and Pixhawk, http://pixhawk.org/, retrieved on 28/03/2019

[8] Pixhawk PSP package, Pixhawk Support From Embedded Coder https://uk.mathworks.com/hardware-support/px4-autopilots.html retrieved on 03/03/2020

[9] BEARD, R., & McLAIN, T., "Small Unmanned Aircraft: Theory and Practice". Princeton, Oxford: Princeton University 2012