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EXECUTIVE SUMMARY OF THE THESIS

Aeroswitch Project: update of SwitchMaster flight simulator

LAUREA MAGISTRALE IN AERONAUTICAL ENGINEERING - INGEGNERIA AERONAUTICA

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1. Introduction

This Master thesis work is the natural development of Aeroswitch project [3], born in the context of academic course *Aircraft Design* at Politecnico di Milano and presented at the 2020 American Institute of Astronautics (AIAA) competition for graduate students.

1.1. Electrification of aircraft

Nowadays, lots of pressure comes from public opinion and customers to improve the effort in designing greener transportation vehicles. However, while electrification of ground applications is well underway, on aircraft is still in the early stages of development. A critical aspect is the fact that aircraft need batteries with high energy densities and power. Despite this, the electric aircraft has higher efficiency and power-to-weight ratio, less or no pollution, lower operation costs, and the possibility to install novel propulsive configurations. One of these is Distributed Electric Propulsion (DEP): its key aspect is the using of a large number of electrically-driven propulsors which are electrically connected to energy sources. The set of propellers creates a blowing effect on the wing, which increase the relative velocity of free stream on airfoils: as a result, equal lift is pro-

duced with smaller surface, then weight.

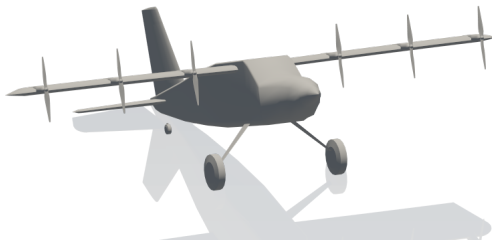
1.2. Aeroswitch concept and the SwitchMaster

As outcome of *Aircraft Design* course, held by professor Lorenzo Trainelli and professor Carlo E.D. Riboldi, AeroSwitch team projected the *Trybrid*. This aircraft exploits the advantages of DEP to simulate the behaviour of a single or multi-engine, propeller driven, trainer. Its first development was the *SwitchMaster* (fig. 1(a)), a scaled demonstrator realized modifying an existing RC model through the installation of DEP. In parallel with *SwitchMaster* physical aircraft building and testing, a flight simulator (fig. 1(b)) of it was developed using X-Plane[©] and Simulink[®] [1]. The main goal of the simulator is creating a platform on which testing a flight control system for the physical aircraft, able to fix the issues in piloting given by DEP. In fact, at low throttle settings, the propeller windmilling highly disturbed the airflow on the wing, negatively affecting flight conduction. As a consequence, the landing phase should be performed with high RPM and a reduced flare

1.3. Goal of the present work

The present work focuses on some critical aspect of flight simulator: in particular, in the latter it was impossible to reproduce experimental flight inputting real flight data. These were reproduced by the pilot through the use of a joystick USB connected: a clear obstacle for an objective evaluation of the simulator fidelity. Consequently, the goals of the present work are:

- development of a procedure to couple X-Plane with Simulink, in order to send to the simulator an input stored during experimental flight test;
- updating of X-Plane aircraft model from experimental data.



(a) Aircraft X-Plane model.



(b) Aircraft real model.

Figure 1: The *SwitchMaster*.

2. Using X-Plane for simulating experimental tests

The role of Simulink in the initial configuration was the one of governing the input to X-Plane from the joystick to flight surfaces and engines. The communication between X-Plane and Simulink is allowed by User Datagram Protocol (UDP): its peculiarity is that no reception control of the message sent is performed: this downgrade the safety, but ensure an high rate of words sent. However, X-Plane allows to send a great set of flight data in output, such as air data

or system states. The interface has been modified in order to substitute the joystick governing block with a series of blocks that permit to send X-Plane some input data, stored in a row vector, with the correct sampling time. This action has been performed with a block that interpolate the time of experimental flight data (sampled every 0.1 s) with X-Plane flight time, in order to send to the simulator the correct input at the correct instant. A test has been conducted to verify the procedure: a rudder input has been delivered to X-Plane with a joystick, and relative output (r and δ_R itself) has been stored. After, the stored input has been sent again via Simulink, and the same output has been overplotted with the original one. With reference to fig. 2(a), it is possible to observe the presence of a delay between real, or target flight histories, and the replicated one. The delay is independent from sampling time of data. From this, it stood out the necessity of interpolating the time with a certain advance, to anticipate a delay in communication between Simulink and X-Plane. The advance time has been fixed to 0.0653 s: repeating the test with the modification, the result obtained has been the desired one in fig. 2(b).

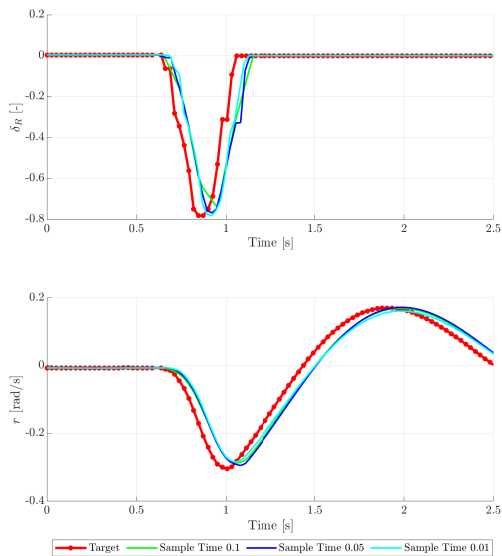
3. Update of X-Plane aircraft model

After having solved the problem of inputting flight data signals to X-Plane, the method to obtain an aircraft model that behaves as the real one has been taken in account. This consists in two steps: in the first it is performed the iterative repetition of a specific experimental flight test for different values of a specific geometrical parameter, saving in an a suitable structure the relevant flight data; in the second a functional, based on the flight data, is calculated to find which configuration (or witch iteration) correspond to the best match of data.

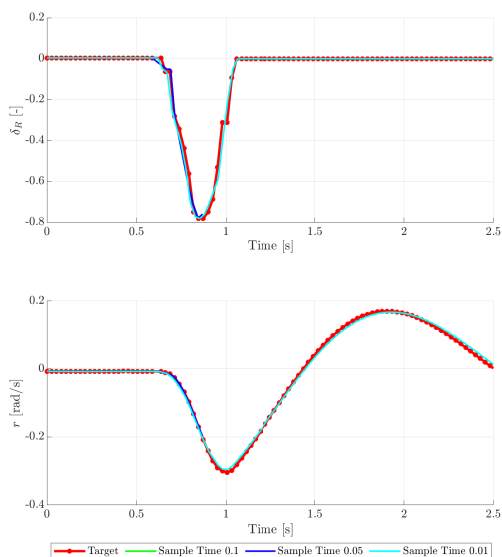
3.1. Iterative repetition of flight test

First step of the procedure is governed by a MatLab routine, able to put in communications Simulink and MatLab. The routine executes following actions:

- Update the aircraft configuration file with new geometrical parameter. This action is performed modifying the aircraft configuration file, written in text format, in X-Plane



(a) Test data without the insertion of advance.



(b) Test data with the insertion of 0.0653 s advance.

Figure 2: Validation test data.

installation folder;

- Update the aircraft model in running simulation on X-Plane. The action is performed pressing a pre-assigned keyboard letter on X-Plane (that execute the instruction) through a MatLab command, that is able to digit keyboard letters on another running program;
- Move aircraft to initial position for flight test. The action is performed likewise previous step;
- Execute Simulink simulation, in order to

perform the manoeuvre on X-Plane;

- At the end of Simulink simulation, flight data are reported on MatLab workspace. Those data should be stored in suitable structures.

3.2. Functional evaluation

After having stored all the data for each iteration, the functional can be evaluated a posteriori: as a result, the configuration that generate flight data closer to the target solution is figured out as the minimum of the functional itself. As in [2], to use the *output error method* it is necessary to define a function to be optimized, that depend on the error between predicted output (simulated aircraft) and real output (real aircraft). The function to be optimized is reported in eq. (1).

$$J(\boldsymbol{\theta}) = J_A + J_B \quad (1)$$

$$J_A = \frac{1}{KN} \sum_{i=1}^N \boldsymbol{\nu}(i)^T R^{-1} \boldsymbol{\nu}(i) \quad (2)$$

$$J_B = \frac{1}{2} (\boldsymbol{\theta} - \boldsymbol{\theta}_{\text{bsl}})^T \Sigma_P^{-1} (\boldsymbol{\theta} - \boldsymbol{\theta}_{\text{bsl}}) \quad (3)$$

J_A , in eq. (2), is a contribution of J that depend on the error between flight data of actual iteration with a target flight history, namely the experimental one. In fact, in vector $\boldsymbol{\nu}$ are collected all the error, instant by instant, of the relevant flight data, weighted on square matrix R . K is the total number of relevant flight data, and N is the total number of instant. J_B , in eq. (3) is a contribution that increase J as the parameter set is different from the baseline. This is aimed to obtain a final geometry that is not so different from the original (ore baseline) one, since the latter is closer to real aircraft model.

3.3. Test of the method

The whole method has been tested as it follows: a default X-Plane aircraft has been piloted in a dutch-roll excitation. Lateral directional flight data (p , r , ϕ , ψ , β) has been stored. Successively, span of the rudder has been increased of a certain value, which as been assumed as baseline. The iterative procedure as been set up, and the functional in eq. (1) as been calculated. The outcome was a rudder span with an error smaller than 5%, which was acceptable.

4. *SwitchMaster* model identification

4.1. Flight model fidelity

Through the upgrade described in section 3, it has been possible to evaluate objectively the *SwitchMaster* flight model with respect to physical aircraft behaviour. During the flight test campaign, many test points has been performed: unfortunately, the difficulty in piloting, together with the gust susceptibility (due to low weight aircraft), have greatly compromised the data. Most of them are not usable for computations and analysis. At the current time, *SwitchMaster* identification and fidelization procedure has been performed firstly by the lateral directional point of view, since no longitudinal manoeuvre has been achieved sufficiently. In a future development also this aspect should be taken in account. A roll excitation and a dutch roll excitation has been taken in account. These flight tests has been repeated on X-Plane: the roll dynamics has been evaluated as really close to the real one, while the lateral had a period mismatch. Consequently, the identification procedure has been set up on geometric parameters that are relevant for yawing, as in fig. 3.

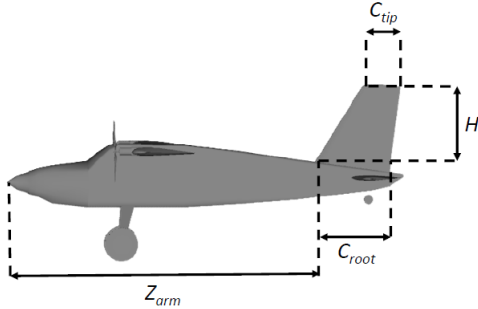


Figure 3: Geometrical parameters of *SwitchMaster*.

4.2. Analysis and results

Using the method described in section 3, the parameter in fig. 3 has been update. Three main cases has been taken in account:

- Case 1: identification of Z_{ARM} and scale factor p , defined as in eq. (5)
- Case 2: identification of p , mean rudder cord over mean vertical chord ratio c , and vertical tail volume ratio C_{VT} , defined as in eq. (4)

- Case 3: identification of c and Z_{ARM} , keeping constant the best C_{VT} identified in Case 2.

$$C_{VT} = \frac{(Z_{ARM} - Z_{CG})S_{VT}}{b_W S_W} \quad (4)$$

$$\begin{aligned} C_{ROOT}(i) &= p(i)C_{ROOT_{bsl}} \\ C_{TIP}(i) &= p(i)C_{TIP_{bsl}} \\ H(i) &= p(i)H_{bsl} \end{aligned} \quad (5)$$

In fig. 4, for each case, the flight history associated with minor functional has been overplotted with real flight data (target) and baseline. Data reported are r , ψ , and β , which are relevant for lateral dynamics. As it is possible to observe, no substantial differences occur in three cases: in particular, the difference between Case 1 and Case 3 is negligible.

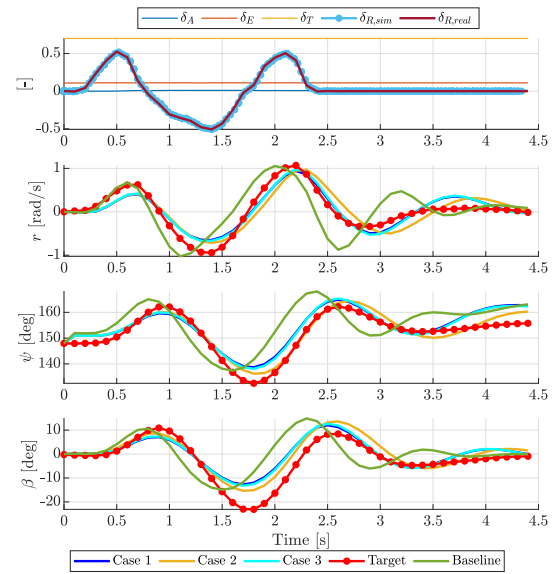


Figure 4: Comparative plot for Case 1, Case 2, and Case 3.

The lower value of the functional is the one of Case 2 ($J = 0.2877$), which also correspond to a configuration (fig. 5(b)) that is the most dissimilar from the baseline. Case 1 has $J = 0.4792$, while Case 3 has $J = 0.5361$. An analysis of the error in time domain and frequency domain has been conducted too. As general consideration, all the solutions considerably reduce the error of baseline case. To define which case improve more the flight model, namely the one that more reduces the error, through a scoring method, all the physical quantity has been compared in each case: two point has been assigned to the case

that improve more a specific quantity, zero point to the one that improve less, a single point to the middle case. Then, all point are summed up. Some extra point has been given to Case 1 and Case 3 because the outcome geometry is similar to the baseline one, as in fig. 5(a) and fig. 5(c). In the end, the winning case was the third one.

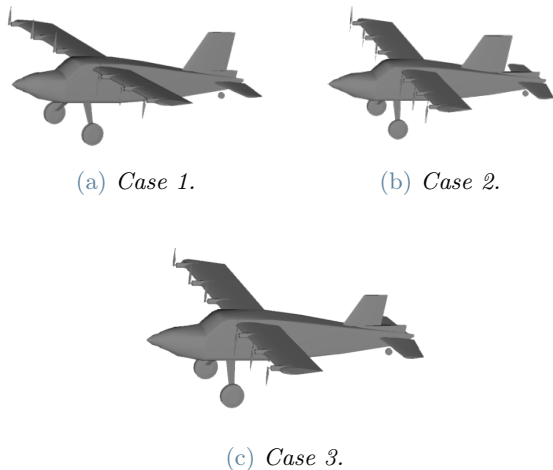


Figure 5: Aircraft configurations in the three different cases.

5. Conclusions

The main goal of the present work was to update the Simulink interface in [1], in order to evaluate the fidelity of *SwitchMaster* flight model, and improve its fidelity. First step has been successfully achieved. Simulink is able to send a command input to X-Plane in order to replicate an experimental manoeuvre, executed on a real aircraft. The operation has been performed with a satisfactory precision, even if small uncertainty is still present, for the existence of the delay in communication between Simulink and X-Plane. The second step has been partially achieved. The iterative procedure correctly worked: unfortunately the outcome was not close enough to the target, namely the real aircraft behaviour. In particular, the flight model has been improved with respect to baseline aircraft, but some issues persist on damping and frequency of the lateral dynamics. Different open points should be faced: the most crucial is understanding if X-Plane dynamics model is suitable for aircraft with peculiar propulsive configuration, such as DEP.

Once the simulator will replicate exactly the behaviour of real aircraft, it will be possible to design control law to manage the peculiarities on piloting given by DEP. Secondly, same control law, validated on simulated X-Plane flight model, can be used to control the physical aircraft and fix the handling quality issues at low speed.

References

- [1] Alberti L. Aeroswitch project: Development of the flight simulator of a distributed electric propulsion demonstrator. Master's thesis, Politecnico di Milano, 2020.
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- [3] Pasquali D. and Tombolini M. Aeroswitch project: Proof of concept of a distributed electric propulsion aircraft enforcing flight symmetry control. Master's thesis, Politecnico di Milano, 2020.