A Software-in-the-Loop Scheme for Accurate Flight Co-Simulation with a Surrogate Hybrid Electric Propulsion Engine Model

Andres LOPEZ PULZOVAN[1,a,*] and Rudy CEPEDA-GOMEZ[1,b]

[1,2]German Aerospace Center (DLR), Institute of Electrified Aero Engines, Lieberoser Straße 13A, 03046 Cottbus, Germany

[a]andres.lopezpulzovan@dlr.de

[b]rudy.cepedagomez@dlr.de

Keywords: flight simulation, turboprop, propeller, software in the loop.

Abstract

Flight simulation constitutes a valuable tool for the evaluation and testing of computational, real-time-capable models of aircraft (sub)systems and components under less idealised conditions than those typically used to test the individual models. In this work, a previously developed, high-accuracy computational model of an electric powertrain is coupled with a commercial flight simulation environment to evaluate the dynamic behaviour of the combined propulsion system under realistic conditions. The paper presents details of the interfaces between simulation environments and example flight experiments, highlighting the interactions between the them and the model under test.

Introduction

Simulations carried out using a toolchain consisting of different software in an automated manner are often referred to as *Software-in-the-Loop*, and the models being tested in this frame are called *Model under Test*. If the model structure and the computational power available allow it, these models can be adequately coupled with a commercial flight simulation software to exchange data in real time, enabling a simultaneous simulation. This process can yield deep insights on the behaviour of the model under test when it operates in complex dynamic conditions and can be used to evaluate the effects of the model on the flight simulation environment. However, these simulations can only be as accurate as the models involved. Aspects like the data exchange rates and simulation time steps of the different tools involved in chain have to be considered to prevent performance bottlenecks and inaccurate results.

A co-simulation work has been carried out in the frame of the DLR project "Do228HEP", in which the possible effects of the electrification of one of the two engines of a Dornier 228-212

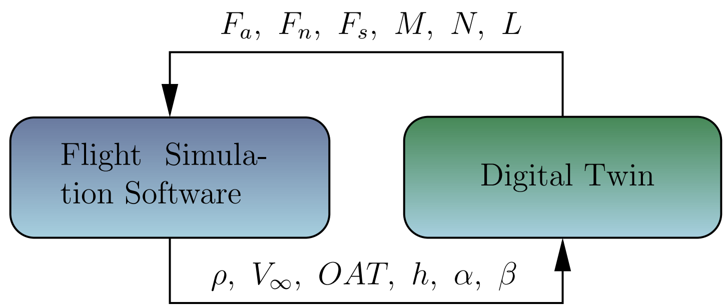

Figure 1: Basic scheme of the co-simulation

twin turboprop aircraft are evaluated. The studied electrification involves the replacement of one of the turboprop engines by an electric motor equipped with a gearbox, moving an identical propeller as the original turboprop. The dynamic behaviour of the planned electric power plant and the existing turboprop one are by nature very different and the dissimilarities have to be compensated by the control system of the electric system.

The presented co-simulation scheme is of special interest for evaluating the possible effects of system failures under conditions closer to reality. The inspection of the data generated in a system physically modelled after a simulation can deliver deep insights on its workings. On the other hand, the presence of a human in the simulation loop brings the capability of incorporating the human response into the investigated scenarios.

Scheme description

A basic scheme of the co-simulation setup is presented in Figure 1. The digital twin of the electric engine calculates the the axial F_a, normal F_n, and side F_s forces; and the roll M, yaw N, and pitch L moments caused by the power plant operation. The flight simulation software provides the air density ρ, true airspeed V_∞, outside air temperature OAT, flight altitude h, aircraft angle of attack α, and sideslip angle β at each timestep.

The digital twin is partially described in detail in Reference [2]. Both power plants are modelled: the original turboprop and the electric power train. The propeller and hydraulic propeller pitch actuation remaining the same, the difference between two models consists of the dynamics of the torque source: an electric motor in the electrified system and a gas generator on the turboprop. The electric motor modelled is a permanent magnet synchronous motor (PMSM) with the capability of simulating its braking torque with open and shorted coils.

The flight simulation software chosen for the setup is X-Plane 11 by Laminar Research, due to its built-in customisation capability through the available Software Development Kit (SDK). Interfacing external software with X-Plane is done through reading and writing of internal value registers, known as *Datarefs*, in real time. To interface with the model, the XPB blockset [4] is used to read and write the datarefs via UDP. Synchronous execution of the digital twin and the flight simulation software, although not guaranteed, can be reliably achieved by a convenient combination of computing power, an appropriate choice of model simulation sample rate, and the use of a model well-suited for real-time execution. As

Parameter	Value
Aircraft weight	5600 kg
Gearbox losses	2% of nominal torque at 100% RPM
Motor mass moment of inertia	0.076373 kg m^2
Propeller mass moment of inertia	6.7 kg m^2
Nominal motor RPM	14977 RPM
Nominal propeller RPM	1591 RPM
Governor speed setting	100% RPM
Air density	1.233 kg/m^3

Table 1: Simulation parameters common to the simulated scenarios

a general rule, [4] recommends simulation sample rates between 5 and 10 Hz when large amounts of data are transferred, and as high as 50 to 100 Hz for small amounts of data.

The data illustrated in Figure 1 is used in the following manner:

- ρ, V_∞: calculation of propeller forces and moments
- OAT, h: restriction of the available torque from the turboprop engine causes by ambient conditions[1]. See [2].
- α, β: change in propeller forces and moments caused by non-axial inflow.

On the flight simulation software side, the internal power plant model is overridden and the respective datarefs for the moments F, N, M, and the forces F_a, F_n, F_s are written on each simulation time step. The values of V_∞ provided by the flight simulation software are passed through a low-pass filter to avoid sudden steps. This is not required for the rest of the variables read from the the flight simulation, since they either do not change fast enough for these steps to be relevant, or their effect is negligible.

Example simulations

A simulation scenario involving failure of the electric power plant is presented. The failure considered consists of a sudden cease of power delivery to the motor, both considering that the coils of the motor stay isolated from each other and considering that the coils are shorted together. Since the modelled motor is a PMSM, short-circuiting the coils while the it freewheels involves the generation of a substantial breaking torque, additional to the friction losses happening in a freewheeling motor with open coils. These losses were modelled as a sole function of the angular velocity of the motor shaft. This failure is simulated during a static, full-power engine run on ground. Ten seconds after the failure, the propeller is feathered as a part of the scenario. The main simulation parameters are presented in Table 1.

[1] In practice, the pilot must manually reduce the power to avoid exceeding the turbine temperature limit.

Results

Fig. 2 shows the results. A failure of the PMSM was injected in after 20 seconds, with a manual opening of the feathering valve of the propeller control system 10 seconds after. The time history of the motor torque and speed, and the propeller blade angle can be observed. A substantial difference on the spool down time can be noticed between the shorted and open coils cases, which is to be expected given the increased braking torque produced with shorted coils. A difference in shaft torque can also be noticed, being lower in the shorted coils case. With respect to the blade angle, it is interesting to observe the behaviour after the failure. As presented in [2], the hydro mechanical propeller pitch control, also present in the electrified powertrain, provides hydraulic pressure to the cylinder in the propeller hub through a gearbox-driven pump. Immediately after the failure, the controller reduces the pitch to the minimum possible, which is twenty degrees with the power levers at 100%, in an attempt to maintain the propeller speed. Eventually, the hydraulic pressure is reduced by the low shaft speed and the blade angle starts rising, caused by the expansion of an antagonistic spring in the hub of the propeller. In the open coils case, it can be noted that the opening of the feathering valve accelerates the increase of the blade angle, while in the shorted coils the speed of the shaft -and therefore the hydraulic pressure- is already too low for the opening of the valve to have an effect.

Conclusion

A co-simulation scheme connecting Simscape and the X-Plane flight simulation software has been presented, with the purpose of obtaining realistic insights about the behaviour of a complex electric power train model. A basic example simulation of a failure case is presented and the physical significance of the results explained.

References

[1] Perry, D. H. and Naish, J. M. (1964). Flight Simulation for Research: Part I. Flight Simulation in Aircraft Stability and Control Research — D. H. Perry. The Journal of the Royal Aeronautical Society, 68(646), 645–652. https://doi.org/10.1017/S0368393100080597

[2] Lopez Pulzovan, A. and Cepeda-Gomez, R. Composition and Parametrization of a Digital Twin of a Propeller Control System using Physical Modelling, 14 March 2025, PREPRINT (Version 1) available at Research Square, https://doi.org/10.21203/rs.3.rs-6202921/v1

[3] The MathWorks, Inc., Simscape [Online; accessed Oct. 2025], https://www.mathworks.com/products/simscape.html

[4] Thomas, P.R. (2020), XPB: X-Plane blockset for Simulink.

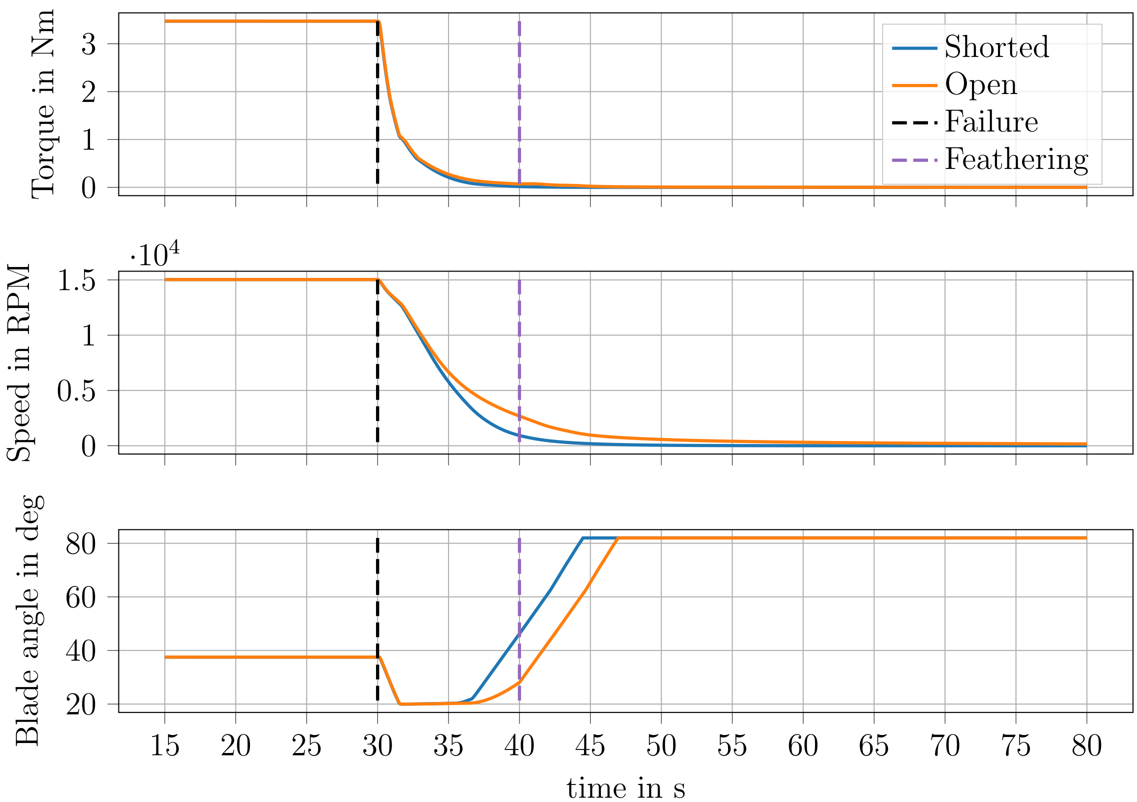

Figure 2: Torque, RPM and propeller blade angle after an electric powertrain failure during a maximum power ground run with feathering after 10 seconds