A Pilot-in-the-loop Facility for Avionic Concept Development

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Abstract—**This paper presents the development and implementation of a real-time pilot-in-the-loop aircraft simulation facility. The facility includes a partial cockpit mockup with hardware pilot interfaces, software-based primary flight displays, out-the-window visuals and a control station. The present work was carried out by the Italian Aerospace Research Centre (CIRA) with the aim of realizing an highly flexible facility to assist and improve the development of innovative technologies for General Aviation cockpit system by undertaking pilot-in-the-loop assessments.**

Index Terms—**pilot-in-the-loop simulation, aircraft simulation facility, avionic system development**

I. INTRODUCTION

The Italian Aerospace Research Centre (CIRA) has started working to develop innovative technologies for General Aviation cockpit system which shall increase awareness and reduce pilot workload in dangerous situations with the purpose of improving safety.

To support the development of these technologies, the Italian Aerospace Research Centre has decided to realize a facility with the following aims:

- To demonstrate concepts for avionics applications by undertaking pilot-in-the-loop assessments.
- To be a test-rig for the rapid development of advanced software for manned vehicles.
- To execute preliminary assessment on software prototypes before hardware-in-the-loop testing.
- To be a General Aviation manned demonstrator.

II. FACILITY DESCRIPTION

The facility, developed using many Common Off The Shelf hardware and software components [1][2][3][4], is named PACO (Pilot-in-the-loop Avionic Concept demOnstrator) and consists of a partial cockpit mockup with hardware pilot interfaces, software-based primary flight displays, out-the-window visuals and a control station. It is capable of integrate and realize real-time pilot-in-the-loop test on the following class of software prototypes (called item):

- Flight Algorithm Items developed in Matlab/Simulink/C++.
- HMI Items developed in VAPS-XT/C++.
- A combination of the first two items.

A set of instructions and requirements have been defined and described in the facility user manual to correctly and successfully integrate the item under test.

Figure 1. PACO cockpit mockup.

The facility can be used in three different modes. The first one is the test mode which permits to execute test to verify an item integration. The second is the simulation mode. This mode permits to execute pilot-in-the-loop assessment on item under test, to use the facility as a General Aviation manned demonstrator and to record a simulation session. In this mode two different starting scenario has been implemented, one with the vehicle on the ground and another with the vehicle on a flight. The last mode is the playback mode which permits to playback a recorded simulation session.

The facility can also operate stand-alone or integrated within the CIRA ISF network [5]. The ISF (Integrated Standard Facility) network consist in a real-time simulated environment where several simulation facilities (able to reproduce in real time the behavior of manned and unmanned aircrafts, air traffic scenario and to

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emulate Air Traffic Management / Air Traffic Control) can interact among them through the simulation of complex scenarios.

III.   FACILITY ARCHITECTURE

The facility consists of two principals simulated components, which are the Aircraft Avionic System model and the Aircraft Dynamics and On-board Sensors model, both modeled in Simulink and compiled using Real-Time Workshop.
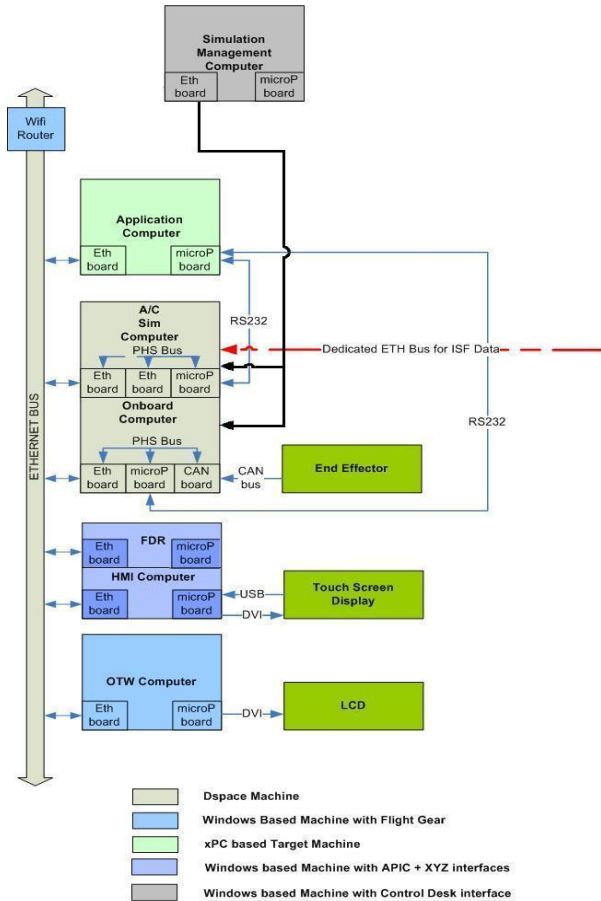

Figure 2.   PACO hardware architecture.

The Aircraft Avionic System model is run on the On-board Computer, see Fig. 2, which is a dSPACE DS1005 PPC processor board connected through a PHS bus to a dSPACE DS4302 CAN Board and to a dSPACE DS4504 Ethernet board. The CAN board is used to receive the signals from the end-effectors commanded by the pilot. The Ethernet board is instead used to connect the processor boards to the facility network.

The Aircraft Dynamics and On-board Sensors model are executed in the A/C Sim Computer, see Fig. 2, which is another dSPACE DS1005 PPC processor board connected through a PHS bus to two dSPACE dS4504 Ethernet boards. One Ethernet board is used to connect the processor boards to the facility network, the other one is dedicated to the communication between the facility

and the ISF network. All the boards (On-board Computer and A/C Sim Computer) are enclosed in a Tandem Autobox dSPACE.

Control Desk, the dSPACE experiment management SW used to interact with the application loaded on the dSPACE processors, is executed on a dedicated workstation named Simulation Management Computer in Fig. 2.

Cockpit end-effectors include throttle levers, a pedal unit and a side stick with trim hats. All the end-effectors have an alimentation tension of 28V and a CAN bus interface.

The facility has two monitors, a LCD used to visualize the Out The Window (OTW) view and a multi touch-screen monitor used to visualize the Human Machine Interface (HMI) software.

The first one is connected to a Rack-Mount windows based PC called OTW Computer where a commercial software, Flight Gear, is used to generate the OTW visuals. The second one is connected to another Rack-Mount windows based PC called HMI Computer which host the HMI software.

A laptop, in Fig. 2 called FDR Computer, is connected to the facility network to collect the Flight Data Record (FDR) through a dedicated software.

To conclude a single board computer based on Processor PC104 standard, in Fig. 2 named Application Computer, is used to host item under test.

IV.   COMPONENTS DESCRIPTION

In this paragraph the software components of the facility, introduced in the paragraph before, are described.

A.   Aircraft Avionic System Model

This component, executed in the On-board Computer and developed with Simulink, emulates the following basic functionality:

- Basic Navigation: this functionality estimates the vehicle state in terms of position, velocity and attitude from the on-board sensor measurements.
- Radio Navigation Management: this functionality estimates the vehicle state using the information provided by the radio navigation systems.
- Basic Autopilot (A/P): this functionality includes the autopilot basic modes in the lateral and longitudinal planes.
- Stability Control Augmentation System (SCAS): this functionality generates the actuators references from the commands of the autopilot, when active, or from the end-effectors.
- Basic Flight Management System (FMS): this functionality is dedicated to the management of the flight plan and to the generation of the trajectory between two way-points using a direct-to-navigation criteria.
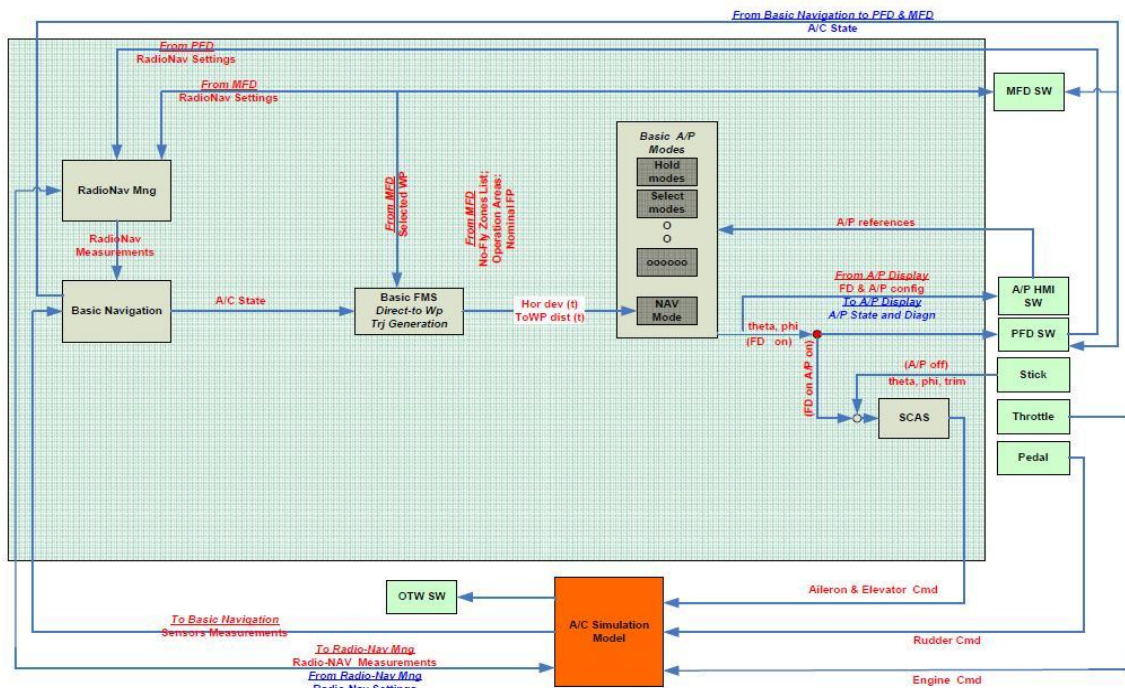
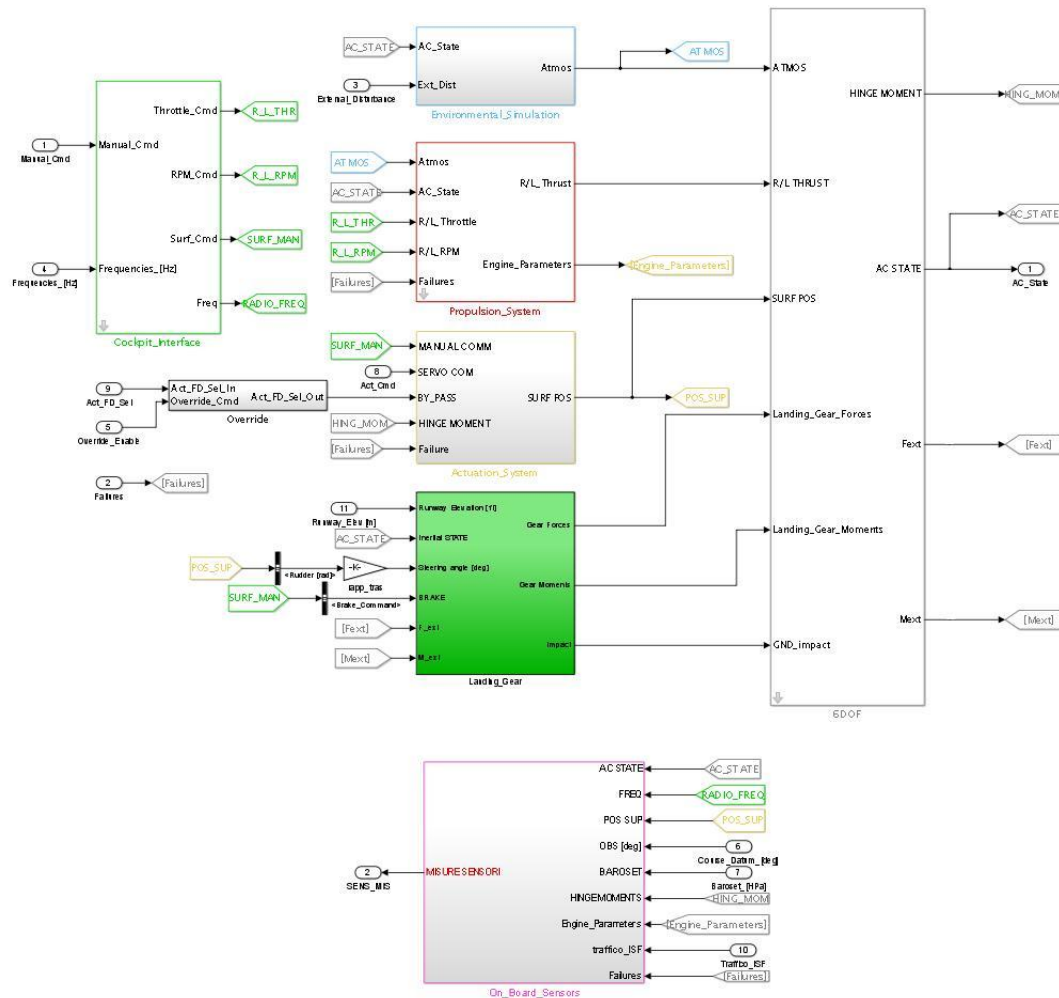Figure 3.   PACO aircraft avionic system logical architecture.

Figure 4.   PACO aircraft dynamics and On-board sensors model top level image.

B. *Aircraft Dynamics and on -board Sensors Model*

This component, installed in the A/C Sim Computer and developed with Simulink, simulate a CS-23 type aircraft for General Aviation and the external environment. It contains an atmospheric model, a six degree of freedom model, an aerodynamic model, a propulsion system model, an on-board sensors model, an actuation model and a landing gear model. A screenshot of the Simulink model top level is represented in Fig. 4.

The atmospheric model computes pressure, temperature, density, wind and turbulence velocities in body axes. It is based on a modified version of the Mathworks Aerospace Blockset atmosphere and wind models.

The six degree of freedom module computes body acceleration, speed, and position from input forces and moments and vehicle mass properties. The equation of motion (EOM) model is a round/rotating earth model supporting airplane dynamics, including the navigation equations [6].

The aerodynamics module computes longitudinal and lateral-directional forces and moments. The inputs to the aerodynamics model are states, state rates, and control deflections. The outputs are aircraft body axis force and moment coefficients and control surface hinge moment coefficients.

The propulsion module simulates the dynamic of two Allison 250 B17F turbo shaft engines. The three components of thrust in aircraft body axes for each engine are the outputs of this block.

The actuation module is used to switch the commands from the end-effectors to the autopilot, when active, and to simulate actuators failures.

The on-board sensors module emulates the Stand-by Instruments, the Air Data System, the Automatic Dependent Surveillance - Broadcast (ADS-B) receiver, the Attitude and Heading Reference System (AHRS), the Global Position System (GPS), the Radar Altimeter, the Magnetometers, the Actuators Position Sensors and the Engine Management Sensors. It also emulates the following navigation sensors: Distance Measuring Equipment (DME), Instrument Landing System (ILS), Non-Directional Beacon (NDB) and VHF Omnidirectional Range (VOR).

The ground reaction module [7] computes forces and moments acting on the aircraft due to landing gear interaction with the ground plane. Nose gear plus left and right main landing gear tires and struts are modeled. The reaction models are enabled subsystems that only take effect when touchdown criteria are met for the individual tire. Brake inputs and nose wheel steering inputs are used for on-ground operation. Weight-on-wheels logic is performed within the model.

C. *Control Station*

A dSPACE Control Desk interface is used to set and manage the facility. It is executed in the Simulation Management Computer. This interface provides different panels, each one can be selected by clicking on the corresponding tab available on the bottom of the interface. The operator can interact with the facility and handle the session by check boxes and buttons available on these panels. Through these panels the operator can start the facility selecting the desired operative modes, check flight data during a simulation, enable failures on-board and change atmospheric conditions.

D. *Flight Data Recorder*

This component, installed in the FDR Computer, is used to collect and visualize the simulated flight data. It consists of two software, one developed with VAPS XT version 3.2.1 which records and saves the variables during a simulation and the other developed with Matlab which allows selection and visualization of the data recorded through a graphic interface.

Figure 5.   PACO flight deck display.

E. Flight Deck Display

This component, installed in the HMI Computer, is the human machine interface software of the facility. It represents on a multi-touch touch screen display a Primary Flight Display (PFD), a Multi-Function Display (MFD), an Engine Indicating and Crew Alerting System (EICAS), the back-up stand-by instruments, the A/P interface and the FMS interface. A screenshot is represented in Fig. 5. This application has been realized with VAPS XT version 3.2.1.

F. Outside the Windows Visuals

Flight Gear, an open-source flight simulator, is used to display out-the-window scenes based on aircraft state data sent by the Aircraft Dynamics and On-board Sensors component.

V. CONCLUSIONS

The development of a highly flexible pilot-in-the-loop aircraft simulation facility has been presented. The facility includes a partial cockpit mockup with hardware pilot interfaces, software-based primary flight displays, out-the-window visuals and a control station. The present work was carried out by the Italian Aerospace Research Centre (CIRA) with the aim of realizing a test-rig for the rapid development of advanced software for General Aviation vehicles and a concepts demonstrator for avionics applications by undertaking pilot-in-the-loop assessments. To conclude it is worthy to remark that the facility was successfully used to assist the development of innovative technologies in the framework of two Italian funded project (TECVOL and SEPARA) and in the framework of the SESAR JU European funded project RAID.

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