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Actuator-based hardware-in-the-loop testing of a jet engine fuel control unit in flight conditions

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ABSTRACT

An actuator-based hardware-in-the-loop (HIL) simulation for testing of a jet engine fuel control unit (FCU) is presented. In this approach, the FCU operates dynamically as the hardware in connection with an integrated flight and propulsion numerical simulation. The simulator is built based on a state-of-the-art hydraulic test bench which experimentally simulates hydraulic loads imposed on the FCU in flight conditions. For this purpose, an electric motor is employed to drive the FCU gear-typed fuel pump using the reference shaft speed signal that comes from the simulation. The HIL simulator developed in this study is finally used to test the FCU and to investigate the interaction between the FCU and overall aircraft performance. The results of HIL simulation demonstrate the functionality of the proposed HIL simulation during flight maneuvers.

1. Introduction

Hardware-in-the-loop (HIL) simulation enables the operation and testing of actual components of a system along with virtual computer-based simulation models of the rest of the system in real time [1,2]. In a typical HIL test, the hardware component consists of a box of electronic components which can communicate with the software models via electrical signals exchanged using a data acquisition card [3]. Several studies have been reported for the use of HIL simulation approach for rapid prototyping of electronic control unit (ECU) of turbojet [4–6] and turbofan engines [7–9].

Recently, the use of HIL simulation to test the mechanical and other components has been attracted. Such simulations which have significant power flows between the real hardware and simulation make their design more challenging. This kind of HIL simulation is often called actuator-based HIL simulation or dynamic substructuring. Gawthrop et al. [3,10] presented an overview to the topic of real-time dynamic substructuring in variety of applications.

In the field of aerospace engineering, several researches have been undertaken to employ the concept of the HIL simulation to examine the performance of aircraft vehicle components within a closed loop virtual simulation of the remaining subsystems. For instance, the authors in [11] have presented the development of an HIL simulation for testing of vision based control systems for unmanned aircraft vehicles (UAVs). The authors have explained how to integrate a camera-in-the-loop simulation with the model aircraft in a wind tunnel. In addition, the study reported in [12] has addressed the testing of electro-hydraulic actuators and their interactions with the representative environment by emulating the aerodynamic loads caused by the aircraft control surfaces. In [13], a study of the performance of a fuel-cell-powered UAV using an HIL simulation of the aircraft in flight has been presented. The authors of [14,15] have presented an integrated flight control development to implement and test the flight controllers on small unmanned aircraft vehicle systems. However, the use of HIL simulation for testing of jet engine fuel control unit (FCU) in flight condition has not been studied.

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The dynamic performance of an electro-hydraulic FCU can be influenced by changes in the characteristics of the operating environment and by changes in the system parameters. Therefore, it is desired to verify the correct operation of electro-hydraulic FCU experimentally using real hardware. In addition, since this hydraulic actuator is an integral part of the flight control loop, actuator faults can influence the handling quality of the aircraft and limits its overall maneuverability. Hydraulic actuator faults, such as loss of supply pressure or nonlinearities arising from the servo valve orifice port shapes or flows and operation under control valve saturation can impair the dynamic response of the hydraulic system and decrease the functionality of the process in which the actuator is embedded.

HIL simulation is a way to shorten the design cycle and improve the reliability and robustness of the FCU, when detailed field testing is not feasible. Accordingly, The FCU can be experimentally tested under operating conditions that resemble, more closely, the intended application without the need to operate the real process. Moreover, the availability of an HIL simulation environment allows the effects of hydraulic actuator faults on the performance of the overall system to be studied in a safe and controlled fashion.

In this paper, an actuator-based HIL simulation framework is developed for testing of jet engine FCU in flight conditions. The HIL simulator is based on a state-of-the-art hydraulic test bench that has the ability to experimentally simulate hydraulic loads. The goal of this novel HIL simulation is to test the engine FCU and to investigate, for the first time, the complex interaction between the FCU hardware and overall aircraft performance. This paper presents a functional overview of the HIL simulator and demonstrates the applicability of the developed experimental framework towards meeting these objectives. To the authors' knowledge, this work presents the first development of HIL simulation framework for jet engine fuel control system that incorporates electro-hydraulic FCU hardware within the real-time integrated flight and propulsion simulation.

The reminder of the paper is organized as follows. The next section describes the configuration and operation of the FCU. The detailed structure of HIL simulation, the software and hardware framework and interfaces are presented in Section 3. Section 4 describes the software simulation including the flight, turbojet engine and ECU models. Interfacing the simulation to hardware is presented in Section 5. In Section 6, the hydraulic test bench for testing of the FCU is explained. The emulator of pump driver and its control system is described in Section 7. Finally, the results of the simulation with the simulated FCU and actual FCU are compared in Section 8. Some concluding remarks are presented in Section 9.

2. Fuel control unit description

Basic components of the proposed electro-hydraulic FCU are shown in Fig. 1. A gear-type fuel pump, which is driven in a fraction of the engine shaft speed, supplies fuel to the system. The unit employs a pressure balanced metering valve, which

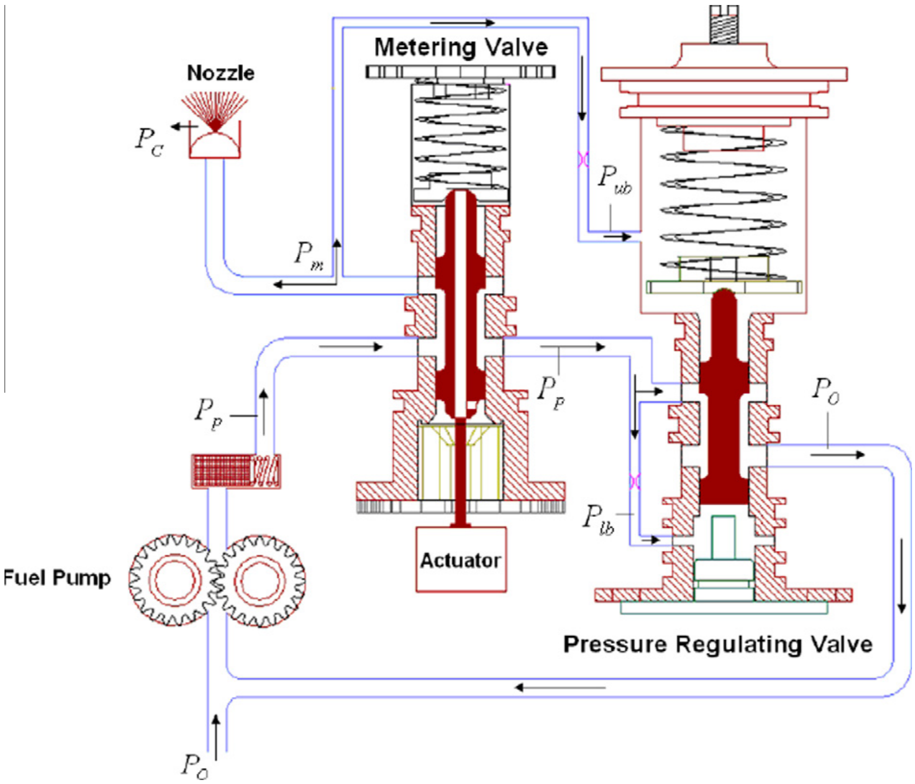

Fig. 1. Fuel control unit (FCU).