Fault-tolerant Control for a Civil Transportation Aircraft

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Abstract

The sensor based backstepping (SBB) control law, based on singular perturbation theory and Tikhonov's theory, is a novel incremental type high gain control approach. This Lyapunov function based method is not susceptible to model uncertainty since it uses measurements instead of reconstructed modeling variables. Considering these merits, we extended the SBB method, in this paper, to handle sudden structural changes in the fault tolerant flight control of a fixed wing aircraft. A new double-loop joint SBB attitude controller has been developed for a Boeing 747-200 aircraft using the backstepping technique. Compared with the double-loop NDI attitude control approach, the double-loop SBB attitude control setup enables the verification of the system stability and allows relatively more interaction between the angular rate loop and the angular loop. The benchmark rudder runaway and engine separation failure scenarios are employed to evaluate the proposed method. The simulation results show that the proposed joint SBB attitude control method can lead to a zero tracking error performance in the nominal condition and can guarantee the stability of the closed-loop system under the failures.

1. Introduction

Under many post-failure circumstances, the aircraft can still achieve a certain level of flight performance with the remaining valid control effectors[1][2]. However, as a consequence of the structure/actuator failures, the control authority or the safe flight envelope of the aircraft is inevitably cut down. Research on previous flight accidents [1][3] shows that it becomes crucial to choose a suitable fault tolerant flight control (FTFC) strategies to keep the stability and safety of the aircraft when the structural failures or actuator failures occur.

Among all fault scenarios, the incidents categorized as 'loss of control in flight' count for as much as 17% of all aircraft accidents [4], and have received most attention. These kinds of failures can be avoided by taking suitable control strategies [1] as suggested by the results of the Flight Mechanics Action Group 16 (FM-AG16), which is a branch of the Group for Aeronautical Research and Technology in Europe (GARTEUR). For example, an FTFC strategy, which involes a fault detection and isolation (FDI) block and a reconfigurable control block, makes it possible to recover the post-failure aircraft from danger [1][2].

A large amount of research has been done on FTFC in the past few decades. For the purpose of providing a validation platform for modern FDI and FTFC strategies, 6 fault scenarios have been embedded in the Reconfigurable Control for Vehicle Emergency Relief (RECOVER) benchmark model by the FM-AG 16 group including El Al flight 1862 and rudder runaway[1].

As suggested by Smaili et al. [1], Alwi and Edwards et al. [3] and Lombaerts and Smaili et al. [5], a powerful and advanced control approach is essential to increase the operational performance of the post-failure aircraft. The chosen control algorithms should have at least two of the following merits: it needs to be robust to the sudden structural changes of the aircraft, not relying on an accurate and full aerodynamic model, or it needs to contain a powerful model identification strategy by itself to provide all of the accurate model information for the FDI and reconfigurable control units in real-time.

A number of FDI methods, as well as reconfiguring control approaches, have been proposed in the literature [6][7] [8][3][9][10]. More recently, the work of Lombaerts et al. [5], as a part of the GARTEUR FM-AG 16 program, has provided practical validation results of an piloted adaptive nonlinear dynamic inversion (ANDI) controller, the kernel of which is a two-step online identification approach to get the