

A Model-based Solution to Robust and Early Detection of Control Surface Runaways

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ABSTRACT

This paper discusses the design of a model-based fault detection scheme for robust and early detection of runaways in aircraft control surfaces servo-loop. The proposed scheme can be embedded within the structure of in-service monitoring systems as a part of the Flight Control Computer (FCC) software. The final goal is to contribute to improve the performance detection of unanticipated runaway faulty profiles having very different dynamic behaviors, while retaining a perfect robustness. The paper discusses also the tradeoffs between adequacy of the technique and its implementation level, industrial validation process with Engineering support tools, as well as the tuning aspects. The proposed methodology is based on a combined data-driven and system-based approach using a dedicated Kalman filtering. The technique provides an effective method ensuring robustness and good performance (well-defined real-time characteristics and well-defined error rates). Simulation results, using In-flight recorded data sets provided by Airbus, are presented to demonstrate the potential of the developed technique.

INTRODUCTION AND PROBLEM SETTING

The Electrical Flight Control System (EFCS, a.k.a. Fly-By-Wire (FBW)), first developed for civil aircraft by Aerospatiale and installed on Concorde (analogue system), and then designed with digital technology on Airbus aircraft from the 80s (A310), now constitutes an industrial standard for commercial applications. It provides more sophisticated control of the aircraft and flight envelope protection functions

[4, 10]. The main characteristics are that high-level control laws in normal operation allow all control surfaces to be controlled electrically and that the system is designed to be available under all possible external disturbances. The EFCS is designed to meet very stringent requirements in terms of safety and availability. Most, but not all of these requirements come directly from the Aviation Authorities (e.g. FAA, EASA, for details see [3]).

The EFCS development on modern civil aircraft led to a growing complexity of systems and equipments. Consequently, the number of failure cases to consider in the aircraft design has increased compared to the historical mechanical flight control system. In particular, system design objectives originating from structural load constraints are more and more stringent for satisfying the newer societal imperatives towards an environmentally-friendlier aircraft (quieter, cleaner, smarter and more affordable aircraft). Highlighting the link between aircraft sustainability and fault detection, it can be demonstrated that improving the performances of fault diagnosis in EFCS allows to optimize the aircraft structural design (weight saving) and then to improve the aircraft performances and de facto to decrease its environmental footprint (e.g. less fuel consumption and noise). EFCS failure cases that may affect structural loads are for example oscillatory failure cases [6, 16], runaway (a.k.a. hard-over) [1] or jamming of a control surface. The state-of-practice, applied worldwide by all aircraft manufacturers, to diagnose these EFCS faults and obtain full flight envelope protection at all times is to provide high levels of hardware redundancy in order to perform consistency tests, cross checks, voting mechanisms and built in test techniques of varying sophistication [7, 8]. This also ensures sufficient

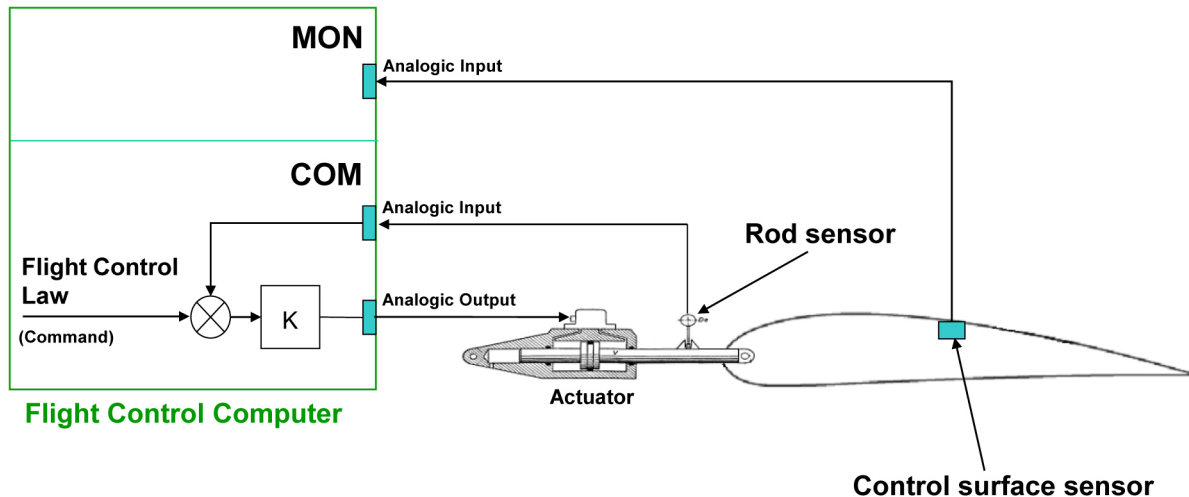


Figure 1. Control surface servo-loop

available control action. This hardware-redundancy fault diagnosis approach fits also into current aircraft certification processes for ensuring the highest level of safety standards.

This paper deals with control surface runaway detection in EFCS. A runaway, or hard-over, is an unwanted control surface deflection that can go until moving surface stops if it remains undetected. It creates additional loads on the aircraft structure and could also disturb the aircraft control, under some circumstances. Runaways are mainly due to electronic component failure, mechanical breakage or FCC malfunctions. Only root causes located in the servo-loop control of the moving surfaces are considered, that is, between the FCC and the control surface, including these two elements (Figure 1).

As a part of hardware redundancy, the typical Airbus FCC architecture consists of two separate channels (Figure 1), a command channel (COM) and a monitoring channel (MON). Each channel monitors the other but each channel has a specific task. The COM channel provides the main functions allocated to the computer (flight control law computation and the servo-control of moving surfaces). The MON channel ensures (mainly) the permanent monitoring of all the components of the flight control system (sensors, actuators, other computers, probes, etc). The industrial state of practice to detect control surface runaway is generally to compare the actual surface position to the theoretical surface position computed by the monitoring channel [8, 9]. An error signal is obtained. The decision making corresponds to a threshold-based approach: if the signal resulting from the comparison is greater than a given threshold during a given time then fault detection is confirmed. When needed, the COM and MON channels use dedicated sensors to perform these comparisons. A detected runaway will result in the servo-control deactivation or computer passivation, and will lead to a hand-over between redundant computers and associated actuators

in case of several actuators per control surface (a.k.a. system reconfiguration).

When the system reconfiguration is triggered the control surface has reached a given position (deflection measured in degrees). This position depends on the runaway dynamic. The goal investigated in this work aims at improving the runaway detection performances while keeping a perfect robustness compliant with the operational constraints. Concretely, the expected benefit is a smaller control surface deflection when the failure detection is confirmed. A smaller deflection means less loads generated on the aircraft structure. The proposed scheme must keep the same coverage in term of runaway dynamic behaviours.

The paper is organised as follows. The motivation for a model based approach is discussed in section 2. Section 3 is devoted to modelling and dedicated Kalman filtering including the steady state Kalman filter with a procedure for optimised gain computation. Section 4 presents some simulation results to demonstrate the efficiency of the proposed approach. Finally, in section 5 some concluding remarks are given.

MOTIVATION FOR A MODEL BASED APPROACH

The conventional monitoring technique for control surface runaways described in the previous section is industrially well mastered and well characterized (high level of robustness and good performance). The technique is validated and certificated for implementation in the on board Airbus FCC. All unanticipated control surface runaways having different dynamic behaviors are covered, without false alarms. It follows that any modification to this technique should provide, first of all, a viable technological solution ensuring better performance while guaranteeing the same