Editorial

CEP Special Section Issue on Advanced Fault Diagnosis for Sustainable Flight Control - The European ADDSAFE Project

A consortium of eight European organizations recently completed the ADDSAFE Project (Advanced Fault Diagnosis for Sustainable Flight Guidance and Control) funded under the European Union's Seventh Framework Programme for Research (FP7). The ADDSAFE Project consortium (DEIMOS – coordinator, AIRBUS, SZTAKI Budapest, Leicester University, Bordeaux University, Hull University, Delft Technical University, DLR Oberpfaffenhofen) involved industrial and academic teams with recognized research expertise in the field of fault diagnosis. In this project, the main industrial partner AIRBUS, defined several challenging *fault detection and diagnosis* (FDD) problems for real-time on-board monitoring of flight control system actuator and sensor faults. The aim of this benchmark was to encourage the application of advanced fault diagnosis techniques for AIRBUS aircraft that could significantly improve the aircraft performance (e.g., weight saving by optimizing the aircraft structural design) or decrease its environmental footprint (e.g., reduced fuel consumption and noise). The rest of seven teams explored the applicability of new advanced model based techniques for solving the formulated FDD challenges and delivered their best synthesis results as ready to use FDD systems to be implemented on the AIRBUS test facilities. The importance of the studies carried out within ADDSAFE arose from the representativeness of the benchmark proposed by AIRBUS as well as from the industrial benchmarking, *verification and validation* (V&V) of all designs performed by DEIMOS and AIRBUS. The latter also included a final extensive industrial evaluation at AIRBUS premises in Toulouse for some of the best designs.

Overall, ADDSAFE was a very successful project, whose main achievements have been presented in 12 papers in two invited sessions organized at the IFAC SAFEPROCESS 2012 conference, held between August 29-31 2012, in Mexico City (Mexico) and at a final workshop at AIRBUS Toulouse (France) in November 2012 co-funded by the consortium partners and the IEEE Control System Society. This special issue section of the Control Engineering Practice includes a selection from these papers containing some of the most representative results achieved within the ADDSAFE Project. All submitted papers significantly extended their original conference versions by including background information on the performed research as well as the latest analysis results (e.g., those obtained during the industrial evaluation). After a thorough peer review process, the following seven papers have been accepted for publication:

1. P. Goupil and A. Marcos, *The European ADDSAFE project: industrial and academic efforts towards advanced fault diagnosis.*
2. S. Hecker and H. Pfifer, *Affine LPV-modeling for the ADDSAFE benchmark.*
3. A. Varga and D. Ossmann, *LPV model-based robust diagnosis of flight actuator faults.*
4. H. Alwi and C. Edwards, *Development and application of sliding mode LPV fault reconstruction schemes for the ADDSAFE Benchmark.*
5. B. Vanek, A. Edelmayer, Z. Szabó, and J. Bokor, *Bridging the gap between theory and practice in LPV fault detection for flight control actuators.*
6. D. Henry, J. Cieslak, A. Zolghadri, and D. Efimov, *A non-conservative H_-/H_∞ solution for early and robust fault diagnosis in aircraft control surface servo-loops.*
7. L. Van Eykeren and Q. P. Chu, *Sensor fault detection and isolation for aircraft control systems by kinematic relations.*

In the first paper, a general overview of the ADDSAFE project is presented and the main activities are described. The paper states the main objective of this European project, which was to facilitate the transfer of model-based fault detection and diagnosis methods from academia to industry. An important aspect of the project described in the paper was the availability of a high-fidelity aircraft model, developed by AIRBUS for advanced flight control and fault diagnosis related studies. This model served for both FDD system synthesis purposes as well as for the V&V of the FDD system designs. An industrial assessment software tool FES (so-called Functional Engineering Simulator) was developed by DEIMOS around AIRBUS model and fault scenarios. The FES was then used by the partners for design and preliminary verification, and by DEIMOS for statistical benchmarking (a highly critical step in an industrial evaluation process) of all the designs based on a wide set of quantitative measures covering fault diagnosis performance and robustness characteristics. The V&V results summarized in this article represent a quantitative measure of the success of the project. Five of the developed designs were successfully validated in AIRBUS V&V setups and are currently undergoing further tests towards a possible real aircraft implementation.

The second contribution presents two approaches for approximating nonlinear dynamic models of a commercial aircraft or its components (e.g., flight actuators) by *linear parameter varying* (LPV) models. Firstly, the authors deal with the approximation of a nonlinear actuator model by a simple LPV model which accurately describes the nonlinear actuator dynamics in the whole flight envelope. Secondly, a new efficient approach is presented for generating *affine* LPV models for the nonlinear aircraft dynamics with large validity regions. The methods are able to enforce the sparsity of the LPV models, which significantly helps to generate equivalent low order linear fractional transformation based representations. Several contributions in this issue rely on the developed LPV models to design robust FDD systems for actuator and sensor fault monitoring.

In the third paper, a LPV model-based synthesis, tuning and assessment methodology is developed and applied for the design of a robust FDD system for several types of flight actuator faults. The robust fault detection is achieved by using a synthesis approach based on an accurate approximation of the nonlinear actuator–control surface dynamics via an LPV model and an optimal tuning of the free parameters of the FDD system using multi-objective optimization techniques. Real-time signal processing is employed for identification of different fault types. The assessment of the FDD system robustness has been performed using both standard Monte Carlo methods as well as advanced worst-case search based optimization-driven robustness analysis. The industrial validation performed on the AIRBUS actuator test bench for the monitoring of jamming, confirmed the satisfactory performance of the FDD system in a true industrial setting.

The fourth paper describes the development and the evaluation of a robust sliding mode observer fault detection scheme applied to an aircraft benchmark problem as part of the ADDSAFE project. A robust sliding mode sensor fault reconstruction scheme based on an LPV model is presented. The proposed scheme has been subjected to various tests and evaluations which cover a wide range of the flight envelope, specific challenging manoeuvres and realistic fault types. Simulation results from various levels of FDD development (from tuning, testing and industrial evaluation) show consistently good results and fast detection times.

The fifth paper compares from a practical point of view two different approaches for addressing *fault detection and isolation* (FDI) problems: the geometric design method and the detection filter (observer) based method, both using the LPV framework. Two inherently different design methods are compared regarding their relevance to aircraft industry, where one of methods is based on a local actuator model, while the second method relies on a global aircraft model. In each case, the successive design steps are discussed, including fault modelling, LPV model generation, LPV FDI filter synthesis, robustness assessment, as well as implementation and computational load aspects.

The authors of the sixth paper discuss the design of a model-based fault detection scheme for robust and early detection of faults in aircraft control surface servo-loops. The proposed strategy employs two fault detectors. The first one is based on a H_∞/H_- residual generator that maximizes sensitivity to any kind of control surface servo-loop faults whilst simultaneously minimizes the influence of unknown inputs. The second fault detector consists of a pure H_∞ residual generator that is sensitive to a restricted set of faults and robust to unknown inputs. This structured strategy allows to discriminate between different fault types occurring in the control surfaces servo-loop. Monte-Carlo campaigns from a highly representative simulator provided by AIRBUS as well as experimental results obtained on AIRBUS test facilities demonstrate the fault detection performance, robustness and viability of the proposed technique.

The seventh paper presents a new model-based approach for the detection and isolation of sensor faults of a civil aircraft. The new FDI approach relies on using aircraft kinematic models to produce virtual sensor measurements. These models describe the kinematic relations between the measured variables and therefore are exactly known (no uncertain parameters). Therefore, the proposed approach is valid for the whole flight envelope, is insensitive to actuator faults, and can reliably be employed even in the case of constant wind conditions. Two practical applications are presented to demonstrate the advantages of the proposed approach.

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