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Vision article

On flight operational issues management: Past, present and future

Ali Zolghadri

University of Bordeaux, CNRS, IMS Lab, 351 cours de la Libération, Bât. A31, Talence cedex 33405, France

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ABSTRACT

This paper provides a brief perspective of academic model-based Fault Detection, Identification and Recovery (FDIR) developments for aerospace and flight systems, and discusses a future paradigm shift in civil aviation operations.

Contents

1. Introduction

The 20th IFAC World Congress celebrated the 60th birthday of IFAC in July 2017 in Toulouse, city which hosts the most important concentration of industrial aerospace activities in Europe. Aerospace has always been a powerful engine of innovation. It needs continuous improvement including insertion of new technologies as it has to meet more and more aggressive performance targets in reliability, efficiency, safety and environmental regulations. In aerospace, moving from basic research to operational and flight-proven systems is a complex process and can take several years. The maturation process may take even more time, up to twenty years or longer, when it is a question of breakthrough and radical innovation and not evolutionary improvements to existing systems. This paper aims at providing a brief perspective of the

E-mail address: ali.zolghadri@ims-bordeaux.fr

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ACRONYMS

ADIRS	Air Data Inertial Reference System
AoA	Angle of Attack
DOP	Distributed Observer and Predictor
EASA	European Aviation Safety Agency
EFCS	Electrical Flight Control System
FAA	Federal Aviation Administration
FBW	Fly-By-Wire
FCC	Flight Control Computer
FDIR	Fault Detection, Identification and Recovery
FEP	Flight Envelope Protection
FTC	Fault Tolerant Control
FTG	Fault Tolerant Guidance
GNC	Guidance, Navigation and Control
HLPV	Hybrid Linear Parameter Varying
IFC&HS	Identification of Flight Configurations and Hazard Situations
IMA	Integrated modular avionics
LOB	Local OBserver
LOC-I	Loss of Control Inflight
MOUR	Manoeuvring Options for Upset Recovery
PFD	Primary Flight Display
PD	Predictive Display
SGM	Set-membership and Gaussian Mergers
SPO	Single Pilot Operations
TO/GO	Take-off Go-around
TPO	Two Pilot Operations
TRL	Technology Readiness Level
V&V	Validation & Verification
UPO	UnPiloted Operations
ZKF	Zonotopic Kalman Filter

relationship between control theory and aerospace industry, beginning with early sixties, approximately the time when IFAC was just born. The focus is on model-based Fault Detection, Identification and Recovery (FDIR), a broad research topic within control theory which is expected to finding fertile ground for application into both aviation and aerospace arenas. For a flight vehicle, FDIR addresses monitoring and reconfiguration issues related to the physical components (sensors, actuators…) as well as the Guidance, Navigation and Control (GNC) system. See Fig. 1.

The paper scrutinizes past and present situation and discusses briefly a future trend for civil aviation operations. Today, when we look back, we have to recognize that the "track record" is poor in terms of flight-proven applications issued from theoretical results produced within the IFAC community. By application, it is understood "*transfer of knowledge resulting in tangible and marketable aerospace technologies which can create economic value and benefits to society*" . This means certification, entry into service, successful mission operations and commercial flight. Hence, simulations on representative benchmarks, demonstrations on testbed platforms, ground test facilities and flight simulators, or in-flight tests and evaluations, are not designated as applications throughout this paper. This point deserves to be emphasized because, strictly speaking, the term application is sometimes employed erroneously in the academic literature. Many academic papers talk about application even when they simply illustrate a design method (with some nice formal properties proven for a class of models) by simulations. The general picture can be better observed on TRL scale which is used to assess the maturity level of a particular technology and is based on a scale from 1 to 9 with 1 being the basic concepts and 9 being the most mature technology (Fig 2). Broadly, classical academic activities cover TRL1 and TRL2 and occasionally TRL3 if feasibility and proofs of concept can be established. TRL6 up to TRL9 correspond to technology integration (fully functional prototype up to flight-proven, successful mission and certification). Levels 4 and 5 represent mostly the applicability gap, or the Death Valley which acts as a very selective filtering process.

The analysis reported in this paper is grounded in author's experience in both basic research in systems & control and applied aerospace research[1] over the last two decades, and the conclusions reached embrace mainly the European situation, although beyond the old continent one can certainly find strong parallels and similarities with the situation in other places. It is hoped that the views reported in this paper could be helpful to reflect about where the effort should be put to improve this situation in the future. For this, we need to understand first how we got to be where we are today. What will happen next depends largely on how we respond to the new challenges and opportunities that lie ahead of the IFAC community. And the challenges today and tomorrow are far greater than those faced in the past and continue to grow as individual systems evolve and operate with greater autonomy and intelligence within a networked and distributed cyber-physical environment.

To set the scene, it is believed that a brief historical overview of control design can be helpful to better situate the emergence of fault tolerant control and fault diagnosis problems which have been widely motivated by flight-critical applications. So, before going through the FDIR era for aerospace systems, the paper starts with a short background of control design. This rapid overview is presented in Sections 2.1 and 2.2. After that, Sections 2.3, 2.4 and 2.5 trace briefly subsequent FDIR developments motivated by aerospace and flight systems. Note that Section 2 is intended to provide a short synopsis rather than an exhaustive survey. I apologize to those who will not find citations of their relevant work there. Section 3 is dedicated to industrial state of practice in fault management. Section 4 is an attempt at explaining the widening gap between advanced methods being developed by the academic community and technological solutions demanded by the aerospace industry. Section 5 focuses on a future challenge in civil aviation operations. Finally, some final thoughts are provided in Section 6. In the sequel, and when it is not specified, the term aerospace cover both aeronautics and space missions. Finally, air-ground interaction issues are not discussed throughout this paper.

2. Episodes

2.1. Act I, scene 1: classical control theory

In the 1940s, the concept of linear control systems and feedback theory emerged with the work of Bode, Ziegler and Nichols using graphical techniques in the frequency-domain. The controllability was defined as the ability of the process to achieve and maintain the desired equilibrium value (Ziegler & Nichols, 1943). The controllers were PI and PID controllers, they were not model-based. Robustness concepts were incorporated in the design techniques in the form of gain and phase margins. Frequency domain techniques and PID control are still the tool of choice in flight control analysis and design. For example, the longitudinal and lateral equations of motion can be approximated by a set of linear differential equations and the frequency tools help aerospace control engineers gain useful insight on how to tune feedback loops. See Aström and Kumar (2014) where the interested reader can find early development of automatic control and its complex story of evolution.

[1] One of the model-based monitoring methods that the author developed with Airbus received certification on new generation A350 aircraft and is flying since January 2015.