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Advances in Aeronautical Informatics

Technologies Towards Flight 4.0

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ISBN 978-3-319-75057-6 ISBN 978-3-319-75058-3 (eBook)
https://doi.org/10.1007/978-3-319-75058-3

Library of Congress Control Number: 2018937708

Printed on acid-free paper

This Springer imprint is published by the registered company Springer International Publishing AG part of Springer Nature
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

To the pioneers of flight,
who made a dream of mankind come true.

To the pioneers in computer science,
who opened us new frontiers of innovation.

Foreword

Since the very beginning of manned flight more than hundred years ago, aeronautics was one of the most advanced fields for generating new technologies. Requirements against safety, reliability, lowest weight, and pilot integration put the highest demand on the engineers to find solutions in these conflicting areas.

The introduction of new navigation and air data sensors and power amplification by pneumatic and hydraulic systems opened the arena for large aircraft and first automated flight segments. After WWII, onboard computing opened the scope for new support functions, auto flight systems, and many more capabilities of modern aircraft. System integration became one of the key elements during design and development of aircraft and step-by-step software design became one of the most important areas in defining the functional structures of new aircraft. The art of designing these aircraft underwent an evolutionary change toward software integrated systems of systems. Today, we are at the threshold to highly automated and unmanned autonomous systems that will pose even more emphasis on information technology and pushing the limits to the highest criticality levels possible.

The Institute of Flight Systems at the German Aerospace Center (DLR) is a leading research institution of flight sciences and airborne systems technologies with strong links to industry and worldwide research. Our involvement in the most advanced aircraft designs and our role in the development of future autonomous systems and aeronautics regulations brought us early to investigate the impact of new computing architectures like multi-core platforms, high-speed reliable networking, data sciences, and semantic infrastructures such as ontologies on airborne systems. Safety critical systems will have to host real-time capable decision-making software that is suited for highly automated verification and qualification.

Information science has developed in the past years with a stunning speed and it is now high time that the links between this science and modern aeronautics are investigated and discussed.

This book is providing a profound compilation of chapters from experts of information communication technologies and aeronautics who share their view about the advances in aeronautical informatics. I would like to thank the authors to present this book which closes an important gap in the literature.

Braunschweig, Germany
February 2018

Stefan Levedag
Director, Institute of Flight Systems
German Aerospace Center (DLR)

Preface

Aeronautical informatics is a cross-disciplinary field that involves aeronautics and computer science. We are witnessing the evolution of Information and Communication Technologies (ICT) through various disruptive innovations that create new paradigms and change our lives. The impact of this evolution is evident on many technical systems. Industry 4.0 refers to this evolution and designates the new era with the keywords "smart" and "connected".

The impact of ICT on how we design and fly aircraft is observable with respect to the progress in aeronautical informatics. In this book, we tried to have a closer look into the advances in this area. The book is organized in *Introduction*, *Information and Communication Technologies Supporting Flight 4.0*, and *The Challenges* sections.

The *Introduction* encompasses Chap. 1 from Umut Durak where he tries to establish a base for the book by elaborating the evolution of aeronautics parallel with the other technical domains. Thereby, in relation to advances in ICT, he introduces the fourth revolution in aeronautics as Flight 4.0.

In *Information and Communication Technologies Supporting Flight 4.0*, there are six chapters that address six fields of advancement. Falco K. Bapp and Jürgen Becker present advances in avionic platforms with the breakthrough in multi-core systems in Chap. 2. Emerging trends in avionics networking are addressed in Chap. 3 by Andreas Reinhardt and Aysegul Aglargoz. In Chap. 4, Christos P. Antonopoulos, Konstantinos Antonopoulos, and Nikolaos S. Voros discuss Internet of Things and Service-Oriented Architecture as the infrastructures for Flight 4.0. Gerrit Burmester, Hui Ma, Dietrich Steinmetz, and Sven Hartmannn present big data and data analytics concepts applied to aeronautics in Chap. 5. In Chap. 6, Carlos Insaurralde and Erik Blasch address utilization of ontologies in aeronautics. The last contribution of this section is Chap. 7 from Shafagh Jafer, Umut Durak, Hakan Aydemir, Richard Ruff, and Thorsten Pawletta. They review the advances in software engineering and their reflections in aeronautics.

The *Challenges* section is composed of three chapters. In Chap. 8, Christoph Torens and Johann C. Dauer and Florian Adolf discuss autonomy and corresponding safety issues particularly in unmanned aircraft domain. Reinhard

Wilhelm, Jan Reineke, and Simon Wegener extend the section with Chap. 9 that elaborates challenges in tackling the real-time requirements as we move toward multi-core avionic platforms. In the last chapter, Ella M. Atkins proposes an expansion to aerospace engineering curricular in order to incorporate aeronautical informatics.

We believe that the notable contribution of this book is highlighting aeronautical informatics as a field of research by providing a comprehensive array of chapters that render various recent advancements in information and communication technologies and their effect on aeronautics. It emphasizes the change in technology landscape of aeronautics as revolutionary. The upcoming era of "smart" and "connected" flight is named as Flight 4.0.

We invite the reader to this unique collection from eminent contributors who elaborate the advancement in their respective fields and explore their applications in aeronautics. We further encourage the reader to contribute for the development of this flourishing multidisciplinary field, aeronautical informatics.

Braunschweig, Germany — Umut Durak
Karlsruhe, Germany — Jürgen Becker
Clausthal-Zellerfeld, Germany — Sven Hartmann
Antirio, Greece — Nikolaos S. Voros

Acknowledgements

This book effort is initiated and partially supported in the context of the ARGO Project (http://www.argo-project.eu/) that is funded by the European Commission under Horizon 2020 Research and Innovation Action, Grant Agreement Number 688131.

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Part I
Introduction

Chapter 1
Flight 4.0: The Changing Technology Landscape of Aeronautics

Umut Durak

Abstract This chapter draws the readers into a comprehensive discussion about the advances in Information and Communication Technologies (ICT) and their influence on the technology landscape of aeronautics. It gives a rough overview of the advances in technical systems from the industrial revolution up until Industry 4.0 and elaborates the reflection of these advancements in aeronautics from the pioneers era toward Flight 4.0. It briefly describes various recent fields of research in ICT such as Cyber-Physical Systems (CPS), Internet of Things (IoT), wireless networks, multicore architectures, Service-Oriented Architecture (SOA), cloud computing, big data, and modern software engineering methodologies as the parts of future aeronautical engineering body of knowledge. Thereafter, it describes aeronautical informatics as an establishing interdisciplinary field of study of applied informatics and aeronautics.

1.1 Aeronautics: The Study of Flight

Aeronautics is defined as the study or the practice of all aspects of flight through the air [1]. It also refers to design, construction, and operation of aircraft [2]. Aeronautical engineering is the corresponding engineering discipline. It applies the scientific principles of flight and engineering in design and development of aircraft and its operation. Aerospace engineering extends the limits of aeronautical engineering with including space flight and astronautics into its scope.

Encyclopedia of Aerospace Engineering from Wiley documents the aspiration of the largest professional organizations of aeronautics, namely Royal Aeronautical Society (RAeS) and the American Institute of Aeronautics and Astronautics (AIAA) in seeking the body of aerospace knowledge [3]. This large-scale reference that covers entire range of scientific and engineering principles of aeronautics and astronautics is organized in eight volumes: fluid dynamics and aerothermodynamics, propulsion and power, structural technology, materials technology, dynamics and control,

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U. Durak et al. (eds.), *Advances in Aeronautical Informatics*,
https://doi.org/10.1007/978-3-319-75058-3_1

environmental impact, manufacturing and operations, vehicle design and systems engineering. This classification provides a comprehensive list for the fields of study in aeronautics in the classical sense.

1.2 The Evolution of Aeronautics

The term technical systems refers to all man-made artifacts, objects, products, tools, and technical works that are a result of a manufacturing activity [4]. Hubka describes evolution of technical systems starting from the early times of machines where each machine is perceived individually as a whole. The studies about the common elements of machines started with the establishment of polytechnical schools in late eighteenth century. Nineteenth century brought the systematic studies of machine elements and mechanisms. The underlying commonalities and patterns across various types of machines ranging from weapons to mining machines and steam engines to aircraft were studied. Engineering is established as the study of machines.

Engineering enabled the age of machinery, the transition from manpower to machine power in various areas. Its effect in production of goods is accepted as a revolution. The transition from hand production methods to machine production is named as industry revolution. Engineering started the pioneers era in aeronautics. Otto Lilienthal [5] as one of the most famous pioneers of this era applied the engineering principles to unpowered airplanes and made the fist successful flight with his glider. The next remarkable step was the success of Wright brothers [6] with the powered aircraft. Among others, these pioneers paved the way to the establishment of aircraft industry at the beginning of twentieth century.

Rapid introduction of machines in wide range of application fields created an enormously increasing demand on automating them. Utilization of the electric, pneumatic, and hydraulic power provided the necessary means. The machines became to be named as systems which are assemblies of numerous elements with the aim to fulfill dedicated function or provide capabilities. The term “technical system” emerged as the recognition of machines as systems. In production, this leap is named as the second industrial revolution and symbolized by mass production. This effected also the production techniques of aircraft. The period between the world wars is named as the golden age of aviation [7]. This was the time where the progress from slow production of wood and fabric aircraft to streamlined production of metal aircraft occurred. Flying stepped toward means of transportation from experimental activity. Aircraft such as Douglas DC-3 marked a turning point air transport in the 1930s and 1940s. It was the time of expansion for commercial airlines companies. Besides revolutionary advances in aerodynamics, the innovation in aeronautical technology rendered various components and aspects of aircraft. Aligned with the advances in technical systems in general, the automation requirements hit the aircraft. The first automatic flight control systems were developed during this period. MacRuer and Graham [8] report that by the late 40s the technology level for all electric control from sensors to servos was already reached. The advances in hydraulics on the other