1 Introduction

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The „Fly-by-Wire" Problem of 1914:

„An aeroplane will last for two or three years in constant use, unless it is very often transported by the railway, when it suffers a certain amount of deterioration if not carefully covered and carried".

First British Air Mail Pilot

Gustav Hamel et al. : „Flying - Some Practical Experiences", Longmans, Green and Co (1914)

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1.1 In-Flight Simulation as Ultimate Tool for Flight Systems Research

During the past five decades, sensor, actuator and image information systems (displays), in conjunction with control laws, provided important technologies to improve the flight performance and characteristics of aircraft and spacecraft. As a prerequisite for this, the revolution in the digital technology that took place in parallel led to an explosive increase in the computing power, which in turn enabled significant progress in the enhancements of features to improve flying qualities, automation, and monitoring for improved flight performance and safety. Figure 1.1 depicts this integration process with its associated developmental technological risks. It is obvious that the interdependency between the three basic elements the flight system techniques will mostly dictate the research focus. In order to achieve a proper balance between effectiveness and flight safety of the integrated systems, it is necessary to account for and to optimize the dynamic interaction between the aircraft, the pilots, and the systems [1, 2].

With the trend of increasing automation, it is the human-automation interaction that is not adequately understood and taken into account during the design process. The pilot-aircraft interactions entail well-trained skills, whereas the pilot-automation interactions pose cognitive workload that is not understood. As a consequence, it must be ensured that during pilot's control inputs through his control panels the presented information and the effect of automatic influence and decisions remain plausible for the pilot in the sense of flight physics. The description of the pilot-related performance potential/capabilities, with regard to the perception of the current flight and system situation, of the ability to work under changing flight and environmental conditions, and his decision-making process in critical flight conditions, represents one of the most complex research tasks for engineers, medical doctors and psychologists in the field of aviation science. In connection with the understanding of whether the pilot, flying an aircraft equipped with complex computer logics, will react correctly in an unfamiliar or unknown flight situation, the pilot represents a weak spot or in other words may symbolize the Achilles' heel of safe flight [3].

Particular importance is also placed on timely proof of the functionality and system safety of new technologies through flight tests. This objective is based on the demand for a timely and cost-effective review of the technical and economic risks associated with the development of operationalization of new methods or critical technologies. Thereby it is essential that today's development and life cycles of civilian or military flight systems cover a period of an engineer's life of about 35–40 years. Thus, there is also the risk of losing interdisciplinary know-how in the aeronautical engineering field. As a consequence, it calls for continuous research and industrial-political efforts to realize the anticipated developments or ongoing system improvements though demonstrator programs or in-flight simulations in reasonable time periods. In international terminology, this is termed as reaching of a technology maturity level (Technology Readiness Level—TRL), which is assigned a value of about 6, that means "*functional and test prototype in operational range*" (see also Sect. 6.1.2).

The interlinkages of flight system techniques depicted in Fig. 1.2 elucidates the individual steps to be followed in an ideal case during the new development or improvement of existing flight systems.

The limited usage of these technologies, due to, say, developmental, political or financial reasons, or of other research tools in related disciplines such as structures or propulsion technologies, culminates to the disastrous effects shown in Fig. 1.3. Such events and the resulting socio-political issues have become a world-acclaimed predicament. As such, *Norman Augustine* needs to be greeted [4].

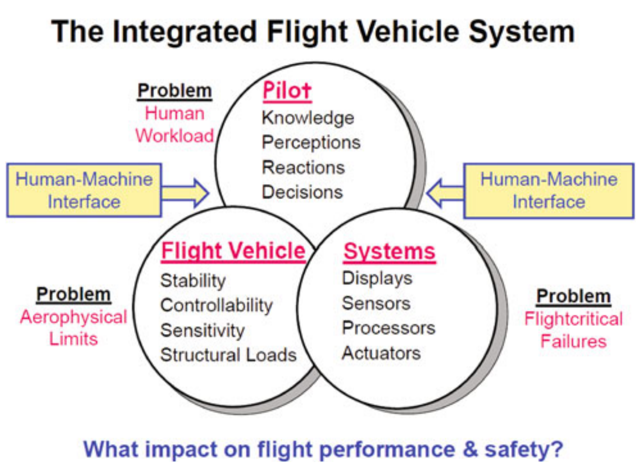

Fig. 1.1 Interactions in integrated flight systems

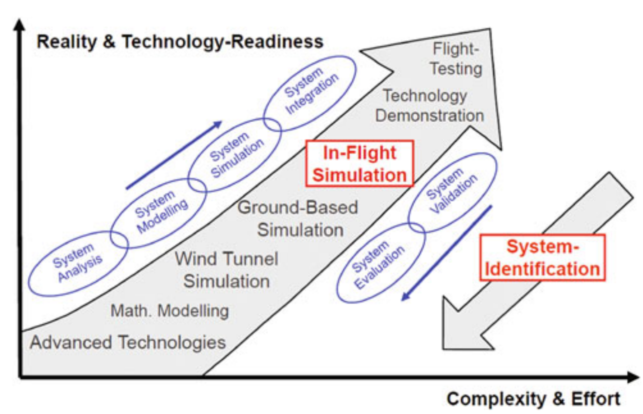

Fig. 1.2 The chain of research tools for flight vehicle system development

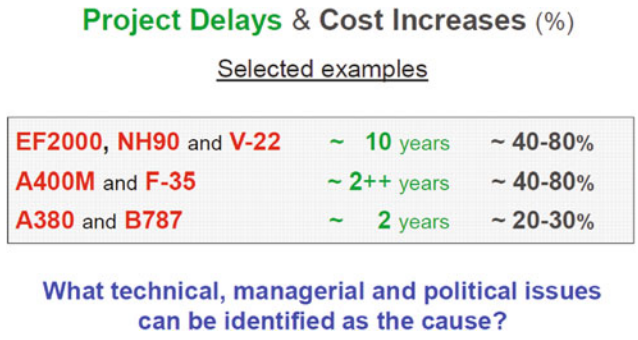

Fig. 1.3 Development risks and realities

The two elements shown in Fig. 1.2, namely the in-flight simulation, the supreme discipline flight testing, and the arts and science of system identification, a symbiosis of creativity and specialized knowledge, offer two versatile and experimentally oriented methods and are of particular value for the verification, optimization, and evaluation of flying qualities of manned or unmanned aerial systems with integrated Fly-by-Wire/Light flight control and information systems. But, it should also be pointed out that the human-in-the-loop ground-based simulation, plays, indeed, an indispensable role in a flight vehicle development program to minimize the more costly in-flight simulation.

A more detailed discussion and definition of the disciplines "in-flight simulation" and "system identification" will be given in Chap. 3. Both these disciplines represent also special, long-term focal points of research activities at the Institute of Flight Systems at the German Aerospace Center (DLR) in Braunschweig. An account of these efforts will be given in Chaps. 7–10.

1.2 Current State of Knowledge

There are a number of national and international, historical reports on the development of electronic flight controls for improving the handling and flying qualities of aircraft and helicopters [5–12].

The hitherto most detailed historical account related to airplanes with variable stability and in-flight simulation comes from one of the fathers of in-flight simulation, *Waldemar O. Breuhaus*, of the former Cornell Aeronautical Laboratory, the company which later became the Calspan Corporation in the USA [13]. Throughout this book, the name Calspan (CAL) will be used for all references to the company.

This historical account was later extended and supplemented by the Calspan expert *Norman Weingarten* with his years of experience [14]. A further well represented and detailed history of aerospace research at Cornell Aeronautical Laboratory and Calspan is given in [15]. In an extremely exciting book that goes beyond the scope of in-flight simulation, one comes across a highly readable autobiography of *William F. Milliken*, a former managing director of Cornell Aeronautical Laboratory (CAL). *William F. Milliken*, *Waldemar O. Breuhaus*, *Irving C. Statler*, *Robert P. Harper* and *Edmund V. Laitone* and others spearheaded at CAL the flight test research in aircraft dynamic response measurements, variable stability flight testing, the importance of test pilot judgements and closed-loop system analysis. Further, the book provides a historical overview of industrial flight testing and the use of aviation-related technologies in US automobile sport by way of Bugatti as an example [16]. Also, the special role of the NASA Ames and Dryden Research Centers (the latter since 2014: Armstrong Research Center) in this field can be easily traced through a few selected examples [17–19]. From the international book world two publications are known which describe experimental aircraft and to a limited extent also in-flight simulators, predominantly developed in the United States or Russia [20, 21].

The importance of in-flight simulation and their technological benefit was emphasized in the first international symposium during 1991 held in Braunschweig. Flight demonstrations with DLR´s in-flight simulators VFW 614 ATTAS and Bo 105 ATTHeS were presented then [22, 23]. A detailed discussion of this symposium took place in the international leading aviation magazine *Aviation Week & Space Technology* ("*Gathering of the In-Flight Simulation Fraternity*") [24].

1.3 The Book Layout

The current compendium is organized into three parts. The first, short part consisting of Chaps. 2 and 3 introduces succinctly the topics addressed in this collection, namely flying qualities background, basics, and benefits. The second part consists of Chaps. 4–6. It provides a brief account of predecessors in Germany in Chap. 4. This is followed by an exhaustive account of variable stability aircraft and in-flight simulators in Chap. 5, covering United States, Canada, England, France, Russia, Japan, China, and Italy. Chapter 6 provides, likewise, an elaborative account of Fly-by-Wire/Light Demonstrators, first from abroad, and in the latter half those from Germany. The third part of the book, consisting of Chaps. 7–12 focuses on the research and development activities in Germany in more detail. It aims at providing the readers with the inside information about these challenging projects to understand the intricacies, efforts required, and the outcome. Each of these chapters in all the three parts provides relevant technical literature to trace the historical developments, the evolution, and the current status in the fields of in-flight simulation and Fly-by-Wire/Light research.

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Author Biography

Peter G. Hamel was the Director of the Institute of Flight Mechanics/Flight Systems of the German Aerospace Center (DLR/DFVLR) (1971–2001). He received his Dipl.-Ing. and Dr.-Ing. degrees in Aerospace Engineering from the Technical University of Braunschweig in 1963 and 1968, and his SM degree from M.I.T. in 1965. From 1970 to 1971 he was Section Head of Aeronautical Systems at Messerschmitt-Bölkow-Blohm in Hamburg. Since 1995 he is an Honorary Professor at the Technical University of Braunschweig and a founding member of three collaborative research centers at the University. He was Chairman of the National Working Group on Helicopter Technology (AKH) (1986–1994) and the appraiser for the National Aviation Research Program (LuFo) until today. He was also the Manager of DLR's Rotorcraft Technology Research Program and the German Coordinator for the former AGARD Flight Mechanics/Vehicle Integration (FMP/FVP) Panel. He is a member of the German Society for Aeronautics and Astronautics (DGLR) and of the American Helicopter Society (AHS), and a Fellow of AIAA. He is the recipient of the AGARD 1993 Scientific Achievement Award, of AGARD/RTO von Kármán Medal 1998, of AHS Dr. A. von Klemin Award 2001, and of the prestigious DGLR Ludwig-Prandtl-Ring 2007.