concern controller design. Consequently, essential features of the problem are scattered throughout the chapters of this book. However, this problem is very difficult, and further research remains to be performed. Therefore, with respect to content, an additional chapter organizing this problem as an independent issue would have been more sophisticated.

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doi:10.1016/S0005-1098(03)00189-4

Advances in Aircraft Flight Control

Mark B. Tischler (Ed.); Taylor & Francis, London, UK, 1996. ISBN 0-7484-0479-1

Modern aircraft flight control design and implementation involves a wide variety of disciplines ranging from aircraft aerodynamics to digital data buses; high integrity and failure survival are all pervading factors.

This book appeared in the Taylor & Francis book series on Systems and Control (see, e.g., Utkin, Gulder, & Shi, 1999). The book provides an excellent addition to the System and Control series and gives a review of current practices in the field of flight control design. The book is an extension of a special issue of the *International Journal of Control* (Tischler, 1994) devoted to applications of modern control techniques to aircraft flight control design. Additional contributions were obtained from an *AGARD Flight Mechanics Panel Symposium* (Anon, 1994). Considerable effort has been expended in ensuring that this book is not merely a bound reproduction of previously published papers. Unlike most books dealing with aircraft flight control which focus on flight control law design principles (Adams, Buffington, Sparks, & Banda, 1994; Bates & Postlethwaite 2002; Blakelock, 1991; Bryson, 1994, Etkin & Reid, 1996; McLean, 1990; McRuer, Ashkenas, & Graham, 1973; Nelson, 1998; Stevens & Lewis, 1992), this book covers the various practical issues seen from an industry perspective, particularly by a "case study" approach. A major portion of the book is on reviews of the flight control design for a number of specific aircraft.

The book consists of four parts: (1) specification and validation methods; (2) rotorcraft and V/STOL vehicles; (3) transport aircraft; and (4) high-performance aircraft. The latter three parts constitute over 90% of the material presented. These chapters typically review an aircraft's mission, modeling and handling qualities requirement, the flight control design methodologies and tools, simulation and flight test. The problems that appeared in the program, and their resolution and "lesson learned from the experience", are also given. A total of 15 chapters are included.

Part 1, *Specification and Validation Methods*, consists of two chapters, addressing two cross-cutting themes, handling qualities and system identification from flight test data, which appear and reappear through the design cases. Overviews of these topics are properly given in the first two chapters for two reasons: (1) all the aircraft to be discussed are piloted and the achievement of acceptable handling qualities is an important design requirement for flight control systems. (2) Like in any control system design, the availability of a model of the plant dynamics is an indispensable first step in the development of a flight control system. The first chapter reviews the current approaches to relating handling qualities specification to flight control design. Emphasis is given to MIL-STD-1797A as the most detailed specification available (fixed wing vehicle). The evolution of the specification in recent years to accommodate highly augmented fly-by-wire aircraft that may have unconventional dynamics is emphasized. Recent efforts to develop "mission-orientated" specifications are reviewed as well. The second chapter summarizes the use of frequency-domain identification techniques in flight control design. Frequency domain methods are emphasized and their convenience connected with frequency domain handling qualities are noted.

Part 2, *Rotorcraft and V/STOL*, consists of four chapters. This Part reviews the control of aircraft with flight regimes extending to low or zero air-speed. The design of flight control systems for these aircraft can be particularly challenging since the low-speed regime offers little in the way of natural aerodynamic damping. Chapter 3 discusses the development and research application of a rotorcraft in-flight simulator capability (ATTHeS) based on a Bo-105 helicopter equipped with a fly-by-wire control system. Before its unfortunate loss in an accident, the ATTHeS was an in-flight simulator implemented with a high-bandwidth explicit model-following control system. A detailed discussion of the ATTHeS model-following control system design and performance as well as examples of handling qualities research using this vehicle are presented.

Chapter 4 provides an extensive overview of rotorcraft flight control design at Boeing Helicopters, beginning with the tactical air guidance system (TAGS) experimental test bed, continuing with the advanced digital optical control system (ADOCS) implemented on a UH-60 helicopter, and ending with the newest development of the RAH-66 Comanche and V-22 Osprey vehicles. This chapter discusses the several advanced flight control design conceptions, such as integrated flight/fire control (IFFC), integrated flight/propulsion control (IFPC), and vehicle management system, etc. The authors indicate the trends for future development.

Chapter 5 discusses the application of nonlinear inverse methods to control systems for short-takeoff and landing (STOL) aircraft. The applications discussed include flight test results from the NASA Ames quiet-STOL research aircraft (QSRA) and manned simulator evaluations of a short take-off vertical landing (STOVL) fighter. Nonlinear inverse methods are attractive means for providing what the flight-control engineers refer to as "full-envelope" flight control laws eliminating the need for gain scheduling.

Chapter 6 treats flight control issues related to the vectored thrust aircraft advanced flight control (VAAC) program. This chapter summarizes moving-base simulation and flight test results with a number of competing longitudinal control systems for low-speed and hovering flight regimes. The impact of increasing control law sophistication upon pilot workload and vehicle handling qualities is demonstrated.

Part 3, *Transport Aircraft*, deals with advanced flight control designs associated with large transport aircraft that possess unique flight control requirements. Chapter 7 summarizes the US advanced tactical transport aircraft C-17 fly-by-wire flight control system development with particular emphasis upon the achievement of acceptable handling qualities. Brief descriptions of the pitch and roll-axis stability and command augmentation systems (SCASs) are given. A more detailed discussion of the flight control problems associated with the landing power-approach mode is also given. The flight control requirements of the demanding air refueling and low-altitude parachute-extraction tasks are also discussed, as is the pilot-induced-oscillation (PIO) phenomenon which occurred in early flight tests. The PIO problem is of continuing interest to the flight control community as its occurrence is often the result of deficiencies in the flight control system.

Chapter 8 reviews control law development for the Airbus series of commercial transport aircraft. The discussion relies heavily on the A320 design, since this was the first of the Airbus fly-by-wire vehicles. The flight control design philosophy is presented followed by a discussion of the A320 and A340 control law design experience. Emphasis is given to the extensive use of simulation tools in various design phases. The chapter concludes with a discussion of the development of a "turbulence damping function" to improve the ride quality in the face of fuselage flexibility. The issue of aeroservoelasticity or the elastic behavior of the aircraft structure, in the design of flight control systems for future and larger transport aircraft is very important to the flight control community.

Chapter 9 discusses modern multivariable control techniques, essentially linear quadratic regulator and linear quadratic Gaussian (LGR/LQG) approaches. Two examples are provided entailing: (1) a study to improve the Boeing 767 lateral autopilot and (2) the development a fighter control system for post-stall flight. The importance of simulation in the design cycle is emphasized, as is Boeing's philosophy regarding control software utility and development.

Part 4, *High Performance Aircraft*, includes six chapters. This Part is about fighter-type aircraft. As indicated in the preface, "multiply-redundant nonconventional control surfaces and relaxed static-stability concepts are utilized to achieve increased maneuverability and agility even at the edges of the flight envelope, while at the same time minimize radar cross-section". Chapter 10 discusses the flight control system for the Lavi aircraft wherein efforts directed toward ensuring acceptable handling qualities are discussed. In the chapter, the importance of simulation is also emphasized. However, this chapter employed more classical control theory.

Chapter 11 describes the two aircraft autopilot designs performed by Alenia. The chapter outlines the Alenia experience with the experimental AMX close-air support aircraft and participation in the development of the Eurofighter EF 2000 flight control system. The autopilot designs were all based upon classical procedures, e.g., analyses utilizing root locus diagrams and Nichols charts. Again, extensive simulation, both piloted and nonpiloted, was used to validate and modify control laws, particularly as regards nonlinear effects.

Chapter 12 discusses the British Aerospace experimental aircraft program (EAP) which served as a forerunner to the Eurofighter 2000. In this instance, the demands of an unstable airframe, high angle-of-attack flight, and the so-called "carefree handling qualities" provided a challenging flight control system design. In this chapter, classical control system design techniques were employed. The flight control system development progressed through three phases: (1) first flight standard; (2) incidence (angle of attack) limiting with carefree flying; and (3) flight testing.

Chapter 13 summarizes the control system design and flight test of the two X-29 forward-swept wing aircraft for both low and high angle-of-attack flight regimes. Basic response types for the longitudinal and lateral flight control systems are outlined. Many texts are directed toward the air-data sensors and redundancy management. Control surface actuator rate limitations were highlighted as important constraints in the design of flight control systems for high-performance aircraft.