Dean&Francis

ISSN 2959-6157

Research on the Evolutionary Pathways and Intelligent Development Trends of Aircraft Cockpit Automation Technology

Bingchen Wu[1,*]

[1]School of Transportation and Logistics Engineering, Wuhan University of Technology, Wuhan, 430000, China

*Corresponding author: 340234@whut.edu.cn

Abstract:

The cockpit is hailed as the aircraft's "brain", playing a crucial role throughout the entire flight and serving as the very core of aircraft control. A well-designed and fully functional cockpit not only ensures flight safety and stability, mitigating potential risks and accidents, but also effectively reduces the pilot's workload. By streamlining operations and alleviating pressure, it enables pilots to maintain high operational efficiency in complex and dynamic flight environments, guaranteeing the smooth execution of every flight. Whereas early, purely mechanical operations required pilots to manually manipulate various mechanical devices, today's highly integrated electronic control systems enable pilots to utilise advanced computer technology and intelligent equipment. The technology within the cockpit has undergone revolutionary transformation, with its rapid pace of development and remarkable technological progress commanding attention. Whilst cockpit automation has markedly enhanced flight safety and operational efficiency, reducing human error and boosting overall reliability, certain unresolved challenges persist due to the ongoing refinement of these technologies in practical application. These include potential anomalies in Boeing's Maneuvering Characteristics Augmentation System (MCAS) under specific conditions, and imperfections in human-machine interface design and feedback mechanisms. These are the difficulties we must now confront and resolve to ensure the further optimisation of technology and the continuous enhancement of flight safety.

Keywords: Intelligent Cockpit; Human-computer interaction; Fly-by-Wire System.

1. Introduction

The aviation industry's objective is to ensure passengers reach their destinations more safely and swiftly, and the rapid advancement of automation technology has provided novel solutions to this challenge. For instance, modern passenger aircraft can now use automatic landing systems during extreme weather conditions, reducing reliance on pilot skill; the introduction of the Traffic Collision Avoidance System (TCAS) has significantly diminished the risk of mid-air collisions. Concurrently, with the emergence of technologies such as autonomous flight and artificial intelligence, the automation level of contemporary aircraft continues to rise, progressively undertaking an increasing array of tasks. However, while automation enhances safety and efficiency, it also introduces novel challenges, such as public trust in emerging technologies, the reliability of automated systems, and human-machine interaction issues.

The evolution of automation has driven significant upgrades in aircraft cockpit technology. Early aircraft featured solely mechanical and hydraulic control systems. It was not until the latter half of the 20th century, with advances in electronics, that the Airbus A320's fly-by-wire (FBW) system heralded the dawn of electronic flight control systems. Entering the 21st century, the widespread adoption of integrated avionics systems, Enhanced Vision Systems (EVS), and Traffic Collision Avoidance Systems (TCAS) has elevated automation in modern airliners to unprecedented levels. For instance, the Autoland system guides aircraft to safe landings in low-visibility conditions, while TCAS significantly reduces the probability of mid-air collisions. Future aircraft cockpits will integrate 5G technology, artificial intelligence, and control systems to develop increasingly intelligent flight decks.

This paper aims to systematically review the technological evolution of aircraft cockpits from traditional mechanical systems to contemporary automation technologies. It explores future trends in aircraft automation, analysing various aspects of this technological progression to provide an academic perspective on the advancement and future development of modern aircraft cockpits.

2. Development of Cockpit Technology

2.1 Automation in the cockpit

2.1.1 The Development of Flight Control Systems

Traditional flight control systems primarily comprise mechanical and hydraulic flight control systems. The mechanical flight control system was the earliest iteration, operating on the principle of translating the pilot's control inputs through mechanical transmission to the aircraft's control surfaces. It found widespread application in early aircraft. With advances in science and technology, hydraulic flight control systems emerged. Compared to mechanical systems, they offer significantly higher energy transmission ratios, enabling superior control precision and responsiveness. However, hydraulic systems retain inherent limitations: any damage is amplified under extreme high-altitude conditions. Consequently, to ensure safety and reliability, ground personnel must conduct regular safety inspections and maintenance on hydraulic flight control systems [1].

By the 1960s, as aircraft performance continued to advance, earlier flight control systems became obsolete, leading to the development of Fly-by-Wire System (FBWS). Unlike previous systems, pilot input commands no longer required mechanical transmission to control surfaces. Instead, these inputs are converted into corresponding electronic signals and transmitted directly to the actuators. This approach not only overcame the drawbacks of mechanical systems, such as their substantial weight and complex structure, but also facilitated easier pilot control. However, fly-by-wire systems retain certain disadvantages. Compared to traditional non-mechanical systems, their design necessitates consideration of electronic and computer technologies. The overall complexity of the system presents significant challenges for development and maintenance, demanding a high level of specialisation from maintenance personnel [2, 3].

2.1.2 Composition of the Flight Control System

ISSN 2959-6157

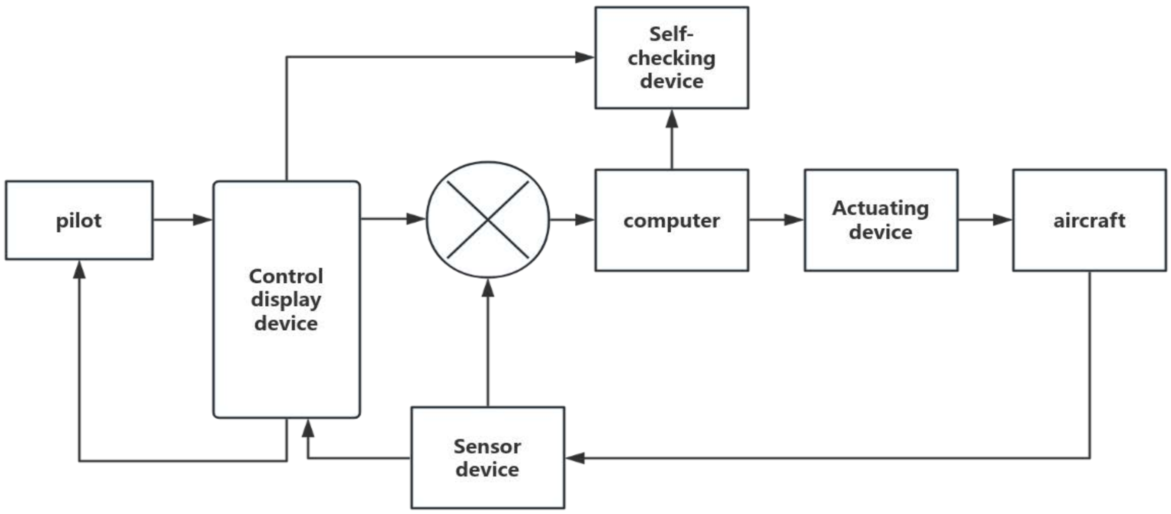

Fig. 1 Basic Components of the Flight Control System [2]

Shown in Fig.1 the control systems of modern aircraft primarily comprise control and display units, sensor computers, self-checking devices, and their information transmission chains. These systems collectively form a closed-loop feedback circuit. Pilots input control commands into the system by operating the control display units. These units simultaneously relay commands to the computer and receive information from the sensor devices, interacting with them. The sensor devices are responsible for gathering relevant aircraft status information, feeding this data back to the control display units, and exchanging signals with the computer. Upon receiving signals from both the control display units and sensor units, the computer processes these inputs before issuing commands to the actuators. The actuators then operate the corresponding aircraft components according to the computer's instructions, thereby achieving effective control of the aircraft. Furthermore, the computer interfaces with the self-diagnostic units, which perform self-checks on critical components such as the computer itself, ensuring the reliability of system operation.

2.1.3 Key Issues in the Electrical Control System

Safety remains a paramount focus in civil aviation research and development at all times. At the system level, overall safety can be enhanced through independence, non-similar design, and comprehensive monitoring. System design must ensure each component can operate autonomously, preventing failures from propagating to other functional systems. Furthermore, design processes must incorporate redundancy provisions for aircraft. Additionally, traditional mechanical control systems remain indispensable; should the aircraft's electronic control systems fail, backup mechanical systems must be guaranteed to take over [2].

3. Evolution and Development Trends of Cockpit Human-Machine Interfaces

3.1 Human-Computer Interaction Technology

3.1.1 The Development of Human-Computer Interaction

Science and technology are constantly advancing, and human-machine interfaces have evolved accordingly with scientific progress. For early aircraft, the adoption of mechanical flight control systems resulted in remarkably simple human-machine interfaces. They comprised only a compass, altimeter, airspeed indicator, and engine tachometer. Limited engine technology at the time resulted in slow aircraft speeds and low take-off altitudes. As aircraft technology advanced, pilots required an increasing array of flight parameters. The rudimentary equipment of the past could no longer meet these demands, though mechanical devices remained predominant. However, the complexity of aircraft data necessitated multi-crew operations. For pilots, the continuous enhancement of aircraft performance led to a dramatic increase in the volume of information they had to process simultaneously. Confronted with an overwhelming influx of data, they must rapidly extract, verify, and interpret the information received, executing correct actions within a fraction of a second. The slightest hesitation could precipitate an accident. This situation necessitated the evolution of human-machine interfaces from simplicity to complexity and back to simplicity. Consequently, improvements in human-machine interface development, particularly the advancement of integrated display technology, became essential to alleviate the workload on pilots [4-6].

3.1.2 Touchscreen technology

Compared to traditional cockpit equipment, touchscreens enable pilots to swiftly read data while simultaneously controlling the aircraft. The direct interaction offered by touch panels is simpler, more precise, and easier to master than the indirect interaction of buttons, making errors easier to correct. Moreover, button-based interfaces necessitate careful consideration of button design. Variations in button size, position, and shape can significantly impact pilots. Only well-designed buttons can help alleviate the burden on pilots during fatiguing flights.

3.1.3 Speech recognition technology

Voice recognition uses machines to convert pilots' spoken commands into corresponding text or instructions. Moreover, voice interaction technology can serve as an assistant to aid pilots in controlling aircraft, though this requires mature AI technology to achieve. However, in voice recognition, engine noise and external environmental factors can interfere with voice command input. Incorrect command recognition may distract pilots and consequently reduce operational efficiency. Moreover, if erroneous data is identified through voice input and the pilot fails to detect this, it could severely compromise flight safety. Additionally, variations in language and accent among pilots present a significant challenge in development [6].

3.2 Traffic Collision Avoidance System (TCAS) technology

In the early days of aviation, with fewer aircraft and smaller scales, route conflicts were not a pressing concern. It was not until the 1950s, following a horrific mid-air collision over the Grand Canyon, that efforts to prevent air disasters led to the development of the airborne automatic collision avoidance system.

TCAS comprises four components: air surveillance, threat detection, vertical advisory, and pilot interface. It uses transponders to gather information on nearby airspace, employing its own computer to analyse relative positions, altitudes, and speeds of aircraft. It determines whether to feed this data into the threat detection system and repeatedly alerts pilots with 'traffic, traffic' to warn of approaching aircraft. Should a potential collision be assessed, the system issues an R A command to the pilot interface. The pilot must then execute evasive manoeuvres within 2.5 seconds to avert the risk of collision [7, 8].

4. The Impact and Development Trends of Automation

The automation of aircraft has brought numerous benefits, enhancing flight safety and technical reliability. Navigation and monitoring systems have improved pilots' understanding of the aircraft's real-time status, significantly reducing their workload, increasing efficiency, and allowing more time for decision-making. However, as with all things, automation carries inherent risks. Compared to the past, pilots now spend more time managing autopilot systems. When these systems malfunction, recovery becomes exceedingly difficult. On 10 March 2019, the Maneuvering Characteristics Augmentation System (MCAS) aboard Ethiopian Airlines Flight 302 malfunctioned. Designed to prevent stalls by automatically lowering the aircraft's nose when the angle of attack became excessive, MCAS erroneously transmitted commands to the autopilot system. This compelled the aircraft to persistently pitch down until it crashed. Throughout this process, the captain repeatedly engaged in a human-machine struggle against the autopilot, yet ultimately failed to save the aircraft, resulting in the loss of 346 lives. An investigation by the Federal Aviation Administration (2013a) revealed that pilots had lost their essential manual flying skills. The report stated: 'Pilots had become accustomed to observing faults occur, having lost the initiative to actively address them.' Pilots must always control the autopilot system, not be controlled by it [9, 10].

The future development trajectory of the cockpit must remain firmly centred on the core objectives of enhancing operational efficiency and increasing profitability. In essence, this entails a gradual transition from the currently prevalent two-pilot collaborative flight model—comprising a captain and first officer—towards a single-pilot operation (SPO) model. This paradigm shift will not only effectively reduce airlines' reliance on and demand gap for experienced, technically proficient pilots, thereby alleviating pilot shortages, but also further optimise human resource allocation through reduced staffing levels. This will lower operational costs and enhance airline profitability. Such transformation aligns with the aviation industry's trend towards greater efficiency and economy, while simultaneously bolstering airlines' competitive edge in the marketplace.

In recent years, rapid advancements in autonomous driving technology and big data modelling have significantly propelled the automation of cockpits towards more intelligent AI-driven systems. This technological advancement not only transforms conventional piloting methods but also provides pilots with more intelligent in-cockpit assistance. Through deep learning and autonomous adaptation to pilot behaviour, intelligent AI systems deliver more precise and real-time support during flight operations. Consequently, these systems evolve from supplementary tools into more reliable and efficient assistants for pilots

ISSN 2959-6157

in the air. This not only reduces pilots' workload but also enhances their operational efficiency.

5. Conclusion

Within the civil aviation sector, the intensity of market competition alongside the constant evolution and elevation of user requirements have become the key drivers propelling continuous technological advancement and innovation. This paper delves into the evolution of aircraft automation technology and its potential future trajectories. It examines multiple dimensions—including the electrification of electronic control systems, the user-friendliness and convenience of human-machine interfaces, and the precision warning and collaborative processing capabilities of TCAS (Traffic Collision Avoidance System)—to detail the current application status, historical transformations, and prospective development trends of these technologies within civil aviation. Through a comprehensive analysis of these core technologies, this study aims to provide readers with a perspective on the development trajectory of aircraft automation technology.

References

[1] Ding, W., Cao, S. B., Liu, M. Y. Development History and Future Trends of Flight Control Systems. Machine China, 2025, (13): 16-19.

[2] Guan, T. Y., Zhang, R., Liu, C. Analysis of the Typical Civil Aircraft Electro-Mechanical Flight Control System Architecture. Mechanical and Electrical Information, 2024, (19): 75-80.

[3] Huang, G. H., Li, Y., Lian, F. H. Overview of the Development of Aircraft Fly-by-Wire Systems. Modern Education Science, 2024, (19): 75-80.

[4] Wu, W. H., Gao, Y., Wang, J. The Evolution, Current Status and Future Trends of Flight Control Systems. Flight Dynamics, 2018, 36(04): 1-5+10.

[5] Meng, H., Dong, Q. P., Zhao, C. L., Ma, X. C., Dong, D. Y. "A Research on the Intelligent Flight Deck Development Trend for the Civil Aircraft." Lecture Notes in Electrical Engineering, 2024, 1153: 111-124.

[6] Liu, W., Yang, J. Z. A Review of Novel Human-Machine Interaction Methods in Civil Aircraft Cockpits. Chinese Journal of Ergonomics, 2024, 30(03): 81-86.

[7] Kuba, S., & Babiceanu, R. F. Navigating Threats: A Vulnerability Analysis of TCAS Interaction with Other Aircraft Systems. AIAA/IEEE Digital Avionics Systems Conference - Proceedings, 2024.

[8] Wei, L., Yang, J. R., Lei, Z. Z. & Qi, M. Z. Airborne Collision Avoidance System Collision Avoidance Logic Analysis. China Science and Technology Information, 2023, (02), 57-60.

[9] Li, X. Z., Li, X. Y., Li, C. Cockpit Automation and Human-Machine Interaction. Avionics Technology, 2024, 55(03): 29-35.

[10] Wang, X. Y., Li, Y., Chang, M. & You, X. Q. The Dangers of Automated Trust and Dependence to Aviation Safety and Their Mitigation. Advances in Psychological Science, 2017, 25(09):1614-16.