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Research on Aircraft Autopilot Systems and Remote Control Technology for Commercial Aircraft

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Abstract:

This article provides a comprehensive review of commercial aircraft autopilot systems and remote control technologies. With the rapid development of artificial intelligence, the Internet of Things, and 5G communication technologies, aircraft piloting is undergoing a profound transformation toward automation and remote control. This article briefly describes the components and operating modes of the autopilot system, introduces the shock wave adaptive control system, and lists several technical and process optimization methods for shock wave adaptive control systems. It also describes the current status and development trends of flight management systems. It also examines the components of the remote control system and the optimization technologies for satellite and very high frequency communications within the communication link. It finds that intelligent perception, autonomous decision-making, and high-performance communication links are essential foundations for efficient and autonomous aircraft operation. This article can provide a reference for the design, development, and engineering application of intelligent flight systems and remote-controlled flight systems for future commercial aircraft.

Keywords: Autonomous driving system; remote control system; intelligent flight.

1. Introduction

With the rapid development of artificial intelligence, the Internet of Things, and 5G communications, the technologies for autopilot and remote control systems for commercial aircraft are maturing. Traditional commercial aircraft are also becoming increasingly automated and remote-controlled. This transformation has effectively improved the stability of commercial aircraft air transport and significantly reduced the burden on pilots. These changes and developments have alleviated pilot shortages and effectively reduced commercial aircraft flight costs.

The autopilot is a core subsystem of automated flight systems, which are divided into two main types: adaptive control systems and flight management

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systems. Currently, global commercial aircraft autopilot technology is evolving from advanced assisted piloting to a higher level of autonomy. Core research focuses on intelligent perception, autonomous decision-making, and onboard system integration, aiming to comprehensively improve flight safety, efficiency, and economics. China is committed to integrating and domestically producing flight control systems, while other countries are focusing on optimizing flight and takeoff and landing under special circumstances, as well as researching unmanned cargo transportation.

To ensure the smooth and stable operation of the autopilot system, remote control systems are crucial to its success. The remote control system of commercial aircraft is mainly divided into four parts: ground control, communication link, onboard control, and auxiliary and support system. The communication link is the key technology for data exchange between the aircraft and the ground. It mainly relies on satellite communication systems and very high frequency (VHF) communication systems. The choice of communication link greatly affects the stability, safety, and timeliness of remote control [1,2]. At present, the development of remote control systems for commercial aircraft focuses more on developing a new generation of aviation communication, navigation, and surveillance systems with ground-based control stations as nodes. In this regard, China focuses on building an aircraft health management and safety monitoring system based on the existing framework, while foreign countries focus on the research of innovative technologies such as unmanned control modes.

This paper is based on the fact that the driving of commercial aircraft is gradually becoming automated under the rapid development of communication technology. It is based on the existing aviation autopilot and remote control related technologies and system overview. Some research reviews are conducted on the composition and working mode of the autopilot system, including adaptive control system and flight management system, as well as the composition of the remote control system and the optimization of the remote control system communication link. This paper first reviews the composition and working mode of the autopilot system, then introduces the adaptive shock wave control technology, and then explains the current status of the flight management system and looks forward to its future development. Finally, it introduces the composition of the remote control system and understands the research on the optimization of satellite communication and very high frequency communication technology in the communication link [1-3].

2. Autonomous Driving System

2.1 Components and Operating Modes of Autonomous Driving Systems

Early autonomous flight systems were relatively simple, primarily consisting of detection devices such as gyroscopes, accelerometers, and altimeters, along with basic circuitry. They mainly corrected the aircraft‘s flight direction by utilizing electrical signals generated from changes in gyroscope parameters. With advancements in computer science, the primary method for controlling these devices has shifted to more precise computer signals, and designs have become significantly more complex. With the assistance of computer systems, even the slightest anomalies in flight status can now be promptly detected [4].

The typical autopilot operating modes for aircraft are divided into two types: the control wheel mode and the command mode. Both autopilot modes require the aircraft to take off and reach a certain altitude before normal operation can commence. In yoke mode, the pilot‘s inputs are converted into electrical signals and transmitted to the autopilot computer. The computer then converts these electrical signals into control commands and sends them to the autopilot hydraulic servo actuators. By controlling these hydraulic servo actuators, the system controls the rudder actuators, thereby controlling the movement of the control surfaces. In command mode, instructions are issued from the control panel or flight management computer to the autopilot computer. After calculating the control commands, the autopilot computer follows the same subsequent process as command mode, ultimately controlling the movement of the control surfaces [5].

2.2 Flight Control System

2.2.1 Adaptive Control System

Adaptive control systems constitute a critical component of flight control systems. This paper provides a detailed examination of an adaptive shock control system for supersonic flight. During transonic flight, shocks on the wing surface generate significant wave drag and flow instabilities, leading to increased fuel consumption and structural vibrations. Adaptive shock control technology is therefore particularly vital for achieving more efficient and environmentally friendly flight. While traditional fixed shock control techniques improve aerodynamic performance at design points, they may increase drag during operating conditions deviating from design parameters. In contrast, adaptive shock control technology features adjustable height and position, enabling sustained aerodynamic performance under more complex and challenging

flight conditions [3].

This paper introduces four adaptive shock control technology approaches: spoiler-based adaptive systems, multi-actuator arrays utilizing shape memory alloys, pneumatically driven cavity expansion structures, and passive and active control methods based on flexible plate structures.

In spoiler-based adaptive systems, deformable spoilers are employed to generate protrusions. These incorporate preformed spoiler structures whose height and position can be adjusted via actuators. The design utilizes flexible composite hinges to eliminate aerodynamic interference at traditional joint points, making it suitable for both normal flight and deceleration conditions.

In shape memory alloy-based multi-actuator arrays, localized deformation is controlled through temperature-induced changes in the alloy, enabling substantial displacement output within confined spaces. These lightweight, fast-responding actuators are primarily suited for small-scale adjustable shape control.

In the pneumatic cavity expansion structure, multiple chambers are embedded within the spoiler. By adjusting cavity pressure to induce deformation, shock control is achieved. A three-chamber design enhances deformation capability while reducing pressure requirements, though it necessitates balancing control system complexity with structural rigidity.

Passive and active control methods for flexible plate structures include passive shock control relying solely on pneumatic pressure differentials to deform the plate, and active control schemes using linear electric actuators to manage bulge morphology and position. Active control via linear electric actuators achieved an 18 mm stroke range in experiments, significantly improving shock position control accuracy.

As a vital component of low-drag aerodynamic design for aircraft, shock wave adaptive control systems have transitioned from theoretical validation to structural integration and wind tunnel testing. Particularly promising are solutions incorporating spoiler-based structural enhancements, which offer substantial engineering applicability without compromising existing flight control functions. These advancements provide critical technological support for the future development of green aviation.

2.2.2 Flight Management System

The flight management system is the core system of trajectory management. The flight management system generates the optimal trajectory based on the flight plan, air traffic control constraints, aircraft performance, and weather conditions. The flight management system coordinates with the autopilot system to improve flight efficiency and reduce flight costs. Among them, the integrated mission management system used in the CS-23 commuter aircraft greatly reduces the burden on pilots by aggregating dangerous information from the sky, traffic, weather, and terrain, and automatically pre-filtering the data [6]. With the continuous growth of global air transport demand, the traditional air traffic control model dominated by ground equipment is difficult to meet current needs. Therefore, the United States, Europe, the International Civil Aviation Organization, and China have successively developed a new generation of air traffic control systems.

The Federal Aviation Administration of the United States proposed the „Next Generation Air Transport System“, which relies on technologies such as broadcast automatic dependent surveillance, data communication, and system wide area information management to optimize flight trajectories and improve airspace utilization efficiency. The European „Single Sky“ project is committed to building a highly interconnected and automated air traffic control system, focusing on key directions such as trajectory optimization and air traffic control automation. The International Civil Aviation Organization, through its continuously updated „Aviation System Block Upgrade Program“, has proposed a number of modules closely related to flight management systems, including performance-based navigation, required arrival time control, and continuous descent operations, which have become an important basis for the evolution of air traffic control systems in various countries. The Civil Aviation Administration of China has successively released the „Civil Aviation Air Traffic Control Modernization Strategy“ and the „Smart Civil Aviation Construction Roadmap“. Relying on emerging technologies such as Beidou navigation and 5G communications, it has gradually built a digital air traffic control system for the entire process, all elements, and all scenarios. Its development path is converging with the „Next Generation Air Transport System“ and „Single Sky“ [7].

Currently, the world‘s mainstream flight management system suppliers include Honeywell, GE, Thales, Rockwell Collins, Universal Avionics, CMC, etc. Among them, Honeywell‘s products are widely used in large aircraft such as B777, B787, and A350; GE and Thales are widely used in B737 and Airbus models respectively [7].

The future development of flight management systems can be divided into two stages: the 1.0 stage based on the interconnected flight management system based on the electronic flight bag and the 2.0 stage based on the cloud platform. The 1.0 stage mainly uses the two-way connection between the electronic flight bag and the airborne flight management system to expand flight plan management, performance calculation, meteorological services and other functions to improve flight safety. The 2.0 stage mainly uses the three-way connection between the elec-

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tronic flight bag, the airborne flight management system and the cloud platform to greatly help the management of long-distance flight plans, online route planning and the resolution of conflicting flights [8].

3. Remote Control System

3.1 Components of the Remote Control System

The remote control system primarily consists of four components: the onboard autonomous control system, the ground remote piloting platform, the air-ground communication link, and the external support and coordination system.

The onboard control system ensures stable flight without human intervention or with minimal human input. By sensing the flight environment, the onboard autonomous control system enables autonomous flight path planning to maintain flight safety. Furthermore, when the ground remote pilot becomes temporarily unavailable or the communication link is interrupted, the onboard autonomous control system can independently sustain a safe flight state [9].

The ground remote piloting platform assumes the functions traditionally performed by the co-pilot and even partially by the captain. Its core components are the remote pilot and the mission support team. The ground platform requires a control interface similar to an aircraft cockpit, including a joystick, display systems, command input devices, and status monitoring modules. Ground pilots can intervene in flight operations in real time. In multi-aircraft mission scenarios, a single remote pilot can simultaneously monitor the operational status of multiple aircraft. Additionally, ground platforms typically incorporate operations engineers and flight dispatchers who collaborate with remote pilots to execute flight missions [10].

Reliable data transmission is fundamental to remote piloting, making the air-ground communication link critical. This link must simultaneously meet high-bandwidth, low-latency, and high-redundancy requirements to ensure real-time transmission of control commands, flight parameters, and monitoring data between air and ground. Furthermore, the communication link must comply with the communication security certification standards set by the International Civil Aviation Organization (ICAO) to guarantee flight safety [10].

External support and collaborative systems primarily include air traffic control systems and intelligent maintenance and health monitoring systems. Remote pilots must achieve seamless communication with air traffic control systems to ensure flight scheduling and airspace safety. Intelligent maintenance and health monitoring systems enable remote diagnostics and fault early warning through real-time data analysis, thereby enhancing aircraft reliability under remote control modes [10].

3.2 Communication Links in Remote Control Systems

3.2.1 Research on Optimizing Satellite Communication Technology

The dynamic adjustment technology for satellite data transmission based on satellite telemetry and control links effectively addresses the issues of fixed data transmission rates and insufficient resource utilization in traditional satellite telemetry and control links. The core objective of this technology is to enhance data transmission efficiency and link utilization between satellites and ground stations, thereby meeting the demand for high-capacity data transmission in modern satellites. This dynamic adjustment technology primarily consists of three components: link status monitoring, adaptive rate adjustment, and switch control strategy optimization. Driven by the urgent demand for high-speed information transmission, future optical satellite communication technology can integrate with 5G communication technology. This integration can optimize terminal device size, advance the realization of integrated air-ground-space networks, and enable intelligent optical satellite communication [1, 11].

First is link status detection. The core prerequisite for the dynamic adjustment mechanism is accurate, real-time perception and control of channel conditions. Satellite telemetry and control links operate in space environments, subject to multiple factors such as ionospheric disturbances and noise interference, resulting in significant uncertainties in signal transmission channels. Therefore, the system must monitor and collect key link parameters, including signal-to-noise ratio (SNR), bit error rate (BER), signal strength, fading depth, and duration. These parameters are critical indicators of link quality. By comprehensively evaluating these metrics, the system can quantitatively model link status and provide real-time decision support for subsequent rate adjustments.

Second is adaptive rate adjustment. Once the communication link status is determined, the system dynamically switches between a set of predefined rates. During periods of high communication quality, it employs higher-order modulation schemes and reduces error-correcting code redundancy to increase the effective transmission rate per unit time. When communication quality deteriorates, it employs lower-order modulation and increases redundancy to enhance interference resistance. This allows the system to switch rates based on the communication environment, achieving the dual objectives of maximizing

throughput and minimizing bit error rate.

Finally, optimizing the switching control strategy effectively prevents new issues arising from overly frequent rate changes. A threshold-based decision with hysteresis mechanism can be employed. This approach sets upper and lower switching thresholds based on different link status indicators, allowing rate switching only when channel parameters exceed a specific threshold range for consecutive periods. Simultaneously, a hysteresis mechanism is introduced to maintain the current rate during minor link state fluctuations, thereby preventing frequent switching caused by transient interference. Additionally, the control strategy incorporates rate switching priority settings and transition time control. Through this optimized design, the dynamic adjustment mechanism balances rapid response with smooth transitions, enabling the system to maintain high reliability and robustness even in dynamic environments.

3.2.2 Research on Optimizing VHF Communication Technology

VHF communication systems are currently the most widely adopted air-to-ground and air-to-air communication method for civil aircraft, primarily handling voice communication and data link functions. To ensure system stability, civil aircraft typically carry two to three independent VHF communication systems, each meeting the C-level design assurance standard. These systems encompass voice communication, data transmission, selective calling capabilities, as well as onboard self-diagnostics, maintenance alerts, and data loading functions. In recent years, Singapore has conducted extensive research in aviation VHF communications, focusing on the development of Space-based VHF Communications. This system involves deploying VHF communication equipment on low-orbit small satellite constellations to enable clear, real-time communication between air traffic controllers and pilots over maritime airspace [2, 12].

The core components of the VHF system comprise transceivers and antennas, which operate in conjunction with the cockpit audio control panel, radio communication control panel, and remote electronic components. As the core component, transceivers are typically housed within the aircraft‘s electronics bay, with their placement guided by principles of safety, maintainability, and electromagnetic compatibility. To prevent a single point of failure from compromising the entire system, transceivers are generally arranged in a distributed layout—installed in separate compartments on opposite sides of the fuselage. Should equipment on one side fail, the other side maintains communication capability, thereby enhancing system redundancy and overall reliability.

Regarding antenna design, VHF systems typically feature two antennas mounted above and below the aircraft to achieve omnidirectional coverage for both airborne and ground communications. Cable routing design is a critical focus in optimizing VHF communication systems. To enhance interference resistance and prevent common-mode failures, the system employs redundancy and isolation principles: two independent transceiver sets utilize completely separate power supplies and signal transmission paths. Cables are routed through different channels within the airframe, avoiding bundling in the same area. This ensures that even if one path fails due to short circuits, overheating, or mechanical damage, the other path remains operational. Additionally, cables incorporate electromagnetic shielding to mitigate the impact of lightning strikes and electromagnetic interference on communications. For Radio Frequency (RF) transmission, signals travel from transceivers to antennas via coaxial cables. To minimize insertion loss and signal attenuation, RF transmission line lengths are kept as short as possible, typically within specified limits, ensuring total transmission loss does not exceed 2dB. Simultaneously, connectors and joints must utilize high-reliability aerospace-grade components to ensure stable electrical contact under high humidity and vibration conditions.

Antenna installation techniques have also been optimized. Traditional methods often employed a “slot seal” structure, where sealant was injected between the airframe skin and antenna base. Over time, this process could lead to incomplete sealing, allowing moisture ingress that caused skin corrosion and degraded electrical performance. The new process employs a “sealing pad + end encapsulation” design: a flexible sealing pad is added at the antenna-airframe interface, while bolt ends and exposed metal parts are encapsulated for protection. This design effectively prevents moisture ingress and facilitates maintenance, significantly reducing labor hours.

4. Summary

This paper explains the autopilot system and remote control system of commercial aircraft, focusing on introducing several key advanced optimization technologies within these two components. The autopilot system comprises multiple subsystems and operates in two modes: control wheel operation and command mode. Shock-wave adaptive control technology enables real-time detection and adjustment of airflow conditions on wing surfaces during supersonic flight, effectively suppressing shock-wave oscillations and reducing wave drag. The flight management system integrates deeply with next-generation air traffic management systems, advancing trajectory management

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toward intelligent and collaborative development. The remote control system comprises four components, with its core being the communication link. Satellite communications adaptively switch modulation schemes and coding rates based on channel quality, enhancing the system's adaptability for remote control. VHF communication significantly improves system interference resistance through optimized equipment layout, materials, and installation techniques. The practical application of these optimization technologies has enhanced the stability and efficiency of automated piloting in commercial aircraft, offering substantial reference value for achieving unmanned operation in commercial aircraft. As automated piloting and remote control systems continue to be refined, they will become increasingly safe and stable in commercial aircraft, potentially even replacing pilot duties.

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