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QUALIFICATION PAPER

(EXPLANATORY NOTES)

FOR THE DEGREE OF «BACHELOR»

SPECIALITY 173 'AVIONICS'

**Theme: 'On-board system of information exchange
of an aircraft'**

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КАФЕДРА АВІОНІКИ ТА СИСТЕМ УПРАВЛІННЯ

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Київ 2025

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Faculty of Air Navigation, Electronics and Telecommunications

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TASK

for qualification paper

Oleg Oleksandrovych Derebera

1. Theme: «On-board system of information exchange of an aircraft» approved by order 355/CT of the Rector of the National Aviation University « 20 » 03 2025 p. №429/CT.
2. Duration of which is from 23 March 2025 to 23 June 2025.
3. Input data of graduation work: information of on-board information exchange protocols, comparison. Newest advancements in the avionics field.
4. The content of the explanatory note: theoretical and practical aspects of the study of onboard information exchange systems of aircraft are presented. An analysis of the current state and development trends of information exchange systems in aviation and their role in ensuring flight safety has been conducted. The prospects for the implementation of intelligent technologies—artificial intelligence, machine learning, and predictive diagnostics—into the structure of onboard information exchange systems are analyzed. Recommendations are presented for improving the efficiency of onboard networks and the potential for their modernization in the context of developing digital systems for next-generation aviation technology.

5. The list of mandatory graphic materials: figures, charts, and graphs.

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№	Task	Duration	Signature of supervisor
1.	Validate the rationale of the graduate work theme	25.01.2025	
2	Carry out a literature review	23.03.2025	
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4.	Develop the second chapter of the graduate work	09.04.2025	
5.	Develop the third chapter of the graduate work	21.04.2025	
6.	Tested for anti-plagiarism and obtained a review of the graduate work	10.06.2025	
7.	Preparation of presentation and report	06.06.2025	

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ABSTRACT

Onboard information exchange systems are critically important elements of modern aircraft. They provide data exchange between the aircraft's subsystems, crew, ground services, and other aircraft. The reliability, speed, and security of these systems directly impact flight safety and operational efficiency of aviation equipment. The complexity of onboard systems architecture requires a transition from traditional federated models to integrated solutions based on high-speed networks. In particular, the AFDX standard (ARINC 664) provides scalability, deterministic data transmission, and a high level of redundancy.

Purpose of graduation work: to analyze the current state, development trends, and prospects for the improvement of onboard information exchange systems of aircraft in order to enhance the efficiency, reliability, and safety of their operation.

The subject of the research: methods, technologies, and standards for organizing information exchange aboard an aircraft.

The object of the research: the process of information exchange of aircraft.

Research methods: a system of general scientific and special empirical and theoretical research methods were used. Empirical methods such as description, comparison, and generalization were also employed.

Scientific novelty: proposed recommendations of enhancement the reliability and security of information exchange onboard the aircraft.

Explanatory notes to graduation work 'On-board system of information exchange of an aircraft' contained 70 pages, 5 figures, 18 graphs, and 50 references.

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INTRODUCTION

Actuality. The development of modern aviation is characterized by a rapid increase in the number of on-board electronic systems that exchange large volumes of data. On-board information exchange systems of aircraft ensure the interaction of various avionics components, which allows to optimize aircraft control processes, increase flight safety and improve the efficiency of aircraft operation.

The transition from traditional analog systems to digital integrated avionics complexes led to a significant complication of the architecture of on-board data transmission networks and set new challenges for ensuring their reliability, safety and efficiency. A modern aircraft contains dozens of electronic systems that exchange thousands of parameters in real time, which requires the implementation of high-performance and reliable data transmission networks.

The concept of integrated modular avionics, which is being actively implemented in modern aircraft, involves combining the functions of various systems in a single computing environment. This places increased demands on information exchange systems, which must provide determinism, high throughput and fault tolerance when transmitting data between avionics modules.

The constant increase in the number of digital systems on board aircraft is accompanied by an increase in the amount of data transferred between them. On-board communication systems must provide not only interaction between avionics components, but also maintain communication with ground services, satellite systems and other aircraft, which creates additional challenges in the design and operation of these systems.

The increase in the level of automation of aircraft control processes and the introduction of the glass cockpit concept are changing the ways of interaction between the crew and on-board systems. Information exchange becomes not only a technical, but also an ergonomic issue, which requires the development of effective interfaces for presenting data to the crew in an easy-to-understand form.

The development of artificial intelligence and machine learning technologies opens up new opportunities for data processing on board an aircraft. The

implementation of intelligent decision support systems, predictive diagnostics and autonomous control systems requires the transformation of traditional approaches to the organization of information exchange and the use of new data transmission and processing technologies.

The growing number of cyberattacks on critical infrastructure, including aviation systems, puts forward new requirements for the protection of information in on-board networks. Ensuring cyber security becomes one of the priority tasks in the design of modern aircraft information exchange systems, which requires the development and implementation of effective data protection technologies.

The purpose and tasks of the research. The purpose of the study is to analyze the current state, development trends and prospects for improvement of on-board aircraft information exchange systems to increase the efficiency, reliability and safety of their operation.

Tasks of the research:

1. Investigate the theoretical basis of the functioning of on-board aircraft information exchange systems, determine their purpose, carry out classification and analyze the principles of construction.
2. To analyze the hardware and software of on-board information exchange systems, to investigate the technical means of implementation, data transfer protocols and standards, as well as the mechanisms of integration with ground control systems.
3. To determine promising directions for the development of on-board information exchange systems, to analyze modern trends in the field of aviation information systems and to explore the possibilities of implementing artificial intelligence technologies.
4. Develop recommendations for improving the reliability and safety of aircraft information exchange, taking into account modern technological capabilities and flight safety requirements.

Object of research: the process of information exchange of aircraft.

Subject of research: methods, technologies and standards for organizing information exchange on board an aircraft.

Practical meaning of work. The results of the research can be used in the design and modernization of on-board information exchange systems of aircraft, development of regulatory and technical documentation, as well as in the educational process of training specialists in the technical operation of aviation equipment. The proposed recommendations for improving the reliability and security of information exchange can contribute to the improvement of existing systems and increase the general level of flight safety.

The theoretical significance of the work. The study deepens the understanding of the principles of the organization of information exchange on board the aircraft, systematizes knowledge about the architecture and functioning of onboard data transmission networks, and also forms a theoretical basis for the further development of aviation information systems taking into account modern technological trends.

Research hypothesis. The implementation of promising technologies of distributed modular avionics, the development of information protection methods and the integration of artificial intelligence systems will allow to significantly increase the efficiency, reliability and safety of on-board information exchange systems of aircraft.

The novelty of the work. A comprehensive analysis of modern on-board information exchange systems of aircraft was carried out, taking into account the latest technological achievements in the field of avionics. Information about existing protocols and data transfer standards is systematized, their advantages and disadvantages are analyzed. Prospective directions for the development of on-board information exchange systems have been determined, taking into account the possibilities of introducing artificial intelligence and machine learning technologies. Recommendations have been developed to increase the reliability and safety of information exchange on board an aircraft.

Research methods. In the process of writing the coursework, a system of general scientific and special empirical and theoretical research methods was used. Empirical methods such as description, comparison and generalization were also used.

Structure of work. The work consists of a table of contents, an introduction, three chapters, nine subsections, conclusions and a list of used sources. The total volume of work is 70 pages.

CHAPTER 1. THEORETICAL BASICS OF ON-BOARD INFORMATION EXCHANGE SYSTEMS

1.1 Purpose and functions of on-board information exchange systems

The on-board information exchange system of an aircraft is a set of technical and software tools designed for the collection, processing, transmission and display of information on board the aircraft. This system provides interaction between various on-board subsystems, crew and ground services [8, p. 60].

In the aviation industry, on-board information exchange systems perform the function of integrating all on-board systems of an aircraft into a single information space, which allows for operational monitoring of the aircraft's condition, control of its technical parameters, and communication between various avionics elements.

The main purpose of the operation of on-board information exchange systems is to increase the efficiency and safety of flights by providing the aircraft crew with accurate and timely information about flight parameters, the state of on-board systems and the environment.

On-board information exchange systems implement the principles of integrated modular avionics, which involves combining the functions of various avionics systems in a single computing environment using standardized interfaces and data exchange protocols. This makes it possible to reduce the weight and dimensions of the equipment, increase reliability and simplify the maintenance process [21, p. 114].

In accordance with the modern requirements of the aviation industry, on-board information exchange systems must provide high data transfer speed, minimum delay, resistance to interference and failures, as well as protection against unauthorized access.

Information exchange systems solve the task of organizing interaction between various sources and consumers of information on board the aircraft, including sensors, computers, indicators and executive devices. Data exchange is carried out using specialized data buses, local networks and wireless communication channels.

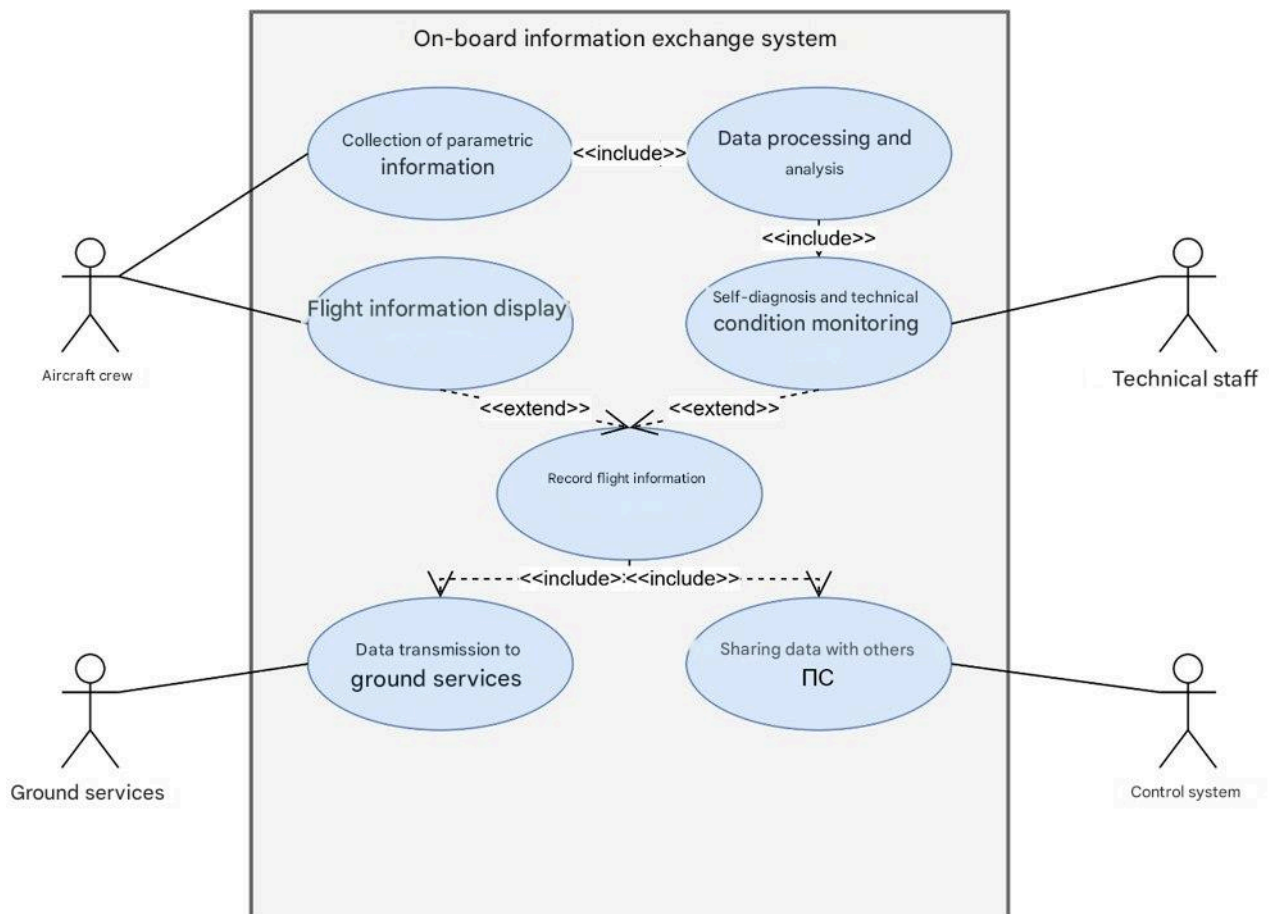


Fig. 1.1 - Diagram of the precedents of the onboard information exchange system of the aircraft

Functional capabilities of on-board information exchange systems include the collection of parametric information from sensors and sensors, processing and analysis of received data, generation of control signals and indications, recording of flight information for further analysis, as well as providing communication with ground services [15, p. 30].

The on-board information exchange system of the aircraft has a modular structure, which allows it to be flexibly configured for specific requirements and tasks. Each module of the system performs specific functions, but at the same time is integrated into the general architecture using standardized interfaces.

Multifunctional displays, which are part of on-board information exchange systems, provide display of flight information in an easy-to-understand form with the ability to quickly switch between different display modes depending on the stage of the flight and the needs of the crew.

Objective control systems, which are an integral part of on-board information exchange systems, carry out continuous monitoring and recording of flight parameters and the technical condition of the aircraft for further analysis and use in the investigation of aviation events [33, p. 85].

Modern on-board information exchange systems constitute a complex integrated infrastructure that ensures the coordination and interaction of numerous aircraft avionics components. These systems implement the principle of an integrated information environment, where data from various sources are processed and redistributed between subsystems to ensure the effective functioning of the aircraft in various flight modes.

Integration with global navigation satellite systems (GNSS) has become an integral part of modern on-board information systems. Thanks to this integration, the accuracy of determining the spatial position and movement parameters of the aircraft significantly increases. GNSS receivers receive signals from satellite groups of different countries (GPS, GLONASS, Galileo, BeiDou), which allows to achieve high positioning accuracy even in difficult conditions. Data from GNSS is integrated with information from inertial navigation systems, which ensures the stability of the navigation solution in case of temporary loss of the satellite signal.

Collision prevention systems, functioning as part of on-board information exchange systems, carry out continuous monitoring of the airspace around the aircraft. They analyze the trajectories of other aircraft and calculate the potential risks of convergence. When a collision threat is detected, the system generates warning signals for the crew and forms recommendations for optimal evasive maneuvers. The algorithms for the operation of such systems take into account numerous factors, including the speed of approach, altitude, direction of movement and characteristics of the aircraft.

Automatic dependent surveillance systems (ADS-B) carry out regular broadcasting of flight parameters: geographical coordinates, absolute altitude, road speed and identification data of the aircraft. This information is transmitted both to ground air traffic control stations and directly to other aircraft equipped with similar

systems. Such distribution of data creates a single information field, which significantly expands the situational awareness of all air traffic participants and increases the overall level of safety in airspace.

Modern on-board information exchange systems are equipped with advanced self-diagnosis functions, which allows monitoring their technical condition in real time. Built-in algorithms continuously analyze the performance parameters of system components, comparing them with reference values and permissible ranges. When deviations are detected, the system generates diagnostic messages that contain information about the nature of the malfunction and recommendations for its elimination. This approach significantly simplifies the process of maintenance and increases operational reliability of the aircraft.

To ensure a high level of reliability, on-board information exchange systems are designed using the principles of redundancy and duplication of critical components. Depending on the category of the aircraft and flight safety requirements, different reservation schemes are used - from double to triple with the majority logic of data processing. Such an architecture guarantees the preservation of the system's operability even when individual elements fail, which is a fundamental factor for maintaining the necessary level of flight safety in difficult operating conditions.

1.2 Classification of on-board information systems of aircraft

On-board information systems of aircraft are classified by the level of integration into autonomous, weakly integrated, medium integrated and highly integrated. Autonomous systems function independently of other systems, and highly integrated systems closely interact with other on-board systems, which ensures complex information processing and decision-making.

By purpose, on-board information systems are divided into pilotage and navigation systems, control and diagnostic systems, communication systems, collision prevention systems, flight data registration systems, and flight control systems. Each type of system performs specific functions, but at the same time it can interact with other systems for data exchange [12, p. 54].

According to the construction architecture, on-board information systems are classified into systems with centralized, decentralized and distributed architecture. Centralized systems have a single information processing center, decentralized systems consist of independent subsystems, and distributed systems combine the advantages of both approaches.

According to the type of processed information, on-board information systems are divided into analog, digital and hybrid. Analog systems work with continuous signals, digital systems operate with discrete data, and hybrid systems combine both types of information processing. On-board information systems are classified by the level of automation into manual, semi-automatic and fully automatic systems. The level of automation determines the degree of human participation in the process of system operation and decision-making.

According to the principle of operation, on-board information systems are divided into deterministic and stochastic. Deterministic systems work according to well-defined algorithms, and stochastic systems take into account random factors and use statistical data processing methods.

Depending on the method of information processing, on-board systems are classified into real-time systems, systems with delayed processing, and systems with predictive functions. Real-time systems provide instant data processing, delayed

processing systems accumulate data for further analysis, and predictive systems are able to predict the development of the situation based on available data.

According to the method of presenting information, on-board systems are divided into analog, digital and combined. Analog systems use arrow indicators, digital systems display information in the form of numerical data and graphic symbols, and combined systems combine both methods of presenting information [32, p. 112]. According to reliability and fault tolerance, on-board information systems are classified into systems with a single-channel, two-channel and three-channel structure. The number of channels determines the level of redundancy and duplication of system components, which affects its reliability and survivability.

According to the method of data transmission, on-board information systems are divided into systems with wired, fiber optic and wireless communication. Each type of communication has its advantages and disadvantages, which determines the scope of their application in specific conditions. Based on the level of information security, on-board systems are classified into open, closed and multi-level access systems. The security level determines the resistance of the system to unauthorized access and cyber attacks.

Modern on-board information systems of aircraft can be classified according to various criteria, one of which is the way of interaction with the user. Command-interface systems represent the earliest form of interaction, where a pilot or other crew member must enter well-defined commands in a specific format. This approach requires the user to know the syntax of the commands, but it ensures the accuracy of the operations and minimizes the possibility of erroneous input due to the rigid structure of the commands. The dialog interface represents a more sophisticated level of interaction, offering the crew an interactive menu with options to choose from and the ability to enter information step by step. This form of interface reduces the cognitive load on pilots, especially in difficult flight conditions when decision-making time is limited. Systems with an intelligent interface are considered the most progressive, which are able to adapt to the individual needs of the user, analyzing his habits, preferences and specific requirements. Such systems can predict

the pilot's intentions, offer optimal options for actions in specific situations, and change the format of information presentation depending on the stage of the flight or operating conditions [34, p. 159].

Functional complexity is another parameter for the classification of on-board information systems. Basic systems provide the implementation of the most necessary set of functions that meet the minimum requirements for safe flight performance. They are characterized by relative simplicity of construction, moderate cost and reduced energy consumption, which makes them optimal for light aircraft or budget segment aircraft. Advanced systems supplement the basic functionality with additional features that improve the comfort of operation, increase the accuracy of navigation, expand the range of controlled parameters and increase the automation of management processes. Fully functional systems represent the highest level of development, realizing the maximum possible functionality using advanced technologies. Such systems are installed on modern mainline and military aircraft, where the requirements for accuracy, reliability and functionality are particularly high.

The level of intelligence of on-board systems reflects their ability to process information and make decisions. Traditional systems function according to clearly defined algorithms laid down by developers at the design stage. They effectively perform standard operations under predictable conditions, but cannot adapt to unforeseen situations without human intervention. Expert systems represent a higher level of intellectualization, using knowledge bases and mechanisms of logical deduction to analyze complex situations. They are able to provide recommendations to pilots based on accumulated experience and established rules, simulating the decision-making process of a human expert. Neural network systems demonstrate the highest level of intellectualization, as they are able to learn on the basis of experience and adapt to new operating conditions. They analyze large volumes of data, discover hidden patterns, and can improve their algorithms without reprogramming.

The evolution of technologies allows us to distinguish several generations of on-board information systems. First-generation systems developed in the 1970s and

1980s were based on analog components with limited data processing capabilities and primitive interfaces. The second generation, which appeared in the 1980s and 1990s, was characterized by the introduction of digital technologies, increased reliability and expanded functionality. Third-generation systems, presented at the turn of the millennium, are characterized by a high degree of integration, the use of network technologies and the introduction of the "glass cabin" concept. Modern systems of the fourth generation demonstrate an unprecedented level of integration, functionality and reliability with a significant reduction in weight, energy consumption and maintenance costs. Each next generation of systems provides a qualitative leap in the development of aviation technology, creating new opportunities for increasing the safety and efficiency of flights.

1.3 Architecture and principles of construction of modern information exchange systems

The architecture of modern aircraft information exchange systems is based on the principles of integrated modular avionics (IMA), which provides for the creation of a single computing environment for performing the functions of various on-board systems. This approach allows you to optimize the use of computing resources, reduce the weight and dimensions of the equipment, and increase the reliability of the system as a whole.

The basis of the architecture of modern information exchange systems is high-performance computing modules connected by high-speed data buses. This approach ensures the flexibility of the system configuration and the possibility of its modernization without significant changes in the hardware part [42, p. 168].

Modern aircraft information exchange systems use standardized protocols and interfaces such as ARINC 429, ARINC 664 (AFDX), MIL-STD-1553B and others. Standardization ensures the compatibility of equipment from different manufacturers and simplifies the process of integrating new components into the existing system.

The architecture of information exchange systems provides for redundancy and duplication of critical components, which ensures a high level of reliability and fault

tolerance. Depending on the aircraft category and flight safety requirements, different reservation schemes are used: from duplication (two channels) to tripling (three channels) with majority logic.

Modern information exchange systems are built according to the modular principle, which involves dividing the system into functionally independent modules with clearly defined interfaces. The modular approach simplifies the process of designing, testing and modernizing the system, as well as increases its reliability due to the possibility of replacing individual modules without changing the structure of the system as a whole.

The distributed architecture of information exchange systems provides for the placement of computing resources in close proximity to the sources and consumers of information. This approach makes it possible to reduce the length of communication lines, increase immunity and reduce the weight of the cable network [25, p. 107]. The architecture of modern information exchange systems uses the principle of resource separation, which provides for the possibility of using the same computing, communication, and interface tools to implement various functions. Separation of resources allows you to optimize the use of hardware and increase the efficiency of the system as a whole.

Information exchange systems of modern aircraft are built according to the principle of a multi-level hierarchy, which involves dividing the system into several levels: the level of sensors and executive devices, the level of primary data processing, the level of complex information processing and the level of interaction with the crew. This approach allows you to structure information flows and optimize the process of its processing.

The architecture of modern information exchange systems uses the principle of functional independence, which provides for the possibility of autonomous functioning of individual subsystems when other components fail. This principle increases the survivability of the system and ensures the ability to perform critical functions even in conditions of partial equipment failure.

Aircraft information exchange systems are built taking into account the principle of ergonomics, which provides for the convenience and intuitiveness of the crew's interaction with the system. The implementation of this principle includes the development of multifunctional displays, sound and light warning systems, management and control bodies [38, p. 171]. The principle of adaptability in the architecture of information exchange systems provides for the possibility of dynamically changing parameters and operating modes of the system depending on the stage of the flight, external conditions and user requirements. Adaptability increases the efficiency of using the system and reduces the load on the crew.

In modern information exchange systems, the principle of intellectualization is implemented, which involves the use of artificial intelligence methods, machine learning, and fuzzy logic for data analysis, anomaly detection, and decision-making. Intellectualization makes it possible to increase the level of automation and reduce the number of errors in information processing. The architecture of modern information exchange systems provides integration with global information systems, such as air traffic control systems, meteorological systems, satellite navigation and communication systems. Such integration expands the functionality of the on-board system and increases the information security of the crew.

Aircraft information exchange systems are built taking into account the principles of cyber security, which include protection against unauthorized access, detection and blocking of cyber attacks, data encryption and user authentication. Implementation of these principles ensures information security and system resistance to external interventions [45, p. 88]. When building modern information exchange systems, the principle of open architecture is used, which provides for the possibility of integrating new components and functions without significant changes in the existing structure. The open architecture provides the possibility of development and modernization of the system during the entire life cycle of the aircraft.

SECTION 2. HARDWARE AND SOFTWARE OF ON-BOARD SYSTEMS

2.1 Technical means of implementing information exchange on board an aircraft

The technical means of information exchange on board the aircraft are a set of hardware and software components that ensure the collection, processing, transmission and presentation of information between various on-board systems and subsystems. Such means include data buses, computers, sensors, actuators, displays and controls.

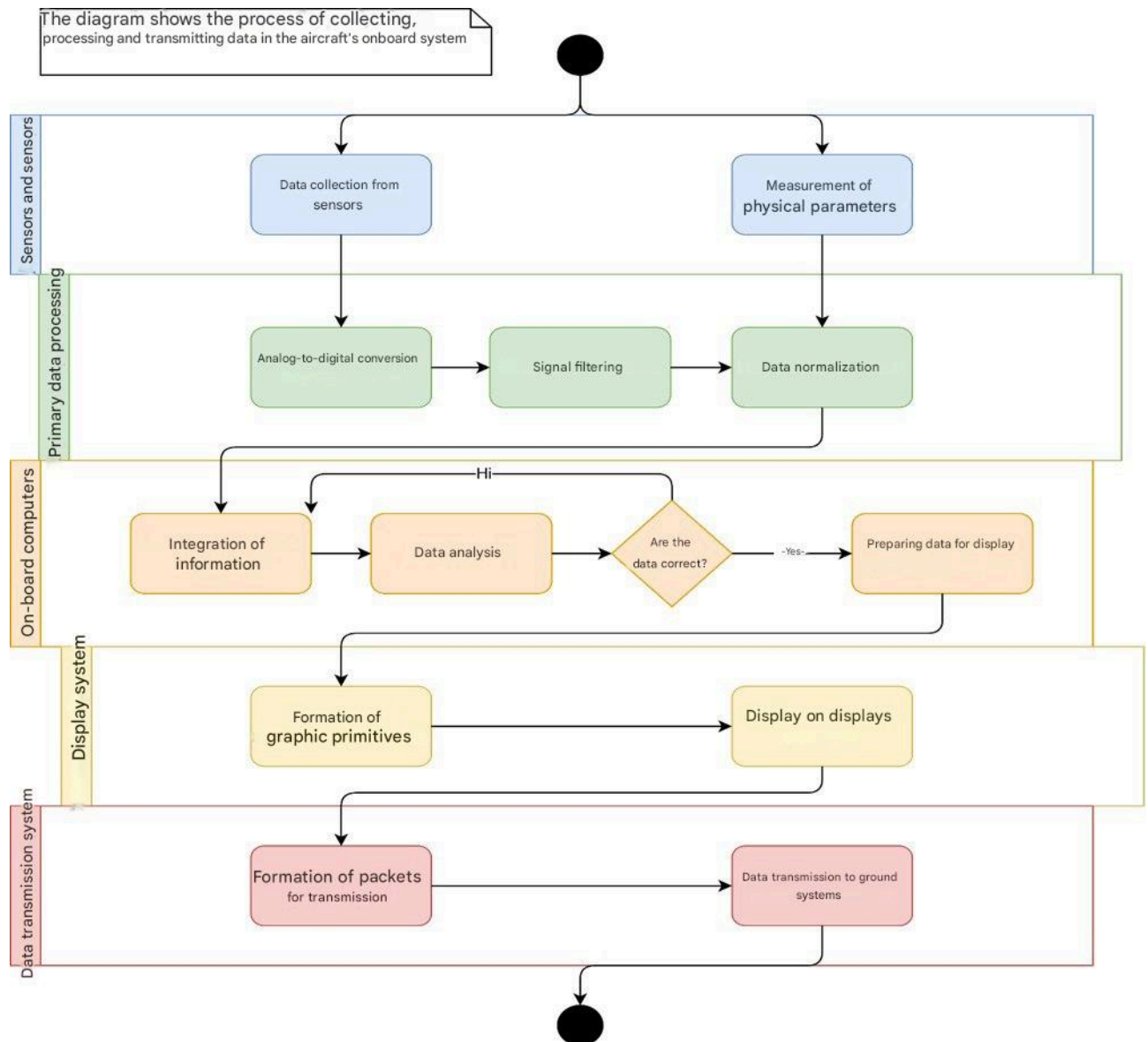


Fig. 2.1 - Diagram of the activities of the process of processing and transmitting information in the on-board system

Data buses are a physical medium for information transmission that includes cable networks, connectors, and electronic components to provide electrical or optical

communication between system elements. Modern aircraft use different types of data buses, such as ARINC 429, ARINC 664, MIL-STD-1553B and others, which differ in data transfer speed, topology, access methods, and reliability level [42, p. 168].

On-board computers are the central elements of the information exchange system, which process data according to specified algorithms. Modern on-board computers are built on the basis of powerful processors, have a modular architecture and provide high performance with minimal weight and dimensions. According to the concept of integrated modular avionics, on-board computers can perform the functions of different systems in a single computing environment.

Sensors and sensors are sources of primary information for the information exchange system. They measure a variety of flight parameters, the state of onboard systems and the environment, converting physical quantities into electrical signals, which are then transmitted via data buses to computers for further processing. Sensors of air parameters, inertial sensors, sensors of position, temperature, pressure, vibration and others are installed on board the aircraft [15, p. 32].

Table 2.1

Types of sensors and sensors on board the aircraft

Sensor type	Measured parameters	Place of installation	Measurement method
Air	Speed, altitude, vertical speed	External cladding	Pneumatic
Inertial	Acceleration, angular velocities	Center of Mass	Gyroscopic
Temperature	Outside air temperature, engine temperature	Exterior cladding, engines	Thermoelectric
Radio altimeter	Height above the surface	The lower part of the fuselage	Radar
GNSS receiver	Coordinates, speed	The upper part of the fuselage	satellite

Interface devices perform the function of a connecting link between various components of the aircraft information exchange system. Their main purpose is to ensure the compatibility of equipment with different types of signals and data transfer protocols. These devices perform a number of necessary operations: convert analog signals into digital format for further processing by computer systems; carry out

coordination of different voltage levels between components; provide galvanic isolation to protect equipment from unwanted electrical influences; carry out data buffering to synchronize the transmission speed between different devices; carry out routing of information flows through specified communication channels. Structurally, interface devices can exist both in the form of autonomous modules and be integrated into the structure of other components of aviation systems [8, p. 61].

In modern aircraft, the display of flight information is implemented through multifunctional displays, which are technologically advanced data output devices. These displays are based on liquid crystal or LED technologies, which provide high image resolution and clear reproduction of all necessary flight parameters, navigation data, and the state of the aircraft's on-board systems. The modern generation of such displays is characterized by the presence of touch interfaces that simplify the crew's interaction with the system, the possibility of flexible setting of display modes in accordance with current flight tasks, and full integration with other on-board systems to ensure comprehensive presentation of information.

For the effective interaction of the crew with the on-board information exchange systems, various control bodies are used. These devices include classic input elements: keyboards, toggles, buttons, rotary knobs, joysticks and other mechanisms through which pilots enter commands and set parameters. The evolution of control systems led to the introduction of the glass cockpit concept, which involves the replacement of traditional analog dashboards with digital displays, which significantly changed the philosophy of human interaction with aviation equipment. In such a cockpit, most of the control functions are implemented through software-configurable devices that can adapt to different flight modes and tasks, providing an intuitive interface and reducing the cognitive load on the crew.

Table 2.2

Characteristics of on-board computers of different generations

Generation	Architecture	Performance (MIPS)	Memory size (MB)	Energy consumption (W)	Year of implementation
First	Centralized	0.1-1	0.1-1	50-100	1970-1980
Others	Federated	1-10	1-10	30-50	1980-1990

The third	Distributed	10-100	10-100	20-30	1990-2000
The fourth	Integrated modular	100-1000	100-1000	10-20	2000-2010
Fifth	Network	>1000	>1000	<10	2010-present time

On-board flight information recording systems, also known as flight recorders, play a fundamental role in ensuring the flight safety of modern aircraft. These technological complexes are designed for continuous recording and storage of parametric information about the state of the aircraft and its systems during the entire flight. Structurally, recorders include several main components: a data collection and primary processing unit, an information recording module itself, and a specialized secure container, which in the professional environment received the unofficial name "black box", although in fact it has a bright orange color to facilitate its detection after aviation events.

Modern on-board recorders are characterized by high technology and productivity. They are able to record from several hundreds to thousands of various parameters with a sampling rate that provides a detailed reproduction of all stages of flight. Recorded data includes flight parameters (altitude, speed, heading, roll, pitch), engine operating modes, fuel and hydraulic system status, electrical network indicators, control positions, and many other characteristics. Modern devices are able to store information for 25-90 hours of flight, which allows for in-depth analysis of several consecutive flights [35, p. 173].

On-board maintenance systems operate in parallel with flight data registration systems. These intelligent complexes perform the role of a permanent technical supervisor of the state of all aircraft systems. Their main function consists in continuous monitoring of operational parameters of equipment, automatic detection and registration of deviations from normal operating modes, as well as formation of diagnostic messages and recommendations for technical personnel.

A feature of modern maintenance systems is their integration with ground-based information processing systems. This architecture provides the ability to transmit data on the technical condition of the aircraft in real time to the ground maintenance centers of the airlines. The engineering staff gets access to detailed

information about the operation of all the aircraft's systems even before it arrives at the destination airport, which allows to prepare in advance the necessary spare parts, tools and schedule routine work. Such optimization of maintenance processes contributes to a significant reduction in aircraft idle time and an increase in the economic efficiency of their operation.

Table 2.3

Comparison of technical characteristics of data buses

Parameter	ARINC 429	MIL-STD-1553 B	ARINC 664 (AFDX)	ARINC 825 (CAN)
Topology	Point to point	General tire	Switched network	General tire
Transmission speed (Mbps)	0.1	1	10-100	0.01-1
Access method	Asynchronous	Team-oriented	CSMA/CD	CSMA/CA
Maximum length (m)	100	300	100	40
Number of subscribers	20	31	>100	127
Year of implementation	1978	1973	2003	2008

Wireless communication systems on board aircraft include radio stations, satellite modems, Wi-Fi access points and other means that provide data transmission without the use of cable connections. These systems allow communication with ground services, other aircraft, and also provide access to information resources for the crew and passengers.

Information protection means are technical and software components that ensure the safety of information exchange on board an aircraft. They include systems for data encryption, user authentication, detection and blocking of cyber attacks, protection against electromagnetic interference, and others. Modern means of information protection are based on the principles of multi-level protection and dynamic adaptation to threats [45, p. 88].

Back-up power supply systems ensure uninterrupted functioning of means of information exchange in the event of a failure of the main sources of electricity. These include batteries, DC generators, inverters and power distribution systems. For the most critical systems, multiple redundancy of power sources with automatic switching in case of failure is used.

The technical means of cooling and thermal stabilization are designed to ensure the optimal temperature regime of the equipment of the information exchange system. These include forced ventilation systems, heat exchangers, thermoelectric coolers, and other devices that maintain component temperatures within a specified range. An effective cooling system increases the reliability and durability of the equipment.

2.2 Protocols and data transfer standards in aviation systems

Protocols and standards for data transmission in aviation systems are a set of rules and specifications that regulate the format, speed, methods of coding, synchronization, and control of the integrity of information during its transmission between components of the aircraft's on-board systems. These protocols are developed by international organizations, such as ARINC (Aeronautical Radio, Incorporated), RTCA (Radio Technical Commission for Aeronautics), SAE International and others, to ensure the compatibility of equipment from different manufacturers and guarantee the reliable operation of systems in conditions of increased requirements for flight safety.

The ARINC 429 standard is one of the most common data transfer protocols in aviation systems. It defines a unidirectional point-to-point data bus where each transmitter can be connected to several (up to 20) receivers. Data is transmitted as 32-bit words, which include 24 bits of useful information, 8 bits for parameter identification, and parity bits for error detection. The data transfer rate is 12.5 or 100 kbit/s. The ARINC 429 standard is characterized by high reliability, ease of implementation and resistance to electromagnetic interference [8, p. 62].

The MIL-STD-1553B protocol was developed for military aviation, but is also used in civilian aircraft. It defines a bidirectional data bus with centralized control, where a single bus controller manages the exchange of data between connected devices (terminals). Data is transmitted in the form of command words, data words and status words using a time multiplexing method. The data transfer rate is 1 Mbit/s. The MIL-STD-1553B protocol provides high reliability through bus redundancy and error detection and correction mechanisms.

Table 2.4

ARINC 429 32-bit word structure

to beat	Appointment	Description
1-8	Identifier (Label)	Defines the type of data and its purpose
9	Parity bit (P)	Provides data integrity control

10	Sign (SDI)	Determines the sign of a numeric value
11-29	Data	A payload that contains information
30-31	Source/Destination Identifier (SSM)	Specifies the data status or receiver address
32	Parity bit (P)	Ensures control of the integrity of the entire word

The ARINC 664 standard, also known as AFDX (Avionics Full-Duplex Switched Ethernet), is a modern solution for data transmission in aviation systems based on Ethernet technology with the implementation of special mechanisms to ensure determinism and reliability. This protocol was developed taking into account the specific needs of the aviation industry, where the reliability and predictability of network operation are of primary importance for flight safety.

The AFDX architecture is built on the principles of packet switching, which allows you to create a flexible network topology in which each node is connected to the switch by a bidirectional communication channel. This organization of the network ensures efficient distribution of traffic and increases the overall reliability of the system, since the failure of one connection does not lead to the failure of the entire network [21, p. 115].

A feature of AFDX is the use of modified Ethernet frames supplemented with special headers that implement three main functions: virtualization of communication channels, control of transmission time intervals, and error detection. Channel virtualization allows you to logically divide a physical network into isolated virtual channels with guaranteed bandwidth, which ensures data transfer determinism. Control of time intervals guarantees a predictable delay in data transmission, and error detection mechanisms increase the reliability of transmitted information.

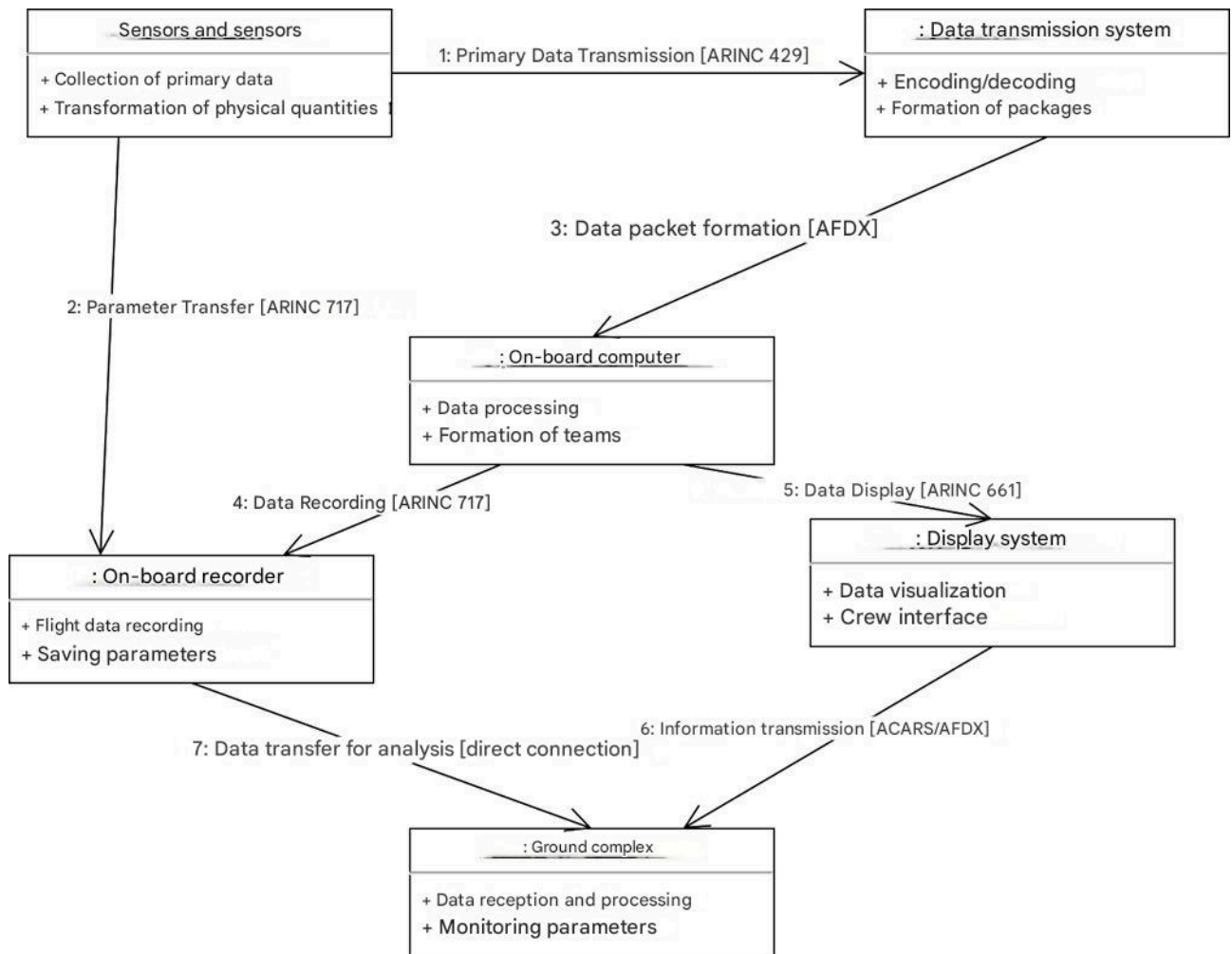


Fig. 2.2 - Diagram of cooperation of system components during flight information processing

The data transfer speed in the AFDX network is 10 or 100 Mbit/s, which meets the requirements of most modern aviation systems. The standard provides for the possibility of scaling the network and connecting a significant number of subscribers, which makes it suitable for use in the avionics of various types of aircraft [21, p. 115].

Another protocol - ARINC 825, is based on the CAN (Controller Area Network) industrial standard and is designed to provide communication between components of on-board systems that do not require high channel bandwidth. The protocol uses a common bus topology with decentralized access implemented by the CSMA/CA method.

This method involves detecting the carrier and avoiding collisions, which allows you to efficiently organize data exchange between different devices without

using a central coordinator. The data format in ARINC 825 includes frames containing an identifier (which also determines the priority of the message), a data block and a checksum to check the integrity of information [7, p. 4].

Transmission rates on the ARINC 825 network range from 10 kbit/s to 1 Mbit/s, which meets the needs of low-speed data exchange between the various subsystems of the aircraft. The protocol is characterized by a high level of reliability and resistance to electromagnetic interference, which is of significant importance in the conditions of aviation equipment.

An additional advantage of ARINC 825 is the presence of mechanisms for automatic detection and isolation of faulty subscribers, which prevents blocking of the entire network due to the failure of one device. This function increases the overall fault tolerance of the system and ensures its operation even in the event of partial equipment failures.

Table 2.5

Comparison of data transmission protocols by reliability parameters

Protocol	Error detection method	Error correction method	Tolerable probability of error	Reliability (MTBF, hours)
ARINC 429	Parity control	Retransmission	10^{-12}	>10000
MIL-STD-1553B	Cyclic code	Retransmission	10^{-10}	>5000
ARINC 664 (AFDX)	CRC-32	Reservation of channels	10^{-14}	>20000
ARINC 825 (CAN)	CRC-15	Retransmission	10^{-11}	>8000
ARINC 818	CRC-32	Error correction	10^{-13}	>15000

Aviation digital video interface ARINC 818 is designed specifically to provide high-speed transmission of video materials between various components of the aircraft's on-board systems. This standard creates a reliable communication channel between devices such as on-board cameras, cockpit displays, video processors and other video equipment installed on an aircraft. The technical implementation of ARINC 818 is based on modified Fiber Channel technology, supplemented with

specialized mechanisms that guarantee accurate synchronization of the video stream and constant monitoring of its integrity [19, p. 112].

The data structure in the ARINC 818 standard has a well-defined format and consists of three main components: a header containing service information about the transmitted data, the actual video content, and a checksum that ensures the integrity of the entire information packet. The range of transmission speeds supported by this standard is impressive in its breadth - from 1 Gbit/s for basic applications to 28 Gbit/s for the most demanding high-definition systems. This bandwidth allows the ARINC 818 to support a variety of video formats, including standard HD streams, ultra-high definition 4K and other specialized formats used in the aviation industry.

In parallel with the ARINC 818 standard, the ARINC 717 protocol is widely used in the aviation industry, which performs fundamentally different functions. This protocol specializes in the efficient transfer of data from onboard flight data recording systems (known as "black boxes") to ground-based data processing and analysis systems. ARINC 717 establishes clear rules for the formatting, representation, and encoding of various flight parameters and performance indicators of onboard systems.

The data format in the ARINC 717 protocol is organized as fixed-length frames containing precise timestamps for synchronization and checksums to verify the integrity of the information. Such a structure ensures the reliability of the registered data when they are further used for flight analysis or investigation of aviation events. The speed characteristics of the ARINC 717 protocol show significant variability depending on the specific application - from a few kilobits per second for basic registration systems to tens of megabits per second for modern complexes with a large volume of parameters monitored at high frequency [35, p. 174].

Both standards play a decisive role in ensuring the reliable functioning of information systems of modern aircraft, although they serve different aspects of information exchange - video content for visual perception by the crew in the case of ARINC 818 and parametric information for analysis and control in the case of ARINC 717.

Table 2.6

Application of data transfer protocols in various aircraft systems

System	Basic protocol	Backup protocol	Transmission speed (Mbps)	Number of parameters
Flight control system	ARINC 429	MIL-STD-1553B	0.1	200-300
Navigation system	ARINC 429	ARINC 825	0.1	100-150
Information display system	ARINC 664	ARINC 818	100	>1000
Flight data registration system	ARINC 717	ARINC 573	0.768	500-1000
Communication system	ARINC 664	ARINC 429	10	50-100
Maintenance system	ARINC 825	ARINC 429	1	200-500

The ARINC 629 standard defines a multipoint data bus with decentralized access based on the time-slotted CSMA/CA method. Each bus subscriber has a defined time slot for data transmission, which provides determinism and prevents conflicts when accessing the bus. Data is transmitted in the form of messages that contain a header, data, and a checksum. The data transfer rate is 2 Mbit/s. The ARINC 629 standard is used primarily in Boeing aircraft.

The ARINC 739 protocol defines the interface between the flight control system and the electronic indication system (EFIS). It regulates the format of presentation of navigational, piloting and other information on multifunctional displays of the crew cabin. Data is transmitted in the form of structured messages that contain graphic primitives, text strings, and control commands. The ARINC 739 protocol provides a unified interface for different types of displays and indication systems.

The ARINC 653 standard defines an application programming interface (API) for real-time operating systems used in on-board computers. It regulates the mechanisms of resource allocation, interprocess communication, error processing and other aspects of the operation of onboard systems software. The ARINC 653 standard provides temporal and spatial separation of software applications, which guarantees

their mutual isolation and increases the reliability of the system as a whole [21, p. 116].

The AFDX (Avionics Full-Duplex Switched Ethernet) protocol is specified in detail in the ARINC 664 Part 7 standard and is a deterministic variant of Ethernet for use in critical aviation systems. It provides guaranteed throughput and latency for each virtual channel through the use of traffic limiting mechanisms, channel virtualization and physical connection redundancy. Each AFDX network subscriber has two independent ports that connect to two independent switches, which provides redundancy at the physical level.

The ARINC 661 standard defines the interface for cockpit displays (Cockpit Display System, CDS) and defines the data exchange format between the flight control system and the graphical user interface. It regulates the set of graphic widgets, their properties, methods of interaction with the user and other aspects of the functioning of the graphic interface. The ARINC 661 standard provides a unified approach to the creation of user interfaces for various types of on-board systems, which simplifies the process of their development and certification.

The ARINC 834 (Aircraft Data Network, Port 802.11 Wireless) protocol defines the use of Wi-Fi (IEEE 802.11) technology for wireless communication on board an aircraft. It regulates frequency ranges, transmission power, encryption methods and other aspects of wireless network operation. The ARINC 834 protocol ensures the compatibility of equipment from different manufacturers and guarantees the safe operation of wireless networks in conditions of increased requirements for electromagnetic compatibility [36, p. 47].

The ARINC 619 standard defines the ACARS (Aircraft Communications Addressing and Reporting System) protocol used to exchange text messages between aircraft and ground services. It regulates the format of messages, their encoding methods, connection establishment procedures and other aspects of system functioning. The ACARS protocol provides a reliable exchange of information about the technical condition of the aircraft, weather conditions, flight plans and other data necessary to ensure the safety and efficiency of flights.

The ARINC 735 protocol defines the interface for the Aircraft Collision Avoidance System (TCAS). It regulates the format of data exchange between TCAS and other onboard systems, as well as between TCAS of different aircraft. The data is transmitted in the form of structured messages that contain information about the position, speed, altitude and other parameters of aircraft, as well as commands to maneuver to avoid a collision.

2.3 Integration of onboard systems with ground control systems

The integration of on-board systems with ground control systems is a process of combining on-board and ground equipment into a single information system to ensure effective control of the aircraft, monitoring of its technical condition and support for decision-making by the crew and ground services. Such integration allows real-time data exchange, analysis of flight parameters and the technical condition of the aircraft, planning of maintenance and increasing flight safety [36, p. 49].

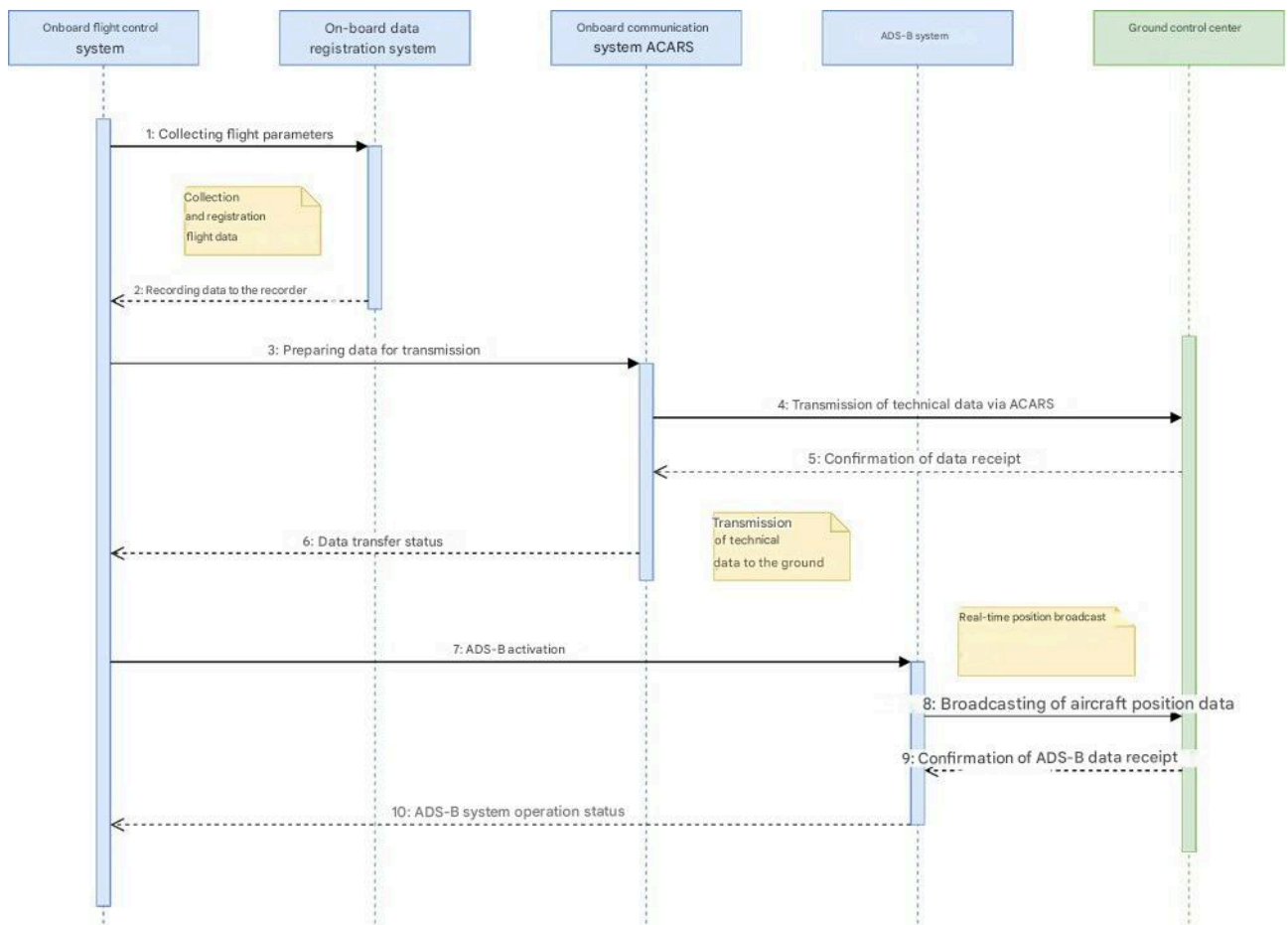


Fig. 2.3 - Diagram of the sequence of data exchange between on-board systems and ground systems

The main channels of communication between on-board systems and ground control complexes are satellite communication, radio communication in the HF, VHF and UHF ranges, as well as data transmission systems over cellular networks. Each type of communication has its advantages and disadvantages, such as range, bandwidth, delay, immunity to interference, and cost. Modern aircraft use combined communication systems that automatically select the optimal channel depending on flight conditions and the availability of ground infrastructure.

ACARS (Aircraft Communications Addressing and Reporting System) is one of the most common means of data exchange between aircraft and ground services. It allows you to transmit text messages, parameters of the technical condition of the aircraft, meteorological information, data on fuel consumption and other parameters. ACARS uses the VHF frequency range (118-137 MHz) to communicate with ground stations, as well as satellite communications to provide global coverage.

Table 2.7

Types of communication channels for integration of on-board systems with ground systems

Type channel	Frequency range	Bandwidth (kbps)	Range of action	Latency (ms)	Resistance to interference
VHF ACARS	118-137 MHz	2.4	300-400 km	100-200	average
HF ACARS	2-30 MHz	1.8	Global	300-500	low
Satellite ACARS	L-band	10.5	Global	500-1000	High
VDL Mode 2	118-137 MHz	31.5	300-400 km	100-200	average
ATN/AOC	L-band	10-100	Global	500-1000	High
GSM/LTE	700-2600 MHz	50-1000	Up to 100 km	50-100	average

The ADS-B (Automatic Dependent Surveillance-Broadcast) system is an advanced technology that ensures the integration of on-board aircraft systems with

ground-based air traffic control systems. This system functions on the basis of automatic transmission of various data about the aircraft: geographic position, speed, flight altitude and a number of other parameters. The transmission of this information is carried out both to ground control stations and to other aircraft in the area of the system.

Technically, the ADS-B system operates in the frequency range of 1090 MHz, providing the transmission of information packets without prior requests with a frequency of 0.5 to 1 second. Such a high rate of data update makes it possible to achieve an extremely accurate determination of the parameters of the aircraft's movement in space. This significantly expands situational awareness both for ground air traffic control services and for pilots of other aircraft [37, p. 322].

In parallel with the development of the ADS-B system, there is an active integration of ground maintenance systems with on-board aircraft equipment. This integration is aimed at creating a comprehensive approach to monitoring the technical condition of aircraft, diagnosing potential malfunctions and effective planning of routine maintenance work.

The interaction mechanism of on-board and ground systems is based on the constant transmission of data on the functioning of various aircraft systems. This transfer can occur either in real-time during the flight or after it is completed during ground maintenance. The received data is processed by specialized software, which performs an in-depth analysis of indicators and detects the smallest deviations from normal operating parameters.

The use of such integrated monitoring systems provides an opportunity to identify potential technical problems at the earliest stages of their occurrence, which allows preventing the development of serious malfunctions. In addition, the analysis of accumulated data makes it possible to optimize the entire process of aircraft maintenance: to determine the optimal timing of preventive works, to predict the need to replace components before they actually fail, to rationalize the use of spare parts and materials.

Parameters of monitoring the technical condition of the aircraft

System	Monitoring parameters	Transmissi on frequency	Data volume (KB/h)	Analysis method
Engines	Temperature, pressure, vibration, fuel consumption	Real time	500-1000	Trend analysis
Hydraulic system	Pressure, flow rate, temperature	Real time	200-300	Threshold values
Electrical system	Voltage, current, power	Real time	100-200	Statistical analysis
Avionics	Self-diagnosis, errors	After the flight	50-100	Analysis of events
Construction	Loads, deformations	After the flight	300-500	Cumulative analysis
Air conditioning system	Temperature, pressure, consumption	Real time	100-150	Threshold values

Modern integration of electronic documentation systems with on-board aircraft systems creates a complete information environment that significantly transforms the process of flight preparation and execution. These systems form a single information space in which the crew receives comprehensive data on the technical condition of the aircraft, detailed information on planned routes, current meteorological reports, accurate aeronautical data and other parameters necessary for the safe and effective performance of the flight task.

The introduction of electronic tablets (Electronic Flight Bag, EFB) into the daily practice of flight crews marked the transition from traditional paper documentation to digital formats. These devices are able to store and quickly display large amounts of information, and also provide a process of automatic data updating through various communication channels - from terrestrial data transmission networks to satellite communication systems. Such a technological transformation has a significant impact on the efficiency of the flight crew, minimizes the risk of errors in information processing and guarantees constant access to up-to-date data at all stages of the flight mission [40, p. 92].

The integration of satellite navigation technologies with on-board aircraft systems has fundamentally changed approaches to determining accurate flight

parameters. Global navigation satellite systems (GNSS) of various countries and consortia - the American GPS, the Russian GLONASS, the European Galileo and others - create a global coverage of navigation signals, which, after processing by onboard receivers, provide high-precision determination of spatial coordinates, velocity vectors and absolute height of the air vessel

To increase positioning accuracy and ensure the integrity of navigation information, satellite navigation is complemented by ground-based differential correction systems that calculate and transmit correction coefficients to the aircraft. These systems compensate for errors arising from the propagation of satellite signals through the atmosphere, and also minimize the influence of other factors that reduce the accuracy of navigation measurements. Such a complex architecture provides reliable determination of the location of the aircraft even in difficult flight conditions [24, p. 50].

The interaction of on-board systems with ground-based air traffic control (ATC) systems creates a single information network that ensures the rational use of air space in compliance with the highest safety standards. To effectively monitor the position of aircraft in space, a complex of technical means is used, which includes ground radar stations of various ranges, automatic dependent surveillance systems (ADS) and other specialized means of surveillance.

Streams of telemetry data from airborne systems are broadcasted to ground control points, where they undergo multi-level processing, are analyzed with the help of specialized software and are visualized for the control staff in an easy-to-understand format. This allows dispatchers to quickly identify potentially conflicting situations in air traffic, develop optimal aircraft separation schemes, and general optimization of routes to increase airspace capacity [31, p. 3].

Table 2.9

Air traffic control systems and their integration with onboard systems

Control system	Functionality	Communication channel	Data type	Position determination accuracy
Primary radar	Determination of position	Passive	Azimuth, range	500-1000 m
Secondary radar	Identification, height	Question-answer	Code of the defendant, height	200-300 m
ADS-B	Position, speed, height	Broadcast	GNSS coordinates, velocity vector	10-20 m
ADS-C	Position, route, parameters	Contractual	Navigation data, flight plans	10-20 m
CPDLC	Management, informing	Bilateral	Text messages, commands	-
MLAT	Determination of position	Passive	Signal reception time	50-100 m

Meteorological systems are integrated with onboard systems to provide the crew with up-to-date information on weather conditions along the flight route and in the airfield area. Data on temperature, wind, pressure, precipitation, thunderstorm activity and other meteorological parameters are transmitted from ground-based weather stations and meteorological satellites to the aircraft through communication systems. In addition, on-board meteorological radars and sensors transmit data on local weather conditions to ground complexes to increase the accuracy of weather forecasts [3, p. 15].

Flight planning systems are integrated with on-board systems to provide route optimization, fuel consumption calculations, alternate airfield identification and other aspects of flight preparation. Data on route, weight and centering, weather conditions, airspace restrictions and other parameters are processed by ground systems and transmitted aboard the aircraft, where they are used by the flight management system (FMS) to automate the piloting process.

Flight safety monitoring systems integrate with onboard systems to provide analysis of flight parameters, identify potentially dangerous situations, and develop recommendations to improve safety. Data from on-board recorders (so-called "black boxes") and self-diagnosis systems are transmitted to ground complexes, where they are analyzed using specialized software. This makes it possible to identify trends, anomalies and deviations from standard procedures that can lead to aviation events [35, p. 175].

The concept of "connected aircraft" provides full integration of on-board systems with ground control complexes through high-speed communication channels. This allows you to monitor the technical condition of the aircraft in real time, optimize routes depending on the weather and air conditions, provide passengers with access to the Internet and other information services, and automate the maintenance process. Implementation of the "connected aircraft" concept requires the development of communication infrastructure, increasing the bandwidth of data transmission channels and ensuring cyber security.

Airworthiness maintenance systems integrate with onboard systems to provide component life monitoring, maintenance planning and spare parts management. Flight data, the number of cycles, operational parameters and other indicators are transmitted from onboard systems to ground systems, where they are used to optimize the maintenance process and increase the efficiency of aircraft use.

Cloud technologies are used to integrate onboard systems with ground control systems through centralized data storage and processing services. Information from onboard systems is transferred to the "cloud", where it is available for analysis, visualization and use by various services of the airline: the technical department, the operations center, the flight safety service and others. The use of cloud technologies makes it possible to reduce infrastructure costs, increase data availability and ensure system scalability depending on the airline's needs [37, p. 4].

Information protection during the integration of onboard systems with ground control systems is provided by a set of technical and organizational measures, such as data encryption, user authentication, access control, network activity monitoring, and

others. Special attention is paid to protecting critical systems such as flight control system, navigation system, engine control system and others from cyber attacks and unauthorized access.

CHAPTER 3. PERSPECTIVES OF THE DEVELOPMENT AND MODERNIZATION OF ON-BOARD INFORMATION EXCHANGE SYSTEMS

3.1 Analysis of modern trends in the development of aviation information systems

Modern trends in the development of aviation information systems are characterized by a rapid transition from federated architecture to integrated modular avionics (IMA). The federated architecture, which involves the use of separate computers for each functional system, is gradually being replaced by the concept of IMA, where several functions are implemented on shared computing resources with a clear separation in terms of time and memory. Integrated modular avionics allows you to reduce the weight and energy consumption of on-board equipment, increase its reliability and simplify the maintenance process [21, p. 114].

The concept of glass cockpit has become a standard for modern aircraft. It involves replacing traditional analog instruments with multifunctional displays that can display different information depending on the stage of the flight and the needs of the crew. Modern display systems provide an intuitive presentation of data, which reduces the cognitive load on pilots and increases situational awareness. Human-machine interfaces are constantly being improved, taking into account ergonomic requirements and psychophysiological features of information perception by humans.

One of the trends is the development of wireless technologies for information exchange both within the aircraft and between the aircraft and ground systems. Wireless sensor networks, Wi-Fi, Bluetooth, ZigBee and other technologies allow reducing the mass of the cable network, simplifying the process of modernization and maintenance, as well as providing access to information in previously inaccessible areas of the aircraft. Wireless communication with ground services through satellite channels and cellular networks ensures constant monitoring of the aircraft's technical condition and optimization of the operation process.

Table 3.1

Comparison of architectural approaches to the construction of aviation
information systems

Characteristic	Federated architecture	Integrated modular avionics	Distributed modular avionics
The principle of organization	Separate calculators for each function	Shared computing resources with partitioning	Computer modules distributed throughout the aircraft
Interconnection of systems	Point to point	Network structure	Network structure with distributed nodes
The mass of the cable network	High	average	low
Energy consumption	Tall	Average	low
Reliability	High due to insulation	High due to reservation	High due to the distribution of functions
Modernization	Complicated	Medium difficulty	Simple
Certification	Separate for each system	Complex with separation	Modular with a step-by-step approach
Application examples	Boeing 747, Airbus A320 early series	Boeing 787, Airbus A380	Prospective aircraft models

In the modern world of aviation information systems, there is a fundamental change in approaches to the organization of data processing. Traditional centralized systems are being replaced by distributed architectures, where computing power is strategically placed right next to the sources and consumers of information. This approach demonstrates significant advantages in the functioning of complex aviation systems.

Distributed architectures significantly reduce time delays when transmitting information between system components. When computing modules are located next to sensors and actuators, data is processed locally, without the need for transmission over long information highways to a central computer and back. This is especially true for real-time systems, where even milliseconds of delay can matter.

The fault tolerance of such systems is significantly increased due to the distribution of functions between many computing nodes. When a single module fails, only part of the functionality is lost, while the rest of the system continues to work. Unlike centralized systems, where the failure of the central computer can lead

to the failure of the entire system, distributed architectures ensure gradual degradation during failures [42, p. 169].

Optimizing the use of computing resources is achieved by placing them where they are most needed. Instead of a single powerful computing center, resources are distributed according to the requirements of specific subsystems. This makes it possible to use computing power more efficiently, reduce the weight of cable networks, and reduce the overall energy consumption of the system.

The distributed architecture demonstrates the greatest efficiency in complex aviation systems with a large number of peripheral devices. Flight control systems processing data from hundreds of sensors and controlling dozens of actuators, electronic equipment systems with numerous interfaces, and life support subsystems with an extensive network of control points all benefit greatly from a distributed approach.

In parallel with this trend, the concept of "connected aircraft" is developing, which takes the information exchange of aircraft to a qualitatively new level. This concept envisages the creation of a single information space that unites on-board aircraft systems, cloud services and ground complexes through high-speed secure communication channels.

This approach opens up wide opportunities for constant monitoring of the aircraft's technical condition. Engine, system and structural performance data is transmitted in real time to ground centers where it is analyzed to identify potential problems before they occur. This allows you to switch from regular maintenance to maintenance according to the technical condition, which increases safety and reduces operating costs.

The optimization of flight routes becomes dynamic - taking into account current weather data, the air situation and the technical condition of the aircraft. The system can automatically adjust the route to bypass turbulence zones, save fuel or optimize arrival time [37, p. 3].

The crew gets access to the latest information about airports, airspace, weather conditions, which increases situational awareness and the quality of decision-making.

Passengers, in turn, can use high-speed access to the Internet, entertainment content and information services throughout the flight.

The implementation of the "connected aircraft" concept requires the development of accompanying infrastructure - the deployment of a network of ground communication stations, the development of satellite data transmission systems, the creation of information processing and analysis centers. A significant increase in the bandwidth of communication channels is necessary to ensure the transfer of growing volumes of data.

Table 3.2

Development trends of data transmission speed in aviation information systems

Type of information bus	Transmission speed in the 2000s (Mbps)	Transmission speed in the 2010s (Mbps)	Projected speed in the 2020s (Mbps)	Main application
ARINC 429	0.1	0.1	0.1	Pilotage and navigation systems
MIL-STD-1553B	1	1	1	Military avionics
ARINC 629	2	2	2	Boeing commercial aircraft
ARINC 664 (AFDX)	10	100	1000	Integrated modular avionics
ARINC 818	1000	3000	10000	Video systems and display systems
Wireless systems (Wi-Fi)	11	150-300	1000-10000	Information and entertainment systems
Satellite communication	0.064-0.128	1-10	50-100	Communication with ground services
Optical data buses	100	1000	10000-100000	Promising management systems

The current stage of development of aviation information systems is characterized by a rapid increase in the level of automation of aircraft control processes, which leads to a significant reduction in the workload of the flight crew. This transformation process takes place due to the creation and implementation of highly effective decision support systems, the functioning of which is based on a comprehensive analysis of massive information flows followed by the formation of reasonable recommendations for pilots in real time [35, p. 86].

The scope of application of automated systems in aviation is constantly expanding, covering not only standard piloting modes, but also complex non-standard and emergency situations that require prompt response and well-considered decision-making. However, despite the high level of automation, the principle of "man in the control loop" remains fundamental, according to which the final decisive word belongs to the aircraft commander and crew members, who make decisions based on data obtained from automatic monitoring and control systems.

At the same time, there is a clear trend towards the complex integration of various sources of information in order to increase the accuracy, reliability and reliability of the received data. The integration process involves the collection, processing and analysis of information coming from inertial navigation systems, global navigation satellite systems (GPS, GLONASS, Galileo), traditional radio navigation aids, airborne and ground-based radar complexes, as well as other sources of aviation information [24, p. 51].

The result of such multi-level integration is the formation of highly accurate and reliable information about the spatial position, movement parameters and technical condition of the aircraft. Advanced methods of digital filtering, statistical analysis, and mathematical modeling are developed and implemented to achieve the maximum efficiency of data processing from disparate information sources.

Modern navigation information processing algorithms are based on the application of various modifications of the Kalman filter, including the extended Kalman filter and the sigma-point Kalman filter, which provide optimal estimation of parameters in dynamic systems taking into account the stochastic nature of the input

data. Neural network information processing methods are also widely used, which allow detecting complex nonlinear dependencies in multidimensional data arrays.

The integration of disparate information sources is implemented on the basis of a multi-level architecture, which includes the level of primary data processing, the level of information integration and the level of formation of information and control signals. This architecture ensures efficient functioning of the system even with partial degradation of individual information channels, which significantly increases the reliability and functional stability of aviation information systems as a whole.

The development of mathematical methods of data processing is accompanied by the creation of specialized computing platforms that provide high performance when implementing complex algorithms for filtering and integrating information in real time. The use of multi-core processors, field-programmable gate array (FPGA) and specialized signal processors allows you to achieve the required performance with minimum weight and size indicators of computing devices.

The processes of automation and integration of information in modern aviation systems are aimed at achieving a single goal - ensuring the highest possible level of flight safety with optimal use of aircraft resources and minimizing the influence of the human factor on decision-making in special situations.

Table 3.3

Evolution of display systems in the crew cabin

Generation of systems	Implementation period	Display technology	Number of displays	User interface	Examples of aircraft
1 generation	1970-1980	Electromechanical devices	>100	Analog controls	Boeing 747-100, DC-10
2 generations	1980-1990	CRT displays	6-10	Buttons, switches	Boeing 757/767, Airbus A310
3 generations	1990-2000	LCD displays	5-8	Keyboards, trackballs	Boeing 777, Airbus A330/A340

4 generations	2000-2010	AMLCD displays	5-6	Cursors, touch panels	Boeing 787, Airbus A380
5 generations	2010-2020	Large LCD/OLED displays	3-5	Touch screens, voice control	Airbus A350, Bombardier C-Series
6 generations	2020+	Flexible displays, AR/VR	1-3	Gestures, gaze, neurointerfaces	Promising models

The development of aviation information systems is characterized by increased requirements for electromagnetic compatibility and resistance to external influences. Increasing the number of electronic equipment and increasing its placement density requires the development of new methods of ensuring electromagnetic compatibility, shielding and filtering of signals. The requirements for the resistance of the equipment to mechanical influences, temperature fluctuations, atmospheric pressure and other environmental factors are also increasing [14, p. 32].

The role of software in aviation information systems is growing. If previously the main functionality was implemented by hardware, now more and more functions are performed software. This makes it possible to increase the flexibility of the system, simplify the modernization process and reduce the weight and dimensions of the equipment. However, at the same time, the requirements for the software development, testing and certification process are increasing. Special development methodologies, such as DO-178C, are used to ensure a high level of software reliability and security.

The development of aviation information systems is accompanied by increased requirements for their cyber security. With the transition to digital technologies and an increase in the number of communication channels with the outside world, the risk of cyber attacks on onboard systems is increasing. New methods and means of information protection are being developed, such as data encryption, user authentication, detection and blocking of attacks, monitoring of network activity, and others. Special attention is paid to the protection of systems such as the flight control system, the navigation system, the engine control system, and others [45, p. 89].

There is a trend towards standardization of hardware and software interfaces of aviation information systems. International standards are being developed, such as ARINC 653, ARINC 664, DO-254, DO-178C and others, which define the hardware and software requirements of on-board systems. Standardization makes it possible to ensure the compatibility of equipment from different manufacturers, simplify the certification process, and reduce the cost of system development and operation.

The development of aviation information systems is characterized by an increase in their energy efficiency. Reducing energy consumption allows you to reduce the weight of the power supply system, reduce heat generation, and increase equipment reliability. Energy-efficient processors, dynamic energy management technologies, optimization of data processing algorithms and other methods are used to reduce the energy consumption of on-board systems.

Active development of methods and means of diagnostics and control of the technical condition of aviation information systems is taking place. Systems of built-in control (Built-In Test Equipment, BITE) are being developed, which carry out continuous monitoring of equipment functioning parameters and detect malfunctions in the early stages. Predictive diagnostics methods are used, which allow predicting equipment failures based on the analysis of trends in parameter changes. This makes it possible to reduce aircraft downtime, optimize the maintenance process and increase flight safety.

3.2 Implementation of artificial intelligence and machine learning technologies

The implementation of artificial intelligence and machine learning technologies in aviation information systems is one of the most promising trends in the development of the industry. Artificial intelligence (AI) is defined as the ability of a computer system to perform tasks that normally require human intelligence, such as pattern recognition, decision making, understanding natural language, and adapting to changing environments. Machine learning (ML), as a subfield of AI, focuses on the development of algorithms and statistical models that allow computer systems to

automatically improve their performance when performing tasks based on accumulated experience without explicit programming [5, p. 57].

In the field of aviation information systems, AI and ML technologies are used to solve a wide range of tasks, including data processing and analysis, pattern recognition, forecasting, optimization, decision support and process automation. The introduction of these technologies makes it possible to increase the efficiency of the on-board systems, reduce the load on the crew, increase flight safety and optimize the process of aircraft operation.

One of the promising areas of application of AI and ML in aviation information systems is pattern recognition, in particular, object identification based on data from various sensors. Neural networks, particularly convolutional neural networks (CNNs), are used to recognize visual patterns such as runways, landmarks, other aircraft, and obstacles. Technical vision systems equipped with AI algorithms can function in conditions of limited visibility, which increases the safety of flights in difficult weather conditions.

Table 3.4

Application of machine learning algorithms in aviation information systems

Algorithm type	Application	Advantages	Limitation	Examples of systems
Convolutional Neural Networks (CNN)	Recognition of visual images, identification of objects	High accuracy, resistance to changing the scale and rotation of images	High requirements for computing resources	Technical vision systems, landing assistance systems
Recurrent Neural Networks (RNN)	Analysis of time series, forecasting	Ability to consider context and sequence of data	The difficulty of learning, the vanishing gradient problem	Failure forecasting systems, weather forecasting systems
Deep Neural Networks (DNN)	Complex data processing, anomaly detection	Ability to discover complex dependencies in data	High computational complexity, the need for large training samples	Technical condition monitoring systems, cyber

				attack detection systems
Support Vector Machines (SVM)	Classification, pattern recognition	High accuracy with small training samples	Limitations when working with large data sets	Fault diagnosis systems, quality control systems
Clustering methods	Data segmentation, anomaly detection	Do not require marked data	Difficulty in interpreting the results	Flight data analysis systems, parameter monitoring systems
Decision trees and random forests	Classification, regression	Interpretability, resistance to noise in data	Tendency to retraining	Decision support systems, expert systems
Deep learning with reinforcement	Management optimization, autonomous systems	The ability to learn in the process of interaction with the environment	The complexity of modeling the environment, the need for a large number of iterations	Automatic control systems, route optimization systems

Machine learning technologies are actively used for predictive maintenance of aircraft. ML algorithms analyze data from sensors that monitor the state of various aircraft components and detect anomalies that may indicate potential failures. Based on historical data and component degradation models, ML systems predict the remaining life of the equipment and recommend the optimal maintenance schedule. This makes it possible to move from scheduled preventive maintenance to maintenance according to the technical condition, which reduces operational costs and increases the reliability of aircraft [5, p. 59].

AI-based decision support systems provide the crew with recommendations in complex situations by analyzing large volumes of data and modeling possible scenarios of events. Such systems are especially effective in non-standard and emergency situations, when it is necessary to quickly process a large amount of information and make an optimal decision. At the same time, the principle of "man in

the control loop" is preserved, i.e. the final decision is made by the crew based on the system's recommendations.

Table 3.5

Comparison of traditional methods of data processing with methods based on artificial intelligence

Characteristic	Traditional methods	Methods based on AI	Advantages of AI methods
Ability to adapt	Limited, needs reprogramming	High, automatic setting	Better work in changing conditions
Processing of unstructured data	limited	High	Ability to work with heterogeneous data
Detection of complex dependencies	limited	High	Detection of hidden patterns
Working with incomplete data	limited	Medium to high	Tolerance for data gaps
Computational complexity	Low to medium	Medium to high	Better results with sufficient resources
Interpretability	High	Low to medium	It is more difficult to explain the results
Requirements for educational data	They do not need or are small	High	The need for large data sets
Robustness to noise in data	Low to medium	Medium to high	Better performance with noisy data
Generalization	limited	High	Better generalization to new data
Possibility of self-study	Absent	present	Improvement with experience

Natural language processing technologies are integrated into voice control systems, allowing the crew to interact with onboard systems using voice commands. This reduces the load on pilots, especially during flight phases with high operational intensity, such as take-off and landing. Speech recognition systems based on neural networks achieve high accuracy even in noisy conditions in the cockpit and can adapt to the individual characteristics of the pilot's voice.

Machine learning algorithms are used to optimize flight routes taking into account a variety of factors, such as weather conditions, air conditions, airspace

restrictions, fuel consumption, and others. AI-based optimization methods make it possible to find optimal solutions in complex multidimensional solution spaces. Dynamic optimization of the route during the flight, taking into account changing conditions, allows to reduce fuel consumption, reduce flight time and increase passenger comfort [5, p. 60].

Computer vision technologies based on AI are used for automatic monitoring of the state of the aircraft structure. Pattern recognition algorithms analyze surface images of the fuselage, wings, engines and other components, detecting cracks, corrosion, deformations and other defects. This speeds up the process of technical inspection, increases its accuracy and reduces the probability of missing defects.

Table 3.6

Effectiveness of implementation of AI and ML technologies in aviation
information systems

System	AI/M.N. technology	Improvement of indicators	Economic effect	Impact on security
Predictive maintenance	Analysis of time series, detection of anomalies	Reduction of unscheduled repairs by 15-20%	Savings of 5-7% of maintenance costs	Reduction of incidents due to technical reasons by 10-15%
Optimization of routes	Optimization methods based on ML	Reduction of fuel consumption by 3-5%	Savings of 2-3% of operating costs	Reduction of risks related to weather conditions
Decision support systems	Expert systems, neural networks	Acceleration of decision-making by 30-40%	Reduction of insurance costs	Reduction of crew errors by 20-30%
Computer vision for inspection	Convolutional neural networks	Acceleration of inspection by 50-60%	Savings on labor costs	15-25% increase in defect detection
Voice control systems	Natural language processing	Reducing the load on the crew by 10-15%	Increasing crew productivity	Reduction of data entry errors by 30-40%
Autonomous control systems	Deep learning with reinforcement	Increase control accuracy by 20-25%	Reducing pilot training costs	Reduction of incidents due to pilot errors by 25-30%

Detection of cyber attacks	Detection of anomalies, classification	40-50% increase in attack detection	Reducing losses from cyber attacks	Increasing the security of systems
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AI-based cyber security systems are used to detect and block cyber attacks on aircraft onboard systems. Machine learning algorithms analyze network traffic, detect anomalies, and classify potential threats. Anomaly detection methods based on autoencoders and other types of neural networks make it possible to detect new, previously unknown types of attacks, which increases the level of security of on-board systems [45, p. 90].

Machine learning methods are used to analyze large volumes of data received from flight recorders (Flight Data Monitoring, FDM). Clustering and anomaly detection algorithms analyze flight parameters, detect deviations from standard procedures and potentially dangerous situations. This allows identification of system problems, development of recommendations to improve flight safety, and optimization of pilot training programs.

Neural networks are used to integrate data from various sources, such as inertial navigation systems, global navigation satellite systems, radio navigation tools, and others. Deep learning methods make it possible to detect complex dependencies between data from different sensors and combine them to obtain more accurate and reliable information about the position and movement parameters of the aircraft. This increases the accuracy of navigation and reduces dependence on individual sources of information.

AI and ML technologies are integrated into autonomous control systems of unmanned aerial vehicles (UAVs). Deep learning algorithms with reinforcement are used to develop management strategies that are optimized in the process of interacting with the environment. Computer vision systems based on convolutional neural networks provide navigation and obstacle avoidance. These technologies increase the autonomy of BPS and expand the range of their application in civil and military spheres [8, p. 63].

Machine learning methods are used to improve the accuracy of weather forecasts used in flight planning and execution. Deep learning algorithms analyze

data from meteorological satellites, ground weather stations, airborne weather radars and other sources, forming more accurate forecasts of weather conditions along the flight route. This makes it possible to optimize routes, reduce risks associated with adverse weather conditions, and increase passenger comfort.

The implementation of AI and ML technologies in aviation information systems is accompanied by the development of specialized hardware for the effective execution of machine learning algorithms on board an aircraft. Neuromorphic processors, graphics accelerators (GPUs), tensor processors (TPUs) and other specialized computing devices provide high performance when performing operations typical of neural networks, with low power consumption and small dimensions.

3.3 Ways of increasing the reliability and safety of aircraft information exchange

Increasing the reliability and safety of aircraft information exchange is one of the priority areas of development of aviation information systems. Reliability of information exchange is defined as the system's ability to maintain operational efficiency and ensure data transmission with specified characteristics under the influence of external and internal destabilizing factors. The security of information exchange includes ensuring the integrity, confidentiality and availability of information, as well as protection against unauthorized access and cyber attacks [14, p. 28].



Fig. 3.1 - State diagram of the on-board information exchange system in different flight modes

One of the main ways to increase the reliability of information exchange is the use of multi-level redundancy of system components. Redundancy can be implemented at different levels: hardware (duplication or tripling of computers,

communication lines, power sources), software (different implementations of the same algorithm), information (different data sources) and time (retransmission of data). The choice of the optimal redundancy scheme depends on system reliability requirements, weight and power consumption restrictions, as well as economic factors.

The use of fault-tolerant data transmission protocols is an effective way to increase the reliability of information exchange. Such protocols provide detection and correction of errors during data transmission, automatic transmission repetition when errors are detected, control of message integrity and other mechanisms that increase the reliability of transmitted information. Examples of fault-tolerant protocols used in aviation systems are AFDX (ARINC 664), MIL-STD-1553B, TTP (Time-Triggered Protocol), and others.

Table 3.7

Methods of increasing the reliability of aircraft information exchange

Method	The principle of action	Advantages	Disadvantages	Field of application
Hardware redundancy	Duplication or tripling of components	High reliability, fast switching	Increased mass and energy consumption	Critical systems (flight control, navigation)
Software reservation	Different implementations of the same algorithm	Protection against software errors	Increasing the amount of software	Control systems, computing systems
Information backup	Using different data sources	Protection against failures of individual sensors	Complexity of complexing algorithms	Navigation systems, control systems
Temporary reservation	Data retransmission	Ease of implementation	Increasing latency	Non-critical systems with low latency requirements
Multi-level reservation	A combination of different types of reservation	Maximum reliability	Complexity, high cost	Especially critical systems

Self-healing systems	Automatic recovery after failures	Minimum downtime	Difficulty of implementation	Promising systems with high reliability requirements
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The use of methods of diagnostics and monitoring of the technical condition of components of the information exchange system makes it possible to detect potential failures in the early stages and take preventive measures. Built-In Test Equipment (BITE) systems continuously monitor equipment operation parameters and detect deviations from the normal operating mode. Methods of predictive diagnostics based on the analysis of trends in parameter changes allow predicting equipment failure and planning its replacement before an emergency situation occurs.

Increasing the electromagnetic compatibility of the components of the information exchange system is a necessary condition for ensuring the reliability and safety of their operation. The use of methods of shielding, filtering, galvanic isolation, optimal routing of communication lines and other technical solutions allows to reduce the level of electromagnetic interference and increase the resistance of equipment to external electromagnetic influences. Special attention is paid to protection against atmospheric electricity discharges, electrostatic discharges and powerful electromagnetic pulses.

Table 3.8

Methods of ensuring cyber security of aviation information systems

Method	The principle of action	Protection level	Resource requirements	Objects of protection
Data encryption	Data transformation using cryptographic algorithms	High	Average	Data during transmission and storage
User authentication	User identity verification	Medium to high	Low	User interface, control systems
Access control	Restrict access to resources based on roles and privileges	Average	Low	Databases, configuration files

Physical separation of networks	Isolation of critical systems from external networks	High	High	Critical management systems
Intrusion detection systems	Analysis of network traffic to detect attacks	Average	Medium to high	Network infrastructure
Secure communication protocols	Using protocols with built-in security mechanisms	High	Average	Communication channels
Regular software updates	Elimination of identified vulnerabilities	Average	High	Software
Staff training	Raising awareness of cyber threats	Average	Low to medium	Human factor

The use of information protection technologies is a necessary condition for ensuring the safety of information exchange of aircraft. Cryptographic protection methods, such as data encryption, digital signature, authentication and integrity control, ensure the confidentiality and integrity of information during its transmission and storage. Cyberattack detection and blocking systems, such as Intrusion Detection Systems (IDS), firewalls, and Data Loss Prevention (DLP) systems, provide protection against unauthorized access and cyberattacks.

Separation of on-board networks into isolated domains with different levels of security is an effective way to increase the security of information exchange. Special systems, such as the flight control system, navigation system and engine control system, are housed in separate domains with a high level of security and limited access. Non-critical systems, such as entertainment systems and passenger information systems, are placed in separate domains with a lower level of protection. Interaction between domains is carried out through special gateways with traffic control and filtering functions.

The application of virtualization and containerization technologies allows to increase the security of information exchange due to the isolation of various software components and the limitation of their access to system resources. Virtual machines and containers with different levels of trust are hosted on a common hardware

platform, but isolated from each other at the operating system level. This allows to reduce the risks associated with the compromise of individual components of the system and to increase the overall level of security [21, p. 116].

Table 3.9

Comparison of different approaches to ensuring the reliability of on-board systems

Characteristic	Traditional federal architecture	Integrated modular avionics	Distributed modular avionics
A method of ensuring reliability	Physical separation of systems	Temporal and spatial separation	Distribution of functions and redundancy
Response to component failure	Switching to a backup system	Redistribution of tasks	Redistribution of functions
Recovery time after failure	Low	Average	Low
Resistance to cascading failures	High	average	High
Redundancy of hardware	High	average	low
Software complexity	low	High	average
Weight and size indicators	High	Average	Low
Energy consumption	Tall	Average	low
Cost of development and certification	average	High	average
Flexibility of modernization	low	average	High

Regular software updates are a necessary condition for ensuring the security of information exchange. Updates include fixes for identified vulnerabilities, increased resistance to new types of cyberattacks, and implementation of new protection mechanisms. The process of updating the software of onboard systems must be strictly regulated and include comprehensive compatibility and security testing to prevent the emergence of new vulnerabilities and bugs.

Application of methods of formal verification of software and hardware makes it possible to identify potential errors and vulnerabilities at the early stages of development. Formal methods, such as theorem proving, model checking, and static

code analysis, provide mathematically rigorous proof of the system's compliance with given specifications. This allows you to detect errors that cannot be detected by traditional testing methods, and increases the overall level of reliability and security of the system.

Improving the qualifications of personnel who develop, operate and maintain information exchange systems is a necessary condition for ensuring their reliability and security. Regular training, cyber security trainings, development and implementation of standard operating procedures, as well as the formation of a safety culture allow to reduce the risks associated with the human factor, which is one of the main causes of incidents in the aviation industry [45, p. 90].

The development of international standards and regulatory requirements regarding the reliability and security of information exchange is a necessary condition for ensuring a unified approach to these issues on a global scale. Standards such as DO-178C (software), DO-254 (hardware), DO-326A (cyber security) define the requirements for the development process, verification and validation of on-board systems, as well as methods for ensuring their reliability and security. Regulatory bodies such as the FAA, EASA and others monitor compliance with these requirements.

The application of risk assessment and management methods allows to systematically identify and control potential threats to the reliability and security of information exchange. The process of risk management includes the identification of threats, assessment of the probability of their realization and potential damage, development and implementation of measures to reduce risks, as well as monitoring the effectiveness of these measures. The use of formalized risk assessment methods, such as FMEA (Failure Mode and Effects Analysis), FTA (Fault Tree Analysis), HAZOP (Hazard and Operability Study) and others, allows to increase the objectivity and systematicity of this process [13, p. 5].

The use of Big Data analysis methods and machine learning makes it possible to detect hidden dependencies and anomalies in the functioning of information exchange systems that cannot be detected by traditional analysis methods. Machine

learning algorithms analyze data from various sources, detect anomalies and classify them according to the level of potential danger. This allows you to identify new, previously unknown types of threats and take preventive measures to neutralize them.

The development of self-recovery and adaptation technologies makes it possible to increase the reliability of information exchange systems due to their ability to automatically recover from failures and adapt to changing operating conditions. Systems with self-healing properties are able to detect component failures, isolate them, redistribute functions between working components and restore normal functioning without human intervention. Adaptive systems are able to change their parameters and operating modes depending on environmental conditions, load and other factors, which increases their resistance to external influences.

CONCLUSIONS

The conducted study of on-board information exchange systems of aircraft allowed to form a holistic view of their purpose, functions, classification and principles of construction. It was determined that on-board information exchange systems form the foundation for the integration of various avionics subsystems into a single complex, ensuring the collection, processing and transmission of data between various components of the aircraft.

Analysis of the architecture and principles of construction of modern information exchange systems revealed a trend of transition from federated architecture to integrated modular avionics, which allows optimizing the use of computing resources, reducing the mass and energy consumption of onboard equipment. A promising direction of development is the introduction of distributed modular avionics, which combines the advantages of centralized and decentralized architecture, ensuring high reliability and flexibility of the system.

A study of the technical means of implementing information exchange on board an aircraft showed a wide variety of components used, including data buses, computers, sensors, actuators and interface modules. Special attention is paid to multifunctional displays and interfaces for interaction with the crew, which ensure effective presentation of information in a form convenient for perception.

Analysis of protocols and data transmission standards in aviation systems revealed a tendency to increase bandwidth, reliability and determinism of data transmission networks. Standards ARINC 429, MIL-STD-1553B, ARINC 664 (AFDX) and others provide different requirements for speed, reliability and network topology, which allows you to choose the optimal solution for a specific application.

Research into the integration of on-board systems with ground control systems has revealed the growing role of digital communication channels that provide real-time data exchange between aircraft and ground services. The development of the concept of "connected aircraft" allows to optimize maintenance processes, increase the situational awareness of the crew and the efficiency of the use of the aircraft.

The analysis of modern trends in the development of aviation information systems revealed areas of improvement, including the transition to a distributed architecture, increasing the level of automation, integration of various sources of information, and the development of data integration methods. The growing role of software and intelligent data processing algorithms is changing approaches to the design and operation of on-board systems.

Research into the possibilities of implementing artificial intelligence and machine learning technologies into aviation information systems has shown the prospects of this direction for the development of decision support systems, predictive diagnostics, big data processing and automation of control processes. Machine learning algorithms make it possible to detect complex dependencies in data, predict equipment failures, and optimize the processes of on-board systems.

The analysis of ways to improve the reliability and safety of aircraft information exchange revealed the need for a comprehensive approach, which includes multi-level redundancy, the use of fault-tolerant protocols, diagnostic methods, information protection technologies and the division of networks into isolated domains. The development of self-healing and adaptation technologies makes it possible to increase the resistance of systems to failures and ensure their effective functioning in difficult operating conditions.

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