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APPLICATION OF INFORMATION-ANALYTICAL SYSTEMS AND AI FOR AVIATION EQUIPMENT LIFECYCLE MANAGEMENT

This article examines approaches to the application of information-analytical systems and artificial intelligence technologies aimed at enhancing the efficiency of aviation equipment lifecycle management. The authors emphasize that the modern aviation industry faces the challenge of the exponential growth of data volumes generated at all stages of the lifecycle, from design to operation. Traditional analysis systems are deemed insufficient for making effective operational and strategic decisions, necessitating the implementation of an integrated management support environment.

The relevance of the study is substantiated by the need to develop comprehensive approaches capable of integrating modern IAS and AI into a unified architecture for aviation equipment LC management. The conducted analysis of recent research confirms that the integration of AI-analytics, big data, IoT-sensorics, and the digital twin concept is a global trend. The authors state that there is a deficit of studies that comprehensively examine the methods for integrating these technologies into the AE LC management system as a holistic process. The goal of the study is to justify approaches to the application of IAS and AI technologies to increase the efficiency of AE LC management.

Based on a systematic analysis, a comparison between the traditional time-based maintenance model and the predictive maintenance model was performed. Methods of machine learning and deep learning were used to substantiate the application of AI, and a structural diagram of the IAS was developed to demonstrate integration.

The direction of technical operation transformation the transition to condition-based maintenance is substantiated in the work. It is proven that this transition is enabled by AI-analytics, which performs fault prognosis and remaining useful life prediction. The authors have identified a typical IAS architecture that integrates onboard data with ground systems. Based on this, a structural diagram for the integration of IAS and AI modules was developed, where the results of prognostic analytics directly form maintenance plans and support the making of engineering decisions.

The effectiveness of implementing AI models is established. Specifically, it is shown that the use of AI makes it possible to reduce fuel consumption by 5–8%, decrease aircraft downtime by 15–20%, and lower the number of unscheduled failures of critical components by 25–30%.

The results of the study provide a methodological basis for implementing intelligent decision support systems in aviation enterprises. The digitalization of AE LC management ensures an increase in safety levels, a reduction in operating costs, and a significant improvement in technical condition prognosis.

Key words: *information-analytical systems, artificial intelligence, lifecycle management, aviation equipment, predictive maintenance, remaining useful life, digital twin, big data.*

Formulation of the problem. The modern aviation industry is characterized by the rapid growth of data volumes generated at all stages of the aviation equipment (AE) lifecycle, from design and manufacturing to operation, maintenance (MRO), and disposal. Concurrently, there is a high level of complexity combining the integration of digital

systems with intelligent sensors and adaptive control tools, as well as modern composite materials.

At the same time, the aviation industry faces the necessity of ensuring the highest standards of flight safety, economic efficiency, and environmental sustainability. The systematic process of aviation equipment lifecycle management (AE LCM) includes

planning, creation, commissioning, ensuring technical readiness, modernization, resource extension, and disposal of aircraft and their components.

A large amount of data from various sources enters these systems. Traditional information processing systems are becoming insufficient for making operational and strategic decisions.

The implementation of information-analytical systems (IAS) and artificial intelligence (AI) methods allows for the creation of an integrated environment supporting management decisions throughout the entire AE LCM. AI models provide deep processing of large data arrays, fault prediction, maintenance optimization, increased flight safety, and economic efficiency of operations.

The integration of AI into AE LCM systems is becoming a global trend. Flight data monitoring platforms, predictive maintenance systems, aircraft digital twins, machine learning systems, and big data already allow for cost reduction by 10–30%, risk mitigation, and improved reliability of aviation systems.

Analysis of recent research and publications. Aviation equipment (AE) lifecycle management (LCM) in modern conditions is marked by an active transition from traditional approaches to digital technologies. Studies show that classical approaches, formed on the basis of regulatory documents from ICAO, EASA, and FAA, define fundamental requirements but do not fully account for the capabilities of modern information-analytical systems (IAS) and AI. This drives increased attention toward digital platforms and prognostic analytics methods as the basis for a new paradigm in technical operation.

A crucial layer of research belongs to the developments of aerospace companies, where digital ecosystems such as Airbus Skywise and Boeing Airplane Health Management demonstrate significant potential in collecting large volumes of operational data. Materials from Honeywell emphasize the effectiveness of combining IoT-sensorics and artificial intelligence for operational diagnosis of aircraft systems [1], confirming the global trend toward shifting from reactive to predictive maintenance.

Work [2] details the application of deep learning, particularly LSTM and CNN architectures, for analyzing the C-MAPSS dataset and modeling aircraft engine failures. Contemporary studies advance these approaches, as authors in [3, 4] demonstrate the effectiveness of deep learning algorithms for resource estimation tasks. In work [5], the authors confirm the ability of AI models to form a holistic concept of prognostic analytics within the management of aviation system LCs.

In scientific publications of recent years, interest in the digital twin concept has significantly increased. Digital twins allow the physical model of the aircraft to be combined with a virtual one, ensuring a continuous cycle of diagnosis and prediction. In the works authors [6, 7, 8], the digital twin is viewed as a key technology for optimizing maintenance, resource planning, and reducing the number of unscheduled failures. Additional studies, published in journals such as *Sensors and Engineering Applications of Artificial Intelligence*, demonstrate the successful integration of IoT platforms with AI modules to create comprehensive decision support systems in the aviation sector [9, 10, 11].

Work [12] examines mathematical modeling of technical condition, optimization of maintenance schedules, and the capabilities of neural networks for fault prediction. Although existing research lays an important methodological foundation, most studies focus on specific aspects of technical operation or traditional analysis methods. This necessitates comprehensive approaches capable of integrating modern AI technologies, digital twins, big data, and IoT systems into a unified LC management architecture. The analysis of sources confirms that global practice is moving toward creating integrated information-analytical platforms with powerful AI analytics, which ensure the transition to prognostic maintenance, reduction of failures, and optimization of costs throughout the entire lifecycle of aviation equipment. Concurrently, there is a deficit of research that comprehensively examines the methods for integrating such technologies into the AE LCM system, which affirms the relevance and necessity of further scientific development in this area.

Task statement. The goal of this research is to substantiate approaches to the application of IAS and AI technologies to enhance the efficiency of aviation equipment lifecycle management. To achieve this goal, it is necessary to sequentially address a number of primary objectives, focusing on the methods, models, and IAS used for monitoring, analysis, and forecasting the technical condition of aviation equipment throughout its lifecycle:

- to analyze the current state of AE LCM and identify the problems and limitations of existing approaches to monitoring and maintenance;
- to substantiate the feasibility of applying artificial intelligence technologies (machine learning, deep models, prognostic algorithms) for assessing the technical condition and remaining useful life of aviation component units;
- to develop a structural scheme for the integration of IAS and AI into the aviation equipment lifecycle management system;

– to determine the prospects for the digitalization of AE LCM processes based on modern AI-oriented technologies.

Outline of the main material of the study. The aggregate stages of an aviation product’s existence, from the moment the concept is formed to its disposal, constitute its lifecycle (LC). Each stage has its own information flows and specifics, which necessitates a change in the technical operation paradigm and creates the foundation for the application of information-analytical systems.

It is established that the traditional approach was based on a scheduled maintenance model, where service intervals were determined by operating hours or calendar time. A number of significant drawbacks of this approach were identified: the inability to account for individual operating conditions, the risk of «overstating» maintenance volumes, high spare parts inventory costs, and the probability of failing to detect early signs of failure.

Based on this, the necessity of transitioning to a digital LC management model is justified, with its key element being condition-based maintenance (CBM). Thanks to CBM, it becomes possible to predict failures based on the analysis of historical

data and to optimize resources to enhance safety and reliability. Predictive maintenance accounts for the individual behavior of components, providing remaining useful life (RUL) prediction, anomaly detection, and analysis of degradation trends, which leads to a reduction in unscheduled failures.

To realize the CBM concept, the typical architecture of the IAS has been investigated and defined. This multi-level digital platform integrates data collection tools from sensors, flight recorders, telemetry channels (ACARS, SATCOM, ADS-B), as well as centralized big data storage of the data lake type. Based on the collected information, monitoring modules and intelligent AI/ML-analytics components function, providing deep data processing, parameter forecasting, and support for decision-making. Such an integrated structure allows for the creation of a holistic digital loop for managing the AE condition.

The IAS provides comprehensive processing of heterogeneous data flowing from onboard monitoring systems, ground maintenance platforms, logistics MRO systems, and aerodrome information systems. Figure 2 demonstrates the main functions that the IAS performs at each stage of the LC.

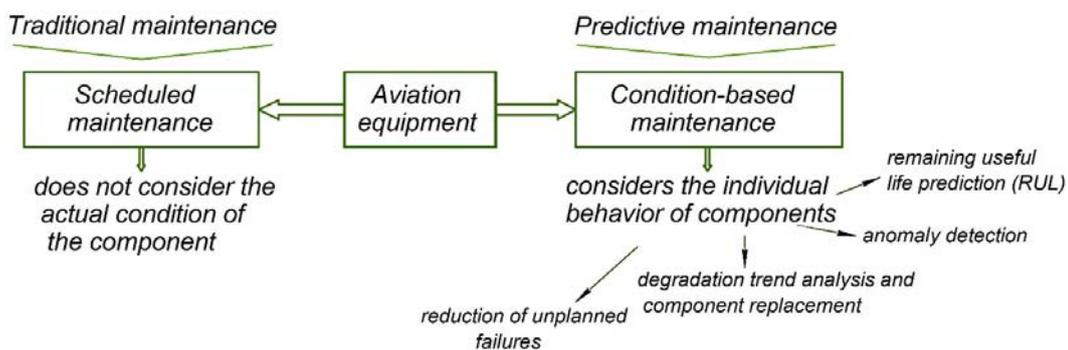


Fig. 1. Comparison of maintenance models

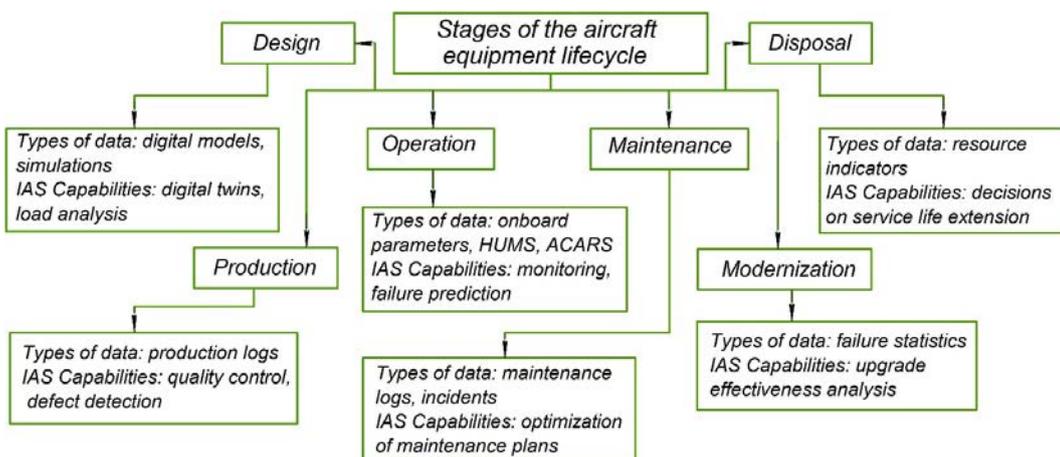


Fig. 2. Main functions of IAS at different stages of aviation equipment lifecycle

AI-analytics is a critically important component. Artificial intelligence technologies are utilized to ensure deep processing of heterogeneous data arrays that flow not only from the aircraft but also from ground-based MRO systems.

Based on the conducted analysis, the application of specific AI algorithms for solving the main problems of technical operation is substantiated. Machine learning (ML) algorithms and deep learning (DL) neural networks, particularly for time series analysis, are applied for remaining RUL prediction and real-time modeling of component degradation processes. Computer vision and NLP additionally provide automated defect detection and technical documentation analysis.

This approach forms the foundation for predictive maintenance (PdM), where the use of AI ensures early anomaly detection, forecasting the need for component replacement, and reducing the number of unscheduled failures by 40–60%. It is also established that AI is capable of increasing operational efficiency by optimizing flight modes, analyzing the impact of the human factor, automatic load monitoring, and minimizing fuel consumption.

An analysis of the results of implementing AI models in global practice demonstrates significant advantages. Specifically, it is established that after AI implementation, fuel consumption is reduced by 5–8%, aircraft downtime by 15–20%, and the number of critical component failures decreases by 25–30%. Furthermore, the time required for finding the causes of failures is reduced by 60–70%. These data are graphically illustrated in Figure 3, which demonstrates the proportion of reduction in key operational indicators due to AI analytics.

It is confirmed that the application of AI and integrated aviation systems covers all stages of the AE lifecycle, forming a continuous flow of data and decisions. At the design stage, AI algorithms enable the modeling of characteristics and prediction of material behavior. In manufacturing, IAS ensures increased quality control accuracy.

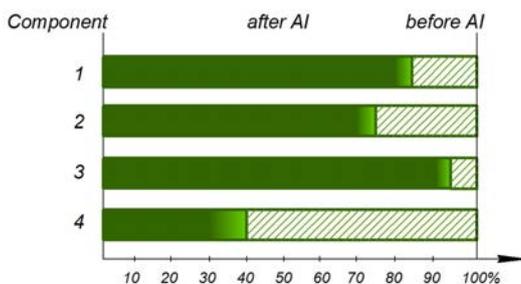


Fig. 3. Results of AI model implementation in global practice: 1 – fuel consumption, 2 – aircraft downtime, 3 – critical component failures, 4 – time required for root-cause analysis

During operation, AI analyzes flight parameters and evaluates crew performance efficiency, while at the maintenance stage, intelligent models determine the optimal time for procedure execution and predict failures. At the final stage of the lifecycle, systems evaluate the economic feasibility of resource extension and model disposal scenarios.

To visualize the interaction of key elements, a structural scheme (Figure 4) has been developed and presented, which illustrates the integration of IAS and AI modules into the maintenance management complex.

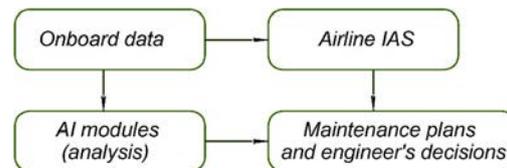


Fig. 4. Scheme of IAS integration into the maintenance management complex

The scheme demonstrates that telemetry sources and onboard data flow into the central airline IAS for aggregation. Subsequent parameter processing is carried out by AI modules, which perform technical condition prognosis and automatic recommendation generation. The results of this analysis directly form the maintenance plans and engineer decisions, which are coordinated based on analytical conclusions.

Thus, it is confirmed that intelligent AI models are not merely an additional tool, but a central element that ensures the transition from reactive to proactive management of the entire aviation equipment lifecycle.

Based on the conducted research, it is substantiated that the integration of IAS and AI technologies forms a new standard for AE LCM.

Conclusions. The main direction of technical operation transformation, the transition from the scheduled preventive model to CBM, is established. It is proven that this transition depends on the implementation of AI-analytics, which allows for failure prognosis and remaining useful life prediction.

The functional architecture of the IAS is substantiated as ensuring the continuous collection, processing, and analysis of heterogeneous data (onboard, operational, MRO). This integrated digital ecosystem guarantees high accuracy of analysis and predictability of engineering decisions.

The main economic and operational advantages of applying AI are determined, including a significant reduction in operating costs (specifically, fuel and downtime) and an increase in safety levels due to proactive anomaly detection.

It is confirmed that AI models are a central element that ensures the proactive management of the AE lifecycle at all its stages, from the optimization of structural solutions during the design phase to the assessment of the economic feasibility of resource extension.

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Єніна І.І., Чорногор Н.О., Мацуї А.М. ЗАСТОСУВАННЯ ІНФОРМАЦІЙНО-АНАЛІТИЧНИХ СИСТЕМ ТА АІ ДЛЯ УПРАВЛІННЯ ЖИТТЄВИМ ЦИКЛОМ АВІАЦІЙНОЇ ТЕХНІКИ

У статті розглядаються підходи до застосування інформаційно-аналітичних систем та технологій штучного інтелекту з метою підвищення ефективності управління життєвим циклом авіаційної техніки. Автори показують, що сучасна авіаційна галузь зіштовхується з проблемою експоненціального зростання обсягів даних, які генеруються на всіх етапах ЖЦ, від проєктування до експлуатації. Традиційні системи аналізу визнані недостатніми для прийняття оперативних стратегічних рішень, що вимагає впровадження інтегрованого середовища підтримки управління.

Актуальність дослідження обґрунтовується необхідністю розробки комплексних підходів, здатних інтегрувати сучасні ІАС та АІ у єдину архітектуру управління ЖЦ АТ. Проведений аналіз останніх досліджень підтверджує, що інтеграція АІ-аналітики, великих даних, IoT-сенсорик та концепції цифрових двійників є глобальним трендом. Автори вказують на обмеженість робіт, які комплексно розглядають методи інтеграції цих технологій у систему управління ЖЦ АТ як цілісний процес. Мета дослідження полягає в обґрунтуванні підходів до застосування ІАС та технологій АІ для підвищення ефективності управління ЖЦ АТ.

На базі системного аналізу проведено порівняння традиційної планово-попереджувальної моделі технічного обслуговування з моделлю прогностичного обслуговування. Для обґрунтування застосування штучного інтелекту використано методи машинного та глибинного навчання, а для демонстрації інтеграції розроблено структурну схему ІАС.

У роботі обґрунтовано напрямки трансформації технічної експлуатації по переходу до обслуговування за реальним технічним станом. Доведено, що цей перехід забезпечується АІ-аналітикою, яка здійснює прогнозування відмов та залишкового ресурсу. В статті визначено типову архітектуру ІАС, яка інтегрує бортові дані із наземними системами. На основі цього розроблено структурну схему інтеграції ІАС та АІ-модулів, де результати прогностичної аналітики безпосередньо формують плани ТО та підтримують прийняття інженерних рішень.

Встановлено ефективність впровадження АІ-моделей. Зокрема, показано, що використання АІ дозволяє скоротити паливні витрати на 5–8%, зменшити час простоювання літаків на 15–20% та знизити кількість незапланованих відмов критичних вузлів на 25–30%.

Результати дослідження надають методологічний базис для впровадження інтелектуальних систем підтримки рішень в авіаційних підприємствах. Цифровізація управління ЖЦ АТ забезпечує підвищення рівня безпеки, зменшення експлуатаційних витрат та значне покращення прогнозування технічного стану.

Ключові слова: інформаційно-аналітичні системи, штучний інтелект, управління життєвим циклом, авіаційна техніка, прогностичне технічне обслуговування, залишковий ресурс, цифровий двійник, великі дані.

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