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ANALYSIS OF DIGITAL TECHNOLOGIES WITH IOT FOR THE MAINTENANCE OF AVIATION EQUIPMENT

The article explores digital IoT-based platforms in the field of aviation maintenance.

Digital platforms based on the Internet of Things (IoT) in aviation maintenance enhance efficiency, accuracy, and operational safety. With connected sensors and big data analytics, IoT enables real-time aircraft condition monitoring, early detection of potential failures before they occur, and optimization of maintenance planning. All of this contributes to reduced downtime, lower maintenance costs, and increased overall reliability of aviation equipment. The use of IoT-powered digital platforms unlocks new opportunities for predictive analytics, automation, and integration of maintenance processes, making aviation more technologically advanced, economically efficient, and safe.

This study examines modern complex IoT platforms, including GE Aviation Predix, Honeywell Forge for Airlines, Airbus Skywise, IBM Maximo for Aviation, Collins Aerospace Ascentia, Rolls-Royce Engine Health Management (EHM), Safran Cassiopée™, Boeing AnalytX, IFS Cloud for Aviation Maintenance, and Lufthansa Technik AVIATAR.

The article tracks the dynamics of the adoption of intelligent aviation IoT platforms and presents their classification. Aviation IoT platforms were categorized into groups: industrial platforms for predictive maintenance, digital platforms for maintenance management and analytics, analytical and monitoring platforms for aviation equipment, monitoring and management platforms for aircraft engines, and platforms for flight data analysis and safety. The study also examines the applicability of IoT platforms for passenger, cargo, business jets, military, light aircraft, and eVTOL aircraft to ensure efficient maintenance operations. Special attention is given to predictive maintenance.

The research investigates the functional capabilities of IoT platform integration with other aviation systems to provide centralized data access and facilitate coordination among technical personnel, airlines, and equipment manufacturers. A detailed analysis of the functional capabilities of these platforms has revealed key features that enhance aviation equipment operational efficiency, optimize maintenance costs, and improve flight safety.

Key words: *Internet of Things, maintenance engineering, digital platforms, aviation equipment, aircraft engine, monitoring.*

Formulation of the problem. The modern aviation industry faces a number of challenges related to increasing the efficiency of aircraft maintenance, reducing operational costs, and ensuring a high level of flight safety. One of the promising solutions is the implementation of intelligent IoT platforms, which enable real-time monitoring of aviation equipment, predictive analytics, and optimization of maintenance processes.

However, despite the active development of such platforms, there is a pressing need for a detailed and comprehensive comparative analysis of IoT platforms. Thus, the necessity to systematize and evaluate the functional capabilities of intelligent IoT platforms for aviation maintenance determines the relevance of this study.

Analysis of recent research and publications. The issue of digital maintenance technologies in aviation has been studied by a significant number of global researchers, including S. Li, M. Dan, I. Kabashkin, V. Perekrestov, L. Yang, S. Fu, N. Avdelidis, M. Kordestani, M. E. Orchard, K. Khorasani, M. Saif, W. Verhagen, B. F. Santos, F. Freeman, P. Kessel, D. Zarouchas, T. Loutas, R. C. Yeun, I. Heiets, A. Altay, O. Ozkan, G. Kayakutlu, C. Che, H. Wang, X. Ni, and others [1–5]. Many publications focus on specific IoT platforms for aviation equipment.

Task statement. The work involves a analysis of IoT-based digital platforms for aviation maintenance. To achieve this goal, a comprehensive comparative analysis of the main platforms is proposed to identify their advantages, disadvantages, and application features.

Outline of the main material of the study. Modern aviation is actively implementing digital technologies to enhance the efficiency and safety of aircraft maintenance. The development of information systems, the IoT, artificial intelligence, and big data enables significant optimization of diagnostics, monitoring, and maintenance planning processes.

Digital technologies play a crucial role in aviation maintenance. Thanks to IoT platforms, airlines can not only prevent failures but also save millions of dollars on maintenance and reduce aircraft downtime [6]. These platforms not only provide in-depth analytics but also facilitate the transition to predictive maintenance, minimizing risks and optimizing aviation companies' expenses.

The use of IoT in aviation began with the need to enhance aircraft reliability and safety through more precise condition monitoring. Before IoT, aircraft maintenance systems operated on a scheduled preventive maintenance basis. At the end of the last century, aircraft manufacturers began equipping planes with onboard diagnostic systems (Health Monitoring Systems) capable of collecting data on engine performance and other components. One of the first real examples of predictive maintenance was Rolls-Royce's "TotalCare" project, which allowed airlines not just to maintain engines according to regulations but to analyze their condition in real-time and predict the need for repairs (Fig. 1).

The advancement of cloud technologies, big data, and machine learning has enabled the full-scale implementation of IoT in aircraft maintenance.

The use of IoT in aviation follows several key stages: real-time data collection, data transmission, processing and analysis, and the generation of recommendations. Sensors monitor the performance parameters of engines, hydraulic systems, avionics, fuel systems, and other critical components, transmitting gigabytes of information. Through onboard communication systems, this data is sent to ground-based processing centers, where it is analyzed in real time. Machine learning algorithms identify patterns, anomalies, and potential failures. The system then predicts possible malfunctions and suggests corrective actions, minimizing the likelihood of failures.

In aircraft maintenance using IoT, various software solutions are employed to collect, transmit, analyze data, and predict potential failures.

We will examine the key IoT platforms for data collection and analysis: GE Aviation Predix, Honeywell Forge for Airlines, Airbus Skywise, IBM Maximo for Aviation, Collins Aerospace Ascentia, Rolls-Royce Engine Health Management (EHM), Safran Cassiopée™, Boeing AnalytX, IFS Cloud for Aviation Maintenance, and Lufthansa Technik AVIATAR. These platforms enhance maintenance efficiency for commercial, cargo, business aviation, and military aircraft (Fig. 2).

These platforms help airlines reduce maintenance costs, improve aircraft operational availability, and prevent unexpected failures through accurate forecasting and data analysis.

Intelligent IoT platforms for aviation maintenance can be categorized into the following groups: industrial

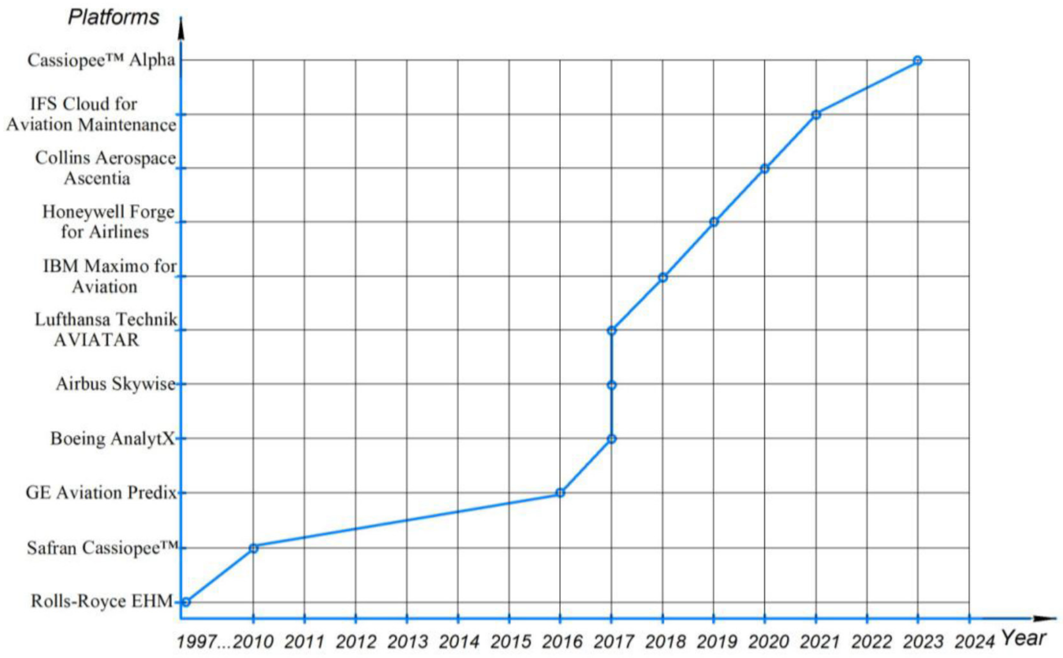

Fig. 1. The dynamics of implementing intelligent aviation IoT platforms

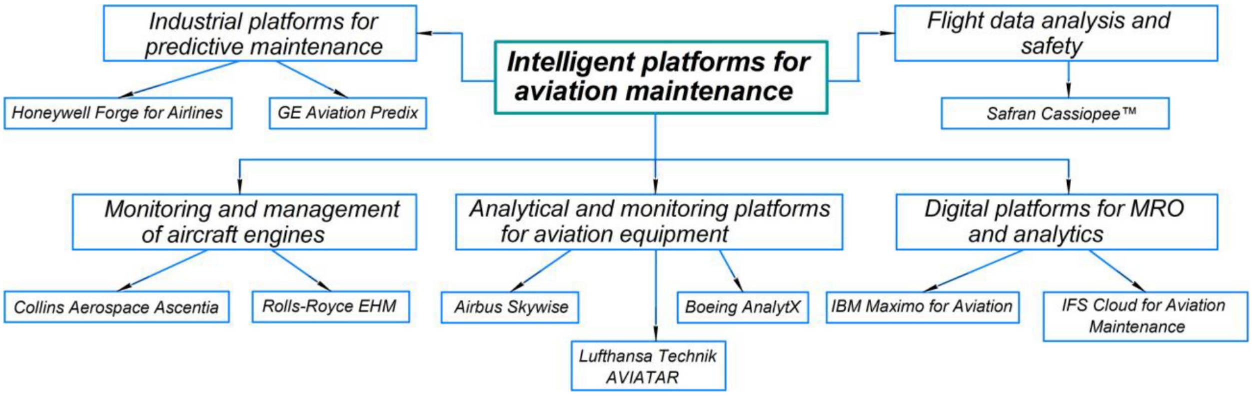

Fig. 2. Intelligent IoT Platforms for Aviation Maintenance

platforms for predictive maintenance, digital platforms for maintenance management and analytics, analytical and monitoring platforms for aircraft, monitoring and management platforms for aviation engines, and platforms for flight data analysis and safety (Fig. 3). We will examine each group in detail.

The key industrial IoT platforms for predictive maintenance include GE Aviation Predix (Platform 1) and Honeywell Forge for Airlines (Platform 2).

The GE Aviation Predix platform enables real-time data collection and analysis from aircraft engines, avionics, hydraulic, and fuel systems [8]. Initially developed as part of the Predix cloud platform for the Industrial Internet of Things (IIoT), it was later adopted for servicing GE and CFM International powerplants. By shifting from reactive to predictive maintenance, Predix forecasts potential equipment failures and recommends optimal maintenance schedules. It integrates with other aviation systems, such as Airbus Skywise, Honeywell Forge for Airlines, and IBM Maximo for Aviation, providing centralized data access and improving coordination among technical personnel. Predix also helps optimize operational costs by reducing maintenance expenses through early fault detection.

The Honeywell Forge for Airlines cloud platform facilitates predictive maintenance by analyzing onboard systems and sensor data to anticipate potential failures. Utilizing machine learning, it assists airlines in planning repairs and avoiding unplanned downtimes. The platform also optimizes fuel consumption by analyzing real-time usage, identifying inefficient routes, and detecting suboptimal engine operation modes, contributing to reduced CO_2 emissions. Its flight monitoring system assesses flight trajectories, weather conditions, and aircraft system performance, automatically detecting deviations from normal operating conditions. Additionally, integration with air traffic control services enhances flight routing efficiency. Furthermore, the platform automates reporting and business process management, consolidating maintenance, fuel cost tracking, and safety oversight into a unified digital environment, with automated reporting capabilities for MRO (Maintenance, Repair, and Overhaul) services.

The primary digital platforms for maintenance management and analytics include IBM Maximo for Aviation (Platform 3) and IFS Cloud for Aviation Maintenance (Platform 4).

The IBM Maximo for Aviation platform, adapted for the aviation industry, manages aircraft assets and maintenance (MRO). It enables real-time engine condition monitoring, automates scheduled and unscheduled repairs, and ensures compliance with regulatory maintenance requirements. Using AI and IoT, the system predicts failures, analyzes component wear, and optimizes repair cycles to minimize unexpected breakdowns. Inventory management tools provide spare parts availability control, demand forecasting, and automated ordering. Maximo complies with FAA, EASA, and ICAO standards, maintains electronic documentation, and automatically records completed tasks and inspections for regulatory authorities.

The IFS Cloud for Aviation Maintenance is a specialized solution for managing aircraft maintenance, ensuring standardized, efficient, and predictable maintenance operations – even for some electric eVTOL aircraft.

Key analytical and monitoring platforms include Airbus Skywise (Platform 5), Boeing AnalytX (Platform 6), and Lufthansa Technik AVIATAR (Platform 7).

Developed in collaboration with Palantir Technologies, Airbus Skywise collects and analyzes aviation data, integrating information from onboard systems, maintenance records, IoT sensors, and airline operational processes. By leveraging Big Data and machine learning, it predicts potential failures. Automated diagnostics of engines, avionics, hydraulic, and fuel systems help prevent unscheduled repairs and extend component lifespans. The platform optimizes operational activities, improving flight scheduling and maintenance, minimizing delays, and reducing fuel costs. Skywise is flexible and scalable, supporting not only Airbus aircraft but also Boeing, Bombardier, and Embraer models, with cloud-based technology for real-time data access.

The Boeing AnalytX platform, powered by IoT, is designed for analytics and fuel optimization. It consolidates data from different Boeing divisions and applies advanced data science techniques combined with aerospace expertise to deliver intelligent solutions aimed at mission readiness, maintenance optimization, and adaptive learning.

The Lufthansa Technik AVIATAR predictive maintenance and process automation platform has enhanced its failure prediction capabilities after integration with Honeywell Connected Maintenance.

For monitoring and managing aircraft engines, the Rolls-Royce EHM (Platform 8) and Collins Aerospace Ascentia (Platform 9) platforms have been developed.

The Rolls-Royce Engine Health Management (EHM) system has evolved since the 1970s and is used for real-time monitoring and analysis of aircraft engine conditions. Its primary goal is to reduce maintenance costs and prevent engine failures by ensuring timely and accurate repairs and support. Through collaboration with Oxford University and the implementation of the QUICK system, EHM has expanded its data analysis capabilities, improving engine reliability.

The Collins Aerospace Ascentia cloud-based analytics platform is designed for managing the reliability and maintenance of aviation systems. It analyzes technical data, predicts failures, and reduces aircraft downtime, helping airlines optimize maintenance costs and enhance passenger comfort. The platform includes Repeaters and Aircraft Health Monitoring modules, which enhance its capabilities. It is used by airlines like Air Europa to monitor Boeing 787, while Rolls-Royce EHM handles engine monitoring for Rolls-Royce engines on Airbus and Boeing aircraft.

For flight data analysis and safety, the Cassiopée™ (Platform 10) is utilized. This platform helps airlines, MROs, Original Equipment Manufacturers (OEMs), and service providers improve operational efficiency and flight safety. The Cassiopée™ Alpha system ensures rapid data processing regardless of fleet size, offering customizable algorithms, an intuitive interface, and seamless integration into an operator's digital ecosystem. The updated Cassiopée™ Alpha version includes enhanced safety analysis and predictive capabilities.

Among the analyzed platforms, IBM Maximo for Aviation is the most flexible for use in general aviation, while GE Aviation Predix can also be applied in certain cases if the aircraft is equipped with the appropriate avionics. Other platforms have limited or no application in this segment due to their focus on large aircraft and extensive operational processes.

For light aircraft, specialized, more affordable and adaptable solutions exist, such as: Garmin Flight Stream + G1000 NXi, ForeFlight / Spidertracks, GE Aviation Digital Solutions.

The results of the study on the support of different aircraft types by modern IoT platforms are presented in Table 1, while usage characteristics are detailed in Table 2.

The detailed analysis allows us to identify the unique features of each platform. For example, Ascentia enhances aircraft engine performance, while EHM utilizes real-time data to assess engine conditions. The Cassiopée platform focuses on safety and reducing maintenance costs, whereas AnalytX has deep integration with Boeing aircraft. A key feature of IFS Maintenance is its flexibility in configuration and modular structure. AVIATAR can integrate with

Table 1

Support for Different Types of Aircraft by Modern IoT Platforms

Platform	Commercial	Cargo	Business	Regional	Light	eVTOL	Military
Platform 1	+	+	+	–	limited	–	+
Platform 2	+	+	+	–	–	–	–
Platform 3	+	+	+	+	+	–	+
Platform 4	+	+	–	–	–	+	–
Platform 5	+	+	+	–	–	–	+
Platform 6	+	+	–	–	–	–	–
Platform 7	+	–	–	–	–	–	–
Platform 8	+	+	+	–	–	–	–
Platform 9	+	–	–	–	–	–	–
Platform 10	+	–	–	–	limited	–	+

Table 2

Comparison of IoT Platforms for Aircraft Maintenance

Platforms	Advantages	Disadvantages
Platform 1	Supports engines and aircraft from various manufacturers Used in military aviation	Limited applicability for light aviation Complex implementation process
Platform 2	Efficient fleet management Large-scale data analysis Used by commercial and cargo operators	No support for light aviation High cost of integration with aviation systems
Platform 3	Used for commercial and military and light aviation Tools for inventory management	High requirements for customization Limited analytics compared
Platform 4	Flexible cloud-based platform Potential integration with eVTOL	Requires significant resources for setup and maintenance
Platform 5	Deep integration with Airbus aircraft Used by major airlines	Poor compatibility with aircraft from other manufacturers High implementation cost
Platform 6	Fuel cost optimization High efficiency for large airlines	Low adaptability for aircraft from other manufacturers
Platform 7	Extensive suite of analytical tools High integration with Airbus Skywise	Primarily focused on Airbus High usage cost
Platform 8	In-depth analysis of Rolls-Royce engine condition Used in commercial and military aviation	Focus only on Rolls-Royce engines Limited application for aircraft with other engine types
Platform 9	Real-time aircraft condition monitoring Used by major airlines	Limited support for aircraft from other manufacturers
Platform 10	Flight data analysis and failure prediction	Limited compatibility with platforms from other manufacturers High cost of deployment across fleets

various airlines. Predix leverages digital twins and integrates with other aviation systems, while Forge improves fuel efficiency and reduces unplanned repairs. Skywise stands out for its integration with Airbus aircraft and accessibility to airlines and suppliers. The Maximo platform is highly customizable and can manage the entire equipment lifecycle.

After a analysis of the functional capabilities of IoT platforms in aviation maintenance, several key characteristics have been identified, along with their impact on aircraft operational efficiency. For example, Ascentia enhances aircraft engine performance, while AVIATAR can integrate with various airlines.

EHM utilizes real-time data to assess engine conditions. The Cassiopée platform focuses on safety and reducing maintenance costs, whereas AnalytX has deep integration with Boeing aircraft. A key feature of IFS Maintenance is its flexibility in configuration and modular structure. Predix leverages digital twins and integrates with other aviation systems, while Forge improves fuel efficiency and reduces unplanned repairs. Skywise stands out for its integration with Airbus aircraft and accessibility to airlines and suppliers. The Maximo platform is highly customizable and can manage the entire equipment lifecycle.

The integration of various digital ecosystems is a crucial aspect of aviation platform development. Platforms such as AnalytX and IFS Maintenance focus on comprehensive maintenance management and spare parts logistics. As a result, aircraft downtime is significantly reduced, and the supply process for critical components is optimized.

Special attention has been given to reducing fuel costs and improving the energy efficiency of air transport. Forge uses fuel consumption analysis algorithms to determine the most economical routes, while Cassiopée provides airlines with analytical tools to optimize fleet operational performance.

Conclusions. The evolution of the implementation of intelligent aviation IoT platforms has been examined. A classification of intelligent platforms has been conducted, dividing them into industrial platforms for predictive maintenance, digital platforms for maintenance management and analytics, analytical and monitoring platforms for aviation equipment, monitoring and management platforms for aircraft engines, and platforms for flight data analysis and safety.

The support of IoT platforms for commercial, cargo, business aviation, military, and eVTOL aircraft has been analyzed to ensure effective maintenance operations. Special attention has been given to reducing fuel costs to enhance the energy efficiency of air transportation.

As a result of the study, the functional capabilities, advantages, and limitations of the analyzed platforms for aviation maintenance have been identified.

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Єніна І.І., Чорногор Н.О. АНАЛІЗ ЦИФРОВИХ ТЕХНОЛОГІЙ З IoT ДЛЯ ТЕХНІЧНОГО ОБСЛУГОВУВАННЯ АВІАЦІЙНОЇ ТЕХНІКИ

У статті автори досліджують цифрові платформи з IoT в галузі технічного обслуговування авіаційної техніки.

Цифрові платформи на основі Інтернету речей (IoT) у технічному обслуговуванні авіаційної техніки забезпечують підвищену ефективність, точність і безпеку операцій. Завдяки підключеним датчикам та аналітиці великих даних, IoT дозволяє здійснювати моніторинг стану повітряних суден у реальному часі, виявляти потенційні несправності ще до їх виникнення та оптимізувати планування ремонтних робіт. Все це сприяє зменшенню простоїв, зниженню витрат на обслуговування і підвищенню загальної надійності авіаційної техніки. Використання цифрових платформ з IoT відкриває нові можливості для прогнозної аналітики, автоматизації та інтеграції технічного обслуговування, що робить авіацію більш технологічною, економічно ефективною та безпечною.

В рамках роботи проведено дослідження сучасних складних IoT платформ, таких як: GE Aviation Predix, Honeywell Forge for Airlines, Airbus Skywise, IBM Maximo for Aviation, Collins Aerospace Ascentia, Rolls-Royce Engine Health Management (EHM), Safran Cassiopée™, Boeing AnalytX, IFS Cloud for Aviation Maintenance, Lufthansa Technik AVIATAR.

В статті відслідкована динаміка впровадження інтелектуальних авіаційних IoT-платформ та проведена класифікація. Авіаційні IoT платформи розподілялися по групах на: промислові для предиктивного ТО, цифрові для управління ТО та аналітики, аналітичні та моніторингові для АТ, моніторингові та управління авіаційними двигунами, аналізу польотних даних та безпеки інтелектуальних платформ. Проводилось дослідження можливості їх застосування в пасажирських, вантажних, бізнес-джетів, військових, легких та eVTOL повітряних суденах IoT-платформам для забезпечення ефективного технічного обслуговування. Велика увага при аналізі приділена предиктивному обслуговуванню. Досліджені функціональні можливості інтеграції з іншими авіаційними системами для забезпечення централізованого доступу до даних та полегшення координації між технічним персоналом, авіакомпаніями та виробниками обладнання. Після проведеного детально аналізу функціональних можливостей платформ виявлені суттєві особливості, які сприяють підвищенню ефективності експлуатації авіаційної техніки, оптимізації витрат на технічне обслуговування та покращенню безпеки польотів.

Ключові слова: *Інтернет речей, технічне обслуговування, цифрові платформи, авіаційна техніка, авіаційний двигун, моніторинг.*