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INNOVATIVE TRAINING COMPLEX WITH ENGINEERING SUPPORT: A NEW LEVEL OF TECHNICAL EXPLOITATION OF AVIATION

Abstract. *This research explores the creation of a novel training complex that includes an engineering support system specifically designed for the technical management of military and specialized aviation equipment. The importance of this study stems from the need to improve the training efficiency of engineering and technical staff, given the growing technical complexity of aviation equipment and the increasing demands for aviation safety. The main aim of this research is to develop an adaptive educational platform that integrates digital twins of aviation systems, fault diagnosis algorithms, and intelligent methods to tailor the educational process. Within this study, the architecture of a comprehensive engineering support system was devised, which includes data collection, digital modeling, and analytics. An adaptive learning algorithm has been introduced, which takes into account the trainee's skill level, experience, and progress in mastering the material, thereby automatically adjusting the curriculum. The use of virtual simulators and simulation models enabled the development of a flexible training system that closely mirrors the actual operating conditions of aviation equipment. To evaluate the proposed system's effectiveness, experimental testing was carried out, comparing the training results of two groups of engineering and technical personnel: the experimental group (using adaptive training with digital models) and the control group (using traditional training methods). The findings showed that the new training complex reduced response time to emergencies by 22%, lowered the number of errors by 30%, and improved the accuracy of procedure execution by 18%. The adaptive training system developed is highly flexible, allowing for customization and integration with modern predictive diagnostics methods for aircraft malfunctions. Implementing such a complex in the training of specialists will enhance aviation safety, reliability, and the economic efficiency of technical aircraft operations.*

Keywords: *aviation equipment, engineering support, digital twins, adaptive learning, training complex, fault diagnostics.*

Introduction.

Modern aviation, both military and civil, is a complex technical system that requires strict compliance with the rules and standards of operation, maintenance, and repair developed by international organizations in aviation security. The main principle in aviation is to reduce the time aircraft spend on the ground [1]; this factor directly depends on the level of training of service engineering personnel and ensuring high-quality technical operations. In connection with the above, the development of training complexes with integrated engineering support systems is an urgent task to increase the reliability and combat readiness of aviation equipment.

To ensure the reliability of intelligent simulators, imitation of the real operating conditions of aircrafts is used by implementing modelling technologies, digital twins, and artificial

intelligence. The introduction of such a simulator will improve the efficiency of training engineering and technical personnel in the aviation industry through the use of multiscenario modes, which will allow the simulation of all possible circumstances that may arise during operation and repair.

Today, simulators for training flight personnel have become widespread in the aviation industry, having received good reviews from both personnel and regulatory authorities in the aviation sector, and the potential of simulator complexes for engineering and technical personnel has not been fully realized [2]. Simultaneously, ensuring a high level of technical maintenance will improve aviation safety and ensure the long-term operation of the equipment. Therefore, the use of such a simulator complex with engineering support tools can significantly increase the effectiveness of training in the educational environment and provide an expansion of training scenarios for retraining and advanced training of engineering personnel without significant financial investment from stakeholders.

The scientific novelty of this study lies in the development of a training complex that combines realistic modelling of the processes of maintenance and operation of aircraft equipment, intelligent fault diagnostic systems, and automated training tools for engineering and technical personnel. If we compare the training complex proposed in this study with those that currently exist, we can highlight the following competitive advantages: the presence of a digital platform that provides access to regulatory documentation, analytical data on the progress of trainees, and the availability of fault-finding algorithms.

The purpose of this study is to develop a training complex with an engineering support system for the technical operation of aircraft for various applications. To achieve this goal, researchers have set the following number of tasks:

1. Develop an integrated engineering support system architecture that includes digital models of aircraft and fault-diagnostic algorithms.

2. Develop an algorithm for the adaptive training of engineering and technical personnel considering aircraft specifications

3. Assess the effectiveness of the developed system and traditional methods for training aviation specialists.

According to the authors [3], one of the promising areas for the development of such systems is the use of digital twin technology for aviation equipment, which allows for the simulation of operational processes and modelling of all types of malfunctions. However, modern literature focuses on civil aviation, and the adaptation of such systems for military and special equipment requires significant work on the modification and consideration of the specifics of operation of such equipment [4].

Another direction that has been actively developed in recent years is the use of automated maintenance and repair management systems integrated with intelligent algorithms to predict unit failures [5] and automatic diagnostic processes [6] of aviation equipment. The use of such integrated methods increases the efficiency of fault detection and generates automatic recommendations for their elimination.

Another problematic issue is the insufficient material and technical base of educational institutions in the field of aviation specialist training, which leads to a lack of practical experience among graduates [7]. The introduction of such simulator complexes into the training process will improve the level of training of engineering and technical personnel and reduce the likelihood of errors under real working conditions [8].

Therefore, the development of a simulator complex with an engineering support system is associated with challenges in the operation and maintenance of aviation equipment [9]. The introduction of such a complex process of training engineering and technical specialists will ensure an increase in the level of aviation safety, reliability, and economic efficiency of aviation

equipment, which in turn will have a positive effect on the combat capability and operational readiness of aircraft [10].

Materials and methods.

To achieve the project objectives, researchers have developed an integrated system architecture. Figure 1 illustrates the architecture of the integrated system.

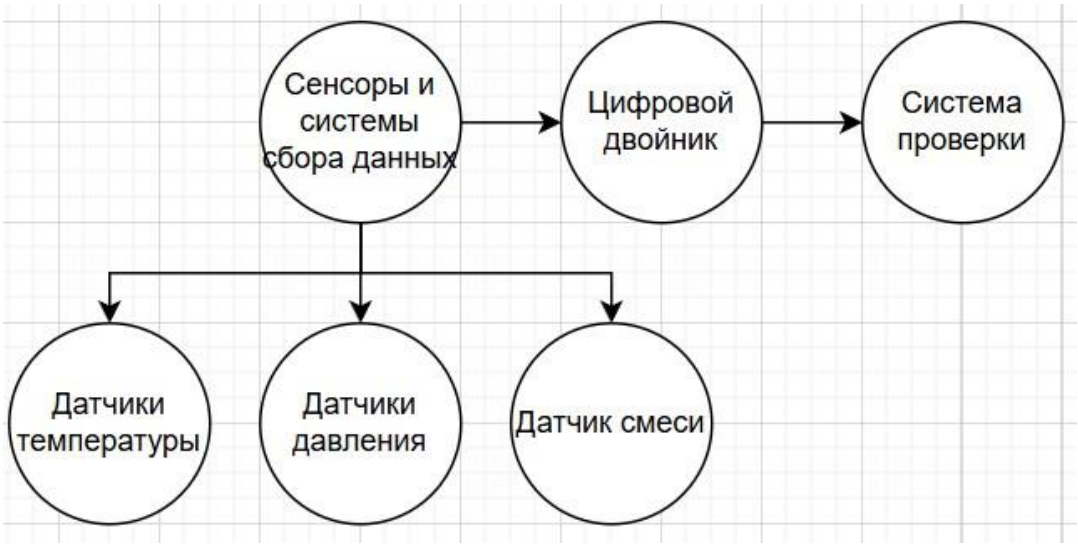

Figure 1 – Structural diagram of the integrated system architecture

The architecture shown in Figure 1 includes a data collection level (sensors and sensors) and temperature, pressure, and mixture sensors. The next level is the digital twin level, which is a simulation model of aviation equipment that includes an object (aircraft) and a tool (deicing machine). The last is the analytical level, which is necessary to assess the correctness of a trainee's actions. The anti-icing preparation of an aircraft is one of the important stages in preparation for departures, because upon reaching certain altitudes, the aircraft encounters extremely low temperatures, down to -50 -60 degrees. To improve the efficiency of training engineering and technical personnel, the use of the adaptive learning algorithm shown in Figure 2 was proposed.

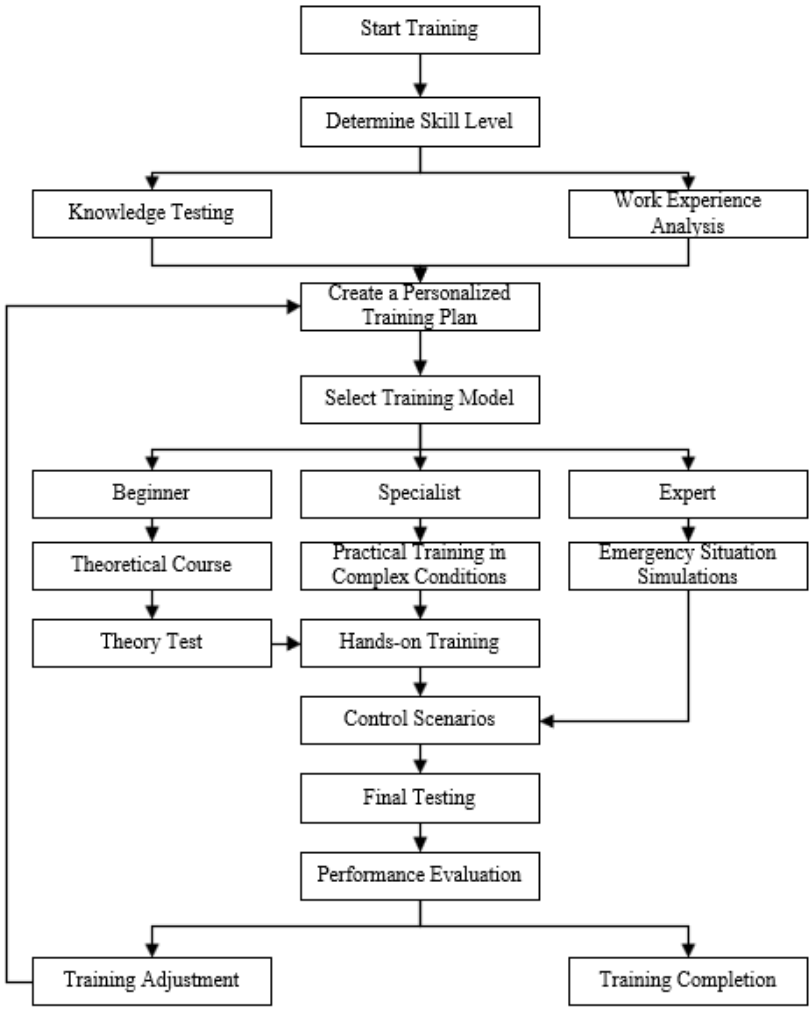

Figure 2 – Block diagram of the adaptive learning algorithm

The block diagram of the adaptive learning algorithm shown in the figure includes five main stages:

Stage 1. Determine the trainee's training level conductinging an entrance test to assess the theoretical knowledge of anti-icing treatment, including regulations, standards, and methods of treatment, as well as practical skills (experience with equipment, reagents, and heating systems). Analysis of the presence of experience in this type of service (beginner: up to 1 year, specialist: from 1 to 5 years, expert: from 5 years). The system created a personal training plan based on the initial data.

Stage 2. Selection of the training model. Based on the results obtained from testing the trainee, the system selected an appropriate training model. The developed system includes three training models: beginner (studying the theoretical course and consolidating the material in basic practical exercises), specialists (practical exercises in more difficult weather conditions), and experts (simulation of emergency situations and training of non-standard cases).

Stage 3. Theoretical training. Access of trainees to electronic training materials developed by international organisations in the field of aviation security, study of interactive cases (incident analysis and study of the most common errors), and testing on the studied material.

Stage 4. Practical training with virtual modelling elements: Virtual simulator with integrated digital twins of aircraft (practising basic algorithms for anti-icing treatment and simulating various weather conditions). Testing professional skills in the control scenarios.

Stage 5. Evaluation of the effectiveness and adaptation of the training. Final testing. Evaluation of errors and analysis of error data. Correction of the training plan (study of additional modules and in-depth training on the simulator).

To evaluate the effectiveness of the developed simulator complex and traditional training methods, a comparative analysis was used within the framework of the project, within which a sample consisting of two groups of 14 people was formed, in accordance with the requirements for training specialists. These groups underwent an entrance test to determine their levels of knowledge. After completing the theoretical course, an exit test was conducted to assess knowledge, a practical exam with modelling of various anti-icing training situations. The Student's t-test was used to compare the results between the two groups.

Results.

For the developed adaptive learning algorithm, software was developed that includes an interface written on the PyQt technology stack for graphical representation. Adaptive learning logic has been implemented, including determining the level of knowledge of the student by passing a theoretical test, after which a personal learning plan is generated, monitoring the student's progress, and adjusting the learning plan. The software used is shown in Figure 3.

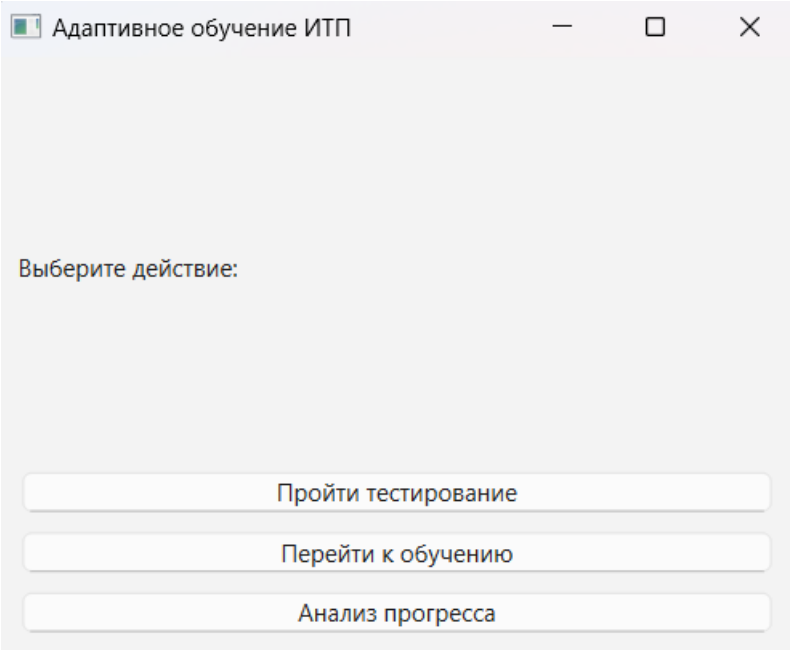

Figure 3 – Appearance of the adaptive learning program

The software shown in the figure includes a front-end interface with three buttons. When pressed, or student goes to a specific subprogram, such as a test base, training materials, and an analytical block. After completing the theoretical part, the student goes to the practical part; the external program for completing the practical part is shown in Figure 4.

Figure 4 – external view of the practical implementation of the simulator

Figure 4 shows the implementation of the practical part of the training complex in the Unreal Engine software environment. The training complex is a digital model of an aircraft and an anti-icing machine from a cradle, where the trainee must process the fuselage of the aircraft. Analysis of the exit test results showed that the results in the experimental group were 18% higher than those in the control group. The practical exam showed that trainees in the experimental group responded 22% faster to emergency situations, and when analysing the implementation of anti-icing protection procedures, it was found that the experimental group made 30% fewer mistakes.

Conclusion and discussion.

The development of the training complex made it possible to create an innovative platform for training engineering and technical personnel in aviation enterprises. The study conducted within the framework of this study confirmed the hypothesis regarding the effectiveness of virtual reality. The inclusion of intelligent technologies in the training process provides a better understanding of theoretical knowledge, improves practical skills, and allows the simulation of a large number of non-standard situations.

An important advantage of the developed training complex is the flexibility and ability to personalise the training process for each student. Owing to the use of adaptive training algorithms, the system automatically adjusts the curriculum, considering the level of knowledge, experience, and dynamics of mastering the material. These algorithms help minimise knowledge gaps, increase the effectiveness of training, and provide higher-quality training of specialists.

The use of digital twin technology allows the simulation of various operating conditions and malfunctions, which allows not only training personnel but also the development of modern aircraft maintenance strategies. As a result, this training complex can be used not only for educational purposes, but also for improving the skills of employees. Despite the high efficiency of this training complex, its implementation under real operating conditions is associated with significant investment costs in the technical equipment of training centres. In addition, during implementation, the following factors must be considered: availability of equipment in the market, ability to provide technical support for digital twins, and intelligent systems. In addition, it is necessary to develop standards and guidelines for the use of the training complex, which must be approved by regulatory authorities in the aviation and military industries. Thus, the development and implementation of such training complexes opens new prospects for the training of

engineering and technical personnel. The inclusion of digital technologies in the process of training specialists will ensure an increase in the level of aviation personnel training, which, in turn, directly affects the safety and reliability of the operation of aviation equipment. Further developments in this project are related to the implementation of augmented reality technologies and machine-learning algorithms.

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ИННОВАЦИОННЫЙ УЧЕБНО-ТРЕНИРОВОЧНЫЙ КОМПЛЕКС С ИНЖЕНЕРНЫМ ОБЕСПЕЧЕНИЕМ: НОВЫЙ УРОВЕНЬ ТЕХНИЧЕСКОЙ ЭКСПЛУАТАЦИИ АВИАЦИИ

Аннотация. *Это исследование посвящено созданию нового учебного комплекса, который включает в себя систему инженерного обеспечения, специально разработанную для технического управления военной и специализированной авиационной техникой. Важность данного исследования обусловлена необходимостью повышения эффективности подготовки инженерно-технического персонала, учитывая растущую техническую сложность авиационной техники и растущие требования к авиационной безопасности. Основной целью данного исследования является разработка адаптивной образовательной платформы, которая объединяет цифровые аналоги авиационных систем, алгоритмы диагностики неисправностей и интеллектуальные методы для адаптации учебного процесса. В рамках этого исследования была разработана архитектура комплексной системы инженерной поддержки, которая включает сбор данных, цифровое моделирование и аналитику. Был внедрен адаптивный алгоритм обучения, который учитывает уровень квалификации обучаемого, его опыт и прогресс в освоении материала, тем самым автоматически корректируя учебную программу. Использование виртуальных тренажеров и имитационных моделей позволило разработать гибкую систему обучения, которая точно отражает реальные условия эксплуатации авиационной техники. Для оценки эффективности предложенной системы было проведено экспериментальное тестирование, в ходе которого сравнивались результаты обучения двух групп инженерно-технического персонала: экспериментальной группы (с использованием адаптивного обучения с использованием цифровых моделей) и контрольной группы (с использованием традиционных методов обучения). Результаты показали, что новый учебный комплекс сократил время реагирования на чрезвычайные ситуации на 22%, снизил количество ошибок на 30% и повысил точность выполнения процедур на 18%. Разработанная адаптивная система обучения отличается высокой гибкостью и позволяет адаптировать ее к современным методам прогнозной диагностики неисправностей воздушных судов. Внедрение такого комплекса в подготовку специалистов повысит авиационную безопасность, надежность и экономическую эффективность технической эксплуатации воздушных судов.*

Ключевые слова: *авиационное оборудование, инженерное обеспечение, цифровые двойники, адаптивное обучение, тренировочный комплекс, диагностика неисправностей.*

ИНЖЕНЕРЛІК ҚАМТАМАСЫЗ ЕТІЛГЕН ИННОВАЦИЯЛЫҚ ОҚУ КЕШЕНІ: АВИАЦИЯНЫ ТЕХНИКАЛЫҚ ПАЙДАЛАНУДЫҢ ЖАҢА ДЕҢГЕЙІ

Андатпа. *Бұл зерттеу әскери және мамандандырылған авиациялық техниканы техникалық басқару үшін арнайы әзірленген инженерлік қолдау жүйесін қамтитын жаңа оқу кешенін құруды зерттейді. Бұл зерттеудің маңыздылығы авиациялық техниканың техникалық күрделілігінің артуын және авиациялық қауіпсіздікке қойылатын талаптардың артуын ескере отырып, инженерлік-техникалық кадрларды даярлаудың тиімділігін арттыру қажеттілігінен туындайды. Бұл зерттеудің негізгі мақсаты-авиациялық жүйелердің цифрлық егіздерін, ақауларды диагностикалау алгоритмдерін және оқу процесін бейімдеудің интеллектуалды әдістерін біріктіретін адаптивті білім беру платформасын әзірлеу. Осы зерттеу аясында деректерді жинауды, цифрлық модельдеуді және аналитиканы қамтитын кешенді инженерлік қолдау жүйесінің архитектурасы әзірленді. Тыңдаушының біліктілік деңгейін, тәжірибесін және материалды меңгерудегі үлгерімін ескеретін, сол арқылы оқу жоспарын автоматты*

түрде реттейтін бейімделетін оқыту алгоритмі енгізілді. Виртуалды тренажерлар мен модельдеу модельдерін қолдану авиациялық техниканың нақты жұмыс жағдайларын дәл көрсететін икемді оқыту жүйесін жасауға мүмкіндік берді. Ұсынылған жүйенің тиімділігін бағалау үшін инженерлік-техникалық персоналдың екі тобының оқу нәтижелерін салыстыра отырып, эксперименттік тестілеу жүргізілді: эксперименттік топ (цифрлық модельдермен адаптивті оқытуды қолдана отырып) және бақылау тобы (дәстүрлі оқыту әдістерін қолдана отырып).). Нәтижелер көрсеткендей, жаңа оқу кешені төтенше жағдайларды жою уақытын 22% - ға қысқартты, қателер санын 30% - ға азайтты және процедураларды орындау дәлдігін 18% - ға жақсартты. Әзірленген адаптивті оқыту жүйесі жоғары икемділікке ие, бұл әуе кемелерінің ақауларын диагностикалаудың заманауи болжамды әдістерімен теңшеуге және біріктіруге мүмкіндік береді. Мамандарды даярлауда мұндай кешенді енгізу авиациялық қауіпсіздікті, сенімділікті және әуе кемелерінің техникалық операцияларының экономикалық тиімділігін арттырады.

Түйінді сөздер: *авиациялық техника, инженерлік қамтамасыз ету, цифрлық егіздер, адаптивті оқыту, оқу кешені, ақауларды диагностикалау.*

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