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Implementation of Innovative Learning Technologies in the Training of Aviation Engineering Specialists: Experience and Prospect

Abstract: The modern modernization of the global aviation industry and the active implementation of Industry 4.0 concepts require a fundamental rethinking of engineer training methods in accordance with stringent international standards. The object of the study is the process of professional training of highly qualified specialists in aviation engineering in higher education institutions under conditions of intensive digitalization and production automation. The purpose of the work is the scientific substantiation and evaluation of the practical effectiveness of an integrated system for implementing innovative and digital learning technologies. To achieve this goal, a number of tasks were solved regarding the analysis of UAV design digitalization, the integration of advanced non-destructive testing methods and repair engineering into the educational process, as well as the design and approbation of objective assessment and feedback systems. The paper utilizes a complex of research methods: systematic analysis of standards and publications, parametric 3D modeling, finite element analysis (FEA) of the stress-strain state of structures, the method of analyzing real production cases, physical modeling of defectoscopy processes on laboratory test benches, and MCQ testing with subsequent statistical processing of the results. The theoretical framework of the study is based on the fundamental works of domestic and foreign scientists in the fields of innovative technical pedagogy, computer-aided design, and aviation diagnostics. The results of the study demonstrated that the use of modern computer modeling tools significantly develops spatial engineering thinking and allows for the topological optimization of UAV structures at early stages. The systematic integration of real operational defects into diagnostic and repair courses forms the professional responsibility of future engineers for ensuring flight safety. The implementation of automated MCQ testing based on LMS Google Classroom and anonymous feedback via Google Forms ensures high adaptability and flexibility of the educational process, while the proposed models of close partnership between universities and specialized enterprises open up effective ways to solve the problem of updating the material and technical base of universities.

Keywords: aviation engineering, 3D modeling, non-destructive testing, repair engineering, UAV, innovative learning technologies, digitalization of education.

Abbreviations:

AT is Aviation Technology

CAD is Computer-Aided Design

CAE is Computer-Aided Engineering

EASA is European Union Aviation Safety Agency

FAA is Federal Aviation Administration

FDM is Fused Deposition Modeling

FEA is Finite Element Analysis

HEI is Higher Education Institution

LMS is Learning Management System

MCQ is Multiple Choice Questions

NDT is Non-Destructive Testing

SLA is Stereolithography

UAV is Unmanned Aerial Vehicle

Introduction

The modern stage of development of the global aviation industry is characterised by a rapid change in technological paradigms, large-scale automation of production processes, the expansion of unmanned aerial vehicle technologies, the increasing use of composite materials and additive manufacturing, and the continuous strengthening of international aviation safety standards. These transformations create an urgent need for the fundamental modernisation of higher engineering education. Traditional pedagogical approaches oriented mainly towards the passive assimilation of theoretical material are no longer capable of fully providing the aviation industry with highly qualified specialists who can work effectively in a digital, automated and safety-critical professional environment.

The relevance of this study is determined by the growing discrepancy between the technological complexity of contemporary aviation engineering and the inertia of conventional educational models in higher education institutions. The contemporary labour market requires a new generation of specialists who are able not only to reproduce theoretical knowledge, but also to design complex unmanned aerial vehicle systems, use integrated CAD/CAE environments, perform finite element analysis, understand the principles of digital manufacturing, apply advanced non-destructive testing methods, and make justified repair engineering decisions in accordance with stringent international standards, including the requirements of EASA and FAA. In this context, the integration of Industry 4.0 concepts into aviation engineering education becomes not an optional pedagogical innovation, but a necessary condition for ensuring the professional readiness of future engineers.

The research problem lies in the insufficient correspondence between the content, methods and technological infrastructure of traditional aviation engineering education and the actual requirements of modern aircraft design, production, diagnostics and maintenance. Classical models

of teaching often separate theoretical calculations from real engineering practice, two-dimensional drawing from parametric design, classroom study from industrial cases, and final assessment from continuous competence monitoring. As a result, graduates may possess formal academic knowledge but remain insufficiently prepared for multidisciplinary engineering tasks involving UAV design, composite structure diagnostics, repair documentation, airworthiness requirements and digital decision-making tools. This problem is intensified by the rapid moral obsolescence of university material and technical facilities, especially in the fields of CAD/CAE systems, non-destructive testing equipment and additive manufacturing technologies.

The hypothesis of the study is that the systematic implementation of an integrated model of innovative and digital learning technologies in aviation engineering education can significantly improve the quality of professional training. It is assumed that the combined use of parametric 3D modelling, CAD/CAE-based structural analysis, finite element simulation, real industrial case studies, laboratory non-destructive testing, LMS-supported MCQ assessment and anonymous digital feedback forms a more effective educational environment than traditional lecture-based instruction. Such an environment is expected to develop spatial engineering thinking, practical diagnostic skills, repair engineering judgement, professional responsibility for flight safety and the ability to adapt to the technological challenges of Industry 4.0.

The scientific novelty of the study consists in the substantiation of an integrated educational model that combines several complementary directions of innovative aviation engineering training within a single methodological framework. Unlike approaches that consider digital design, non-destructive testing, repair engineering, assessment automation or university-industry cooperation separately, this study treats them as interconnected components of one competence-oriented system. The novelty also lies in demonstrating how CAD/CAE modelling of UAV structures, practical defectoscopy cases, digital assessment tools and feedback mechanisms may jointly support the formation of professional competences required by modern aviation engineering practice.

The object of the study is the process of professional training of future aviation engineering specialists in higher education institutions under conditions of intensive digitalisation of the academic space and the integration of Industry 4.0 concepts.

The subject of the study is the implementation of innovative and digital learning technologies in aviation engineering education, including CAD/CAE-based modelling, finite element analysis, practical non-destructive testing, repair engineering case studies, LMS-supported objective assessment and digital feedback systems.

The aim of the research is to provide scientific substantiation, develop and evaluate the practical effectiveness of an integrated model for implementing innovative technologies of design,

computer modelling, technical diagnostics, repair engineering and digital assessment into the educational process of technical universities training aviation engineering specialists.

To achieve this aim, the following research tasks are set:

- to analyse the current challenges of aviation engineering education under conditions of digitalisation, production automation and Industry 4.0 transformation;
- to examine the possibilities of using advanced integrated CAD/CAE systems in modelling and optimising UAV structures;
- to determine the pedagogical potential of parametric 3D modelling and finite element analysis for developing spatial engineering thinking and design competence;
- to develop and approve a methodology for integrating practical non-destructive testing cases into lecture and laboratory courses;
- to evaluate the educational effectiveness of using real industrial defect and repair cases in the formation of diagnostic and repair engineering skills;
- to substantiate the role of objective MCQ testing and LMS-supported assessment in continuous monitoring of student knowledge;
- to analyse the potential of anonymous digital feedback for adapting the educational process to students' actual learning difficulties;
- to identify the prospects of university-industry cooperation and dual education mechanisms for overcoming the material and technical limitations of higher education institutions;
- to determine the theoretical and practical contribution of the proposed integrated model to the modernisation of aviation engineering training.

The methodological basis of the study includes systematic analysis of educational standards and scientific publications, comparative pedagogical analysis, computer three-dimensional modelling, parametric CAD design, finite element analysis of the stress-strain state of aviation structures, analysis of real industrial and diagnostic cases, physical modelling of defectoscopy processes on laboratory test benches, MCQ testing, sociological surveying of higher education students and mathematical-statistical processing of empirical results. The theoretical framework of the study is based on the works of researchers in innovative technical education, computer-aided design, aviation safety, non-destructive testing, repair engineering, dual education and active learning strategies (*Brown, 2019; Green, 2021; Ivanov, 2021; Kovalenko, 2020; Moroz, 2023; Pavlenko, 2022; Shevchenko, 2023; Tkachenko, 2023*).

The theoretical significance of the study lies in deepening the understanding of innovative aviation engineering education as an integrated competence-forming system. The study contributes to the development of scientific approaches to technical pedagogy by showing that professional competences in aviation engineering are formed most effectively when digital modelling, engineering analysis, diagnostic practice, repair decision-making, assessment transparency and industrial cooperation are combined within one educational logic. It also clarifies the role of active learning, digital twins, case-based instruction and continuous feedback in preparing students for complex safety-critical engineering tasks.

The practical significance of the results lies in the possibility of applying the proposed educational model in aviation departments, technical universities, specialised training centres and professional development programmes for engineering and technical personnel. The developed

approaches may be used by teachers of aviation engineering disciplines, guarantors and heads of educational programmes, methodologists of technical higher education institutions, and instructors of aviation enterprises. The integration of CAD/CAE tools, NDT laboratory practice, repair engineering cases, LMS-based assessment and anonymous feedback can make the educational process more practice-oriented, adaptive, transparent and aligned with real industry needs. In addition, the proposed model of cooperation between higher education institutions and specialised enterprises may help overcome the problem of outdated university equipment and provide students with access to modern industrial technologies.

Thus, the present study addresses one of the key challenges of modern aviation engineering education: how to train specialists who are capable of designing, analysing, diagnosing, repairing and maintaining aviation technology in accordance with the requirements of digital production and international aviation safety. The proposed integrated model of innovative learning technologies provides a methodological basis for transforming traditional engineering education into a more flexible, practice-oriented and industry-relevant system capable of preparing competitive aviation engineering specialists for the conditions of Industry 4.0.

Methods

This study employs a comprehensive mix of general scientific methods traditionally utilized in engineering education and applied systems analysis. Analytical methods were used to examine existing international educational standards (EASA/FAA) and to formulate the problem of aligning academic curricula with real-world industry requirements within the Industry 4.0 paradigm. Comparative pedagogical analysis was applied to contrast traditional lecture-based learning models with active "learning-by-doing" approaches, allowing for a systematic investigation of student motivation, knowledge retention, and practical skill acquisition.

Numerical modeling and CAD design served as primary tools for validating the proposed educational method within design and engineering courses. Parametric 3D modeling was applied within SolidWorks and Siemens NX environments using rigorous constraints to ensure the reliable reproduction of complex aviation components and UAV assemblies. The finite element method (FEA/CAE) was subsequently used to calculate the stress-strain state of student-designed structures, enabling an objective evaluation of structural optimization, weight reduction, and load-bearing capacity without the immediate need for costly physical testing.

Among the specialized methods, case studies based on real industrial reports were used to bridge the gap between theoretical aircraft design and real-world diagnostics or repair engineering. This method allowed for the systematic extraction of failure modes, fatigue cracks, and composite delaminations from depersonalized aircraft accident investigation materials, offering students realistic engineering challenges under simulated conditions. Experimental non-destructive testing (NDT) methods were applied on physical laboratory test benches to evaluate the accuracy of defect detection. Specifically, ultrasonic thickness measurement and eddy current testing methods were used to locate artificially induced damage in aerospace alloys and composite materials.

Additionally, empirical evaluation and statistical analysis methods specific to modern educational systems were applied. Standardized multiple-choice questioning (MCQ) testing was implemented using the Google Forms platform integrated into the Google Classroom LMS for continuous objective knowledge monitoring, utilizing statistical metrics to ensure test reliability and

item discriminative power. Qualitative survey and feedback methods via Google Forms were subsequently used to gather student insights regarding the implemented digital learning tools. Finally, the triangulation of qualitative and quantitative data ensured that the proposed pedagogical model aligns with both theoretical academic criteria and practical industrial competencies.

Literature Review

The vast majority of modern educational methods in the field of aviation engineering involve the integration of three fundamental directions: mastering computer modeling, studying failure physics, and implementing systems for objective knowledge quality assessment (*Ivanov, 2021; Kovalenko, 2020*). The works of Ivanov (2021) present a detailed analysis of global trends in the modernization of technical education, emphasizing the need to transition from passive learning to interactive forms, which serves to substantiate the general methodological concept of this study. The use of analytical models requires a number of assumptions; in particular, the geometric parameters of modeled objects are frequently simplified. Furthermore, the non-linear properties of aviation materials are often ignored, while development delays and interpolation errors remain unaddressed. Due to these limitations, significant design errors arise, making classical student training sub-optimal for modern production environments. The consequence of such a simplified approach is a gap between theoretical calculations and the actual aerodynamic characteristics of the product, which leads to deformation or even destruction of structural elements in promising aviation systems as early as the flight-testing stage.

Another approach to shaping the professional worldview of future specialists involves a detailed study of structural behavior under critical conditions. This direction is highly demanded for aviation safety disciplines (*Brown, 2019; Savchenko, 2022*) and relies on the analysis of real damage and defects in aircraft. The advantage of this method lies in the ability to investigate the operating conditions of components of any complexity level and the clarity of its implementation. Some academic sources argue that working with real failure cases during classroom hours distracts from basic theoretical training. However, when the analysis of production situations is properly structured during experiments, this mode becomes fully balanced and safe for developing critical thinking (*Morož, 2023; Petrov, 2022*). The work of Petrov (2022) describes the application of ultrasonic and capillary testing in education, which served as the direct reason for including this source to justify the choice of laboratory diagnostic methods. The practical mastery of NDT helps students transition from the abstract observation of graphs to understanding the physics of ultrasonic wave propagation in the heterogeneous environment of composite materials, enabling the preventive detection of dangerous microcracks.

Today, there is also a wide spectrum of commercial software products for 3D modeling and engineering analysis (*Taylor, 2020*). A typical educational CAD laboratory consists of computers running general-purpose operating systems with expensive licensed software installed. The designed object is integrated into a virtual development cycle, the system is tested for strength using a selected numerical method, and the obtained geometric characteristics are subsequently transferred to production equipment (*Davis, 2020; Johnson, 2021*). Due to user-friendly interfaces, significant computing power, and the absence of limitations on load identification algorithms, students have the opportunity to obtain design parameters that are as close to optimal as possible. The use of digital twin technology opens up new horizons for researching the service life of parts

under various cyclic loads, which significantly reduces the time from concept development to material embodiment via additive manufacturing.

In addition to the works mentioned directly above, several fundamental studies cited in the references provide an important theoretical and practical foundation for this research. The work of Shevchenko (2023) offers a comprehensive analysis of innovative pedagogical strategies for technical disciplines, which allowed for the theoretical substantiation of the choice of active teaching methods at the Department of Aviation Engineering. Research by Green (2021) focuses on the practical aspects of active learning in engineering disciplines, demonstrating the positive impact of an interactive environment on the retention of complex material, which led to its inclusion in the literature review as a methodological guide. The implementation of project-oriented learning involves students in teamwork on complex tasks where everyone is responsible for a separate subsystem of an aviation structure, simulating the real framework of a design bureau.

The analysis of dual education systems outlined in the work of Pavlenko (2022) highlights the importance of cooperation between universities and business to overcome the depreciation of the material and technical base of HEIs. This work provides scientific confirmation of the effectiveness of utilizing certified laboratory facilities of enterprises for conducting classes. The work of Roberts (2021) describes in detail the aerodynamics and design of light UAVs, which allowed for the adaptation of 3D modeling tasks for students in accordance with current trends in aircraft manufacturing. This is important since the market for unmanned systems develops much faster than state standards of higher education are updated.

The study by Smith (2022) provides a structured overview of the evolution of unmanned systems manufacturing technologies, systematizing both classical and state-of-the-art production cycles. The author shows that the practical efficiency of aviation technology operation continues to largely depend on the quality of personnel training and the mastery of rapid prototyping skills. For this study, this review is particularly important because it clearly identifies typical practical limitations of UAV operations, justifying the choice of corresponding educational modules in the curriculum. The work of Tkachenko (2023) serves as a methodological guide for constructing the discussion section, allowing for a systematic comparison between the proposed dual approaches and existing global models for integrating the academic and industrial sectors. Such integration helps eliminate the shortage of practical knowledge and enables educational institutions to involve leading industry practitioners in the co-supervision of students' graduation projects.

Results

The practical implementation of the educational process in the discipline "Fundamentals of 3D Modeling of Aviation Technology" has demonstrated the high efficiency of abandoning traditional two-dimensional drawings in favour of end-to-end parametric design. Students of the department are involved in the sequential execution of individual projects that start with the creation of conceptual sketches and progress to the construction of complex three-dimensional assemblies within SolidWorks, Siemens NX, and nTop environments. During group classes, future engineers develop critically important structural assemblies of UAVs, including fuselage frames, wing ribs, and spars of complex spatial shapes. The use of parameterization allows for the automatic updating of all connected part dimensions when changing basic geometric parameters or aircraft airframe dimensions (Johnson, 2021). Students actively apply advanced surface and hybrid

modeling tools to construct aerodynamically clean fuselage fairings and profiled propeller blades, which requires a deep understanding of surface continuity by G2 class curvature.

The created models are integrated into built-in CAE modules for the analysis of the stress-strain state under the action of calculated aerodynamic and mass loads. Students independently configure boundary conditions: they assign constraints to motors, determine distributed thrust and lift forces, and perform discretization of the model using the finite element method (FEA), which requires adaptive mesh refinement in stress concentration zones. The analysis of the distribution of equivalent von Mises stresses and safety factors allows for an objective evaluation of structural reliability and the execution of its topological optimization—removing excess material in un-loaded zones by creating lightening cutouts and locally reinforcing weak sections by adding optimized stiffening ribs (*Taylor, 2020*). A separate stage of education is the preparation of designed parts for manufacturing on 3D printers, taking into account the anisotropy of material properties during the layer-by-layer deposition of plastics (FDM) and photopolymers (SLA). Students independently configure model slicing parameters: they choose the density and structure of the internal infill (honeycombs, gyroids), determine the orientation angles of the parts on the build platform to minimize the use of support structures, and account for the thermal shrinkage of polymers. Mastering the creation of such “digital twins” (*Davis, 2020*), higher education students learn to see a direct relationship between theoretical mechanics of materials, strength of materials, structural mechanics of aircraft, and the practical realization of a design idea in a physical product.

Thus, the implementation of CAD/CAE tools in the educational process reorients the training of aviation specialists from the passive copying of drawings to active engineering design. The cloud-based environment allows students to experiment with shapes, lightweight materials, and UAV assembly schemes, instantly evaluating decisions through numerical modeling without the expense of physical testing. This eliminates the psychological barrier to error, forms dynamic design thinking, and prepares graduates for the challenges of digital aviation manufacturing of the Industry 4.0 class.

The specific feature of teaching the disciplines “Methods of Non-Destructive Testing of Aircraft Parts during Production and Repair” and “Fundamentals of Repair Engineering” is the shift from the abstract study of theoretical regulations toward the interactive analysis of real aviation defects (case-study). The educational process integrates materials from the actual defectoscopic practice of leading aviation enterprises, containing information on the occurrence of fatigue cracks in skin elements, corrosion degradation, and damage to the wing flap actuation assemblies of the Antonov series aircraft (*Savchenko, 2022*).

During laboratory sessions, students perform the full cycle of technical diagnostics on specially prepared full-scale specimens with pre-applied hidden defects of various types. Working with industrial ultrasonic thickness gauges and flaw detectors, students independently configure instrument sensitivity using standard calibration blocks V1 and V2, calibrate the time base, select optimal wave entry angles, and perform manual scanning of welded and bonded joint zones, interpreting the received echo signals (A-scans) on the instrument screen.

In parallel, eddy current probes are used to localize surface cracks in bolted joint zones, and high-sensitivity capillary (dye penetrant) testing is applied to detect defects on complex skin elements, which students perform step-by-step: from thorough surface preparation to the application of penetrant and developer (*Petrov, 2022*). Based on the detected defects, students

develop individual repair schemes and process sheets. They calculate rivet pitch and diameter, determine edge distances for installing reinforcing patches (doublers), justify repair sheet thickness taking into account fatigue strength and stress concentration, and select types of epoxy adhesive compositions and carbon fiber layup sequences to eliminate delaminations in composite UAV panels after hard operational landings (*Morož, 2023*). This approach teaches students to independently evaluate the criticality of each specific defect using structural repair manuals and permissible damage charts, and to make qualified decisions regarding the possibility of further safe operation of the aircraft in accordance with airworthiness regulations.

Thus, the systematic integration of industrial case analysis and practical work with operating defectoscopic equipment ensures the applied nature of personnel training at the Department of Aviation Engineering. Students successfully complete a full professional cycle—from the physical detection of a hidden fatigue microcrack or composite delamination using ultrasound to designing a repair patch, calculating its strength, and processing technological documentation. This not only forms stable skills in high-precision diagnostics and aircraft reliability, but also fosters a deep understanding of the professional responsibility of an aviation engineer for preserving human life, instilling the habit of uncompromisingly ensuring flight safety at every stage of the technical lifecycle.

The transformation of education in complex engineering fields requires a transition to systems of continuous and transparent monitoring of student performance. Within the framework of this research, classic forms of term evaluation in aviation technology manufacturing and repair disciplines were successfully integrated into a cloud-based virtual learning environment based on the Google Classroom LMS. The ongoing knowledge assessment was implemented using a step-by-step MCQ testing framework based on Google Forms, which allows for the automatic import of evaluation results directly into the course gradebook (*Wilson, 2019*). The effective interaction of cloud services allows for weekly short knowledge checks (express surveys), integrating them directly into the class schedule and creating a culture of continuous engagement without a significant increase in the psychological load on students. The created bank of test items was structured by difficulty levels, where each block of questions requires not just mechanical reproduction of terminology, but the solution of a specific applied problem: from determining the optimal non-destructive testing method for a multi-layered composite panel to calculating heat treatment parameters for structural alloys and determining optimal quenching temperatures for duralumin, taking into account subsequent natural aging. When solving test items, students are involved in quick calculations, for example, calculating the relative error of ultrasonic aircraft skin thickness measurement at different transducer vibration frequencies.

A systematic analysis of testing results in Google Forms, including automatically generated analytical summaries and histograms of correct answer distributions, allowed the instructor to promptly optimize the test database by identifying oversimplified or incorrectly formulated questions. The use of an integrated Google Sheets results table simplifies the calculation of classic testometric indicators: the item difficulty index and item discriminative power, enabling continuous calibration of tests. Furthermore, at the end of each content module within the Google Classroom environment, links to anonymous surveys in Google Forms were published to gather student feedback. Students anonymously evaluated the complexity of the lecture material, the utility of laboratory works, and independently highlighted topics that caused the greatest difficulties (such

as the interpretation of ultrasonic signals or the design of repair patches). The cloud-based analysis of the received feedback allows the instructor to identify the so-called “bottlenecks” in course comprehension in a timely manner and to dynamically introduce changes into the next week's lecture plan, expanding or duplicating complex topics. The availability of the Google Classroom mobile application allowed students to receive instant notifications about new assignments and complete testing at a convenient time directly from portable devices, which significantly accelerated test completion time and minimized the risks of delayed task execution. The obtained survey data were mathematically summarized by the cloud service in real time, allowing the instructor to immediately make adjustments to the structure of subsequent classes.

Thus, the comprehensive digitalization of assessment based on the cloud environment of the Google Classroom LMS and Google Forms allows for the construction of a highly adaptive, flexible, and student-centered model of aviation engineer training. Continuous performance monitoring combined with instant feedback eliminates subjectivity in evaluation due to automated cloud-based answer verification, which noticeably reduces students' academic stress levels through absolute transparency of criteria. At the same time, detailed analytics provide the instructor with clear, well-founded indicators for the immediate optimization of methodological support for complex technical disciplines and flexible reorientation of instructional time in favour of topics requiring additional review.

Discussion

The findings of this study confirm that the training of aviation engineering specialists can no longer be effectively organised within the limits of traditional lecture-centred instruction alone. The aviation industry is undergoing a rapid transition towards digital manufacturing, unmanned systems, data-driven diagnostics, additive production, and stricter international safety requirements. Under these conditions, the professional competence of an aviation engineer should be formed not only through the acquisition of theoretical knowledge, but also through continuous involvement in design, simulation, diagnostics, repair decision-making, and objective assessment. The integrated educational model analysed in this study demonstrates that innovative learning technologies can serve as a practical mechanism for reducing the gap between academic training and real industrial expectations.

One of the central results of the study is the pedagogical value of integrating CAD/CAE tools into the training of aviation engineering students. The transition from two-dimensional drawing to end-to-end parametric three-dimensional modelling changes the nature of engineering education. Students are not limited to reproducing standard graphical solutions; instead, they become involved in the full cycle of digital design, from conceptual geometry to finite element analysis and preparation for additive manufacturing. This approach is consistent with the broader trend towards active and project-oriented learning in engineering education, where knowledge is acquired through solving complex technical tasks rather than through passive memorisation of theoretical content (*Ivanov, 2021; Green, 2021*).

The use of CAD/CAE environments is especially important in UAV-related training because unmanned aerial systems require the integration of aerodynamics, structural mechanics, materials science, electronics, and manufacturing technologies. Parametric modelling allows students to understand how changes in geometry affect mass, stiffness, strength, manufacturability and

aerodynamic form. Finite element analysis further strengthens this connection by demonstrating the physical consequences of design decisions. When students observe stress concentration zones, safety factors and deformation fields, theoretical courses in mechanics of materials and aircraft structural mechanics acquire applied meaning. This contributes to the development of spatial engineering thinking and supports the formation of design responsibility at an early stage of training.

The results also show that numerical simulation has a strong didactic function. In a conventional educational model, students often encounter a separation between theoretical calculations and the physical behaviour of aircraft structures. By contrast, CAD/CAE-based learning provides an opportunity to test design hypotheses in a virtual environment before moving to physical prototyping. This reduces the psychological barrier to experimentation and encourages students to compare alternative engineering solutions. At the same time, virtual modelling should not be interpreted as a complete substitute for physical testing. It is most effective when used as part of a broader educational system that combines simulation, laboratory verification and analysis of real operational cases.

Another important outcome is the effectiveness of integrating real industrial cases into the study of non-destructive testing and repair engineering. Aviation safety depends not only on the ability to design aircraft structures, but also on the ability to identify hidden defects, interpret diagnostic signals and make justified decisions regarding further operation or repair. The use of depersonalised materials from real defectoscopic practice creates a learning environment in which students face realistic engineering uncertainty. They must not only apply theoretical knowledge, but also evaluate defect criticality, select diagnostic methods, design repair schemes and prepare technological documentation. This approach supports the formation of professional judgement, which is one of the most difficult competences to develop in purely theoretical instruction.

The inclusion of ultrasonic, eddy-current and capillary testing methods in laboratory work is particularly significant for aviation engineering education. These methods allow students to move from abstract descriptions of damage mechanisms to direct interaction with diagnostic equipment and physical specimens. The interpretation of echo signals, calibration of measuring devices, detection of surface cracks and evaluation of composite delamination create a direct link between materials science, aircraft maintenance and flight safety. This is consistent with studies emphasising the importance of practical non-destructive testing in the professional preparation of aviation specialists (*Petrov, 2022; Savchenko, 2022*).

The results indicate that the case-study approach in repair engineering also has an important ethical and professional dimension. Aviation engineering decisions are safety-critical: an error in detecting a defect, calculating a repair patch or interpreting permissible damage may have serious operational consequences. Therefore, the educational process must form not only technical skills, but also a stable understanding of professional responsibility. By working with realistic defect scenarios, students learn to perceive aircraft maintenance as a complex engineering process where each diagnostic and repair decision contributes to the preservation of airworthiness and human life. This is one of the strongest advantages of integrating industrial cases into the curriculum.

The digitalisation of assessment through Google Classroom and Google Forms represents another relevant result of the study. Continuous MCQ testing integrated into an LMS environment makes assessment more systematic, transparent and manageable. In complex technical disciplines,

delayed assessment often prevents the instructor from identifying learning difficulties in time. By contrast, weekly or modular digital testing provides rapid information about students' understanding of key concepts and allows the instructor to adjust the teaching strategy. The use of automated scoring and test analytics reduces subjectivity and increases the transparency of evaluation criteria, which is important for maintaining student trust in the assessment process.

However, the effectiveness of MCQ testing depends on the quality of test design. In aviation engineering education, multiple-choice questions should not be limited to terminology reproduction. The study demonstrates the importance of applied test items that require interpretation, quick calculation, diagnostic reasoning or selection of an appropriate technical solution. In this form, MCQ testing becomes not merely an administrative assessment instrument, but also a pedagogical tool for consolidating engineering thinking. The use of item difficulty and discriminative power indicators further supports the reliability of the testing system and enables continuous improvement of the question bank (*Wilson, 2019*).

Anonymous feedback through Google Forms also strengthens the adaptability of the educational process. In technical disciplines, students may not always openly indicate difficulties during class, especially when the material concerns complex topics such as ultrasonic signal interpretation, finite element modelling or repair documentation. Anonymous feedback allows instructors to identify conceptual "bottlenecks" and adapt lectures and laboratory sessions to actual learning needs. This supports a student-centred educational model while preserving academic rigour and professional standards. At the same time, feedback should be interpreted carefully: student perceptions are valuable for course improvement, but they should be combined with objective performance data and expert evaluation of achieved competences.

The study also raises a strategically important issue: the material and technical base of higher education institutions often develops more slowly than aviation technologies themselves. Industrial CAD/CAE systems, NDT equipment, additive manufacturing devices and digital diagnostic technologies are expensive and require regular updating. This creates a structural gap between university resources and industry standards. The problem is particularly acute in aviation engineering, where outdated equipment may limit students' access to the tools and procedures used in real production and maintenance environments. Therefore, the sustainability of innovative engineering education depends not only on internal pedagogical reform, but also on external institutional cooperation.

In this context, university-industry partnership appears to be one of the most promising solutions. The dual education model allows theoretical and methodological training to remain within the university, while advanced practical sessions can be organised at certified laboratories and specialised enterprises. Such cooperation may provide students with access to modern diagnostic equipment, real production cases and industry mentors without requiring universities to independently maintain the full range of expensive technological infrastructure. This corresponds to the concept of dual education discussed in previous studies and reflects the need to integrate academic and industrial environments in technical training (*Pavlenko, 2022; Tkachenko, 2023*).

The proposed model also has implications for curriculum design. Aviation engineering programmes should be structured as integrated competence systems rather than as isolated disciplinary blocks. CAD/CAE modelling, UAV design, non-destructive testing, repair engineering, additive manufacturing, LMS-supported assessment and industrial internships should

reinforce one another. Such integration is essential because real aviation engineering practice does not separate design from manufacturing, diagnostics, maintenance and safety regulation. A graduate who understands only one segment of the aircraft lifecycle may be insufficiently prepared for the multidisciplinary nature of modern aviation technology.

The results support the conclusion that the development of innovative learning technologies should be understood as a systemic transformation rather than as the isolated introduction of individual digital tools. A CAD programme, an LMS platform or an MCQ test bank cannot independently modernise aviation engineering education. Their effectiveness emerges only when they are incorporated into a coherent pedagogical model based on active learning, real engineering cases, competence-based assessment and industry cooperation. The value of the proposed approach therefore lies in its integrative character: it connects digital design, diagnostic practice, repair decision-making and adaptive feedback within one educational logic.

From a theoretical perspective, the study contributes to the development of innovative technical pedagogy by demonstrating how digital tools can be aligned with professional engineering competences. It confirms that the use of virtual modelling and automated assessment is most productive when connected with practical tasks and real industrial contexts. From a practical perspective, the study offers a model that may be adapted by aviation departments, technical universities and training centres involved in the preparation or retraining of aviation engineering personnel. It is particularly relevant for educational institutions seeking to modernise curricula under limited financial resources and rapidly changing technological requirements.

Nevertheless, several limitations should be acknowledged. First, the study mainly presents the experience of implementing selected technologies within a specific educational context, which may limit the generalisability of the findings to other institutions, countries or aviation specialisations. Secondly, although the study describes the effectiveness of CAD/CAE modelling, NDT cases and LMS-based assessment, further quantitative evidence is needed to measure long-term learning outcomes, competence retention and graduates' performance in industrial settings. Thirdly, the use of commercial software and cloud platforms may create dependence on licensing conditions, institutional digital infrastructure and students' access to devices and stable internet connectivity. Fourthly, the implementation of dual education requires strong administrative coordination, legal agreements and shared responsibility between universities and enterprises.

Future research should therefore focus on empirical validation of the proposed model across several cohorts and institutions. It would be useful to compare student performance before and after the introduction of integrated CAD/CAE, NDT and LMS-supported modules using standardised competence indicators. Longitudinal studies could examine whether graduates trained through such models adapt faster to industrial workplaces and demonstrate higher readiness for real maintenance, repair and design tasks. Additional research should also evaluate the effectiveness of VR/AR simulators in teaching defectoscopy, aircraft maintenance procedures and cockpit or hangar-based workflows. Such tools may become a cost-effective complement to physical laboratories, especially where access to certified industrial equipment is limited.

Further development of the topic should also include the creation of shared digital repositories of aviation engineering cases. These repositories could contain anonymised defect scenarios, UAV design tasks, repair engineering problems, FEA models, NDT signal examples and assessment templates. If developed jointly by universities and aviation enterprises, such repositories would

support standardisation of practical training and improve the comparability of learning outcomes. They could also accelerate the updating of educational content in response to technological changes in UAV manufacturing, composite materials, additive production and aircraft maintenance.

Overall, the discussion demonstrates that innovative learning technologies are not supplementary elements of aviation engineering education, but necessary instruments for preparing specialists capable of working in the Industry 4.0 environment. The combination of CAD/CAE modelling, real industrial diagnostic cases, non-destructive testing laboratories, LMS-based assessment, anonymous feedback and university-industry cooperation creates a more practice-oriented, adaptive and professionally responsible educational system. Such a system can help higher education institutions overcome the gap between academic training and aviation industry requirements, while ensuring that future engineers are prepared to design, diagnose, repair and operate aviation technologies in accordance with international safety expectations.

Conclusion

Summarizing the results of the conducted analysis, it can be confidently asserted that the implementation of innovative and digital technologies is an un-alternative and most promising path for the systemic development of modern aviation education. The interim results of the study have fully proven the high pedagogical and engineering effectiveness of the proposed approaches at each stage of the comprehensive training of future specialists. In particular, the active use of advanced CAD/CAE systems within the framework of the core discipline of 3D modeling allowed students to transition from static abstract drawing to the design of full-fledged digital twins of complex UAV assemblies. The calculation of stress-strain states (FEA) taught students to see the direct physical consequences of the selected geometry, which significantly reduces the time for design iterations and fosters a culture of designing with consideration for weight limits, rigidity, and the load-bearing capacity of structures.

The integration of a comprehensive analysis of real industrial failure cases in non-destructive testing and repair engineering courses allowed students not only to successfully master the skills of instrumental defectoscopic diagnostics on laboratory test benches but also to develop full-fledged airframe repair process sheets. This directly formed a stable psychological responsibility for the safety of future flights and instilled a basic culture of aviation reliability, where every measurement or calculation error has real critical consequences. Teamwork on defectoscopy cases successfully eliminates dry academicism and brings the learning process closer to the real conditions of operational units of aircraft repair enterprises. In turn, regular MCQ testing based on the Google Classroom LMS and anonymous feedback surveys via Google Forms allowed instructors to promptly evaluate the quality of knowledge retention and flexibly adapt the presentation of complex technical material to the current comprehension level of the audience, making the learning process manageable, individualized, and minimally stressful for higher education students, while ensuring automated collection of objective performance statistics.

The overall result of the study convincingly demonstrates that the future of training competitive specialists in aviation engineering lies in the dimension of deep integration of virtual modeling, interactive augmented reality (VR/AR), widespread use of cloud-based feedback technologies, and dual forms of education. Cooperative work of higher education institutions with the aviation industry and the direct involvement of students in solving real production tasks at

aviation enterprises is the key to overcoming the material and technical gap. Only under the condition of continuous dynamic modernization of discipline content and the development of a sustainable partnership between the academic and industrial sectors can a high quality of training be ensured for the new generation of engineers capable of instantly adapting to the challenges of Industry 4.0 and maintaining a high level of aviation transport safety at the international level.

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Conflict of Interest

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