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Artificial Intelligence in Aviation: New Professionals for New Technologies

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Abstract: Major aviation organizations have highlighted the need to adopt artificial intelligence (AI) to transform operations and improve efficiency and safety. However, the aviation industry requires qualified graduates with relevant AI competencies to meet this demand. This study analyzed aviation engineering bachelor's programs at European universities to determine if they are preparing students for AI integration in aviation by incorporating AI-related topics. The analysis focused on program descriptions and syllabi using semantic annotation. The results showed a limited focus on AI and machine learning competencies, with more emphasis on foundational digital skills. Reasons include the newness of aviation AI, its specialized nature, and implementation challenges. As the industry evolves, dedicated AI programs may emerge. But currently, curricula appear misaligned with stated industry goals for AI adoption. The study provides an analytical methodology and competency framework to help educators address this gap. Producing graduates equipped with AI literacy and collaboration skills will be key to aviation's intelligent future.

Keywords: aviation; artificial intelligence; education; competency gaps; curriculum analysis; semantic analysis

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1. Introduction

The aviation industry is under increasing pressure to adopt artificial intelligence technologies (AI) to improve efficiency, safety, and competitiveness. Major aviation organizations have called for the implementation of AI to transform operations and address challenges.

The rapid advancement and adoption of artificial intelligence technologies are fundamentally transforming the landscape of the aviation industry [1]. From flight planning to aircraft maintenance, AI-driven tools like machine learning, natural language processing, and computer vision are being integrated across nearly every aspect of modern aviation [2]. While AI innovation holds great promise for augmenting human capabilities and enhancing safety and efficiency, it also poses new challenges for aviation education and training. This paradigm shift requires aviation professionals to possess competencies in emerging technologies and their applications in order to be effective in increasingly AI-mediated work environments [3].

This paper discusses the importance of re-evaluating and transforming aviation curricula, teaching methodologies, and learning outcomes to equip the next generation of aviation specialists with the knowledge and skills needed in an AI-driven industry. The integration of aviation and AI encompasses two key dimensions: using AI technologies within aviation systems and using AI in aviation education itself. Thus, developing appropriate AI competencies requires both conceptual knowledge of core AI concepts as well as applied skills in implementing and managing AI tools. Furthermore, aviation professionals must be cognizant of the ethical, legal, and social implications of relying on AI technologies for critical transportation operations and infrastructure.

However, for the aviation sector to successfully integrate AI, there needs to be a sufficient talent pool of graduates with the required skills and knowledge. The research objective of the paper is the analysis of transforming aviation education for an AI-driven future. It is timely and important for two reasons. First, the aviation industry is looking to universities to produce graduates with AI competencies to fill the growing demand for AI skills. Second, for aviation programs to remain relevant and aligned with industry needs, they must evolve to include AI-related content that develops students' capabilities in this critical area.

Through a review of current aviation training frameworks, analysis of industry workforce needs, and examination of best practices in AI education, this paper proposes core focus areas and competencies that aviation curricula need to integrate in order to produce graduates poised to enter an increasingly automated, intelligent aviation ecosystem. The insights from this study aim to provide guidance to aviation education leaders as they adapt their programs to the future of the industry. Equipping students with both specialized domain knowledge and new digital skills will be key to developing the next generation of aviation professionals [4].

The study focuses on aviation engineering bachelor's programs at European universities because Europe has a large aviation industry and a strong higher education system. By analyzing program descriptions and syllabi, the research seeks to determine the extent to which AI-related topics such as machine learning, deep learning, computer vision, and natural language processing are incorporated. The findings will provide insights into how prepared European aviation graduates are for the AI transformation and what competencies are needed for the next generations of aviation professionals (NextGen) for the efficient operation of the next technologies of the aviation industry (NextTech) to produce the AI talents needed for the aviation sector.

2. Related Works

This literature review provides a comprehensive examination of prior research at the intersection of AI and aviation education. It synthesizes key themes, findings, and insights on the growing role of AI in the aviation industry and the resulting impacts on workforce competencies and training programs.

2.1. Artificial Intelligence in the Aviation Industry

Aviation is one of the most technologically advanced industries, which is reflected in the significant interest of researchers in the application of artificial intelligence in the aviation industry.

2.1.1. AI in Air Traffic Management

Air Traffic Management (ATM) faces growing complexity and requires improvements to ensure aviation safety, with computer science, especially AI, playing a pivotal role.

The paper [5] discusses the increasing complexity of air traffic management and the potential role of explainable artificial intelligence in improving the safety and acceptance of AI systems by end users in the aviation industry.

The article [6] proposes using long short-term memory neural networks to analyze aircraft surveillance data to detect conflicts and provide air traffic controllers with improved situational awareness to transform air traffic management into a more automated, efficient, and safer next-generation system.

The study [7] investigates explainable AI techniques to increase transparency and trust in automated air traffic management systems, training machine learning models on aviation and meteorological data to enable real-time risk prediction and generate explanations that air traffic controllers can analyze.

The paper [8] examines requirements like verification, certification, and user acceptance needed to operationally deploy AI techniques in air traffic management, arguing research into explainable AI and verification should advance in parallel and ground-based systems will require certification as automation increases.

The paper [9] examines AI's relevance in the ATM domain, introduces the Descriptive, Predictive, and Prescriptive model for explainable Artificial Intelligence, and emphasizes the need for further research and validation for AI systems' acceptance in ATM.

The methodology for Machine Learning (ML) systems in air traffic control, specifically in a conflict detection tool, is evaluated in [10]. Results revealed that the methodology lacks time-dependent analysis, indicating that for certain systems, standard classification and regression metrics cannot be universally applied due to their variability over time.

The robust data-driven method for Aircraft Trajectory Prediction using a Neural Network based on the Generative Adversarial Network framework is presented in [11]. Enhanced with Blockchain Ledger Technology for secure storage of predictions, the system effectively resists adversarial attacks, as demonstrated by performance evaluations using proposed simulation.

2.1.2. AI in Aviation Safety

A lot of publications are oriented on AI and Machine Learning Applications in Aviation Safety.

The systematic review [2] investigates natural language processing (NLP) applications in aviation safety domains from 2010–2022. The study highlights specific NLP techniques, their performance, current challenges, and potential future advancements for enhancing aviation safety and efficiency.

The paper [12] presents a methodology using natural language processing and machine learning techniques like label spreading and support vector machines to identify and classify human factor categories from aviation incident reports, achieving high predictive performance despite limited labeled data.

Go-arounds in commercial aviation are safety-critical operations that abort landing attempts. The paper [13] uses machine learning and data analytics, specifically the HDBSCAN clustering algorithm, to categorize go-arounds at San Francisco International Airport in 2019, identifying typical and anomalous patterns, with anomalous go-arounds often displaying deviations from standard procedures and higher energy states during the first approach.

The methodology for analyzing text-based aviation safety narratives uses natural language processing and categorizes them using k-means clustering and t-SNE visualization is introduced in [14]. Applied to the Aviation Safety Reporting System, the method uncovers 10 major clusters and 31 sub-clusters, revealing insights not evident from existing labels and enhancing our understanding of aviation safety incidents.

The paper [15] introduces the Safety Analysis of Flight Events (SAFE) methodology, a machine learning approach to better understand risk factors during flight by synthesizing data cleaning, correlation, supervised learning, and visualization. Demonstrated on commercial airline data, SAFE successfully identifies critical parameters for specific safety events and highlights the importance of aligning machine learning outputs with human conceptualization of incidents.

The study [16] outlines a methodology using learning methods and predictive modeling to identify failure by human factors in the aviation industry. Achieving promising predictive results, the research suggests the potential of the approach but emphasizes the need for larger datasets in future investigations.

The research [17] assesses the use of generative language models, notably ChatGPT, to enhance aviation safety analysis by generating incident summaries and identifying human factors from the Aviation Safety Reporting System dataset. The study recommends a human-in-the-loop system to responsibly leverage these models in aviation safety, emphasizing collaboration and continuous improvement.

2.1.3. AI in Aviation Maintenance

Maintenance is one of the most sought-after areas of application of artificial intelligence and, at the same time, the widest area for its applications.

The study [18] explores the use of Convolutional Neural Networks in conjunction with autonomous drones for automating aircraft maintenance visual inspections. Building on previous work, the paper introduces techniques to improve defect detection performance, achieving higher accuracy rates in identifying issues like dents by focusing on specific image augmentations and pre-classification.

The novel machine learning and IoT-based approach to predict the thermal performance of aircraft wing anti-icing systems is proposed in [19]. When tested, this approach using an artificial neural network proved more efficient and time-saving than traditional computational fluid dynamics methods, suggesting its potential application in aviation.

The paper [20] surveys the use of statistical and machine learning methods to enable a more efficient, accurate, and data-driven analysis of aircraft environmental impacts like fuel burn, emissions, and noise, summarizing key research themes, representative works, and opportunities to further integrate these techniques to support the sustainability of aviation operations.

The article [21] proposes using deep neural networks and transfer learning with images from aircraft lap joints to automatically detect corrosion with precision comparable to trained operators, which could support maintenance personnel and enable more automated condition-based maintenance.

The study [22] delves into active vibration control in helicopters, focusing on individual blade control (IBC) to diminish vibration loads at the hub. By integrating various models and methods, including a fuzzy neural network, the research suggests that IBC can reduce hub vibration loads, offering valuable insights for designing helicopter vibration control laws.

The four data-driven frameworks to predict the exhaust gas temperature baseline of aeroengines, essential for engine health analysis and flight safety, are proposed in [23]. Using data from the real engine, machine learning methods were trained, with the Generalized Regression Neural Network model showing the highest accuracy and efficiency, making it suitable for practical airline applications.

The article [24] reviews the application of machine learning in lithium-ion battery research, specifically in material research, battery health estimation, and fault diagnosis, with a focus on aviation batteries and green aviation technology. The study explores the strengths and weaknesses of different machine learning applications, aiming to foster a deeper understanding and future advancements in the field.

The paper [25] highlights the use of machine learning, specifically a Multilayer Perceptron neural network, to model the transient performance of aero engines, with a focus on heat transfer during transient operation. This model, trained on finite element simulation data and refined with measurements from aero engines, accurately replicates engine thermal transients.

The data-driven approach for predicting base pressure in suddenly expanded flows, which affects the base drag in aerodynamic vehicles, is presented in [26]. Using machine learning models trained on data from response equations, the platform accurately predicts base pressure, which can help optimize base drag in rockets and missiles.

The study [27] introduces machine learning techniques, specifically Deep Neural Network (DNN) and Random Forest Classifier (RFC), to predict null motions in a 4-Control Moment Gyroscope used for satellite attitude control. The RFC method shows superior accuracy over the DNN, allowing for reliable predictions of null motions even for maneuvers not in the training data.

2.1.4. AI for Autonomous Unmanned Aircraft

There are many research activities presenting applications of AI for unmanned aerial vehicles (UAV), especially to increase the autonomy of unmanned systems.

The paper [28] provides a thorough survey of AI-based autonomous UAV networks, highlighting their potential in improving network performance. After reviewing over 100 articles, the study confirms the feasibility and cost-effectiveness of AI-based UAVs for future network design and highlights areas requiring further research.

The use of digital twins (DTs) for autonomous aircraft, emphasizing the importance of data management, is discussed in [29]. It explores data augmentation via synthetic data generation to address real-life data availability issues, specifically focusing on hybrid turbo-shaft engines in drones/helicopters, demonstrating the effectiveness of the rolling linear regression and Kalman filter algorithms in simulating real-life operational data.

A controller designed using an evolutionary neural network for autonomous quadrotor flight, aiming to guide the quadcopter to a specific position while considering attitude limitations, is presented in [30]. The developed neurocontroller, trained with a custom evolutionary algorithm, demonstrated efficient path-following in simulations while maintaining precision and speed.

The study [31] explores the use of deep learning methods, specifically using acoustic signals, to detect UAVs. Convolutional Neural Networks proved most effective, with ensemble techniques reaching an accuracy, suggesting potential for integrating with radar and visual methods in the future.

The model of an AI-based system for secure communication and classification in drone-enabled emergency monitoring is described in [32]. The model ensures data security through an encryption process and then classifies emergency situations using deep learning, showing improved performance when tested on the professional dataset.

The paper [33] introduces an anomaly detection model for unmanned aerial vehicles that improves accuracy by using an enhanced graph neural network combined with a transformer, graph attention mechanism, and a multi-channel fusion mechanism. Experimental results indicate that the Graph Deviation Network outperforms other methods in accuracy and computational efficiency on two datasets from unmanned systems.

2.2. AI in Official Documents of Civil Aviation Organizations

Several key civil aviation organizations have released official documents highlighting the growing role of AI in the industry and providing recommendations for its implementation.

The International Civil Aviation Organization (ICAO) has emphasized preparing the next generation of aviation professionals for an AI-enabled future [34]. In their 2017 Training Report, ICAO highlighted the need to augment aviation training with AI technologies and build competencies to utilize AI tools. Additionally, ICAO's 2019 Working Paper on artificial intelligence and digitalization in aviation outlines guidance for implementing AI in areas like air traffic management. It encourages further R&D and building workforce expertise in AI [4].

The European Union Aviation Safety Agency (EASA) released its Artificial Intelligence Roadmap in 2020 [35]. This strategic document calls for increased research into aviation AI applications, addressing relevant safety and societal risks. It provides an analysis of AI use cases and proposes an AI oversight framework. EASA aims to support the development, testing, and approval of aviation AI systems.

EUROCONTROL's FLY AI report from 2020 stresses the need to accelerate AI adoption, specifically in air traffic management [36]. It recommends building a shared AI infrastructure, fostering an "AI culture", and developing expertise through training and education programs. EUROCONTROL also established a task force on AI in aviation to drive progress.

Though this research focuses on European aviation education, it is worth seeing the trends across the ocean, keeping in mind that air transportation is one of the most globally integrated industries. In 2022, the Federal Aviation Administration (FAA) released a description for certification of a new course: Technical Discipline: Artificial Intelligence—Machine Learning [37]. This document states that Machine Learning works to retain and broaden U.S. leadership in research and knowledge related to how machine learning may be used in aviation systems and how to evaluate the integration of components based on machine learning with aircraft software.

In 2018, the International Air Transport Association (IATA), in its white paper [38], pronounced that the IATA is eager to raise awareness and support airlines and the wider value chain to reap the benefits of new technologies such as AI. Through applied research and development, proof of concepts, pilots, and engagement with the academic and start-up sectors, we aim to accelerate innovation [38].

The above-discussed civil aviation authorities' efforts to prepare for AI align with the broader strategy taking shape at the highest levels of European governance. As outlined in the European Commission's 2021 European AI strategy [39] (EU AI Act: the first regulation on artificial intelligence), it aims to establish the EU as a world leader in human-centric, trustworthy AI across sectors, including transportation. This demonstrates awareness at the policymaking level about AI's transformative potential and the need to build an ethical, excellence-focused framework to realize benefits while assuring safety. The concrete rules and plans put forward by European authorities, both within aviation specifically and AI strategy broadly, reinforce the pressing need to equip students through updated aviation curricula and research that keeps pace with AI's rapidly evolving role in the field.

In April 2021, the EU Commission presented its AI package, including:

- Communication on fostering a European approach to AI [40].
- a review of the Coordinated Plan on Artificial Intelligence (with EU Member States) [41].
- proposal for a regulation laying down harmonized rules on AI (AI Act) and relevant Impact assessment [42].

Finally, to illustrate global aviation authorities' adherence to AI promotion, there is a list of some of the ICAO initiatives [43] aimed at boosting knowledge of machine learning and artificial intelligence:

- Partnering in the United Nations AI for Good Annual Global Summit, presenting the work session on AI in aviation, as well as participating in mobility sessions.
- Hosting internships, developing in-house deep learning AI models showcasing natural language processing techniques for aeronautical information management, as well as document summarization.
- Supporting local AI company networks, start-ups, and incubators such as Thales AI@Centech and Concordia District 3 by providing ideas and coaching.
- Collaborating with McGill on the introduction of AI in aviation inside the McGill data science and machine learning program.
- Broadening the horizon of AI in aviation through workshops organized in collaboration with the Consortium for Research and Innovation in Aerospace in Quebec (CRIAQ).
- Exploring the creation of an AI in Aviation Focus Group under the auspices of the International Telecommunication Union to address issues related to compliance and certification.

These documents demonstrate that civil aviation authorities recognize AI as an essential emerging technology. While highlighting the transformative potential of AI, they also outline important considerations around safety assurance, ethics, and workforce preparedness. The policy guidance coalesces around further R&D investment, infrastructure modernization, and education to develop an AI-ready aviation system and workforce. The findings reinforce the imperative for universities to equip students with both core AI competencies and specialized aviation domain knowledge.

2.3. AI in Aviation Education

Despite the technological advancements in the area of AI in general, certain academic fields remain markedly underexplored, with the integration of AI in aviation education being a prime example. This section carries out an analysis of the existing literature, highlighting the noticeable absence of extensive academic discourse on this pertinent subject.

As we embarked on a comprehensive review of the available literature at the intersection of AI and aviation education, we encountered a significant academic void. Only a handful of studies have touched upon the adoption, implementation, or impact of AI in the realm of aviation training and education, underscoring a stark contrast with other fields where AI has been making substantial inroads.

The scarcity is particularly surprising given the transformative potential of AI across educational paradigms and its specific implications for sectors as critical as aviation. This lack of scholarly attention prompted us to not only conduct this review but also undertake our own research inquiries to contribute to this underrepresented area.

In this section, we analyze the limited studies available at the time of this paper. Each of these works offers unique insights into different facets of AI's role and potential in aviation education, yet together, they also highlight the collective dearth of deeper, more comprehensive explorations. This analysis underscores the necessity for a more robust academic focus on how AI could revolutionize aviation education, a sector where safety, innovation, and efficiency are paramount.

Our study and subsequent research are steps toward filling this academic lacuna, emphasizing the urgency for further studies. The limited literature signals not a lack of importance but rather an expansive horizon for potential research in integrating AI within aviation education, thereby pioneering innovations in this high-stakes field.

At present, interest in the use of AI in education in general and in universities has grown significantly, which is reflected in research on this topic.

The paper [44] explores the role of AI applications in education, arguing they can help address modern challenges in accessing learning through technologies like social robots, smart learning, and intelligent tutoring systems, though statistical testing is needed to generalize the findings.

The article [45] explores the application of AI in education over the past 30 years, emphasizing its interdisciplinary nature and the evolution of the field in the context of modern technologies. It presents findings in the research areas of AI in Education, Educational Data Mining, and Learning Analytics, discussing their history, objectives, methodologies, applications, and challenges. It provides an overview of the interdisciplinary field of AI in education, summarizing the state-of-the-art in subfields like Artificial Intelligence in Education, Educational Data Mining, and Learning Analytics, which combine AI and learning sciences to facilitate adaptive learning environments and improve teaching and learning using digital technologies.

The paper [46] proposes a fifth-generation university model adapting to emerging AI by rethinking competencies and human–AI responsibilities, arguing that with proper IT adoption, society is technically ready to expand technology use and free up human resources for creative activities.

Some researchers are oriented on AI study and AI applications for education and training in aviation.

The study [47] introduces a hybrid expert model that evaluates student pilot outcomes to enhance the quality of aviation education by integrating intellectual knowledge analysis, fuzzy set theory, and a systems approach. The model was developed using data from 696 undergraduate pilot students and demonstrated its effectiveness in assessing individual educational results for personalized study counseling.

The virtual simulation-pilot engine that uses AI tools to accelerate air traffic controller training by recognizing, understanding, and responding to spoken communications from trainees is introduced in [48]. The system incorporates state-of-the-art AI models and can be enhanced with real-time data or deliberate errors, achieving impressive accuracy rates in word recognition and callsign detection.

The study [49] introduces a new method using machine learning and virtual reality to distinguish between experienced pilots and novices based on eye tracking and flight dynamics data. The Support Vector Machine algorithm achieved the highest accuracy in predicting flight skills, surpassing existing pilot selection methods and showing potential for use in other fields like astronaut selection.

The aviation industry's anticipated growth and the current effects of COVID-19 emphasize the need for enhanced pilot training. The paper [50] proposes a machine learning-aided framework for simulator-based pilot training that offers objective performance evaluation and personalized feedback, aiming to surpass current training limitations.

2.4. The Key Literature Gaps and Opportunities for Further Research

While existing studies have made valuable contributions to understanding AI applications in aviation and their implications for workforce development, several research gaps persist. Firstly, most literature focuses on AI use cases within specific operational domains like maintenance or air traffic control. Comprehensive reviews assessing AI adoption across the entire aviation ecosystem are limited. Industry surveys provide high-level insights but lack in-depth analysis of organizational implementation challenges. Additionally, policy guidance advocates aviation AI investment but does not always translate into detailed competency definitions for various work roles. Extensive research is needed to map the full range of conceptual knowledge and applied skills required by different aviation professionals to work effectively with AI systems.

Another critical gap is the structured content analysis of current aviation curricula to evaluate alignment with modern AI competency needs. Instructional strategies and best practices for teaching AI technologies in aviation educational contexts also need further research through controlled experiments. Assessment frameworks, as both AI systems and resulting competency requirements rapidly evolve over time, have received minimal focus. Moreover, studies examining collaboration methods between industry, regulators, and academia to coordinate AI competence development are sparse. Finally, research on the ethical, legal, and sociotechnical implications of AI adoption, specifically within the aviation context, remains in the early stages.

In summary, while the discourse has made important strides, ample opportunities exist for additional research to address these gaps. Future studies should utilize diverse methodologies to comprehensively evaluate AI use cases, empirically assess system performance, gather workforce perspectives, validate tailored competency models, analyze curricula, develop evidence-based pedagogies, implement educational pilots, examine collaborative governance, and investigate responsible AI considerations for aviation. This can help drive rigorous, data-driven workforce planning and ensure aviation retains its position as a leader in technological advancement by harnessing AI's benefits while proactively managing its risks.

The literature review acknowledges the transformative impact of AI on aviation and the pressing need to re-envision aviation education. However, significant gaps persist regarding the core competencies needed for aviation professionals working with AI and the optimal strategies for integrating AI effectively and responsibly into aviation curricula.

The current paper aims to build on existing literature by proposing an aviation-specific AI competency framework and implementation roadmap to equip the emerging workforce with the knowledge, skills, and mindsets required in an AI-driven era, proposing a competency framework and implementation roadmap tailored to the unique context of aviation education.

3. Materials and Methods

The rapid pace of artificial intelligence advancement is transforming numerous aspects of the aviation industry. From flight planning to aircraft maintenance, AI technologies like machine learning and natural language processing are enhancing operations, infrastructure, and passenger experiences. However, integrating these disruptive innovations necessitates developing a workforce with new competencies to leverage AI safely, effectively, and responsibly. Aviation education programs must adapt to provide graduates with the knowledge, skills, and mindsets required in an AI-driven era.

This paper proposes a methodology to identify core AI competencies needed across aviation domains and reform curricula accordingly (Figure 1). The proposed seven-stage methodology provides a rigorous approach to identifying aviation AI competency needs and reforming curricula accordingly. By mapping core knowledge domains, examining AI adoption trends, analyzing program content, and formulating recommendations, aviation educators can make evidence-based changes.

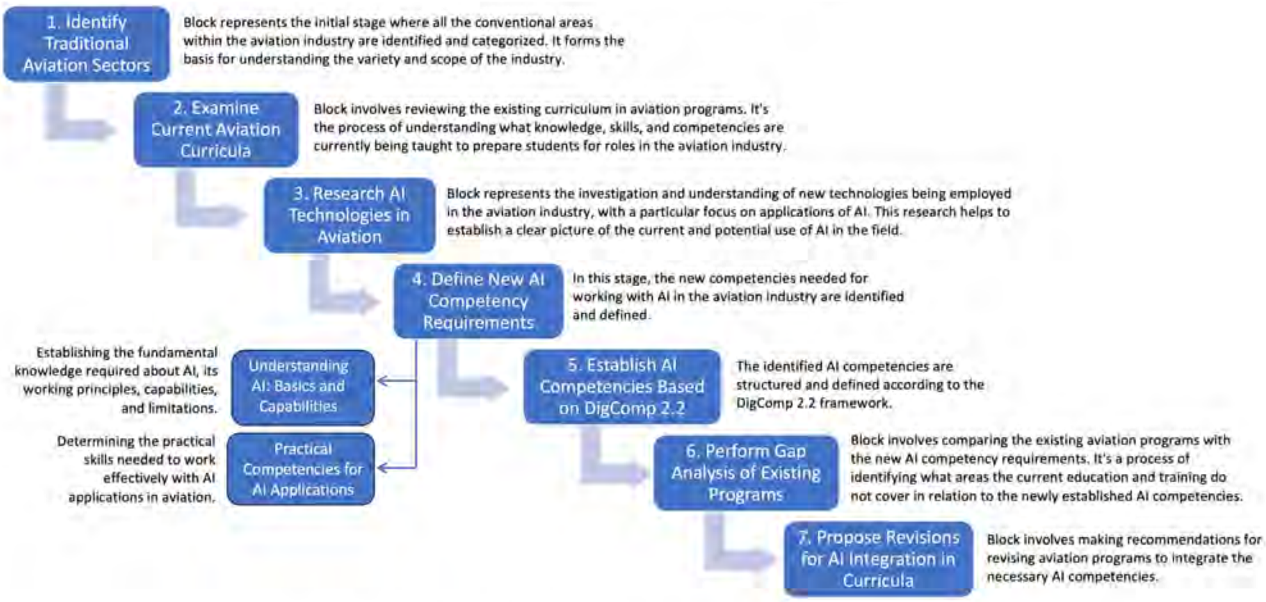

Figure 1. A Methodology for Developing AI Competencies in Aviation Education.

This study employs a grounded theory approach to develop an initial conceptual framework identifying core competencies needed for aviation professionals working with AI systems [51]. Grounded theory utilizes qualitative data to inductively derive theories that help explain phenomena [52]. It is an established methodology for developing conceptual frameworks and models in areas with limited existing research [53]. The iterative process involves concurrently gathering data, constant comparison analysis to find patterns, developing categories and relationships through open and axial coding procedures, and integrative organization of categories into a theoretical formulation [54]. This grounded theory approach is well-suited for studying emerging competency requirements as it allows critical capabilities to emerge progressively from the data. Through structured qualitative coding of industry documents, focus groups, and expert interviews, core themes around needed AI knowledge and skills were identified and organized into a proposed competency framework. Further validation will strengthen the model, but grounding initial framework development in accepted grounded theory procedures establishes methodological rigor.

Data collection included a structured literature review, analysis of civil aviation authority documents, and focus groups/interviews with aviation education experts. The literature review followed a systematic process of searching scholarly databases, screening based on defined inclusion/exclusion criteria, assessing study relevance and quality and synthesizing findings related to AI adoption in aviation and resulting skill needs [55]. Civil aviation authority reports were analyzed using qualitative content analysis techniques to extract major themes and trends related to AI strategy and workforce requirements [56]. Focus groups and interviews with aviation educators were conducted using semi-structured protocols to capture perspectives on gaps in student competencies and proposed approaches for updating curricula and teaching methods to address AI integration [57]. Interview transcripts were coded using descriptive coding methods to identify key categories related to needed competencies and framework organization [58]. By integrating findings from the literature, analyzing pertinent documents, and considering aviation educator viewpoints, we bolstered the study's trustworthiness. Our methodological approach adhered to recognized best practices for qualitative data collection and analysis. To ensure consistency and depth in our methodology, we adopted several procedures grounded in established standards [59]. The synthesis of insights from academic sources, civil aviation documents, and feedback from focus groups provided a robust foundation for the identification of themes associated with AI competencies. Two researchers independently coded the focus group transcripts and then cross-checked results to ensure consistency and reduce potential bias, a process known as peer debriefing [60]. Additionally, detailed records were maintained throughout data collection and analysis to provide transparency and allow an external audit if required, known as an audit trail [61]. Memos during coding and theoretical integration supplemented the audit trail. These measures of triangulation, peer debriefing, and auditing helped ensure the qualitative reliability of the competency framework development process.

The competency framework was developed using an inductive analysis process aligned with established qualitative techniques [62]. Initial open coding of the literature, documents, and focus group transcripts identified emergent categories related to needed AI knowledge and skills. Through constant comparison, these categories were refined and organized into higher-level competency areas. Axial coding elucidated relationships between these competency areas to integrate them into a coherent framework. Selective coding determined overarching themes encompassing the framework components. This iterative process of concurrent data gathering, analysis, and theorization allowed the competency framework to be progressively elaborated and expanded based on new insights. The goal was to ground the framework directly in the data rather than imposing predefined categories. This inductive development provides a data-driven model of essential competencies, increasing validity and alignment with aviation industry needs related to AI integration.

The defining components of grounded theory practice include the following steps with specific examples for the current research (Figure 1):

- Data collection, sources: comprehensive review of current literature, industry reports, publications, and interviews with seasoned industry professionals spanning various roles for Block 1; aviation program curricula, course catalogs, and descriptions from multiple universities for Block 2; data on current and emerging applications of AI across aviation, including documents, news articles, expert interviews, conference presentations for Block 3; job postings, industry reports, and expert interviews for Block 4.
- Constructing analytic codes and categories from data: “flight operations”, “maintenance and engineering”, “air traffic management”, etc., for Block 1; “pilot training”, “aviation law”, etc., for Block 2; “flight simulation”, “aircraft design”, etc., for Block 3; “to learn AI prediction capabilities for flight planning”, “to use AI for data analysis”, etc., for Block 4.
- Using the constant comparative method, which involves making comparisons during each stage of the analysis.
- Advancing theory development during each step of data collection and analysis: this research employs AI instead of regular extensive surveys.
- Axial Coding: grouping open codes into higher-level competency categories for each aviation field or based on the area of aviation and type of AI application, e.g., category “Pilot training”, “AI in Pilot Training” for Block 3, “Core AI Knowledge” for Block 4.
- Memo-writing to elaborate categories, specify their properties, and identify gaps.
- Sampling aimed toward theory construction, not for population representativeness.
- Conducting the literature review after developing an independent analysis.

Blocks 1, 2, 3, and 4 of this research methodology rely on iterative data collection and analysis based on the Grounded Theory. Block 6 employs Natural Language Processing with semantic text annotation. Block 5 is achieved through the systematic DigComp 2.2 document review and qualitative coding and categorization of competencies. Block 7 synthesizes the obtained results into the recommendations.

As AI proliferates within the industry, determining specific impacts on aviation roles and required capabilities is essential for alignment. By scanning the AI landscape, analyzing current programs, and mapping competencies to validated frameworks, this methodology generates data-driven recommendations for closing emerging competency gaps.

Focus areas include both conceptual AI literacy as well as specialized applied skills for human-AI collaboration. Grounding findings in established digital competence frameworks facilitates legitimacy and adoption. Grounding recommendations in the European Digital Competence Framework provide a validated structure.

While adapting traditional fields to rapidly advancing technologies poses challenges, methodical competency mapping helps ensure graduates have future-proof capabilities. By following this research approach, aviation programs can continuously integrate emerging tools like AI while maintaining rigor and industry relevance. In a landscape of constant change, a data-driven methodology provides a steady compass for navigating complex innovations.

For the development of a new curriculum, this study employs a text-mining methodology leveraging semantic analysis techniques and natural language processing tools. The objective is to identify keywords semantically related to the domain of digital competencies and subdomains of Artificial Intelligence and Machine Learning. The data source is [63], a database containing university study programs aimed at matching student needs with university offers.

This methodological approach aims to provide aviation educators and policymakers with a systematic tool to continuously refresh programs and develop talent ahead of evolving industry advancements. Though adapting to traditional domains is inherently challenging, a rigorous approach allows competency needs to lead to transformation. As aviation enters a new era of technological innovation, re-evaluating workforce preparedness and equipping students with future-oriented education will be critical.

4. Results

In this section, the competency framework is used to analyze the curricula of European aviation bachelor's programs to identify gaps between industry needs and graduate preparation. This methodology, combining industry AI mapping, competency modeling, and aviation program benchmarking, revealed that current aviation curricula do not adequately focus on building the AI literacy and competencies required by an increasingly AI-driven aviation industry.

The following sections detail the key findings that emerged from each stage of the methodology.

4.1. Traditional Aviation Sectors: Identifying and Categorizing the Foundational Pillars

Block 1 of the proposed methodological approach (Figure 1) represents the initial stage where all the conventional areas within the aviation industry are identified and categorized. It forms the basis for understanding the variety and scope of the industry.

The aviation industry is a large and diverse sector encompassing many conventional areas that each play a unique role in enabling flight. To understand the full scope of the aviation industry, it is helpful to identify and describe the key traditional sectors that comprise it.

The airline sector is arguably the most visible face of aviation. Commercial airlines provide scheduled air transportation services for passengers and cargo using large jet aircraft. Major airlines operate extensive domestic and international route networks. Regional airlines feed passengers from smaller cities into the major airlines' hubs. Charter airlines offer unscheduled flights on demand. The airline sector generates the majority of the industry's revenue from fares and cargo shipping charges.

A second core aviation sector is aircraft manufacturing. Major manufacturers like Boeing and Airbus design and produce large civil jet aircraft. Business jet makers like Bombardier and Gulfstream supply the corporate and private markets. Manufacturers of small piston-engine aircraft cater to personal flying and training markets. These original equipment manufacturers (OEMs) provide a steady supply of new aircraft for airlines, businesses, and individuals.

A third traditional sector is airports. Commercial airports serve airlines and general aviation. Operators manage airport infrastructure, including runways, terminals, air traffic control towers, navigation aids, and more. Larger airports essentially function as small cities. Revenue comes from fees paid by airlines, tenant businesses, and passengers.

General aviation refers to all civilian flying apart from scheduled airlines and the military. It includes private pilots, flight schools, corporate aviation, air taxi services, agricultural aviation, and more. Companies like Cessna and Cirrus design manufacture popular small aircraft for personal flying and training. General aviation relies on a vast decentralized network of small airports and heliports.

Other support sectors like aircraft maintenance keep planes flying safely. Aviation fuel provides the vital energy source for flight. Air navigation service providers manage the air traffic control systems guiding aircraft through the sky. Aviation training education establishments train pilots, mechanics, air traffic controllers, and other skilled workers.

The initial identification and understanding of these conventional sectors provide the foundation to study the aviation industry as a whole. The taxonomy of traditional aviation sectors is shown in Figure 2. The data represented in the taxonomy are an amalgamation of literature reviews, encompassing over 70 research articles and industry reports. Furthermore, we conducted 18 in-depth interviews with seasoned industry professionals within the frame of the "COST Action TU1408 Air Transport and Regional Development" project (https://tsi.lv/projects/cost-action-tu1408-air-transport-and-regional-development-atard/ accessed on 7 August 2023), ensuring a comprehensive representation of the field. The taxonomy figures were constructed by categorizing and cross-referencing findings from these diverse sources, reflecting a holistic view of the topic.

4.2. Aviation Training and Education: Examine Current Aviation Curricula

Block 2 of the proposed methodological approach (Figure 1) involves reviewing the existing curriculum in aviation programs.

Aviation education is comprehensive and covers many fields, each leading to different types of professional careers. The general classification of education programs for the aviation industry, their area of appointment, and the competencies for today's aviation professionals required are shown in Table 1. The table represents a synthesis of information garnered from multifaceted sources. These sources include a meticulous analysis of about 40 pertinent research articles, whitepapers, and case studies from the literature. Additionally, our team held targeted discussions with industry professionals within the frame of the "Intelligent Transport and Transport Management study module" project (https://tsi.lv/projects/intelligent-transport-and-transport-management-study-module-inteltrans/ accessed on 7 August 2023), gathering their insights and experiences to provide an enriched context. These elements were methodically integrated to develop this table, presenting a balanced overview of the field.

4.3. Industry Demand for Artificial Intelligence Competencies in Aviation Graduates

Block 3 of the proposed methodological approach (Figure 1) represents the investigation and understanding of new technologies being employed in the aviation industry, with a particular focus on applications of AI.

The aviation industry has always been at the forefront of technological advancement, pioneering innovations that redefine air travel. Today, artificial intelligence promises to bring the most radical transformation yet in how aircraft are designed, flights are managed, and passenger experiences are optimized.

Across the entire aviation value chain, AI techniques like machine learning and neural networks are demonstrating new capabilities. The key AI application areas include (this information is derived from a comprehensive review of relevant literature, interviews with industry professionals, and a synthesis of pertinent professional documentation:

- Flight planning and optimization—AI can analyze weather patterns, air traffic, runway conditions, and other variables to generate optimal flight plans that minimize fuel costs and emissions while maintaining safety.
- Predictive maintenance—Machine learning algorithms can monitor aircraft performance and usage data to anticipate potential equipment failures before they occur.
- Air traffic management—AI systems can better manage complex air traffic flow, optimizing aircraft sequencing and routing to improve efficiency and capacity at airports.
- Passenger experience—Chatbots, virtual assistants, and other AI tools can provide personalized recommendations and 24/7 automated customer service for passengers.
- Safety and accident investigation—AI techniques like computer vision and natural language processing can extract insights from flight recorder data and reports to identify risks.

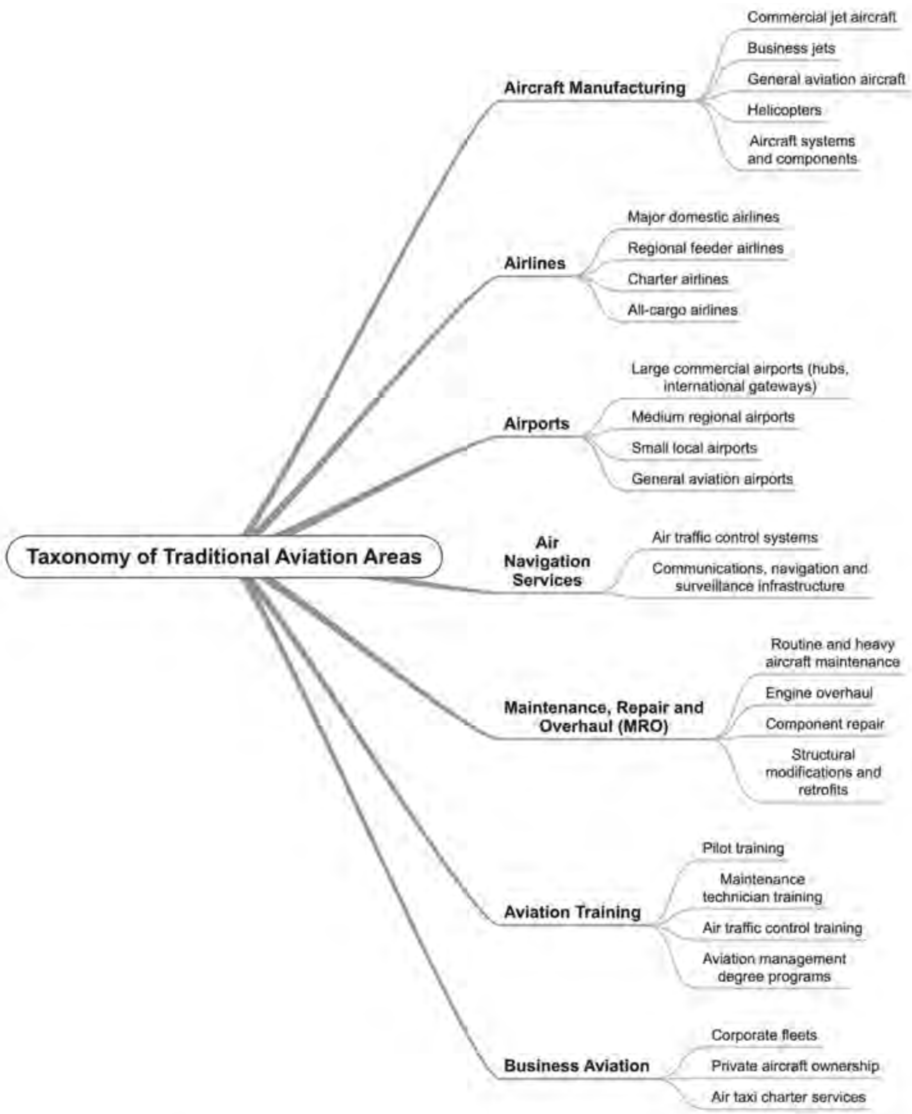

Figure 2. Taxonomy of traditional aviation sectors.

However, AI's potential extends far beyond operational enhancements. Airports are deploying computer vision systems to automate security checks and congestion monitoring. Airlines use AI to personalize recommendations, boost customer satisfaction, and tailor pricing strategies. Even passengers benefit from AI chatbots, real-time travel alerts, and interactive maps.

Table 1. The general classification of education programs for the aviation industry.

Aviation Programs	Area of Appointment	Basic Competencies
Pilot training	These programs are intended for individuals who want to become professional pilots. The graduates can work for commercial airlines, cargo airlines, charter flights, or in private aviation.	Aerodynamics, navigation, weather forecasting, flight planning, aircraft operations, emergency procedures, and Federal Aviation Regulations.
Aerospace Engineering	Aerospace engineers design aircraft and spacecraft. They work in manufacturing, analysis and design, research and development, and the federal government.	Aerodynamics, structures and materials, propulsion systems, stability and control, aircraft design, systems integration, CAD (Computer Aided Design), simulation, and modeling.
Aviation Management	Graduates can work in airlines, airports, or aviation authorities. They handle operations, logistics, budgeting, safety procedures, and human resources.	Aviation law, safety management, airport planning, airline operations, financial management, human resource management, strategic planning, and regulatory compliance.
Air Traffic Control	Air Traffic Controllers work in control towers, approach control facilities, or route centers, coordinating the movement of air traffic to ensure that planes stay safe distances apart.	Air traffic control principles, aviation safety, navigation, weather, Federal Aviation Regulations, decision-making, and stress management.
Aircraft Maintenance and Repair	These graduates can work in airline companies, maintenance, repair, and overhaul (MRO) organizations, and aircraft manufacturing firms.	Aircraft systems, inspection procedures, maintenance techniques, troubleshooting, Federal Aviation Regulations, use of maintenance manuals, and aircraft electrical systems.
Aviation Technology	Aviation technologists often work as aviation technicians or technologists at airline companies, airports, or aviation authorities. Their job is to work on the equipment and technology that make aviation possible.	Principles of flight, aircraft systems, aviation safety, Federal Aviation Regulations, avionics, navigation systems, and maintenance procedures.
Aviation Safety	Aviation safety specialists work with airlines, aviation authorities, and organizations to manage and prevent risk in aviation operations.	Accident investigation, safety management systems, risk assessment, aviation law, human factors in aviation, emergency response planning, and safety culture.
Aeronautics/Aviation Science	This is a broader field, leading to various professions in aviation, from piloting to administration.	Aerodynamics, flight operations, navigation, weather, aviation management, air traffic control, aviation law, safety procedures, and aircraft systems.

But to fully unlock these benefits, aviation must cultivate an AI-ready workforce. This necessitates updated training programs that integrate both deep AI capabilities as well as ethics education. Collaboration between industry, regulators, and academia will be critical. Standards must also evolve to ensure the safe and regulated use of autonomous technologies.

The path forward must balance innovation with caution. But by harnessing AI responsibly, aviation can pioneer a new era of safety, sustainability, and passenger centricity. AI promises to take the industry to unprecedented heights, but realizing this requires proactive preparation and investment today. The aviation community must come together to chart an AI flight plan that lifts everyone higher.

The regulatory bodies of international civil aviation in their documents highlight AI as a pivotal emerging technology. Their guidance coalesces around further R&D paired with proactive workforce preparation through education and training initiatives. This provides a policy foundation suggesting aviation programs need to update curricula to produce graduates ready to meet the industry's goal of widescale AI adoption.

The FLY AI report from EUROCONTROL [36] provides a "FLY AI Action Plan" advocating extensive training, education, and collaboration to build workforce readiness in AI across the aviation community. This underscores the imperative for aviation programs to equip students with relevant skills.

EASA's AI Roadmap [35] points to the significant impact AI could have in transforming aviation operations like maintenance and air traffic management. This future vision relies on having personnel capable of developing, deploying, and managing AI technologies effectively and safely.

The taxonomy of aviation areas with AI applications is shown in Figure 3. The taxonomy is a product of a comprehensive research methodology. Starting with an exhaustive dive into the literature, we assessed about 40 articles and professional documents relevant to our study. Complementing this, within the frame of the "Ecosystem for European Education Mobility as a Service: Model with Portal Demo" project (https://tsi.lv/projects/ecosystem-for-european-education-mobility-as-a-service-model-with-portal-demo/ accessed on 7 August 2023) we engaged in dialogue with industry experts, absorbing their hands-on knowledge and perspectives. Many of the aviation-related topics have been deeply studied in the doctoral research projects supervised by the authors. Topics of this research can be accessed from the list of PhD students at Transport and Telecommunication Institute (https://tsi.lv/research/phd/list-of-phd-students/ accessed on 7 August 2023).

4.4. Aviation Education and Industry Demand for AI Competencies

In Block 4 of the proposed methodological approach (Figure 1), the new competencies needed for working with AI in the aviation industry are identified and defined.

AI enables major improvements in aviation systems themselves while also transforming aviation education into a more student-centric, real-world learning experience with interactive AI technologies. This dual integration will be key to developing both AI-powered aviation systems and an AI-competent workforce.

ICAO has called for integrating AI across all aspects of aviation, from operations to training. Its Next Generation of Aviation Professionals initiative [34] specifically emphasizes the need to prepare the coming workforce for increasingly AI-driven aviation ecosystems.

Today, artificial intelligence is being integrated into the aviation industry in two main directions:

Through direct integration into aviation technologies and operations;

Through integration into aviation education and training.

A brief description of both directions of AI implementation is shown in Table 2. The table has been meticulously curated, rooted in a thorough exploration of pertinent literature. T Augmenting this, we had detailed conversations with leading industry professionals to capture their first-hand knowledge and practical experiences within the frame of the "Fundamentals of Design Competence for Our Digital Future" project (https://tsi.lv/projects/fundamentals-of-design-competence-for-our-digital-future/ accessed on 7 August 2023).

The integration of AI in aviation necessitates transforming aviation education programs to build two critical sets of competencies:

1. Understanding AI Concepts and Applications in Aviation (NextTech)
2. Working Effectively with AI Systems (NextGen)

The term "NextGen" refers to the new generation of aviation specialists and workers needed as the industry adopts innovative new technologies and faces shifting needs.

The term "NextTech" refers to those new, leading-edge technologies being rapidly adopted across the aviation industry, especially artificial intelligence tools like machine learning, neural networks, natural language processing, and more.

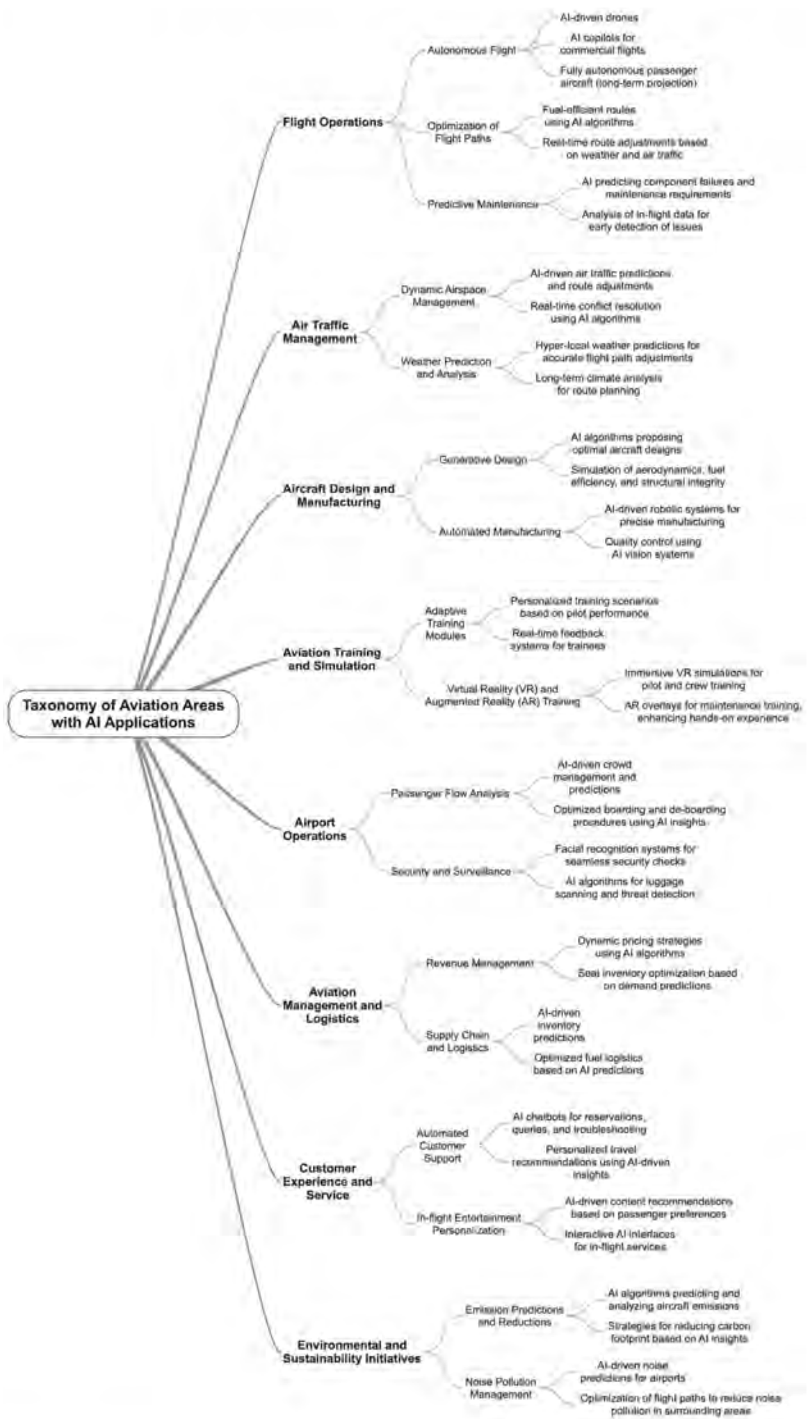

Figure 3. The taxonomy of aviation areas with AI applications.

When discussing the first NextTech direction, aviation professionals will need foundational knowledge of the following:

- Core AI approaches like machine learning, neural networks, and computer vision.
- How these techniques can be specifically applied in flight operations, maintenance, air traffic control, etc.
- AI system components, architecture, capabilities, and limitations.
- Data requirements, integration needs, and infrastructure for implementing aviation AI.
- Existing and emerging use cases of AI in the relevant aviation domain.

Table 2. The description of AI implementation in the aviation industry and aviation education.

Area of AI-Driven Aviation Industry	Aviation Industry	Aviation Education
Pilot training	AI can be used to optimize flight paths for efficiency and safety, simulate different flight conditions for pilot training, and assist with real-time decision-making during flights.	AI can be used to personalize the learning experience for each trainee, provide virtual reality-based training, identify weaknesses in a trainee's skill set, and track progress over time.
Aerospace Engineering	AI can be used to design more efficient aircraft, simulate, and analyze various flight conditions, and predict maintenance needs.	AI can be used to provide hands-on experience with designing aircraft in a virtual environment, help students understand complex concepts through simulation, and use predictive modeling to enhance their understanding of aircraft design and maintenance.
Aviation Management	AI can be used for flight scheduling, route optimization, fuel management, and analyzing passenger behavior to improve customer service.	AI can be used to simulate various management scenarios, teach students about decision-making algorithms, and provide real-world case studies for analysis.
Air Traffic Control	AI can be used to predict flight patterns, manage air traffic flow, and enhance communication between pilots and air traffic controllers.	AI can be used to provide immersive training experiences, simulate different traffic scenarios, and help students understand the complexities of air traffic management.
Aircraft Maintenance and Repair	AI can be used for predictive maintenance, fault detection, and quality assurance, thereby reducing downtime and increasing the safety of aircraft.	AI can be used to simulate different maintenance scenarios, help students understand the nuances of aircraft systems, and provide hands-on experience in a virtual environment.
Aviation Technology	AI can enhance aviation technology by improving navigation systems, enhancing cockpit automation, and optimizing fuel efficiency.	AI can be used to provide students with an understanding of how AI technologies are developed and applied in aviation and to train them on the latest aviation technologies.
Aviation Safety	AI can be used to analyze accident data, predict potential safety issues, and assist in creating safety protocols and emergency response strategies.	AI can be used to simulate different safety scenarios, analyze historical accident data, and train students on risk assessment and management.
Aeronautics/Aviation Science	AI can be applied broadly in aeronautics, from enhancing aerodynamics to optimizing fuel consumption, improving safety, and aiding in aircraft design.	AI can be used to teach students about the different ways AI can be applied in aeronautics, provide simulations for hands-on learning, and assist in research and development projects.

When discussing the second NextGen direction, professionals must also gain new competencies required in an AI-augmented work environment:

- Interpreting and critically evaluating AI system outputs.
- Knowing when to rely on AI vs. human expertise.
- Communicating and collaborating effectively with AI agents.
- Maintaining ethical and responsible AI implementation practices.
- Identifying challenges and limitations of AI systems in practice.
- Adapting workflow to integrate AI tools into business processes.
- Continuously monitoring AI system performance and improvements.

Whereas previously, aviation professionals developed skills for tools and technologies of their era, integrating AI systems now necessitates new competencies uniquely tailored to the capabilities and constraints of modern AI. Aviation education programs must transform to adequately prepare students across both the conceptual AI knowledge and applied human-AI collaboration dimensions. This two-pronged approach will empower professionals to harness the benefits of AI safely and effectively throughout the aviation industry.

The integration of AI in aviation demands a new set of competencies for professionals in each of these fields. Table 3 shows how these competencies could be classified for each aviation area. Table 3, similar to Table 2, has been derived from the same foundational sources of information. Both tables utilize data and findings from the same comprehensive project, ensuring consistency in the presented content. This methodological approach ensures that the insights and conclusions drawn are cohesive and interconnected, providing readers with a seamless understanding of the subject matter from multiple perspectives.

Table 3. Core AI-driven competencies for the aviation area.

Area of AI-Driven Aviation Industry	Understanding AI (NextTech)	New Conditions (NextGen)
Pilot Training	Professionals should understand the principles of AI and machine learning and how AI systems assist in flight planning, optimization, and real-time decision-making.	Professionals need to be adept at interpreting data from AI systems, understand the limitations of AI, and know how to respond when AI systems fail or give unexpected outputs.
Aerospace Engineering	Engineers should understand how AI can aid in the design process, simulation, and predictive maintenance. They should be able to use AI tools for optimization and modeling.	Engineers should adapt to a collaborative environment where AI tools assist them. They must learn how to input correct parameters, interpret results, and troubleshoot AI systems.
Aviation Management	Professionals should understand how AI can optimize scheduling and routing and improve customer service. They should be aware of AI tools used in decision-making processes.	Managers must know how to integrate AI decision-making tools with human oversight, how to manage data-driven teams, and how to make final decisions when AI suggestions conflict with traditional methods.
Air Traffic Control	Professionals should understand how AI can predict flight patterns and manage air traffic. They should be able to use AI-enhanced communication tools.	Controllers need to learn how to make decisions when AI predictions conflict with human judgment, how to use AI tools under stressful conditions, and how to troubleshoot these tools when necessary.
Aircraft Maintenance and Repair	Professionals should understand how AI is used in predictive maintenance, fault detection, and quality assurance. They should be proficient in using AI-based diagnostic tools.	Technicians should know how to interpret results from AI diagnostic tools, when to rely on these tools versus manual checks, and how to keep AI tools up to date with evolving technologies.
Aviation Technology	Professionals should understand how AI is improving navigation systems, cockpit automation, and fuel efficiency. They should be proficient in the latest AI technologies.	Technologists need to understand how to implement and manage AI tools, interpret the data from these tools, and troubleshoot issues that arise during their operation.
Aviation Safety	Professionals should understand how AI is used to analyze accident data and predict potential safety issues. They should know how to use AI tools for risk assessment.	Safety specialists need to know when to rely on AI tools for risk prediction and when to trust human judgment, how to interpret AI-produced safety data, and how to manage AI tools for optimum safety.
Aeronautics/Aviation Science	Professionals should understand the broad applications of AI in aeronautics, from enhancing aerodynamics to optimizing fuel consumption.	Aeronautics professionals need to understand how to use AI for research and development, how to interpret results from AI tools, and how to integrate AI with traditional aeronautic practices.

These competencies will equip aviation professionals to work effectively with AI tools and make decisions based on AI data while still retaining critical human oversight and judgment. Figure 4 provides a taxonomy of AI applications in aviation training that summarizes the possible applications of AI in the education process.

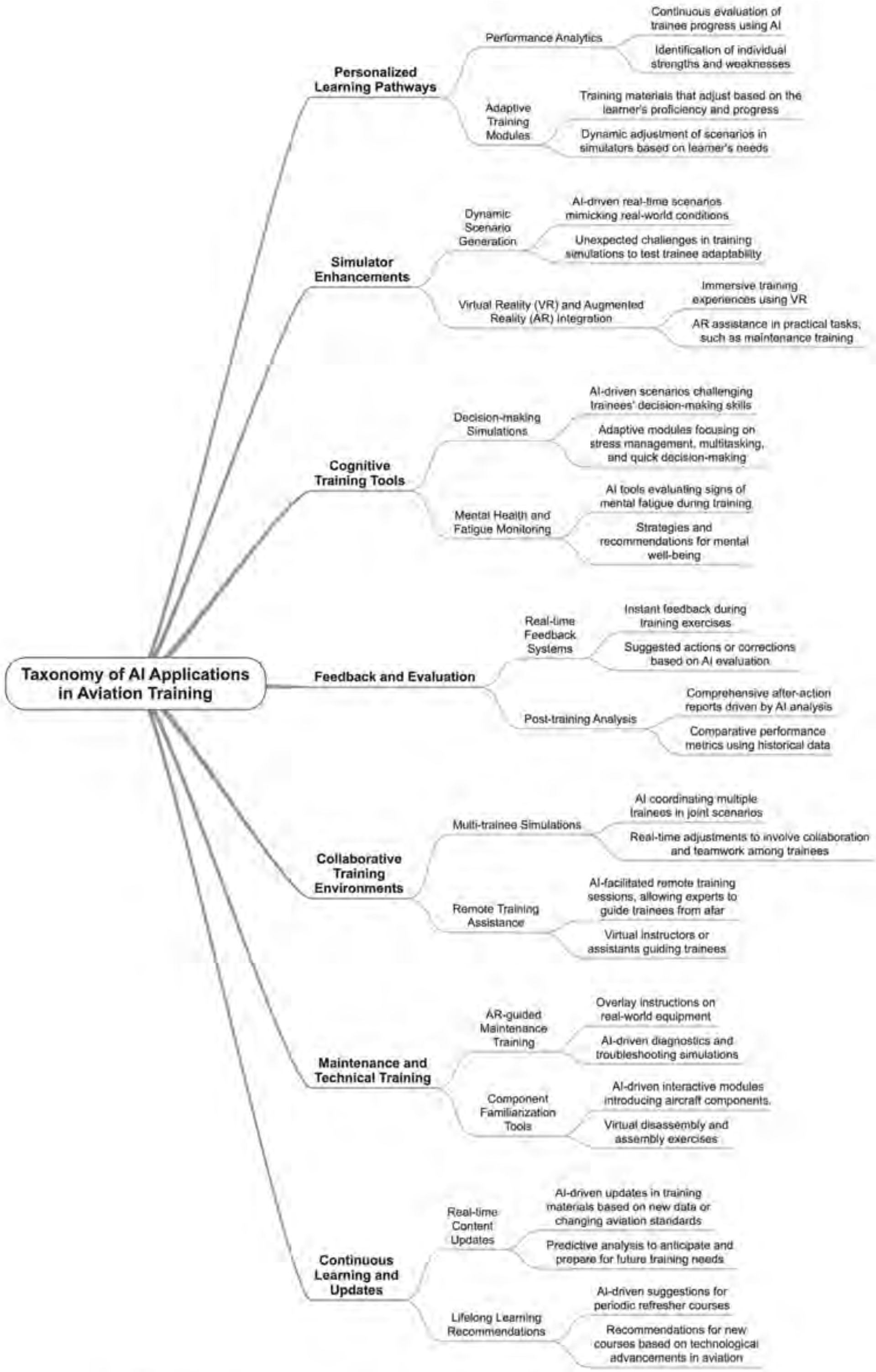

Figure 4. Taxonomy of AI applications in aviation training.

4.5. Proposal for Including AI-Driven Aviation Competences in DigComp 2.2 Framework

In Block 5 of the proposed methodological approach (Figure 1), the identified AI competencies are structured and defined according to the DigComp 2.2 framework.

AI competencies fall under the category of digital competencies. These competencies are currently described in "The European Digital Competence Framework for Citizens"

(DigComp 2.2) [64]. The DigComp 2.2 framework provides a detailed understanding of what it means to be digitally competent. It includes five competence areas:

- Area 1. Information and data literacy.
- Area 2. Communication and collaboration.
- Area 3. Digital content creation.
- Area 4. Safety.
- Area 5. Problem-solving.

This structure is indeed an effective way to illustrate competency development across different aviation proficiency levels. Using this structure, the AI competencies for the aviation fields can be expanded, as shown in Table 4.

4.6. Gap Analysis of Existing Programs: Required Transformation in Aviation Bachelor Programs' Implementation

Block 6 of the proposed methodological approach (Figure 1) involves comparing the existing aviation programs with the new AI competency requirements. It is a process of identifying what areas the current education and training do not cover in relation to the newly established AI competencies.

The emergence of artificial intelligence as part of numerous aviation technologies implies significant transformations in the set of necessary competencies and ways of training aviation specialists.

Table 4. AI-driven aviation competencies in DigComp 2.2 framework.

Aviation Area	Proficiency Levels	Knowledge	Skills	Attitudes
Pilot Training Competence Area: Problem-Solving (Area 5 in DigComp 2.2) Competence: Incorporation of AI in flight planning and decision-making	Foundation Level: Understand the basic principles of AI and how AI systems assist in flight planning and decision-making. Intermediate Level: Able to interpret data from AI systems and apply it in decision-making processes. Advanced Level: Able to optimize the usage of AI systems in flight training and make critical decisions based on AI data.	Understand AI principles, applications of AI in flight training, and limitations of AI.	Able to use AI systems for flight training, interpret AI data, and make decisions based on AI outputs.	Maintain a problem-solving attitude, adaptability to new technologies, and ethical awareness in AI usage.
Aerospace Engineering Competence Area: Digital Content Creation (Area 3 in DigComp 2.2) Competence: Application of AI in aerospace engineering and design	Foundation Level: Understand how AI can aid in the design process and predictive maintenance. Intermediate Level: Able to use AI tools for aircraft design and simulation. Advanced Level: Able to use AI tools to optimize designs, troubleshoot AI system errors, and adapt AI tools for specific engineering tasks.	Understand AI principles, applications of AI in aerospace engineering, AI tools, and programming languages.	Able to use AI tools for aircraft design, interpret results from AI systems, and troubleshoot these systems.	Maintain a creative and analytical mindset, adaptability to new technologies, and ethical considerations in AI usage.
Aviation Management Competence Area: Problem-Solving (Area 5 in DigComp 2.2) Competence: Incorporation of AI in aviation management processes and decision-making.	Foundation Level: Understand the basic principles of AI and how AI can optimize scheduling and routing and improve customer service. Intermediate Level: Able to use AI tools in team decision-making processes and customer service. Advanced Level: Able to integrate AI decision-making tools with human oversight, manage data-driven teams, and make final decisions when AI suggestions conflict with traditional methods.	Understand AI principles, applications of AI in aviation management, AI tools, and data analysis.	Able to use AI tools for decision-making, interpret AI data, and manage AI in a team environment.	Maintain a problem-solving attitude, adaptability to new technologies, and ethical awareness in AI usage.
Air Traffic Control Competence Area: Communication and Collaboration (Area 2 in DigComp 2.2) Competence: Application of AI in air traffic control processes and communications.	Foundation Level: Understand the basic principles of AI and how AI can predict flight patterns and manage air traffic. Intermediate Level: Able to use AI-enhanced communication tools and collaborate with AI in traffic management. Advanced Level: Able to make decisions when AI predictions conflict with human judgment, use AI tools under stressful conditions, and troubleshoot these tools when necessary.	Understand AI principles, applications of AI in air traffic control, AI-enhanced communication tools, and data analysis.	Able to use AI tools for air traffic management, interpret AI data, and manage AI in high-stress situations.	Maintain a problem-solving attitude, adaptability to new technologies, and ethical considerations in AI usage.

Table 4. *Cont.*

Aviation Area	Proficiency Levels	Knowledge	Skills	Attitudes
Aircraft Maintenance and Repair Competence Area: Digital Content Creation (Area 3 in DigComp 2.2) Competence: Application of AI in aircraft maintenance and repair processes.	Foundation Level: Understand the basic principles of AI and how it can be used in predictive maintenance, fault detection, and quality assurance. Intermediate Level: Able to use AI tools for predictive maintenance and fault detection and implement AI findings into repair strategies. Advanced Level: Able to use AI for diagnostics, troubleshoot AI system errors, and keep AI tools up to date with evolving technologies.	Understand AI principles, applications of AI in aircraft maintenance and repair, AI tools, and data analysis.	Able to use AI tools for aircraft maintenance and repair, interpret AI data, and implement AI in repair strategies.	Maintain a problem-solving attitude, precision in implementing AI suggestions, adaptability to new technologies, and ethical awareness of AI usage.
Aviation Technology Competence Area: Problem-Solving (Area 5 in DigComp 2.2) Competence: Incorporation of AI in aviation technology systems.	Foundation Level: Understand the basic principles of AI and how AI can be used to improve navigation systems, cockpit automation, and fuel efficiency. Intermediate Level: Able to use AI tools for enhancing aviation technology, interpret AI data, and implement AI findings into technology improvements. Advanced Level: Able to manage and troubleshoot AI tools, integrate AI with traditional aviation technology practices, and adapt AI tools to specific technology needs.	Understand AI principles, applications of AI in aviation technology, AI tools, and data analysis.	Able to use AI tools for aviation technology, interpret AI data, and implement AI in technology improvements.	Maintain a problem-solving attitude, precision in implementing AI suggestions, adaptability to new technologies, and ethical considerations in AI usage.
Aviation Safety Competence Area: Safety (Area 4 in DigComp 2.2) Competence: Integration of AI in aviation safety measures and risk assessments.	Foundation Level: Understand the basic principles of AI and how it can be used in accident prediction, risk assessment, and safety improvement. Intermediate Level: Able to use AI tools for safety management, interpret AI data, and implement AI findings into safety strategies. Advanced Level: Able to use AI for comprehensive risk prediction, manage AI tools for optimum safety, and make critical decisions when AI predictions conflict with human judgment.	Understand AI principles, applications of AI in aviation safety, AI tools, and data analysis.	Able to use AI tools for aviation safety, interpret AI data, and implement AI in safety strategies.	Maintain a safety-first attitude, precision in implementing AI suggestions, adaptability to new technologies, and ethical awareness in AI usage.
Aeronautics/Aviation Science Competence Area: Digital Content Creation (Area 3 in DigComp 2.2) Competence: Application of AI in aeronautical research, development, and design.	Foundation Level: Understand the basic principles of AI and how it can be used to enhance aerodynamics, optimize fuel consumption, and assist in research and development. Intermediate Level: Able to use AI tools for aeronautical research and design, interpret AI data, and implement AI findings into aeronautical strategies. Advanced Level: Able to interpret results from AI tools, integrate AI with traditional aeronautical practices, troubleshoot AI system issues, and keep AI tools up to date with evolving technologies.	Understand AI principles, applications of AI in aeronautics/aviation science, AI tools, and data analysis.	Able to use AI tools for aeronautical research and design, interpret AI data, and implement AI in aeronautical strategies.	Maintain a problem-solving attitude, precision in implementing AI suggestions, adaptability to new technologies, and ethical considerations in AI usage.

For these transformations to be successful, universities will need to ensure that their IT infrastructures are up-to-date and capable of supporting AI systems and that they have a clear strategy for how AI will be integrated into their operations. Additionally, universities will need to invest in the training and development of their staff to ensure that they are able to effectively utilize AI technologies and respond to any challenges that arise [46].

Particular attention should be paid to special competencies that were required precisely after the advent of the mass use of AI.

As an example of using the proposed methodological approach to the development and modernization of aviation educational programs, let's consider the case study using the Aviation Engineering Bachelor Program as an illustration.

This study employs a text-mining methodology leveraging semantic analysis techniques and natural language processing tools. The objective is to identify keywords semantically related to the domain of digital competencies and subdomains of Artificial Intelligence and Machine Learning. The data source is Educations.com [63], a database containing university study programs aimed at matching student needs with university offers.

Initially, 65 bachelor's degree programs under the Aviation category were selected for screening. After further filtering, 14 universities offering 16 relevant engineering aviation study programs that remained matching the initial concept of examining engineering aviation studies were selected for analysis. Programs focusing predominantly on management were excluded. The program descriptions on the homepages were annotated for keywords within the semantic field of digital competencies and of machine learning and artificial intelligence subfields. The keywords were not pre-selected due to the ambiguity of natural language.

The annotation was performed by three subject matter experts with PhDs in natural language processing and aviation engineering. The annotated corpus is available at [65].

The methodology comprises:

- Screening 65 aviation-related bachelor's programs to identify relevant engineering programs.
- Excluding programs focusing predominantly on management, 16 programs were selected for final analysis.
- Annotating program descriptions for keywords related to the digital field and machine learning and artificial intelligence subfield.
- Leveraging the expertise of subject matter experts in natural language processing and aviation engineering
- Making the annotated corpus available to facilitate further research.

This rigorous methodology aims to identify aviation engineering programs with a potential focus on emerging technologies such as artificial intelligence and machine learning. The annotated corpus can serve as a basis for further quantitative and qualitative analyses to gain insights into a current reflection of AI technologies in the obtained competencies of young aviation professionals.

Sixteen engineering aviation programs from 14 universities, listed in the Educations.com database [63], were annotated for keywords semantically related to the digital competencies field and to the artificial intelligence subfield.

This corpus, *European Aviation Engineering Bachelor Programs,* has one document with 25,197 total words and 3423 unique word forms. Basic characteristics are as follows:

- Vocabulary Density: 0.136.
- Readability Index: 17.653.
- Average Words Per Sentence: 27.5.

The most frequent words in the corpus are engineering (387), aircraft (190), students (152), year (136), and course (134).

Table 5 reflects the programs and annotated words in the semantic field of digital competencies and in the semantic subfield of machine learning and artificial intelligence.

To visualize links between terms, the visualization using Voyant Tools [66] was conducted. The tool can show both how often a word showed up and what words came most after that word. It shows the graph of all the most common words in the form of a network analysis graph. This tool can show both how often a word showed up and what words came most after that word. For keywords, it is the corpus frequency; for collocates it is the frequency in the context of the linked keywords.

The frequency and links diagram in Figure 5 gives a link analysis of the first 12 words in the corpus. This diagram, for example, shows links for the words engineering (the most frequent word in the corpus with a frequency of 387) with links to aircraft (190 links), students (152), knowledge (39), mechanics (29), and aerospace (27).

The links and frequencies would demonstrate which topics and concepts are most central in the corpus based on word associations.

Also, closely related concepts that frequently co-occur in the text will tend to cluster together in the cirrus diagram, visualized in the Voyant Tools text analysis environment [66], in Figure 6, visually indicating semantic similarity in 125 first most frequent terms. The word "*Engineering*" is the center of the semantic cloud, which is reflected by its frequency.

Table 5. DigComp keywords distribution among European Aviation Engineering bachelor programs.

Study Program	University, Country	Digital Competences Field	AI and ML Competences Subfield
1. BSc Aviation Engineering	Kaunas University of Technology Lithuania, Kaunas	Computer, Information Technology, Automate	Automate: Automated aircraft design systems
2. Aerospace Engineering Design	Universidad European, Madrid, Spain	Computer, Digital, Robot-, Automate	Automate: The basic principles of flight control and automation.
3. Aviation Engineering	Transport and Telecommunication Institute, Latvia		
4. BSc in Aeronautical Management	Higher Institute of Education and Sciences, Portugal	Computer	
5. Aerospace Engineering	Brunel University London, UK	Computer, Digital, Robot, Software, Programming	Simulator: Full-motion engineering flight simulator.
6. Aircraft Engineering with Pilot Studies	University of Salford, UK	Computer, Robot, Automate, Software, Programming, Coding	Simulator: Merlin MP520-T Engineering Flight Simulator provides you with practical experience in aircraft design), Automate: This module will give you an in-depth knowledge of flight instruments, flight management, and automatic flight.
7. Aviation Engineering	Kingston University, UK	Digital, Software	
8. Professional Aviation Engineering Practice	City College Norwich, UK	Computer, Digital	
9. BSc Transport (Avia)	Silesian University of Technology, Germany	Computer, Information Technology, Automate, Programming	Automate: IT module (automation and control, information technology, programming, etc.)
10. Aircraft Engineering	University of the Highlands and Islands, UK	Software	
11. Aerospace Engineering in Air Navigation	Rey Juan Carlos University, Spain	Computer, Programming, Database	
12. Aerospace Engineering in Transportation and Airports	Rey Juan Carlos University, Spain	Computer, Automate, Programming, Database	Automate: The fundamentals of fluid mechanics; the basic principles of flight control and automation.
13. Aerospace Engineering in Aerospace Vehicles	Rey Juan Carlos University, Spain	Computer, Automate, Programming, Database	Automate: The fundamentals of fluid mechanics; the basic principles of flight control and automation.
14. Aircraft Maintenance Engineering	Solihull College & University Centre, UK	Computer, Software	Simulator: The Centre for Advanced Aeronautical provision is fully equipped, including an aviation hangar housing a Jetstream aircraft and a 737 simulator.
15. Aerospace Engineering	University of Cardiff, UK	Digital	Simulator: This course will include a live flight experience, which is reinforced with SIM work in a Flight Simulator.
16. Bachelor of Engineering in Aeronautical Engineering	University of Limerick, Ireland	Computer	

The diagram in Figure 6 visually represents the intensity and relatedness of the topics and concepts within the aviation engineering bachelor corpus. Critically, AI is missing completely from the word cloud.

The diagrams visually demonstrate that universities stress the concept of *engineering*, the concept of knowledge, and air transportation-related words in their initial communication to students, displaying the future 4 or 5 years of studying outcomes. The concept of artificial intelligence is not reflected in the diagrams.

The focus has to be on learning outcomes that demonstrate both conceptual knowledge and practical application of AI techniques using real-world aviation data and technologies.

Figure 5. Frequency and links of the first 12 words in the corpus.

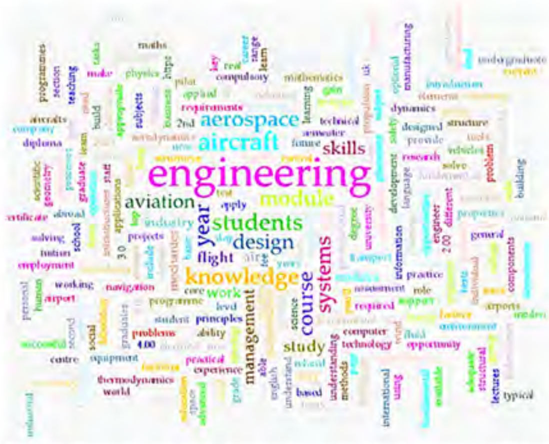

Figure 6. Cirrus diagram of the Aviation Engineering Bachelor corpus, 125 first most frequent terms.

4.7. Summary of Results

This subsection presents the main results obtained using the methodology proposed in the previous Section 3. The following tables and figures reflect the results of the corresponding Blocks from the methodology in Figure 1:

- Block 1: Figure 2. "Taxonomy of traditional aviation sectors".
- Block 2: Table 1. "The general classification of education programs for the aviation industry".
- Block 3: Figure 3. "The taxonomy of aviation areas with AI applications".
- Block 4: Table 2. "The description of AI implementation in the aviation industry and aviation education", Table 3. "Core AI-driven competencies for the aviation area" and Figure 4. "Taxonomy of AI applications in aviation training".
- Block 5: Table 4. "AI-driven aviation competences in DigComp 2.2 framework".
- Block 6: Table 5. "DigComp keywords distribution among European Aviation Engineering bachelor programs", Figure 4. "Frequency and links of the first 12 words in the corpus", and Figure 5. "Cirrus diagram of the Aviation Engineering Bachelor corpus, 125 first most frequent terms".

The results obtained through this multi-faceted methodology reveal that current aviation bachelor's programs do not sufficiently develop the AI competencies and literacies needed for the industry's increasing technological transformation. While foundational digital skills are incorporated, focused instruction in core areas like machine learning, data science, and human-AI collaboration is generally lacking but urgently required. Bridging this gap will demand proactive efforts to map competencies, redesign curricula, upskill faculty, and collaborate across academia, industry, and government. Aviation education must keep pace with the field's accelerating digital future. Equipping the next generation with relevant knowledge and abilities will allow human expertise to complement aviation AI technologies synergistically. This study provides an initial competency framework and implementation roadmap aimed at guiding aviation training programs to prepare graduates for leading this intelligent aviation future.

5. Discussion

While Table 5 shows that many aviation and aerospace engineering programs incorporate digital technologies and computer skills, it does not indicate a strong focus on artificial intelligence and machine learning competencies at the bachelor's level. As seen in Table 5, while keywords related to digital technologies appear frequently, explicit mentions of AI and ML topics are rare. Only 9 out of 16 programs' descriptions contained any AI/ML keywords, and they are just generic terms like "simulation" and "automate-".

There are several potential reasons for the limited focus on AI and ML competencies in aviation bachelor's programs. Firstly, AI and ML are still emerging technologies in aviation, so programs may be cautious about altering curricula until the benefits are proven and technical challenges are resolved. Additionally, AI skills like data science do not fit neatly into traditional engineering curricula. Aviation companies are also still evaluating how to integrate AI operationally, so clear workforce requirements have not emerged yet. Furthermore, aviation AI involves advanced applications more common at the graduate level. There are also regulatory and ethical implications still being assessed that give programs pause. Finally, faculty themselves often lack exposure to guide students in these rapidly evolving topics. In summary, aviation bachelor's programs appear slow to adapt due to the cutting-edge nature of AI, lack of industry clarity on needs, the specialized skills required, and faculty themselves needing upskilling in this novel area. More collaboration between academia, industry, and regulators could help define aviation AI competency requirements to spur curricular innovation. While digital technologies are becoming increasingly integrated into aviation engineering programs, full-fledged AI and ML competencies are likely still beyond the scope of most bachelor's level curricula at this point. As the industry and technologies mature, we may see more bachelor's programs emerge that aim to produce "AI-ready" aerospace engineers.

Based on the analysis of evolving industry needs, the following framework is proposed for integrating essential AI competencies into aviation programs. The framework comprises three primary areas.

A. Conceptual AI Knowledge Areas

To work effectively with AI systems, aviation professionals require foundational knowledge across key AI concepts, including:

- Machine learning—understanding supervised, unsupervised, and reinforcement learning models.
- Neural networks—knowledge of deep learning architectures and training techniques.
- Natural language processing—comprehending how NLP systems analyze text and language.
- Computer vision—principles of how AI can identify patterns in visual data.
- AI ethics—awareness of ethical issues like bias, transparency, and responsibility.

Aviation curricula should incorporate modules on each of these topics to cultivate conceptual literacy regarding the techniques and technologies powering modern AI systems.

B. Technical Skills and Tool

Hands-on abilities to build, implement, and apply AI systems are critical. Key skills include:

- Coding in languages like Python and R to program AI algorithms.
- Working with AI development platforms such as TensorFlow and PyTorch.
- Data analysis and visualization to prepare, understand, and interpret AI training data.
- Using AI APIs and cloud services like AWS AI to integrate smart systems.
- Monitoring, maintaining, and retraining AI models in production environments.

Aviation programs need to provide lab courses and projects that allow students to actively experiment with AI tools and technologies.

C. Human-AI Collaboration Skills

Since AI will work alongside humans, aviation professionals need abilities like:

- Identifying high-value opportunities for AI augmentation in aviation tasks.
- Communicating and coordinating effectively with AI agents.
- Judging when to rely on AI systems vs. human expertise and experience.
- Explaining and justifying AI model behaviors and decisions.
- Monitoring AI for accuracy, errors, bias, and unintended consequences.

Developing these collaboration abilities requires curriculum activities and simulations working jointly with AI systems.

While identifying the AI competencies needed in aviation education is crucial, equally important is laying out actionable steps to integrate these competencies into aviation curricula. A detailed roadmap can provide guidance to put the methodology into practice in order to achieve the desired workforce development outcomes.

A roadmap that breaks down the methodology into discrete, sequential stages empowers stakeholders to undertake the multi-faceted process of curriculum reform [67]. By clearly delineating activities like forming expert teams, collecting aviation AI adoption data, holding industry workshops, mapping competencies, and formulating recommendations, aviation educators can progress through the methodology in a structured manner.

The roadmap approach lays the groundwork for iterating on the methodology over time. As new technologies emerge, the process can be repeated to continuously refresh competencies. By maintaining the roadmap structure, future competency identification initiatives can build on existing foundations in a consistent fashion.

A roadmap for implementing an aviation AI competency methodology could include the following step-by-step procedures (Figure 7):

1. Form a cross-functional research team. Assemble a team that includes aviation educators, AI experts, industry representatives, and education policymakers. This facilitates collaboration and buy-in.
2. Select focus aviation domains. The team selects which professional areas and occupations to focus the competency analysis on based on the maturity of AI adoption.
3. Gather data on AI adoption. Conduct an environmental scan to collect data on current and emerging AI applications across the focus aviation domains.
4. Hold industry workshops. Host workshops with aviation organizations to identify examples of AI integration and resulting competency requirements.
5. Map core aviation competencies. Analyze focus aviation professions to identify traditional education requirements and learning outcomes.
6. Identify new AI knowledge needs. Determine essential conceptual AI competencies professionals will require specific to their role.
7. Identify new applied AI skills. Determine key applied skills needed to collaborate and work alongside AI technologies in each domain.
8. Develop AI competency framework. Organize identified competencies into a structured framework mapped to an established digital competence model.
9. Collect aviation program data. Gather syllabi, learning outcomes, and course information from existing aviation programs.
10. Compare programs vs. frameworks. Analyze programs to identify gaps between current and needed AI competencies.
11. Formulate recommendations. Develop specific recommendations to address competency gaps through curricular updates and new courses.
12. Share recommendations. Disseminate the competency framework and implementation roadmap to aviation education institutions and accreditation bodies.
13. Track adoption. Establish mechanisms to monitor uptake and iterate on the framework over time to align with evolving technologies.

Figure 7. Roadmap for implementing an aviation AI competency methodology.

By building aviation education programs that cultivate this combination of conceptual, technical, and collaborative competencies, universities can equip graduates to operate at the forefront of intelligent aviation systems and harness the benefits of AI responsibly and effectively. In Table 6, there are some examples of how AI-based competencies could be integrated into professional aviation courses in European bachelor's programs.

Table 6. Examples of courses with embedded AI content.

Courses	Embedded AI Content
Aircraft Systems	Introduce AI-based fault detection and diagnostics tools for troubleshooting aircraft systems. Have students train machine learning models on aircraft sensor data.
Aerodynamics	Incorporate AI simulation and modeling tools like neural networks to predict aircraft performance. Students can compare AI aerodynamic models vs. analytical models.
Aviation Data Analytics	Focus on developing skills in analyzing aviation data sets using Python/R and applying machine learning techniques for tasks like predictive maintenance.
AI for Pilots	Dedicated course on AI applications in avionics, air traffic control, and flight planning. Hands-on projects with flight simulators and AI assistants.
AI for Aviation Operations	Survey AI use cases across airlines, airports, MROs, and air navigation. Group projects on prototyping AI tools for ops optimization.
Aviation Information Systems	Adding AI components like virtual assistants, chatbots, and recommendation engines. Assignments on natural language processing applications.
AI Ethics in Aviation	Seminar-style course discussing responsible use of AI in aviation, examining biases, privacy concerns, etc. Student debates on regulatory issues.

Both foundational and specialized AI courses could be offered, integrated into traditional aviation engineering topics, or as dedicated AI programs. The focus should be on experiential learning using real-world data.

While aviation industry leaders are advocating AI adoption, this vision has not yet fully translated into updated competency requirements for bachelor's graduates. The lack of AI curricular focus indicates a potential gap between stated goals for an AI-driven future and current educational preparation.

As the field evolves, dedicated bachelor's programs in aviation-focused AI may emerge. But presently, students seem to be obtaining foundational exposure to digital technologies rather than specific AI/ML skills. Further research should probe the causes and explore solutions to align aviation engineering education with the growing integration of artificial intelligence in the industry. More collaboration between educators, regulators, and aviation technology professionals can help define the required competencies and curricular innovations needed.

While integrating AI competencies into aviation curricula is critical, thoughtful implementation will be vital to ensure effective outcomes.

A. Implementation Challenges and Mitigation Strategies:

- Curriculum redesign requires time and faculty/industry consensus. A phased rollout focusing first on electives and pilot modules can help build gradually.
- Developing new lab infrastructure and purchasing AI software/hardware entails financial investment. Pursuing public and private funding sources can help overcome costs.
- Faculty will need support in developing expertise in AI technologies. Multi-phase professional training, industry exchanges, and hiring specialized AI lecturers can build capacity.
- Increased emphasis on data science may require trade-offs with traditional aviation coursework. Holistic curricular reviews should aim for balanced integration.
- Legal and ethical risks around data privacy, AI bias, and model transparency will need ongoing governance. Developing codes of conduct and review boards can help manage concerns.

B. Future Research Needs

- Ongoing studies will be needed to benchmark implementation efforts and assess the efficacy of AI aviation education.
- More research should identify effective pedagogies for teaching technical AI concepts in aviation contexts.
- Additional work should explore how aviation AI competencies translate into career readiness and performance.
- Research partnerships between institutions will be valuable to share best practices in aviation AI education.

C. Implications for Students, Educators, Regulators, and Industry

- Students will gain relevant skills for the AI-driven job market while also maintaining aviation expertise.
- Educators take on new curriculum design and teaching challenges but prepare students for the future.
- Regulators and accreditors enable progress by supporting new standards and program iterations.
- Industry stakeholders aid training programs via partnerships and can recruit work-ready graduates.

The thoughtful integration of AI competencies into aviation education promises a generational step forward. But realizing the vision will require ongoing research, creativity, collaboration, and commitment from all involved stakeholders.

This study has certain limitations that should be considered when interpreting the findings:

14. The study only considers aviation engineering programs at European universities that are listed in the Educations.com database and described in English. Programs from other regions and databases are excluded.
15. The analysis relies on program descriptions at university homepages such as syllabi, and course outlines as the sole data source. Other sources were not consulted. The concept is that universities demonstrate the most important study outcomes openly

on their web pages. The study assumes that the most relevant information about programs, including key learning outcomes, is communicated through program descriptions on university websites. However, extended syllabi and course outlines not presented on the program homepage may have provided additional insights into the extent of artificial intelligence and machine learning content within the programs.

16. The annotation of key terms related to artificial intelligence and machine learning depends on the semantic interpretation of the experts involved. The ambiguity of natural language precludes the use of pre-defined keyword lists. This introduces a degree of subjectivity into the annotation process.
17. The study only considers programs at the bachelor's level. Postgraduate programs are outside the scope of this research.
18. The annotated corpus has not been validated through independent annotation by additional experts or computational methods.

These limitations mean that the findings may not be generalizable to all aviation engineering programs globally. The study provides a preliminary analysis of a subset of European bachelor's programs with respect to their potential focus on artificial intelligence and machine learning. Further research with an expanded scope and more rigorous methodology would be needed to draw firmer conclusions.

Nevertheless, within the constraints of its limitations, this exploratory study provides novel insights and a basis for future investigations into this important topic.

As we contemplate the integration of AI into the aviation industry, several pivotal questions arise that warrant comprehensive exploration:

1. The Anticipated Evolution of AI in Aviation. Over the coming decade, we envision AI solidifying its presence across the aviation landscape. Key areas of integration include maintenance—where predictive maintenance powered by AI will be the norm—air traffic management, in-flight services, and the enhancement of passenger experiences. Moreover, AI-enhanced simulations are expected to become a cornerstone of pilot training, revolutionizing the manner in which pilots are equipped to handle real-world scenarios.
2. Challenges and Considerations for AI-centric Aviation Education. A global introduction of an AI-centric curriculum in aviation is fraught with challenges. These range from reconciling diverse pedagogical standards and contending with varying levels of technological infrastructure to ensuring educators themselves are proficient in the principles and pragmatic applications of AI.
3. Safety Protocols in the Age of AI. The sanctity of safety in aviation remains paramount. To ensure that AI's integration does not inadvertently compromise this, stringent testing of AI systems in simulated environments is essential. Collaborations with AI specialists during the design and execution phases, complemented by persistent human oversight—especially in high-stakes decision-making junctures—will be critical.
4. AI Technologies Taking the Lead. While AI's tentacles will spread wide, certain technologies are poised to be especially transformative. We project that machine learning models (especially for predictive maintenance), natural language processing (for augmenting passenger experience), and reinforcement learning (for optimizing air traffic patterns) will be at the forefront.
5. Harmonizing Human Expertise with AI. The future lies not in choosing between human expertise and AI but in orchestrating a harmonious collaboration between the two. Continuous training and the upskilling of aviation professionals will be instrumental in achieving this balance.
6. Navigating the Ethical Airspace. The ethical implications of integrating AI into aviation are profound. From ensuring unbiased AI behavior to championing transparency and explainability in AI-driven decisions, the industry must tread with caution and conscience.
7. The Quest for Global AI Standardization in Aviation. This is perhaps one of the most challenging endeavors, necessitating collaborations between global aviation

bodies, adaptive regulatory frameworks, and an agility to keep pace with swift technological evolutions.

Incorporating these discussions enables a holistic understanding of the road ahead, arming stakeholders with the insights needed for an informed, strategic embrace of AI in aviation.

6. Conclusions

This study analyzed aviation engineering programs at European universities to determine if they are sufficiently preparing graduates for the AI transformation underway in the aviation industry. The results reveal a lack of emphasis on building conceptual knowledge and hands-on skills in core AI technologies within current bachelor's level curricula. While foundational digital competencies are often incorporated, explicit development of machine learning, data science, and human-AI collaboration abilities appears limited.

The reasons likely include the relative newness of aviation AI, its specialized nature, and challenges to implementation that cause programs to take a cautious approach. However, the policy guidance and initiatives from major regulatory bodies clearly indicate that AI is considered an essential emerging technology across all operational domains. Developing an expert workforce is critical to realizing the proclaimed benefits and safely managing risks.

A comprehensive methodology and competency framework were proposed to help aviation educators systematically identify skill gaps and reform curricula accordingly. This entails both conceptual AI literacy and applied human-AI interaction competencies relevant to professionals. A detailed implementation roadmap can guide the multifaceted process of integrating AI effectively into aviation programs while maintaining rigor. As the field continues maturing, dedicated bachelor's programs focused on aviation AI may emerge. But waiting for full technological maturity risks aviation education lagging behind industry advancements. Thoughtful, phased implementation of AI competencies promises aviation graduates who can contribute meaningfully to the industry's intelligent future. This will require collaboration between educators, regulators, and technology leaders to match the rapid pace of AI progress.

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