International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 11 Issue: 10 | Oct 2024 www.irjet.net p-ISSN: 2395-0072

Navigating the Skies: The Necessity for Upgrading Air Traffic Control Systems

Andrew Renault[1], Michael Johnson[2]

[1] *Grad Student, Dept. of Aeronautical Science, Capital Technology University, South Laurel, Maryland, USA*
[2] *Adjunct Professor, Dept. of Aeronautical Science, Capital Technology University, South Laurel, Maryland, USA*

* * *

Abstract - *The existing Air Traffic Control (ATC) systems face mounting challenges due to increasing global air traffic, the widespread use of Unmanned Aerial Vehicles (UAVs), and outdated radar and communication technologies. These issues are exacerbated by emerging cybersecurity threats and human factors risks, creating significant safety and operational concerns. The ATC infrastructure, originally designed for conventional manned aircraft, struggles to meet the demands of modern aviation, which includes managing higher air traffic volumes and diverse aircraft types. This paper examines the limitations of current ATC systems, emphasizing the need for technological upgrades such as multi-sensor radar integration, AI-driven decision support, and robust cybersecurity measures. Additionally, the paper explores human factors considerations and the challenges associated with UAV integration. The discussion highlights the necessity for comprehensive reforms to ensure the continued safety, efficiency, and resilience of airspace management. Future recommendations include enhancing radar coverage, implementing encrypted communication protocols, and developing adaptive automation solutions that improve safety outcomes while accounting for human limitations.*

Key Words: ATC, UAV, AI, Cybersecurity, Flight Safety, Human Factors

1. INTRODUCTION

Air Traffic Control (ATC) systems are currently encountering unprecedented challenges that threaten the safety and efficiency of the global aviation industry. The continuous surge in global air traffic and the rapid proliferation of Unmanned Aerial Vehicles (UAVs) have significantly strained traditional ATC frameworks. Originally designed to manage manned aircraft within structured environments, the existing radar and communication technologies are increasingly inadequate for addressing the complexities of today's airspace. The integration of UAVs, along with the sheer volume of flights, has outpaced the capabilities of these outdated systems, exposing critical limitations that must be addressed urgently [1, 2, 3, 4, 5].

In addition to handling increased traffic and UAV integration, ATC systems face evolving cybersecurity risks and safety concerns linked to human factors. These digital vulnerabilities and operational challenges further complicate an already congested airspace, underscoring the necessity for modernizing ATC infrastructure. Without substantial upgrades in technology, security measures, and safety protocols, ATC will struggle to keep pace with the demands of contemporary aviation [5, 6].

To meet these challenges, immediate advancements are required in key areas such as radar and communication protocols, AI-driven automation, and enhanced cybersecurity strategies. These improvements are crucial to accommodate the growing diversity of airspace users while mitigating safety risks associated with congestion, unauthorized UAV operations, and potential digital threats [7, 8, 9].

2. THE PROLIFERATION OF UAVS

The integration of UAVs into the airspace presents significant challenges for current ATC systems, which were originally designed for manned aircraft operations. UAVs typically operate at lower altitudes, often in airspace that is more congested and complex than traditional flight corridors [9, 10, 11, 12]. Their rapid proliferation, driven by commercial, recreational, and industrial uses, has created an urgent need for new traffic management solutions to safely accommodate these aircraft within shared airspace. As the number of UAVs continues to rise, the pressure on existing ATC frameworks intensifies, necessitating innovative strategies to maintain airspace safety and efficiency [13, 14].

UAVs introduce specific risks related to mid-air collisions and increased airspace congestion, especially in low-altitude regions where both manned and unmanned aircraft operate. Traditional radar systems, which rely on cooperative data exchange and transponder signals from aircraft, struggle to detect UAVs that may lack such equipment. This reduced visibility significantly complicates the management of UAVs within existing ATC systems, where manual tracking of these vehicles is impractical due to their sheer numbers and rapid movement [10, 11, 12]. Current ATC systems are not equipped to handle the unique characteristics of UAVs, leading to a growing need for advanced detection and monitoring capabilities.

Efforts to integrate UAVs into national airspace involve the development of specialized Unmanned Traffic Management (UTM) systems, which aim to provide autonomous traffic management solutions for UAVs. However, these systems are still in the early stages of development and face numerous technological, regulatory, and operational challenges. Considerable investment is required to advance UTM infrastructure, including enhancing radar capabilities, deploying more sophisticated tracking systems, and establishing comprehensive regulatory frameworks that address the unique requirements of UAV operations [10, 11, 12]. As UAV usage expands across various industries, including delivery, agriculture, and surveillance, the importance of improving detection technologies and refining traffic management strategies becomes ever more critical for ensuring the safety of both manned and unmanned aircraft in shared airspace [3, 5, 7, 9].

Figure 1: UAV impacts to ATC

3. INCREASE IN GLOBAL AIR TRAFFIC

The global demand for air travel is rising sharply, with substantial growth expected in passenger numbers, as well as civilian, military, and freight flights. The Federal Aviation Administration (FAA), aviation agencies, and major airplane manufacturers project a 2.7% annual increase in U.S. air traffic, forecasting approximately 1.8 billion passengers by 2036 [6, 16, 17, 18, 19]. On a global scale, billions of passengers are anticipated to travel annually by 2040, significantly intensifying airspace congestion and placing enormous strain on existing ATC systems [2, 6]. The rapid expansion of air travel, driven by economic growth, the globalization of markets, and the increased accessibility of air transportation, necessitates immediate upgrades to ATC infrastructure to prevent widespread delays and inefficiencies.

As airspace congestion worsens, the limitations of radar-based ATC systems become increasingly apparent. Traditional radar technologies, which are the backbone of current ATC operations, struggle to manage the large volume of data required for real-time traffic monitoring and control [1, 2, 6]. These systems rely on maintaining greater aircraft separation distances to ensure safety, but this approach reduces airspace efficiency and increases the potential for mid-air collisions as traffic density rises [2, 5, 6, 7]. The inability to handle higher traffic volumes with existing technology results in more frequent delays and diminished operational effectiveness, underscoring the need for technological advancements in air traffic management.

Forecasts predict that air traffic will increase over the next two decades, propelled by growing passenger demand, expanding airline fleets, and the economic integration of global markets [6, 12, 16, 17, 18, 19]. However, current radar systems are not equipped to accommodate this surge in traffic. The reliance on wide separation distances to maintain safety becomes increasingly untenable as flight operations expand, creating bottlenecks in airspace usage and elevating safety risks. Addressing these challenges will require modernizing ATC systems to integrate real-time data processing capabilities, AI-driven traffic management solutions, and more advanced communication technologies to optimize flight operations and improve airspace utilization [1, 12, 13, 22]. Additionally, investments in automation and predictive analytics will be crucial for enhancing traffic flow management and reducing congestion-related delays.

Table 1: Air Traffic Forecast Data and ATC limitations.

Year	Projected Passengers (in billions)	Annual Traffic Growth (%)	Projected ATC Limitations	Impact on Airspace Efficiency
2024	1.3	2.7%	Radar Data Limitations	Increased Separation Distances
2030	1.6	3.0%	Inefficient Data Processing	Delays, Airspace Congestion, Inefficiencies
2036	1.8	3.1%	Automation Safety Challenges	Mid-Air Collision Risks, Loss of Separation
2043	2.4	3.5%	Cybersecurity Vulnerabilities	Threat to ATC Operations and Safety Systems

4. LIMITATIONS OF RADAR AND COMMUNICATIONS

The reliance on outdated radar and communication systems presents significant challenges in current ATC operations. Although traditional radar systems have provided reliable service in the past, they are increasingly inadequate for managing the complexities of modern aviation. These systems offer limited coverage, particularly at low altitudes, and suffer from delays in relaying critical information, which hampers the ability to ensure safe and efficient airspace management [6]. As the aviation landscape evolves with the rise of UAVs and increasing air traffic, the limitations of conventional radar technology have become more pronounced, necessitating the adoption of more advanced solutions.

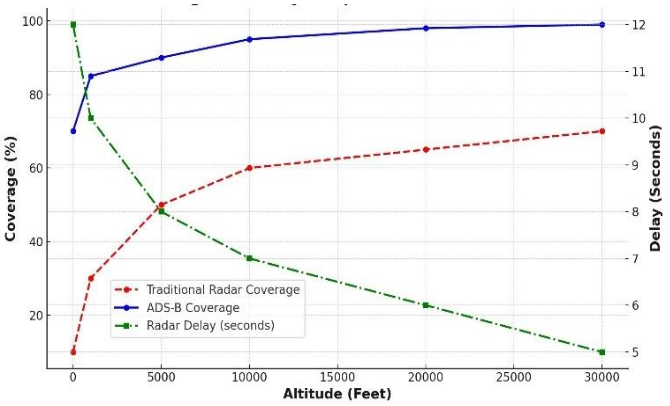

Chart 1: Comparison of Radar Coverage and Delays: Traditional vs. ADS-B Systems.

The transition to NextGen ATC systems, spearheaded by the FAA, aims to address these shortcomings by leveraging cutting-edge technologies. NextGen incorporates Automatic Dependent Surveillance-Broadcast (ADS-B) and Performance-Based Navigation (PBN) to enhance aircraft tracking and communication accuracy. ADS-B, which utilizes satellite-based tracking, enables more precise real-time data exchange between aircraft and ATC, thereby reducing required separation distances and improving operational efficiency [6]. Despite these advancements, ADS-B is not without its challenges. The system remains vulnerable to cybersecurity threats, such as spoofing and data interception, due to the unencrypted nature of its signals, posing risks to aviation safety and security [14, 15, 22, 23].

Table 2: Comparison of Radar and ADS-B Systems

System	Low Altitude Coverage	Real-Time Data	Delay Time (Seconds)	Cybersecurity Risk
Traditional Radar	Limited	No	10–30	Low
ADS-B	Extensive	Yes	1–5	High

Moreover, the shift towards NextGen technologies, while a significant improvement over traditional systems, does not fully resolve the limitations associated with radar coverage and communication capabilities. Conventional radar systems, originally designed to provide high-altitude coverage for manned aircraft, struggle to reliably track low-altitude UAVs and other aircraft operating in complex and congested airspaces [3, 7, 9, 10, 12]. As UAV usage continues to grow and airspace becomes more crowded, the demand for more comprehensive and resilient tracking solutions increases.

Addressing these issues will require ongoing advancements in radar technology, including the integration of multi-sensor data fusion and satellite-based enhancements. These upgrades are essential for expanding low-altitude coverage and delivering more precise real-time information to ATC operators [10, 12]. Additionally, incorporating advanced cybersecurity measures into ADS-B and other NextGen technologies will be critical for mitigating the risks associated with unencrypted communication signals and ensuring the safety of future air traffic management [6, 14].

5. SECURITY CALLENGES IN ATC SYSTEMS

The modernization of ATC systems involves integrating advanced technologies like ADS-B and PBN, both aimed at enhancing navigation accuracy and operational efficiency. While these systems represent significant improvements over traditional radar-based ATC, they also introduce new security challenges that must be addressed to maintain aviation safety.

PBN allows aircraft to follow more precise flight paths using satellite-based systems and onboard avionics [15, 30]. This capability improves airspace utilization, reduces congestion, and enables more flexible routing. However, PBN's reliance on satellite signals exposes it to vulnerabilities such as jamming, where signal interference can degrade navigation accuracy, and potential malware insertion, which could disrupt the integrity of navigation data. Despite these risks, PBN offers stronger resistance to spoofing attacks than ADS-B due to its multi-layered verification processes and reliance on encrypted data transmissions [15, 30, 32].

NextGen Systems and Vulnerabilities: The shift towards NextGen technologies, including ADS-B, has improved tracking accuracy through satellite-based surveillance, enabling real-time data exchange between aircraft and ATC. However, the unencrypted nature of ADS-B signals makes them susceptible to spoofing and data interception, posing risks to the integrity of air traffic management [22, 23]. Upgrading traditional radar and communication systems is essential to support NextGen capabilities and manage the growing complexity of airspace, especially with the increasing number of UAVs [10, 28, 29].

Radar and Communication Limitations: Traditional radar systems are still widely used, but they struggle with low-altitude coverage and are not effective for tracking UAVs. Enhancements such as multi-sensor fusion and satellite-based improvements are necessary to fill coverage gaps and provide real-time information to controllers [10, 22, 23, 28]. With the rising number of UAVs and air traffic in general, modernizing radar and incorporating robust cybersecurity measures is crucial for future ATC operations.

The increasing risk of hijacking UAVs or even manned aircraft poses significant threats, as malicious actors could exploit hijacked aircraft for terrorism, potentially using them as weapons to target critical infrastructure or densely populated areas.

Table 3: Cybersecurity Threat Matrix for ATC Systems

Threat Type	ADS-B	Performance Based Navigation (PBN)	Ground Communication	UAV Control
Spoofing	High	Low	Medium	High
Jamming	Medium	Medium	Low	High
Data Interception	High	Low	High	High
Denial of Service (DoS)	Low	Medium	High	Medium
Malware Insertion	Low	High	High	Medium

6. HUMAN FACTORS

Human factors continue to play a crucial role in air traffic safety, as the increasing volume of air traffic and technological complexity place significant demands on air traffic controllers. Safety remains a primary concern in ATC operations, with human factors contributing significantly to the risk of errors. As ATC systems evolve and become more sophisticated, the workload on controllers can escalate, leading to cognitive overload, fatigue, and stress. These factors are known to increase the likelihood of operational mistakes, which are a leading cause of aviation accidents [8, 20, 21, 26]. Managing these human factors is critical for maintaining safety and efficiency in the ATC environment.

Efforts to mitigate these risks focus on integrating automation, AI-driven decision support, and human-centered system design. Advanced decision-support tools that reduce the cognitive load on controllers while enhancing situational awareness can improve safety outcomes by providing timely and accurate information to assist in decision-making [1]. However, balancing the benefits of automation with the need for human oversight remains a significant challenge. Over-reliance on automated systems can lead to automation bias, where controllers may trust the system's outputs without adequately verifying them, potentially overlooking errors or system failures [24, 32, 33]. This issue underscores the need for ATC systems to support a collaborative approach that combines automated assistance with active human engagement.

Moreover, as ATC systems increasingly incorporate AI and machine learning, new challenges arise concerning human-machine interaction. A trust survey on automation has highlighted that many air traffic controllers harbor concerns about AI's increasing role in decision-making, fearing that it may undermine their authority or lead to situations where they are unable to intervene effectively during system failures [31]. Ensuring that AI-driven tools are transparent and interpretable for human operators is essential to building trust and enabling effective collaboration between humans and automated systems. Incorporating human-centered design principles into future ATC systems will be crucial to achieving this balance. Such designs should prioritize user interface ergonomics, intuitive information displays, and adaptive automation levels that can be adjusted according to the controller's workload and situational demands.

In addition to cognitive factors, physical and environmental conditions can also impact controller performance. Noise, lighting, workstation ergonomics, and shift patterns all influence stress levels and fatigue, further affecting safety outcomes. Addressing these factors through comprehensive fatigue management programs, ergonomic improvements, and scheduling optimization can help reduce human error and enhance overall ATC system resilience [27, 30].

As air traffic continues to grow and ATC systems become more integrated with new technologies, ongoing training and competency development for air traffic controllers will be essential. Training programs should include simulations of high-stress scenarios and emphasize the importance of maintaining situational awareness while using automated tools. Future ATC research should explore the long-term effects of automation on human performance and investigate strategies to enhance human-machine teaming in complex operational environments [13, 24, 26, 27].

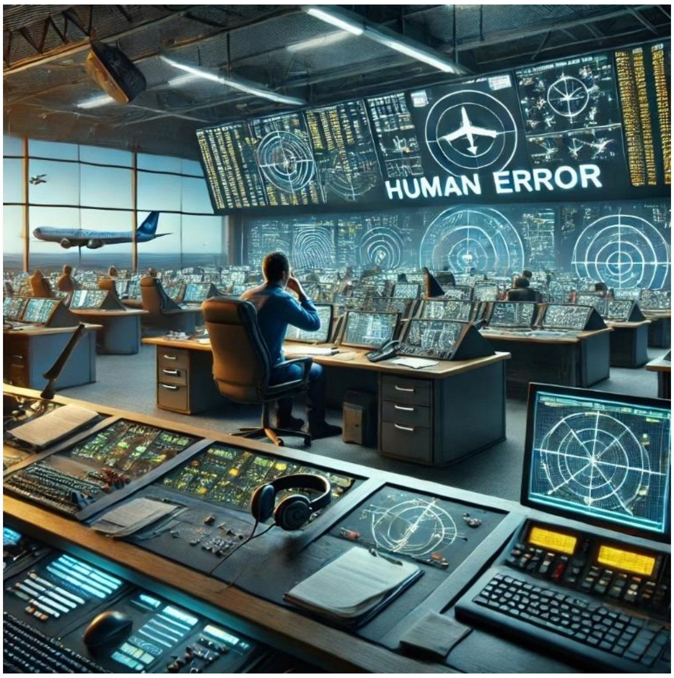

Figure 1: Human Error impacts to ATC

7. CONCLUSIONS

The escalating demand for air travel, coupled with the rapid growth of UAVs and the limitations of existing radar and communication systems, underscores the urgent need to modernize ATC systems. The current infrastructure, originally designed for conventional manned aviation, is increasingly inadequate for addressing the complexities of contemporary airspace management. Critical issues include not only outdated technology but also emerging cybersecurity vulnerabilities and human factors challenges that significantly impact safety and operational efficiency [21, 24, 25, 32].

To meet the needs of modern aviation, comprehensive upgrades are essential. These upgrades should focus on integrating AI-driven decision-support systems, multi-sensor radar enhancements, and robust cybersecurity measures to improve situational awareness and risk mitigation capabilities. For example, enhanced radar systems can provide better low-altitude coverage for UAVs, reducing the risk of mid-air collisions in congested airspaces. Furthermore, AI can assist controllers by automating routine tasks, thus allowing them to concentrate on more complex decision-making scenarios, reducing the likelihood of human error.

Cybersecurity remains a prominent concern, with the adoption of technologies like ADS-B, which, despite improving tracking accuracy, exposes ATC systems to data interception and spoofing risks. Therefore, implementing encrypted communication protocols and AI-based threat detection algorithms is crucial to countering these threats.

The modernization of ATC is not just a technological necessity but a strategic imperative for global aviation safety. The reforms needed extend beyond hardware upgrades to include regulatory changes, stakeholder coordination, and significant investment in training programs. Without these measures, the growing risk to air traffic management's safety and efficiency could lead to severe disruptions, potentially impacting millions of passengers and airspace users worldwide.

8. FUTURE RESEARCH

Future research will focus on several key areas to support the ongoing modernization of ATC systems:

1. **AI-Enhanced Decision Support Systems**: Investigate advanced AI algorithms capable of providing real-time traffic management support while ensuring transparency and interpretability for air traffic controllers. This research should explore AI's potential to adaptively assist controllers under various levels of airspace congestion.

2. **Human-AI Collaboration**: Conduct studies on balancing automation with human oversight, preventing over-reliance on automated systems. Research should examine the dynamics of human-machine interaction, aiming to maintain situational awareness and reduce automation bias.

3. **UAV Regulatory Frameworks**: Continue developing comprehensive regulations for UAV integration, emphasizing the need for standardized tracking technologies and clearly defined operational protocols within shared airspace. Such frameworks should also address the requirements for collision avoidance and airworthiness standards.

4. **Cybersecurity Innovations**: Investigate novel encryption methods and AI-based intrusion detection systems tailored to ATC environments. The focus should be on strengthening resilience against spoofing, jamming, and malware threats.

5. **Multi-Sensor Radar Integration**: Explore the potential for integrating multiple sensor types (e.g., radar, ADS-B, satellite-based systems) to improve real-time coverage and situational awareness. This research should also assess the feasibility of using emerging technologies such as quantum radar for more precise tracking capabilities.

REFERENCES

[1] A. Degas et al., "A survey on artificial intelligence (AI) and eXplainable AI in air traffic management," *Applied Sciences*, vol. 12, no. 3, p. 1295, 2022. doi: https://doi.org/10.3390/app12031295.

[2] C. Cummings, "Air traffic flow and congestion of the skies," 2022. [Online]. Available: https://www.proquest.com/dissertations-theses/air-traffic-flow-congestion-skies-models-insights/docview/2707696219/se-2.

[3] J. Z. Wells, "Application of path prediction techniques for unmanned aerial system operations," 2021. [Online]. Available: https://www.proquest.com/dissertations-theses/application-path-prediction-techniques-unmanned/docview/2735849146/se-2.

[4] Y. Pang, "Artificial intelligence-enhanced predictive modeling in air traffic management," 2023. [Online]. Available: https://www.proquest.com/dissertations-theses/artificial-intelligence-enhanced-predictive/docview/2814233441/se-2.

[5] C. Xia et al., "A conflict risk analysis of MAV/UAV flight in shared airspace," *International Journal of Aerospace Engineering*, vol. 2021, pp. 1–14, 2021. doi: https://doi.org/10.1155/2021/1692896.

[6] Alliance for Aviation Across America, *Air Traffic Control Modernization and NextGen*, 2023. [Online]. Available: https://aviationacrossamerica.org/issues/atc-modernization/.

[7] A. Hamissi and A. Dhraief, "A survey on the unmanned aircraft system traffic management," *ACM Computing Surveys*, vol. 56, no. 3, Art. 68, 2024. doi: https://doi.org/10.1145/3617992.

[8] P. Domogala and P. Marien, *100 years of air traffic control*, 2022. [Online]. Available: https://ifatca.org/100-years-air-traffic-control/.

[9] R. T. Q. Overmyer, "Democratization of aviation," 2023. [Online]. Available:

https://www.proquest.com/dissertations-theses/democratization-aviation-content-analysis/docview/2854824094/se-2.

[10] M. S. Krämer and K. D. Kuhnert, "Multi-sensor fusion for UAV collision avoidance," in *Proceedings of the 2018 2nd International Conference on Mechatronics Systems and Control Engineering*, 2018. doi: https://doi.org/10.1145/3185066.3185081.

[11] D. Sacharny, “A lane-based approach to large-scale unmanned aircraft systems traffic management,” 2022. [Online]. Available: https://www.proquest.com/dissertations-theses/lane-based-approach-large-scale-unmanned-aircraft/docview/2735900420/se-2.

[12] S. U. Gunawardana, “A rule-based dialog management system for integration of unmanned aerial systems into the national airspace system,” 2012. [Online]. Available: https://www.proquest.com/dissertations-theses/rule-based-dialog-management-system-integration/docview/2454363866/se-2.

[13] C. J. Boyer, “Air traffic leadership perceptions on the use of machine learning for air traffic safety,” 2020. [Online]. Available: https://www.proquest.com/dissertations-theses/air-traffic-leadership-perceptions-on-use-machine/docview/2559697262/se-2.

[14] USGAO, “FAA needs a more comprehensive approach to address cybersecurity as agency transitions to NextGen,” *GAO Reports*, GAO-15-370, 2015. [Online]. Available: https://www.gao.gov/assets/gao-15-370.pdf.

[15] S. Khandker et al., "Cybersecurity attacks on ADS-B implementations," *IEEE Transactions on Aerospace and Electronic Systems*, vol. 58, no. 4, pp. 2702–2719, 2022. doi: https://doi.org/10.1109/taes.2021.3139559.

[16] FAA, *Aerospace Forecast: Fiscal Years 2024–2044*, U.S. Department of Transportation, 2024. [Online]. Available: https://www.faa.gov/data_research/aviation/aerospace_forecasts/.

[17] IATA, *20 Year Passenger Forecast*, 2024. [Online]. Available: https://www.iata.org/en/services/data/market-data/20-year-passenger-forecast/.

[18] Boeing, *Commercial Market Outlook 2024–2043*, 2024. [Online]. Available: https://www.boeing.com/commercial/market/commercial-market-outlook/.

[19] Airbus, *Global Market Forecast 2024–2043*, 2024. [Online]. Available: https://www.airbus.com/en/products-services/commercial-aircraft/global-market-forecast.

[20] C. A. Harris, “ATC specialists' perceptions of simulation for developing job-related competencies,” 2021. [Online]. Available: https://www.proquest.com/dissertations-theses/air-traffic-control-specialists-perceptions/docview/2620068007/se-2.

[21] F. L. Lazaro et al., "Human factors in aviation accidents," *Applied Sciences*, vol. 14, no. 2, 2024. doi: https://doi.org/10.3390/app14020640.

[22] T. H. Aldhyani and H. Alkahtani, "Cybersecurity algorithms for autonomous vehicles," *Sensors*, vol. 22, no. 1, 2022. doi: https://doi.org/10.3390/s22010360.

[23] A. Ray, “Machine learning-based spectrum fingerprinting,” 2023. [Online]. Available: https://www.proquest.com/dissertations-theses/machine-learning-based-spectrum-fingerprinting/docview/2808151612/se-2.

[24] L. P. Armbrister, “Automation in aviation safety,” 2023. [Online]. Available: https://www.proquest.com/dissertations-theses/automation-aviation-advancement-hindrance-safety/docview/2861553125/se-2.

[25] A. Reyes-Muñoz et al., "RPAS contingency management in non-segregated airspace," *Applied Sciences*, 2023. doi: https://doi.org/10.3390/app13031408.

[26] T. T. İnan and N. G. İnan, "Factors in fatal aviation accidents," 2022. doi: https://doi.org/10.15394/ijaaa.2022.1672.

[27] F. P. Moreno et al., "Machine learning models for air traffic complexity," *Symmetry*, vol. 14, no. 12, 2022. https://doi.org/10.3390/sym14122629.

[28] M. Jones et al., "UAV path-planning for complex environments," 2023. doi: https://doi.org/10.1145/3570723.

[29] K. H. Chelioti et al., "UAV monitoring advancements for infrastructure," 2023. doi: https://doi.org/10.32738/jeppm-2023-0023.

[30] F. Enayatollahi et al., "PBN-based time-optimal terminal air traffic control using cellular automata," 2021. doi: https://doi.org/10.1109/taes.2020.3048787.

[31] J. Hicks, “Aviation systems–trust survey development,” 2023. [Online]. Available: https://www.proquest.com/dissertations-theses/generalizable-method-case-application-development/docview/2814746979/se-2.

[32] K. J. O'Donnell, “Improving ADS-B console functionality,”2020. [Online]. Available:

https://www.proquest.com/dissertations-theses/exploring-strategies-human-computer-interaction/docview/2429005268/se-2.

[33] R. Li, Z. Zhou, Y. Cheng, and J. Wang, "Failure effects evaluation for ATC automation system," *Applied Computational Intelligence & Soft Computing*, vol. 2017, pp. 1–8, 2017, doi: https://doi.org/10.1155/2017/8304236.

BIOGRAPHY

Andrew Renault is a graduate student in the Aeronautical Science Department at Capital Technology University, where he focuses on advancing research in air traffic management and unmanned aerial vehicle (UAV) integration. With over 30 years of engineering experience in the aerospace industry, Andrew has contributed to a variety of projects ranging from aircraft design to systems optimization. His expertise spans both technical and regulatory aspects of aerospace operations, making him a key voice in discussions on modernizing air traffic control systems and addressing emerging challenges in aviation.