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RESEARCH ARTICLE

Unmanned aerial vehicles and aviation safety: a qualitative study

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Abstract
Technological developments and affordable price structures have increased the usage of unmanned aerial vehicles (UAVs) across almost all sectors, hence increasing demand. Since UAVs can fly and perform various tasks without requiring a human operator, the most dangerous and time-consuming tasks previously performed by humans in many sectors are now accomplished by using UAVs. The increased use of UAVs has also introduced critical safety and security risks, including airspace congestion, collisions and malicious use, and therefore, identifying and assessing the risks associated with UAVs and finding ways to mitigate them is of great importance. This qualitative study investigates the safety and security risks posed by the increased use of UAVs and discusses ways to mitigate these risks. Semi-structured interviews with aviation professionals, including pilots, air traffic controllers and academicians, were conducted, and the collected data were analysed by using MAXQDA 24 qualitative analysis software. The results indicate that 86% of participants emphasised air traffic density as a major safety concern, while 71% underlined the need for dedicated air corridors and robust legal frameworks to reduce collision risks. These insights suggest that the safe integration of UAVs into current aviation systems demands a multifaceted strategy involving regulatory interventions, such as clearly defined UAV flight zones and essential technological enhancements. Overall, the study underscores the urgent need for coordinated efforts–legal, technological, and inter-institutional–to ensure the secure incorporation of UAVs into national airspace.

Nomenclature

- UAV (Unmanned Aerial Vehicle): An aircraft that can fly without a human pilot on board, either autonomously or via remote control.
- Aviation Safety: The state in which aviation-associated risks are reduced and controlled to an acceptable level, focusing on the protection of people, equipment, the environment, and operational efficiency.
- Aviation Security: The protection of civil aviation from unlawful interference, focusing on prevention of illegal acts.
- SHT-IHA (Türkiye's UAV Regulations): The Directive issued by the Directorate General of Civil Aviation (DGCA) for UAV certification, registration, and liabilities.
- SMS (Safety Management System): A structured approach to managing safety in aviation, including policies, procedures, and accountability.
- Collision Risk: The risk posed when UAVs operate in airspace and may collide with other aircraft, people, or buildings.
- Air Corridor: A designated airspace area meant exclusively for UAV operations, intended to reduce collision risk.

- Air Traffic Density: The measure of how congested an airspace is due to UAVs and other aircraft.
- Cybersecurity Threats to UAVs: Includes jamming, malware attacks, data theft, and spoofing attacks, affecting UAV reliability and safety.
- Privacy Violations: The risk posed by UAV surveillance and data collection capabilities, impacting personal privacy.
- Legal Regulations: Rules governing the operation, licensing, and use of UAVs, addressing both civil and military aviation needs.
- Hardware Innovations: Technological advances such as AI, sensors, collision avoidance, and blockchain-based data protection used in UAV design.
- Occupational Stress (for UAV Operators): The mental load and psychological strain associated with UAV operations, including long hours and crisis decision-making.

1.0 Introduction

The UAV is an 'aircraft that can fly without the need of a human pilot onboard' [1]. In other words, UAVs are aircraft that can fly either autonomously or be controlled remotely. Technological advancements and innovations have made aerial vehicles, such as UAVs, highly accessible and affordable, which has increased the usage and applications of UAVs in various fields, including but not limited to agriculture, military operations, aerial photography and search and rescue operations.

The increased UAV use has also heightened concerns about airspace safety and security. In the domain of aviation, the terms safety and security are often conflated. Aviation safety is 'the state in which risks associated with aviation activities, related to, or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level' [2]. These activities focus on ensuring the safety of people, equipment, the environment, operations and corporate reputation [3]. On the other hand, aviation security is about safeguarding civil aviation against acts of unlawful interference [4]. In other words, security refers to preventing illegal actions, while safety focuses on keeping risks at or below an acceptable level.

In Türkiye, the legal status of UAVs is primarily governed by the Directive on Unmanned Aerial Vehicles (SHT–IHA) issued by the Directorate General of Civil Aviation (DGCA), in line with the provisions of Turkish Civil Aviation Law No. 2920. As UAVs represent a relatively novel category of aircraft, many states–Türkiye included–have adapted international standards, particularly those established by the International Civil Aviation Organization (ICAO), to shape their domestic regulations. The SHT-IHA directive outlines essential procedures related to UAV certification, registration and liability. For example, insurance coverage is mandatory for UAVs, and third-party liability insurance is required for UAVs weighing over 25 kg (SHT-IHA, Article 10). In addition, the registration procedures of UAVs are also carried out based on the system determined by the SHGM (SHT-IHA, Article 11). UAV regulations in Türkiye are also similar to the legislation in other countries. In particular, the United States, Canada and ICAO have introduced similar regulations for UAVs. These similarities emerge as a result of the comparative law method [5].

In aviation, safety is assured through safety management systems (SMS). The ICAO defines SMS as 'a systematic approach to managing safety, including the necessary organisational structures, accountabilities, policies, and procedures' [3]. Although the primary objective in aviation has always been the complete elimination of risks, achieving a zero-risk environment is inherently impossible [6]. Therefore, in aviation, risks must be mitigated to a tolerable or acceptable level; otherwise, the operation must cease.

Each aircraft that enters the airspace increases the operational risks, including but not limited to the risks of collisions, loss of control and malicious use. The same holds true for UAVs. Therefore, the safe integration of UAVs into airspace and air traffic is of vital importance for the future of the aviation industry. Authorities have been formulating regulations to ensure flight safety and security, but these efforts are still far from the desired level. For example, in Türkiye, registering with the Directorate General of Civil Aviation's UAV registration system is mandatory for those who sell, buy, produce, import and operate UAVs weighing 500 g or more. However, UAVs weighing less than 500 g are freely available and require no legal action to be taken. Moreover, over 200,000 applications were made within the first six months of the opening of the registration system [7], which shows people's enthusiasm for owning and operating UAVs. Considering the hundreds of thousands of UAVs sharing the same airspace with other aircraft, especially passenger aircraft, the significance of the associated threats and risks becomes clearer.

Despite their popularity, widespread use and application areas, few studies have been conducted to assess the impact of UAVs on our daily lives, particularly on flight safety. Hence, UAVs, their use cases, current and future threats and the risks associated with those threats, as well as the regulations intended to mitigate such risks and ensure aviation safety and security, need to be thoroughly assessed. This assessment must not only focus on aviation safety but also on technological, environmental, ethical, economic, and legal perspectives.

- *The ethical perspective* includes privacy violations, which refer to infringing on individuals' privacy via UAVs equipped with cameras or sensors, as well as surveillance and misuse. The technological perspective includes collision avoidance, battery lifetime and range limitations and communication disruptions.
- *The environmental perspective* includes energy consumption, which may increase pollution and disturb wildlife habitats. The economic perspective highlights job creation and the economic benefits of UAV technology.
- Finally, *the legal perspective* includes licensing requirements, the role of ICAO and cross-border regulatory challenges.

UAVs pose several safety and security threats (Table 1), including but not limited to hijacking, privacy breaches and cyberattacks [8]. Moreover, vulnerabilities in the hardware, software and communication systems of UAVs [9, 10] may pose additional security risks, including targeting GPS through jamming and spoofing and controlling data communication streams [11]. Researchers recommend a number of solutions that include encryption, privacy-aware implementations and countermeasures against malware to address these problems [12]. In addition, novel technologies like intrusion detection systems, blockchain and machine learning are being researched for potential solutions [10]. Safe and secure integration of UAVs into national airspace requires the establishment of comprehensive safety frameworks and regulatory measures in addition to the solutions already mentioned [13, 14].

In the literature, a range of solutions has been proposed, including encryption techniques, privacy-aware system designs, anti-malware measures [12], and emerging technologies such as intrusion detection systems, machine learning algorithms, AI-driven collision avoidance systems and blockchain-based flight data management platforms [10]. However, these solutions also underline the evolving nature of UAV integration and the necessity for adaptive regulatory measures, the establishment of comprehensive safety frameworks and regulatory measures to ensure the safe and secure integration of UAVs into the national airspace [13, 14].

This study addresses concerns through expert viewpoints and evaluates risks to airspace safety and security that are concomitant with the growing use of UAVs. Therefore, our research questions are: "What are the specific risks posed by UAVs? How can these risks be effectively addressed and mitigated through safety management systems and legal regulations?" Furthermore, this study contributes to the aviation literature by examining the perspectives of aviation professionals through a qualitative lens, employing MAXQDA for in-depth content analysis and proposing actionable solutions for safely and securely integrating UAVs into the current airspace. This study highlights that addressing the challenges posed by UAVs requires more than a single-faceted strategy, advocating instead for a comprehensive, multi-stakeholder approach that integrates legal, technological and societal perspectives.

Table 1. *Potential safety and security risks posed by UAVs*

Category	Risks	Description
Safety risks	**Altitude loss**	UAVs may lose altitude, which can threaten the safety of operations. At times, it happens when the navigation systems are not working properly or due to sudden changes in weather conditions, which cause UAVs to lose their height and enter restricted areas or crash [15].
	Loss of control	If control is lost, the operator may become unable to manually pilot the UAV, leading to a potentially hazardous situation. Such incidents can result from software errors, hardware malfunctions or signal interference, which may cause the UAV to behave unpredictably or crash [16].
	Loss of communication	A failure in communication between the UAV and the ground control station may result in the UAV not responding to operator commands. This issue can be caused by signal loss, power outages or cyberattacks, potentially preventing the UAV from completing its mission or placing it at significant risk [17].
	Collisions	Most especially in congested and urban airspaces, UAVs run the risk of colliding with people, buildings or other aircraft. When there is poor visibility or when there are navigational errors, the risk of crashes increases [18].
	Navigation system failures	Navigation systems are essential for the safe operation of UAVs. Any fault might cause the UAV to lose its route and fly into prohibited airspace. While total failures can lead to the loss of the UAV, partial failures can induce system incapacity [19].
	Weather conditions	Due to their lightweight structure, UAVs are particularly vulnerable to adverse weather conditions and may struggle to maintain stability in strong winds. Such conditions can lead to motor malfunctions, battery failures or even crashes. Additionally, the lack of waterproofing makes UAVs unsuitable for operations in rainy environments. In foggy conditions, limited visibility and disrupted signal transmission further increase the likelihood of losing control. Weather factors such as wind, high temperatures, fog and precipitation can significantly impair UAV performance, making them more prone to accidents. These risks underscore the critical importance of ensuring that both UAV operators and dispatchers carefully review weather forecasts before each flight [17, 20].
	Corrosion	UAV components, especially those exposed to harsh environmental conditions, may suffer corrosion over time, weakening their structural integrity and leading to critical component failures. To mitigate this risk, regular maintenance and preventive measures are vital [19].
	Operator's lack of knowledge	Unfamiliarity with the flight area can lead UAVs to inadvertently enter restricted or no-fly zones, thereby increasing the risk of accidents. Insufficient knowledge of the operational environment may also result in poor decision-making, further elevating the likelihood of incident occurrence [21].
	Rotor failures	UAVs rely on their rotors to sustain lift and to maintain stability. A mechanical failure in rotors can lead to loss of control. Regular maintenance and pre-flight checks are needed to mitigate this risk [19].

Table 1. *Continued*

Category	Risks	Description
	Takeoff and landing incidents	The takeoff and landing phases are widely recognised as the most hazardous segments of UAV operations. During these critical stages, incidents such as short landings, runway excursions or unintended deviations from the flight path may occur. Therefore, ensuring safe takeoff and landing procedures is essential for overall UAV operational safety [22].
Security risks	**Jamming**	UAVs often rely on cellular networks or remote control systems for communication, which makes them inherently vulnerable due to limited built-in security protections. Malicious actors may exploit this weakness by transmitting jamming signals, which can distort the UAV's positional data, causing it to deviate from its assigned route, misinterpret its location or lose connection with the ground control station. Such attacks not only compromise the operational integrity of UAVs but also allow unauthorised access to sensitive data, which may subsequently be disseminated to external entities. These threats present significant challenges to the secure deployment and management of UAVs [11, 23].
	Susceptibility to malware	Malware installation, UAV commandeering and data theft are among the methods hackers use to disrupt the operations of drones. Well-equipped cybersecurity precautions are required to protect UAVs against these threats [16].
	Data theft	UAVs usually carry sensitive information such as details regarding missions, flight paths and their surveillance footage, which are often accessed or stolen by adversaries. It is possible to mitigate security threats using methods such as data encryption. Encryption, with effective antivirus applications, tends to be the most important form of security measures [10, 12, 24].
	Malicious use	UAVs might be used for harm as they could carry weapons, bombs or other instruments of crime. They are triply fit for clandestine operations and covert missions since they are small and fast [20].
	Technical issues	Technical problems may result in a UAV losing power or crashing. Attackers may purposefully cause such problems to undermine the operations. It takes routine maintenance and observation to reduce these risks [12].
	Operational errors	The inadequacy of UAV operators' flight skills could cause serious damage to individuals or property. Fatigue, inadequate training, or poor decision-making can all contribute to operator errors, which can cause mishaps or mission failure. Errors of this kind may only be avoided by regular process assessment and adequate training of UAV operators [18].
	Violation of privacy	Privacy violation itself is a huge issue in terms of personally identifiable privacy. The fact that drones themselves are now being equipped with advanced sound and video recording systems means that personal space could be violated by illegal surveillance. It becomes a serious matter when one's privacy is violated; it can actually become dangerous, especially if trespassing on crowded locations and private properties. As technology continues to evolve, so does the need for ensuring privacy protection [25].
	Violation of airspace	Article 3 of the Chicago Convention stipulates that none of the state aircraft of the member countries of the treaty has any right to fly over or land in a foreign state without any permission. However, the binding force of these two articles alone is not enough to legalise UAV operations. There needs to be more regulations, especially concerning airspace violations, infringement upon states' sovereignty and breaches of humanitarian and human rights norms [26].

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2.0 Methods

In this qualitative study, we used semi-structured interviews. Qualitative research is an iterative process that advances scientific understanding by bringing the researcher closer to the subject of study and generating novel and meaningful distinctions [27]. The data analysis was primarily focused on determining participants' perceptions of the expanding use of UAVs and the risks that they represent to aviation safety.

First, we asked participants to rate their knowledge of UAVs on a scale from 0 to 10 and whether they had ever used UAVs of any kind. Afterward, we asked questions about the risks associated with UAVs, how to mitigate these risks and the regulations that need to be formulated.

Aviation safety and UAVs:

- What do you believe are the impacts of UAVs on flight safety, and what potential risks could these impacts entail?
- What steps should be taken to mitigate these risks to an acceptable level?
- Do you think that the existing aviation infrastructure (such as air traffic controllers (ATCs), aerodromes, airspace capacity and navigation aids) is capable of managing the increasing density of UAVs?

Regulations:

- Are you familiar with the regulations related to UAVs?
- What are your thoughts on these regulations and the issues they cover?
- What is your opinion on the degree of implementation, effectiveness, sufficiency and frequency of compliance monitoring of these regulations?

The data was gathered by asking the above questions to 15 aviation professionals. Given the qualitative nature of this study, the sample size of 15 participants was chosen to prioritise the professionals' insights to understand this complex and multifaceted issue. This approach aligns with qualitative research standards, where smaller samples allow for detailed exploration of complex issues [27]. We also tried to get the professionals from different backgrounds and fields of aviation, including pilots, air traffic controllers and academicians, to ensure a diverse range of perspectives and a comprehensive understanding of the risks and challenges associated with UAV integration.

The sample included five pilots, five ATCs and five academicians in the field of aviation management. Participants were selected based on their experience and awareness of UAV operations. While the sample size encompasses a variety of views, future studies might consider having representatives from the regulatory authority and UAV manufacturers to reflect broader perspectives.

The interviews took place virtually using video conferencing software, and the participants' responses were transcribed verbatim vis-à-vis the audio files for the purpose of analysis. The transcripts from the recorded interviews were then analysed through MAXQDA software for the analysis of content [28, 29]. Starting with the identification of predominant themes from the transcripts using an inductive approach [29], the coding process proceeded.

Recurrent themes and expressions were strongly determined by these codes, which were then grouped according to their semantic connections. An analysis of the findings was made using the code relations browser, with regard to measuring the relationship between major concepts integrated from qualitative and quantitative values. Co-occurrence analysis was also carried out to understand the relationship among codes. This study bases its measurement on the frequency and context in which two or more codes occur together as an indicator for determining the link between the two concepts involved [29]. The demographics of the participants are presented in Table 2.

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Table 2. The demographic characteristics of the participants

R	Gender	Age	Education	Profession	UAV Knowledge Level	UAV Usage	Professiona Experience (Year)
1	Male	28	Bachelor's	Pilot	5/10	Yes	3
2	Male	25	Bachelor's	Pilot	6/10	Yes	1
3	Male	40	Bachelor's	Pilot	8/10	No	10
4	Male	30	Master's	Pilot	6/10	No	5
5	Male	42	Bachelor's	Pilot	7/10	No	12
6	Female	35	Master's	ATC	5/10	No	7
7	Female	45	Master's	ATC	7/10	Yes	9
8	Male	35	Bachelor's	ATC	6/10	Yes	4
9	Male	38	Bachelor's	ATC	7/10	Yes	5
10	Male	30	Bachelor's	ATC	7/10	No	2
11	Female	42	PhD	Academic	5/10	Yes	12
12	Female	55	PhD	Academic	4/10	Yes	30
13	Male	40	PhD	Academic	5/10	Yes	5
14	Male	59	PhD	Academic	6/10	Yes	29
15	Male	55	PhD	Academic	5/10	Yes	32

3.0 Findings

The security and safety threats associated with the growing use of UAVs in aviation safety were listed in Table 1. An important observation is that the risks identified by the participants during the interviews align with the existing literature. The interviews were transcribed, thoroughly reviewed for coding and analysed based on their meanings. The frequency of codes used together within the same sentence or paragraph was analysed using MAXQDA 24 to determine the relationships between the assigned codes. The interaction between different codes was quantitatively analysed using the Code Relations Browser (CRB). The purpose of this analysis was to interpret the relationships between codes both qualitatively and quantitatively. Words, sentences and paragraphs in the interview transcripts were analysed and coded, resulting in the identification of nine main codes: six related to risks and three to ways of mitigating them.

The relationships between the codes were analysed based on how frequently they were coded together within the same sentence or paragraph. As a result of this analysis, the interactions between various codes were assessed. The primary goal of this assessment was to reveal the strong and weak relationships between the codes. Additionally, the elements used in the participants' evaluations were considered.

The relationships revealed by the CRB provide insights into the risks posed by UAVs and potential solutions to mitigate these risks. The most critical finding was the strong connection between the risks and the necessity for legal regulations, as well as the establishment of dedicated air corridors for UAVs. Participants' responses regarding the effects of UAVs on flight safety and the potential risks they create, as ranked by the participants, align with the existing literature presented in Table 1. This consistency highlights a high level of participant awareness regarding UAV-related risks.

The findings revealed the following key relationships:

- Collision with Other Aircraft and Legal Regulations co-occurred 25 times, indicating that the risk of UAVs colliding with other aircraft is closely tied to air traffic rules and legal regulations. Significant threats arise due to insufficient airspace management and incomplete regulatory frameworks. The use of UAVs around people highlighted the need for tighter safety regulations and better-defined legal frameworks. Regulation of flight operations in highly congested areas would include a strict licensing mechanism as a primary consideration. For example, one pilot

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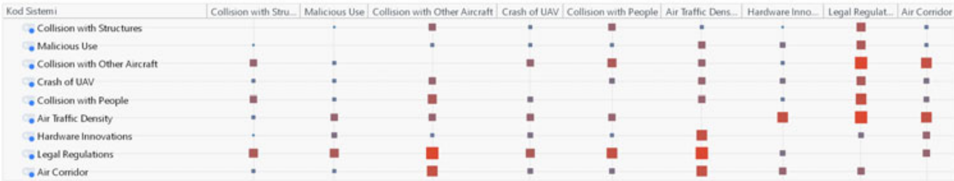

Figure 1. *Code relations.*

highlighted, 'The absence of clearly defined UAV flight zones is a recipe for disaster in already congested airspaces'.

- Air Traffic Density and Legal Regulations were used, in combination, 25 times. Such an occurrence emphasises the need for urgent rules governing UAV operation within controlled air corridors so as to avoid congested traffic levels. Some aeronautical problems arise because of UAV operations at lower altitudes, hence the need for such regulations.
- Air Traffic Density and Hardware Innovations co-occurred 21 times to indicate the need for technological advancement to cater to the increase in traffic levels. Such innovations include advanced sensors, AI-powered collision avoidance systems, and GNSS technologies that help safely integrate UAVs into the system.
- The Collision with Other Aircraft and Air Corridor codes co-occurred 20 times, highlighting the necessity for dedicated UAV flight zones or air corridors. Participants proposed that segregating flight zones, which will isolate UAVs from manned aircraft, could significantly reduce collision risks.

Furthermore, while pilots suggested immediate and stricter legal regulations, ATCs expressed their concerns about the applicability of enforcing legal regulations without proper technological advancements. On the other hand, academics demonstrated a balanced approach, suggesting public awareness along with technical and legal measures to ensure the sustainable integration of UAVs into the current airspace. Since all participants approached the issue from their own perspective, although some ethical issues surfaced in discussions, such as UAV misuse for surveillance, they were not uniformly prioritised across professional groups. This suggests that, despite being imminent and evident, the ethical issues have not attracted the attention of aviation professionals; hence, there is a need for more interdisciplinary dialogue.

The findings in Fig. 1 emphasise the relationship between various risk factors and the importance of comprehensive regulations. Similarly, the frequent linkage of the Air Corridor code with collision risks and air traffic congestion suggests that allocating dedicated airspace for UAVs could reduce collision risks.

The connection of the Hardware Innovations code with air traffic congestion and risks highlights the importance of technological solutions for ensuring UAV safety. Threats such as collision risks (with humans, structures and other aircraft) and malicious use remain key concerns affecting the safety and security of UAV operations.

Overall, participants' perspectives indicate that the safe integration of UAVs requires a combination of legal regulations, technological innovations and airspace management strategies. The code-based frequency analysis conducted using the MAXQDA software revealed varying levels of emphasis placed on certain codes within participant responses (Fig. 2). Among the participants, 86% mentioned Air Traffic Density, indicating that the increasing use of UAVs has made airspace congestion a significant safety concern. Additionally, 71% of the participants used the codes Collision with Other Aircraft and Air Corridor, underscoring the frequent emphasis on collision risks and the necessity of establishing dedicated air corridors for UAVs.

Another finding that emerged from the analysis conducted using the MAXQDA software is the single-case model analysis. The single-case model analysis evaluates the answers of all participants as if they

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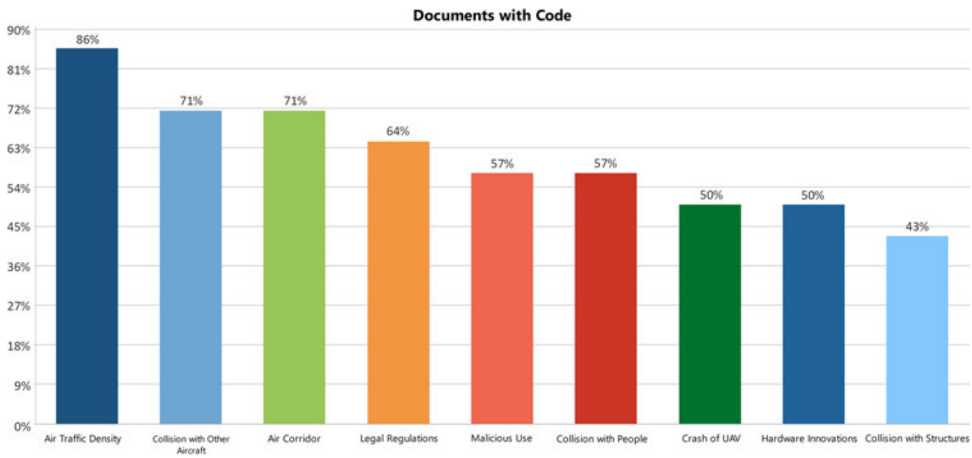

Figure 2. *Documents with code.*

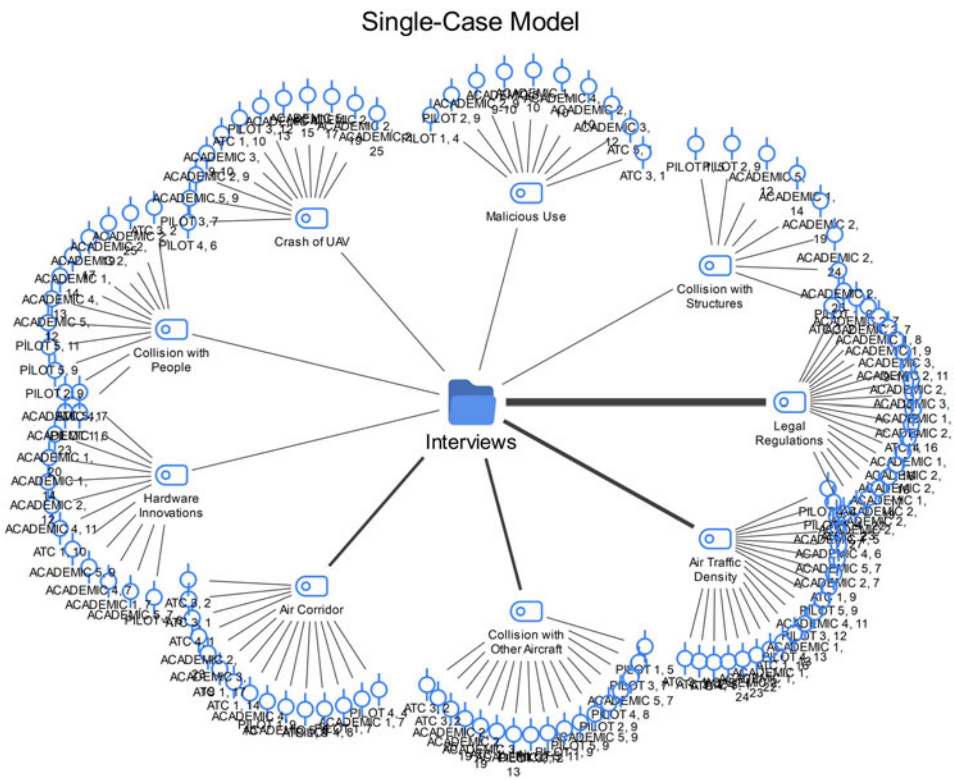

Figure 3. *Single-case model.*

were responses from a single person. In this analysis, the participants' responses are combined and assessed as a unified dataset, resulting in a single, consolidated code relationship. The terms such as Academic 1, Pilot 2 on the edges of Fig. 3 indicate which participant addressed which topic. Thus, it can be seen which topics the participant groups prioritise more.

The aim of this analysis is to identify shared perspectives among participants, highlighting their common concerns and ideas. In this study, the shared concerns revolve around key factors related to UAV

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risks, threats and legal deficiencies. The single-case model is shown in Fig. 3, which illustrates the frequency of co-occurrence between UAV-related risks and corresponding mitigation strategies, based on qualitative analysis of participant responses. The strength of the codes' relationships progresses clockwise, gradually decreasing. In the single-case model, the thicker the line, the stronger the relationship, and the thickest line is between Interviews and Legal Regulations, which means that the participants' view on the importance of:

- Making UAV pilot licensing requirements more challenging
- Introducing mandatory re-examinations after a few years
- Requiring applicants to undergo psychological tests during the license acquisition process

The single-case model presented in Fig. 3 demonstrates that legal regulations, air traffic management and technological advancements are the primary areas of concern in UAV safety discussions. The interconnected nature of risks and solutions underscores the necessity of a multidisciplinary approach, integrating legal, operational and technological frameworks to ensure safe UAV integration into civil aviation.

The second thickest line extends to Air Traffic Density, the third to Collision with Other Aircraft, and the fourth to Air Corridor. This progression indicates that participants perceive regulatory measures, particularly those linked to licensing and pilot assessment, not only as a legal necessity but also as a preventive mechanism against operational risks. The prominence of the connection to Air Traffic Density suggests a shared concern regarding the increasing complexity of shared airspace and the need for stricter oversight to ensure safe integration of UAVs. Similarly, the notable linkage to Collision with Other Aircraft underlines the participants' awareness of mid-air risks and their emphasis on the role of training and regulation in mitigating such incidents. Finally, the moderately strong relationship with Air Corridor highlights the importance attributed to clearly defined flight routes for UAVs, reinforcing the belief that structured airspace management is essential for maintaining overall air traffic safety.

When participants are analysed based on their professional groups as a single-case study, it is observed that:

The academic group (Fig. 4) has evaluated the impact of UAVs on aviation from a broad perspective. Their primary focus has been on legal regulations, as this group often addresses shortcomings in the regulatory framework, aiming to establish a legal infrastructure that ensures the safe integration and use of UAV technology. Hardware innovations also emerge as a priority for academics, reflecting their recognition of the role technological advancements play in mitigating UAV-related risks.

In addition, their emphasis on air traffic congestion highlights the management challenges arising from the rapid increase in UAV operations. Overall, academics have utilised their theoretical knowledge to address both safety and ethical issues comprehensively.

Academics (Fig. 4) emphasised legal regulations most, stressing the need for well-defined frameworks, pilot licensing, compliance enforcement and continuous legal updates to ensure safe UAV integration into civil aviation. They also highlighted the role of hardware innovations in risk mitigation, advocating for AI-driven collision avoidance, blockchain-based data security, and enhanced cybersecurity measures to prevent UAV hijacking. Air traffic congestion was another major concern, with proposed solutions such as structured UAV corridors and AI-based air traffic management. Regarding collision risks, academics explored potential threats to aircraft, people, and infrastructure, recommending automated geofencing, smart sensors and mandatory risk assessments. Finally, they addressed ethical and operational considerations, including concerns about UAV surveillance, data privacy and the potential for misuse in unlawful activities.

The single-case model of pilots (Fig. 5), drawing from their aviation experience, is the group most focused on the collision risk between UAVs and other aircraft. In other words, Fig. 5 portrays the UAV pilot as a central actor in airspace safety, with responsibilities and risks extending far beyond technical operation. Their role is framed by regulation, challenged by dense and dynamic environments and ultimately pivotal in avoiding both human and material harm, and they perceive UAVs as a direct threat to flight safety. Their sensitivity to this issue stems from their professional emphasis on prioritising safety.

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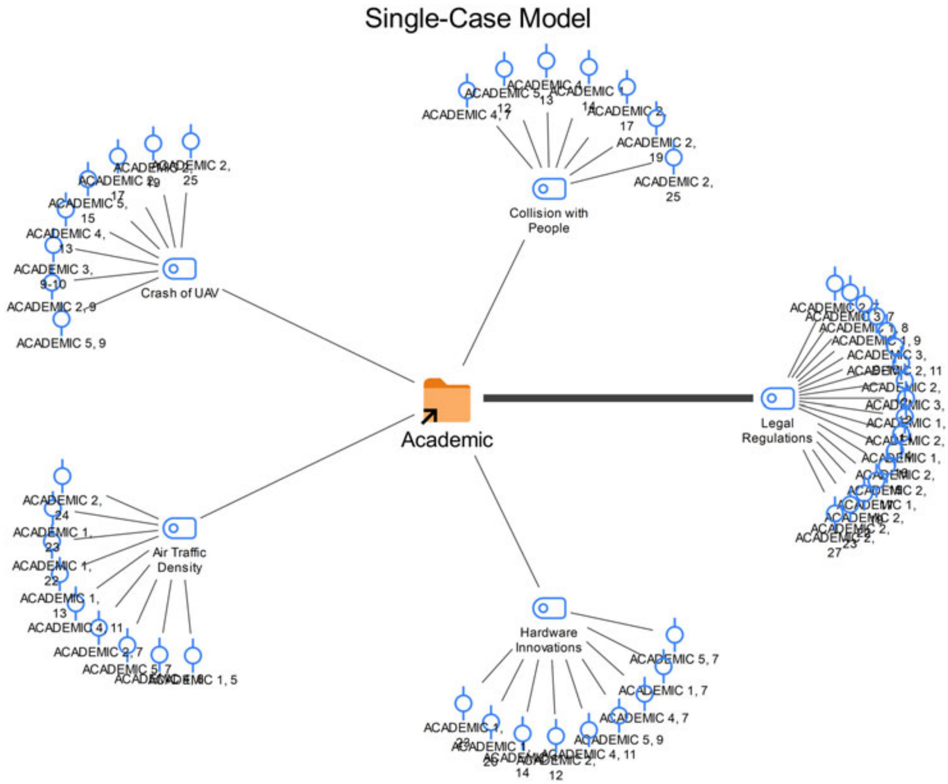

Figure 4. *Single-case model of academic group.*

The pilot group also highlighted the importance of legal regulations and suggested that UAV pilot licensing requirements should be made more stringent. Air traffic congestion is another significant concern for pilots, as the increasing presence of UAVs complicates flight path planning and maintaining safe separation distances.

The thickness of the lines again reflects the strength and frequency of these associations–i.e. the thicker the line, the more emphasis participants placed on the connection. The thickest lines in this model extend from Pilot to Legal Regulations, Collision with Other Aircraft, and Air Traffic Density. These strong connections suggest that participants perceive the pilot's role as fundamentally shaped by the legal and structural frameworks in which they operate. Specifically:

- The strong link with Legal Regulations implies that participants believe pilots' actions and competencies are heavily influenced–or should be influenced–by regulatory oversight, including licensing procedures, training requirements and compliance monitoring.
- The strong association with Collision with Other Aircraft shows a clear concern with situational awareness and coordination, especially in increasingly crowded and mixed-use airspaces. This highlights the perceived need to improve pilot training on airspace management and real-time risk assessment.
- The line to Air Traffic Density underlines a concern about workload and pressure on pilots operating in high-density environments, indicating that pilot error may become more likely as airspace grows more complex and congested.

Moderately thick lines can be seen connecting Pilot with themes such as Collision with People, Air Corridor and Crash of UAV. These show that participants also see the pilot as a risk mitigator–someone whose actions can prevent accidents, particularly in populated or structurally sensitive areas.

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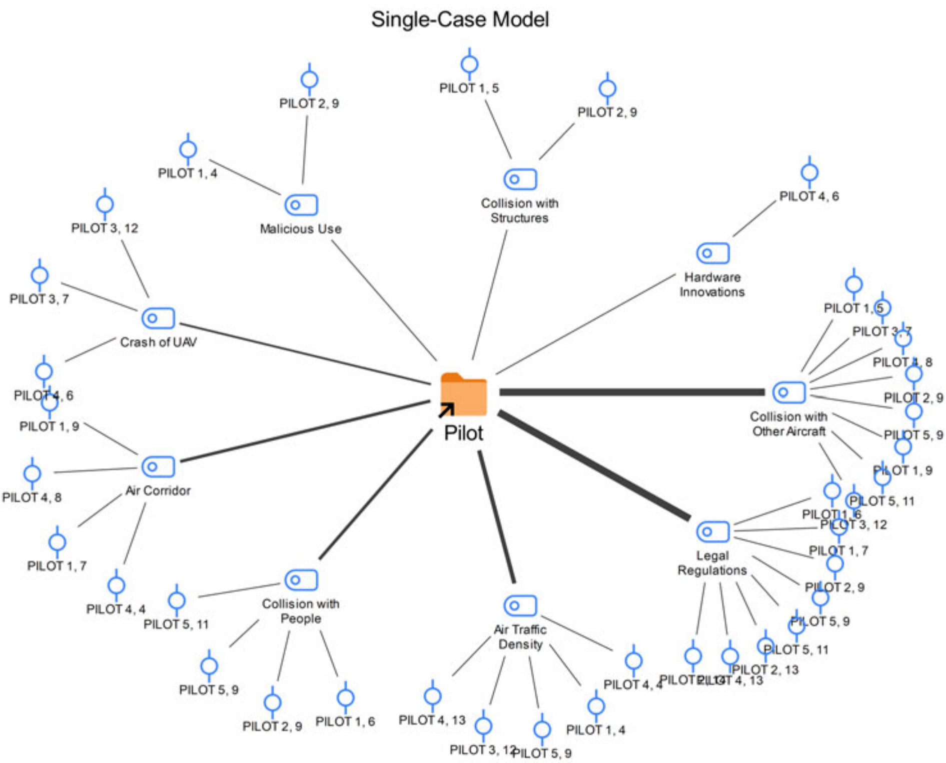

Figure 5. *Single-case model of pilot group.*

Weaker but still present connections, such as those to Malicious Use, Hardware Innovations and Collision with Structures, reflect broader concerns that, while less central, still influence the discourse around UAV pilot responsibilities. Interestingly, these peripheral nodes suggest that pilots are also seen as part of the defense mechanism against misuse or technical failure, not just operational error.

Moderate to weak lines appear between ATC and Legal Regulations, Hardware Innovations and Malicious Use, suggesting that while these themes are relevant, they are not central to the ATC role as perceived by participants.

Air traffic controllers (Fig. 6), drawing on their professional expertise, have concentrated on the effects of UAVs on airspace. Their major concerns primarily involve the issue of air traffic management and the organisation of air corridors. ATCs noted that increased UAV activity renders airspace regulations inadequate and escalates accident probability. ATC highlighted the insufficiency of legal frameworks governing the unregulated use of UAVs in airspace.

The strongest connection is observed between ATC and Air Traffic Density, indicating a significant emphasis on the role of ATC in managing increasingly congested airspaces. Participants appear to view ATC as a critical coordinator in ensuring that UAVs can be safely integrated into environments traditionally dominated by manned aircraft. This association reflects concerns about workload, situational awareness and the need for adaptive airspace management strategies.

A similarly thick line links ATC to Air Corridor, highlighting participant perspectives that structured, predefined routes are essential for UAVs and should be clearly managed or enforced by air traffic authorities. This implies a shared understanding that ATC must evolve beyond traditional radar-based control to include digital oversight of UAV pathways, especially in low-altitude or urban airspaces.

The third strongest link connects ATC to Collision with Other Aircraft, underscoring the perceived responsibility of ATC in preventing mid-air incidents. Participants appear to expect ATC to take a proactive role in deconfliction strategies, even though UAVs often operate in lower-altitude Class G airspace,

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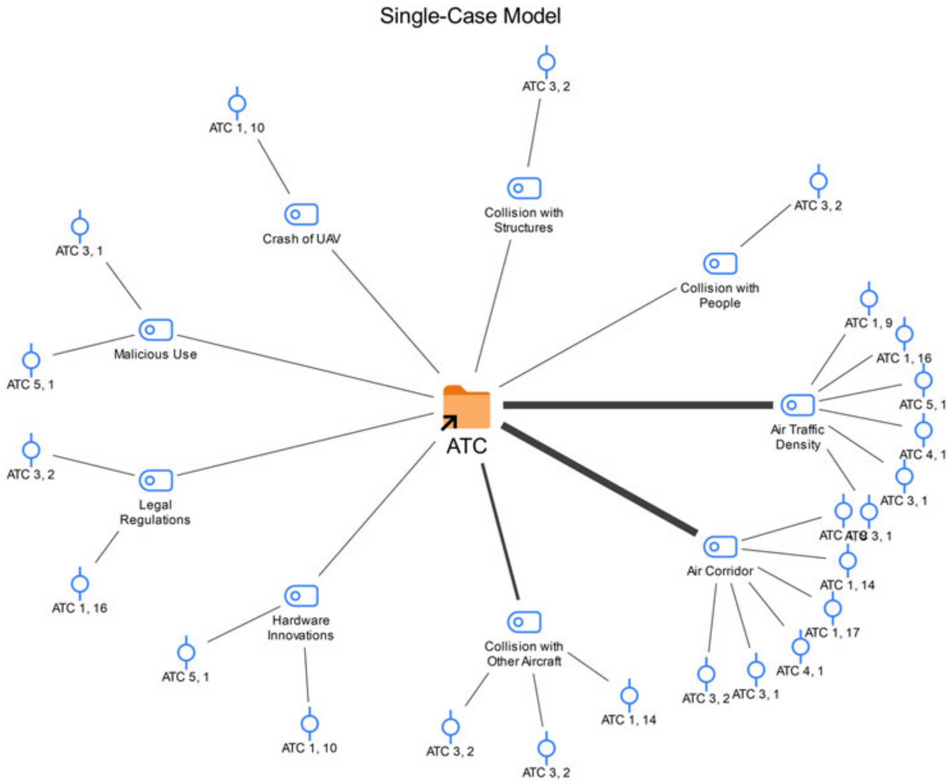

Figure 6. *Single-case model of ATC group.*

which traditionally requires less ATC involvement. This finding indicates a growing expectation for ATC modernisation and UAV-inclusive communication systems.

According to findings, each professional sector prioritised issues based on their particular expertise and experience. The academic group, which is wider in perspective, focused more on the legal and societal impacts of UAVs. And while the ATC group stressed the technical and operational constraints of airspace management, pilots, on the other hand, gave priorities directly from their actual experience concerns on flight safety and collision hazards. These differences demonstrate that each group has developed a problem-solving attitude with respect to UAV issues and related challenges in alignment with their professions.

The word cloud (Fig. 7) developed through the MAXQDA programme further interprets participants' evaluations regarding the impacts of UAVs on aviation safety. The more common words mentioned by participants are most pronounced in the word cloud.

The participants used the word *risk* dominantly (48 mentions), which is not surprising, given that this study is about risk and risk assessment. However, it may still be considered a highlight of the central concern of aviation professionals regarding UAV integration. Closely following the word *risk* were *safety* (31) and *security* (28), reinforcing the study's core thematic pillars. High frequencies of words like *legal* (17), *threat* (16), *system* (14), *UAV* (14), *collision* (14) and *corridor* (14) reflect a strong emphasis on regulatory and infrastructural challenges. Words like *licence* (11), *air traffic* (10), *crash* (10) and *regulation* (10) further underscore stakeholder concerns about operational oversight and risk mitigation. Words such as *education* (7) and *people* (5) also point to the human factors and public awareness dimensions of UAV safety. This distribution of words clearly aligns with the study's findings and justifies its focus on legal frameworks, risk assessment and the necessity of multi-stakeholder strategies for safe UAV integration.

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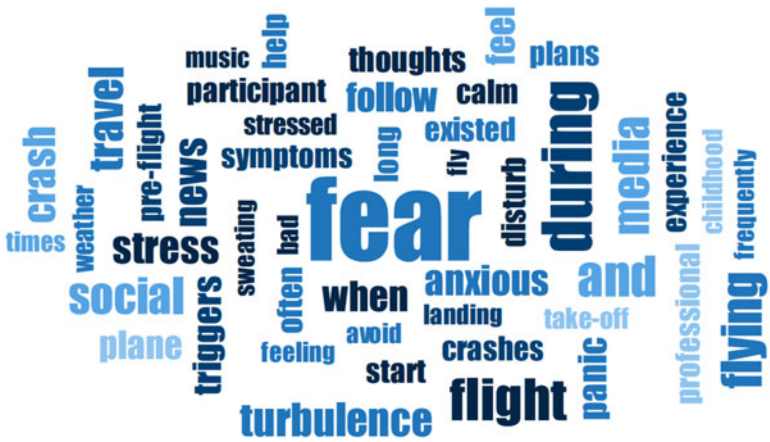

Figure 7. *Word cloud.*

The study's findings corroborate many of the risks underscored in the literature, such as risks due to collisions and air traffic density [15, 18]. It thus builds upon the existing academia, substantiating theoretical discussions with expert insights and highlighting regulatory framework gaps. For example, the frequent co-occurrence of the code Legal Regulations with other risk factors is consistent with studies addressing deficiencies in the domain of regulatory frameworks [11, 13]. Moreover, the study attempts to clarify how aviation professionals value risks and recommend actions related to their mitigation.

According to the participants, system-wide improvements are required. For example, blockchain technology was proposed as a possible path to data security and manipulation-proof flight records [12]. An entirely new data storage system built on blockchain may open new windows for the improvement of transparency about unmanned aerial vehicle flight data and for reinforcement of compliance with regulatory requirements. Additionally, autonomous UAV management systems hold promise as one of the remedies for reducing air traffic density [10].

The qualitative data analysis was enhanced through an iterative coding process, focusing not only on co-occurrence frequencies but also on the contextual relationships between identified themes. Using MAXQDA, the responses were analysed to uncover underlying patterns and the rationale behind participants' perspectives.

4.0 Discussion

The integration of UAVs in civil airspace presents both opportunities and challenges, particularly concerning aviation safety and security. This study has illuminated several critical areas where UAVs pose risks, emphasising the necessity of robust legal frameworks, technological advancements and airspace management.

The findings align with literature that suggests UAVs can pose risks like loss of control, loss of altitude, collision with people or objects and security threats like jamming and misuse. Human factors are a significant component of flight, and psychological evaluation is part of verifying pilots to ascertain how well they would handle adverse situations during flight. For example, the Federal Aviation Administration (FAA) requires regular medical checks for commercial pilots. The medical checks include examinations of mental status and ability to fly [30]. They are carried out to assess whether pilots can manage flying stresses well. Equally, UAV operators have critical roles in the air and are subject to many hazards.

The research indicates UAV drivers will also be exposed to occupational stressors such as long working hours and shift work, which could adversely affect their mental health [31]. While UAV operators'

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levels of clinically significant symptoms of Post-Traumatic Stress Disorder (PTSD) are low at 2–5%, the influence of occupational stress on their health continues to be a concern.

Despite these findings, the current laws do not mandate the taking of psychological tests for UAV pilots. Using these screenings would help find those who are most likely to face adverse mental effects from the special stresses of UAV work. Adding psychological testing to the licensing process could improve safety in the air by ensuring that UAV pilots have enough mental strength to handle the stress of their job. These threats are exacerbated by the growing air traffic and the rapid expansion of UAVs in civilian applications.

One of the main findings of this study is the strong association between UAV-related threats and the absence of comprehensive legal regulations–a concern that was extensively emphasised by the participants. Notably, 64% of respondents advocated for more stringent legal measures, underscoring the urgent need for regulatory bodies to prioritise UAV legislation. The proposed legal framework should include stricter licensing conditions for UAV operators, such as periodic re-certification and mandatory psychometric assessments.

A comparative analysis of international practices reveals that the United States FAA has implemented detailed regulatory measures for UAV integration into national airspace. As of December 21, 2015, the FAA mandated the registration of all recreational UAVs weighing between 0.55 pounds (250 g) and 55 pounds (25 kg) before flight operations. If the operator is under the age of 13, the registration process must be completed by a parent or legal guardian. Upon registration, the FAA assigns a unique identification number, which must be visibly displayed on the UAV. Importantly, a single registration may cover multiple UAVs owned by the same individual. Failure to comply with these requirements may result in civil penalties of up to $27,500 or criminal penalties, including fines and imprisonment [32].

The FAA permits both recreational and commercial UAV operations, provided they adhere to specific regulatory frameworks. Commercial use falls under Part 107 of the Federal Aviation Regulations, which outlines conditions such as pilot certification, operational limitations and mandatory registration. Recreational use is governed by Section 44809 of the FAA Reauthorization Act of 2018, which allows UAV flights under defined safety conditions–these include maintaining a visual line-of-sight, flying below 400 feet in uncontrolled airspace and passing the Recreational UAS Safety Test (TRUST) [5].

The European Aviation Safety Agency (EASA) published a 50-page report titled ‘Introducing the Regulatory Framework for the Operation of UAVs’ to assist in integrating UAVs into the sky. This 2015 report identifies the UAV market as being worldwide, growing and diversified. It aims at establishing rules that ensure growth becomes safe, secure and ecologically friendly. This rule covers UAVs of any weight [33]. The European Aviation Safety Agency (EASA) introduced a regulatory prototype, referred to as a ‘prototype Commission regulation’, aimed at supporting the safe and secure integration of UAVs into low-altitude Class G airspace. This initiative focuses on establishing the regulatory foundations for future UAV Traffic Management (UTM) systems, rather than representing an operational UTM platform or technical system. The system encompasses generic requirements like non-collision with other UAVs or objects, safe separation from human-crewed aircraft, and situational awareness by UAV operators of all potential threats and hazards [34].

The research shows that UAVs need their air lanes. By 71% of the respondents saying there needs to be a set height at which to fly, the research essentially guarantees that UAVs will be a threat to manned aircraft as well as stationary objects if there are not specific places where they are allowed to fly. This need for air corridors is also present in other studies that call for separate UAV flight paths to reduce the risk of collisions. While there are benefits to using predefined air corridors, their use is limited by practical considerations, such as cooperation across borders and differences in national regulations. Likewise, integrating AI technologies into UAV systems takes a lot of investment and cooperation from the industry, which can be slow. UAVs are used in various applications like surveillance of territories, attacking, border protection, support for combat search and rescue, smuggling prevention and mine clearing. UAVs also raise some moral concerns, like invasion of privacy. Especially, camera-equipped UAVs used in search and rescue missions have the potential to invade people’s privacy by filming their private lives.

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In addition, the fact that artificial intelligence manages UAVs raises questions about the ethical dimension of wars. This raises critical ethical questions regarding accountability in autonomous warfare, such as who bears responsibility for collateral damage caused by AI-controlled UAVs. The psychological problems and responsibilities of UAV pilots also stand out as important ethical issues. The example of a UAV pilot's guilty conscience after accidentally harming civilians clearly demonstrates this concern [35]. Some examples of ethical issues that may arise from UAVs today include:

- US military UAV pilot Brandon Bryant resigned from his post and became a human rights defender after causing the deaths of two civilian children by using a UAV in an operation he participated in [35].
- An example in Turkey is the capture of a UAV user who violated the privacy of a student dormitory by monitoring it. This situation has been considered within the scope of cybercrime due to the lack of sufficient legal regulations. Such incidents reveal the importance of ethical and legal issues in using UAVs [36].

While participants acknowledged the importance of hardware innovations in reducing risks, this aspect received less emphasis compared to legal regulations and airspace management. However, as noted in previous studies, system failures such as rotor malfunctions and navigation errors can result in catastrophic outcomes, emphasising that technological solutions are very important. One of the contributions of this study is its emphasis on the role of public awareness and the importance of operator training. The findings suggest that aviation safety is not solely the responsibility of technology and policy but also societal engagement. Educating the public about UAV safety and the implications of misuse is crucial for ensuring safe operations, particularly in urban environments. The study provides a comprehensive understanding of the risks that UAVs pose to aviation safety and reinforces the need for a multifaceted approach combining legal, technological and educational interventions to mitigate these risks. The integration of UAVs into the airspace will continue to be a significant challenge, but with predictive measures, the aviation industry can address these challenges effectively.

5.0 Conclusion

The safe integration of UAVs into unsegregated airspace is of great importance for aviation safety and security. UAVs are used in many different areas, such as agriculture, reconnaissance, search and rescue, mapping, environmental monitoring, emergency interventions and scientific research [37]. In addition to the variety of their areas of use, the acquisition of UAVs has also become quite easy today, and they can even be ordered online. This fact complicates the situation even more, because the use of such an easily obtained aircraft should also be limited, considering the threats it poses to other aircraft. Such an easily obtained aircraft and license also increases the risks that can be associated with UAVs. With the development of UAV technology and its entry into our lives to this extent and its integration with many of the jobs we do, it is inevitable to take many steps to ensure flight safety. As a result of the increasing use and applications of UAVs, issues such as airspace integration, potential collision scenarios, complexity of air traffic management systems and safety and security gaps come to the fore. In this context, the study aims to examine the effects of UAVs on aviation safety and to help take strategic steps to develop aviation safety and security standards.

The data obtained from the study revealed results parallel to those in the literature. For example, the results show that the risks arising from UAVs stem from legal deficiencies and system-hardware shortcomings. The analysis further indicates that the safe and secure integration of UAVs into the airspace can only be achieved by eliminating the aforementioned legal and technical deficiencies.

To ensure safe and secure integration, cooperation and coordination between the society, public institutions and organisations, non-governmental organisations and private companies are essential. Aviation organisations should conduct studies in cooperation by presenting their suggestions that will benefit the perception of society to the state authorities. These studies can take the form of educating the public

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about UAVs and developing their knowledge. Thus, the use of UAVs for the purpose of serving the public will be encouraged and provided to a certain extent. All these applications can be carried out under the umbrella of the corporate social responsibility project of aviation companies and organisations. This social responsibility will become a necessity in time as a result of the rapid development of technology and the integration of UAVs into social life. When viewed from an international perspective, it is of great importance in terms of aviation safety for aviation organisations such as ICAO and EASA to come together and increase the number of joint studies they have carried out on UAVs.

5.1 Implications for practitioners

Recommendations for aviation authorities

- Aviation authorities should determine precise and clear regulations for the safe use of UAVs. These regulations should cover elements such as UAVs flying at certain altitudes and geographical areas, procedures for emergencies and post-flight reporting. Contributions to global flight safety should be ensured by compliance with international aviation standards (International Civil Aviation Organization) [38].
- Flight training schools and programmes for UAV pilots are to be established. These programmes are to provide basic flight data, flight safety and crisis management. Further, certification procedures will ensure that UAV operations become safer.
- Understanding the need for integrated air traffic management systems (UTMs) should be developed to prevent collision with other aircraft by creating zones where UAVs must manoeuver. This system ensures safer flight of UAVs and the maintenance of airspace order [39].

Recommendations for UAV operators

- UAV operators are required to conduct maintenance and monitoring tasks properly prior to, during and after the flight. These maintenance tasks will enhance flight safety and avoid system failure. It is also necessary to update all the system software [40].
- UAV pilots need to check the weather carefully prior to flight. They should never fly under poor weather conditions because turbulent weather can make them lose control of UAVs and lead to accidents.
- UAV operators need to be ready for emergency situations. They should decide on the steps to take in emergencies, and operators should review these steps regularly.

Recommendations for industry stakeholders

- Development of autonomous flight, sensing technologies and data processing infrastructures should be pursued to enhance the security, safety and efficiency of UAVs [41].
- Inter-government and private sector cooperation will help develop UAV technologies and promote public awareness about UAVs.
- Industry stakeholders should ensure the security of the data collected by UAVs during their flights and avoid violating personal privacy [42].

5.2 Future research

Future research should focus on several critical areas to ensure the safe integration of UAVs into the airspace. First of all, international and national regulatory bodies (e.g. ICAO, EASA) need to take a more proactive role. The establishment of a standardised legal framework, especially stricter licensing processes and global harmonisation of rules governing UAV operations, will increase airspace safety and security [13]. However, UAV manufacturers also need to contribute to security measures. AI-powered collision avoidance systems, geo-fencing software that works autonomously, and blockchain-dependent management of flight logs are some technologies that can be implemented to enhance the safety of UAV flight [10]. Both manufacturers and regulating bodies should work together to develop such technologies.

Additionally, air corridors need to be defined to manage the increasing UAV traffic in the airspace. The allocation of flight routes solely for UAVs will reduce the possibility of collision and maximise the airspace utilisation. Studies to be conducted in this regard need to involve guarantees for the safe sharing of the airspace by manned and unmanned aerial vehicles [19].

Cyber threats should also be one of the areas of concern for future research. Studies need to be conducted on the vulnerability of UAVs to cyber threats, the development of data encryption methods for anti-jamming and malware attacks, the development of improved unauthorised access detection systems and the development of secure communication protocols [11].

Additionally, the effects of UAVs on privacy and ethics should be examined in detail. Risks such as surveillance, data collection and intrusion into individuals' private lives are serious concerns that can restrict the areas of use of UAVs. Ethical guidelines for the use of UAVs and implementing them with laws [20] are necessary.

Finally, it is of great importance to raise public awareness of UAV security and increase training programmes for UAV operators. Operators who do not receive appropriate training can create serious security risks both in the airspace and at ground level. Therefore, training standards for operators should be increased, and public awareness campaigns should be organised [24].

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