Traffic & Transportation

Identification of Potential Urban Air Mobility (UAM) Safety Hazards from Helicopter Accident Data – Methodology and Preliminary Results

Jordi PONS-PRATS[1], Jovana KULJANIN[2], Fedja NETJASOV[3], Jorge SAENZ DE TEJADA MILLAN[4]

Original Scientific Paper
Submitted: 17 July 2024
Accepted: 27 Jan 2025

[1] Corresponding author, jordi.pons-prats@upc.edu, Physics Department – Aeronautical Division, Universitat Politècnica de Catalunya · BarcelonaTech (UPC), Castelldefels, Spain; Centre Internacional de Mètodes Numèrics a l'Enginyeria (CIMNE), Barcelona, Spain
[2] jovana.kuljanin@upc.edu, Physics Department – Aeronautical Division, Universitat Politècnica de Catalunya · BarcelonaTech (UPC), Castelldefels, Spain
[3] f.netjasov@sf.bg.ac.rs, Faculty of Transport and Traffic Engineering, University of Belgrade, Belgrade, Serbia
[4] jorge.stm98@gmail.com, Physics Department – Aeronautical Division, Universitat Politècnica de Catalunya · BarcelonaTech (UPC), Castelldefels, Spain

Publisher:
Faculty of Transport and Traffic Sciences, University of Zagreb

ABSTRACT

Safety is paramount for aviation. The development of urban air mobility (UAM) is not excluded from considering it, however, while research generally focuses on technical and operational issues, few have been done regarding safety. It is clear that there are a lot of unknowns regarding either the design or operation of the UAM vehicles, so this research paper proposes to extract as much information as possible from helicopter accidents in urban environments. While no detailed technical information about UAM vehicles and operations is available, helicopters represent an interesting source of data. It is considered that the UAM vehicles with vertical take-off and landing capabilities present similar characteristics to helicopters. Building on a previous report by the authors [1], a set of accident reports from several safety agencies worldwide has been analysed. The reports have been shortlisted according to the relevance of the scenario; selecting those which happened in an urban environment or close to urban areas. Relevant hazards have been identified and assessed by experts in order to understand how they could translate to UAM operations. Identified hazards could serve for risk assessment of future UAM operations as well as for the development of risk mitigation measures or policies.

KEYWORDS

urban air mobility; UAM; advanced air mobility; safety; hazard identification; helicopter operations.

1. INTRODUCTION

Over the last few decades, rapid urbanisation combined with global population growth has caused large metropolitan cities across the globe to face the ubiquitous problem of congested transport systems and pollution [2]. Due to the tremendous influx of people in the urban areas, the cities are expanding at a rapid pace causing the saturation in the absorption capacity of ground traffic before it can be adapted. This situation creates an exponential increase in commuting times due to the resulting congestion levels. On the other hand, the available space for new ground infrastructures is becoming more and more scarce in any big metropolis around the world, which can make it more difficult to solve the need for more space to enlarge the existing infrastructures.

The use of public means of transport has reduced delays between 38% and 48% [3], but the use of ground infrastructure remains the same, being very limited. UAM is considered a new sustainable transport paradigm, which aims to mitigate congestion in densely populated areas. By utilising airspace as a third dimension, UAM will reach the expected reduction in congestion [4]. The UAM concept relies on several key technologies, including advancements in batteries, distributed electric propulsion and autonomous systems. These technologies not only support the sustainability of this mode of transport but also pave the way for new aircraft designs, commonly referred to as electric vertical take-off and landing (eVTOL) aircraft. The mission type is not yet well defined. Potentially, it could cover medical service transportation, airport shuttle and passenger transportation between suburban areas and the city centre, among others. Some of these potential missions are well established in cities or regions around the world, but which are the ones that will lead the implementation of UAM is not still clear. There is a long journey till UAM fully develops and fully integrates into the public transport system, but, in the meantime, one can expect to identify its footprint on mobility.

The current attention of the academic literature and other industrial reports on UAM is mainly focused towards two broad areas of interest – aircraft technology associated with eVTOL aircraft and market operations [5]. Such thematic division is reasonable as eVTOL aircraft need to meet specific technical requirements to be successfully exploited for the given missions in the market. On the other hand, very few papers in the safety-related area reflect an insufficient progress in research of UAM aircraft which imposes entirely new safety hazards due to its distinctive design. For example, the rotor system in eVTOLs is designed with multiple redundant components which protect from complete propulsion failure in flight [6], as opposed to the feature of autorotation typically available in helicopters as a way to safe descent. The switch to new configurations and technologies makes safety a challenging issue to constantly track since what applies to helicopters could no longer apply to UAM vehicles. Bearing in mind that UAM aims to operate over urban and suburban areas with dense populations, the safety assessment of its operations will become of vital importance to mitigate the safety risk and enable successful and wide implementation. Safety assessment will, in turn, be conditioned by the concept of operations which will envision how these new vehicles will be integrated into the current ATM system. The SESAR recently published its fourth edition of the U-space Concept of Operations (ConOps) which establishes the foundation of how the U-space system should be used from a user's perspective, and how it should behave [7]. Leveraging on the information provided by Airbus UTM Blueprint [8], SESAR envisions that the U-space will gradually evolve from the fundamental concept till full integration of U-space as automation levels increase over time. The document also identifies potential risks and impacts associated with different flight paths and proposes strategies to mitigate possible risks. Based on the initial findings described in [1], and to complement the existing findings, this study aims to shed some light on hazard identification as an initial step towards the risk mitigation process, as defined by ICAO Annex 19 Doc 9859 [9]. For this purpose, the Delphi study was performed by gathering a group of experts from the aviation field with a solid background in the UAM field who provided their feedback on the list of hazards previously identified by the group of authors. The study examines the list of hazards in the context of the early phase of UAM implementation in which the human will still have a prominent role in piloting the aircraft. Thus, the paper does not intend to provide an exhaustive list of all possible hazards but rather aims at identifying the relevant hazard categories coupled with the most critical hazards which may impose a particular safety concern in the UAM operations. In order to accomplish this goal, the study attempts to relate some of the previously identified hazards in helicopter service to the new eVTOL vehicles due to the similarities they share with respect to the operating environment as well as some commonalities in aircraft design.

The rest of the paper is organised as follows. Section 2 provides a summary of the background related to helicopter-based services. Section 3 describes the methodological approach the analysis follows, while section 4 provides the preliminary results related to hazard identification. Section 5 describes the results obtained from the root cause analysis, identifying differences among the flight stages. Section 6 complements the previous one with the concluding remarks we obtained as an outcome of the experts' assessment. Finally, section 7 summarises the findings of the analysis.

2. HISTORICAL BACKGROUND AND HELICOPTER-BASED SERVICE

There is no existing background on VTOL vehicle accidents in urban passenger transport, as many of these new vehicles are still undergoing certification, with many others in the deployment phase. While helicopters may not be a perfect comparison, they serve as a logical benchmark for eVTOL operations due to similarities in design and operation. Therefore, the paper examines previous helicopter-based operations in urban areas by analysing the findings extracted from their accident reports. Therefore, at the initial stage, it is of great importance to analyse the market evolution of helicopter-based service together with the underlying factors which led to the cease of the operations. The insight into helicopter-based service will enable us to envision potential contextual settings in which these new vehicles will operate with a focus on their technical and operational requirements. This will facilitate the initial definition of a set of hazards applicable to the UAM mode of transportation. In 1947, the first commercial operations with helicopters in the U.S. targeted mail transport. Till 1953, the passenger service was not introduced. By the mid-60s, the number of passengers reached between 400k and 1.2 million per year in cities like Los Angeles, San Francisco, New York and Chicago. The main offered services were airport shuttle, airport transfer, charter and private services [10, 11]. The investment in new infrastructure, mainly in those congested areas, helped to increase the demand, leading to revenue increase of up to 50% in the following years. The lack of space in the city downtown introduced the need to look for other locations, being the tall building rooftops a clear objective. It helped the development of the business and the attraction of new customers. The companies offering this kind of transport services grew fast.

Moreover, the helicopter service faced numerous challenges on its path of development. The economic viability of the business was not initially ensured, so like other transportation services, it was supported by subsidies. This fact meant that one should demonstrate the public utility and the competitiveness of the sector, or in other words that it could be viable. In comparison, at the same moment, the airline industry was already viable, so it created a false positive feeling towards the helicopter airline business. The final result was that the helicopter transport services received a similar amount of support than other more mature transportation services, while the same level of exigence and control was applied by the aeronautical authorities. Among different factors which may influence the viability of the helicopter service, seating capacity, speed of the aircraft and frequency of service were found to be important as a means to become a self-sufficient industry [12, 13]. During the operational years, seating capacity increased faster than any other air service due to market expansion and equipment improvements. By 1963, the average number of seats per aircraft had quadrupled to 20.7, up from 1961. As seat capacity expanded, the average passenger load factor declined from 51.1% in 1959 to 50.5% in 1960 and 40.7% in 1962 [14]. The sector faced financial challenges, as well as key handicaps such as noise pollution, and privacy and safety issues due to accidents and incidents over the decade. The sector shifted towards commercial operations targeting rich customers due to high ticket prices, seeking to offset costs through additional services. On the other side, the general public felt the negative impact of running these services above urban areas. Despite increasing popularity, discontent and reliability difficulties led to the cessation of operations. While helicopter services in the U.S. faced challenges, Brazil still offers a contrasting example of how helicopter-based transportation can thrive in a different socio-economic environment. Brazil was a pioneer in developing and implementing early UAM transport concepts, alongside the United States. Overcrowded and saturated ground transport infrastructures in major cities like São Paulo or Rio de Janeiro helped in the development of helicopter-based transport services. The country’s infrastructure did not keep up with the economic growth, resulting in traffic congestion and longer commuting times. The wealthier population sought other modes of transportation due to rising organised crime and unsafe streets [15]. Seating capacity in Brazil was significantly lower than in the U.S. due to market share and consumer demographics, meaning a higher number of operations. The increased frequency of operations resulted in world-record traffic volumes. By the end of 2000, there were 800 private helicopters in total, with half of them being used just in São Paulo [16]. In the rush hour, the air space could be very crowded, with a large number of simultaneous flights. By 2008, the number of helicopters increased by 30% [17]. The number of vehicles, together with the demand for transport services helped to quickly increase the number of facilities [18]. This fast increase did not help to keep track of all the facilities and services, so a lack of data and statistics can be detected. The Brazilian and U.S. business models, although with different approaches, demonstrated the feasibility of the UAM networks in crowded and heavily saturated cities. Financial difficulties and public acceptance were the main reasons for the cease of operations in the U.S. Today, a completely different scenario can be identified in Brazil due to the socio-economic situation; the need for helicopter transportation has kept growing. Since the target customers are high-income people, financial issues are not foreseen. Nowadays, the number of facilities in the two main Brazilian cities, namely São Paulo and Rio, is huge compared to other major cities worldwide [19]. From the described experience, one can easily detect the two main societal acceptance issues to tackle; safety and noise, although several strategies have been proposed they are not fully solved [20]. How to handle the number of operations is also a technical issue, in this case, related to air traffic control (ATC) management. São Paulo, for instance, decided to create a specific ATC service. It is the first and only city to apply this measure. Although the recent study demonstrated the viability and competitiveness of this concept on short and medium-haul distances when compared to other means of transportation including commercial aviation and high-speed train (HST) [12], there is still a burden of issues to be tackled before the final implementation. Societal acceptance, and noise and safety in particular, is and will be a potential stopper for the development of such a transport service. This issue concerns either manufacturers, operators and authorities.

3. METHODOLOGY

This study introduces the methodological framework which enabled us to identify the final selection of the potential hazards that apply to the UAM operations (see *Figure 1*). The framework aims to provide an iterative process to refine and shortlist those hazards identified from helicopter accidents which could be eventually applicable to UAM. As observed, the framework is composed of four different and interrelated modules, which were combined progressively in an interactive manner.

— Identification of relevant accidents and incidents: Several relevant databases (Bureau d'Enquêtes et d'Analyses (BEA), National Transportation Safety Board (NTSB), Air Accidents Investigation Branch (AAIB), Centro de Investigação e Prevenção de Acidentes Aeronáuticos (CENIPA), among others) containing the accident and incident reports were examined in order to identify relevant accidents and extract those reports that had a link with the topic under research. The first selection was based on criteria such as the aircraft being a helicopter, and whether the causes of the accidents could be translated to urban operations, although the criteria of the location was not so strict. Hundreds of reports from the above-mentioned databases were analysed, but a first selection of around 200 reports was made.

— Categorisation of the hazards: Reading the accident reports one can extract the type of failure. As a general criterion, the meaning of each category can be summarised as; mechanical includes everything related to an engine or system failure; operational includes everything related to a failure to understand the conditions when performing the flight; procedure includes those mistakes on applying the defined procedures, either aircraft or company procedures; equipment includes the failure of the equipment of the facility or area of operation; weather includes all the weather-related issues, from wind conditions to visibility; human-related are related to human factors, from training to poor judgement; collision implies the collision with any type of obstacles or with the ground; maintenance includes those failures that can be attributed to lack of maintenance; and finally unknown includes those other issues not previously considered.

— Identification of the initial set of hazards: The first selection was refined following the criteria of location (urban environment), and clarity of accident causation description. This second iteration of the selection process has led to a set of 64 reports, from which 61 are used for the described analysis. It is worth mentioning that some of the reports provide the occurrence categorisation (referring to ICAO list), rather than the list of hazards that led to the particular event. Therefore, based on the respective accident/incident description and the corresponding set of occurrences, we endeavoured to identify the potential set of hazards. In order to draw credible conclusions on the hazards involved, we employed the experts' judgement at this stage, who performed the validation activities on the previously identified hazards. A summary table of those cases is provided as an annex of this manuscript (9).

— Identification of the hazards related to UAM operations. Once the initial set of hazards has been identified, they need to be considered through the lens of UAM operations. At this stage, the initial list of the hazards, which includes all the identified hazards, has been shortened eliminating some of the hazards that have been considered not relevant or applicable to the new vehicle operations. At the end of this stage, all hazards have been eventually classified into three main categories that are already acknowledged in the relevant literature, i.e. operational, environmental and technical.

— Experts assessment. The list of hazards identified in the previous paragraph has been exposed to experts from a variety of domains in aviation including academia and safety experts. The goal of this step was to discuss the previously identified hazards as well as to identify the new ones based on the experience and feedback provided by the experts. The experience and the imagination of the experts are exploited throughout the brainstorming sessions to identify as many hazards as possible. While doing this, we attempted to follow the guidelines proposed by the NLR's brainstorming approach [21] by fostering an open atmosphere and avoiding criticism and/or analysis during the brainstorming. As a result of this step, the final list of the hazards has been derived.

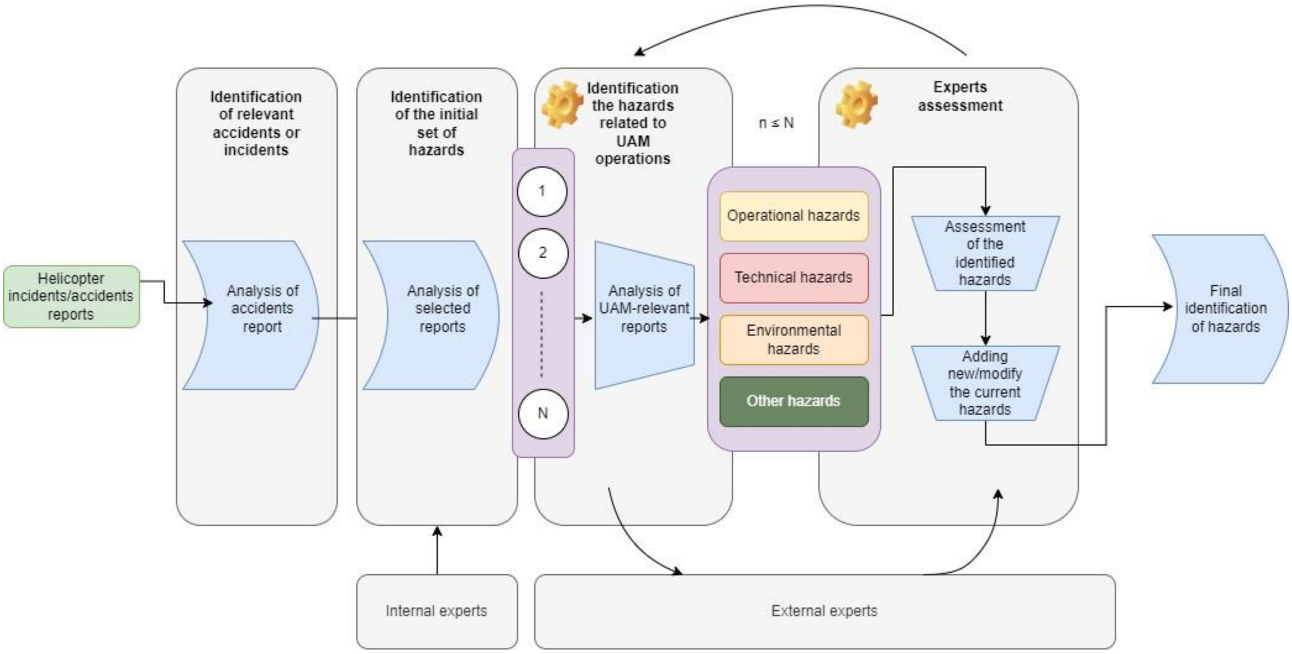

Figure 1 – Methodological framework

4. SAFETY CONTRIBUTION FACTORS

Before detailing the identified hazards, several key factors have been highlighted that could significantly alter the safety landscape in the transition to UAM operations. The aim of this study is to ensure that fruitful conclusions can help to increase the safety of UAM operations. The primary goal is to identify potential safety gaps and tendencies that can be extrapolated to UAM operations based on the analysis of helicopter operations. The UAM vehicle configuration and concept of operations are still not fully defined and standardised, so the helicopter starting point can be helpful.

Thus, this analysis focuses on identifying potential hazards rather than investigating the specific causes of accidents. In any case, it is acknowledged that the specific UAM vehicles performance and characteristics, as well as the concept of operations could modify the results of this analysis.

The factors that could significantly impact safety in UAM operations are discussed below.

4.1 Automation

Automation is envisioned to be gradually implemented in the aviation industry. According to the definition provided in DOT/FAA/CT-96/01 [22], automation can be defined as “independent accomplishment of a function by a device or system that was formerly carried out by a human”. Based on the definition, one could easily draw the conclusion that automation will significantly affect the role of humans in the aviation system primarily by reducing pilots’ manual workload and enabling them to focus on other critical tasks [23]. Based on the current advancements in urban air mobility (UAM) systems, two distinct approaches to automating future eVTOLs can be anticipated [24]. The first approach, referred to as the “pilotless path”, involves developing eVTOLs as fully autonomous vehicles from the very beginning. Given the significant challenges this concept presents during early implementation stages, initial operations are expected to occur within controlled environments, with a gradual transition to autonomous functionality in more diverse and complex settings. On the other hand, the “piloted path” is less challenging and more acceptable from the societal point of view as the process from crewed piloting to fully autonomous will be sequential. In other words, the transition from a system which offers no assistance to pilots to a system which acts autonomously without human intervention is deemed to be gradual and smooth, thereby changing the role and the engagement of pilots in each subsequent level. Even though automation will bring substantial benefits which will eliminate the inefficiencies in the system, it will also impose particular challenges in human response. Namely, [25] claimed that these new technologies will bring novel hazards in the cognitive domain as the pilot will face variations and disturbances that they have not experienced in the current system, mainly during non-nominal (emergency) operations. Having in mind that the role of humans will be mainly focused on monitoring the system which brings them in a passive position, the unexpected situation will trigger the need for rapid response and decision-making [26]. It must be noted that this reaction will occur after extended periods of automated flight, which can be mentally tedious and diminish human readiness for an immediate and effective response. This opens up a "pandora's box" of challenges regarding adequate training in this new environment, which must address how to maintain engagement, improve situational awareness and ensure readiness for swift action when intervention is needed. Furthermore, well-established studies conducted among commercial aviation pilots could provide a valuable foundation for designing effective training for this emerging role. For example, [27] highlighted that, although training for abnormal conditions enhances pilots' abilities, they may still fail to respond effectively when faced with unexpected situations that elicit surprise. Another clear example of how poor and inadequate training of crew staff in the semi-automated environment can lead to fatal accidents is the issue of B737 MAX. As described in [28], one of the most significant factors contributing to the failures of the 737 MAX was a software design problem together with a single sensor input. The flawed design of the MCAS (manoeuvring characteristics augmentation system) system combined with the fact that a single AOA (angle-of-attack) sensor was used, despite the known risk of sensor failures, led to an unpredictable behaviour of the aircraft by the pilot. The investigation conducted by Indonesia's National Transportation Safety Committee revealed that the flight crew attempted to recover the aircraft from a dive triggered by a malfunctioning sensor, which caused the MCAS to repeatedly pitch the aircraft downward. Having in mind that the future eVTOLs will heavily rely on the sensor data for stability and navigation, one could expect that their failure may impose critical safety concerns on operations. *Table 1* illustrates potential hazards associated with human errors that may arise within contextual settings characterised by varying levels of automation. While taxonomies of automation differ significantly in their granularity – ranging from fine-grained classifications with ten levels, as proposed by [22], to broader frameworks like that of [29] with six levels of automation – a common conceptual thread persists. These frameworks emphasise a progressive reduction in human involvement as system intelligence increases, transitioning from individual-level operations to collective, interconnected systems. Building on this notion, *Table 1* outlines the most significant hazards associated with human operations in these environments, ending in scenarios where systems are fully autonomous and operate independently of human intervention.

Table 1 – Human errors associated with different levels of automation

Low automation (pilot-in-command or assisted operations)	**Moderate automation (shared control between humans and AI)**	**High automation (supervised autonomy with limited human oversight)**	**Full automation (completely autonomous operations)**
Human errors: - Pilot fatigue or stress leading to operational mistakes - Inadequate situational awareness in complex urban environments - Miscommunication with air traffic control (ATC) or ground operators	Human-AI interaction risks: - Ambiguity in decision-making responsibilities between human pilots and AI systems - Over-reliance on automation, leading to pilot skill degradation - Ineffective or delayed human intervention during system malfunctions	AI and system failures: - Inability to handle edge cases or novel scenarios not encountered during training - Software bugs or glitches in autonomous decision-making algorithms; risk of cascading failures in networked systems	System-dependent risks: - Total reliance on AI systems with no human intervention during emergency - Failure to adapt to unanticipated scenarios or anomalies (e.g. uncharted obstacles, power failures)

Automation in helicopters

The European Aviation Safety Agency (EASA) currently defines 4 levels of automation for helicopters, based on their navigation equipment and onboard computer aids. As described in [30], there are four levels of automation, which relate to the equipment and computer aids. The interested reader can find the detailed description on the provided reference, but the levels are no automation, stability augmentation system (SAS), stability augmentation system (SAS) plus auto flight control system (AFCS) 3-axis mode, and stability augmentation system (SAS) plus auto flight control system (AFCS) 4-axis mode. The items are sorted according to the level of assistance or automation, up to the last one that does not require any pilot input.

The EASA certification of UAM vehicles is based on three levels of automation: manual flight, automated flight and autonomous flight. At this point, the reader should consider the temporal framework for the development, implementation and certification of the required technology to reach the final level. This last level means a fully autonomous flight, even without a pilot on board or remotely. It not only implies full capacity to control the vehicle but also the capacity to get situational awareness. Although automation can easily lead to a safer operation, the lack of capacity to get situational awareness, and to anticipate the outcome of potentially hazardous scenarios should be considered while progressing along the defined levels of automation.

Design of future UAM vehicles and its relationship with helicopters

Worldwide, there are a great number of manufacturers which invest huge amounts of effort in designing the fundamentally new design concept of flying vehicles compared to the ones we can find in commercial aviation. This new design is mainly driven by distributed electric propulsion (DEP) and recent advances in electric technologies. The future UAM vehicle market is expected to include a large number of different eVTOL vehicles, some of which are tremendously different from the design that already exists in commercial aviation. eVTOL Aircraft Directory (see evtol.news/aircraft) is one of the most comprehensive databases currently available, which includes information on different types of eVTOL aircraft. As of 23 October, the database contains a total of 988 vehicles that can be classified into four categories: 378 vectored thrust, 187 lift+cruise, 312 wingless multicopters and 111 hover bikes/personal flying devices.

Although there are multiple classifications of eVTOL which can be currently found in relevant literature, they make a distinction between two broad categories – “wingless” and “powered lift”. The latter can be further divided into vectored thrust, independent thrust and combined thrust. These vehicles demonstrate very good performance during the cruise phase allowing faster speeds and thus, longer flight distances thanks to its fixed-wing-based concept. However, these advantages come with some compromise, mainly during hovering. For example, vectored thrust vehicles rely on a single propulsion system for take-off/landing and cruise, which inevitably results in a design compromise of the propulsion system. On the other hand, vehicles characterised as independent thrust are equipped with two separate power trains for VTOL and cruise. The VTOL propellers are used exclusively during take-off and landing, then folded away during the cruise phase when dedicated cruise propellers take over, thus ensuring aerodynamic efficiency. Moreover, combined thrust vehicles combine the characteristics of previously described concepts.

However, the second group of vehicles (“wingless”) would be particularly relevant for this study, as they share common characteristics with the current helicopter design. They are also called “rotary-wing cruises” as they generate lift exclusively with rotating wings during the cruise phase [31]. They include all types of multicopter configurations, and also conventional helicopters. Unlike the first group of vehicles, the rotary wing group owns very good hover and VTOL characteristics making them particularly advantageous in densely populated areas where a vertical trajectory is essential for avoiding nearby obstacles. One of the main disadvantages resides in their limited speed and flight efficiency during the cruise phase. The representative of this type of vehicle is the Volocopter VC200 which has a unique design with 18 fixed-pitch propellers placed in a stacked configuration (see www.volocopter.com). The vehicle is designed as a two-seat aircraft with a speed range between 50 and 62 mph, and a maximum range of around 25 km. The aircraft features are optionally-piloted which opens an opportunity to fly autonomously in the future.

Equipment and avionics for automation

As previously mentioned, in order to achieve a high level of automation which entails the integration into an ecosystem of urban transport, eVTOLs need to be supported by robust infrastructure capable of providing accurate localisation and perception. [29] provides the framework for eVTOL perception and localisation which relies on three different pillars, i.e. localisation and state estimation, environmental perception and surveillance and situation awareness. Each pillar is reflected in the required equipment and tools which combine traditional methods and AI techniques. For instance, localisation and state estimation are based on the employment of tightly coupled GPS/INS integration, seen as an efficient approach to overcoming the issue of GNSS signal degradation in complex urban environments. Recently, a group of authors from NASA proposed a method which fuses data from different sources such as GPS, inertial and optical sensors including cameras and lidar as a way to improve state estimation. Moreover, environmental perception which is essential for operations in low-altitude urban airspace is ensured by a variety of technologies including airborne radar systems, lidar and visual simultaneous localisation and mapping (SLAM). Finally, surveillance and situational awareness are integral capabilities of eVTOL systems for enabling autonomous operations, driven by extensive data generated by localisation, state estimation and environmental perception systems. The cornerstone of the modern air transportation system is based on the ADS-B which is essentially a surveillance technique that relies on aircraft broadcasting their identity, position and other information derived from onboard systems (GNSS etc.). According to the FAA, all eVTOLs are mandated to be equipped with ADS-B systems supporting in this way the broader infrastructure of unmanned aircraft system traffic management (UTM).

All the above-mentioned systems present a radical shift from the mechanical and early electronic technologies employed in helicopters, giving rise to a completely new set of hazards which have not existed in the past. As already discussed, the main technological advancements in navigation design are similar to those found in autonomous driving unmanned systems [32, 33] and encompass the introduction of gyroscopes, accelerometers and other perception sensors. These sensors are responsible for maintaining balance, particularly in the hovering and take-off phase. However, failures in these sensors could compromise the safety of the system, introducing an array of novel hazards that were not encountered with earlier technologies. *Table 2* outlines some of the potential hazards that could occur due to the sensor malfunctions.

Table 2 – Potential hazards related to sensor failure in the context of future UAM operations

Potential hazard	Description
Loss of stability and control	eVTOL vehicles often rely on multiple sensors (gyroscopes, accelerometers and GPS) to maintain balance, especially during hover and vertical take-off/landing phases. A failure in these sensors can lead to unstable flight or uncontrolled movements, potentially resulting in accidents.
Navigation and positioning issues	Sensors like GPS, LiDAR and radar are essential for eVTOL navigation, particularly in urban settings with obstacles. A failure in positioning sensors can make the vehicle lose its sense of location, increasing the risk of collision with buildings, power lines or other obstacles
Degraded collision avoidance	Many eVTOL systems are equipped with sensors for detecting nearby objects and avoiding collisions (e.g. radar, lidar or vision sensors). If these sensors fail, the vehicle might not detect or respond to obstacles in its path, compromising safety.
Impact on autonomy and pilot assistance	For autonomous or semi-autonomous eVTOL operations, sensor data are crucial for decision-making and control. Sensor failures can disrupt automated functions or force pilots to take manual control, which could be challenging in high-traffic or complex urban environments.
Reduced redundancy and system reliability	eVTOL designs often incorporate sensor redundancy to handle failures. However, when one sensor fails, the system becomes more vulnerable to further failures, reducing overall operational reliability and safety.
Communication and data transmission losses	Some sensors facilitate communication with ground control or other aircraft. A failure in these sensors could disrupt communication, potentially isolating the vehicle and preventing it from receiving or transmitting critical information.

4.2 Human factors

Human factor issues are strictly related to automation. It is easy to understand that the replacement of the pilot action with automated actions would reduce the potential risk associated with human mistakes. The key issue arises not with full manual or full autonomous operations, but in scenarios where partial automation requires pilot interaction. Studies like [34, 35, 36] assess the workload and reaction time in emergency or special situations and demonstrate that pilots with less experience can fail to react in the proper way and within the required margin of time. [34] found that partial automation increased pilot workload in emergency scenarios, while [35] highlighted the challenges of response time during limited visibility operations. These special situations can be operations at night or limited visibility, with failure-induced vibrations or close to obstacles, which can easily relate to emergencies. As the previous studies demonstrated, partial automation can lead to additional human-related issues, since lack of training or experience could easily lead to misinterpretation of the actions the automated system is taking or a contradictory set of actions between the automated system and the pilot. Since full automation will not occur from one day to another, additional protection systems and more training will be required during the transition phases.

4.3 Coordination of stakeholders

The collaborative approach among manufacturers, regulators and operators as a final customer will stand as an important milestone in the advancement of future urban air mobility (UAM) operations, laying the groundwork for safe and efficient integration. To achieve this, each stakeholder within the ecosystem must thoroughly understand its role and the broader impact on the system. For example, EASA highlighted the challenges associated with implementing machine learning (ML) and, more broadly, artificial intelligence (AI) in onboard aircraft systems in its report, concepts of design assurance for neural networks (CoDANN) [37]. In collaboration with its partner Daedalean AG, EASA identified key risks associated with the use of machine learning systems in safety-critical applications, as outlined in the [37]. This effort underscores the importance of a systematic and cooperative approach to addressing the complexities of emerging technologies in the UAM landscape.

5. RESULTS

5.1 Accident report analysis

As described in the summary *Table 9* in the appendix, the analysis of the collected data has been performed. The first approach includes all the reports, while the second splits the list by flight phase: approach, cruise and departure. Both approach and departure include the landing and the take-off, respectively. *Table 3* summarises the cause categories (hazards) across different flight phases. Considering the fact that each report could define up to 3 root causes, a total of 146 causes have been identified; 34% of the total corresponds to the approach phase, 40% to the cruise and 24% to the departure. Although the differences are relatively small, approach and cruise phases account for over 70% of the total causes, while departure only 24%. Upon analysis, the primary root cause category is operational, accounting for 34% of all causes, 43% on approach, 24% during cruise and 34% on departure. Taking the whole set of reports, we can identify pure operational causes, as the main group within the categories. Although not reflected in the data in *Table 3*, in a deeper analysis, where the details of the categories are available (like the split into aerodynamic effects, loss of tail rotor effectiveness (LTE), night operations or confined operations), one can see that any of them does not take more than 3% each. There is no other root cause that takes similar figures in all the flight phases. Mechanical and weather-related causes are the second most common, with weather being more prevalent during the cruise phase. An “unknown” category is included for cases where investigations did not conclude with a specific root cause. It is clear that does not provide any insight on the safety measures, but one should acknowledge that this situation could happen. Similarly, regarding the flight phases, there is a specific report that was not able to clearly identify which flight phase was involved, while the causes were well-determined.

As mentioned, each report provided up to 3 relevant causes; some only indicated one, and some two. Few of them provided more than three, but in those cases, only the three main ones were considered. As mentioned, *Table 3* considers all cases as a whole, while it is also interesting to detect the relationship chain among causes, trying to understand the effect of the initial one. For this purpose, we used the sunburst plot, which helps to easily display hierarchical data.

Figure 2, together with *Table 4*, shows the causality chain for all the selected causes for all the flight phases ensemble. This visual helps illustrate the chain of root causes, showing how operational issues may lead to mechanical failures or collisions, among other outcomes. The reader can follow the causality selecting the initial cause (according to the reports), to identify the second cause and the third cause. Each of them is listed with the total amount of counts and the partial percentage at each level. One can see that the most common causes are the operational and weather-related ones. The operational ones can produce either a mechanical failure, a collision or another operational cause, while a human-related cause is less probable. It is interesting to see how likely it is to chain together several operational causes. A similar situation happens when analysing the weather-related issues, that lead to operational causes.

Table 3 – Root cause categories per flight phase

Root cause category	All phases	App phase	Cruise phase	Dep phase	N/A
Mechanical	21 (14%)	9 (18%)	8 (14%)	4 (11%)	0 (0%)
Operational	49 (34%)	21 (43%)	14 (24%)	12 (34%)	2 (67%)
Procedure	9 (6%)	1 (2%)	4 (7%)	4 (11%)	0 (0%)
Equipment	4 (3%)	1 (2%)	1 (2%)	2 (6%)	0 (0%)
Weather	22 (15%)	6 (12%)	12 (20%)	4 (11%)	0 (0%)
Human-rel	18 (12%)	4 (8%)	9 (15%)	4 (11%)	1 (33%)
Collision	13 (9%)	2 (4%)	8 (14%)	3 (9%)	0 (0%)
Maintenance	9 (6%)	5 (10%)	3 (5%)	1 (3%)	0 (0%)
Unknown	1 (1%)	0 (0%)	0 (0%)	1 (3%)	0 (0%)
	146	49 (34%)	59 (40%)	35 (24%)	3 (2%)

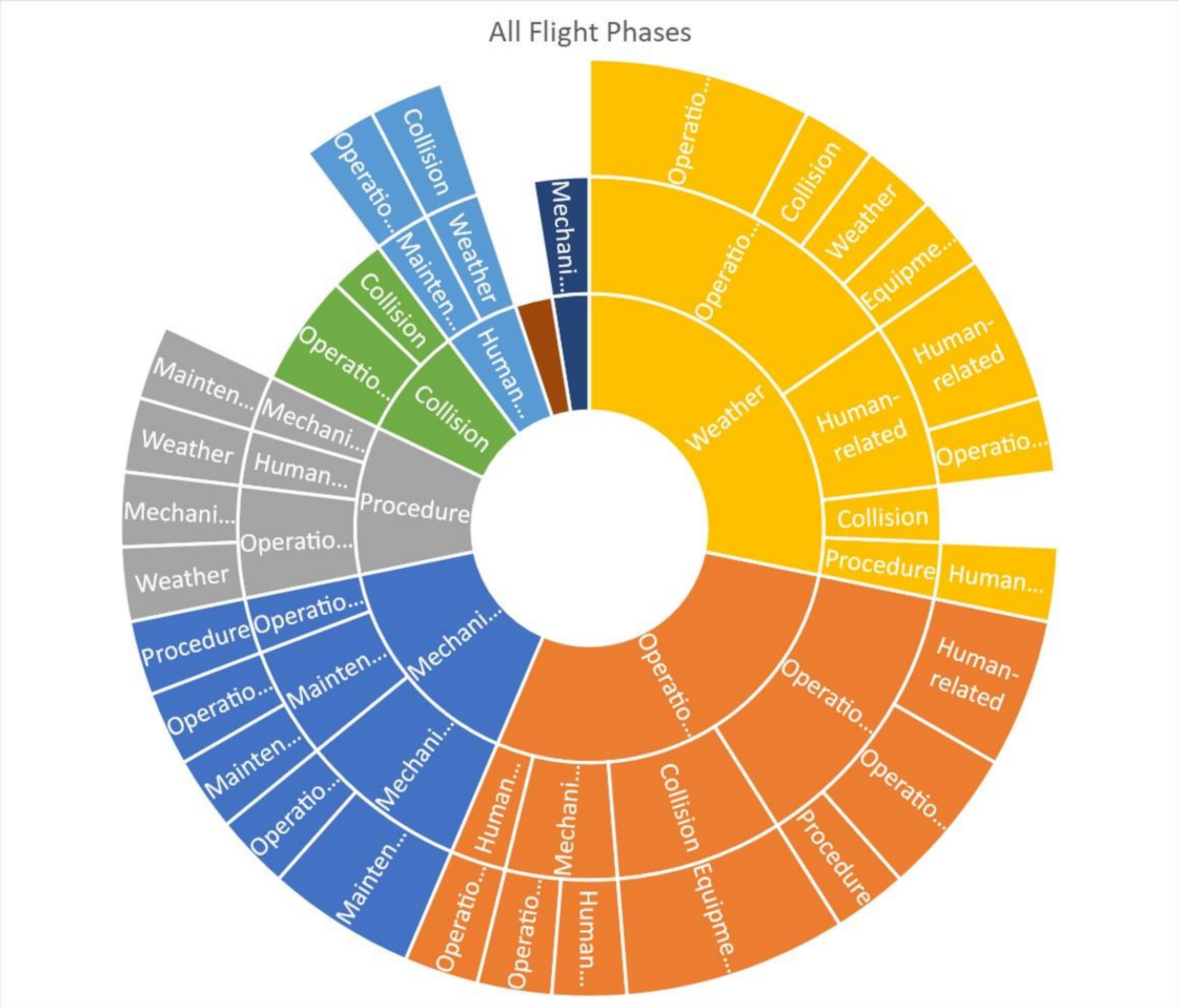

Figure 2 – All flight phases; the hierarchical relationship among cause categories

The following section examines the root causes during each flight phase – approach, cruise and departure. Splitting the reports according to the flight phase, one can analyse data in *Figure 3* and *Table 5* for the approach phase, in *Figure 4* and *Table 6* for the cruise phase, and in *Figure 5* and *Table 7* for the departure phase of the flight. In these cases, the overall behaviour is similar to the described for the merged data. The restricted number of cases also limits the possibility of identifying the same figures and causality chains, but it is still possible to identify the operational causality chain either in the approach or departure phase, while it does not show up in the cruise phase. It could be caused, as mentioned, due to the limited amount of reports, more than on the flight phase itself. In general, the expansion of the causality tree, which in the merged case can have three or four branches at the next level, is reduced to two branches in the split cases.

It is interesting to see how, amongst other relevant relationships, mechanical cause could lead to either mechanical or operational, while operational can lead to mechanical and collision, or collision if one considers the third level. Weather causes can lead to an operational one. Collisions can easily lead to a secondary collision or other operational causes, while procedure-related causes can lead to human-related causes. Also relevant is that, during the cruise phase, the causality chain is less likely to feature operational issues leading to collisions, possibly due to the steady-state nature of this flight phase. In summary, operational causes dominate the identified hazards, particularly during the approach and departure phases. Mechanical and weather-related causes also feature prominently, with weather playing a larger role during the cruise phase. These findings highlight the importance of addressing operational and weather-related risks in the design of UAM systems, particularly in the context of urban flight operations where approach and departure phases are critical.

Table 4 – Root cause categories of all flight phases

Cause 1		Cause 2		Cause 3	
Type 1	**Count, (%)**	**Type 2**	**Count, (%)**	**Type 3**	**Count, (%)**
Mechanical	11 (18%)	Mechanical	3 (33%)	Operational	1 (33%)
				Maintenance	2 (67%)
		Operational	3 (33%)	Procedure	1 (100%)
		Maintenance	3 (33%)	Operational	1 (50%)
				Maintenance	1 (50%)
Operational	16 (26%)	Mechanical	4 (25%)	Operational	1 (50%)
				Human-related	1 (50%)
		Operational	7 (44%)	Operational	2 (40%)
				Procedure	1 (20%)
				Human-related	2 (40%)
		Human-related	1 (6%)	Operational	1 (100%)
		Collision	4 (25%)	Equipment	3 (100%)
Procedure	6 (10%)	Mechanical	1 (20%)	Maintenance	1 (100%)
		Operational	2 (40%)	Mechanical	1 (50%)
				Weather	1 (50%)
		Human-related	2 (40%)	Weather	1 (100%)
Weather	17 (28%)	Operational	8 (53%)	Operational	3 (50%)
				Equipment	1 (17%)
				Weather	1 (17%)
				Collision	1 (17%)
		Procedure	1 (7%)	Human-related	1 (100%)
		Human-related	5 (33%)	Operational	1 (33%)
				Human-related	2 (67%)
		Collision	1 (7%)		
Human-related	4 (7%)	Weather	2 (67%)	Collision	1 (100%)
		Maintenance	1 (33%)	Operational	1 (100%)
Collision	5 (8%)	Operational	2 (67%)		
		Collision	1 (33%)		
Maintenance	1 (2%)	Mechanical	1 (100%)		
Unknown	1 (2%)				
	61		52		33

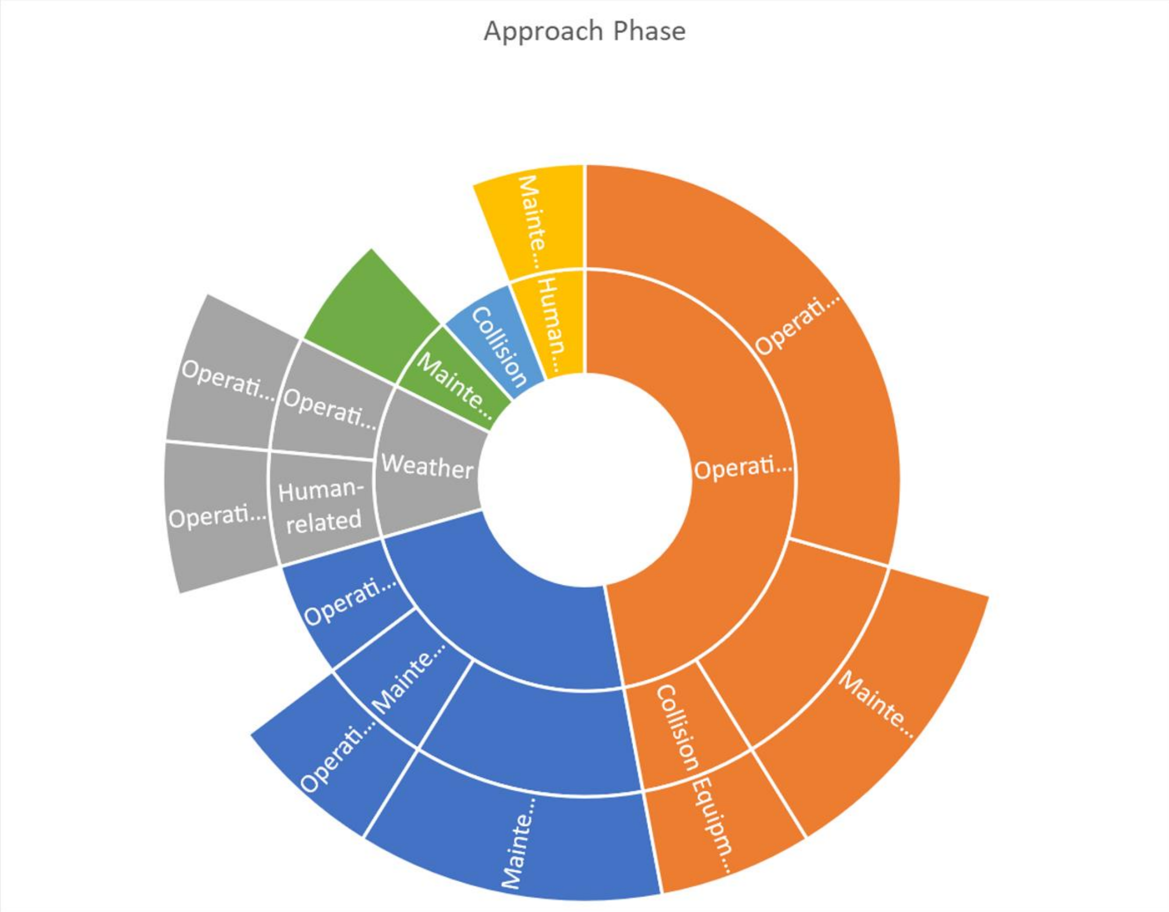

Figure 3 – Approach phase; the hierarchical relationship among cause categories

Table 5 – Root cause categories for the approach flight phase

Cause 1		**Cause 2**		**Cause 3**	
Type 1	**Count, (%)**	**Type 2**	**Count, (%)**	**Type 3**	**Count, (%)**
Mechanical	5 (24%)	Mechanical	2 (50%)	Maintenance	2 (100%)
		Operational	1 (25%)		
		Maintenance	1 (25%)	Operational	1 (100%)
Operational	7 (33%)	Mechanical	1 (14%)	Maintenance	2 (100%)
		Operational	5 (71%)		
		Collision	1 (14%)	Equipment	1 (100%)
Weather	6 (29%)	Operational	2 (50%)	Operational	1 (100%)
		Human-related	2 (40%)	Operational	1 (100%)
Human-related	1 (5%)	Maintenance	1 (100%)		
Collision	1 (5%)				
Maintenance	1 (5%)	Mechanical	1 (100%)		
Unknown	0 (0%)				
	21		17		8

Figure 4 – Cruise phase; the hierarchical relationship among cause categories

Table 6 – Root cause categories for the cruise flight phase

Cause 1		**Cause 2**		**Cause 3**	
Type 1	**Count, (%)**	**Type 2**	**Count, (%)**	**Type 3**	**Count, (%)**
Mechanical	4 (17%)	Operational	1 (33%)	Procedure	1 (100%)
		Maintenance	2 (67%)	Maintenance	1 (100%)
Operational	4 (17%)	Mechanical	3 (75%)	Operational	1 (50%)
				Human-related	1 (50%)
		Collision	1 (25%)	Equipment	1 (100%)
Procedure	3 (13%)	Operational	2 (67%)	Mechanical	1 (50%)
				Weather	1 (50%)
		Human-related	1 (33%)	Weather	1 (100%)
Weather	7 (30%)	Operational	3 (43%)	Operational	1 (33%)
				Weather	1 (33%)
				Collision	1 (33%)
		Human-related	3 (43%)	Human-related	2 (100%)
		Collision	1 (14%)		
Human-related	2 (9%)	Weather	2 (100%)	Collision	1 (100%)
Collision	3 (13%)	Operational	2 (67%)		
		Collision	1 (33%)		
	23		22		14

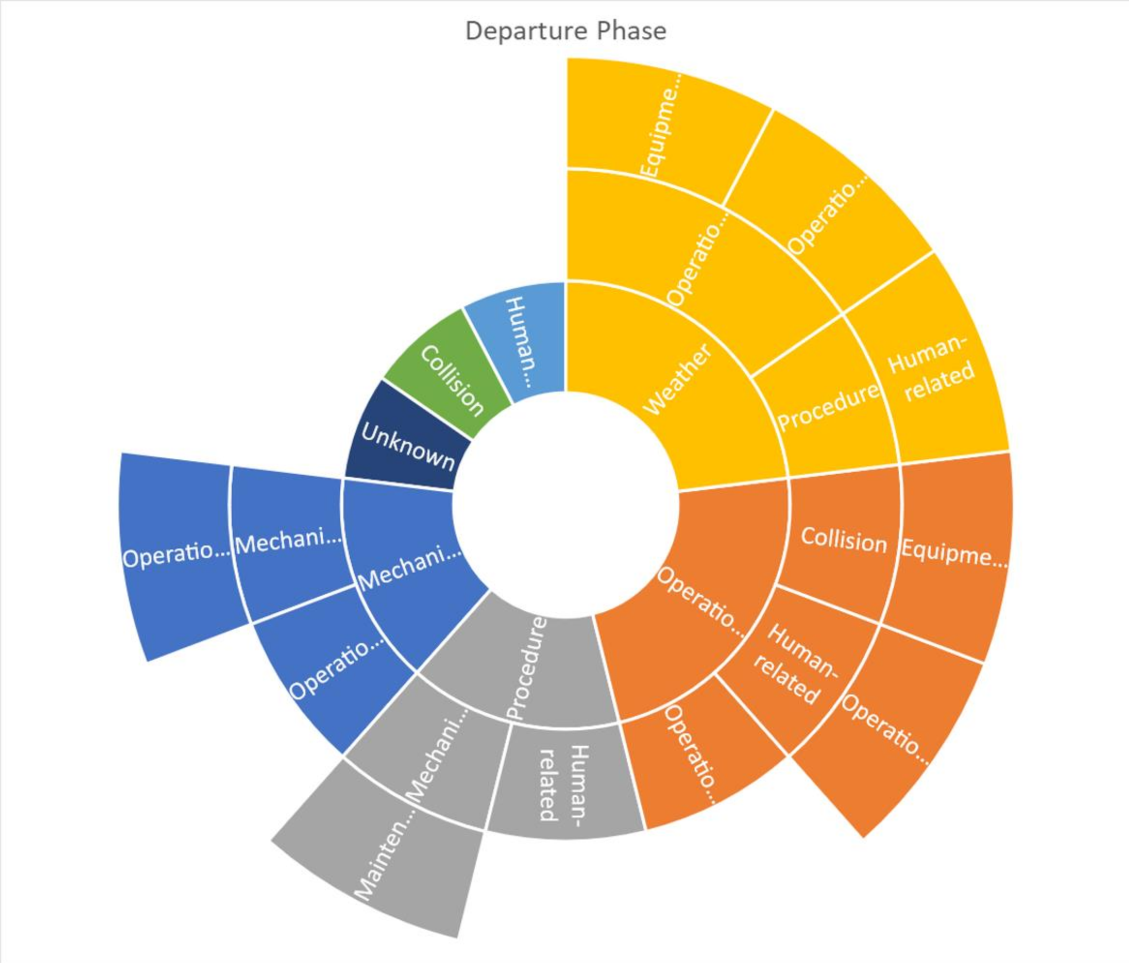

Figure 5 – Departure phase; the hierarchical relationship among cause categories

Table 7 – Root cause categories for the departure flight phase

Cause 1		Cause 2		Cause 3	
Type 1	**Count, (%)**	**Type 2**	**Count, (%)**	**Type 3**	**Count, (%)**
Mechanical	2 (13%)	Mechanical	1 (50%)	Operational	1 (100%)
		Operational	1 (50%)		
Operational	4 (25%)	Operational	1 (25%)		
		Human-related	1 (25%)	Operational	1 (50%)
		Collision	2 (50%)	Equipment	1 (50%)
Procedure	3 (19%)	Mechanical	1 (50%)	Maintenance	1 (100%)
		Human-related	1 (50%)		
Weather	4 (25%)	Operational	3 (75%)	Operational	1 (50%)
				Equipment	1 (50%)
		Procedure	1 (25%)	Human-related	1 (100%)
Human-related	1 (6%)				
Collision	1 (6%)				
Unknown	1 (6%)				
	16		12		7

6. EXPERT ASSESSMENT AND DISCUSSION

The aim of this analysis was also to identify potential root causes (hazards) that could apply to UAM operations. To achieve this goal, a brainstorming session was held with experts from both the Polytechnic University of Catalonia (UPC) and the University of Belgrade - Faculty of Transport and Traffic Engineering (UB - FTTE). During the discussion, several key points were highlighted.

Temporal scope is a relevant issue for this discussion, since it is related to the level of automation, and the human-machine interaction, as well as the progress on the implementation of digitalisation and the UAM services.

As automation and human-machine interaction in UAM vehicles advance, human-related causes may become increasingly less relevant.

UAM vehicles, with a commanding pilot on-board could be considered as an helicopter. The fact that the vehicles is piloted could make that the applied procedures would be similar, or even the same as the ones for helicopter operations In the short term, human-related causes will remain relevant.

Other causes, such as mechanical failures, operational issues or weather-related hazards, may be similar, data extrapolation to the UAM environment should be a subject of future research.

In addition to the expert feedback, specific flight phases such as take-off and landing were analysed for their impact on UAM operations. Take-off and landing phases present a set of characteristics that define a board's scope of execution procedures. These procedures have been carefully analysed by the European Aviation Safety Agency (EASA) and FAA. The definition of these flight phases is provided in [38] and [39]. The specific characteristics of the take-off and landing operations make them the most critical flight phases. On the other hand, the main causes extracted from the analysis present the same level of occurrence for all three flight phases. Results proposed three levels of causes (represented by a circular ring on the sunburst plot), according to the description provided in the accident report. Flight phases do not show a significant difference with regard to the causes identified at each level.

In summary, expert feedback helped to confirm and match the findings with the UAM operations. It helped to highlight the specificity of the UAM operations and vehicles compared to the proposed analysis of the helicopter accidents. Remarks about available documents also improved the outcome of the analysis.

7. CONCLUSIONS

UAM must address all necessary safety considerations to achieve large-scale operations. The lack of experience and real data regarding UAM operations is a serious drawback when analysing safety issues. Even with a current lack of data, it is of paramount importance to understand safety issues before new vehicle types are introduced into exploitation. Therefore, the study is structured around the use of helicopters data that could facilitate the preliminary safety assessment of new vehicle operations under specific assumptions, acknowledging the limitations due to the differences between helicopter-type vehicles and new configurations.

The methodological approach consists of four steps. The first three steps involved collecting relevant accident reports for helicopter operations near urban areas and extracting the main root causes. Analysing these causes and their relationships was the main outcome. The fourth step was the discussion with experts, in a joint session with safety and the academic experts. The session included a description of the results and preliminary conclusions to later move to an open discussion about how to transfer the acquired knowledge to the UAM operations and vehicles.

The obtained results can be summarised as a list of identified hazards (causes); which ranges from mechanical to weather issues, adding operational, procedures and human-related causes as well. The analysis demonstrated that operational and weather-related causes have been determined as the most relevant ones, accounting for a large percentage of occurrences; not only when considering all data as a whole, but also when splitting the data into different flight phases – approach, departure or cruise.

An attempt to determine relationship amongst causes has also been proposed. The causality chain of the three main identified causes has been stated and analysed. The limited number of reports, mainly when dealing with the split into flight phases, makes the analysis rather challenging. But some relationships have been identified; namely between operational and mechanical issues, weather and collision, to mention two of the most relevant ones.

Finally, how to extrapolate results to UAM is not an easy task. One should consider some specific features of those vehicles, which are not so clear right now. Perhaps the main one is the level of automation. Researchers, like [31], agree that the introduction of automation will be gradual from fully manual, to pilot-assisted, to fully autonomous. This feature could take human-related root causes into high to low levels of relevance (corresponding to fully manual to fully autonomous). It seems clear that mechanical issues will be still present, although the vehicle and the propulsion system change. According to the propulsion system, the probability of a mechanical failure could be also reduced when applying electric technology due to the reduction of the number of movable parts in the system. Other types of mechanical failures could be still present or could be replaced by electrical or avionics failures, so from a conceptual point of view the hazard will be still there. Maintenance-related mechanical failures will be still probable since it is not foreseen that this kind of operation could be easily automated. The same could happen when considering collisions. The more autonomous the vehicle will be, the lower the probability of colliding with known obstacles, but collisions with unexpected objects (small drones, birds, unidentified vehicles, etc.) could still happen. On the other hand, it is expected that the UAM operations will take place in a very crowded, if not saturated airspace, so collisions could be still possible.

One could take the knowledge from helicopter accidents and foresee how this could be applied to UAM. *Table 8* tries to summarise the probability of occurrence for the identified root causes, comparing what has been concluded from the helicopter accident reports with what could be applicable to UAM vehicles and operations. Very briefly, similarities are enough to consider that helicopter accidents could be an appropriate starting point when analysing UAM safety, while no specific data are available. The existing and past helicopter-based transport services demonstrate that the type of operations to be performed will be similar enough, and only vehicle performance and systems could differ (namely, energy and propulsion systems, as well as autonomous operations).

Table 8 – Safety knowledge to UAM

Root cause	**Helicopters**	**UAM**
Mechanical	Medium probability	Medium probability
Operational	High probability	High probability
Procedure	Low probability	Low probability
Equipment	Low probability	Low probability
Weather	High probability	High probability
Human-related	High probability	High to low probability
Collision	Medium probability	Medium probability
Maintenance	Low probability	Low probability
Unknown	Low probability	Low probability

Urban air mobility (UAM) can undoubtedly benefit from lessons learned in drone operations, particularly in the areas of air traffic management and interaction with urban infrastructure. It is reasonable to anticipate that the UAS (drone) sector will evolve at a faster pace than eVTOL operations, enabling the identification of potential hazards and the implementation of efficient risk mitigation strategies. However, the current stage of drone deployment limits the extent to which meaningful conclusions can be drawn for application in the UAM domain. This is largely because drone operations are often confined to remote areas with low population densities, where they typically provide infrequent medical or logistics services. Even in scenarios where drones operate in densely populated areas, their activities are governed by strict regulations under the specific operations risk assessment (SORA) framework. This methodology evaluates both air and ground risks, ensuring compliance with safety objectives at specified levels of robustness. In contrast, eVTOL operations demand a much higher degree of certification and oversight, reflecting their inherently complex and high-risk nature. Finally, the industry still lacks a comprehensive database on drone accident and incident reports in the urban areas which prevents drawing some particular conclusions and translating them to the UAM domain.

The present research should open the door to consider safety hazards when planning UAM operations. Further work should consider either more relevant accident reports, but mainly data from initial UAM operations.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to their colleagues from the University of Belgrade (UB-FTTE), and the Technical University of Catalonia (UPC, ICARUS Research group), for their contribution to the expert assessment brainstorming session conducted as part of this research; special thanks to Dr Bojana Mirkovic, and Dr Emir Ganic UB-FTTE, and Dr Cristina Barrado, Dr Enric Pastor, and Prof. Xavier Prats, UPC. This research has been partially supported through the CIMNE Severo Ochoa Centre of Excellence (2019-2023) under the grant CEX2018-000797-S funded by MCIN/AEI/10.13039/501100011033. This work was partially funded by the Ministerio de Economia y Competitividad of Spain under contracts PID2020-116377RB-C21 and PID2023-152053OB-C21. The author Jordi Pons-Prats is a Serra Hunter Fellow.

ANNEX: Summary table of selected reports

Table 9 reflects the collected data, once processed, for all the selected reports. Those reports which were considered not relevant for the present research are not listed here. As described, only those reports related to operation in or close to urban areas have been considered. The total number of considered reports is undetermined, but could easily reach more than 300, while the selected ones are limited to 61.

Table 9 – Preferred table style example with text in cells centred

REPORT	PHASE	Cause 1	Cause 2	Cause 3
AAR7709	*Approach*	*Mechanical*	*Operational*	
WPR18MA087	*Approach*	*Weather*	*Operational*	
ASN151250	*Approach*	*Weather*		
ARAIB/AAR-1307	*Approach*	*Weather*		
LAX01LA243	*Approach*	*Mechanical*	*Mechanical*	*Maintenance*
CEN18FA391	*Approach*	*Operational*	*Operational*	
EW/G2016/07/05	*Approach*	*Operational*	*mechanical*	
ERA19LA171	*Approach*	*Weather*	*Operational*	*Operational*
CHI06GA174	*Approach*	*Mechanical*	*Maintenance*	*Operational*
GAA18CA117	*Approach*	*Operational*	*Operational*	*Operational*
EW/G2015/11/08	*Approach*	*Operational*	*Collision*	*Equipment*
AO-2017-083	*Approach*	*Collision*		
LAX02LA161	*Approach*	*Operational*	*Operational*	*Operational*
NYC98LA058	*Approach*	*Weather*	*Human-related*	*Operational*
ASN56469	*Approach*	*Weather*	*Human-related*	
F-GD940729	*Approach*	*Mechanical*		
i-ii970706	*Approach*	*Operational*	*Operational*	*Human-related*
f-bg970622	*Approach*	*Maintenance*	*Mechanical*	
AAR 1/2016	*Approach*	*Operational*	*Operational*	*Procedure*
BEA f-hr101019	*Landing*	*Human-related*	*Maintenance*	*Operational*
AAR 1/2018	*Landing*	*Mechanical*	*Mechanical*	*Maintenance*
ERA10CA109	*Cruise*	*Procedure*	*Operational*	*Weather*
DCA20MA059	*Cruise*	*Weather*	*Human-related*	*Human-related*
LAX93FA093	*Cruise*	*Weather*	*Operational*	*Weather*

REPORT	PHASE	Cause 1	Cause 2	Cause 3
ERA09LA020	*Cruise*	*Operational*	*Collision*	*Equipment*
ERA18MA099	*Cruise*	*Operational*	*Mechanical*	*Management*
CEN17FA252	*Cruise*	*Operational*	*Mechanical*	*Operational*
CEN18FA033	*Cruise*	*Collision*	*Operational*	
LAX08FA052	*Cruise*	*Collision*	*Operational*	
DCA20IA034	*Cruise*	*Collision*	*Collision*	
CEN18FA259	*Cruise*	*Operational*	*Mechanical*	*Human-related*
BEA 3a-p101207	*Cruise*	*Human-related*	*Weather*	
BEA f-sa100806	*Cruise*	*Procedure*	*Human-related*	*Weather*
AAR 3/2014	*Cruise*	*Human-related*	*Weather*	*Collision*
AAR 3/2015	*Cruise*	*Procedure*	*Operational*	*Mechanical*
AAR 2/2004	*Cruise*	*Mechanical*	*Operational*	*Procedure*
AAR 1/2003	*Cruise*	*Mechanical*		
AAR 4/1997	*Cruise*	*Weather*	*Human-related*	*Human-related*
F-FG970704	*Cruise*	*Weather*	*Collision*	
f-ns970423	*Cruise*	*Weather*	*Operational*	*Collision*
f-hp970514	*Cruise*	*Weather*	*Operational*	*Operational*
BEA xc-m111111	*Cruise*	*Weather*	*Human-related*	
AAR 2/2014	*Cruise*	*Mechanical*	*Maintenance*	*Maintenance*
BEA f-cy111019	*hovering*	*Mechanical*	*Maintenance*	
LAX00TA318	*Departure*	*Mechanical*	*Mechanical*	*Operational*
CEN15LA288	*Departure*	*Weather*	*Operational*	*Equipment*
LAX95FA079	*Departure*	*Weather*	*Procedure*	*Human-related*
LAX99LA293	*Departure*	*Procedure*	*Mechanical*	*Maintenance*
CEN12FA621	*Departure*	*Mechanical*	*Operational*	
CEN16LA168	*Departure*	*Weather*	*Operational*	
ERA12MA005	*Departure*	*Operational*	*Operational*	
EW/G2018/05/15	*Departure*	*Collision*		
NYC08IA145	*Departure*	*Operational*	*Collision*	*Equipment*
A010/CENIPA/2013	*Departure*	*Operational*	*Collision*	
IAD05MA078	*Departure*	*Weather*	*Operational*	*Operational*
A-068/2005	*departure*	*Operational*	*Human-related*	*Operational*
F-GLRR	*Departure*	*Procedure*		
G-JIMW	*Departure*	*Human-related*		
BEA f-ec100904	*Take off*	*Procedure*	*Human-related*	
BEA2023-0020	*Take off*	*Unknown*		
DFW08CA064	*N/A*	*Operational*	*Operational*	*Human-related*

REFERENCES

[1] Sáenz De Tejada Millán J. Assessing UAM emergency procedures in existing or new heliports [B.S. thesis]. Universitat Politècnica de Catalunya; 2022. http://hdl.handle.net/2117/371230

[2] Higgins CD, Adams MD, Réquia WJ, Mohamed M. Accessibility, air pollution, and congestion: Capturing spatial trade-offs from agglomeration in the property market. *Land Use Policy*. 2019;84:177-91. Available from: https://www.sciencedirect.com/science/article/pii/S0264837718311165. DOI: 10.1016/j.landusepol.2019.03.002.

[3] Anderson ML. Subways, strikes, and slowdowns: The impacts of public transit on traffic congestion. *American Economic Review*. 2014;104(9):2763-96. ISSN: 0002-8282; DOI: 10.1257/aer.104.9.2763.

[4] Bluenest. Landing on a brand new world, Blenest whitepaper; 2023. [Accessed: 2023-10-24]. https://www.bluenest.io/whitepaperv1.

[5] Garrow LA, German BJ, Leonard CE. Urban air mobility: A comprehensive review and comparative analysis with autonomous and electric ground transportation for informing future research. *Transportation Research Part C: Emerging Technologies*. 2021;132:103377. ISSN: 0968-090X , 1879-2359; DOI: 10.1016/j.trc.2021.103377.

[6] Fredericks W. Impact of operational requirements on intra-urban VTOL conceptual design. In: 16th AIAA Aviation Technology, Integration, and Operations Conference; 2016.

[7] EUROCONTROL S. U-Space Concept of Operations (CONOPS), 4th Edition; 2023. [Accessed: 2023-10-23]. https://www.sesarju.eu/sites/default/files/documents/reports/U-space%20CONOPS%204th%20edition.pdf.

[8] Balakrishnan K, et al. *Blueprint for the sky*. Paris, France: AIRBUS; 2018.

[9] ICAO. DOC9859, Safety Management Manual; 2017. [Accessed: 2023-10-23]. https://www.icao.int.

[10] Hobbs CP. Hidden history of transportation in Los Angeles. Arcadia Publishing; 2014. ISBN-13: 978-1540211415

[11] Wallace B. Helicopter Airline History; 2022. [Accessed: 2023-12]. https:// helicopterairlinehistory.com/.

[12] Correnti V, Capr`ı S, Ignaccolo M, Inturri G. The potential of rotorcraft for intercity passenger transport. *Journal of Air Transport Management*. 2007;13(2):53-60. DOI: 10.1016/j.jairtraman.2006.11.009

[13] Dajani JS, Stortstrom RG, Warner DB. The potential for helicopter passenger service in major urban areas; NASA report, 1977.

[14] Program HAS. Hearings before the United States Senate committee on commerce.; 1965.

[15] Murray MJ. *The evolving spatial form of cities in a globalising world economy: Johannesburg and Sao Paulo*. vol. 5. HSRC Press; 2004. ISBN 13: 978-07969-2072-0

[16] Romero S. Sao Paulo Journal; Rich Brazilians rise above rush-hour jams.; 2000. [Accessed: 2022-05]. https://www.nytimes.com/2000/02/15/world/sao-paulo-journal-rich-brazilians-rise-above-rush-hour-jams.html.

[17] Phillips T. High above Sao Paulo’s choked streets, the rich cruise a new highway.; 2008. [Accessed: 2022-05]. https://www.theguardian.com/world/2008/jun/20/brazil.

[18] Miracle O. Brazil’s Helicopter City.; 2021. Accessed: 2022-05. https:// foundandexplained.com/.

[19] Burgueño S. Number of private heliports and helidecks as of 2021.; 2021. [Accessed: 2022-05]. https://www.statista.com/statistics/874975/brazil-number-private-heliports-helidecks/.

[20] Brähler V, Flörke S. Above the rooftops of a megacity: The helicopteromania of São Paulo.; 2011. Accessed: 2022-05. https://lab.org.uk/sao-paulo-the-worlds-biggest-helicopter-fleet/.

[21] de Jong HH. Guidelines for the identification of hazards: How to make unimaginable hazards imaginable? The Netherlands: NLR; 2004. NLR-CR-2004-094.

[22] Ahlstrom V, et al. Human factors design guide update (report number DOT/FAA/CT-96/01): A revision to chapter 5–automation guidelines. William J. Hughes Technical Center (US); 2001.

[23] Gardini KC, Chiavelli FH, Scarpari JRS, de Andrade D. Conceptual models of startle, surprise and automation bias analyzed through recent aviation accident reports. *Journal of Aerospace Technology and Management*. 2022;14:e3022. DOI: 10.1590/jatm.v14.1282

[24] Xiang S, et al. Autonomous eVTOL: A summary of researches and challenges. *Green Energy and Intelligent Transportation*. 2024;3(1):100140. DOI: 10.1016/j.geits.2023.100140.

[25] Rankin A, Woltjer R, Field J. Sensemaking following surprise in the cockpit—a re-framing problem. *Cognition, Technology & Work*. 2016;18:623-42. DOI: 10.1007/s10111-016-0390-2.

[26] Landman A, et al. Dealing with unexpected events on the flight deck: A conceptual model of startle and surprise. *Human factors*. 2017;59(8):1161-72. DOI: 10.1177/0018720817723428.

[27] Casner SM, Geven RW, Williams KT. The effectiveness of airline pilot training for abnormal events. Human factors. 2013;55(3):477-85. DOI: 10.1177/0018720812466893.

[28] Gannous A. Interstices in the Certification of Safety Critical Avionics Software: Boeing 737-MAX MCAS Case Study. In: *2023 Congress in Computer Science, Computer Engineering, & Applied Computing (CSCE). IEEE*; 2023. p. 2664-7. DOI: 10.1109/CSCE60160.2023.00425.

[29] Wei H, et al. Autonomous navigation for eVTOL: Review and future perspectives. *IEEE Transactions on Intelligent Vehicles*. 2024. DOI: 10.1109/TIV.2024.3352613.

[30] European Helicopter Safety Team. *Automation and flight path management*. Brussels: EASA, European Commission; 2015.

[31] Straubinger A, et al. An overview of current research and developments in urban air mobility–Setting the scene for UAM introduction. *Journal of Air Transport Management*. 2020;87:101852. DOI: 10.1016/j.jairtraman.2020.101852.

[32] Chen L, et al. Milestones in autonomous driving and intelligent vehicles: Survey of surveys. *IEEE Transactions on Intelligent Vehicles*. 2022;8(2):1046-56. DOI: 10.1109/TIV.2022.3223131.

[33] Teng S, et al. Motion planning for autonomous driving: The state of the art and future perspectives. *IEEE Transactions on Intelligent Vehicles*. 2023;8(6):3692-711. DOI: 10.1109/TIV.2023.3274536.

[34] Scarpari JRS, et al. Quantitative assessment of pilot-endured workloads during helicopter flying emergencies: An analysis of physiological parameters during an autorotation. *Scientific Reports*. 2021;11(1):17734. DOI: 10.1038/s41598-021-96773-y.

[35] Steele-Perkins AP. Human factors in helicopters: Human factor problems of operating helicopters at sea. *Proceedings of the Royal Society of Medicine*. 1976;69(4):255-6. DOI: 10.1177/ 003591577606900405.

[36] Cline PE. Human error analysis of helicopter emergency medical services (HEMS) accidents using the human factors analysis and classification system (HFACS). *Journal of Aviation/Aerospace Education & Research*. 2018;28(1):43- 62. DOI: 10.15394/jaaer.2018.1758.

[37] EASA. Roadmap, artificial intelligence, A human-centric approach to AI in aviation. European Aviation Safety Agency; 2020.

[38] EASA. Helicopter flight instructor manual; 2015. [Accessed: 2022-09]. https://www.easa.europa.eu/document-library/general-publications/ehest-helicopter-flight-instructor-manual.

[39] Federal Aviation Authority, FAA. *Helicopter flying handbook*; 2022. [Accessed: 2022-09]. https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/helicopter_flying_handbook.

Jordi Pons-Prats, Jovana Kuljanin, Fedja Netjasov, Jorge Saenz de Tejada Millan

Identificació dels perills potencials per a la seguretat de la mobilitat aèria urbana (UAM) a partir de dades d'accidents d'helicòpter: metodologia i resultats preliminars

Resum

La seguretat és primordial per a l'aviació. El desenvolupament de la Mobilitat Aèria Urbana (UAM) no s'exclou de considerar-lo, però, si bé la recerca generalment se centra en qüestions tècniques i operatives, s'han fet pocs pel que fa a la seguretat. És evident que hi ha moltes incògnites tant pel que fa al disseny com al funcionament dels vehicles de la UAM, per la qual cosa la proposta d'aquest treball de recerca és extreure el màxim d'informació possible dels accidents d'helicòpters en entorns urbans. Tot i que no hi ha informació tècnica detallada sobre els vehicles i les operacions de la UAM, els helicòpters representen una font interessant de dades. Es considera que els vehicles UAM amb capacitats d'enlairament i aterratge verticals presenten característiques semblants als helicòpters. A partir d'un informe anterior dels autors ([1]), s'ha analitzat un conjunt d'informes d'accidents de diverses agències de seguretat d'arreu del món. Els informes han estat preseleccionats segons la rellevància de l'escenari; seleccionant aquells que van passar en un entorn urbà, o propers a zones urbanes. Els experts han identificat i avaluat els perills rellevants per entendre com es podrien traduir a les operacions de la UAM. Els perills identificats podrien servir per a l'avaluació de riscos de futures operacions UAM, així com per al desenvolupament de mesures o polítiques de mitigació de riscos.

Paraules clau

Mobilitat Aèria Urbana, UAM, Mobilitat Aèria Avançada, Seguretat, identificació de perills, operacions amb helicòpters.