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Article

Challenges to the Operational Safety and Security of eVTOL Aircraft in Metropolitan Regions: A Literature Review

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Abstract.

The start of urban air mobility operations using helicopters began in 1940s in Los Angeles to transport passengers and mail between various locations. However, the concept of urban air mobility (UAM) only emerged in the 1960s. Its implementation used helicopters to avoid congestion by land, typical of populated metropolitan regions. However, there was a severe limitation in using these aircraft because of accidents, huge operating costs, and high noise generation levels. In 2010, a new UAM concept conceived electric vertical take-off and landing (eVTOL) vehicles. These vehicles, in principle, would be safer, with lower operating costs and less noisy than helicopters. Several aircraft manufacturers have developed dozens of eVTOL models, focusing on the feasibility of using them for UAM in some metropolitan regions. However, we must consider several challenges to materialize this new concept, including those related to operational safety and security. Among these challenges is these vehicle operations integration to the airspace structure and the air traffic control system, the new embedded and ground systems development, the ground infrastructure implementation to support the operations, the reliability of air navigation systems, the meteorological information provision in real-time and with complete coverage of metropolitan airspaces to be used by eVTOL, and others. Despite some similarities, this new UAM concept will not be identical for all urban regions due to differences related to topographies, weather, urban construction patterns and air traffic control systems. Therefore, local studies are essential to support gradual and safe implementations of operations with these vehicles. This paper presents a literature review, identifying and discussing the utmost safety and security-related challenges researchers observe.

Keywords: UAM, eVTOL, Air Mobility, Metropolitan regions, Challenges.

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1. Introduction

Metropolitan regions worldwide present an increase in demand for displacements in terrestrial transport modes each year, increasing congestion levels and economic impacts [1]. In 2018, an estimate showed that Americans spent an average of 97 hours in traffic jams at an average cost of $1,348 per passenger [2]. In these scenarios, the demand for alternative means of transport increases, especially for those that use air modes within large urban centers [1].

The start of urban air mobility operations using helicopters began in the 1940s in Los Angeles to transport passengers and mail between various locations, including Los Angeles International Airport and Disneyland [3]. It is noteworthy, however, that the concept of urban air mobility (UAM) emerged only in the 1960s. The UAM concept implementation began to meet demands for displacements in and around metropolitan regions to avoid traffic congestion in terrestrial transport modes. Helicopters provide point-to-point displacement services at defined times [3].

According to Wu & Zhang [3], helicopter operations in urban areas over the years decreased. This decrease occurred because of the communities' low acceptance, some fatal accidents, and the noise level produced during operations. Several other factors also contributed, in a complementary way, to this reduction in the use of helicopters for UAM, such as the small number of helipads, limited air traffic control infrastructure, high operating costs with maintenance, fuel, and crew, logistical problems, and operational limitations in scenarios of unfavorable weather [4].

In 2020, the Federal Aviation Administration (FAA), the body that regulates civil aviation in the United States, developed a new operational concept for the UAM, which envisages operations in urban and suburban environments, with a perspective of scalability of operations in the long term. This design uses electric vertical take-off and landing (eVTOL) vehicles. National Aeronautics and Space (NASA) announced the concept in 2010 [1]. Advances in battery storage capacities and reduced densities due to lighter materials made eVTOL vehicles possible. In addition, other advances such as the development of multi-engine controls, the distributed propulsion advent, and the associated energy efficiency to enormous computing capabilities also help make it possible [5]. Around 70 eVTOL vehicle manufacturers worldwide have invested billions of dollars in developing and competing to build the best model. However, to employ these vehicles in a new UAM concept, it is essential to understand the demands of stakeholders, the operational needs to incorporate them into airspaces, and the impacts they will have on air traffic control systems [1].

The FAA established some assumptions and guiding principles for creating a new UAM operating environment and defined three phases of implementation: initial operations, operations defined in Operational Design 1.0, and mature operations. These phases differ in terms of airspace structures, the technologies employed, and the level of automation of operations [1]. However, according to Wu & Zhang [2], several issues to be considered in implementing this UAM model can impact its viability and scalability. The vertiports' location, for example, is essential in allowing integration with other modes of transport and developing a route structure that meets the demands of users and makes the model economically viable. According to Rizzi et al. [6], it is also essential to develop a strategy for engaging communities even before concerns related to the safety of eVTOL vehicle operations arise. Addressing these concerns with the populations around the sites to implement vertiports is necessary for accepting the new UAM model.

Since transport services using eVTOL aircraft will be competitive with land modes rather than complementary, integration is even more necessary. According to Rothfeld et al. [7], there must be time savings with the use of eVTOL concerning land travel, and for this, it will be necessary to reduce processing times and that there is ease in the conditions and access and egress from vertiports.

The number of available vertiports will directly impacts accessibility and the rate of use of services by users. In addition, transfer time between modes will decrease with the increase in the number of vertiports, becoming negligible after a certain number of vertiports, which will directly impacts the number of potential users of eVTOL aircraft. In addition, variation in demand for services and their associated cost-effectiveness in this UAM model will likely be more sensitive to ticket prices than the number of implemented vertiports [2].

The analysis of operations with helicopters simulating the flight of eVTOL aircraft in 32 trajectories allocated in three different cities (Dallas, Los Angeles, and Boston) and prepared according to criteria varying in terms of flight distance, the volume of passengers, types of market, distinct geographic characteristics and levels of traffic congestion, identified some common operational constraints. The most impactful operational constraints consist of the acceptance of aeronautical noise by the communities affected by the flights, the availability of areas for landings and takeoffs in large urban centers, and the high demand for the currently implemented air traffic control system [4].

There will be demand for the allocation of vertiports at airports due to the need for displacement between them and other vertiports located in cities. However, airports with passenger terminals between the runways have a reduced possibility of integrating eVTOL and conventional aircraft operations, especially in adverse weather conditions because of the impossibility of flying in visual air taxiing segments at low altitudes, which makes quick access to vertiports difficult and increases the risk associated with air traffic incidents due to the requirement that all eVTOLs share the maneuvering area and carry out the taxiing in a similar way to the conventional aviation that operates at the airport, flying over the taxiways at low altitude, as helicopters currently do [8].

It is essential to clarify the difference between safety and security in aviation and their roles. Safety refers to the guarantee of an acceptable level of the risks associated with aviation activities or the support of aircraft operations [9]. On the other hand, security safeguards civil aviation against unlawful interference through practical measures and human and material resources [10]. Another fact accepted in aviation is that achieving an absolute level of operational safety is impossible since a total avoidance of failures and errors is unachievable [11]. Any complex and large-scale systems will exhibit failures or unexpected behavior at some point because of unpredictable or not understood interactions between their components [12].

Through a literature review, this article points out challenges related to the safety and security of in-flight operations of eVTOL vehicles in a new concept of UAM and ways to enable operations that meet acceptable levels of operational safety.

2. Review Approach

The authors employed a systematic literature review to identify and analyze works related to the chosen topic. This review sought to follow the planning procedure of the systematic review proposed by Kitchenham (2007), which includes several steps: the need to carry out this review identification, the review specification, and the review protocol development. In addition, the planning process for writing this article also followed the recommendations of Kitchenham (2007). According to him, it is essential to identify and select the researched works related to the purpose of the proposed review. Finally, the review included only those works considered relevant after a detailed analysis of their content.

This review's relevance justification is the need to gather literature concerning challenges related to operational safety and security of eVTOL vehicle operations in flight. Considering and addressing these challenges will permit a new concept of UAM implementation with eVTOL vehicles, guaranteeing acceptable operational safety and security levels. The authors used articles, theses, dissertations, reports, and operational concepts from some databases as information sources. Regarding the review protocol, the authors used three databases: Science Direct, Web of Science, and Google Scholar. Keyword combinations used the following terms: "safety," "security," "urban air mobility," "UAM," "risk," "dangers," "challenges," "barriers," and "eVTOL." The search included research materials from the last six years.

The selection process considered within the study scope for further analysis and inclusion in the article identified documents with several challenges related to the safety and security of eVTOL vehicle operations and actions to ensure acceptable levels of safety and security. Among them are challenges related to certification, regulation, and standardization of operations with this type of vehicle, crash prevention and mitigation, integration of operations with the air traffic control system, cyber security, monitoring of the navigation systems performance, and weather conditions in urban environments, and contingency management through operations centers.

The eVTOL Vehicles Operational Safety and Security Challenges in Urban and Suburban Regions

According to Mueller et al. [13], it is possible to classify the many eVTOL vehicles under development into two categories: "large multicopters" and "powered lift aircraft." In the first category, lift in all phases of flight is generated by propellers or rotors. In the second one, convertible rotors or wings ensure lift during the take-off process and transition to lift obtained by wings during cruise flight. Regardless of the category, these vehicles will operate in a network of vertiports. Under ideal conditions, the flight between a vertiport of origin and a destination will consist of two segments on the ground (take-off and landing) and an air segment (cruise).

The eVTOL vehicles will likely operate similarly to regular aviation on demand. Among the leading causes of accidents recorded for the aircraft that operate according to this model are loss of control in flight, failures in the functioning of the power supply systems, unintentional flight in instrument meteorological conditions, operations at very low altitudes, and finally, collisions. After the release of these vehicles, continued testing by manufacturers to demonstrate high levels of safety will contribute to their acceptance by the public and potential users [14].

According to Bauranov & Raskas [15], from a qualitative and quantitative risk analysis carried out by the precepts of the Operational Safety Management System, it was shown that risks associated with control errors of eVTOL vehicles, sabotage, and collision with birds tend to grow. The conclusions pointed out that manned eVTOL flights will be less safe than those performed by aircraft operating in commercial aviation and will not comply, at first, with the ICAO guides related to air collisions.

Usually, users do not accept a new mode of transport until their safety perception meets a high standard. This demand emerges because, according to Maslow's pyramid, which ranks needs that direct human behavior, the physiological and safety requirements must first be satisfied so that human beings pursue others of a higher hierarchy. Issues related to convenience and comfort are secondary to safety [16].

According to technology experts, the factors that can potentially influence users' perception of safety concerning eVTOL vehicles are pilot proficiency, resilience to operate in bad weather, collision detection, and avoidance systems. Other relevant potential factors are automatic emergency landing systems, protection against hacked autonomous flights or disabled pilots, and the ability to handle medical emergencies [16]. Additionally, it is noteworthy that the operational concepts, technologies, and procedures to support operations must meet at least minimum criteria to provide an acceptable level of operational safety [13].

Ensuring the safety of occupants of eVTOL vehicles can be achieved through collision avoidance and mitigating the effects of a collision. While the first is related to the development of accident prevention systems, the second is associated with developing systems that protect users when a crash occurs. Collision avoidance systems use systems already used by autonomous motor vehicles [14].

According to Littell [14], hybrid material systems can mitigate the effects of a collision, combining materials composed of low-density carbon and Kevlar shaped in a tubular form capable of absorbing more energy than tubes developed only by carbon compounds. Additionally, proper development of seating and containment systems can further mitigate impacts. Many eVTOL vehicle manufacturers consider using parachutes or Ballistic Recovery Systems (BRS). These devices, however, have been developed for use in small fixed-wing aircraft and must be adapted to these vehicles' operational and structural characteristics.

Figure 1. Tube developed only by carbon compounds (left) and tube developed with kevlar and carbon compounds mixed (right) post-test deformation. Source: [14]

Integrating eVTOL vehicle operations into the currently implemented air traffic management system will take place in the context of low-density operations. In this context, they will fly routes now available for helicopter traffic under visual flight rules (VFR) with pilots onboard (Edwards, Verma & Keeler, 2019). Under these rules, the aircraft pilots are responsible for separating from other aircraft and with the terrain, sequencing with the other aircraft, and planning the trajectories they will follow. Furthermore, eVTOL vehicles would not need new embedded technologies to fly under VFR in these airspaces. However, this is not a long-term solution due to limitations in scalability related to operational safety factors, such as the increasing difficulties of separation with other aircraft, with the ground, with obstacles, and with areas where there is degradation of weather conditions. [13]. In addition, there is a maximum number of aircraft an air traffic controller can safely manage in controlled airspace [16].

According to Edwars et al. [16], an integration study in the initial phase of operations showed that a rise in the density of aircraft increases the workload of air traffic controllers, which creates a risk of loss of situational awareness for these professionals and a greater possibility of air traffic incidents. Even so, mitigation is possible by establishing operational agreement letters and optimized routes supported by technologies that reduce the need for communication between pilots and air traffic controllers and avoid entry into controlled airspaces.

However, mitigation through operational letters of agreement and optimized routes is only feasible for the initial implementation phase. It is essential to develop new technologies and procedures that will facilitate the transition of the model from the initial phase to the successive stages safely to allow the scalability of operations [3].

Technology advancements have historically reduced accident rates on all generations of existing aircraft. Because of the high-reliability level in aviation systems, human factors remained the main area to improve the safety levels of operations [11]. In the past, pilot involvement was considered a redundant system in supporting technology. However, the crews are now potential sources of error [17].

One possible method to verify the safety of new components and systems of eVTOL aircraft is to compare them to similar pre-existing systems that have complied with stipulated safety standards [17]. In addition, it is necessary to perform fast-time simulations, flight demonstrations, and evaluations of human interactions with the systems under development to ensure that it is feasible and that the safety of air operations will not be compromised [3]. The flight demonstrations must allow progress in implementations at a slow pace, with tests considering the best possible safety conditions. For example, flights on simple trajectories over uninhabited areas should be considered [17].

According to Vascik et al. [4], the allocation of some vertiports in several airports is due to the demand for displacement between them and other vertiports located in different parts of the city. For this to be viable, there is a need for secure integration of eVTOL vehicle operations with airport operations.

There are restrictions on the safe integration of eVTOL aircraft operations in flight under VFR and airport operations due to the separations required because of the wake turbulence produced by conventional aircraft and the increased workload of air traffic controllers, especially at airports with large volumes of operations. The reduction of these restrictions is possible by considering divergent departure procedures, which safely reduce the separation required due to wake turbulence. In addition, implementing more spaced arrival procedures allows simultaneous operations without joining distinct flows, with segments of air taxis at low altitudes to the vertiports. Therefore, there will be a reduction in the frequency of interaction with air traffic controllers, substantially reducing the risk of loss of situational awareness and the likelihood of air traffic incidents [8].

There are more significant difficulties in integrating aircraft operating under instrument flight rules (IFR) because of the requirement for larger separations between aircraft during the final approach. The mitigation of the separation issue is possible by using approaches to converging runways in the airports where they are viable [8].

To integrate eVTOL vehicle operations into airspaces, under IFR, with minor and more flexible separations than those used for conventional aviation, it is essential to develop technologies centered on the vehicle itself. Among these technologies, the ones that present to pilots the traffic flying in the aircraft's surroundings, separation algorithms, and radio command and control communication links stand out. This integration is essential to allow aircraft operating under VFR that lose the ability to see and avoid other aircraft due to adverse weather conditions to continue their flights under IFR safely. In addition, it will be possible to avoid other safety issues, such as collisions with ground obstacles due to low visibility conditions [13].

According to Bauranov & Rakas [15], in more mature phases of operation of eVTOL vehicles in the new UAM model, with a more automated air traffic control system and with higher traffic densities, it is considered to reduce the separation between aircraft, safely, according to the level of development of the system. In this way, it will be possible to increase the capacity of airspaces. In addition, according to Panesar et al. [12], it will be necessary for operators of cellular telephony services to act collaboratively to ensure secure and continuous datalink communications at peak times so that they are available during the occurrence of some disruption emergency.

It is also necessary to develop exclusive airspace structures for eVTOL vehicles, such as exclusive corridors. These corridors will allow operations at low altitudes, with high traffic densities and reduced separations between them, sufficient to avoid dangers caused by wake turbulence. Systems that arrange the eVTOL vehicles in sequences and manage their flow, considering that they will be of different models and with varying envelopes of speed, will assure the safety of the operations in these corridors [13].

Safe separations between eVTOL vehicles may be flexible, depending on their structure and capabilities. It will be possible to ensure safe and non-standard separations in some airspaces, carried out, when necessary, by the aircraft, according to the principle of sense and avoid. Radars, lidars, or cameras installed in these vehicles, their energy capacity, and complex algorithms will resolve imminent conflicts between them [15]. All these embarked technologies will permit eVTOL vehicles to fly in an instrument weather environment as if flying under VFR [13].

Despite using of the sense and avoid principle, allowing more minor separations, and avoiding collisions between aircraft autonomously, its use in dense airspaces can generate a chaotic scenario impacting the flow and, consequently, the efficiency of operations. In addition, to sense and avoid technology, there is a need to implement strategic traffic conflict resolution tools based on the analysis of desired trajectories and other navigation support technologies. Some of these tools are maps that point to regions of restricted access and generate scenarios of meteorological conditions data of the airspaces of interest, tactical path allocators, and dynamic restricted areas whose entry is not recommended or negotiated [15].

According to Maxa et al. [18], the systems on board eVTOL vehicles to transport passengers, especially in the more mature phases of operation, will be complex and connect them to systems on the ground. These systems will expose many sensitive interfaces to cyber-attacks and the need to create security mechanisms to protect critical navigation data, sensors, and command-in-control components. Developing recovery mechanisms to land a vehicle with compromised systems safely is also vital.

Therefore, it is crucial to develop operations centers that concentrate on various elements essential to the operations. These centers will be responsible for planning and monitoring the flights of eVTOL vehicles. Aircraft need to be able to detect abnormal behavior and trigger a recovery mode automatically. This recovery mode should be able to select alternative routes and locations for emergency landings. It is also necessary to control aircraft from the ground, detect intrusions to communication systems and networks and send alerts to ground stations [18].

It is essential to ensure redundancy for the electrical systems and the rotors so that the eVTOL vehicle continues to fly in the event of electrical failures or if one of the rotors stops working. The so-called Distributed Electric Propulsion (DEP) is capable of generating redundancy in rotors and batteries and is the ideal system to ensure operational safety when individual components fail [14].

Furthermore, to contingencies that may affect individual aircraft, such as loss of an electric motor, loss of communications system, onboard medical emergency, or loss of aircraft separation assurance system, some contingencies may affect the entire fleet of eVTOL vehicles simultaneously. Some examples are the interdiction of some vertiport, degradation of the GNSS signal, adverse meteorological conditions, and conventional aircraft in an emergency descent crossing eVTOL corridors [13]. Dealing with the many possible emergencies will require interconnected infrastructure, with an intense level of coordination between different stakeholders. In this way, making decisions in real-time will be possible. [12].

Strategies must guide the implementation of intrusion detection systems for this UAM new model with eVTOL vehicles. These strategies must define their locations to be accurate and detect as many threats as possible. The best model of intrusion detection systems for this context is specification-based. In this model, the behaviors of a system are described based on its functionalities and security policies. The detection of a security breach occurs if any operation is outside these specifications. Recording all behaviors deemed appropriate in an intrusion detection system generates no false alarms when unusual but appropriate behavior occurs. With this, there is the possibility of detecting unknown attacks in advance [18].

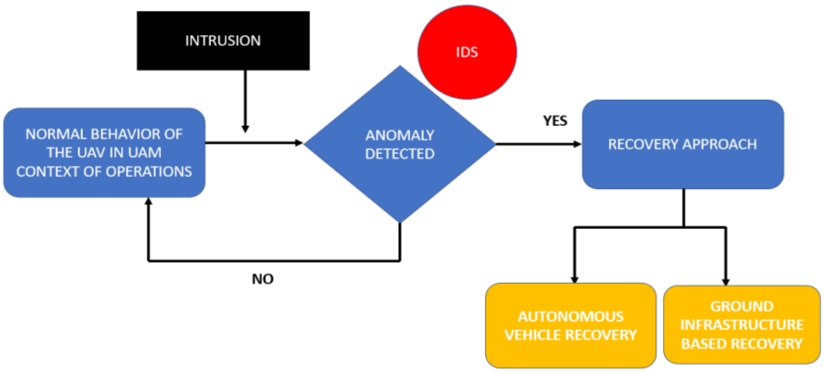

Figure 2. Recovery-based approach overview. Source: (Adapted from [18]).

According to Bijjahalli et al. [19], another essential requirement to enable safe operations of eVTOL vehicles is the guarantee of a high-performance navigation system, which is associated with performance predictor systems. This performance predictor system is necessary since the Global Navigation Satellite System (GNSS) in dense urban environments, called urban canyons, remains impaired due to problems such as multipath signal and dilution of precision. The cause of these problems is the unfavorable geometry of satellites that depend on a clear line of sight between receiving antennas and orbiting satellite.

Moreover, to reduce pilots' workload in more mature operational environments with higher traffic densities and ensure an acceptable level of safety for operations, it is required to introduce a level of automation that monitors the conformation of trajectories, the protection envelopes, and the performance of aircraft sensors. However, according to Panesar et al. [12], additional navigation support infrastructure should be developed so that it is not needed to use only GNSS. This navigation support infrastructure will create a security buffer to deal with high-pressure scenarios with high traffic demand.

According to Reiche et al. [20], weather conditions impact the willingness to fly of potential users of eVTOL aircraft, even though more than 50% of them accept to fly even in adverse conditions. The biggest concern, however, relates to flying in conditions of rain, snow, low visibility, and turbulence. However, these potential users are not apprehensive about flying in extreme cold or heat conditions. Maybe this lack of apprehension is because they do not understand the dangers of these conditions, such as the possibility of freezing of aerodynamic surfaces, excessive air rarefaction, and loss of aircraft power.

The impacts arising from meteorological conditions are different in different regions, so it is necessary to develop aircraft with varying characteristics for use in each region. Additionally, meteorological information measurement and dissemination systems must be improved to support eVTOL vehicle operations. The currently existing systems do not provide real-time information and do not have full airspace coverage. It will be necessary to implement sensors for meteorological purposes coupled with 5G networks and use artificial intelligence to improve weather forecasts. [20].

The weather conditions generated by the friction of moving air with buildings which cause sudden changes in wind direction and speed, bring the necessity for real-time monitoring with full coverage in metropolitan regions. Depending on the degree of these variations, the vehicle may have excessive energy expenditure to maintain a stabilized flight [15]. This energy expenditure could impair the vehicle's autonomy once the charge is only sufficient for the intended flight and, in an emergency, to access alternative vertiports and in-flight waits [17].

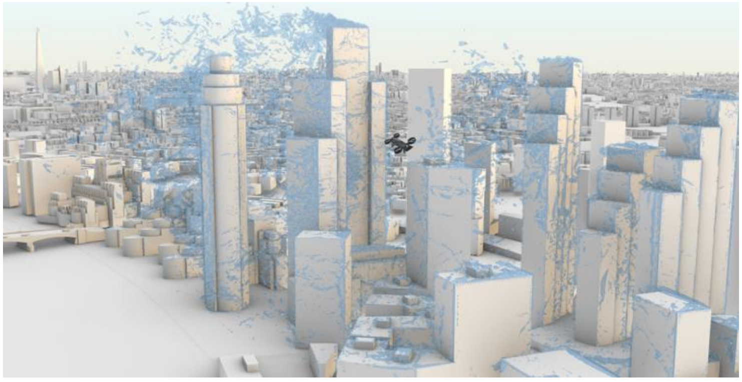

Figure 3. A snapshot in time of a cloud-based (DES) where the turbulent wind formations generated by the buildings, part of the urban canopy, are visible. Source: WSP

It is noteworthy that even advanced control algorithms may not guarantee the level of navigation precision to avoid obstacles on the ground and the excessive approach of other aircraft. According to studies undertaken by NASA, winds more significant than 5 m/s can make it impossible for smaller unmanned aircraft to fly [15].

3. Discussion

This article identified several aspects of the operational safety and security of eVTOL vehicles operating in urban and suburban environments in a new UAM concept. Some of these aspects are the way to integrate them into the existing airspace structure at present implemented air traffic control system. Suppose vehicles use the corridors customized for helicopter operation to travel between vertiports implemented in urban and suburban regions, as suggested. In that case, there is an accommodation limit to the safe number of aircraft in these corridors, especially in controlled airspaces, because of the limitations of existing air traffic control systems, which require voice communication between pilots and air traffic controllers.

In metropolitan regions, where helicopter traffic is already heavy and the air traffic control system is saturated, the insertion of eVTOL vehicles, even in the initial phase, will lead to operations restrictions. Even inserting a few additional traffic in these airspaces can increase the probability of air traffic incidents because of their capacity depletion and the situational awareness of pilots and air traffic controllers' losses. Implementing routes that avoid controlled airspace regions, establishing operational agreement letters that reduce oral communications between pilots and air traffic controllers, and defining standardized procedures that decrease interactions can mitigate the risk of incidents caused by heavy traffic. Using technologies to exchange automatic information between air traffic control facilities and pilots with no oral communication is essential. However, this type of solution is not always viable. It will depend on the site's topography, the region's meteorological conditions, the complexity of local air traffic flow scenarios, and the possibility of implementing technological solutions.

Considering that the operations of eVTOL aircraft can scale in metropolitan regions, it is necessary to develop technologies that allow these aircraft autonomously to detect and separate themselves to maintain adequate operational safety levels. This increase in automation levels will reduce the workload of pilots and air traffic controllers. In addition, implementing cybersecurity, operations management, and ground control systems must prevent the eVTOL vehicles from being "hacked" and placed at risk or, even if an attack occurs, from having their control re-established by ground operations centers.

It is important to highlight that operations management and ground control centers will be essential for adequate emergency management and the coordination of air traffic conflicts between eVTOL vehicles and other conventional aircraft, particularly in the airports' vicinity with high traffic demand. Furthermore, these centers would allow the strategic trajectories negotiation between the different eVTOL vehicles and the other unmanned and conventional aircraft to prevent crossing trajectories at conflicting altitudes and positions.

Finally, it is necessary to monitor the performance conditions of navigation systems and weather conditions in different regions where there is a demand to implement this new concept of UAM. This monitoring is necessary due to the large density of buildings forming the so-called urban canyons in which eVTOL aircraft will operate, which makes it difficult for the GNSS navigation systems to function correctly. Additionally, gust winds without a defined pattern can affect flight safety. The greater or lesser degree of these interferences will depend on the characteristics of the urban and suburban regions.

4. Conclusion and Challenges

The new concept of UAM, using eVTOL aircraft to travel in urban centers and their surroundings to avoid congestion on the ground, is getting closer to its implementation in several places worldwide. However, numerous challenges exist to overcome and obtain success in these implementations. Among these challenges is the location of points where it is feasible to install vertiports in sufficient quantity to ensure the economic viability of the system and that generate reduced processing times, the certification of aircraft and vertiports, acceptance of users in the use of aircraft eVTOL due to the perception of safety and noise generation, the adequacy of air traffic management systems to the new concept and, in particular, issues related to operational safety and security.

Addressing safety and security issues are crucial for implementing a new UAM concept using eVTOL vehicles. From the initial phases of implementation to the more mature phases of operation, it is essential to identify operational safety risks related to technical, functional, and human factors. The scalability of operations must have a gradual implementation, with the support of simulations, ensuring acceptable levels of operational safety at each stage.

As a last remark, it is necessary to understand that, in using certain regions' implementations as a reference for others, challenges related to operational safety and security may be different. These differences are, for example, related to topographies, weather, urban construction patterns, and other air traffic control systems. So, each region needs specific studies to identify aspects that may impact the safety of operations more accurately.

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