Incorporating Safety Excellence into Urban Air Mobility (UAM): Insights from Commercial Aviation, Rotorcraft, and Unmanned Aerial Systems (UAS)

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Abstract

This paper focused on safety considerations in Urban Air Mobility (UAM) through a cross-industry examination of commercial aviation, rotorcraft, and unmanned aerial systems (UAS). Although UAM promises transformative benefits, there are safety concerns remaining. Based on the Federal Aviation Administration (FAA)'s Concept of Operations (ConOps), the literature review explained the fundamental concepts of UAM. In commercial aviation, regulatory framework, pilot training and certification, vehicle design and maintenance, and emergency response planning are emphasized. For rotorcraft, safety requirements for vertical flight, collision avoidance systems, heliport standards, and weather adaptability are crucial. Leveraging UAS advancements, the study suggested autonomous systems, sense-and-avoid technology, and remote piloting for enhanced safety in the UAM sector.

Incorporating Safety Excellence into Urban Air Mobility (UAM):

Insights from Commercial Aviation, Rotorcraft, and Unmanned Aerial Systems (UAS)

The fantastical notion of flying cars once relegated to the realm of science fiction has begun its descent into reality. What was a cherished aspiration for generations of children, depicted in countless films and novels, is now taking its first steps towards practical application through Urban Air Mobility (UAM). This transformative transportation system holds the promise of revolutionizing the way people navigate their cities, offering the potential for significantly faster commutes, reduced traffic congestion, and a more environmentally friendly transportation landscape (Steiner, 2019).

In collaboration with the National Aeronautics and Space Administration (NASA) and a consortium of industry professionals, the Federal Aviation Administration's (FAA) Office of NextGen Air Transportation System (NextGen) published a fundamental document in 2020: the Concept of Operations (ConOps) for UAM. This document outlines a vision for a future where automated passenger and cargo vehicles seamlessly integrate into urban environments, collaborating with each other to ensure safe and efficient transportation within and around cities (FAA, 2020).

The potential benefits of UAM are undeniable. Imagine drastically reduced travel times, alleviating daily commutes and transforming how we access essential services within our urban centers. Traffic congestion, a significant source of frustration and economic inefficiency, could become a relic of the past. Furthermore, UAM offers the potential for a cleaner transportation future, with reduced reliance on traditional, emissions-heavy vehicles (Steiner, 2019).

However, alongside the undeniable promise lies a crucial challenge: safety. As with any new and complex transportation system, UAM raises a multitude of safety concerns. This paper aims to address the foundational concepts and operational standards of UAM. By drawing insights from established safety practices in complementary fields – commercial aviation, rotorcraft operations, and unmanned aerial systems (UAS) – the UAM industry can gather valuable lessons to guide the development and implementation of a safe and sustainable UAM system.

Urban Air Mobility – Concept of Operations

In 2020, the first version of UAM ConOps was published to describe a new, future concept of operational environment, and the FAA published the version 2.0 in 2023 based on the collaborative work and feedback given to the previous version. UAM is a subset of Advanced Air Mobility (AAM), which is "an air transportation system that moves people and cargo between local, regional, intraregional, and urban locations not previously served or underserved by aviation using innovative aircraft, technologies, and operations" (FAA, 2023, p. iv). While AAM consists of a wide range of services, including passenger, cargo, and other operations in urban and rural environments, UAM mostly focuses on flight services within and between urban areas. UAM aims to address current transportation issues by offering a quieter, safer, and more cost-effective travel option. This is particularly relevant considering the significant amount of time people spend stuck in traffic. For instance, a statistic highlights that Americans lose an estimated 8.8 billion hours annually due to traffic congestion, with projections indicating a further rise by 2023 (FAA, 2020).

Section 3 of the ConOps v.1.0 detailed three distinct UAM operational phases, which would be determined by factors, including aircraft automation and the Pilot in Command's (PIC) location. Initially, UAM operations would adhere to existing rules and regulations. Subsequently, during ConOps 1.0 operations, regulatory adjustments would be essential, incorporating enhancements outlined by Community Business Rules (CBRs), UAM structure, automation, and new technologies. Finally, the mature state operations would require advancements in both the UAM ecosystem and aircraft systems to facilitate functions such as data sharing, Demand Capacity Balancing (DCB), and similar capabilities (FAA, 2020).

Section 4 of the same document introduced the UAM operational concept, envisioning a system designed to facilitate the movement of aircraft through one or more UAM corridors (FAA, 2020). The UAM Corridor is a performance-based airspace structure with defined parameters and rules for access and operations. UAM shares similarities with UAS Traffic Management (UTM), as operators are entrusted with integration, implementation, and operational supervision. Operational standards are guided by CBRs, while regulatory responsibilities and data exchange for Air Traffic Control (ATC) and the National Airspace System (NAS) rest with the FAA. UAM operators may conduct scheduled or on-demand service operations for customers or intermodal operators, acquiring information from the Provider of Services for UAM (PSU) and Supplemental Data Service Provider (SDSP) services.

The PIC holds ultimate responsibility for flight operations and safety, with support from the PSU in meeting UAM operational requirements and ensuring airspace usage adheres to safety standards. UAM corridors are important in enabling secure and streamlined UAM operations, reducing the need for ATC separation services. Initially connecting two aerodrome locations, these corridors may eventually interconnect, forming more intricate networks as UAM operations progress. UAM separation is achieved through the exchange of flight intentions, strategic resolution of conflicting intentions, and the establishment of procedural regulations. The PSU network communicates the availability of UAM corridors, with DCB coming into play during periods of excessive corridor demand. Notably, the FAA suggests that the evolution of

UAM operations may have implications for airspace separation approaches in the future (FAA, 2020).

The initial integration of UAM entails commencing with operations of minimal complexity and a gradual transition toward a more dynamic operational pace. This method offers several advantages, including streamlining UAM implementation by utilizing existing capabilities that meet performance criteria and bypassing the necessity for an all-encompassing regulatory and operational framework. It is important to highlight, though, that this does not suggest the absence of regulatory challenges related to the safety aspects of UAM (FAA, 2020).

The second version of ConOps reflected many changes in the industry and proposed the new concepts and challenges. Especially, the FAA acknowledged that as the volume of UAM operations is expected to increase, the current capabilities of the Air Traffic Services (ATS) workforce resources might be challenged (FAA, 2023). Therefore, solutions that promote enhanced shared situational awareness and collaboration among operators are needed. The industry vision for UAM involves incorporating new aircraft designs and technologies, such as Distributed Electric Propulsion (DEP) and Electric Vertical Takeoff and Landing (eVTOL) capabilities (FAA, 2023). State and local governments are encouraged to actively plan for UAM infrastructure, including vertiports and vertistops, to ensure transportation equity and accommodate demand. A highly automated, cooperative environment, referred to as Extensible Traffic Management (xTM), has been envisioned as part of the future service environments and the NAS. UAM aircraft will need to comply with ATS requirements when operating in the ATS environment, and capable aircraft may choose to utilize ATS operating outside of a cooperative area based on operational advantages. Overall, the development and integration of UAM requires collaboration among stakeholders, advancements in technology, and regulatory guidance to support the changing aviation landscape (FAA, 2023).

Commercial Aviation

As discussed before, although UAM is introduced as a novel type of air transportation which is expected to bring many benefits to the society, the regulators are concerned that as the demand for UAM increases, there might be various safety challenges that need to be delegated accordingly. Therefore, this section of the paper will detail the insights drawn from commercial aviation that are applicable to the field of UAM.

Regulatory Framework

Regularly scheduled air carriers, as a part of commercial aviation, receive an authority from the FAA to operate scheduled air service in the form of the Code of Federal Regulations (CFR) Title 14 Part 121 certificate (FAA, 2021). Generally, these carriers are U.S. based airlines, regional air carriers, and cargo operators. 14 CFR Part 121 is articulated through 28 distinct subparts. Each subpart within Part 121 is designed to address specific operational nuances, providing a tailored approach to regulatory compliance. These subparts encompass a comprehensive range of operational aspects, including but not limited to operating requirements, aircraft maintenance and inspection, training and qualification, flight operations, air traffic and airspace rules, and safety management systems (SMS) (Operating Requirements: Domestic, Flag, and Supplemental Operations, 2023). This holistic approach ensures that the regulatory oversight provided by the FAA covers various critical elements crucial for the safe and efficient functioning of air carriers operating under Part 121 regulations. Furthermore, the thorough regulatory framework established by 14 CFR Part 121 underscores the FAA's commitment to upholding the highest standards of safety and operational excellence within the commercial aviation sector.

One distinct difference about Part 121 operators is that the FAA requires them to develop and implement an SMS. Part 135 Air Carrier and Operators, on the other hand, are not required to implement an SMS (although the FAA proposed a new rule to expand the SMS applicability to Part 135). Organizations can proactively and comprehensively address safety through the implementation of Safety Management Systems (SMS). This system encompasses a formal safety policy, established methods for identifying and mitigating hazards, and initiatives to foster a positive safety culture. Ultimately, an SMS serves to guarantee the organization's overall safety performance (FAA, 2015). The SMS helps the organization in making effective and informed safety decision, and CFR Part 5 specifies a basic set of processes that are integral to an effective SMS.

Based on publicly available information, there is a lack of clarity regarding the regulatory classification — whether UAM operators will fall under Part 121 or Part 135 (Wisk Aero, 2022). Crucially, both regulatory pathways emphasize the importance of an SMS as an integral component of UAM operations. While the regulations propose specific safety measures, it is highly recommended for UAM operators to tailor their SMS to meet their unique operational needs. This customization not only aligns with regulatory requirements but also enables operators to proactively address safety risks and continuously enhance their safety performance.

Pilot Training and Certification

14 CFR Part 61, Subpart G outlines the requirements for becoming an airline transport pilot (ATP). These requirements include:

- Being at least 23 years old.

- Being able to read, speak, write, and understand the English language.
- Being of good moral character.
- Holding a commercial pilot certificate with an instrument rating.
- Meeting the aeronautical experience requirement.
- Passing a knowledge test.
- Passing a practical test.
- Holding a first-class medical certificate to act as pilot in command (PIC).
- Having 1,500 hours of total flight time, 500 hours of cross-country flight time, 250 hours as PIC, 100 hours of night flight time, 75 hours of instrument training, and 50 hours in the class of rating sought. (Federal Aviation Administration, 2013, para. 3)

In essence, this exhaustive set of prerequisites ensures that an individual attaining the status of an ATP has not only met but exceeded the minimum standards. By adhering to these strict requirements, the aviation industry work with pilots who are not only technically proficient but also possess the judgment and skillset required to guarantee the safety and security of each flight.

The findings indicate that analogous to the case in traditional aviation, UAM pilots should be subject to experience requirements that are either comparable to or, in some instances, potentially exceed those currently in place, with the primary goal of ensuring flight safety. The dynamic and condensed nature of urban airspace demands a high level of proficiency and adaptability, making it imperative for UAM pilots to meet intense experience and competency standards.

For example, Wisk Aero outlines the requirements for their Senior Test Pilot position, which include experience in several key areas:

- Conducting flight tests on programs pursuing certification from the FAA, Transport Canada Civil Aviation (TCCA), or the European Union Aviation Safety Agency (EASA).
- At least 10 years of flight test experience as a test pilot.
- Graduation from an accredited Test Pilot School or equivalent experience.
- Possession of an FAA Commercial Pilot or ATP certificate.
- Experience in type certification programs for fixed-wing or rotary-wing aircraft, or complex systems.
- Additional unspecified qualifications. (Wisk Aero, n.d., para. 4)

Other UAM companies like Joby Aviation require a similar level of experience, if not more. This commitment to a strong skill set and comprehensive experience aligns with the overarching goal of fostering safe and efficient UAM operations in urban environments.

Vehicle Design and Maintenance

The FAA sets many requirements for vehicle design and maintenance in commercial aviation to ensure the safety and airworthiness of aircraft. Aircraft manufacturers must obtain type certification from the FAA for each aircraft model. This involves demonstrating compliance with FAA design and performance standards. Also, compliance with the FAA's airworthiness standards, outlined in 14 CFR Part 25 for transport category aircraft, is mandatory (Airworthiness Standards: Transport Category Airplanes, 2014). These standards cover various aspects of aircraft design, including structural strength, systems reliability, and overall performance. Aircraft operators are also required to establish and adhere to a Continued

Airworthiness Program (CAP) as per 14 CFR Part 121. These programs involve regular inspections, maintenance, and modifications to ensure ongoing airworthiness. In addition, operators must develop and implement maintenance programs that comply with the requirements outlined in 14 CFR Part 121, and aircraft manufacturers provide detailed maintenance manuals that specify procedures for inspections, repairs, and maintenance tasks. These manuals are crucial references for maintenance personnel and must be followed in accordance with regulations. Also, maintenance tasks must be performed by FAA approved maintenance organizations or personnel with the appropriate certifications. These organizations follow FAA regulations and guidelines to ensure the quality and safety of maintenance activities (Operating Requirements: Domestic, Flag, and Supplemental Operations, 2023).

Similarly, when the FAA sets comprehensive regulatory frameworks that extend to UAM operations, this research highlights UAM stakeholders must navigate and comply with these regulatory measures to establish a solid foundation for the safety and reliability of urban air transportation. For example, the manufacturers should implement rigorous design criteria for UAM vehicles, ensuring the incorporating of the latest safety features, redundancy systems, and collision avoidance technology. They also need to establish maintenance protocols that adhere to aviation industry standards, with regular inspections and meticulous quality control measures. This commitment is not merely a regulatory necessity but a strategic imperative to have public trust and confidence in the UAM sector. As the UAM industry continues to evolve dynamically, this alignment with aviation standards serves as a foundation for navigating the complexities of urban airspace, thereby contributing to the overarching goal of shaping a safe and efficient future for urban air transportation. Moreover, collaboration between regulatory bodies and industry stakeholders will be essential to address emerging challenges and ensure seamless integration of

UAM into existing transportation infrastructures, fostering a sustainable and equitable urban mobility ecosystem.

Emergency Response Planning

14 CFR Part 121 in the United States outlines regulations for air carriers operating scheduled air transportation. Emergency response planning is a critical aspect of ensuring the safety and preparedness of air carriers. Part 121 operators are required to develop and implement an Emergency Response Plan (ERP). This plan should address various aspects of emergency situations, including accidents, incidents, and other unforeseen events. The ERP must ensure a coordinated and timely response to emergencies (Operating Requirements: Domestic, Flag, and Supplemental Operations, 2023). It should define the roles and responsibilities of personnel involved in emergency response, both within the air carrier and in coordination with external agencies. The plan should also establish effective communication protocols to ensure swift and accurate dissemination of information during emergencies. This includes communication within the organization, with emergency services, regulatory authorities, and other relevant parties.

Part 121 operators must have procedures for promptly notifying appropriate personnel and agencies in the event of an emergency, which includes notifying the FAA and National Transportation Safety Board (NTSB) as required by regulations. Regular training and drills are essential components of emergency response planning. Part 121 operators are required to conduct training exercises to test the effectiveness of the ERP and ensure that personnel are adequately prepared to respond to various emergency scenarios. Although there are more, these requirements aim to ensure that all Part 121 carriers are well-prepared to manage and respond to emergencies, ensuring the well-being of passengers and crew members. Compliance with these regulations is essential for maintaining a high level of safety in commercial aviation operations (Operating Requirements: Domestic, Flag, and Supplemental Operations, 2023).

Likewise, the results point to that UAM operators need to formulate and execute thorough emergency response plans encompassing diverse scenarios, such as vehicle malfunctions, challenging weather conditions, and unforeseen events. In creating these emergency response plans, UAM operators must prioritize clear communication protocols, describe specific roles and responsibilities for personnel, and conduct regular training and drills to ensure a well-prepared team. Collaborative efforts with local emergency services and law enforcement are important to guarantee a well-coordinated and efficient response to any incidents that may arise. Furthermore, UAM operators should establish mechanisms for continuous improvement through post-incident reviews and lessons learned sessions. This commitment to learning and refinement contributes to the ongoing enhancement of emergency response capabilities and overall operational resilience. By embracing these proactive measures, UAM operators not only fulfill regulatory requirements but also instill confidence among stakeholders, including passengers and the communities they serve.

Rotorcraft

UAM shares common elements with rotorcraft due to the Vertical Takeoff and Landing (VTOL) capability inherent in both modes of air transportation. Therefore, it is crucial to integrate valuable insights and lessons from rotorcraft operations into the development and implementation of UAM initiatives. This cross-disciplinary learning can enhance the safety, efficiency, and overall effectiveness of UAM operations, benefiting from the accumulated knowledge and experiences in the field of rotorcraft aviation. By leveraging the extensive experience accumulated in rotorcraft safety and operations, UAM development can progress with a stronger foundation, ensuring smoother integration into existing airspace.

VTOL Systems

VTOL aircraft encompass a diverse range of aircraft, including fixed-wing designs capable of vertical take-off and landing, helicopters, and other rotor-powered options like tiltrotors (National Air and Space Museum, n.d.). Many helicopter manufacturers establish strict safety requirements for its VTOL capabilities. One specific example is the FAA regulations, particularly under 14 CFR Part 29 for the airworthiness standards for rotorcraft. This regulation addresses aspects such as control movement, freedom from jamming, and reliability, emphasizing the need for safe and effective powerplant control systems. Manufacturers are required to demonstrate compliance with these regulations during the certification process. They conduct rigorous testing and analyses to ensure that the helicopter's VTOL capabilities meet or exceed the established safety standards. The FAA's certification process involves thorough examinations of design aspects, performance characteristics, and safety features related to VTOL operations (Safety Regulations, 2007). Additionally, helicopter manufacturers often adhere to industry standards developed by organizations like the EASA, the International Civil Aviation Organization (ICAO), and the Vertical Flight Society (VFS). These standards provide additional guidelines and best practices for VTOL capabilities, contributing to a comprehensive approach to safety in helicopter design.

Drawing on the regulatory frameworks established for rotorcraft operations, this paper indicates that UAM stakeholders should integrate key lessons and safety measures into their own operational frameworks. Similar to the meticulous adherence to 14 CFR Part 29 for rotorcraft, UAM operators should ensure that their VTOL capabilities meet or surpass the specified safety standards. This involves comprehensive testing, analysis, and certification processes to demonstrate compliance with regulatory requirements. Furthermore, UAM initiatives would benefit from aligning with international aviation organizations and industry bodies that contribute to the formulation of best practices and safety standards. Organizations such as the EASA and ICAO offer valuable insights and guidelines applicable to VTOL operations. By incorporating the safety principles established for rotorcraft, UAM manufacturers not only facilitates regulatory compliance but also fosters a culture of safety and adherence to established standards within the burgeoning field of UAM.

Advanced Collision Avoidance Systems

Modern helicopters are equipped with advanced collision avoidance systems to enhance safety and prevent potential collisions. Two notable systems employed in helicopters are the Traffic Collision Avoidance System (TCAS) and Helicopter Terrain Awareness and Warning System (HTAWS). “TCAS is a family of airborne devices that function independently of the ground-based air traffic control (ATC) system and provide collision avoidance protection for a broad spectrum of aircraft types. All TCAS systems provide some degree of collision threat alerting, and a traffic display” (FAA, 2011, p. 5). It provides pilots with advisories to avoid potential collisions by issuing resolution advisories (RAs) for vertical maneuvers, instructing pilots to climb or descend to avoid conflicting traffic.

HTAWS, on the other hand, “is an alerting system that provides the helicopter pilot with audible and visual alerts for terrain and obstacles” (FAA, 2022, p. 4). It uses a combination of Global Positioning System (GPS) data and a digital terrain database to warn pilots of potential terrain hazards, helping to prevent controlled flight into terrain (CFIT) accidents. Specifically, the FAA estimated that passengers and public safety benefits from installing HTAWS on all commercial helicopters after considering the following factors: Department of Transportation (DoT) guidance on valuing the reduction of fatalities and injuries by regulations, costs of medical care, replacement value of the destroyed aircraft, and more (FAA, 2022). While the specific features and capabilities may vary among helicopter models and operators, the overall goal is to enhance safety and mitigate the risk of collisions, especially in busy airspace and challenging flying conditions.

This paper indicates that by incorporating comparable collision avoidance features and advanced safety systems similar to those utilized in modern helicopters, UAM can significantly enhance their operational safety. The implementation of TCAS, HTAWS, or something comparable can increase the ability of UAM vehicles to detect and respond to potential threats or obstacles in their flight paths. Integrating such advanced avionics not only aligns UAM with established safety standards but also ensures a proactive approach to preventing collisions and enhancing overall airspace safety, contributing to the robustness and reliability of urban air transportation systems.

Heliport Standards

Heliport standards are thoroughly regulated by the FAA to ensure the highest levels of safety, efficiency, and uniformity in helicopter operations. These comprehensive standards encompass a multifaceted approach, addressing various critical elements in heliport design, construction, and operation (Notice of Construction, Alteration, Activation, and Deactivation of Airports, 1991). Specific dimensions and lighting requirements for helipads are specifically defined, ensuring visibility and guidance for pilots during takeoff and landing maneuvers. The FAA also mandates precise markings on the helipad to facilitate clear communication between air traffic controllers and helicopter pilots (Notice of Construction, Alteration, Activation, and

Deactivation of Airports, 1991). Obstacle clearance zones are designated to minimize potential hazards, enhancing safety during critical flight phases.

Heliports are required to have firefighting facilities, including strategically placed fire extinguishers, to ensure rapid response capabilities in case of emergencies (Notice of Construction, Alteration, Activation, and Deactivation of Airports, 1991). Wind indicators, such as windsocks, contribute to the safe assessment of wind conditions, helping pilots make informed decisions. Furthermore, reliable communication systems, including radio equipment, are a vital component to facilitate effective communication between heliport personnel and ATC. Access control measures are implemented to restrict unauthorized entry and ensure the security of the heliport facility. Emergency procedures are required, providing clear protocols to manage and respond to potential hazards or accidents. The FAA's oversight and adherence to these standards collectively contribute to the creation of a secure and standardized environment for helicopter operations throughout the nation (Notice of Construction, Alteration, Activation, and Deactivation of Airports, 1991).

Similarly, this paper highlights that UAM companies engaged in the establishment of vertiports or vertistops must conscientiously adhere to principles similar to those governing traditional heliports. As heliports follow the regulations outlined in 14 CFR Part 157, UAM developers and operators should embrace comparable standards for the construction, activation, and alteration of their vertiport infrastructure. It is imperative for UAM companies to consider and comply with Advisory Circulars (ACs) and guidelines issued by aviation authorities, such as AC 150/5390-2 providing guidance on heliport design, to ensure safe and efficient vertiport operations (FAA, 2023). Additionally, state and local regulations, similar to those applicable to heliports, are likely to influence the development of vertiport facilities. Upholding these regulations and guidelines will not only foster regulatory compliance but also contribute to the creation of a standardized and secure environment for the growing field of UAM.

Weather Adaptability

The weather adaptability of rotorcraft, including helicopters, relies on a combination of advanced technology, pilot skills, and operational considerations to ensure safe and efficient performance in various weather conditions. Rotorcraft are equipped with advanced avionics and instruments that provide crucial information to pilots regarding weather conditions, such as airspeed indicators, altimeters, attitude indicators, and weather radar. These instruments help pilots navigate through adverse weather situations and maintain control of the aircraft. Also, many rotorcrafts are equipped with weather radar systems that allow pilots to detect and navigate around areas of turbulence, thunderstorms, and other hazardous weather phenomena. Weather radar provides real-time information about precipitation intensity and helps pilots make informed decisions to avoid dangerous weather (Airbus, 2016). Rotorcraft operating in colder climates may be equipped with de-icing systems to prevent the buildup of ice on critical surfaces, such as rotor blades and sensors. De-icing systems help maintain the aerodynamic efficiency and overall safety of the aircraft during icy conditions. Furthermore, pilot training is a crucial element in ensuring weather adaptability. Pilots undergo extensive training to handle various weather scenarios, including adverse conditions like low visibility, high winds, or turbulent weather. Experience and proficiency in instrument flight are particularly important for navigating through low-visibility conditions.

Similar to rotorcraft, this paper indicates UAM vehicles will be equipped with advanced avionics, weather radar systems, and de-icing technologies to navigate through diverse weather scenarios. UAM companies must prioritize the integration of these technologies to ensure real-time weather monitoring, detection of hazardous conditions, and informed decision-making by pilots. Regulatory compliance is significant, with UAM companies expected to adhere to weather minimums and operational standards set by aviation authorities. These regulations guide UAM operations to ensure a high level of safety and reliability, mirroring the principles established for traditional rotorcraft. By embracing and applying these principles, UAM companies can establish a foundation for safe, efficient, and all-weather urban air transportation, contributing to the viability and acceptance of this innovative mode of travel.

UAS

A UAS “is an unmanned aircraft and the equipment necessary for the safe and efficient operation of that aircraft. ... It is defined by statute as an aircraft that is operated without the possibility of direct human intervention from within or on the aircraft” (FAA, n.d.). UAS and UAM share similarities in their reliance on innovative aerial technologies and their potential impact on the future of aviation. Both UAS and UAM involve the potential for autonomous or semi-autonomous operations. While UAS operate without a human pilot on board, some UAM concepts also envision autonomous or semi-autonomous flights, especially as the technology advances. They are also equipped with advanced avionics and sensors that are important in ensuring safe and precise flight, obstacle avoidance, and navigation in complex urban environments. Therefore, safety lessons learned from UAS operations are valuable for the emerging UAM sector.

Autonomous Systems

Autonomous systems are important in UAS as it enables unmanned aerial vehicles (UAVs) to operate without continuous human intervention. Autonomous systems enable precise navigation and flight control, allowing UAVs to follow predetermined flight paths, waypoints, or complex routes. This capability is crucial for executing missions with accuracy and reliability. UAS often employ autonomous systems for automated takeoff and landing procedures, which ensures smooth and controlled operations, reducing the reliance on manual piloting during critical phases of flight. Autonomy extends to payload operations, where UAS can autonomously control sensors, cameras, or other equipment. It is particularly valuable for tasks such as aerial surveys, monitoring, or data collection. Autonomous systems enable the coordination and synchronization of multiple UAVs in a swarm. This allows for collaborative tasks, such as distributed sensing, mapping, or search and rescue operations, where the UAVs autonomously work together to achieve common objectives. Autonomous systems enable remote monitoring and control, allowing operators to oversee UAS operations from a distance. In the event of anomalies or emergencies, operators can intervene and take control, ensuring human oversight when necessary. The integration of autonomous systems in UAS contributes to their versatility and adaptability across various applications, from surveillance and reconnaissance to agriculture, delivery, and beyond.

Similar to the way autonomous systems are leveraged in UAS, this paper highlights that UAM companies are challenged to integrate advanced autonomy features to ensure the safe and efficient operation of VTOL aircraft in urban environments. By embracing and adapting these foundational principles, UAM companies not only cultivate a culture of safety but also construct a robust framework for reliable, efficient, and autonomous urban air transportation. The integration of advanced autonomy features emerges essential, as it will unlock the potential of UAM in shaping the future of smart cities. As these autonomous systems become intrinsic to UAM operations, they stand as foundations for realizing a transportation model that is not only innovative but, more significantly, inherently safe and adaptive to the evolving needs of urban communities.

Sense and Avoid Technology

"The Sense and Avoid (S&A) system plays a profoundly important role in integrating UASs into the National Airspace System (NAS) with reliable and safe operations" (Yu & Zhang, 2015, p. 152). The primary goal is to replicate the situational awareness and collision avoidance capabilities typically provided by a human pilot in manned aircraft. UAS equipped with S&A technology are equipped with a sophisticated sensor suite. This suite typically includes a combination of sensors such as radar, light detection and ranging (lidar), cameras, and other relevant sensors capable of providing comprehensive data about the surrounding airspace. The information collected by various sensors is processed in real-time by onboard computer systems. This data fusion enhances the accuracy and reliability of the UAS's perception of the surrounding environment. S&A technology also identifies and detects potential obstacles or hazards in the UAS's flight path. This can include other aircraft, buildings, terrain, or any object that poses a collision risk. The system continuously updates this information as the UAS navigates through its mission. The S&A system assesses the collision risk associated with detected obstacles. It considers factors such as the relative speed, distance, and trajectory of the UAS and the detected object. This assessment helps determine whether evasive action is necessary. The integration of S&A technology is crucial for enabling beyond visual line of sight (BVLOS) operations of UAS, especially in complex and dynamic environments. This technology contributes significantly to the overall safety and reliability of unmanned aerial missions.

This paper indicates that UAM companies, envisioning a future of autonomous and efficient aerial transportation, need to adopt the foundational principles of S&A technology.

Similar to UAS, UAM vehicles must integrate sophisticated sensor suites, data fusion mechanisms, and advanced decision-making algorithms to detect and navigate around potential obstacles in their operational airspace. The seamless execution of evasive maneuvers, considering factors such as relative speed and trajectory, is helpful for UAM companies in ensuring collision avoidance and maintaining the highest standards of safety during their autonomous flights. By embracing these principles, UAM can emphasize their commitment to safe, reliable, and efficient urban air transportation, aligning with the safety-centric approach exemplified by UAS operations.

Remote Piloting and Supervision

14 CFR Part 107 outlines the requirements for obtaining a remote pilot certificate, which is necessary for individuals operating UAS for commercial purposes. The same regulation establishes various operating limitations for UAS operations, including altitude restrictions, daylight operation requirements, and restrictions on flying over people not directly involved in the operation (Small Unmanned Aircraft Systems, 2016). Remote piloting relies on communication links, often established through radio frequency (RF), satellite communication, or other wireless technologies. These links enable real-time communication between the ground control station and the UAV. Telemetry data, including information about the UAV's altitude, speed, heading, battery status, and other critical parameters, is continuously transmitted from the UAV to the ground control station (GCS) ("Radio Telemetry," n.d.). This data is essential for the operator to make informed decisions during the flight. The GCS serves as the hub for remote piloting and supervision. It typically includes a console with control interfaces, displays, and communication equipment. Operators at the GCS are responsible for supervising the UAV's operations. They make decisions based on the telemetry data, live video feeds, and any

additional information available. In complex or dynamic situations, the operator may need to intervene to ensure the safety and success of the mission.

This paper highlights that much like UAS operators, UAM companies engaging in remote piloting must ensure compliance with certification requirements for remote pilots, adhere to operating limitations, and establish effective contingency plans. The principles of maintaining communication links, utilizing GCS, and overseeing UAM operations from a remote location is almost identical to the remote piloting and supervision practices in UAS regulations. Embracing these shared principles is important for UAM companies, laying the foundation for safe, efficient, and compliant autonomous urban air transportation.

Conclusion

In conclusion, UAM presents a transformative potential for revolutionizing transportation, offering faster commutes, reduced traffic congestion, and environmental benefits. However, ensuring the safety of this novel transportation system remains paramount. This paper indicated the fundamental concepts and operational standards of UAM based on valuable insights from established regulations and practices employed in commercial aviation, rotorcraft, and UAS.

Commercial aviation serves as a benchmark for UAM’s safety framework. 14 CFR Part 121, which emphasizes the implementation of an SMS, provides a critical foundation for UAM development. Moreover, UAM pilots should possess experience levels comparable to those mandated for ATPs to effectively navigate the complexities of dynamic urban airspace. Additionally, existing FAA standards for vehicle design and maintenance in commercial aviation offer valuable guidance for UAM stakeholders. These standards emphasize the importance of incorporating safety features, redundancy systems, and rigorous maintenance protocols into

UAM vehicles. Furthermore, the comprehensive ERPs mandated by Part 121 serve as a model for UAM. These plans necessitate thorough pre-planning, clear communication protocols, defined roles for various stakeholders, and ongoing training to ensure a well-coordinated and effective response to diverse emergency scenarios.

Lessons gleaned from rotorcraft operations are equally crucial for UAM's safety development. The established safety standards for VTOL operations, advanced collision avoidance systems, and regulated heliport standards present valuable guidance for UAM development. This reseach highlighted that UAM operators should collaborate closely with aviation regulators and organizations to ensure their VTOL capabilities meet established safety standards in line with those governing rotorcraft operations. Implementing advanced collision avoidance systems, similar to those employed in rotorcraft, will significantly enhance UAM safety and fosters alignment with existing industry standards. Additionally, adhering to established heliport standards ensures uniformity, safety, and efficiency in UAM infrastructure development. Furthermore, weather adaptability, a critical aspect of rotorcraft operations, necessitates the integration of advanced avionics, weather radar, and de-icing technologies into UAM vehicles. This commitment to advanced weather management systems ensures regulatory compliance, optimal operational safety, and all-weather performance for UAM.

Finally, insights gathered from UAS operations hold significant value for UAM development due to their shared reliance on innovative technology and their transformative impact on the aviation landscape. The safety principles established through UAS operations, particularly those pertaining to autonomous flight and advanced sensor technology, provide valuable lessons for UAM. This paper indicated that the safe, efficient, and compliant integration of autonomous systems, sense-and-avoid technology, and remote piloting principles will be crucial for UAM’s successful implementation within urban airspaces. By embracing these shared safety principles and adhering to established regulatory frameworks, UAM companies can build a strong foundation for success in this evolving and dynamic transportation sector. By prioritizing safety and drawing on the experience of established aviation sectors, UAM holds the potential to transform not only people’s commutes but also their cities, fostering a more efficient, sustainable, and interconnected urban landscape.

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