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Aviation Safety for Urban Air Mobility: Pilot Licensing and Fatigue Management

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Abstract
Urban Air Mobility (UAM) is an emerging air traffic system designed for passengers and cargo in and around urban environments. Both the Federal Aviation Administration of the United States and the European Union Aviation Safety Agency endorse a phased development approach for UAM, commencing with manned aviation and subsequently transitioning to remotely piloted and autonomous operations. This article focuses on legal considerations related to aviation safety, with a specific focus on pilot licensing and crew fatigue management. An analysis of existing aviation law provisions suggests that the International Civil Aviation Organization can work with local authorities to create regulations governing both on-board and remote pilots involved in UAM operations. Safety standards in air law can apply *mutatis mutandis* to on-board pilots until specific regulations are developed. In the longer term, there shall be domestic laws on both on-board and remote UAM pilots.

Keywords Urban Air Mobility · Aviation safety · Pilot licensing · Fatigue management · Remote pilots

1 Introduction

1.1 Basic information about the Urban Air Mobility

Industrial stakeholders and the general public foresee the operation of the electric vertical take-off and landing (e-VTOL) aircraft and unmanned aviation systems (UAS) in and around urban environments, offering a more environmentally friendly, intelligent, integrated, and sustainable mobility solution [1]. These new operational paradigms promise to bring societal benefits, including environmental protection, economic growth, and enhanced well-being. One prominent example of such operations pertains to the concept of Urban Air Mobility (UAM). Traffic congestion and pollution from ground traffic pose escalating challenges in a number of cities across the globe. Local governments and industrial stakeholders are actively seeking sustainable mobility solutions. In this connection, UAM exhibits the potential to resolve these challenges through eco-friendly and intelligent means.

Airbus invented the term ‘UAM’ as early as 2016. The United States (US)’ National Aeronautics and Space Administration (NASA) subsequently refined the concept, defining UAM as a system for air transportation of passengers and cargo within urban environments.

In recent years, various documents and initiatives within the European Union (EU) have also acknowledged the concept of UAM [2]. The European Union Aviation Safety Agency (EASA) is a specialised agency established under Regulation (EC) No 1592/2002, dedicated to ensuring confidence in the safe of air operations across Europe. EASA has provided a precise definition of UAM as a subset of Innovative Air Mobility (IAM) operations conducted within, to or out of urban environments [3].

Policy and academic deliberations identify a range of UAM applications intended to fulfil diverse functions, often requiring a variety of aircraft types. Operations can encompass manned, remote-piloted, or autonomous aircraft.

Firstly, UAS can play a pivotal role in facilitating last-mile delivery of cargo and food through the deployment of compact unmanned aircraft. Industrial stakeholders anticipate that unmanned aviation will offer a cost-effective means of delivering packages to private residencies or central distribution hubs. On 15 October 2023, the Civil Aviation

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Administration of China awarded its first license for urban drone deliveries to a Chinese technology company, Antwork Technology [4].

Secondly, eVTOL aircraft can transport passengers in response to ground transportation congestion. For instance, the Passenger Air Transport Services (PATS), commonly known as air taxi services, could carry travellers from airports to various city locations, between different city regions, or between locations outside the city and its centre, and vice versa. Given the growing pollution and congestion in urban settings, short-distance PATS aim to provide an environment-friendly and efficient alternative to ground transportation, while seamlessly integrating into urban mobility systems.

Thirdly, prospective UAM applications encompass civil surveillance, governmental operations, and emergency scenarios. Drones can conduct autonomous inspection and maintenance of critical infrastructure, such as bridges. Furthermore, additional use cases may involve precision agriculture, initial visual assessment of incident sites, and police surveillance. Another notable example pertains to the transportation of emergency and medical supplies, including organs and blood.

1.2 Three Steps of the UAM Development

The UAM concept is closely related to the autonomy technology employed in operations, enabling the optimisation of activities in major metropolitan areas, reducing human errors, and keeping labour costs to a minimum. As noted above, UAM will offer mobility solutions within urban areas, with operations potentially affecting a substantial population on the ground. Aviation safety standards serve as a fundamental prerequisite for the operation of low-level air traffic within urban environments. Thus, prospective UAM operators must deliver secure and reliable air services to foster sustainable development and enhance societal acceptance. In this connection, both the EASA and the US Federal Aviation Administration (FAA) advocate a phased approach in developing UAM operations [5]. This approach signifies a gradual transition toward reduced reliance on human pilots.

UAM operations will initially use newly certified vehicle types capable of flying in urban environments and some cases – such as PATS – would require on-board pilots. The pilot-in-command is the individual on board the vehicle who holds the ultimate responsibility for operations and aviation safety. During this phase, national civil aviation authorities will take the task of certifying vehicles within the prevailing regulatory and operational environment. As regulatory frameworks evolve, with a particular focus on technical standards for aviation safety and environmental protection, increased operational frequency will accommodate a broader range of UAM applications.

In December 2020, the EUROCONTROL Experimental Centre initiated the 'Concept of operations for European UTM systems – Extension for urban air mobility' (CORUS-XUAM) to showcase the application of U-space services and regulations to manned UAM operations. It is anticipated that UAM operations will progressively integrate U-Space, offering a set of new services underpinned by advanced digitalisation and automation of functions. These services are specifically designed to ensure safe, efficient, and secure access to airspace for a multitude of drones [6].

In the second stage of UAM development, the shift from manned aircraft to remotely operated aircraft can foster heightened operational frequency. The acceptance, adoption, and integration of unmanned aviation into society are by no means assured, yet these elements are pivotal to the successful and sustainable advancement of UAM. As per a study conducted by EASA on the acceptance of UAM by citizens, the survey participants express a greater openness to operations featuring on-board pilots or, at the very least, remote pilots stationed on the ground, as opposed to fully autonomous aircraft operations.

The third stage of UAM operations' maturity necessitates the formulation of new operational regulations and enhancements to infrastructure, facilitating the secure operation of autonomous aircraft within congested urban environments. Academic and policy deliberations characterise UAM as a comprehensive and holistic urban aviation network encompassing both manned and unmanned aviation. Autonomous operations are a crucial component of the UAM industry. The envisioned U-space regulatory package in the EU can promote the execution of unmanned operations without compromising the safety, health, or welfare of individuals on the ground, thereby offering a secure and efficient avenue for the development of UAM applications. The establishment and implementation of U-space in potential UAM operations shall align with societal acceptance considerations which encompass concerns about aviation safety, environmental impact, and privacy.

From the perspective of manufacturers and operators, most companies intend to initiate operations rooted in manned aviation. Examples include Volocopter (Germany), Lilium (Germany), and Bell (the US). In contrast, only a limited number of companies have intentions to launch their UAM endeavours centred around unmanned aviation, encompassing both remote-controlled and autonomous operations. Notable examples include EHang (China) and Wisk (the US).

1.3 Aviation Safety and the Purpose of this Article

Traditional air law rules encompass various aspects, including air service agreements, passenger rights, ownership and substantial control, infrastructure, airport, pilot licensing, flight time limitations (FTLs), luggage, insurance, etc. Not all aviation regulations and principles are relevant to UAM operations. For instance, the part of air law related to cross-border flight operations and concerning issues such as air service agreements as well as ownership and substantial control hardly matters in the future progress of UAM operations which are limited to urban transport. This is relevant to settle the debates over jurisdiction and governance in UAM matters. Policy and academic discussions increasingly pay attention to the question of whether the national civil aviation authority (CAA) or local and municipal authorities shall assume the duties of regulating UAM operations.

The three-stage approach may necessitate distinct standards for each stage. One of the key issues regarding regulatory approaches pertains to the applicability of existing aviation rules to UAM operations *mutatis mutandis*. Otherwise, this novel mode of mobility necessitates the establishment of a new legal acceptance beyond air law to ensure the secure and efficient integration of drones and other unmanned aircraft in urban environments.

A crucial element in defining UAM, alongside a metropolitan operational setting, is the safe completion of operations. Safety concerns come first in terms of their relative significance among factors influencing public acceptance and, consequently, the regulatory approach. Both prospective passengers and people on the ground alike hold high expectations for safety standards in aviation, given the remarkable safety track record of the civil aviation industry. While aviation safety primarily pertains to the safety of passengers on board UAM vehicles, it also holds close relevance to individuals on the ground, considering that as the UAM concept revolves around operations above urban environments.

Issues of personnel licensing and fatigue management are integral components of the safety regulation of UAM operations. The three phases of UAM development imply a significant role for pilots, particularly on-board pilots in the first stage and remote pilots in the second stage. Nevertheless, it is not automatically clear how air law rules for personnel licensing and fatigue management shall apply to on-board and remote pilots for UAM operations. This article aims to answer this question by first providing the context, defining the UAM concept, and elucidating the role of pilots in a crawl-walk-run framework for UAM development in Part 1. Following this, Part 2 delves into the question of whether civil aviation authorities can take on the responsibility of formulating technical standards for pilot licensing and fatigue management. While recourse to the US materials does occur, the focus of this article is on EU law and international air law. Part 3 then scrutinises the existing rules in air law regarding pilot licensing and fatigue management. Part 4 examines these two issues in the context of UAM by identifying safety-related challenges and recommending the development of national legislation and, where feasible, international standards under the auspices of ICAO. Part 4 also explores a wider context of the role of UAM pilots and examines the question of whether UAM pilots shall be subject to aviation regulation or ground traffic regulation. The article concludes with a summary of discussions and presentation of regulatory recommendations.

2 Institutional Aspects

2.1 ICAO

The Convention on International Civil Aviation (Chicago Convention (1944)) strives for the global harmonisation of standards and procedures relevant to air navigation, with a particular focus on aviation safety. The Convention has 193 State Parties as of writing, which include all Member States of the United Nations except Liechtenstein. ICAO, a specialised agency of the United Nations, was established by the Chicago Convention (1944). Article 44 of the Chicago Convention (1944) outlined the responsibilities and duties of ICAO which notably include the promotion of safe and orderly growth of international civil aviation.

Concerning unmanned aircraft, ICAO has been pursuing two technical workstreams based on operation-centric and risk-based approaches.

On the one hand, ICAO's efforts are dedicated to addressing the Remotely Piloted Aircraft Systems (RPAS). The Remotely Piloted Aircraft Systems Panel (PRASP), established under the umbrella of ICAO, is working to bring RPAS into non-segregated airspace and aerodromes. RPAS constitute a novel element within the aviation system, necessitating joint endeavours by ICAO, States, and the industry to comprehend, define and ultimately integrate them. Given that RPAS are based on cutting-edge advancements in aerospace technologies, ICAO underscored that the integration of RPAS into non-segregated airspace may pose challenges encompassing various aspects, including remote pilot licensing and medical qualification.

On the other hand, ICAO actively participates in policy discussions concerning other unmanned aircraft systems. Within this workstream, ICAO has instituted the UAS Advisory Group (UAS-AG) and disseminates guidance, best practices and practical examples through the *ICAO UAS Toolkit* website. Furthermore, ICAO has created the model UAS regulations which offer a template for ICAO member States to contemplate for adoption in regulating UAM operations. Especially, the model regulations address the certification of remote pilots for unmanned aircraft.

UAM is a mobility system that offers transportation of passengers and goods in cities and regions. It is unlikely that UAM operations will traverse national borders. Since the Chicago Convention (1944) and the ICAO SARPs exclusively apply to international civil aviation, UAM operations, for the most part, do not come under the regulation of international air law. However, this does not mean that the ICAO regime has no involvement in the regulation of human performance in UAM.

National aviation authorities bear the responsibility for overseeing their respective national airspace, including low-altitude UAM operations as a logical extension. The integration of UAM in cities requires due consideration of aviation and aviation technology. ICAO plays a crucial role in securing international consensus for airspace regulation and significantly influences how States perceive their domestic air laws. In this new era marked by the emergence of UAM, ICAO can collaborate with relevant local authorities through channels such as the UAM Initiative Cities Community (UIC2) in Europe and the World Economic Forum's Cities and Regions Coalition, fostering the modernisation of aviation regulatory frameworks.

Safety regulation first requires technical expertise, alongside its policy and legal facets. ICAO has developed SARPs as well as other regulatory documents like the Regional Supplemental Procedures (SUPPS) [7]. Collectively, these documents underscore ca comprehensive technical safety framework for civil aviation. The ICAO regime can provide specialised expertise in the regulation of aviation personnel. Furthermore, numerous underdeveloped States lack the requisite resources and expertise to formulate technical standards for UAM operations. Some States have opted to delegate certain responsibilities in traditional civil aviation, as mandated by Article 28 of the Chicago Convention (1944), to international agencies or other States [8]. Concerning prospective UAM use cases, regulatory challenges will arise in the context of aircraft operational specifications of aircraft, integrated air and ground traffic management, and the ongoing evolution of aviation technology. Some States may encounter challenges in developing a functional and effective regulatory framework for UAM operations. Consequently, States can base their decision-making on the legitimacy and expertise of ICAO.

ICAO has provided several documents pertaining to unmanned aviation, such as the Manual on Remotely Piloted Aircraft Systems (RPAS) [9], and the Circular 328 – Unmanned Aircraft Systems (UAS) [10]. The RPAS and UAS markets are both pivotal components in the development of the UAM use cases. Although these documents are advisory, States and organizations can use them as a starting point for introducing domestic regulations. As standards and policies created by States and organisations evolve, there is the potential to include domestic experience in the ICAO's guidance materials. Furthermore, ICAO may adopt non-binding documents to place the aviation industry as a leading force in fostering collaboration with ground transportation stakeholders and promoting coordination of UAM operations with traditional civil aviation activities.

Since UAM is oriented toward domestic operations, national aviation authorities will hold relevant responsibilities for administering and regulating the safety of operations within their airspace. This will especially be the case during the initial UAM development.

2.2 What about the EU?

The EU is actively looking into how UAM services may be integrated into local and regional development. To better understand how social acceptance of UAM operations will be in the EU, EASA performed a comprehensive study in 2020. The study examined how EU residents perceived various UAM use cases and identified valuable insights that can inform EASA's formulation of the forthcoming regulatory framework. Notably, the EASA study did not delve into personnel management from an aviation perspective; instead, it focused on projecting the repercussions of the UAM industry on obsolete jobs and creation of new jobs.

Building upon the findings of this study, EASA has launched preparatory activities which will contribute to the establishment of regulations for both on-board and remote pilots of UAM vehicles. While EASA has been encouraging the development of safety-related standards for UAM operations, the national aviation authorities of the EU Member States will be the main institutions. These national authorities are tasked with creating regulations of licensing and fatigue management and collaborating harmoniously with EASA in this regard.

3 Pilot Licensing and Fatigue Management in Air Law

3.1 Pilot Licensing

3.1.1 Pilot Licensing in the ICAO SARPs

Besides the main text, the Chicago Convention (1944) comprises nineteen detailed technical Annexes including Standards and Recommended Practices (SARPs). These SARPs cover the fundamental technical and operational facets of international civil aviation. ICAO develops and regularly amends the SARPs under Article 37 of the Chicago Convention (1944). This provision furnishes a robust legal foundation for ICAO to establish air rules.

Annex 1 to the Chicago Convention (1944) comprises SARPs that establish the baseline standards for personnel licensing. On 14 April 1948, ICAO adopted Annex 1 which has been subject to numerous amendments, with the latest version dated in July 2022. Over the past decade, these amendments include changing age limits for pilots engaged in international commercial air transport in 2013, regulating the issuance of remote pilot licenses in 2018, and introducing an electronic licensing system related to the Electronic Personnel Licence Task Force in 2022.

Globally common concerns regarding the safety of air navigation encourage States to accept, through domestic legislation, the agreed benchmarks of international standards and recommendations included in Annex 1 [11]. Annex 1 is thus of particular importance for aviation safety. SARPs within Annex 1 contribute to an integrated regulatory framework for pilot licensing. They address pilot and crew members' qualifications, flying hours and experience requirements, as well as retirement age, which will be relevant to the safety of flights [12]. Annex 1 aims to foster harmonisation of disparities in licensing requirements among States.

3.1.2 Pilot Licensing in the EU Law

The EU is an international organisation with supranational characteristics. It is neither a party to the Chicago Convention (1944) nor a member of ICAO. Nevertheless, the active engagement of the EU and its Member States in international civil aviation necessitates a close collaboration between the EU and ICAO. Through a series of ICAO-EU Memorandum of Cooperation Joint Committee meetings, two entities support and promote each other's activities in regulating air transport.

In the context of air law, Regulation (EC) No 1008/2008 sets out common rules for the operation of air services in the community. There are also aviation rules scattered throughout other EU legislation. As an illustration, Regulation (EU) No 965/2012 lays down technical requirements and administrative procedures related to air transportation. It includes provisions related to the designation as the pilots-in-command. Furthermore, on 3 November 2011, the European Commission published Regulation (EU) No 1178/2011, which stipulates technical requirements and administrative procedures related to civil aviation crew members. In addition to regulating the licensing of pilots, the Annexes provide additional definitions concerning pilots and other crew members.

EASA plays a key role in the regulation of crew members. Regulation (EU) 2018/1139, which serves as the normative foundation for EASA, delineates the technical regulations applicable to crew members, including pilots and cabin crew, along with individuals involved in their medical assessment and training. Regulation (EU) 2018/1139 specifically covers the training of pilots and their minimum medical fitness to ensure flight safety [13]. Notably, EASA does not issue licences. In each Member State, the respective national aviation authority is responsible for license issuance, provided that they adhere to the minimum standards created by the ICAO SARPs and the EU law.

3.2 Fatigue Management

3.2.1 Fatigue Management in the ICAO SARPs

Within the realm of air operations, pilot fatigue holds a significant relevance to aviation safety as it directly affects the fitness of personnel for aircraft operation. Multiple factors can contribute to pilot fatigue, including long flying hours, early starts, night duties, long duty-on-call periods, irregular work patterns, as well as multiple sectors.

Pilot fatigue is a significant consideration when determining a person's suitability for duty. As ICAO noted, fatigue is a physiological condition of decreased mental or physical performance ability that can affect a person's attentiveness and ability to carry out operational activities crucial to safety [14]. A fatigued person may lose 80% of the capacity to pay attention and 70% of responsiveness to operational details [15]. Pilots' ability to perform safely is compromised by fatigue on a mental as well as a physical basis. Pilot weariness is thought to be a factor in 15–20% of all fatal air accidents that are caused by human error.

Inadequacy of current technical standards contributes to the following three causes of pilot fatigue. Firstly, no comprehensive system for tracking total flight hours per pilot in Europe or around the world has been established by States [16]. Secondly, airlines can circumvent restrictions on flight hours by changing the home base of the pilot and such at their discretion and as many times as they want. Thirdly, prescriptive Flight Time Limits (FTLs) rules themselves cannot prevent high fatigue during air operations. Airline pilots conduct air operations according to complicated flight schedules, subject to uncertainty connected to difficulties in interpreting such concepts as disruptive schedules, night duties and the status of acclimatisation. Out of the concerns about labour costs, airlines may be tempted to exploit the workforce where pilots are increasingly being required to fly long hours so long as national regulations permit.

Annex 6 to the Chicago Convention (1944) provides the rules relating to the duties of pilots in both scheduled and unscheduled international air transport operations for hire or compensation. It contains SARPs which highlight the importance of pilot fatigue management. Specifically, Standard 4.10 urges States to establish regulations based on scientific standards, expertise, and operational skills to ensure that personnel can operate at an adequate level of alertness. This provision explains that national statutory rules shall specify limitations applicable to flying time, flight duty period, duty period restrictions, and rest period needs. Airlines shall establish their flight arrangements within statutory limitations including flight duty period and rest period, or the Fatigue Risk Management System (FRMS).

3.2.2 Fatigue Management in the EU Law

Regulation (EC) No 1899/2006 provides safety rules on pilot fatigue by introducing mandatory flight duty limitations and rest requirements. Based on this regulation, EASA has initiated rules to deal with fatigue issues. Regulation 83/2014, which came into force on 19 February 2016, was drafted by EASA to harmonise flight time rules for EU crew members. This Regulation provides an administrative framework for Community carriers to limit the flight time of crew members for safety purposes. Regulation 83/2014 added to and amended the rules on duty time limitations already contained in Annex III of Regulation 965/2012 laying down technical requirements and administrative procedures related to air operations. While Regulation 965/2012 is binding on all Member States, States remain free to maintain their national regulations, provided that they serve to improve the safety standards contained in the Regulation. Furthermore, national laws of Member States provide for administrative and criminal sanctions for infringements of the provisions on working and rest time, which may extend as far as suspension of the Air Operator Certificate.

4 Pilot Licensing and Fatigue Management for UAM

4.1 On-Board Pilots in UAM Operations

4.1.1 Licensing

According to an EASA study, at least until 2030, there may not be an unmanned means of transporting people through urban areas. Initial UAM operations – especially PATS – will focus on manned vehicles.

ICAO, as well as competent authorities at regional and national levels, are exploring how to regulate pilot licensing and training in light of challenges arising out of the urban operational environment and technical specifications of eVTOL. One question revolving around policy discussions is whether current aviation regulations on personnel licensing shall apply to on-board pilots involved in UAM operations.

Industrial stakeholders tend to hold prudential requirements for on-board pilots in UAM operations. The UAM industry is in its initial stage of development. Given that our society will not accept a trade-off in terms of business when it comes to aviation safety, even a small number of accidents, like those involving self-driving cars, can quickly damage the public's opinion of the industry. UAM should be held to the highest standards possible to promote acceptance. UAM operators may require commercial pilots to manipulate their vehicles and those pilots are subject to a higher level of licensing requirements than those for general aviation pilots.

For example, Uber addresses its prospective UAM business and highlights that it will have the US Federal Aviation Regulation (FAR) Part 135 standards of pilot licensing [17]. The Part 135 standards apply to commercial aviation pilots, which are more stringent than those laid down in Part 91 for pilots in helicopter or general aviation operations. The training program for commercial aviation pilots is a time-intensive proposition. According to Part 135, trainee pilots shall have 500 h of visual pilot-in-command experience and 1200 h of instrument experience before they can get licenses. The reason for choosing Part 135 as its baseline proxy is that pilot inexperience and poor maintenance result in a number of accidents in the context of general aviation. However, the stringent training requirements, combined with a shortage of qualified pilots in commercial aviation, may have negative impacts on the sustainable growth of UAM. To facilitate the development of this emerging industry, competent authorities should consider building up a set of new and specialised regulations for pilot licensing requirements, taking into account operational specifications of UAM. Especially, support of automatic and autonomous technologies can change the way pilots operate vehicles and thus skill requirements.

4.1.2 Fatigue Management

During the prospective UAM operations where on-board pilots manipulate vehicles, accumulating weariness, sleep deprivation, and the number of sectors flown may negatively affect aviation safety. Competent authorities shall further take into account different specifications of UAM operations when they consider the applicability of fatigue management rules from current air law.

The concept of UAM focuses on short-distance airborne operations about which literature has discussed the intra-city, peri-city, inter-city, and rural–urban-rural operations. Whatever the UAM operations are, populated urban environments must be included in the aerial segment. In this connection, on-board pilots would experience a different set of fatigue causes, in comparison with those causes impacting pilots who serve in traditional civil aviation. Existing technical standards for fatigue management may not be fully applicable to UAM pilots. For example, the flight duty period is a basic concept in calculating flight hours and rest periods a pilot ‘clocks up’. The flight duty time, as defined by Regulation (EEC) No 3922/91, begins when an operator requests that a pilot report for flights and ends after the last trip that the pilot participates in as a flight crew member. This definition, however, cannot accommodate the operational specifications of UAM where the pilots take on responsibility for several flights in succession and over short distances. The physical and emotional exhaustion of UAM pilots arising out of extenuating works – which may demand much time in standby mode – can discourage their physical activity practices and result in accumulative fatigue.

Another example is related to the fact that, in traditional air operations, especially international air services, pilots can in many cases experience the negative effects of crossing different time zones and changes in home bases. However, the UAM pilots can hardly be subject to these fatigue causes.

Furthermore, the deployment of eVTOL will optimise air operations with the support of automation systems, which can reduce human errors and keep labour costs to a minimum. The automated operations will contribute to the alleviation of pilot proficiency requirements and ultimately encourage the development of full autonomy in many UAM use cases, especially cargo delivery. In this regard, the concept of UAM seems to imply optimistic scenarios for regulating pilot fatigue.

Future UAM services provide new possibilities for cities, regions, and their residents by integrating with surface mobility networks sustainably. In this sense, the air mobility of UAM can be seen as the upward extension of contemporary urban mobility. As a complementary mobility ecosystem, UAM use cases will exist, operating similarly to and in concert with the current ground mobility system. UAM and ground traffic may in this regard result in similar challenges of fatigue management as both of them are operations in urban environments. Safety-related challenges may arise out of on-demand and stand-by duties, the distinction between peak and off-peak hours, as well as emotional stress about manipulating vehicles in a populated environment. Nevertheless, even for ground traffic, different types of drivers may face unique challenges regarding fatigue accumulation, including considerations about rest breaks, shift rotation schedules, technology utilisation, as well as crisis management plans. Regulations for UAM operations shall borrow lessons from these considerations inherent in different types of ground traffic modes to create specialised and flexible rules on fatigue management.

Future research shall examine the contributing factors to pilot fatigue in different types of UAM use cases. Discussions shall acknowledge the facts that, on the one hand, the technology development can decrease the workload of on-board pilots and, on the other, low-altitude air traffic above populated areas, as well as a rapid succession of take-offs and landings may give rise to new regulatory problems. Competent authorities may develop fatigue management regulations for on-board pilots in UAM operations based on data gathered for the autonomous control systems and pilot fatigue in traditional aviation operations. These regulations must be adaptable enough to address the regulatory difficulties brought on by various use cases., complex urban environments, and the emergence of new technologies.

4.2 Remote Pilots in UAM Operations

4.2.1 Licensing

While the initial UAM operations may assume a pilot aboard an aircraft, the concept of UAM does not preclude remotely piloted or automated operations. While the remotely piloted aircraft would be a crucial component in prospective UAM use cases, there are no explicit standards to determine how much manipulation of flight controls and what operational interventions are necessary to be defined as manipulation or piloting of aircraft, which is essentially related to the concept of remotely piloted aircraft.

In the ICAO Manual on RPAS, Chapter 8 addresses licensing and competencies. While this manual is non-binding, it provides guidance materials which represent the culmination of best practices and procedures used in prior RPAS approvals by ICAO, as well as input from government agencies, industry and other stakeholders. According to the guidance, the remote pilot is a new category of aviation professional. Unlike manned aviation, a single remote pilot licence which covers all types of scenarios is expected to be developed. It should be noted that both the ICAO Manual on RPAS and the ICAO Model UAS Regulations are recommended harmonised approaches to remote pilot licensing, without legally binding effects.

In the US, the FAA has created a rule *Operation of Small Unmanned Aircraft Systems Over People (NPRM)* [18]. For civil unmanned aircraft weighing less than 55 pounds, the FAA published remote pilot certification and operating guidelines. These regulations, however, do not allow small, unmanned aircraft to fly over people or at night without obtaining an authorisation. The NPRM suggested changing these regulations to allow normal operations in urban settings. Specifically, it provided requirements for remotely piloted aircraft, which include two key elements: remote ID which refers to the capability of an unmanned aircraft to identify remote pilot stations while it is in flight; and initial training, recurrent training, and knowledge test of remote pilots [18].

In cases of remote-piloted operations, there is a need to identify in detail what tasks are included for remote pilots, as well as what skills and qualifications are needed for each of the phases of operation. Under the ICAO Manual on RPAS and normative discussions among States, the tasks of the operator and the remote pilots overlap and need to be distinguished from a regulatory point of view. Furthermore, the current tasks and responsibilities of the pilots-in-command as defined in air law can be distributed amongst several other personnel involved in the operation of unmanned aircraft, such as a flight operations officer/flight dispatcher.

4.2.2 Fatigue Management

The UAS control stations provide the place where remote pilots manipulate prospective UAM aircraft. Remote pilots take on important roles in guaranteeing aviation safety. Fatigue can have an adverse effect on remote pilots in a manner that is at least comparable to that of on-board pilots. The significance of managing fatigue in remotely piloted operations has been emphasised by ICAO in the Manual on RPAS. When RPAS operators have crew scheduling schemes and operational shifts, they shall establish procedures and policies to address pilot fatigue by administering their pilots' operation shift schedules, flight, and duty time, as well as rest periods.

Remote and on-board pilots are subject to different operational specifications which may lead to different fatigue factors. Pilot fatigue in UAS missions has, however, received little attention. To close the research gaps and facilitate the creation of policies for UAM operations, industrial stakeholders and competent authorities shall collaborate to enable the formulation of UAM operations policy. Caution is required when competent authorities address fatigue in remotely piloted operations. Remote pilots may manipulate more than one vehicle at the same time and are thus subject to the increasing workload. Furthermore, there is extra stress of control system failure, and sensory isolation when remote pilots operate the UAS. Specifically, sensory isolation is the absence of spatial and vestibular cues, which means that pilots must pay attention to operational data from multiple sources and interpret them. All these factors explain a looming cloud of uncertainty in managing the fatigue of remote pilots.

The FAA conducted a study to establish duty and rest guidelines for UAS pilots using lessons learned in manned aviation, as well as remotely piloted operations in the military sector [19]. This study mentioned factors which negatively impact the physiological performance of remote pilots and thus their ability to manipulate the UAS and perform safety-related duties. Remotely piloted operations and manned operations share some fatigue concerns, such as cumulative pilot fatigue, time of day, shift work, fitness for duty, and length of duty.

To encourage sustainable development of UAM, future research shall analyse how to regulate fatigue of remote pilots through identifying and mitigating identified fatigue causes. Policy discussions shall further consider practical specifications of prospective operational cases. For instance, operators can mitigate native impacts of pilot fatigue by assigning operational duties for one aircraft to multiple pilots, or by giving the pilot the responsibility of overseeing an automated system rather than the role of a traditional pilot who controls the flight surfaces of the aircraft throughout the operations. In light of unique challenges about task saturation, cognitive and perceptual loads, as well as automation systems, fatigue management in the context of remotely piloted operations requires a different set of standards from those for on-board pilots. To proceed further with fatigue management approaches, safety regulation requires inputs from technical experts involved in unmanned aircraft operations.

In light of similarities between remote pilots and air traffic controllers in serving operational duties, research in Air Traffic Control (ATC) can provide guidance on shift work and fatigue countermeasures in UAM air carrier operations [19]. For example, much of the research finds that elements of fatigue are present during early mornings and daytime operations even with a 24/7 operational requirement and a three-shift scheduling system [19]. Several ICAO guidance documents for ATC services describe multiple approaches to managing fatigue. Recommendations for predicative, proactive, and retroactive methods in identifying fatigue hazards are provided. These may help establish fatigue management rules for remote pilots involved in UAM operations.

4.3 The Wider Context

Regarding the ever-increasing interest in UAM use cases and the particular role of pilots in a three-stage approach to the development of UAM, an examination of how pilot licensing and fatigue management shall be regulated by competent domestic authorities becomes highly significant. After an overview of current rules laid in air law and their applicability in prospective UAM operations, an interim conclusion is that both on-board and remote pilots need a new integrated regulatory framework to provide safety standards. While aviation authorities may apply existing rules to on-board pilots during the initial periods of operations, they must recognise the necessity to make legislative and administrative changes along with the economic and technological development of UAM.

This section focuses on a wider context of defining the role of UAM pilots. UAM will be an integrated mobility system which is closely related to ground transportation. While the aviation sector contributed to extensive consultations and discussions about UAM, ground traffic can also provide lessons which help the establishment of standards of pilot licensing and fatigue management. The reason is obvious: UAM pilots and ground drivers will be subject to similar challenges of operating in complex urban environments and populated areas. Furthermore, the concept of UAM is not to substitute the ground mobility system but to enhance the ground mobility system by adding a new vertical dimension. There will be multidimensional urban mobility which provides cities that are more reachable and liveable for the public. Lessons learned from managing ground traffic can help industrial stakeholders and competent authorities regulate UAM in an integrated and sustainable way.

The UAM pilots, especially remote pilots, are not necessarily associated with the status of airline pilots. There will likely be less stringent licensing requirements and fatigue management rules for UAM pilots.

Firstly, new regulatory approaches to pilot licensing shall contain requirements less stringent than those for pilots in commercial air transport, which can reduce training costs and encourage the development of the UAM markets. As regards airline pilots, there are three main training requirements: basic training, type training, and line training [20]. All these programs implicate considerable training costs. In the context of UAM, the sense-and-avoid systems and other autonomation systems reduce the workload of pilots. Competent authorities and industrial stakeholders can and probably choose to have less stringent training requirements and fatigue management rules as regards UAM pilots, especially remote pilots.

Secondly, in the context of prospective UAM use cases, each UAM vehicle will only have limited cargo and passenger capacity. With the development of UAM operations, the increasing demands mean that there will be a large group of pilots until the technology and societal acceptance allow autonomous operations or the mechanism where one remote pilot can simultaneously operate multiple aircraft. Less stringent but sensible safety standards can prevent or at least mitigate the risks of pilot shortage which has been a serious challenge in the international civil aviation market [21].

Thirdly, the extensive duty-on-call times and adjusting to different time zones would not pose challenges for UAM pilots. Automation technologies can greatly reduce the workload arising out of direct mechanical control and enable pilots to focus more on situational awareness.

The pilots in prospective UAM operations will witness changes in their status from professional operators of aircraft to a new role. The successful development of UAM in the initial periods can boost public confidence and societal acceptance, as well as the evolution of aircraft technologies. Thus, the experience and skill requirements for on-board and remote pilots shall be lower than those for airline pilots. Considering the close relationship between UAM and traditional ground mobility systems, the new role of pilots will be an integrated concept which considers current safety standards concerning pilots and ground drivers. This integrated role will be a key component in the prospective multidimensional urban mobility. Policy and academic discussions shall focus on creating specific and self-standing rules for UAM pilots based on this policy orientation.

Looking ahead, pilots in UAM operations are not only related to safety regulation and technical standards but undoubtedly contractual employment relations between pilots and operators. Within the progressive development and expansion of the UAM industry, there will be increasing labour demands until the point when technological development and social acceptance allow more remote-piloted operations. In this connection, on-board pilots become the stepping stone to the progress of future UAM operations. Labour standards are beyond the scope of this article. Nevertheless, it should be noted that precarious employment relations or working conditions may negatively affect aviation safety.

In prospective UAM use cases, the changing demands of on-board pilots may unintentionally encourage the adoption of atypical employment and/or other forms of cost-cutting labour practices by operators. Problematic labour standards not only prejudice the social protection and human rights of pilots but can also result in safety concerns.

Individual States may create different domestic regulations for UAM operations, possibly based on labour laws and policies. However, this means that operators need to adapt to different domestic rules, sustaining regulatory burdens. In contrast, a globally harmonised approach can provide guidance in creating licensing and fatigue management rules on a case-by-case basis, without compromising conventional flight rules and aviation safety. Hence, globally applicable rules are preferable to fragmented and different domestic rules.

5 Conclusion

Both EASA and the FAA have envisioned a three-stage approach to starting prospective UAM use cases. According to this approach, both on-board and remote pilots play a major role in ensuring the sustainable development of UAM. Pilot licensing and fatigue management are thus crucial issues in light of the safe and reliable completion of UAM operations. This article first examines current regulations in air law since the concept of UAM requires due consideration of aviation and aviation technologies. In Annexes to the Chicago Convention (1944), ICAO includes SARPs addressing pilot licensing and fatigue management. However, UAM focuses on domestic operations. While ICAO can provide technical support and engage with local government, domestic competent authorities will be responsible for issuing or rendering valid pilot licenses and clocking up flight hours of pilots. As regards on-board pilots in UAM operations, training and fatigue management standards are applicable in the initial periods of development. As regards remote pilots, unique operational specifications highlight that current air law cannot provide an optimal solution. In the long term, there shall be a new set of rules to regulate UAM pilots with a view of defining sensible roles of both on-board and remote pilots. These new rules will take into account the challenges of expensive training costs and pilot shortage in traditional civil aviation, on the one hand, and the integration with ground mobility systems and safety standards applicable there on the other.

Availability of Data and Materials Not applicable.

Declarations

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