Human Factors Training Implications for Urban Air Mobility Operations

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ABSTRACT

Advanced air mobility (AAM), of which urban air mobility (UAM) is a subset, signifies an exciting and advanced mode of air transportation that combines novel aircraft configurations with progressive levels of automation to offer convenient and efficient modes of air transportation (Mitchell et al., 2021). The design of these innovative aircraft will utilize advanced autonomous systems and are proposed to minimize pilot training requirements and scale operations (Mathur et al., 2019; Thippavong, 2018). Further, the operational context of UAM will be characterized by low-altitude flights, single pilot operations, unique weather phenomena such as mechanical turbulence, and novel propulsion systems. Early phases of UAM will involve manned flights (FAA, 2023) and as the industry plans for a new era of UAM pilots, there are several considerations for development of training procedures that have distinct differences from traditional aviation contexts. For example, the aircraft being proposed utilize higher levels of automation than current commercial aircraft. While it is being suggested that this will decrease the amount of training required, pilots will need to develop an understanding of the automation functions, which will impact training requirements. Further, the aircraft being proposed have novel technology such as battery-powered propulsion systems. This change from fuel management to battery power management will have implications for training. There will also be changes to various aspects of operations, such as extremely repetitive, short-haul flights, within single-pilot operations with changes to communication with air traffic control. In this paper we will examine key differences between proposed UAM and traditional aviation contexts that have implications for training related to four key areas: (1) automation, (2) the pilot interface, (3) operations, and (4) pilot characteristics. We will highlight key differences between these two aviation contexts, identify implications for how these changes may impact training, and provide considerations for future training research and development.

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INTRODUCTION

City congestion is a significant problem in many urban areas that has several negative impacts including increased travel times, increased pollution and economic consequences (Afrin & Yodo, 2020). Urban Air Mobility (UAM) is viewed as a potential answer to the rising congestion within densely populated cities. UAM, a subset of Advanced air mobility (AAM), signifies an exciting and advanced mode of air transportation that combines novel aircraft configurations with progressive levels of automation to offer convenient and efficient modes of air transportation (Mitchell, 2021). Instead of relying solely on traditional ground-based transportation, UAM aims to utilize short-haul, low-altitude flights, and highly automated aircraft to transport passengers and cargo within the urban and suburban environment. Moreover, future commercial operators will utilize advanced propulsion technology such as hybrid or electrical propulsion systems in these Electric Vertical Takeoff and Land (eVTOL) aircraft to provide positive impacts to the environment such as energy efficiency, reduced emissions, and noise reduction. The design of these innovative aircraft will utilize advanced autonomous systems and are proposed to minimize pilot training requirements and scale operations (Mathur, et al., 2019; Thipphavong, 2018). Early phases of UAM will involve manned flights (FAA, 2020), and as the industry plans for a new era of UAM pilots, there are several considerations for development of training procedures that have distinct differences from traditional aviation contexts. The FAA Concept of Operations released in 2023 (FAA, 2023) envisions the initial UAM operations flying within current regulatory and operational structures. However, as UAM operations mature and increase in tempo, this will require a revamp of the regulatory and operational systems in place, incorporating special UAM corridors into the airspace system. In the long term, UAM will make use of the increased presence of automation to transition from single pilot operations to remotely piloted or completely autonomous operations. This is a distinct difference from current commercial aviation operations, which require two pilots in the cockpit to ensure safety. In this paper we will examine key differences between proposed UAM and traditional aviation contexts that have implications for training related to four key areas: (1) automation, (2) the pilot interface, (3) operations, and (4) pilot characteristics. These implications are relevant for military operations as we see similar shifts towards more automated systems such as Future Vertical Lift (FVL) program for the next generation of rotorcraft (Gertler, 2020), and the heightened interest for integrating embodied and embedded artificial intelligence (AI) into working military teams (Kase et al., 2022). These advancements allow for a reduced number of operators to perform the same number of functions, as seen with the F-35, but require the users to rely on autonomous components more frequently, highlighting a need for increased automation transparency and training. The operational structure offered by UAM may also be leveraged by military aviators, given the potential increase in available helipads and vertiports. This would require the military operators to be familiar with the operational requirements for utilizing such bases, therefore making current training implications important for military personnel. Training implications associated with pilot characteristics are also relevant to the military as increasing the diversity of pilot recruits could counter the shrinking pool of military aviators (Russell, 2023). This paper aims to highlight these training implications and associated research needs and questions.

UAM TRAINING IMPLICATIONS

Automation

Automation Systems
Automation in aviation is defined as an advanced system that independently carries out a task without human intervention...
(Ahlstrom, 2016). The majority of modern commercial airliners are equipped with a combination of advanced automation systems such as the flight management system (FMS), autopilot, auto-throttle, auto land, and flight director, which augment pilot performance by lowering the pilots’ workload and enhancing the overall performance of the aircraft (Stroe et al., 2017). When engaged, automatic flight control systems like the autopilot can fly the aircraft, correct for wind, auto-land (Stroe et al., 2017), whilst the pilot monitors the autopilot’s performance. Further, the FMS assists pilots with tasks such as route and aircraft performance planning by providing performance data including speed and required fuel, based on pilot inputs such as the flight profile and environmental factors (e.g., barometric pressure). In such automation systems, the pilot is in direct control of the aircraft and interacts with the automated system by inputting required parameters and monitoring the outputs of the system. The pilot can disable these systems and take full manual control of the aircraft when needed (Stroe et al., 2017). Moreover, in military aviation, fighter jets that are advanced in automation such as the F-35 have digital fly-by-wire (FBW) systems that blend all the axis during flight maneuvers simplifying the flying task, a concept similar to simplified vehicle operations (SVO) proposed for future UAM eVTOLs (Goyal et al., 2021; Osman et al., 2022).

The FAA defines the aircraft automation level, referred to as level of automation (LOA), as “the level of “PIC” engagement with the UAM aircraft enabling systems” (FAA, 2023 p. 6). eVTOL aircraft are proposed to progress through three LOAs as the technology and the industry mature. First, during the initial phases of UAM, the LOA will be Human-within-the-Loop (HWTL) during which the pilot will directly control the automation, and automation schemes similar to the current crewed, fixed-wing and rotary-wing aircraft will be adopted (FAA, 2023). Second, the Human-on-the-Loop (HOTL) LOA will be implemented in the midterm stage of UAM operations, characterized by a significant shift in pilot roles from direct control to supervisory control of the aircraft. Pilots will need to actively monitor the systems, and automation capabilities will be designed to allow pilot intervention when desired (FAA, 2023). The third and highest LOA is Human-over-the-Loop (HOVTL) which will be manifested at the mature stage of UAM and will require little to no pilot interaction resulting in unmanned and remote-controlled operations (FAA, 2023). Remote controller roles will include passive monitoring and engagement with the eVTOLs if requested by the automation.

UAM pilot training must evolve in tandem with vehicle technology. The HWTL stage is likely to mirror current technology capabilities in aviation and will have pilots heavily involved in the flying tasks. The HOTL stage will shift pilots’ roles to heavy monitoring of highly autonomous systems. Research has shown that there are human performance challenges associated with heavy monitoring (Kyriakidis et al., 2019), such as vigilance decrement, inattention blindness, mind wandering (Casner & Hutchins, 2019), and poor situation awareness (Papadimitriou et al., 2020). As such, it may be relevant to refocus training to effective strategic monitoring, seeking proficiency in this skill set. Training in effective monitoring should focus on strategies such as mental model training to enable pilots to develop sense-making skills, effectively switch attention, improve noticing and projection of situations, and remain engaged and focused. Research has shown such strategies help pilots to create mental models of the current state of the system, in order to better anticipate changes, and appropriately respond when required (Mumaw et al., 2000). Research evaluating the effectiveness of such monitoring training will be needed to identify strengths and weaknesses and develop guidance on refinement.

Another training implication associated with automation in UAM is the proposed reduction in training resulting from advanced automation (Emmerson et al., 2023a; GAMA, 2019; Holmes et al., 2017). This has been theorized (Emmerson et al., 2023a; GAMA, 2019) and has also been supported by scholars who argue that the automation schema for eVTOLs will not require pilots to achieve the equivalent number of hours in training as traditional commercial pilots because the focus will not be on flying but on managing the automation (Denham, 2016; Emmerson et al., 2023b; Thorsen, 2016). For example, a simulation-based study by Emerson et al. (2023) reported that an increase in automation lowered the variations in learning trajectories between ab initio and experienced pilots. Further, irrespective of previous flight experience, there were no significant differences in attaining proficiency between experienced and novice pilots in semi-automated and highly automated flight, although novices would require more training to attain proficiency. However, other researchers propose that the increased complexities of automation create novel and higher cognitive demands associated with more analytical decision-making (Kaber & Endsley, 1997; Stroe et al., 2017). As such, automation management training focusing on operational knowledge of automation may help offset these new challenges. Additionally, training on variations in control between the automation and the pilot and leveraging human-agent trust research might be beneficial to help pilots collaborate with the automation as a partner “crew member” rather than view it as a separate entity or tool. For example, by utilizing methods such as adaptive trust calibration (Chancey et al., 2021), training on shared control (Kyriakidis et al., 2019), and enhancing knowledge of the effective use of automation (Parasuraman & Riley, 1997) can aid in synergizing the pilot-automation relationship and developing effective automation mental models (Plant & Stanton, 2012). Research is still needed to determine how much training is needed, what the training should entail, what new automation management skills are required, and how to leverage human agent team research to enhance pilot-automation teaming. Such methods will need to be
evaluated in UAM-specific scenarios to determine their effectiveness in equipping UAM pilots with the desired skills for optimum performance.

Another training implication focuses on the deskilling of pilots as a result of automation reliance and removal of the requirement for pilots to manually fly, while still requiring pilots to perform aeronautical decision-making and/or conflict separation. Research suggests that deskilling may occur as the pilot will not be actively involved in flying, resulting in pilots being less prepared when the automation encounters situations for which it is not designed or programmed, and the pilot needs to intervene (Casner et al., 2014; Haslbeck & Hoermann, 2016). This is especially relevant to the HOTL level of automation because the eVTOLs will be so advanced that they will rarely require pilot intervention except during rare off-nominal situations when pilot skills will be called upon after extended periods of inactivity. It may be necessary to require mandatory recurrent simulator training (Parker & Grote, 2019) during which pilots could perform in lower LOAs or practice scenarios that require them to apply and polish degrading skills. Another recommendation by the FAA is the “back to basics” training during in which pilots can be trained to fly without automated systems and focus on basic aerodynamics foundational knowledge (Chialastri, 2012) and finding a balance between automation training and manual flight training (ICAO, 2019). Further research questions should focus on determining what current pilots’ skills might become task-irrelevant in normal UAM operations but essential to have for off-nominal conditions and align training accordingly.

**Automation Flight Rules**

The second aspect of UAM automation will be manifested in the induction of novel flight rules, namely automated flight rules (AFR; FAA, 2023). Traditionally, pilots operated in two basic flight regulation categories such as visual flight rules (VFR) and instrument flight rules (IFR) during which varying flight restrictions are enforced by the FAA. In VFR, pilots can only operate a flight in clear meteorological conditions (e.g., clear to partly cloudy skies with unrestricted visibility) to enable them to see where the aircraft is going. In IFR pilots can utilize an instrument-equipped aircraft to fly in low visibility conditions because they will depend on the instrument readings to safely navigate the airspace. A new set of flight rules, AFR, has been introduced in UAM. AFR are “rules applied within UAM corridors, which reflect the evolution of the current regulatory regime (e.g., VFR/IFR) and take into account advancing technologies and procedures (e.g., Vehicle-to-Vehicle [V2V] and data exchanges)” (FAA, 2023 p. 4). AFR will factor advanced vehicle automation and its capabilities into flight rules as additional and new regulations with associated restrictions for AFR pilots beyond those in IFR or VFR. For instance, the allocation of the role of traffic separation to automation in specific conditions (FAA, 2023) and rules pertinent to the exchange of airspace information between eVTOLs.

There are multiple training implications that will accompany the introduction of AFR. First, there will need to be knowledge of, and procedural training on, what entails AFR and how AFR builds on the current flight rules. As such, the FAA will need to introduce and clarify requirements for AFR flight training such that future eVTOL pilots can be appropriately trained within AFR and equipped on the limitations of flight in AFR conditions. Additionally, as AFR will evolve with advances in vehicle automation, revision in training may be necessary to keep pilots up to date with the corresponding changes in AFR. Regulatory guidance and research is needed to determine pilot proficiency in AFR and serve as a basis for required training.

**The Pilot Interface**

**Simplified Displays**

Traditionally, in commercial aviation, the pilot interface is comprised of several displays typically consisting of primary flight display (PFD), navigation display (ND), engine indicating and crew alerting system, multi-function display, and (FMS) display. Pilots interact with the various displays either using a touchscreen, buttons, knobs, or keypad to input information to the aircraft’s systems. Traditionally, there are two sets of displays. One set of displays is utilized by the pilot flying and the second set of displays is used by pilot monitoring. The advent of novel technologies has brought several notable changes to the characteristics of a pilot interface. For example, pilot interfaces have, in many cases, transitioned from analog displays to digital displays, offering improved clarity, resolution, and flexibility in presenting information. Pilot interfaces are now also shifting towards using graphical user interface (GUI) including touchscreens, cursor control devices, and menu-driven interfaces to facilitate pilot efficiency (FAA, 2021; Young et al., 2006; Wright & O’Hare, 2015).

Based on currently available information, the pilot interface for eVTOL aircraft is expected to differ from traditional pilot interfaces in several ways. A market survey by Chauhan et al. (2023) of the various eVTOL aircraft under development indicated that eVTOL pilot interfaces would typically include 1-3 large, touchscreen displays, tailored for single pilot operations, and customizable to accommodate a range of information both traditionally available and novel (e.g., electrical propulsion/battery information). Further, eVTOL pilot interface trends included reduced information redundancy, and the use
of synthetic vision system (SVS) and other advanced sensors to facilitate flights in a populated metropolitan area. One particular goal in UAM is to simplify pilot interfaces and consolidate information onto a smaller number of displays. Simplified displays will feature streamlined control panels designed to include only essential controls, reducing the number of switches, knobs, and buttons, and will integrate pilot interfaces that adapt to the current phase of flight or situation (Reed, 2022).

There are several training implications associated with the emerging eVTOL pilot interfaces. For example, eVTOL aircraft handling and operational characteristics are different from traditional fixed-wing aircraft and rotorcraft. Pilots will need specific training to effectively navigate and interact with the simplified displays. This training should focus on familiarizing pilots with the layout, functionality, and information presentation of the simplified interface (Sarter & Woods, 2017). Secondly, pilots will require training on how to interpret different types of information presented through the simplified displays. This includes understanding and discerning critical operational data, alerts, automation outputs, and other relevant information for efficient decision-making (Mosier et al., 2017). Future research should focus on the display’s usability, efficacy, and impact on pilot training. There are several research questions that need to be further investigated, for example, what are the cognitive and perceptual benefits and limitations of using simplified displays, and how can pilots be trained to optimize their visual scan patterns to enhance training outcomes? What are the potential safety benefits and risks associated with simplified displays, and how can training be designed to mitigate any potential risks?

**Battery Information**

In a traditional fixed-wing aircraft and rotorcraft, propulsion systems are typically combustion-engine based and pilots manage fuel consumption and flight planning through a combination of calculations, regulations, and operational procedures. Traditionally, pilots start by calculating the fuel required for a specific flight, considering the distance to be flown, the aircraft's fuel consumption rate, wind conditions, anticipated delays, and alternate airport requirements. These calculations, which take into account any contingency fuel, such as reserves for unexpected delays or diversions, are used to determine the amount fuel required and are based on aircraft performance charts, flight manuals, and established fuel planning guidelines (FAA, 2016). During the flight, pilots usually monitor the fuel consumption using the fuel flow indicator embedded in engine indicator and crew alerting system (EICAS) or the electronic centralized aircraft monitor (ECAM) to determine consumption rate, level of reserves, to determine if sufficient reserves are available to reach the destination or an alternate airport. The pilots can make adjustments to the fuel consumption by employing various fuel management strategies to optimize fuel consumption, such as flying at optimum altitudes and speeds, utilizing fuel-saving techniques by using the information displayed on the navigation and flight management displays about most direct routes, or request take-off and landing trajectories that save fuel. The pilots are trained to adhere to regulatory requirements and guidelines related to fuel planning, minimum fuel reserves, and contingency planning (Hassan et al., 2021). During flight, pilots utilize the aircraft synoptics displays that help them to ensure they operate within the required safety margins.

eVTOL aircraft will use electric propulsion systems, and the concept of fuel management will be replaced by energy management. Pilots will need to consider the available battery power availability and discharge rate, among other parameters, to estimate the range, which is quite different from the fuel management process as it is less consistent over time. The pilot interface must provide adequate information to support the pilot effectively monitoring battery power availability. There is currently limited research regarding what information is necessary to facilitate this, and various battery information displays are being conceptualized. This includes presenting information such as power usage during vertical takeoff, climb, cruise, and descent (Yang et al., 2021). The way electric battery information is presented to the pilot will play a key role in the pilot’s ability to discern the state of battery charge, temperature, and other parameters that can affect battery performance and longevity, especially when performing the required energy planning for their mission (Melo et al., 2020). One major difference in fuel planning that pilots will need to consider for their mission is the locations of charging stations. Further, for different phases of an eVTOL flight and flight characteristics (e.g., hover), the pilots will need to be trained to understand the implications of using an electrical battery to power their flight (Sripad et al., 2021).

There are several training implications associated with the battery information displays for eVTOL aircraft. First and foremost, the pilots will need to be trained to understand how an electric battery performs in flight. For example, the battery discharge rate is not constant and is dependent on various factors, for example, temperature and wind conditions (Yang et al., 2021). This will require a revision of how pilots are currently trained in calculating the fuel required for one flight cycle. The emergence of eVTOL aircraft presents training implications for pilots, specifically regarding the management of electric propulsion systems and understanding the significance of electric battery information displayed on the pilot interface for mission requirements (Tarhan et al., 2021). Additionally, the presentation of battery information on the pilot interface will undergo changes as the use of electrical batteries necessitates a shift in how propulsion data is conveyed to pilots.
Consequently, pilots will require training to effectively interpret and evaluate the provided information throughout different flight phases (Wilde et al., 2022; Luo et al., 2021). There are several research questions for future study. For example, what are the best practices for incorporating training on displays with electrical battery information into existing pilot training programs, and how can training effectiveness be maximized? What are the optimal ways to present battery-related information on displays to enhance pilot situational awareness and monitoring of electrical systems? How does pilot training on displays with electrical battery information affect overall flight safety, including the ability to manage and respond to battery-related emergencies and failures?

**Unified Controls**

Traditionally, when inflight, the pilot generally uses the control column (in some smaller aircraft), control yoke (in most general aviation and commercial aircraft), or sidestick (in some modern fly-by-wire aircraft) to manipulate the aircraft's attitude, control its pitch and roll (Federal Aviation Administration, 2021). By moving the control input forward or backward, left or right, and applying appropriate forces, pilots can adjust the aircraft's attitude and make it climb, descend, bank, or level off. The control column, control yoke, or sidestick includes an elevator control (for changing the aircraft's angle of attack), aileron control (which the pilot use to change the aircraft’s bank angle), and trim controls, typically located on the control column, control yoke, or as separate buttons switches, which the pilot uses to adjust the aircraft's longitudinal (pitch), lateral (roll), and directional (yaw) trim. Using the aircraft’s rudder pedals, located on the cockpit floor, allows pilots to control the aircraft's yaw turn-rate. Finally, the pilot can control the airspeed of the aircraft using throttle(s) or thrust levers to control the engine power and aircraft speed.

With the advent of eVTOL aircraft, there are going to be changes to how the pilot will control the aircraft. One such concept currently being proposed is the unified control concept, a simplified control system that integrates control of both the vehicle's position and attitude using a unified framework, which allows for simpler and more efficient control (Lombaerts, Kaneshige, & Feary, 2020). This approach uses a combination of traditional control methods and new technologies, such as machine learning, to create a single control system that can handle a variety of flight scenarios. (Lombaerts, Kaneshige & Feary, 2020; Milz & Looye, 2022). The eVTOL inceptor, also known as a sidestick, differs from a traditional control stick in several ways. One of the primary differences is that instead of separate control columns or sticks for pitch, roll, and yaw, the inceptor will serve as a unified control device, combining these inputs into one device (Emerson et al., 2023). The eVTOL inceptors also incorporate additional functions beyond basic control inputs. They may feature buttons, switches, or touch-sensitive surfaces on the sidesticks, allowing pilots to engage autopilot systems, manipulate flight modes, adjust system settings, or interact with avionics systems. While traditionally pilots need to select different flight modes from the conventional pilot interface, the inceptor may feature buttons or switches that allow the pilot to select different flight modes or configurations, such as vertical takeoff and landing, hover, forward flight, or transition between different flight phases (Thurber, 2021).

One of the foremost training implications for eVTOL pilot interfaces is the integration of rotorcraft and fixed-wing training procedures so that the pilots are trained to understand the control inputs and techniques required for smooth takeoffs, landings, and hover operations (Hartmann et al., 2017). Pilots transitioning from traditional control systems, such as control yokes or cyclic controls, will require training to become familiar with the operation and handling characteristics of an inceptor. This includes understanding the different movements and inputs required for pitch, roll, and yaw control and providing enough practical experience to over-ride the long-established mental model and performance patterns developed in traditional aviation contexts (Dollinger et al., 2021). Training programs will need to address the nuances of flying eVTOLs using inceptors, including the necessary techniques for managing power, thrust, and aircraft attitude during different flight phases. Secondly, it may require changes to current pilot training programs to incorporate new procedures and protocols that support unified control concepts. Finally, a major training implication is that currently there are few simulators that can accurately reflect an eVTOL aircraft’s control concept. While eVTOL manufacturers are using simulators for their individual designs, they are not accessible to outside researchers, limiting the available research related to pilot training requirements. There are several research questions related to the novel nature of the unified control concept that need further investigation. For example, what is the influence of using unified controls with respect to the pilot maintaining field heading, airspeed, and altitude? How can training prepare pilots to utilize unified control interfaces for effective and efficient operation of the vehicle by both novice and experienced pilots? What are the cognitive and perceptual demands of the control system for pilots, and how can training be optimized to reduce the workload and enhance the situational awareness of the pilot?

**Operations**

**Single Pilot Operations**

* [2023] Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC)
Traditionally in commercial aviation, two qualified pilots are in the cockpit at any given time to ensure safe and efficient operations for large passenger transport aircraft. From a human factor’s perspective, there are many benefits to having a two-person crew while operating an aircraft. During two-pilot operations, there is a shared workload, which is especially advantageous during high workload phases of flight including taxi, takeoff, and landing (ALPA, 2019). The shared workload between two pilots also enhances situational awareness within the cockpit, improving decision-making capabilities and allowing for mutual performance monitoring and backup behaviors (Krivosnos, 2007). A two-pilot cockpit permits each pilot to concentrate on task-specific operations, mitigating the probability of errors occurring due to task overload (ALPA, 2019).

Future UAM fights will be single pilot operations (SPO). Shifting from two-pilot to single-pilot operations removes some of the barriers of error mitigation, creating higher cognitive demands for the individual pilot (Liu et al., 2016). Pilots may experience an increase in workload, a reduction in real-time flight coordination and communication with their counterparts, and a decline in team-assisted decision making (ALPA, 2019). Although humans are capable of functioning under highly demanding cognitive conditions, they have a limited capacity for cognitive work (Liu et al., 2016). An increase in the cognitive workload required of the single pilot can be mitigated with additional autonomous components and support within flight deck, and their communication network (Liu et al., 2016). Enhancing flight planning strategies, improving rerouting and emergency support operations, and increasing the decision-making capabilities for complex tasks are further strategies to alleviate the pilots elevated workload (Lim et al., 2017).

There are several training implications associated with this shift. For example, for SPO to demonstrate an equivalent level of safety and efficiency, training procedures that align with UAM ConOps must be considered. This adoption would require the implementation of novel training methods, as the current procedures rely on the pilot-in-training garnering skills from flying with a more experienced pilot or captain. This method would be unavailable for UAM operations. Transitioning to SPO, has the potential to expedite trainees to captains immediately resulting in an urgent need for use-training on advanced automation tools and developing counter measures for skill degradation (Liu, et al., 2016; Lim, et al., 2017). From a human factor’s standpoint, the identification, redesign, and certification of minimum training requirements and regulations for distinct SPO-operators must be considered before operational implementation (Lim, et al., 2017). There are several research questions to be answered that could aid in this process. For example, can additional simulator training accelerate new pilot expertise levels to the point at which they are prepared for SPO? If so, how much training is necessary and what does this training need to incorporate? Research could leverage these questions to provide further insight on the effects of SPO in a UAM domain.

Flight Route Characteristics, Operational Tempo, and Support
In a traditional aviation context, the schedule of commercial operations has been reasonably paced. The typical flight route includes significant downtime during cruise at altitude, routes which are usually free from difficult terrain, and are well supported by weather detection components and products that help pilots avoid dangerous weather scenarios, such as thunderstorms and extreme wind conditions. These flights rely heavily on ATC assistance for communication, navigational allocation, and separation assurance (Bazargan, 2016). ATC also continuously provides pilots with real-time terrain, weather, and hazard information. Pilots may also garner support from their airlines operational center, which imparts services such as flight planning and meteorological updates. In addition, pilots are supported by the presence of a cabin crew, which aids in shouldering tasks such as surveilling the passengers to ensure passenger safety. Further, the majority of the flight route for traditional commercial operations is spent in the cruise phase, which is generally a lower workload and lower stress phase.

UAM flight routes are proposed to be short-haul, on-demand flights with frequent and recurrent stops within urban environments. As a result, navigating in complex airspace environments and adapting to abruptly changing flight conditions will prove to be an essential requirement of UAM pilots. These taxing aspects of UAM operations may increase pilot workload and stress levels compared to traditional commercial pilots who fly longer, more predictable routes. The performance context of these flights is novel and the frequent take-offs and landings within these flight routes can contribute to pilot fatigue which may add strain to pilots’ cognitive processes. UAM flight operations also face novel weather phenomena due to the challenges of complex airflow patterns surrounding the large urban structures, resulting in mechanical turbulence (Labadd, et al., 2022). Current technology does not specifically support pilots in detecting and reacting to such phenomena, therefore potentially increasing the exertion required of the pilots when flying UAM routes.

There are several training implications associated with these shifts. The new workload demands associated with UAM flights, such as the need to navigate through busy urban areas and manage frequent take-offs and landings, may require additional training for pilots to ensure they are prepared for these demands. Additionally, UAM pilots may need to be trained on new weather products to detect mechanical turbulence, which can be a significant risk factor for UAM operations. Due to the potential stress associated with the novel flight routes, there may be a need to incorporate stress training into UAM pilot
training programs. eVTOL aircraft also have unique flight characteristics and require specialized knowledge and skills (Voipio, 2022). Training programs for UAM pilots should focus on specific skills needed for UAM operations, such as operating in low altitude and congested environments or working with advanced technologies, while also emphasizing safety protocols and emergency procedures. According to prior literature, important areas that will have to change is the curriculum of flight training. Currently, commercial pilots study topics such as high-altitude aerodynamics and the granular details of jet engines. Neither of these topics is of relevancy for UAM operations. Therefore, UAM pilot training programs must be designed to address the specific demands and risks associated with UAM flight routes, while also ensuring that pilots are adequately prepared to manage the unique challenges of this new mode of transportation (Pelli & Rieddel, 2020; Grayden et al., 2020). Several research questions associated with these changes could further inform training design for the UAM domain, including: What are the differences in workload and stress response between these differing flight routes and how can pilots effectively prepare for this? What are the unique psychological demands of UAM operations, such as the perceived risk associated with frequent descents and flying near urban terrain and how can pilots be trained to mitigate these risks? Is it more effective or efficient to train novice pilots compared to experienced ones, due to the previously engrained mental models? Addressing such research questions will aid in understanding the training implications associated with the differing operational characteristics of UAM.

Pilot Characteristics

In the current commercial aviation structure pilots are required to undergo rigorous training and acquire a significant amount of experience before being able to assume the role of captain. The FAA (2022) also requires commercial airline pilots to have some educational background such as a high school diploma or equivalent, and some airlines in the U.S. also require pilots to have bachelor’s degree in the field of aviation. In addition to educational qualifications, a commercial pilot must accumulate a minimum of 250 hours of flight time, while an airline transport pilot’s license requires a minimum of 1,500 hours (FAA, 2021). In addition to logging flight hours, commercial pilots must also gain experience in different types of aircraft, weather conditions, flight environments, and experience dealing with emergencies or unusual situations (FAA, 2021). “The FAA is proposing alternate requirements for meeting pilot in command (PIC) flight time and cross-country flight time requirements in part 61 and expanding the opportunity for pilots to obtain powered-lift ratings at the commercial pilot certificate level through part 135 training programs” (FAA, 2023 p. 10). The goal of requiring experience is to ensure that pilots are fully prepared to handle the complexities and challenges of flying commercial aircraft operations, and to prioritize the safety of passengers and crew (NTSB, 2009). Moreover, in current commercial aviation, it is standard for pilots to gain experience by working their way up through the ranks. According to a report by the National Transportation Safety Board (NTSB), “many pilots in today’s air transportation system begin their flying careers by serving as flight instructors, then advance to flying small commuter aircraft or regional jets, and then advance to flying larger transport-category aircraft” (NTSB, 2018, p. 19). Other relevant characteristics of the pilot are age and biological sex. According to FAA (2022), approximately 60% of the commercial pilots are in the age range of 25 and 60 years and only 7% of the population are females. Furthermore, there has been research indicating that commercial pilots typically have personality traits high in Conscientiousness and low in Neuroticism (Chaparro et al., 2020; Sharma & Carroll, 2023).

UAM operations may not require the same level of pilot experience and certification as traditional commercial aviation. As UAM aircraft are being designed to operate with a single pilot and eventually autonomously, it has been proposed that this could significantly reduce the pilot training requirements (Thipphavong, 2018; Voipio, 2022). Certification requirements for UAM pilots may also vary depending on the operator or manufacturer, allowing for greater flexibility and innovation in the development of UAM technologies by designing the aircrafts that are capable of simplified vehicle operations (NASA, 2018). For instance, an operator may build autonomous systems that will assist UAM pilots in navigation, communication, and other operational tasks. Further, there is already a pilot shortage and even if the UAM industry demand does not rival that of commercial aviation, it will be a challenge to meet (Maxwell & Roa, 2021). The aviation industry is continuously seeking ways to increase the pilot workforce and reduce the ongoing pilot shortage, including by providing higher pay, more work-life balance, and quick career progressions from the role of first officer to captain (Lutte, 2018). However, to meet these demands there is a need to recruit and train pilots that are outside of the typical pilot demographics. The UAM industry is looking at ways to increase the diversity of the pilot workforce by engaging more women and underrepresented groups (Hunt et al., 2018). For example, some OEMs are partnering with high schools and colleges to develop training programs and career pathways for aspiring pilots (Pilot Career News, 2019).

There are several training implications associated with the potential change to pilot characteristics. As UAM industry aims to have a more diverse workforce, including women and pilots with less experience, new recruitment and training methods may need to be incorporated. Research has shown that women are drawn to careers that have a positive influence on the society.
(Osman et al., 2023). Reframing the way recruiters talk about UAM, highlighting the societal impacts, such as providing economically affordable public transportation, may spark more interest in the workforce from women. Further, to attract more women pilots, UAM operators could offer more attractive career paths like quick promotions, advancing or transitioning to commercial aviation after fewer years as a pilot (Pelli & Riedel, 2020). Osman et al. (2023) identified 17 different instructional and engagement strategies, such as collaborative gamification and early exposure, that have been shown to increase the participation and involvement of women and minorities in STEM fields such as cybersecurity. Many of these strategies are likely to generalize to aviation. Further, as existing research has primarily concentrated on white male pilots in aviation, it is vital to broaden future studies to include a more diverse range of participants, taking into account more varied backgrounds and perspectives. To ensure the safe and efficient operation of UAM, several research questions need to be addressed. Researchers should investigate the key challenges and considerations in training UAM pilots from diverse backgrounds and with varying levels of experience and expertise. Investigating the impact flying-experience has on training effectiveness in a UAM context would provide further insight into how to best tailor and modify new training methods. Researchers should also consider the individuals background, such as how cultural phenomena or differing educational backgrounds, for example, impact the development of crucial skills such as situational awareness, decision-making, and communication for safe operations in complex urban environments. Other possible research questions include: how will training be molded to trainees with different levels of experience across aviation domains? What are the most effective training methods for developing the necessary skills and equal experience required for safe UAM operations? What can be leveraged from cross-cultural training procedures to advance procedural training in aviation sectors?

CONCLUSIONS AND FUTURE RESEARCH

From the evidence presented above, traditional methods utilized in current commercial aviation training will not be sufficient to maintain optimized performance for UAM operations. The increase in automation, advanced pilot interfaces, novel operational characteristics, and varying trainee characteristics present a gap between current training methods and future UAM training needs. Further, as advancements continue in this industry, employment of eVTOL aircraft and associated technology will move beyond use in the civilian sector. The capabilities brought forth by the UAM industry have already begun to generate interest from military sectors (Doo, 2022). The dynamic capabilities of eVTOL aircraft point to promising applications within military transport and logistics, supplementing operational readiness due to the heightened autonomous capacities, light weight aircraft, and urban operational networks (Doo, 2022). eVTOL aircraft also offer enhanced mobility components due to the timely, on-demand, and cost-effective aspects of the aircraft. The advancements within the UAM industry provide the military with new tools to enhance operational readiness and the ability to address challenges brought on by modern warfare (Doo, 2022; Wang, 2023).

Accelerated research in the UAM domain is crucial for understanding the human factors implications associated with this emerging industry. Understanding how to optimize the interaction between humans and novel UAM technology is critical, and effective training is a key part of this. Training implications related to the automation, pilot interface, operations, and pilot characteristics of UAM stand out as starting points to consider as research and development aims to facilitate effective training and operations relevant to commercial and military sectors alike. Future research should aim to address the research questions provided to further training effectiveness for UAM operations.
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