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HUMAN FACTORS CONSIDERATIONS FOR URBAN AIR MOBILITY

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Before urban air mobility (UAM) flights are safely integrated into the current airspace system, it is necessary to identify and address human factors issues associated with UAM. Various industry and academic institutions are currently exploring a range of different aspects of UAM, such as vehicle concepts, airspace integration, and ground infrastructure, all of which have human factors implications. These human factors issues, which will heavily influence how UAM operations will evolve with growth in demand and autonomous technology, are in need of research. Potential human factors issues include UAM pilot's trust in automation, situational awareness, visual scanning, decision-making capabilities, as well as workload and stress of pilots, air traffic controllers, and ground personnel, to name a few. This paper aims to examine UAM's current research and identify potential human factors issues in need of future research.

Introduction

The idea of using manned flying vehicles for inter-city transport first emerged in the 1940s with the advent of helicopters, which provided vertical take-off and landing capability without requiring extensive and costly infrastructure, such as the case with fixed-wing aircraft (Straubinger et al., 2020). New technological advances in the aviation industry, such as electric propulsion systems, efficient battery technology, and UAM concept aircraft, have laid the foundation for the development of UAM (Straubinger et al., 2020). Many academic institutions and industry stakeholders are currently working on understanding how components of UAM, like vehicle design, airspace corridors, operational models, and infrastructure, need to be developed. It is crucial to identify and examine potential human factors issues associated with these UAM components. With UAM, there will be an entirely new class of aircraft, new cockpit designs, new operational procedures, and new infrastructure. It is likely to affect the pilot's situational awareness, decision-making capabilities, trust in automation, stress, and workload. UAM also has the potential to significantly impact the general public's trust in automation, air traffic controllers (ATC) interactions with the pilots, and the comfort of the passengers riding in the vehicles. This paper aims to examine UAM's current research and identify potential human factors issues and areas in need of future research.

UAM Concept of Operations

The National Aeronautics and Space Administration (NASA) has proposed a three-phase UAM maturity level (UML) scale to measure UAM growth over the coming years, based on air traffic density, operational complexity, and automation (Patterson et al., n.d). The initial stage of

UAM integration into the National Airspace System (NAS) will involve developing UAM aircraft, determining the UAM aircraft certification process, and establishing UAM corridors in controlled airspace to identify the level of changes necessary for safe integration (Pinto Neto et al., 2019). During early UAM integration, it is critical to understand the effect of increased traffic in the NAS on air traffic controllers' workload and their ability to manage two potentially different types of separation techniques. Workload is related to the difficulty of the task at hand, aircraft count, cluttering, and use of restricted airspace (Stein, 1985). It is necessary to empirically study controller capabilities in this performance context to set safe and effective performance standards.

The Intermediate state represents low density, medium complexity operations. In this state, operations are tested with more scalable and weather-tolerant designs and consideration for local regulations (Pinto Neto et al., 2019). There will be an increase in the use of automation for low and medium-density UAM operations, which will require development of collaborative and robust automated systems. Research has shown that low-level automation may increase pilot workload, but high-level automation may result in a loss of pilot awareness of the state of aircraft or airspace, which can lead to errors and reduced performance (Gill et al., 2012). Further, research has shown that as level of automation increases and pilots move towards a supervisory position, the trust in automation will vary based on the number of aircraft under supervision, decision-making capabilities, and ability to identify automation failures (Ruff et al., 2002; Dikmen & Burns, 2017). Not only will levels of automation increase as UAM operations mature, but pilot-in-command distance will increase as pilots transition from onboard piloting to remote piloting and monitoring of multiple aircraft. Research is needed to understand the impact on pilot trust in and use of automation, and ultimately on performance and safety.

The mature state is associated with high density and highly complex operations with fully autonomous systems, including a large-scale, widely distributed UAM flight network (Pinto Neto et al., 2019. In this state it is assumed that the majority of UAM flights will be remotely operated, where the pilot will be given the task of supervising multiple flights. Due to the remote and supervisory nature of their responsibilities, research has shown that it can result in potential loss of situational awareness of aircraft state because of absence of visual, auditory, proprioceptive, and olfactory sensations during remote operations making it more difficult for the pilot to maintain an awareness of the aircraft's state (Hobbs & Lyall, 2016). This is complicated by the added roles of monitoring multiple aircraft simultaneously. Empirical research is needed to understand how many aircraft an operator can effectively supervise at once and under what conditions performance and safety can be optimized.

UAM Vehicle Concepts

Aircraft with VTOL capability are the primary vehicles under consideration, including three basic conceptual models: Quadrotor, Side-by-Side Helicopter, and Lift + Cruise VTOL aircraft. These designs will be prone to localized turbulence and poor visibility due to large infrastructure near the landing and take-off facilities (Price et al., 2020). Research has shown that the combined effect of degraded visual environment and turbulence can lead to workload exceeding the pilot's capability and lead to a significant decrease in pilot's ability to maintain situational awareness and control of their aircraft (Hoh, 1990; Ji et al., 2021). Therefore, there is a need to empirically study UAM pilot performance under these circumstances.

UAM pilots will be required to maintain separation and aircraft stability while operating at low altitudes, the time in flight in which there is typically the highest workload and the greatest levels of risk. With increased task demand, anxiety can influence the pilot's ability to perform adequately, as stress and anxiety will use up the necessary cognitive resources, causing the performance to deteriorate (Dismukes et al., 2015). A potential research gap is investigating the impact pilot workload, and stress levels will have on the pilot's ability to operate in the UAM environment.

New cockpit designs also introduces human factors issues. Research has shown that if the outputs provided to the pilots are less predictable, unexpected automation surprises can compromise the pilot's situational awareness and degrade performance (Dorneich et al., 2012). It is, therefore, necessary to examine how emerging UAM cockpit designs can effectively support pilots in maintaining situation awareness and making effective decisions. As UAM moves to fully automated operations, the ground control station interface will also have to be designed to facilitate situational awareness and support for aeronautical decision-making (Williams et al., 2001).

As UAM operations transition to automated flights, it is important to identify designs that will ensure appropriate levels of trust in automation (e.g., transparency). Research has shown that human-automation interaction can lead to unbalanced mental workload, reduced situational awareness, decision biases, mistrust, overreliance, and complacency (De Visser & Parasuraman, 2011). It is necessary to study how emerging UAM automation interfaces will impact pilot trust in and use of automation.

UAM Infrastructure

The ground infrastructure for electric VTOL flights needs to be designed to handle different levels of traffic from single flights to multiple flights taking off simultaneously. One of the key elements of infrastructure being proposed are vertiports, a type of airport that is designed explicitly for aircraft capable of vertical take-off and landing, passenger embarking and disembarking, pre-and post-flight checks, aircraft battery charging, and general day-to-day maintenance of the aircraft systems (Taylor et al., 2020). These vertiports will either be located at ground level or positioned on the top of high buildings, and ground staff will be tasked with performing their task under sometimes severe environmental conditions, including at great heights where winds can be high. The total area available to handle multiple aircraft at vertiports will be less than traditional airports or helipads. Research has shown that as the number of aircraft increases, it results in more complex operations and faster turnaround time, resulting in pilot and ground personnel error, workload, and misjudgment (Cardosi & Yost, 2001). Also, due to smaller space available, the number of ground personnel would also be limited. As ground operations increase, ground personnel will have less time to complete a task which can result in increased levels of stress (Sun & Chiou, 2010). Further, ground staff working hours, physical work, and lack of rest contribute to fatigue (Rosskam et al., 2009), a precursor to unsafe acts and accidents. There is a need to study how UAM infrastructure constraints will impact ground worker's workload, stress, and performance.

UAM Roles and Responsibilities

According to the Federal Aviation Administration (2020), UAM pilot/operator, state/local/federal authorities, service providers, aerodrome facilities, NAS users, and public interest stakeholders will hold prominent roles and responsibility in developing UAM. ATC's responsibilities in overseeing UAM operations will be extensive, including setting up the UAM airspace corridor based on the functional design of flights, time of the day, departure & approach paths, location, availability of vertiports, and separation with other UAM flights and manned flights. Airspace can accommodate more aircrafts if they are flying under visual flight rules (VFR) (Holcombe, 2018). This principle can be applied to UAM flights; however, the effect of attention and distraction for controllers and pilots, as well as UAM pilot's visual scanning performance in the highly congested conditions of this context, needs to be studied. As air traffic will increase, there is the potential for an increase in the air traffic controller's perceived workload (Hah et al., 2006). Controllers will have to monitor a greater number of aircraft, and research has shown that inattentional blindness, attentional blink, and working-memory capacity are top contributing factors for ATC operational errors (Xing & Bailey, 2005). Therefore, there is a need to study these phenomena in a UAM performance context.

It is also important to consider public perception and the passenger ride quality. Factors like vehicle inputs (manual or automatic maneuvering capabilities), vehicle characteristics (e.g., aircraft motion, vibration, noise, seat geometry, temperature, ambient lighting conditions), passenger motivation and willingness, cost, flight routes, schedule, and convenience (Edwards & Price, 2020) can influence passenger perception. These factors need be studied to ensure optimal ride quality and UAM acceptance.

Conclusions

Like any new concept, there is a need to identify the primary research areas that will help develop successful UAM operations. This paper aimed to identify key components of UAM and the associated human factors issues. Key human factors areas in need of future research include UAM pilot's trust in automation, situational awareness, visual scanning performance, decision-making capabilities; pilot, controller, ground personnel's workload and stress; and passenger ride quality and public perception. Understanding these areas of research will not only help the aviation community better understand how to implement UAM successfully but will also help the UAM stakeholders develop standards and procedures that keep "the human" in mind.

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