The new paradigm of Safe and Sustainable Transportation: Urban Air Mobility

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Abstract. Urban Air Mobility (UAM) is a revolutionary air transportation system that enables on-demand air travel. To enable successful air transportation, efficient management of large-scale aircraft is a critical factor to consider. In a dynamic environment, it is difficult to establish control rules due to uncertainty. To ensure the security and safety of both passengers and unmanned aerial vehicles, the UAM fleet needs a secure air traffic management system. However, regulations, infrastructural requirements, operation robustness, and communication still have problems to address. In this study, we summarize the challenges to deploying UAM widely. This overview discusses potential barriers to the UAM systems in terms of communication, control, and operations. Furthermore, we also provide open issues and research challenges in the paper.

Keywords: Urban Air Mobility (UAM), flying vehicles, on-demand air mobility, Unmanned aircraft (UA), Vertical Takeoff and Landing (VTOL).

1 Introduction

Urban aerial mobility (UAM) has attracted significant attention due to its potential to alleviate ground traffic congestion. Unmanned aerial systems (UAS), also known as unmanned air vehicles (UAV) or drones, have experienced a surge in usage in recent years, especially in civilian applications [1]. To reduce transportation times, avoid ground traffic, and enable point-to-point flights between cities, it is imperative to explore evolving mobility concepts and paradigms. UAM has the potential to revolutionize the aviation industry and disrupt mobility systems and urban planning. UAM refers to a safe, sustainable, environment-friendly, and cost-effective on-air transit system for passengers, commodities delivery, and on-demand access inside and beyond urban regions [2].

Recent technology developments in electrification, automation, and vertical take-off and landing (VTOL) are creating opportunities for new aircraft designs, services, and business models. These factors are coming together to create new possibilities for on-demand UAM vehicles to transport goods and move people across cities. Compared to conventional aircraft designs, UAM vehicles have diverse and unique requirements and boundary conditions [3]. Several of the leading aviation companies are advancing

VTOL technologies and prototyping and mass-producing the next generation of VTOL vehicles used by air taxi services.

Due to VTOL capabilities, this demand differs significantly from commercial airlines. The aircraft will start from airports known as vertiports and will have to maintain specific rules and guidelines to avoid collision with other aircraft, avoid high-rise buildings, and abide by air traffic control (ATC) rules and restrictions. Since the altitudes will be similar and the aircraft will be closer to the ground, collision avoidance is significant. In addition, migrating birds, rain, winds, and clouds are also crucial factors to consider. Another key challenge to success in the UAM is maintaining safe flight in a highly dynamic environment.

In this paper, we will provide an overview of UAM and discuss key aspects of this technology. These aspects include UAM operational concepts and communication techniques such as data type, communion reliability, localization and navigation, network topology, and collision avoidance. We will also discuss the challenges and opportunities associated with UAM development and its potential impact on society.

In the next section, we discuss various aspects of UAM operation. Following that, we review communication techniques for UAM. Afterwards, we provide open research issues and challenges for UAM. We conclude this study in the next section.

2 Operational Concepts of UAM

The basic UAM design factors affecting the selection of a particular aircraft type and the subsequent design specification are shown in Fig. 1. Although the concept of UAM has been around for a while and is gradually taking shape in certain ways, its application to specific needs for aircraft varies greatly. This applies to various design ranges, capacities, and cruising speeds of top-level aircraft requirements [4].

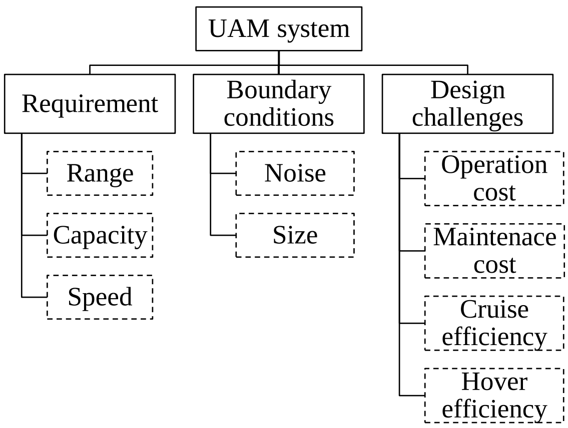

Fig. 1. Crucial factors for UAM systems development.

2.1 Power source

Recently, there has been an increase in popularity of aerial vehicles (AVs) due to the emergence of innovative distributed electric propulsion (DEP) and advanced electric technology [5]. These technologies have enabled us to combine strongly divergent and underlying operational needs to design different aircraft types. The development and possibilities of DEP have enabled researchers and companies to design aircraft with acceptable system complexity and weight for both rotary-wing and fixed-wing-based cruise vehicles. Rotary-wing vehicles create lifts with spinning wings during flight. They are often constrained by cruise speed during cruise flights, hence have range limitations. However, they possess excellent hover and VTOL capabilities.

2.2 Level of Autonomy

Drones can be operated in a variety of ways, including fully autonomous operation, human-piloted operation, or a combination of both. The degree of autonomy and the need for a human pilot will depend on the specific UAV system and the regulatory environment in which it operates. Fully autonomous UAVs are designed to operate without a human pilot, using sensors and navigation systems to make decisions independently [6].

2.3 Air traffic management (ATM)

UAM presents challenges that cannot be addressed by conventional ATM methods [7]. ATM services, including current and next generation systems, manage all types of flights of commercial and military aircraft. Commercial flights are supposed to provide secure passenger and container deportation between well-known airports whereas military aircraft serve and secure the country’s airspace from enemy attacks and provide support to ground troops. As the number of autonomous aircraft increases, UAM will need separate ATM systems or an adapted one that can handle on-demand, high-volume, short-range flights in close proximity to urban airspace.

3 Communication Techniques in UAM

UAM system requirements must consider the difficulties and variations between different environments, such as waterbodies, rural locations, and urban areas. There will be sporadic obstructions on line-of-sight (LOS), non-line-of-sight, and blind-line-of-sight links, which pose greater threats than in current aviation environments. Navigation signaling accuracy and latency will also be emphasized.

3.1 Data Type

Command and Control (C&C) includes information related to flight controls, safety systems, navigation, and communication. This data type is dynamic and constantly changing, as real-time evaluation of flight operations for potential aborts will require a significant amount of data from flight system diagnostics. Aerial vehicle handling and operation may benefit from live visuals to facilitate remote operation, such as artificial intelligence applications across cloud services. All additional data, such as post-flight data or passenger information, will come under the non-C&C category [8].

3.2 Spectrum & Carrier Frequencies

Communication systems have congested bandwidth and transmission spectrum. To implement an UAM communication system, modern frequency bands can be used, including sub-6 GHz, 3rd generation partnership project, millimeter wave bands (24-86 GHz), and low earth orbit bands [9].

3.3 Communication Reliability

AVs and standard aviation systems (such as helicopters) differ significantly in terms of their proximity to terrestrial barriers and architectures due to their low altitude in urban and rural areas. This creates a communication challenge known as shadowing and obstruction or blockage. Such effects can cause enough attenuation to break a connection. Therefore, several links must be used to connect AV to C&C stations. Air-ground communication is typically preferred over satellite or high-altitude platform (HAP) system links for LOS links due to high power efficiency and less delay [10].

3.4 Network Topology

Multiple communication links can be established using multi-point receiver and transmitter schemes through central or decentralized fifth-generation technology standard techniques and systems for UAM networks. Mobile ad-hoc networks can also offer multiple links, which often require more sophisticated network-layer techniques, such as adaptive routing [11]. Several connectivity options are available through HAPs or satellite communications.

3.5 Navigation and Localization

A high-accuracy positioning system will be necessary as the number of UAM nodes increases for situational awareness and self-awareness [12]. The development of robust tracking algorithms and fusion sensors that are sufficiently complex to provide accurate information and positional awareness is crucial for UAM operations.

3.6 Collision Detect-and-Avoid (CDAA) Systems

The use of ground based CDAA for routing UAM terminal area activities is a crucial factor in integrating UAM into urban and nearby urban airspace. This may be achieved through both on the ground and with onboard assistance. The National Aeronautics and Space Administration (NASA) [13] performed 11 flights and 200 staged interactions with other aircraft using an Ikhana aircraft fitted with a prototype continuous descent approaches (CDA) system. The CDA sensor and radar, traffic warning, and collision avoidance system were all installed in the aircraft. Since UAM operations are intended to be autonomous, the CDA process cannot be detected only in defined UAM operating systems are all important considerations. This is because UAM systems with flight routes to the central management system, and cooperative data exchange via onboard sensor technology that tracks other UAM systems are equally necessary.

4 Open Research Issues and Challenges

Despite its aim of delivering safe, sustainable, economical, and accessible transportation, UAM faces obstacles, including public acceptability and public safety. Many lucrative operating criteria, such as flying limits over residential areas, nighttime operability, inclement weather, and development of green technologies, might make UAMs more manageable. Moreover, the development of VTOLs and UAMs will certainly need significant cooperation and investment from both the private and governmental sectors to build infrastructure and scale operations. On top of these, safety issues, and public perception of UAM have to be additionally concerned.

To balance economic interests, technological progress, and the public good in the future, more research, strategic planning and execution, and analysis of UAM implications are required. Ensuring the safety of the aircraft and people is of crucial importance. Since UAM comes with extensive benefits, there are also a number of limitations, such as maintaining safe flight at low altitudes, avoiding hazards such as bird collisions, and weather effects. Furthermore, in urban areas, high rise buildings are too frequent, and this makes the UAM flight trajectory significantly complicated. These issues make UAM implementation in urban areas very challenging [14]. Thus, collision avoidance in UAM can be a fascinating research topic for future studies.

In addition, UAM encounters various challenges such as safety, ATC regulation, noise, public acceptability, weather conditions, environmental implications, infrastructure, and security [15]. Furthermore, a UAM concepts success or failure will also be significantly influenced by the requirement for minimal noise emissions, which is a high concern for public acceptance. Despite aiming to provide safe, sustainable, inexpensive, and accessible mobility, UAM must deal with concerns including societal equality, public acceptability of noise, and safety.

5 Conclusion

Aeronautical communication is entering a new era thanks to UAM. To successfully deploy UAM technologies, some key requirements must be met. These include techniques to establish high-speed and high-accuracy data communication links and mid-air vehicle-to-vehicle communication. All these technologies must be reliable and robust. In this paper, we aim to discuss the on-demand UAM system and examine its operational and communicational aspects, as well as the challenges and opportunities it presents. There are several challenges associated with UAM system deployment, including infrastructure development, safe flight operations, and integration with existing transportation networks. Despite aiming to provide safe, sustainable, inexpensive, and accessible mobility, UAM must deal with issues including societal equality, public acceptability of noise, and safety.

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