Scientific Research Publishing

Advances in Aerospace Science and Technology, 2024, 9, 75-84
https://www.scirp.org/journal/aast
ISSN Online: 2473-6724
ISSN Print: 2473-6708

Exploring the Promises and Challenges of Urban Air Mobility (UAM)

Yusuf Karimli[1], Aniello Daniele Marano[2]

[1]Engineering Department, Landau School, Baku, Azerbaijan
[2]Aerospace Engineering Department, University of Federico II, Naples, Italy
Email: yusufkarimli08@gmail.com, daniele.marano.dm@gmail.com

How to cite this paper: Karimli, Y. and Marano, A.D. (2024) Exploring the Promises and Challenges of Urban Air Mobility (UAM). *Advances in Aerospace Science and Technology*, **9**, 75-84.
https://doi.org/10.4236/aast.2024.93006

Received: July 26, 2024
Accepted: August 20, 2024
Published: August 23, 2024

Abstract

This paper is focused on a higher-level report of a new generation of Unmanned Aerial Vehicle (UAV) technologies. Starting from the structural scalability of civil tiltrotors, design strategy and requirements for UAVs, and advanced composite materials, the increased speed and productivity requirements for tiltrotors have spawned several investigations associated with proprotor aero elastic stability augmentation and aerodynamic performance enhancements. The research emphasized the Large Civil Tilt Rotor as the configuration with the best potential to meet the technology goals, and the design, including the challenges of the Large Civil Tilt Rotor (LCTR). The design presented was economically competitive, with the potential for substantial impact on the air transportation system. The research includes some manufacturers of helicopters, drones and tiltrotors carrying out design studies and production of prototypes, as well as research projects aimed at designing, manufacturing, qualifying, and flight-testing the new wing of the Next-Generation Civil Tiltrotor Technology Demonstrator. Promises of Vertical Take-off and Landing (VTOL) aircraft, UAVs, Digitalization of Urban Air Mobility (UAM), and the "U-space" concept are discussed in the paper. The eight SUMP principles and possibilities of future advancements are emphasized.

Keywords

Thermodynamics, Aerospace Innovations, Sustainable Energy Systems, Fluid Dynamics, Aeronautical Engineering, Green Technology, Digital Development of Engineering, Urban Air Mobility

1. Introduction

The investigation identified the LCTR as the configuration with the best potential to meet the technology goals. The design presented was economically competitive, with the potential for substantial impact on the air transportation system. The keys to achieving a competitive aircraft were low drag airframe and low disk loading rotors; structural weight reduction, for both airframe and rotors; drive system weight reduction; improved engine efficiency; low maintenance design; and manufacturing cost comparable to fixed-wing aircraft. Electric VTOL aircraft are expected to open a novel and stimulating market for UAM. As operations grow and mature, UAM is anticipated to become a commonplace form of transportation in some areas. Many airspaces and Air Traffic Management (ATM) challenges need to be handled to facilitate the implementation and extension of UAM in a globally uniform manner. Urban aviation operations will become more complex, with a higher density and tempo due to more flights and faster turnaround times. The ATM problems related to battery-powered, piloted, and passenger-carrying operations will need to be resolved. Furthermore, to adapt to this new environment, ground infrastructure will change as well. Several vertiports run by various organizations will serve several fleet operators. The investigation's most promising idea was LCTR. The optimization and analysis of the LCTR are covered in this study, including the rotor. Its wing design highlights the tiltrotor's most distinctive feature, its wing, while showing performance, stability, and load data. In terms of speed and range, tiltrotor aircraft are superior to traditional helicopters. While a tiltrotor can travel nearly twice as far as a helicopter, it can also convert from helicopter mode to aircraft mode for high-speed flight, which is less constrictive regarding unfavorable aerodynamic effects [1]. A helicopter is limited at high speeds by compressibility effects on the advancing side of the rotor and can stall on the retreating side. The vertical mobility aspect above cities and regions: current trends, prospects, and difficulties. Technical sketch of a tiltrotor is depicted in **Figure 1**.

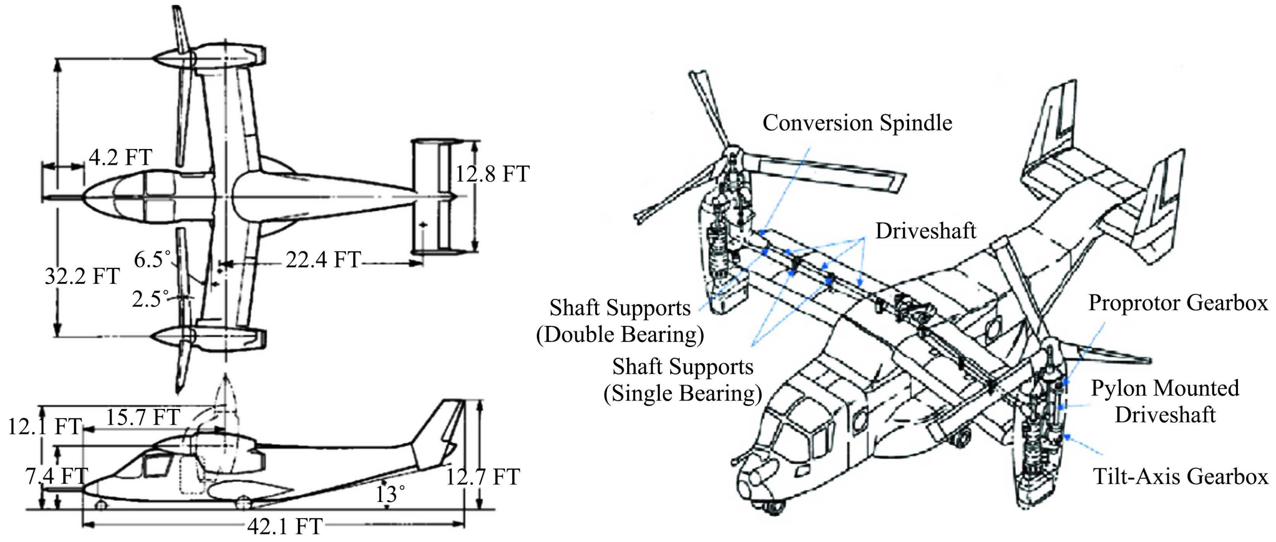

Figure 1. Technical drawing and detailed sketch of tiltrotor (Research Gate, Effects of Rotor Design Variations on Tiltrotor Whirl-mode stability) [2].

2. Requirements and Design Strategy

Unbelievably, urban reality and urban mobility planning is more closely related to UAM, or more simply, the air traffic in and around the urban and larger metropolitan airspace for services such as the transportation of passengers and freight. As this document will explain, UAM is not just another mode of transportation and instead necessitates a comprehensive planning strategy that includes not only the integration of UAM into the transportation system but also the urban infrastructure and general livability of the city, as well as its support infrastructure on the ground. Though some readers may find this futuristic and unrealistic, more positive and sustainable alternatives may be closer than they think. For instance, drones, also known as unmanned aerial vehicles or UAVs, or Unmanned Aerial Systems (UAS), are already being used extensively for sensor-based data collection, such as for traffic and incident monitoring, the upkeep of industrial installations and structures like bridges and runways, building information modeling (BIM), emergencies, and medical cases. The target goal of UAM is to transport people directly, or on non-stop flight segments, from their origin to their destination using VTOL or Short Take-Off and Landing (STOL) aircraft. Conversely, VTOL aircraft present an equally attractive image when it comes to transporting packages and cargo during non-stop flight segments between their origin and destination. A point-to-point service network requires a lot more aircraft than a hub-and-spoke network, thus if both visions are fully fulfilled, there will undoubtedly be a lot of aircraft flying along roads and between buildings in an urban area. Furthermore, rotorcrafts are maneuvering easier as well as landing and hovering vertically in addition to flying laterally, backwards, and forward [3].

3. Civil Tiltrotors

Creating a new, intricate product involves a lot of work and costly experiments. A civil tiltrotor wing design project is an excellent example, where the development cost accounts for a sizable portion of the cost of the finished product [4]. From a general point of view, the tiltrotor configuration is considered a step beyond the state of the art in terms of performance, design, architecture, and product supportability. This was recently confirmed by the US Government Accountability Office, which identified a tiltrotor vehicle as a vehicle for the future long-range assault aircraft (FLRAA). The methodology developed in this paper allows a quick scale-up and preliminary validation of the tiltrotor wing structure starting from the Technology Demonstrator (TD) data. The tiltrotor wing is one of the most critical airframe subsystems of the entire aircraft due to several requirements, often contrasting each other, to be fulfilled [5]. The specific concern of tiltrotors is the airframe mode placement. Those modes involve significant movement of the hub center in the rotor disc aircraft directions (usually caused by local deformation of the rotor and nacelle supporting structure). They shall have their frequency outside of prescribed bands to avoid forced response oscillations. In addition, the lowest elastic airframe mode shall have a frequency not lower than a prescribed value to avoid coupling with aero mechanical modes. Finally, the wing box architecture shall be capable of hosting fuel bladders, hydraulic systems, electrical systems, flight sensor routing, and interconnecting drive shafts by respecting redundancy and segregation requirements. The Next-Generation Tiltrotor (NGCTR-TD) is a demonstrator designed by Leonardo Helicopters to test various technologies [6]. The following are some of the main advancements associated with these technologies:

- Creation of a novel, high lift, low drag wing that is optimized to enhance downwash impingement in helicopter mode (Hovering). The two new faces that increase downwash impingement are an outboard flaperon and a large morphing surface that rotates downward in helicopter mode to reduce the wing area beneath the rotors.
- Constructing a compact structural wing box because the moveable surfaces take up over half of the wing chord length.
- Creating a composite wing structure with excellent integration [7].

4. Structural Designing Results

UAVs new technology introduced to society that deviates from the norm also changes the way we do business, software and analytical capabilities enhances and increases the use of rotor aircraft hardware. Hence, tiltrotor is more of an efficient design for smaller rotorcrafts. As a result, wider-body and specifically commercial aircrafts are used to fly long-haul and ranged distances. To increase the aero elastic stability of a tiltrotor aircraft, a structural optimization framework was created using a two-level optimization technique. Increasing the flutter speed through structural modification of the wing was the aim of the upper-level optimization. The European Aviation Safety Agency (EASA) huge aircrafts (CS-25) and large. rotorcrafts (CS-29) offer the requirements for the NGCTR-TD's airworthiness specifications because of the vehicle's special qualities. Custom standards are also necessary because not all requirements for helicopters and aircraft encompass all possible scenarios and characterize a tiltrotor [8]. Propels in material improvements have usually been considered for significant advancements in execution in many advanced composite constructions and continue to be crucial in determining the consistent quality, execution, and affordability of these systems. Fiber-reinforced composite materials that are lightweight, strong, and stiff are gaining ground as component materials to improve the efficiency and maintenance of various transportation forms, including those used in the aviation sector. Because of their advanced internal engineering, they offer enormous potential for joining multifunctionality in expansion. One limiting factor in their more widespread misuse is typically poor execution below impact stacking, a fundamental aspect of any vehicle design that results in notable declines in quality, stability, and solidity. Their inability to plastically deform leads to the production of abandons and damages, which preserve vitality [9].

5. Advanced Composite Materials

Creating aircraft and spacecraft is the focus of the engineering field known as aerospace engineering. Aeronautical engineering includes materials science and engineering as essential components, much like many other engineering fields that deal with the materials used to build aeronautical structures. While most aerospace structures are made of metal, developments in materials science, particularly in composites science and technology, have made it possible to create new, promising materials for aeronautical engineering. Composites are materials that combine two or more components to create a hybrid that takes advantage of each component's unique properties. The field of aerospace engineering has recently shown a great deal of interest in fiber-reinforced polymer composites (FRPs), which are created by reinforcing various matrix types (such as polymeric, ceramic, metallic, etc.) using fibrous materials. The aerospace industry has seen a more than 50% increase in the use of composite materials in recent years (Research Gate, 2016) specifically implementing an intelligent airframe in Airbus A350XWB. Composite materials are used in the aerospace industry for primary and secondary structural parts like engine cowls, radomes, antenna dishes, vertical and horizontal stabilizers, center wing boxes, aircraft wings, pressure bulkheads, landing gear doors, tall cones, flap track panels, vertical and horizontal stabilizers. The increasing use of composite materials in commercial aircraft is depicted in **Table 1**.

Table 1. Increased growth of composite use in aircraft over the years increased composite usage in A350 XWB [10].

An intelligent airframe composite material	Total part of the airframe in the aircraft
AI/AI-Li	19%
Steel	6%
Composite	53%
Titanium	14%
Misc.	8%

Eleven percent of the long-range, twin-engine, over 300-passenger Boeing 777 was made of composite materials when it was introduced in 2000 (**Table 2**). Almost 50% of The Boeing 787 Dreamliner's materials were composites (about 32,000 kg of carbon fiber composites made from 23 tons of carbon fiber). Approximately 32 billion US dollars' worth of development costs of Boeing 787 Dreamliner by 2023 include the composite materials which were used in engine components of the aircraft. According to this projection, 2665 MT of composites were produced by 2023, valued at US$1.7 billion (Boeing company, 2023). Given the strict temperature requirements, ceramic matrix composites are predicted to have enormous potential for use in aircraft engine components.

Table 2. Increased use of fiber-reinforced polymer composites in aircraft structures [11].

Boeing 777	Boeing 787
Launched in 2000	Launched in 2007
11% FRPs	50% FRPs
70% Aluminum	20% Aluminum
7% Titanium	15% Titanium
11% Steel	10% Steel
1% Others	5% Others

6. Digitalization of Aerospace

Many firms are currently vying to be the first to regularly provide "air taxi" services in cities and regions, helped along by substantial venture capital donations. Alongside the developments of electrical vertical take-off and landing (eVTOL) aircraft, research is also done into UAM control systems, network design, the necessary ground infrastructure (vertiports, for example), and the integration of UAM-related aircraft into the current busy airspace over cities. To put it loosely, "air taxis" are electric aircraft (e.g., eVTOLs) that can transport large cargo and passengers in the context of urban mobility and sustainability. Consequently, some form of sophisticated urban ATM is required to coordinate aviation operations in the urban airspace, not only in the future as represented in movies but also in the present day, especially if traffic densities increase [12].

The growing relevance of UAM is leading cities and regions to claim the low-level airspace above them as part of their metropolitan area. However, cities and regions need to realize that they do not have general control over the airspace. Because air law is handled at the national or international level, the appropriate officials also live there. Generally, the local level's impact may be limited to evaluating ground dangers and related infrastructure, contingent upon the regulatory framework of the specific Member State. This covers technological issues as well as regulation, legislation, and governance, the latter of which is handled by the European Union through frameworks and regulations that are binding on all EU members. One example is the introduction of the "U-space" idea [13]. The EU designed a legal framework for using UAS and its possible uses within the Union. In the end, U-space provides a legal framework that strives for the safe, secure, sustainable, and effective operations of UAS, including air taxis in future urban airspace, to manage scalable airborne traffic that is following society's demands. A sound regulatory framework such as the "U-space" is a facilitator rather than a "barrier".

Additionally, it is a necessary condition for the ethical and long-term implementation of urban air mobility services on a large scale within a city or area. The integration of UAM services with current or upcoming surface mobility services is just one of many issues that must be considered when preparing for UAM operations. Other factors include aviation safety and security. To do this, the most important thing when analyzing the UAM environment is to communicate public and wider societal benefits in a variety of dimensions, such as enhancing accessibility, quality of life, and economic and environmental elements, aside from basic safety and security issues. Europeans are firmly in favor of UAM use cases that have a clear societal benefit, according to a new EASA study on the social acceptance of UAM. This covers all forms of emergency and medical transportation, including those used in disaster relief situations.

7. Promises of Advanced Aerial Vehicles

The anticipation that increasingly autonomous (IA) systems will yield substantial benefits in terms of safety, dependability, efficiency, affordability, and/or previously unachievable mission capabilities is propelling the development and application of IA systems for civil aviation at an accelerated rate. IA systems cover a wide spectrum of technologies, from the automatic systems used today, like autopilots and remotely piloted unmanned aircraft, to the more complex systems required to enable fully autonomous aircraft that operate without the need for human air traffic controllers or pilots. These systems are being envisioned for aircraft, air traffic control, and other ground-based components of the national airspace system. They are distinguished by their capacity to carry out increasingly complex mission-related tasks with significantly less human intervention for extended periods, sometimes at remote distances. Encouraging civil aerospace and aviation transport companies to use eco-fuel and develop unmanned aerial vehicle technologies would lead to increased fluctuations in the greenhouse effect and prevent the depletion of the ozone layer [1]. From 1950 to 2018 the global urban population has quadrupled and by 2023 4.4 billion people will be living in urban areas, making up to 55% of the global population.

The United Nations expects the trend to increase up to 68% by 2050 [14]. UAM is one of the leading technologies that is expected to foster the solutions for the future of urban population growth. The vitality to drive the propellers is given by either hybridized or completely zapped control. UAS are as of now broadly utilized in observation and recording and they are presently getting to be ever progressively imperative within the setting of UAM. Future UAM systems will inevitably be went with by novel impetus design, such as a cluster of disseminated drive frameworks (DPS) [15] and multi-rotor arrangements, owing to their operational prerequisite to vertically take-off and arrive inside "vertiports" arranged in thickly populated cities. The fruitful usage and food of UAM, as well as its societal acknowledgment as a concept, nearly completely depends on the streamlined and aeroacoustics execution within the take-off and landing phases of the mission. Typically, since when working exceptionally near to the ground, UAM airplane deliver noteworthy, streamlined annoyances commonly known as the "Ground Effect". Operation inside "Ground Impact" is likely to lead to changes in aeroacoustics and expanded clamor levels, in expansion to modifications in flight soundness and pushed prerequisites. In comparison to other factors crucial to this evaluation, the total quantity of aviation fuel burnt as well as the total emissions of carbon dioxide, NOx, and water vapor by aircraft are well known. The CO_2 emissions from aviation gasoline are 3.15 grams per gram of fuel, meaning that a Boeing 737 - 400 emits 115 grams of CO_2 for every passenger kilometer. 780 km/h is the average speed. Aircrafts are the first highest carbon emitters, emitting 13,500 kg per flight (**Table 3**). Hence, the reduction of speed or using a different technology while constructing and designing the engine of the aircraft to release twice as little CO_2 would result in positive outcomes.

Table 3. Urban CO_2 emissions [16].

CO_2 Emission source	Annual accounted CO_2 emissions
Cars	880 kg
Food	3000 kg
Sewage	140 kg
Natural gas	1360 kg
Electricity	490 kg
Planes	13,500 kg (50,000 miles)

8. Conclusions

In conclusion, studies on the benefits and drawbacks of UAM have highlighted the role that big civil tiltrotor may play in achieving technological objectives. The aircraft design that is showcased in the paper is both economically competitive and can significantly alter the air transportation industry. The future of UAM appears bright, thanks to developments in composite materials, low disk loading rotors, and an airframe with minimal drag. Moreover, the incorporation of eVTOL aircraft into UAM can transform urban transportation. It is expected that UAM operations will become a standard mode of transportation in some areas as they grow and mature. Enabling the adoption and extension of UAM on a worldwide scale will require standardizing airspace and ATM. To fully exploit the potential of UAM, the research emphasizes the significance of ongoing developments in structural scalability, aero elastic stability augmentation, and aerodynamic performance enhancements. The "U-space" concept and the "T-WING project" are important steps in the direction of realizing this vision. Highlighting the opportunity to develop technologies and new opportunities for companies at COP 29 which will be held in Azerbaijan in November 2024. There is a Sustainable Urban Mobility Planning and Monitoring (SUMP) principle that applies to every kind of transportation. The setting of UAM, however, is unique because these ideas are usually applied to surface and ground transportation modes

The eight SUMP principles in the context of UAM:

- Plan for sustainable mobility in the "functional city"
- Cooperate across institutional boundaries

- Involve citizens and stakeholders
- Asses current and future performance
- Define a long-term vision and a clear implementation plan
- Develop all transport modes in an integrated manner
- Arrange for monitoring and evaluation
- Assure quality

Acknowledgements

Y. K. author and A. D. M. author (Ph.D.) thank Universita degli di Napoli Federico II for the extensive research platform and provided research materials.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Exploring the Future of Urban Air Mobility. https://ae.gatech.edu/news/2018/07/exploring-future-urban-air-mobility

[2] Effects of Rotor Design Variations of Tiltrotor on Whirl-Mode Stability. https://www.researchgate.net/publication/23847162_Effects_of_Rotor_Design_Variations_on_Tiltrotor_Whirl-Mode_Stability

[3] National Aeronautics and Space Administration: Designs and Technology Requirements for Civil Heavy Lift Rotorcraft. https://ntrs.nasa.gov/citations/20080047712

[4] Belardo, M., *et al*. (2021) On the Preliminary Structural Design Strategy of the Wing of the Next-Generation Civil Tiltrotor Technology Demonstrator. *International Journal of Aeronautical and Space Sciences*, **22**, 613-624.

[5] Autonomy Research for Civil Aviation. https://nap.nationalacademies.org/catalog/18815/autonomy-research-for-civil-aviation-toward-a-new-era-of

[6] Performance, Loads, and Stability of Heavy Lift Tiltrotors. https://ntrs.nasa.gov/citations/20060013409

[7] Belardo, M., *et al*. (2021) Wing Structure of the Next-Generation Civil Tiltrotor: From Concept to Preliminary Design. *Aerospace*, **8**, Article 102.

[8] Aeroelastic Tailoring for Stability Augmentation and Performance Enhancements of Tiltrotor Aircraft. CEAS/AIAA/ICASE/NASA LaRC International Forum on Aeroelasticity and Structural Dynamics. https://ntrs.nasa.gov/citations/19990050923

[9] Rana, S. and Fangueiro, R. (2016) Advanced Composite Materials for Aerospace Engineering. Woodhead Publishing. https://www.sciencedirect.com/book/9780081009390/advanced-composite-materials-for-aerospace-engineering

[10] Composite Usage in Airbus A350 XWB. https://www.researchgate.net/figure/Composite-usage-in-Airbus-A350-XWB_fig2_308882060

[11] 787 Propulsion System and Composite Materials for the Dreamliner. http://www.lb.boeing.com/commercial/aeromagazine/articles/2012_q3/2/

[12] The Future of Air Mobility and Urban Airspace. https://airspaceworld.com/news/the-future0vertical,metropolitan%20areas%20around%20the%20world

[13] New EASA Study on Social Acceptance of Urban Air Mobility in Europe. https://www.easa.europa.eu/en/full-report-study-societal-acceptance-urban-air-mobility-europe

[14] The Vitality to Drive the Propellers. https://www.who.int/health-topics/urban-health#tab=tab_1

[15] Mehrabi, A. and Davari, A.R. (2020) Outwash Flow Measurement around the Subscale Tandem Rotor in Ground Effect. *Engineering Science and Technology, an International Journal*, **23**, 1374-1384. https://www.sciencedirect.com/science/article/pii/S2215098620342075

[16] Urban Air Mobility and SUMP. https://urban-mobility-observatory.transport.ec.europa.eu/system/files/2023-11/urban_air_mobility_and_sump.pdf