TECHNISCHE HOCHSCHULE INGOLSTADT

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# The Future of AI in Air Traffic Management: Coordinating Autonomous Airliners and UAM within Busy Airspaces using AI

## SEMINAR PAPER

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# Affidavit

I certify that I have completed the work without outside help and without using sources other than those specified and that the work has not yet been submitted in the same or a similar form to any other examination authority and has been accepted by them as part of an examination. All statements that have been adopted literally or analogously are marked as such.

Ingolstadt, 8 May 2025

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# Abstract

The summary gives the reader a rough overview of the content (brief problem definition, approach, solution approaches and possibly key findings). The scope should be about half a page. This chapter is not mandatory and should only be considered optional.

# Contents

# 1 Introduction

## 1.1 Artificial Intelligence

Artificial intelligence (AI), along with its subfields machine learning (ML) and deep learning (DL), has emerged as fundamental tools in the modernisation and optimisation of various industries, including aviation [1]. ML involves the development of algorithms and models that enable computers to learn from data and make informed decisions without being explicitly programmed [1]. DL, a subset of ML, utilises artificial neural networks that mimic the structure and function of the human brain to process complex patterns and large datasets [1]. In combination with AI-driven tools such as natural language processing (NLP) and computer vision, , these tools are being integrated across a wide range of aviation applications, from flight operations and maintenance to passenger services and air traffic management [1].

## 1.2 Urban Air Mobility

According to European Union Aviation Safety Agency (EASA), urban air mobility (UAM) refers to an air transportation system for passengers and cargo in urban environments, with the transportation performed by an electric aircraft capable of vertical takeoff and landing (VTOL), either remotely piloted or with a pilot on board. Commercial operations in European cities are expected to begin as early as 2025, with initial applications focusing on drone-based goods delivery and passenger transport using piloted aircraft [2]. Several pilot projects are currently underway. European manufacturers such as Airbus, with its CityAirbus NextGen, and Volocopter, with its VoloDrone, are actively developing and testing aircraft designed for both passenger and cargo transport [3].

The anticipated benefits of UAM include faster and more sustainable transportation, reduced congestion, and extended urban connectivity. However, major concerns remain regarding safety, environmental impact, noise pollution, and cybersecurity. Public acceptance and user confidence will be critical factors for the successful implementation of UAM in Europe [4].

Currently, many UAM vehicles are in the development or testing phase, with a long-term objective of achieving fully autonomous operations using unmanned aerial vehicles (UAVs) [5].

## 1.3 Autonomous Airlines

Autonomous airliners represent a branch of UAVs, consisting of fixed-wing aircraft capable of flying and navigating without direct intervention of a human pilot. Although modern commercial airliners already automate approximately 93% of flight functions, such as autopilot systems and automatic dependent surveillance-broadcast (ADS-B), there remains a growing demand to implement higher levels of autonomy. Increased automation is seen as a path toward enhanced safety, greater scalability, and improved affordability.

Human error is cited as the leading cause in approximately 80% of general aviation accidents. As a result, the vision for autonomous airliners includes minimising single points of failure in both design and operation by removing the human from direct aviate-navigate-communicate roles and replacing them with reliable, intelligent automation [6].

While fully autonomous aircraft are technically feasible today, they have not yet been deployed for public use [6]. This limited adoption can be attributed to several key factors [7]:

a) public acceptance rates remain below the 50% threshold typical for early adopters of innovative technologies,

b) persistent public trust in the value of direct human pilot presence and intervention, and

c) unresolved regulatory and cybersecurity concerns.

## 1.4 Air Traffic Management

Air traffic management (ATM) refers to the systems and services that ensure the safe anf efficient movement of aircrafts during all phases of operations, through controlled airspaces and on the ground at airports [8]. It comprises serveral components, including air traffic control (ATC) (its main component), airspace management (ASM), air traffic flow management (ATFM), and air traffic service (ATS) [9].

Air traffic controllers (ATCOs) are responsible for directing aircraft safely and efficiently, managing takeoffs and landings, maintaining safe distances between aircraft en route and handling emergencies. Their role demands high levels of situational awareness, rapid decision-making, and the ability to manage multiple tasks under high stress conditions. These indispensable skills, such as judgement, flexibility and the ability to handle unexpected situations, remains critical and are not easily replicated by automated systems, despite advancements in digitalisation [10].

However, the rapid expansion of commercial aviation, UAM, and UAVs have significantly increased the complexity of ASM [11]. With air traffic volume increases, the scalability of the system is limited by the finite capacity of ATCOs, who are subject to workload constraints and cognitive overload [12]. Fatigue and informaion overload have become key contributors to operational inefficiencies and potential safety risks [11]. Furthermore, human limitations in reaction time and decision-making speed highlight the need for intelligent, automated support systems that can enhance overall system performance.

Integrating UAM into air traffic flow poses a significant challenge due to their unique performance characteristics, which differ from those of fixed-wing aircraft. These differences can lead to suboptimal use of airport capacity [9]. Compounding the issue is the current shortage of ATCOs, alongside the long training periods required to qualify new personnel, this has amplified the demand for AI-based solutions in ATM. AI technologies are able to solve these challenges through real-time data processing, predictive analytics, and autonomous decision-making capabilities [11]. While some automations already exist in some areas [13], existing systems often rely on rigid rule-based frameworks and lack the flexibility and adaptability needed for dynamic environments [12].

The integration of UAV into ATM has led to the development of a new branch known as UAS traffic management (UTM). As UAVs often operate across both controlled and uncontrolled airspaces – and ATCOs are only responsible for controlled airspaces – a key challenge arises: there is no ATC service in uncontrolled airspaces. This lack of oversight increases the risk of mid-air collisions or accidents involving other UAVs, manned aircraft, ground vehicles, or natural and artificial obstacles. Therefore, a dedicated system like UTM is essential to ensure safe and efficient UAV operations in all types of airspace [14].

The integration of UAM and UTM into the existing ATM framework will not only stress current infrastructure but also require faster, more adaptive decision-making [15] – an area where AI technologies can provide substantial value.

# 2 Foundation Enablers

## 2.1 Satallite-Based Navigation & Communication

The satalite-based system uses Global Positioning System (GPS) and Global Navigation Satellite Systems (GNSS) to improve accuracy of flight paths. Compared to the traditional ground-based ATM, the satalite-based system offers real-timereal-time and global coverage of air traffic across the globe. Their integration to ATM reduces error caused by outdated or incomplete radar data, which can lead to miscommunication or unsafe distance separation between aircrafts.

The transition towards a satalite ATM offers a safer and more efficient ATM as it helps ATCOs to make better informed decisions even in remote or congested airspaces [16].

## 2.2 Infrastructure Upgrades

The legacy (or outdated) systems are not designed to support the precision and real-time data provided by satellite technologies, it calls infrastructure upgrades [16].

For example, in United States of America (US), under Next Generation Air Transportation System (NextGen), from the Federal Aviation Administration (FAA) has revamped ATC infrastructure for communications, navigation, surveillance, automantion, and information management to increase the safety, efficiency, capacity, predictability, flexibility, and resiliency of US avaiation [17]. This aims to revitalise FAA infrastructure with new radar systems, air traffic control terminals, and increased hiring. This includes the replacement “outdated technologies” such such as binoculars for visual checks and floppy disks for data storage. There is also a need to transition from ageing copper wire telecommunications to modern alternatives such as fibre, wireless, and satellite networks [18].

## 2.3 Remote & Digital Towers

Remote Tower Service (RTS) is a system which allows aerodrome ATC or Flight Information Service (FIS) to be provided from a location other than the aerodrome (away from the physical airport tower) whilst maintaining a level of operational safety which is equivalent to that achievle using a manned Tower at the aerodrome to oversee both air and ground movements [19]. An RTS combines advanced technology, real-time visual feeds and efficient communication to enhance air traffic control while allowing controllers to operate remotely. An RTS requires a number of high-definition cameras/sensors along with a vast network of signal cabling equipment to allow for fast data transfer (without lag) ensuring seamless communication between the controller and the aerodrome.

Integrating RTS has helped with cost savings, enhanced technology, staffing issues, and safety improvements [20].

# 3 Unified Airspace Challenge

# 4 UAS Traffic Management (UTM)

The goal of UTM is to create a system that can integrate drones safely and efficiently into air traffic that is already flying in low-altitude airspaces. That way, package delivery and fun flights won't interfere with helicopters, airplanes, nearby airports or even safety drones being flown by first responders helping to save lives. [**nasa_utm_2021**]

## 4.1 Differences compared to ATM

The system is a bit different than the air traffic control system used by the FAA for today's commercial airplanes. UTM is based on digital sharing of each user's planned flight details. Each user will have the same situational awareness of the airspace, unlike what happens in today's air traffic control [**nasa_utm_2021**].

UAM vehicles typically operate at lower altitudes, often within urban areas, requiring a different set of rules and procedures for separation, navigation, and ASM, compared to traditional aviation, which predominantly operates at higher altitudes. UAM vehicles expected to operate with much higher traffic density than conventional aviation. This necessitates advanced automation and communication systems for collision avoidance, route planning, and real-time traffic management. UAM designed for shorter point-to-point trips, often serving as urban air taxis. This requires a different approach to traffic management, including take-off and landing procedures, queuing at landing pads, and managing very short flight segments. Many UAM are electric or hybrid-electric, leading to differences in energy management and charging infrastructure requirements. UTM for AAM must consider these factors when planning routes and ensuring availability of charging infrastructure. UAM may involve decentralized takeoff and landing locations, such as vertiports, rooftops, and helipads. UTM systems must manage these multiple points of origin and destination, requiring coordination and communication between various stakeholders. [**carc_amc**].

## 4.2 Challenges of Integration

Integrating helicopters, or in general vertical take-off landing vehicles (VTOL), into the air traffic flow is a challenge due to their special performance characteristics compared to fixed0wing aircraft, resulting in non-optimal usage of airport capacity [9].

#### 4.2.1 Maturation, Validation, and Deployment of U-space Services (U1 and U2)

#### 4.2.2 Development of Advanced U-space Services (U3 and U4) for High Traffic and Complex Scenarios

#### 4.2.3 Enabling UAM through Autonomous Operations Integration in Complex Airspace

#### 4.2.4 Integration of ATM, UAM, and U-space Systems and Interfaces

#### 4.2.5 Addressing Social Acceptance, Environmental Impacts, and Sustainability in UAM

#### 4.2.6 U-space Application Concepts for Very Low Level (VLL) Airspace

# 5 Autonomous UTM (aUTM)

# 6 Discussion

# 7 Conclusion

# Acronyms

**ADS-B** automatic dependent surveillance-broadcast. 2

**AI** artificial intelligence. 1, 3

**ASM** airspace management. 2, 3

**ATC** air traffic control. 2–4

**ATCO** air traffic controller. 2–4

**ATFM** air traffic flow management. 2

**ATM** air traffic management. 2–4

**ATS** air traffic service. 2

**DL** deep learning. 1

**EASA** European Union Aviation Safety Agency. 1

**FAA** Federal Aviation Administration. 4

**FIS** Flight Information Service. 4

**GNSS** Global Navigation Satellite Systems. 3

**GPS** Global Positioning System. 3

**ML** machine learning. 1

**NextGen** Next Generation Air Transportation System. 4

**NLP** natural language processing. 1

**RTS** Remote Tower Service. 4

**UAM** urban air mobility. 1, 3

**UAV** unmanned aerial vehicle. 1–3

**US** United States of America. 4

**UTM** UAS traffic management. 3

**VTOL** vertical takeoff and landing. 1

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