

Abstract

Towards Persistent Innovative Air Mobility Through Autonomous In-Flight Docking, Power Source Exchange, and Functional Module Reconfiguration

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Innovative Air Mobility is expected to transform logistics, infrastructure inspection, emergency response, offshore operations, and future passenger transportation. However, current air mobility concepts remain strongly dependent on fixed infrastructure, including charging stations, maintenance facilities, vertiports, and droneports. Most unmanned aerial vehicles and future air mobility platforms must periodically interrupt their missions to land, recharge, replace batteries, or undergo mission reconfiguration. These operational interruptions reduce mission persistence, limit scalability, and create significant infrastructure requirements. Recent research has demonstrated significant progress in autonomous aerial docking, including vision-based docking systems and airborne docking guidance frameworks for unmanned aerial vehicles [1,2]. In parallel, automated battery swapping has emerged as a promising approach to extend mission endurance and enable persistent unmanned aerial operations [3,4]. Furthermore, autonomous docking and charging infrastructure concepts have demonstrated the potential for reducing operational downtime and increasing vehicle availability [5]. While these developments represent important advances, existing approaches predominantly rely on ground-based infrastructure or focus on either docking or energy replenishment individually. This work proposes a novel architecture for persistent air mobility based on autonomous in-flight docking and the exchange of both power sources and mission-specific functional modules between aerial vehicles. Instead of requiring a mission vehicle to interrupt its operation and return to a fixed location, a dedicated servicing vehicle autonomously approaches, establishes a docking connection, and exchanges energy or functional modules while the mission vehicle remains operational. The proposed approach extends established rendezvous, proximity operations, and docking principles into the domain of Innovative Air Mobility and investigates their potential to support continuous autonomous operations with minimal interruption [6]. The proposed architecture expands beyond conventional battery replacement concepts. In addition to energy replenishment, mission-specific payloads and functional modules may be exchanged during operation. Such modules may include sensing systems, communication equipment, inspection payloads, computing resources, emergency response equipment, or other application-dependent systems. This capability enables dynamic adaptation of vehicle functionality according to changing mission requirements without requiring a return to base. Consequently, vehicles may be reconfigured during deployment, potentially increasing mission flexibility, asset utilization, and operational efficiency. The concept is particularly relevant for operations where infrastructure availability is limited or where mission persistence is critical. Representative application scenarios include offshore inspection and maintenance, maritime surveillance, infrastructure monitoring, cargo logistics, disaster response, environmental monitoring, and long-duration autonomous operations. In such environments, reducing dependence on fixed infrastructure may significantly improve operational resilience while enabling new mission profiles that are currently constrained by vehicle endurance and servicing requirements. The realization of autonomous in-flight servicing requires advances across several research domains. Reliable relative navigation and positioning must be achieved throughout the docking process, potentially under challenging environmental conditions and in Global Navigation Satellite System denied environments. Furthermore, autonomous docking operations require robust perception systems, trajectory planning capabilities, collision avoidance strategies, and fault-tolerant control architectures. Artificial intelligence and machine learning technologies may contribute to perception, navigation, mission planning, and operational decision-making, while simultaneously introducing challenges regarding verification,

trustworthiness, certification, and regulatory acceptance. From an air mobility ecosystem perspective, the proposed concept introduces an alternative infrastructure paradigm. Rather than relying exclusively on static ground infrastructure, future air mobility networks may incorporate mobile servicing assets that dynamically support vehicles during operation. Such an approach could reduce infrastructure density requirements, increase mission availability, improve operational scalability, and support high-utilization air mobility systems operating in urban, regional, maritime, and remote environments. Furthermore, the concept may complement future U-space ecosystems by enabling autonomous servicing operations that are coordinated within digitally managed airspace environments. A conceptual evaluation of the proposed architecture suggests several potential benefits. First, mobile servicing assets may reduce dependence on fixed infrastructure and associated operational constraints. Second, the integration of autonomous docking with power source and functional module exchange may increase mission persistence and vehicle utilization. Third, the approach may enable new operational concepts for offshore, maritime, and remote-area missions where access to infrastructure is limited. These findings indicate that autonomous in-flight servicing could become an enabling technology for future scalable air mobility ecosystems. This paper discusses the underlying architecture, identifies key technical challenges, and outlines future research directions necessary for implementation. Particular attention is given to autonomous docking operations, mission persistence, operational safety, infrastructure implications, and integration within future Innovative Air Mobility ecosystems. The principal contribution of this work is the introduction of a mobile infrastructure paradigm based on autonomous in-flight exchange of power sources and mission-specific functional modules. To the author's knowledge, existing research has not investigated the integration of autonomous aerial docking, energy replenishment, and functional mission reconfiguration into a unified architecture for persistent air mobility operations. The presented work aims to stimulate discussion regarding the role of mobile infrastructure and autonomous servicing technologies in the development of next-generation Innovative Air Mobility systems.

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Biography

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