Urban Air Mobility: Regulation and Control of Vertical Takeoff and Landing Vehicles

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Abstract— **Urbanization directly and indirectly affects many of the UN sustainability challenges. Urban mobility is one of the key issues, directly impacting the access to good and services, quality of life and the environment. In the past few years, aerial transportation for cities grew out of the science fiction domain to reality. The domain of Urban Air Mobility (UAM) was born to leverage the sky to better link people to cities and regions, providing scalable possibilities to connect. The number of Vertical Takeoff and Landing (VTOL) vehicle projects is rapidly growing in both commercial and recreational applications. These aerial systems are currently mostly used for surveillance, mapping and delivery, however, mature research and development projects are reported from all over the world, targeting human-operated or autonomous passenger transport vehicles. The anticipated massive spread of VTOL aircrafts will radically change the cityscapes. While opening up the urban space to elevated traffic, major safety and environmental concerns arise. Therefore a global, harmonized regulation is needed for the domain, primarily focusing on the safety of these new vehicles.**

Index terms—**Urban Air Mobility, Smart City, Autonomous Vehicle Safety, Flying Cars Regulations**

I. Introduction

Sustainability of the urban environment is a critical issue [1].

Flying cars, or more exactly, technology referred to as Vertical Takeoff and Landing vehicles (VTOLs) are considered to be the next great step in the evolution of passenger transportation. However, similarly to the current status of autonomous ground vehicle development, their legislation and regulations are lagging behind their technological maturity. In the past years, initiatives have been formed around the world to address regulation issues, which are dominantly derived from best practices regarding drones or UAVs (Unmanned Aerial Vehicles), although the regulatory bound to autonomous vehicles also serve as a baseline for these initiatives. It is a common view that (electric) VTOLs will be autonomous, provided that by the time the underlying technology of flying cars will be advanced enough for global deployment, the autonomous vehicle technology will have been proven its maturity.

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The definition and categorization of VTOL aircrafts, along with their comprehensive environmental impact assessment are constantly evolving. Yet, it is arguably an underdeveloped area, limiting the widespread use of VTOLs in industry, commerce and transportation. This paper reviews the most important safety and regulatory aspects of passenger VTOL vehicles, discussing the possibility of transition of existing ground autonomous vehicle regulations to aviation, aiming to establish common grounds for current and future research. There are four key aspects of this domain's sustainable development:

- Technology development: we have seen an unprecedented growth in VTOL concepts and prototypes, providing a good basis for future Urban Air Mobility services.
- Airspace management: a vertical control system of radars, beacons, flight-management services, communication systems and integrating servers are needed to coordinate, organize and manage all UAV traffic. This is called the Unmanned Traffic Management (UTM) system.
- Regulatory framework: transparency and liability must be increased in the sector, especially given the high number of start-ups (new players) and AI-incorporated (unproven) technologies.
- Infrastructure: needs to find new way to leverage existing infrastructure, such as creating over-the-roof landing sites for VTOLs.

In all these domains, autonomy plays a key role, therefore it offers an opportunity to link the global aerial robot developer and autonomous aerial system regulatory community together[1].

II. State-of-the-art and key concepts

Autonomous vehicles are designed to operate in symbiosis with traditional, human-operated vehicles, sharing the infrastructure and physical space at all times. As a result, they need to respond to unexpected changes in the local environment, e.g., road works and traffic police gestures, a wide range of visibility and traffic conditions. Clearly, VTOLs are not subject to most of these boundaries, as during point-to-point traveling, no physical obstacles or changing road/path conditions occur. However, take-off and landing, along with low-altitude flying, are posing new challenges, even though

[1]https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/air-mobility-solutions-what-theyll-need-to-take-off

the supporting technology has been widely used in the past 50 years in commercial aviation.

In the past years, the number of commercial drones has increased rapidly, revolutionizing discovery, delivery and surveillance services. Regulations may vary among countries, targeting general use (e.g., flight zones, insurance, licensing or training) and technical requirements (e.g., build, flight altitude) [2]. The amount of regulations targeting the take-off and landing sequences of VTOLs is limited, although flying cars are expected to be able to use any suitable runway, highlighting the importance of collision avoidance and path planning.

Surveys have also been designed to model competition among an electric air taxi service, autonomous ground vehicles and traditional ground vehicles for an urban commuting context in the United States of America, highlighting that beyond technological and regulatory aspects, individuals' perceptions and attitudes influence the pace of introduction of this novel mean of transportation [3].

Some of the terms frequently used in this paper have been defined similarly throughout the literature in the past years. When referring to them, we used the guidelines set by the following definitions:

- *Unmanned Aerial Vehicle (UAV)* or *Unmanned Aircraft (UA)*: a more generic term for an aircraft without a human pilot on board. A UAV is a component of an unmanned aircraft system, which includes the vehicle, a ground-based controller, and a system of communications between the two.
- *Drone*: in this context, it means an aircraft without a human pilot on board, interchangeable with UAV. Originally, it referred to any vehicle that can operate without a drive or pilot inside it.
- *VTOL*: A vertical take-off and landing vehicle is one that can hover, take off and land vertically, regardless of its control mode.
- *Flying car*: a common language term for a type of personal air vehicle or roadable aircraft that provides door-to-door transportation by both ground and air.
- *Autonomous ground vehicle* (for reference): in this context, a surface vehicle equipped with L3 (partial) or higher level of automation by the definition of the Society of Automotive Engineers (SAE).

III. Regulations

A number one priority for establishing a safe UAM ecosystem is an embracing, yet safety-concerned regulatory environment.

Currently, regulations are lead by individual national bodies, formalized, along four aspects of the operations: drone mass, population density, altitude and use case. Surveys have identified six approaches to national commercial drone regulation, which can be directly transferred to future regulations of VTOLs. Note that these components are not relevant to the ground autonomous vehicles, leaving space for improvement and elaboration of this topic [2].

1) Outright ban: Commercial use of drones is not allowed.
2) Effective ban: Formal processes exist for commercial drone licensing. It is not uncommon that these requirements are either impossible to meet or there is a systematic disapproval of licenses.
3) Requirement for constant visual line of sight (VLOS): A drone must be operated within the pilot's visual line of sight. Range, altitude and operational domain are limited this way.
4) Experimental uses of beyond visual line of sight (BVLOS): With certain restrictions and pilot ratings, exceptions to the constant VLOS requirement are possible.
5) Permissive: Relatively unrestricted legislation in commercial drone use. A regulatory body exists that may give operational guidelines or require licensing, registration, and insurance. Following the required procedures, the operation of commercial drones is straightforward.
6) Wait-and-see: Little or none of the drone-related legislation was enacted, the outcomes of other countries' regulations is monitored.

In December 2020, the US Federal Aviation Administration (FAA) announced final rules for Unmanned Aircraft, in general. According to the new rules, a Remote Identification (Remote ID) will be required for drones, allowing operators of small drones to fly over people and at night under certain conditions. The press release mentions that as of December 2020, there are over 1.7 million drones registered in the US, operated by more than 203,000 FAA-certificated remote pilots [4].

EU Regulation 2019/947 was applied on December 30, 2020 by the European Union Aviation Safety Agency (EASA), addressing most types of operations and their levels of risk. It defines three categories of operations [5]:

- Open: operations in the lower risk bracket, where safety is ensured provided the drone operator complies with the relevant requirements for its intended operation. Three further subcategories were added. Risks in this category are considered low, and therefore no authorisation is required before starting a flight.
- Specific: riskier operations, where safety is ensured by the drone operator obtaining an operational authorization from the national competent authority before starting the operation. The drone operator is required to conduct a safety risk assessment in order to obtain this authorization.
- Certified: the safety risk is so high that certification of the drone operator and the aircraft is required to ensure safety, as well as the licensing of the remote pilot(s).

The European Union member states are required to comply with these regulations. These countries are allowed to complete the existing regulations as long as the added paragraphs do not soften the original regulatory rules. Additionally, state-level documents do not have to re-list the EU-level regulations, as the two documents complement each other.

IV. Safety

The overall aim of regulatory bodies is the increas produc safety, both in terms of technical safety, ensuring product/service reliability, and transportation system integrity, which means that the UTM can ensure the safe ensemble of existing road/aerial traffic and the novel, 3D layout of trrafic routes.

The popularity of drones and UAVs increased the demand for unified policies and regulations to support commercial VTOL applications. As the technology is reaching maturity, this requirement has increased further recently. It is expected that passenger drones/VTOLs may become widely available and operation by 2030, though the operation is expected to remain semi-automated [6]. At the current stage of VTOL development, autonomous ground vehicle industry can serve as a guideline for increasing public awareness and acceptance of the technology, gaining support to accelerate regulatory administration. However, publicised adverse safety incidents can affect the perception of the public and limit the pace of acceptance, as clearly shown by prior recent accidents by Uber and Tesla [7].

A particular, and arguably the most challenging safety-related task regarding VTOLs is the regulation of takeoffs and landings, i.e. going airborne with the vehicles and returning to the ground. There is a need of a complex safety risk analysis to adhere to the requirements of national airspace agencies. In the US, it is overseen by the NAS (National Airspace System) [8]. When the problem is approached from the traditional aviation regulatory point of view, it is crucial that the operation, navigation and motion control of the VTOLs is system-wise redundant, and the redundancy is ensured by a physically separated backup system. It is also required that even manned VTOLs are capable of moving to safe state during flight, similarly to the requirements of autonomous ground vehicles at SAE L4 autonomy [9]. Other (primary) regulatory bodies should be involved in assigning minimum safety standards (such as FAA in the US), which can be mandated by private air traffic controllers in individual countries or states [10].

Adverse weather conditions also weigh in for VTOL safety regulations. Snowstorms, high wind and heavy rain may not only degrade the sensing capabilities of the vehicles and human operators, but may also affect the motion stability of the vehicle itself. Both automotive and aviation industries offer certified simulation environments for hardware-in-the-loop testing that may be used for VTOLs in order to set safe operation domains. Decision factors include wind speed, precipitation intensity and type, visibility conditions etc., which may all differ among prototypes and commercially available vehicles. Simulation environments will require advanced dynamical and environmental/weather models, and these can also serve as a training and pilot certification environment for human-operated VTOLs. Among others, these aspects were also considered in the formulation of dedicated certification and test centers[2].

[2]https://mydronespace.hu/

A. *Autonomy everywhere – SAE classification*

A first step in creating a consensus on development, application and scaling of UAM is the proper identification of the related technologies and challenges, wherein autonomy takes priority.

In recent years, manufacturers and regulatory bodies initiated multiple public discussions for defining the "level of autonomy" of a ground vehicle. They investigated the human–machine roles in environment monitoring and decision making, along with the intended use-case. The first definition was created by the National Highway Traffic Safety Administration (NHTSA) in 2013 [11]. SAE International (established by the Society of Automotive Engineers) developed a new taxonomy marked J3016_201609, suggesting six levels of automation in a functionally consistent and coherent manner, as discussed in details in [12], [13]. This LoA approach has already been applied successfully to other safety-critical domains, such as surgical robotics [14]. Drone Industry Insights proposed a similar 6-level drone automation scale based on the SAE taxonomy, taking real-life examples from the unmanned drone industry, as shown in Fig. 1 [15]. The authors argue that the the frequency and volume of data, and the sophistication of the on-board computers are posing a limiting factor for higher levels of drone autonomy, adding that there is no regulatory base for allowing the commercial use of level 5 drones.

- Level 0: No drone automation. The pilot is in full control of every movement, drones are controlled 100% manually at all times.
- Level 1: Pilot assistance. The pilot remains in control of the overall operation and safety of the vehicle, one vital function can be taken over by the drone.
- Level 2: Partial automation. The pilot is still responsible for the safe operation of the vehicle and must be ready to take control. The drone is able to take over control in terms of heading, altitude and speed, under human supervision.
- Level 3: Conditional automation. The drone is equipped with limited perception and decision making during the flight, and notifies the pilot if intervention is needed.
- Level 4: High automation. The drone is capable of automatic navigation and flight control, but it includes backup systems and remains operational after a single system failure.
- Level 5: Full automation. The drone can handle all aspects of the flight, from takeoff to landing, carrying out its intended tasks, e.g., delivery, inspection or mapping.

While drones are traditionally small and agile, VTOLs are expected to be more bound to infrastructure regulations, with a more distinguished tasks to be carried out during flight. This affects how the levels of autonomy should be defined for takeoff and landing, cruising and other tasks. Due to the fact that VTOLs are intended to carry human passengers at critical heights, decision making, collision avoidance and safe state transition are crucial along with reliable handover mechanisms for partial and conditional automation, or their

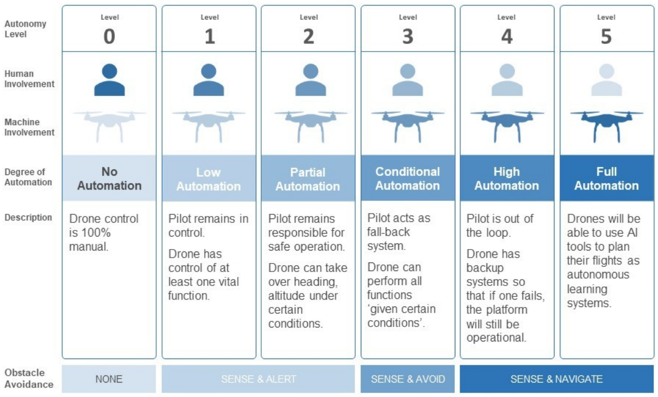

Fig. 1. Drone regulations: a similar classification to the one defined by SAE for surface vehicles. *Image credit: Drone Industry Insights.*

equivalent for VTOLs. The proposed levels of autonomy for VTOLs are shown below.

V. Infrastructure requirements

It is argued that an optimally functioning network of VTOLs offers a clear navigational benefit to passenger and freight transport at a fraction of the average journey time required by ground transportation – comprising an efficient UAM ecosystem. A traditional ground journey of 20 minutes is constrained by congestion, road geometry and geography/topography, while a direct flight path redeems these constrains and reduces the end-to-end travel distance by 60%. Naturally, in the latter case, the infrastructure needs to be ready for allowing takeoffs and landings, VTOL parking/storage. In literature, these sites are referred to as *vertiports*, whose standardization and certification procedures are also a topic being addressed by regulatory bodies [16]. Regulations are often derived from existing, enacted guidelines, such as high-rise helipads (helicopter takeoff and landing sites) and ground aircraft landing lots. The layout, specifications and design of vertiports is subject to optimization, which is dominantly done by Monte Carlo simulation and supporting heuristic optimization techniques, in order to guaranty passenger safety and maximize efficiency [17]. However, a point-to-point direct flight may increase the traffic control complexity, when the number of operational VTOLs reaches a critical level. NASA proposed constrained flight corridors, strategically located over low-risk areas, considering noise pollution, damage mitigation and traffic flow optimization [18].

The functional range of motion of VTOLs in another critical area, which shall see new requirements based on testing and simulation. Sustainability and cost efficiency are the two major factors, however, aerodynamic properties, VTOL geometry and the landing/takeoff site availability introduce new boundary conditions for the 3D path planning problem. Path planning efficiency also affect the operation strategy of ridesharing companies, such as Uber of Lyft, who already expressed their interest in extending air taxi services to ridesharing. In metropolitan areas, it is expected that these services will be allowed in a dedicated airspace, however, federal regulators prefer the introduction of an integrated airspace based on a holistic approach, which is shared by all VTOLs (commercial or personal) [19].

Infrastructure related regulations and policies need to consider the power and accumulator charging constrains of the operation domain. Similarly to electric ground vehicles, energy density, cost-effectiveness an battery life cycle are all limiting factors in the supporting technology, however, given the interest of stakeholders and forecasted market size (est. \$498m in 2019, reaching \$3583m by 2030), improvements are expected to reach commercial use in the near-term [20]. VTOLs are envisioned to be equipped with split power engines, separating the source of rotational force from the rotation speed itself [21]. Thus, novel policies will need to consider the navigation and maneuverability capabilities of VTOLs, and technical requirements need to be met both from the infrastructure and vehicle design aspects.

Additional regulations need to be created regarding the user interface for both human-operated and autonomous VTOLs, that would partly or entirely redeem the traditional infrastructure interface for ground transportation, such as road markings and topology, traffic signs and artifacts. It is evident that the efficiency of levitated road side markers and intersection control units is low, therefore advanced navigation software, augmented reality based user interfaces and novel information systems need to be introduced into VTOLs, if not operated remotely. Regulations would monitor and set requirements for heads-up display units aiding navigation, along with the customizable software and standardized ground communication protocols.

VI. Discussion

The global urbanization rate is rapidly growing, putting up great challenges in maintaining urban mobility levels and setting our cities on a sustainable development path. The need to open to vertical with Urban Air Mobility is particularly urging in the USA, where drivers waste over 3 bn gallons of fuel annually and 7 bn extra hours stuck at traffic annually [22]. It is believed that focused research and standardized regulatory requirements would facilitate the spread of VTOLs and other UAM systems, leading to a sustainable urban mobility environment. This paper identified and discussed some of the key open issues on this development roadmap, and proposed some classification framework along urging for fair and transparent categorization and regulation directions.

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