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Operational Requirements Analysis for Electric Vertical Takeoff and Landing Vehicle in the Brazilian Regulatory Framework

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ABSTRACT

Air passenger transport is expected to change, in the next years, the urban air mobility (UAM) environment. New technologies are enabling the introduction of a new concept of aircraft, referred to as electric vertical takeoff and landing vehicle (eVTOL), with vertical take-off and landing capability, distributed electric propulsion system and low noise level compared to helicopters. This article presents an analysis of the Brazilian Civil Aviation Regulations (RBAC) No. 91 and 135, which address the minimum requirements for commercial operations of commuter and on-demand public passenger transport with airplanes with up to 19 seats. The objective of this article is to identify the technical and regulatory barriers to initiating the eVTOL operation in Brazil and to validate the current operational air traffic rules. After the analysis of the operational requirements and the current Air Traffic Management (ATM) infrastructure for helicopter operation, the minimum required and recommended navigation, communication and surveillance equipment are identified, as well as the main operational limitations for the operation of this type of aircraft in transporting passengers. This analysis is just the beginning of a broader study and there are many challenges to support an increased eVTOL operations.

Keywords: eVTOL; ATM system; eVTOL certification; Urban air mobility.

INTRODUCTION

The urban air mobility (UAM) scenario is going to be modified in the upcoming years with the release of a new mode of transportation using aircraft with electric propulsion, low noise level and with the capacity to perform vertical takeoff and landing.

The main utility of this new type of aircraft will be in the commercial transport of passengers and cargo in urban environments. The aeronautical industry is developing some new aircraft concepts denominated electric vertical takeoff and landing vehicle (eVTOL) in order to improve UAM in metropolitan areas.

The operation of these aircraft, according to several studies that have been already published, will be carried out in different phases depending on the operation's density and level of automation. This article is limited to manned eVTOL operation, with

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the intent to identify possible legal obstacles and to validate the current Brazilian aeronautical regulations applicable to scheduled and on-demand services public transport. The initial operation should take place in low density and complexity operation and under the existing Air Traffic Management (ATM) system.

Based on the concepts of conducted studies and on the current aeronautical regulations, the proposal of this article is to determine the feasibility of the commercial operation of a manned eVTOL, within the current ATM system installed in Brazil, without the need for extensive changes in regulatory and infrastructure in the ATM framework to support the operation of an aircraft with different design and operation specifications compared to conventional aircraft.

The main objective, therefore, is to validate the available embedded technology and the current operational regulatory framework as being compatible for safe eVTOL operations in the UAM environment.

METHODOLOGY

This article is an exploratory research of qualitative and applied nature, with the objective of analyzing documents, applied to the commercial operation of carrying-passenger transport and to the current ATM infrastructure, to validate the initial eVTOL operation in Brazil.

Bibliographic documents published by the industry and existing aeronautical legislation was reviewed with the intent to assist the development of the proposed study.

Finally, a list of mandatory and recommended navigation, communication and surveillance equipment is identified that complies with the current operational requirements applicable to airplane and helicopters.

RESULTS AND DISCUSSION

Analyses of Operational Requirements for the Application of EVTOL in UAM Environment

Several studies have assumed that regulatory and technical changes will be needed that aim to allow thousands of eVTOL to operate simultaneously in shared airspace with traditional aircraft, such as helicopters. However, the horizon that enables a high-density operation of eVTOL is a far-term vision from the current scenario presented by the industry. For the entry into service of the eVTOL in the UAM environment, a low demand for aircraft operating commercially in the transport of passengers is expected. For this reason, after certification of the first eVTOL, it is assumed that no adaptations to regulations and current ATM infrastructure will be required to support eVTOL operation similar to helicopters operations in visual corridors.

The use of the shared airspace with general aviation and helicopters may slightly increase the workload of air traffic controllers and possibly frequency congestion. Thus, this article consists of analyzing the Brazilian legislation and the current ATM system to validate the initial eVTOL operations.

Urban Air Mobility (UAM)

UAM is defined as a subset of a broader concept called Advanced Air Mobility (AAM), according to the document "Concept of Operations v1.0," published by the Federal Aviation Administration (FAA 2020a). While AAM refers to air transport operations of cargo and people in large urban centers and between cities, the UAM concept focuses only on the urban and suburban environments.

Recently, significant technological advances in the electrical energy storage (batteries capacity) allowed the design of aircraft with a distributed electric propulsion system, providing a reduction of operating costs and noise emission, in addition to increased safety (FAA 2020a). The introduction of the UAM concept presents new approaches to the aviation sector, which will allow a new way of transportation providing alternatives to the current modes of ground transportation in this environment.

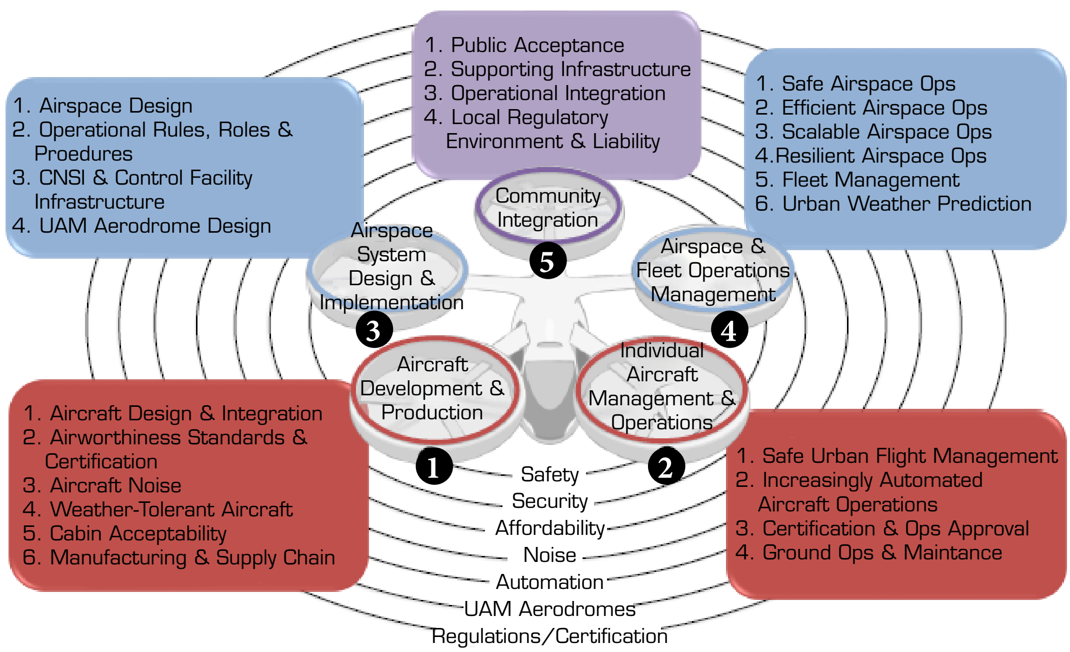
In this context, many companies have been designing and testing prototypes of eVTOL, with vertical takeoff and landing capability, to be operated within this urban operating environment and in accordance with this new commercial aviation business model (Booz Allen Hamilton 2018).

Challenges of UAM in the ATM context

There are indications that many different eVTOL's configurations will be introduced in the airspace. There will be an increasing frequency of air operations when compared to the existing air traffic. Thus, new capabilities of the aircraft and the ATM system will be required to support the demand of the intended operations.

The National Aeronautics and Space Administration (NASA 2020), in its study "Urban Air Mobility Operational Concept (OpsCon) Passenger-Carrying Operations," considered several typical missions for commercial passenger transport. Based on the proposal for this new model of transportation, multiple barriers were identified for carrying out these missions related to the UAM vision.

The UAM scenario, as depicted in Fig. 1, is represented by five pillars containing the technical and regulatory barriers identified for each of the indicated pillars. This article focuses on barriers related to two different pillars of the proposed organizational structure: *Individual Aircraft Management & Operations* and *Airspace System Design & Implementation*. Pillar 2 addresses the challenges related to operations accuracy, pilot scalability and operational safety, including operational approval and certification for this new air operation model. Pillar 3 addresses aspects of air traffic infrastructure and operating rules for UAM, including equipment to enable secure communication, navigation and surveillance.



Source: Retrieved from Patterson *et al.* (2021, p. 4).

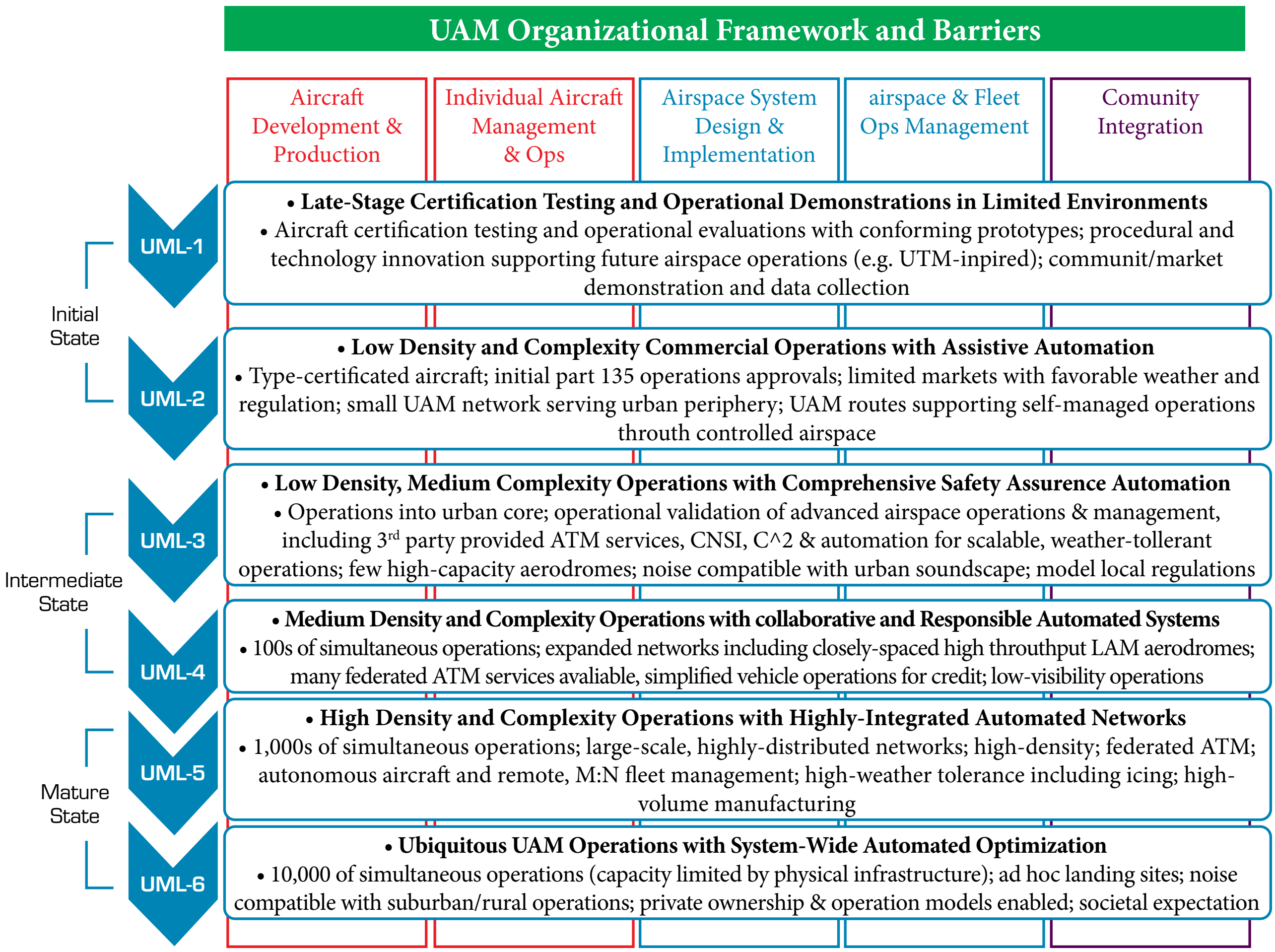
Figure 1. Barriers associated with the five pillars of NASA's UAM organizational framework.

This article is based on some aspects addressed in the analysis of two technical and regulatory barriers identified by NASA (2020), with the objective of identifying and validating the existing operational procedures and rules applied for helicopter operation, which can also be applied for the entry into service of the eVTOL.

One of these barriers, described in the context of pillar 2, is identified as *Certification & Ops Approval* and is associated with challenges that need to be overcomed to enable eVTOL operations in the UAM environment, considering the existing regulatory and technological aspects for carrying out commercial air operations. Another barrier identified is described in pillar 3, called *Operational Rules, Roles, & Procedures*, which deals with regulatory and technical challenges for defining operational rules and procedures, as well as proposals for new concepts of airspace management, which will allow safe and reliable eVTOL operations.

In order to contributes to the necessary evolution of the current ATM infrastructure to efficiently and safely support the high demand of eVTOL operation, NASA developed the UAM Maturity Level (UML) scale, which defines the stages of the entire evolution of the UAM ecosystem (Fig. 2).

The purpose of this scale is to progressively show the six stages that must be considered to overcome the barriers identified for each pillar of the UAM organizational structure (Patterson *et al.* 2021).



Source: Retrieved from Patterson *et al.* (2021, p. 5).

Figure 2. Description of the UMLs.

The levels of this organizational structure evolve from the initial state to the greater operational maturity state, being represented by the stages from UML-1 to UML-6. The UML-1 stage represents the initial phase of eVTOL development with experimental testing using prototypes. This article focuses on the analysis of operations characterized by the initial UML-2 stage, defined as *Low Density, and Complexity Commercial Operations with Assistive Automation*, which involves low density and complexity commercial operations of type-certified eVTOL, considering small increment in the aircraft's flight control level of automation. The commercial operation, at UML-2 stage, is limited only to manned flight.

According to NASA (2020), the entry into service of the eVTOL at UML-2 stage will be based on commercial operations conducted in urban environments under the regulation 14 Code of Federal Regulations (CFR) Part 135, issued by the FAA, that regulates commuter and on-demand public air transport operations. At UML-2 stage, helicopter special routes are the proposed solution to support operations in the UAM environment, under the existing airspace management system.

Proposed concepts of eVTOL in development

In this UAM scenario, many traditional technologies will be incremented to meet the need for the eVTOL operating environment, increasing the level of automation of the systems embedded in the aircraft. Therefore, new design features and emerging technologies will accelerate the start-up of eVTOL in the near horizon.

Definition of eVTOL model for analysis

There are many eVTOL concepts under development that apply new technologies to enable efficient and safe operation in the urban environment, without degrading operational safety. Lesser-known or startup companies and traditional manufacturers with great experience in the aeronautical field are developing eVTOL introducing distributed electric propulsion systems (which improve people's perception of reducing the emission of environmental and noise pollutants), multiple rotors, high voltage batteries for energy storage, composite materials, and modern manufacturing techniques.

NASA conducted a market survey and identified potential eVTOL projects under development (Booz Allen Hamilton 2018). Based on the comparison of the technical specifications presented in the analysis for each selected eVTOL and other additional public information (Vertical Flight Society 2021), the eVTOL model is defined as reference considering the most critical characteristics to ensure the representativeness of the operational requirements analysis in the context of the existing ATM system. Therefore, for the evaluation of the UAM operation scenario in Brazil, the most critical conditions of existing projects for each of the characteristics presented for the hypothetical eVTOL model have been considered (Table 1).

Table 1. The eVTOL model proposed as reference for analysis.

Maximum range (km)	MTOW (kg)	Engine type	Wingspan (m)	Length (m)	Cruising speed (km/h)	Operation altitude (m)	Maximum passenger capacity	Flight configuration
40	3175	Electric	14	8.5	250	300	4	Multirotors + wing

Source: Elaborated by the authors.

The maximum range of 40 km was defined as the shortest range among the projects, which covers most of the city of São Paulo for this study. The maximum takeoff weight (MTOW) of 3,175 kg is a reference adopted from the European Aviation Safety Agency SC-VTOL (EASA 2019) and FAA 14 CFR Part 27 (FAA 2018) regulations, which covers the operation of most conventional helicopter models on existing helipads. The foundation of the concept for the eVTOL operation refers to low noise levels compared to helicopters, distributed electric propulsion system, combined with a single pilot operation over densely populated metropolitan area. The maximum passenger capacity is between 2 and 6 and the average operating altitude is close to 300 m in a UAM environment, which may change depending on the rules adopted by the local aviation authority.

This proposed eVTOL model will be used as reference for the operational requirements analysis, adopting the most critical conditions among all known projects in the initial development phase. It is important to note that, so far, there is no eVTOL certified and operating in an UAM environment.

eVTOL's airworthiness standards and certification

It is assumed that the eVTOL model adopted as a reference must comply with all airworthiness requirements and safety standards required to certify this new type of aircraft. New operating specifications and emerging technologies are being incorporated into the eVTOL projects under development, characterized with the capacity to land and takeoff vertically with rotors driven by distributed electric propulsion, automated flight control system, high voltage batteries, among other factors.

There are a variety of eVTOL concepts, which can be configured with fixed-wing or rotary-wing aircraft characteristics (Booz Allen Hamilton 2018). For this and other factors discussed, the eVTOL certification process is one of the barriers identified by NASA for the UAM ecosystem and, according to Graydon *et al.* (2020), the certification path to be followed will depend on the adopted configuration of the vehicle.

Therefore, depending on the eVTOL design configuration, it may be certified as normal category aircraft under 14 CFR Part 23-64 (FAA 2016) or as rotary-wing aircraft according to 14 CFR Part 27-49 (FAA 2018). The EASA published a special condition (SC-VTOL) for eVTOL with MTOW up to 3,175 kg and maximum passenger capacity with up to nine seats (EASA 2019).

eVTOL operational models for passenger-carrying missions

NASA (2020) proposes in its study that the commercial operation of eVTOL in the USA can be established under the current aeronautical regulation's framework, such as the FAA operational regulation 14 CFR Part 135. In Brazil, the related regulation is the Brazilian Civil Aviation Regulation (RBAC) 135, published by the Civil Aviation Agency of Brazil (ANAC 2021a), which regulates public air transport operations of airplanes with a maximum certified seating configuration for passengers of up to 19 seats and maximum payload capacity of up to 3,400 kg (7,500 lb), or helicopters.

Considering the different concepts under development and the eVTOL's characteristics suggested as reference for this article, the most probable application should be as scheduled or on-demand commercial operations conducted under the regulation 14 CFR Part 135-142 (FAA 2020b).

Within the scope of the regulation, several types of missions in the UAM scenario have been considered for carrying-passenger transport. Based on the technical and operational capabilities of eVTOL, some mission profiles have been proposed (Patterson *et al.* 2018):

- Routine trips around and within cities, commuting people to/from work;
- Airport shuttles;
- Transfer from one side of town to another to avoid heavy traffic; and
- Passenger connections to other existing forms of transportation.

Considering the missions proposed in the UAM domain, Table 2 shows five different types of operation models for commuter and on-demand passenger transport, most of which are characterized as non-scheduled public air transport. These operation models are not necessarily connected to a specific example of a mission profile presented by Patterson *et al.* (2018). Several of these UAM missions may be conducted within any of the operational models regulated by 14 CFR Part 135 (FAA 2020b).

Table 2. Typical characteristics of the different operational models.

Operational Model	Approx Number of Passengers	Operating Regulations
Private Service	1-6	Part 91
Air Taxi	1-4	Part 135
Air Pooling	3-6	Part 135
Semi-Scheduled Commuter	6-19	Part 135
Scheduled commuter	6-19	Part 135 or 121

Source: Retrieved from Patterson *et al.* (2018, p. 3).

The current RBAC 135 establishes minimum requirements for the commercial operation of aircraft and helicopters. In addition to this regulation, air service operators must also comply with RBAC 91 (ANAC 2021b), which regulates the general operating requirements.

Additionally, the Brazilian airspace is governed by special air traffic rules and procedures for aircraft and helicopters, defined by the Department of Airspace Control (DECEA). There are interactions between the operational requirements established by ANAC and the rules and procedures applicable for the airspace stated by DECEA for the definition of navigation, communication and surveillance equipment required for commercial operations in Brazil. All regulations and operating procedures issued by these aeronautical aviation authorities must be adhered to ensure safe and reliable operation of the eVTOL in the UAM environment.

Requirements for initial operation of eVTOL in Brazil

Initially, eVTOL operations are expected to be conducted in accordance with the current ATM system's regulations and procedures. Considering the introduction of eVTOL into the air transport system in low density operation, current rules and procedures, established for the existing ATM system framework, can provide the oversight of the UAM operations. It is expected a higher density and complexity of operations in the future, requiring changes to the existing ATM system also shared with conventional aircraft, such as helicopters.

The eVTOL, in the UAM domain, will perform intended missions with a vertical takeoff and landing capability similar to helicopters. However, due to unique configuration, there are differences between eVTOL and helicopters' characteristics. Supported by the existing ATM system framework, the enter into service of eVTOL at UML-2 stage will require voice communication capability, navigation and surveillance equipment, required by both RBAC 91 and 135 operational regulations and all existing Brazilian air traffic procedures, likely to helicopters on operations in conventional visual corridors.

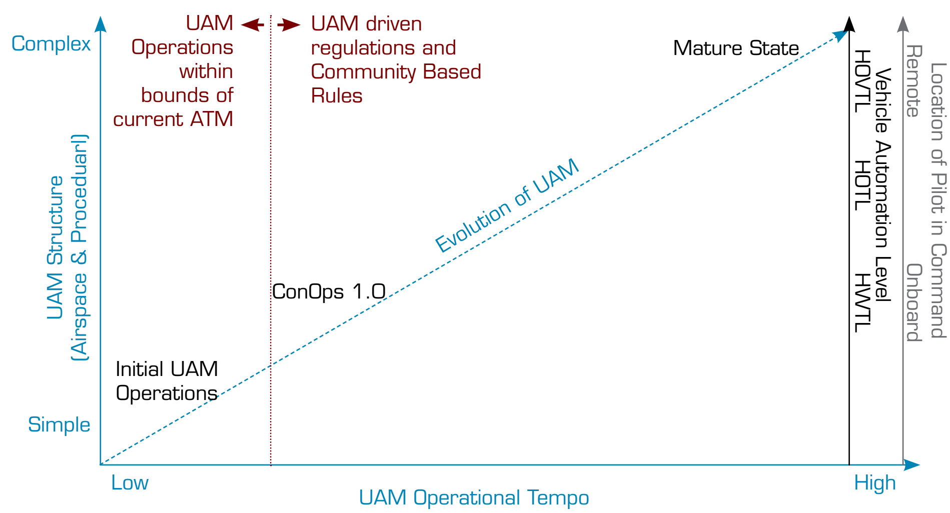
Definitions for operational requirements analysis

Along with carrying-passenger on-demand transport, UAM operations should maintain an equivalent or higher safety level than that established to the current operational safety standards required for public transport operations conducted under the US regulation 14 CFR Part 135 (Deloitte Consulting 2020). Initial eVTOL operations will be conducted by aircraft type certificated in accordance with the airworthiness requirements and consensus standards applicable to this type of aircraft.

The FAA (2020a), in its study to establish the UAM concept of operation, defines that the evolution of the air mobility operational environment should occur at different stages of maturity: 1) Initial UAM operations, 2) ConOps 1.0 (Concept of Operations) and 3) Advanced stage operations.

Therefore, the stage defined for Initial UAM Operations (FAA 2020a) and UML-2 (NASA 2020) are expected operational scenarios for the introduction of eVTOL to conduct low density and complexity commercial operations. It is important to register that fully autonomous eVTOL operation is not expected to occur in the near horizon, due to the absence of appropriate regulations and onboard navigation and surveillance technologies that are adequate and available to support a high density and simultaneous eVTOL operations.

The FAA (2020a), as indicated in Fig. 3, defined the first stage of evolution of the UAM operating environment as being represented by a low operational density, simplified aircraft level of automation with the pilot-in-command always on board in direct control of the aircraft systems (human-within-the-loop) and, finally, use of the existing airspace infrastructure used for the operation of conventional helicopters.



Source: Retrieved from FAA (2020a, p. 8).

Figure 3. Evolution of the UAM Operational Environment.

The analysis of the eVTOL operation in large cities, such as São Paulo, considers key assumptions to evaluate the Brazilian Civil Aviation Regulations, applicable to the scheduled and nonscheduled commercial operations. Based on the characteristics of the identified configurations, the eVTOL model, proposed as reference for this article's analysis, may be defined as a powered-lift aircraft, capable of vertical takeoff and landing flights and nonrotating airfoil for lift during horizontal flights. NASA (2020) classifies a powered-lift aircraft as a non-traditional aircraft, compared to conventional fixed-wing aircraft designs and rotary-wing aircraft such as helicopters.

Due to the MTOW of 3,175 kg, defined for the eVTOL model, it is characterized as a small aircraft and applicable for commercial passenger transport, whether regional or in an urban environment. Existing regulations do not fully address the new technologies and typical operational characteristics expected for this new aircraft model in the UAM domain.

Although there is no specific operational regulation for eVTOL classified as powered-lift, the objective of this article is to validate the current requirements for operation at UML-2 stage and to identify possible restrictions or regulatory barriers in the Brazilian Civil Aviation Regulations framework for public air transport. The RBAC 91 and RBAC 135, regarding the applicability of operational requirements for aircraft equipped with piston or turbine engines, there are no references to new technologies in current regulations, such as aircraft with a distributed electric propulsion system with multirotor. Therefore, the definitions stated in regulations for the propulsion system should be disregarded from the analysis. For the validation of navigation, communication and surveillance equipment required for passenger-carrying UAM transport in Brazil, under the existing ATM system, key assumptions should be considered to apply for the eVTOL applicability.

At UML-2 stage, this analysis should consider the unique design and operational characteristics of this type of aircraft, in addition to the capacity of the ATM system. For this study, therefore, the initial operation of eVTOL in Brazil is limited to: 1) Day and night operation under visual flight rules (VFR) conditions; 2) Flight over densely populated areas; 3) Commercial operation of passenger and cargo transportation; 4) Use of registered or certified infrastructure; and 5) Single pilot operation.

There was a variety of operational limitations that must be established at the initial stage of operation to maintain an adequate operational safety level. In this context, considering the existing operational requirements, the following constraints should be considered: 1) Operation under instrument flight rules conditions; 2) Extended overwater operation; 3) Operation with two pilots; 4) Operation over uninhabited terrain areas; and 5) Flight in adverse weather conditions, including icing.

Defining the eVTOL assumptions and limitations for the initial stage of operation, it should be outlined that these new aircraft models will share the same helicopter special routes (HSRs), simplifying and ensuring the operational safety of the ATM system. According to DECEA, HSRs are established with the purpose of exclusively allowing visual helicopter flights under specific conditions. Under the context of UAM, the use of HSRs will provide to the eVTOL, in such manner, the capability to safely landing at a suitable area away from people and properties on the ground.

Therefore, it is critical that the UAM aircraft operations be supported by an operating environment designed to promote cooperative operations in the airspace shared with conventional helicopters and general aviation.

Required equipment for operation and other limitations

EmbraerX and Airservices Australia (2020, p. 23) define Horizon 1 as the introduction of eVTOL operation managed by existing procedures and technologies within the current ATM system paradigm. The operations will start with low density and complexity with manned eVTOL, according to current operational and air traffic rules. Therefore, the eVTOL will have on board pilot, requiring voice communication capabilities as part of the flight information exchange between the pilot and the entire ATM system. During the Horizon 1 phase, similar concept to the UML-2 stage, the existing ATM practices for airspace clearance will be the same as those applied for other types of conventional aircraft, such as helicopters. Therefore, for the introduction of the operation, the eVTOL will not have guaranteed or priority access to shared airspace (Embraerx and Airservices Australia 2020).

However, for the eVTOL operation in Brazil at UML-2 stage, the existing infrastructure and regulations can support, without major adaptations, the initial operations of these aircraft sharing the airspace on HSRs. Compulsorily, the current established altitudes and the visual references that guide the operation of helicopters in HSRs should be also followed by the eVTOL. Possibly, during operation, the flight authorizations already granted may be reviewed to adjust the eVTOL operation in an emergency condition once the aircraft will have restricted operation in hover mode because of low battery density (Embraerx and Airservices Australia 2020).

The entry into service of eVTOL shall be provided through voice communication upon arrival in controlled airspace. For this article, it is assumed that the certified eVTOL will follow the special air traffic rules and procedures and the VFR applied to helicopters, as defined by DECEA (2018). Based on the regulations RBAC 91 and RBAC 135, the aircraft is required to install navigation, communication and surveillance equipment, which are in line with the rules of the Brazilian ATM system.

Required equipment for eVTOL operation

Primarily, the analysis of the minimum operational requirements for general aviation in Brazil, should be evaluated. According to the regulation (ANAC 2021b), it is mandatory to install two equipment onboard the aircraft for communication and navigation purposes: VHF two-way radio communication and mode A/C or mode S transponder (Table 3).

Table 3. Required equipment for operation according to RBAC 91.

Section	Requirement	Equipment
91.205	Instrument and equipment requirements - powered civil aircraft with standard category airworthiness certificates	VHF Two-way radio communication
91.215	Transponder and automatic altitude reporting equipment	Transponder Mode A/C or Mode S

Source: Elaborated by the authors.

The equipment mentioned above are very traditional and normally equip the aircraft operating in general and commercial aviation. The VHF two-way radio communication is an equipment that operates at very high frequencies for the purpose of performing airborne communications between the aircraft and the air traffic control service units (ANAC 2021c). The mode A/C or mode S transponder is a secondary radar transceiver installed on board which automatically receives radio signals from the interrogator located on the ground and which selectively responds, with a pulse or group of pulses, only to those interrogations carried out in the mode and code for which is selected (DECEA 2020, p. 350).

To conduct a scheduled and on-demand air transport operation in Brazil, in addition to complying with general aviation requirements, it is also needed to comply with the complementary requirements applicable for commercial operation, regulated by RBAC 135 (ANAC 2021a). Considering the required navigation, communication and surveillance equipment onboard the aircraft, the eVTOL must, additionally to RBAC 91, also install a radio navigation equipment (Table 4).

Table 4. Required equipment for operation according to RBAC 135.

Section	Requirement	Equipment
135.143	General requirements	Transponder Mode A/C or Mode S
135.161	Communication and navigation equipment: passenger transport under night VFR or day VFR conditions in controlled airspace	VHF Two-way radio communication Radio navigation equipment

Source: Elaborated by the authors.

It is mandatory to install radio navigation equipment on aircraft carrying passengers in VFR night flight condition and should be capable of receiving signals from ground stations. The VHF two-way radio communication equipment is also required to allow the passengers transportation under VFR (night and day) flight conditions in controlled airspace.

Therefore, the navigation, communication and surveillance equipment listed in Tables 3 and 4 are the minimum equipment required to ensure a safe operation of eVTOL in Brazil at UML-2 stage in the helicopter visual corridors.

Recommended equipment for eVTOL operation

To ensure international harmonization in regulations and to promote increased operational safety, the installation of other equipment is strongly recommended. In Brazil, there is no requirement to install ADS-B on aircraft. For this reason, the FAA 14 CFR requirements are indicated (Table 5).

Table 5. Recommended equipment for UAM operation.

Section	Requirement	Equipment
CFR §91.225	Automatic Dependent Surveillance-Broadcast (ADS-B) Out equipment and use	ADS-B
CFR §91.227	Automatic Dependent Surveillance-Broadcast (ADS-B) Out equipment performance requirements	ADS-B
135.151	Cockpit voice recorders	CVR (*Cockpit Voice Recorder*)
135.152	Flight data recorders	FDR (*Flight Data Recorder*)

Source: Elaborated by the authors.

As of January 1, 2020, the installation of the Automatic Dependent Surveillance – Broadcast (ADS-B) on aircraft, operating in the United States of America's airspace, has been required by the FAA to enhance the safety and efficiency of operations in the National Airspace System (NASA 2020).

Brazil has an air traffic control management system called Sagittarius, which is capable to determine the position of the aircraft and send information to allow the surveillance of the operations by the air traffic controller, through the data collected from radars, satellites, and equipment such as the ADS-B (Atech 2021). By this way, it is strongly recommended to install ADS-B in eVTOL at the introduction of operation, as the existing ATM system in Brazil already supports ADS-B equipped aircraft, and DECEA has plans for the implementation of continental ADS-B.

In addition to the existing installed capacity of the ATM system, DECEA reissued guidelines for the national ATM operational design planning, which provides interoperability between ATM and UAM systems. In the UAM domain, the proposal is that the balance between demand and system capacity oversee operators and service providers, under the State's supervision (DECEA 2021).

Another equipment recommended in Table 5, outside of the Communications, Navigation and Surveillance system, is the voice and data recorder. Considering the eVTOL model, used as reference for the analysis of this article, the installation of these recorders is not required. However, due to the unique features of the UAM operation, the installation of this equipment is also strongly recommended because there is no service history operation of this new concept of aircraft. EASA, the Civil Aviation Agency for certification of aeronautical products in Europe, considered in its SC-VTOL the nonconventional operation of the eVTOL, adding requirements to install Flight Data Recorder and Cockpit Voice Recorder for eVTOL in the certification.

Therefore, it's identified in this analysis, considering other aeronautical authorities, that the installation of voice and data recorders and ADS-B equipment are strongly recommended for UML-2 stage of eVTOL operation in the city of São Paulo.

The eVTOL, thus, to ensure an efficient and safe operation in Brazil, must include all navigation, communication and surveillance equipment listed as mandatory. For an increased operational safety, it is also needed to install the recommended equipment for UAM operations. The analysis indicates that the existing Brazilian regulatory framework allows, at UML-2 stage or Horizon 1, the commercial operation of eVTOL.

Operational limitations

As analyzed, the RBAC 135 includes requirements applicable for eVTOL operation. However, due to the applicability of new technologies for this type of aircraft, there will be operational limitations because the existing regulatory framework does not cover all the unusual operational characteristics of the eVTOL (Table 6).

Table 6. Operational limitations.

Section	Requirement	Operational Limitation
91.111	Operating near other aircraft	Comply with DECEA rules
91.119	Minimum safety altitudes	Comply with DECEA rules
91.144	Temporary restrictions on flight operations during abnormally high barometric pressure conditions	Comply with DECAE rules
91.149	Information about potentially hazardous meteorological conditions	Meteorological conditions should be informed to DECEA
135.213	Weather reports and forecasts	Information and forecasts reported by DECEA
135.209	VFR fuel supply	Fuel reserve for airplanes and helicopters

Source: Elaborated by the authors.

Fuel reserve, required for airplane and helicopters operating under VFR conditions, is an operational limitation applicable to eVTOL. This and other operational requirements should be reviewed to fill the gaps identified for this new concept of aircraft designed with distributed electric propulsion system, containing low energy density batteries that provide a short distance flight, being impractical to have energy reserve as legislated by the FAA and ANAC.

The other operational limitations, as depicted in Table 6, are required by RBAC 135 in order to ensure the operator will comply with the rules and procedures established by DECEA, regarding the separation criteria from other aircraft, minimum heights and altitudes away from obstacles and use of meteorological information to build the flight planning in order to avoid potentially adverse weather conditions.

Therefore, based on the analysis of the current regulation applied to commuter and on-demand public transport, the eVTOL may have its operation, at initial UML-2 or Horizon 1 phase, validated to use the existing ATM system, accommodating the flights on the REH in the city of São Paulo.

SYNTHESIS AND LIMITATIONS OF THIS STUDY

In this article, the mandatory and recommended navigation, communication, and surveillance equipment are identified (Table 7) to comply with the existing operational and ATM requirements to support the eVTOL at UML-2 stage, which means low density and complexity operations.

The objective of this analysis is to identify possible regulatory and technical barriers that would prevent the initial operation of eVTOL at the UAM domain in Brazil.

Table 7. Required and recommended equipment.

Mandatory	Recommended
VHF Two-way radio communication	ADS-B
Transponder Mode A/C or Mode S	FDR (*Flight Data Recorder*)
Radio navigation equipment	CVR (*Cockpit Voice Recorder*)

Source: Elaborated by the authors.

The analysis provided also verified that the current regulations do not fully reflect the design characteristics, concept of operation and definitions of this type of aircraft. Therefore, as this analysis is subjective on this stage of the UAM development phase, based only on a general vision of the operational scenario that does not exist and on current regulations, the result of this analysis may undergo possible changes with the progress of further discussions related to UAM.

CONCLUSION

The analysis of the initial commercial operation of manned eVTOL in Brazil's UAM domain concludes that efforts from industry and government authorities will be required, in the near future, to promote regulatory change in legal framework. The density and complexity of operations will increase in the UAM scenario and the operational requirements should be established to support this new type of business.

Analyzing the Brazilian Civil Aviation Regulations and the existing air traffic rules, related to commercial operations of commuter and on-demand passenger transport, the introduction of eVTOL in UAM environment at UML-2 stage is possible without the need for regulatory and infrastructure adaptation of the ATM system.

Considering the numerous concepts under development, some of the projects will be certified in short term and gradually integrated into the existing operating environment readily available for conventional aircraft.

In this stage, therefore, the initial eVTOL operation will be performed in low density and complexity. Due to the application of new technologies and different operating concepts, the current regulations will have to be reviewed to support the operation in a more advanced maturity level.

It is concluded that the existing operational environment in Brazil, both operational regulations and ATM rules and procedures, is capable of adapting eVTOL in UAM environment for low density and complexity operations.

AUTHORS' CONTRIBUTIONS

Conceptualization: Agustinho JR; **Methodology:** Agustinho JR, Bento CAM; **Formal analysis:** Agustinho JR; **Investigation: Data/evidence collection:** Agustinho JR; **Resources:** Agustinho JR, Bento CAM; **Data Curation:** Agustinho JR; **Writing - Original Draft:** Agustinho JR; **Writing - Review & Editing:** Agustinho JR, Bento CAM

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