Initial Research on The Vertiport for The Urban Air Mobility

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Abstract. The eVTOL (electricic Vertical Take-off and Landing) aircraft provides an important guarantee for the realization of the UAM (Urban Air Mobility) system. The reasonable setting and construction of the eVTOL ground infrastructure usually play important roles to operate UAM system safely, efficiently and economically. This study introduces the main composition, types and factors influencing eVTOL ground infrastructure placement, according to the setting of traditional helipads, vertiport should be set up with Touchdown and Liftoff (TLOF), Final Approach and Takeoff (FATO) and Safety Area (SA), the ground infrastructure placement were affected by the factors such as the population density, the average income, the commercial centers, tourist attractions, the large transportation hub and extreme commuting, then the main function will be defined based on the scale of the vertiport. The construction and design of the eVTOL ground infrastructure is a complex and systematic work that involves multiple factors and it is also one of the important issues that need to be resolved urgently.

Keywords: UAM; eVTOL; The Placement of Vertiport; The Types of Airport

1 INTRODUCTION

The increasingly urbanized world makes more people settle in cities which arise more and more megacities or supercities. The travel radius for the people who live in these cities has continuously widened. In recent years, traffic jams in big cities have become one of the most intractable problems [1]. The conflicts of travel demand, travel time and cost among the residents in cities have aroused wider concern. Although the government has proposed some proactive and effective measures to relieve the pressure from the traffic congestion in cities, especially in the megacities or supercities (such as building subways to improve public transit capacity and service quality, reducing private cars on the roads, etc.). While traffic congestion

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in big cities had been a major problem preventing the development of the cities for the past half century. Under this situation, many aircraft manufacturers have also been involved in the development of new urban transit modes [2]. For example, Uber released a white paper in the name of “Fast-Forwarding to a Future of On-Demand Urban Air Transportation” and held a special summit for Urban Air Mobility (UAM) in 2016 [3].

The concept of Urban Air Mobility (UAM) was first proposed by NASA which essentially provides air transportation services for goods and people [4]. In the past, aircraft take-off and landing in short-distance and ultra-short-distance were considered the most suitable mean of transportation for air travel in cities [5]. A new form of aircraft (eVTOL- electric vertical take-off and landing) has been produced due to the technological progress in aviation electrical engineering, battery, Autopilot, communication and navigation. Apparently, eVTOL provides a more attractive option for passengers in Urban Air Mobility system and has attracted many companies' attention in recent years. Obviously, eVTOL would be the prior choice to promote the construction of the future Urban Air Mobility system of the advantages of low cost, low noise and flexible operation for eVTOL.

The construction of the helipad for eVTOL in the background of UAM is a complete project which combines different research fields, like ground facilities management, communication and navigation monitoring system, airport planning, etc. There is rarely experience in research, construction and planning for this new type of aircraft-eVTOL [6]. Based on the similarity of eVTOL and the traditional aircraft (helicopter), the management experience of aircraft in the big city (like Sao Paulo) may give enlightenment for the development of eVTOL, Bosson and T.A. proposed that the traditional aircraft share the helipad with eVTOL [7]. The traditional heliport can be divided into several types for their locations (like surface-level heliport, elevated heliport, helideck), eVTOL aims to provide transportation service should make reasonable planning for the heliport sits and balance the relationship between the cost and requests from customers within the UAM system. Research shows that 90% of accidents within heliports are caused by lacking systematic plan, design and running of the heliport [6]. In the future, the biggest challenge for UAM system is how and where to build interaction places in cities for aircraft and customers to parking, take-off, landing and boarding [8].

This thesis presents the recent developments in UAM and compiles a detailed review of the minimal requirements for UAM ground infrastructure, introducing the types of vertiport and the main influencing factors of vertiport location. Aiming to provide a reference for vertiport design and construction. The structure of this thesis is as follows: Chapter 1 offers three types and their proposed designs of vertiport. Chapter 2 contains a summary of the literature review about the criteria that influence vertiport selection. Chapter 3 discusses the construction of vertiport in the city. Chapter 5 consists of a case study about the implementation of the AHP-Delphi method.

2 THE STRUCTURE OF A VERTIPORT

2.1 Pad

Pads are defined as the area designated for landing and taking off of aircraft and consist of three components. The touchdown and lift-off area (TLOF) is generally a load bearing surface on which the aircraft lands and takes off. This area, in turn, is inside the closing strategy and take-off place (FATO), a described region over which the pilot completes the ultimate segment of the method in the shape of a hover or a touchdown and from which the take-off is initiated. Finally, the safety area (SA) is located around the FATO. The SA is the area on a pad that surrounds the FATO and serves to reduce the risk of damage to aircraft that inadvertently stray from FATO. Fig. 1 outlines a pad.

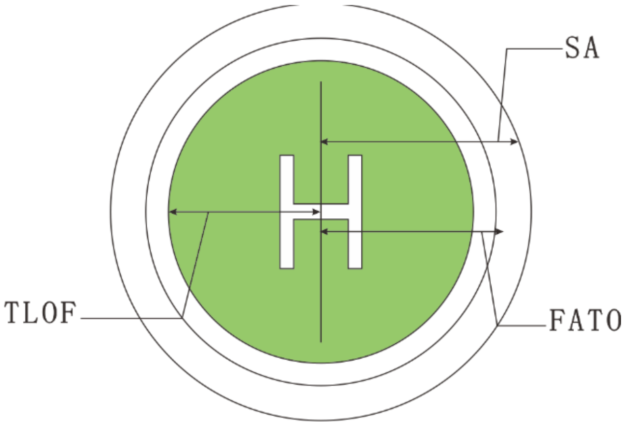

Figure 1. Diagram of three elements for helipad

By considering helicopters as the closest vehicle type to eVTOL vehicles, a minimum requirement for a vertiport could be established. Both helicopter and eVTOL vehicles are approaching and departing vertically. However, to simplify the analysis process, this thesis assumes that the heaviest eVTOL vehicle in the future will be similar to an SUV car (around 2,000 Kg). As shown in Table 1, both heliport and proposed vertiport designs were culled from various academic papers, working papers, and best-practice standards.

Table 1 The dimension of three elements for helipad

Name	***TLOF***	***FATO***	***SA***
Alexander&Syms, 2017	13.72m	21.34m	30.48m
Syed et al. 2017	13m	19.81m	28.96m
Antcliff et al. 2016	15.24m	30.48m	60.96m
FAA, 2012	RD	0.5RD	0.83RD
ICAO, 2009	0.83D	1D	0.25D

2.2 Forecast the Footprint of Pad

Table 1 summarizes the minimum vertiport size standards for different aircraft manufacturing companies. Table 2 contains the parameters such as the size, payload, maximum take-off weight, max speed, flying time and eVTOL size. According to table 2, the biggest eVTOL size is 13m. Be this number on the safe size to anticipate the unknown future, then rounded up to 15 m. Assuming 15 m is the safe span of eVTOL in the future, the TLOF size is 15 m. The FATO size is referring to the FAA standard, which is 1.5D. Consequently, 22.5 m is the minimum FATO size in this study. Assuming that the wingspan of eVTOL is 15m, the minimum radius of pad is 13.7m and the footprint is 592m^2.

Table 2 Statistics of eVTOL under development (including wingspan data).

Vehicle	*Configuration*	*Power*	*payload (kg)*	*Maximum take off weight (kg)*	*Max speed (km/h)*	*Flying time (min)*	*Size (m)*
Airbus Vahana	tilt-rotor+fixed wing	electric	90	815	220	-	6.25*5.70*2.81
Archer	tilt-rotor+fixed wing	electric	375	3175	241	40	
ASX MOBi	tilt-rotor	electric	453	-	241		11.58*7.92*1.83
Aurora CAV	four-axis eight-rotor (coaxial twin-rotor)	electric	225	339	-	-	4.57*5.49*1.22
Aurora PAV	eight rotors+fixed wings	electric	225	800	180	-	8.00*8.00*8.00
AutoFlightX V1200	six rotors+fixed wings	electric	-	-	-	-	-
Bartini Flying Car	tilt-rotor	electric	400	1100	300	30	5.20*4.50*1.70
Beta Alia	four rotors+fixed wings	electric	160	2721	-	-	-
Bell Air Taxi (Bell Nexus)	tilt-rotor	Hybrid	-	-	288	60	-
BlackFly v3	tilt-rotor	electric	110	255	100		4.08*4.10*1.52
Carter Aviation Air Taxi	single rotor compound helicopter	electric	499	-	281		12.00*12.80
CityAirbus	four-axis eight-rotor (coaxial twin-rotor)	electric	250	2200	120	15	8.00*8.00
Ehang216	eight-axis sixteen-rotor (coaxial twin-rotor)	electric	220	-	130	21	5.61*5.61
Elory(AA360)	eight-axis sixteen-rotor (coaxial twin-rotor)	electric	120	480	70	25	4.20*2.30*1.80
EmbraerX eVTOL Concept	eight rotors+fixed wings	electric	-	1000	-	-	-
Joby S4	tilt-rotor	electric	-	-	322	40	7.30*10.70
Lilium Jet	tilt-rotor	electric	200	640	300	-	8.5*13.9
Overair (Karem) Butterfly	tilt-rotor+fixed wing	electric	300	-	322	30	-
Pipistrel 801	eight rotors+fixed wings	electric	375	-	282	-	-
Robinson R44	helicopter	electric	272	1134	148	20	-
Skai	tiled six-axis six-rotor	hydrogen fuel cell	450	-	170	240	-
VOLOCOPTER 2X	tiled eighteen rotor	electric	160	450	100	27	9.15*7.35*2.15
Wisk (Kitty Hawk) Cora	twelve rotors+fixed wings	electric	181	-	180	37	6.4*11.0

2.3 Vertiport Layout

Depending on the arrangement of the components of the pads in relation to the gates, four common topologies can be derived (Fig. 2): Linear Topology, Satellite Topology, Pier Topology and Remote Apron Topology.

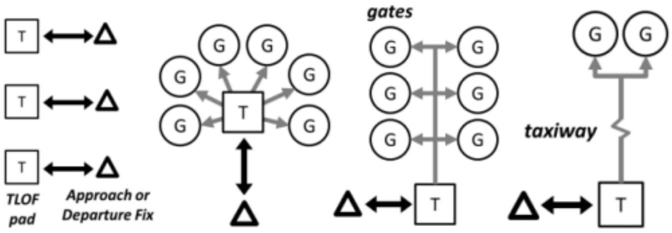

Figure 2. Layout of vertiport [9]

3 TYPES OF VERTIPORT

Lineberger et al. [10] explain that a vertiport requires different infrastructure components depending on its intended use and distinguish three types:

(1) Vertihub- For UAM infrastructure, large vertiports should be located on the periphery of urban areas. Vertiports should provide maintenance and repair infrastructure for eVTOLs, as well as a central control system for their operation. There should be at least one UAM vertiport in each city for the UAM network to run smoothly.

(2) Vertiport- There are also several vertiports located in the heart of the city, and they can accommodate both freight and passengers. The vertiports are used for both boarding and disboarding as well as takeoffs and landings. There is usually space for multiple eVTOLs to land at the same time, and each is equipped with a fast charging and refueling system, as well as basic security measures.

(3) Vertistop- The smallest vertiports consist of only one or two landing pads. They are used only for picking up and setting down passengers and cargo and serve as connecting points between the larger vertiports.

3.1 Surface-Level Heliports

A surface-level heliport shall be provided with at least one FATO. At the heliport, just one aircraft is typically permitted to make a final approach and take off simultaneously. A heliport has at least one TLOF (touchdown and liftoff area).

Vertihubs define the biggest UAM ground infrastructure type. The cost of acquiring land is the major factor for placing vertihub. Vertihub could be placed either in the city center or periphery area. Fig. 3 is one out of two proposed designs for vertihub. In addition, vertistop can also be built at the intersection of urban traffic roads and the roadside of expressways. The vertistop only used for passengers on-boarding and off-boarding. It has several operational advantages including eVTOL vertical takeoff and landing as well as its small occupied area (Fig. 4).

Figure 3. Diagram of vertistop in city

Figure 4. Layout of two types vertihub [8]

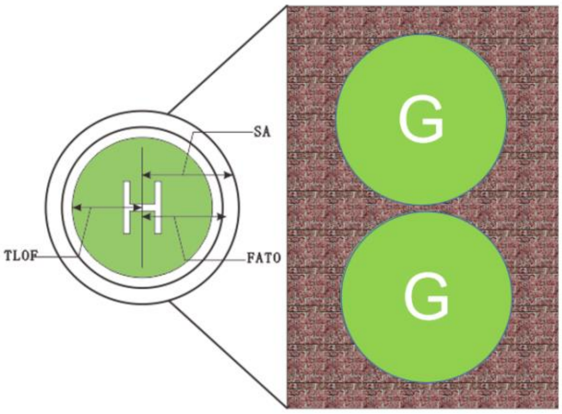

Figure 5. Elevated heliport

3.2 Elevated Heliports

Helicopter operations are located on elevated sites normally only when there is no suitable space at ground level. On elevated heliports, the FATO and the touchdown and lift-off area will be coincidental. An elevated heliport shall be provided with at least one FATO. The elevated heliports offer a particularly compelling opportunity to repurpose otherwise unused real land as a vertiport, which can be set at the top of a building in a commercial center or a transportation hub (railway station, airport terminal). If there is not enough space, the FATO outside TLOF can not be load-bearing, as shown in Fig. 5.

3.3 Water Heliport

Water heliport refers to the helipad built on the water surface, which is suitable to be built in areas with many lakes. A water heliport shall be provided with at least one FATO. Floating barge vertiports were proposed in the San Francisco city area to provide approach and departure aircraft paths over the water (Fig. 6). These types of vertiport infrastructure are already in use in New York City, Vancouver, and many other cities with existing operational procedures.

Figure 6. Water Heliport in San Francisco [8]

4 FACTORS INFLUENCING VERTIPORT LOCATION

In order to facilitate the implementation of the UAM, this thesis defines what factors influence the location of vertiports. A critical issue affecting UAM implementation is vertiport [2, 8]. However, there are a few research studies on the question. Demand is a selection criterion to be considered when attempting to simulate UAM operation and UAM ground infrastructure planning. A number of factors will impact the location of the vertiport, such as operating costs, construction costs, urban planning and noise level. This section presents several influential factors.

4.1 Population Density

Population density refers to the number of people living in a given region. The purpose of the transportation infrastructure is to attract a maximum number of passengers, as well as to provide maximum coverage of the area [11]. German et al. [12] considered the number of inhabitants to be an estimate for potential customers in the process of selecting terrestrial UAM infrastructure sites. The greater number of inhabitants in the catchment area of the terrestrial infrastructure of

UAM, the higher likelihood of operating UAM captures potential passengers. Therefore, this argument takes population density as one of the factors determining the location of vertiport.

4.2 Average Income

Average income is the average value of the total income of the population within a specific sector. However, several different revenue level formats were used in the studies to determine the location of the vertiport, for example, Syed et al. [13] Use the number of family members whose income exceeds a certain standard value as a proxy for the degree of family wealth. Vascik & Hansman [2] assumed that high property valuation extrapolates demand for wealthy commuters.

In the initial operation of the UAM, the price of flying with an eVTOL is expected to be high. The UAM fare is considered to be more expensive than a ride on uberX service. Consequently, three studies mentioned above used the income level of a population in a specific region as an indicator of demand. This thesis chooses average income as a demand factor because a higher average income means more potential passengers for the initial operation of UAM [14].

4.3 Urban Commercial Center

A vital market is created when flying to another destination where traffic jam hotspots surround you, for business trips that are often constrained by time constraints. Due to its lower noise level, UAM operation with eVTOL vehicles may be a turning point for business trips. Any elevated ground infrastructure can be used to land for eVTOL, as long as many offices are nearby and eventually corporate demand increases.

The office rent price factor is an approximation of a company's business travel budget. Companies in urban commercial centers with higher rents tend to have better financial conditions, which means they can afford more operating costs (including employee travel costs) [3]. As a result, there is more potential demand for UAM in the area of high office rental prices. This premise also makes this thesis incorporate the office rental price factor as one of the factors influencing vertiport location.

4.4 Tourist Attractions

In terms of tourist attractions, there are places that attract both international and domestic tourists. As a result of tourism, urban transportation modes are in high demand [15]. Consequently, any transportation node should cover tourist attractions in its catchment area. Tourists should be able to arrive at tourist attractions in a convenient way [16, 9]. Many tourist attractions in Los Angeles region are served by charter helicopter companies, for example, Dodger Stadium, Angel Stadium/Honda Center, Orange County, Santa Monica and downtown Los Angeles [2].

It is estimated that eVTOL vehicles could capture 5 - 20% of the total travel demand generated by tourism [17]. Tourist attractions factor is one of the factors influencing vertiport placement due to the potential demand for tourism trips.

4.5 Large Transportation Hub

Large airports and large intercity train stations are making up large transportation hubs. According to the current helicopter charter services route in Los Angeles, there is a potential demand for UAM from major transport hubs [2]. When it comes to intermodality, major transportation nodes are also crucial. Taking railway station as a proxy for vertiport, the planning process of railway station takes intermodality between train and another mode of transport into account [9]. The major transport node factor is selected as one of the influencing factors based on the three previously mentioned demand considerations.

It would be easier for long-distance travelers to change modes of transportation almost seamlessly at major transportation hubs if vertiport were provided at such nodes. eVTOL vehicles could serve the first and last mile in a long distance trip, in which airplane or high speed intercity train acts as the main leg carrier. In the initial operation of UAM, it is likely that major transport nodes will generate potential passengers based on the characteristics of chartered helicopters.

4.6 Extreme Commuting

In order to obtain an advantage in travel time, eVTOL vehicles are expected to carry passengers who are willing to pay more. Most of the time, these are people who travel through traffic jam hotspots or long distances [2]. Extreme commuters are the person who endure long distance trip, translated into 90 minutes, one way to get into their office [18]. UAM demand can be derived from high numbers of extreme commuters.

There are six factors that may affect the location of vertiport. However, the location of a vertiport requires much more consideration than the above-mentioned factors. Such as noise pollution and the influence of existing heliport location on site selection. Therefore, the location of vertiport is a systematic project.

5 AHP-DELPHI ANALYSIS

The AHP is a method of generating coefficients or weights from a set of criteria, factors, or alternatives according to their importance [19]. Saaty wrote that AHP has three principles: decomposition, comparative judgments, and synthesis of priorities [20]. The breakdown consists of organizing the problem on several levels, for example at the upper level, the secondary level and the sub-criteria. Secondly, comparative judgments consist of a pair comparison matrix based on multiple criteria. Finally, synthesizing priorities means creating solutions based on organized levels. The Delphi method uses experts to provide advice on specific topics or domains, which are not implemented and uncertain, as well as on the lack of appropriate data. In general, group opinion is regarded as more valid than individual opinion. Delphi method relies on this premise to generate consensus by utilizing a group of experts [21]. As part of an attempt to provide robust insights into group decision making processes, Tavana, Kennedy, and Rappaport integrated AHP into the Delphi structure [22]. They took a pairwise comparison from AHP and iterative process and anonymity from Delphi, as the main characteristics that compose this AHP-Delphi method.

Fadhil [3] used AHP-Delphi analysis method to study the factors that affecting the location of vertiport(such as population density, median income, office rent price, points of interest, major transport node, annual transport cost, job density, extreme commuting, existing noise). There are 13 experts from different backgrounds in the analysis, they altogether gathered and introduced and explained factors to them. Having known the importance of each factor, once everyone has finished answering the pairwise comparison, compare the importance of the two indicators every time. After three comparisons, compare and sort the results. To enhance the results, Fadhil [3] interviewed two experts with over 15 years of experience to provide deeper forecasting methods. The purpose of this interview is to get more insight into UAM operations and other factors that may be considered when analyzing vertiport.

Two experts have different perspectives on the vertiport than the experts from real-time AHP-Delphi analysis. Although the results are not uniform, the experts from real-time AHP Delphi analysis tend to perceive major transport node, points of interest and job density as the major factors. In expert interview, expert A thinks median income, office rent price and annual transport cost are the major factors. According to expert A, the analysis of vertiport should differ between cities. It depends on the restrictions and rules in place. Expert B thinks points of interest, annual transport cost and median income are the major factors. For expert B, public perception of technological advancement in a particular area would also play a major role in determining where vertiport will be placed.

6 CONCLUSION

This thesis makes an effort to understand all of the recent developments in UAM and compiles a detailed review of the minimal requirements for vertiport by combining a variety of books, articles, work reports and regulations, introduces the types of vertiport and the main influencing factors of vertiport location. Although any uncertainty in UAM and eVTOL vehicle development, the implementation of UAM might be made easier by this thesis. Overall, it can be concluded that the study offers a solid foundation for future investigation into vertiport infrastructure However, several areas still require improvement. For example, the physical structure of vertiport is not considered, as not every building, has a square flat rooftop where eVTOL vehicles can land on.

In a word, the construction of vertiport is just getting started. The development of eVTOL forces researchers and engineers into thinking about how this mode will play an important role in future urban mobility. It is meaningful to study the related problems of vertiport construction in advance.

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