A DESIGN OF VFR APPROACH AND DEPARTURE PROCEDURES OF UAM AT VERTIPORTS ADJACENT TO THE AIRPORT

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Abstract

In this study, we conducted an in-depth literature survey and analysis to establish operational procedures for urban air mobility (UAM) at vertiports adjacent to airports. The study focuses on identifying key elements vital for the establishment and operation of UAM vertiports adjacent to airports, addressing challenges such as vertiport placement, airspace integration, and adherence to visual flight rules (VFR) procedures. Based on the in-depth literature survey and analysis, the approach and departure procedures of UAM to the vertiport adjacent to Incheon International Airport (ICN) were designed. This study provides the key elements for the operation procedures of UAM, an exemplary design of the VFR approach and departure procedures, and the future directions of the research.

Keywords: Airport, approach and departure procedure, urban air mobility, vertiport, visual flight rules.

1. Introduction

Urban air mobility (UAM) or advanced air mobility (AAM) is a type of vehicle that is considered to be the future of mobility in urban areas, thanks to its vertical take-off and landing (VTOL) capability. It has great potential to be utilised for the connection between points in urban areas and even between the city centre to the airports. The VTOL capability, quieter noise characteristic, and electric-powered propulsion are key points of this potential application. In the next decade, we expect to see early trials of "aviation-on-demand", allowing personal air travel and transport of goods at affordable costs. Recent reports from the Department of Business, Energy and Industrial Strategy and Department for Transport expect autonomous aviation is set to unleash £45bn in benefits to the UK economy by 2030 [1]. Despite its potential, we understand there are significant challenges that need to be addressed in every aspect. This implies that all sectors, including politics, economics, infrastructure, or technology, should collaborate to address these challenges and unlock their potential. One major challenge is that we need to operate UAM/AAM in urban environments which are fundamentally different from current civil aviation. Furthermore, connecting flights from the urban area to airports is considered one of the key routes. In such operational environments like urban areas or vertiports adjacent to airports, safety will be of the utmost importance, understanding the impacts of the difference, and developing the strategies and approaches to mitigate the impacts will be the key to success.

The types of aerial platforms discussed within UAM/AAM are different from typical fixed-wing aircraft or helicopters in civil aviation. The main types of aerial vehicles under development are electric vertical take-off and landing (eVTOL) aircraft and multi-rotor aircraft. The operational environment is urban, and its wind conditions are different from the wind conditions in current civil aviation. Within such an environment, we might need to have new types of infrastructure such as vertiport. There is a gap in establishing the operation procedures of the UAM/AAM approach and departure procedures at the vertiport. To this end, this study aims to survey recent studies and discussions on the operation procedures of the UAM/AAM approach and departure at the vertiport adjacent to airports and design exemplary procedures in Incheon International Airport (ICN). The main contributions of this paper are listed as follows:

1. **Literature Survey on UAM/AAM**: Comprehensive survey using the preferred reporting items for systematic reviews and meta-analyses (PRISMA) methodology, focusing on approach and departure procedures and vertiport operations adjacent to airports.

2. **Operational Procedure Design**: Formulation of the specific operational procedures for UAM/AAM approach and departure at selected vertiport sites adjacent to ICN, considering factors like proximity to airports, UAM/AAM vehicle types, and vertiport designs.

3. **Identification of Future Directions**: Recommendations for procedure updates with multiple types of vertiport, new vertiport site evaluations, and downwash evaluations.

The rest of this paper is composed as follows: Section 2 presents the surveyed papers and the key findings from the survey and Section 3 introduces the designed approach and departure procedures at vertiports adjacent to the airport. Section 4 discusses the further examination of the designed procedures. Finally, in Section 5 we conclude this paper.

2. Literature Survey

This section summarises the literature survey of the approach and departure procedures of UAM/AAM at the vertiports adjacent to airports. Although many conceptual studies for the application of the UAM/AAM to real life are done, no technical studies have been conducted for the approach and departure procedures of UAM/AAM up to the best of our knowledge. In addition, for the integration or separation from the current civil aviation airspace, the study on procedures at the vertiport adjacent to the airport is necessary. We conducted a systematic literature survey to point out the important factors which need to be considered in designing the approach and departure procedures and to design the approach and departure procedures of UAM/AAM at the vertiport adjacent to the airport. The survey is done with PRISMA, an evidence-based methodology for the systematic survey methodology [2]. One of the main reasons for adopting PRISMA is that this methodology allows transparent, reproducible, and unbiased review with additional grey literature such as survey papers, technical reports, or books.

2.1 Preliminaries: Survey Scope

2.1.1 Approach and Departure Procedures

The approach and departure procedures are the protocols that the aircraft must follow for their safety during the final approach and departure phases. They are one of the most critical procedures in the operation of the aircraft, as most accidents occur during this phase. An analysis from Airbus stated, "Most of the accidents over the last 20 years occurred during approach and landing phases" [3]. If we include the take-off phase as well, the proportion of accidents increases to close to 90% of all accidents. In this survey, we considered the approach and departure procedures and take-off and landing (TOL) phases as well to ensure a safe approach and departure and the separation and integration of airspace, considering the characteristics of the vertiport adjacent to airports.

2.1.2 Urban Air Mobility and Advanced Air Mobility

UAM or AAM is the type of vehicle considered as the future of mobility in urban areas. The distinguishing factors that set UAM/AAM apart from conventional aircraft are the VTOL capability and electric-powered propulsion, enabling operations in busy urban areas. In this survey, we specifically considered eVTOL aircraft with fixed-wing such as lift-cruise type aircraft.

2.1.3 Vertiport

A vertiport, as defined by the European Union Aviation Safety Agency (EASA) [4], is a TOL facility designed for the operation of VTOL-capable aircraft. According to EASA, a vertiport is described as "an area of land, water, or structure used or intended to be used for the landing and take-off of VTOL-capable aircraft." Similarly, the Federal Aviation Administration (FAA) [5] defines a vertiport as "an area of land, or a structure, used or intended to be used, for electric, hydrogen, and hybrid VTOL aircraft landings and takeoffs and includes associated buildings and facilities."

2.2 Survey with PRISMA

The literature survey was conducted using the PRISMA [2] to ensure a transparent, reproducible, and unbiased review. Aligned with the survey focus outlined in the previous section, the following keywords were defined:

- UAM/AAM operation procedures or concept of operation.
- UAM/AAM final approach and departure procedures or TOL procedures.
- Airport and aerodrome.
- Vertiport, vertipad, or vertiport design, vertiport regulations, etc.

Based on these keywords, a total of 23 pieces of literature were identified during the search across various databases and organisations. However, not all the literature found during this search aligns with the scope of our study. A screening step was implemented to ensure a detailed and effective survey. During this screening, literature that was deemed irrelevant or failed to meet specified criteria was excluded. The exclusion criteria for this screening are as follows:

- Documentation with expired or cancelled status (usually for policy or regulation papers).
- Documentation that only introduces operation without final approach and departure.
- Documentation that only introduces vertiport design without operational procedures (e.g., dimensions of landing pad, lighting, taxiway, etc.).

The screening process was executed based on the specified criteria, and the results are presented in Table 1.

Table 1 – Literature survey result in number

	Databases	Organisations	Total
Found	8	15	23
Excluded	3	10	13
Included	5	5	10

The process of the literature survey including identification and screening with PRISMA is shown in the PRISMA 2020 flow chart [2] in Fig. 1.

2.2.1 Literature from Database

A total of eight pieces of literature were found in the databases, and five of them were included in the survey, while the rest of the three were excluded following the exclusion criteria. Most of the literature included here are research papers for the vertiports adjacent to airports. Vitalle *et al.* applied the rapid random tree (RRT) algorithm for the design of the route of the UAM approach to or depart from the Tampa International Airport (TPA) [6]. This research applied the suggested profile of the UAM by Uber and trajectory data of the commercial flights in TPA collected by the FAA Performance Data Analysis and Reporting System (PDARS) to suggest the route for the UAM. Feldhoff and Soares Roque utilised a discrete event simulation tool, Anylogic, to analyse the vertiport candidates for UAM adjacent to Cologne Bonn Airport [7]. This study adopted *ICAO Annex 14 volume II Heliports* and the *ICAO DOC 9261 Heliport Manual* as regulatory works and evaluated the candidates based on criteria such as passenger accessibility, obstacle clearance, and noise impact. Rimjha *et al.* estimated the demand for the UAM and studied the placement of the vertiport near Los Angeles International Airport (LAX) based on the estimated demand [8]. However, this study simply considered the airspace boundary and buffer from this airspace for the vertiport adjacent to LAX. Vascik and John Hansman proposed a study to integrate the UAM into the existing airports with conventional flights in terms of air traffic control (ATC) [9]. This study provides five operating schemes for UAM in the airport:

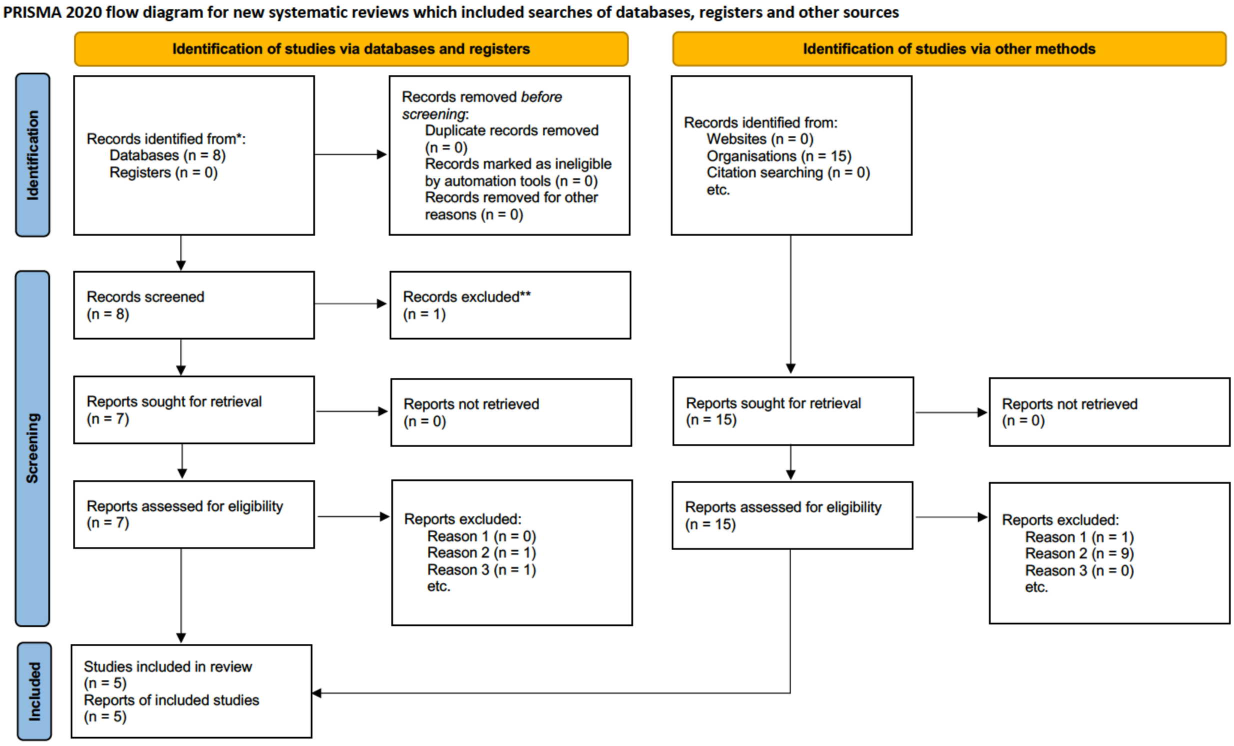

Figure 1 – PRISMA 2020 flow chart

independent operations, widely spaced operations, closely spaced operations, mixed-use operations, and converging/diverging operations based on the distance between conventional aircraft operations. In addition, this study provides case studies of these integration strategies at airports, such as San Francisco International Airport, Atlanta International Airport, and Boston International Airport. Last but not least, Schweiger and Preis conducted a systematic review of the vertiport design and the recommendations for the vertiport design [10]. This review includes not only research papers but also currently proposed regulatory literature. The review pointed out that only a few studies provide a realistic and implementable proposal while the rest of them describe only a vision of the vertiport. In addition, the review suggested considering the realistic operational constraints and requirements. A summary of surveyed literature from databases is shown in Table 2.

Table 2 – Summary of the surveyed literature (Databases)

Reference	Summary
[6]	Provides the route design using RRT for the vertiport adjacent to Tampa International Airport.
[7]	Provides the idea of selecting the position of vertiport in the Cologne Bonn airport and the airspace integration.
[8]	Estimates demand of UAM in the Los Angeles International Airport and suggests the position of vertiports for the separation.
[9]	Provides the operational procedure for UAM and integration of the UAM to existing airports with runways or vertiports.
[10]	A systematic review of vertiport design and the recommendations for the vertiport design for future study.

2.2.2 Literature from Organisations

The thorough search returned a total of 15 pieces of literature from the organisations. Five of them were included in this survey, while the remaining 10 were excluded by applying the exclusion criteria. The organisations here are mostly regulatory organisations such as EASA and FAA or research institutes such as NASA. EASA provides an overview of the operation of UAM and the vertiport design based on the helicopter category A in [4]. This document introduces the design of the vertiport, including the slope design for the approach and departure, but mainly focuses on the operation of UAM or AAM. The in-depth exploration of vertiport design has been elaborated in a distinct document titled *Prototype Technical Specifications for the Design of VFR Vertiports for Operation with Manned VTOL-Capable Aircraft Certified in the Enhanced Category (PTS-VPT-DSN)* [11]. This document, presented by EASA, is a regulatory-like document for vertiport design [11], which focuses only on vertiport design and operation. This document provides guidelines for VFR vertiport design, including the approach and departure slope. More details on this document will be covered in Section 3.1.1. FAA provides interim guidance for the design of the vertiport for UAM, VTOL-capable aircraft, more generally, including the approach and departure slope [5]. More details on this document will also be covered in Section 3.1.2. An airport information publication (AIP) for ICN (RKSI) issued by the Ministry of Land, Infrastructure and Transport (MOLIT) is included in this survey for the VFR procedures of ICN [12]. This document introduces the VFR procedures of conventional aircraft, including rotorcraft. More details on this document will also be covered in Section 3.1.3. Joby Aviation and NASA researched instrument flight rules (IFR)-like approach and departure procedures [13]. This research was done with Joby Aviation's S4 simulator, which accommodates the dynamics and characteristics of the UAM, Joby S4, and defines the experimental IFR-like procedures for Marina Municipal Airport. A summary of surveyed literature from organisations is shown in Table 3.

Table 3 – Summary of the surveyed literature (Organisations)

Reference	Summary
[4]	Provides the overview of operation and vertiport design of VTOL aircraft based on helicopter category A.
[11]	A prototype technical specifications as regulatory-like material for the design of VFR vertiports, including the slope design for approach and departure.
[5]	An interim guidance for the design of the vertiports for VTOL capabilities, including guidance for VFR approach and departure (Subject to extend to advisory circulars).
[12]	Provides the existing VFR approach and departure procedures and airspace information of Incheon International Airport (ICN).
[13]	Provided UAM/eVTOL IFR-like approach and departure procedures with Joby S4 simulator and tradeoff findings for designed approach and departure procedures.

2.3 Key Findings from Survey

Here we presented the key findings from the literature survey. Firstly, the crucial factors for the UAM final approach and departure procedures have been identified. Notably, the glide path angle (or slope) of the final approach and departure, based on the UAM's performance, is among the most significant factors in designing the approach and departure procedures.

Considering that we are focusing on the approach and departure procedures of UAM at the vertiport adjacent to airports, it is essential to survey the elements within the context of such vertiports. Key considerations for UAM vertiports adjacent to airports have been derived from the survey. One critical element is the distance of the vertiport from the active runway, as mentioned in the guidelines of both EASA [11, p. 45] and FAA [5, p. 44]. In addition, given that airports are used by active commercial flights and the airspace is under the control of the airport ATC, careful consideration must be given to airspace separation and integration. The existing VFR procedures of the adjacent airports, including reporting points, also should be respected and incorporated when designing the VFR procedures for the vertiport adjacent to airports. Lastly, obstacles around the airport, such as buildings, ATC towers, and radar facilities, should be taken into account in slope and safety-bound design.

However, some aspects need further investigation for real-life applications. Most literature and guideline materials are based on helicopter dynamics or are designed for helicopters due to the lack of sufficient UAM and AAM performance or flight data. Both EASA and FAA acknowledge the need for updates based on performance in [11, p. 47] and [5, p. 2]. Notably, many eVTOL aircraft incorporate fixed-wing aircraft aspects, and the different aerodynamic properties of these aircraft should be considered. These findings are outlined as follows:

- Current vertiport suggestions are primarily based on helicopters.
- Many eVTOL aircraft incorporate aspects of fixed-wing aircraft.
- Different aerodynamic properties of these aircraft should be incorporated.

3. Approach and Departure Procedures at Vertiports

In this section, the designed VFR approach and departure procedures at the vertiports adjacent to the ICN based on the literature survey from the previous section is presented. The procedures presented here are designed to align with the selected guideline materials, which have been our primary focus.

3.1 Focused Literature Selection

To design the approach and departure procedures at the vertiports adjacent to the ICN, literature and guideline materials needed to be selected. Three metrics are considered for this selection, and these are: Documents that provide 1) the final approach and departure procedures, 2) integration and separation of the airspace in the airport, and 3) vertiport and route candidates. Among a total of 10 papers surveyed above, we selected four articles based on these three metrics. Based on the first metric, *Prototype Technical Specifications for the Design of VFR Vertiports for Operation with Manned VTOL-Capable Aircraft Certified in the Enhanced Category (PTS-VPT-DSN)* by EASA [11] and *Engineering brief (EB) 105: Vertiport design* by FAA [5] were selected. Based on the second metric, *Airport Information Publication (AIP) RKSI* by MOLIT [12] and finally, based on the third metric, *Vertiport and route candidates adjacent to ICN* by Incheon Industry-academy Collaboration Institute (IAIAC) were selected. The details of this literature are described in the following sections.

3.1.1 EASA PTS-VPT-DSN

The *PTS-VPT-DSN* [11], offers guidelines for vertiport design. It is important to note that this document is a living document and subject to updates. The *PTS-VPT-DSN* addresses crucial aspects of vertiport design, including the approach and departure slope. The curved approach is specified in this document: the sum of the radius of the arc defining the centreline of the approach surface and the length of the straight portion originating at the inner edge should not be less than 575 m ($S + R \geq 575$ m and $R \geq 270$ m where $S = 305$ m) [11, p. 48]. This curved slope is illustrated in Fig. 2.

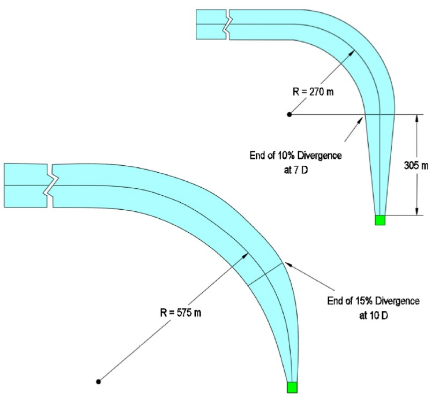

Figure 2 – Curved approach from [11], ©EASA

PTS-VPT-DSN provides three types of slopes for the approach and departure, which can be chosen by the operator based on the dynamic characteristic of the eVTOL, as illustrated in Table 4.

Table 4 – Types of slopes, summarised and reproduced from [11] (Safety Area (SA)), ©EASA

Surface and dimensions	Slope design categories		
	A	B	C
Approach and take-off climb surface:			
Length of inner edge	Width of SA	Width of SA	Width of SA
Location of inner edge	SA boundary (Clearway boundary if provided)	SA boundary	SA boundary
Divergence: (1st and 2nd section)			
First section:			
Length	3 386 m	245 m	1,220 m
Slope	4.5% (1:22.2)	8% (1:12.5)	12.5% (1:8)
Second section:			
Length	N/A	830 m	N/A
Slope	N/A	16% (1:6.25)	N/A

EASA requires having at least two surfaces for the approach and departure, with a recommended separation of at least 135° but ideally separated by 180°. However, the number of separations may be decreased if the safety assessment such as "the local meteorological conditions including the prevailing winds" determines that it would not affect safety [11, p. 51]. In addition, *PTS-VPT-DSN* provides the obstacle-free volume for vertiports in congested areas [11, p. 62]. The generic vertical approach and departure procedures volume is shown in Fig. 3.

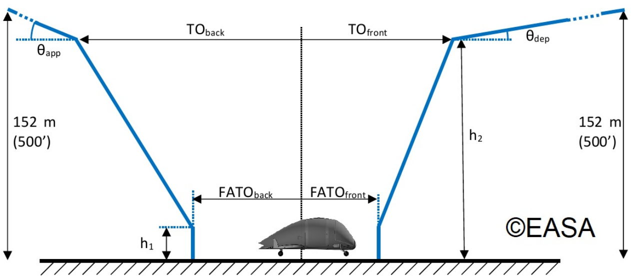

Figure 3 – Generic vertical approach and departure procedures volume from [11], ©EASA

Finally, *PTS-VPT-DSN* provides the recommended distance of the vertiport from the active runway [11, p. 45] to minimise the effect of the wake turbulence. The recommended distance of the edge of the final approach and take-off area (FATO) from the edge of the runway is given in Table 5.

Table 5 – Recommended separation distance of vertiport, reproduced from [11], ©EASA

If aeroplane mass and/or VTOL-capable aircraft mass are	Distance between FATO edge and runway edge or taxiway edge
up to but not including 3,175 kg	60 m
3,175 kg up to but not including 5,760 kg	120 m
5,760 kg up to but not including 100,000 kg	180 m
100,000 kg and over	250 m
Note: The values specified in this table are primarily intended to mitigate risks of wake turbulence encounters. In addition to this table, when positioning a FATO intended to be used simultaneously with a nearby runway or taxiway, attention should be given to other CS ADR-DSN requirements such as the minimum runway strip width. The local environment should be taken into account when setting the separation between the FATO and nearby infrastructure elements to ensure the safety of simultaneous operations.	

3.1.2 FAA EB105: Vertiport Design

EB 105, proposed by FAA [5], offers guideline for vertiport design. Similar to *PTS-VPT-DSN*, this document is a living document and subject to updates. *EB 105* covers important aspects of designing the vertiport, including the approach and departure slope. The preferred slope is suggested to align with the predominant wind direction with an 8:1 surface slope (12.5%). This requires a horizontal distance of 4,000 feet (1,219 m) and a vertical distance of 500 feet (152 m). *EB 105* also requires more than one approach and departure path with at least 135° separation [5, p. 23]. These requirements are illustrated in Fig. 4.

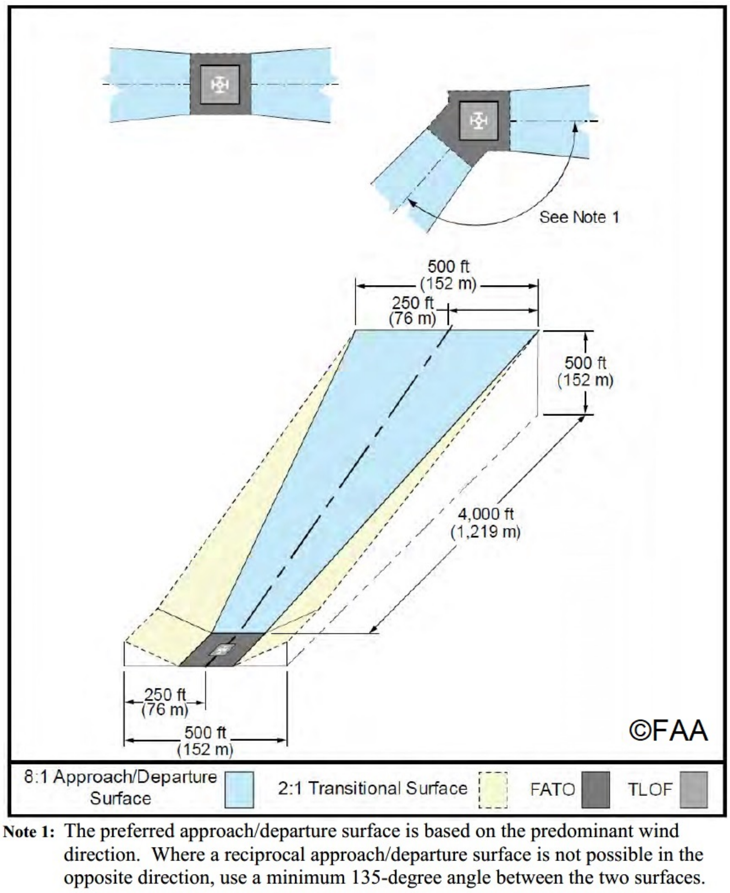

Figure 4 – Preferred slope design from [5], ©FAA

EB 105 also provides the recommended distance of the vertiport from the active runways [5, p. 44] to minimise the effect of the wake turbulence. The recommended distance of the centre of the FATO from the centreline of the runway is shown in Table 6.

Table 6 – Recommended separation distance of vertiport, reproduced from [5], ©FAA

Reference VTOL Aircraft MTOW	Airplane Size	Distance from vertiport FATO centre to runway centreline
12,500 pounds (5,670 kg) or less	Small airplane (12,500 pounds (5,670 kg) or less)	300 feet (91 m)
12,500 pounds (5,670 kg) or less	Large airplane (12,500-300,000 pounds (5,670-136,079 kg))	500 feet (152 m)
12,500 pounds (5,670 kg) or less	Heavy airplane (Over 300,000 pounds (136,079 kg))	700 feet (213 m)

The key points of the two documents for approach and departure procedures design can be summarised as shown in Table 7.

Table 7 – Comparison of EASA and FAA for approach and departure procedures design

Item	EASA [11]	FAA [5]
Location	Generic (including the airport) + City (obstacle free volume)	Generic (including the airport)
Location adjacent to airports	Distance from edge of FATO to edge of runway: 250 m (Most extreme case)	Distance from centre of FATO to centreline of runway: 213 m (Most extreme case)
Curved approach	Can be used (guideline provided)	Can be used (not examined by FAA)
Approach heading	Prevailing wind direction	Predominant wind direction
Slope condition	Horizontal: 1,220 m Vertical: 152.5 m 12.5% (1:8) (Category C)	Horizontal: 1,219 m Vertical: 152 m 12.5% (1:8)
Separation condition	Minimum two routes Separation minimum 135° Can be reduced to one	Minimum two routes Separation minimum 135° Can't be reduced to one

3.1.3 MOLIT AIP RKSI

The *AIP RKSI* (ICN) by MOLIT [12] outlines the VFR procedure for the existing helipad near the ICN cargo terminal, identified as one of the candidate sites for vertiports. In addition, this document specifies the VFR reporting points for approaching and departing aircraft. The VFR procedure for the existing helipad is illustrated in Fig. 5:

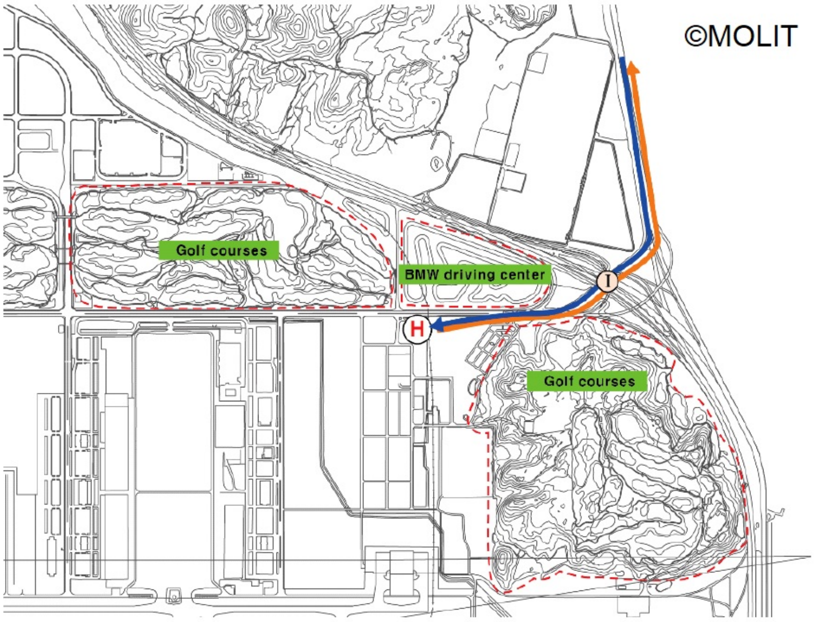

Figure 5 – VFR procedure for helipad in ICN from [12], ©MOLIT

3.1.4 IAIAC Vertiport and Route Candidates

The document *Vertiport and Route Candidates* by IAIAC offers information on vertiport candidate sites adjacent to ICN and potential routes to/from these candidate vertiport sites. The vertiport and route candidates near ICN are presented in Fig. 6:

3.2 Designed Procedures

In this section, the designed approach and departure procedures for two vertiport candidate sites are described. The approach and departure procedures are considered from the end of the corridor to

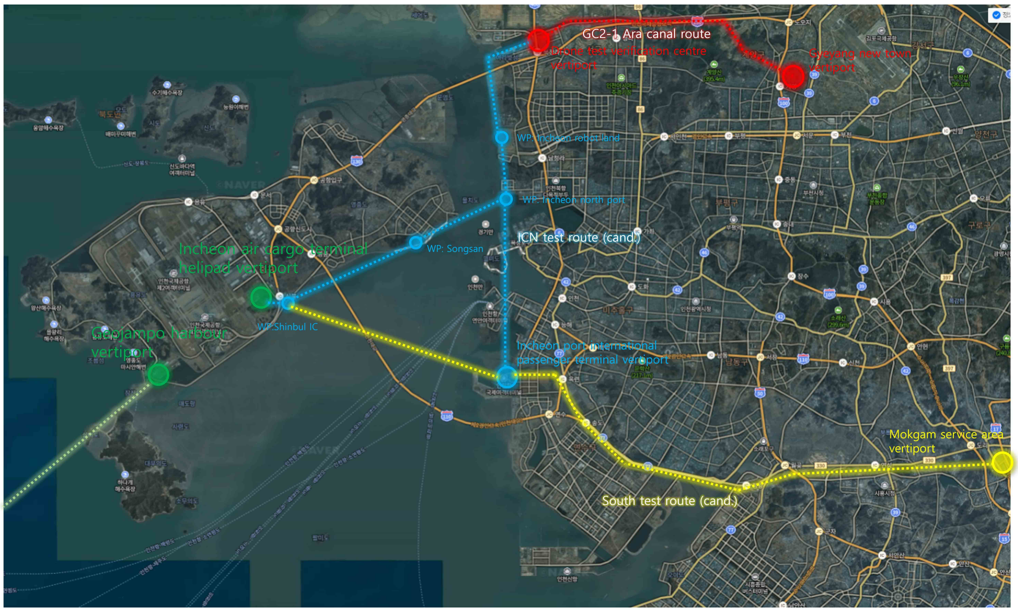

Figure 6 – Vertiport and route candidates, ©IAIAC

the vertiport. The slope designs are based on EASA *PTS-VPT-DSN* [11] and FAA *EB 105* [5], taking into account the region's predominant wind direction. It is noteworthy that slope design category C was selected from EASA *PTS-VPT-DSN* [11] due to the following reasons: 1) Slope category can be selected according to the vertiport environment and the VTOL-capable aircraft operator [11, p. 47], and 2) category A cannot be utilised in the current vertiport environment and slope based on category B can't fulfil the FAA's guideline (12.5%).

3.2.1 Vertiport 1

The designed approach and departure procedures for the vertiport candidate site, an existing helipad near the ICN cargo terminal, are presented here. The waypoints, VFR reporting point, and dimensions are illustrated in Fig. 7.

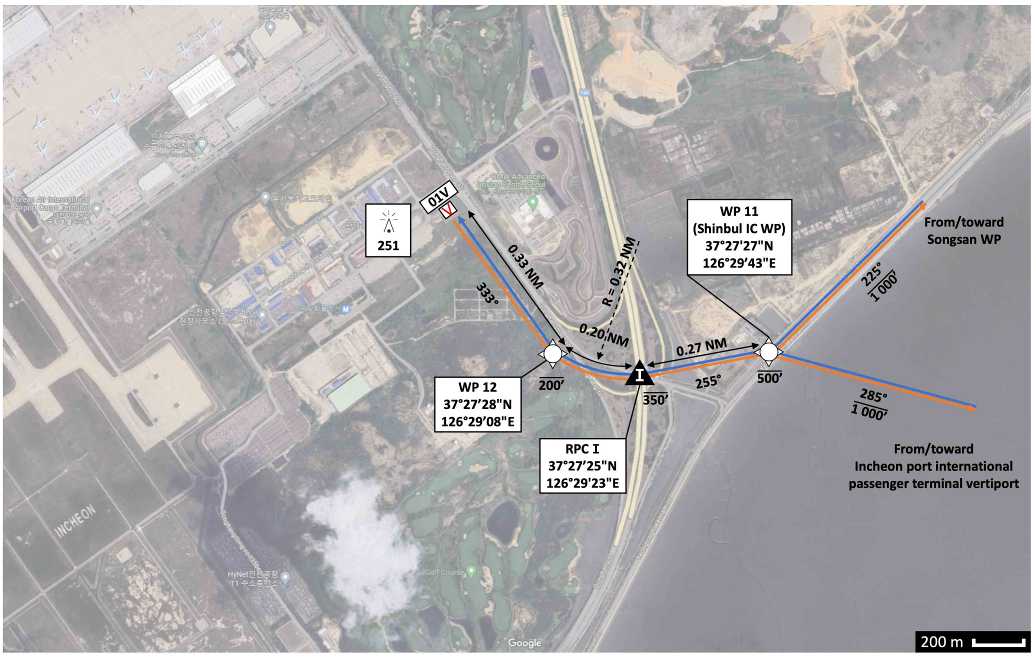

Figure 7 – Final approach and departure route to/from vertiport 1

In addition, the approach and departure procedures profile is shown in Fig. 8.

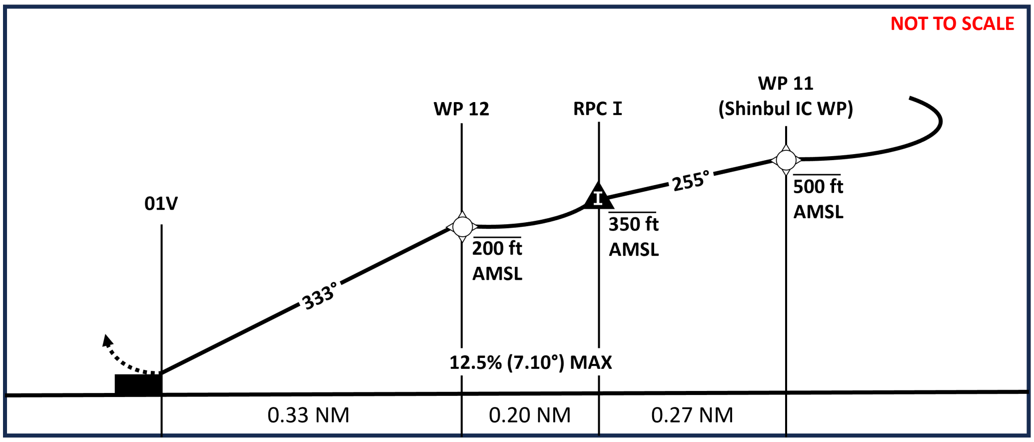

Figure 8 – Final approach and departure profile to/from vertiport 1

The route design is based on MOLIT *AIP RKSI* (ICN) [12], with the route passing by VFR reporting point 'I' and vertiport and route candidates, specifically the Shinbul IC waypoint. The slope design adheres to EASA *PTS-VPT-DSN.D.405* [11], utilising slope design category C and a curved slope. However, for this vertiport, the slope can only comply with the guideline if a curved slope is considered, a factor not evaluated by FAA based on FAA *EB 105* [5]. In addition, the altitude limit is considered from [12]. The details of the designed VFR final approach procedure (between WP 11 to 01V) are as follows:

- The final approach procedure starts at WP 11 (Shinbul IC WP).
- Fly at or below 500 feet via WP 11 and descend until 350 feet, maintaining a heading of 255°.
- Fly at or below 350 feet via RPC "I", turn toward WP 12, and descend to 200 feet.
- Fly at or below 200 feet via WP 12 while maintaining the heading of 333°.
- The glide path angle should not exceed 7.10° (12.5%).

It is important to note that the reporting point 'I' is situated in the middle of the final approach, and the heading of 333° is based on the predominant wind direction of the region.
However, there are some remarks on this designed procedure. Firstly, the designed procedure is a curved approach based on the VFR procedure in MOLIT *AIP RKSI* (ICN) [12]. In addition, the designed procedure requires further safety and noise examination, including downwash analysis and other slope categories might be applied for this approach based on the performance of the aircraft. Another issue is present in this procedure; only one approach or departure path can be designed in this vertiport due to surrounding facilities and airspace limitations. Considering this limitation, a modification of the vertiport's position, route, or regulatory requirements might be necessary to meet the separation guidelines of both EASA and FAA in the future, especially with increased traffic.

3.2.2 Vertiport 2

The designed approach and departure procedures for the vertiport candidate site on Geojampo Harbour are presented here. The waypoints, VFR reporting point, and dimensions are shown in Fig. 9. In addition, the approach and departure procedures profile is shown in Fig. 10.

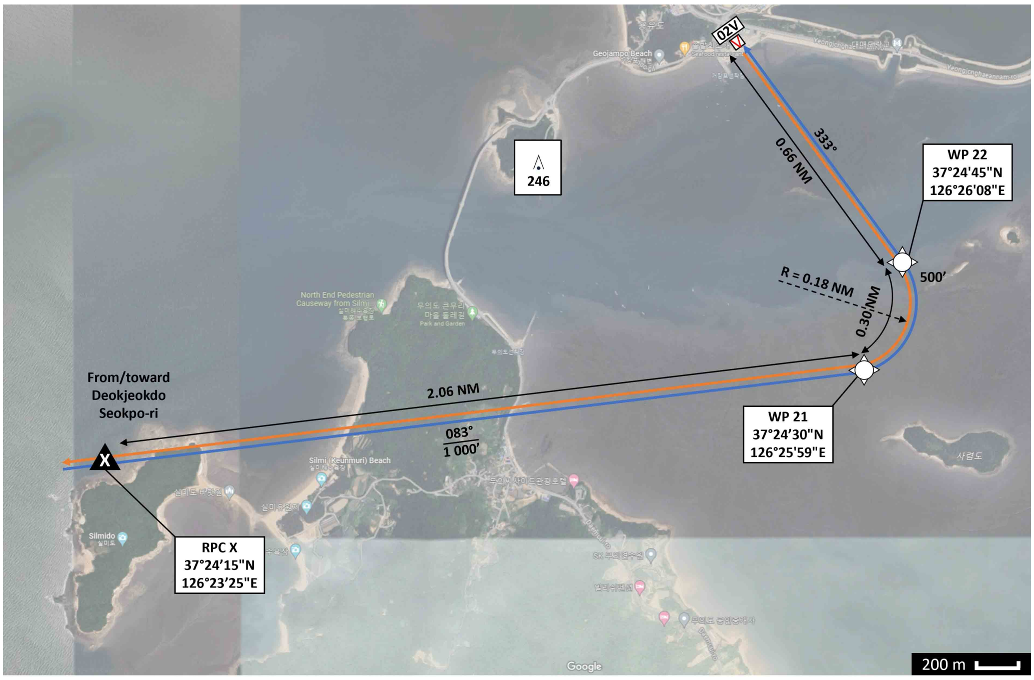

Figure 9 – Final approach and departure route to/from vertiport 2

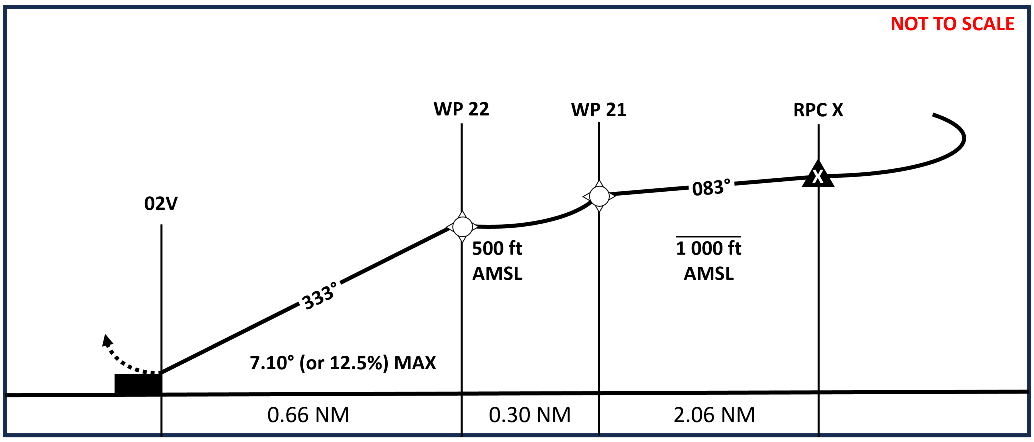

Figure 10 – Final approach and departure profile to/from vertiport 2

The route design is based on MOLIT *AIP RKSI* (ICN) [12], with the route passing by VFR reporting point 'X' and vertiport and route candidates, specifically flying over Shilmido. The slope design follows EASA *PTS-VPT-DSN.D.405* [11]: General, utilising slope design category C and the preferred slope based on FAA *EB 105* [5]. In addition, the altitude limit is considered from [12]. The details of the designed VFR final approach procedure (between WP 21 to 02V) are as follows:

- The final approach procedure starts at WP 21.
- Fly at or below 1,000 feet via RPC "X," maintaining a heading of 083°.
- Turn toward WP 22.
- Fly at 500 feet via WP 22 and descend while keeping the heading to 333°.
- The glide path angle should not exceed 7.10° (12.5%).

It is important to note that the heading of 333° is based on the predominant wind direction of the region.

However, there are some remarks on this designed procedure as well. Firstly, other slope categories might be applied to this approach based on the performance of the aircraft. Another issue, similar to vertiport 1, is that only one approach or departure path can be designed in this vertiport due to surrounding facilities and airspace limitations. Considering this limitation, a modification of the vertiport's position, route, or regulatory requirements might be necessary to meet the separation guidelines of both EASA and FAA in the future, especially with increased traffic. Finally, an additional path may be provided if we consider an alternative vertiport type such as elevated (or rooftop) or an obstacle-free volume vertiport as shown in Fig. 3 [11, p. 63].

4. Further Examination of Designed Procedures

EASA and FAA provide guidelines stating that the approach and departure routes are recommended to be designed based on the predominant (or prevailing) wind direction to avoid downwind operation in [11, p. 51] and [5, p. 23]. The procedures designed in the previous sections for vertiport 1 and vertiport 2 are based on this requirement from the documents. However, as noted in the previous sections, the designed procedures can't fulfil another requirement that recommends the provision of at least two approach and departure routes in [11, p. 51] and [5, p. 23] due to surrounding infrastructures. In this section, we examined further 1) with an alternative vertiport type such as an elevated (or rooftop) or an obstacle-free volume [11, p. 63] vertiport or 2) without predominant wind direction condition.

4.1 Other Vertiport Types

The only vertiport type considered for the approach and departure procedures of candidate sites previously was a simple helipad-like vertiport on the ground. Here, we additionally considered the other types of vertiport: elevated (or rooftop) vertiport and obstacle-free volume proposed by EASA (see Figs. 3) to check the feasibility of multiple slopes for the candidate sites. In this study, the elevated vertiport which is assumed to be located 147 feet (45 m) above the ground and reference volume type 1 [11, p. 73] which provides a vertical approach and departure from/to 100 feet (30.5 m) above the ground, are considered. This reference volume type 1 is shown in Fig. 11. Note that "D" in the figure is the diameter of the smallest circle enclosing the VTOL aircraft projection on a horizontal plane (see [11, p. 5] for the definition of the dimension "D").

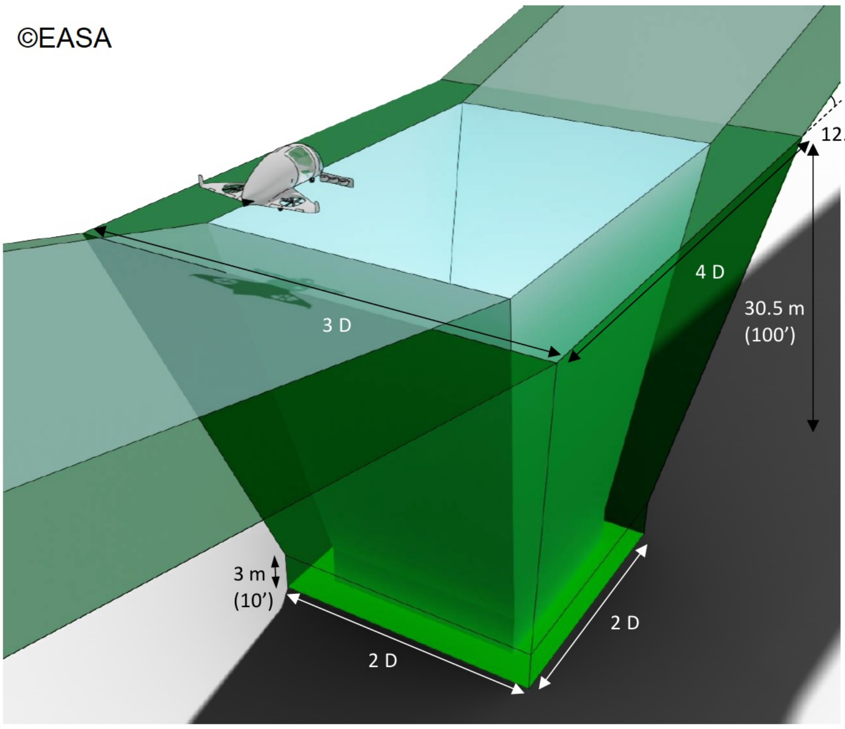

Figure 11 – Reference volume type 1 dimensions (with the SA) from [11], ©EASA

In the case of vertiport 1, an additional slope could potentially be provided with conditional modifications to MOLIT *AIP RKSI* (ICN) [12] and further examination of downwash effects and infrastructure height. The current version of MOLIT *AIP RKSI* (ICN) [12] offers only one possible VFR approach route to avoid downwash onto the congested area [12, p. 58]. Therefore, designing an additional slope for vertiport 1 is currently impossible. However, considering that the provided VFR procedure aims to avoid downwash onto the congested area, and the downwash effect may not be significant from 147 feet above ground level (AGL) for an elevated vertiport or 100 feet AGL for reference volume type 1, an additional slope (heading 153°) separated by 180° from the previously designed slope (heading 333°) could be provided. This would require careful examination of downwash onto the leisure facilities and other infrastructures, especially on the cargo terminal on the north side of vertiport 1, and the modification of MOLIT *AIP RKSI* (ICN) [12]. To approach this slope, the aircraft would need to pass by the Shinbul IC waypoint and VFR reporting point 'I'. The approach procedure would then commence from WP 13 toward vertiport 1. The slope design adheres to EASA *PTS-VPT-DSN.D.405* [11], utilising slope design category C and a curved slope. However, for this approach, the slope can only comply with the guideline if a curved slope is considered, a factor not evaluated by FAA based on FAA *EB 105* [5]. The waypoints and dimensions of the additional slope for the approach and departure procedures for vertiport 1 are illustrated in Fig. 12.

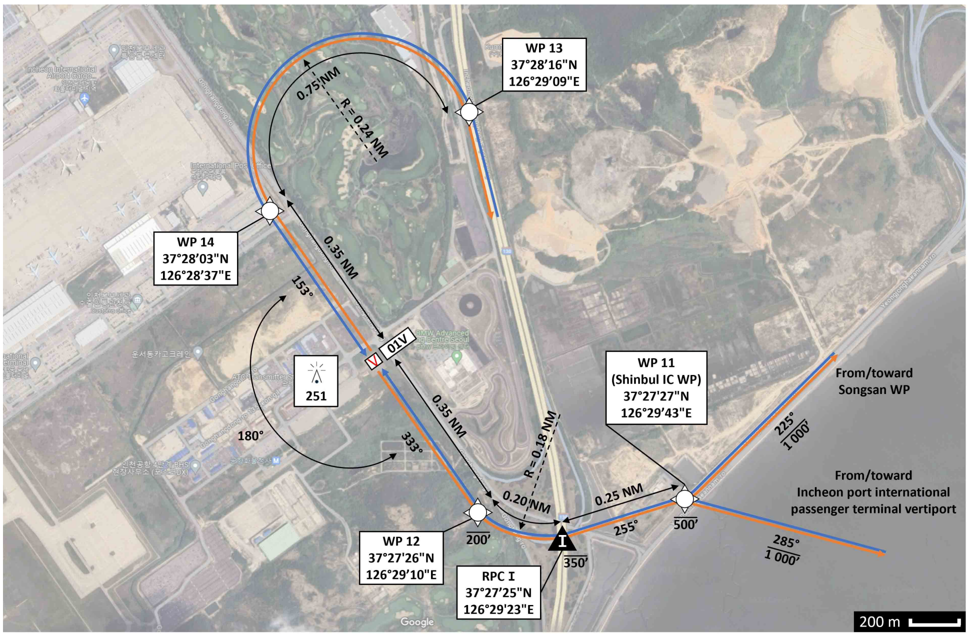

Figure 12 – An additional final approach and departure route to/from vertiport 1

For vertiport 2, an additional slope can be provided if other types of vertiports are considered. An additional slope (heading 153°) can be established, separated by 180° from the previously designed slope (heading 333°), meeting the requirements of separation in [11] and [5]. This additional slope is free from infrastructure or ground obstacles on the north side of vertiport 2. To approach this slope, the aircraft would need to pass by the VFR reporting point 'X'. The approach procedure would then commence from WP 23 toward vertiport 2. The slope design adheres to EASA *PTS-VPT-DSN.D.405* [11], utilising slope design category C and a curved slope. However, also for this approach, the slope can only comply with the guideline if a curved slope is considered, a factor not evaluated by FAA based on FAA *EB 105* [5]. The waypoints and dimensions of the additional slope for the approach and departure procedures for vertiport 2 are illustrated in Fig. 13.

However, there are some remarks on this additional slope. Firstly, the designed procedure incorporates a curved approach, to avoid hills near the vertiport and align with the VFR reporting point as outlined in MOLIT *AIP RKSI* (ICN) [12]. In addition, as previously noted for vertiport 1, while the downwash effect may not be significant from 147 feet AGL for an elevated vertiport or 100 feet AGL for reference volume type 1, it is important to conduct a more comprehensive examination of downwash effects and infrastructure height. This examination becomes particularly critical to assess

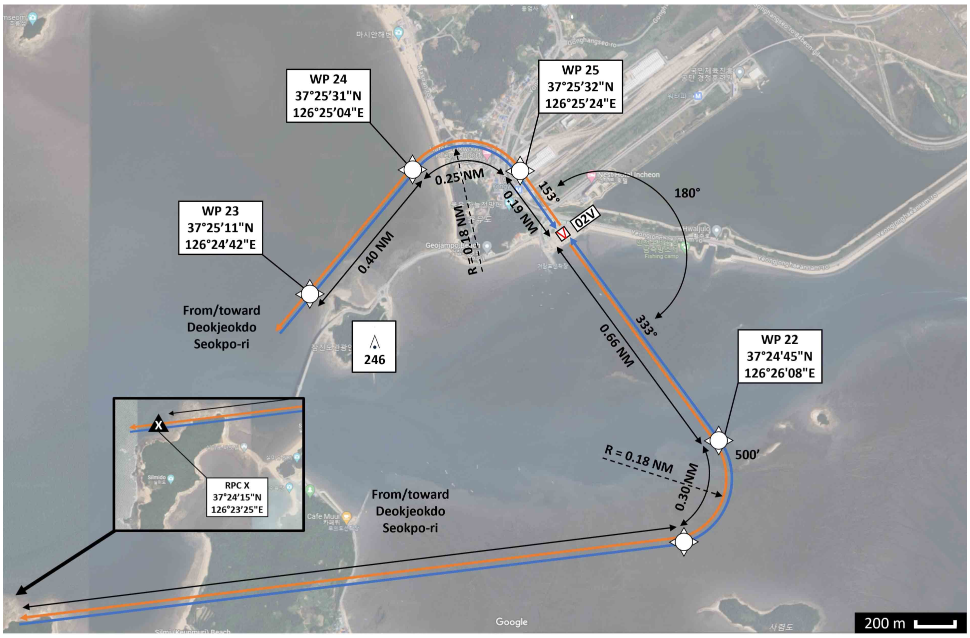

Figure 13 – An additional final approach and departure route to/from vertiport 2

the impact of downwash on the railway near WP 25, preventing potential infrastructure damage or operational disruptions to the railway.

It is important to note that the detailed downwash examination falls outside the current study's scope. This kind of examination necessitates precise aerodynamic characteristics of the eVTOL models and an accurate elevation map. As such, it was not conducted in this study.

4.2 Without Predominant Wind Direction Condition

In this section, we examined the feasibility of multiple approach and departure slopes while assuming no predominant wind direction condition. The requirement for a predominant wind direction is specified in both [11] and [5] to avoid downwind operations and minimise crosswind effects. As indicated in MOLIT *AIP RKSI* (ICN) [12], the predominant wind direction in the ICN area is 333° or 153°.

In the case of vertiport 1, one possible additional approach and departure slope is aligned approximately 189°. This slope can meet the minimum separation requirements of both documents, [11] and [5], being 135° from the previously designed slope by 144°. As mentioned in the previous section, however, this slope can be utilised only with a careful examination of downwash, modification of MOLIT *AIP RKSI* (ICN), and considering an alternative vertiport type, as discussed previously. It is worth noting that this slope might be preferable to the heading 153° slope discussed earlier, as it can effectively avoid flying over airport infrastructure, including the cargo terminal.

In the case of vertiport 2, two new approaches and departure slopes can be considered if no predominant wind direction is considered. They are heading 65° and heading 290° slopes, aligned with the seashore on the west side of vertiport 2 and the breakwater on the east side of vertiport 2, respectively. These slopes can meet the minimum separation requirements of both documents, [11] and [5], being 135° from each other. However, the heading 65° slope should involve a curved approach to avoid the transmission tower in Jamjindo (246 feet). In addition, these two approaches have a high risk of crosswind during the approach and departure phase, which should be examined carefully. The directions of the slopes for vertiport 1 and vertiport 2 are shown in Fig. 14.

It is important to note that the examination of the effect of the wind direction on the eVTOL and the detailed slope design for this approach route falls outside the current study's scope. This examination also requires precise aerodynamic characteristics of the eVTOL models and meteorological data. As such, it was not conducted in this study.

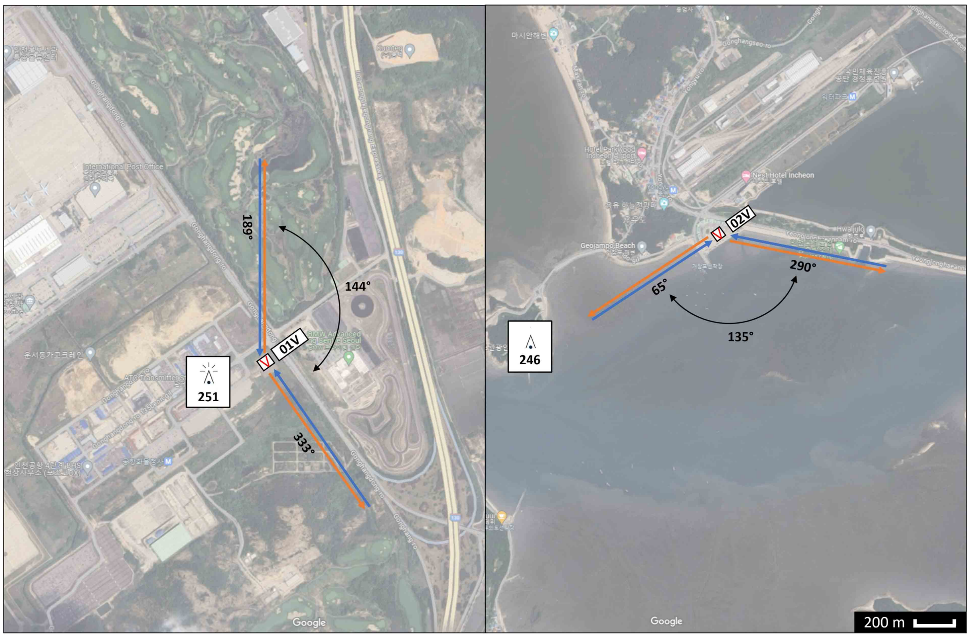

Figure 14 – Possible approach and departure slopes for vertiport 1 (left) and vertiport 2 (right)

5. Conclusion

A comprehensive literature survey was conducted to identify key elements crucial for establishing the approach and departure procedures of UAM/AAM to/from vertiports adjacent to airports and a conceptual design for these procedures was done in this study. The key elements identified from the literature survey include the minimum safe distance from active runways, airspace integration, adherence to current VFR procedures and the identification of obstacles. It was also identified that considering the distinct aerodynamics of UAM/AAM compared to traditional helicopters requires further attention. Two vertiport candidate sites adjacent to Incheon International Airport were considered to design the procedure and the designed procedures for each candidate site are presented in Section **??**. However, neither of the designed procedures could meet the separation requirements set by authorities for having more than one slope for approach and departure. Furthermore, the design of approach and departure procedures for UAM operations requires future exploration, such as an in-depth analysis of safety aspects, including downwash effects, and the potential need for modifications to vertiport infrastructure to accommodate more than one slope. A further examination of the designed procedures with alternative vertiport types and without predominant wind conditions was conducted. This examination showed that additional slopes could be provided if an elevated or obstacle-free volume vertiport is considered or if the predominant wind direction condition is not taken into consideration in the design for both candidate sites. However, the result of this examination can be considered for application only after further careful study, particularly concerning downwash effects and other safety concerns. In addition, a roadmap for future work in the field of UAM procedure design was identified:

- **Procedure Update**: Updates to approach and departure procedures based on flight tests and aerodynamic data of UAM/AAM are essential for refining and enhancing safety measures.
- **New Candidate Sites Suggestion**: Identifying and evaluating new candidate sites is important for the continued development of UAM infrastructure if current vertiport sites prove insufficient with updated procedures.
- **Emergency Landing Procedures**: Developing and considering emergency landing procedures and missed approach procedures are crucial for ensuring safe operations in potential adverse scenarios.

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8. Copyright Statement

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