**DOT/FAA/TC-26/35**

Federal Aviation Administration
William J. Hughes Technical Center for
Advanced Aerospace
Aviation Research Division
Atlantic City International Airport
New Jersey 08405

# Helicopter and Electric Vertical Takeoff and Landing Aircraft Research 2020–2025

September 2026

Final Report

This document is available to the U.S. public through the National Technical Information Services (NTIS), Springfield, Virginia 22161.

This document is also available from the Federal Aviation Administration William J. Hughes Technical Center for Advanced Aerospace at actlibrary.tc.faa.gov.

U.S. Department of Transportation
**Federal Aviation Administration**

## NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof. The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the objective of this report. The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the funding agency. This document does not constitute FAA policy. Consult the FAA sponsoring organization listed on the Technical Documentation page as to its use.

This report is available at the Federal Aviation Administration William J. Hughes Technical Center for Advanced Aerospace's Full-Text Technical Reports page: actlibrary.tc.faa.gov in Adobe Acrobat portable document format (PDF).

**Technical Report Documentation Page**

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| DOT/FAA/TC-26/35 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| HELICOPTER AND ELECTRIC VERTICAL TAKEOFF AND LANDING AIRCRAFT RESEARCH 2020–2025 | September 2026 |
| | 6. Performing Organization Code |

| 7. Author(s) | 8. Performing Organization Report No. |
|---|---|
| Maria Muia, Ph.D.*, Zachary Shuman*, David Hall*, and Ryan King** | |

| 9. Performing Organization Name and Address | 10. Work Unit No. (TRAIS) |
|---|---|
| *Woolpert, Inc.<br>4454 Idea Center Boulevard<br>Dayton, Ohio 45430<br><br>**Department of Transportation<br>Federal Aviation Administration<br>William J. Hughes for Advanced Aerospace<br>Atlantic City International Airport, NJ 08242 | 11. Contract or Grant No.<br>692M15-24-D-00001 |

| 12. Sponsoring Agency Name and Address | 13. Type of Report and Period Covered |
|---|---|
| Department of Transportation<br>Federal Aviation Administration<br>Office of Airports Safety and Standards<br>800 Independence Avenue, S.W.<br>Washington, DC 20591 | Final Report |
| | 14. Sponsoring Agency Code<br>AAS-100 |

15. Supplementary Notes

The Federal Aviation Administration Aviation Research Division Contracting Officer's Representatives (CORs) were Ryan King and Russ Gorman.

16. Abstract

In 2019, the Federal Aviation Administration (FAA) Airport Technology Research and Development Branch (ATR) initiated a research project to evaluate electric vertical takeoff and landing aircraft (eVTOL) and their potential impact on airport and heliport design standards. Work commenced through the award of a Broad Agency Announcement (BAA) to solicit information from various eVTOL aircraft design concepts at the time and to identify and assess any known takeoff and landing performance that may change the way ground infrastructure is designed. The goal was to develop a set of minimum standards for the design and establishment of landing areas for civil use of eVTOL aircraft. Over the course of 6 years, the FAA conducted numerous research activities via an additional BAA in 2022, followed by a support contract for vertiport design awarded in 2024. As the research and subsequent policy evolved, research tests included both helicopters and eVTOLs due to their similarities and the FAA's decision to move toward a unified infrastructure standard in Engineering Brief (EB) 105A.

This document is meant to serve as a concise presentation of the FAA's research performed to date on ground infrastructure in this evolving and dynamic realm of advanced air mobility (AAM). The content is arranged as a road map through various research campaigns, to help the reader understand the approach, the iterative methodologies used, and findings and conclusions. Research activities comprised literature reviews and gap analyses, vertiport modeling and simulation, and field assessment and quantification of downwash and outwash wind velocities and landing accuracy for helicopters and eVTOLs.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| Vertical flight, Helicopters, eVTOL, Downwash and outwash, Heliports, Vertiports, Landing accuracy | This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov. |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 28 | |

TABLE OF CONTENTS


| | | Page |
|---|---|---|
| EXECUTIVE SUMMARY | | viii |
| 1. | INTRODUCTION | 1 |
| 2. | PURPOSE | 1 |
| 3. | SCOPE | 1 |
| 4. | RESEARCH SUMMARY | 2 |
| 4.1 | Literature Review and Gap Analysis | 2 |
| 4.1.1 | Vertiport Design for eVTOL—Literature Review | 2 |
| 4.1.2 | Vertiport Design for eVTOL—Gap Analysis | 3 |
| 4.2 | Vertiport Capacity | 3 |
| 4.2.1 | Vertiport Design for eVTOL: Task 3 eVTOL Modeling and Simulation | 3 |
| 4.2.2 | Atlantic City International Airport 30% Vertiport Design Plans | 4 |
| 4.3 | Downwash and Outwash—Helicopter | 4 |
| 4.3.1 | Helicopter Downwash and Outwash Surveys—Phase 1 | 4 |
| 4.3.2 | Helicopter Downwash and Outwash Surveys—Phase 2 | 6 |
| 4.3.3 | Helicopter Downwash and Outwash Surveys—Phase 3 | 7 |
| 4.4 | Landing Accuracy—Helicopter | 8 |
| 4.4.1 | Helicopter Landing Surveys—Phase 1 | 8 |
| 4.4.2 | Helicopter Landing Surveys—Phase 2 | 12 |
| 4.4.3 | Helicopter Landing Surveys—Phase 3 | 13 |
| 4.5 | Downwash and Outwash—eVTOL | 13 |
| 4.5.1 | Electric Vertical Takeoff and Landing (eVTOL) Downwash and Outwash Surveys | 13 |
| 4.5.2 | Electric Vertical Takeoff and Landing Downwash and Outwash Surveys Addendum 1 | 15 |

4.6 Landing Accuracy—eVTOL 17

4.6.1 Landing Survey Results for eVTOL 17

5. CONCLUSION 17

6. REFERENCES 18

LIST OF FIGURES


| Figure | | Page |
|---|---|---|
| 1 | Sensor Array Layout | 6 |

LIST OF TABLES


| Table | | Page |
|---|---|---|
| 1 | Helicopters Included in DWOW Surveys—Phase 1 | 5 |
| 2 | Overall Maximum Speeds Measured for All Helicopters and All Surveys in Phase 1 | 5 |
| 3 | Helicopters Surveyed in Phase 2 at a Field Elevation of 1,243 MSL | 7 |
| 4 | Overall Maximum Speeds Measured for All Helicopters for All Surveys in Phase 2 | 7 |
| 5 | Helicopters Surveyed in Phase 3 | 8 |
| 6 | Overall Maximum Speeds Measured for All Helicopters for All Surveys in Phase 3 | 8 |
| 7 | All Helicopter Landing Accuracy Summary—Phase 1 | 10 |
| 8 | All Helicopter Landing Accuracy Summary—Phases 1 and 2 | 12 |
| 9 | Helicopter Target Surveys | 13 |
| 10 | Overall Maximum Speeds Measured for All eVTOL Aircraft | 15 |
| 11 | Maximum DWOW Velocity Measured by Distance | 16 |
| 12 | Landing Survey Results | 17 |

# LIST OF ACRONYMS

| | |
|---|---|
| AAM | Advanced Air Mobility |
| AC | Advisory Circular |
| ACY | Atlantic City International Airport |
| ATR | Airport Technology Research and Development |
| BAA | Broad Agency Announcement |
| CONOPS | Concepts of Operation |
| DCA | Downwash and outwash caution area |
| EB | Engineering Brief |
| eVTOL | Electric vertical takeoff and landing |
| FAA | Federal Aviation Administration |
| FATO | Final approach and takeoff area |
| ICAO | International Civil Aviation Organization |
| LG | Landing gear |
| OEM | Original equipment manufacturer |
| SA | Safety area |
| SD | Standard deviation |
| TOW | Takeoff weight |
| TLOF | Touchdown and liftoff area |
| UAM | Urban Air Mobility |
| VTOL | Vertical takeoff and landing |
| VVPM | Viscous vortex particle method |

# EXECUTIVE SUMMARY

In 2019, the Federal Aviation Administration (FAA) Airport Technology Research and Development Branch (ATR) initiated a research project to evaluate electric vertical takeoff and landing aircraft (eVTOL) and their potential impact on airport and heliport design standards. Work commenced through the award of a Broad Agency Announcement (BAA) to solicit information from various eVTOL aircraft design concepts and to identify and assess any known takeoff and landing performance that may change the way ground infrastructure is designed. The goal was to develop a set of minimum standards for the design and establishment of landing areas for civil use of eVTOL aircraft. Over the course of 6 years, the FAA conducted numerous research activities via an additional BAA in 2022, followed by a support contract for vertiport design awarded in 2024. As the research and subsequent policy evolved, research tests included both helicopters and eVTOLs due to their similarities and the FAA's decision to move toward a unified infrastructure standard in Engineering Brief (EB) 105A.

The publication of EB 105A was a major turning point. Building on this success, the FAA decided to pursue the development of a single Advisory Circular (AC) for vertical flight infrastructure design that would combine and update heliport design standards from AC 150-2539-2D, *Heliport Design*, with the guidance in EB 105A and subsequent research findings into a new AC for Vertical Flight Infrastructure design focused on safely accommodating operations of traditional helicopters, powered lift aircraft, and short takeoff and landing aircraft.

This document is meant to serve as a concise presentation of the FAA's research performed to date on ground infrastructure in this evolving and dynamic realm of advanced air mobility (AAM). The content is organized as a road map through various research campaigns, to help the reader understand the approach, the iterative methodologies used, and findings and conclusions. Research activities comprised literature reviews and gap analyses, vertiport modeling and simulation, and field assessment and quantification of downwash and outwash wind velocities and landing accuracy for helicopters and eVTOLs.

The outputs of these research endeavors informed the publication of design standards for ground infrastructure including EB 105, *Vertiport Design,* published in September 2022, an update to EB 105, i.e., EB 105A, *Vertiport Design, Supplemental Guidance to Advisory Circular 150/5390-2D, Heliport Design*, published in December 2024, and will culminate in the publication of Draft AC 150-5390-4, *Vertical Flight Infrastructure,* anticipated in early to mid-fiscal year 2027.

## 1. INTRODUCTION

The FAA Airport Technology Research and Development Section, Emerging Technology Unit has been conducting research since 2020 to support the Office of Airports (ARP) in establishing a unified set of design guidance and safety standards for vertical flight infrastructure that accommodate operations of all vertical takeoff and landing aircraft including emerging eVTOLs and traditional rotorcraft.

## 2. PURPOSE

This document is meant to serve as a concise presentation of the FAA's research performed to date on ground infrastructure in the evolving and dynamic realm of advanced air mobility (AAM). The content is presented as a road map through various research campaigns, to help the reader understand the approach, the iterative methodologies used, and findings and conclusions for each research campaign.

## 3. SCOPE

The material contained in this document covers vertical flight aircraft infrastructure design research efforts from years 2019–2025.

1. Literature Review and Gap Analysis
    a. February 2021, *Vertiport Design for eVTOL—Literature Review*
    b. March 2021, *Vertiport Design for eVTOL—Gap Analysis*
2. Vertiport Modeling and Simulation
    a. July 2022, *Vertiport Design for eVTOL: Task 3 eVTOL Modeling and Simulation*
    b. *Atlantic City International Airport (ACY) 30% Vertiport Design Plans*
3. Helicopter Downwash and Outwash (DWOW)
    a. February 2025, *Helicopter Downwash and Outwash Surveys—Phase 1*
    b. July 2025, *Helicopter Downwash and Outwash Surveys—Phase 2*
    c. January 2026, *Helicopter Downwash and Outwash Surveys—Phase 3*
4. eVTOL DWOW
    a. December 2024, Report DOT/FAA/TC-24/42, *Electric Vertical Takeoff and Landing (eVTOL) Downwash and Outwash Surveys* (Muia et al., 2024)
    b. November 2025, *Electric Vertical Takeoff and Landing (eVTOL) Downwash and Outwash Surveys Addendum 1*
5. Helicopter Landing Accuracy
    a. March 2024, *Helicopter Landing Surveys—Phase 1*
    b. October 2024, *Helicopter Landing Surveys—Phase 2*
    c. December 2025, *Helicopter Landing Surveys—Phase 3*
6. eVTOL Landings Accuracy
    a. Ongoing, eVTOL Landing (takeoff weight [TOW] under 4,500 lb)

## 4. RESEARCH SUMMARY

This section provides an overview of the initiatives and findings from each effort listed above.

### 4.1 LITERATURE REVIEW AND GAP ANALYSIS

#### 4.1.1 Vertiport Design for eVTOL—Literature Review (February 2021)

The first element of the FAA's research campaign regarding ground infrastructure needs for newly emerging eVTOL aircraft was a literature review. The review focused mainly on facility design (e.g., touchdown and lift-off surfaces (TLOF) and final approach and takeoff areas (FATO)) as opposed to subjects like air traffic management, system networking, and market analysis. Literature was generally limited to documents published within the last decade due to the vast differences between historic vertical takeoff and landing (VTOL) aircraft designs and present-day; however, this limitation was exceeded when deemed necessary to ensure no relevant information was omitted regarding the VTOL concept and how its governing regulations have evolved. For example, U.S. Federal Government reports related to heliports and helicopters were included. The primary goal of the review was to establish a foundation for a gap analysis between current understanding and regulations and the need for vertiport design guidelines.

From this literature review, some overarching conclusions were drawn regarding historic and future infrastructure for VTOL aircraft. The cancelled Advisory Circular (AC) 150/5390-3, *Vertiport Design*, was based on civil tiltrotors modeled after military tiltrotor technology (FAA, 1995). The intended aircraft never made it into commercial use. AC 150/5390-2D, *Heliport Design*, is based on helicopter technology (FAA, 2023a). The emerging eVTOL aircraft and concept(s) of operation (CONOPS) are not entirely modeled after either of these designs or operational templates. Some authors have described futuristic concepts for busy urban air mobility (UAM) terminals accommodating quick turnaround times and thousands of passengers per day (Ploetner et al., 2020). This high volume is supposedly required for the necessary return on investment to implement the UAM concept. Ultimately, eVTOL aircraft and the UAM industry are so novel, very little original research has been completed on how a vertiport should be designed. Available literature at the time of this literature review focused on throughput capacity based on different topology with the criteria for the topology grounded in existing U.S. and international heliport standards.

The review found that helicopters today are certified as either Category A or Category B (FAA, 2023b & 2023c). Category A helicopters certify they can remain in flight if one engine fails; Category B helicopters do not. International Civil Aviation Organization (ICAO) (2020) standards include performance classes developed around the ability of the helicopter to land safely or continue flight after engine failure. The analysis indicates that the idea of performance-based vertiport standards is logical due to the large variation in designs for emerging eVTOL aircraft, and it seemed like a transferable concept. However, determining what the performances classes should be would require a significant understanding of the eVTOL aircraft characteristics, which had yet to be established.

### 4.1.2 Vertiport Design for eVTOL—Gap Analysis (March 2021)

This gap analysis summarized the discontinuities related to eVTOL vertiport design found during the literature review discussed above (Section 3.1.1) and categorized them in the following subject areas:

1. Vehicle size
2. Landing area design/geometry
3. Approach/departure
4. Load bearing
5. Aircraft Parking
6. Power plant specifications
7. Battery type/size/charging specs (electric)
8. Noise

Researchers concluded that of all passenger-carrying aircraft that exist today, helicopters have the most in common with the eVTOL aircraft currently being designed; hence the industry's inherent move to view FAA AC 150/5390-2C, *Heliport Design* (FAA, 2023a), as the most obvious source for facility development standards. While the heliport design AC is noted as an obvious starting point for developing eVTOL vertiport design standards, it indicates there are large gaps in the knowledge base regarding eVTOL aircraft that must be addressed to develop those standards.

As a result of the literature review, gap analysis, and Original Equipment Manufacturer (OEM) outreach, immediate focal points for field research began to emerge including aircraft downwash and outwash (DWOW), landing accuracy, approach and departure slopes, and capacity.

## 4.2 VERTIPORT CAPACITY

### 4.2.1 Vertiport Design for eVTOL: Task 3 eVTOL Modeling and Simulation (July 2022)

The objective of this study was to support the ongoing evaluation and development of vertiport design guidance through conceptual testing, simulation, and modeling of a vertiport based on the draft FAA standards in effect at the time, i.e., a draft version of the initial EB 105 (FAA, 2022). This effort conceptually tested the EB standards through six case studies that simulated planning of and modeling operations for a vertiport. It established a nominal facility capacity in terms of operations per hour and identified design, environmental, and vehicle performance factors that can affect capacity. It offered several key findings:

- Specific requirements, such as the need for eVTOL to turn into the wind or toward a taxiway exit as part of a typical arrival or departure operation, can impact the TLOF and FATO characteristics and impact capacity. Additionally, tugs that support taxi movements and the ingress and egress of emergency and support equipment, can also impact design requirements.

- Separation requirements between adjacent TLOFs to support dependent and independent operations would allow for increased capacity and need to be provided.

- Taxiway and taxilane design standards are needed as they may impact operations and capacity.

- Apron design standards as related to parking positions (size, marking, etc.) passenger ingress and egress, service vehicles, and separation standards can impact capacity.

- Physical space requirements, separation distances, and operational requirements (such as activities permitted near charging aircraft) are concerns in physical and operational planning that impact capacity.

#### 4.2.2 Atlantic City International Airport 30% Vertiport Design Plans (July 2022)

Part of the modeling and simulation task included the development of 30% plans for converting the FAA's experimental heliport at ACY to a vertiport based on the design standards set out in FAA EB 105, *Vertiport Design* (FAA, 2022). These plans included a vertiport operational area, consisting of pavement sections and associated safety areas for departures and arrivals, associated vertiport lighting and pavement markings, and other utilities' infrastructure. The design aircraft weight was 12,500 lb with a controlling dimension of 50 feet. The design incorporates elementary applications of the EB 105, the selected location, the chosen pavement design option (mill and overlay), and the preliminary design for the vertiport and approach lighting.

### 4.3 DOWNWASH AND OUTWASH—HELICOPTER

#### 4.3.1 Helicopter Downwash and Outwash Surveys—Phase 1 (February 2025)

This was performed under the FAA's modern campaign to collect DWOW using full-scale aircraft surveys. It covers seven helicopters that, for various reasons detailed below, were not all surveyed in the same way or at the same location. Although the make and models were not identified in the report, their takeoff weight and disc loading were shown.

The DWOW surveys were performed at various times and airports and conducted under daylight visual meteorological conditions. DWOW wind data were collected with a ground array of anemometer sensors surrounding the TLOF, FATO, and safety area (SA) while pilots were asked to perform several preset maneuvers. The surveys were conducted in real world conditions with no attempt made to control ambient wind conditions. MATLAB® was used to process the datasets. Time series plots were produced along with various statistics. Ambient wind speeds and directions were collected for reference, but no process was undertaken to remove ambient wind from the results.

The first field survey conducted under this DWOW campaign was designed to consist of four chartered helicopters (i.e., DLA-2-H2 through H5), each representing various weights and sizes. While on this survey, a public agency was conducting helicopter training operations at the same airport and volunteered their helicopter (i.e., D-2-H6) for the survey also, which the research team accepted.

The next two helicopters surveyed occurred during field surveys to collect data on eVTOL aircraft (which are discussed in Section 3.5). During these eVTOL surveys, the participants volunteered two helicopters, (i.e., D-1-H1 and D-8-H13), which were added to the testing. Accordingly, this activity was broken into two sections: planned research and ad hoc research, and the sensor array configuration varied among them.

Information about the surveyed aircraft is shown in Table 1. The overall maximum speeds measured for these seven helicopters are summarized in Table 2.

Table 1. Helicopters Included in DWOW Surveys—Phase 1

| Helicopter ID | Initial Takeoff Weight (lb) | Controlling Dimension (ft) | Rotor Diameter (ft) | TLOF (ft) | FATO (ft) | SA (ft) |
|---|---|---|---|---|---|---|
| DLA-2-H2 | 6,975 | 42.50 | 36.06 | 36 | 65 | 105 |
| DLA-2-H3 | 5,415 | 41.47 | 35.07 | 36 | 64 | 104 |
| DLA-2-H4 | 5,200 | 42.45 | 35.07 | 36 | 65 | 105 |
| DLA-2-H5 | 1,520 | 26.40 | 23.60 | 22 | 40 | 80 |
| D-2-H6 | 3,000 | 31.31 | 26.41 | 26 | 48 | 88 |
| D-1-H1 | Unknown | 38.3 | 33 | 32 | 59 | 99 |
| D-8-H13 | Unknown | 39.2 | 33.5 | 33 | 60 | 100 |

Table 2. Overall Maximum Speeds Measured for All Helicopters and All Surveys in Phase 1

| Overall Maximum | Speed (mph) | |
|---|---|---|
| Instant Max (mph) | 99.95 at 18 ft from TLOF Center | |
| Max 3-s M95% (mph) | 84.50 at 11 ft from TLOF Center | |
| **Maximum by Distance from TLOF Center** | **Instant Max (mph)** | **Max 3-s M95% (mph)** |
| 0-20 | 99.95 at 18 ft | 84.50 at 11 ft |
| 21-40 | 99.9 at 32 ft | 75.78 at 32 ft |
| 41-60 | 99.42 at 50 ft | 64.54 at 52 ft |
| 61-80 | 39.95 at 65 ft | 33.36 at 69 ft |
| 81-100 | 39.76 at 95 ft | 33.84 at 85 ft |
| 100+ | 32.57 at 106 ft | 29.41 at 106 ft |
| *The statistics shown are independent of each other. The maximums for any one sensor or any specific statistic may not come from the same time window or the same survey.* | | |

As detailed previously, this research was conducted in a real-world environment where heliports and vertiports will be operated, so ambient conditions could not be controlled. Therefore, results may be higher or lower if conducted at another time or location. The FAA deems a maximum wind velocity of 34.5 mph as the safety threshold acceptable for people and property on the ground. This value finds its roots from previous FAA research (Ferguson, 1994). The FAA's *Rotorwash Analysis Handbook* indicates that most rotorwash-related mishaps can be avoided if separation distances are maintained so that impacting rotorwash-generated velocities do not

exceed 30 to 40 knots (34.5–46 mph) across the ground (Ferguson, 1994). The results of this first set of field surveys did not locate the distance at which the winds decreased below 34.5mph; however, they exhibited that DWOW at the SA for all the helicopters surveyed surpassed the 34.5 mph threshold. This was true for both the instantaneous maximum velocity measured and the maximum 3-second, moving 95 percentile (Max 3-s M95%). As a result, the researchers recommended the establishment of a DWOW caution area (DCA) around heliports. The creation of a DCA was one of the principal changes included in the release of EB 105A (FAA, 2024) and is discussed further in Section 3.5.1.

4.3.2 Helicopter Downwash and Outwash Surveys—Phase 2 (July 2025)

Phase 2 was a continuation of the previous research undertaken in Section 3.3.1. This phase began with a field survey to measure DWOW from three helicopters made available by an OEM. During this field survey, an additional five helicopters were added from public agencies operating in the area who volunteered to participate.

For this phase, additional ultrasonic anemometers were acquired, and the ground sensor array layout was modified to extend further from the center of the TLOF than the original layout used for the surveys conducted under Section 3.3.1. Figure 1 shows the layout of the sensor array. This extended layout was implemented to capture wind velocities at further distances from the center of the TLOF to locate where the velocity decreased below the 34.5 mph threshold.

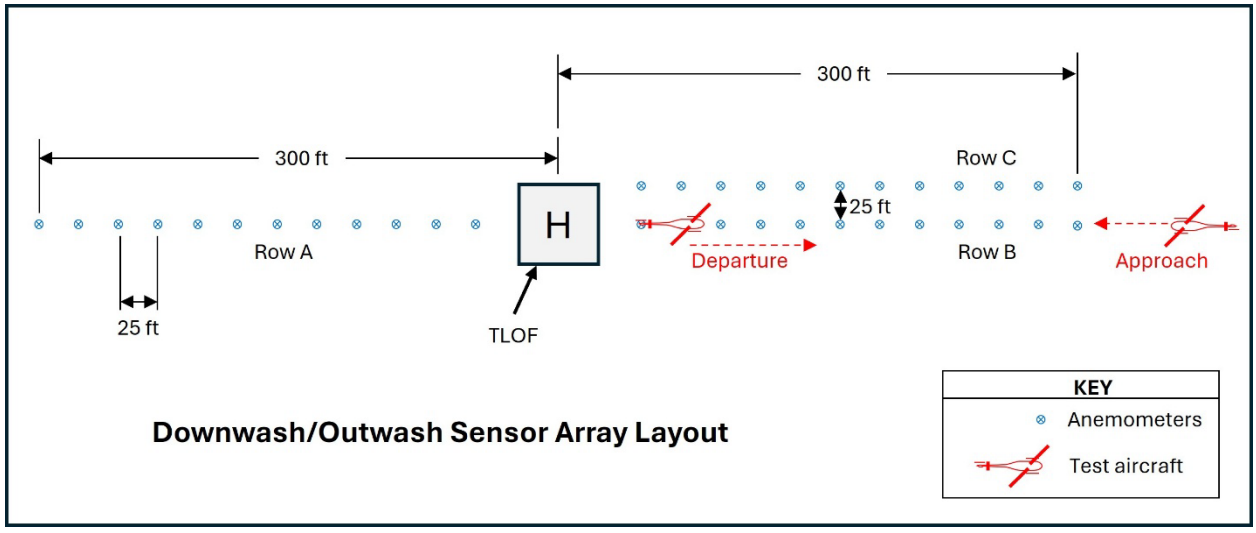



Figure 1. Sensor Array Layout

The locations where the wind velocity fell below 34.5 mph for each helicopter for all the surveys in this phase are shown in Table 3. For one helicopter, the wind velocity at the sensors farthest from the TLOF was greater than 34.5 mph. Table 4 shows the overall maximum speeds measured at different distances for all helicopters for all surveys in Phase 2.

Table 3. Helicopters Surveyed in Phase 2 at a Field Elevation of 1,243 MSL

| Helicopter ID | Initial Takeoff Weight (lb) | Disk loading | Sensor distance from TLOF center where wind velocity was below 34.5 mph | |
|---|---|---|---|---|
| | | | Maximum (ft) | Max 3-s M95% (ft) |
| DLT-9-H14 | 2,500 | 2.92 | 100 | 100 |
| DLT-9-H15 | 1,370 | 2.75 | 100 | 75 |
| DLT-9-H16 | 2,550 | 2.98 | 103 | 100 |
| D-9-H17 | 9,500 | 5.25 | 276 | 225 |
| D-9-H18 | 3,050 | 5.61 | 152 | 100 |
| D-9-H19 | 4,900 | 5.09 | 276 | 100 |
| D-9-H20 | 6,400 | 6.47 | 300 | 225 |
| D-9-H21 | 7,000 | 6.88 | +301 | +301 |

Table 4. Overall Maximum Speeds Measured for All Helicopters for All Surveys in Phase 2

| Overall Maximum | Speed (mph) | |
|---|---|---|
| Instant Max | 75.42 | |
| Max 3-s M95% | 99.98 | |
| **Maximum by Distance from TLOF Center (ft)** | **Instant Max (mph)** | **Max 3-s M95% (mph)** |
| 0-74 | 99.98 | 75.42 |
| 75-99 | 98.63 | 69.51 |
| 100-124 | 68.95 | 57.80 |
| 125-149 | 71.56 | 51.71 |
| 150-174 | 90.86 | 51.71 |
| 174-199 | 65.94 | 50.22 |
| 200-224 | 73.66 | 48.55 |
| 225-249 | 55.96 | 42.73 |
| 250-274 | 57.05 | 41.58 |
| 275-299 | 45.45 | 41.64 |
| 300+ | 40.52 | 34.76 |
| *The statistics shown are independent of each other. The maximums for one statistic may not come from the same time window or the same survey as the other statistic.* | | |

4.3.3 Helicopter Downwash and Outwash Surveys—Phase 3 (October 2025)

Phase 3 was a continuation of the previous research discussed in Sections 3.3.1 and 3.3.2. The sensors for this phase were generally in the same locations as for Phase 1 but slightly extended farther out from the TLOF center. This phase was completed in one field trip at one airport with an elevation of 5,515. The four aircraft surveyed (i.e., DLT-11-H23 through H26) were de-identified to be consistent with anonymity in prior phases, but their takeoff weight and disk loadings are shown in Table 3.

The helicopters and the location where the wind velocity fell below 34.5 mph for all the surveys in Phase 3 are shown in Table 5. Table 6 shows the overall maximum speeds measured at different distances for all helicopters for all surveys in Phase 3.

Table 5. Helicopters Surveyed in Phase 3

| Helicopter ID | Initial Takeoff Weight (lb) | Disk loading | Sensor Dist. from TLOF center where velocity was below 34.5 mph | |
|---|---|---|---|---|
| | | | Maximum (ft) | Max 3-s M95% (ft) |
| DLT-11-H23 | 4,620 | 4.80 | Beyond 326 | 276 |
| DLT-11-H24 | 6,296 | 6.15 | 326 | 276 |
| DLT-11-H25 | 4,700 | 4.86 | 326 | 301 |
| DLT-11-H26 | 5,846 | 6.63 | 300 | 251 |

Table 6. Overall Maximum Speeds Measured for All Helicopters for All Surveys in Phase 3

| Overall Maximum | Speed (mph) | |
|---|---|---|
| Instant Max | 99.33 | |
| Max 3-s M95% | 70.70 | |
| Maximum to TLOF Center (ft) | Instant Max (mph) | Max 3-s M95% |
| 0-74 | 98.47 | 70.70 |
| 75-99 | 99.33 | 64.65 |
| 100-124 | 96.04 | 67.89 |
| 125-149 | 72.35 | 52.20 |
| 150-174 | 55.75 | 53.23 |
| 174-199 | 61.93 | 57.62 |
| 200-224 | 62.35 | 50.65 |
| 225-249 | 65.81 | 51.60 |
| 250-274 | 58.53 | 55.01 |
| 275-299 | 50.76 | 41.44 |
| 300-324 | 56.47 | 42.85 |
| 325+ | 53.46 | 37.73 |
| *The statistics shown are independent of each other. The maximums for one statistic may not come from the same time window or the same survey as the other statistic.* | | |

## 4.4 LANDING ACCURACY—HELICOPTER

### 4.4.1 Helicopter Landing Surveys—Phase 1 (March 2024)

To understand the landing accuracy of helicopters, researchers measured the landing scatter for the four chartered helicopters used in the research discussed in Section 3.3.1 (i.e., DLA-2-H2 through H5). The test was designed to have each aircraft land 30 times for a total of 120 landings. All landings were conducted on a TLOF designed to general aviation standards to accommodate the controlling dimension of the largest helicopter in the survey.

The objective of the research was twofold: 1) to measure where the helicopter landed in relation to the center of its intended touchdown point (i.e., TLOF) and 2) to calculate if any part of the helicopter rotor would overhang a TLOF designed specifically for that aircraft as described in FAA AC 150/5390-2D, *Heliport Design* (FAA, 2023a). Accordingly, the distance from the rotor center and landing gear (LG) center to the TLOF center was measured for each landing. The reasoning behind the second objective is based on the phenomenon known as ground effect. When a helicopter operates close to a load-bearing surface, the surface impacts its flight characteristics because of the interaction of the rotor airflow (also known as downwash) with the surface. Having only some parts of the rotor in ground effect while other parts are out of ground effect (e.g., potentially on an elevated TLOF on a rooftop) may result in a nonuniform hovering performance for the aircraft, which could impact aircraft performance and/or controllability. The results from this research are summarized in Table 7.

Table 7. All Helicopter Landing Accuracy Summary—Phase 1

| Helicopter ID | DLA-2-H5 | | | | DLA-2-H4 | | | |
|---|---|---|---|---|---|---|---|---|
| | CD = | 26.4 | TLOF = | 21.9 | CD = | 42.5 | TLOF = | 35.2 |
| | RD = | 23.6 | | | RD = | 35.1 | | |
| | TOW = | 1520 | | | TOW = | 5200 | | |
| | **Crosswind Component** | **LG Center from TLOF Center** | **RD Center from TLOF Center** | **RD Center from Mean Landing** | **Crosswind Component** | **LG Center from TLOF Center** | **RD Center from TLOF Center** | **RD Center from Mean Landing** |
| Mean* | 1.56 | 1.20 | 1.36 | 1.12 | 4.04 | 1.69 | 1.77 | 1.47 |
| Maximum | 7.48 | 3.46 | 3.80 | 3.03 | 6.89 | 3.87 | 4.04 | 4.50 |
| SD | NA | 0.75 | 0.80 | 0.74 | NA | 1.16 | 1.20 | 0.92 |
| Mean TLOF Overhang of Rotor | | | 2.20 | | | | 1.69 | |
| Maximum TLOF Overhang of Rotor | | | 4.64 | | | | 3.96 | |

| Helicopter ID | DLA-2-H3 | | | | DLA-2-H2 | | | |
|---|---|---|---|---|---|---|---|---|
| | **CD =** | 41.5 | **TLOF =** | 34.4 | **CD =** | 42.5 | **TLOF =** | 35.3 |
| | **RD =** | 35.1 | | | **RD =** | 35.1 | | |
| | **TOW =** | 5415 | | | **TOW =** | 6975 | | |
| | **Crosswind Component** | **LG Center from TLOF Center** | **RD Center from TLOF Center** | **RD Center from Mean Landing** | **Crosswind Component** | **LG Center from TLOF Center** | **RD Center from TLOF Center** | **RD Center from Mean Landing** |
| Mean* | 5.07 | 4.33 | 4.61 | 0.90 | 3.24 | 1.93 | 2.40 | 1.47 |
| Maximum | 6.16 | 5.96 | 6.25 | 1.69 | 6.42 | 4.54 | 4.60 | 4.37 |
| SD | NA | 0.73 | 0.73 | 0.38 | NA | 1.03 | 0.93 | 0.89 |
| Mean TLOF Overhang of Rotor | | | 4.93 | | | | 2.29 | |
| Maximum TLOF Overhang of Rotor | | | 6.57 | | | | 4.49 | |

CD = Controlling dimension
RD = Rotor diameter
SD = Standard deviation

This Phase 1 research concluded that all pilot/helicopter combinations resulted in LG touchpoints that were always within the TLOF and largely close to the center. The precision of the landings was better than accuracy, likely due to pilot discretion for landing aiming point. Of particular interest, the research revealed that the FAA design standards for TLOFs do not always guarantee the design helicopter's rotor will be contained within it, leaving it susceptible to non-uniform performance if the area beyond the TLOF is void or sloping. This research influenced TLOF and FATO sizing.

4.4.2 Helicopter Landing Surveys—Phase 2 (October 2024)

This study was a continuation of the research described in Section 3.4.1. Similarly, its objectives were also to measure where the helicopter landed in relation to the center of its intended touchdown point (TLOF) and to calculate if any part of the helicopter rotor would overhang a TLOF. For Phase 2, six different helicopters ranging in weight, size, and complexity were captured for 363 additional landings, for a total of 483 when combined with Phase 1. This survey was distinct from Phase 1 in that the data collection was passive, leveraging real-world conditions with pilots landing without direct knowledge of the survey. The results from the Phase 1 study (Section 3.4.1) were included with this study and are summarized in Table 8..

Table 8. All Helicopter Landing Accuracy Summary—Phases 1 and 2

| Helicopter ID | RD | GA TLOF Size | Built-in TLOF Overhang | Mean Absolute Crosswind | Mean RD Center to Landing Location Center | Mean Landing TLOF Overhang of Rotor |
|---|---|---|---|---|---|---|
| LA-7-H7 | 35.90 | 35.28 | 0.63 | 5.56 | 1.68 | 2.00 |
| DLA-2-H4 | 35.07 | 35.23 | -0.16 | 4.04 | 1.77 | 1.69 |
| DLA-2-H3 | 35.07 | 34.42 | 0.65 | 5.07 | 4.61 | 4.93 |
| LA-7-H8 | 37.00 | 35.19 | 1.81 | 4.29 | 2.63 | 3.54 |
| LA-7-H9 | 37.00 | 35.19 | 1.81 | 4.60 | 2.41 | 3.31 |
| LA-7-H10 | 35.00 | 34.36 | 0.64 | 5.95 | 1.66 | 1.98 |
| LA-7-H11 | 36.00 | 35.69 | 0.31 | 5.68 | 3.99 | 4.15 |
| LA-7-H12 | 35.33 | 34.01 | 1.32 | 2.29 | 2.17 | 2.83 |
| DLA-2-H5 | 23.60 | 21.91 | 1.69 | 1.56 | 1.36 | 2.20 |
| DLA-2-H2 | 35.06 | 35.28 | -0.21 | 3.24 | 2.40 | 2.29 |

RD = Rotor diameter
GA = General aviation

The average distance from the rotor center to the landing location center for all the landings was 2.46 feet. As described with Phase 1 (Section 3.4.1), FAA design standards for TLOFs do not guarantee the design helicopter's rotor will be completely contained within its boundary, leaving the aircraft susceptible to nonuniform performance if the ground area beyond the TLOF is void or sloping. This research influenced TLOF and FATO sizing.

### 4.4.3 Helicopter Landing Surveys—Phase 3 (November 2025)

Phase 3 of this research had slightly different objectives than Phases 1 and 2. As vertical flight infrastructure standards were being developed by the FAA, the overarching objective of Phase 3 was to measure how close a pre-identified point on a helicopter's landing gear could be placed to a target on the ground. In addition to influencing TLOF and FATO sizing, the objective of this phase was to provide information for use by the FAA's Aircraft Certification Service (AIR)when conducting voluntary landing testing with future eVTOL OEMs.

Three entities provided helicopters for this phase, and the surveys occurred at three different airports at different times. A total of 340 surveys were conducted in visual meteorological conditions. The helicopters and their associated results are included in Table 7. Helicopters DLT-9-H15, DLT-9-H14 and DLT-9-H16 were flown by members of a flight school. All other makes were flown by pilots from an OEM or an air ambulance company.

Table 9. Helicopter Target Surveys

| **Helicopter Target Surveys – Distance from identified part of skid to target** | | | |
|---|---|---|---|
| **Helicopter ID** | **Quantity** | **Mean Landing Distance from Target (ft)** | **Mean Crosswind Component (mph)** |
| DLT-9-H15 | 104 | 2.31 | 3.33 |
| DLT-9-H14 | 9 | 1.73 | 1.91 |
| DLT-9-H16 | 16 | 1.72 | 3.78 |
| LT-10-H22 | 86 | 1.25 | 2.34 |
| DLT-11-H23 | 31 | 1.08 | 2.71 |
| DLT-11-H26 | 30 | 1.45 | 7.51 |
| DLT-11-H24 | 32 | 1.83 | 3.19 |
| DLT-11-H25 | 32 | 0.93 | 5.48 |
| **Total** | **340** | | |
| **Overall Mean** | | **1.64** | |
| **Standard Deviation** | | **1.88** | |
| **95 Percentile** | | **3.93** | |

All landings were relatively accurate i.e. less than about two feet from the target, except for three conducted in helicopters DLT-9-H15, DLT-9-H14, and DLT-9-H16, which could be considered outliers.

## 4.5 DOWNWASH AND OUTWASH—eVTOL

### 4.5.1 Electric Vertical Takeoff and Landing (eVTOL) Downwash and Outwash Surveys (DOT/FAA/TC-24/42)

In December 2024, the FAA published report DOT/FAA/TC-24/42, *Electric Vertical Takeoff and Landing (eVTOL) Downwash and Outwash Surveys* (Muia et al., 2024), which describes the collection of VTOL DWOW using the same full-scale aircraft survey methodologies used in the

research described in Section 3.3.1. This research measured the DWOW of three prototype eVTOL aircraft—all under 6,500 lb—for their maximum velocity at various locations on a vertiport. In addition to the ground-level array used for helicopter research, a vertical array of ultrasonic three-dimensional anemometers was added for collecting the DWOW wind velocities. The vertical array was designed to capture the DWOW velocities at different levels for use in validating computer simulation and modeling of DWOW for eVTOL, but only one of the OEMs was agreeable to flying their aircraft in proximity to the array. The DWOW surveys were performed at various times and locations and conducted under daylight visual meteorological conditions. DWOW wind data were collected at each anemometer location on the ground or vertical sensor array. The aircraft pilots performed several preset maneuvers within the bounds of their respective aircraft flight envelopes set for prototype aircraft. The survey measurements for the three prototype eVTOL aircraft included in the research were compared to viscous vortex particle method modeling and simulation where possible.

It should also be noted that no OEM performed the requested maneuvers as specifically planned and/or with the sensor layout sought. The locations of the tests were dependent upon the OEM and impacted by the specific conditions of each location. All were conducted at airports with the appropriate FAA Form 7460 filing and airspace case approval received. Weather, operational restrictions placed on the aircraft by the FAA or the OEM, and airport boundaries and structures all limited the location of the sensors and the maneuvers performed by the aircraft. As a result, no two tests were ever the same.

The surveys conducted under this phase of the campaign occurred in 2023 and 2024 before any OEM had a certified aircraft. All the aircraft were prototypes, and none were of the weight that the OEM intended to develop for certification. Regardless, the FAA obtained pertinent information as they developed their first guidance document on vertiport design, EB 105 (FAA, 2022).

The first survey of the eVTOL DWOW campaign included 14 sensors near the edges of the TLOF, FATO, and SA. The velocities recorded were still higher than the 34.5 mph threshold; so for the next two surveys, more sensors were added and placed in various locations around the landing area that included distances farther away from the TLOF. Even at the farthest distance, the velocities were still higher than 34.5 mph. The overall maximum speeds measured for these surveys are shown in Table 10.

The research revealed that eVTOL aircraft DWOW at the SA and beyond surpasses the 34.5 mph threshold. Additionally, it was noted that, while the maximum moving 3-second 95 percentile are lower than the instantaneous maximums measured, instantaneous winds can be more upsetting for people than sustained winds due to a phenomenon known as the “startle response.”

Table 10. Overall Maximum Speeds Measured for All eVTOL Aircraft

| **Overall Maximum** | **Speed (mph)** | |
|---|---|---|
| Instant Max (mph) | 99.62 at 41 ft from TLOF Center | |
| Max 3-s M95% (mph) | 83.59 at 23 ft from TLOF Center | |
| **Maximum by Distance to TLOF Center (ft)** | **Instant Max (mph)** | **Max 3-s M95% (mph)** |
| 0–25 | 99.32 | 83.59 |
| 26–50 | 99.62 | 79.36 |
| 51–75 | 99.24 | 66.00 |
| 76–100 | 85.90 | 63.73 |
| 101–125 | 65.04 | 59.27 |
| 125+ | 69.03 | 63.96 |

Regarding computer modeling and simulation, the survey measurements for the eVTOL aircraft were compared to viscous vortex particle method (VVPM) modeling and simulation where possible. The research revealed that the graphic processing unit (GPU) cards available at the time of the study limited the ability to model and simulate these aircraft because of the numerous propeller blades and their proximity to each other. While particles closer to the aircraft were tracked effectively, their paths did not reach distances where DWOW velocities would be considered safe for people. These limitations made VVPM alone an unlikely tool for forecasting where people and property would not be affected by high winds.

4.5.2 Electric Vertical Takeoff and Landing Downwash and Outwash Surveys Addendum 1

This research includes the results of one additional eVTOL aircraft. This aircraft was also a prototype and under 6,500 lb. Because the previous research had not identified a distance where the velocity fell below 34.5 mph, more sensors were added and placed farther from the center of the TLOF. The highest velocity at each sensor location across all the surveys are shown in Table 11.

Table 11. Maximum DWOW Velocity (mph) Measured by Distance

| Feet from TLOF Center | Maximum | Max 3-s MM | Max 3-s MM+2MSD | Max 3-s M95% |
|---|---|---|---|---|
| 55 | 77.36 | 44.42 | 66.58 | 57.02 |
| 60 | 96.56 | 45.78 | 70.56 | 62.98 |
| 61 | 71.95 | 41.15 | 61.79 | 61.22 |
| 65 | 96.64 | 45.11 | 60.70 | 58.71 |
| 75 | 63.45 | 39.66 | 57.03 | 53.56 |
| 79 | 62.39 | 35.45 | 55.19 | 45.60 |
| 80 | 70.93 | 40.55 | 60.81 | 58.85 |
| 81 | 66.68 | 39.83 | 54.30 | 53.41 |
| 84 | 73.82 | 38.98 | 56.03 | 52.93 |
| 95 | 49.41 | 30.90 | 45.82 | 43.03 |
| 98 | 63.42 | 38.87 | 63.63 | 53.99 |
| 100 | 80.25 | 39.48 | 70.40 | 66.15 |
| 103 | 73.04 | 38.64 | 60.82 | 57.73 |
| 115 | 39.19 | 27.00 | 38.98 | 35.69 |
| 117 | 58.96 | 32.33 | 49.78 | 51.67 |
| 120 | 95.47 | 37.65 | 61.01 | 57.95 |
| 123 | 63.83 | 36.92 | 60.35 | 54.06 |
| 135 | 34.55 | 22.87 | 33.69 | 29.51 |
| 137 | 61.42 | 26.33 | 39.68 | 33.34 |
| 140 | 75.24 | 42.89 | 66.54 | 60.58 |
| 142 | 88.64 | 36.47 | 60.83 | 54.41 |
| 155 | 27.62 | 20.33 | 27.74 | 24.74 |
| 157 | 69.51 | 25.93 | 43.85 | 45.06 |
| 160 | 62.90 | 38.76 | 58.97 | 55.27 |
| 162 | 94.28 | 31.75 | 53.34 | 47.08 |
| 174 | 31.20 | 19.89 | 28.03 | 23.29 |
| 176 | 66.14 | 21.57 | 36.45 | 29.86 |
| 180 | 62.75 | 31.73 | 62.53 | 58.57 |
| 182 | 41.39 | 27.16 | 44.83 | 37.42 |
| 195 | 26.82 | 20.34 | 29.59 | 25.49 |
| 196 | 37.79 | 18.76 | 27.04 | 25.21 |
| 200 | 44.97 | 27.22 | 51.59 | 42.39 |
| 202 | 38.05 | 23.39 | 37.74 | 36.17 |
| 220 | 51.24 | 23.78 | 45.06 | 37.55 |
| 221 | 37.27 | 25.05 | 41.58 | 35.97 |
| 240 | 66.00 | 25.21 | 46.10 | 37.52 |
| 241 | 32.48 | 23.27 | 34.49 | 30.11 |
| 260 | 28.57 | 19.80 | 31.26 | 28.09 |
| 261 | 29.61 | 20.26 | 32.72 | 28.27 |
| 280 | 24.57 | 20.33 | 27.80 | 23.54 |
| 281 | 25.72 | 18.88 | 26.84 | 23.37 |

Note: The statistics shown are independent of each other. The maximums for any one sensor or specific statistic may not come from the same time window or the same survey.

## 4.6 LANDING ACCURACY—eVTOL

### 4.6.1 Landing Survey Results for eVTOL (TOW under 4,500 lb)

As with helicopters, to understand the landing accuracy of eVTOL aircraft, the FAA sought to perform landing surveys with eVTOL OEMs in the FAA certification process. However, most of the OEMs were not conducting flights with full-scale aircraft or performing transition from lift-born flight to wing-born, and/or they had other aircraft demands restricting use of the aircraft. However, during this campaign two OEMs did participate to some degree in the testing, but never as originally planned so the data was never written into a formal report. The results of their participation are shown in Table 12.

Table 12. Landing Survey Results

| | **eVTOL #1** | | | | | **eVTOL #2** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **D, D-p** | 29.99 | 29.99 | | **TOW=** | 850 | 43.64 | 43.64 | | **TOW=** | 4350 |
| | **Crosswind Component** | **LG Farthest Point from TLOF Center** | **LG Center from TLOF Center** | **PD Center from TLOF Center** | **PD Center from Mean Landing** | **Crosswind Component** | **LG Farthest Point from TLOF** | **LG Center from TLOF Center** | **PD Center from TLOF Center** | **PD Center from Mean Landing** |
| **MEAN*** | 4.55 | 6.68 | 1.97 | 1.92 | 1.86 | 2.03 | 6.38 | **1.53** | **2.19** | 1.07 |
| **MAX** | 13.70 | 11.63 | 7.58 | 5.95 | 6.05 | 4.27 | 7.98 | 3.72 | 4.52 | 2.59 |
| **SD^** | | 1.39 | 1.53 | 1.13 | 1.15 | | 0.55 | 0.81 | **0.90** | 0.63 |

D = Controlling dimension; D-p = Diameter of all propulsion units; LG = Landing gear

Note that eVTOL #2 did not perform full approach and departures and did not appear to get out of ground effect, but merely "hopped" from one side of the apron to another.

## 5. CONCLUSION

In 2019, the Federal Aviation Administration (FAA) Airport Technology Research and Development Branch (ATR) initiated a research project to evaluate electric vertical takeoff and landing (eVTOL) aircraft and their potential impact on airport and heliport design standards.

Research activities comprised literature reviews and gap analyses, vertiport modeling and simulation, and field assessment and quantification of aircraft (i.e., helicopters and eVTOLs) landing accuracy and their DWOW velocities.

The outputs of these research endeavors informed the publication of design standards for ground infrastructure including Engineering Brief (EB) 105, *Vertiport Design*, published in September 2022 (FAA, 2022), and its update EB 105A, *Vertiport Design, Supplemental Guidance to Advisory Circular 150/5390-2D, Heliport Design*, published in December 2024 (FAA, 2024).

Based on the research described, in 2025, the FAA Office of Airports Safety and Standards decided to pursue creation of a unified set of infrastructure guidance that would combine EB 105A and the existing Advisory Circular for Heliport Design into a single Advisory Circular for vertical flight infrastructure. That Advisory Circular, AC-150/5390-4, *Vertical Flight Infrastructure*, is anticipated to be published in fiscal year 2027 (FY27) and updated as necessary as certified versions of advanced air mobility (AAM) aircraft emerge.

## 6. REFERENCES


FAA. (1995). *Vertiport design* (AC 150/5390-3 [Cancelled 2010-07-28]. https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/23096

FAA. (2022). *Vertiport design* (EB 105). https://nbaa.org/wp-content/uploads/aircraft-operations/emerging-technologies/advanced-air-mobility-aam/20220921-FAA-Engineering-Brief-105-Vertiport-Design.pdf

FAA. (2023a). *Heliport design* (AC 150/5390-2D). https://www.faa.gov/airports/resources/advisory_circulars/index.cfm/go/document.current/documentNumber/150_5390-2

FAA. (2023b). *Private pilot for rotorcraft category helicopter rating Airman Certification Standards* (FAA-S-ACS-15). https://www.faa.gov/training_testing/testing/acs/private_helicopter_acs_15.pdf

FAA. (2023c). *Commercial pilot for rotorcraft category helicopter rating Airman Certification Standards* (FAA-S-ACS-16). https://www.faa.gov/training_testing/testing/acs/commercial_helicopter_acs_16.pdf

FAA. (2024). *Vertiport design, supplemental guidance to Advisory Circular 150/5390-2D, Heliport Design* (EB 105A). https://www.faa.gov/airports/engineering/engineering_briefs/eb_105a_vertiports

Ferguson, S. (1994). *Rotowash analysis handbook, Volume I. Development and analysis* (DTIC ADA283719). U.S. Department of Transportation, Federal Aviation Administration. https://archive.org/details/DTIC_ADA283719

International Civil Aviation Organization (ICAO). (2020). *International standards and recommended practices: Annex 14 to the Convention on International Civil Aviation: Aerodromes: Volume II, Heliports* (5th ed.). https://elibrary.icao.int/product/286513

Muia, M. J., Stanley, J., Anderson, T., Hall, D., Shuman, Z., Goericke, J., Batther, J., Habana, Z., He, C., & Saberi, H. (2024). *Electric vertical takeoff and landing (eVTOL) downwash and outwash surveys* (Report No. DOT/FAA/TC-24/42). https://doi.org/10.21949/5hy5-z760

Ploetner, K. O., Al Haddad, C., Antoniou, C., Frank, F., Fu, M., Kabel, S., Lllorca, C., Moekel, R., Moreno, A. T., Pukhova, A., Rothfeld, R., Shamiyeh, M., Straubinger, A., Wagner, H., & Zhang, Q. (2020). Long-term application potential of urban air mobility complementing public transport: an upper Bavaria example. *CEAS Aeronautical Journal*, *11*(4); 991–1007. https://doi.org/10.1007/s13272-020-00468-5