

White Paper on Downwash/Outwash of Vertical Takeoff/Landing Aircraft in Civilian Aviation

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Abstract

Thousands of helicopter operations occur safely and without incident every day. Despite this, some recent fatal accidents, and a concerning number of unreported incidents, show there are emerging safety challenges. To ensure the safety of large-scale future ‘flying taxi’ and helicopter operations requires concerted technical and regulatory innovation. One of the biggest safety risks comes from downwash and outwash (DWOW). This is the high-speed air pushed underneath a helicopter or flying taxi to hold it up in the sky. DWOW has been the cause of recent helicopter-related accidents [2, 4, 21] and research shows DWOW may be more intense for flying taxis [5, 6]. The trend toward larger, heavier rotorcraft will inevitably see increased incidents unless careful planning is implemented to mitigate DWOW hazards.

1 Introduction

Every day, highly trained and experienced pilots safely fly thousands of helicopter operations without incident. Many of these flights often require operating to and from legacy landing areas, where maintaining safe distances away from the helicopter helps minimize risk. As exemplified in Figure 1, these landing areas are frequently surrounded by other structures or located close to pedestrian traffic. In the future, traditional helicopters will be supplemented by new entrant aircraft featuring alternative lift configurations such as multirotors, fans and jets. Operators of these alternative Vertical TakeOff and Landing aircraft (“VTOLs” or “verticraft”) are highly interested in leveraging existing building infrastructure and adopting high levels of piloting automation. Commercial success across the industry will be dependent on the safety of both the aircraft and people on the ground, particularly during takeoff, landing, and ground maneuvers.

Current vertical lift infrastructure design criteria includes a series of relatively small clear areas aimed at providing enough space to protect the aircraft from damage during final approach, takeoff, and ground maneuvers [8]. Acknowledging the potential risks of rotor downwash and outwash (DWOW) on persons and property, the UK Civil Aviation Authority (CAA) recommends designating additional exclusion zones around hospital helipads based on helicopter size [7]. The International Civil Aviation Organization (ICAO) also recommends an exclusion zone around heliports to mitigate risks from helicopter downwash [14]. In the US, additional exclusion zones have not historically been defined for vertical lift, although initial steps have been taken [11, 9]. Note: Throughout this document, the term “heliport” is used collectively to refer to all helicopter and verticraft landing areas: helipads, helistops, helicopter landing sites (HLS), and vertiports.

A number of recent fatal accidents, and a worrying unknown number of unreported incidents related to the trend toward larger, heavier rotorcraft, show that careful planning must be implemented to mitigate outwash hazards [2, 4]. Furthermore, unique DWOW characteristics for multirotor systems *may* require increased clear space for smaller, lighter aircraft as compared to traditional rotorcraft.

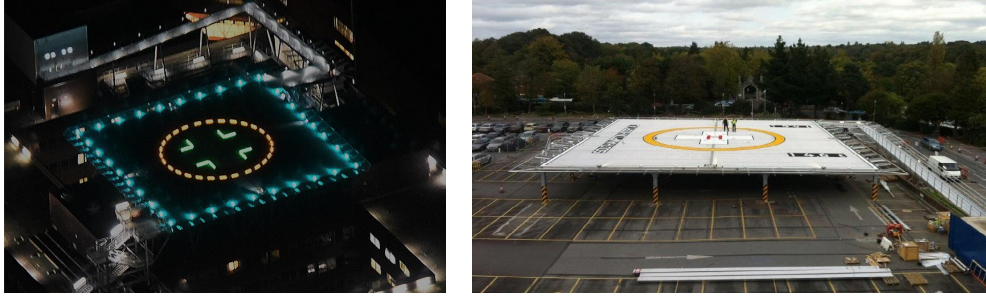


Figure 1: Examples of heliports with surrounding infrastructure from the CAA’s CAP 1264 [7].

2 Problem Statement

Vertical lift aircraft accelerate air downward, and generate upward thrust. If the aircraft is operating near the ground, this downwash is deflected sideways, creating outwash, as depicted in Figure 2. Outwash is air which flows from the aircraft towards nearby bystanders and objects. Outwash may cause injury by destabilizing nearby pedestrians, turn loose objects into dangerous projectiles, or cause damage to nearby aircraft and infrastructure [4].

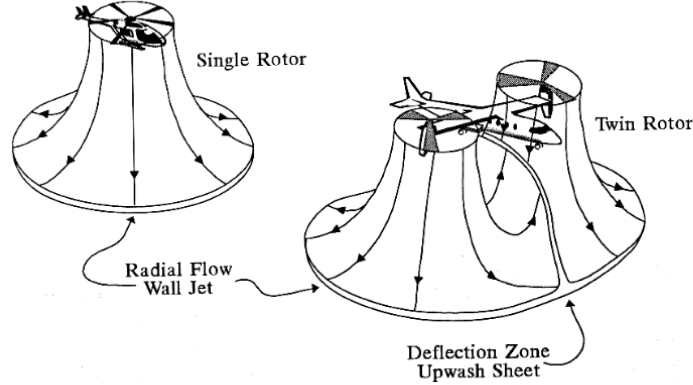


Figure 2: Sketch of the simplest understanding of rotor outwash from [18]. The downwash turns at the ground plane, and for dual rotors high outwash forms where the two downwash columns meet.

Consider an existing helicopter operating on an existing heliport and increase the aircraft size proportionately (both weight and rotor disk area). The downwash velocity at the aircraft remains the same, but the outwash felt by an observer at a constant distance will increase. This is because the strong outwash only occurs near the ground. This height expands for larger aircraft. Secondly, the mean outwash strength usually decreases with normalized distance from the aircraft, using an appropriate reference length or area. These relationships together have generally been taken to imply an increasing safety distance, in absolute length units, as the size of the rotorcraft increases [3].

However, altering the disc loading or the number of rotors may invalidate these baseline outwash assumptions. The uniformity of the downwash velocity over the height of a person, the “gustiness” of the flow, and the levels of turbulence at various azimuths from the aircraft, may change drastically [6]. Variation in aerodynamic force and outwash velocity with azimuth for a reference VTOL is shown in Figure 3. These considerations will impact downwash guidance for new entrant aircraft. For example, the simple rule of limiting the access of personnel to areas where the outwash exceeds 34.5 mph [11] is based on the effect of the outwash produced by large, military helicopters on fit, healthy males [12], and may not be directly relevant when considering the effects of the outwash produced by smaller aircraft or alternative configurations on a more broadly representative spectrum of the population.

Additionally, some of the conclusions used even for current modeling break down in particular situations. Persons can generally move safely by leaning into even a very strong constant wind. However, strong buffeting at low average outwash speeds, or a sudden change in the strength of the outwash, can cause someone to fall badly [2]. The danger posed by outwash can thus dissipate much

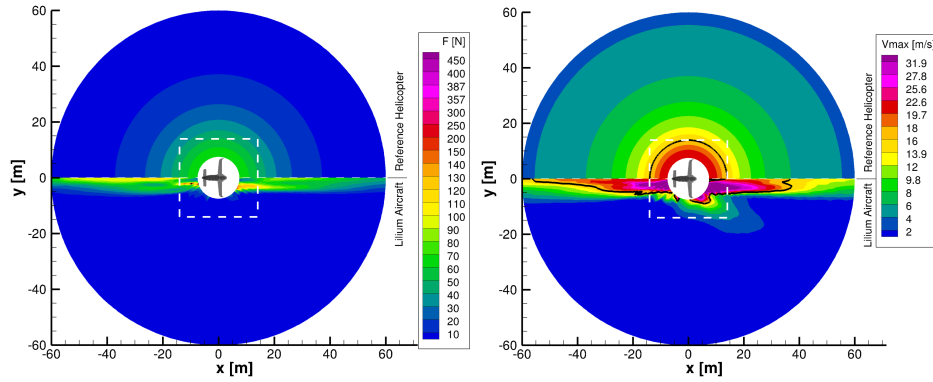


Figure 3: Outwash for the now-defunct Lilium Pegasus aircraft from [13]. Left: estimate of the outwash-force exerted on a human, Right: maximum outwash velocity. The risks posed to a bystander at a given distance from the aircraft varies considerably with azimuth.

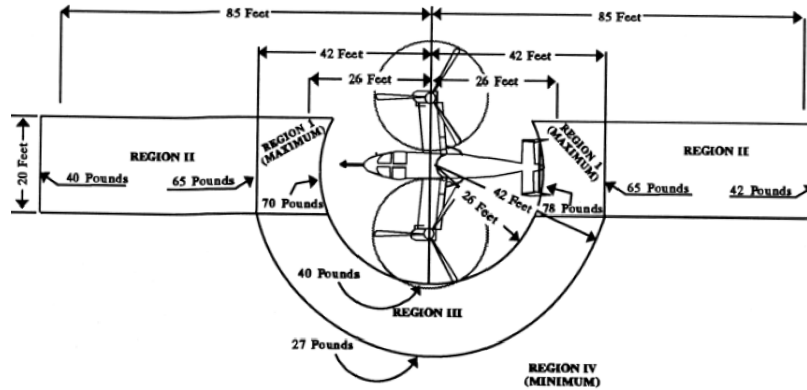


Figure 4: Sketch of the setback areas around an XV-15 rotorcraft from [12]. The extended danger areas fore and aft of the XV-15 can be seen, while the sides of the XV-15 are relatively safe.

more slowly with distance from the aircraft than the reduction in the average flow would suggest [5]. Also the belief that downwash and outwash from elevated heliports will pass over the heads of bystanders at a lower level is almost always wrong.

Particularly if we consider multirotor aircraft (and to a lesser-extent helicopters), the time-varying thrust from the different high-thrust rotors combines to form an outwash which varies considerably depending on the observer’s position around the aircraft. Figure 4 provides a birds eye view of the outwash exclusion zones defined around a two-rotor aircraft. There is a wealth of online material regarding V-22 Osprey outwash, for example, which shows some of the worst cases of this problem. Note that multirotor aircraft in development for civilian use are considerably lighter than the V-22 Osprey, but may still be restricted to heliports which would accept a helicopter of far greater weight.

Additional work is also required to adequately define specific operational caution areas for persons on the ground. Existing accident reports note that signage is not sufficiently clear for civilians near heliports. A two-step warning system may be needed, including an acute “step-back-area” and a less acute “downwash caution area” with specific recommendations for action when flight operations are imminent [20].

Many incidents appear to take place during the aircraft’s final approach to the heliport (final 100 m/300 ft), in which pilot technique and ambient wind play a strong role in DWOW development. More clearly defined approaches will reduce unexpected DWOW danger around heliports.

3 What is needed

The current simple approaches to outwash safety, if slavishly applied to novel aircraft and heliport designs, may yield overly conservative or, more critical, overly optimistic recommendations. An improved statistical database for nonfatal outwash events would improve understanding of where current guidelines are succeeding and where they are failing. Advanced prediction methods, developed for other aerodynamic problems, can be readily applied to outwash, promoting safe practice while also enabling an increase in the number of potential heliports for this rapidly expanding industry.

Aerodynamic interactions between a heliport and nearby structures may inadvertently amplify the outwash, just as local wind effects are amplified in cities [19]. The power in the outwash is similar to the jet engine power of the aircraft, and this cannot simply disappear if a barrier is inserted. Modern numerical methods exist to help improve safety in heliport design, but these must be adapted for the outwash problem.

Particularly rapidly changing outwash speeds (gusts) appear in many cases to be the limiting factor for safety distances around the aircraft [5]. Figure 5 depicts the gusting outwash produced by a helicopter in hover. The relationship between ramping rates, gust strength, and the average flow speed is currently not well understood. Better modeling can inform safe aircraft setback distance with greater confidence.

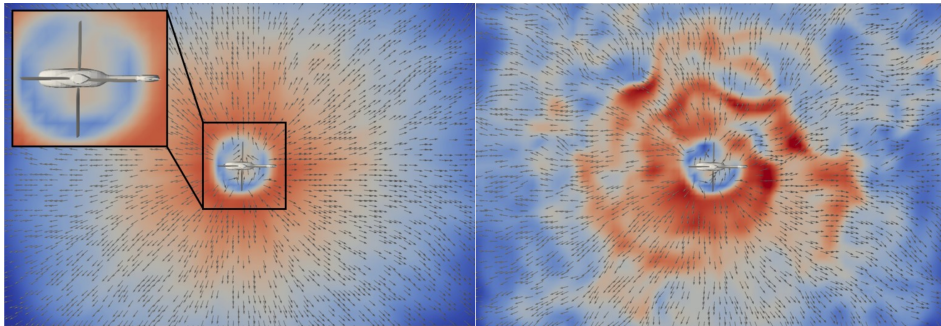


Figure 5: Mean (left) and instantaneous (right) outflow fields computed using Sophrodyne’s VTM numerical model[22]. The gusts change both the strength and direction of the outwash locally.

To better understand outwash variability and associated dangers across aircraft types and sizes, we must develop a standardized sensor positioning methodology. Techniques of positioning sensors around multi-rotor aircraft with complex outwash profiles has been shown to be a difficult problem [17]. The experimental measurement of the outwash will continue to be the last layer of verification in the safety evaluation of an aircraft for the foreseeable future.

A good, comprehensive test data for multi-rotor aircraft similar to that published in the Rotorwash Handbook [12] is required, i.e., means, peaks, time histories for (1) multi-rotors, (Moog Surefly), (2) vectored-thrust (Joby, Archer) and (3) lift+cruise (Beta) to see which modeling is required to predict these metrics at a given level of accuracy. A possible approach would be to provide outwash danger contour maps for a step back zone and a downwash caution area relative to the aircraft similar to Fig.4. OEMs should realize that sharing of information will contribute to overall safety and avoid burdensome evaluations of the aircraft due to an accident.

We need to start developing guidelines for how fully automated flying systems will replace the pilot’s assessment of danger on the ground. In the investigation report [2], the investigators note that several previous accidents had been avoided due to the pilots’ critical evaluation of the danger to bystanders on the ground. There does not currently appear to be an automated system to replace this expertise in the outwash scenario, although technology exists to create one.

Certification by simulation [1, 15] potentially offers a cost-effective alternative to experiments, especially considering the requirement for low wind speeds during testing. A small number (1-3) of standard test cases should be defined with publicly freely available experimental data which will be used to support analytical model development and as validation to assist vertical lift aircraft certification to outwash regulatory standards by simulation, reducing costs. The proposed outwash database will be in the time domain, use a proven appropriate bandwidth sensor, include real time weather data., and provide the spatial position of the helicopter in relation to the sensors.

The authors suggest that, for more complex rotor systems, the existing classification of helipads based on a length (D) and weight (MTOW), will need to be augmented by at least one additional number. The final system should protect the aircraft, bystanders, other aircraft surrounding infrastructure on busy heliports.

4 Conclusions and call to action

In the future, outwash will increasingly be a concern in urban areas, exacerbated by interaction of buildings with outwash and the general public’s proximity to urban heliports. It is foreseeable that many different types of vertical lift aircraft than currently exist will be flying in the future. They will be landing at many different heliport configurations, and the pairings of aircraft and heliports are important for outwash. We need to manage the dangers of outwash to maximize safety for passengers, ground personnel and third parties in the vicinity of operations.

This document aims to reassure the reader that outwash can be managed with the tools available to engineers. The advancements in numerical methods, aerodynamics, and measurement technology in the last 50 years will allow us to rapidly improve the current state of the art to include new configurations. A combination of prediction methods, from expensive scientific analysis to better understand the fundamental physics, through engineering solutions to rapidly design safe operating conditions, to the simplest methods for pre-design and planning of heliports are required. This would reflect the methods available in other fields related to the aerodynamics of aircraft.

The main call to action is to initiate a technical working group with the appropriate regulatory organization to evaluate the present requirements related to outwash safety in this fast-moving topic. This group could review any proposed new regulations and initiate a review of what additional requirements could be appropriate and cost effective for long term safe vertical lift operations.

Additionally, a need for the following points can already be foreseen:

1. Develop a simple reporting system for outwash “events” to improve statistical monitoring of safety-related issues.
2. Develop a classification system for manufacturers to decide which classes of heliports are safe for each aircraft to use regarding outwash. Corresponding certification requirement already exists in the EASA system for VTOL aircraft (SC-VTOL.2400(c)(3)[10] and VPT-DSN.C.230 [9]).
3. A two-step warning system with appropriate warning systems (signage, tannoy announcements, or lights) should be developed, including an acute “step-back-area” and a less acute “downwash caution area” with specific agreed warning sign language that clearly defines an action (Vacate area!) when flight operations are imminent.
4. Since many accidents occur while the aircraft is in the approach or take-off phase in proximity to the heliport, trajectories should be defined, to improve outwash safety around heliports. This will include recommendations for piloting strategies.
5. Define and evaluate available outwash sensor technology to propose a minimum industry standard for future outwash (flight) testing. This will be partially an update of the 1993 evaluation [16].
6. Define a list of required flight test evaluations for an openly available database to support A) analytical model development and B) validation for vertical lift aircraft certification by simulation.
7. Develop a flight test evaluation methodology to evaluate the danger associated with single and multi-rotor VTOL aircraft, realizing that the danger might vary with position around the aircraft.
8. Develop a simple metric to define the danger associated with “gustiness” within the outwash. A method of combining this metric with the unsteady flow caused by buildings should be developed. More complex metrics should be developed to allow more nuanced definitions of danger areas.
9. Develop methods of assessing the aerodynamic interactions between nearby aircraft outwash, wind and nearby structures. This should include turbulence and helipad elevation.
10. Support numerical certification-by-simulation options of varying accuracy and cost, with a view to both the replacement of complex measurements with simpler, cheaper computations, and the establishment of a full-fidelity incident-investigation simulation suite.

References

- [1] AIAA, “When Flight Modelling Is Used to Reduce Flight Testing Supporting Aircraft Certification”, AIAA R154-2021, 2021.
- [2] AAIB, “Report on the accident to Sikorsky S-92A, G-MCGY at Derriford Hospital, Plymouth, Devon on 4 March 2022”, Report 2/2023
- [3] Airbus Helicopters, “Noise & Downwash Considerations for Ground Operations,” SPM No. 3684-P-00, 2021.
- [4] ATSB, “Safety risks from rotor wash at hospital helicopter landing sites”, ATSB Transport Safety Report AD-2022-001, 2023.
- [5] CAA, “Protecting the Future: Trials and Simulation of Downwash and Outwash for Helicopters and Powered Lift Aircraft”, CAP 3075, 2025.
- [6] CAA, “Understanding the downwash/outwash characteristics of eVTOL aircraft”, CAP 2576, 2023.
- [7] CAA, “Standards for helicopter landing areas at hospitals”, CAP 1264, 2026.
- [8] EASA, “Certification Specifications and Guidance Material for the design of surface-level VFR heliports located at aerodromes that fall under the scope of Regulation (EU) 2018/1139 (CS-HPT-DSN)”, 2019.
- [9] EASA, “Prototype Technical Specifications for the Design of VFR Vertiports for Operation with Manned VTOL-Capable Aircraft Certified in the Enhanced Category”, PTS-VPT-DSN, 2022.
- [10] EASA, “Proposed Special Condition for small-category VTOL aircraft”, SC-VTOL-01, 2018.
- [11] FAA, “Engineering Brief #105A: Vertiport Design, Supplemental Guidance to Advisory Circular 150/5390-2D, Heliport Design”, 2024.
- [12] Ferguson, S. W., “Rotorwash Analysis Handbook, Volume I Development and Analysis”, Federal Aviation Administration, Washington D.C., Technical Report DOT/FAA/RD-93/31,I, June 1994.
- [13] Gardner, A.D., “Lilium Pegasus outwash in hover”, DLR Internal report DLR-IB-AS-GO-2024-57, 2024.
- [14] International Civil Aviation Organization (ICAO) “Heliport Manual (Doc 9261) - Part I - Onshore Heliports,” Technical Report, 6th Edition, 2026.
- [15] Mauery, T., Alonso, J., Cary, A., Lee, V., Malecki, R., Mavriplis, D., Medic, G., Schaefer, J., Slotnick, J., “A Guide for Aircraft Certification by Analysis”, NASA/CR-20210015404, 2021.
- [16] Meyerhoff, C. L., Lake, R. E., and Gordge, D. N., “Rotorwash Wind Sensor Evaluation,” Technical Report, DOT/FAA/RD-92/10, 1993.
- [17] Muia, M.J., Stanley, J., Anderson, T., Hall, D., Shuman, Z., Goericke, J., Batther, J., Habana, Z., He, C., Saberi, H., “Electric Vertical Takeoff and Landing (eVTOL) Downwash and Outwash Surveys”, FAA Report number: DOT/FAA/TC-24/42, 2024.
- [18] Preston, J. R., Troutman, S., Keen, E., Silva, M., Whitman, N., Calvert, M., Cardamone, M., Moulton, M., and Ferguson, S. W. “Rotorwash Operational Footprint Modeling,” Tech. rep., Missile Research Development and Engineering Center Redstone Arsenal AL Missile Guidance directorate, 2014.
- [19] Souza Branco, D., Stephens, I., White, M. and Watson, N. A. “Assessing the Interaction of Helicopter Rotor Downwash and Turbulent Airwakes near Hospital Landing Sites”, 50th European Rotorcraft Forum, Marseille, France, September 10–12, 2024.
- [20] Souza Branco, D., Watson, N. A., and Jones, S. “Initial Analysis of Helicopter Downwash Measurements at Southampton General Hospital Helipad” Technical Report, HELIUHS/UOL01041224, 2024.
- [21] USAF, “United States Air Force Aircraft Accident Investigation Report”, 2 APR 25, PACAF, HH-60W, Kadena AB, AIB REPORT, 2026
- [22] Wolf, C.C., Braukmann, J.N., Schwalbe, J., Weise, T., Gardner, A.D., Brown, R.E., “Measurement techniques and data evaluation for VTOL outwash maps”, Vertical Flight Society’s 82nd Annual Forum & Technology Display, West Palm Beach, FL, May 5-7, 2026.

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