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Compatible Land Use for Heliports and Vertiports: A Safety Perspective

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Airport land use planning is crucial for safety, long-term utility, and environmental congruity. While there have been a number of studies of aircraft accidents in reference to runways for the purposes of safety and land use standards, little research exists on safety and land use compatibility for heliports and no such data exists for vertiports. This study aimed to provide a better understanding of safety and land use issues near heliports through a focus on the geographic distribution of helicopter accidents in relation to the point of takeoff or landing. The findings of this study provide initial guidance for the design of land use compatibility and safety zones pertaining to heliports and how these can be adapted to vertiports. Accident data exhibited a stochastic spatial pattern of accident occurrences, with the highest concentration occurring within a proximity of 40 feet from the designated takeoff/landing location. Almost all (90%) accidents took place within 400 feet of the takeoff/landing reference point. Sizes and shapes of safety and land use zones are outlined. Recommendations for future studies are also provided.

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Introduction

The significance of considering land use factors in airport planning and operation cannot be underestimated. Proper land use management involves identifying and describing safety criteria, accident potential, and noise exposure to ensure operational safety, the long-term utility of airfields, as well as harmony with the surrounding environment. Integrating these factors into airfield planning is crucial for addressing current and future land use around these facilities.

The primary goal of land use planning around airports is to safeguard the adjacent areas from risks of aircraft accidents. Historically, most accidents are localized along the extended runway centerline, and, for this reason, land use compatibility plans have been focused on properties beyond runway thresholds with some lateral protection that incrementally decreases as one gets further from the runway (Arnaldo Valdés et al., 2011; Cardi et al., 2012). Although less frequent, accidents do occur in runway lateral zones. Such deviations occur due to runway excursions, turning accidents, and events that occur while an aircraft maneuvers prior to landing or following takeoff (Cardi et al., 2012). Unfortunately, numerous tragic accidents including large losses of life and property have occurred due to poor land use planning and implementation near airports (Flight Safety Foundation, 2023).

While a fair amount of research has been completed concerning airport land use compatibility and safety, little research has been conducted on land use compatibility for heliports. As noted by the State of California Department of Transportation (CalTrans) Division of Aeronautics (2011) “very little information is available upon which to base safety compatibility guidelines for heliports. No useful compilation of data on the location of helicopter accidents in the proximity of heliports is known to exist,” (p. 71). What research that does exist mostly focuses on noise and many of the studies are over 40 years old. Because of similarities between heliports and vertiports as well as between helicopter and eVTOL performance, this lack of research is particularly problematic in light of the expected widespread use of vertiports by advanced air mobility in the near future (Arkel, 1966; Bishop, 1965; Peisen & Thompson, 1988; Smith, 2001; Stokes et al., 1984; Wei et al., 2023). As of mid-2023, research on vertiports and adjacent environs is scant with the only published research on land use around vertiports being focused on zoning, current land usage, socio-economic factors, and proximity to other modes of transit (Wei et al., 2023).

Overview of the Study

Without more comprehensive flight performance and testing data being available from eVTOL manufacturers (termed Original Equipment Manufacturers [OEMs]), researchers must utilize what information is presently accessible. Several OEMs have made assertions concerning how their products are either similar to or different from helicopters. While expected eVTOL performance may be, in some respects, different from helicopters, the flight patterns around vertiports are generally expected to be similar to how helicopters interact with heliports (Amprius Technologies, 2023; Archer, 2021; Courtin et al., 2021; Stonor, 2023). For example, vertiports may have preferred or published approach and departure paths to avoid obstacles or sensitive properties just as helicopters do at heliports. Takeoff and landing profiles may also differ however, the current published airspace protection slope ratios are the same for vertiports as they are for heliports supporting the notion of similarity, rather than dissimilarity, of flight profiles (Bassey, 2022; Federal Aviation Administration [FAA], 2023). Also, aerodynamic limitations of eVTOLs, namely vortex ring state (VRS), will likely demand flight profiles more analogous to helicopters than perhaps originally envisioned (Brown, 2022; Pradeep & Wei, 2019).

To better understand safety issues regarding land use around heliports and vertiports, this study was initiated to investigate the geographic distribution of helicopter accidents as well as to make available the resulting database of precise accident locations. This study was modeled on previous research on accident distributions in relation to airports in order to formulate land use compatibility standards and guidelines. The methods used in previous studies were adapted to prepare land use compatibility recommendations for heliports and vertiports (Arkel, 1966; Arnaldo Valdés, 2011; Cardi et al., 2012; Smith, 2001).

Purpose of the Study

Land use around aviation transport hubs has been, and will continue to be, a source of conflict among hub users, developers, businesses, and neighboring citizens. In order to responsibly address the concerns of each stakeholder group, local planning entities must base land use decisions on the best data available to minimize the impact of aviation operations on safety and quality of life. This study aimed to collect helicopter accident locations during critical flight phases (takeoff, departure maneuvering, approach, landing, and post-landing) in relation to heliports. From this data, recommendations for land use compatibility guidelines for heliports and vertiports were sought to be generated (Orange County Airport Land Use Commission, 2008; Santa Clara County Airport Land Use Commission [SCCALUC], 2015; Tracy, 2023).

Research Objectives and Research Questions

The research objectives of this study were twofold. One was to produce a contemporary database of helicopter accident geographic locations. Accident inclusion was limited to critical phases of flight and only for those with a departure point or destination designated as a heliport. Secondly, the location data was to be used to provide recommendations for land use compatibility adjacent to heliports and, by association, vertiports. To achieve these goals, two research questions were utilized to guide this study:

RQ1: Where did accidents occur involving helicopters departing from or arriving at a designated heliport while being operated in a critical phase of flight defined as takeoff, departure maneuvering, approach, landing, and post-landing?

RQ2: Based upon the collected distributions of helicopter accidents near heliports, what recommendations for land use compatibility can be provided in consideration of previous research and guidelines?

Review of Literature

Standards for and oversight of land use compatibility near air transit hubs, e.g., airports, heliports, and vertiports, fall primarily on three parties: the FAA, state departments of transportation (DOTs), and local governments. The FAA provides guidance for the protection of air transit hubs from incompatible land use in the local vicinity. The FAA (2022a) outlines its recommendations in *Advisory Circular 150/5190-4B Airport Land Use Compatibility Planning,* providing descriptions of “major incompatible land uses that conflict with or are impacted by operations at local public-use airports” (p. 1). The FAA relies primarily on grant assurances to enforce these types of protections (FAA, 2022a).

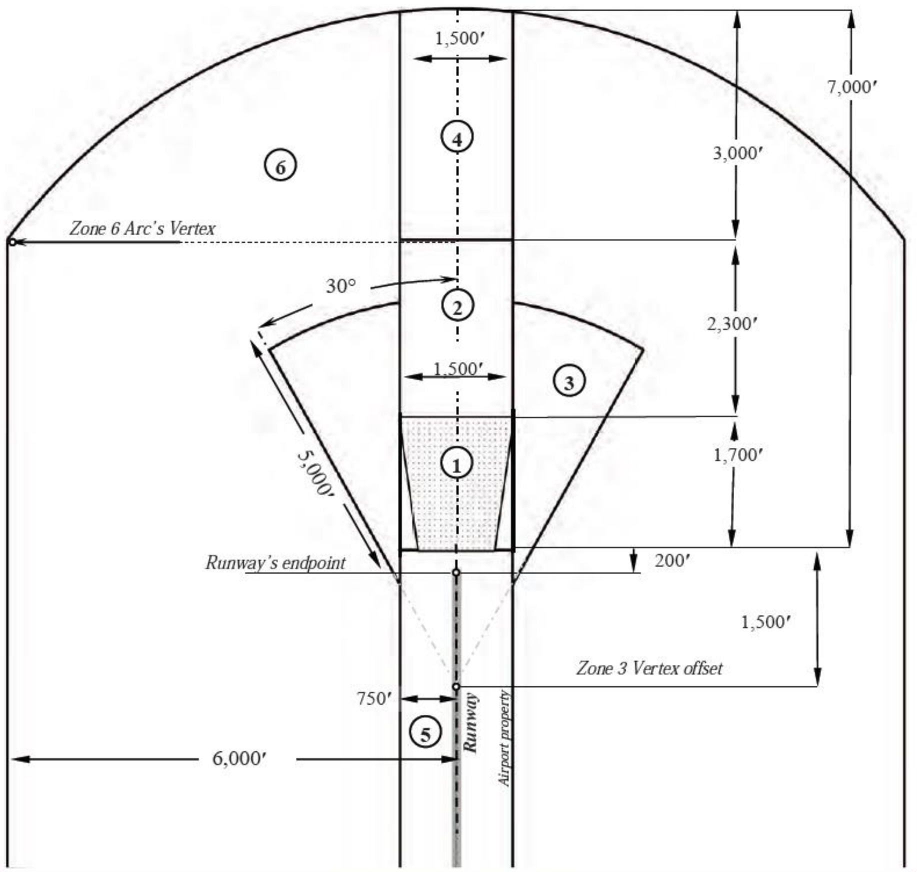
Most state DOTs in the U.S. have published their own airport land use compatibility guidelines or guidebooks. These publications provide more specific details as to what should or should not be permitted in specific geographic locations in relation to all available runways. Normally this is presented as “compatibility zones” which designate the measurements of specific areas in which recommended land uses apply (see example in Figure 1) (Washington State Department of Transportation [WSDOT] Aviation Division, 2011).

Figure 1

Land Use Compatibility Zones Map

Compatibility Criteria **Appendix F**

Airport Runways 3,000 to 5,000 Feet



Airport Compatibility Zones			
Dimensions	**Length**	**Width**	**Notes**
Zone 1	1,000′	750′*	Zone 1 includes the runway's RPZ. The RPZ is depicted by ordered stipple within Zone 1 ▨ *RPZ dimensional standards are dictated by runway approach type.
Zone 2	1,500′	750′	NA
Zone 3	3,000′	*	*Plot Zone 3's vertex 1,500′ from the runway's endpoint
Zone 4	2,500′	500′	NA
Zone 5	*	500′	Zone 5 ends 200′ past the runway's endpoint
Zone 6	5,000′	5,000′	Set the vertex for Zone 6's arc parallel to the end of Zone 2

RPZ – Runway Protection Zone

Note. From WSDOT Aviation Division (2011).

Lastly, local governments such as county planning commissions, city planning departments, as well as related governing councils provide land use compatibility zoning, codes, studies, and plans. These can be a mix of comprehensive county or city plans, airport layout plans, airport master plans, construction height restriction zones, city or county codes or laws, economic studies, environmental studies, and provisions to promote safe operations to protect persons and property on and near airports and, in limited cases, heliports (King County, 2023, Los Angeles Department of Transportation [LADOT], 2021; SCCALUC, 2015).

Defining Land Use Compatibility

While the concept of compatible land use around ATPs may seem intuitive, there are a range of definitions and nuances used by each type of stakeholder, e.g., FAA, airports, cities, and counties. For the purposes of discussion in this research, the FAA definition of land use compatibility will apply. The FAA (2022a) recommends protecting ATPs from:

> residential use within airport noise contours; airspace obstructions and hazards to safe navigation to and from the airport such as tall structures, light, glare, electronic/radio, smoke, steam, or other atmospheric interference emanating from nearby land uses; land uses that attract birds and other wildlife hazards to the airport and its immediate environs; and land uses with concentrations of people or property within airport runway protection zones (p. 1).

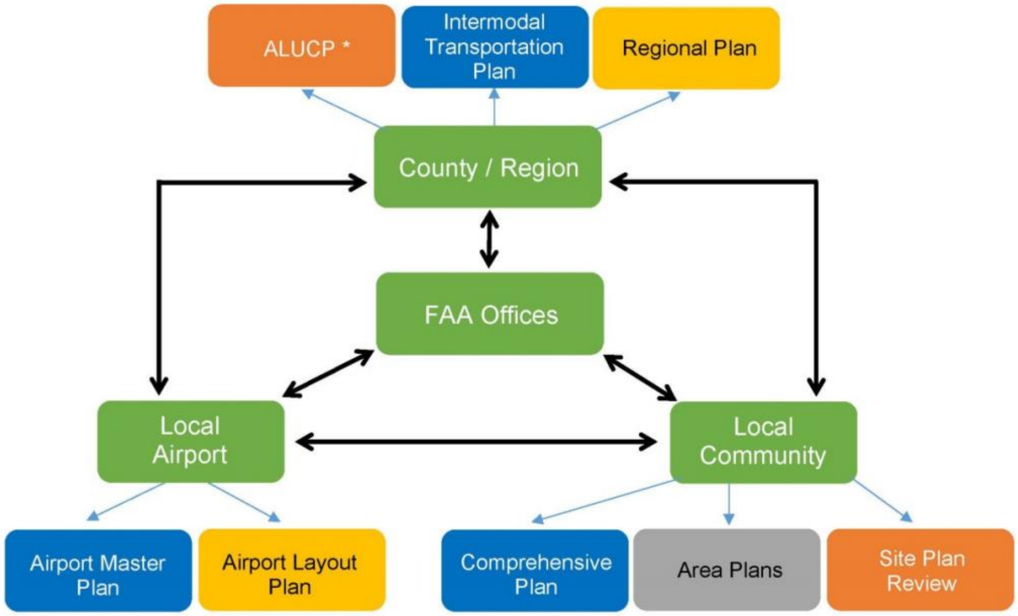
Further, the FAA (2022a) states that land uses that are compatible with ATPs can be defined as "those uses that can coexist with a nearby airport without constraining the safe and efficient operation of the airport or exposing people living or working nearby to potential negative environmental or safety impacts" (p. 1). See Figure 2 which outlines the common relationships among stakeholders during land use compatibility planning.

FAA (2022a) outlines the common concerns regarding airport land use compatibility, including the need to maintain unobstructed space for aircraft maneuvering, protect navigational facilities, and preserve airport capacity. FAA highlights how airspace can be obstructed physically, visually, and atmospherically and has established standards and procedures to protect the national airspace from physical obstructions with the goal being the protection of arriving and departing aircraft and the subsequent safety of persons and property on the ground (FAA, 2022a).

The consequences of aircraft accidents are directly proportional to the population density near an airport. To reduce the severity of these catastrophes, it is essential to restrict the number of buildings and people in close proximity to an airport. Two types of accidents, controlled descents and loss of control are the most common to have an impact on land use near airports. Guidance on usage density restrictions emerged from derived protections from both categories of accidents. One example of land use to be avoided in proximity to an ATP is a building where there are occupants with limited mobility or who need assistance evacuating, such as a hospital, school, or nursing home. As such, these types of uses are prohibited in areas closest to runways, departure paths, and arrival paths (FAA, 2022a).

Figure 2

Airport Land Use Compatibility Planning: Interaction of Stakeholders



*ALUCP – Airport Land Use Compatibility Plan (if applicable – predominately applies to airports in California)

Note. From LADOT (2021).

The analysis of aircraft accident distribution is crucial in developing compatibility or safety zones for airports. Studies have explored the distribution of accidents in relation to the runway of arrival or departure, placing accident markers at the event location and grouping accident data points according to their geographic concentration. This results in a comprehensive depiction of accident patterns in proximity to runways, revealing a distinct spatial arrangement characterized by a cluster of accidents in relation to a standardized runway (Ayers et al., 2013; Basta et al., 2007; Cardi et al., 2012; Cooper & Chira-Chavala, 1998; Janic, 2000; Yim, 2014). Figure 3 shows an example distribution plot.

Accident distribution contours are then crafted from cluster data and in turn used to create land use compatibility zones, safety zones, airport overlays, or additional standards for underlying zoning districts with the areas of highest accident risk classified as the most restrictive land use zones. In turn, FAA ACs have incorporated accident data to develop their recommendations on land use around airports. Furthermore, the land use guidebook of CalTrans Division of Aeronautics (2011), which relies heavily on accident data, has long been the reference document for land use compatibility standards across the U.S. While previous studies on accident distributions and related documents have provided a level of standardization for land use at most airports in the U.S., data on helicopter accidents at heliports, airports, and unimproved sites appears to be absent from land use compatibility standard development processes (CalTrans Division of Aeronautics, 2011; Cardi et al., 2012; WSDOT Aviation Division, 2011).

Existing Documents and Research Related to Standards for and Land Use Around Heliports and Vertiports

The amount of documentation and research on standards for, and land use around, heliports is rather limited. Equivalent data for vertiports is virtually non-existent. What information was available at the time of this study is outlined in the subsequent subsections.

Current Standards for Heliport and Vertiport Design

The FAA has set the requirements for heliport design in *AC 150/5390-2D* and has recently released an engineering brief outlining the planned design standards for vertiports (FAA, 2022b; 2023). Each document provides some background information and general guidance then goes into detailed descriptions of various feature dimensions and safety considerations.

Heliports. *AC 150/5390-2D* presents a set of criteria to identify an appropriate location for heliports, encompassing heliports intended for general aviation, transportation, and medical facilities. FAA underscores the need to consider future requirements for instrument flight rules (IFR) operations and facility development. Additionally, the possibility of using military helicopters in disaster relief operations at a heliport should be considered.

FAA (2023) provides standards pertaining to the optimal positioning and architectural configuration of Final Approach and Takeoff Areas (FATOs), Touchdown and Liftoff Areas (TLOFs), and Safety Areas at heliports (see Figure 4). The FATO is the area over which the helicopter flies its final approach to a hover or from which a departure is flown. The TLOF is a load-bearing area, normally centered in the FATO, on which the helicopter lands and/or takes off. TLOFs are typically paved.

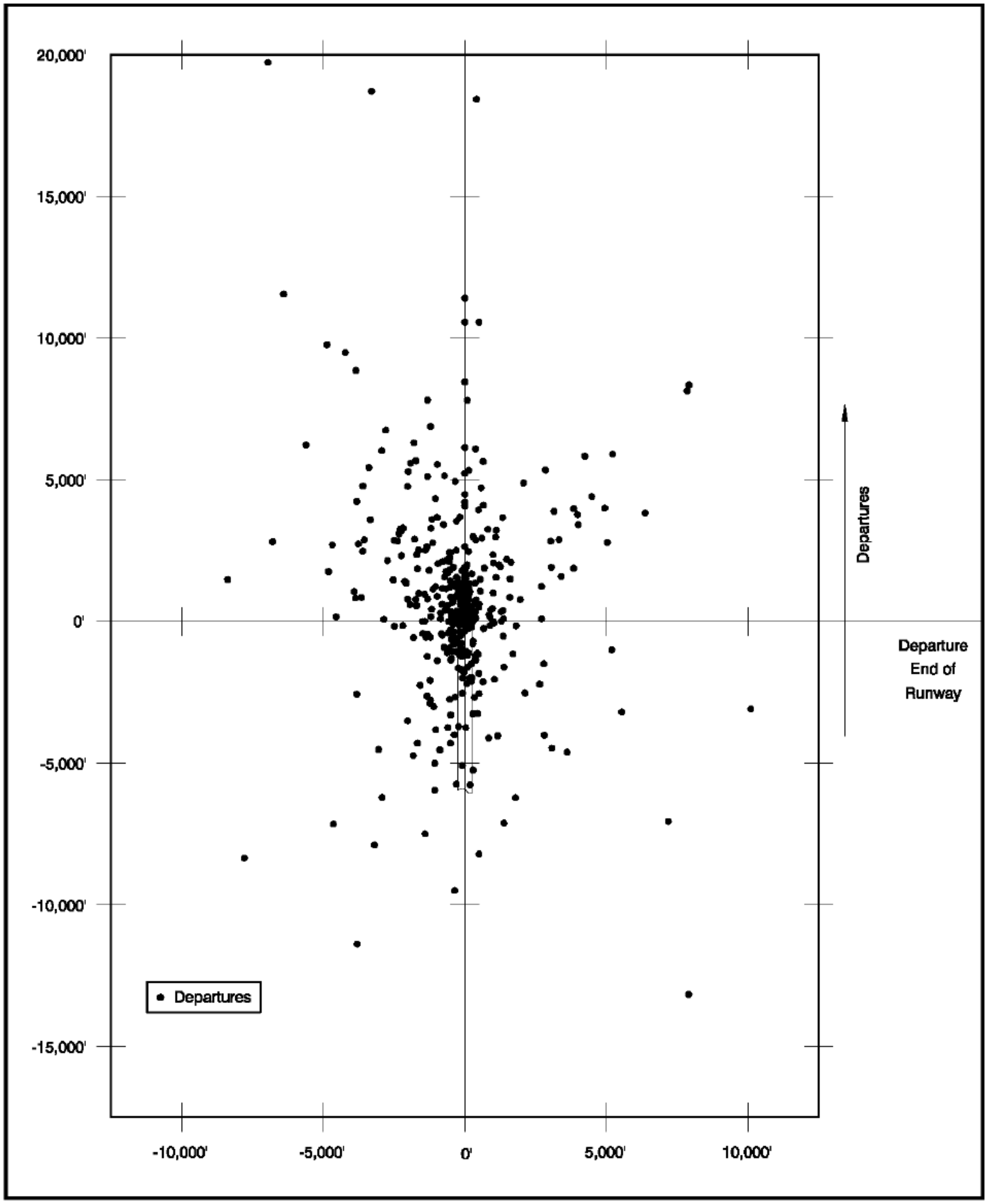
TLOF and FATO minimum dimensions are based on the heliport type (general aviation, transport, or hospital) and the controlling dimension "D" of the design helicopter. The variable D is defined as the greater of the overall length and overall width of a helicopter. A design helicopter is defined as the largest helicopter that is expected to operate at the heliport. TLOF and FATO dimensions are calculated by applying a multiple of D. For example, see Table 1 for the means of calculating these values for a transport-type heliport.

FAA (2023) also recommends a Horizontal Protection Zone (HPZ) for every approach and departure surface to enhance ground-level protection for individuals and assets. In densely populated areas, heliport owners should control the maximum size of the HPZ. The FAA discourages residential zones and public gathering spaces within HPZs. It is suggested that local and regional governments should implement zoning laws to regulate land use and use air rights and property easements to mitigate encroachment (FAA, 2023; Tracy, 2023; Vancouver Municipal Code, 2023).

Vertiports. Based on the literature analysis and consultation with OEMs, it is evident that vertical take-off and landing (VTOL) aircraft are expected to exhibit performance characteristics akin to helicopters. However, the existing body of knowledge regarding their operating characteristics, performance metrics, maneuverability, and the specific information requirements pertaining to vertiport obstacles remains limited and is rapidly evolving. It is projected that Advanced Air Mobility (AAM) would exhibit high levels of density, frequency, and operational complexity, necessitating safety measures and infrastructure comparable to the requirements established for heliport architecture in the Transport Category (FAA, 2022b; Weitering, 2023).

Figure 3

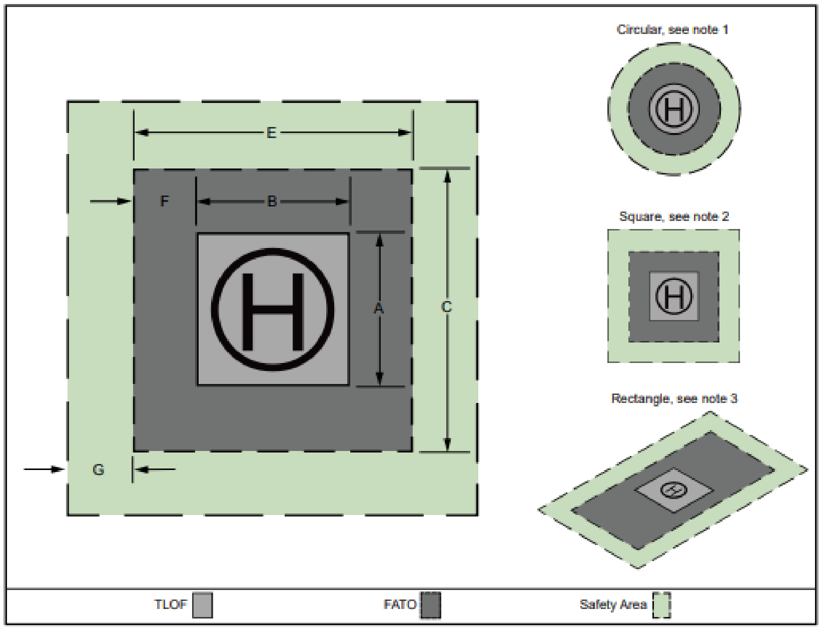
Distribution of accidents in reference to runway



Note. From CalTrans Division of Aeronautics (2011).

Figure 4

Heliport design standards



Note. From FAA (2023).

Table 1

Dimensions for heliport design

HELIPORT FEATURE	DIMENSION
TLOF Width	0.83 x D[1]
TLOF Length	0.83 x D[1]
FATO Length	1.66 x D[2]
FATO Width	1.66 x D[2]
Separation between TLOF and FATO perimeters	0.34 x D
Safety Area Width	0.42 x D[3]

[1] But not less than 50 ft

[2] But not less than 100 ft

[3] But not less than 30 ft

The EB outlines the design and geometry of the takeoff and landing zones inside a vertiport facility, specifically focusing on the TLOF, FATO, and Safety Area. TLOF and FATO minimum dimensions are based upon the controlling dimension "D" of the reference aircraft (see Figure 5). The reference aircraft represents an eVTOL that integrates certain performance and design characteristics of nine emerging aircraft currently in development. This reference aircraft is used to specify certain performance and design characteristics that informed the vertiport design guidance in this EB. Variable D is defined as "the diameter of the smallest circle enclosing the VTOL aircraft projection on a horizontal plane, while the aircraft is in the takeoff or landing configuration, with rotors/propellers turning, if applicable" (FAA, 2022b, p. 14). The dimensions of the TLOF, FATO, and Safety Area are dictated by multipliers of D. See Table 2 for the means of calculating these values for vertiports. Figure 6 is provided to aid the visualization of vertiport dimensions.

Table 2

Dimensions for vertiport design

VERTIPORT FEATURE	DIMENSION
TLOF	1D
FATO	2D
Safety Area	3D[1]

[1] 1/2D is added to the edge of the FATO

The EB also outlines the need for a Safety Area, which is a specifically defined region surrounding the FATO with the primary objective of mitigating potential harm to VTOL aircraft in the event of their departure from the FATO. The placement of the Safety Areay can vary, since vertiports may be situated at ground level, on high structures, roofs, above bodies of water, or in unobstructed airspace.

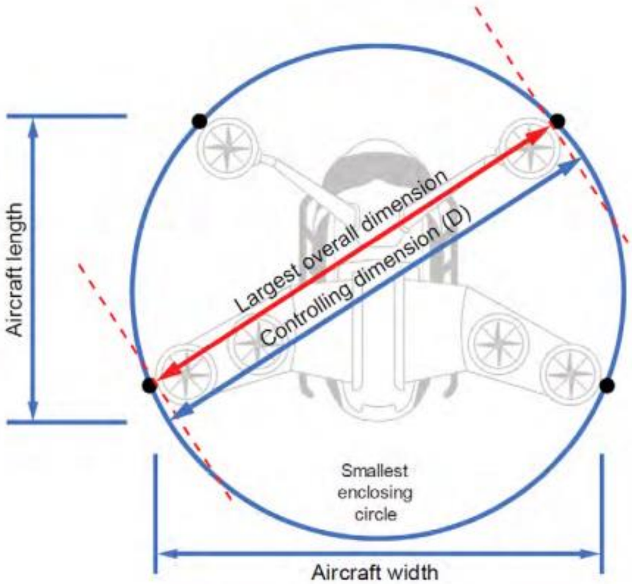
Safety regulations recommend a minimum width and length of the Safety Area equal to half the distance from the Final Approach and Takeoff Area (FATO). The area's geometric form should align with the TLOF and FATO, and maintain equal distances between the perimeters (FAA, 2022b).

When deliberating on sites at which to establish a vertiport, stakeholders must collaborate with local authorities, agencies, and neighboring airports to obtain licensing and permission prerequisites. FAA evaluates plans, but preliminary collaboration can mitigate potential airspace, operational activities, safety measures, capacity, and financial impacts (FAA, 2022b).

Within one of the few vertiport urban planning policies developed so far, LADOT (2021) issued a policy framework to analyze the interrelationships between different land uses in the vicinity of vertiports to identify synergistic associations and potential conflicts. This proposed framework aimed to provide recommendations for ensuring the safe maneuvering of AAM aircraft during crucial flight stages, including takeoff and final approach (CalTrans Division of Aeronautics, 2011; FAA, 2022a; Windus, 2015). Lastly, initial evaluations of vertiport safety areas have been circular in shape and likely to be divided into quadrants or other levels of subsections based on surrounding terrain, obstacles, and land uses (Johnson, 2023).

Figure 5

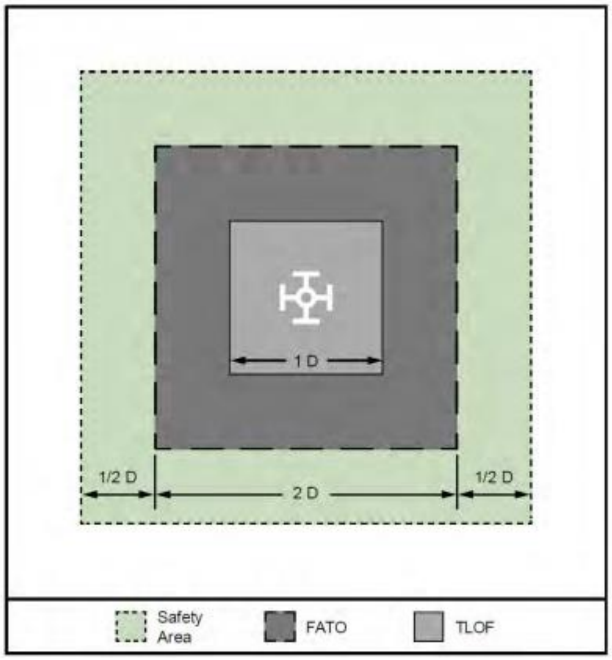
Definition of controlling dimension for vertiports



Note. From FAA (2022b).

Figure 6

Vertiport design standards



Note. From FAA (2022b).

Method

When conducting diligent land use compatibility planning, research has shown that it is paramount to have thorough safety data. Only with this information can informed decisions be made about the design of compatibility zones. Thus, this study sought to identify helicopter accidents that occurred during critical phases of flight when in proximity to a heliport. This study enlisted similar procedures used in previous studies. Such procedures followed the following workflow. First, accident reports meeting the necessary criteria (e.g., helicopters, specific phases of flight) were collected from the NTSB database. Results were then filtered based on the inclusion or absence of necessary data, such as the coordinates of the actual location of an accident rather than a generic or assumed location (such as an airport). Next, the latitude and longitude of each accident were plotted using ArcGIS. The distance and direction from each accident site to the heliport of departure or arrival were measured. The distance/direction coordinates were then drawn on an XY chart on which all accidents used in the study were plotted. The goal of this process was to be able to present geographic distributions of accidents in relation to a reference heliport on a single chart using a standardized scale (Arnaldo Valdés et al., 2011; Ayres, Jr. et al. 2013; Cardi et al., 2012; Cooper & Chira-Chavala, 1998; FAA, 1991).

Sampling Procedures

Sampling of data was guided by the processes demonstrated by Arnaldo Valdés et al. (2011), Ayres, Jr. et al. (2013), Cardi et al. (2012), Cooper and Chira-Chavala (1998), and FAA (1991). This resulted in a standardized search protocol that was used to query the NTSB accident database for applicable cases. The following decisions were made in alignment with Cooper and Chira-Chavala (1998):

- Only accident records were utilized (i.e., no incident data was used)
- Only the events involving a heliport were included – remote or off-heliport flights were excluded
- Helicopters had to be in a critical phase of flight at the time of the accident (takeoff, departure maneuvering, approach, landing, and post-landing)
- Measurements were made in reference to the center of the helipad
- Accidents were mapped as an X-Y scatterplot with the center of the helipad as the 0-0 point of the X-Y axes

It should be noted that initially, the sampling protocol was planned to identify heliports with published or obvious preferred approach or departure directions and plot accidents along a line that paralleled the preferred routes. Unfortunately, there were no accidents in which the heliport had a preferred direction for approach or departure that could be garnered from the accident report text, satellite imagery, or docket data.

The NTSB accident database was accessed through its Case Analysis and Reporting Online (CAROL) search interface. Queries to this system include “civil aviation accidents and selected incidents that occurred from 1962 to present within the United States, its territories and possessions, and in international waters” (NTSB, 2023). Due to NTSB database limitations, helicopter accident reports for events before 1982 do not include the latitude and longitude of the events; therefore, these had to be excluded. The following search parameters were utilized to winnow the results:

- County: United States

- Event type: Accident
- Aircraft category: Helicopter
- Airport name (contains): heli
- Phase of flight:
    - Taxi-into takeoff position
    - Takeoff
    - Takeoff-rejected takeoff
    - Initial climb
    - Approach
    - Landing
    - Landing-aborted after touchdown
    - After landing

In order to ensure the greatest data coverage possible, an alternate search was conducted in which the airport name rule was removed and, in its place, the key term "helip" was added. This was used to capture cases in which the airport name did not include "heli" but a heliport or helipad was described somewhere in the report.

The initial search resulted in 258 cases. Data was uploaded to Microsoft Excel for processing. The queries were combined into one worksheet. At this point, all duplicates and reports missing latitude and longitude were removed (NTSB, 2023).

Sample Size

Data cleaning resulted in 89 accidents that contained the minimum attributes. Further analysis led to the elimination of five accidents because it was determined that the accident did not occur in a defined critical phase of flight or did not involve a known destination or departure point. The remaining 84 accidents represent 11.1% of all helicopter accidents occurring during a critical phase of flight in the U.S. since 1982.

Measures

Accident locations were measured in latitude and longitude which was used to plot them in ArcGIS. Heliport locations were made available through a publicly available data layer within ArcGIS. The distance and direction between each accident site and its related heliport were measured using the ArcGIS distance and direction tool. Within this tool, the distance and bearing features utilizing the map point option were selected. This resulted in the geodetic distance in feet and angle in degrees between an accident location and the heliport associated with the accident.

Accident data was accessed from the NTSB accident database. This archive is considered to be a highly reliable source as it was developed and is overseen by the U.S. federal government. All of the reports have been investigated and written by highly qualified subject matter experts (NTSB, n.d.).

Research Design

NTSB data was downloaded into an Excel spreadsheet. This data was uploaded to ArcGIS for further processing. ArcGIS has the capability to extract the latitude and longitude from Excel files. This feature was used to obtain accident locations from the file. These resultant accident sites were fused with an ArcGIS layer depicting the location of U.S. heliports.

Each heliport site was examined for its accuracy. Incorrect locations for heliports were corrected visually using ArcGIS to ensure the reference point was at the center of the pertinent helipad. Next, distance and direction from the heliport reference point were measured in ArcGIS as previously outlined. Accidents were individually examined to see how they related in proximity to the heliport listed in the specific case. It was found that there were several cases in which the reported accident location was clearly erroneous. For example, the coordinates of a city center were given, or the scene in photos evidently did not match satellite imagery. In these cases, the researcher was forced to use materials in the NTSB accident docket to determine the actual location of the accident (e.g., satellite imagery, accident photos, pilot and witness statements, and forms). In instances where there was not enough information to determine a precise position, the case was removed.

Recorded locations were added to the generalized heliport-helicopter X and Y-axis plot. This graph was then examined for distance and azimuth patterns to garner potential guidance as to the development of land use compatibility from a safety perspective as was done in previous studies. In short, areas with the highest concentration of accidents were classified with the most restrictive land-use guidelines. In areas where accident concentrations were lower, the recommended land-use restrictions became less stringent (Cardi et al., 2012; Cooper & Chira-Chavala, 1998).

Results

The culled accident data were analyzed per the research design. The resultant heliport and relevant accident locations were plotted on a maps of the United States (see Figures 7a, 7b, and 7c). For each accident, the site azimuth and distance in reference to the applicable takeoff or landing location were calculated and plotted. Views of the raw accident plots were created on three scale levels. On the 400-foot scale (Figure 8), there is a random distribution of accident locations. Upon zooming out to the 1,000-foot scale (Figure 9), a pattern of concentration becomes more apparent where just beyond the 100-foot threshold accident frequency and proximity decrease significantly. The 1 NM scale image (Figure 10) clearly shows that all but a few accidents occurred within close proximity to the reference site.

Next, accident plot data was analyzed to develop cumulative percentages of events in the form of density maps. Figure 11 shows that 50% of accidents occurred within approximately 40 feet of the reference heliport/site. It was determined that 75% of accidents took place within 170 feet of the reference site and 90% transpired within roughly 400 feet of the reference site.

Additional analysis of accident data was conducted to assess the rates of occurrence in reference to metrics available from the NTSB accident database that may be beneficial in guiding land use decisions around heliports and vertiports. Among the mapped accidents, most (43%) resulted in no injuries. Fatalities occurred in 21% of cases, serious injuries occurred in 16% of cases, and 20% of events led to minor injuries (see Figure 12).

Figure 13 shows the various accident causal factors. The majority (52%) were the result of human (personnel) factors. The next largest causal category was mechanical at just over one-third (34%) of accidents. The environment was causal in 4% of accidents and 9% took place due to an undetermined cause.

Figure 7a

Map of Contiguous US and Puerto Rico heliports (triangles) and accidents analyzed in this study (stars)

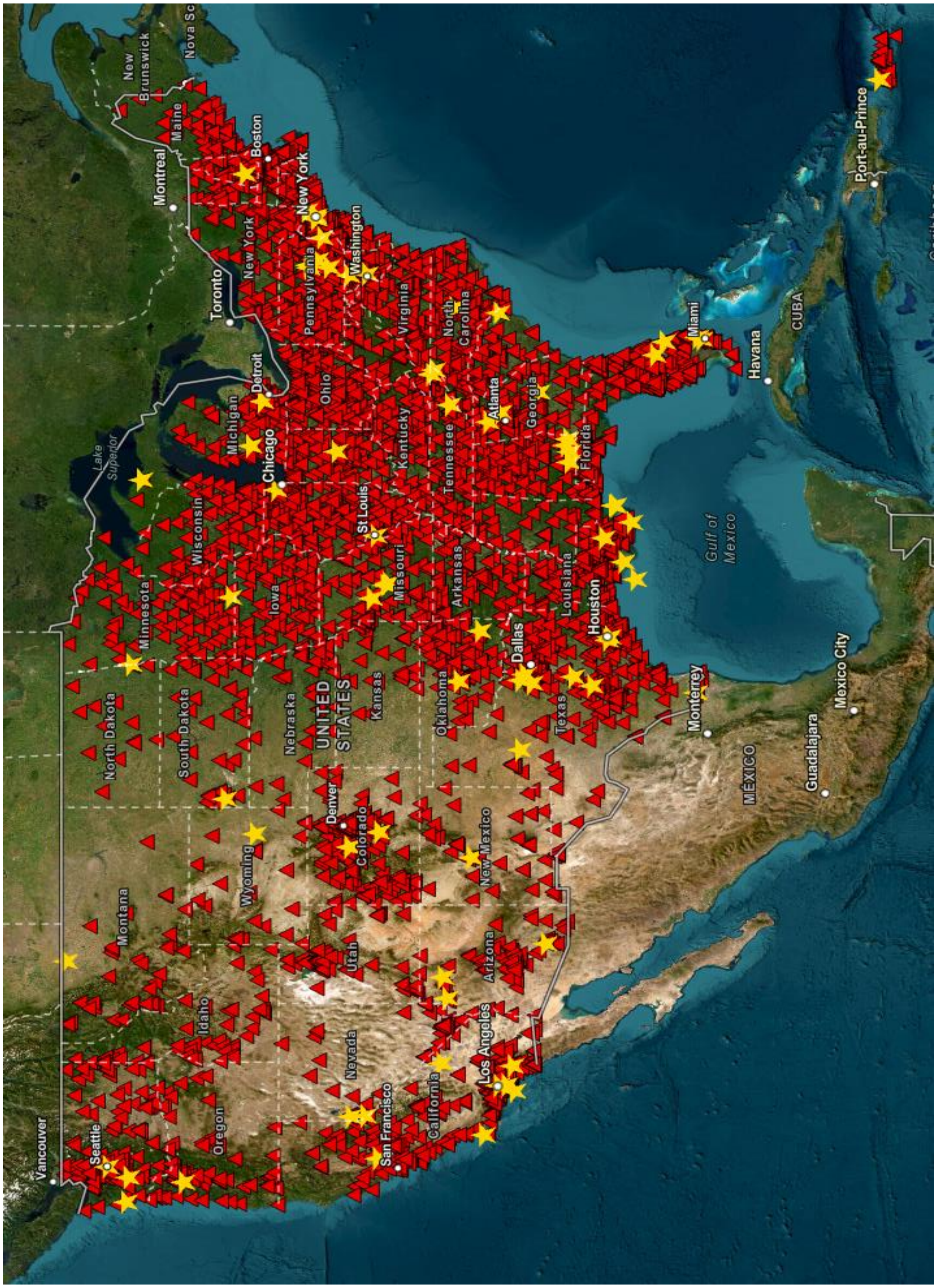


Figure 7b

Map of Alaska heliports (triangles) and accidents analyzed in this study (stars)

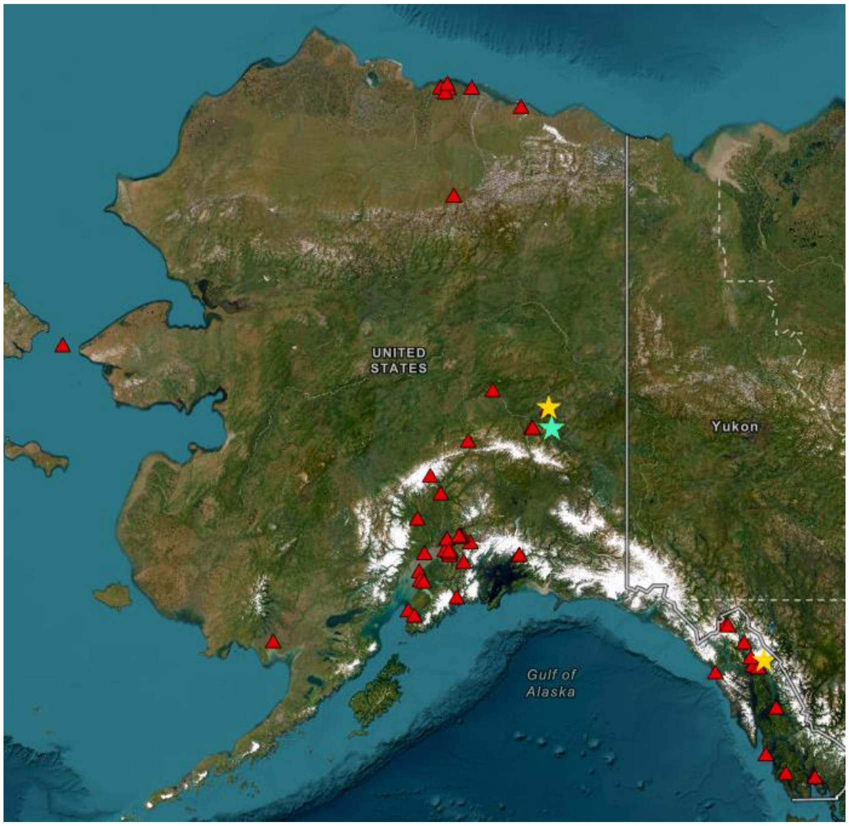


Figure 7c

Map of Hawaii heliports (triangles) and accidents analyzed in this study (stars)

Figure 8

Accident locations within 400 feet in relation to takeoff/landing site (scale 1000 feet multiplied by X-Y values)

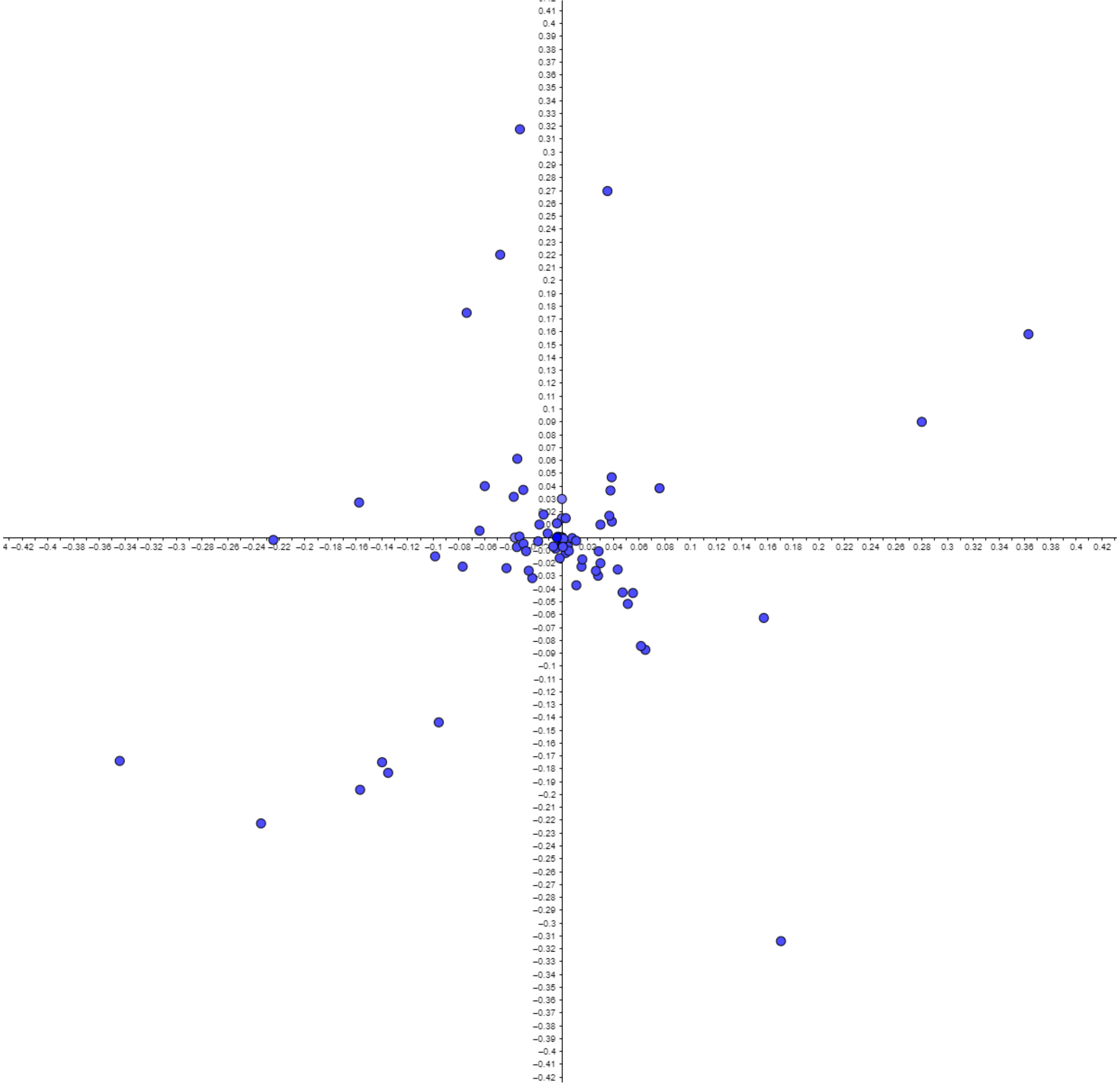


Figure 9

Accident locations within 1000 feet in relation to takeoff/landing site (scale 1000 feet multiplied by X-Y values)

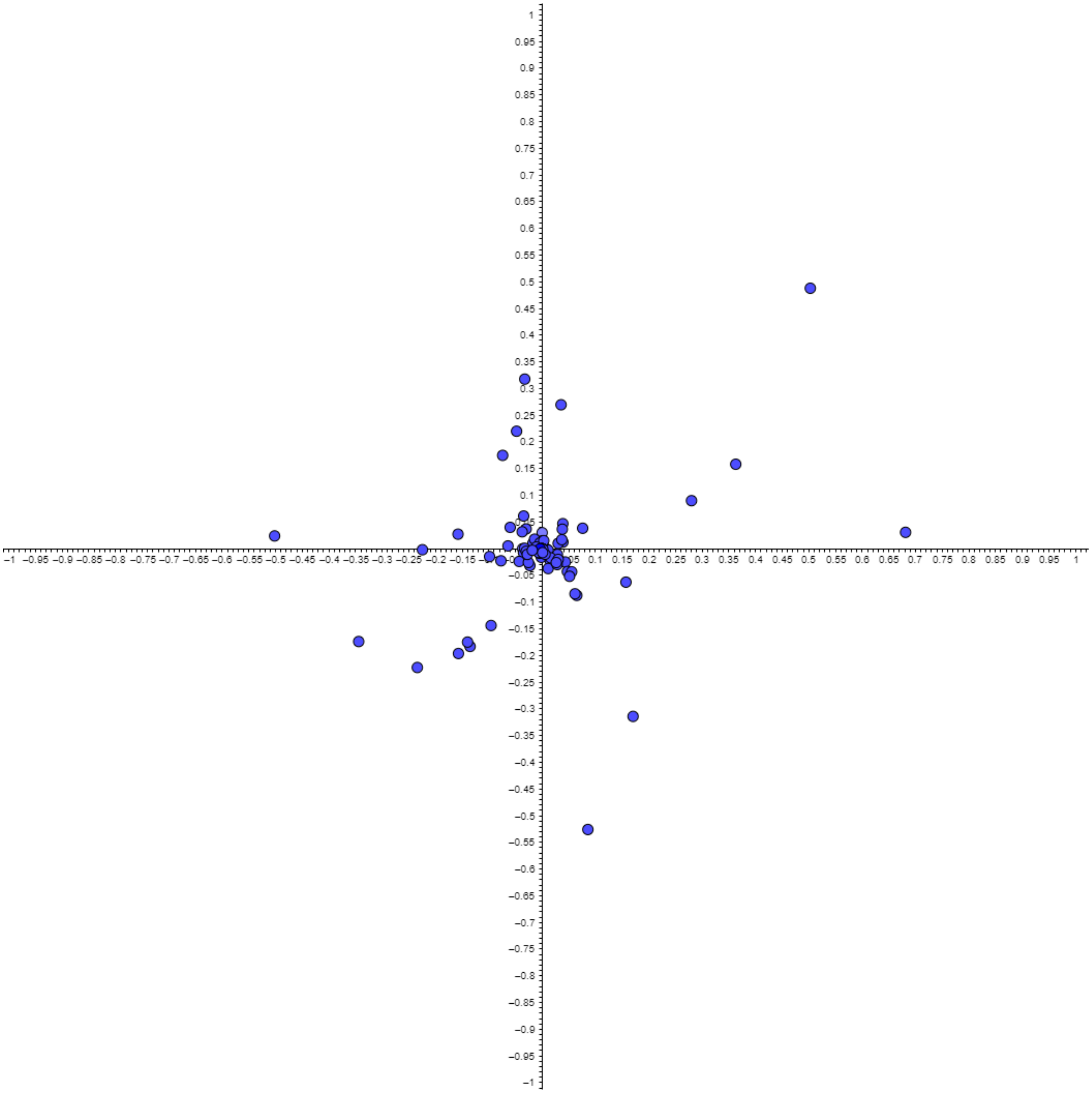


Figure 10

Accident locations within 1 NM in relation to takeoff/landing site (scale 1000 feet multiplied by X-Y values)

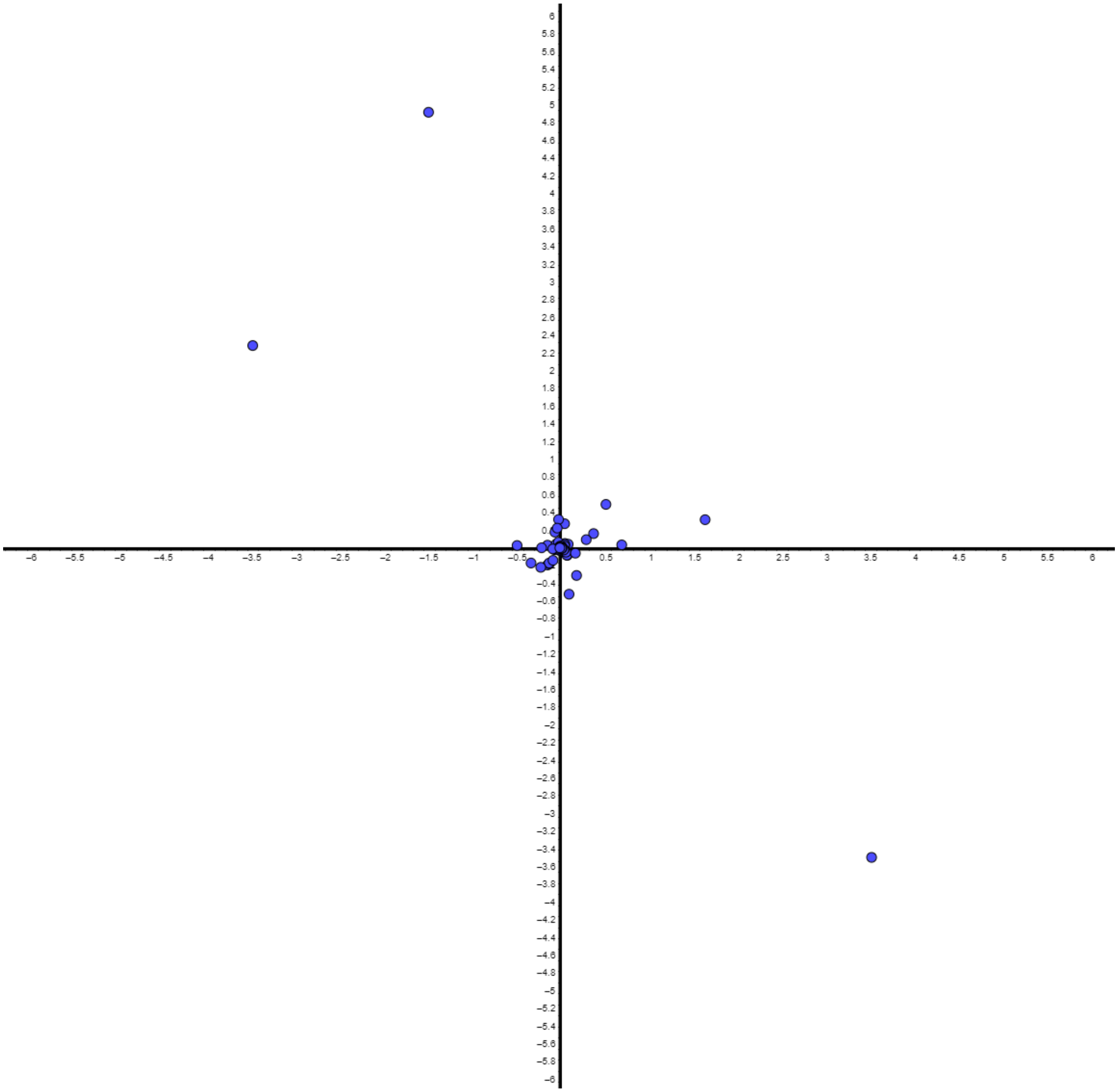


Figure 11

Cumulative percentage of accidents within highlighted areas as noted by X-Y distances (scale 1000 feet multiplied by X-Y values)

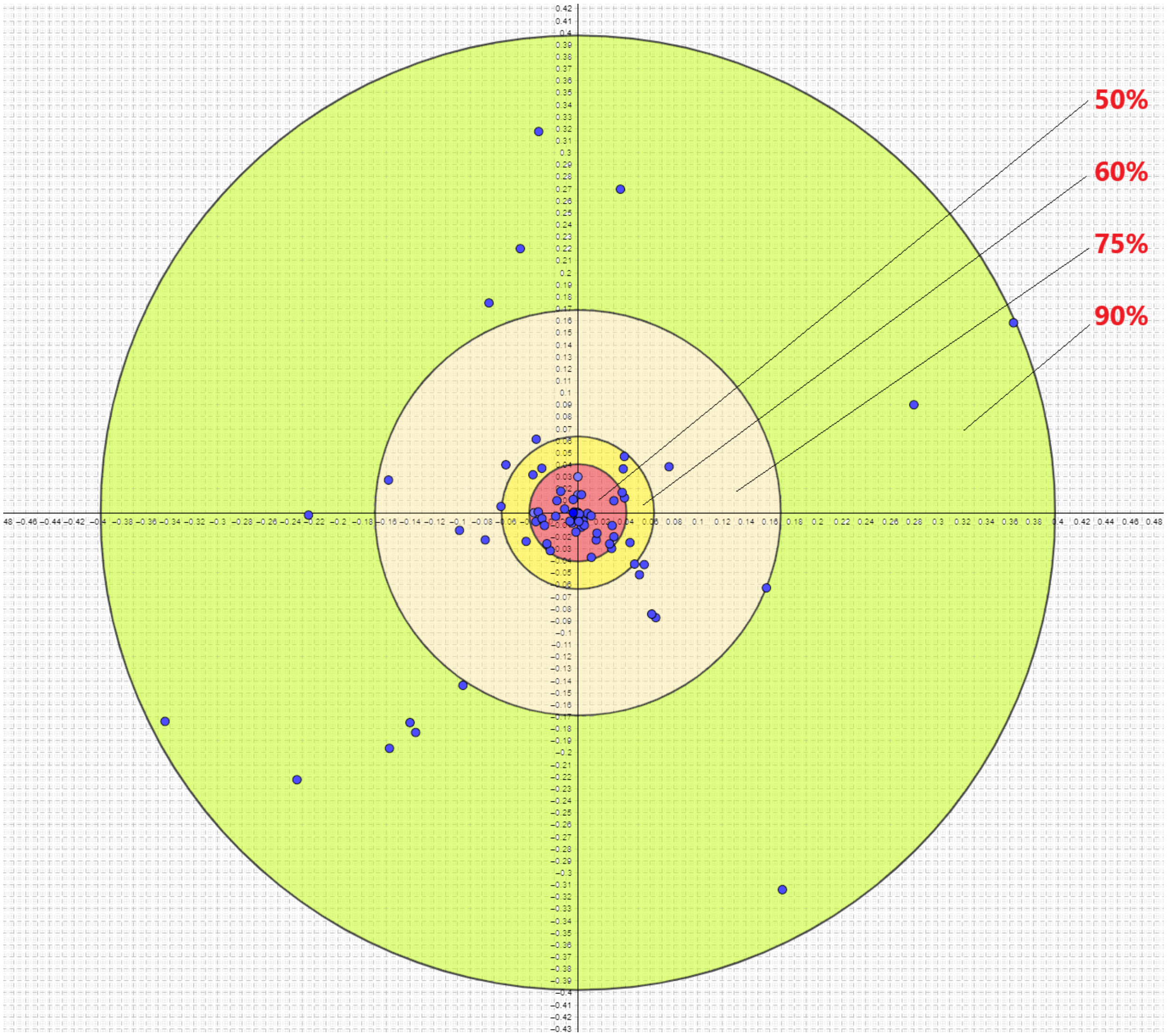


Figure 12

Percent of accidents by level of injury

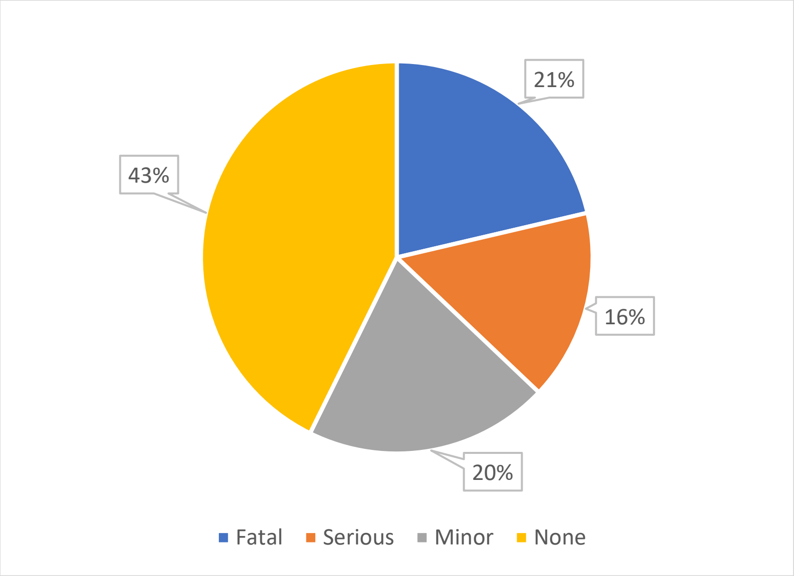
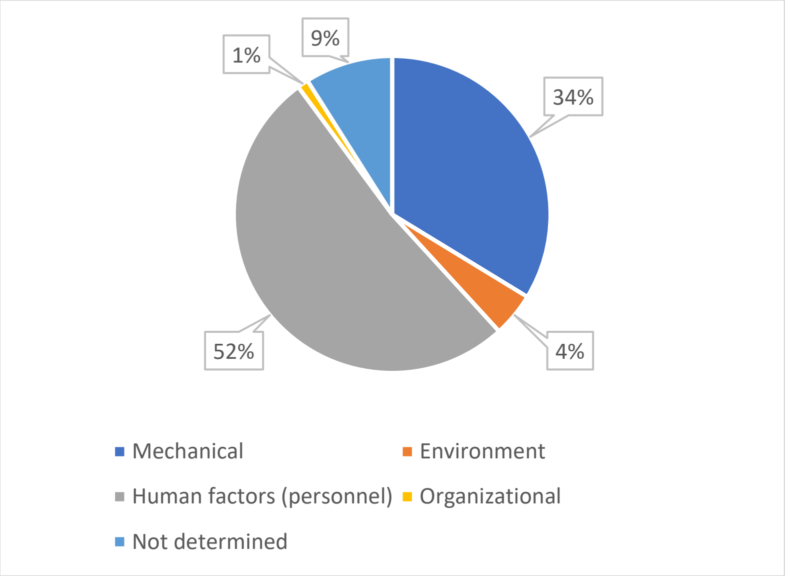


Figure 13

Percentage of accidents by causal factor



The percentages of accidents that occurred during the landing (32%) and takeoff (35%) phases were nearly identical. Accidents on approach accounted for 16% of accidents while accidents in the climb phase totaled 10%. When adding takeoff with initial climb, 45% of accidents took place at or just after takeoff. For approach and landing, the combined percentage equated to 42% (see Figure 14).

Accidents were slightly more concentrated in the spring (30%) and fall (24%) months while the percentage of events in both the winter and summer were the same (23% each) (see Figure 15). Accidents were nearly evenly split between day and night, with approximately 48% of mapped accidents occurring during nighttime hours and 52% during daytime hours. Only 3.5% of the accidents occurred in instrument meteorological conditions (IMC) with the remaining occurring in visual meteorological conditions (VMC).

Most (66%) accidents involved aircraft operating under 14 CFR Part 91 (see Figure 16). The next largest group of accidents involved aircraft operating under Part 135 which regulates commuter and on-demand flight as well as helicopter air ambulance operations. The remainder of accidents involved public (5%), external load operations (2%), and agricultural (1%) rotorcraft.

The majority of accidents (65.5%) involved non-medical rotorcraft. The remaining purposes of flight are outlined in Figure 17. The largest category (25%) was “not provided” thus researchers were unable to identify with certainty what the purpose was in such cases, however, it appeared most likely to be personal use based on rotorcraft and pilot data. Personal flying was the next largest group (23.8%) followed by positioning (22.7%) which almost exclusively involved air ambulance operations.

Figure 14

Percentage of accidents by phase of flight

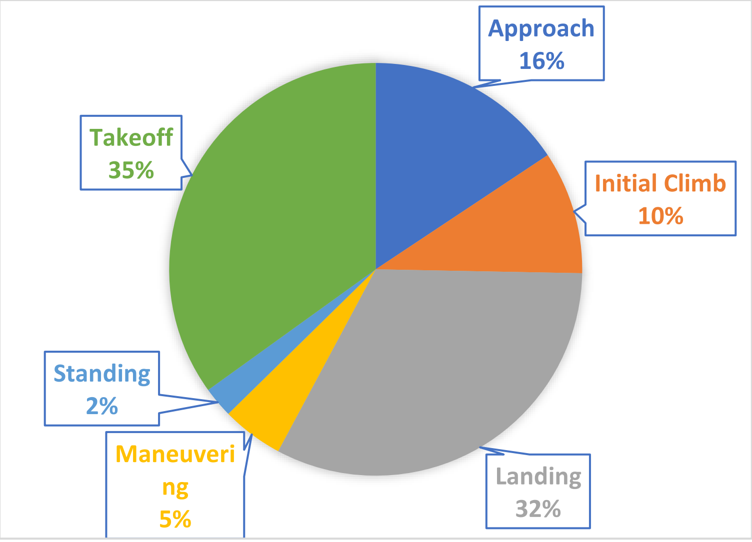


Figure 15

Percentage of accidents by season

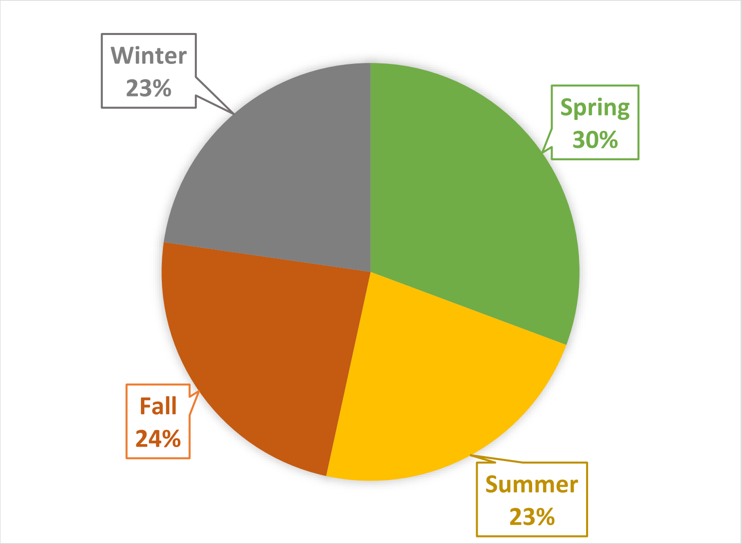
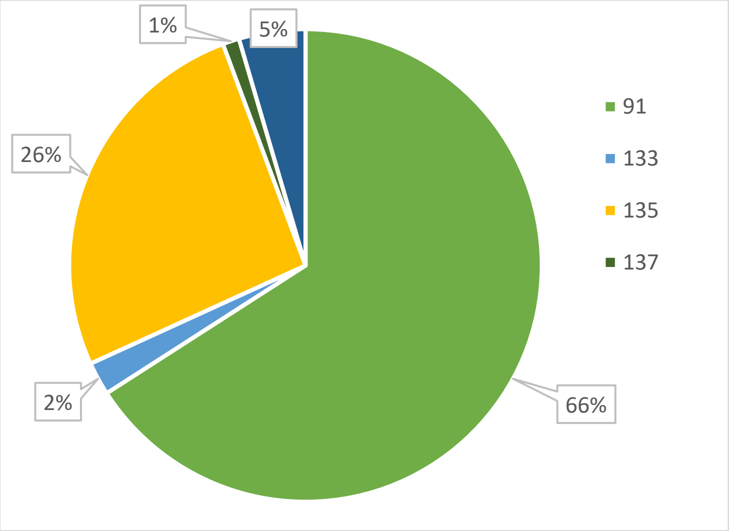


Figure 16

Percentage of accidents by operation 14 CFR part



Data on the details of the involved aircraft yielded information about the type and number of engines as well as the manufacturer. Approximately 20% of accidents had one reciprocating engine (see Figure 18). This type of aircraft is primarily used in flight training and recreational flying. The remaining 80% of accidents involved turbine-powered aircraft which are more sophisticated and expensive to own and operate. Thus, turbine rotorcraft are characteristically limited to corporate and air ambulance flights. Roughly 62% of turbine accidents involved rotorcraft with one engine and just short of 18% had two engines.

Among manufacturers, the top three involved in accidents were Bell (25%), Eurocopter (20%), and Robinson (17%) (see Figure 19). Each of the remaining manufacturers encompassed less than 5% of accidents.

Figure 17

Percentage of flights by purpose

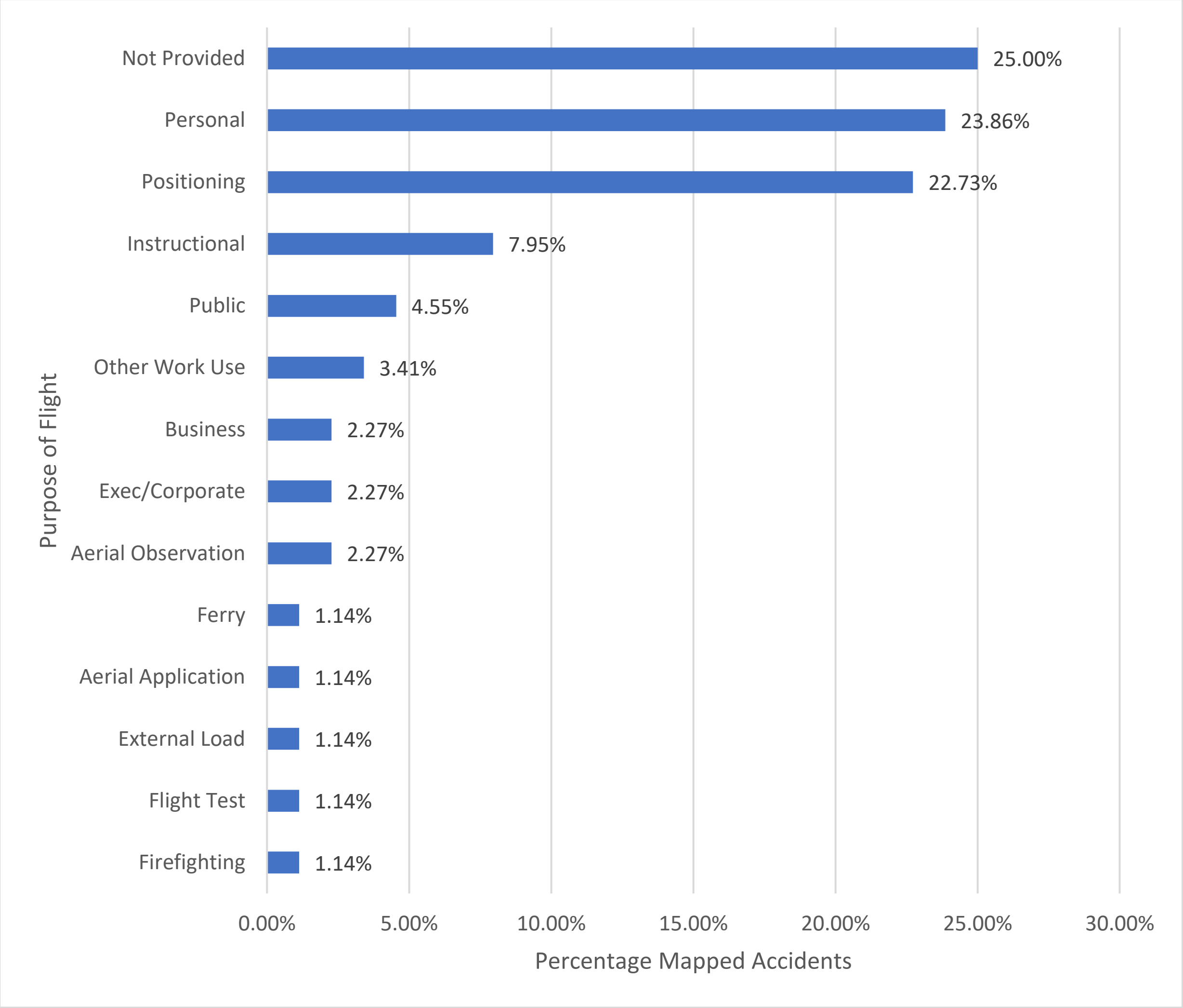


Figure 18

Percentage of flights by engine type and quantity

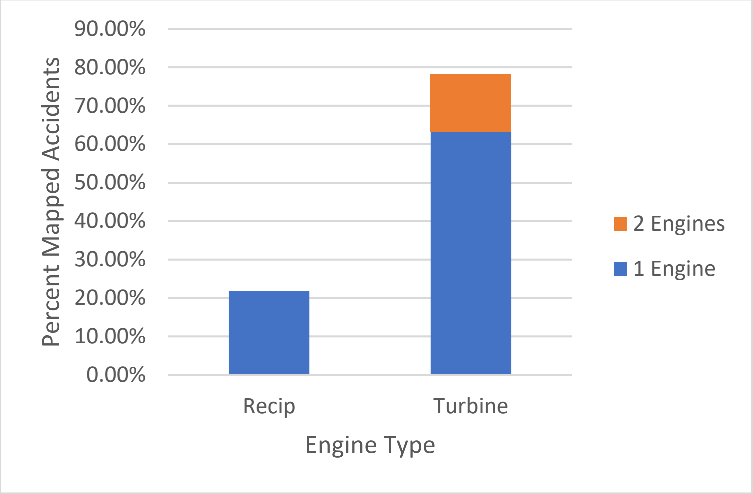
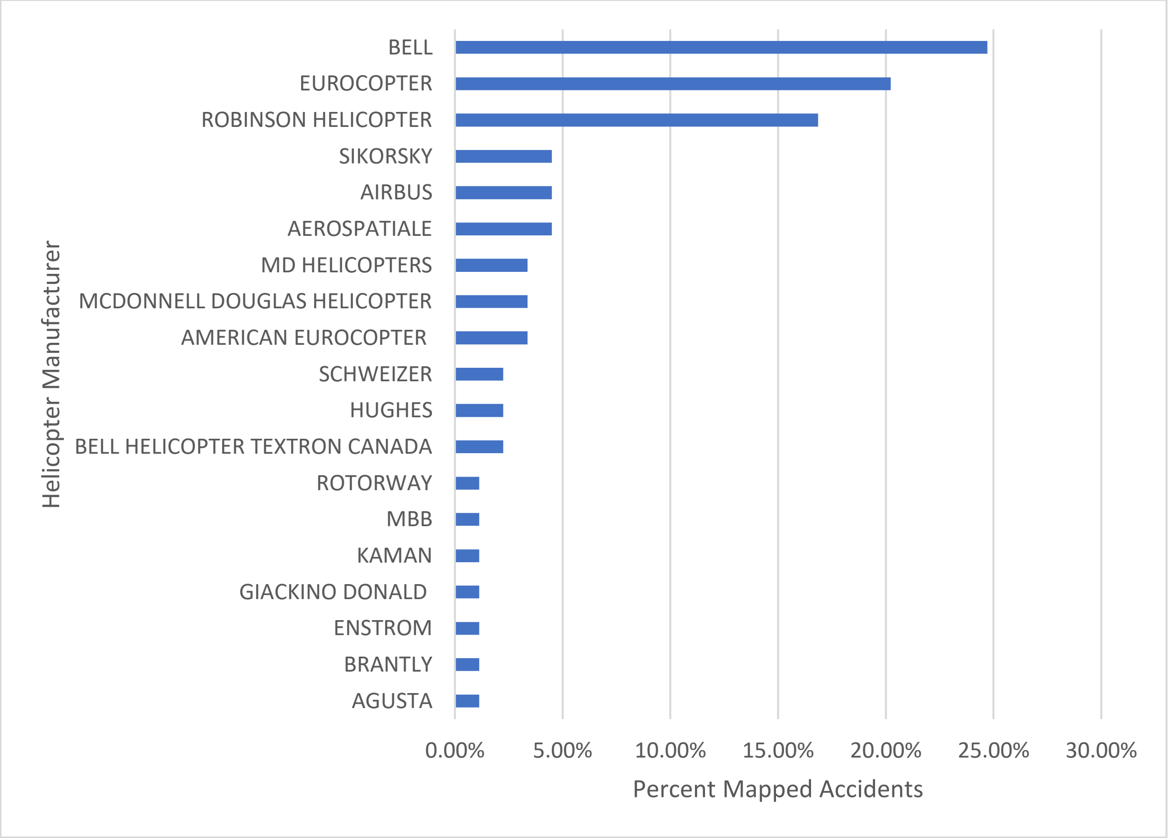


Figure 19

Percentage of accidents by manufacturer



Discussion

The results of this study provide a range of insights into the distribution of accidents around heliports and takeoff/landing sites as well as the attributes of such events. In general, the findings of this study align with previous studies on helicopter accident distributions. Overall, accidents identified in previous studies as well as the current study seem to be randomly and closely located to takeoff/landing reference points. Parallel to previous studies, the current research indicates some level of clustering is identifiable when viewing the distributions from a larger scale (Adams et al., 1992; FAA, 1991; LADOT, 2021; Windus, 2015).

Comparison with Previous Helicopter Accident Studies

The sample size in FAA (1991), numbering 63 analyzed events, was slightly lower than this study (84 events). The basic pattern of accident distribution found in this study was relatively random, particularly within 1,000 feet. This matches the description of the distribution discovered by FAA (1991):

> In general, the mishaps occurred to a variety of helicopter operators throughout the year, randomly throughout the day, over a range of density altitudes, and across the entire United States. While some of the general factors may have influenced individual mishaps or even several mishaps, no one factor played a major role in the mishaps… helicopter mishaps may occur anywhere on the facility. Although some locations appear to have a significantly larger portion of the mishaps, no location at a facility appears immune (p. 25).

Approximately 57% of mishaps identified in FAA (1991) occurred in close proximity to the reference point/heliport which is analogous to the findings of the current study with 50% of events occurring within 60 feet of the reference point/heliport.[1] The findings in Adams et al. (1992), ranging from 37 to 48%, differed significantly from the approximately 90% of accidents occurring within a mile of the landing site. Because precise distances between an accident site and the reference point were not provided by the Adams et al. (1992) study, the utility of comparing its findings with that of the current study is limited.

The percentage of accidents occurring during the takeoff phase (35%) was comparable to that in Adams et al. (1992) (34.7%). The same was determined to be true about landing accidents (32% in the present study vs. 36.3% in Adams et al. [1992]).

In reference to civilian operations, 67% of mishaps took place under 14 CFR Part 91 and 33% under Part 135 (FAA, 1991). Compared to the current study, the Part 91 values were essentially equal, and the current study's Part 135 value was only slightly less at 26%. When comparing purposes of flight between the current study and Adams et al. (1992), there were significant differences identified in categories that were termed the same, thus considered to be eligible for comparison (e.g., both studies had "personal" as a possible purpose of flight).

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[1] It was determined that it would be prudent to conduct *z*-tests of two proportions of unequal sample size to support claims of "no difference" between groups. In cases when it is stated values in the current and previous studies are comparable or similar, $p > 0.05$, i.e., there was no statistically significant difference.

Assessing the percentage of accidents occurring in piston versus turbine aircraft as well as those with two turbine engines both in the current and Adams et al. (1992) studies, there were no significant differences. Although the capacity to compare percentages of accidents in reference to helicopter manufacturers between the studies was quite limited, Adams et al. (1992) explicitly identified Bell helicopters in its accident rates data, thus supporting the current findings showing that Bell had one of the highest percentages of accidents.

A notable finding was that there was a significant difference between the percentage of single-engine piston-engine helicopters registered (53%) versus the percentage of flight hours flown by these aircraft (25.9%). There were also significant differences between the percentage of all turbine-engine helicopters registered (47%) and the percentage of hours flown by these aircraft (74.1%). Therefore, while turbine helicopters make up only around half of the U.S. civilian fleet, these rotorcraft are flying almost three-quarters of all rotorcraft flight hours. The percentage of hours flown corresponds with the percentage of turbine helicopters involved in accidents, therefore they are involved in the number of accidents that logically would be expected (Adams et al., 1992).

Implications for Land Use Compatibility Near Heliports and Vertiports

The data collected in this study provides a solid foundation for assessing potential guidance and standards for safety zones as well as land use compatibility in the vicinity of heliports and, potentially, for vertiports. The consistency among the findings of the current study with previous studies (i.e., Adams et al., 1992 and FAA, 1991) is reassuringly validating.

The distribution of accidents identified in this study makes clear that current safety zone recommendations for heliports may be inadequate for both helicopter and eVTOL operations. Using the Joby pre-production aircraft as an example, which has a wingspan of 35 feet, under current standards, the FATO would be 70 feet by 70 feet. Including the recommended safety area, the protected area around the vertipad would be 105 feet by 105 feet or 11,025 square feet. In contrast, the area with elevated risk identified in the current study (area in which 75% of accidents occurred) was within an approximate radius of 170 feet which translates to 28,900 square feet, or just over two and half times larger than current standards. This reinforces the need to develop appropriate compatibility and safety zones that align with available accident data.

As Windus (2015) stated, it is critical that local planning bodies develop Height Restriction Areas (HRA), Safety Restriction Areas (SRA), and Overflight Restriction Areas (ORA). The HRA should protect the heliport or vertiport from objects that penetrate Part 77 surfaces or obstruct operations. SRA considers the safety of people and property on the ground as well as helicopter/eVTOL occupants. The ORA ensures the consideration of noise, height, and safety in the development of the least obtrusive flight paths to and from a heliport/vertiport in relation to its overall surroundings. The findings from this research advocate for the adoption of these “Areas” or some sort of equivalent.

LADOT (2021) stated many of the same recommendations which, again, are supported by the accident data from the current study. As noted previously, local governments and planning bodies should carefully consider vertiport safety and influence zones with a focus on the height and land use impacts within each zone. Additionally, criteria for vertiport traffic volumes and time of day restrictions may be deemed necessary. It makes sense, based on the current study data, that safety and compatibility zones should be tailored to individual sites especially if a vertiport only allows arrivals and departures in specific directions. Lastly, standards and processes for vertiport site selection approval are necessary must be established to guide infrastructure stakeholders as well as to protect the public and property on the ground (LADOT, 2021).

In the context of previous studies as well as current research, it is undoubtedly reasonable to advocate for expanded safety zones around both heliports and vertiports. Based on the distribution of accidents, it is logical that any protection or land use compatibility zones be circular or equidistantly symmetrical and centered around the vertipad/helipad. Rational considerations for zone delineations, adapted from guidance from Cardi et al. (2012) and Garbell (1988), are the 60-foot, 170-foot, and 400-foot thresholds as the latter two of these distances are not incorporated in current heliport/vertiport design recommendations, and standards. Moreover, the 60-foot zone includes the areas of the most concentrated accident activity, and the remaining zones contain incrementally higher volumes of accidents.

Further protection should be afforded within heliport/vertiport areas of influence which include any specified departure and arrival paths. These extended protection or compatibility zones must not only be based on the data from this study but also on noise data and local restrictions or policies. Additional research that is necessary to develop comprehensive safety and land use compatibility zones is described in the future research section of this study.

Limitations and Delimitations

This study was constrained by specific limitations. The first was the lack of data collected by the NTSB before 1982. Before this date, the NTSB did not provide the latitude and longitude for helicopter accidents. Moreover, for pre-1982 reports, detailed findings were scarce. This removed a number of potential accidents for inclusion in this study due to the impossibility of pinpointing the location of accidents with any level of confidence. Even when examining more recent accident records, there were several cases in which the actual location of an accident was either misidentified or was tagged to a generic location such as the airport reference point or a city center. The researcher was forced to use satellite imagery, accident photos, pilot and witness statements, and various forms to determine the actual location of an accident. Unfortunately, in a few cases of erroneous location coordinates, there was not enough information to sleuth the actual accident site. Therefore, these cases also had to be omitted. This highlights yet another limitation – the NTSB does not consistently make docket contents (e.g., photos, analysis reports, statements) available to the public.

Although the researcher is proficient in the use of ArcGIS, another limitation is that there may have been minor errors in measuring the direction and distance an accident occurred in relation to a takeoff/landing reference point. There was also the potential for plotting errors, though plots were verified by the researcher on three, and sometimes more, separate occasions through the data analysis phase of the study.

The delimitations of the study were the constraints used in the NTSB database search. For example, only helicopter accidents in critical phases of flight were included. Further, the search was limited to those involving a heliport/helipad or other stated takeoff/landing site. It was plausible that this could have led to the omission of events that may have met the requirements for inclusion, but for some reason were misclassified or did not mention the keywords or letter combinations used in the search. No accidents were included in locations outside the U.S. which may have yielded a slightly larger sample size. This research also precluded the use of imprecise or seemingly erroneous database information. While the sample size could have been slightly larger with the inclusion of such data points, the quality and precision of the research findings would likely have been jeopardized.

Conclusions

The current study analyzed accident data from heliports and vertiports in the United States, focusing on the location of such events. The results of this study successfully attained responses to the research questions. First, by identifying helicopter accident locations and second by garnering recommendations for the development of safety and land use compatibility zones for heliports and vertiports.

In sum, the study found that the majority of helicopter accidents occur within close proximity to the heliport or takeoff/landing site. The accidents were randomly distributed, with the highest concentration occurring within 40 feet of the reference heliport or takeoff/landing point. This suggests that the design and operation of heliports and vertiports should consider the potential for accidents and take steps to mitigate the risk. The study also found that accidents occurred with relatively equal frequencies with respect to season, time of day, and critical phases of flight.

Similar to other sectors in the aviation industry, human factors were the primary factor in the accidents analyzed in this study. Specific to the analyzed accidents, many of the events involved human errors related to operational judgment, such as proper clearance from objects on or near the takeoff/landing site. Thus, greater margins of safety in terms of land use and obstacle placement would likely help to mitigate risk during critical phases of flight.

This study presents a paradigm for assessing safety zones and land use compatibility near heliports and vertiports. Current safety zone recommendations may be inadequate for helicopter and eVTOL operations. It is recommended that local governments and agencies adopt Height Restriction Areas (HRA), Safety Restriction Areas (SRA), and Overflight Restriction Areas (ORA) to protect heliports and vertiports from nearby objects and buildings. Local governments and planning bodies should also consider heliport and vertiport compatibility and influence zones. Expanded safety zones around heliports and vertiports should be based on accident and noise data as well as any additional local restrictions. It may be deemed necessary to restrict traffic volumes and operations at certain times of the day to minimize negative impacts on adjacent communities.

Overall, the study provided valuable insights into the distribution and causes of helicopter accidents. This information can be used to improve the design, operation, and maintenance of heliports and vertiports, and to reduce the risk of accidents.

Recommendations

Based on the findings of this study, some specific recommendations can be made:

- Heliports and vertiports should be located in areas that allow for operations with minimal conflict with obstacles/buildings and impact on adjacent communities.
- The design of heliports and vertiports should consider areas most at risk for accidents, as well as the potential for noise and other environmental annoyances.
- “Fly-friendly” flight procedures should be made mandatory, such as noise abatement procedures, to minimize negative impacts of operations on the local area.
- Operators should develop procedures to deal with emergencies such as accidents, fires, and environmental hazards.

- Land use guidelines should be developed specifically tailored for heliports and vertiports based upon the findings of this study in conjunction with existing and future research.
- Encourage the NTSB to improve quality assurance in data collection, specifically in reference to precise accident location coordinates.
- Encourage the NTSB to make all docket files available within the accident database.

Suggestions for Future Research

Based on the findings of this study, the following suggestions for future research are offered:

- A study on the potential noise and other annoyance factors produced by helicopters and eVTOLs should be conducted to provide further guidance on land use compatibility in the vicinity of heliports and vertiports.
- A study combining the safety data from this study and noise data from the recommended study should be completed to provide comprehensive safety and land use compatibility zone design recommendations.
- Repeat studies when more data becomes available about eVTOLs and vertiport operations.

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