2012

Using three-dimensional flight patterns at airfields to identify hotspots for avianeaircraft collisions

W. David Walter
United States Department of Agriculture, wdwalter@psu.edu

Justin W. Fischer
USDA/APHIS/WS National Wildlife Research Center, Justin.w.fischer@aphis.usda.gov

John S. Humphrey
USDA/APHIS/WS National Wildlife Research Center, John.S.Humphrey@aphis.usda.gov

Trey S. Daughtery
United States Department of Agriculture, Rudolph.Daughtery@usmc.mil

Michael P. Milleson
United States Department of Agriculture, Michael.P.Milleson@aphis.usda.gov

See next page for additional authors

Walter, W. David; Fischer, Justin W.; Humphrey, John S.; Daughtery, Trey S.; Milleson, Michael P.; Tillman, Eric A.; and Avery, Michael L., "Using three-dimensional flight patterns at airfields to identify hotspots for avianeaircraft collisions" (2012). *USDA National Wildlife Research Center - Staff Publications*. 1205.
https://digitalcommons.unl.edu/icwdm_usdanwrc/1205

Authors

W. David Walter, Justin W. Fischer, John S. Humphrey, Trey S. Daughtery, Michael P. Milleson, Eric A. Tillman, and Michael L. Avery

Applied Geography 35 (2012) 53–59

Contents lists available at SciVerse ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

Using three-dimensional flight patterns at airfields to identify hotspots for avian–aircraft collisions

W. David Walter[a,*], Justin W. Fischer[a], John S. Humphrey[b], Trey S. Daughtery[c], Michael P. Milleson[b], Eric A. Tillman[b], Michael L. Avery[b]

[a] *United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center, 4101 LaPorte Avenue, Fort Collins, CO 80521-2154, USA*

[b] *United States Department of Agriculture, Animal and Plant Health Inspection Service, National Wildlife Research Center, Florida Field Station, 2820 East University Avenue, Gainesville, FL 32641, USA*

[c] *United States Department of Agriculture, Wildlife Services, Marine Corps Air Station, Beaufort, SC 29904, USA*

Keywords:
Aviation hazard
Birdstrike
Black vulture
Cathartes aura
Coragyps atratus
Flight behavior
Satellite telemetry
Turkey vulture

ABSTRACT

In the United States, black vulture (*Coragyps atratus*) and turkey vulture (*Cathartes aura*) pose significant birdstrike risks to aircraft. Understanding flight behaviors of vultures in and around military and civilian airfields is necessary to alleviate these risks. Using satellite telemetry data collected from 11 black vultures and 7 turkey vultures equipped with Global Positioning System backpack harness technology, we collected data on location and altitude near the Marine Corps Air Station (MCAS) in Beaufort, South Carolina from September 2006 to September 2008. We used military aircraft flight landing patterns to visualize a new concept, a flight altitude cone of depression (FACOD), which models a three-dimensional flight pattern over the airfield. We then identified areas in and around MCAS where vulture flight paths penetrated the FACOD and locations of vultures were proximate to flight approach routes that posed potential risk to aircraft for a birdstrike. Combining altitude of in-flight locations of vultures or other species with three-dimensional flight patterns of aircraft provides a novel method for managers of military and domestic airfields to assess birdstrike risk and to focus corrective actions.

Published by Elsevier Ltd.

Introduction

Coincident with rising black vulture (*Coragyps atratus*) and turkey vulture (*Cathartes aura*) populations have been reports of increased property damage, livestock depredations, and aircraft safety issues (Avery, 2004; Lovell, 1997). Consistently, black and turkey vultures collectively represent one of the most destructive wildlife groups to civil aircraft, both in terms of numbers of incidents and economic cost (Dolbeer, Wright, Weller, & Begier, 2011). Furthermore, since 1995, turkey and black vultures rank number 3 and 4, respectively, in costs due to aircraft collisions involving the United States Air Force (USAF, 2011). Hazards posed by vultures to civil and military aircraft are influenced by both daily and seasonal movement patterns of vultures and their flight altitudes near airfields.

Recent incidents of birdstrikes causing monetary damage to aircraft and human injuries/fatalities have aviation personnel searching for methods to prevent further collisions between aircraft and avian species. For example, US Airways Flight 1549 crashed into the Hudson River after a birdstrike 5 miles (~8 km) from New York's LaGuardia Airport at an elevation of 2900 ft (~884 m; Marra et al., 2009). At Marine Corps Air Station (MCAS), Beaufort, South Carolina, three birdstrikes with vultures have occurred since 2006 at altitudes between 61 and 458 m above ground level (Avery et al., 2011). Most research in areas of high avian–aircraft collisions, however, only summarizes altitudes and related characteristics of avian flight behavior (DeVault, Reinhart, Brisbin, & Rhodes, 2005; Dolbeer, 2006) or identifies alternate methods that are limited because of their expense and range of identifying avian species (<1 km) currently limits their wide-scale use (Beason, Humphrey, Myers, & Avery, 2010).

Inherent limitations in every method would suggest that no single approach to birdstrike prevention will suffice and other methods should be explored (Beason et al., 2010). An effective understanding of

---

* Corresponding author. U.S. Geological Survey, Pennsylvania Cooperative Fish & Wildlife Research Unit, Pennsylvania State University, 403 Forest Resources Bldg, University Park, PA 16802, USA. Tel.: +1 814 867 4763; fax: +1 814 863 4710.

E-mail addresses: wdwalter@psu.edu (W.D. Walter), Justin.W.Fischer@aphis.usda.gov (J.W. Fischer), John.S.Humphrey@aphis.usda.gov (J.S. Humphrey), Rudolph.Daughtery@usmc.mil (T.S. Daughtery), Michael.P.Milleson@aphis.usda.gov (M.P. Milleson), Eric.A.Tillman@aphis.usda.gov (E.A. Tillman), Michael.L.Avery@aphis.usda.gov (M.L. Avery).

0143-6228/$ – see front matter Published by Elsevier Ltd.
doi:10.1016/j.apgeog.2012.05.002

localized flight patterns and altitudes of vultures would contribute substantially to lessening avian–aircraft strike risks to pilots at military and civilian airfields. Concomitant with avian behavior and movements, risk of birdstrike is related to flight patterns and altitudes of aircraft, especially during takeoff and approach at a given airfield (Dolbeer, 2006). We propose novel geostatistical methods to model the flight path of approaching aircraft in three-dimensions. Within this novel method, we incorporated the in-flight locations of black vultures and turkey vultures equipped with global positioning system (GPS) technology (Avery et al., 2011). Our goal was to identify altitudes and areas ("hotspots") where vultures pose the greatest risk to aircraft based on in-flight locations and aircraft flight patterns. We then provided suggestions for use of our methods with alternate types of data (i.e., thermals, roost structures) to aviation personnel to identify hotspots that have high potential for avian–aircraft collisions to potentially reduce risk of birdstrikes.

Data and methods

Study area, GPS harnessing, and data collection

Our study occurred in and around Marine Corps Air Station (MCAS), Beaufort, South Carolina, USA that has a year-round population of black vultures and turkey vultures (Fig. 1). The study site

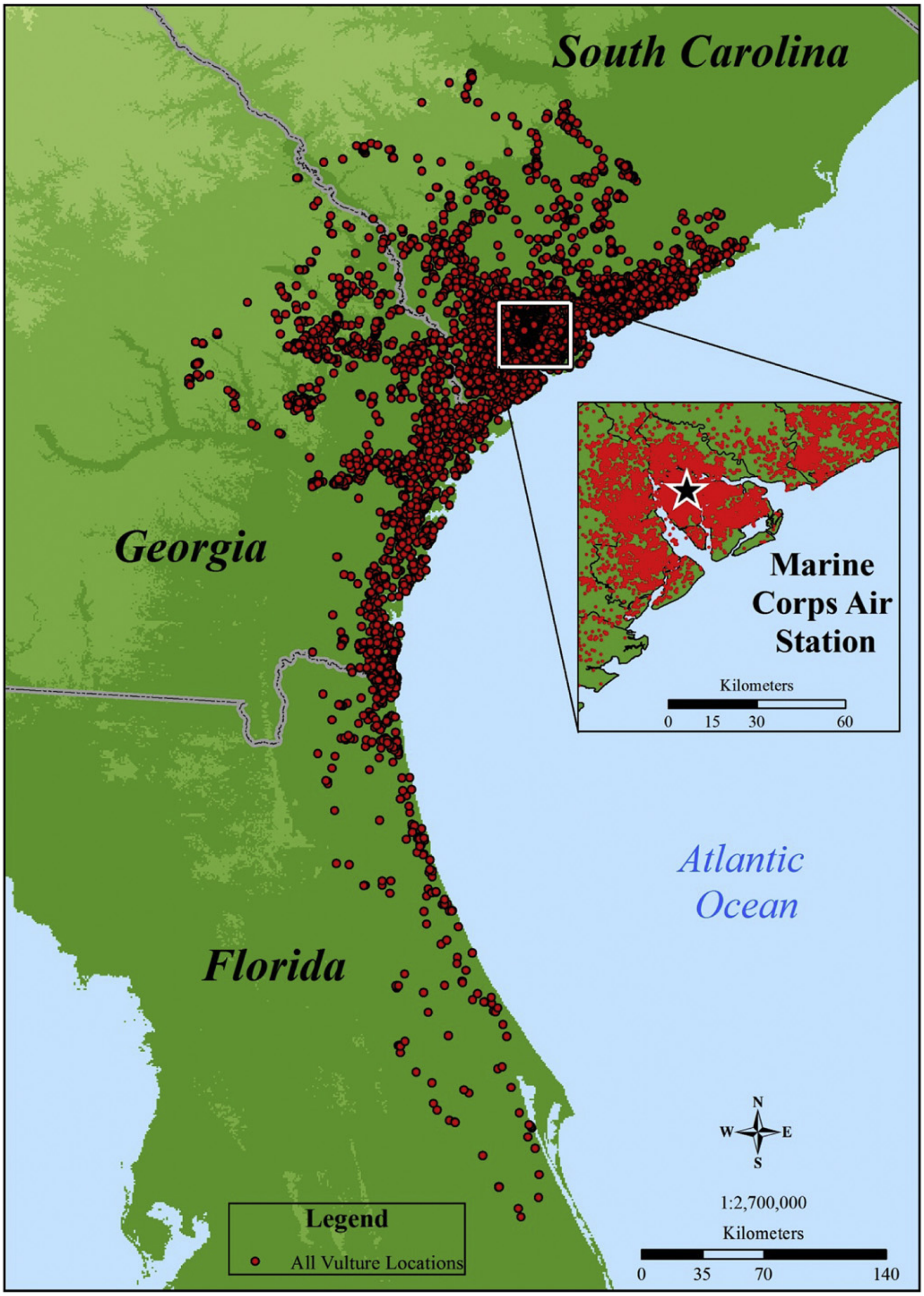

Fig. 1. Study area occupied by black vultures and turkey vultures at a Marine Corps Air Station (represented by the star on the inset) in Beaufort, South Carolina with migrations to central Florida, 2006–2008.

(32.4735° N, 80.7194° W) is at about 3 m in elevation in the low-country salt marsh ecosystem region of coastal South Carolina. Predominate landcover types available included: evergreen forest (21%), open water (19%), emergent herbaceous wetlands (19%), woody wetlands (9%), developed open space (7%), and grassland/herbaceous (7%).

We captured vultures using a baited walk-in trap (9.3 × 3.1 × 1.8 m) and marked them for visual identification with uniquely coded white cattle ear tags (Allflex, Inc., Dallas, TX) attached to the patagium of the right wing. We equipped vultures with GPS satellite transmitters model PTT-100 (Microwave Telemetry, Columbia, MD) using a backpack harness (Humphrey, Avery, & McGrane, 2000). Transmitters weighed 70 g, which conforms to the 4% of body mass limit for a 2-kg vulture permitted by the United States Fish and Wildlife Service Bird Banding Lab for attachment of avian transmitters. All transmitters recorded GPS location, altitude, heading, and speed hourly with a horizontal spatial accuracy of 15 m radius based on manufacturer's technical specifications under ideal conditions (i.e., unobstructed satellites). We used this estimate of location error because field based estimates of error (i.e., in-flight, tree roosts) were not possible. The duty cycle changed with the season to encompass the local dawn-dusk period (Beason et al., 2010). We released all captured birds at the trap site and monitored their movements for at least 3–4 weeks to establish a baseline of local flight activity.

We retrieved locations of vultures equipped with GPS technology via ARGOS satellite services every 2–3 days from 1 October 2006 to 30 September 2008 and plotted locations in ArcMap 9.2 (ArcMap; Environmental Systems Research Institute, Redlands, California). We determined percent of locations that were in-flight, mean altitude by month, and mean altitude by time of day both annually and seasonally using GPS technology (Avery et al., 2011). To include locations recorded only during flight (i.e., excluding roost locations), we filtered GPS locations by removing all GPS points that had a flight speed ≤ 0 km/h (Avery et al., 2011). We used the 2001 National LandCover Dataset to identify landcover types available to vultures around MCAS because flight behavior has been influenced by landcover type (Devault et al., 2005; Homer, Huang, Yang, Wylie, & Coan, 2004).

Three-dimensional models

We created a three-dimensional surface of MCAS aircraft flight patterns to visualize that surface in relation to in-flight locations of vultures. Although each airfield has multiple approach and departure routes, for our analysis we modeled a specific flight pattern used for military training. We obtained a Geographic Information System (GIS) layer for the training pattern from MCAS personnel and created a flight altitude cone of depression (FACOD) in ArcMap. We used ordinary kriging, a geostatistical technique to interpolate the value of a cell based on known adjacent cells, to predict values between points along each flight path ($n = 2$) and between flight paths ($n = 4$) to create a continuous raster surface (i.e., FACOD). Cross-validation accuracy of the predictive model chosen to create the FACOD was conducted. Parameters used to assess model accuracy included: mean prediction error (MPE), root-mean-squared prediction error (RMSPE), average standard error (ASE), standardized mean prediction error (SMPE), and standardized root-mean-squared prediction error (SRMSPE). The MPE and SMPE should be near 0 if prediction errors are unbiased (Johnston, Ver Hoef, Krivoruchko, & Lucas, 2001). The variability in prediction has been correctly assessed if ASE is similar to RMSPE (Johnston et al., 2001). The SRMSPE should be close to 1 if prediction standard errors are valid (Johnston et al., 2001). The FACOD was then brought into ArcScene 9.2 (Environmental Systems Research Institute, 2008, Redlands, CA), along with in-flight locations for black vulture and turkey vulture, to allow three-dimensional visualization. We also calculated vulture flight paths between consecutive bird locations in ArcMap and then determined the

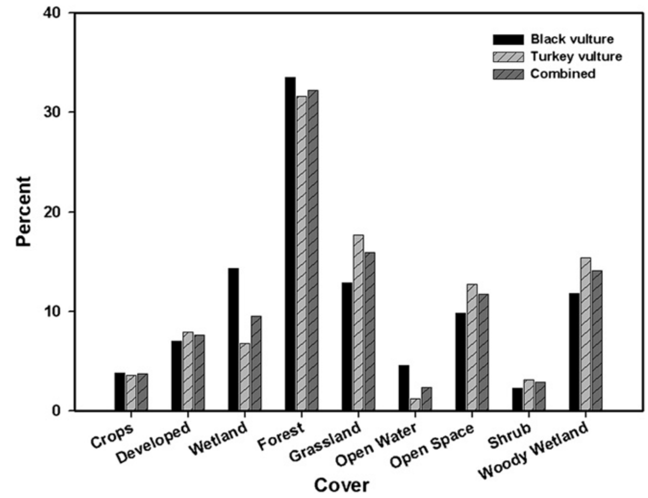

Fig. 2. Percent of in-flight locations by habitat categories within flight altitude cone of depression for black vultures and turkey vultures at a Marine Corps Air Station in Beaufort, South Carolina, USA, 2006–2008.

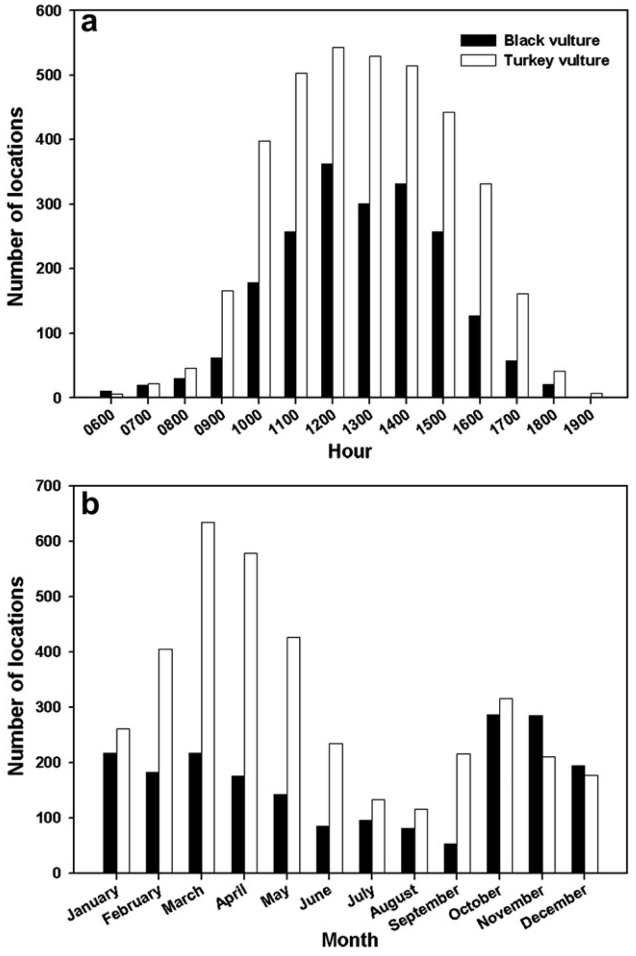

Fig. 3. Number of in-flight locations by a) time of day and b) month within the flight altitude cone of depression for black vultures ($n = 11$) and turkey vultures ($n = 7$) at the Marine Corps Air Station in Beaufort, South Carolina, USA, 2006–2008.

intersection of these vulture flight paths with the FACOD. Consecutive hourly locations were limited due to the preprogramed GPS duty cycle, missed GPS fixes, and GPS fixes removed due to data screening criteria, so consecutive locations for each bird were used to create flight paths.

To be more specific to the MCAS straight-in landing flight pattern, we also created a three-dimensional buffer around the 4 flight paths for landing aircraft that represented areas potentially unsafe for approaching aircraft. The training pattern begins with the aircraft at an altitude of 1500 ft (~457 m) at 5 nautical miles (~8 km) from the runway. The aircraft then descends 300 ft (~91 m)/nautical mile until it reaches the runway at 0 ft altitude and proceeds to land. We created a 100 m buffer in three-dimensions around each flight path (hereafter termed HALO). The HALO represented a more detailed view of potential for birdstrikes based on wing dimensions of aircraft and variability in flight to landing at the airfield. Although the FACOD summarizes altitudes that vulture penetrate potential airspace of aircraft in the area, we summarized mean altitude within the HALO and distance from the airfield that vultures may come in contact with an approaching aircraft.

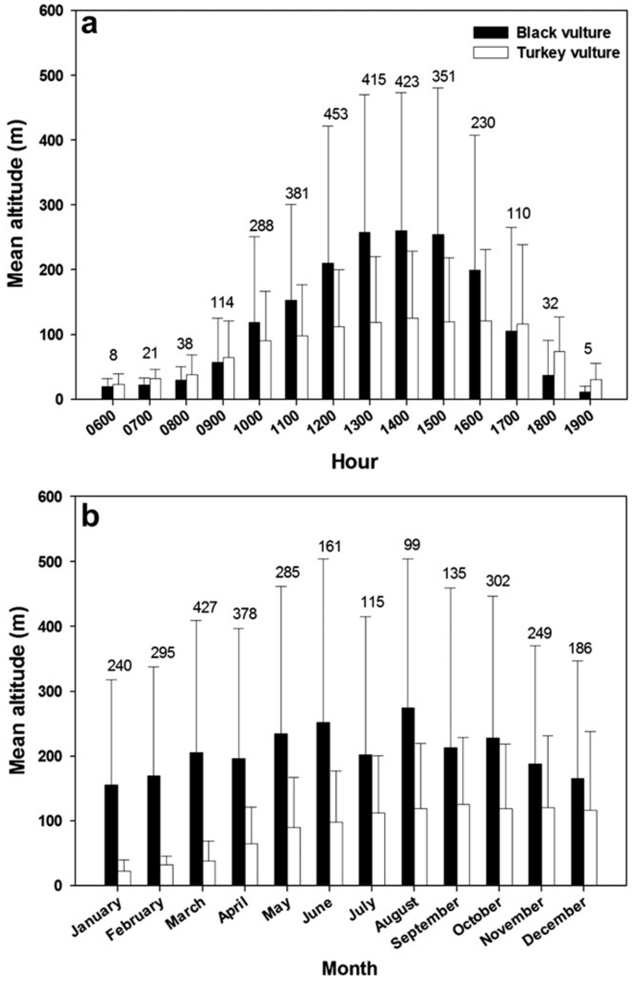

Fig. 4. Mean altitude (m) by a) time of day and b) month within the flight altitude cone of depression for black vultures ($n = 11$) and turkey vultures ($n = 7$) at a Marine Corps Air Station in Beaufort, South Carolina, USA, 2006–2008. Error bars represent the standard deviation of altitude around the mean for each category and species. Numbers above error bars represent mean number of locations across species used to estimate the mean altitude at each time and month category.

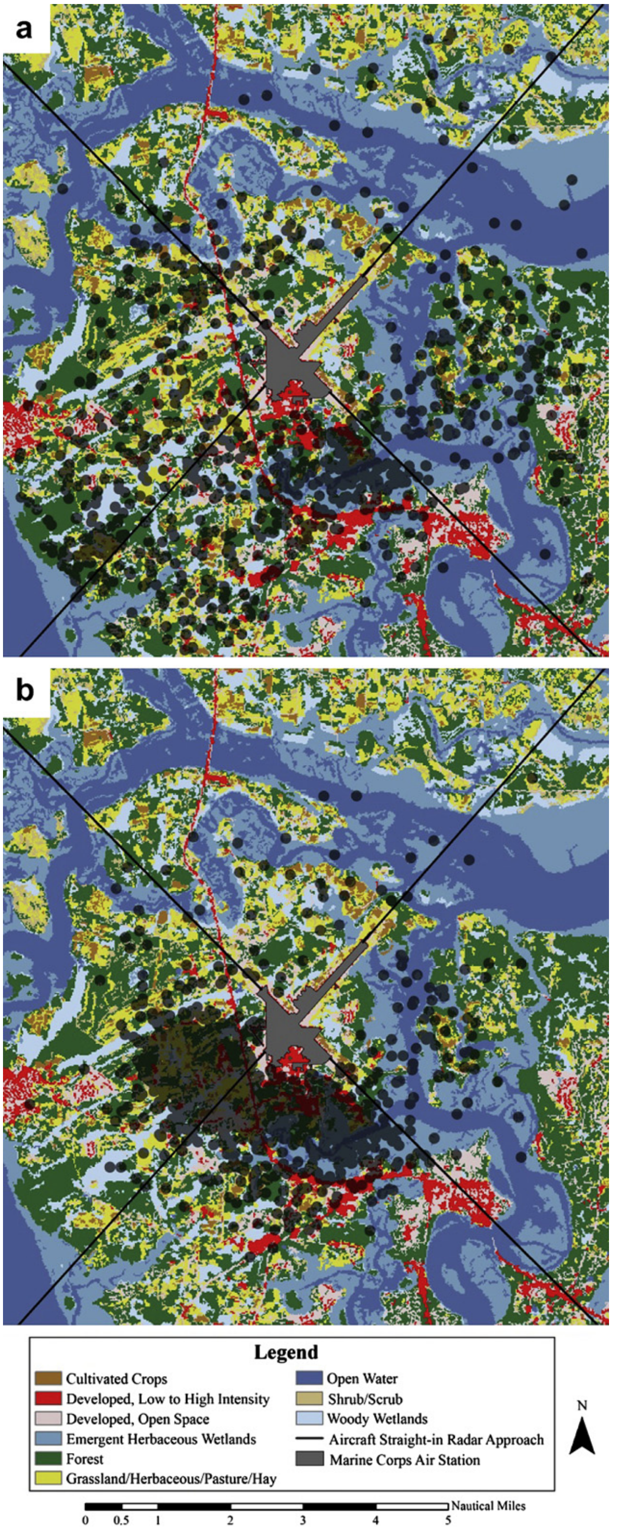

Fig. 5. All black vulture (a; $n = 2030$) and turkey vulture (b; $n = 3716$) locations used to identify in-flight paths that intersected (see black dots) the flight altitude cone of depression (black lines are aircraft straight-in radar approaches) at a Marine Corps Air Station in Beaufort, South Carolina, USA. Base layer is predominate 9 landcover categories from the 2001 National Landcover Dataset.

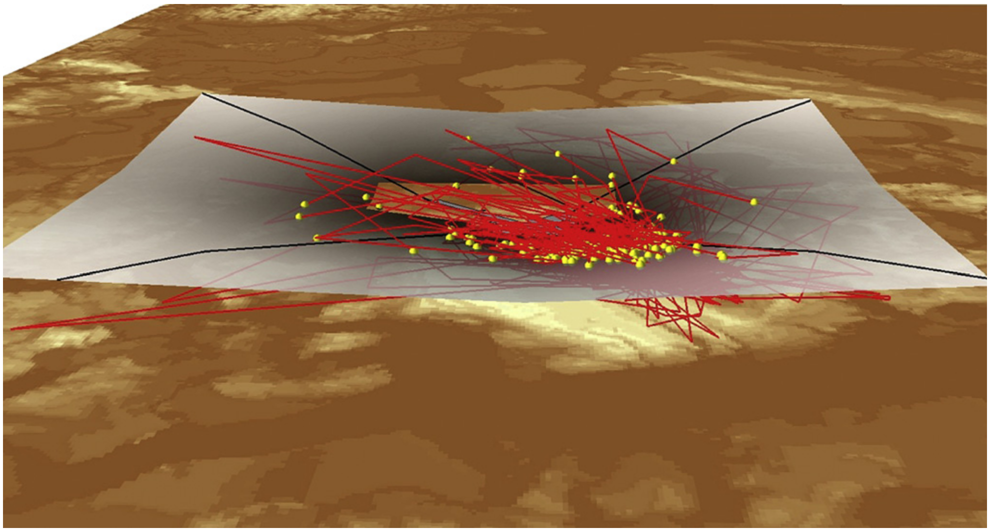

Fig. 6. Three-dimensional view of the flight altitude cone of depression (FACOD; black lines are aircraft straight-in radar approaches) with an example of vulture locations that penetrated the FACOD at a Marine Corps Air Station in Beaufort, South Carolina, USA. Red lines are a vulture's flight paths and yellow circles are penetration altitudes. Base/background layer is a digital elevation model. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Results

The FACOD was approximately square in shape (16.8 × 15.5 km) and encompassed an area of 261 km^2. Cross-validation procedures revealed that predictions made using the ordinary kriging method to be adequate ($\text{MPE} = -21.33$, $\text{SMPE} = -0.20$, $\text{ASE} = 94.66$, $\text{RMSPE} = 69.63$, $\text{SRMSPE} = 0.53$). We collected 108,419 locations for black vultures and turkey vultures that included roosting and flying locations (Avery et al., 2011). After removing erroneous location data (e.g., 2-dimensional fixes, negative altitudes), birds that were alive for <3 months, roosting locations, and locations occurring outside of the FACOD, we had 2030 and 3716 in-flight locations for black vultures ($n = 11$) and turkey vultures ($n = 7$), respectively, for analysis. Mean altitude of in-flight locations within the FACOD were 200 ± 203 m (SD) and 108 ± 95 m (SD) for black vultures and turkey vultures, respectively. Median altitude of in-flight locations within the FACOD was 125 m and 83 m for black vultures and turkey vultures, respectively. Percent of in-flight locations within the FACOD was nearly twice as high in the forested habitat than any other habitat regardless of species (Fig. 2).

Similar to all in-flight vulture locations (Avery et al., 2011), a majority of black vulture and turkey vulture locations within the FACOD were recorded between 1000 and 1600 h (Fig. 3a) and both species spent more time in-flight within the perimeter of the FACOD in late-winter (Feb–Mar) to early-spring (Apr–Jun; Fig. 3b). Although considerable variability occurred in mean altitude of in-flight locations within the FACOD, black vultures consistently occurred at higher altitudes within the FACOD than turkey vultures during mid-day (Fig. 4a) and during any given month (Fig. 4b). Furthermore, most black vultures and turkey vulture flight paths penetrated the FACOD in the southeast (Fig. 5a) and southwest (Fig. 5b) portions, respectively, of MCAS identified as a mixture of forested and developed, low to high intensity in our landcover data.

Only 40% and 42% of flight paths intersected with the FACOD for black vultures and turkey vultures, respectively. Mean altitude of flight paths that intersected the FACOD was 196 ± 98 m (SD) and

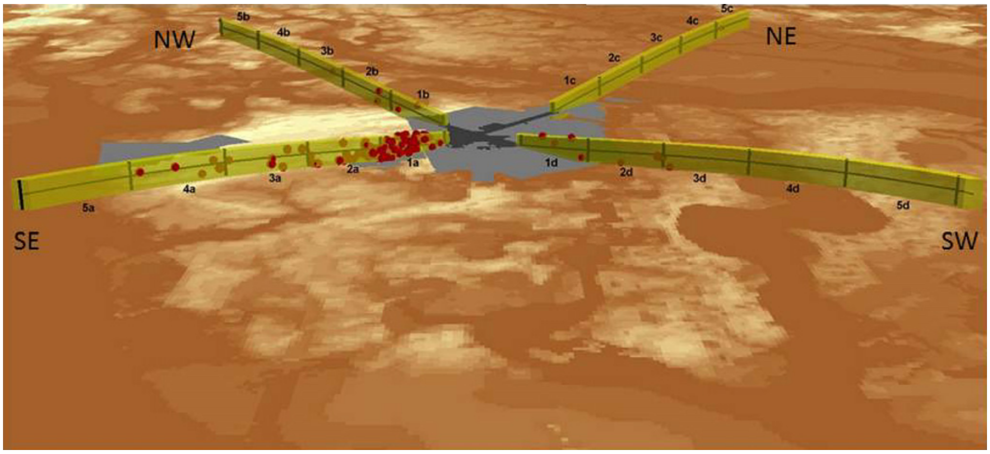

Fig. 7. All vulture locations within the 100 m^2 buffer (HALO) around the aircraft straight-in radar approach at a Marine Corps Air Station in Beaufort, South Carolina, USA. Circles represent vulture locations that were within the HALO creating risk for birdstrikes with aircraft. Numbers represent distance in nautical miles from the airfield (1–5) with letters representing each path of the HALO (a–d).

111 ± 50 m (SD) for black vultures and turkey vultures, respectively (Fig. 6). Median altitude of flight paths that penetrated the FACOD was 182 m and 104 m for black vultures and turkey vultures, respectively.

For locations within the perimeter of the straight-in landing approach for aircraft (i.e., HALO), only 1% and 3% of black vulture and turkey vulture locations, respectively, occurred within the HALO (Fig. 7). Occurrence within the HALO was disproportionate for turkey vultures (87%) compared to black vultures (13%). Of the vulture locations within the HALO, 89% ($n = 121$) were in the southwest flight path of the HALO (path a) with the fewest locations (1%, $n = 1$) in the northeast (path c). Mean (±SD) altitude of locations within the HALO was 130 ± 82 m, 125 ± 55 m, 107 ± 81 m for the northwest, southeast, and southwest paths, respectively. Mean altitude of locations within the HALO for individual vultures ranged from 10 m to 425 m. Ninety-five percent of locations for turkey vultures occurred within 2 nautical miles of the MCAS runway.

Discussion

Understanding aircraft flight patterns in conjunction with flight altitude of vultures and other avian species is integral to understanding potential for birdstrikes around airfields. We combined flight patterns of aircraft in three-dimensional space around MCAS with vulture in-flight locations and identified only 6% of locations and 16 of 18 vultures (89%) intersected the FACOD within 5 nautical miles (8 km) of MCAS. Most of the flight paths of vultures intersected the FACOD on the southeast to southwest side of the airspace of approaching aircraft (Fig. 5a, b). We recognize that flight paths of vultures used in our analysis were not determined by paths between hourly locations because of current limitations of GPS technology and that vultures can travel great distances (horizontally and vertically) within the 1 h GPS duty cycle interval. Our intent here was solely to present and describe the usefulness of this novel spatial (two-dimensional and three-dimensional) birdstrike risk assessment approach and not to predict or analyze the error associated with limitation of current GPS technology. Identification of area-specific intersections of the FACOD could help to focus bird harassment activities which should result in safer flying conditions. Although altitude of in-flight locations varies by time of day, month, and season (Avery et al., 2011), the same appears to be the case for locations that intersected with the FACOD. Therefore, understanding when vultures intersected with the FACOD can better predict hotspots within three-dimensional airspace or “hazard areas” to limit landing or patterns of flight practice to minimize potential for birdstrikes.

Three-dimensional flight patterns can be used in a variety of ways to document areas that pose the greatest risk for birdstrikes to civil or military aircraft. As in our example, a FACOD was created over an area of unique habitats (e.g., open fields vs. evergreen forest) and areas were identified where penetration of the FACOD occurred. DeVault, Reinhart, Brisbin, and Rhodes (2004) found that vultures have larger home ranges and spend more time soaring in forested landscapes compared to agricultural landscapes. The proportion of forested and open landscapes within the FACOD likely determined feeding opportunities and roosting locations, and therefore, directly influences the number of in-flight locations (Coleman & Fraser, 1987; DeVault et al., 2005).

A three-dimensional layer of roosting structures could also be created to determine if roost sites are correlated to areas where vultures penetrate the FACOD after leaving roosts. The southwestern portion of the runway where vultures penetrated the FACOD is a high vulture use area. Vultures have been documented to congregate in large groups at various altitudes on various tree species and structures such as transmission line support towers, communication towers, and water towers (Avery, Humphrey, Tillman, Phares, & Hatcher, 2002; Buckley, 1996; Stolen & Taylor, 2003). Communal roosting sites are considered focal areas and vultures leaving the roost pose increased threats to aircraft safety. If bird altitude locations are not available, a three-dimensional layer of structure heights could be created to document initial soaring areas for vultures and other species common to communal roosting.

While we understand that our methods are not the only available, it is important to understand all aspects of avian–aircraft strikes to be better able to make informed decisions on aircraft flight patterns to alleviate birdstrikes. For example, temperature fluctuations may also influence flight patterns of vultures and raptors so soaring is likely influenced by daily variability in thermals that changes within habitat type and geographic area (Arrington, 2003; Byman, 2000). Anthropogenic thermals have also been considered important in determining flight altitudes and duration of activity for turkey vultures (Mandel & Bildstein, 2007). Therefore, a three-dimensional layer of thermals could be created to assess if intersection with the FACOD is correlated to thermals for a given area.

Conclusion

Integrating aircraft flight patterns and bird flight behavior will improve our understanding of the potential for birdstrikes around airfields and also lead to more effective preventative measures. Based on our findings within the FACOD and HALO, for example, MCAS could revise flight schedules to avoid potentially high risk periods of the day and focus harassment efforts on roosting sites on the southern portion of the airfield with a high concentration of in-flight vulture locations. Three-dimensional visualizations of aircraft flight patterns could be considered complementary to summaries of altitude distributions in areas prone to birdstrikes (i.e., military and civilian airfields). Creating 3-dimensional flight patterns with knowledge of altitude of avian species, roosting structures, or thermals can greatly assist in understanding hazard areas around airfields to minimize birdstrikes and potential for human fatalities and injuries. Although we used GPS technology on vultures, our 3-dimensional concepts could be created from various three-dimensional strata available to the aviation industry. For example, 3-dimensional flight patterns at individual airfields could be compared to altitudes of species-specific birdstrikes available on the FAA National Wildlife Strike Database (http://wildlife-mitigation.tc.faa.gov/public_html/index.html#access) to approximate altitudes and areas with the most potential for risk of birdstrikes for species common to the area.

Acknowledgments

Funding for this research was provided by the Southern Division, Naval Facilities Engineering Command. Funding source had no involvement in study design, data analysis, or manuscript submission. We thank the MCAS personnel for description of flight patterns used in designing the flight altitude cone of depression. We appreciate the assistance and support of N. Myers throughout the project.

References

Arrington, D. P. (2003). *Flight characteristics of non-migrating and migrating populations of turkey vultures*. PhD, Purdue University, West Lafayette, Indiana, USA.

Avery, M. L. (2004). Trends in North American vulture populations. *Proceedings of the Vertebrate Pest Conference, 21*, 116–121.

Avery, M. L., Humphrey, J. S., Daughtery, T. S., Fischer, J. W., Milleson, M. P., Tillman, E. A., et al. (2011). Vulture flight behavior and implications for aircraft safety. *Journal of Wildlife Management, 75*, 1581–1587.

Avery, M. L., Humphrey, J. S., Tillman, E. A., Phares, K. O., & Hatcher, J. E. (2002). Dispersing vulture roosts on communication towers. *Journal of Raptor Research, 36*, 45–50.

Beason, R. C., Humphrey, J. S., Myers, N. E., & Avery, M. L. (2010). Synchronous monitoring of vulture movements with satellite telemetry and avian radar. *Journal of Zoology, 282*, 157–162.

Buckley, N. J. (1996). Food finding and the influence of information, local enhancement, and communal roosting on foraging success of North American vultures. *The Auk, 113*, 473–488.

Byman, D. H. (2000). Behaviors of turkey and black vultures at a winter day perch. *Northeastern Naturalist, 7*, 297–308.

Coleman, J. S., & Fraser, J. D. (1987). Habitat use and home ranges of black and turkey vultures. *Journal of Wildlife Management, 53*, 782–792.

DeVault, T. L., Reinhart, B. D., Brisbin, I. L., Jr., & Rhodes, O. E., Jr. (2004). Home ranges of sympatric black and turkey vultures in South Carolina. *The Condor, 106*, 706–711.

DeVault, T. L., Reinhart, B. D., Brisbin, I. L., Jr., & Rhodes, O. E., Jr. (2005). Flight behavior of black and turkey vultures: implications for reducing bird-aircraft collisions. *Journal of Wildlife Management, 69*, 601–608.

Dolbeer, R. A. (2006). Height distribution of birds recorded by collisions with civil aircraft. *Journal of Wildlife Management, 70*, 1345–1350.

Dolbeer, R. A., Wright, S. E., Weller, J. R., & Begier, M. J. (2011). *Wildlife strikes to civil aircraft in the United States, 1990–2009*. Serial report no. 16. Washington, D.C., USA: U.S. Department of Transportation, Federal Aviation Administration.

Homer, C., Huang, C., Yang, L., Wylie, B., & Coan, M. (2004). Development of a 2001 National Land-Cover Database for the United States. *Photogrammetric Engineering & Remote Sensing, 70*, 829–840.

Humphrey, J. S., Avery, M. L., & McGrane, A. P. (2000). Evaluating relocation as a vulture management tool in north Florida. *Proceedings of the Vertebrate Pest Conference, 19*, 49–53.

Johnston, K., Ver Hoef, J., Krivoruchko, K., & Lucas, N. (2001). *Using ArcGIS geostatistical analyst*. New York, N.Y., USA: Environmental Systems Research Institute.

Lovell, C. D. (1997). The United States air force bird avoidance model for low-level training flights. In C. D. Lee, & S. E. Hygnstrom (Eds.), *Proceedings of the great plains wildlife damage control workshop* (pp. 162–170), Nebraska City, Nebraska, USA.

Mandel, J. T., & Bildstein, K. L. (2007). Turkey vultures use anthropogenic thermals to extend their daily activity period. *The Wilson Journal of Ornithology, 119*, 102–105.

Marra, P. P., Dove, C. J., Dolbeer, R., Dahlan, N. F., Heacker, M., Whatton, J. F., et al. (2009). Migratory Canada geese cause crash of US Airways Flight 1549. *Frontiers in Ecology and the Environment, 6*, 297–301.

Stolen, E. D., & Taylor, W. K. (2003). Movements of black vultures between communal roosts in Florida. *Wilson Bulletin, 115*, 316–320.

USAF Safety Center. (2011). Top 50 USAF wildlife strikes by cost FY1995–FY2011. http://www.afsc.af.mil/shared/media/document/AFD-080130-040.pdf Accessed 06.01.12.