HIGHLIGHT ARTICLE

Modeling Bird Hazards to Aircraft: A GIS Application Study

Russell P. DeFusco, United States Air Force

Bird collisions with aircraft pose a serious threat to flight safety worldwide. These incidents cost many millions of dollars in damages and all too frequently end the lives of aircrews and their passengers (Figure 1). Commercial aircraft record thousands of bird strikes annually and more than 200 fatalities have been attributed to these collisions. The most notorious accident occurred at Boston's Logan International Airport in 1960 when a Lockheed Electra struck a flock of European Starlings (Sturnus vulgaris) and crashed, killing 62 people. Military aircraft are particularly vulnerable to bird strikes as they routinely operate at lower altitudes and higher speeds than commercial aircraft.

The United States Air Force (USAF) reports around 3,200 bird strikes each year. Since 1985, these strikes have caused the loss of 14 jet aircraft, with 7 resultant fatalities, and cost over 65 million dollars per year (DeFusco 1988, Merritt and Dogan 1992). Several recent accidents illustrate the significant hazard various birds pose to military aircraft.

- An F-4 fighter on a training mission to Spain in 1987 struck a Griffon Vulture (Gyps fulvus) which penetrated the aircraft canopy, and killed the pilot instantly. The navigator in the back seat was killed when the aircraft hit the ground moments later.
- During the same year, a B-1 bomber struck an American White Pelican (Pelecanus erythrorhynchus) near La Junta, Colorado. A fire erupted, causing the aircrew to lose control of the aircraft. Three of the 6 crew members perished when the aircraft crashed. The reported cost of that accident was in excess of $215 million.
- In September 1992, a Turkey Vulture (Cathartes aura) penetrated the canopy of an Air Force trainer, killing the pilot. An instructor in the back seat landed the aircraft safely.

Bird strikes occur during all phases of flight, but are most likely to result in catastrophic damages during low-level missions and on training ranges because the number of birds is highest at lower altitudes (Figure 2). Aircraft frequently operate in these remote locations at altitudes from 50 to 300 meters above ground level and from 350 to 600 knots indicated airspeed. Unlike in the airfield environment where birds may be dispersed, there is no way to control birds in the low-level environment. Aircrews depend upon bird distribution information to avoid potentially hazardous areas. The USAF is producing a computerized Bird Avoidance Model (BAM) to provide this information. The model will provide localized data on bird distributions and abundance throughout the continental United States. The Department of Defense Legacy Resource Management Program is partially funding the development of this model. Research toward this effort is being conducted as part of an Air Force sponsored doctoral program by the author at the University of Colorado.

The variety of birds struck by aircraft numbers in the hundreds, but several orders of birds pose the most

Figure 1. The lead Air Force demonstration team pilot was killed in this 1981 accident when his T-38 struck a gull on takeoff during a practice session.

serious hazards (Table 1). Notable among these are the raptors (Falconiformes). In the United States, the species causing the single greatest hazard is the Turkey Vulture (Figure 3). This is due to a number of factors including its large body mass (over 2 kilograms), widespread geographic distribution, and flight behaviors. Turkey Vultures most often make foraging and migratory flights at the same altitudes as military flight operations. Compounding this problem is the fact that vultures rarely take evasive action to avoid collisions. Adult vultures have no known airborne predators and certainly have not evolved to deal with the closure rates associated with aircraft encounters. Consequently, Turkey Vultures have cost the Air Force over 21.6 million dollars, 3 crashed aircraft and 2 fatalities since 1989. The Turkey Vulture was thus chosen as a priority species to begin the modeling process.

Table 1. Birds reported struck by USAF aircraft, 1987-1991.

Bird	Percent Identified
Vultures and Hawks	32.6
Gulls	29.5
Doves	10.9
Ducks and Geese	10.5
Herons and Egrets	6.8
Starlings	4.8
Horned and Meadowlarks	3.7
Pelicans	1.1

Modeling Turkey Vulture populations must begin within the broader context of their biogeography. Understanding the forces shaping the distribution and abundance of a species enables the narrower task of modeling these patterns to be approached in a more realistic manner. Traditional biogeographical studies concentrate largely on the presence or absence of species within a defined region. These studies place a great deal of emphasis on the ranges of the organisms under study, with particular attention paid to the factors which limit these ranges. Such traditional approaches focus on the two-dimensional occurrence of species and often ignore a critical third dimension of species abundance patterns within their ranges. This third dimension may reveal much more of what is important to a population of organisms than the limits imposed at the extremes of their range. Fortunately, modern Geographic Information Systems (GIS) can easily handle these three-dimensional analyses. The USAF effort to model hazardous bird species could not be done without the aid of an advanced GIS.

Species' ranges and abundance patterns may be shaped by biotic interactions of competitors, predators, prey, parasites, or disease. While biotic interactions may influence the proximate details of range boundaries, physical tolerances to abiotic factors may ultimately determine a species' range. External abiotic environmental factors, such as physical barriers to expansion, temperature extremes, availability of water or other resources, may be the primary forces shaping species' biogeographic ranges. The goal of this study is to determine how such factors correlate with known distribution patterns to create a predictive model of vulture occurrence on a continental scale. Analysis of seasonal abundance on such a scale requires an enormous amount of data before coherent patterns are revealed. It also requires a computer system capable of handling these data. The Geographic Resource Analysis Support System (GRASS) geographic information system is used for processing all data layers described below. GRASS was chosen for this project as it was developed by the Department of Defense for just such applications and is public domain software readily accessible to all potential users.

Spatial distribution and abundance patterns of Turkey Vultures were obtained by analyzing data from the U.S. Fish and Wildlife Service's Breeding Bird Survey (BBS) and the National Audubon Society's Christmas Bird Count (CBC). Turkey Vultures are ideal for these type surveys as they are relatively common, highly conspicuous, easily identifiable, widely distributed, and therefore provide robust data sets.

The Breeding Bird Survey is a standardized survey conducted each year at various locations throughout the United States during the spring and early summer (see Robbins and Van Velzen 1967). The BBS was initiated in 1965 to develop a reliable index of North American bird populations. Surveys are conducted along established routes on secondary roads in largely rural areas. The starting point of each route is recorded in degrees and minutes of latitude and longitude. The direction of the route from the starting point is randomly selected and followed every year. Fifty, three-minute stops are made at 0.8 kilometer intervals along each 39.5 kilometer route. Total numbers of each bird species seen or heard during stops are recorded for the route. Data are compiled by state and entered into the national database. Survey results have been recorded each year from 1966 to present and all available data from each complete year is included in this study. A surface was created from 2,791 BBS sites

these strikes have caused the loss of 14 jet aircraft, with 7 resultant fatalities, and cost over 65 million dollars

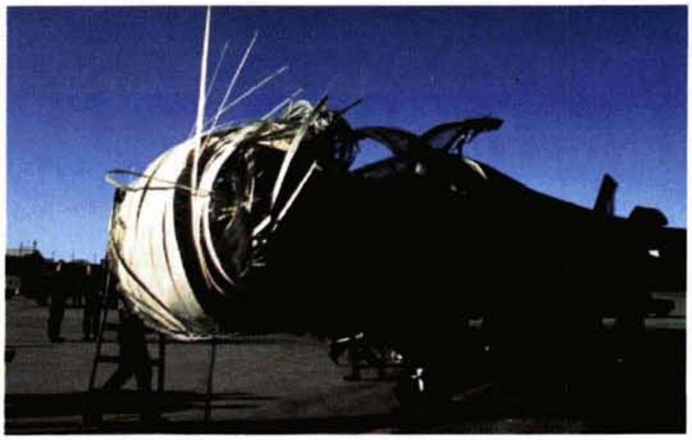

Figure 2. This USAF F-111 struck a Red-tailed Hawk on a low-level training mission in New Mexico.

using a spatial interpolation model in a Lambert Azimuthal Equal Area projection (Figure 4).

Christmas Bird Counts are conducted over a 24-hour period during the two weeks surrounding Christmas day each year (see Root 1988). Many thousands of volunteers participate in these annual counts and several million hours of observation have been recorded since their nception in 1900. The center point of each established count circle is recorded by degrees and minutes of latitude and longitude and observers generally cover the same areas each year. Participants are allowed to conduct surveys anywhere within a 12.1 kilometer radius of the center point. Parties of individuals may split up to simultaneously cover different parts of the count circle during the survey period. The total number of party hours are recorded in addition to the total number of each species observed during the survey. Data are compiled by state and entered into a national database. All available data for each year from 1960 to present are used in this study. Figure 4 depicts the interpolated surface generated from 2,660 CBC sites in a Lambert Azimuthal Equal Area projection. Note that the CBC cannot be directly related to the BBS as results are reported differently for each survey technique.

Maps generated by the above processes can be used to determine a relative risk of bird strikes by season along any low-level training route in the continental U.S. Route courses projected onto the interpolated bird distribution surfaces indicate the relative magnitude of the risk (see cover graphic and Figure 4). A profile of these projected route courses can be used to compare routes or route segments. The area under the profile curve is a measure of the bird strike risk for the entire route relative to any other route. Figure 5 depicts two such profiles. For example, a flight planner given this information could choose to fly Instrument Route (IR)-117 versus IR-170 during summer to minimize the potential risk of encountering Turkey Vultures. Note however, that the relative risk of a Turkey Vulture strike is lower for IR-170 than for IR-117 during the winter.

While interpolated surfaces derived from BBS and CBC data certainly provide valuable information for flight planners, finer resolution may possibly be attained by examining environmental factors impor-

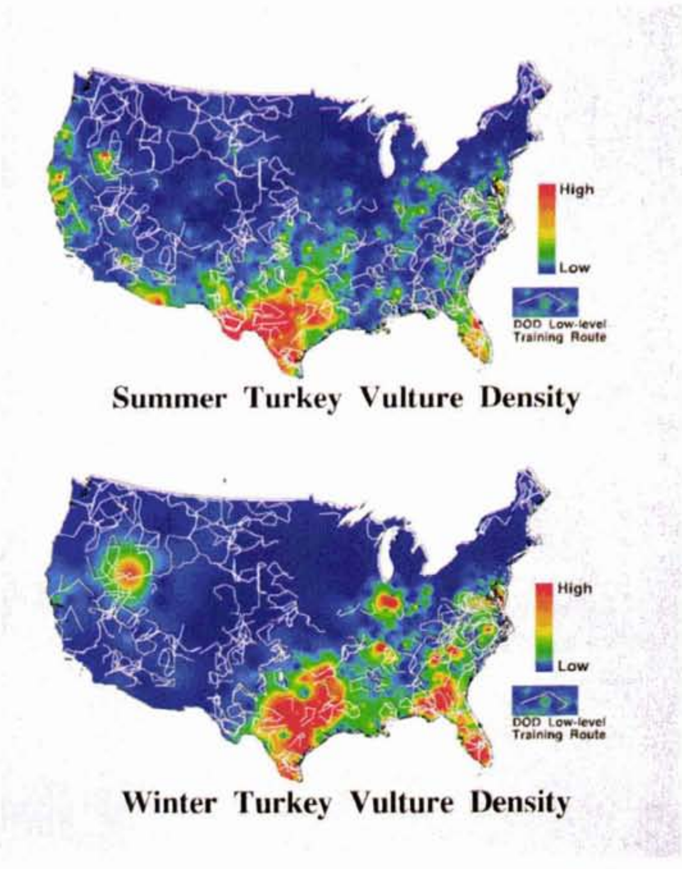

Figure 4. Interpolated surfaces on Turkey Vulture densities derived from Breeding Bird Survey (top map) and Christmas Bird Count (bottom map) data with Department of Defense low-level training routes superimposed.

Figure 3. Remains of a juvenile Turkey Vulture protrude from the wing of a C-130.

tant to the vulture. Such information can augment the know databases for better localized resolution in the final model. For example, the high density of vultures depicted in Figure 4 around the Nevada-Utah-Oregon boarders results from one high CBC site with few surrounding surveys to dampen the peak. Such anomalies may be more realistically represented if those factors which attract birds to such areas were known and considered in the modeling process. Geographic, climatic, and physiographic data layers were all prepared for such correlational analysis with the bird data described above. Geographic coordinates of all data layers were converted into a Lambert Azimuthal Equal Area projection with a one kilometer cell size for conformity and spatial registration with the BBS and CBC data. The one kilometer cell size is appropriate given the vulture's rather coarse use of its habitat. The Lambert projection was selected as many of the environmental variables obtained from the USGS Earth Resources Observation System (EROS) Data Center were provided in this format. Parameters of this projection are available on the Conterminous U.S. Advanced Very High Resolution Radiometer (AVHRR) Companion Disc where many of the remotely sensed environmental variables described below are also contained.

The USAF effort to model hazardous bird species could not be done without the aid of an advanced GIS.

The GRASS program was used to generate a buffer with a 12.1 kilometer radius around the central coordinates of each bird survey site. This buffer corresponds to the radius of the original CBC count circles. The inclusive area within each circle is 441 square kilometers, represented by 441 pixels of 1 square kilometer each. These areas are then overlaid on various environmental parameters to determine if a statistical relationship exists between the number of vultures observed and the environmental factor or combination of factors at each site. The factors considered in this modeling effort include the following:

- Elevation: Data were derived from a Digital Elevation Model (DEM) from the 30-arc second data set distributed by the National Geophysical Data Center. Analysis is performed on the mean elevation contained within the 441 square kilometer overlap area for each survey site. A measure of surface roughness is also derived from the variance of elevations measured for each 1 square kilometer block within these areas.
- Hydrography: Data were obtained from the EROS data center as derived from the "National Atlas of the United States of America" (1970). Analysis is performed on the linear distance to permanent water sources for each vulture survey site.
- Temperature: Point data were obtained from 1,528 monitoring stations through the National Climatic Data Center and converted to interpolated surfaces representing mean monthly temperatures, annual minimum and maximum temperatures and the mean number of days above 0oC (frost-free days). Bird data layers are overlaid to determine if vulture numbers correspond to temperature variables.
- Precipitation: Point data were obtained from 1,877 monitoring stations through the National Climatic Data Center and surfaces generated representing mean monthly and total annual precipitation. Additionally, data on snow cover were obtained from the National Oceanic and Atmospheric Administration (NOAA) National Snow and Ice Data Center. These surfaces are analyzed in the area of overlap with bird survey areas for correlation with ob served vulture numbers.
- Primary Productivity: Measures of productivity were obtained from the EROS Data Center and derived from spectral data remotely sensed by NOAA-11 AVHRR satellites as the maximum biweekly Nor malized Difference Vegetation Index (NDVI). Mean monthly and annual NDVI measurements within each bird survey area are considered for statistical correlation with vulture numbers.
- Ecoregions: There are 76 ecoregions in the conterminous U.S. as defined by the Environmental Protection Agency (EPA) and Major Land Resource Areas (MLRA) as compiled by the Soil Conservation Service (SCS). These data were obtained from the EROS Data Center on the AVHRR companion disc. Analysis of vulture numbers as associated with these regions may indicate preferences for certain habitats over others.
- Vegetation and Land Use: Land use and land cover data were obtained from the EROS data center as derived from AVHRR spectral imagery (see Loveland et al. 1991). Correlational analysis on vulture numbers associated with the various classes of vegetation and land uses may reveal habitat preferences important in determining the ultimate distribution and abundance of these birds throughout their range.

It is necessarily assumed that Turkey Vultures are limited, as are all species, by a combination of external biotic and abiotic environmental factors which have led to their present day distribution patterns. For example, preliminary analyses for this study indicate a significant correlation between

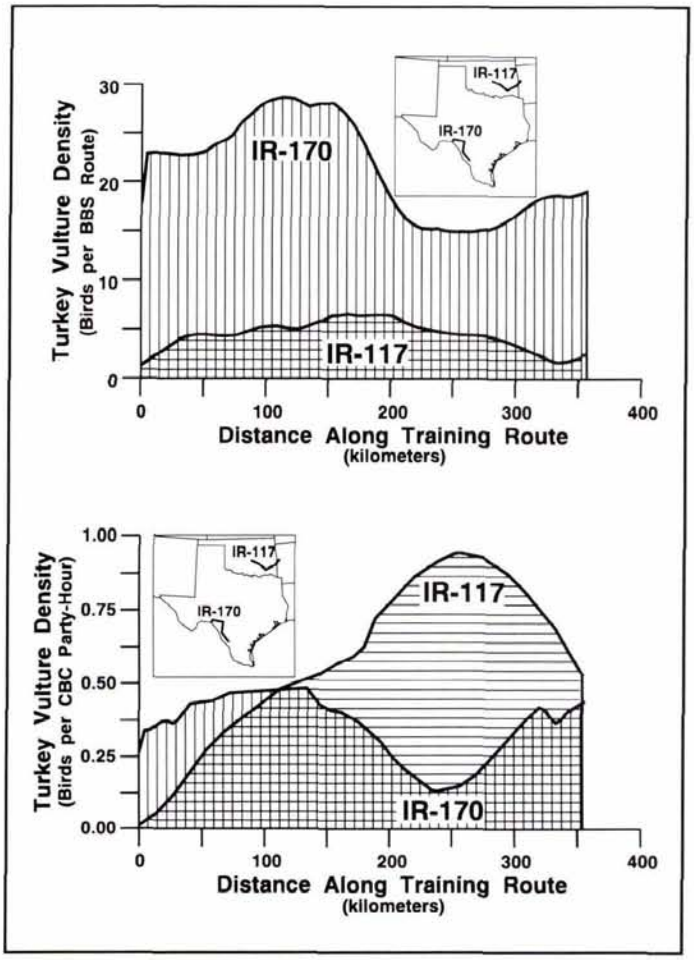

Figure 5. Profile view of DoD Instrument Routes (IR) 170 and 117 projected onto the interpolated bird density surfaces for summer (top graph) and winter (bottom graph). The area under a curve represents the cumulative relative risk of a bird strike for the route.

Turkey Vulture abundance and proximity to permanent water sourc environmental factors may enable much finer resolution of vulture abundance patterns than is currently possible with interpolated BBS and CBC data. The above array of environmental factors, while by no means exhaustive, may reveal those variables which are important in determining species distribution patterns. If so, these factors can be readily used in a GIS-based model to predict occurrence and abundance of vultures throughout their range. Refinements are especially needed in areas of the country that are under sampled or unsampled by the BBS and CBC. Research toward this effort is ongoing and is scheduled for completion in mid-1994.

At this point it is difficult to predict all the patterns which may emerge from this study. It is expected however, that some of the many variables will serve as predictors, if not determinants, of Turkey Vulture distribution and abundance in the conterminous United States. These will be used to create a more comprehensive picture of Turkey Vulture behavior and ecology. Once the modeling technique is demonstrated as feasible for the Turkey Vulture, other species will be included in the USAF Bird Avoidance Model. The resultant model will appreciably alter the way the USAF operates and help create a safer environment for aircraft which share airspace with the birds.

Acknowledgments: Many people have assisted immeasurably in collecting and preparing data for this project and the above paper. I cannot begin to thank them all, but several deserve special mention here. Michael Hodgson of the Department of Geography at the University of Colorado (CU) encouraged me to prepare this manuscript and the associated cover and graciously reviewed the document. Carl Bock of the Department of Environmental, Population and Organismic Biology at CU serves as major professor for my doctoral program and had many helpful suggestions along the way. Ronald Merritt and Michael Thompson of the USAF Bird Aircraft Strike Hazard Team provided much of the bird strike statistics. Bruce Peterjohn provided the BBS data from the U.S. Fish and Wildlife Service. James Lowe provided the CBC data from the National Audubon Society. Jesslyn Brown of the USGS EROS Data Center provided much information on several of the environmental data sets used herein. John Eischeid and Daniel Haynes of CIRES and the National Snow and Ice Data Center provided environmental data. Kenneth Shepardson of Spectrum Sciences and Software, Inc. provided the innumerable data transformations for the many and diverse data sets needed for this study. Dane Williams of ERDAS, Inc. provided much assistance in preparing a draft of the cover graphic for this issue. James Zack of the GIS, Remote Sensing and Cartography Lab at CU produced the computer graphics in this article and journal cover. I am indebted to them all.

About the author: Russell P. DeFusco is a Captain in the United States Air Force. He is a graduate of the United States Air Force Academy with a Master's degree in wildlife biology from Colorado State University. He is a former chief of the USAF Bird Aircraft Strike Hazard Team and assistant professor of biology at the Air Force Academy. He is currently pursuing a PhD in the department of Environmental, Population and Organismic Biology at the University of Colorado. Address: Environmental, Population and Organismic Biology, Campus Box 334, Boulder CO 80309-0334; tel. 303-492-8699

References:

DeFusco, R.P. 1988. United States Air Force bird strike summary (1986-1987). Proceedings, Bird Strike Committee Europe Meetings 19:385–397.

Loveland, T.R., J.W. Merchant, D.O. Ohlen and J.F. Brown. 1991. Development of a land-cover characteristics database for the conterminous U.S. Photogrammetric Engineering & Remote Sensing 57(11):1453–1463.

Merritt, R.L. and R.L. Dogan. 1992. Bird strikes to U.S. Air Force aircraft 1987-1991. Proceedings, Bird Strike Committee Europe Meetings 21:393–401.

Robbins, C.S. and W.T. Van Velzen. 1967. The Breeding Bird Survey, 1967 and 1968. U.S. Fish and Wildlife Service, Special Science Report, Wildlife No. 102.

Root, T.A. 1988. Atlas of Wintering North American Birds An Analysis of Christmas Bird Count Data. University of Chicago Press, Chicago.