AVIAN SURVEYS AT NAS ALAMEDA FOR THE BIRD-AIRCRAFT STRIKE HAZARD PROGRAM

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1992 TRANSACTIONS OF THE WESTERN SECTION OF THE WILDLIFE SOCIETY 28:48-58

Abstract: Naval Air Station Alameda, on the San Francisco Bay, California, was visited from December 1990 to December 1991 to document the diversity and abundance of bird species, and the movements of birds in relation to the airfield and flight operations. The results of this research will be used in the Navy's Bird-Aircraft Strike Hazard (BASH) Program. We found no differences in number of birds observed between mornings and afternoons. A seasonal difference was found with higher numbers of birds occurring during the late fall-winter and the late winter-spring compared to the summer months. Numbers of birds increased with decreasing visibility, the presence of fog, and increasing cloud cover. Bird numbers also increased as temperatures and wind speeds increased. Daily and seasonal flight patterns were observed for gulls (Larinae), double-crested cormorants (*Phalacrocorax auritus*), Caspian and least terns (*Sterna caspia* and *S. antillarum*), red-winged blackbirds (*Agelaius phoeniceus*), and house finches (*Carpodacus mexicanus*). The mean altitude of flight for the year for all birds combined was 215 m; however, flight altitude was highly variable. During all 4 seasons, 22.5% of the birds were observed in San Francisco Bay and channels foraging in the water. The greatest number of bird-aircraft collisions was documented during the winter. Management strategies for reducing bird-aircraft strikes include increasing airfield personnel awareness, airfield habitat manipulation, and modifying the timing of flight occurrences.

Bird-aircraft strikes are of major concern to the aviation community. Since the first fatality in 1912, incidents involving bird collisions have increased as aircraft speed and number of aircraft flights have both increased. There are about 1500 bird strikes recorded annually for United States civil airplanes, and the United States Air Force loses as much as $50 million a year in material damage because of bird-strikes (Steenblik 1989).

Military aircraft are especially prone to strikes because they frequently fly at high speeds and at low altitudes where birds are most active. Three-fourths of all bird strikes occur at or near airports, usually during take-offs and landings (Solman 1971). For this reason, numerous studies have dealt with the reduction of bird populations and bird-strikes on and around airfields (e.g., Murton and Wright 1968; Gauthreaux 1974, 1976; Will 1985). In 1981, the U.S. Department of the Navy responded to the bird aircraft problem by implementing its present mandatory Bird Aircraft Strike Hazard (BASH) reporting system to document collisions and to develop management plans for avoiding bird-aircraft interactions. The effectiveness of BASH management programs was immediate: four Naval air stations that started bird-aircraft strike hazard reduction programs in 1984 reported 57-78% fewer bird-strikes in 1984 than in 1983 (Walker and Bennet 1985).

A primary reason for the initiation of this project at Naval Air Station (NAS) Alameda, was its location on San Francisco Bay and the associated presence of many water birds. Gulls (Larinae) are most frequently mentioned as the birds creating the chief hazards to aircraft at airports near coastal areas (Blockpoel 1976). Gulls are attracted to open water of bays, solid waste disposal sites, and the large, open, flat areas provided by airports and the shallow pools that can form on asphalt after rain (Cogswell 1974).

Our objectives were to: (1) document the diversity and abundance of birds on all parts of the air station, including the helicopter pads, the 2 runways, the taxiways, and the solid waste disposal site, (2) determine movements of birds in relation to the above areas and flight operations, and (3) make recommendations for the reduction of bird strikes at NAS Alameda.

STUDY AREA

The study area was the Naval Air Station, Alameda, in Alameda County, California, located on the east shore of the San Francisco Bay near Oakland. San Francisco

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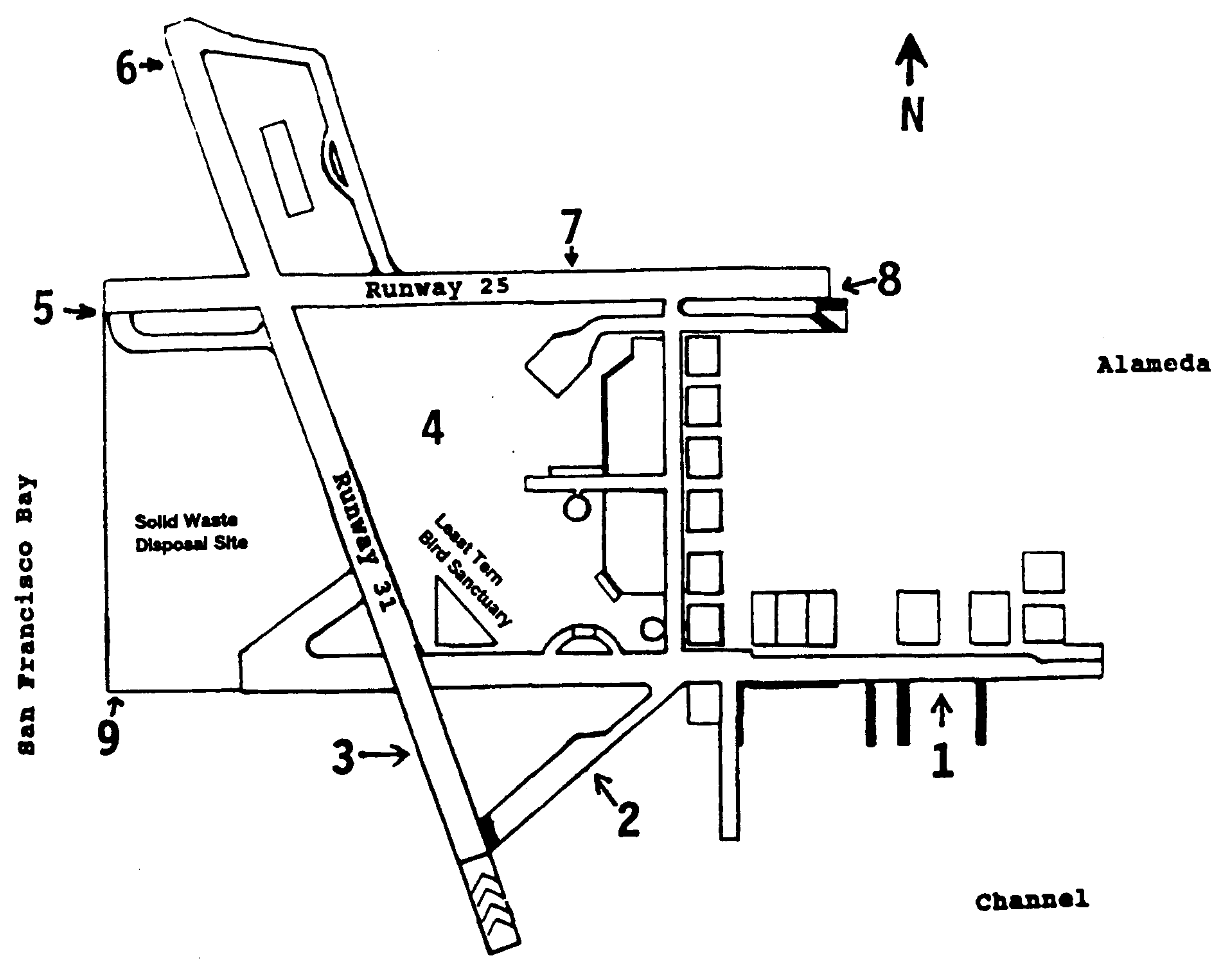

Fig. 1. NAS Alameda and the location of the 9 observation points.

Bay comprises the largest coastal wetland system in California and provides important resting and feeding sites for millions of birds during annual migration along the Pacific flyway (U. S. Fish and Wildl. Serv. 1985). The study area included the entire airfield, focusing on the 2 runways, the helicopter pads, and the solid waste disposal site. Runway 25 runs in an east-west direction and runway 31 runs in a northwest-southeast direction (Fig. 1). NAS Alameda accomodates nearly 70,000 flight operations annually (including take-offs, landings, touch-and-goes, and overflights). Of these operations, approximately 25% are jet-pattern operations, 25% are helicopter pattern operations (pattern operations are "touch and goes"), and the remaining 50% are departures and arrivals. Over 50% of the total operations and the majority of fixed wing operations take place on runway 31 (West. Div. Naval Facilities Eng. Command 1986).

METHODS

The year was divided into 4 seasons to facilitate data collection and analysis: season 1 = late fall-winter, November through January; season 2 = late winter-spring, February through April; season 3 = late spring-summer, May through July; season 4 = late summer-fall, August through October. These seasonal divisions were created after comparing numbers of birds per month using 1-way analysis of variance (ANOVA) and Tukey's multiple comparisons test (Sokal and Rohlf 1969:204-

206). Consecutive months with no significant differences in the mean number of birds were combined into the 4 seasons.

Observation Point Counts

In November, 1990, nine permanent census points were established around the airfield to count and observe birds (Figure 1). The points were located from 500 to 1500 m apart to reduce the probability of double-counting birds (Verner 1985). Two points were located about 500 m apart and the remaining points were 1000 to 1500 m apart. All birds observed and heard within a 500-m-radius were recorded for 30 minutes at each point. Birds were identified to species with binoculars. Distance to a bird was estimated in meters, and a clinometer was used to measure the angle from the observer to the bird to estimate its altitude of flight.

During the first 6 months of the study, data were collected from 15 minutes prior to sunrise to approximately 3 hours after sunrise; midday for 3 hours centered around noon; and in the afternoon from 3 hours before sunset until approximately 15 minutes after sunset. Data were collected for 2 days every other week. Morning, midday, and afternoon points were done in the same order the first day, then reversed the following day. For the second 6 months the method of data collection was modified to collect data on a weekly basis. Censuses occurred from 15 minutes before sunrise to approximately 6 hours after sunrise, and then in the afternoon from 6 hours before sunset to approximately 15 minutes after sunset. Morning and afternoon points were surveyed in the same order during 1 week, then reversed the following week.

The direction each bird was observed in and its direction of flight was measured with a compass. A visual estimation of cloud cover, visibility (we used four codes of increasing visibility in m), temperature, wind speed, wind direction, background noise (high, medium, low), and presence or absence of fog and precipitation were recorded at each point.

The mean altitude of flight of all birds was calculated for the year and then by season separately. The percentage of birds flying in the following categories by season were also calculated: $\leq$25 m, >25-100 m, >100-250 m, >250-500 m, >500-1000 m, and >1000 m.

Numbers of birds recorded at each 30 minute census point were averaged over a season to obtain mean number of birds per half hour. Seasonal means were calculated for both morning and afternoon periods. Morning and afternoon mean bird numbers for all four seasons combined were compared, and morning and afternoon means within each season were compared using 2-tailed t-tests (Sokal and Rohlf 1969:229-231).

Seasonal means (combining mornings and afternoons) were compared using 1-way ANOVA and Tukey's multiple comparisons procedure (Sokal and Rohlf 1969:204-206). Numbers of birds among the 9 observation points were also compared with 1-way ANOVA and Tukey's multiple comparisons procedure. A 2-way factorial ANOVA was used to compare the 30-min means between time and season factors, and a 3-way ANOVA was used to compare means between time, season, and the observation points (Sokal and Rohlf 1969:299-356). Spearman rank-correlation coefficients (Lehmann and D'Abrera 1975:300) were used to compare the total number of birds observed with weather condition variables. A significance level of $\underline{P} < 0.05$ was used in all analyses.

Bird Flight Patterns

Birds observed flying in a specific direction during data collection periods were recorded as flying north, south, east, west, northeast, northwest, southeast, or southwest. Bird numbers in each directional category were combined for each morning and afternoon over a season to see if general trends in flight direction were evident. For ease of interpretation, the following directions were combined for the analyses: north and northwest, east and northeast, south and southeast, and west and southwest. Total percentages of birds flying in these four directions were calculated, and then the total percentages were broken down into the various species. A chi-square analysis of the frequencies of these directions was used to test if the numbers within categories were equally distributed (Sokal and Rohlf 1969:701-704). Log-linear analyses (Fienberg 1980:13) were used to test for relationships among flight direction, time (morning versus afternoon), season, and julian date.

Habitats

The location of the bird in relation to the airfield and the habitat it was observed in was recorded during a census period. Most habitats on the site were classified by dominant vegetation. However, several habitats were classified descriptively; i.e., asphalt, flooded asphalt, and rocky seawall (Figure 1). The percentages of birds recorded in the various habitats by season were calculated.

Bird-Aircraft Collision Reports

Bird-aircraft strike reports were obtained from a Navy listing of all reported bird-aircraft collisions and total flight operations per year from 1981 to 1991. Bird strike data are usually reported as strike-rates, which are the number of strikes per 10,000 aircraft movements (Burger 1985). Annual strike-rates were calculated for

Table 1. Mean numbers of birds counted per observation point for 30-minute counts made in morning vs. afternoon at NAS Alameda during 1990-1991.

Season[1]	Time	Mean	N	SD	P-value[2]
1	AM	188.9	102	367.6	0.31
	PM	290.3	96	905.7	
2	AM	216.9	77	335.7	0.33
	PM	174.3	80	184.1	
3	AM	97.5	80	96.0	0.97
	PM	96.9	76	90.3	
4	AM	74.7	112	61.2	0.47
	PM	68.8	94	55.9	

[1] Season 1 = late fall-winter
Season 2 = late winter-spring
Season 3 = late spring-summer
Season 4 = late summer-fall
[2] AM vs PM t-test.

1981 through 1991. Seasonal and monthly flight operations were not available and, therefore, seasonal comparisons of bird-strike rates could not be made.

The bird-aircraft strike reports were summarized as: the number of strikes per season; the number of strikes by solitary birds or flocks of birds; the number of strikes by phase of flight (the Navy's categories, such as landing or take-off); and the number of strikes per type of bird (the Navy's categories, such as small bird, tern, or gull). These numbers provide an overview of when strikes occurred, what birds were hit, and whether these birds were hit in flocks or singly.

RESULTS

Observation Point Counts

During all 4 seasons there was no significant difference between numbers of birds recorded in the morning versus the afternoon (Table 1). Seasonal differences in numbers of birds recorded at census points were found between late fall-winter (season 1) and late spring-summer (season 3), and late summer-fall counts (season 4, $P < 0.0001$). The greatest numbers of birds during both morning and afternoon counts occurred in late fall-winter. Significantly ($P < 0.0001$) greater numbers of birds were also recorded during late winter-spring compared to late summer-fall (Table 1). Mean numbers of birds among the 9 census points (both morning and afternoon combined) differed significantly over the year (Table 2, $P < 0.0001$). Significantly more birds ($P < 0.05$, 1-way ANOVA) were recorded at point 9, located at the west end of the solid waste disposal site, than all other points except 3, which was located at the southwest end of runway 31 adjacent to the bay.

Table 2. Mean number of birds for the individual observation points (all 30-minute counts combined) at NAS Alameda during 1990-1991.

Point	Mean	N	SD
1	128.9	76	110.6
2	95.2	80	63.8
3	226.7	84	736.5
4	63.0	75	56.6
5	135.1	85	120.7
6	183.5	83	483.0
7	66.3	81	40.6
8	109.3	82	126.8
9	359.7	71	709.7

Neither the 2-way interaction between time and season on number of birds recorded, nor the 3-way interaction between time, season, and point were significant ($P = 0.31$ and $P = 0.96$, respectively).

Total numbers of birds detected were inversely correlated with visibility (*rho* = -0.21, $P < 0.0001$) and positively correlated with the presence of fog (*rho* = 0.14, $P < 0.0001$), increasing temperature (*rho* = 0.17, $P < 0.0001$), cloud cover (*rho* = 0.07, $P = 0.03$), and wind speed (*rho* = 0.02, $P = 0.28$).

Bird Flight Patterns

The overall mean altitude of flight for all seasons and temporal periods combined was 215 m. However, that altitude of flight throughout the year was highly variable (s.d. = 325.3). The mean altitude varied across the 4 seasons, but all means were between 169 and 245 m (Table 3). During all 4 seasons, large percentages of birds were flying between 25 and 100 m (30.2%). During season 4, a large percentage of birds (31.5%) flew below 25 m (more than the other 3 seasons). Overall, small percentages of birds were found flying between 500 and 1000 m (8.7%) and above 1000 m (3.0%).

The percentage of birds flying in each of the 4 flight direction categories varied for each season (Table 4). Differences in flight direction numbers were attributable to seasonal and temporal effects. The partial associations from log-linear analysis of flight direction of birds over

Table 3. Mean altitude of birds flying by season, the percentage of birds flying by height classification by season, and the overall altitude of flight and height classification at NAS Alameda during 1990-1991.

	Season[1]				
	1	2	3	4	All
Flight altitude (m)					
Mean	198.0	245.3	231.3	169.0	215.4
SD	337.7	332.1	344.6	245.7	325.3
N	5,520	5,807	3,054	2,721	17,102
Percent of birds flying at each altitude class (m)					
<25	22.0	2.8	23.4	31.5	17.2
>25-100	30.2	35.2	24.4	26.1	30.2
>100-250	25.1	31.8	20.6	20.2	25.8
>250-500	13.9	17.3	15.5	11.9	15.0
>500-1000	5.1	9.0	14.1	9.3	8.7
>1000	3.6	3.8	2.0	1.1	3.0

[1] Season 1 = late fall-winter
Season 2 = late winter-spring
Season 3 = late spring-summer
Season 4 = late summer-fall

the year were high for the time (552.3, $P < 0.0001$) and for the season (42474.9, $P < 0.0001$) effects. In addition, the interaction between time and season was also highly significant (2725.9, $P < 0.0001$). The high partial association values indicate that over the course of the year, time, season, and time and seasonal interactions affected the flight patterns of birds.

No consistent flight patterns were found on a daily basis within a season when all bird species were combined (Table 5). Flight patterns of birds within a season were found to be affected by time (AM vs PM) and julian date and the interactions between time and date. The percentages of birds flying in the four directional categories were not equally distributed ($P < 0.0001$, Table 4).

When the flight direction percentages were broken down by bird species, specific flight patterns were observed. For the late fall-winter mornings, 50.3% of all species of birds observed were flying south-southeast (Table 4). Of those birds heading south-southeast, 62.4% were unknown and mixed gulls and 11.6% were surf scoters (*Melanitta perspicillata*). In addition, 19.2% of all birds were seen heading to the north-northwest in the mornings. Surf scoters (53.7%), mixed and unknown gull species (22.0%), and double-crested cormorants

Table 4. Percentage of birds recorded for each flight direction category at NAS Alameda, 1990 - 1991.

Season[1], Time	Flight Direction				Chi-square
	N/NW	S/SE	E/NE	W/SW	
1 AM	19.2	50.3	12.7	17.8	5400.8[2]
PM	23.6	30.1	11.9	34.3	2897.9[2]
2 AM	19.4	27.5	13.7	39.5	2394.0[2]
PM	30.2	26.3	16.2	27.2	562.8[2]
3 AM	20.4	27.4	18.3	33.9	228.8[2]
PM	30.7	21.7	8.0	39.7	946.5[2]
4 AM	25.5	31.1	21.6	21.8	76.2[2]
PM	35.8	24.7	17.0	22.4	203.1[2]

[1] Season 1 = late fall-winter
Season 2 = late winter-spring
Season 3 = late spring-summer
Season 4 = late summer-fall
[2] $P < 0.0001$.

(*Phalacrocorax auritus*, 10.3%) comprised the majority of the individual bird species. In the afternoons during this same season, a large percentage of birds were observed flying west-southwest (34.4%). The majority of these birds were surf scoters (58.8%) and mixed and unknown gulls (29.4%). Also, 30.1% of the birds were observed flying south-southeast and the majority of those birds were surf scoters and gulls (52.4% and 34.8%, respectively).

During late winter-spring mornings, 27.5% of the birds were seen flying south-southeast, and gulls (46.8%), surf scoters (13.3%), and double-crested cormorants (10.6%) were the majority of birds. In addition, 39.5% of all birds were seen heading to the west-southwest in the mornings. Surf scoters and gulls made up the majority of the birds heading in that direction (36.3% and 27.4%, respectively). In the afternoons of this same season, 30.2% of the birds were observed flying north-northwest and these birds included gulls (48.0%) and double-crested cormorants (28.8%). Also in the afternoons, 27.2% of the birds were seen flying west-southwest and gulls (42.5%), red-winged blackbirds (*Agelaius phoeniceus*, 10.0%), and surf scoters (11.9%) were the majority of birds.

During the late spring-summer mornings, 33.9% of the birds were observed flying west-southwest. The

Table 5. Summary of partial associations from log-linear analysis of flight direction of birds at NAS Alameda during 1990-1991. All likelihood-ratio chi-squares were significant ($P < 0.0001$).

Season[1]	Time	Date	Time X Date
1	2474.8	69304.0	4354.5
2	364.2	12608.8	1270.3
3	32.8	1327.4	846.6
4	43.2	368.7	513.6

[1] Season 1 = late fall-winter
Season 2 = late winter-spring
Season 3 = late spring-summer
Season 4 = late summer-fall

majority of those birds were Caspian terns (*Sterna caspia*, 18.6%), western gulls (*Larus occidentalis*, 16.7%), least terns (*Sterna antillarum*, 13.9%), and red-winged blackbirds (10.0%). Also in the mornings, 27.4% of the birds were seen flying to the south-southeast and these birds included western gulls (22.9%), double-crested cormorants (16.2%), and Caspian terns (14.8%). In the afternoons, 30.7% of the birds were observed heading north-northwest, the opposite direction from the mornings. The majority of birds heading north-northwest were shorebirds (30.3%), western gulls (12.0%), double-crested cormorants (11.7%), and Caspian terns (10.9%). Also in the afternoons, 33.9% of the birds were observed flying west-southwest and these birds included western gulls (20.9%), least terns (14.6%), unknown passerine species (11.7%), and Caspian terns (11.5%).

During the late summer-fall mornings, 31.1% of the birds were observed flying south-southeast. Double-crested cormorants and western gulls comprised the majority of birds flying south-southeast (34.5% and 16.9%, respectively). Also in the mornings, 25.5% of the birds were seen flying to the north-northwest and these birds included western gulls (26.1%), house finches (*Carpodacus mexicanus*, 17.9%), and mixed gulls (10.1%). In the afternoons, 35.8% of the birds were observed flying north-northwest and these birds included double-crested cormorants and western gulls (56.2% and 12.3%, respectively). Also in the afternoons during the same season, 24.7% of the birds were seen flying south-southeast including western gulls (26.8%) and mixed gulls (21.6%).

Habitats

Habitats present at NAS Alameda did not differ substantially among seasons, but the percent of birds detected in the habitats varied by season (Table 6). During the late fall-winter (season 1), 33.7% of the birds detected were observed in the water (bay and channels) and 12.4% were detected on the asphalt (runways, buildings, and hangars). The majority of birds in the water were surf scoters (23.0%), unknown ducks (18.0%), western grebes (*Aechmophorus occidentalis*, 12.6%), and gulls (18.1%). The majority of birds observed resting on the asphalt were gulls (54.8%).

Table 6. The percentage of birds observed among the seasons in habitats at NAS Alameda, 1990 - 1991.

	Season[1]			
Habitats	1	2	3	4
Asphalt - dry	12.4	14.3	11.1	12.4
flooded	2.9	0	0.2	0
Baseball field-rec area	1.1	0.9	2.6	3.0
Exposed mudbank	3.4	12.1	28.1	4.1
Field of dirt	2.9	0	0.7	3.8
Field of grass	4.4	0	6.4	7.0
General workshop area	1.7	0.1	1.3	2.2
Grass - < 4" tall	6.2	14.9	2.1	2.8
4-12" tall	2.6	2.7	2.8	4.1
> 12" tall	1.4	1.5	0.9	1.3
Iceplant	0.3	0.1	0.3	0.2
Mixed vegetation	15.4	6.9	22.6	38.9
Pickleweed species	1.6	3.2	1.2	0.9
Pier	2.0	3.5	2.0	1.0
Rocky seawall	6.1	2.3	5.8	7.5
Rumex species	0.1	0	0.4	0.7
Trees - Monterey cypress	0.4	0.1	0.3	0.8
mixed tree species	0	0.1	0.1	0.5
Water	33.7	36.4	11.2	8.8
Total	98.6	99.1	100	100

[1] Season 1 = late fall-winter
Season 2 = late winter-spring
Season 3 = late spring-summer
Season 4 = late summer-fall

During the late winter-spring, 36.4% of the total birds were detected in the water, 14.9% in the short grass, 14.3% on the asphalt, and 12.1% were found on exposed mudbanks. The majority of birds in water were surf scoters (24.2%), unknown scaups (*Aythya* sp., 28.8%), and western grebes (14.9%). The majority of birds in the short grass were Caspian terns (22.4%), red-winged blackbirds (13.3%), and unknown passerines (18.4%). Again, the birds observed on asphalt were mostly gulls

Table 7. Bird strike-rates for NAS Alameda from 1981 through November 1991.

Year	Total Operations[1]	Strike-rate[2]
1981	59,451	0.50
1982	68,213	1.03
1983	69,437	0.29
1984	65,430	0.61
1985	62,527	0.48
1986	52,025	0.58
1987	56,128	0.18
1988	50,531	0.79
1989	58,816	1.19
1990	60,426	0.33
1991	46,864	0.21
All	649,848	Mean 0.56
		SD 0.31

[1]Total operations included take-offs, landings, touch-and-goes, and overflights.
[2]Strike-rates are the number of bird strikes per 10,000 aircraft movements.

(69.0%). Birds observed on exposed mudbanks included American wigeon (*Anas americana*, 27.1%), Caspian terns (46.4%), and sandpipers (*Calidris* sp., 16.9%).

During the late spring-summer, 22.6% of the birds were detected in the mixed vegetation, 28.1% were on an exposed mudbank, 11.2% in the water, and 11.1% on the asphalt. Most of the birds observed in the mixed vegetation included Caspian terns (65.8%) and western gulls (10.3%). Caspian terns comprised 83.4% of the birds located on the exposed mudbank. The birds observed in the water were Caspian terns (35.8%) and gulls (36.5%). The birds using the asphalt included least terns (38.5%), rock doves (*Columba livia*, 10.2%), and western gulls (14.4%).

During the late summer-fall, 38.9% of the birds were detected in the mixed vegetation and 12.4% resting on the asphalt. Of the birds observed in the mixed vegetation, 60.6% were house finches and 11.5% were Caspian terns. The majority of birds observed on the asphalt were gulls (29.6%), rock doves (14.5%), and European starlings (*Sturnus vulgaris*, 10.9%). For a detailed breakdown of the percentage of birds in each habitat for each observation point, see Ellison et al. (1992).

Bird-Aircraft Collision Reports

Thirty-seven bird-aircraft collisions were reported for NAS Alameda from 1981 through November 1991.

Table 8. Bird-strike reports by season including total strikes reported, the phase of flight in which strikes occurred, and type and number of birds involved in the strikes from 1981 through November, 1991.

	Season[1]				
	1	2	3	4	All
Total strikes					
AM	1	2	5	1	9
PM	7	11	4	6	28
Phase of flight					
Climbing	1	0	0	1	2
Descent	0	0	1	0	1
Final approach	3	2	3	2	10
Landing	2	3	1	1	7
Low level	0	0	0	1	1
Missed approach	2	4	1	0	7
Take off	0	2	2	1	5
Traffic pattern	0	2	1	1	4
Type of animal					
Bat	1	0	0	0	1
Bird -all sizes	2	6	3	4	15
-small	0	1	1	1	3
-medium	0	0	1	0	1
-large	1	0	1	0	2
Gull	3	5	3	1	12
Sandpiper	0	1	0	0	1
Tern	1	0	0	0	1
Vulture	0	0	0	1	1
Bird numbers					
Flock	4	7	0	2	13
Single	4	6	9	5	24
Total (strike reports)	8	13	9	7	37

[1] Season 1 = late fall-winter
Season 2 = late winter-spring
Season 3 = late spring-summer
Season 4 = late summer-fall

The mean strike-rate for this period was 0.56 and ranged from a high of 1.19 in 1989 to a low of 0.18 in 1987 (Table 7).

A large percentage of strikes over the 11 years (45.9%) occurred during landing or while approaching an airstrip to land. During all 4 seasons, high percentages of strikes occurred during missed approaches (18.9%) and take-offs (13.5%). Only 13.5% of all strikes occurred during actual flights (low-level flying and traffic patterns), and only 5.4% occurred during climbing and 2.7% during descent (Table 8).

The majority of collisions (64.9%) involved solitary birds (Table 8). Most of the strikes within individual bird type categories were also caused by solitary birds. There were 2 bird categories in which the majority of strikes involved flocks: sandpipers (100%) and small birds (66.7%). For solitary bird-strikes, gulls accounted for 29.2% of the strikes and unknown birds for 45.8%.

DISCUSSION

Bird activity levels at NAS Alameda were evenly distributed throughout the day. This even distribution is probably the result of foraging behaviors of gulls, terns, and other aquatic birds that forage throughout the day. In spite of this distribution of activity, relatively more bird-strikes occurred in the afternoon and evening for all of the seasons except late spring-summer. According to the Western Division Naval Facilities Engineering Command (1986), flight operations were evenly spaced from 07:00 to 19:00; however, we noted that flight operations appeared concentrated between 13:00 and 17:00. Such a concentration might explain why the majority of collisions occurred in the afternoons. Burger (1985) found that strikes not involving gulls occurred evenly throughout the day at John F. Kennedy International Airport, but gull strikes occurred between 05:00 and 09:00 which is contrary to the findings at NAS Alameda where gull activity was constant throughout the day.

Our observed seasonal variations in numbers of birds were not surprising given that the San Francisco Bay is a major stopover location during migration and wintering area along the Pacific Flyway. As long ago as the early 1940s, Bartholomew (1942, 1943) noted that large flocks of water birds congregated around the San Francisco Bay Area during the winter months. Numbers of birds today are not as high, but there are still large concentrations of aquatic birds present in the fall, winter, and spring (U. S. Fish and Wildl. Serv. 1985). More bird-strikes were reported at NAS Alameda during the late winter-spring as opposed to the other 3 seasons. This could be due to seasonal differences in bird abundances or possibly to increased pilot awareness during the winter months. Monthly and seasonal variations in the bird aircraft strike-rates were also found at JFK Airport (Burger 1985). Pilot-reported strike-rates peaked in May and November during the spring and autumn migration and low strike-rates occurred from December through March.

Variation in bird numbers among the 9 census points can be explained by habitat differences between the points. Overall, the solid waste disposal site located on the southwest corner of NAS Alameda had significantly more birds than any other area of the base. The disposal site is a sanitary landfill not in operation for the past 15-20 years. In 1971, this dumpsite handled 150 tons of unknown refuse a day, refuse material was dumped sporadically, and gulls were observed all day (Davidson et al. 1971). Since then, the area has been closed and revegetation has occurred. Most of the area is now covered with weeds, tall grasses, and coastal shrubs. A large lagoon is located at the southern end and a salt marsh at the northwest end.

The dumpsite area exhibits a diversity of habitats that attract birds. In the late winter-spring, shorebirds and waterfowl were numerous on the exposed mudbank and lagoon, including a resident flock of 60 Canada geese (*Branta canadensis*). An upraised flat area of short grass and mixed vegetation at the east end of the site attracted up to 500 Caspian terns roosting during late May and June. The mixed vegetation (mainly tall weeds) contained many birds especially in the spring and summer months. Weeds are known to attract birds. Bollinger and Caslick (1985) found a positive correlation between blackbird damage to cornfields and the amount of weeds present in the fields. In our study, during the late spring and summer, red-winged blackbirds were numerous in the dumpsite area and in the mixed vegetation at point 2 because of the presence of weeds. The blackbirds would fly to the west-southwest from the buildings and hangars at the east end of the base to the dumpsite crossing runway 31 along the way. House finches were also commonly observed in the dumpsite and were noticed flying to the north-northwest in the mornings within the dumpsite, foraging in the weeds.

In addition to the dumpsite, the area at the northwest end of the dumpsite, adjacent to the bay and the west end of runway 25, contained larger numbers of birds than other areas of the base. This site was more fragmented than the other sites and hence had many edges. It has been well established that edge habitats affect overall species diversity and the total abundance of wildlife (e.g., see Shaw 1985:38-40).

The short grass areas around the taxiway, runway, and centerfield areas attracted small flocking birds. Hild (1983) speculated that birds use short grasses because they have a clear view of predators. Many western meadowlarks (*Sturnella neglecta*), horned larks (*Eremophila alpestris*), killdeer (*Charadrius vociferus*), and rock doves were found feeding on insects and seeds in short grass areas. Unfortunately, these small flocking birds represent a serious threat to aircraft. When a flock is hit, several birds can be ingested at once and the probability that birds will be ingested in more than one engine is high (Caithness et al. 1967). Bird collisions at

NAS Alameda have involved flocks of unknown small birds.

The number of birds detected decreased as visibility increased while bird numbers detected increased with the presence of fog. The correlation coefficients were weak, however, indicating the associations were weak. Fog reduces visibility, but may improve the transmission of sound (Robbins 1981) so more birds would be detected by sound alone. During conditions of low visibility, birds may fly within sight of the shoreline, using it as a guide, and thus fly closer to the observer whereas during clear conditions, the birds may be more dispersed.

We also found that as cloud cover increased, the number of birds detected increased. Although heavily overcast days can delay the dawn chorus and cause early cessation of evening activity, heavy cloud cover may cause bird activity to increase later in the morning (Robbins 1981). In addition, an increase in cloud cover obscures bright sunlight which may aid in visual detection. Cloud cover may also serve as a good background for viewing birds as they fly overhead.

As temperature increased, bird detections increased. Robbins (1981) found that unusually low temperatures tended to inhibit activity of birds, and unusually high temperatures in the summer also shortened activity periods. For the NAS Alameda site, the range of temperatures was not extreme and an overall positive correlation was probably due to an increase in bird activity with warmer temperatures.

The majority of birds detected in this study flew below 500 m. This result is important for military aircraft because 95% of bird-strikes in the United States occur under 600 m, and 70% occur under 150 m, where the density of birds is greatest (Stables and New 1968). A large percentage of bird-strikes at NAS Alameda occurred during landing or while approaching a runway. Similar results were found in Europe, with the majority of strikes occurring during landings and on the final approaches to land (Hild 1983).

The environment surrounding NAS Alameda is an important factor in explaining directional flight patterns of birds on a seasonal basis. The importance of habitats surrounding airports has been observed at several other airports around the world. For example, the Invercargill Airport in New Zealand was built on a reclaimed swamp near an extensive estuary and rubbish dump. These areas served as a rich feeding ground for waders, waterfowl, and gulls. Flight patterns of gulls were traced from the Invercargill city rubbish dump to the estuary (Caithness et al. 1967). Like Invercargill, NAS Alameda has a complex distribution of habitats including open water, open space, a vegetated solid waste disposal site, and rocky outcroppings. This combination of feeding sites, flat open areas for loafing, and the bay attracts many birds, especially gulls. The largest concentrations occurred on the open water. Gulls and shorebirds are also attracted to asphalt areas, especially if the areas are flooded because of poor drainage (Solman 1978). Birds are attracted to fresh water as a drinking source, but also use fresh water for bathing.

Many of the bird-strikes at NAS Alameda, when the species struck was recorded, involved gulls. Gulls account for 40% of the world's reported bird-strikes and are considered to be the most serious threat to aircraft, especially at coastal airports (Seubert 1976, Murton and Wright 1968). Gulls do indeed represent the greatest threat to aircraft at NAS Alameda; however, they might be avoided because they follow predictable daily flight patterns. Cogswell (1974) noted a southeast movement of gulls in the mornings along rocky seawalls from the active Alameda disposal site towards the San Leandro Bay and the two dumpsites active there, and also a movement of gulls to the northwest originating from the waste site at Alameda. Similar patterns of flight were observed around NAS Alameda during our study.

During the late spring-summer, Caspian terns roosted on the upraised areas at the eastern end of the solid waste disposal site. The foraging behavior of these birds explains their general flight pattern from the southern rocky seawall boundary of the dumpsite, west to the bay to feed. Also, during the spring, least terns bred on the sanctuary located in the south end of the centerfield. Least terns are designated a Federally endangered species (Ainley ad Hunt 1991). The species nests at estuarine and coastal sites from the San Francisco Bay southward. A recovery program has been in place for the last 10 years throughout California (Ainley and Hunt 1991). About 70 pairs of least terns breed every year from June into the first week of July at the asphalt sanctuary. These birds fly from the sanctuary to the western channel and bay area to forage, crossing the south end of runway 31 on the way. Thus, because they also fly at low altitudes, there is a large chance for their colliding with military aircraft.

MANAGEMENT IMPLICATIONS

Based on our results and the current literature, recommendations for reducing bird-strike rates are:

1) Increase pilot and airfield personnel awareness of bird-strike hazards and the attractions an airfield has to birds. The majority of collisions at NAS Alameda were with solitary birds and a high percentage of these birds were not identified to species. By emphasizing bird-strike reporting and the identification of every bird involved in a strike to the species level, more specific management programs can be developed. Even a few bird remains left on the runway can be positively identified

to species. If the identification of bird remains is not possible, all information that can be collected is important, including the time of day of the strike, the runway on which the strike occurred, the size and number of birds involved in the strike, height when the strike occurred, and the weather conditions.

2) Pilots should be made aware of the movements of birds from their roosting and feeding sites and of their general behaviors in nearby habitats. At NAS Alameda, flight patterns of particular concern are least terns as they fly across runway 31 during spring, and the movements of gulls from the southern rock breakwater to daily feeding sites during all seasons. During the spring, flight operations that occur low over the southeast end of runway 31 should be avoided. The flight patterns of Caspian terns, house finches, and red-winged blackbirds toward and within the solid waste disposal site are also of concern. Low level flights over the dumpsite should be avoided, especially during spring and summer months.

3) Bird control programs should be employed during times of the day when the most bird-strikes occur. Most bird-strikes at NAS Alameda occurred in the afternoons and evenings, but it was unknown whether this was due to more flight operations during those times. If there are more flights occurring in the afternoons and evenings, we recommend that total flights be spread more evenly throughout the day and not be concentrated in the afternoons. Bird control programs such as scaring methods should be employed during afternoons and evenings.

4) Plane activity levels should vary seasonally at airports where bird densities vary seasonally. For NAS Alameda, bird numbers were the highest in the winter and lowest in the summer. Plane activity could be increased during the summer, but strikes might increase because of the presence of immature birds. Thomas (1972) speculated that immature (and therefore inexperienced) gulls may be involved in more strikes than mature gulls.

5) The habitat should be manipulated to discourage large flocks of birds on or near airfields. Keeping the grass heights 20-30 cm around the airfield has been suggested as adequate in deterring these social feeders by several authors (Caithness et al. 1967, Blockpoel 1976). For instance, the grassy areas at NAS Alameda that needed special attention included areas directly adjacent to the taxiways and runways.

6) At coastal airports, flocks of gulls and shorebirds can congregate around asphalt areas after rain because of the flooding from inadequate drainage. The asphalt areas around the helicopter pads and taxiways collected water after rains and large flocks of ring-billed gulls, California gulls, and western gulls were observed resting there. Draining off excess water from these areas would prevent birds from concentrating near where helicopters take-off and land.

ACKNOWLEDGEMENTS

We thank our base contacts at NAS Alameda: Dave Wigon, Felix Marquez, and Andrea Steele in the Operations Deputy Officer Office, and Lt. CMDR Jeff Smith, Ian Netherton, and USN Operations Officer P.C. Knott. The assistance of Steven Kovach, Kent Livezey, Michael Stroud, and Ron Hudson at WESTDIV is also gratefully acknowledged. Special thanks to Amy Jo Kuenzi and Lori Merkle for their time and assistance in preparing the manuscript, and to Dr. Al Stangenberger for his help with preparing the data for analysis. This study was funded by the Western Division, Naval Facilities Engineering Command, San Bruno.

LITERATURE CITED

Ainley, D.G., and G.L. Hunt, Jr. 1991. Status and conservation of seabirds in California. ICBP Technical Publication 11:103-113.

Bartholomew, G.A. 1942. The fishing activity of double-crested cormorants on San Francisco Bay. Condor 44:13-27.

Bartholomew, G.A. 1943. The daily movements of cormorants on San Francisco Bay. Condor 45:3-19.

Blockpoel, H. 1976. Bird hazards to aircraft. Books Canada Inc., Buffalo, New York, USA. 235pp.

Bollinger, E.K., and J.W. Caslick. 1985. Factors influencing blackbird damage to field corn. J. Wildl. Manage. 49:1109-1115.

Burger, J. 1985. Factors affecting bird strikes at a coastal airport. Biological Conservation 33:1-28.

Caithness, T.A., M.J. Williams, and R.M. Bull. 1967. Birds and aircraft: a problem on some New Zealand airfields. Proc. N. Z. Ecol. Soc. 14:58-62.

Cogswell, H.L. 1974. Ecological factors in the hazards of gulls to aircraft in a bayside complex of airports and solid waste disposal sites. Pages 27-108 *in* S.A. Gauthreaux, Jr. ed. A conference on the biological aspects of the bird/aircraft collision problem. Clemson University, Clemson, S.C.

Davidson, G.R. Jr., T.V. Degeare, Jr., T.J. Sorg, and R.M. Clark. 1971. Bird/aircraft hazards at airports near solid waste disposal sites. Report No. SW-116 for the Federal Solid Waste Management Program. 30pp.

Ellison, L.E., L.S. Hall, J.J. Keane, and A.J. Kuenzi. 1992. Avian surveys at Naval Air Station (NAS) Alameda for the bird-aircraft strike hazard (BASH) program. Unpubl. report for the U.S. Navy, Western Division, Natural Resources Branch, San Bruno, CA. 62pp.

Fienberg, S.E. 1980. The analysis of cross-classified categorical data. Second edition. Massachusetts Institute of Technology Press, Cambridge, Massachusetts, USA. 385pp.

Gauthreaux, S.A., ed. 1974. A conference on the biological aspects of the bird/aircraft collision problem. Clemson Univ., Clemson, SC. 427pp.

Gauthreaux, S.C., ed. 1976. Proceedings of the bird hazards to aircraft seminar and workshop. Clemson Univ., Clemson, SC. 230pp.

Hild, J. 1983. Combating the bird strike hazard. Airport Forum 8(5):67-71.

Lehmann, E.L., and H.J.M. D'Abrera. 1975. Nonparametrics: statistical methods based on ranks. Holden-Day, Inc., Oakland, CA. 457pp.

Murton, R.K., and E.N. Wright, eds. 1968. The problem of birds as pests. Academic Press, New York, NY. 254pp.

Robbins, C.S. 1981. Bird activity levels related to weather. Pages 301-310 *in* C.J. Ralph and J.M. Scott, eds. Estimating numbers of terrestrial birds. Studies in Avian Biology 6.

Seubert, J.L. 1976. Status report -- Bird hazards to aircraft. Pages 72-192 *in* S.A. Gauthreaux, ed. Proceedings of Bird Hazards to Aircraft Seminar and Workshop. Clemson University, Clemson, S.C.

Shaw, J.H. 1985. Introduction to Wildlife Management. McGraw-Hill Series in Forest Resources. McGraw-Hill, Inc. New York. 315pp.

Sokal, R.R., and F.J. Rohlf. 1969. Biometry. W.H. Freeman, San Francisco. 859pp.

Solman, V.E.F. 1978. Gulls and aircraft. Environmental Conservation 5:277-280.

Stables, E.R., and N.D. New. 1968. Birds and aircraft: the problems. Pages 3-14 *in* R.K. Murton and E.N. Wright eds. The problems of birds as pests. Academic Press, New York.

Steenblik, J.W. 1989. Bird strikes. Airline Pilot 58(10): 8-31.

Thomas, G.J. 1972. A review of gull damage and management methods at nature reserves. Biological Conservation 4:117-127.

U.S. Fish and Wildlife Service. 1985. Bird checklist for San Francisco Bay and San Pablo Bay National Wildlife Refuges. RF-11640-3. U.S. Government Printing Office, Region No. 8. 20pp.

Verner, T.C. 1985. Assessment of counting techniques. Pages 247-302 *in* R.F. Johnston, ed. Current Ornithology Vol. 2. Plenum Press, New York.

Walker, T.C., and C.W. Bennett. 1985. Apparent efficacy of bird aircraft strike hazard programs at four naval stations. Pages 115-121 *in* P.T. Bromley, ed. Proceedings E. Wildlife Damage Control Conference 2. North Carolina State Univ., Raleigh, NC.

Western Division Naval Facilities Engineering Command. 1986. Appendix F Final. Air installations compatible use zones study update for NAS Alameda, California. Unpubl. report. Prepared for the West. Div. Naval Facilities Engineering Command, San Bruno, CA. 49pp.

Will, T.J. 1985. Air force problems with birds in hangars. Pages 104-111 *in* P.T. Bromley, ed. Proceedings E. Wildlife Damage Control Conference 2. North Carolina State Univ., Raleigh, NC.