Caracterization of the Birdstrike hazards to the space shuttle orbiter

Major Jeffrey J. Short, USA)

CHARACTERIZATION OF THE BIRDSTRIKE HAZARDS TO THE SPACE SHUTTLE ORBITER

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ABSTRACT

The National Aeronautics and Space Adminstration requested an evaluation of the Space Shuttle Orbiter windshield system with regards to the possibility of birdstrikes. To support their damage assessment analysis, the Air Force Wright Aeronautical Laboratories Aircraft Windshield System Programs Office directed a characterization of the bird populations at the three primary Shuttle landing sites: Kennedy Space Center, Florida; Edwards AFB and Vandenberg AFB, California. The objective of this effort was to determine the expected birdstrike risk of Shuttle approaches/landings.

The USAF Bird Avoidance Model (BAM), developed for the Bird-Aircraft Strike Hazard Team by the University of Dayton Research Institute, is used to examine bird hazards on high-speed, low-level flight routes in the continental United States. The BAM calculates the birdstrike risk on a route by estimating the number of birds occupying the route airspace at a particular time. The BAM was used to determine the relative birdstrike risk to the Shuttle by defining the segments of a typical approach at each of the landing sites.

The BAM estimates for Kennedy Space Center (KSC) were multiplied by the proportion of the local bird population segregated into discrete weight categories. This yielded the probability of a birdstrike involving a bird of a particular weight. The bird population data was collected from the Merritt Island National Wildlife Refuge which is located adjacent to KSC. This analysis indicated that the chance of the Shuttle hitting a 2-pound bird is close to 4 per 100 approaches during the fall each year. One out of every 100 landings would involve a 3-pound bird during the fall and early winter. The predominant risk comes from waterfowl at KSC with the chance of encountering larger (over 4-pound) raptors greater during the summer.

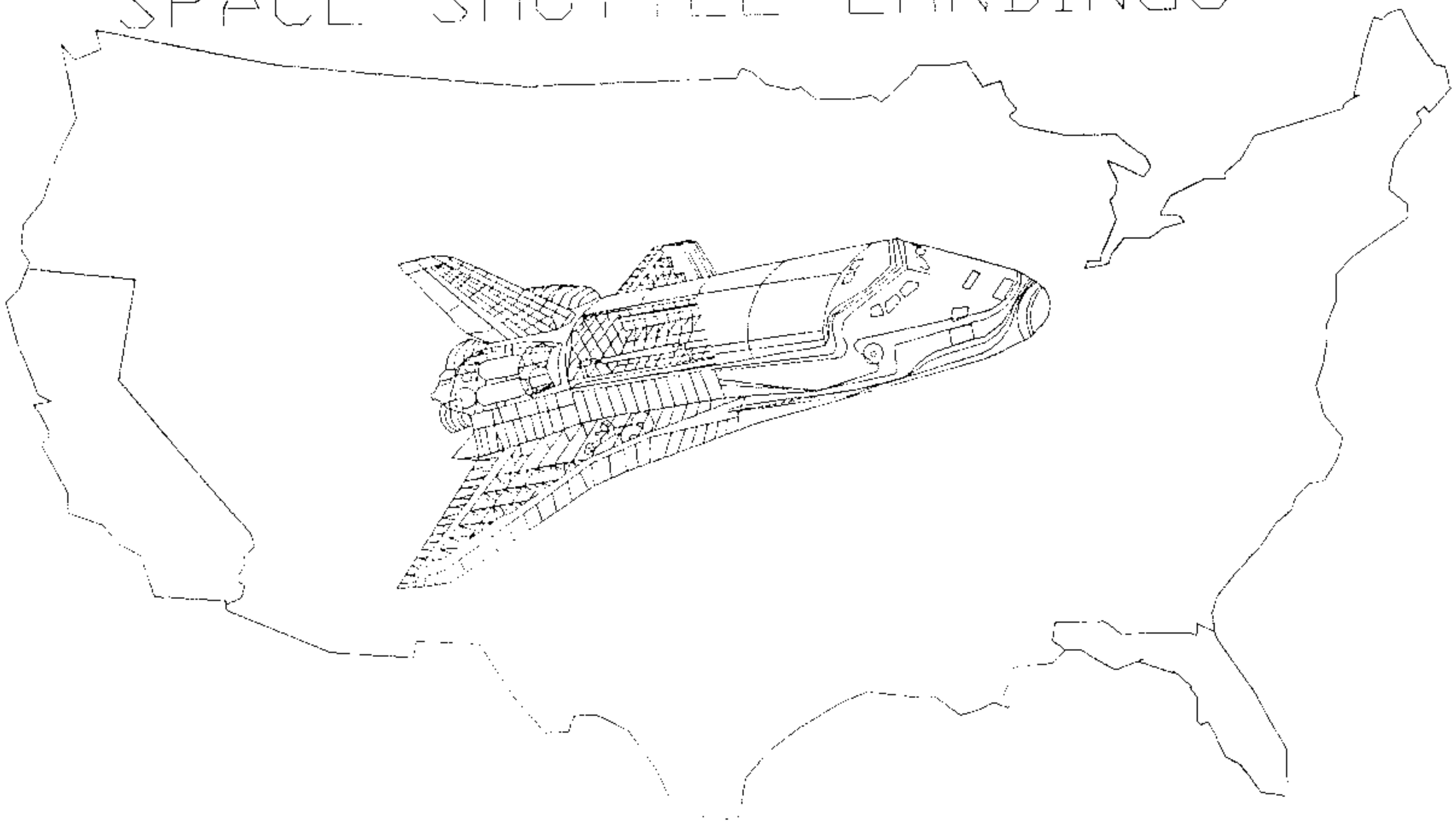
No discrete bird population data was available from the California sites so only the BAM estimates were used for comparison of birdstrike risk. The analysis showed that the birdstrike risk to the Shuttle is highest in the fall at all sites. Based on the BAM, the birdstrike risk ranges from 2 per 100 approaches at KSC and Edwards AFB to 2 per 1000 flights at Vandenberg AFB. Waterfowl create the majority of the birdstrike hazards during

from fall through early spring while raptors comprise the major hazard during the summer. Night landings would expose the Shuttle to the highest birdstrike risks, especially during the fall and spring migrations.

This was the first application of the BAM on other than military aircraft. Though the BAM is certainly an imperfect model, it provides a method of quickly estimating the relative birdstrike risk from waterfowl and raptor populations in the continental United States. More bird population data is needed for other bird species (gulls, blackbirds) known to present hazards to flight to improve the BAM's predictive ability.

Reliable bird population data from the region around the landing site, combined with the BAM estimates, can provide design engineers with a good idea of the bird hazards that the Shuttle will encounter during particular time periods. If some aspect of the design is inadequate to provide an acceptable level of birdstrike resistance, the flight hazards can be minimized by scheduling Shuttle landings at a particular site to a time when the birdstrike risk is lowest. If rescheduling is not feasible, then measures to reduce the birds along the Shuttle approach could be implemented.

BIRD STRIKE RISK FOR SPACE SHUTTLE LANDINGS



BIRDSTRIKE RISK FOR SPACE SHUTTLE LANDING SITES[1]

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INTRODUCTION

NASA has long been concerned with the possibility of birdstrike damage to the Shuttle. Beginning in 1974 (Reference 1), the Air Force's Bird-Aircraft Strike Hazard (BASH) Team has recommended measures to reduce the risk of birdstrikes at the Kennedy Space Center (KSC) Shuttle Landing Facility (SLF) and other operational landing sites. BASH Team assistance was provided to NASA several times in the last 7 years regarding the SLF. Over the past 10 years, the BASH Team has conducted surveys of the bird hazards at the other primary Shuttle landing sites, Edwards AFB and Vandenberg AFB, California. Once implemented, those recommendations made by the BASH Team effectively decreased the overall attractiveness of the airdrome to birds, considerably reducing bird hazards to both the Shuttle and other aircraft using the facilities.

The SLF is located next to the Merritt Island National Wildlife Refuge (MI NWR) which hosts hundreds of thousands of waterfowl and tens of thousands of waders, shorebirds, raptors and songbirds. The movement of these birds in and around the MI NWR constitute a significant hazard to the Shuttle (or other aircraft) landing at the SLF. One birdstrike is known to have occurred during a Shuttle landing at the SLF (Mission 1042A, 11 Feb 85 at 1215 hours GMT).

The objective of this study was to quantify the birdstrike hazard to the Shuttle at its three primary landing sites in the United States. One goal is to characterize the distribution of birds at the landing sites. Another goal is to determine the range of weights of those birds to model the expected amount of damage expected from a single birdstrike. Sufficient bird population data exist for the Florida site but the information needed for an in-depth study of the California sites is incomplete. Therefore, this report will concentrate on the bird hazards at the SLF.

1 Taken from AFWAL Technical Report 87-3083, A Characterization of the Birdstrike Risk to the Space Shuttle Orbiter at its Primary Landing Sites.

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Bird Weight Distribution

Determining the weight distribution of birds requires knowledge about the predominant bird species of a population and their associated body weights. Bird weights vary with sex, age, subspecies and season. Combining this information with behavioral information on the chronology, geographic and vertical distribution of their movements provides the basic biological inputs into a hazard assessment model; i.e., how many birds of a known hazard potential might interfere with the Shuttle's approach.

Monthly waterfowl censuses (1978-84), performed by U.S. Fish and Wildlife Service (USFWS) and quarterly surveys of raptors, waders and shorebirds (Reference 2) were analyzed to characterize the bird population at MI NWR. Monthly waterfowl censuses were consolidated into quarters to be consistent with the survey data. Body weights were assigned to each species according to the highest mean weight published in "Body Weights of 686 Species of North American Birds" (Reference 3). No consideration was given to the sample size, whether the birds were male or female, their breeding condition, or the season they were collected. Where sample range (geographic distribution) was identified, the mean weights for the easterly occurring subspecies were used. All weights were converted to pounds.

Census data show that most waterfowl leave the MI NWR by May of each year and return in October. Large raptors are present year-round but comprise almost half of the bird population from April through September. Many raptors follow the Florida coastline during fall migration. The bird population data was separated into three groups to compare the weight distribution of the waterfowl, raptor and wader/shorebird populations (Table 1). Table 2 shows the consolidated distribution of weights for the three groups. The large numbers of waterfowl (311,900) eclipsed both raptor (3,387) and wader/shorebird (96,285) proportions of the total population at MI NWR.

The cumulative distribution frequency (CDF) of the weights of the bird populations at MI NWR were calculated from the annual proportion of each weight class for a bird group (see Table 1). Weights for the population samples involved in birdstrikes characteristically fit a Weibull curve (References 4 and 5). The CDF (Figure 1) for the MI NWR waterfowl population approximates a Weibull distribution but the raptor and wader/shorebird curves are flatter, indicating a higher percentage of heavy birds in the population; e.g., Black Vulture (4.7 pounds) and Wood Stork (6.0 pounds), respectively.

Figure 2 shows the CDF for weight when combining all MI NWR bird groups (from Table 2) throughout the year. Again, the weight distribution for all bird groups combined resembles a Weibull Curve. The occurrence of birds greater than 3 pounds from April through September flattens the distribution,

TABLE 1. Quarterly Distribution of Bird Weights at MI NWR.

WATERFOWL POPULATION N=311,900

Weight Class(Lbs)	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Annual
1.0	0.0836	0.1277	0.5547	0.0621	0.08104
2.0	0.7408	0.6915	0.1434	0.7481	0.73486
3.0	0.1753	0.1808	0.3015	0.1896	0.18383
4.0	0.0003	0.0000	0.0004	0.0001	0.00023
6.0	0.0000	0.0000	0.0000	0.0000	0.00000
>6.0	0.0000	0.0000	0.0000	0.0001	0.00003

RAPTOR POPULATION N= 3,387

Weight Class(Lbs)	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Annual
1.0	0.4741	0.1842	0.0710	0.4060	0.34928
2.0	0.1034	0.0614	0.0772	0.0855	0.08562
3.0	0.0233	0.1023	0.1235	0.0744	0.06761
4.0	0.2888	0.5048	0.4537	0.3248	0.36374
6.0	0.1034	0.1364	0.2469	0.1026	0.12400
>6.0	0.0069	0.0109	0.0278	0.0068	0.00974

WADER/SHOREBIRD POPULATION N= 96,285

Weight Class(Lbs)	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Annual
1.0	0.6405	0.6804	0.7126	0.6301	0.66345
2.0	0.0636	0.0274	0.0313	0.0587	0.04648
3.0	0.1529	0.1279	0.1341	0.1528	0.14281
4.0	0.0794	0.0365	0.0670	0.0745	0.06543
6.0	0.0199	0.0434	0.0257	0.0205	0.02674
>6.0	0.0437	0.0845	0.0293	0.0634	0.05510

TABLE 2. Cumulative Weight Distributions for MI NWR Birds.

Weight Class(Lbs)	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Annual
1.0	0.16287	0.54988	0.67950	0.15244	0.21950
2.0	0.64331	0.16987	0.04990	0.63682	0.56848
3.0	0.17127	0.13849	0.16092	0.18310	0.17328
4.0	0.01307	0.04067	0.06093	0.01386	0.01848
6.0	0.00340	0.03650	0.02421	0.00387	0.00728
>6.0	0.00608	0.06459	0.02454	0.00991	0.01299

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indicating that heavy birds make up a higher percentage of the total population. Most of the duck population has left by early spring leaving the heavier raptors to dominate more of the population.

Bird Avoidance Model

In 1981, the University of Dayton Research Institute (UDRI), under contract from the BASH Team, developed and implemented the Bird Avoidance Model (BAM). BAM quantifies birdstrike risk as a function of mission profile, route-of-flight, date, time of day, and aircraft frontal area (References 6 and 7). The original purpose of the BAM was to compare low-level flight routes on the basis of bird risk to allow flight scheduling to avoid the worst hazards. It would also enable route planners to redesign flight segments to minimize the risk of birdstrikes. This study is the first application of the model to characterize bird weight distributions.

Birdstrike risk is defined by BAM as the number of birds that will be encountered along a flight route during a particular mission. BAM uses latitude, longitude, and segment altitude to calculate birdstrike risk on each segment. The risks are summed over all segments to give the total birdstrike risk for the entire route. BAM allows the user to compare routes/route segments based on an expected number of birdstrikes for each mission or per mile.

The BAM results are shown as the number of expected birdstrikes per flight for each week and for each daily period. BAM output also offers the option of a segment-by-segment summary and a breakdown of the effect of local and migratory movements of waterfowl or raptors.

The BAM contains exhaustive data on waterfowl refuges, migration, breeding grounds, and raptor concentrations in the contiguous 48 states. Originally, BAM was based solely on waterfowl populations and their migrations. Quantifiable data on raptor populations and movements and breeding populations of waterfowl were included in BAM in 1985.

The BAM assumes a uniform distribution of birds within a standard radius of known congregation points such as breeding grounds or wildlife refuges. For example, the model uses a maximum population of 155,000 waterfowl at MI NWR to calculate birdstrike risk. However, monthly censuses conducted by USFWS personnel there show an annual average waterfowl population of over twice that amount (311,900). This contradiction is due to the fact that almost half the MI NWR population consists of coots. BAM uses only duck, goose and swan data to estimate waterfowl hazards. Because of their high numbers, coots were included in analysis by multiplying the waterfowl results by a factor of two.

Shuttle Operations

To assess the birdstrike risk to Shuttle operations, it is necessary to know the distribution of birds along the flight path. The Shuttle uses the same approach window (airspeeds and procedures) for each landing. However, the bird populations and their habits are quite different at each operational site.

The estimate of birdstrike risk is a function of the number of birds within a volume defined by the frontal area swept along the length of the flight route. The frontal area is the square footage of a component/aircraft as it approaches head-on. For the Shuttle, the frontal area varies from 768.7 to 944.1 square feet corresponding to 3 to 8 degrees nose-high attitude. For this analysis, the nominal 5 degrees (818 square feet) was used. This corresponds to the area subtended by the wings, nose and fuselage of the Shuttle.

The BAM calculates the number of birds expected for any segment -as defined by geographic coordinates and base altitude- of a standard or user-defined flight route. In this analysis, a typical Shuttle approach was constructed for the SLF with information provided by a 1974 BASH study (Reference 1) and Ms. Karen Edelstein (NASA). The Shuttle intercepts a 19-degree glide angle at 12,600 feet AGL approximately 6 miles from the runway and flies to a point 1700 feet AGL and 8,000 feet from the runway where it intercepts a 1.5- degree glide slope until touchdown. The final approach was broken into a series of segments based on nominal altitudes at the end of segment. The geographic coordinates for each segment were approximated from a 1:2,000,000 map.

BAM RESULTS

BAM estimates include the effects of both waterfowl and raptors but not wader/shorebird populations. It would be inappropriate to combine wader/shorebird population data with either bird category because their habits are so different. However, an estimate based only on bird population levels at MI NWR throughout the year would indicate that wader/shorebird hazards would be intermediate between the other two groups and would vary between 1 to 3 hazards per 1000 Shuttle approaches.

Separate BAM estimates were obtained for waterfowl and raptors to better show the size distribution effects attributable to each population. Waterfowl risks were multiplied by two to correspond with the increased waterfowl populations exhibited by the MI NWR censuses. Each risk was multiplied by the proportion of the MI NWR population of a particular size class (see Table 2) during a certain quarter. For example, the risk of hitting a raptor in week 14 was multiplied by the probability that the raptor would weigh 3 to 4 pounds (from Table 1) for that period (week 14 is in the Apr to Jun quarter). The total weekly risk for the SLF was determined by summing waterfowl and raptor risks over all periods.

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The highest level of risk occurs in the first and last quarter of each calendar year. When plotted (Figure 3), the resultant risk estimates show levels of bird activity and the size relationships of expected birdstrikes. This graph indicates that the most serious birdstrike hazards at the SLF occur in the last quarter of the year when almost 5 of every 100 shuttle flights will impact a bird weighing 1 to 2 pounds and 1 of every 100 will weigh 2 to 3 pounds.

Figures 4 and 5 show the individual effects of waterfowl and raptors, respectively. Two- and three-pound waterfowl present the most risk to Shuttle operations at the SLF at levels almost three orders of magnitude higher than raptors. However, during the summer months, 4-pound raptors comprise the prevalent bird hazard.

Figures 4 and 5 also indicate that the waterfowl hazard is much more predictable than the raptor hazard. This suggests that waterfowl hazards are avoidable.

Relative Birdstrike Risk

Since bird census data were not available for the Edwards AFB and Vandenberg AFB, California, their bird weight distributions were not determined. However, a comparison between the three sites was possible, using the BAM risk estimates. No mathematical manipulations were made to bring the bird population estimates up to current census levels. (Remember, the waterfowl risks for the SLF were doubled in Figures 3 and 4 to include coots. The estimated risks were plotted to show relationships.

Figure 6 shows that KSC and Edwards have roughly the same timing of birdstrike risk; the greatest risk occurs in the fall which is roughly twice the risk of the springtime. A breakdown of the birdstrike risk for each site by period of day, with minor differences, shows essentially the same trends (Figures 7 through 9). Birdstrike risks at midday are approximately half those in early morning or evening. Comparisons of waterfowl risks can be made when additional population data are available from the California sites.

BAM estimates for raptors can be compared directly between the three landing sites (Figure 10). There is no nighttime risk of hitting a raptor since they are diurnal and are not known to migrate at night. It is important to note that there is twice the chance of hitting a raptor in the late summer and early fall at Vandenberg as at either the SLF or Edwards.

DISCUSSION

Based on the BAM analysis, the Shuttle can expect to hit at least two birds in every 100 approaches at either KSC or Edwards and one bird in every 200 approaches at Vandenberg. This level of birdstrike hazard is due to the relatively large proportion of waterfowl in the nearby bird populations and is the most intense during the fall migration and subsequent overwintering each year.

Waterfowl typically migrate at altitudes below 5,000 feet AGL and are most likely encountered at altitudes below 500 feet AGL during local movements; e.g., when engaged in feeding activities around refuges. They tend to travel in flocks and fly directly between resting areas and feeding sites. Waterfowl are frequently involved in multiple birdstrikes (more than one bird at a time) with USAF aircraft.

Large birds can cause serious damage to aircraft. A 4-pound bird will release 15,928 foot-pounds of energy when struck at 300 knots. The risk of hitting a 4-pound raptor ranges from about one in the summer to six in the fall for every 10,000 approaches at the SLF and Vandenberg, respectively. Raptor populations comprise a relatively small part of the birdstrike risk at all landing sites but the hazard may be greater to the Shuttle because of their large size and soaring behavior. Their flight paths are erratic and may reach thousands of feet in the air creating problems at the higher Shuttle approach altitudes and speeds.

Wader/shorebird populations are not included in the BAM, (as well as other major components of typically hazardous bird populations such as gulls) so their effects on birdstrike risk at the various sites are not included in this analysis. This means that the calculated birdstrike risk estimates presented here are somewhat less than the actual risks expected, especially during the summer months when waders/shorebirds are concentrated in large nesting colonies. These two groups constitute a substantial part of the birdstrike hazard at KSC in the summer months (Reference 2). For example, in 1981 nesting colonies of the Least (now called Little) Tern used the overruns of the SLF, creating BASH problems for aircraft. Also, sizable rookeries of wading birds are located on MI NWR and feeding movements of Cattle Egrets on the SLF airdrome create a major hazard. Large populations of gulls and extremely large birds (e.g., Brown Pelicans) could create serious hazards if ever attracted to the vicinity of the SLF.

The BAM mathematically depicts patterns of bird movement according to basic assumptions about similarities of flight habits; i.e., what a certain bird population is doing at a certain moment and at what altitude they are doing it. Since the BAM makes no distinction other than numbers of birds found at certain altitudes during certain periods, it is possible to include taxonomically diverse groups of birds in the analysis. For instance, the soaring behavior exhibited by certain waders, especially the Wood Stork, at MI NWR would create a hazard to flight similar to soaring raptors. However, including Wood Storks as a part of the raptor analysis --with the assumption that the Wood Stork flights occur in similar ways-- would only increase the estimated birdstrike risks at the SLF by approximately one birdstrike per 1000 flights for those birds 6 pounds and over.

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Since this analysis is based on a frontal area of 818 square feet, an evaluation of the birdstrike risks to any component of the Shuttle, such as the windscreen, can be made. For example, if the windscreen area is 40 square feet, the birdstrike risk would be about 5 percent those depicted in the figures.

The design for the windscreen should represent the highest level of bird hazard encountered. At KSC, the chance of hitting a 2- to 3-pound duck close to touchdown ranges between 1 and 5 per 100 flights except during summer. While the probability of hitting a 4-pound bird may be numerically remote in the fall and winter each year, the warmer months offer a good chance of encountering a soaring, large (heavier than 4-pound) bird, such as a vulture or stork, at higher approach altitudes and consequently, higher airspeeds.

Operational constraints on where and when an approach may be conducted could reduce the prospect of a birdstrike; however, this could adversely affect mission accomplishment. Scheduled landings should be avoided at night during the fall migration. The raptor hazard could be avoided by scheduling daytime landings in the winter months or by early morning landings in the summer.

CONCLUSIONS

BAM results for the SLF show that as much as 5 percent of the shuttle approaches in the early winter months would encounter a 2-pound bird while about 1 percent would involve a 3-pound bird. About one Shuttle approach in every 10,000 at the SLF would involve a 4-pound raptor. The possibility of hitting a wader/shorebird are estimated at between 1 and 3 per 1000 approaches.

Birdstrike risk to the Shuttle will be highest in the fall at all landing sites. The relative birdstrike risk (waterfowl and raptors for all daily periods) was highest at the KSC SLF during the first 2 months and last 3 months every year. The highest risks from raptors occur at Vandenberg AFB during the late summer. Nighttime risks are highest at KSC and Edwards in the early winter.

Approach birdstrike hazards are created by waterfowl at low altitudes and, to a lesser extent, by raptors at high altitudes. The raptor strikes have a higher potential for damage because of their large size and because of increased Shuttle speeds at high altitudes. Some soaring waders could create a hazard similar to raptors.

Missions could be scheduled to avoid the highest birdstrike risks normally found during migratory periods. Other bird control techniques could be used in conjunction with bird avoidance procedures to reduce the probability of birdstrike to the Shuttle.

Integration of information on population levels of waders/shorebirds and gulls (including nesting colonies and feeding movements) would enhance the BAM's capabilities to predict birdstrikes and the weight distribution of those birds involved.

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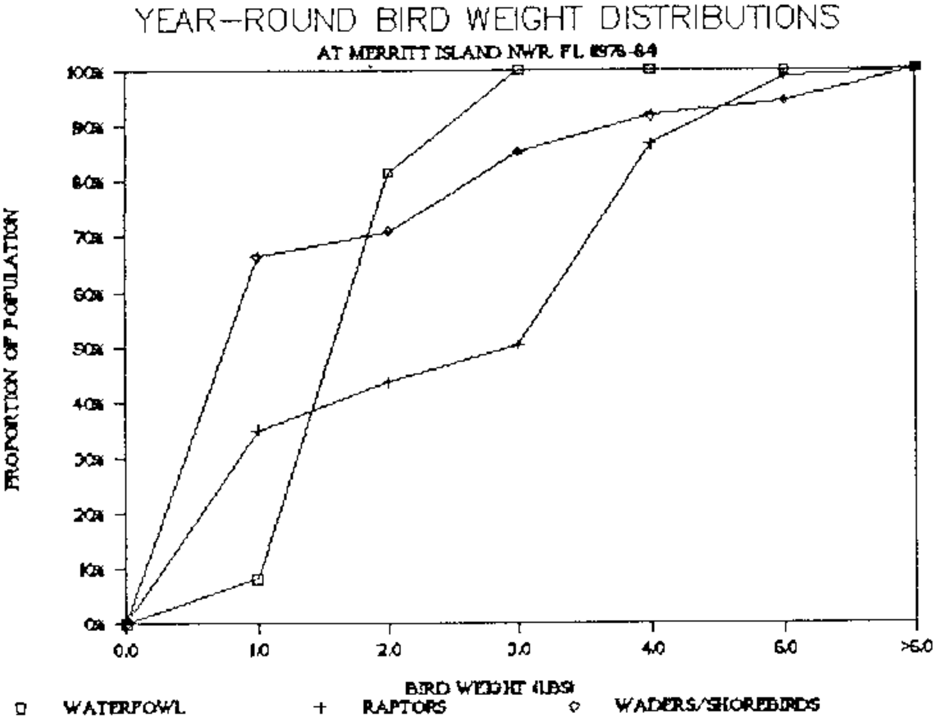
FIGURE 1


YEAR-ROUND BIRD WEIGHT DISTRIBUTIONS
AT MERRITT ISLAND NWR, FL 1978-84
PROPORTION OF POPULATION
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
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1.0
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BIRD WEIGHT (LBS)
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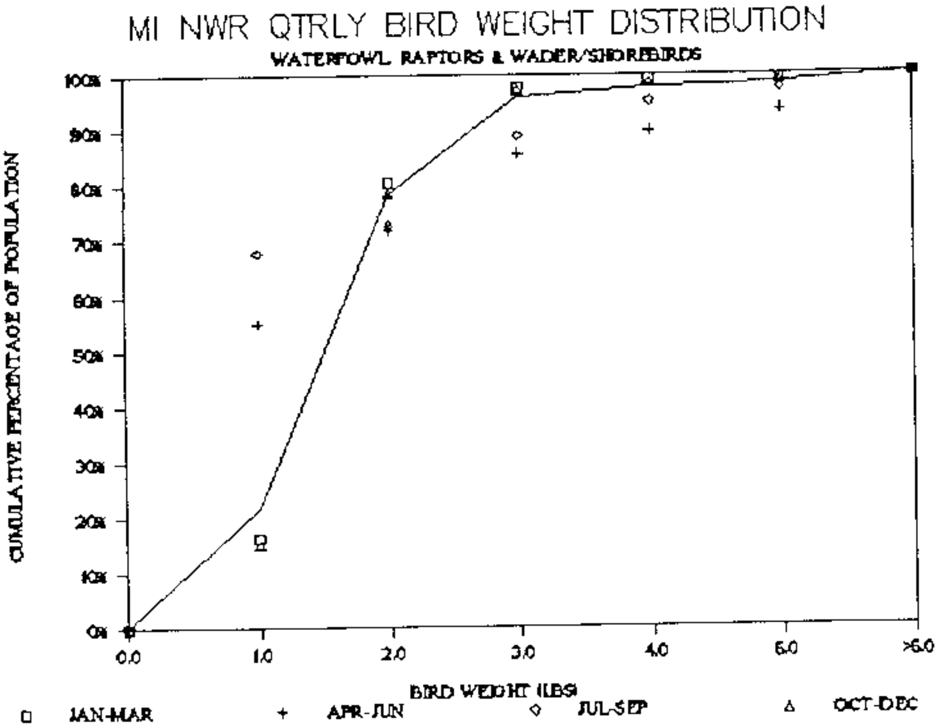
FIGURE 2



MI NWR QTRLY BIRD WEIGHT DISTRIBUTION
WATERFOWL, RAPTORS & WADER/SHOREBIRDS
CUMULATIVE PERCENTAGE OF POPULATION
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40%
30%
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BIRD WEIGHT (LBS)
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FIGURE 3. KSC SLF BIRDSTRIKE RISK

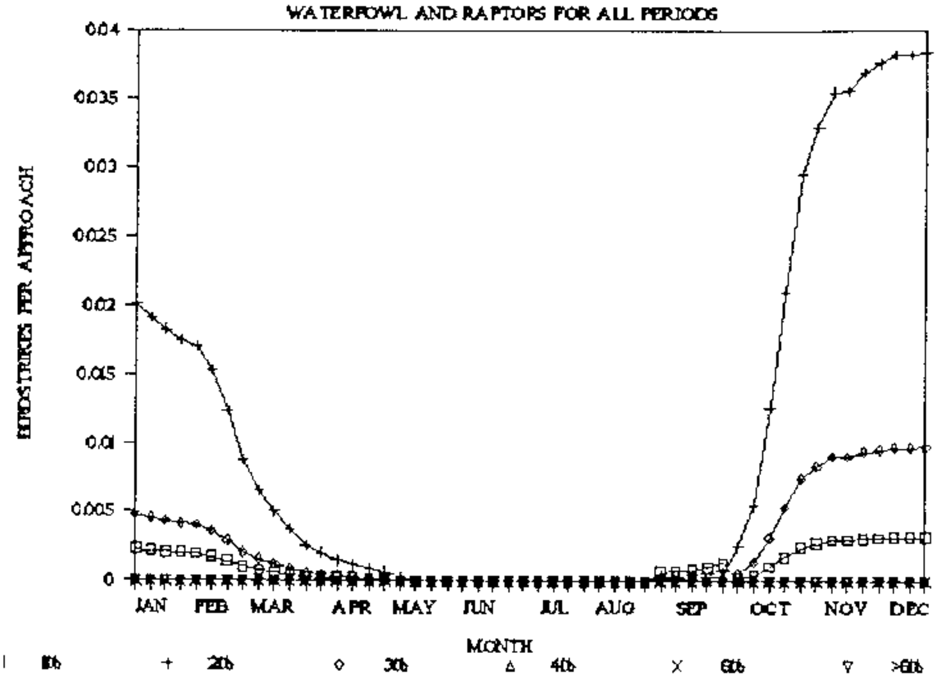
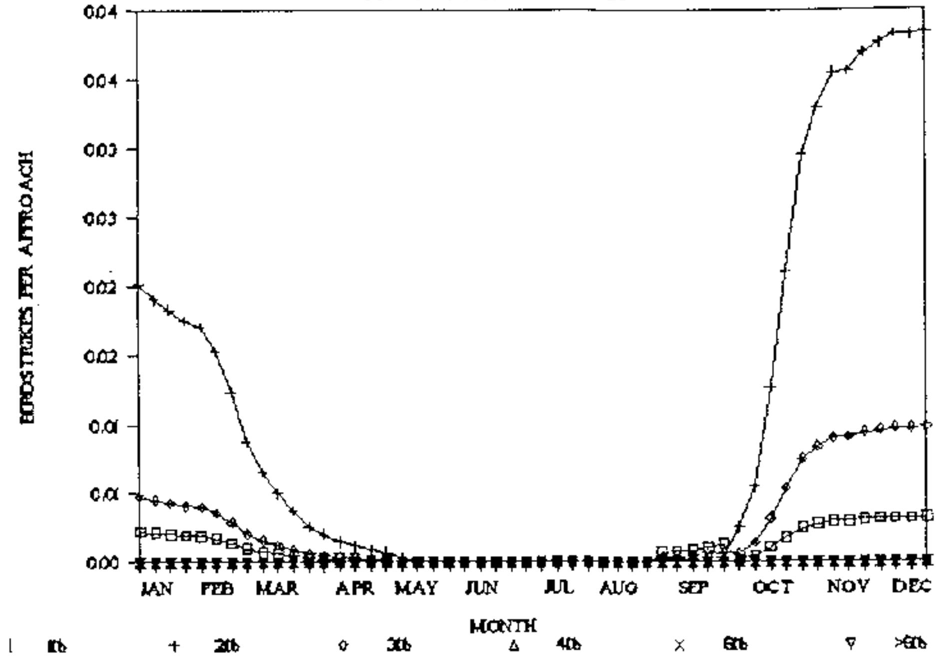


FIGURE 4. KSC SLF WATERFOWL RISK

COMBINED FOR ALL PERIODS



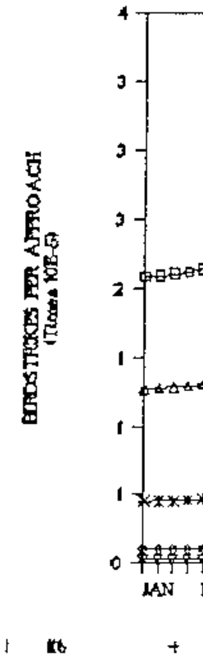


FIGURE 5. KSC SLF RAPTOR RISK

COMBINED FOR ALL PERIODS

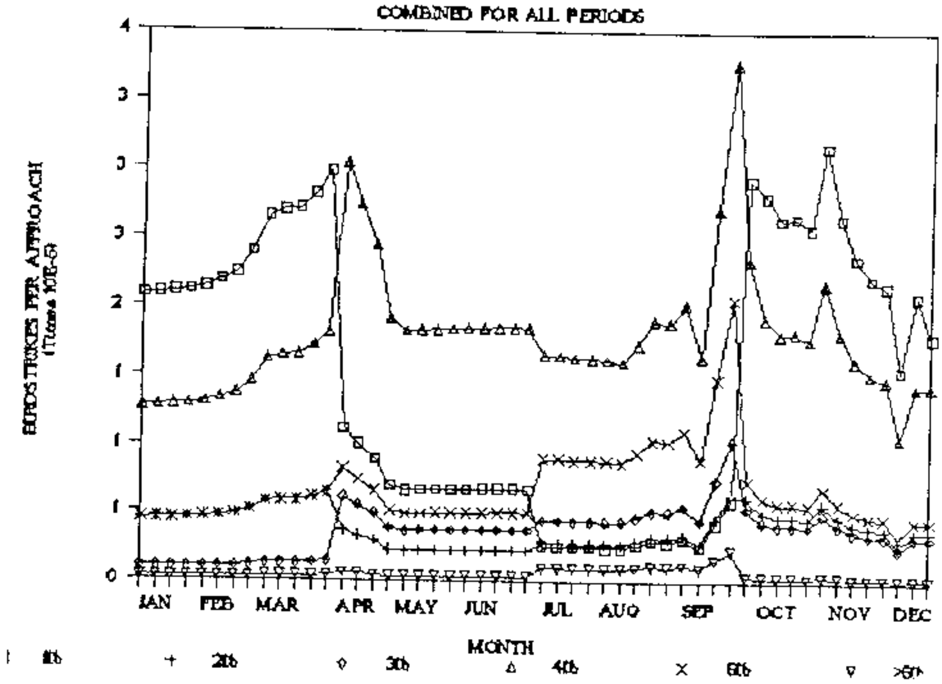
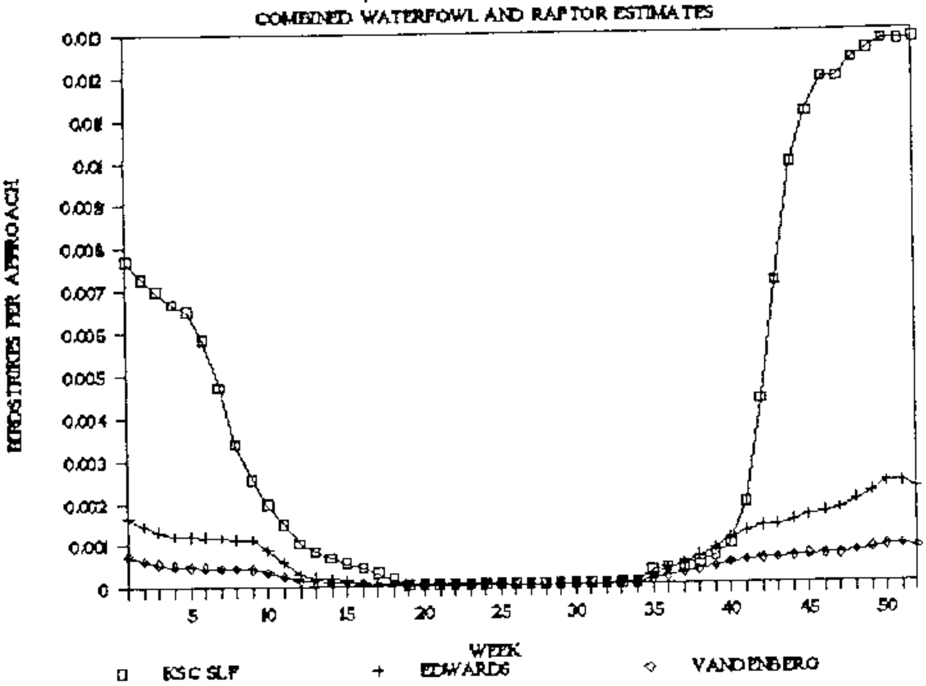


FIGURE 6

TOTAL A.M./P.M. RISK FOR SHUTTLE

COMBINED WATERFOWL AND RAPTOR ESTIMATES



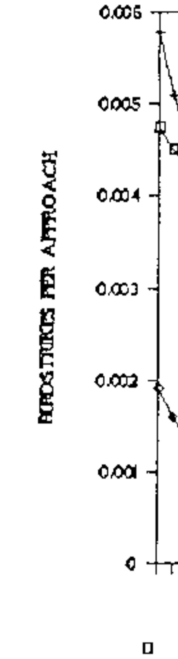


FIGURE 7

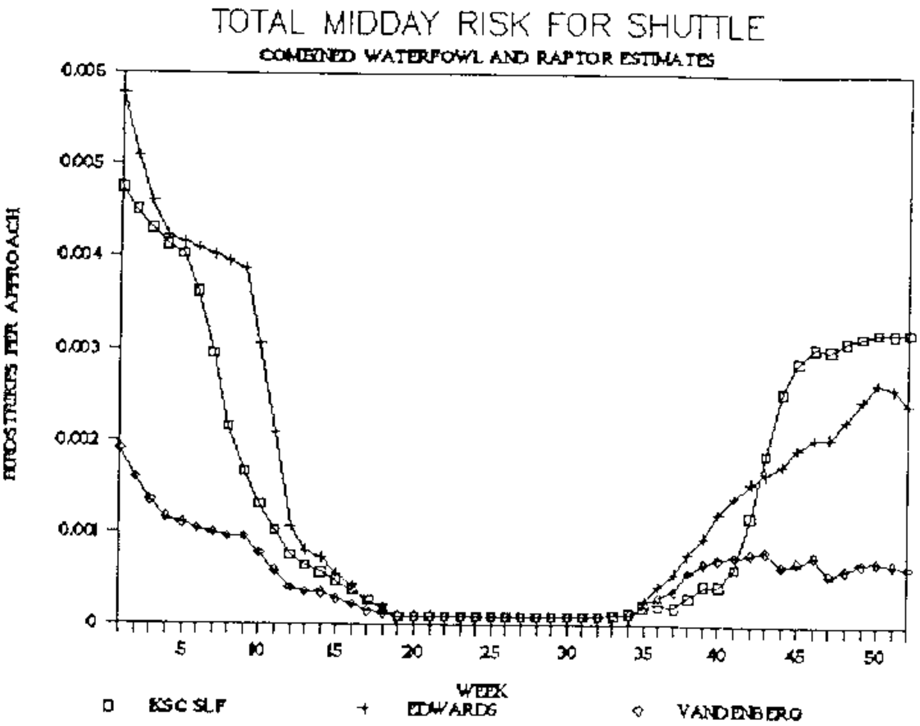
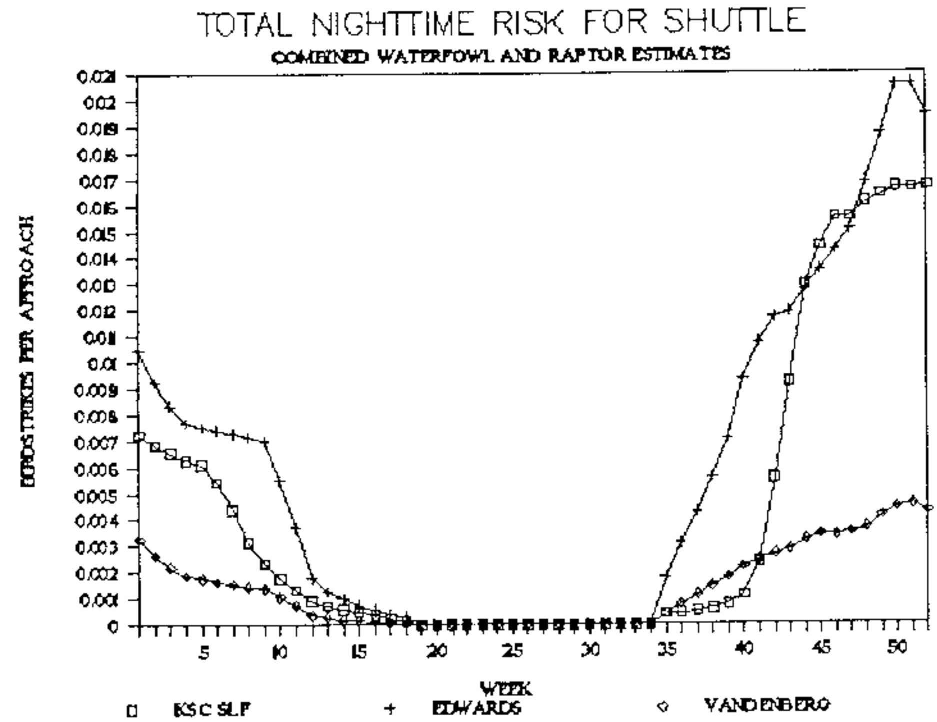

TOTAL MIDDAY RISK FOR SHUTTLE
COMBINED WATERFOWL AND RAPTOR ESTIMATES
BIRDSTRIKES PER APPROACH
0.006
0.005
0.004
0.003
0.002
0.001
0
5
10
15
20
25
30
35
40
45
50
WEEK
KSC SLF
EDWARDS
VANDENBERG

FIGURE 8



FIGU

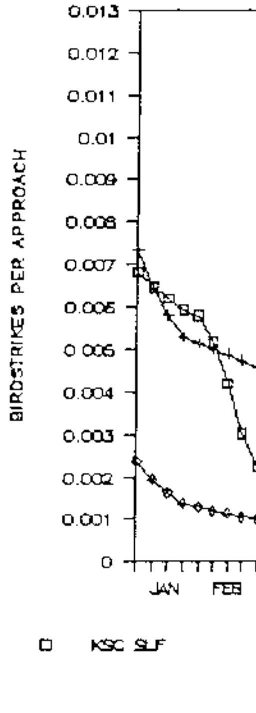


FIGURE 9. RELATIVE BIRDSTRIKE RISK

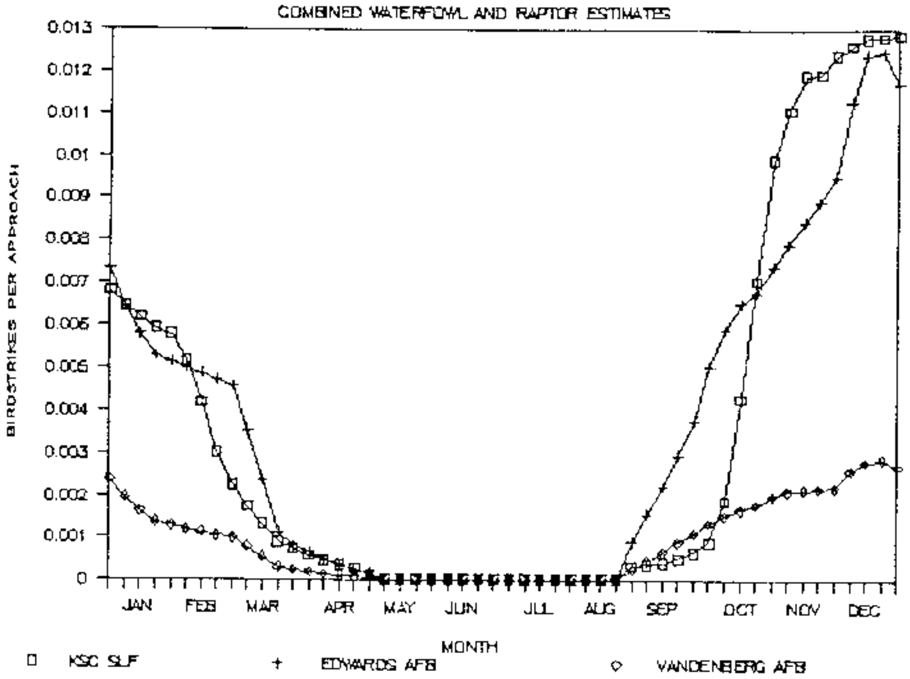
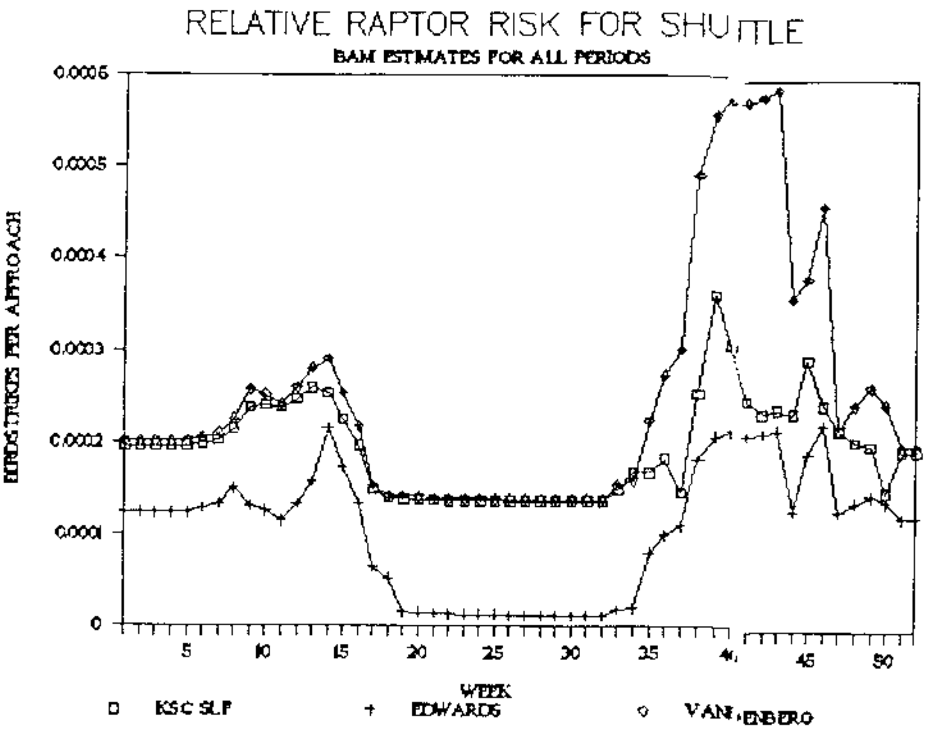
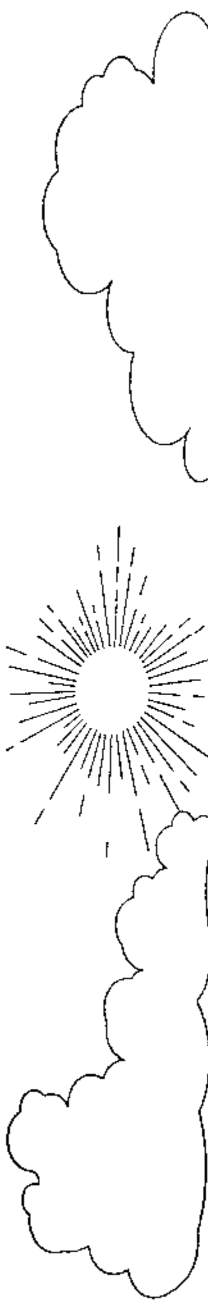


FIGURE 10


RELATIVE RAPTOR RISK FOR SHU TLE
BAM ESTIMATES FOR ALL PERIODS
BIRDSTRIKES PER APPROACH
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
5
10
15
20
25
30
35
40
45
50
WEEK
KSC SLF
EDWARDS
VAN EN ERO




Birdstrikes Happen