A Peterson's Guide to Radar Ornithology?

Some day it may be possible to identify a number of species by their radar "signatures." A state of the art report.

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IN THE PAST TWO DECADES radar has made some of the greatest contributions to the study of bird migration; this technique has revealed the general patterns of avian migration at night when most migrants make their journeys. A powerful search radar can detect the movements of birds over thousands of square kilometers, and some radars which can determine the altitude of migrants have revealed mass migrations at altitudes of 6000 meters above the earth; tracking radars have followed single birds for more than 100 kilometers. The advance of radar ornithology, however, has been stymied by an apparent paradox: nocturnal migrants detected by radar have not been identified as to species, and accurately identified birds have not been followed in their migrations by radar. In this paper we would like to discuss the problem briefly in the hope of stimulating some of the readers of this journal to report observations they may have made under particularly favorable conditions.

IDENTIFICATION OF MIGRANTS BY RADAR

THERE ARE MANY DIFFERENT types of radar used for observing migration (Eastwood, 1967). All of them indicate that there are small, slowly moving objects aloft which are not simply drifting with the wind; these we assume to be birds or insects. If we can determine the direction, speed and altitude of these objects (as with a weather radar), and can measure the velocity of the wind at that altitude with a weather balloon, we can then calculate the flight speed (or airspeed) of the bird. (The movement of a bird over the surface of the earth is the vector sum of airspeed and the speed of the wind.) Both visual observations and aerodynamic calculations (Pennycuick, 1969) indicate that certain flight speeds are charactertistic of many if not all bird species and, thus, calculated airspeed should be helpful in identifying migrants.

Potentially the most useful information for identification is the radar signature of an object being followed by a tracking radar. This is the change in effective radar echoing area of the object with time and is obtained from tracking radars which follow a single object at a time, plotting its path accurately in three dimensions.

Almost any object which is not a perfect sphere will change its effective echoing area, or radar cross section, as it moves. Radar signatures have long been used to identify aircraft and missiles. Several papers in the last decade report progress in identifying birds and insects by means of radar signatures (Konrad *et al.*, 1968; Schaefer, 1969, 1976; Williams *et al.*, 1972; Vaughn, 1974; Emlen, 1974). These studies report that radar signatures of many different birds are recognizably different. The obvious next step is to make a catalog of radar signatures of known birds and then use this as a guide for the identification of birds detected with radar when they cannot be visually identified. Emlen (1974) tracked birds released from a balloon. Vaughn (1974, 1978) released birds from a helicopter, and Bruderer *et al.* (1972) and the authors identified birds flying during the day with telescopes mounted on the radar antenna. The radar signatures obtained in all these studies were usually much more variable than the signatures of birds flying on long straight flights at night.

THE MAJOR PERIODIC fluctuations in radar signature are almost certainly due to movement of the wings in birds and insects (Eastwood, 1967, and Schaefer, 1976). Both high speed photography (Ruppel, 1978) and direct visual observation show that birds are able to change their wingbeat rate by 50% on take off and landing and, thus, it is not surprising to find great variation in the radar signature of a bird flying close to the ground or recently dropped from a balloon or helicopter. Vaughn, using the superb facilities of NASA at the Wallops Flight Center has gone farthest in analyzing these data, and he believes it is possible to remove most of the observed variation by making very precise corrections for rate of climb or fall. These corrections will, however, answer only part of the question; one still must know how variable is the radar signature of a single bird, or, more exactly, a species of birds.

We approached this problem by examining the variability in the radar signatures of unidentified nocturnal migrants tracked over unusually long distances. For this analysis we used tracks of birds obtained with the missile tracking radars at Wallops Flight Center (NASA) between 1969 and 1973. Information on the radars and our tracking techniques may be found in Williams and Williams (1972) and Williams *et al* (1977).

CLASSES OF RADAR SIGNATURES

ALL RADAR SIGNATURES obtained with the radars at Wallops Island fall into one of the four categories shown in Figure 1. The birds giving signatures illustrated in Figures 1a and 1b were identified, in diurnal observations (with a 1 m focal length telescope mounted on the radar antenna), as soaring birds (1a) or a small flock of birds (1b). Neither of these types of signature shows periodic fluctuations. The soaring records however, do illustrate the very great change in average radar cross-section with aspect: the strength of the echo from the Turkey Vulture tracked in Figure 1a varied by more than 40 db (a factor of 10,000) as it circled on a thermal updraft.

Only the signatures shown in Figures 1c and 1d, termed "continuous" and "bursting" are likely to lead to identification of nocturnal migrants. Even these broad categories are not mutually exclusive as occasionally bursting records show 20 to 30 seconds of continuous activity, and continuous records are at times interrupted by brief periods of inactivity. This seems reasonable for the wing-beat patterns of ascending or descending birds; but such changes are also seen in records from birds flying straight and level paths (although the radar track would probably not show deviations of less than 10 m). Thus, even at this stage of analysis there is evidence that migrants may alter flight behavior significantly.

VARIABILITY IN THE RADAR SIGNATURES OF SINGLE BIRDS

ONE MIGHT ASSUME THAT the shape of the signature records—curved, sharp-pointed or rather flat—might be useful, but inspection of even a few such records (see Figure 2) clearly shows great changes in this parameter in a single record. These changes are due to two factors: first, the radar signature records are taken from the Automatic Gain Control (AGC) in logarithmic form and, thus, a sinusoidal record such as that in Figure 1c does *not* indicate sinusoidal changes in the radar reflectance of a bird; and second, small changes in the aspect of the bird relative to the radar (whether the bird is viewed head on, tail on, or broadside) produce very large changes in the radar signature (see Eastwood, 1967). We are, thus, left with the primary frequency of oscillation or fundamental frequency of the radar signature as the most important parameter and will concentrate the remainder of this discussion on that topic.

METHODS

BETWEEN 1969 AND 1973 we obtained over 500 tracks of free flying birds with the large tracking radars at Wallops Island, Va. The two radars used for the data reported in this paper were the SPANDER: 10 cm wavelength, 3.4 MW peak power, beamwidth 0 39° at the 3 db points, and the FPS-16: 5 cm wavelength, 1 MW peak power, 1.2° beamwidth at the 3 db points. We recorded radar signatures every 5 minutes for 20 seconds on a paper chart recorder run at 4 in/sec. for the SPANDAR and at 10 cm/sec. for the FPS-16 radar. The signature in both cases consisted of peak detected Automatic Gain Control voltage. More details of the specifications of the radars used and the procedures followed are given in Williams and Williams (1972).

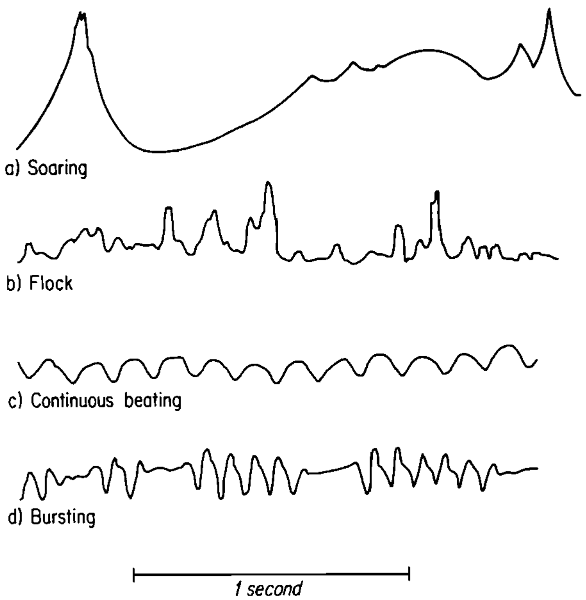

Figure 1. Examples of four types of radar signatures. a and b were from diurnal migrants identified with a telescope during the day. c and d are examples of signatures from nocturnal migrants. Some signatures like c and d have been obtained for 2 to 3 hours with little change

From all available tracks we selected those most likely to give consistent signature records. The criteria for selection were as follows: all tracks had to be straight and relatively level (less than 1 m/sec. rate of climb or fall) and taken during periods of moderate or heavy spring or fall avian migration as determined by radar (see Williams *et al.*, 1977). All tracks had to be more than 15 minutes long, have a low noise level, show clear, regular fluctuations in the radar signature, and have a signal-to-noise ratio greater than 20 db. We were interested only in birds with significant aspect changes in their tracks, and rejected all tracks with aspect changes of less than 45°. Fundamental frequency of the radar signature was determined by visual inspection in those portions of the 20-second records showing the clearest pattern. The distance between peaks at their sharpest points was measured with dividers and converted into an instantaneous frequency. The measurement error of 0.2 mm was the

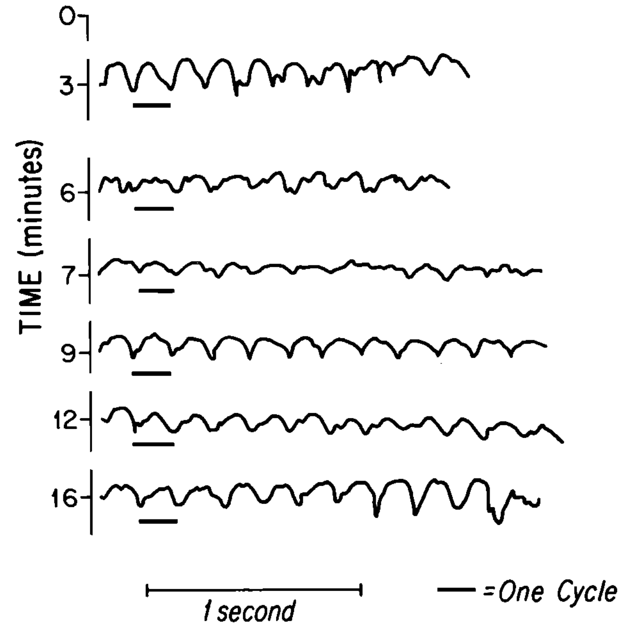

Figure 2. Six radar signatures from a single bird taken at different times. Elapsed time from the start of the track is given for each record. The bar indicates the length of a single cycle of the fundamental frequency of the signature. The length of cycle shown by the bar remains relatively constant but the shape of the signature changes markedly from record to record.

major source of error, especially for records showing high frequencies; at 17 Hz the error would be about 4% and at 8 Hz, 2%.

RESULTS

IF THE FUNDAMENTAL frequency of a radar signature is to be used in identification it must be a relatively unvarying characteristic of the bird. Each of the points in Figure 3 represents the standard deviation (s.d.) of ten measurements of the fundamental frequency of a radar signature. A cross represents the s.d. of ten points evenly distributed over all records available for that bird. A triangle indicates the s.d. for ten points evenly distributed over a 20-second record of radar signature, and a circle shows the variation within ten consecutive cycles of a single record. The data for each bird are enclosed by a dotted line; in cases for which data from two birds are enclosed in the same area, the data are distinguished by open *vs* solid symbols.

Figure 3 shows that the variability in fundamental frequency for nocturnal migrants is often very low (s.d. = 5% in 20-minute flights). In no case did the signatures from migrants show the extreme changes recorded in released birds (Vaughn, 1974; Emlen, 1974). Changes in the fundamental frequency within a 20-second record were rarely greater than changes recorded for 10 sequential wingbeats. This conclusion was tested by comparing the variance of the two sampling methods. Only tracks (B and F) gave significant F ratios ($p < .01$) and in both cases the significant difference was entirely due to a single aberrant point.

It thus appears that the radar signature of these birds is quite constant over relatively short periods of time (20 seconds). Is the same constancy true over periods of 20 minutes? To test this we subjected the measurements taken from different records but for the same bird track to an analysis of variance. Five of the records (B, D_2, E, F, G_2) showed no significant difference in the fundamental frequency over all the records for that track. One (A) showed a difference at the $p < .05$ level of confidence and four (C_1, C_2, D_1, G_1) showed differences at the $p < .01$ level of confidence. Thus, in most cases the variability in long records was similar to that in short records, but in four cases the fundamental frequency was significantly different at various times in the same track. If we had been using a less powerful radar which could only track these birds for 5 minutes we would have concluded that the different parts of what were in fact one track were different birds or perhaps different radar species.

For those tracks exhibiting a "bursting" type of signature (see Figure 1), the relative length of the active and inactive phases has been used to distinguish different types of signatures (Bruderer and Steidinger, 1972). Although the tracks of birds we used were nominally straight and level there were departures from absolutely level flight. In Figure 4 we plot the percent time in the active phase *vs* the rate of climb or fall. This figure contains data from those tracks with bursting signatures which showed more than .25 m/sec. change in the rate of climb or fall during their

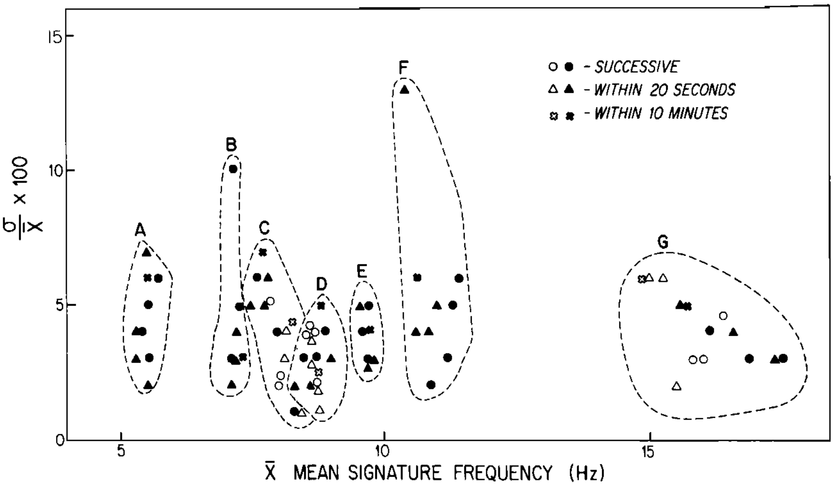

Figure 3. Standard deviation in the fundamental frequency of radar signatures as a function of the average fundamental frequency. Symbols represent data from different sampling techniques (see text). Data from one or two tracks are enclosed by a dotted line. Open and closed symbols distinguish data from different birds. Data sets are identified by letters; when two birds are identified by the same letter, the one with the lower average fundamental frequency (x) is referred to as C_1 and the other as C_2.

track. The relationship between rate of climb or fall and relative length of the active phase is apparent even for these very small rates of altitude change. Percent activity within a signature is, thus, a very labile aspect of the radar signature and might change as birds encountered slight updraft or downdrafts on even straight and level flights. Emlen (1974) reports similar findings for White-throated Sparrows (*Zonotrichia albicollis*).

In conclusion, the fundamental frequency of the radar signature appears to be the most reliable indicator for species identification, with class of signature (bursting *vs* continuous) and percent time beating for bursting signatures being less reliable. Vaughn (1978) using very long records of flights with a sophisticated system for determining frequency from tape recorded AGC output shows correlations between rate of climb or fall, airspeed, and the signature frequency which may considerably reduce variation in the fundamental frequency that we found.

VARIABILITY IN THE OBSERVED FLIGHT BEHAVIOR OF BIRDS

IF WE ARE TO USE the radar signatures described above to identify birds, we

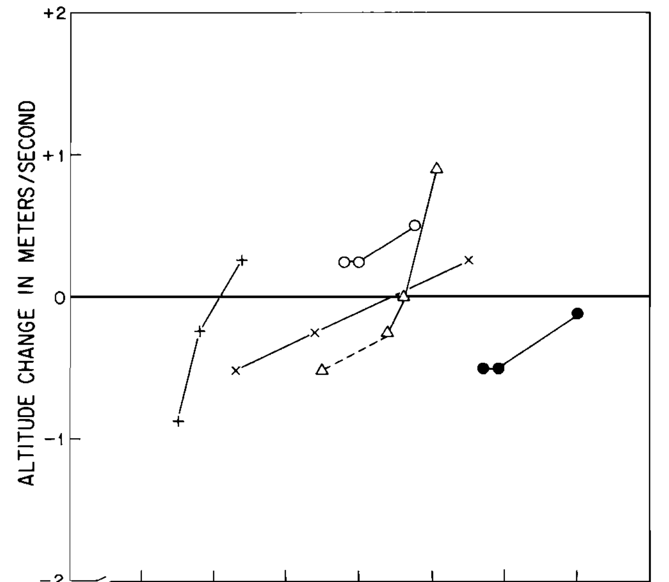

Figure 4. Variation in the relative length of the active and inactive phases of "bursting" radar signature records with change in rate of climb or fall.

must have information on the flight behavior of identified birds under similar circumstances. We first approached the problem by making high speed films of birds flying during the day near the ground. Almost none of these films was of birds making straight, level, long distance flights. As might have been predicted, analysis of such films showed great variability (up to 100%) in the wingbeat frequency of the birds. We, therefore, are suspicious of the values for both airspeed and wingbeat frequency (see Greenewalt, 1975 for review) which have been published for many species of birds. We then attempted to track migrants during the day with radar and identify them with large telescopes as they flew near the radar. This proved most frustrating as the closest distance which a bird could be followed with these large radars was very near the greatest distances that a bird could be identified with the best optical equipment. Reliable results could only be obtained with diurnal migrants such as waterfowl. (The tabular results of this work will be sent to readers on request.)

Accurate airspeeds and wingbeat rates might be obtained from birds released from helicopters or balloon and then tracked by radar. However, as we mentioned before, such birds often seem disinclined to begin their migratory journeys after this treatment. Emlen and Demong's (1978) work on White-throated Sparrows seems to be a step forward, as some of the many birds they released did appear to begin straight and level flight in an appropriate migratory direction, but the effort involved in obtaining these data for even a single species was very great and probably is not possible for a large number of species. Vaughn's approach of correcting observed flight behavior for departures from straight and level flight holds promise but needs to be widely applied before it can provide a means of identifying unknown nocturnal migrants.

Despite high technology and the dedicated work of many scientists we still remain at the impasse stated as we began this paper. Radar offers the possibility of identifying nocturnal migrants flying beyond the limits of human vision. On the basis of the observed variation in airspeeds alone and the variations in fundamental frequency we found, it seems likely that radar signature and airspeed might reliably distinguish 50 to 100 different "radar" species of birds under the best of conditions with a conservative estimate being about 30 radar species. However, at present we lack the information on the flight behavior of identified migrants needed to make use of these radar identifications.

Observations of the flight speed and wingbeat rate of birds should also specify the direction and speed of the wind and should assure that the tracks are straight and level for a distance of perhaps half a kilometer or more. To be sure, such observation conditions are not easy to come by and yet some readers of this journal may well have encountered such an opportunity, perhaps during the early morning reorientation flights of nocturnal passerine migrants. If such data are at hand or could be easily obtained, they would be of great interest to those of us who use radar.

ACKNOWLEDGEMENTS

WE THANK THE MANY people on the staff of Wallops Station, NASA who assisted in this work. Many friends and graduate students assisted in obtaining the radar signatures. In particular we wish to thank Carol McClintock for her assistance in analyzing the signatures and her helpful comments on the manuscript. Charles Vaughn of NASA assisted in elucidating many of the more technical aspects of this problem. This research was supported by the National Science Foundation grants GB 13246 and 43252 to the Woods Hole Oceanographic Institution and NASA contract NGR 33-183-003 with the State University of New York.

SUMMARY

THE VARIABILITY OF THE radar signature of *enroute* nocturnal migrants in nearly steady state flight was determined for flights of 15 to 20 minutes.

The fundamental frequency of the radar signature was the only parameter judged to be a reliable discriminator of different signatures.

Although the standard deviation of the radar signatures was low (about 5%) several signatures from single birds showed significant changes over the period of observation.

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