Estimated flight time for transatlantic autumnal migrants

Radar indicates that small birds may take more than 80 hours to accomplish a 3500 km nonstop flight.

Timothy C. Williams, Janet M. Williams, Leonard C. Ireland and John M. Teal

ABSTRACT

A network of nine radar sites was used to estimate the flight time of autumnal migrants crossing the western North Atlantic Ocean between the northeastern North American coast and Bermuda and Antigua, West Indies. Arrival of large numbers of birds at Bermuda showed a significant increase during the day with a peak of 1600 G.M.T.; if this peak corresponds to the sharp onset of departures after sunset recorded at North American coastal sites, a flight time of approximately 18 hours between the coast and Bermuda is indicated. Arrival at Antigua of large numbers of birds from the north and northeast showed a gradual increase during the day. Observations at North American coastal radars indicated that departures were most likely to be moderate or heavy 64-70 hours before significant numbers of birds were detected at Antigua. After passing over Antigua, the birds presumably arrived at the northern coast of South America about 18 hours later.

Introduction

In a recent issue of this journal (*AB* 31:251-267) we reported observations made with a network of up to nine radar sites in the area of the western North Atlantic Ocean (Williams *et al.*, 1977). In that paper we showed that large numbers of relatively small, relatively slowly-flying birds make a nonstop flight from the eastern coast of North America to the Caribbean and South America each fall during late September and early October. In the present paper we use the data from these radars to estimate the time needed to accomplish this long, over-water flight.

Methods

A complete description of the radars used for these observations will be found in Williams *ibid.*

In all years, observations were made during the last week of September and the first two weeks of October. Some years, observations at some stations were extended an additional week before or after this time period (*q.v.*, Williams *op.cit.*, for dates of operation).

At most radar sites we were able to observe for six to eight hours per day. At Halifax, Cape Cod, Wallops Island and Miami, observations usually began shortly before local sunset and continued until midnight (2000-0400 G.M.T.). Most observations at Bermuda were made between 0800 and midnight (1200-0400 G.M.T.) with less than 10% of all observations being made at other times. The approximate distribution of observations at Bermuda and Antigua may be obtained from the number of observations in each 2-hour period in the lower histograms of Figs. 2 and 3.

Radars in the Caribbean operated only 0800-1600 local time (1200-2000 G.M.T.). On three occasions radar operators operated at night for our benefit. At all sites observations were interrupted by equipment failures or other projects with higher priority. At Wallops Island, Bermuda and the Caribbean sites radar observations were not usually possible on weekends or holidays.

As described in Williams *id.*, data were obtained by time exposure photographs which recorded the position of targets on the radar Plan Position Indicator (PPI) display (*q.v.*, Eastwood, 1967, for further information). Slowly-moving targets produced streaks on the photographs indicating direction, density, and speed of movement of migrants (*q.v.*, Gauthreaux, 1970). PPI photographs were scored on a relative 4-point density scale (no movement, light, moderate, or heavy) established for each radar. The reader is also referred to Williams *id.*, for definitions of terms used in this paper, methods of scoring and analysis of radar data, and sources of meteorological data.

Results

NIGHTFALL AND THE PASSAGE of a cold front over the eastern coast of North America in the fall will typically trigger the southeastward departure of several million birds over the western North Atlantic (Drury and Keith, 1962; Drury and Nisbet, 1964; Richardson, 1972; Williams *et al.*, 1977). Many, but not all, of these birds continue their southeast flight over the area of Bermuda (Williams *op.cit.*). The flight path of these birds is altered in the area of the Sargasso Sea by the strong northeast trade winds and the birds are drifted westward toward the Caribbean and South America under the influence of these easterly winds (Williams and Williams, in press).

Radar sites used for determining the time of departure from the North American coast were located at Halifax, Nova Scotia; Cape Cod, Mass.; and Wallops Island, Va. Arrival of birds was detected by radars at Bermuda, Antigua and Barbados (in the Caribbean), and Tobago (150 km from the South American coast).

At all radar sites, migration occurred in waves; several days might pass with little or no activity followed by the passage of large numbers of birds for a day or two. The intervals between migratory activity were more pronounced at sites farther from the coast. At coastal sites there was almost always some bird movement at night. At Bermuda there were short periods when we failed to detect significant number of birds. In the Caribbean it was common to have several days pass without detecting migrants. As was also noted by Richardson (1976), the onset of migration in the Caribbean was not as sharply delineated as the sudden jump in density at coastal sites just after sunset. At Bermuda a density change from light to heavy was not observed to occur in less than two hours, and in the Caribbean such changes in density were not recorded in time spans of less than six hours. Thus autumnal migrants appear to depart as a coherent mass from coastal sites but then spread out considerably as they move over the Atlantic.

UNFORTUNATELY FOR OUR ANALYSIS, waves of migrants moving across the Atlantic did not occur as clearly defined pulses of activity. Departures from the coast were likely to occur for two or three consecutive nights with activity varying at different points along the coast. Additionally, not every departure from the coast was followed at a reasonable interval by radar observations of large numbers of migrants in the Caribbean (*q.v.*, Williams *op. cit.*). We therefore concentrated on determining the most probable times of departure for the migrants we observed moving over Bermuda and Antigua.

To estimate the birds' flight time between the North American coast and Bermuda, we first selected days of moderate or heavy migration at Bermuda. Each 2-hour interval (within those days for which we had data) was then classified as light, moderate, heavy or no migration. (Chi Square tests were used to determine whether the observed distributions differed significantly from a uniform distribution. The probability of an event occurring by chance alone as indicated by these tests is given at appropriate points as $p<.05$ or $p<.01$.) These data are presented in the form of histograms in Fig. 1. Each bar of the histogram indicates the percentage of bird movements classified as moderate (shaded) or heavy (solid). The number of observations is given above each bar; if there is no number for a 2-hour period, there were fewer than three observations at that time and the data were excluded. The two parts of the figure share a common and continuous time scale which has been offset to separate the Bermuda observations from those on the coast (see below).

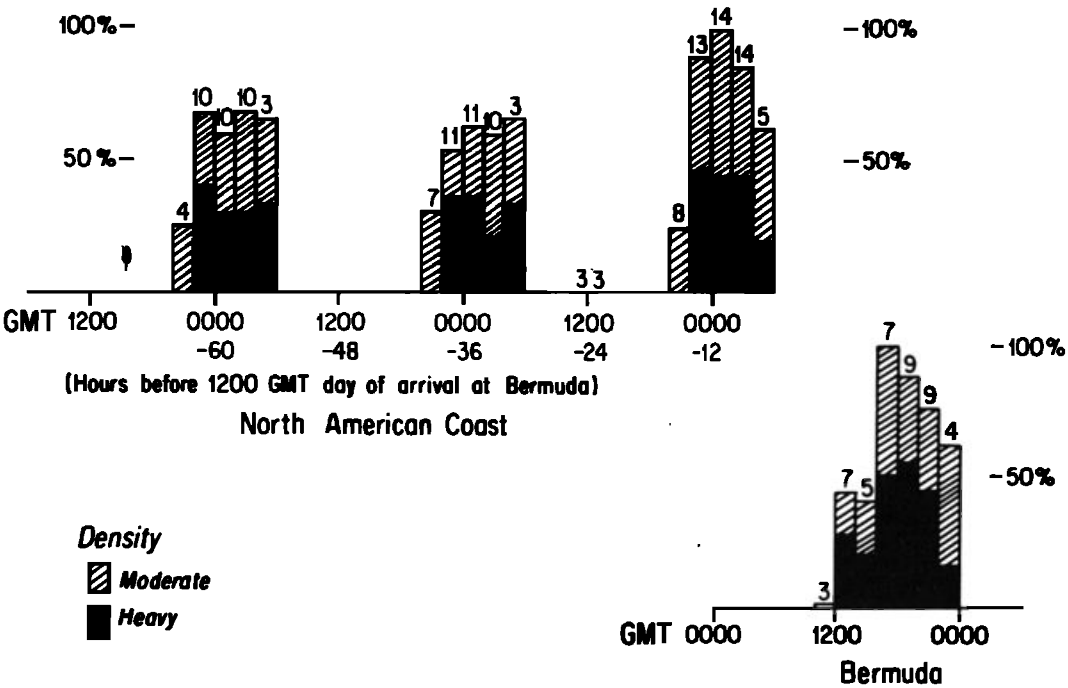

Figure 1. Density of migration at Bermuda and coastal radar sites. Lower histogram shows frequency of moderate and heavy migration by 2 hr intervals for those days during which a moderate or heavy migration was recorded at some time at Bermuda. Each bar indicates the percent of days during which a moderate (hatched) or heavy (solid) migration was recorded during that 2 hr period. Upper row of histograms gives the distribution of moderate and heavy offshore (90° to 190°) migrations recorded at radar sites on the North American coast, 1, 2 and 3 days before the day of arrival at Bermuda. All times G.M.T. Number of days of observation including days with no or light migration are given above each bar in histogram. Figure includes all data for which observations were made on at least 3 days during a given time period. Time is G.M.T. (subtract 4 hrs for Eastern Daylight Saving Time or Bermuda Local Time).

A sharp increase in density tended to occur at about 1600 G.M.T. (local noon) at Bermuda ($p<.01$), as shown in the lower histogram of Fig. 1. All available data from Halifax, Cape Cod and Wallops Island were used to determine the maximum density of offshore departures by 2-hour periods for the North American coast (upper row of histograms, Fig. 1). We did not make diurnal observations for most sites since Drury and Keith (1962), Drury and Nisbet (1964), Swinebroad (1964) and Richardson (1972) reported that major departures usually begin between sunset and and midnight. Figure 1 indicates that *migration on the North American east coast is most likely to be moderate or heavy the night before migration is detected in Bermuda* ($p<.05$). The abrupt increase in migration at Bermuda at about 1600 G.M.T. is, therefore, probably owing to the arrival of large numbers of birds which departed the North American coast shortly after sunset the previous evening, a flight of *ca.* 18 hours.

Figure 2 presents the same sort of analysis for birds arriving at Antigua from the north and northeast. The lower histogram in Fig. 2 does not show a sharp increase in density, as did the similar data for Bermuda. Instead there is a slow but statistically significant ($p<.05$) increase during the day (nocturnal data were not available). The upper row of histograms shows that departures of birds from the North American east coast were most likely to be heavy three nights before we detected migration at Antigua ($p<.05$). If the slow increase in density of bird migration recorded at Antigua corresponds to departure from the coast just after sunset, the data in Fig. 2 suggest a transit time of 64-70 hours. Large numbers of slower migrants could have taken up to 84 hours and still have escaped detection owing to our lack of noc-

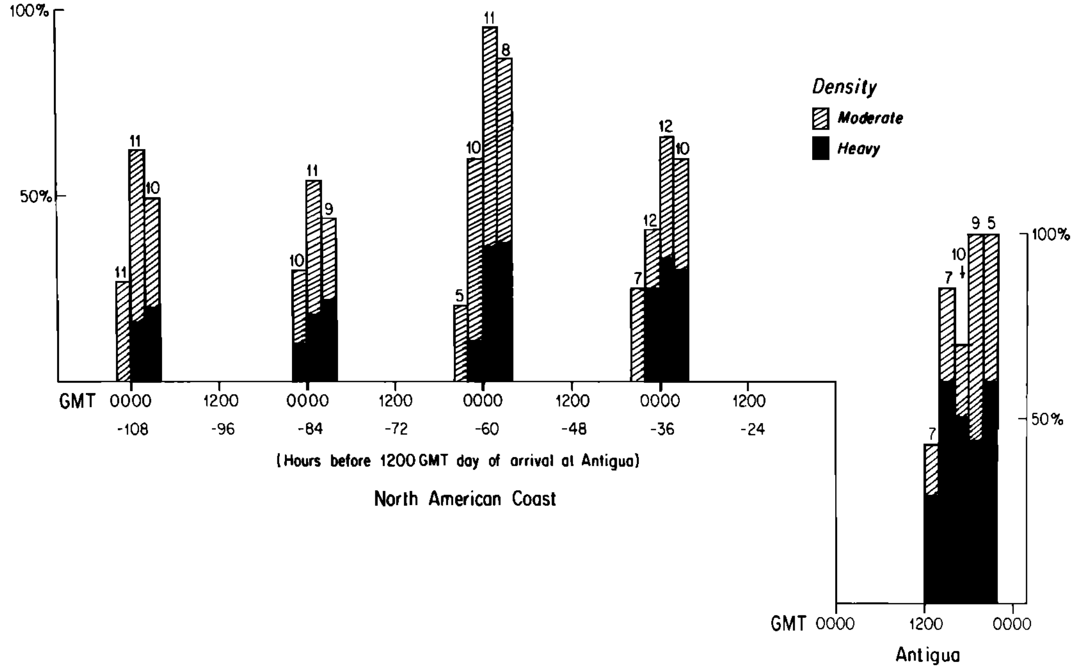

Figure 2. Density of migration at Antigua and coastal sites. Lower histogram shows the distribution of moderate and heavy migrations with directions from 170° to 270° for those days during which a moderate or heavy migration was recorded at Antigua. Upper row of histograms gives the distribution of moderate and heavy offshore (90° to 190°) migrations recorded at radar sites on the North American coast 2, 3, 4 and 5 days before the day of arrival at Antigua. Symbols and presentation of data as in Fig. 1.

turnal observations at Caribbean radars.

TO DETERMINE MIGRATION TIMING and routes accurately, it would be necessary to operate a large number of stations along the east coast, in the Caribbean, and at intermediate points. This condition was approached in 1973 with a total of eight stations operating. In addition to these land-based stations, radar observations were made from a ship in the North Atlantic as described by McClintock *et al.* (in press). The sequence of events following the departure of birds from the United States coast October 3, 1973 is illustrated in Fig. 3, in which symbols for bird movements and wind velocities are superimposed on satellite photographs of the study area.

Figure 3a shows the beginning of a departure from the North American coast. A cold front had must moved offshore from Cape Cod to Florida. As indicated from cloud patterns, this front crossed the shoreline between Cape Cod and Halifax. Heavy movements along the coast and offshore were recorded that night at Wallops Island. Figure 3b shows the pattern of bird movement the next day The frontal system had become stationary between Bermuda and the coast. Birds penetrated the frontal system moving southeast over the ship all day and reached Bermuda by mid-afternoon. On October 5, Fig. 3c, these birds were probably between Bermuda and the Caribbean, beyond the range of our radars Bird movements at the ship (*ca.* 400 km northwest of the front) appeared to be scattered in all directions, although the bird density was scored as heavy (see Williams and Williams, in press, for a discussion of this phenomenon) Figure 3d shows large numbers of birds reaching the Caribbean October 6, with heavy movements reported at Antigua at 1600 G.M.T. (transit time *ca.* 64 hours) and Barbados in the evening (transit time *ca.* 72 hours). Operations at Tobago were suspended at noon (it was a Saturday), and by that time no major movement had been detected.

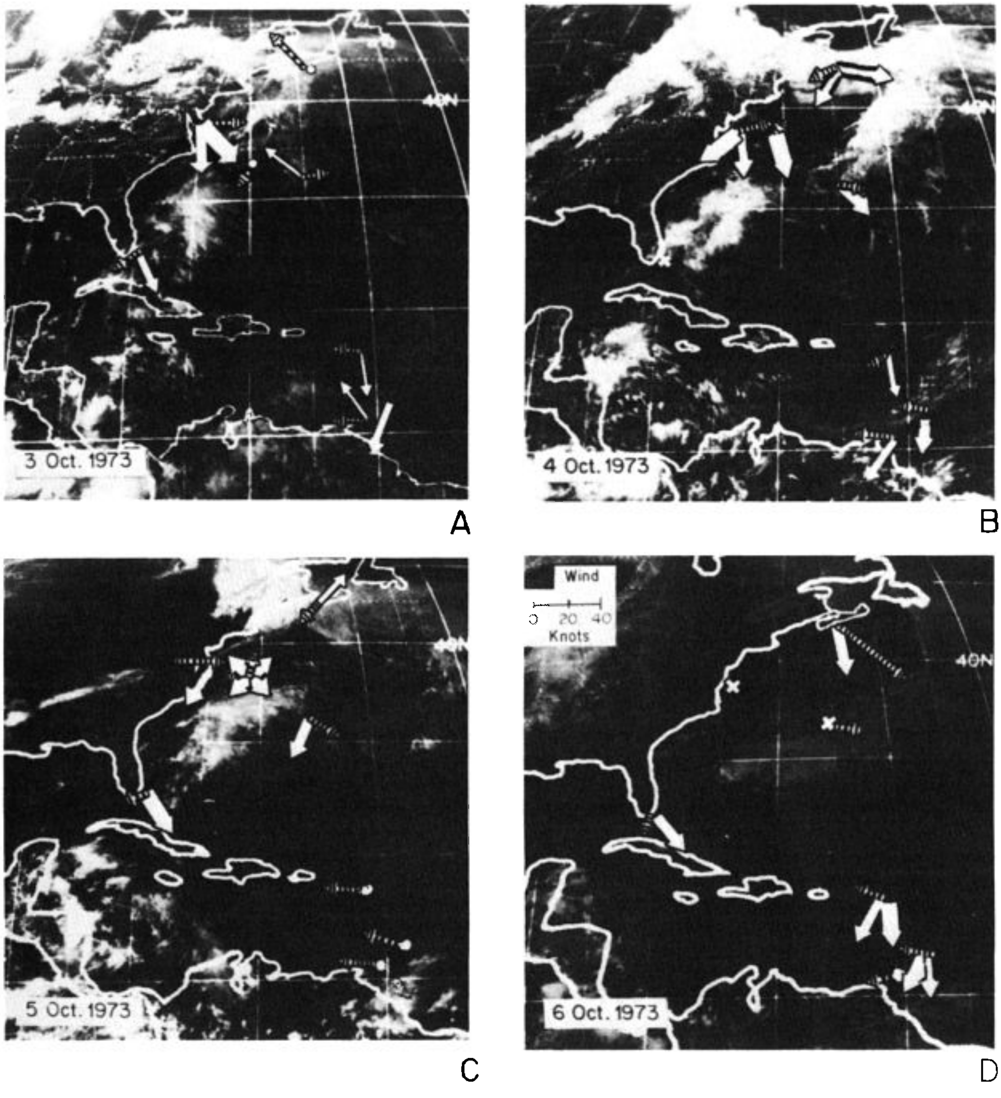

Figure 3a, b, c, d. Bird migration over the North Atlantic Ocean. Average direction of bird migration and direction of wind superimposed on weather satelite photographs of the western North Atlantic Ocean. Satellite photographs taken at 1900 G.M.T. Data for Halifax, Wallops Island and Miami taken from about local sunset to midnight. Data for Bermuda, Antigua, Barbados and Tobago taken from 0900 to 1700 local time. Data from ship gathered from 0800 G.M.T. to 0800 G.M.T. the next day. Coastlines outlined in white. Solid arrows indicate direction and density (light, moderate, heavy) by width of arrow. Solid dot indicates no detectable migration; an X no observations. Dotted arrows give wind velocity at the average altitude of birds taken within 4 hrs of the radar observations; speed scale for wind in Figure 4d.

As reported by Williams *id.*, radar does not indicate birds landing at Antigua; only at Tobago does low altitude flight suggest termination of migration. Thus, the total nonstop flight for birds moving across the Atlantic should probably include the 800 km between Antigua and the South American coast. If birds covered this distance at the average speed observed at Antigua (43 km/hr), the continuation of the flight to South America would take approximately 18 hours. Thus our data suggest the total nonstop flight between northeastern North America and South America is probably *ca.* 82-88 hours.

Discussion

THE RESEARCH REPORTED here was performed on a time-available basis at the radar installations; thus, there are many gaps in our observations. Most serious of these is the lack of nocturnal observations in the Caribbean and to a lesser extent at Bermuda. Thus, the estimate of flight time to the Caribbean may be in error by 12 hours and we might have missed a second peak in arrivals at Bermuda after midnight. In both cases this would increase the estimated flight time. Greenewalt (1975) has recently reviewed the aerodynamics of bird flight and concludes that the Blackpoll Warbler *(Dendroica striata)* should be able to fly about 3400 km nonstop. The calculated velocity for maximum range is 34 km/hr (Greenewalt *ibid.*) for this bird, suggesting the capability of flight for 100 hours, which is somewhat greater than the estimate by Nisbet *et al.* (1963) of *ca.* 80 hours. Estimates of maximum flight duration derived from wind tunnel studies (Tucker, 1968, 1972; Torre-Bueno, 1976) produce lower estimates of maximum flight duration (*q.v.*, Greenewalt, *id*), *ca.* 60 hours for small birds. Our observations support these aerodynamic calculations and suggest that measurements in wind tunnels may overestimate the metabolic cost of flight to free-flying birds. A second possibility is that migratory birds may use local wind conditions to reduce the energetic cost of flight; such an effect was clearly shown in radiotelemetric studies of free-flying gulls (Kanwisher *et al.*, in press).

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— *Swarthmore College, Swarthmore, Pa 19081 (Williams and Williams), 2221 E. Court St., Flint, Mich. 48053 (Ireland), Woods Hole Oceanographic Institution, Woods Hole, Mass. 02543 (Teal).*