THE EFFECTIVENESS OF AIRCRAFT-TYPE (APS) RADAR IN DETECTING BIRDS

Richard R. Graber and Sylvia Sue Hassler

Radar has proven itself a useful tool in ornithological studies (Lack, 1959*a*, *b*; and 1960 *a*, *b*). Lack and others have used high-powered weather radar to detect birds, and this technique along with the lunar-observation and audio-observation methods holds great promise for solving problems relating to bird migration.

In the fall of 1959, Frank C. Bellrose, William W. Cochran, and Graber inaugurated a radar study of nocturnal migration of birds in Illinois, supported by the National Science Foundation and the State Natural History Survey. Most of our data on migration will be presented in subsequent papers. For the benefit of others who may wish to use aircraft-type radar in migration studies, the present paper deals with the method and its effectiveness.

Data for this particular study were collected at the University of Illinois airport, Champaign, Illinois.

METHODS

Aircraft radar (AN/APS series) are readily obtainable and though they are less powerful than the large, fixed base weather radars, we found it expedient for financial reasons to try detecting migrants with the smaller set.

An APS–31 radar was installed in a small building on the University of Illinois airport in an open area free from obstructions. The regular antenna for this set did not provide a 360° sweep and was replaced with an antenna from an APS–15 radar. With this antenna, a parabolic dish about 29 inches in diameter, the radar beam width was about 3 degrees to the half-power points.

The APS–31 radar has a wave length of 3 cm and utilizes about 9 amperes at 115 volts, 400 cycles and 40 amperes at about 28 volts dc. The transmitter-receiver frequency is 9,375 megacycles and the peak R-F output—52 kw. For the 5-mile range used in this study, the output pulse duration was 0.5 microsecond, 800 pulses per second. The antenna rotated at the rate of about 10 rpm.

The antenna was fixed on a pivot so that it could be set to sweep 360° either in a vertical plane—perpendicular to the horizon (Fig. 1), or on a horizontal plane (Fig. 2). For the migration study the antenna was usually set for horizontal sweep tilted 30° above the horizon.

The radar had two 5-inch diameter indicators (scopes), one for direct viewing and a second to which a 16-mm motion picture camera was mounted.

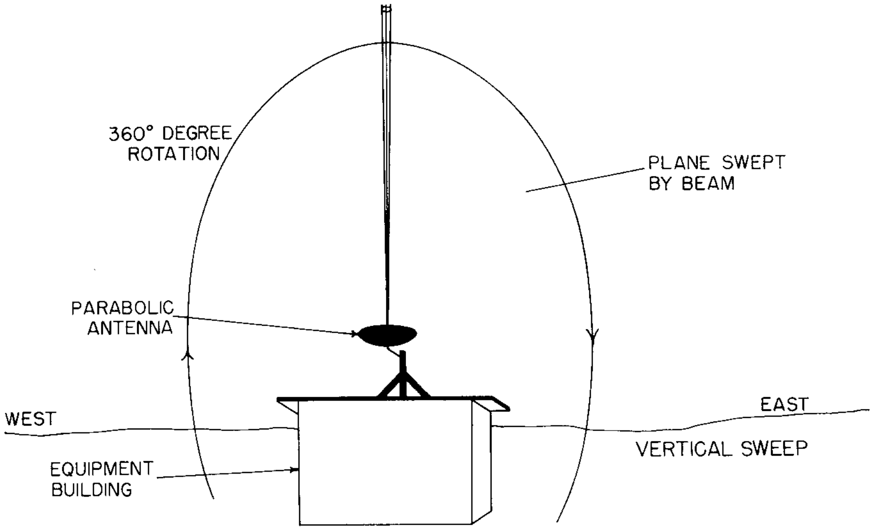

FIG. 1. Diagram showing 90° (vertical) scan of radar antenna. Radar beam rotates 360°, sweeping in an east-west plane. Beam width is approximately 3° to the half-power points.

The camera with single-frame action was modified so that the shutter remained open except when the film was advanced. It was triggered through a timing mechanism which advanced a single frame at regular intervals. The lengths of exposure could be varied and, in practice, we usually used exposures of one or two minutes.

In our migration study the radar was usually operated from just before sundown to sunup. On the night of 28–29 September 1960, beginning at 1830 CST, William Cochran and Graber attended the radar throughout the night, switching the antenna at roughly ½-hour intervals from 30° (horizontal) to 90° (vertical) scan until 0100 when the antenna was left on vertical. During the periods of vertical scanning we also observed migrants in the beam of a floodlight. The floodlight consisted of twelve 250-watt reflector lamps mounted in a line on a 6-foot board. This battery of lights was beamed directly upward to cover the same area as a portion of the vertical radar sweep. Using the lights and radar simultaneously, one observer manned the radar indicator to look for targets directly above the radar, while the other observer lay on his back with 7 × 50 binoculars looking up the light beam. Using comparative data from vertical versus horizontal scanning, and flood-

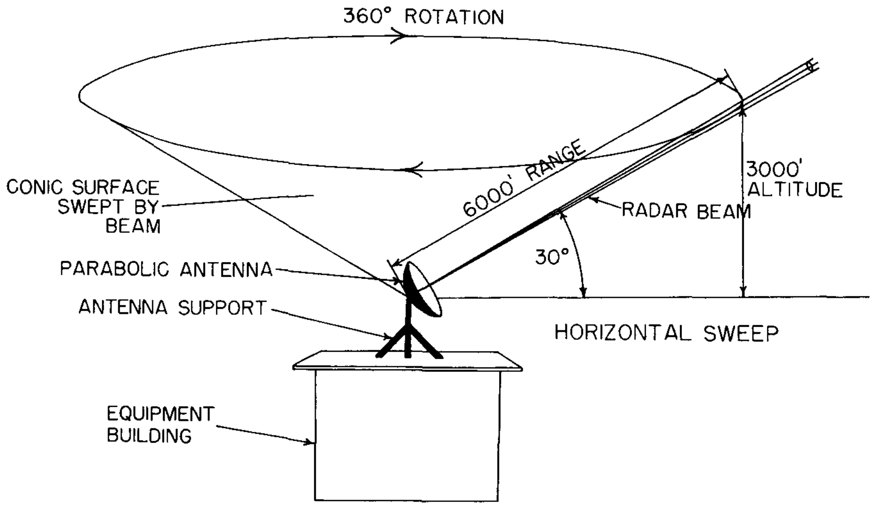

FIG. 2. Diagram showing 30° (above horizontal) scan of radar antenna. Radar beam reaches upward one foot of altitude for every 2 feet of range.

light observations, we were able to learn something of the characteristics and limitations of the radar in bird detection.

Most of the data reported represent the night of 28–29 September, but for the brief discussion of different types of targets we have selected photographs from our collection of radar film representing two years of data collecting.

The identification of targets in our photographs is based on direct identification with the use of lights as described above, and, in part, on aural identification and seasonal distribution of the targets during the two years of study. Characteristics of the echo track, such as shape and speed, are also helpful.

EFFECTIVENESS OF THE APS RADAR

The APS–31 may be considered typical of a whole series of airborne radars with peak output of about 40–50 kw. Because of its wave length and power characteristics, we expected it to be capable of detecting birds, but did not know how effective it would be in this task.

The night of 28–29 September brought one of the heaviest flights of migrants through the Champaign region recorded in 1960. On both vertical (Figs. 1 and 3) and horizontal scan (Figs. 2 and 4) numbers of targets were apparent on the scope, and from our radar film for this night we collected data on over 18,000 bird targets.

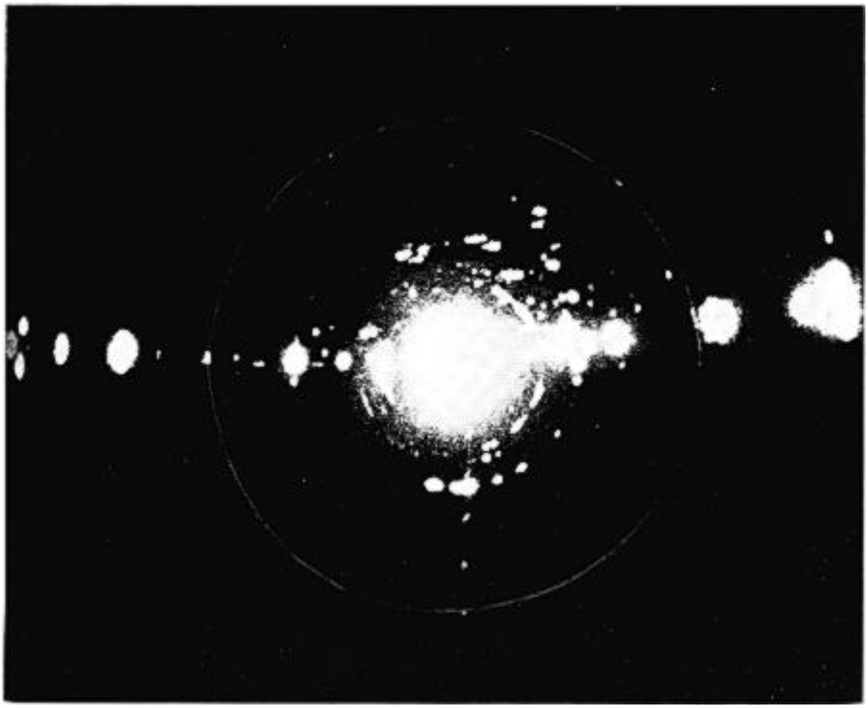

FIG. 3. Enlargement of a one-minute exposure of a 16-mm-radar-film frame showing presentation on radar indicator (scope) with antenna on 90° (vertical) scan. Circle indicates two nautical miles from radar antenna. Large white marks to left and right of center are ground targets showing actual horizon. White spots above horizon are passerine birds. White spots below horizon are ground targets from spurious radar beams deflected from roof of radar building.

When the antenna was scanning vertically, we could see occasional targets which appeared to be directly over the radar shack. With the floodlights on, we could see through binoculars that these radar targets were reflections from single passerine birds. In about one hour we saw 14 targets which appeared to be directly over the radar shack. Eleven of these were observed in the lights. According to the range markers on the radar scope these targets ranged in altitude from 4,500 to 9,000 feet, and even the highest was detectable in the lights. It was not possible to accurately identify the birds as to species. From the reflected light all appeared whitish below. There appeared to be two sizes of birds, but all that we saw were passerines. The fact that the birds were seen singly is in keeping with lunar observations, as recorded by Lowery (1951)

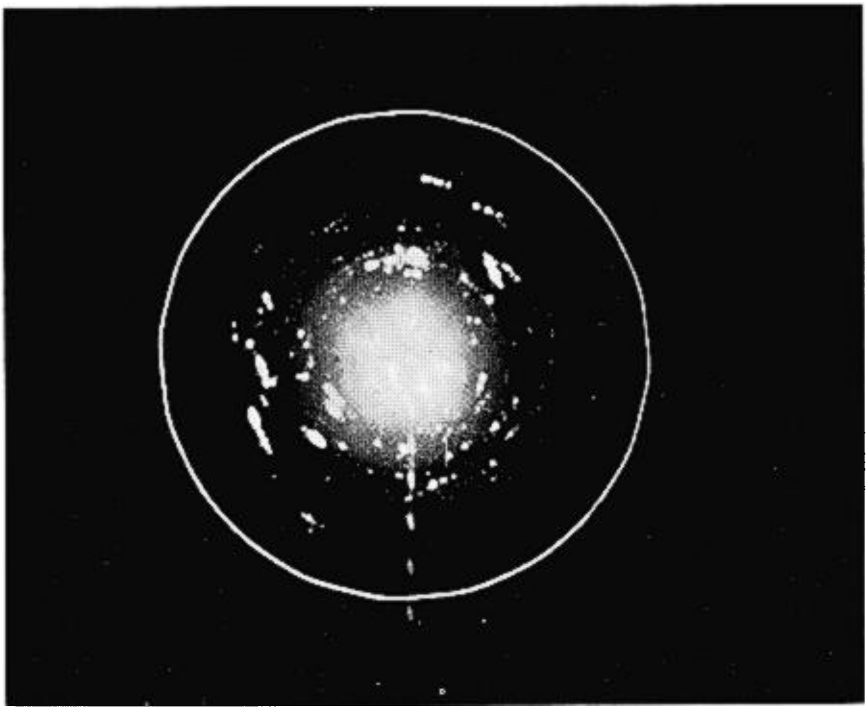

FIG. 4. Enlargement of a 16-mm-radar-film frame (1-minute exposure) showing presentation on radar indicator with antenna on 30° (above horizontal) scan. Circle indicates two nautical miles from radar. White center represents radar recovery time and some ground clutter. Distinct white spots and streaks out from center are typical echoes from passerine birds. Streaks show track of a bird flying tangential to the sweep, the bird having been intercepted by the radar beam in several rotations of the antenna. Single white spots are echoes from birds intercepted only once by the radar beam. Altitude of each target is ½ of the range.

and others, which show a uniform, not a flocked, distribution of migrants at night. The echoes observed on the radar indicators were distinct bright points of light the size of large pinheads.

On vertical scan such targets were usually picked up only in one sweep of the radar beam, but sometimes in two consecutive sweeps (Fig. 3). On 30° scan targets moving tangential to the sweep at constant altitude were picked up repeatedly by consecutive sweeps of the beam (Fig. 4). Echoes from the moving bird left a trace (a line or a series of points) on the scope which marked the progress of the bird showing direction of the movement and roughly the speed (Fig. 4).

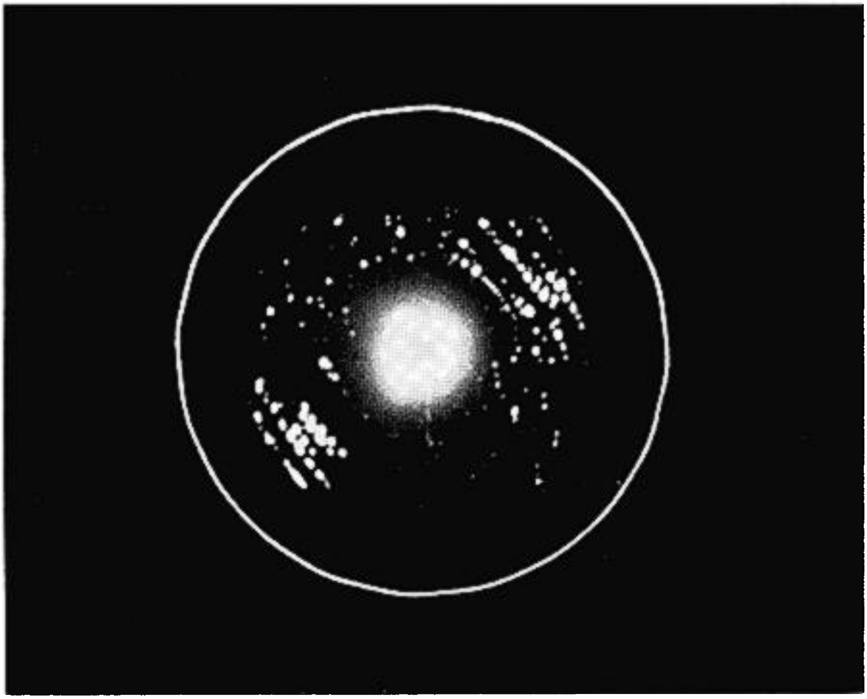

FIG. 5. Enlargement of a 16-mm-radar-film frame (2-minute exposure) showing presentation on radar indicator with antenna on 30° (above horizontal) scan. White center ring represents radar recovery time and some ground targets. Distinct white streaks and spots out from center are typical echoes from waterfowl. Rows of spots show tracks of a waterfowl flock intercepted repeatedly by radar beam in several rotations of the antenna. Single white spots are echoes from birds intercepted only once by radar beam. Altitude of each target is ½ of the range (22 October 1960, Champaign, Illinois).

The targets shown in Figs. 3 and 4 are typical of single passerine birds. Waterfowl (Fig. 5) are usually flocked in migration, but the difference in the size of the echo from a flock of large birds and that for a single small bird is not proportionate to the actual difference (see Figs. 4 and 5). Airplanes (Fig. 6) are more highly reflective even than waterfowl flocks, and, of course, have higher velocity. Approximate average speeds for the three types of targets figured are 40 mph, 80 mph, and 200 mph for, respectively, the passerine, waterfowl, and airplane targets. Precipitation targets—rain, snow, etc.—(Fig. 7) may cover up bird echoes, but the two types could not readily be confused. Heavy concentrations of insects are detectable by radar, and in the few

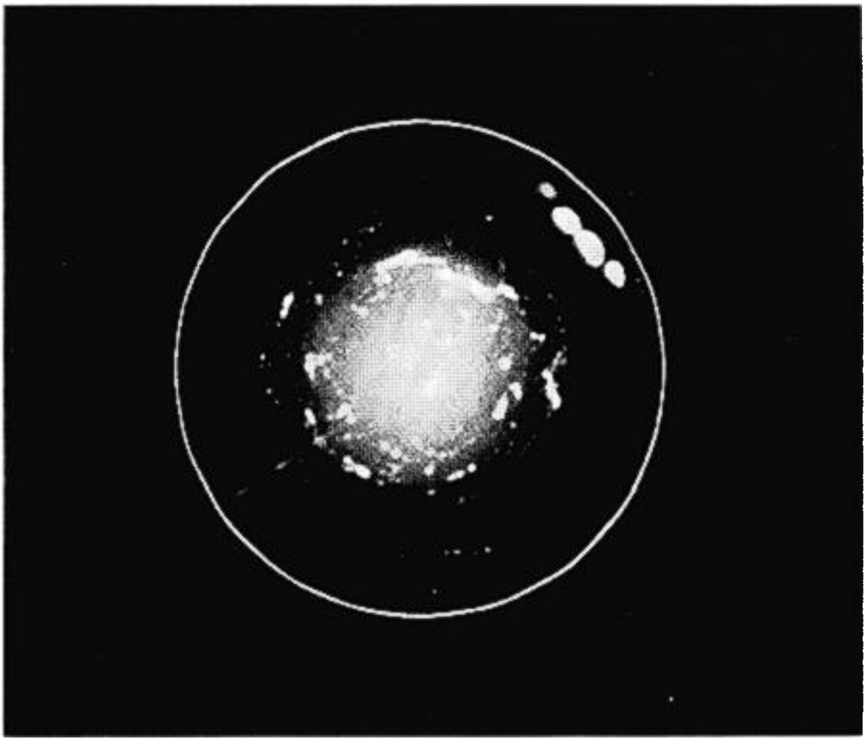

FIG. 6. Enlargement of 16-mm-radar-film frame (2-minute exposure) showing presentation on radar indicator with antenna on 30° (above horizontal) scan. Large white spots near range mark show track of airplane intercepted in four rotations of the radar beam.

instances when we have observed such phenomena the echo was most like precipitation.

Comparison of data from vertical and horizontal scan.—In the following discussion certain basic and inherent characteristics of the technique of observation should be borne in mind.

On 30° (horizontal) scan the center of the radar beam reaches an altitude of 1 mile for every 2 miles of range where range is the straight-line distance from radar antenna to target. On 90° (vertical) scan the altitude-range relationship of the beam varies from place to place in the scan, but at the zenith, 1 mile of range equals 1 mile of altitude.

Because the radar transmits roughly a 3° beam of energy, the area of coverage of the beam increases with range. Thus, the diameter of the beam

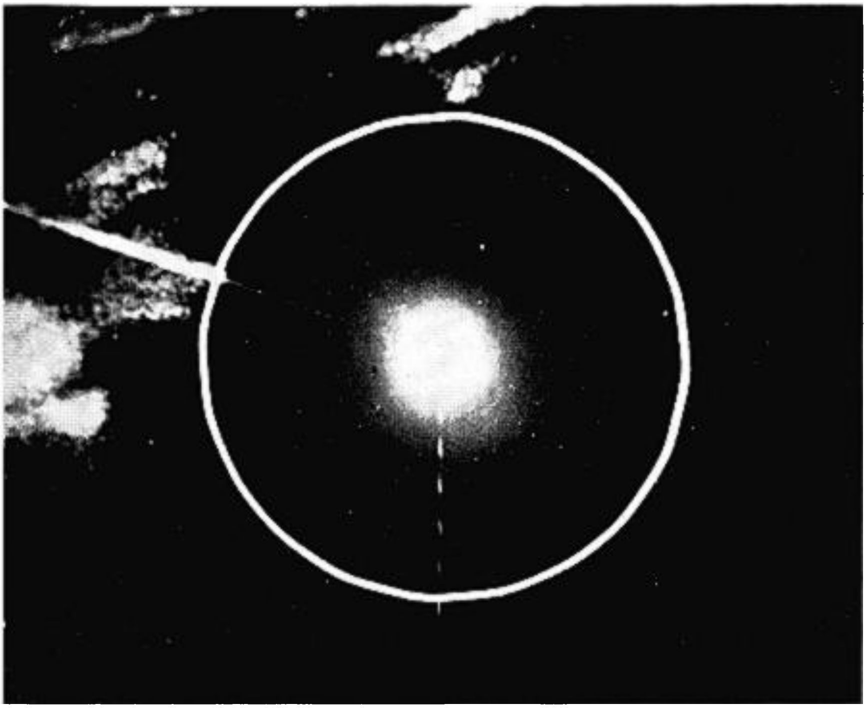

FIG. 7. Enlargement of 16-mm-radar-film frame (2-minute exposure) showing presentation on radar indicator with antenna on 30° (above horizontal) scan. Trace of radar beam may be seen to left of center, intercepting areas of rain at altitudes above 6,000 feet.

at a range of 2,000 feet would be about 105 feet while at range 6,000 feet the diameter would be about 314 feet. While the area of coverage increases with range, the radar energy is also diffused as the range increases. These two opposing factors affect the probability of detecting a given target at a given range.

The difference in results from the two types of scan is at once apparent (Fig. 8). Vertical scan showed a broader altitudinal distribution of birds than did 30° scan. Minimum and maximum altitudes recorded from the two points of view were, respectively: vertical—1,000 feet and 13,000 feet; 30° —1,400 and 8,000 feet. In the altitude range between 2,000 and 4,000 feet (actual range: 4,000–8,000 feet) horizontal sweep picked up about three to four times as many targets per unit of area as the vertical coverage, but above

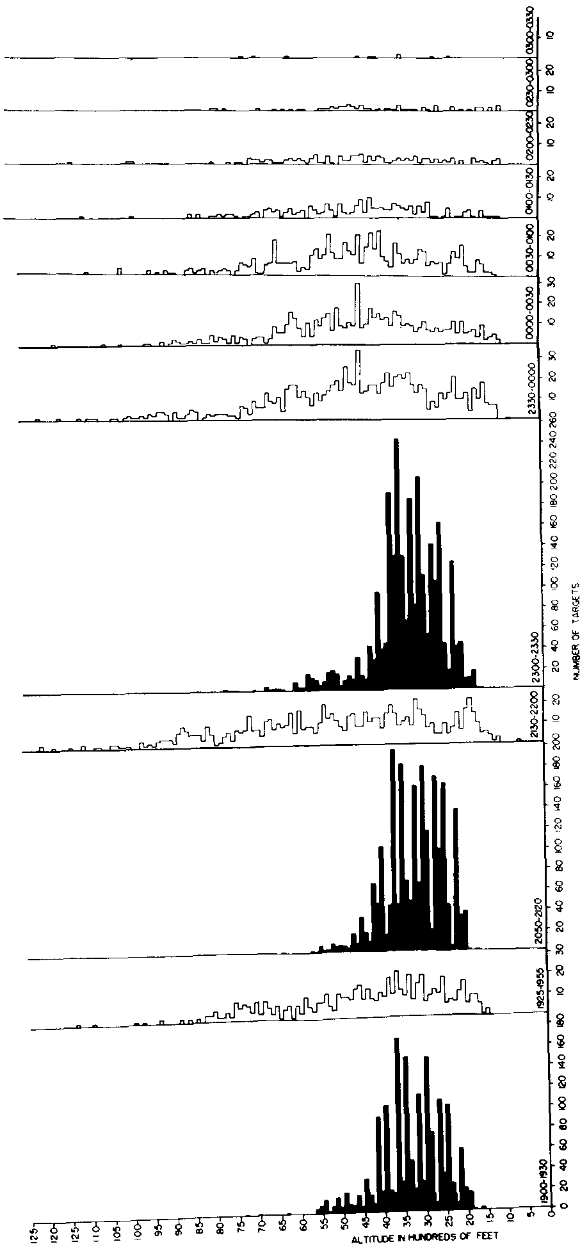

FIG. 8. Altitudinal distribution of migrants as observed on radar. The total number of bird targets at each 100-foot level is shown for periods of approximately ½-hour duration. Data representing periods of observation (1900–1930, 2050–2120, and 2300–2330 CST) with the radar antenna on horizontal (30°) scan are shaded. Unshaded portions of the graph represent observations made with the radar antenna scanning in a vertical plane.

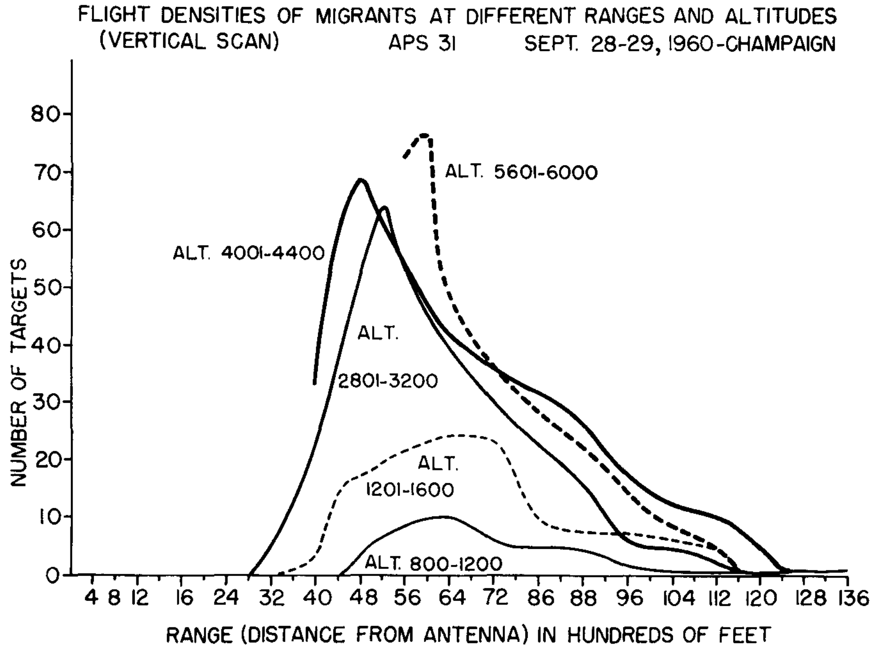

Fig. 9. Comparison of flight densities of migrants at different range and altitude levels. The maximum point of each curve is at the range where the radar is most effective in detecting birds. The range of peak effectiveness varies slightly with altitude but maximum effectiveness occurs at a range between 5,000 and 6,500 feet.

altitudes of 4,000 feet the number of targets detected on 30° scan fell off steeply despite the expanding (3°) beam width. Apparently, at a range above 4,000 feet and below 8,000 feet the transmitted energy becomes diffused to the extent of reducing the radar's effectiveness in detecting birds. Further analysis of vertical scan data, considering range versus altitude, indicates more precisely that the range above which effectiveness is reduced is about 6,400 feet (Fig. 9). This should be considered the range for solitary passerine birds, as our lighting observations showed this type of migration on the night of the experiment. We have recorded strong echoes from waterfowl at ranges up to nearly four nautical miles (24,000 feet) and on the night of our experiment some birds were detected on vertical scan at altitudes up to 13,000 feet. Obviously other factors than just range affect the picture. Birds near the center of the beam are more likely to be detected than those at the edge. What the difference in reflectivity might be for birds of different species or what factors affect this reflectivity we cannot say at present. The difference in results from the two types of scan is not surprising, and can be attributed to the innate limitations of the equipment and of the two methods. Vertical scan provides better altitudinal information at both the lower and higher extremes of coverage.

Because of the inherent recovery time of the radar, the radar receiver cannot detect targets in the first 1,000 feet of range (see opaque halo in Figs. 4 and 5). This range of "blind area" must be considered minimal as ground targets are most likely to be picked up close to the antenna and may cover up as much as an additional 500–1,000 feet of range. This means that with the antenna on 30° tilt, the first 750–1,000 feet of altitude are occluded. On vertical scan, however, objects at low altitude may be picked up at any range beyond 1,500 to 2,000 feet. More high-altitude targets were detected on vertical scan because in the region of the zenith, range and altitude are equal, while on 30° scan, altitude is always only half of the range.

In considering the greater number of targets detected on horizontal scan it should first be pointed out that half of the vertical sweep is lost when the rotating antenna is pointed toward the ground. In addition, horizontal sweep provided maximum coverage at the altitudes where flight densities of migrants were highest.

The temporal pattern.—Lowery (1951) presented lunar observation data which indicated that migrants did not usually fly throughout the night. The number of flying migrants increased progressively after sunset to a peak density between 2230 CST and midnight, falling off steeply after 0100 to virtually zero by 0230.

This is precisely the kind of pattern shown in our radar film for 28–29 September (Fig. 8), and it is the typical autumn pattern shown in most of the radar data collected at Champaign, Illinois, in the past two years. This pattern indicates that birds are landing, or at least descending, after midnight, yet there is no conspicuous increase at this time in the number of birds at lower altitudes (Fig. 8). The inherent "blindness" of the radar at short range, and low altitudes (because of recovery time and ground clutter) has already been pointed out, and accounts for this void in our observations.

Although radar is a very useful tool in migration studies, the inherent weaknesses of the technique must be recognized.

FLIGHT DENSITY DETERMINED BY RADAR

The most accurate available figures on flight densities of migrants are those obtained from lunar observations (Lowery, 1951, and others).

In further evaluating the radar technique, it is useful to compare flight density levels as determined from radar observations with published figures ascertained from moon watching.

As already noted, the flight of migrants on 28–29 September was extensive, and the peak density occurred around 2300 CST (see above). From 2300 to 2330 CST, 2,670 bird targets were detected with the radar on 30° scan. Direct observations of the indicators showed that most of these birds were holding south-southeast headings (150°–180°), but a large number were also moving 190°–210°.

For density determinations, vertical scan would appear to provide better basic data than horizontal scan, since vertical scan, in effect, resembles an east-west curtain of energy through which the migrants pass on their southerly headings.

This "curtain" is actually the sweep of a 3° beam, passing a given point every six seconds. There is a possibility, of course, that birds pass through the area covered by the beam without actually being intercepted by the energy. Within well-defined limits the possibility of a bird passing through the area of coverage undetected is better if it passes close to the antenna than if it passes at greater range. For instance, the diameter of the beam at a range of 1,000 feet is 52 feet, while at 6,200 feet range the diameter is 324 feet. At the shorter range a bird would have to be flying only 6 mph to cross the beam area undetected, while at the greater range the bird's speed would have to be better than 36 mph to pass undetected, even if the migrant's flight was timed perfectly to miss the sweep. Depending on this timing, the migrant's speed could be as much as 70 mph and it might still be "caught." On this particular night migrants were making ground speeds between 34 and 45 mph and it seems reasonable to assume that most migrants were probably intercepted by the vertically directed beam at ranges over 6,000 feet. There are other reasons for considering range in calculating flight densities.

It has already been pointed out that recovery time of the radar receiver and the presence of ground targets at short range reduce the effectiveness of the radar in detecting birds close to the antenna. It has also been shown that the effectiveness of the APS radar in detecting birds is reduced at ranges much above 6,400 feet. For the most accurate possible estimate of density it is advisable, therefore, to calculate flight densities at specific altitudes and ranges. Densities for the lower altitudes should be calculated for ranges distant from the antenna, but not exceeding 6,400 feet. Densities for the higher altitudes (above 6,400 feet) should be calculated at minimum range, i.e., where range equals altitude.

In an hour (2230–2300 and 2330–0000 CST) representing the peak of the night's migration, 177 bird targets were counted at all altitudes up to 6,500 feet in the 500-foot range sector from 6,000 to 6,500 feet. If our 500-foot sector is representative, the flight density to this altitude would be about 1,870 birds crossing a mile in one hour. To this should be added the densities for higher altitudes (6,500 feet and above). To calculate densities at these higher altitudes we have counted the number of migrants at each hundred-foot level within ¼ mile either side of the radar zenith. In this area range is very nearly equal to altitude. Within this sector 50 birds were counted during the peak hour of migration at altitudes above 6,400 feet. This is a flight density of 100 birds crossing a mile line per hour. This calculation does not take into account two factors: (1) that the diameter of the beam increases as the range increases, and (2) that the effectiveness of the radar in detecting birds is reduced to an unknown extent at ranges above 6,400 feet. The density figure for higher altitudes is, therefore, less reliable.

The estimated peak flight density for all altitudes on 28–29 September was 1,970 birds per mile per hour. Although we have no comparative data representing other techniques for this night, Lowery (1951) lists hourly densities for spring migrants as high as 2,700 birds per mile at midwestern localities.

ACKNOWLEDGMENTS

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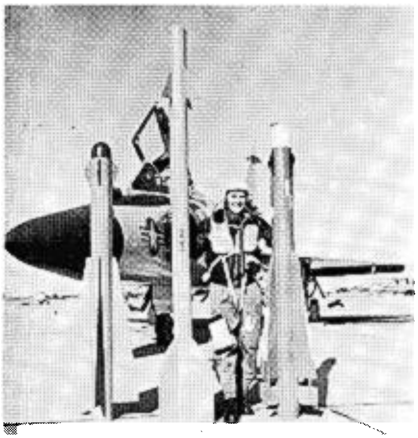

Lieutenant Colonel Gerald T. Rogers, shown here in his present niche—that of jet pilot and chief of engineering for a satellite-tracking system—is a new Life Member of the WOS. He is a Life Member also of the AOU. An electrical-engineering graduate of MIT, Colonel Rogers is interested in bird flight, navigation, distribution, and migration. He has published several general notes in *The Auk* on rare bird specimens from Panama, Alabama, and North Carolina. Also, he has collected resident bird specimens in New Guinea.