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FLIGHT SAFETY ASPECTS OF PRECISION RADAR NEAR AIR BASES IN BIRD-AIRCRAFT COLLISION AVOIDANCE

Warren L. Flock

Colorado University

Prepared for:

Air Force Weapons Laboratory

October 1972

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13 ABSTRACT

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The utility of a GEC-AEI No. 654 radar for warning of bird hazards at airfields has been evaluated at Gunbarrel Hill and Valmont Reservoir, near Boulder, Colorado, from 16 March to 19 December 1971. Morning and evening flights of Mallards, Canada Geese, etc., provide good test radar targets at these locations. The 654 radar is useful as it is, but improvements are recommended to allow detection of birds at greater ranges. Some doppler radar signature data were also taken with a cw radar at Baller Lake in spring 1971. Experience with this radar provides a basis for recommending further development of signature capability. Such capability should allow determining quickly if a target is caused by birds or not, the type or size of bird, and whether the echo is from one or a small or large number of birds. A coherent pulse radar would be ideal in many respects for signature determination, but coherent transmitting tubes are expensive. Therefore, both coherent and non-coherent radars, including an improved version of the 654 radar with amplitude signature capability, should be investigated further.

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FOREWORD

This report was prepared by the University of Colorado, Boulder, Colorado, under Contract F29601-70-C-0076. The research was performed under Program Element 63723F, Project 683M3E01.

Inclusive dates of research were 18 June 1970 through 1 February 1972. The report was submitted 29 August 1972 by the Air Force Weapons Laboratory Project Officers, Sgt Robert C. Beason and Capt John P. Nemergut (DEE).

This report has been reviewed and is approved.

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SECTION I

INTRODUCTION

A GEC-AEI No. 654 radar was tested to evaluate its usefulness for monitoring bird activity in the vicinity of airports. The radar was first put into operation at Gunbarrel Hill, a field station of the Department of Commerce which is 12 miles (19 km) from the Boulder campus of the University of Colorado, on 15 March 1971. The radar was at Gunbarrel Hill until 20 June 1971, when it was moved to Valmont reservoir. This site is about 4 miles (6.5 km) from the Boulder campus on Public Service Company of Colorado property. A cw X-band radar was also used at Baller Lake in the spring of 1971 to obtain radar signatures of birds in flight.

The remainder of this introduction is devoted to a survey of pertinent literature and previous related research. Sections II and III then describe the equipment, sites, and techniques employed and the results obtained. Section IV discusses radar systems considerations, Section V contains recommendations, and Section IV is a conclusion.

The contract was concerned with the application of radar at airfields, in order to minimize the hazard of collisions between birds and aircraft in the near vicinity of the runways. Literature concerning the detection and observation of birds by radar is thus pertinent to the contract and this report. The volume, Radar Ornithology, by Eastwood (Ref. 1), provides an excellent treatment of this topic and lists the important references to 1967. Myres (Ref. 2) lists essentially all references on the subject to 1969.

Some of the literature and research considered to be most interesting or important and some that has appeared, or been carried out, since 1969 is mentioned here.

The first discussions ot radar echoes from birds to appear in the open scientific literature are the notes by Brooks (Ref. 3) and Lack and Varley (Ref. 4), both based on observations during World War II. Brooks' very brief note mentioned war-time observations from ships at sea and stated that he planned to use radar to study bird migration. Lack and Varley discussed experiences with radar echoes from birds in England during World War II and mentioned classified war-time reports on the subject. Bonham and Blake (Ref. 5) refer to a 1939 U.S. Naval Research Laboratory report on radar echoes from birds. During World War II, radar "angels," (echoes of unknown origin from regions of the atmosphere where targets could not be detected visually) were reported commonly, especially as higher-power radars were introduced, and some persons suggested that birds were the cause of the "angels."

In spite of these early observations, it was not until about 1957-58 that radar was used to a great extent to record bird movements, with the subject of radar angels remaining a controversial one until about 1966. One of the most fruitful studies relating to angels is that by Hardy, Atlas, and Glover (Ref. 6), based on work with the high-power, multi-frequency radar facilities at Wallops Island, Virginia. The studies showed that echoes can be received from clear-air atmospheric inhomogeneities, insects, and birds and that the diffuse atmospheric echoes can be distinguished from point-target insect and bird echoes. The Wallops Island program was concerned mainly with atmospheric phenomena rather than birds, but the results do not conflict with the now well established fact that birds are an important source of radar angels and clutter. Insects can apparently be a significant source of echoes also, especially in radars designed for close-in "seeing." Atmospheric echoes, arising from variations in refractive indices of air as distinguished from echoes from rain, snow, and hail, can be observed only by radars having high power and high sensitivity.

A number of studies of radar echoes from birds have been made in Europe, especially in Switzerland and Great Britain. Sutter (Ref. 7), with the aid of visual observers at five locations near the Zurich airport, established a definite correlation between radar and visual observations at times when conditions were favorable for both types. Weitnauer (Ref. 8), using the same Zurich radar, studied the nocturnal flights of swifts and, with the aid of an aircraft vectored to position by radar, observed that swifts were indeed flying in regions from which radar echoes were received. Numerous radar studies of birds have been made in England since 1957; only a few will be mentioned here. Eastwood and Rider recorded radar echoes from a sea-breeze front (Ref. 9) and it was determined later (Ref. 10) that it was swifts that were actually responsible for the echoes. Eastwood, Isted, and Rider (Ref. 11) established that expanding-ring radar echoes were caused by starlings leaving their roosts. Lack (Refs. 12-16) made an extensive and highly significant series of studies, of bird migration over the North Sea and portions of England, by radar means.

In the United States, Drury and coworkers (Refs. 17-19) used an Air Force L-band radar at Cape Cod, Massachusetts, to study migration along the New England Coast. Bellrose and coworkers in Illinois

(Refs. 20-23) have made considerable use of radar in their studies of bird migration and the hazard of collisions between birds and aircraft. Bellrose has given much attention to waterfowl migration and has used WSR-57 S-band U.S. Weather Bureau radars as well as a 3-cm aircraft-type radar.

The Federal Aviation Administration (FAA) of the United States operates an extensive network of L-band Air Route Surveillance Radars (ARSR) and S-band Airport Surveillance Radars (ASR) (Ref. 24). Persons inquiring about their use for bird detection before 1968, however, were told that bird echoes had been eliminated from FAA radars by using STC (sensitivity-time-control) circuitry. STC reduces radar sensitivity for close targets and alleviates excessive clutter and brightness near the centers of PPI (Plan Position Indicator) displays. The FAA STC circuits were designed to eliminate echoes from targets with a radar cross-section equal to or less than 0.01 meter^2, this figure corresponding nominally to the radar cross section of a gull (Ref. 25). It was apparently overlooked, however, that birds commonly fly in flocks and that a relatively large number may be in the common volume interrogated by a radar at a particular instant even if the birds are not concentrated into flocks. Thus it developed that FAA radars are really well suited for study of bird movements (Refs. 26, 27).

Following the discovery that FAA-type radars were suitable for observing bird movements, Flock obtained data from a number of FAA radar facilities, including the Denver airport and the Denver, Kansas City, Chicago, Houston, Washington, D.C., and Seattle FAA centers (Ref. 27). Polaroid photographs were taken of the radar screens on short visits to the centers. About 18 months of automatic-camera data were obtained from the North Platte, Nebraska FAA radar in 1968-69, and seven months of data were obtained from the Denver airport in 1969. Bellrose, Flock and FAA personnel manned the FAA centers of Chicago, Kansas City, and Denver on 21-23 March 1969; simultaneous radar data were obtained from 14 different radars (Ref. 28). The Seattle, Washington; Cape Charles, Virginia; and New Orleans, Louisiana, radars showed especially interesting bird activity during visits to the Seattle; Washington, D.C.; and Houston FAA centers, respectively. Puget Sound was outlined by bird echoes at Seattle, considerable overwater migration was observed at Cape Charles, and an impressive songbird migration was recorded at New Orleans in May, 1968.

Prior to the work with the FAA radars, mentioned above, very little radar data were available from the western United States, and to this date the Pacific coast and Salt Lake City areas, etc., have received little or no attention. No radar data were available from Alaska until Flock visited the Tin City (Cape Prince of Wales) and Cold Bay AC&W (Aircraft Control and Warning) radar sites and all six active Alaskan DEW (Distant Early Warning) sites (Pt. Lay, Wainwright, Pt. Barrow, Lonely, Oliktok, and Barter Island) in portions of the spring and late summer seasons of 1969, 1970, and 1971 (Refs. 29 & 30).

Canada has played a very active role in radar studies of birds, especially with regard to the hazards of collisions between birds and aircraft. In Canada the Associate Committee on Bird Hazards to Aircraft arranged the 1969 World Conference on Bird Hazards to Aircraft, held 2-5 September 1969 at Queen's University, Kingston, Ontario (Refs. 2 & 28). The Associate Committee also has published an extensive series of field notes, one of which is a highly useful discussion of the various adjustments, etc. which affect radar system performance (Ref. 31). A publication of the Canadian Wildlife Service, Studies of Bird Hazard to Aircraft, serves to illustrate other recent Canadian radar studies of birds (Refs. 32 & 33). Also of interest is a paper relating weather and migration in eastern Canada, utilizing digitized data from NORAD centers (Ref. 34).

Long-range surveillance radars, such as the FAA ARSR and comparable Air Force radars, including those of the AC&W and DEW systems in Alaska, are not capable of detecting birds within the first two or three miles (4 or 5 km) of the radar, because of their long transmitted pulses (commonly 2 μsec or more) and the lack of attention in the design process to close-in detection. They may monitor bird movmeents well over a range from a few miles to 50 nautical miles (NM) or more (93 km or more). The ASR airport radars (pulse length 0.833 μsec) monitor bird movements well out to 10 or 15 NM (18 or 28 km) and are better than the ARSR radars for close-in seeing but are still rather limited in this respect. GCA-type airport radars (ground-control-approach radars) are capable of close-in detection but are usually set up only for particular runways and not for surveillance of the entire surroundings. Schaefer (Ref. 35) has proposed that low-cost marine radars, which are designed for close-in detection, should be suitable for monitoring bird activity near airfields. In general, the hazard to aircraft tends to be greatest in the vicinity of airfields, when the aircraft are of necessity at low altitudes. The contract reported on here was devoted to evaluating the utility of such a radar, namely the GEC-AEI No. 654 radar. This radar is described in Section II and discussed further in Section IV.

Radar has some capability for identification, as well as detection, of birds. The capability is based in good part on the concept that birds beat their wings at a unique rate by species, or over only a limited range of frequencies. Greenewalt (Ref. 36) asserts that the wingbeat rate is given by the relation

$$f\ell^{1.15} = 3540$$

for both birds and insects, where f is the wingbeat rate in Hz (cycles per second) and ℓ is the length of the wing in centimeters. Wingbeat rates for hummingbirds are stated to be between 20 and 80 Hz by Greenewalt, ducks apparently have rates of about 8 to 10 Hz, and large birds and herons have rates of only a few or close to one Hz. Whether or not it is true that wingbeat rates are strictly constant, the wingbeat characteristics offer some possibility for identification, as the wingbeat causes variations in the amplitude and doppler frequency of echoes from birds. These variations tend to be complex, and it appears that the various species, or types at least, have distinctive radar signatures, involving unique features in addition to merely the wingbeat rate alone. Research on radar signatures has been carried out by Schaefer (Ref. 37), Konrad (Ref. 38), Houghton (Refs. 39 & 40), Gehring (Ref. 41) and Bruderer (Ref. 42). Bonham and Blake (Ref. 5) discussed the subject of radar signatures as early as 1956. One limitation of much of the research on radar signatures to date is that it has involved amplitude variations only. Green and Flock (Ref. 43), however, have obtained some doppler frequency data, for ducks such as the Shoveler (Spatula clypeata), Cinammon Teal (Anas cyanoptera), etc., which show that the doppler signature is distinctive and useful.

Real-time signature capability would be valuable for an airport bird-warning radar, because it would allow determining quickly if a given target is a bird or not, the type or species of bird, and probably whether one or two, a small number, or a large number of birds were contributing to a given echo (Ref. 44). Even some experienced air traffic controllers have difficulty at times in determining quickly if a given target is a bird or not.

SECTION II

EQUIPMENT AND TECHNIQUES

654 Radar

The GEC-AEI No. 654 radar used in this study (hereafter referred to as the 654 radar) was manufactured by the Associated Electrical Industries Ltd. (now Marconi Radar Systems Ltd.) New Parks, Leicester, England. The radar is a compact, largely solid-state radar consisting of motor-generator, transceiver, PPI, and antenna drive subunits. Some of the important system characteristics are as follows:

Table I 654 Radar Parameters

Frequency:	9445 MHz
Peak Transmitter Power:	20 kw
Pulse Length:	0.05, 0.1, 0.25, and 1.0 microsecond
Pulse Repetition Frequency:	2000 pulses per second or 1000 pulses per second
12-Foot (3.66m) Slotted Waveguide Antenna	
Horizontal Beamwidth:	0.7°
Vertical Beamwidth:	24°
4-Foot (1.22m) Parabolic Antenna Beamwidth	2° conical
Antenna Rotation:	22 rpm
PPI:	13 inch (33cm) cathode-ray tube
Range Scales:	0.75, 1.5, 3, 6, 12, 24, and 48 NM (1.4, 2.8, 5.6, 11.1, 22, 44, and 89 km)

The radar normally operates with 0.05 μsec pulses on the 0.75 and 1.5 NM ranges, with 0.25 μsec pulses on the 3 and 6 NM ranges, and with 1 μsec pulses on the 12, 24, and 48 NM ranges. However changes were made in the circuitry so that any pulse width can now be obtained on any range. The slotted-waveguide antenna, the only antenna normally supplied with the radar, is best for observing birds sitting on the water and at close range generally. The parabolic antenna is best for following flights of the ducks and geese at a distance.

The radar is housed in a 16.5-foot (5 m) Red Dale Special Cargo trailer, manufactured in Longmont, Colorado (Figure 1). The radar antenna drive unit is mounted on a metal frame which is attached to a metal structure that encircles the trailer. Four cables secure the top frame to the ground. This arrangement has allowed the trailer to withstand winds without damage. Figure 2 shows the trailer with the parabolic antenna in place and shows the ladder, which allows access to the roof. The trailer is equipped with an air conditioner for warm weather and an electric heater for use in cold weather. Figure 3 shows part of the trailer interior, including the wall-mounted transceiver unit and the floor-mounted display unit.

The 654 radar was selected for these tests because it was the only one with a horizontal beamwidth of only 0.7°. The price and performance compared favorably generally with those of the other manufacturers.

The 654 radar has a 13-inch PPI CRT, and this PPI unit is quite satisfactory as to size and utility. The operating controls include the main and range-selector switches, and intensity, tuning,

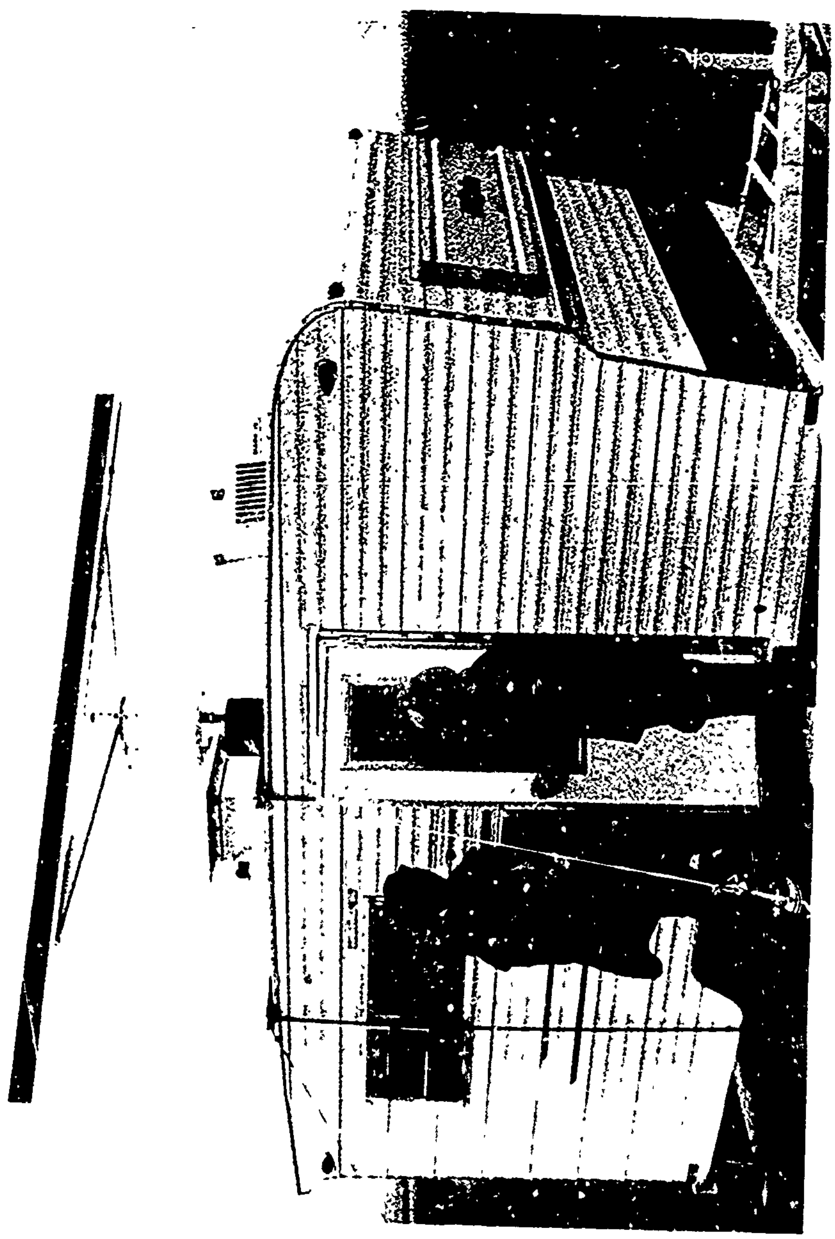

Figure 1. Red Dale Special Cargo Trailer with 12-foot Slotted-Waveguide Antenna

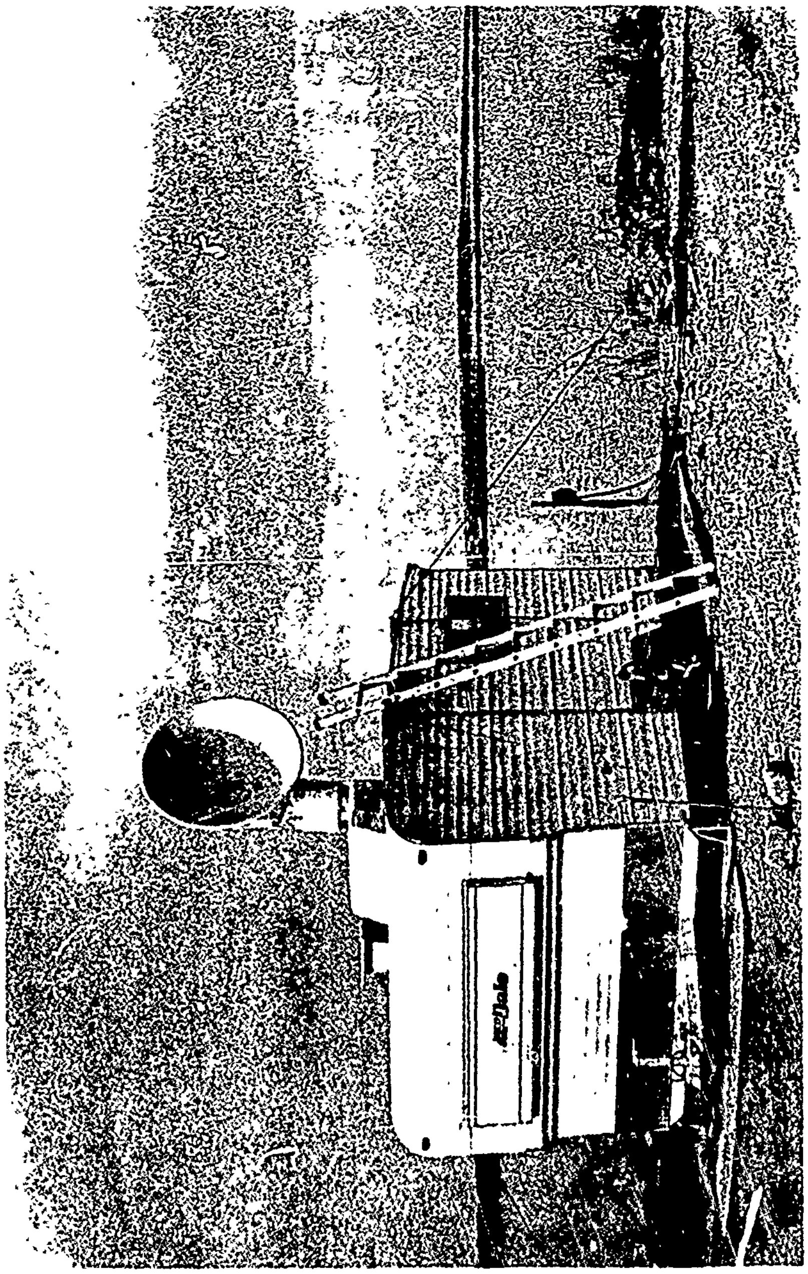

Figure 2. Red Dale Special Cargo Trailer with 4-foot Parabolic Antenna, at Valmont Reservoir.

Figure 3. Interior of Trailer, showing Transceiver Mounted on Wall and PPI Display Unit

differentiator, gain, sea clutter, and picture alignment controls. The differentiator tends to make echoes shorter in duration and makes the scope appear cleaner. The Sea Clutter control is actually an STC (sensitivity-time-control) circuit which can be used to decrease sensitivity for close-in targets. When looking for bird echoes, it is generally not desirable to use very much STC. The use of the differentiator is often advantageous as it allows separating a number of closely spaced echoes. The Picture Alignment control allows the radar picture to be reoriented, i.e. with north at 0°.

The performance of the 654 radar in detecting birds and data obtained by using it will be discussed in later sections. The radar is compact, convenient, and useful but has certain limitations for bird detection. The utility of the radar would be increased by the addition of MTI (moving-target-identification) circuitry as considerable ground clutter may show on the PPI and birds can be lost in the clutter. When the picture brilliance is set at a high level, faint return trace echoes may show. Improved circuitry design would eliminate those. The video amplifier came with a "three-tone" circuit to make weak signals appear faint. This circuit was disabled, as it suppressed weak bird echoes. A standard synchro system would be preferable to the present system for synchronizing the antenna and sweep relations and would allow stopping the antenna at a given azimuth more readily. The only actual malfunction of consequence encountered is that the high-voltage CRT circuit has been somewhat unstable, resulting in poor PPI focus at times. The radar does not have a focus control. The focus is not a critical function of CRT accelerating voltage, but the focus does deteriorate when this voltage drops excessively.

CW Radar

An X-band cw radar was assembled from components available at the Aeronomy Laboratory, Department of Commerce Boulder Laboratories, by Mr. John Green, and used to obtain radar signatures in the spring of 1971. The radar utilized two identical klystrons, one as a transmitting tube and one as a local oscillator. One waveguide horn was used as a transmitting antenna, and one was used as a receiving antenna. The frequencies of the klystrons were stabilized by Dymec Oscillator Synchronizers. The output power of the transmitting klystron was about one watt. The transmitted and received signals were compared and in-phase and out-of-phase components of the received signal were recorded for later analysis by Sonograph and Rayspan spectrum analyzers and a digital computer. The cw radar gave useful results, but a more thoroughly engineered, convenient version would be essential in any future effort.

The cw radar work was funded by the Department of Commerce and was carried out by Mr. John Green in partial fulfillment of the requirements for an M.S. in Electical Engineering from the University of Colorado. The work is discussed briefly here because it is pertinent to, and was at least in part inspired by, this contract.

Photography

Two types of cameras were used to photograph the PPI display in order to obtain permanent records of the appearance of the echoes caused by birds. These were a Polaroid Model 180 camera, with Close-up and Portrait Kits to allow focusing to a shorter than normal distance, and a Beattie-Coleman KD-5 camera accommodating 100 (or 150) foot (30.5 or 45.7m) reels of 35 mm film. Type 107 (3000 speed) Polaroid film was used in the Model 80 camera and Kodak 2484 Pan Film was used in the KD-5 camera.

The Polaroid camera is very useful, its advantages being light weight and small size and the ability to immediately analyze the resulting photograph. The Polaroid camera was used quite extensively on the project, for both one-rotation and time exposures up to one minute in duration. When it became desirable to take data continuously, the Beattie-Coleman camera was used instead. Disadvantages of the Polaroid camera are that it is manually operated, that it is impractical to record continuously with it, and that the room must be rather dark when using it.

The KD-5 Beattie-Coleman camera has the advantages that it is automatic and can continuously record about 1600 frames on a 100-foot reel. The camera is made for a five-inch (12.5 cm) oscilloscope, and must be mounted at the end of a hood about 23 inches (58 cm) from the scope face when used to photograph a thirteen-inch (33 cm) scope. (Figure 4). The scope face can be seen by looking through the camera viewer, but this feature is somewhat awkward. Therefore a polarized-light viewer has been installed on the hood allowing the camera to be operated without darkening the room. Thus one can sit near the scope and look out the window to observe birds with binoculars, yet look through the scope viewer when desired, the camera functioning automatically all the while. The disadvantage of the KD-5 camera is that film must be developed before the results are seen, which may be several weeks.

Figure 4. PPI Unit with Beattie-Coleman KD-5 Camera and Hood.

The length of exposure of each frame of the 35 mm film was determined by a timer, which could be set to give a large variety of exposure periods and repetition rates. For photography of the 654 scope exposures between 15 seconds and one minute were most suitable. A 30-second exposure repeated every minute seemed to be quite satisfactory. The timer was made from a Controls Company of America Kit No. 302-850, obtained from Newark Electronics.

Sites

The Gunbarrel site, at the Gunbarrel Hill Department of Commerce field station about 12 miles (19 km) northeast from the Boulder campus, overlooks Baller Lake, 1.5 NM to the east. The site has an unobstructed view of the lake, which is about 47 m lower than the radar antenna. The site was selected for testing the 654 radar because Baller Lake was known to be frequented by over 1,000 ducks and geese in the winter and spring. Thirty-six visits were made to the site, mostly in the early morning and evening, on thirty days, the visits generally lasting about 1.5 or 2 hours.

The cw radar was operated at the very edge of Baller Lake. The antennas were pointed out over the lake, and data were obtained when waterfowl, gulls, swallows, etc. flew through the antenna beams at sufficiently close range. No electric power is available at the lake, and gasoline-powered generators were utilized.

The Valmont site, at the edge of Valmont reservoir of the Public Service Company of Colorado is about 4 miles (6.5 km) east of the Boulder campus. The reservoir consists of three sections as shown in Figure 5, which also shows a grid system that was used to describe the locations of radar targets. The radar trailer at Valmont reservoir is immediately adjacent to the lake, with the antenna

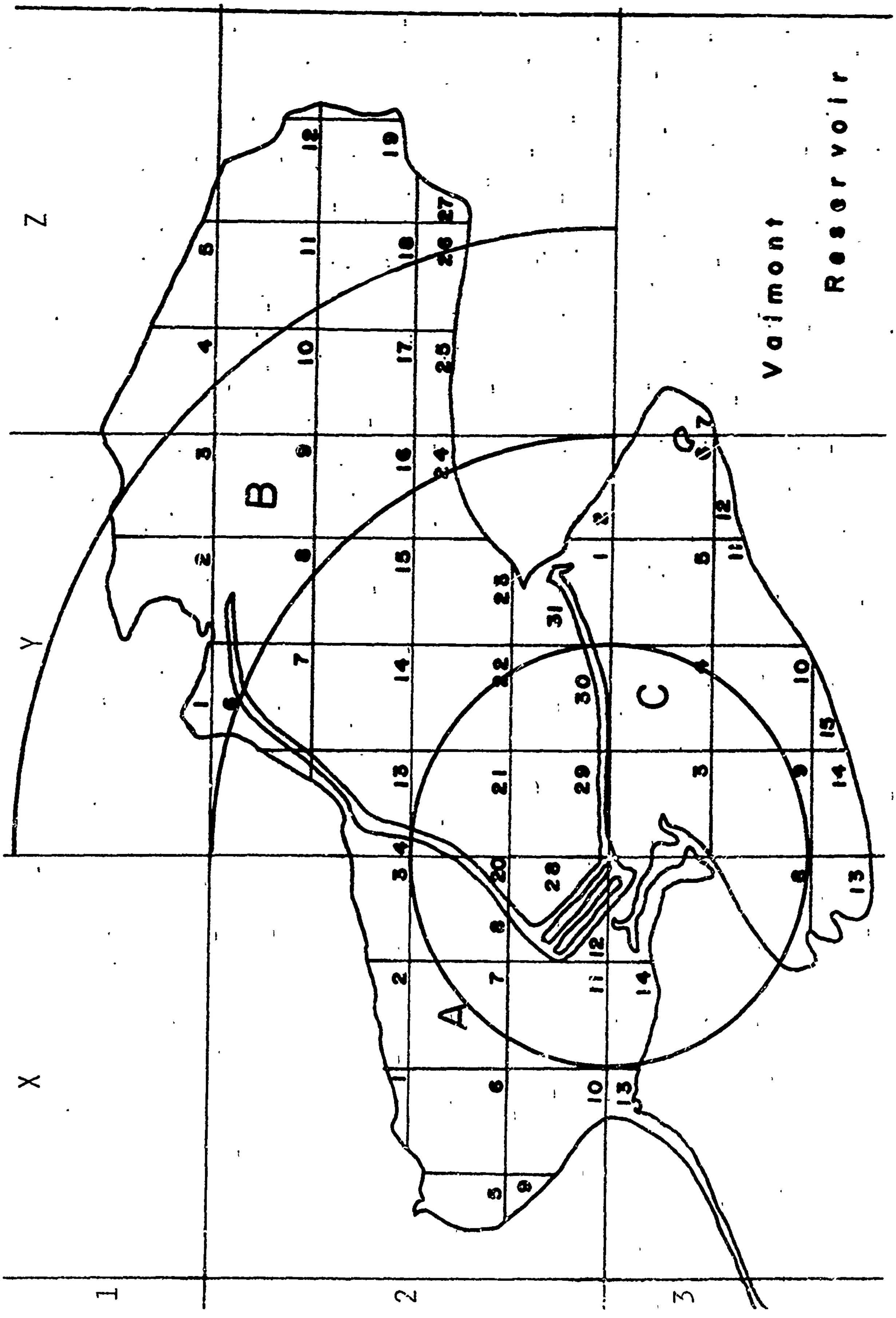

Figure 5 Grid Map of Valmont Reservoir. The small squares are 0.125 NM on a side.

approximately 5.5 m above the water level. With reference to Figure 5, the radar is located at an intersection of the large grid system, specifically where the line separating the X and Y bands intersects the line separating the 2 and 3 bands. The radar has a good view of the B and C areas of the reservoir and has reasonable coverage of the A area. About 50 visits were made to the site, mostly in the early morning and evening, the visits generally lasting about 1.5 or 2 hours. On 19 December 1971, however, about 12 hours were spent at the site while on a few days the visits lasted only an hour or less.

The Valmont reservoir is frequented by large numbers of ducks and geese, especially in fall and winter. Estimates on 19 December 1971, for example, were 5000 Mallards (*Anas platyrhynchos*) and 2500 Canada Geese (*Branta canadensis*). Gulls were often present in numbers also, the Franklin's Gull (*Larus pipixcan*) in late summer and the Ring-billed Gull (*Larus delawarensis*) and Herring Gull (*Larus argentatus*) in fall and winter. Because the electrical power plant of the Public Service Company uses water from the reservoir for cooling, the reservoir never freezes solidly in winter. The reservoir area, although owned by the Public Service Company, is a state game refuge.

SECTION III

RESULTS

Gunbarrel Hill and Baller Lake

The principal bird activity seen from Gunbarrel Hill was that over Baller Lake to the east. Most observations at Gunbarrel Hill were made using the slotted-waveguide antenna because it gave an excellent radar map of the surroundings and birds could therefore be located readily with respect to the lake. Also it appeared that birds at higher altitudes would be missed if the parabolic antenna were tilted low enough to receive echoes from the lake. Figure 6 shows the PPI screen as it appeared on a 3 NM range at Gunbarrel Hill. This photograph constitutes a map of the area. Baller Lake, outlined by echoes from the trees surrounding it, appears on the far right. The approximately horizontal line that nearly touches the south end of the lake corresponds to Colorado Highway 52. The approximately vertical line west of Baller Lake corresponds to U.S. Highway 287. Detailed examination has established that individual farm houses, power poles, haystacks, etc. can be distinguished. A flock of birds is shown over the south arm of the lake in Figure 6.

The birds on Baller Lake were mostly Mallards, which have interesting flight habits. The birds leave the lake at the very first sign of light in the morning and most return near sunrise or soon afterwards. They always head south towards Boulder Creek. A similar pattern is shown in the evening though not as reliably, with the ducks leaving before sunset and returning after sunset. Ducks feed rapidly, and although the flights are short they apparently

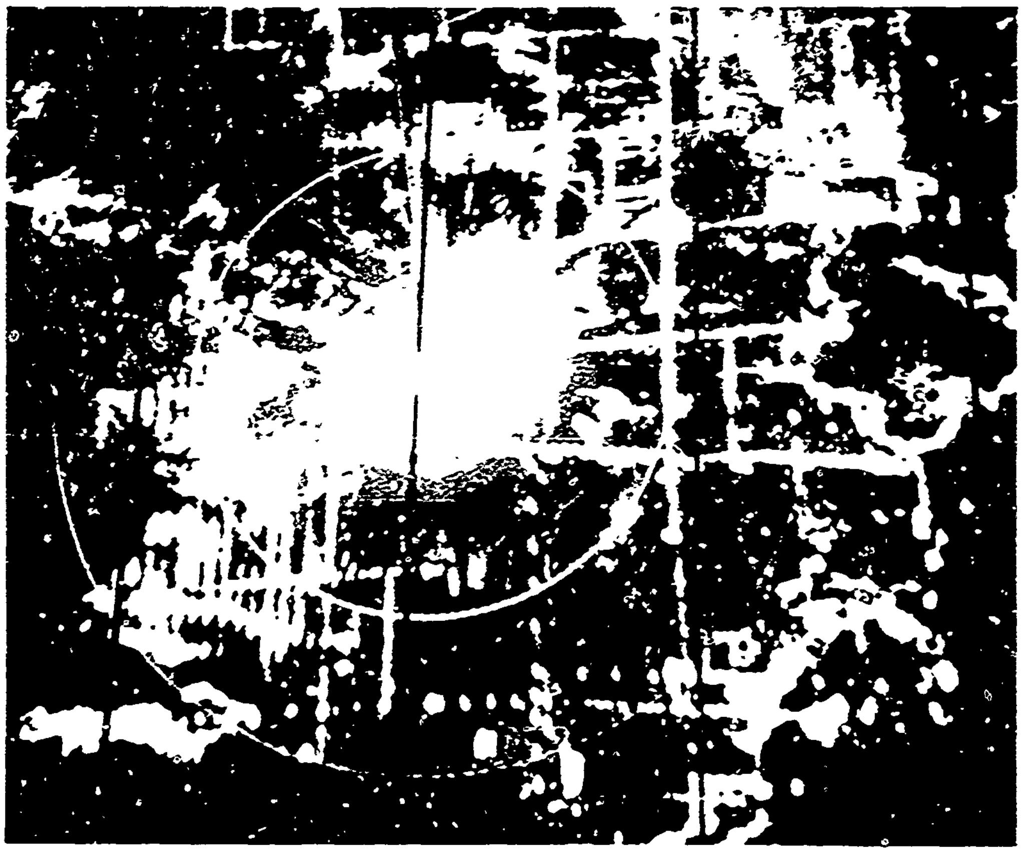

Figure 6. Radar Screen at Gunbarrel Hill, One Rotation Exposure, 0.25 Microsecond Pulses, 3 NM Range, 0540 MDT, March 27, 1971

allow the birds to feed in areas away from the lake. The flights also provide the birds with exercise, so that they are in condition to migrate when the proper time comes. The flights show clearly, and sometimes spectacularly on the radar screen (Figure 7). Also birds that are flushed from the lake, by persons walking along its edge, show clearly on the radar screen. Most of the Mallards, which were present in numbers up to about 1000, left on about April 10, but some of the waterfowl remained.

The cw radar at the edge of Baller Lake was located such that some of the morning and evening waterfowl flights passed overhead. The results from the cw radar will be described more fully in Mr. Green's M.S. dissertation, but Figure 8 shows the nature of the doppler-frequency signatures obtained. Mr. Green spent three week-ends at Baller Lake in April-May, 1971. Permission to use the lake was granted by the Boulder and White Rocks Rod and Gun Club.

Observations of birds very far from the Baller Lake-Boulder Creek area were rather few. On numerous occasions single targets were observed moving to the north and these were presumed to be migrating birds. The record was never very impressive. Although at times some relatively heavy migratory movement must take place, the Boulder area does not appear to be a good one for observing migration. The parabolic antenna was generally used when watching for migration, and various tilt angles up to 30° above the horizontal were tried.

Photographic documentation of results from Gunbarrel Hill is provided by 168 Polaroid prints, obtained by using 21 packs of type 107 Polaroid film in a Model 180 Polaroid camera. Four strips

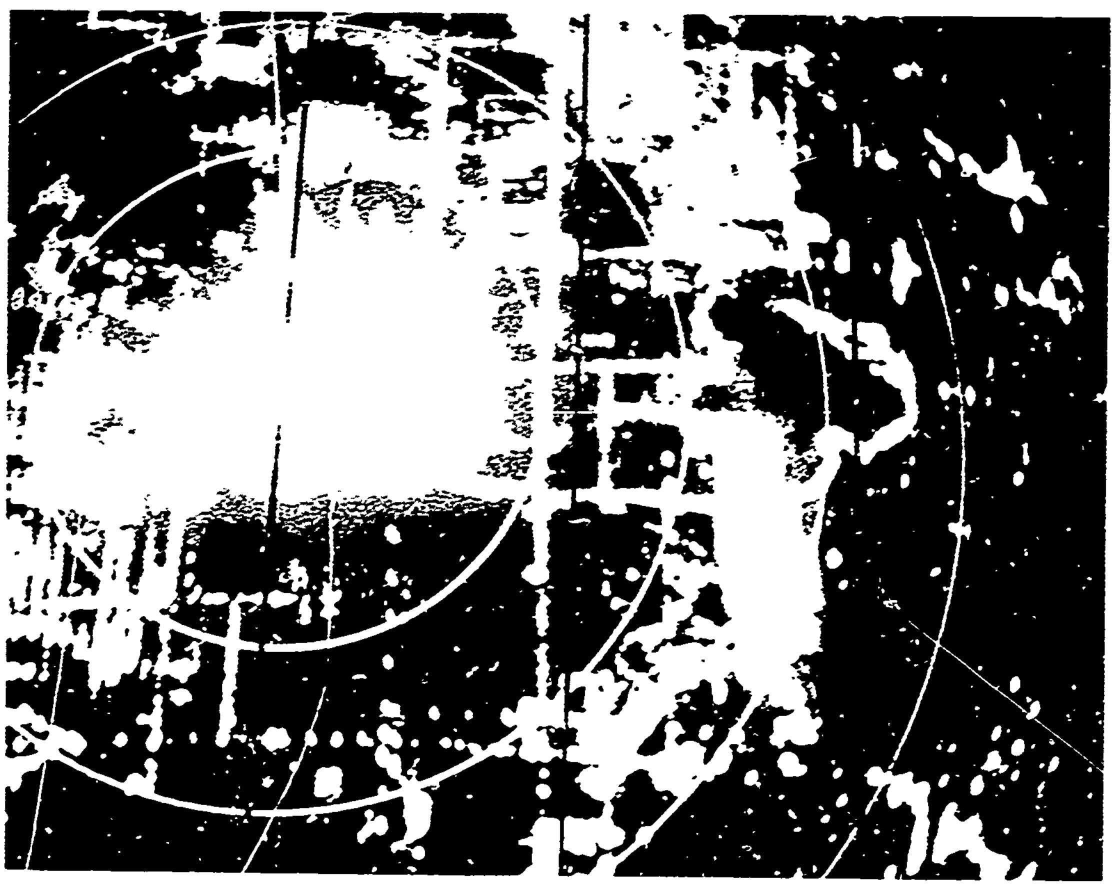

Figure 7. Radar Screen at Gunbarrel Hill, One Minute Exposure, 0.25 Microsecond Pulses, 3 NM Range, 0553 MDT, March 20, 1971

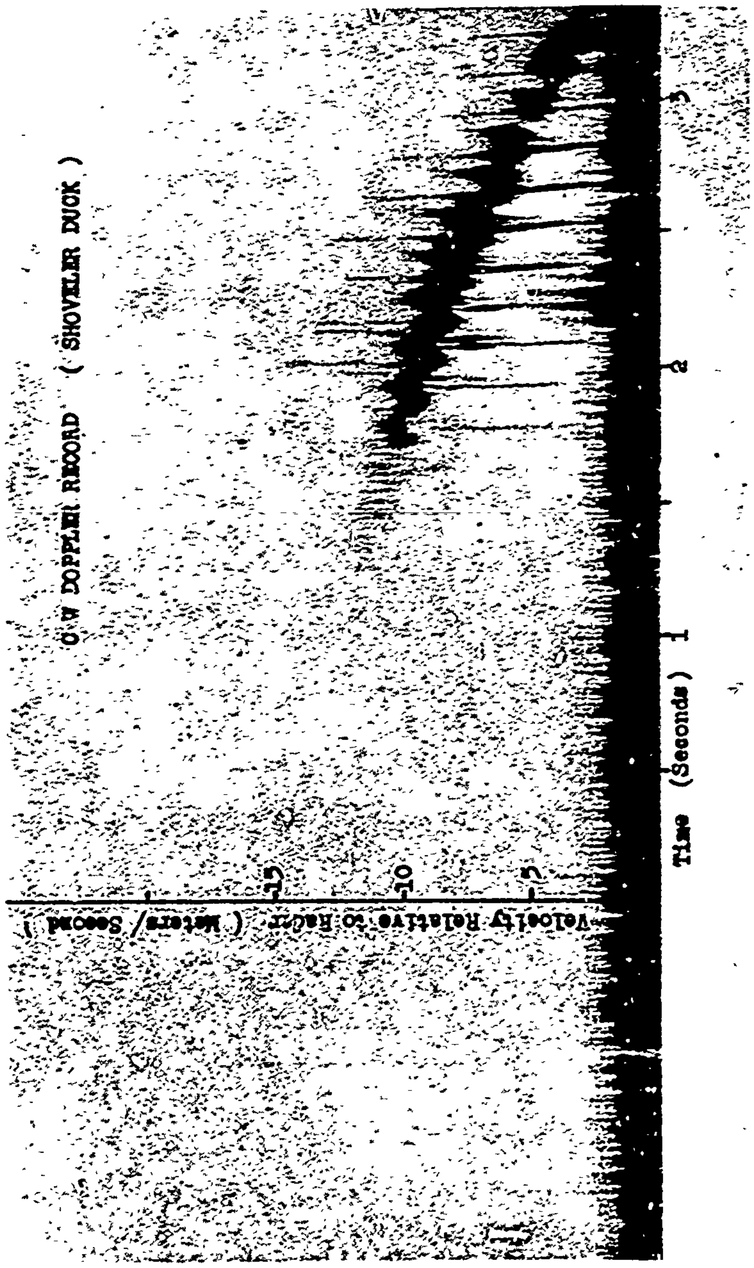

Figure 8. Doppler Frequency Record, Baller Lake, April 11, 1971

of 35mm film were also exposed in the Beattie-Coleman KD-5 camera (about 550 frames).

Valmont Reservoir

When the 654 radar was first put into operation at Valmont reservoir on 2 July, 1971, few ducks were present and the Canada Geese (about 500) were largely flightless. Thus few echoes from waterfowl were recorded. However a number of swallows, mostly Barn Swallows (*Hirundo rustica*), were commonly present and Franklin Gulls had arrived by mid August. Ducks and geese then increased in numbers until about 1 October and remained at a high level through most of December. The cold weather and high winds of January apparently caused a decrease in numbers. On 19 December 1971, an estimated 5000 Mallards and 2500 Canada Geese were at the lake. The most intensive and interesting observations were conducted from about 1 October to 19 December. As the radar was adjacent to the water at Valmont, much use was made of the 0.75 NM and 1.5 NM ranges. The 3 NM and 6 NM ranges were also used extensively for monitoring flights away from the lake. Figure 9 shows bird echoes on the PPI screen, on the 0.75 NM range. The waters of the three portions of the reservoir give no reflection when winds are calm, and bird echoes stand out clearly when the birds fly over the water. Echoes can be seen on the scope, on the 0.75 NM range, as close as about 0.08 NM (150 m).

In the warm weather of summer, the PPI display commonly showed many small discrete targets out to a range of 0.375 to 0.5 NM (0.7 to 0.9 km) at times when only a few birds, mostly swallows, could be seen visually (Figure 10). It is believed that most of these echoes were caused by insects. The echoes were most numerous during

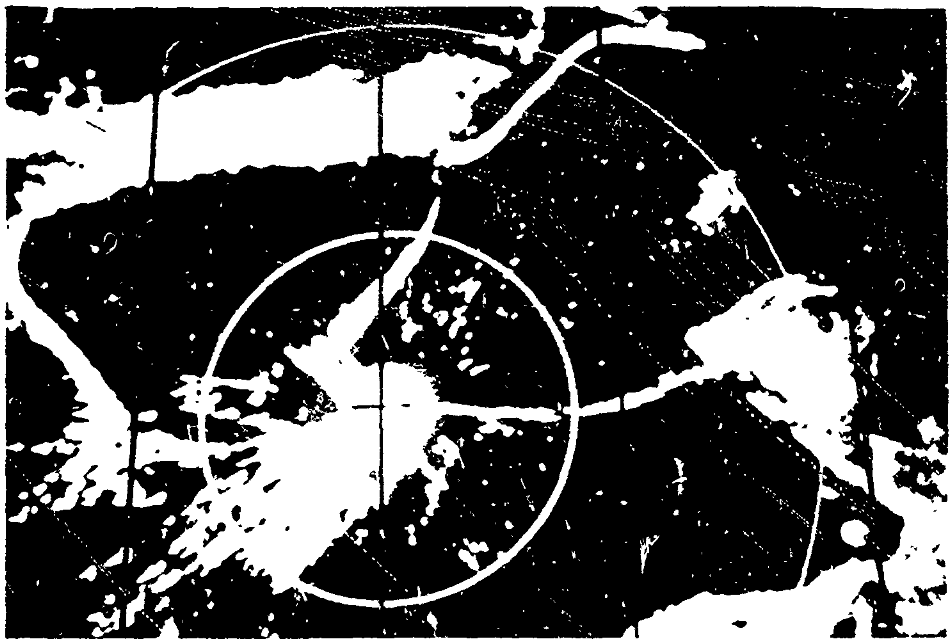

Figure 9. Radar Screen at Valmont Reservoir, 0.75NM Range, Showing Bird Echoes, One Rotation Exposure, 0.05 Microsecond Pulses, 1845 MDT, Oct. 10, 1971

Figure 10. Radar Screen at Valmont Reservoir, 0.75 NM Range, Showing Insect Echoes, One Rotation Exposure, 0.05 Microsecond Pulses, 1330 MDT, July 24, 1971

the middle of the day and were not seen during cold weather.

Local bird activity over the reservoir was observed clearly on the 0.75 and 1.5 NM ranges. The 0.75 NM range did not include the far end of sector B of the reservoir but produced high-resolution coverage of the remainder, as Figures 9 and 10 show. Figure 11 shows the 1.5 NM coverage of the PPI screen. Individual bird echoes were seen frequently out to ranges of about 0.75 NM or farther. In general it was difficult, however, to correlate individual visual observations and radar echoes, especially when the birds were much farther than 0.5 NM. The use of a pair of walkie-talkies helped but it has not been practical as yet to actually determine a maximum distance at which an individual bird can be seen. Gulls and blue herons were commonly seen singly, but ducks and geese were generally in at least small numbers.

The morning and evening flights of the Mallard and Canada Geese were the principal features of interest at Valmont reservoir, although gulls were often present in numbers as well (Franklin Gulls in late summer and early fall and Ring-billed and Herring Gulls later). The Mallards had the same general habits as at Baller Lake. They left the lake in the morning when light was only beginning to show in the eastern sky, and they returned near sunrise and shortly afterwards. In the evening the same performance was repeated, with the birds leaving before sunset and returning after sunset when it was quite dark. Flights were generally to the east along the Boulder Creek Valley, although on one occasion the flights took a more northerly direction and went to the west of Gunbarrel Hill rather than south of it. These remarks should be qualififed by the fact that sometimes an observer arrived in the morning only in time to see the return

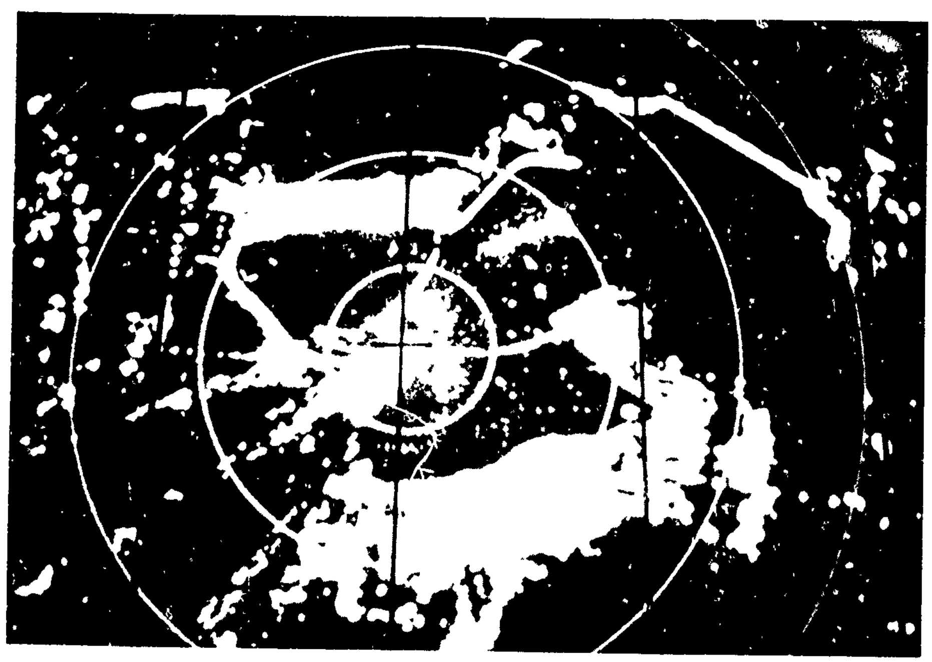

Figure 11. Radar Screen at Valmont Reservoir, 1.5 NM Range, 0.05 Microsecond Pulses, 15 Second Exposure, 1823 MDT, October 10, 1971

flight of the ducks and left in the evening after only seeing an outgoing flight. The observations do not necessarily rule out the possibility that some ducks stay away all night. The observed flights provide only a small amount of time for feeding but as mentioned earlier ducks can feed rapidly. The flights also provide exercise and are perhaps associated with the migratory urge. Presumably on some date or dates in spring the birds take off on a morning or evening flight and do not return.

The habits of the Canada Geese are different from those of the Mallards and obviously are related to feeding. Flocks of geese commonly leave in the morning but only after sunrise, in contrast to the Mallards' predawn departure. The geese feed in nearby fields, mostly in Boulder Creek Valley to the east but in all directions to some extent. There is some movement in and out during the day, but the movement is greatest within an hour after sunrise and in the late afternoon before sunset.

The major flights of ducks and geese at Valmont reservoir made huge radar echoes, sometimes covering the radar screen between Valmont reservoir and Gunbarrel Hill, close to 3 NM to the northeast. Flights were commonly followed to about 6 NM and more from the radar, but the intensity and frequency of targets dropped off considerably after 6 NM. Occasionally targets could be seen out to about 12 NM. Figure 12 shows the 3 NM coverage of the radar and Figure 13 shows the 6 NM coverage. In Figures 12 and 13, the large echo to the northeast near 3 NM is from Gunbarrel Hill, the echoes to the west are from stationary objects and mountains, and the echoes between 2 and 3 NM to the east (about 100° from north) are from stationary objects. The other echoes in the northeast quadrants of

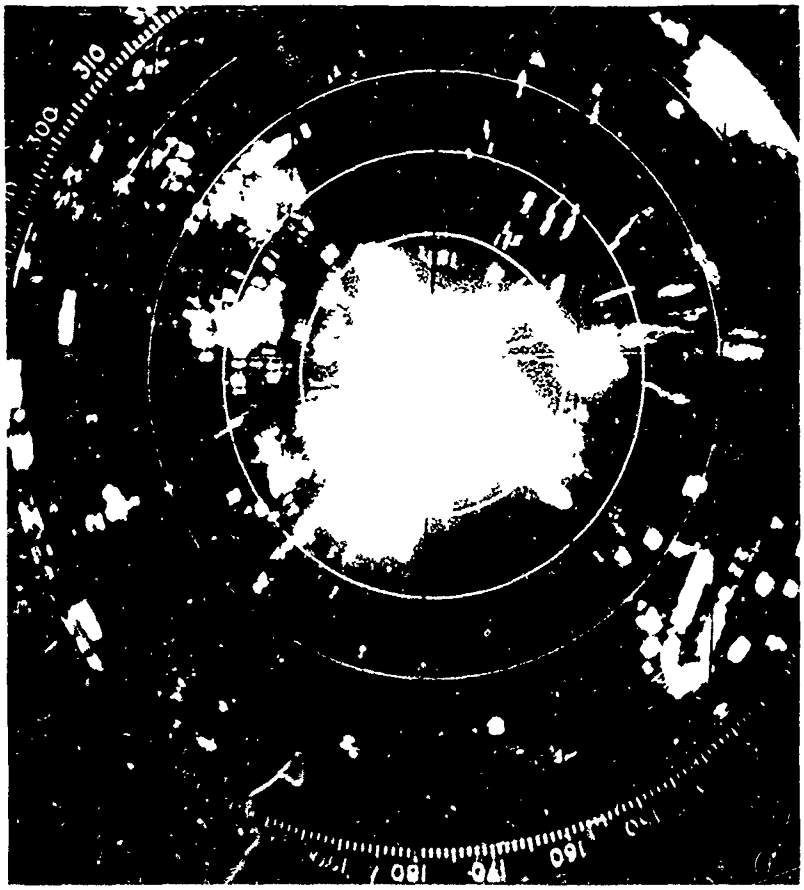

Figure 12. Radar Screen at Vamont Reservoir, 3 NM Range, One Microsecond Pulses, 30 Second Exposure, 1712 MST, November 20, 1971. Shows Discrete Bird Echoes in Northeast Quadrant.

both figures are due to birds.

During strong winds, wave echoes were observed to ranges near 0.5 NM (0.9 km) on Valmont reservoir, which gives no reflection during calm periods. When the slotted-waveguide antenna was used, birds could be seen sitting on the surface of calm water out to about 0.375 NM (0.7 km) depending on the size of the birds, etc. These results are similar to those which could be expected in the case of a radar overlooking a runway. Detection of birds on a runway is considered further in the following section.

Documentation of results at Valmont reservoir is provided by 96 Polaroid prints and four reels, or partial reels, of 35 mm film (about 3400 frames). The parabolic antenna was used from July 2 to 20. The slotted-waveguide antenna was used until 16 November 1971, and the parabolic antenna was used after that date.

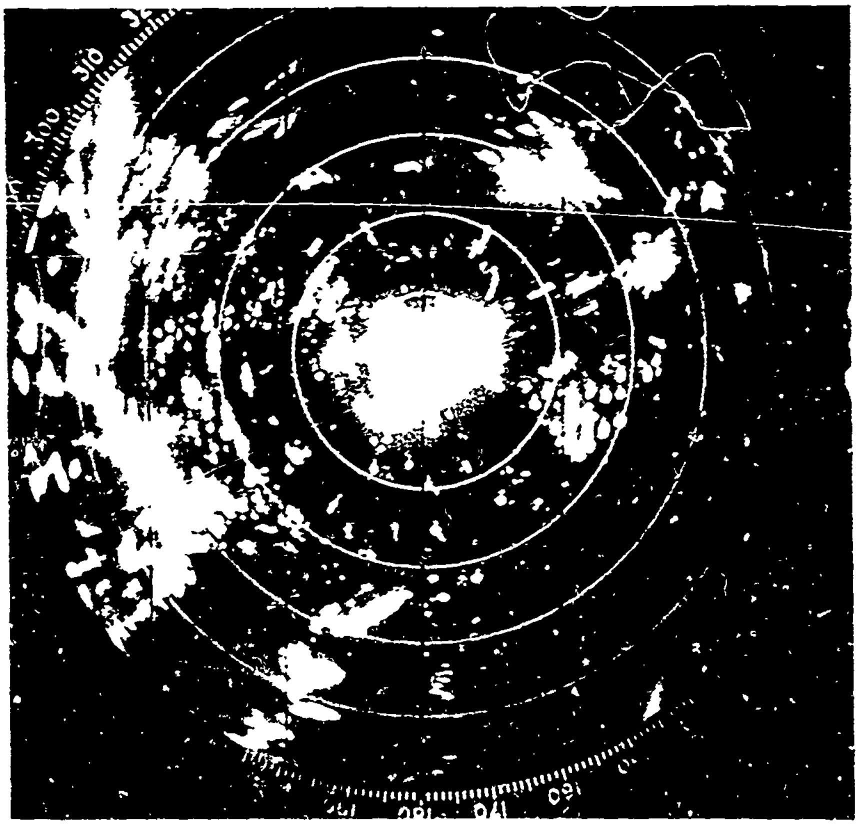

Figure 13. Radar Screen at Valmont Reservoir, 6 NM Range, One Microsecond Pulses, 30 Second Exposure, 1647 MST, November 20, 1971. Shows Birds Leaving Reservoir to East

SECTION IV

RADAR SYSTEM CONSIDERATIONS

Applications of Low-cost Surveillance Radars

Information about the 654 Radar, which was utilized in this study, was first supplied by Dr. Glen Schaefer at the World Conference on Bird Hazards to Aircraft (Ref. 35). Dr. Schaefer recommended the radar as a low-cost, off-the-shelf item which could be deployed at airports to give warning of the presence of birds in the immediate vicinity, especially on and near the runway itself. Soon after arrangements for purchasing the 654 radar were finalized, the report discussing the performance of the radar more fully was received from Dr. Schaefer. In the report, he amplified his earlier remarks and he also placed one qualification on his recommendation, i.e., that some modification be made to the slotted-waveguide antenna in order to obtain a narrower beamwidth in the vertical direction and thus be able to detect birds on the runway at a greater distance.

We concur in this qualification and with most of his discussion, but reach different conclusions in some respects. In particular we put less emphasis on obtaining low-cost, off-the-shelf radars and more emphasis on obtaining optimum performance. Whereas Dr. Schaefer put major emphasis on the runway area itself, it is felt here that the radar should be able to warn of birds to a distance of at least five nautical miles in any direction as well. Also it is considered that the antenna vertical beamwidth should not be narrowed to the extent that some birds in the immediate vicinity may go undetected because they are outside the antenna beam. The emphasis on performance does not mean that no heed is taken of cost. However, it may be preferable to pay $15,000 to $20,000 for a radar having improved performance rather than $6,000 for a radar which may monitor the runway satisfactorily but which does not provide adequate surveillance of the surroundings.

The general concept of using a radar similar to the 654 for warning of the presence of birds at air fields is a good one. Although improvements are desirable, especially for Air Force or FAA operational use, individuals or organizations unable to afford a costlier radar might obtain good service from the 654. This type of radar is also a very useful tool for studying bird movements and behavior in a local area. Such studies are pertinent to aircraft safety because if bird habits and flight patterns are established, it may be feasible to adjust aircraft operations and flight patterns accordingly. For accumulating data concerning bird behavior, it might be desirable to have personnel nearby at all times but to let the radar run unattended between active observational and camera servicing periods. If very much automatic camera data are to be taken test film strips should be developed on a regular basis to insure best photographic results. It would also be desirable if the site personnel had the facilities and time to develop the film reels themselves. This step would avoid the delays in sending film away for processing and consequent delays in taking remedial measures if operational procedures are found to be less than optimum.

Low-cost, short-range radars might be used at some locations where they are the only radar, but in other situations a short-range radar might be used at a location where a longer-range radar was also present. Long-range radars do not detect birds within the first few miles of the radar. Thus the long-range and short-range radars would supplement each other, and the combination would provide more effective warning of bird hazards than either alone. The long-range radar might detect approaching concentrations of birds as far as 50 NM away, and the short-range radar could follow the approaching birds into the immediate vicinity of an airfield.

The usefulness of a 654-type radar would be enhanced if it had radar signature or identification capability, to identify birds as to general type or size by recording signal modulations caused by the wingbeat of birds. Identification would be useful for both airport safety and biological research purposes. Accordingly a short-range radar with signature capability would provide an even better supplement, or complement, to a long-range radar than a conventional short-range radar. The combination in this latter case would be truly optimum.

In the case of detecting birds on a runway, or the similar situation of detecting birds on the surface of water, one depends on the runway, or water surface, being sufficiently smooth that no reflections are received from it. On the other hand the birds must cause sufficient "roughness" if the birds are to be detected when sitting or standing on the runway. A commonly used criterion of roughness is known as the Rayleigh criterion (Ref. 45). The criterion can be explained by considering an area having two different levels from which reflection can take place (Figure 14). For convenience two parallel rays are drawn in such a way that one is reflected from the AA surface and a second is reflected from the BB

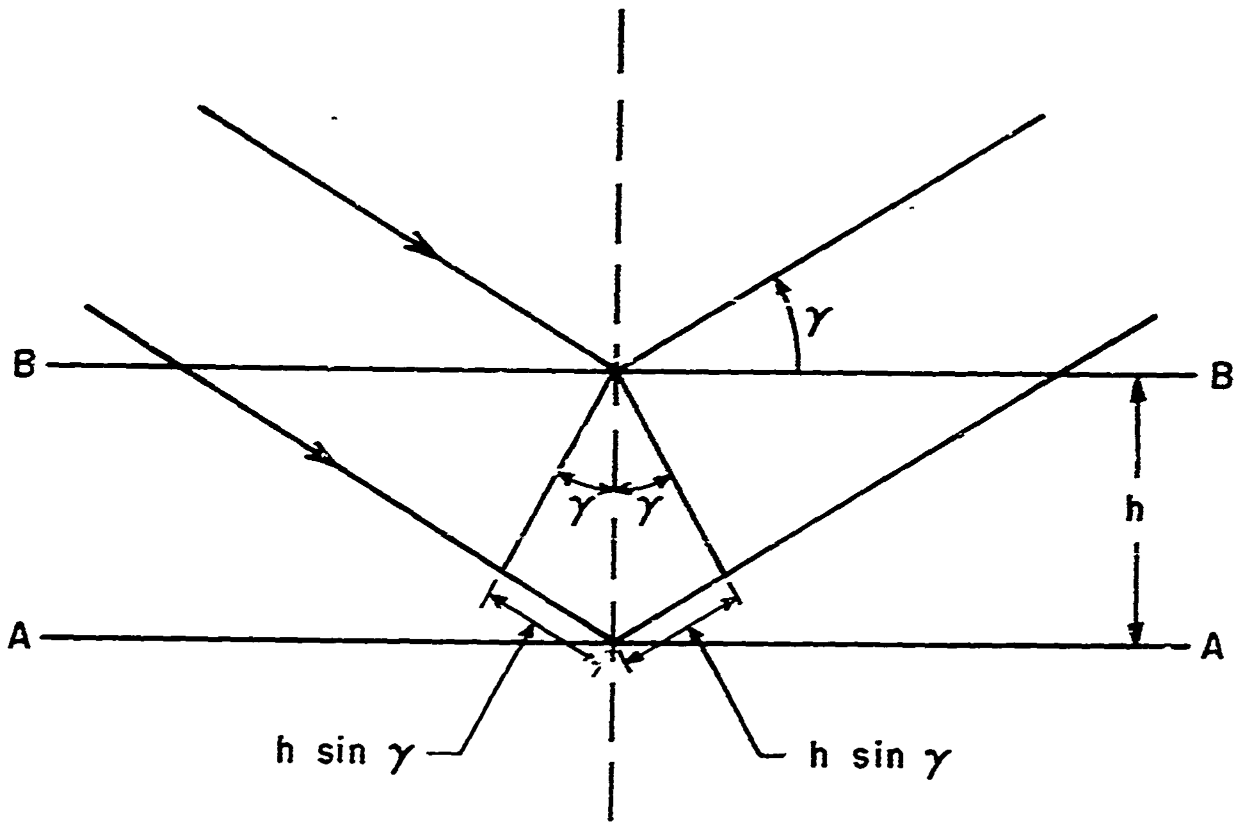

Figure 14. Basis for Roughness Criterion. The Path Length of a Ray Reflected from Surface AA Exceeds that of a Ray Reflected from Surface BB by $2h\sin\gamma$

surface at a point directly above the reflection point on the AA surface. The difference in path length of the two rays, Δr, that is incurred in the reflection process is given by

$$\Delta r = 2h \sin \gamma \tag{3.1}$$

where γ is the angle of incidence measured from the horizontal and h is the difference in height between the surfaces. The phase difference in the two paths is then

$$\Delta\phi = \frac{2\pi}{\lambda} \Delta r = \frac{4\pi h}{\lambda} \sin \gamma \tag{3.2}$$

If $\Delta\phi$ equals π radians, the rays will be out of phase and will cancel each other. If $\Delta\phi$ is very small the two rays will be almost in phase. If the two rays cancel so that there is no energy transmitted in the forward direction then the energy must have been redistributed in other directions including the backward direction. Some angle between 0 and π radians may be taken, rather arbitrarily, as a dividing line such that, if an angle of $\pi/4$ radians is chosen for example, a surface is considered rough if

$$\frac{\pi}{4} \leq \frac{4\pi h}{\lambda} \sin \gamma ,$$

or

$$h \geq \frac{\lambda}{16 \sin \gamma} \tag{3.3}$$

Also $\sin \gamma$ may be expressed as H/R, where H is radar antenna height and R is distance to the radar antenna. Thus

$$h \geq \frac{\lambda R}{16 H}$$

or

$$H \geq \frac{\lambda R}{16 h} \tag{3.4}$$

The equations say that the radar antenna height, H, must be a certain value or greater in order to detect a target of height h at a distance of R. The necessary value of H increases with R and varies inversely as h. As the choice of $\pi/4$ as a dividing line was arbitrary and the criterion does not take into account target shape, etc., the expression gives only a crude estimate of the necessary value of H. However if λ=3.17 cm, R=2000 m, and h=0.2 m, corresponding roughly to a standing gull (Ref. 35) then $H \geq 20$ m, a figure in general agreement with Schaefer's analysis of the problem (Ref. 35). At Valmont reservoir, H was only about 7 m and birds on the water were detectable only to about 700 m. Thus additional height would be needed to detect bird targets on a surface at a greater distance. Furthermore the 654 radar needs a narrower vertical beamwidth to detect birds at a very much greater distance. H should not be much greater than 20 m because as H increases additional areas illuminated by the radar will appear rough and backscatter incident radiation. If one were interested only in detecting airborne targets he would want to keep H to a minimum. For detecting birds on a runway extending 2000 m from a radar, or on a comparable expanse of water, the antenna height should be about 20 m.

Three-centimeter radars, other than the 654, which have been used for studying bird movmeents include the M33C (Ref. 46) and the APS (an aircraft radar) (Ref. 47). Both are rather old military surplus radars and tend to be difficult to maintain. An advantage of the 654 radar is that it is modern, compact, largely solid-state, and relatively easy to maintain. The M33C is actually a combination 10-cm surveillance radar and 3-cm tracking radar. Apparently the

3-cm system tends to function more reliably than the 10-cm system. The tracking feature could be an important advantage, especially for signature work, as it tends to solve the problem of following an individual target for a sufficient period of time to get a good signature. In the absence of tracking capability, one must simply let the birds fly through the radar beam, which can at least be pointed in a desirable direction. Another approach would be to use a very broad beam. In this case, signature operations would be restricted to short ranges, but this feature has the advantage that the birds can then be readily identified visually and photographed. Some degree of manual tracking may also be feasible for signature operations.

Performance Calculation

One means of determining whether given radar parameters should provide adequate performance or not is to attempt to calculate performance on the basis of the radar equation. For this purpose consider a calculation of the maximum range at which a single bird target can be detected. The bird will have a certain radar cross-section, σ, which will be taken as 0.01 meter^2, corresponding nominally to a gull (Ref. 25). The equation for maximum range is

$$R_{max} = \left[\frac{W_t G^2 \lambda^2 \sigma L}{(4\pi)^3 k T B_n F_n (S/N)_{min}} \right]^{1/4} \qquad (3.5)$$

where R_{max} is the maximum range at which the target of cross-section, σ, can be detected, W_t is the peak power of the transmitted pulse, G is the antenna gain, λ is the wavelength, L is an efficiency or loss factor, k is Boltzmann's constant (1.3×10^{-23}), T is absolute temperature, B_n is receiver bandwidth, F_n is receiver noise figure, and $(S/N)_{min}$ is the minimum signal-to-noise ratio required (Ref. 48). The factor kTB_nF_n is the receiver noise power.

The nominal peak power, W_t, for the 654 radar is 20,000 watts and this figure will be used in the calculation even though it is not known that the actual peak power is this value. Gain can be calculated by using

$$G = \frac{31,000}{\theta_{HP}\phi_{HP}} \tag{3.6}$$

where θ_{HP} and ϕ_{HP} are the half-power beamwidths in degrees in the two orthogonal directions. This expression assumes a beam efficiency of 0.75 (Ref. 49). Considering first the slotted-waveguide antenna, the quoted beamwidths are 0.7 and 24 degrees. Thus G=1850 (33 db). The wavelength is 0.032 meter or 3.2 cm. An efficiency factor, L, of 0.5 (3 db) is used to account for waveguide losses, etc. T is taken as the standard temperature of 290° K. For considering maximum range, the receiver bandwidth that the radar employs with a 1 microsecond pulse should be used. This bandwidth is 5×10^6Hz. The quoted receiver noise figure of 13 db corresponds to a F_n value of 20 ($13=10\log_{10}20$). It is assumed that an S/N ratio of 2 is necessary. Inserting these figures

$$R_{max_1} = \left[\frac{(20,000)(1850)^2(0.032)^2(0.01)0.5}{(4\pi)^3(1.3\times10^{-23})(290)(5\times10^6)(20)(2)}\right]^{1/4}$$

$$R_{max_1} = 3900 \text{ meters} \cong 2 \text{ NM} \tag{3.7}$$

Whether this range is actually acheived in practice with the present radar or not is not known. If the transmitted power and noise figure are less than the specified values and if a higher signal-to-noise ratio than 2 is needed before a target is recognized, then a shorter maximum range would be indicated.

Suppose now that the parabolic antenna is used instead of the slotted-waveguide antenna. For this case the beamwidths are 2° in both directions and G_2=7,750 (38.9 db). The maximum range R_{max_2} in this case is 4 NM. Thus the parabolic antenna gives a maximum range about twice that of the slotted-waveguide antenna. This figure of 4 NM might be considered as acceptable except that the vertical beamwidth of the antenna is so narrow that many close-in birds would not be within the antenna beamwidth. Also, as stated above, there is doubt about the reliability of some of the figures used in Eq. (3.7) and a margin of safety may be desirable. The calculation is for a single bird, however, and flocks can be detected at significantly longer ranges.

Possible Improvements to 654 Radar

The radar equation can be used as a basis for considering possible improvements to the radar. One possible measure is a lower receiver noise figure than 13 db. It may be practical to achéive a noise figure as low as 8 db. For detecting targets at maximum range, the receiver bandwidth can be lowered to 1 MHz to correspond to the pulse length of 1 microsecond. An improvement of noise figure by 5 db corresponds to an improvement by a numerical factor of about 3.16 inside the bracket of Eq. (3.1) and decreasing the bandwidth gives a factor of 5, resulting in an improvement in maximum range of nearly 2. If an antenna having the same gain as the parabolic antenna but with a horizontal beamwidth of 0.7°and a vertical beamwidth of 5.7° were used, performance should be adequate (maximum range of an individual bird of nearly 8 NM according to the calculations). An antenna having even a somewhat broader beam in the vertical direction, say 8°, would probably still be satisfactory for most purposes.

On the other hand if maximum range were important a 2° vertical beamwidth, as suggested by Schaefer, would have an advantage. Acheiving this vertical beamwidth and maintaining a horizontal beamwidth of 0.7° at the same time results in a rather large antenna, perhaps one meter or 3 feet high as well as 12 feet long. Also this vertical beamwidth is so narrow that some close-in birds could be missed because they were outside the beam. If it is essential to have a 0.7°x2° beam at times to obtain optimum performance at maximum ranges, considering either airborne birds or birds on the runway, then it would be desirable to have an adjustable antenna that could have a vertical beamwidth of 2° or 8°.

Another measure to increase performance would be to use a higher transmitter power. However, this course would seem desirable only if other measures have been exhausted and further improvement in performance was desired.

SECTION V

RECOMMENDATIONS

A principal purpose of the research reported here is to recommend a radar to be used near airports for minimizing the hazard of collisions between birds and aircraft. (The same type of radar would also be useful for research on bird behavior and migrations.) Instead of making one single recommendation several possibilities are considered.

<u>Conventional Pulse Radar with no MTI</u>

Although the 654 radar is useful as it is, certain improvements in the radar would enhance the usefulness for bird detection. Some possible improvements were discussed in Section IV, and a further discussion follows.

1. An antenna having a narrow horizontal beamwidth (0.7° to 1°), together with a vertical beamwidth of 6° to 8° should be used. The 12-foot slotted-waveguide antenna has a vertical beamwidth which is excessively broad for a land-based surveillance radar. A possible option is an antenna which can provide about a 0.7°×8° or a 0.7°×2° beam, with ability to change from one to the other automatically. (This type of option is available in the case of some other operational Air Force radars.)

2. A receiver noise figure of about 8 db, with built-in test equipment for measuring the noise figure and/or minimum detectable signal, is needed.

3. A proper match between pulse width and receiver bandwidth is necessary to acheive maximum signal-to-noise ratio. The 654 radar

uses a 5 MHz bandwidth with a one microsecond pulse. The bandwidth should be 1 MHz in this case.

4. Receiver and/or video gating circuits should be modified to completely blank signals during the return trace of the PPI sweep. The return trace signals that show on the 654 radar are somewhat annoying.

5. A synchro system for linking the antenna and indicator, with provision for stopping, aiming, and sector scanning would be much preferable to the present arrangement. (See Section II).

6. The radar should have suitable voltage-regulation and power supply circuits so that it can operate satisfactorily from commercial 60 Hz power without the necessity of using a noisy motor-generator set. (The motor-generator set that came with the radar has been replaced with a 120-240 v step-up transformer.)

7. Trigger and video output terminals should be provided in case an auxiliary A scope presentation is desired.

Another minor problem with the 654 radar, is that the high-voltage supply circuit is somewhat temperature sensitive and unstable, with the result that the CRT focus deteriorates at times. The condition should be remedied and it may be desirable to incorporate a focus control in the process.

It is recommended that radar manufacturers be contacted about the possibility of producing a radar similar to the 654 radar, but one incorporating the improvements mentioned. A related recommendation of lower priority is that the possibility of incorporating at least some of the improvements into the present radar be investigated and acted on to the extent feasible.

MTI Capability

MTI capability is desirable in general for surveillance radars, and economy is the only reason for not having this capability. MTI aids greatly in eliminating ground clutter and echoes from stationary objects, thus facilitating the observation of bird movements by radar. The importance of MTI varies with the site. It may not be crucial for runway surveillance alone but may be essential for area surveillance in some locations. Some form of MTI would be highly desirable, at least as an additional cost option, for use with a radar which otherwise has the characteristics of the 654 radar, together with improvements listed in section 4.2. It is recommended that manufacturers that are contacted about an airport-surveillance radar be asked to consider supplying a unit with MTI as well, perhaps as an extra cost option. In the case of a radar having MTI video, normal video signals should also be available.

The normal video signals should be available because some loss in sensitivity results when MTI is used and targets having near zero radial velocity are eliminated by MTI. Being able to switch to normal video may allow checking whether MTI is eliminating many zero-radial-velocity targets or not. Also if MTI is not needed for some portion of the display or is needed little if at all in some particular radar location, then normal video can be used instead to the extent feasible. Finally normal video allows more of the surface features to show and provides a better radar map of the surroundings than MTI video. Thus if may be desirable to switch temporarily to normal video to facilitate locating targets with respect to surface features. It may be less essential that normal video signals be available in a radar used in a research program than in one used for operational purposes.

Signature Capability

Signature capability would be highly desirable for a close-in surveillance radar or for an auxiliary radar to be used in conjunction with a surveillance radar (see Section I). Such capability is still a subject of research, however, and it is recommended that the necessary research be carried out to determine what the optimum radar facilities would be for this purpose. It is recommended that three different options be considered and that a final decision, about which option or options should be adopted ultimately for operational purposes, be deferred.

Noncoherent Pulse Radar

Some signature capability can be obtained with a noncoherent pulse radar, if the radar can be stopped to interrogate a given region continuously. In some cases it may be satisfactory to stop the rotation of the surveillance radar momentarily to accomplish the signature function. If stopping the rotation can not be tolerated then separate radars will be needed to carry out both surveillance and identification (signature determination) simultaneously.

The basis for signature capability with a noncoherent pulse radar is the nature of the returned pulse-amplitude variations. An echo from a single bird should show a characteristic signature, a principal feature of which is amplitude modulation at the wingbeat frequency. This same wingbeat frequency should show in the spectra of echoes from groups of birds. For obtaining signature data, the radar should provide trigger and video outputs for an auxiliary A-scope presentation. With the signals displayed on the A-scope, a Princeton Boxcar Integrator can provide the pulse envelope amplitude for echo pulses occurring in the desired range interval. For real-time identification some additional processing or filtering will be necessary to extract the wingbeat modulation frequency. It is recommended that the option of using a noncoherent pulse radar for signature determination be investigated further.

Coherent Pulse Radar

A coherent pulse radar has the advantage that the doppler frequency of the echo can be determined, as well as the amplitude variations. The doppler frequency variations may be as useful or more useful than amplitude variations for signature purposes, and it is an advantage to be able to record both. Also range gating can be used with a pulse radar, and the coherent pulse radar has an advantage over a simple cw radar in that respect. In addition a coherent pullse radar inherently has MTI capability. Since a coherent pulse radar would be ideal in many respects, it is recommended that it be investigated further.

CW Radar

A cw radar has the advantage of simplicity and low cost as compared with a coherent pulse radar. Its principal shortcoming is that it cannot discriminate as to range. It was originally planned to use a cw radar for signature or identification purposes. Then the idea of a coherent pulse radar was favored, because it appeared that coherent operation could be obtained by modifying the present pulse radar. Also a coherent pulse radar would be ideal in many respects as mentioned earlier. However transmitting tubes for coherent radars tend to be very expensive. In the event that it is decided as a matter of policy that rotation of a surveillance radar can not be stopped and an auxiliary radar must be used for identification, then the cw radar may be attractive for this purpose. Also the cw radar is well suited for use as a research tool, for obtaining individual bird signatures originally, as distinguished from operational use. And since a signature radar could not be used for operational purposes until sufficient research on radar signatures had been completed, the subjects of signature research and operational use are inseparable at this time. The cw radar option should be kept open.

Tracking Radar

The recommendations made here emphasize compact, portable radars which may be available, or may be constructed, in the Boulder area, but it should be mentioned again (see Section IV) that a tracking radar has advantages for signature work. Reference 38 refers to signature work accomplished with a tracking radar at Wallops Island, Virginia. It may be that there are Air Force tracking radars that are well located for signature work. This possibility should be kept in mind and exploited if an opportunity develops.

Observations and Tests of Performance

Observations of radar performance in the field are an essential part of any radar program and no amount of time spent in an office or laboratory will substitute for watching and photographing radar scopes and gaining first-hand experience with the details of radar signals. It is therefore recommended that additional operational experience with 654-type radars be obtained whenever feasible, especially at different locations than those utilized to date and especially as various modifications or improvements are made to the radar or radars utilized. A single experienced observer can do a good job of assessing the radar performance after hours of watching the scope and visually monitoring the area with binoculars at the same time, and after taking the studying photographic data. Obtaining precise data on exactly what birds are seen at what distances and altitudes is considerably more difficult and usually requires an observer at the radar and at least one remote observer. An effort should be made to obtain data of this type whenever possible. A few intense observational periods involving several remote observers would be highly benefical. However the importance of such data should not be overestimated, as one or two experienced observers at the radar and/or large amounts of photographic data can supply a quite satisfactory, statistically significant description of radar performance. In any case it is recommended that in the present program highest priority be given to obtaining a radar, or radars, of improved performance and to developing signature capability, rather than to making further observations of the performance of the 654 radar as it is. Any further tests of the 654 radar in essentially its present form should be conducted in such a way as to interfere as little as possible with the higher priority of obtaining a radar of improved performance.

The observations to date have been made at locations convenient to Boulder. At the present stage of the program, however, attention should begin to be devoted to Air Force installations themselves. One possibility is to take the present radar to one or two airfields at an early date, but this may interfere with the use of the radar for research and development purposes. Also, if the radar is to be taken to an airfield, consideration needs to be given to whether the radar should be operated in the trailer in which it is presently housed or placed at a height of 20 m as discussed in Section IV. Attention needs to be given in addition to analysis of present radar facilities at or near the fields and to consideration of how a 654-type radar would fit in with present radars and other operational facilities, because, as stated earlier, a 654-type radar may function best as a supplement or complement to present facilities. Preliminary investigations of these types can be made as early as the summer of 1972.

It remains to be seen when sufficient progress, in improving the 654 radar and/or developing signature capability, will have been made to justify, from that viewpoint, taking the radar to an airfield. One very important consideration will be whether both coherent signature capability and improved range performance can be combined in one radar within budget limitations. In any case, a coherent radar would be extremely valuable for obtaining signatures and studying the signature problem, and the information derived from testing it will be applicable to the other types of signature radars (noncoherent pulse and cw) as well.

SECTION VI

CONCLUSION

The GEC-AEI No. 654 radar has been and will continue to be a useful research tool. Emphasis should now be placed on improving the present radar and obtaining signature capability, rather than on testing the radar further as it is or with only slight modifications. Additional detailed observations and tests will be highly desirable, however, if performed after sufficient time has been devoted to research and development efforts, or in such a way as to not interfere with these efforts. Concurrently with the research activity, manufacturers should be contacted to see which ones are interested in supplying suitable improved radars at reasonable cost. Research is needed primarily on signature and MTI capability, but practical problems remain as to how best to improve the basic performance of a 654-type radar.

The development of a coherent pulsed radar having signature capability would constitute a major step forward and should be promoted to the extent possible. However, such a radar will be rather expensive, especially if it is to be capable of detecting a single bird to 5 NM or more as well as providing signature data. Thus improved but still rather low priced pulse radars, perhaps having signature capability based on amplitude variations as an option, will very likely still be desirable, and attention should be given to the lower priced options as well as to the coherent pulsed radar.

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