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RADIO AND ELECTRICAL ENGINEERING DIVISION

A BIRD HEIGHT FINDING RADAR FOR AIR TRAFFIC CONTROL

A PROGRESS REPORT

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OTTAWA

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ABSTRACT

The National Research Council's Associate Committee on Bird Hazards to Aircraft requested an investigation of the best type of radar to provide air traffic controllers with information of hazardous flocks of airborne birds in the vicinity of airports. During three successive spring migrations of the Lesser Snow Geese through the Winnipeg area, the authors have tested the following types of radar: (a) surveillance radar, (b) tracking radar, and (c) nodding-beam height finder. As a result of the trials and discussions with air traffic control personnel, the conclusion was reached that a radar with stepped antenna scan and automatic detection, and providing three-dimensional positions of bird flocks would provide the best answer. In addition, this radar would also give information on hazardous weather conditions. Further calculations, experiments, and discussions are being carried out prior to writing preliminary specifications for the new radar.

CONTENTS

A BIRD HEIGHT-FINDING RADAR FOR AIR TRAFFIC CONTROL

A Progress Report

F.R. Hunt* and H. Blokpoel**

INTRODUCTION

Collisions between birds and aircraft are a hazard to flight safety in both civil and military aviation. In Canada, 70 per cent of bird strikes on civil aircraft occur within the boundaries of airports (1). The problem of birds colliding with aircraft en route is also very real, as exemplified by the crash of a Viscount after hitting migrating Whistling Swans near Baltimore, Maryland, at an altitude of 6,000 feet (2).

After reviewing the problem of in-flight bird strikes in commercial operations, Gunn and Solman (3) conclude that the great majority of serious bird strikes occur in the take-off, climb out, approach and landing regimes (jetliners cruising at 12,000 feet or more are unlikely to encounter birds) and with small birds in dense flocks (starlings caused the crash of an Electra (4)), medium-size birds like gulls in relatively dense flocks, or large birds like swans, geese and cranes, flying individually or in flocks. They suggested that a bird warning system be developed covering the airport's surroundings.

A near disaster collision between a Boeing 737 and a flock of migrating snow geese about twelve miles northeast of Winnipeg in spring 1969 provided the impetus for a project to develop such a bird warning system. The NRC Associate Committee on Bird Hazards to Aircraft asked the Canadian Wildlife Service (CWS) to (a) monitor the spring 1970 snow goose migration over the Winnipeg area and (b) develop methods to warn of this flight and of similar bird movements elsewhere. Since 1971 the project has been a joint effort of the CWS and NRC. Results of the trials in 1970, '71, and '72 were presented in interim reports to the Associate Committee.

The aim of this paper is to summarize the main developments and results, to propose a bird radar for use in Air Traffic Control (ATC) and to describe its general features and mode of operation. The preliminary specifications for the recommended radar will be prepared by the senior author after further laboratory experiments and discussions with ATC experts.

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EXPERIMENTAL WORK

(a) ATC Surveillance Radars (AASR-1, ASR-5)

Monitoring of the spring snow goose migration in 1970 was done by making (a) a time-lapse 16 mm film of the master display of the AASR-1 radar at Winnipeg International Airport, (b) routine field observations in the vicinity of Winnipeg, and (c) simultaneous visual observations of flocks from the ATC tower and the ASR-5 display located in the tower. The AASR-1 (23 cm) and the ASR-5 (10 cm) are the long- and short-range surveillance radars, respectively, used at Canadian airports. Details and specifications of these radars are given in the Air Traffic Control Manual (5). Solman (6) described the film technique.

The average weight of a Lesser Snow Goose is about 2 kg (7). If we assume the radar cross section at X-band (3 cm) to be about $0.6\,\pi r^2$ where r is the radius of a water sphere of equivalent weight (8), then the echoing area of a single snow goose will be about 100 cm^2. Thus a flock of 100 geese, if contained within the radar pulse volume, would have an echoing area of about 1 square meter. This value is consistent with our admittedly small sample of visual observations of bird numbers and radar data on the same flock of geese. The cross section of such a large bird at 23 cm and 10 cm will have approximately the same value.

The radar films showed the migrating goose flocks as big echoes that could be identified as goose echoes by their size, distribution, speed, direction, range, and time of presence on the scope. There was good agreement between sightings of migrating goose flocks and the presence of good echoes on the radar screen. Blokpoel (9) reported on the staging areas, migration routes, phenology, numbers, heights, and speeds of the spring 1970 snow goose migration.

Regarding the development of a suitable bird warning system, we considered two possible approaches: (a) a migration forecast system, and (b) a real-time warning system. The migration forecast system should make it possible to predict major flights based on weather forecast together with a knowledge of such flights in previous years and the way the birds respond to weather changes. The junior author is preparing a report on this aspect of the project and it will not be dealt with in this paper.

The real-time warning system should provide air traffic controllers with sufficient information on the presence of hazardous bird flocks aloft to enable them to keep aircraft at a safe distance from those flocks. As mentioned in the introduction, only aircraft flying below about 10,000 feet are likely to encounter birds. Thus, for the great majority of airliners the bird hazard lies within the terminal control area.

Radar can detect birds and has been used for many studies of bird movements (see Eastwood (10) for a review). It is, however, usually rather difficult to detect and follow bird echoes on a radar scope because most are small, "painting" intermittently, and moving very slowly. Many controllers tend to consider bird echoes as angels (echoes from unknown targets). By taking time-lapse film or time-exposure pictures (6) the bird nature of many angels can often be demonstrated. Projection of the time-lapse film shows all targets moving many times faster than in real-time and thus even small, slowly moving bird echoes can be recognized. Time exposure pictures show bird echoes as bars rather than dots.

As expected, the Winnipeg radar films showed the goose migration very clearly. However, taking film or even time-exposure pictures would be too cumbersome and time-consuming for use in air traffic control. Fortunately, the bright scan display can provide a real-time effect very similar to that of time exposures. Bright scan displays have a variable trail-time, with which the persistence of echoes on the scope can be varied. As shown in Plate I, the use of a long echo persistence produces teardrop-shaped bird echoes that can be easily recognized. Plate I also shows the so-called MTI wedges, i. e. , sectors devoid of bird echoes due to cancellation by the moving target indicator (MTI) of all those echoes that have no radial speed. By switching off the MTI the controller will get a better picture of the real bird situation at the cost of cluttering up his screen with permanent echoes (Plate II).

The effects of the MTI and other radar settings on apparent density of bird echoes on the screens of AASR-1 and ASR-5 radars were reported by Richardson (11) who concluded that "Adjustments in radar performance usually have their greatest effect on echoes at long range and on fine passerine-type echoes, no doubt because such echoes are close to the threshold of detection". Most of the radar settings would not seriously effect the visibility of the "goose echoes" on the displays at Winnipeg. Most goose flocks were large (an average of about 200 birds), and on one occasion the outgoing flocks were still producing big echoes at a range of 83 nautical miles (nmiles) where the echoes suddenly disappeared, apparently because the birds had reached the radar horizon at their altitude. Even in cases where the radar settings cancelled many smaller bird echoes, the "goose echoes" were still visible, though often as much smaller echoes. In such cases aircraft echoes were also much smaller.

We felt that, given a judicious use of trail-time and MTI, the controllers had very useful equipment at their disposal to detect large bird flocks and their positions relative to aircraft. It was, however, obvious that controllers would also need a tool to determine quickly the height of the hazardous bird targets.

Elementary descriptions of height-finding radars and their use in bird detection can be found in Eastwood's book (10).

(b) Tracking Radar (WF-3)

In an attempt to provide migration heights to controllers, the Associate Committee purchased a Plessey wind-finding radar (WF-3) in 1971 for evaluation during the spring migration at Winnipeg. This is an economically priced tracking radar designed to follow weather balloons carrying light corner reflector targets in order to determine wind direction and velocity. Its main characteristics are given in Appendix I, and Plates III and IV show the display rack and antenna. A conversion chart was required to obtain the altitude from the range and elevation angle information readouts. Specification of the required lock-on signal strength could not be obtained but if one estimates that this is -95.7 dBm, then the lock-on range of the radar on a 1 square meter target is about 12 nmiles.

The operator at the AASR-1 display selected goose echo targets, usually in the southwest quadrant, and at ranges between 10 and 20 nmiles. This quadrant was chosen because the goose echoes on the MTI display were most numerous there. The range and azimuth of these flocks were passed to the WF-3 operator who was to obtain the altitude of the flock. As soon as the WF-3 operator obtained this height, he passed the information back to the ATC operator who recorded the target's position, altitude and the total time required for height finding. If a height was not obtained in 4 minutes the attempt was abandoned. Tests were restricted to days when snow geese were known to be flying.

The AASR-1 radar at Winnipeg was at some distance from the WF-3 and the parallax introduced in passing range and azimuth information was great. This added a problem during the tests but it could be eased in operation by the use of a suitable conversion table.

Of 92 requests for flock heights, 44 positive answers were provided; i.e., 47% of the requests. The geese flew at altitudes of less than 2,000 feet at ranges of about 15 nmiles and this made it difficult for the operator to differentiate between the geese and the many ground echoes. When the radar was locked on a target, tracking had to be maintained for at least 10 seconds in order to ensure that the target was moving. If the target turned out to be a ground echo, the original range and azimuth data were no longer valid and other readings had to be obtained from the ATC radar. We also found that the manual elevation and azimuth controls on the radar were too coarse to allow the operator to carry out a simple search in these coordinates around the target's reported position.

The radar was then moved to the National Research Council's Field Station in Ottawa. Antenna patterns were made and it was found that the first side lobes were only 13 dB down at an angle of 3° to 3.5° from the main lobe. Thus it is not surprising that the ground echoes caused so much difficulty in Winnipeg.

An inexpensive B-scope was added to the equipment to aid the operator in differentiation between moving targets and permanent echoes. We found this of little use in practice because the antenna's mechanical drive permitted only very slow azimuth scans. However, as part of the B-scope unit, a circuit for a programmed search about a selected azimuth coupled with a finer elevation control had been installed and was found to be useful to the operator.

While the radar was at the Field Station, tests were carried out to determine its capability in acquiring low elevation targets and the time required to lock on such targets. A jet Ranger helicopter was used since its speed and radar cross section approximated those of a flock of geese. It was flown in and out along radial lines from the ATC surveillance radar at Ottawa airport. The permanent echoes, compared to those at Winnipeg Airport, were negligible along the radial lines chosen.

The minimum elevation angle for lock-on turned out to be 0.9° which corresponds to 2100 feet at 20 nmiles. Since the altitudes and slant ranges of the helicopter were known, the true elevation angles could be determined. The standard deviation of the WF-3 elevation angle readouts from the true elevation angle was 0.43°. This value is larger than the manufacturer's specified value of 0.15° and may be due to our measurements being made at low angles of elevation where the ground clutter could influence the radar's operation. Thus it is not too surprising that the flocks of geese tracked at Winnipeg sometimes showed apparent height changes of 500 feet a minute. Lock-on time on a strong target was usually less than 1 minute after being seen on the WF-3 A-scope.

The results obtained with the WF-3 tracking radar were too poor to recommend its use in the air traffic control environment. Improvements to its antenna and control circuits would be economically unsound. Hence, the senior author submitted a memorandum (12) to the Associate Committee suggesting the employment of a nodding-beam height finder and included a preliminary specification, (Appendix II).

(c) <u>Nodding-beam Height Finder</u>

Since the cost of building one of the proposed radars solely for test purposes was too great, a suitable substitute was sought. This was found in the Quadradar (AN/FPN-36) which, although designed primarily for use in ground-controlled approaches by aircraft, also has a height-finder capability which approximates that of the proposed radar. A comparison of it and the proposed radar is given in Appendix II. A Quadradar was installed and maintained at Winnipeg airport by the Canadian Forces at the request of the Associate Committee in the spring of 1972.

The aims and methods of the tests with the Quadradar were identical to those with the WF-3. We did not use the circular polarization, FTC, or STC fixes of the Quadradar as these had not been specified in the proposed height finder.

A total of 80 attempts were made and heights were obtained on 65. Of the 65 successful attempts, the average time necessary to obtain and pass the height information to the ATC center was 63 seconds. Ranges of 20 nmiles or greater were obtained in all quadrants. The height distribution of the flocks successfully measured is shown in Table I.

TABLE I.

Flock Height Distribution

Height, ft	Number of Flocks
0- 999	32
1000-1999	20
2000-2999	10
3000-3999	3

Of the 15 missed, 2 were at ranges of less than 10 nmiles and may have been missed because the maximum antenna elevation angle of 6^{o} was too low. Another possible reason is the parallax in target coordinates between the Quadradar and surveillance radar as it had been impossible to obtain a suitable coordinate conversion chart. A third possibility is that the flock was flying low and the operator could not distinguish between it and ground echoes in the time allotted.

Another three targets were at ranges greater than 20 nmiles. Since these were in the southwest quadrant and they were flying northeast, it probably would have been possible to obtain their altitudes at a later time.

There remain ten targets between 10 and 20 nmiles on which heights were not obtained. For some of these the explanations offered under the short- and long-range failures apply. For others, the fault could lie in the different blind sectors of the Quadradar and the surveillance radar. The two radars were separated by at least 1 mile and the surveillance radar antenna was mounted on a tower.

The lowest angle at which a flock was detected was 0^{o} at a range of 16 nmiles. The height accuracy obtained with the Quadradar is approximately $\pm$ 100 feet. Since this radar was designed primarily for landing aircraft, no corrections in the altitude readouts have been made for earth curvature or beam bending. However, if the Quadradar was used operationally for bird height determination, a table of range versus height correction factors could be used, the corrections to be simply added to the value read off the height indicator.

The results obtained with the Quadradar indicate that it or the proposed nodding-beam height finder are suitable for the altitude determination of migrating flocks of large birds.

STEPPED ANTENNA SCAN RADAR

Although a nodding-beam height finder would be useful in the present ATC environment, we found through discussions with ATC personnel in Ottawa and Winnipeg that its use would be limited in future environments, (a) since future ATC surveillance radars will not report bird echoes due to additional circuitry to remove slow moving weather clutter, (b) because of manning problems, and (c) because the operators do not like the long trail times on the bright scan displays. Thus, a new automatic radar, independent of the present radars, is required that will provide a combined surveillance and height-finding capability to a range of 20 nmiles from the airport. The radar would employ digital techniques for the detection and storage of targets. The initial cost would be greater than a nodding-beam height finder but the operating cost would be considerably lower as no controller would have to be assigned to this radar.

Although precise numbers remain to be resolved, the radar would use an antenna that is stepped in elevation, perhaps $\frac{1}{2}^{o}$ every antenna rotation for 10 scans, and then returns to 0^{o} to commence the series again. Although one or two minutes would be required to complete the coverage pattern, this is satisfactory since bird targets move relatively slowly at ground speeds of 25 to 60 knots.

Range slices corresponding to various altitudes would be selected at each elevation angle. For example, at 2^{o}, ranges between 3 and 7 nmiles would correspond to a 1000-foot altitude, 8 to 12 nmiles would correspond to 2000 feet and so on out to 30 nmiles. Detected targets would be stored in range, azimuth, and altitude 'bins'. Because digital techniques are employed, it would then be simple to display the danger areas on the ATC bright scan displays without the use of a bright scan converter. The danger areas could be displayed either mixed or unmixed with the normal display of aircraft.

The danger area of a flock of birds would appear as a bright square on the display. A multi-position switch on each bright scan display would allow the controller to display the danger areas in any altitude slice of 1000 feet from 0 to 10,000 feet or all danger areas from 0 to 10,000 feet. Normally, he would leave the switch in the "all altitude" position until a danger area appears. Then running quickly through the switch positions he could obtain the actual altitude of targets in the danger area.

Alternatively, the controller with an aircraft flying at a known altitude could switch to that altitude slice and look for areas dangerous to that aircraft. It should be noted that although the data are renewed once every one or two minutes, the latest data are always available from storage. Since the targets are slow moving, this will not significantly affect operations.

It is well known that radar returns from meteorological phenomena (heavy rain, thunderstorms, hail) which are potentially dangerous to aircraft are as strong as or stronger than aircraft or bird echoes unless special circuitry is included in a radar. Since the proposed radar will deliberately avoid the use of such circuits, it will also serve to provide warnings to controllers of potentially dangerous weather conditions and the altitude extent of such danger if less than 10,000 feet.

This radar will also display potentially dangerous small aircraft unequipped with beacons which can unexpectedly appear in the vicinity of an airfield much to the consternation of the controllers. However, no advantages are anticipated here because of the relatively slow data renewal rate of two minutes for this radar. Thus, an aircraft flying at 120 knots would cover 4 nmiles between points, making it very difficult to track with this radar alone. Since the danger area and any returns from the aircraft as seen by the surveillance radar appear simultaneously on the display, it may be possible to obtain the height from the bird radar and the track from the surveillance radar.

Further calculations, laboratory experiments, and discussions with ATC personnel are being held. At their conclusion, the senior author will submit a preliminary specification for the proposed stepped antenna scan radar to the Associate Committee.

ACKNOWLEDGMENTS

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APPENDIX I - TRACKING RADAR WF-3 CHARACTERISTICS

Specifications

Antenna (parabola with spinning feed)	
Beamwidth	2.3 degrees
Offset	0.8 degrees
Spin Rate	1500 per minute
Elevation	-5 to +55 degrees
Slew Rate	2 degrees/second
Azimuth	0 to 720 degrees
Slew Rate	10 degrees/second
Gain	32 dB
Wavelength	3 cm
Peak Transmitted Power	55 kW
Pulse Length	1 μsec
PRF	800 pps
Receiver Type	Linear
Radar Display	A-scan
Range, azimuth, elevation	Nixie Tubes
Modes of Operation	(1) Automatic Track (2) Manual Control of azimuth, elevation (3) Azimuth and Elevation following of optical sight

In modes 2 and 3 manual operation of the range gate is required before subsequent switching to automatic track.

REFERENCE

1. Windfinding Radar WF-3 Operator's Manual TP1087, Issue 1, Plessey Radar Limited, England, Oct. 1968.

APPENDIX II - NODDING-BEAM HEIGHT FINDERS' CHARACTERISTICS

TABLE I

Quadradar and Proposed Radar Specifications

	Quadradar (1)	Proposed Radar (2)	Units
Wavelength	3	3	cm
Peak Transmitted Power	150	50	kW
Pulse Length	0. 6	1. 0	μsec
PRF	1500	700-900	pps
Minimum Detectable Signal	99	101	dBm
Antenna (elevation only for Quadradar)			
Vertical Beamwidth	0. 85	0. 5	degrees
Horizontal Beamwidth	2. 5	3	degrees
Gain	39	40	dB
Elevation Scan	-1 to +6 or -1 to +30	-1 to +11	degrees
Nod Rate	30	10	per minute
Receiver Type	linear	logarithmic	
Display Type	B-scan	B-scan	

The main differences between the two radars are in the azimuth control of the nodding beam. The Quadradar has a second antenna with a csc^2 pattern which is sector scanning a 30^o azimuth. A second B-display is associated with this azimuth antenna. The elevation and this second azimuth antenna are connected alternately to the radar's transmitter-receiver. A coarse azimuth toggle switch is used to position the sector covered by the azimuth scan and the position of the center of this sector appears on an illuminated compass rose. When a target is seen on the azimuth B-display, a second toggle switch is used to position an azimuth strobe associated with the nodding-beam antenna over the target. A height strobe is then placed over the target on the height scope and the height is read off a counter.

In the suggested radar, a dial calibrated in degrees was to be used to direct the nodding-beam antenna at the target from information derived from the ATC surveillance radar.

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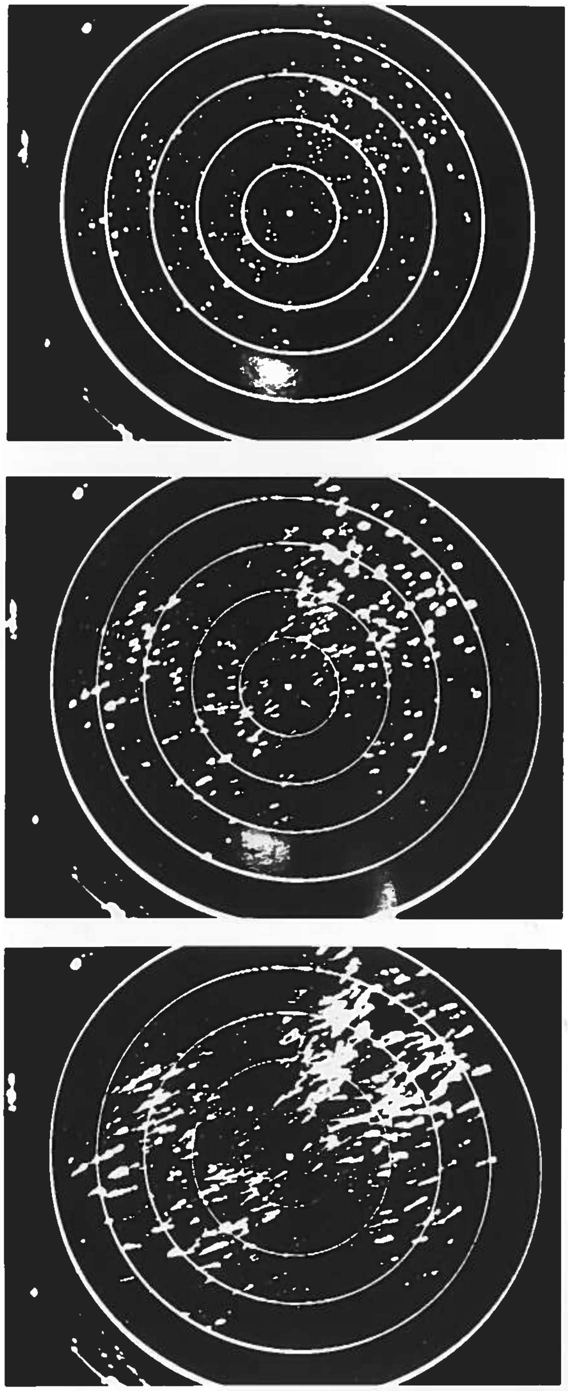

(a) 50 seconds

(b) 2 minutes

(c) 9 minutes

PLATE I - AASR-1 BRIGHT SCAN DISPLAY WITH MTI

Display Conditions: Maximum trail time. Range rings = 10 nmiles. Magnetic north at top of photographs. Time 0014 CDT 16 May 1970. Winnipeg International Airport. 50 seconds etc. is the elapsed time following erasure of all information on the display.

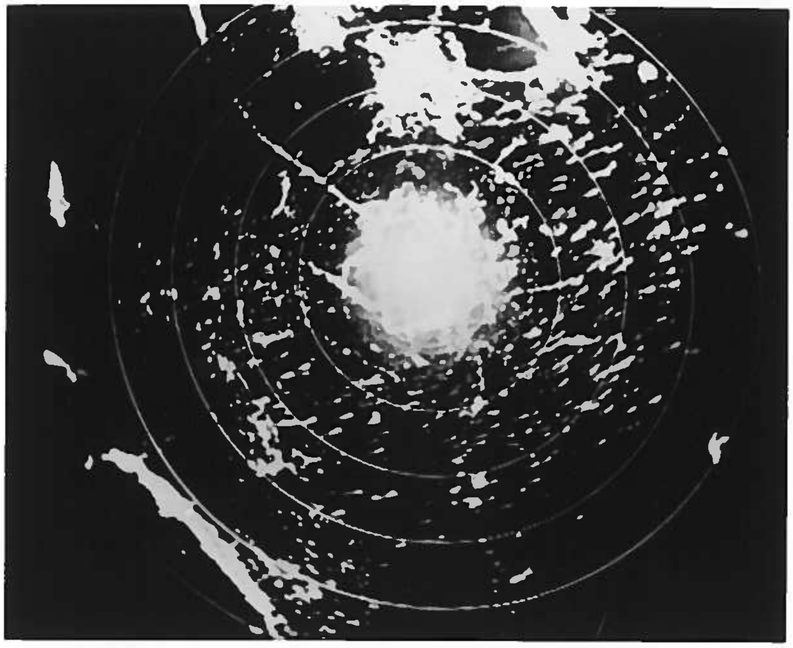

PLATE II - AASR-1 DISPLAY WITHOUT MTI

Display Conditions: Identical to Plate (c)
Time 0219 CDT 16 May 1970

PLATE III - WF-3 DISPLAY RACK

PLATE IV - WF-3 ANTENNA UNIT

Elevation Angle = 30° Approximately

PLATE V - QUADRADAR ANTENNA UNIT