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MET.O.15 INTERNAL REPORT

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PRELIMINARY EVALUATION OF THE C-130 WEATHER RADAR (E290) AS A CLOUD PHYSICS TOOL

BY

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1. Introduction.

A general outline of the operation and capabilities of the E290 weather radar is set out in appendix II and in the EKCO aircrew operating manual.

Although the main function of the E290 weather radar is to enable the aircrew to locate (and avoid) precipitating cloud, it is also a potentially useful tool for the cloud physicist. In order to exploit this potential, a radar displayhas been installed in the instrument van, and this work was undertaken with three aims in view:

(i) To obtain a good working knowledge of the radar.

(ii) To find out if the radar could be used for qualitative or quantitative measurements of precipitation.

(iii) To find out what work is involved in analysing and interpreting the radar data and whether it is worthwhile automating the radar output.

In order to achieve these aims the airborne radar was compared with a ground based radar and also a series of ground calibration checks were made.

2. Radar Intercomparison.

2.1 Flight Plans.

A series of aircraft flights were undertaken in January and February 1976 in conjunction with the Meteorological Research Unit at Malvern who had a 43 S weather radar located at Castle Martin in South West Wales. These flights were primarily for M.R.U. Malvern who were working on a cold front project in that location and this governed the flight plan. One of the major shortcomings of this flight plan was that the two radars were only sampling the same size volume of air on a limited number of occasions. Despite the fact that the flight plan was not the most suitable, a comparison of the two radars was made. Some basic parameters of the two radars are shown in Diagram 1.

The flight plan consisted of flying along a given track, from a fixed starting point firstly at 24K feet and then returning to the starting point at 16K feet. This was followed by two more legs, one at 10K feet and finally at 3K feet. This whole pattern was repeated throughout the period of precipitation.

During the operational period about six missions were flown. On each of these the E290 was operated in the WEA mode on the 20 nautical mile range. The radar beam was angled so that it hit the ground just beyond the 20 nautical mile range mark, at each of the aircraft heights.

2.2 Data Recording and analysis.

The aircraft radar display was photographed every second using two Telford 16mm cameras (f.4). Each photographic frame was marked with the date, time (Aircraft Data Recording System Clock) and the angular tilt of the radar.

The 16mm film was analysed in the following way:- The negative was projected, using a 16mm micro-film reader, on to a base board. Some densitomitry was done on the projected image using a light detecting resistor coupled to a five level discriminator. The levels were set by eye, at the start of the analysis, from level 0 where no echo was seen to level 4 where the echo was very intense. The intensity levels were recorded on 'FORTRAN' coding forms and then punched by Met O 12. This method of data extraction is time consuming (3 photographic frames per man hour). Two computer programs were written to handle the data and to present it in a simple way. The computer programs are described more fully in Appendix 1.

2.3 Results

Two of the six flights were analysed in detail, 28-1-76 (four legs) and 12-2-76 (three legs). Malvern supplied their P.P.I. and R.H.I results for the 28-1-76 and their P.P.I. and a cross section along the track of the aircraft for 12-2-76.

(a) The cross section for 12-2-76 suggested that the 43S threshold was at least one level more sensitive than the E290. Diagram 2.

(b) There were areas of good general agreement between the two radars but also areas where the 43S saw more than E290.

(c) It was difficult to compare the echoes of the E290 during two successive passes through the rain, even though only a short time had elapsed between the two.

(d) The echo equalisation on the E290, (an echo at 20 nautical miles should give the same intensity on the screen as the same echo at 5 nautical miles), appeared to be over emphasing the near returns.

(e) The E290 radar on occasions appeared to be over emphasing the echo on the side edges of the viewing area.

These observations will now be discussed in turn.

2.4 Discussion

(a) Radar Sensitivities

From the cross section taken on 12-2-76 (Diagram 2) the 43 S appeared to be at least one level more sensitive than the E290 radar. However, as only one section was suitable for comparison it is too early to draw any definite conclusions. Although the E290 (X Band) is supposed to be more sensitive at detecting raindrops than the 43 S (S Band) the peak power output from the 43 S is over twenty times greater than the E290. The 43 S is especially tuned to make it as sensitive as possible to echo whereas the E290 is not. It is possible that the 'Wea' mode on the E290 is not the best mode to use and that by using 'Man' the overall sensitivity of the radar can be increased. The Malvern data, although recorded photographically is level selected before the cathode ray tube whereas the E290 levels are taken from the film. Due to the poor dynamic range of the tube some data could be lost.

(b) Comparison of echoes from the two radars.

It was very reassuring to see that there were areas of broad agreement between the radars but surprising to see areas of heavy echo reported by the 43 S that the E290 failed to detect. The general outline of an area of echo, seen by both radars was quite similar with respect to position and shape but individual levels were much harder to correlate. This discrepancy could be explained by the different size sample volumes used in the comparison. The approximate limits of the beams are show in Diagram 3. The E290 for this initial trial was used between 5 and 20 nautical miles whereas the 43 S was used between 20 and 55 nautical Miles. It can be seen from the diagram that in general the volume sampled by the 43 S was much greater than that sampled by the E290 and this makes a comparison between the two radars hard to interpret.

(c) Consistency of echoes received by E290 radar.

When comparing one pass through some precipitation with another separated by only a short time it was difficult to compare the two in detail. Once again the general outline was in reasonable agreement but the internal structure proved hard to correlate. There are several possible reasons for this: firstly the precipitation pattern changed between successive passes; secondly the E290 could have been sampling different parts of the precipitation on successive passes; and thirdly the same echo could have looked different when viewed from different height levels.

The first consideration is a possibility, but over the time in question, (sometimes as short as ten minutes), so large a change is unlikely. The second is a more probable explanation. If the radar beam was misaligned within itself (with regard to constant sweep angle and tilt angle) comparisons between successive passes would be made more difficult because of the different angles used for each height. Thirdly, it has not been established in practise whether the same area of precipitation gives the same echo when viewed from different heights and angles. Theoretically if the objects are spherical and attenuation plays no part they should give the same answer, but this has not been verified in practice.

(d) Echo Equalisation

Having analysed the data from the run flown at 3K feet, with the radar looking directly ahead it became apparent that the echo equalisation was not correctly adjusted. An echo at 20 nautical miles was much weaker than the same echo at 5 nautical miles.

(e) Non uniformity of E290 echo.

On some occasions it appeared from the analysis that there was an emphasis of the echo towards the edges of the screen and this has been borne out by the observations of the C-130 aircrew who, on numerous occasions, have reported this phenomenon. This may have been caused by the radar not scanning at a constant angle of tilt. Let us make the assumption that the rainfall was greater near the ground: then if the radar was not scanning at an even angle of tilt certain parts of its travel could well be at different height levels. This would mean that the echo was heavier at certain positions on the screen. Now if the beam was at its lowest near the edges of the screen this may account for the observed effect. Another possible reason is that the radome with its parabaloid shape and lightning conductors distorts the shape of the beam.

3. Ground Calibration

3.1 Reasons for Ground Calibration

The initial comparison between the two radars throws some doubt on the setting up of the E290 radar. A series of ground checks were made to find out if: (1) the echo equalisation had been correctly adjusted for the comparison; (2) if the radar beam was in its theoretical position.

3.2 Echo Equalisation

The E290 display was taken out of the aircraft and tested on the bench. It was found that it was not set up according to the manufacturers handbook. The error was in the direction measured on the trial but the exact magnitude of the difference was not able to be determined. It was adjusted.

3.3 Beam Position

(a) Initial trial, with constant azimuth

The C-130 was positioned on the runway, with the radar looking directly ahead, and a Wessex helicopter was moved to where the radar beam was theoretically positioned. The helicopter was moved up and down in the beam to ascertain the upper and lower limits of the beam. This was done at 5, 10, 15 nautical miles.

Two conclusions were reached from this trial. (1) the radar beam directly ahead of the aircraft was about $1\frac{1}{2}^{\circ}$ higher than indicated. A later trial supported this difference and it was found to be the interface between the E290 dish and the program unit supplied by M.R.U. It was corrected.

(2) There was a considerable discrepancy between the navigators display and our display. The navigators display was far more sensitive than ours and ours was much more noisy. The noise was subsequently traced to an unscreened lead but the cause of difference in sensitivity has not been found. Subsequent checks failed to duplicate the fault and it is possible that a plug was either dirty or not fixed in properly for the trial and by performing these extra checks the connections were remade correctly.

(b) Second trial, with Variable Azimuth

The initial trail was repeated but this time data was obtained throughout the whole sweep of the radar beam. The centre of the beam was lower at the edges than in the centre of the sweep diagram 4. This confirms the photographic analysis from the earlier experiments and enhances the assumption of rainfall rates mentioned in paragraph 2(e). The amount of droop was within the specification of the radar ($\pm 1^{\circ}$). It is therefore a problem that subsequent analysis must take into account.

4. Summary

(i) Some progress has been made in understanding the performance of the E290 weather radar. Some effects of beam misalignment and echo equalisation have been identified and corrected where possible.

(ii) The initial flight trials in precipitation, comparing the airborne radar with a ground radar, leave the basic question of the degree of usefulness of the radar in cloud physics studies unanswered. However, there is broad agreement between the radars on many occasions but also some areas of disagreement.

(iii) Data analysis by the method established for these trials is very time consuming.

5. Recommendations

(i) A check on the variation of tilt with azimuth must be made.

This can easily be performed by observing the echo from the sea surface and filming the display. This may have to be checked prior to any field project using the radar.

(ii) Adapt the analysis computer program to correct for the variation of tilt with azimuth.

(iii) Obtain a polar diagram of the aerial to find out what effect the lightning conductors and paraboloid radome have on the beam.

(iv) Further flights should be carried out with the express purpose of comparing the radar performance:- (a) with itself, ie repeated scans of the "same" precipitating area from different heights and distances and (b) with an accurately aligned ground radar.

(v) If the radar is to be used as a research tool a more efficient data processing system must be devised.

(vi) Investigate which mode of the radar should be used.

APPENDIX I

M15 KLINE (R.Allt)   Data Analysis - Computer programmes

This program produces on Calcomp film, a diagram representing a vertical section through the atmosphere in the plane of the aircrafts flight path. Intensity values were taken at one nautical mile intervals directly in front of the aircraft. Taking into account the vertical divergence of the radar beam, the program records this information in the elements of an array, each of which represents a particular position in space. The volume sampled increases with distance from the aircraft and a suitable 'Credibility Rating' is associated with each distance and hence each item of data. Values in the array are updated as the 'Credibility Rating' improves. The best available data for a particular volume remaining in the array. Echoes very close to or far from the aircraft are ignored as they are likely to be unreliable. When all the data falling within the bounds of the array has been processed, the array is printed out diagrammatically, with dots delineating the area which has been scanned by the radar. See diag.5. The scale of the diagram can be altered at will.

E RADA   G WATTS

This program produces, on Calcomp film, a horizontal section of the atmosphere at various height levels. Each 16mm frame is divided into 144 areas [Diagram 6] and for each of these a level of the intensity is recorded. The processing of the radar data involves calculating the position (relative to the aircraft origin) of each element of the radar screen and resolving it on to a horizontal plane. A symbol representing the radar echo strength is then plotted at this position. A picture is thus built up of the echo 'seen' by the radar.

The program reads in two initial data cards, the first of which sets up the calcomp output by specifying the size of the plotting area and the origin (ie initial aircraft position in plotting dimensions). The second data card defines the aircraft origin in kilometres and time, its speed in metres per second and its bearing in degrees from north. Subsequent data cards contain the radar echo strengths for each element of the radar screen and the angle of tilt.

APPENDIX II

EKCO 290 Weather Radar   Characteristics and Operation

The Ekco 290 weather radar is mounted on the Meteorological Research Flight C-130 and is primarily an aid to navigation. The aerial, which scans the 180° ahead of the aircraft (1 sec), is mounted in a pod on top of the fuselage. There are three radar displays in the aircraft and they are for the pilot, navigator and in the instrument cabin. Although the navigator has master control either of the two other displays can be in control. When control is in the instrument cabin a unit designed by M.R.U. can change the angle of tilt in programable mode from +15° to -15° in 3° steps. During the trials the radar has been used on a fixed angle rather than in the programme mode because persistense on the cathode ray tube makes the data hard to interpret.

There are four modes of operation of the radar ('Wea', 'Cont', 'Man', 'Map') and three range scales. (20,50, 150 nautical miles). For the trials described in this report the radar was worked on the Wea mode and the 20 n.m. range. The Wea mode was chosen because the total echo received by the radar is displayed on the screen whereas in the Cont mode echoes exceeding certain values appear as 'holes' on the screen. The 20 nautical mile range was chosen because (a) resolution is a maximum and (b) on the whole of this range the receiver gain is automatically controlled, so that signal amplitude is independent of range.

Diagram: 1

COMPARISON OF E290 WITH 435

	Wavelength	Beam Width	Max Range	Peak Power	P.R.F.	Scan Time
E290	3cms (X Band)	2·8°	150 N.M.	30 KW	400 c/s	180° in 1 sec
435	10cms (S Band)	2·0°	55 N.M. approx	650 KW	275 c/s	360° in 60 sec

Diagram 2: CROSS-SECTION THROUGH PRECIPITATION 12-2-76

(using modified angle of tilt)

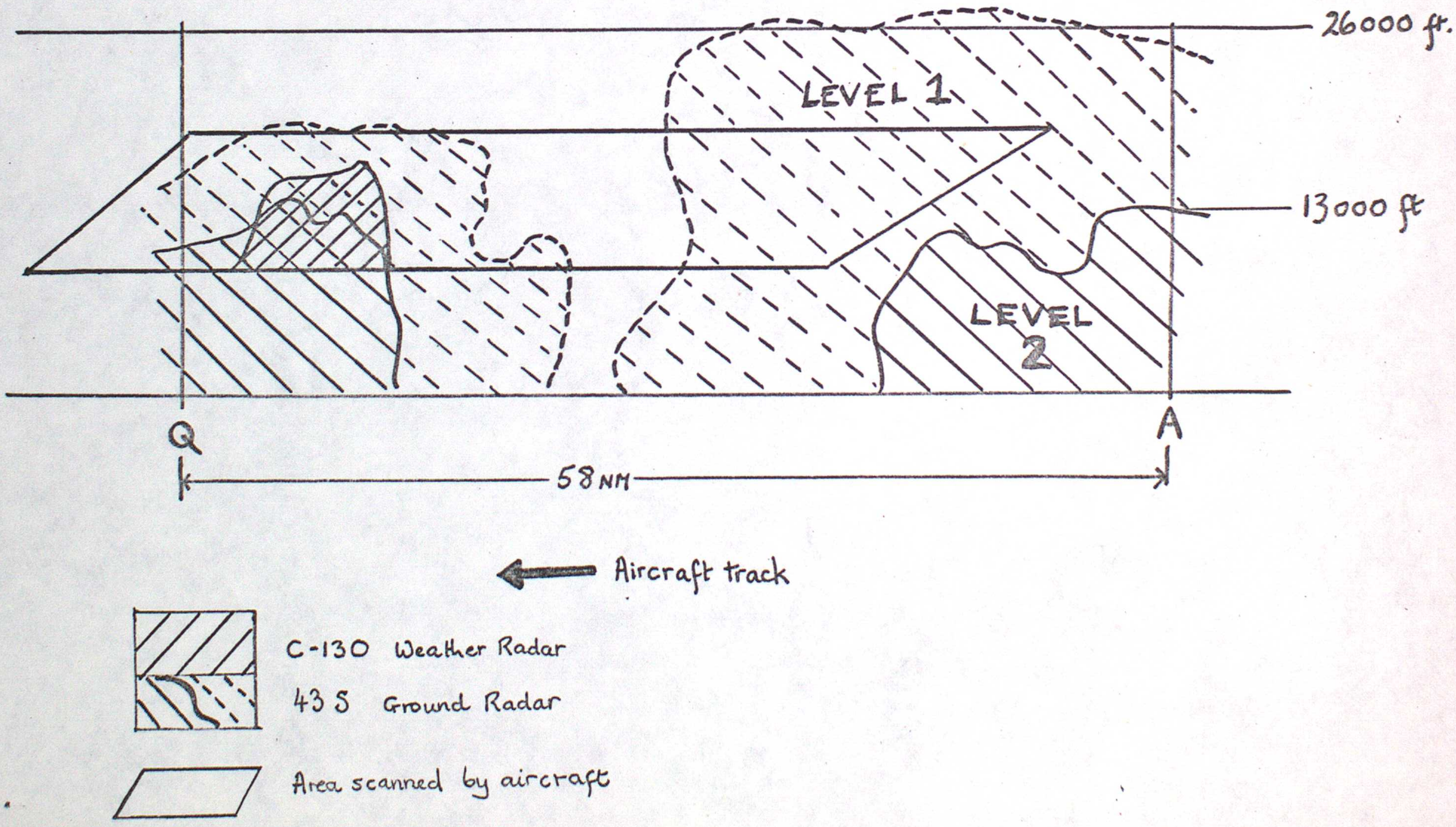


Diagram 3

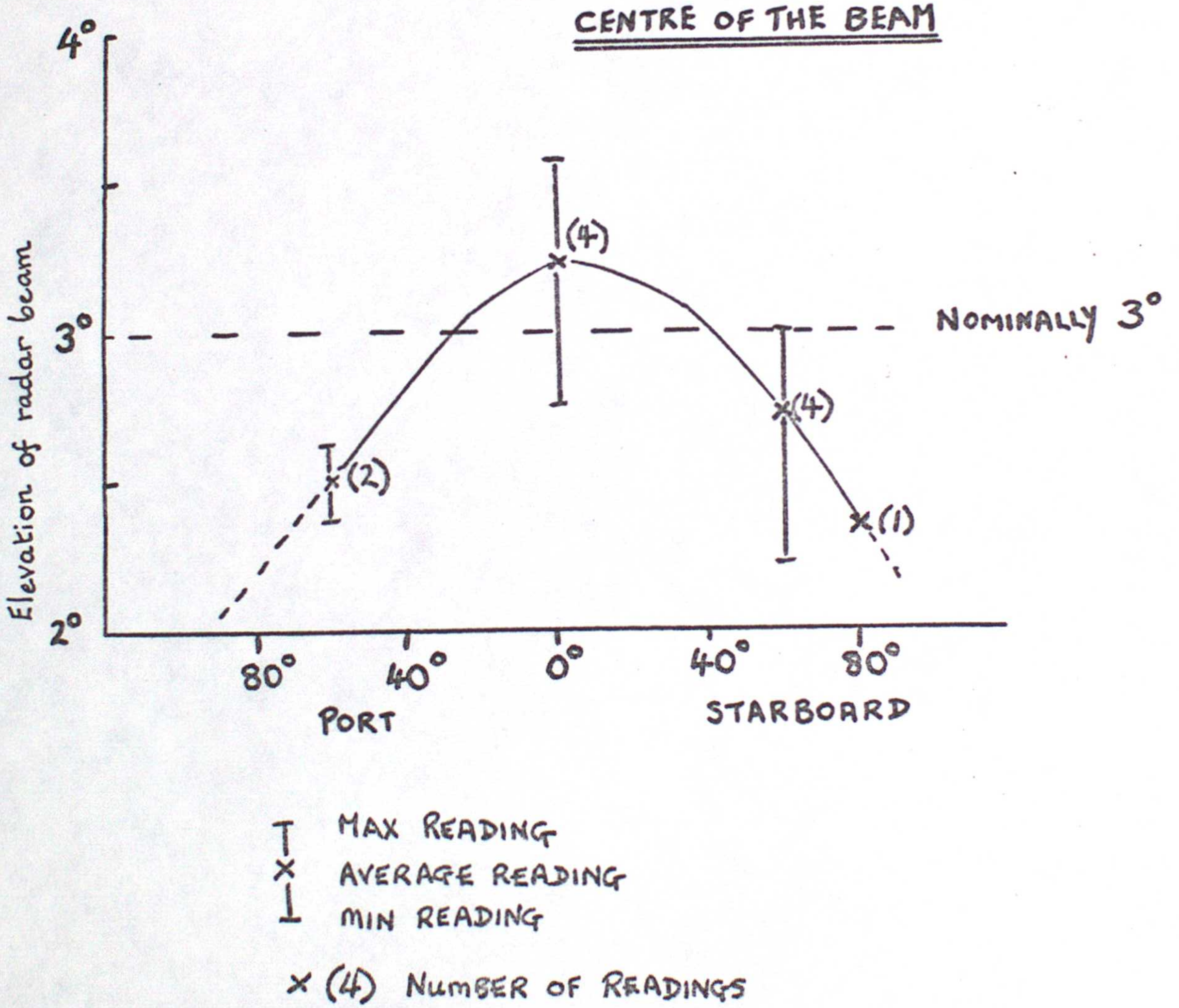
Comparison of Radar Beams.

(This assumes that both radars are on the ground)

RANGE (Statute Miles)		5	10	20	30	40	50	60
E290 3°	Top of beam	1400	2700	6000				
	Bottom of beam	12	50	200				
435 2°	Top of beam		900	4800	6000	8200	10500	13000
	Bottom of beam		50	200	450	800	1250	1800

(Heights in feet)

Diagram 4


CENTRE OF THE BEAM
4°
3°
2°
Elevation of radar beam
NOMINALLY 3°
(4)
(4)
(2)
(1)
80°
40°
0°
40°
80°
PORT
STARBOARD
MAX READING
AVERAGE READING
MIN READING
× (4) NUMBER OF READINGS

PAGE 1 Diagram 5: AIRBORNE WEATHER RADAR

DATE	FLIGHT	RUN	ROUTE	A/C HEIGHT	START	END
28/01/76	123	17	A S	10000	16/17/43	16/40/0

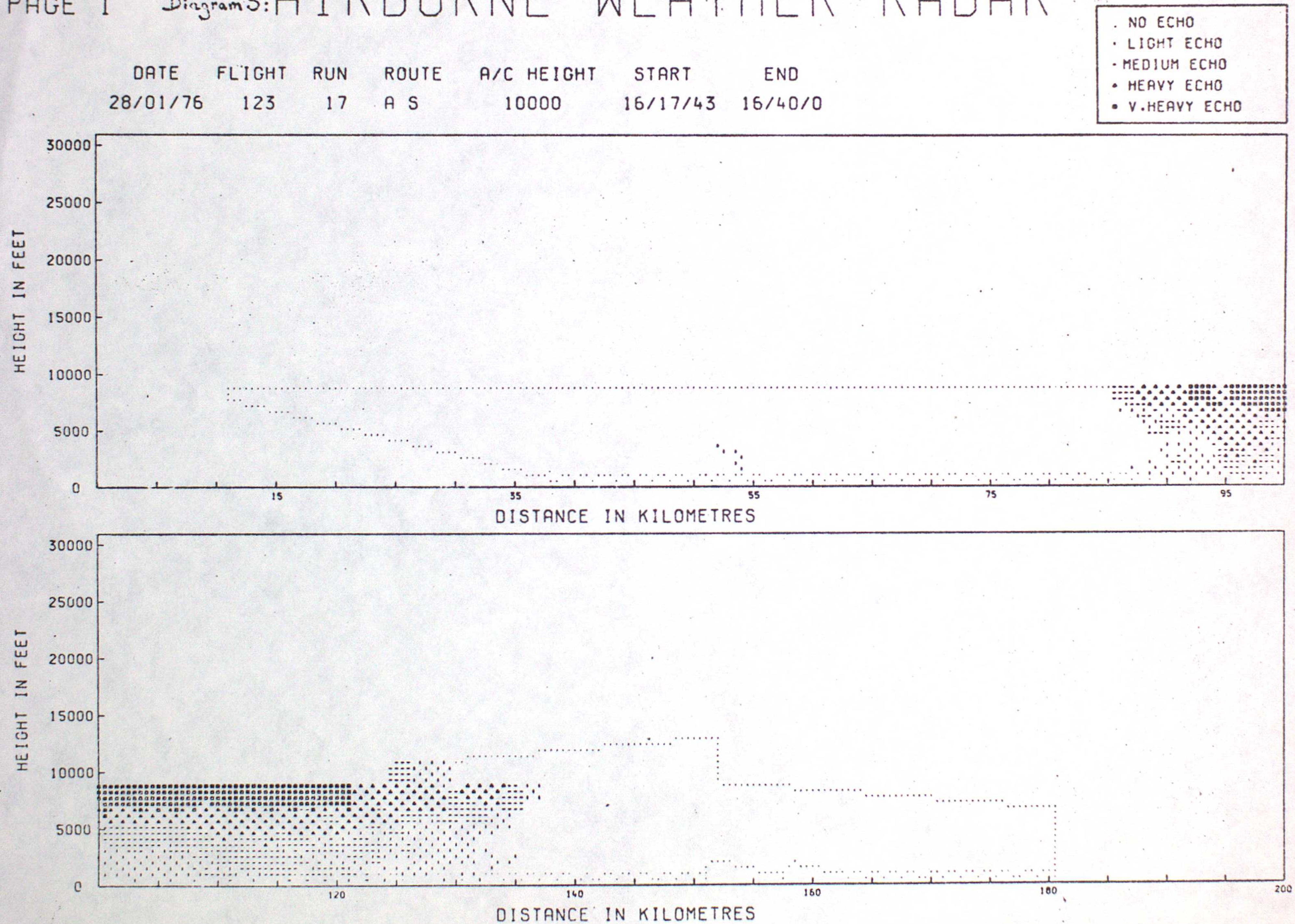
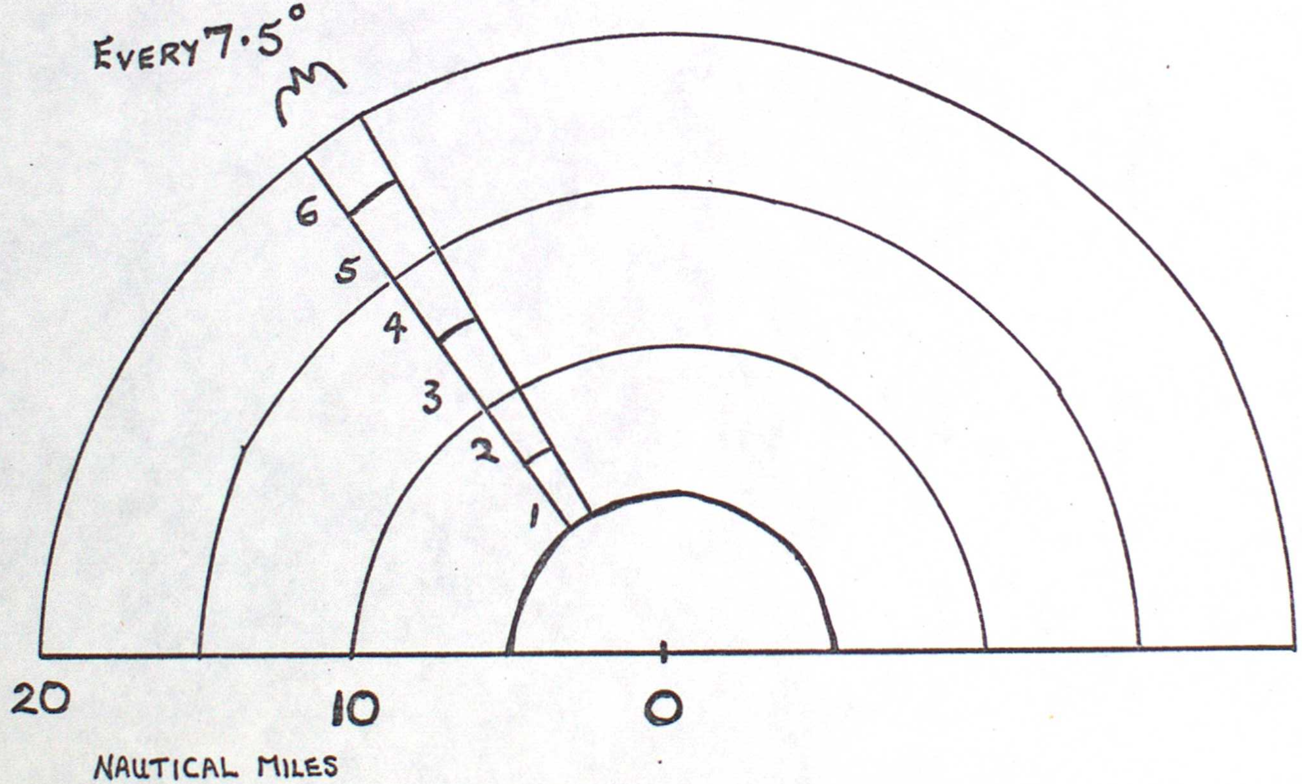


Diagram 6: BASE BOARD LAYOUT



TOTAL:
144 SQUARES
PER FRAME