LOW COST WEATHER RADAR SIMULATION

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ABSTRACT

There has been a growing interest in the use of Airborne Weather Radar simulation from both military and commercial operators of transport aircraft. This interest, in part, stems from the need to train aircrews to fly through weather conditions, which at one time would have been given a "wide berth", without sacrificing safety margins. This change in requirement has arisen due to escalating fuel costs.

To date, the cost of full radar simulation has restricted its use to the more sophisticated aircraft simulators. The Link-Miles Division of Singer has developed a low cost or simple Weather Radar Simulator for use on transport aircraft simulators. This paper describes the simulation techniques adopted and shows how recent advances in semi-conductor technology have been incorporated to produce a system capable of being fully integrated into an aircraft simulator.

INTRODUCTION

The evaluation of the picture as it appears on the display of a weather radar indicator is a skill that increases with experience. The information the picture yields when interpreted correctly can mean a significant reduction in operating costs, and of even greater importance make a major contribution to flight safety. Discrimination between safe and potentially turbulent areas in cloud formations early enough during a flight can avoid unnecessary "dog-legging" with the inherent advantages in maintainability schedules and fuel saving.

In a situation where a complete detour is impractical the penetration of weather patterns may be required. Using a radar simulator, cloud pattern penetration techniques can be mastered in the safety of the training complex. Also the weather situations displayed are under instructor control, which means both tropical or temperate zone weather systems modified by seasonal variations can be presented at the "flick of a switch". It is this flexibility coupled with the safety and fuel saving aspect which renders this system a useful tool in aircrew training.

Despite the obvious advantages offered by weather radar simulation, in general this facility has not been fitted to transport aircraft simulators in the past. This is mainly attributed to the relatively high capital outlay of such a system. However, recent advances in semi-conductor and micro-computer technology has presented designers with the opportunity to develop systems which would have been impractical or prohibitively expensive a few years ago. Two such areas in which this has been apparent are in the microprocessor and semi-conductor memory fields.

This paper will show how these technological advances have been exploited to produce a microprocessor based low cost system.

APPROACH

A flexible approach was adopted in the design of the weather radar simulator so that its use would not be restricted to a specific type of aircraft or radar system. A stand-alone configuration was considered as this would facilitate installation to existing aircraft simulators with a minimum of modification. Thus the simulator would store all cloud information and perform those tasks normally accomplished by the radar receiver/transmitter and antenna sub-systems.

Whilst most radar systems use performance characteristics to ARINC 564, the simulator would not be restricted to these. Indeed the design described is based on an EKCO E290 Radar System which does not conform to ARINC 564 characteristics.

DESCRIPTION OF DESIGN

The weather radar simulator, a block diagram of which is illustrated in Figure 1, is intended for use with an aircraft simulator which is assumed to be controlled by a computer, referred to here as the

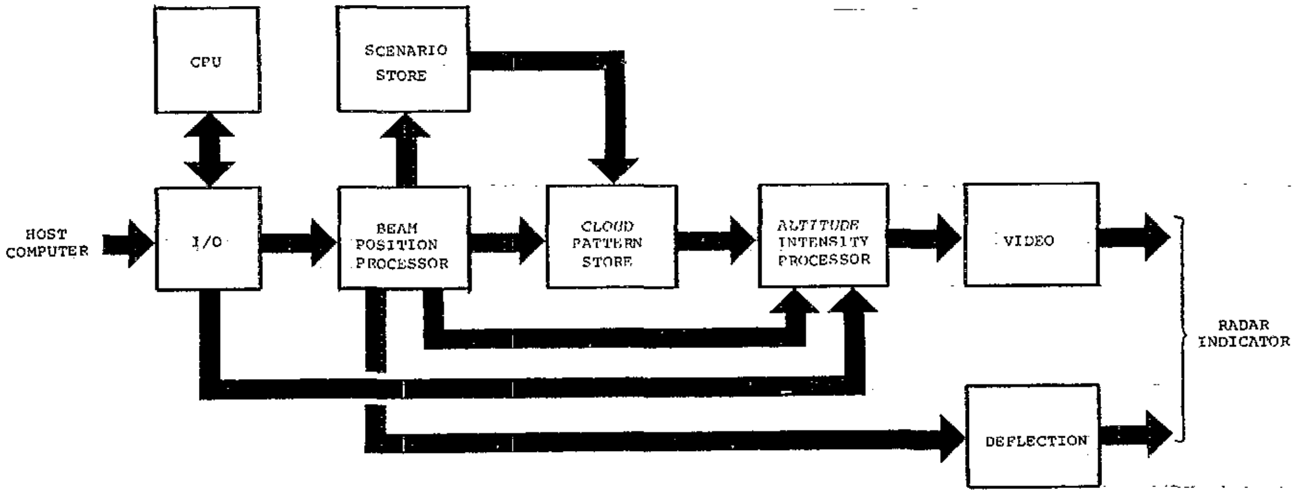

FIGURE 1. BLOCK DIAGRAM - LOW COST WEATHER RADAR SIMULATOR

"host computer" and serves to produce a simulated radar signal for display on a standard weather radar indicator mounted in the cockpit of the aircraft simulator.

Input/Output

The interfacing between the host computer and the weather radar simulator is achieved via an input/output section. Aircraft location parameters and also control data, such as radar status information, are fed from the host computer via a parallel data path. The data are received and distributed via output ports to other sections of the weather radar simulator under control of a 16 bit microprocessor. The microprocessor supervises the input of each data word and performs a software parity check to verify data validity. It then controls distribution of the data to the relevant output port of the input/output section. It also includes provision for manipulation of the incoming data so as to modify the aircraft position information to give the impression of a dynamic weather system.

Thus, although the embodiment described employs a store with data representing fixed cloud formations, cloud movement can be simulated by applying a progressive shift to the input aircraft position information.

Beam Position Processor

Aircraft location parameters are fed from the input/output section via an output port to the beam position processor. This section performs three main tasks:-

(a) system timing.

(b) generation of simulated antenna azimuth position data.

(c) calculation of the X-Y co-ordinates of points on the radar beam path.

System timing is derived from an internal crystal oscillator from which are obtained pulses at a pulse repetition frequency (PRF) of 400Hz., which is the frequency typically used in the E290 Radar.

The beam position processor generates angles, representing antenna azimuth position over a range ±90° of aircraft heading, in the form of a 12 bit data word. This is output to the video processing section, which will be described further below. Assuming, as above, a 400Hz PRF and a typical 120°/sec. scan rate, the antenna azimuth rotation between successive radar pulses is 0.3°.

Using the X-Y coordinates of the aircraft position input from the host computer, along with the simulated antenna position information generated as described above, the X-Y coordinates of the radar beam at successive positions over the range under consideration are derived. Based on the E290 Radar performance characteristics a range of 175 nautical miles is covered, and to achieve maximum resolution at short range the simulated range increments are non-linear. Thus the beam position for range values between 0 and 20 n.miles is based on a 0.25 n.miles increment, while values between 20-50 n.miles are based on a 0.5 n.miles increment and for the 50-175 n.miles a 1.00 n.miles increment is used. This produces a total of 265 range increments per scan. With a PRF of 400Hz this gives a radar beam position update rate of 9.4μS. The radar beam position is calculated for each of the 265 range increments for every 0.3° azimuth scan.

To take into account the beam width characteristics of the antenna main lobe, two other beam positions are calculated at angles ±1.75° of the boresite.

The X-Y coordinates are calculated using:-

$$X = R\sin(\theta+\phi)+X_{a/c} \text{ n.miles}$$

$$Y = R\cos(\theta+\phi)+Y_{a/c} \text{ n.miles}$$

where R = Range

θ = aircraft heading angle

ϕ = antenna pointing angle

$X_{a/c}$, $Y_{a/c}$ = X-Y coordinates of aircraft location.

Therefore, for each 9.4µS period, three values of X-Y coordinates are obtained.

Cloud Store

The X and Y beam coordinates are used to read out information from a cloud store. Basically the store contains a cloud map in which the area covered is divided into cells in which information is stored of cloud intensity, together with base and ceiling heights. The manner in which this information is stored will now be discussed in more detail. The cloud store contains three memories each with a capacity of 64K bytes provided by thirty-two 2K x 8 erasable programmable read only memories (EPROMS). The first memory, the scenario memory, stores up to 16 scenarios. Each scenario occupies a memory space of 4K x 8, representing 4096 cloud pattern locations on a 64 x 64 matrix. Each memory location contains an 8 bit data word which is a code specifying which of a pre-determined number of possible cloud patterns occurs in that particular cloud pattern location. The six most significant bits of each of the X and Y coordinates from the beam position processor provide a 12 bit address to the scenario memory. The remaining 4 bits, for selection of the desired scenario, are input from an output port on the input/output section. The selection originating from the instructor's facility.

The 8 bit data format used in the scenario memory is in principle capable of selecting from up to a maximum of 256 patterns, but only 16 cloud patterns have been provided for this particular application. The cloud patterns are stored in the second and third memories. Each cloud pattern occupies a memory space of 4K x 16 and represents an area of sky 32 x 32 n.miles to a resolution of 0.5 n.miles square. Therefore, a cloud pattern consists of 4096 cloud cells on a 64 x 64 matrix. The cloud pattern memories receive

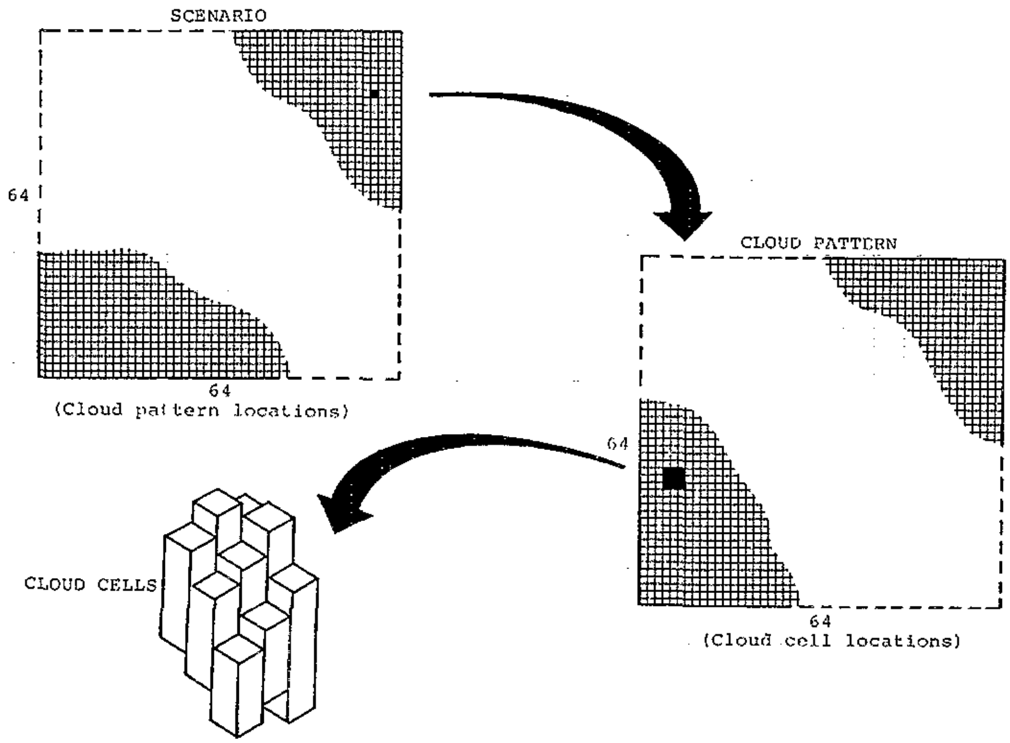

FIGURE 2. CLOUD STORE CONFIGURATION

a 12 bit address from the beam position processor (i.e. the least significant bits of the X and Y beam coordinates), and 4 bits from the scenario memory. The 16 bit data format used in the cloud pattern memory contains information on cloud cell intensity, and cloud base and ceiling heights. This data is formatted as:-

3 bits - cloud intensity (8 levels)

8 bits - ceiling height (in units of 1,000 ft.)

8 bits - base height (in units of 1,000 ft.)

1 bit - unused

This arrangement enables a three-dimensional cloud map to be formed covering an area of 2048 x 2048 n.miles x 64,000ft. A scenario is configured by coding any of the 16 cloud patterns into each of the 4096 locations in the scenario memory, as illustrated in Figure 2. It will be appreciated that the two tier memory arrangement described represents a very substantial reduction in memory requirements compared with that which would be required if a separate memory location were provided for each cell of the total area to be covered.

It will be appreciated that the cloud store arrangement described does not admit the possibility of two or more discontinuous sections of cloud within a single cloud cell. Obviously the cloud pattern memory capacity could be expanded to permit the inclusion of more than one set of intensity and height data per cell to admit the possibility of overlaying cloud formations.

Altitude and Intensity Processor

The cloud information from the cloud store is fed to the altitude and intensity processor. The first task of this section is to establish whether the radar beam height lies within the altitude range specified by the base and ceiling heights of the cloud cell under consideration.

The radar beam height is given by the aircraft height modified by the antenna tilt components. The latter is given by:-

$$Z_{tilt} = k.R\sin(\alpha) \text{ (feet)}$$

where R = range of beam (n.miles)

α = antenna tilt angle (degrees)

k = conversion constant (feet/n.miles)

Thus the altitude processor receives aircraft height information from the host computer via a output port of the input/output section, range information from the beam position processor, and antenna tilt angle as selected by the user at the radar control panel. The latter can be input directly from the control panel, or in this application via the aircraft simulator linkage, to be output eventually by the host computer. Using these data inputs the height of the instantaneous beam position is calculated. This height is compared with the base and ceiling heights of the cloud cell under consideration (from the cloud store). If the beam falls within these heights, the cloud cell intensity data from the cloud store is routed to the intensity processor.

The intensity processor serves to determine the intensity of the "paint" on the radar indicator. This can be achieved by using the standard radar equation:-

$$P_r = \frac{P_t G A_e \sigma}{(4\pi)^2 R^4}$$

where P_r = reflective power

P_t = transmitted power

G = maximum radiation power gain

A_e = effective receiving antenna area

σ = echo range of target

R = range

However, radar equation computation is avoided by following a simplified procedure. The intensities of all the cloud cells the beam has passed through before reading the location under consideration are accumulated, and this accumulated intensity along with the range are used to address a look-up table, (e.g. a read only memory) containing empirically derived weighting factors. In this way a radar return intensity signal is obtained as an 8 bit data word. Although this involves a degree of approximation, it has been found in practice that the resultant signals are sufficiently accurate for the purpose, particularly when (as is usually the case) the raw radar returns are processed to a degree by the indicator unit before actually being displayed on the cathode tube. This is especially valid in the case of colour displays which are now replacing the older direct view storage tube (DVST) type displays.

Normally the data corresponding to the centre (boresite) position is used unless this does not encounter any cloud, in which case the intensities at either side of the main lobe are considered.

The intensity values are computed sequentially for the 265 range increments, and owing to the non-linear increments used, the resultant signal has a non-linear range/time relationship. For use with a conventional radar display unit these signals must be linearised and this is achieved by clocking the intensity value for each range increment into a read/write memory at one rate and clocking them out at another rate synchronised to the display. To maintain continuity of data flow, two memories are used which are interchanged after each radar scan. Finally, the altitude intensity processor converts the calculated 8 bit intensity word for each range increment into an analogue signal.

Video Processor

The final stage of the weather radar simulator comprises a video processor and deflection section. The video processor serves to receive the video signal from the altitude and intensity processor and to add a number of special effects required to add realism to the radar "paint", and these are mixed with the video signals. The special effects include:-

(a) spurious noise

(b) height ring

(c) ground returns

(d) H.F. spoking

(e) radome icing

The composite radar signal is amplified and output via a coaxial line to the radar indicator. In addition a pre-pulse synchronisation signal, derived from the beam position processor, is also amplified and output to the radar indicator.

The deflection section produces indicator deflection signals corresponding to the antenna pointing angle, the latter being output as a 12 bit word from the beam position processor. These are converted into signals which would normally be output by a synchro-resolver mounted on the antenna mechanism of an actual radar system.

SUMMARY

The weather radar system described was developed to meet the requirements of one particular customer. There are several enhancements which, although not taken up by that customer, can be added to this system. These include:-

(a) Storm cell growth and decay: where storm cells appear to move in relation to each other, whilst increasing and decreasing in size.

(b) Windsheer Vectors: whilst the present system is capable of operating on the entire weather map using a common windsheer vector, this enhancement will cause movement of the weather map using several windsheer vectors differing in both height and direction.

The following photographs were taken of an E290 radar indicator driven by the radar simulator. Figure 3 illustrates a squall-line ahead and just to starboard of the aircraft track. Figures 4a-4f are a sequence of six frames showing the negotiation of a complex weather system generated by the radar simulator.

ABOUT THE AUTHOR

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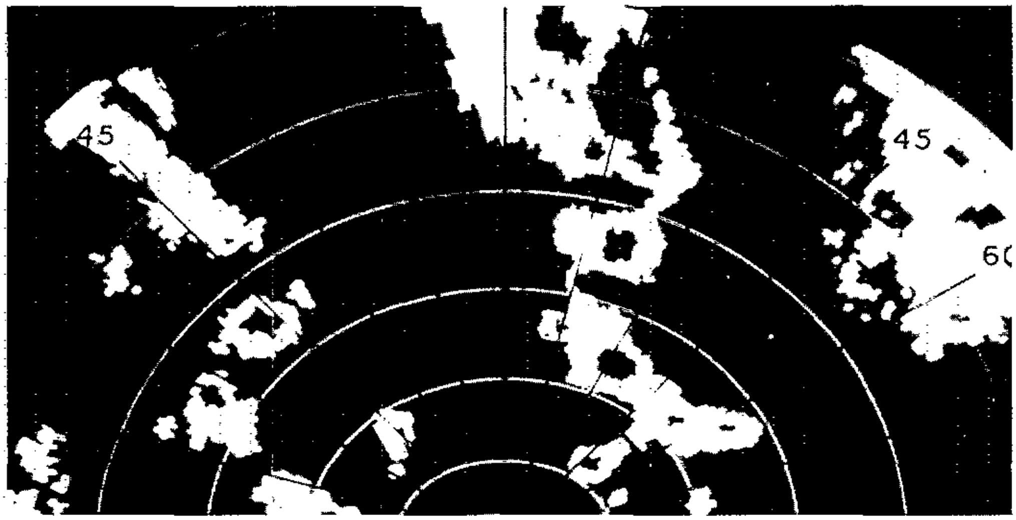

FIGURE 3.

FIGURE 4a.

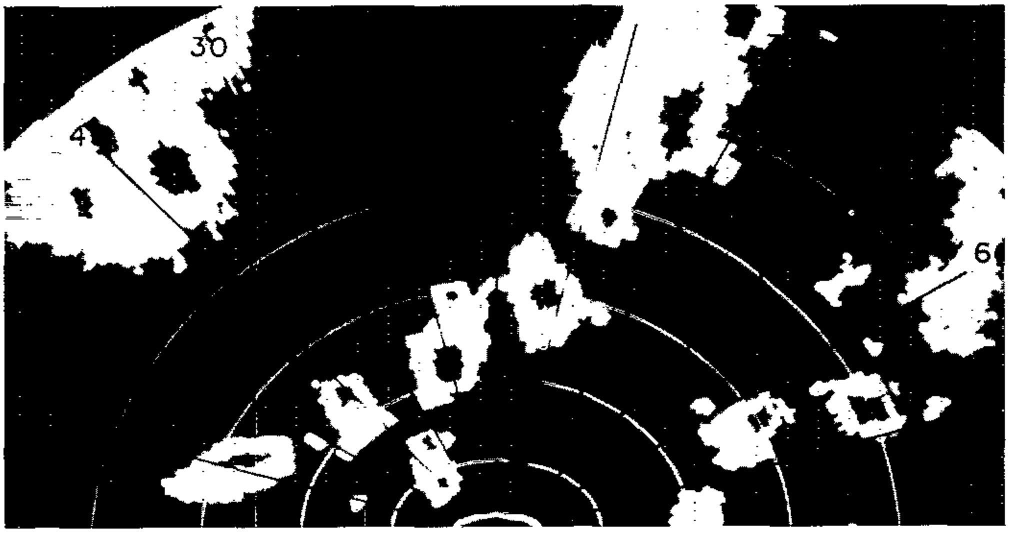

FIGURE 4b.

FIGURE 4c.

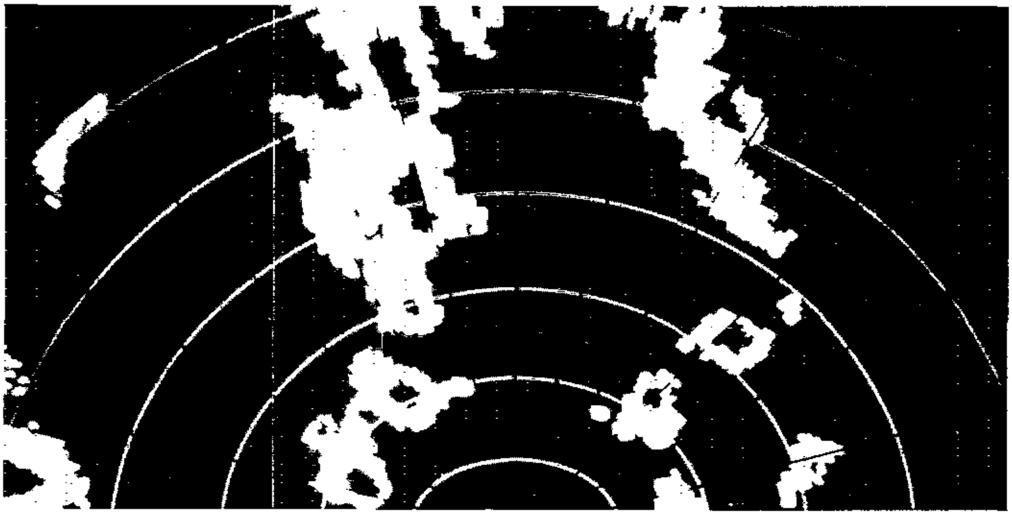

FIGURE 4d.

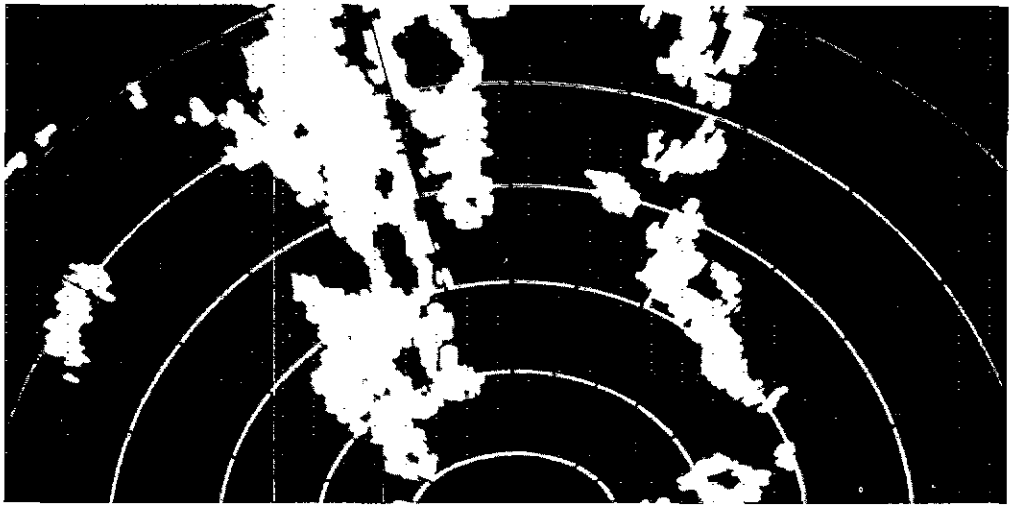

FIGURE 4e.

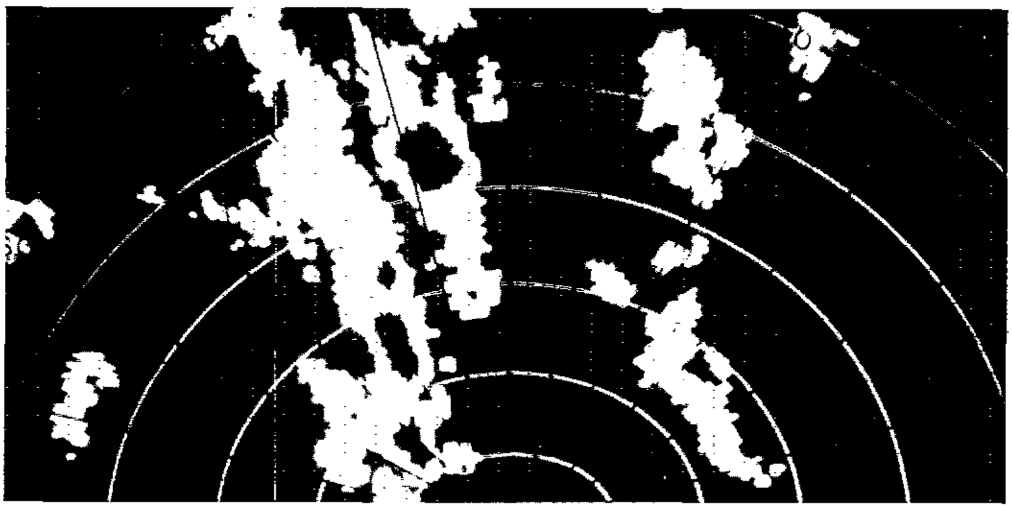

FIGURE 4f.