4.13. RADAR DETECTION OF BIRDS IN AN OPERATIONAL ENVIRONMENT.

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F.R. Hunt

INTRODUCTION

Except for the last stages of the take-off, the most disastrous time for a bird/plane collision is when both are in flight. Equally true is that when both are flying, radar can be used most effectively in avoiding the collision.

It has been found that most collisions occur during the spring and autumn migrations. When discussing radar as a collision avoidance aid, we break down the migration into two types. The first is called broad area migration and consists of a large number of birds, mainly passerine, not flying in flocks and extending over an area of many square miles. This type of migration usually occurs at night. Examples of this migration can be seen in the "white-outs" of PPI photographs such as seen in some of Richardson and Gunn's work at Cold Lake[1]. This type of migration is particularly dangerous to single-engined jet aircraft flying long distances at low altitudes such as military aircraft on some training missions. In general, broad area migration is not hazardous to multi-engined transport aircraft which usually spend most of their flying time above the birds' altitudes.

The second type of migration, of which we see a great deal in Canada, is the flocks of large water fowl -- for example flocks of 50 to 500 birds each weighing a kilogram or more. A strike by a single bird can cause extensive damage to an aircraft when flying at landing or take-off speeds. Multiple strikes by a flock can and have caused catastrophic crashes of large civilian transport aircraft.

The third danger to all types of aircraft is large flocks of birds such as dunlins or gulls near the ends of runways which are likely to fly up in the path of an approaching aircraft. In Canada, we have not yet looked at the possible use of radar in this area. However, we are keeping a watching brief as to what is being done in other countries. Therefore, this third problem will not be discussed further at this time.

ECONOMICAL CONSIDERATIONS

It is certainly true in Canada and I suspect that it is true in other countries, that all new equipments must be cost-effective. Since statistically the most serious bird hazards exist for only a few months of the year, it is difficult to justify the cost of new radars. Elaborate new equipment which would separate birds from other targets on the basis of velocity, wing beat patterns, or other means are also ruled out. However, there do appear to be solutions which utilize existing radars or very cheap new radars. The guidelines that we have used can be stated briefly as follows:

1. The information produced by such equipments must be displayed to air traffic controllers in a form that is readily interpretable in order that the controllers' workloads are not significantly increased.

2. Personnel will not be required for operating the equipment; i.e., it should be fully automatic.

3. Increase in maintenance personnel should be minimal.

4. Initial and operating costs should be as low as possible consistent with other requirements.

BROAD AREA MIGRATION

Although many types of radar can be used in this application, the two solutions which I will describe appear to be the only ones economically feasible.

1. The Surveillance Radar:

This is the most familiar type of radar which locates targets in range and azimuth. Because of the antenna size and transmitter powers required to detect birds at suitable ranges, it is a very costly radar and should only be considered if one is already sited in close proximity to the area where the bird hazard exists. If such a radar does exist, then one must consider its coverage. A typical radar provides vertical coverage (Fig. 1) to 50,000 feet from 70 miles out up to an upper elevation angle of 30°. If the radar and the area under consideration is separated by some distance, then one is likely to miss low flying birds either because of the actual radar horizon or because the radar's antenna is tilted up in order to eliminate some ground echoes. If the low angle coverage is sufficient, is the high level coverage sufficient? This is applicable when short distances separate the radar and the hazardous area and here the 30° upper elevation angle becomes a problem. Normally, I assume a 5,000-foot height above ground level as the maximum altitude for birds. This height is of course open to argument. I realize that there are many instances of birds flying above this level, but statistics do indicate that 95% of the birds fly below this level. To cope with all possible altitudes would require a new costly radar or antenna.

If the radar's vertical coverage is satisfactory, the next problem is the transmitter's power. Before one can begin to answer this question, the size of the radar target must be considered. Present day aircraft design tends towards making the aircraft safe against a strike by a 500-gram bird. If we introduce a safety factor of 10 into our radar design to allow for the queer things that happen to radar cross-sections at the radar wavelengths and bird sizes considered, then we arrive at a bird weight of 50 grams. This has a radar cross-section of about 10 square centimeters and this I have assumed as the minimum-sized bird to be detected. Having decided on the minimum size, then one must consider how many of these minimum-sized birds must occupy a horizontal pulse packet area at the center of the hazardous area in order to be detected. This is the most difficult number to arrive at because it involves the radar pulse length, horizontal beamwidth of the antenna, distance separating the radar and the hazardous area and lastly, an educated guess at what is a hazardous bird density. Having determined the number of birds in the horizontal pulse packet, and thus the target's cross-section, simple calculations will show whether the radar transmitter is sufficiently powerful.

If the radar is satisfactory, then all that is required is the addition of the automatic detection system described by Lt. Clausen[2] at a previous meeting. Briefly it consists of a log receiver, whose output is gated on over the hazardous area and the number of resulting echoes displayed on an electronic counter. Suppose the maximum count possible is 100,000 -- that is, the number of counts obtained if the whole of the hazardous area were covered with birds. The air traffic controller is then told to stop all low flying in the area if the count is above ten thousand. If the count is above one thousand, he stops all but necessary flying and below one thousand counts unrestricted flying is permitted. This method has proved satisfactory for broad area migration and I will not go further into it.

2. Vertically Looking Radar:

What can one do if there is no existing surveillance radar near to the hazardous area or if one wants more precise information on the altitude at which the birds are flying. One can buy a cheap off-the-shelf marine radar and connect it to a stationary vertically looking antenna (Fig. 2). Suggested specifications are:

a) Transmitter. X-band, 40 KW peak power, 0.1 to 0.5 μseconds pulselength.

b) Antenna. 1-1/2 to 2 meter diameter parabolic fitted with a metal skirt to minimize radiation at 90° to the main lobe.

c) Receiver. Sensitivity -85 to -90 dBm fitted with sensitivity time control following a $1/R^4$ law.

We have found the use of STC to be important; otherwise the equipment detects insects and very small birds at the nearer ranges. The output is range gated. In Ottawa we used six levels of 1,000 feet each, starting at 500 feet above sea level. Each range gate is followed by a simple digital video integrator in order to eliminate false alarms due to noise. The integrators are then followed by two-digit counters. Thus a single bird flying at 2,000 feet would produce a count in the counter corresponding to the 2,000-ft. level.

We used the 60-cycle line frequency connected to a count-down unit to provide a precise 9.1-minute period of counting. The operator is provided with a chart which gives bird migration traffic rate versus the number of counts in each altitude band. Bird migration traffic rate is defined in our case as the number of birds crossing a nautical mile front per hour. If one divides the migration traffic rate by an assumed average velocity of the birds (say 20 knots in still air) then one can arrive at a bird density per unit area. Using a chart similar to one given in a paper by myself[3], one can then arrive at the probability of a bird strike for an aircraft flying in the area of the vertically looking radar (Fig. 3).

The radar and recording equipment can be mounted in a truck with the antenna fitted on the roof. This is very convenient as the equipment is then extremely mobile and can be shifted from one area to another as required. It is also possible to remote the radar and automatic detection equipment and situate the display system at the aircraft base. Transmission of the data every 9.1 minutes can be carried out by very simple digital transmission equipment over telephone line or radio.

FLOCK MIGRATION

1. Surveillance Radar:

All the rules noted on the use of this type of radar for detection of broad area migration also apply here. However, radar detection of flocks is much easier since the birds involved have individual radar cross-sections of 50 to 200 sq. cms. and often the flocks have in excess of 100 birds in them. Since a flock occupies a range less than that of the equivalent radar's pulse length, the flock's radar cross-section is usually in excess of 1 square meter. Equipment similar to Lt. Clausen's is employed. We used our version of the equipment at Winnipeg this year during the annual snow goose migration. Again the display was an electronic count which could be related to flock density per nautical square mile by means of a chart shown in the slide (Fig. 4). A second slide shows the probability of a strike on a flock per nautical mile flown by an aircraft (Fig. 5). This latter chart does make certain assumptions; however, the result is probably valid to within an order of magnitude.

In practice we ran into difficulties because of unknown echoes at the shorter ranges. These were due to either MTI breakthrough (we were connected to the output of the radar's MTI receiver), replies from single birds or atmospheric returns. My own thought at present is that they were due to single migrating birds although further analysis is required. We therefore changed the 100° sector to a longer range of 26 to 36 nmiles where this phenomenon did not affect the results. Good correlation was obtained between the indicated flock density and manual counts made on the PPI. Time lapse photography was also carried out of the migration and this will permit a more quantitative correlation at a later date.

This was an experimental piece of equipment. In operation the radar coverage would be split into eight sectors - each 90° wide and gated in range from 10 to 20 and 20 to 30 miles. Each sector would be fitted with a counter. Digital division would be employed to provide direct readout in flock numbers per sector. At the end of each counting period (about 5 minutes), the new count would be transferred to the display and remain there on display until the end of the next count period. Thus, the latest count would always be displayed.

2. Height Finder Radar:

Although not all people in air traffic control are agreed that the determination of the height of flocks of migrating birds is necessary, many controllers think it is desirable since large aircraft are more manoeuvrable in altitude than in the horizontal plane. In the past we have considered the use of nodding-beam height finders or tracking radars. However, both of these require a trained operator and therefore their cost effectiveness is questionable.

Canada at present has and is acquiring more C-band weather radars for use at or near airports. These radars have facilities for height finding and the addition of an antenna programmer. Thus the generation of an antenna sweep pattern necessary for automatic bird height finding would not require costly modifications. The type of sweep pattern required, is one where during the first horizontal scan of the antenna, the vertical beam lies along the horizon. During the second horizontal scan, the vertical beam is stepped up to 0.7° above the horizon. This stepping of the vertical beam is continued until an elevation angle of 10° is obtained. Then the antenna is returned to 0° and the stepped scan repeated. This pattern of antenna scan is also useful in the radar's original role of weather detection.

The radar receiver would be followed by a digitizer which would combine video integration, range, azimuth and elevation coordinate determination. Processing after this would depend upon the type of display to be used.

I have suggested two types of display to ATC. For illustrating these displays I have used a computer to produce a series of flocks which are randomly oriented in the horizontal plane. These flocks are also randomly oriented in a 2,000-ft. height band, whose average altitude increases from 1,000 ft., 40 miles south of the radar to 5,000 feet, 40 miles north of the radar. This could be typical (except for direction) of the geese seen at Winnipeg. Both displays show the same flocks. Maximum flock densities include all the flocks of the minimum flock densities.

The first type of display was preferred by a senior controller with whom I discussed the problem in detail. He preferred it because of its simplicity and the ease of grasping essential information. My own feelings are that it supplies sufficient information for warning pilots during daylight hours. I am not sure about it during nighttime. Certainly the first display is the cheaper of the two methods.

This display (Fig. 6) is a commercially-available CRT display with a TV-type scan of alpha-numeric characters. It has a built-in memory to store and display the information until the next data renewal at the end of three minutes. The area covered by the system is broken down into 8-45° wedges, each further broken down into 3 range scales of 0-10, 10-20, and 20-30 miles. The number in the top left-hand corner indicates that there are 11 flocks flying between 2,000 and 7,000 feet in the north-east sector between 20 and 30 miles. The next slide (Fig. 7) shows the results when the flock density is reduced by a factor of four. Dangerous weather conditions would also be displayed on this equipment. The first number might be astronomical because of the horizontal area of the weather, but the minimum and maximum altitudes would be correct.

The other type of display has been briefly described by Blokpoel and myself in a report[4] that many of you have seen. The danger area of each flock appears as a square or circle surrounding the position of the flock on the controller's bright scan display mixed with aircraft radar and beacon returns. In the case of the next figures, I have used a square whose side is 4 miles corresponding to the danger area of a flock flying at 40 knots (Fig. 8).

A multi-position switch on the controller's display would allow him to display the danger areas in any thousand-foot slice or all danger areas from 0 to 10,000 feet. The first slide shows the results in the all-altitude switch position. The density here is about one-fifth of the maximum density obtained at Winnipeg. Even this density gives a crowded display and perhaps we should show only the flock's last position and allow the controller to visualize the danger area mentally.

Normally the controller would leave the switch in the all-altitude position until a danger area appeared. Then running quickly through the switch positions he could obtain the actual altitude of the flock. Alternatively, the controller with an aircraft flying at a known altitude could switch to that altitude slice and look for areas dangerous to the aircraft. The next figure shows the results when the controller switches to the two-thousand foot level (Fig. 9). A reduction in the number of flocks is obvious in the north half. The question arose as to the advantage of using an antenna with a 0.5° beamwidth instead of the existing 1° beamwidth. The next slide (Fig. 10) shows that there is about a 30% reduction in the number of echoes in the altitude slice. At the cost of a new antenna system, approximately double the size of the existing one, this improvement does not appear to be cost effective. The last slide (Fig. 11) returns to a 1° beamwidth and shows the effect of reducing the number of echoes by four in the all-altitude position.

CONCLUSIONS

In Canada, we feel that we have practical answers now for the operational use of radars for the detection of both types of bird migration. The problem now appears to be persuading Air Traffic Control that the automatic detection equipments and displays can produce useful information for the controllers and to have such equipment manufactured. In the case of both flock and broad area migrations, ATC still must answer the question of how vital is height information to them.

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4. Hunt, F.R. and Blokpoel, H. A Bird Height Finding Radar for Air Traffic Control - A Progress Report ERB-873, Radio and Electrical Engineering Division, National Research Council of Canada, March 1973.

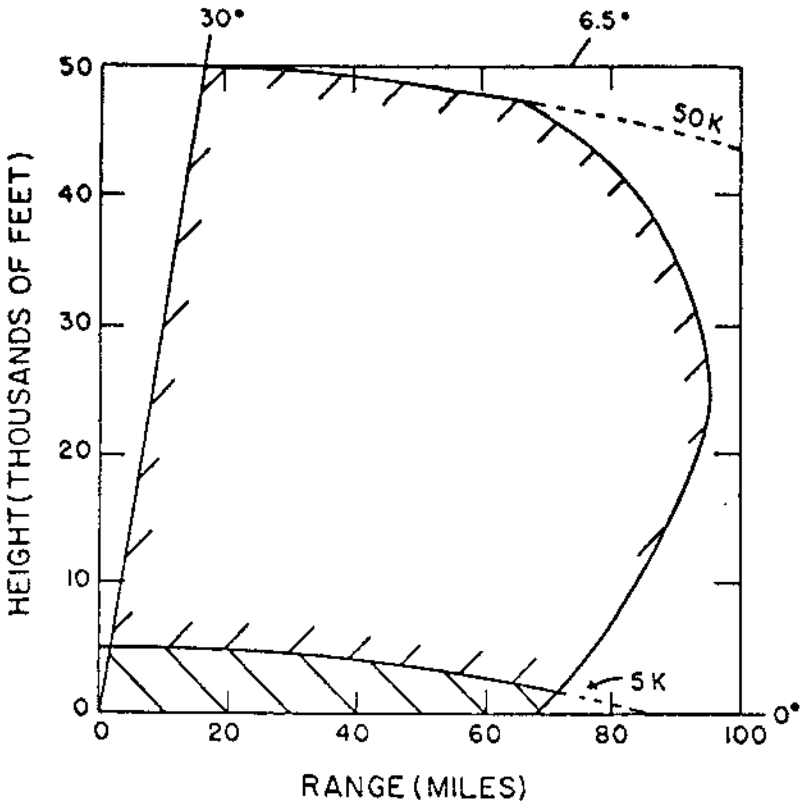

Fig. 1 Surveillance Radar Vertical Coverage

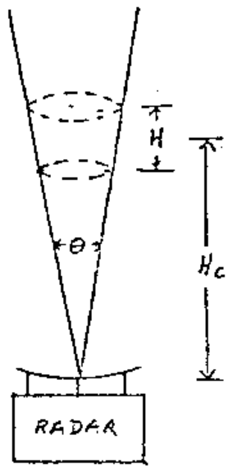

Fig. 2 Vertically Looking Radar

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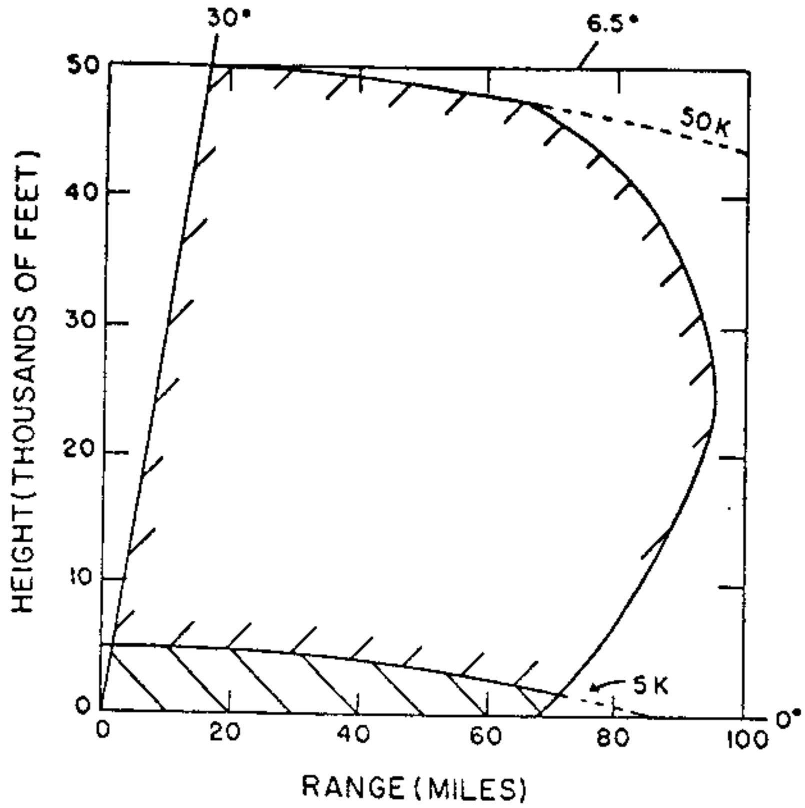

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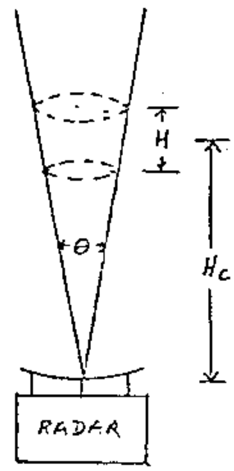

Fig. 2 Vertically Looking Radar

BIRD MIGRATION RATE
VERTICALLY LOCKING RADAR

COUNT TIME = 9.1 MINUTES, ANTENNA BEAMWIDTH = 1.1 DEGREES
HEIGHT BAND = 1000 FEET, HEIGHT OF RADAR ASL = 300 FEET

	MEAN HEIGHT IN FEET (ASL)						
COUNT	1000	2000	3000	4000	5000	6000	7000
1	2.58E+03	1.23E+03	7.73E+02	5.64E+02	4.44E+02	3.66E+02	3.11E+02
2	5.96E+03	2.45E+03	1.55E+03	1.13E+03	8.88E+02	7.32E+02	6.23E+02
3	8.94E+03	3.68E+03	2.32E+03	1.69E+03	1.33E+03	1.10E+03	9.34E+02
4	1.19E+04	4.91E+03	3.09E+03	2.26E+03	1.78E+03	1.46E+03	1.25E+03
5	1.49E+04	6.14E+03	3.86E+03	2.82E+03	2.22E+03	1.83E+03	1.56E+03
6	1.79E+04	7.36E+03	4.64E+03	3.38E+03	2.66E+03	2.20E+03	1.87E+03
7	2.09E+04	8.59E+03	5.41E+03	3.95E+03	3.11E+03	2.56E+03	2.18E+03
8	2.38E+04	9.82E+03	6.18E+03	4.51E+03	3.55E+03	2.93E+03	2.49E+03
9	2.68E+04	1.10E+04	6.95E+03	5.07E+03	3.99E+03	3.29E+03	2.80E+03
10	2.98E+04	1.23E+04	7.73E+03	5.64E+03	4.44E+03	3.66E+03	3.11E+03
11	3.28E+04	1.35E+04	8.50E+03	6.20E+03	4.88E+03	4.03E+03	3.42E+03
12	3.58E+04	1.47E+04	9.27E+03	6.77E+03	5.33E+03	4.39E+03	3.74E+03
13	3.87E+04	1.60E+04	1.00E+04	7.33E+03	5.77E+03	4.76E+03	4.05E+03
14	4.17E+04	1.72E+04	1.08E+04	7.89E+03	6.21E+03	5.12E+03	4.36E+03
15	4.47E+04	1.84E+04	1.16E+04	8.46E+03	6.66E+03	5.49E+03	4.67E+03

(a) Migration Traffic Rate

BIRD STRIKE PROBABILITY/NAUTICAL MILE FLOWN
VERTICALLY LOCKING RADAR

FRONTAL AREA OF A/C = 10 SQ. FT., COUNT TIME = 9.1 MINUTES, ANTENNA BEAMWIDTH = 1.1 DEGREES
HEIGHT OF RADAR ASL = 300 FEET, ASSUMED VELOCITY OF BIRDS = 25 KNOTS
HEIGHT BAND = 1000 FEET

	MEAN HEIGHT IN FEET (ASL)						
COUNT	1000	2000	3000	4000	5000	6000	7000
1	1.56E-04	8.08E-05	5.09E-05	3.71E-05	2.92E-05	2.41E-05	2.05E-05
2	3.93E-04	1.62E-04	1.02E-04	7.43E-05	5.85E-05	4.82E-05	4.10E-05
3	5.89E-04	2.42E-04	1.53E-04	1.11E-04	8.77E-05	7.23E-05	6.15E-05
4	7.85E-04	3.23E-04	2.04E-04	1.49E-04	1.17E-04	9.64E-05	8.20E-05
5	9.81E-04	4.04E-04	2.54E-04	1.86E-04	1.46E-04	1.21E-04	1.03E-04
6	1.18E-03	4.85E-04	3.05E-04	2.23E-04	1.75E-04	1.45E-04	1.23E-04
7	1.37E-03	5.66E-04	3.56E-04	2.60E-04	2.05E-04	1.69E-04	1.44E-04
8	1.57E-03	6.47E-04	4.07E-04	2.97E-04	2.34E-04	1.93E-04	1.64E-04
9	1.77E-03	7.27E-04	4.58E-04	3.34E-04	2.63E-04	2.17E-04	1.85E-04
10	1.96E-03	8.08E-04	5.09E-04	3.71E-04	2.92E-04	2.41E-04	2.05E-04
11	2.16E-03	8.89E-04	5.60E-04	4.08E-04	3.22E-04	2.65E-04	2.26E-04
12	2.36E-03	9.70E-04	6.11E-04	4.46E-04	3.51E-04	2.89E-04	2.46E-04
13	2.55E-03	1.05E-03	6.61E-04	4.83E-04	3.80E-04	3.13E-04	2.67E-04
14	2.75E-03	1.13E-03	7.12E-04	5.20E-04	4.09E-04	3.37E-04	2.87E-04
15	2.94E-03	1.21E-03	7.63E-04	5.57E-04	4.38E-04	3.62E-04	3.08E-04

(b) Bird Strike Probability

Fig. 3 Vertically Looking Radar Charts

FLOCK DENSITY DETERMINATION USING SECTOR AUTOMATIC DETECTION EQUIPMENT

AASR-1

RADAR PARAMETERS--

ANTENNA ROTATION RATE..........................	6.0 RPM
ANTENNA HORIZONTAL BEAMWIDTH....................	1.35 DEGREES
PULSE RECURRENCE FREQUENCY......................	365 HZ

AUTOMATIC DETECTION EQUIPMENT PARAMETERS--

MINIMUM RANGE..................................	15.5 NMILES
MAXIMUM RANGE..................................	25.9 NMILES
SECTOR WIDTH...................................	101.0 DEGREES
AREA COVERED BY ADE............................	377.85 SQ. NMILES
MEASUREMENT TIME...............................	5.3 MINUTES
FLOCK DENSITY AT ONE FLOCK PER PULSE PACKET....	12.67 FLOCKS / SQ. NMILE
RANGE BIN SIZE.................................	2.00 MICROSECONDS
AVERAGE AREA OF PULSE PACKET...................	0.08 SQ. NMILES
TOTAL NUMBER OF POSSIBLE COUNTS................	2097152
NUMBER OF NOISE OR PERMANENT ECHO COUNTS.......	0

NUMBER OF COUNTS-FLOCK DENSITY PER SQUARE NAUTICAL MILE
NOTE XXE-Y DENOTES THAT THE NUMBER XX IS MULTIPLIED BY 10 TO THE POWER -Y

200	1.21E-03	6200	3.75E-02	12200	7.37E-02	18200	1.10E-01	24200	1.46E-01
400	2.42E-03	6400	3.87E-02	12400	7.49E-02	18400	1.11E-01	24400	1.47E-0
600	3.62E-03	6600	3.99E-02	12600	7.61E-02	18600	1.12E-01	24600	1.49E-01
800	4.83E-03	6800	4.11E-02	12800	7.73E-02	18800	1.14E-01	24800	1.50E-01
1000	6.04E-03	7000	4.23E-02	13000	7.85E-02	19000	1.15E-01	25000	1.51E-01
1200	7.25E-03	7200	4.35E-02	13200	7.97E-02	19200	1.16E-01	25200	1.52E-01
1400	8.46E-03	7400	4.47E-02	13400	8.10E-02	19400	1.17E-01	25400	1.53E-01
1600	9.67E-03	7600	4.59E-02	13600	8.22E-02	19600	1.18E-01	25600	1.55E-01
1800	1.09E-02	7800	4.71E-02	13800	8.34E-02	19800	1.20E-01	25800	1.56E-01
2000	1.21E-02	8000	4.83E-02	14000	8.46E-02	20000	1.21E-01	26000	1.57E-01
2200	1.33E-02	8200	4.95E-02	14200	8.58E-02	20200	1.22E-01	26200	1.58E-01
2400	1.45E-02	8400	5.07E-02	14400	8.70E-02	20400	1.23E-01	26400	1.59E-01
2600	1.57E-02	8600	5.20E-02	14600	8.82E-02	20600	1.24E-01	26600	1.61E-01
2800	1.69E-02	8800	5.32E-02	14800	8.94E-02	20800	1.26E-01	26800	1.62E-01
3000	1.81E-02	9000	5.44E-02	15000	9.06E-02	21000	1.27E-01	27000	1.63E-01
3200	1.93E-02	9200	5.56E-02	15200	9.18E-02	21200	1.28E-01	27200	1.64E-01
3400	2.05E-02	9400	5.68E-02	15400	9.30E-02	21400	1.29E-01	27400	1.66E-01
3600	2.17E-02	9600	5.80E-02	15600	9.42E-02	21600	1.30E-01	27600	1.67E-01
3800	2.30E-02	9800	5.92E-02	15800	9.55E-02	21800	1.32E-01	27800	1.68E-01
4000	2.42E-02	10000	6.04E-02	16000	9.67E-02	22000	1.33E-01	28000	1.69E-01
4200	2.54E-02	10200	6.16E-02	16200	9.79E-02	22200	1.34E-01	28200	1.70E-01
4400	2.66E-02	10400	6.28E-02	16400	9.91E-02	22400	1.35E-01	28400	1.72E-01
4600	2.78E-02	10600	6.40E-02	16600	1.00E-01	22600	1.37E-01	28600	1.73E-01
4800	2.90E-02	10800	6.52E-02	16800	1.01E-01	22800	1.38E-01	28800	1.74E-01
5000	3.02E-02	11000	6.65E-02	17000	1.03E-01	23000	1.39E-01	29000	1.75E-01
5200	3.14E-02	11200	6.77E-02	17200	1.04E-01	23200	1.40E-01	29200	1.76E-01
5400	3.26E-02	11400	6.89E-02	17400	1.05E-01	23400	1.41E-01	29400	1.78E-01
5600	3.38E-02	11600	7.01E-02	17600	1.06E-01	23600	1.43E-01	29600	1.79E-01
5800	3.50E-02	11800	7.13E-02	17800	1.08E-01	23800	1.44E-01	29800	1.80E-01
6000	3.62E-02	12000	7.25E-02	18000	1.09E-01	24000	1.45E-01	30000	1.81E-01

Fig. 4. SADE Flock Density Chart

FLOCK STRIKE PROBABILITY USING SEARCH RADAR AUTOMATIC DETECTION EQUIPMENT

AASR-1

RADAR PARAMETERS--

ANTENNA ROTATION RATE............................	6.0 RPM
ANTENNA HORIZONTAL BEAMWIDTH.....................	1.35 DEGREES
PULSE RECURRENCE FREQUENCY.......................	365 HZ

AUTOMATIC DETECTION EQUIPMENT PARAMETERS--

MINIMUM RANGE....................................	15.5 NMILES
MAXIMUM RANGE....................................	25.9 NMILES
SECTOR WIDTH.....................................	101.0 DEGREES
AREA COVERED BY ADE..............................	377.85 SQ. NMILES
MEASUREMENT TIME.................................	5.3 MINUTES
ASSUMED NO. OF BIRDS IN FLOCK....................	100
X-SECTION OF SINGLE BIRD.........................	100 SQ. CMS.
X-SECTION OF 100 BIRDS...........................	1.00 SQ. METERS
ASSUMED FRONTAL DIMESIONS OF BIRD................	5X 2 FEET
FLOCK DENSITY AT ONE FLOCK PER PULSE PACKET....	12.67 FLOCKS / SQ. NMILE
RANGE BIN SIZE...................................	2.00 MICROSECONDS
AVERAGE AREA OF PULSE PACKET.....................	0.08 SQ. NMILES
WIDTH OF HEIGHT BAND.............................	5000 FEET
TOTAL NUMBER OF POSSIBLE COUNTS..................	2097152
NUMBER OF NOISE OR PERMANENT ECHO COUNTS.......	0
ASSUMED AIRCRAFT FRONTAL DIMENSIONS..............	150X 4 FEET

NUMBER OF COUNTS/PROBABILITY OF FLOCK STRIKE PER NAUTICAL MILE FLOWN
NOTE XXE-Y DENOTES THAT THE NUMBER XX IS MULTIPLIED BY 10 TO THE POWER -Y

200	1.55E-07	6200	4.79E-06	12200	9.43E-06	18200	1.41E-05	24200	1.87E-05
400	3.09E-07	6400	4.95E-06	12400	9.58E-06	18400	1.42E-05	24400	1.89E-05
600	4.64E-07	6600	5.10E-06	12600	9.74E-06	18600	1.44E-05	24600	1.90E-05
800	6.18E-07	6800	5.26E-06	12800	9.89E-06	18800	1.45E-05	24800	1.92E-05
1000	7.73E-07	7000	5.41E-06	13000	1.00E-05	19000	1.47E-05	25000	1.93E-05
1200	9.27E-07	7200	5.56E-06	13200	1.02E-05	19200	1.48E-05	25200	1.95E-05
1400	1.08E-06	7400	5.72E-06	13400	1.04E-05	19400	1.50E-05	25400	1.96E-05
1600	1.24E-06	7600	5.87E-06	13600	1.05E-05	19600	1.51E-05	25600	1.98E-05
1800	1.39E-06	7800	6.03E-06	13800	1.07E-05	19800	1.53E-05	25800	1.99E-05
2000	1.55E-06	8000	6.18E-06	14000	1.08E-05	20000	1.55E-05	26000	2.01E-05
2200	1.70E-06	8200	6.34E-06	14200	1.10E-05	20200	1.56E-05	26200	2.02E-05
2400	1.85E-06	8400	6.49E-06	14400	1.11E-05	20400	1.58E-05	26400	2.04E-05
2600	2.01E-06	8600	6.65E-06	14600	1.13E-05	20600	1.59E-05	26600	2.06E-05
2800	2.16E-06	8800	6.80E-06	14800	1.14E-05	20800	1.61E-05	26800	2.07E-05
3000	2.32E-06	9000	6.96E-06	15000	1,16E-05	21000	1.62E-05	27000	2.09E-05
3200	2.47E-06	9200	7.11E-06	15200	1.17E-05	21200	1.64E-05	27200	2.10E-05
3400	2.63E-06	9400	7.26E-06	15400	1.19E-05	21400	1.65E-05	27400	2.12E-05
3600	2.78E-06	9600	7.42E-06	15600	1.21E-05	21600	1.67E-05	27600	2.13E-05
3800	2.94E-06	9800	7.57E-06	15800	1.22E-05	21800	1.68E-05	27800	2.15E-05
4000	3.09E-06	10000	7.73E-06	16000	1.24E-05	22000	1.70E-05	28000	2.16E-05
4200	3.25E-06	10200	7.88E-06	16200	1.25E-05	22200	1.72E-05	28200	2.18E-05
4400	3.40E-06	10400	8.04E-06	15400	1.27E-05	22400	1.73E-05	28400	2.19E-05
4600	3.55E-06	10600	8.19E-06	16600	1.28E-05	22600	1.75E-05	28600	2.21E-05
4800	3.71E-06	10800	8.35E-06	16800	1.30E-05	22800	1.76E-05	28800	2.23E-05
5000	3.86E-06	11000	8.50E-06	17000	1.31E-05	23000	1.78E-05	29000	2.24E-05
5200	4.02E-06	11200	8.66E-06	17200	1.33E-05	23200	1.79E-05	29200	2.26E-05
5400	4.17E-06	11400	8.81E-06	17400	1.34E-05	23400	1.81E-05	29400	2.27E-05
5600	4.33E-06	11600	8.96E-06	17600	1.36E-05	23600	1.82E-05	29600	2.29E-05
5800	4.48E-06	11800	9.12E-06	17800	1.38E-05	23800	1.84E-05	29800	2.30E-05
6000	4.64E-06	12000	9.27E-06	18000	1.39E-05	24000	1.85E-05	30000	2.32E-05

Fig. 5. SADE Flock Strike Chart

11/2/7			5/2/6			4/2/7
	10/2/5		1/2/4		6/3/5	
		0/0/0	1/2/3	3/2/4		
7/0/5	5/2/5	3/2/4		2/2/4	5/2/5	10/0/6
		6/2/4	3/2/4	2/2/4		
	3/0/4		6/0/4		3/0/4	
7/0/4			8/0/4			10/0/5

Fig. 6 Height Display

Flock Density = $0.4/\text{nmile}^2$

1/2/4			3/2/5			0/0/0
	3/3/5		1/2/4		1/3/4	
		0/0/0	0/0/0	0/0/0		
2/0/5	1/2/3	1/2/4		0/0/0	2/3/4	2/0/5
		2/2/4	2/2/4	1/2/3		
	0/0/0		1/2/3		0/0/0	
4/0/3			2/0/3			3/2/5

Fig. 7 Height Display

Flock Density = $0.1/\text{nmile}^2$

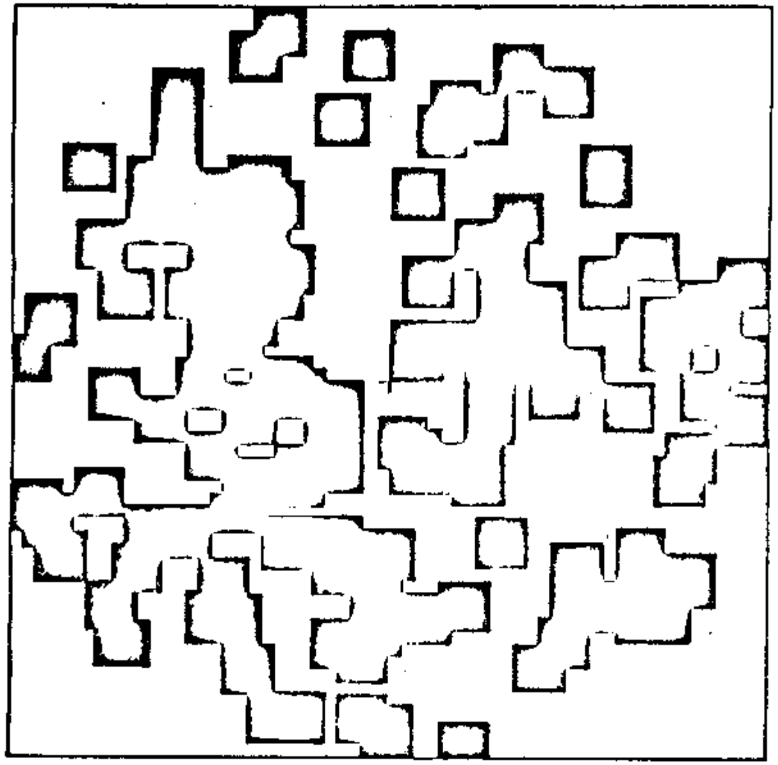

Fig. 8 Height Display

All Altitude

Flock Density = 0.4/nmile^2

Antenna Beamwidth = 1.0°

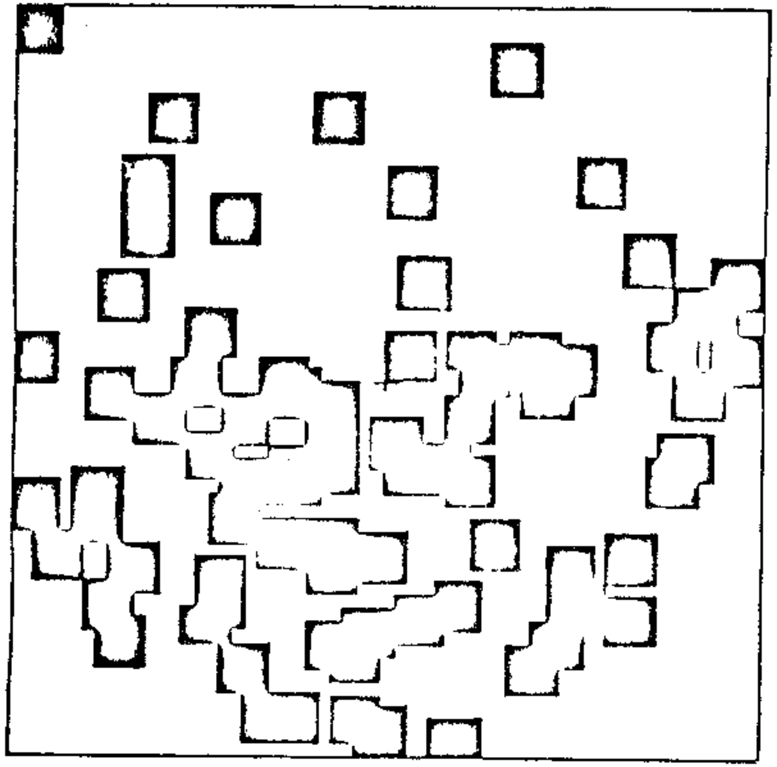

Fig. 9 Height Display

2000 ft. Altitude

Flock Density = 0.4/nmile^2

Antenna Beamwidth = 1.0°

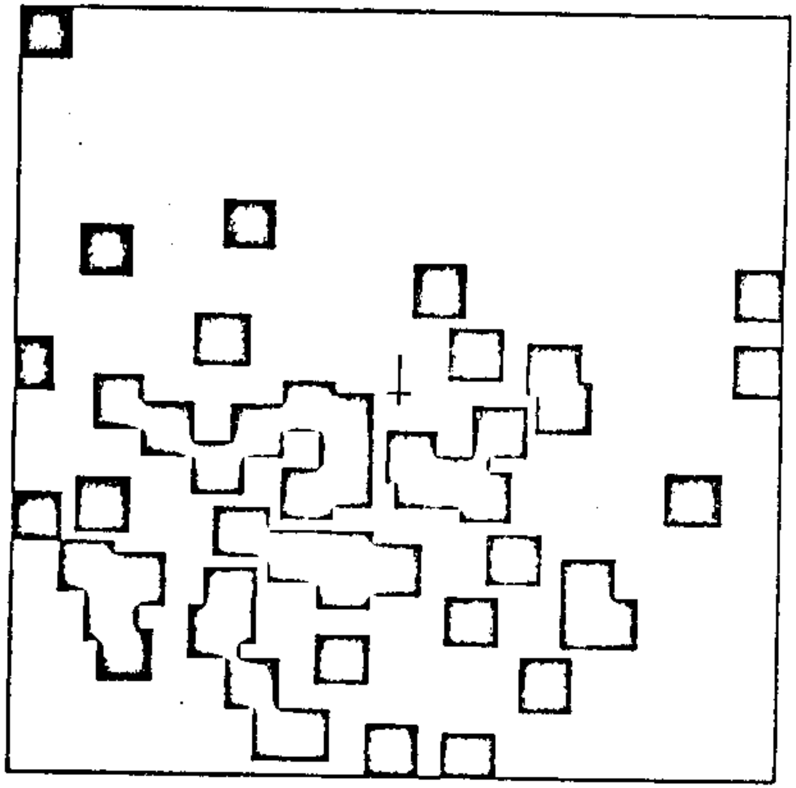

Fig. 10 Height Display

2000 ft. Altitude

Flock Density = $0.4/\text{nmile}^2$

Antenna Beamwidth = 0.5°

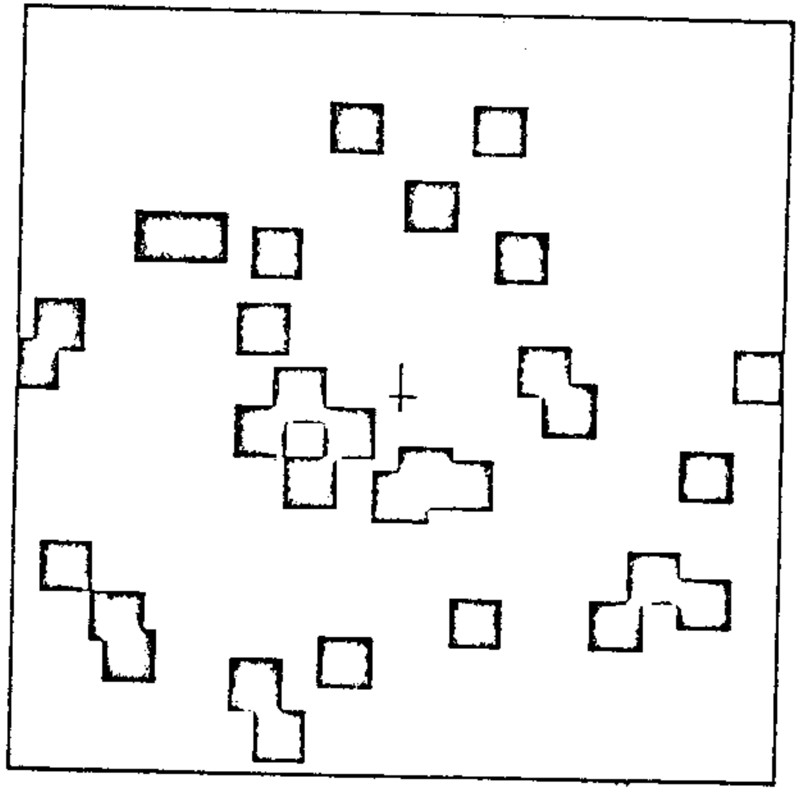

Fig. 11 Height Display

All Altitude

Flock Density = $0.1/\text{nmile}^2$

Antenna Beamwidth = 1.0°