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THE APPLICATION OF RADAR

FOR BIRD STRIKE PREVENTION

Compiled for the Bird Strike Committee Europe
(radar working group)
by

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and

B. Bruderer[2]

The following pages of the "radarbooklet" (from a total of 75 pages, 37 figures and photo's, one colormap) may serve as an introduction for those readers who were not present in Helsinki or did not receive a copy yet. The first edition is still available through the first author. He also appreciates to receive all comments that may help to produce a next edition.

The Hague, - may 1990 - first edition

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PREFACE

During the periodical meetings of Bird Strike Committee Europe it was felt necessary to have a booklet on the application of radar for bird strike reduction. Neither another textbook on radar, nor a pure biological story about bird movements, but a collection of empirical experiences that could serve as a reference for discussions. This booklet is an attempt to fulfil this wish.

Readers will quickly find out that the first part (up to the color plate at page 27) does not deal with radar. The booklet starts with a identification of the "en route" bird strike problem on the basis of bird strike statistics, because the bird strikes themselves offer the best clue to understanding the real nature of the problem. The next subject is a short biological treatment of bird movements, partly based on radar ornithological studies.

The radar part of the booklet is mainly a collage of short introductions and illustrations. Each chapter deserves much more detail, but we prefer to refer to more detailed publications. However, improvements and additions, especially on new developments, are most desirable for future editions.

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F-104 Starfighter after collision with an eiderduck (Sommateria mollisima, 4 lbs) at 4000 ft. Leakage of fuel let the aircraft enflame during landing.

1. INTRODUCTION

1.1. Aims

Radar has proven to be a powerful tool for detection and quantification of the flying activity of birds. When applied correctly, it can help aircraft to avoid regions and air layers with high bird densities. Reducing the number of collisions between aircraft and birds seriously improves flight safety. High costs and even fatal accidents are at stake.

The aim of this booklet is to stimulate the operational use of radar for bird strike reduction. Although several European air forces practice radar warning for bird movements within their operational procedures, many others do not or profess their belief in so-called BIRTAMS (BIRd information To Air Men) only verbally. Civil operational use is nearly absent. Nevertheless there seems to be a continuous need for information about the flight activity of birds, simply because aircraft and birds collide again and again.

Within Bird Strike Committee Europe (BSCE) it is felt necessary to produce a brochure on these matters. The development of measures to separate aircraft and birds needs cooperation between truly different diciplines. The right procedures can only be achieved by combining information on three different topics: the operations of aircraft, the movements of birds, and radar techniques. However, it is clear that even with the best data, processed in an optimal way, it never will be possible to exclude bird strikes completely. A certain risk always has to be taken when flying.

One could ask whether there still is a need for a booklet introducing basic aspects of "radar ornithology" after the clear and comprehensive text-book under this title by Eastwood (1967). Apart from the size and unavailability of this book there were other reasons to review a number of aspects.

First, after the boom of radar ornithological publications in the Sixties the attention for methodological aspects faded away. Those who continued to extract more information on bird migration by means of radar discovered important limitations. Where these were not taken into consideration they seriously biased conclusions. In particular, the proper quantification and assessment of the altitudes of bird migration suffered from over- enthusiasm during the early years.

The second reason for writing the booklet is our concern about how seldom the available useful knowledge has been applied to flight safety problems. It is considered as the first task of the Radar Working Group of BSCE to bring together practical experience. In order to do so, a second main task is to stimulate research on spatial and behavioural aspects of bird movements. The lack of correct quantitative descriptions of these purely biological matters have often appeared to be the bottleneck. The third reason for publishing the brochure is the development of new radars and video processing techniques. While modern radars become less suitable for direct

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recording of bird movements, recent developments in computer technology offer new and fascinating possibilities. However, the capacity of extracting information on birds directly from the raw video signal should be a formal part of the system design.

1.2. Overview

We will start with a general survey of the bird strike problem, followed by some research results on the distribution of flying birds in time and space. By comparing these data we evaluate the risks of bird strikes and arrive at certain priorities with respect of technical and methodological means to detect or predict bird movements (chapter 2). Chapter 3 and 4 deal with general aspects of the radar techniques and with the types of equipment used succesfully in ornithological research. In chapter 5 we decribe and discuss different types of applications of radar to operational warnings about bird movements. In chapter 6 current and potential research in radar ornithology is discussed with respect to desirability for flight safety. Illustrations are primarily taken from the research work of the two authors in the areas of the Alps and the Dutch lowlands.

1.3. Acknowledgements

The publication of this booklet has been made possible thanks to reproduction facilities of the Royal Netherlands Air Force. The RNLAF also provided most of the radar pictures and the photo's. The color map with bird migration patterns was made available by the Schweizerische Vogelwarte. The authors are much indepted to Dr R.P.Larkin for comprehensive comments and suggestions.

2. GENERAL SURVEY OF THE PROBLEM

The question of when and where avoidance of birds is practical can be answered in two ways. A first approach is bird strike statistics, using the bad experiences of the past. The problem is that statistical data may be biased for varying reasons. Their usefulness is often reduced by poor reporting. Further, new types of aircraft and altered flight performances might invalidate earlier conclusions. The second approach is by properly analyzing the flying activity of birds and aircraft in three dimensions. From the combination of both data sets theoretically we should be able to predict exactly the hazardous situations. However, the main shortcoming is our knowledge about the spatial distribution of birds. Therefore we start our analysis with the first approach. In chapter 2.2. we continue with some general ornithological information on bird movements partly based on radar studies.

2.1. Bird strikes

2.1.1. How to define a bird strike

Given enough reports certain patterns in the distribution of bird strikes in time and space show up. However, before drawing any firm conclusion, one should realize that not all types of collisions are equally well reported. Serious accidents, of course, cannot be overlooked. But the number of heavily damaged aircraft is relatively small. So, one also wants to include in the analysis incidents with no or only slight damage. Whether or not such bird strikes are, or even can be, documented is partly a matter of attention of the crew and partly dependent on which part of the aircraft was struck. Further, the rate at which identifiable bird remains are found affect the chance of a certain bird strike to be discovered and properly classified.

Bird strikes above the runway are more likely to be reported than bird strikes "en route". Ground personnel may observe collisions directly which were not noticed by the air crew. Bird remains found along the runway, and for that reason considered as corpi delicti, selectively enlarge the proportion of bird strikes belonging to the category "local". The relative overestimation of these cases may even become an absolute one when also slip stream victims are included. These are birds smashed against the ground in the turbulent air behind big airliners without hitting the aircraft itself . Another type of bias is the fact that big and white birds will be seen or found easier than dark and small ones.

We define a bird strike simply as a physical collision between an aircraft and a bird or flock of birds, thus neither including slipstream victims and near-misses nor defining a certain damage and/or risk level.

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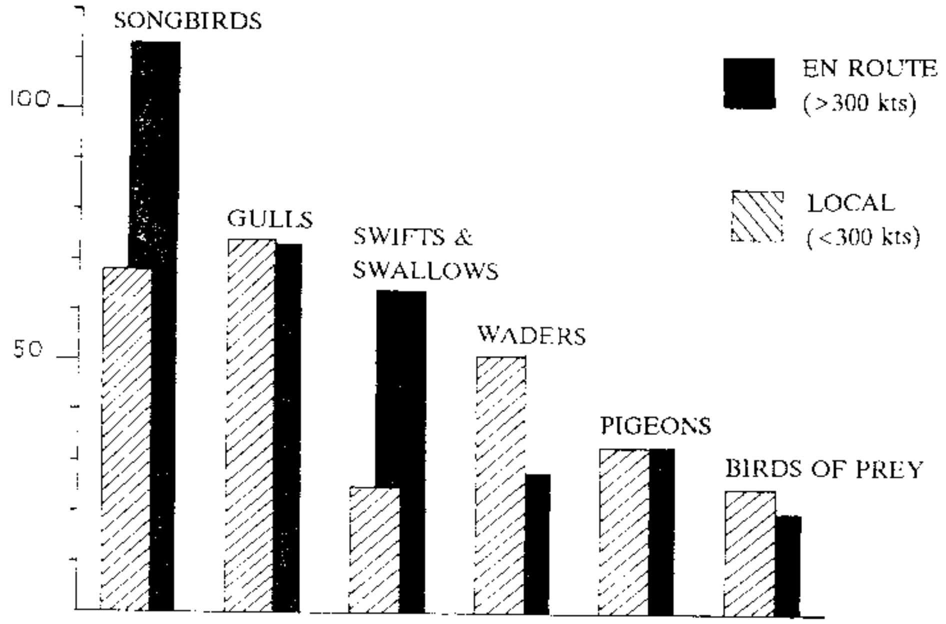


figure 1 Number of bird strikes for RNLAF jet fighters (1977- 1983) per bird category. Flight phases were ranked as "local" (<300 kts) or "en route" (>300 kts) (see fig 15).

One could object that including all minor bird strikes without damage provokes an enormous reporting effect. We reject this argument when it is induced by the consideration: who reports most bravely ends up highest at the (black) list of ratio's. Honest collection and analysis of data is a conditio sine qua non. Furthermore, comparison of military bird strike statistics from several countries indicates a fairly fixed ratio of damaging to non-damaging cases given a good reporting standard.

2.1.2. Species and damage

All species that spend much time in the air may become victims of aircraft. Jet fighters during low level training missions provide the most bias-free sample. They usually fly at high speeds therefore minimizing evasive manouvres by the birds. Further, they cover large distances over a wide spectrum of landscapes causing their bird victims not to be a typical airfield population. Figure 1 shows that certain species are more involved in "local" strikes (lapwing, a common wader in Holland) while others collided mostly with aircraft "en route" (swifts and swallows). Sorting out the bird strikes with respect of season proves that "en route" bird strikes often include migrating birds, while bird strikes at airfield reach a peak when unexperienced young birds arrive there from the surroundings. This peak is over before most birds leave the area indicating that the birds quickly learn to avoid the danger. Further analysis per species gives results that nicely can be explained in ornithological terms (Buurma, Dekker & Brom 1986), which in turn indicates that aircraft can be seen as devices correctly sampling the air space with respect of birds.

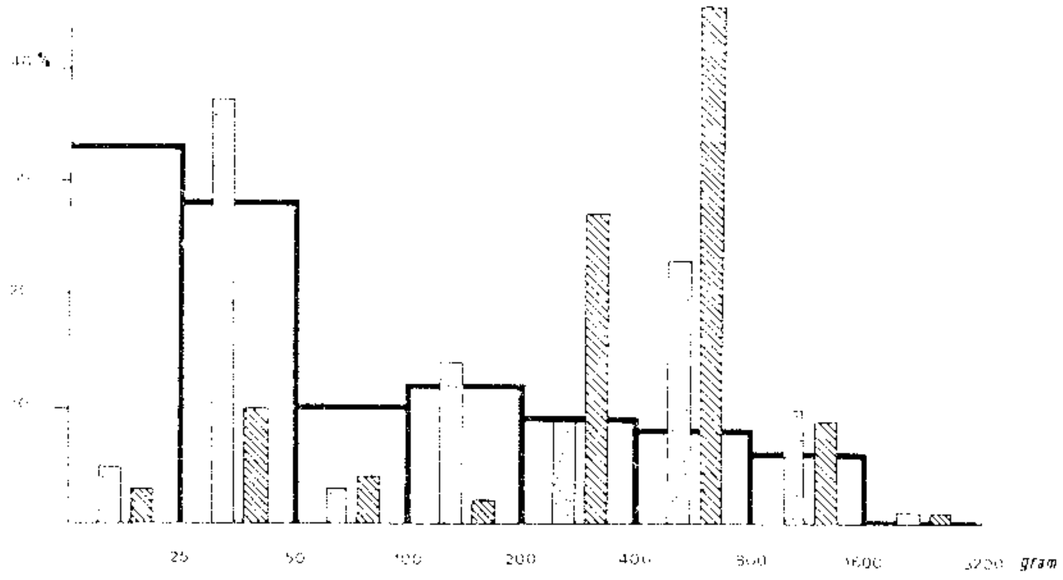
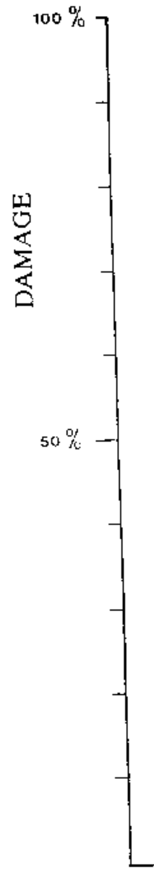


figure 2 Weight distribution of birds breeding in The Netherlands (white columns) and of those involved in collisions with RNLAF jet fighters during the period 1964-1976 (shaded bars) and the period 1977-1982 (dotted bars). Weights in 8 weight classes. Breeding bird totals for all species and 11 million pairs.

For risk assessment and airworthiness standards the weight of the birds concerned is more important than their type. Figure 2 illustrates the weight distribution of Dutch breeding birds compared with all birds involved in collisions with Dutch fighter aircraft (Buurma 1984). Heavier birds are overrepresented. Years with extreme attention to collecting all possible data and analyzing bird remain microscopically (the second period) show bigger proportions of smaller birds. Nevertheless, the smallest birds do not show up, which is explained below.

The damage to aircraft due to bird collision is related to impact speed in the first place because speed quadratically influences impact energy while weight of the bird is only linear related. This is shown in figure 3 for three out of five curves that represent birds weighing over 100 grams. Even birds of moderate weight cause over 60 % of damage when the fighter concerned is on cruising speed. Small birds however do not penetrate the compressed air layer in front of fast flying fighter aircraft. This of course is only valid for the tapered parts of the aircraft. Small birds must be sucked into engines very frequently and perhaps cause delayed and indirect damage. This, however, isn't easy to document.



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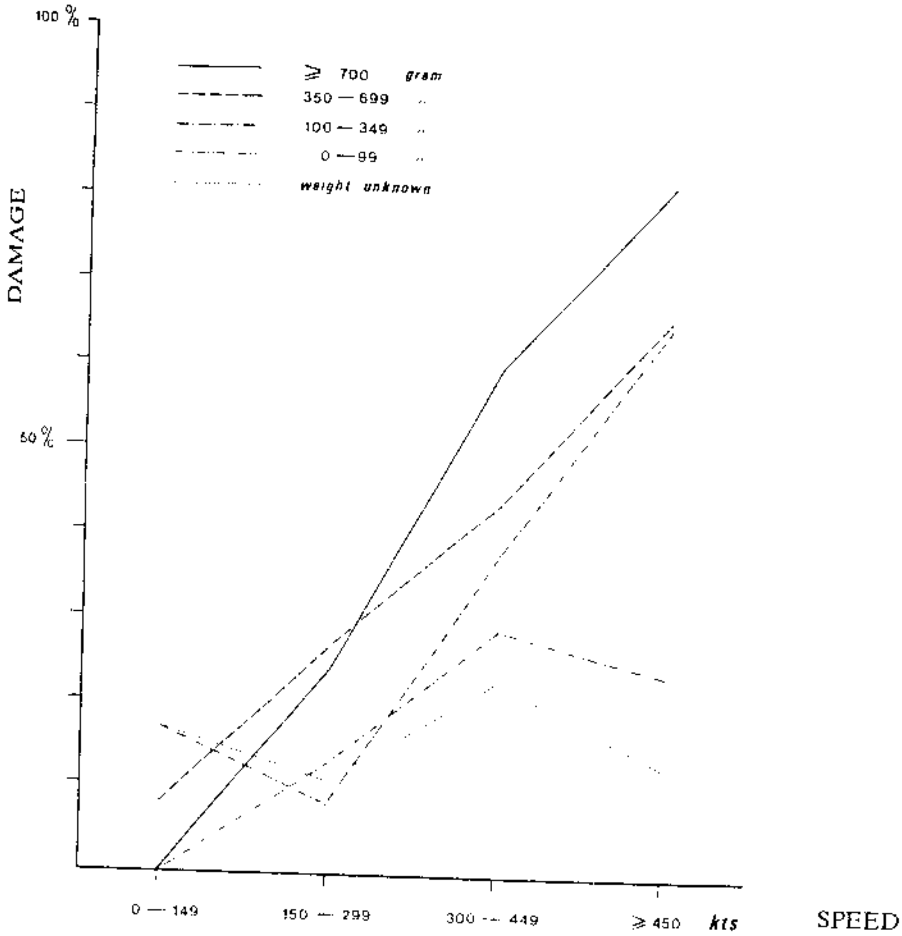

figure 3 Percentage of bird strikes with damage in 5 weight classes of birds against aircraft speeds (RNLAF, period 1977- 1982).

2.1.3. Geographical distribution

As illustrated by figure 4 "en route" bird strikes show a wide spread, better indicating home ranges of the RNLAF jetfighter family than the distribution or flightlines of birds. The only clusters of birds occur in the special low flying areas and shooting ranges where the aircraft increase their bird strike risk by extreme low level flying. By their nature local bird strikes are confined to the direct surroundings of airfields.

figure 4 Geographical distribution of RNLAF bird strikes "en route" (dots) and "local" (squares) for the period 1977-1981. Black dots indicate damage cases, while the black part of the squares indicates the percentage of damage in the "local" bird strikes.

2.1.4. Number of bird strikes over the year

The occurence of birds throughout the year is nicely illustrated by the number of bird strike victims, even if the numbers are fairly small. Clear differences can be found which nicely fit into what is known about the occurence of particular species in farmland (=airfield environment) and the timing of their migratory, dispersal and local flights.

This static information may help to plan certain flying activities of aircraft in order to avoid bird strikes. It becomes even more promising as far as short-term variations of bird presence are concerned: day-to-day variations of the bird strike rate occur, especially within the "en route" category. In certain years the RNLAF experienced clusters of collisions during days with increased migratory activity of birds. Normally, this is of course masked by flight restrictions which prevent a large part of "en route" bird strikes by relatively few cancellations of low level missions.

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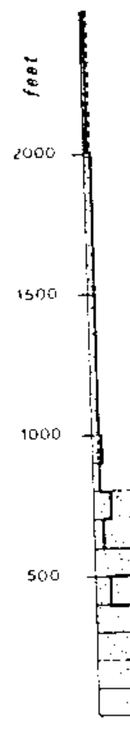

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2.1.5. Frequency of bird strikes with height

We start with the proposition that a proper height distribution can only be expected when we select those flight phases during which the aircraft cover equal distances within each air layer. This is approximately true between 0 and 1500 ft for take-off, final-approach, landing, and, in case of militairy aircraft, touch-and-go and overshoot. In these flight phases the aircraft fly with a more or less fixed angle to the earth surface. There may be some doubt whether the birds are equally sampled in each air layer because low speeds may enlarge the success of evasive actions i.e. especially in the lowest 100 ft. But if the assumptions are reasonable figure 5a illustrates the average altitudinal distribution of birds over the year. It indicates the high density of flying birds within the lowest 100 feet. Because during the flight phases low-level-en-route and high-altitude- cruise certain standard flight levels are practisized figure 5b largely reflects the the heights of those standard flight levels rather than the heights of the birds. Civil aircraft have usually only a "local" problem; the total height distribution from bird strikes suffered by UK airliners nicely fits into the military selection of "local" bird strikes (fig 5a).

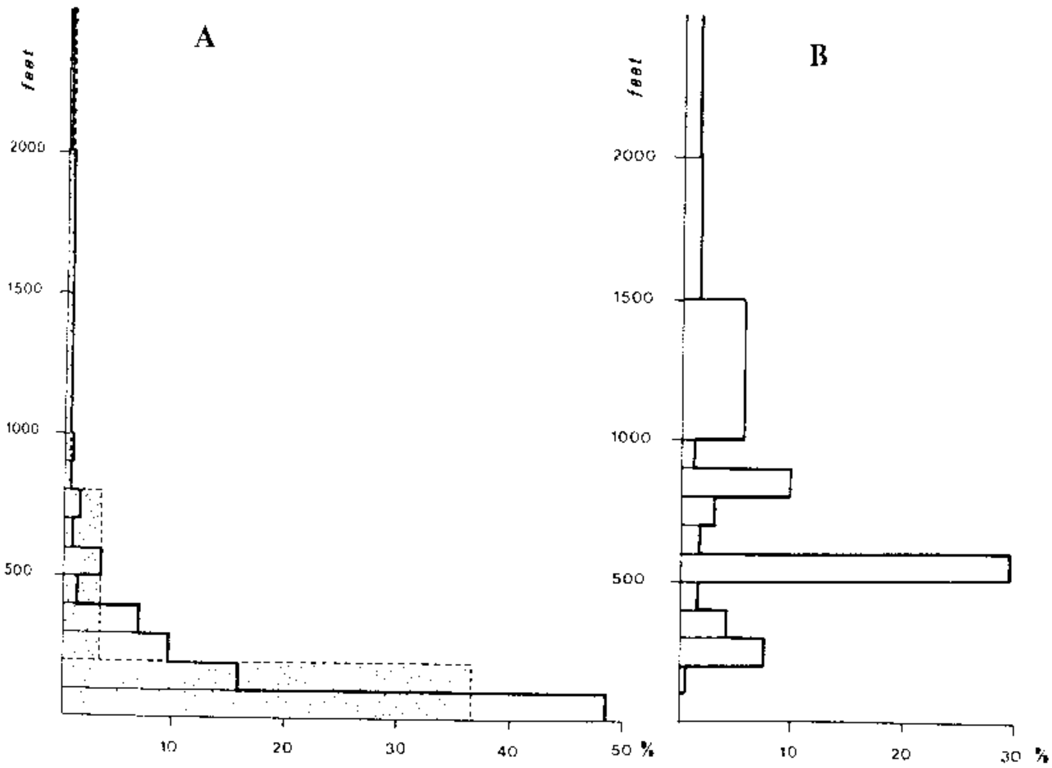

figure 5 Height distribution of RNLAF bird strikes in 100 ft air layers. A: bird strikes during take-off, final approach, landing, touch-and-go and overshoot (n=294). Dashed distribution: civil aviation. B: bird strikes during low level and high altitude cruise (n=466).

2.2. Distribution of flying birds in time and space

Most birds are able to fly, and use this ability for different purposes: when searching for food, in courtship displays, in roosting flights, dispersal and migration. Referring only to potentially hazardous flights in the open air space, this chapter aims at a description of the different types of flight in order to identify the times and locations of highest risk.

2.2.1. Local movements

Thanks to the low radar coverage above flat country radarfilms from Holland (Buurma 1977, 1987) show patterns of intens local bird movement. By day a dense tangle of bird activity can often be observed just outside the region where the radar screen is saturated by ground echoes. These very low flying birds are not easily discernable on the scope of long range radars. Furthermore, moving target suppression facilities of radars working at small scale often eliminate most birds. Outside this zone, i.e. better visible to the radar operator, the following types of higher local bird movements can be observed.

Bird activity in thermals This common type of bird flight shows up regularly in rising air currents around noon and in summer. The movements are often a combination of insect feeding, searching for food patches, display and also migration. The birds concerned are often large soaring birds like buzzards, dynamic gliders as swifts and several other species. These movements produce a serious part of all bird strikes. Extreme examples of this dangerous flying activity may be found in warm and dry regions. In India military flying has been forbidden between 10.00 and. 14.00 hrs because of the risk of colliding with vultures and kites. Another nice example of a bird strike prevention measure is the issuing bird plagued zones in Israel which in fact indicate the narrow routes of those migrants that primarily use thermals (Leshem 1988).

Feeding and roosting flights Depending on the distance to cover, certain foraging flights can be clearly visible by radar. A nice example is the "air-lift" from the Dutch Waddensea towards a huge garbage dump 65 km. inland (figure 6). Each morning some 15.000 Herring Gulls move en masse inland. At noon the first well-fed birds start to return to their normal quarters in small flocks, causing one long line of echoes at the radar screen. This situation appeared so hazardous that the RNLAF had to initiate a re-routing of NATO linkroute 10A. Other feeding flights, also from roosts, are the well known Starling exoduses. Because of the synchronisation of their departure into waves they produce expanding ringlike echoes. During winter in Holland these rings sometimes can be followed up to 50 km. from the roost (fig. 7). In general non-migratory bird activity over land shows distinct peaks around sunrise and sunset. Ducks, waders and gulls often dominate echoes around these times.

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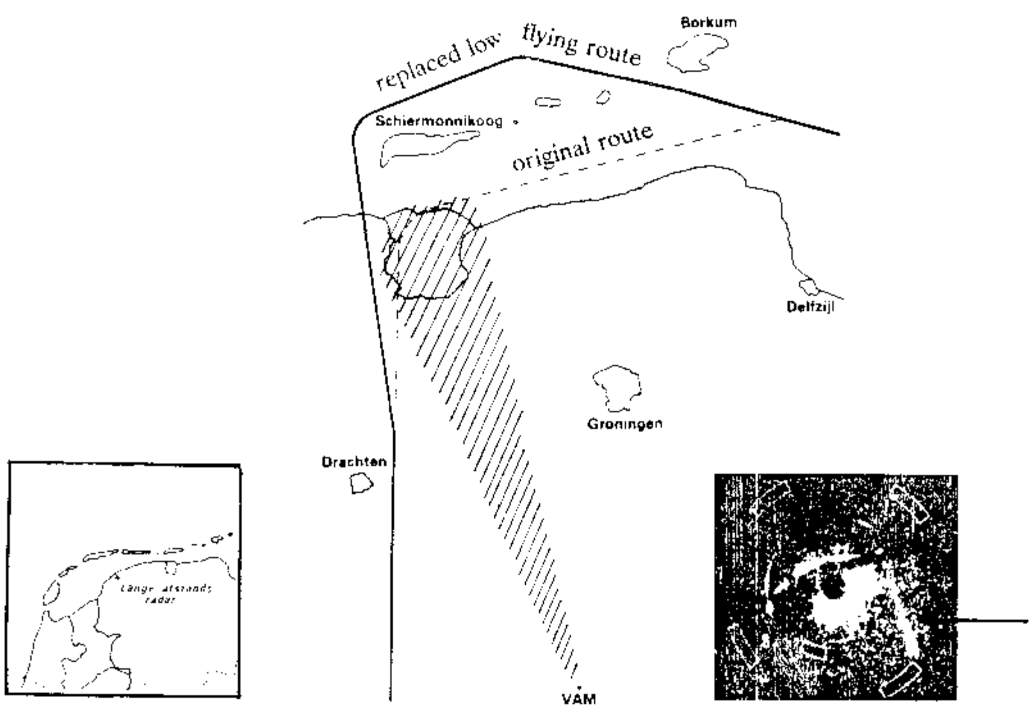

figure 6 Former (dashed) and new routing of NATO link route 10.4.
Insert left: map of the northern half of The Netherlands with location and bird range of the radar. Insert right: radar picture (single antenna rotation) with line of echoes from the giant garbage dump (VAM) towards the Waddensea.

Tidal movements In the coastal zone, and especially in the bird- rich Waddensea, tidal flights are very apparent and continue during the night. The birds act like commuters between the tidal flats and the high tide refugia along the borders of the Waddensea.

2.2.2. Migration

Global pattern and seasonal variation Migratory movements of birds occur wherever seasonal changes in climate lead to periodic food shortage. In the temperate regions this is usually the case during the winter period, while in the subtropic areas many birds are short of food during the period of draught; in the tropics food supply may be continuous. In any case migration is pronounced in the transitional phases between "rich" and "poor" seasons. The worldwide seasonality of migration depends on the different type of climates (fig 8 and 9). It is complicated by the historic and the irregular shape of the different climatic belts, and especially by the varying behaviour of different bird species. To reduce it down to a few lines is extremely difficult and (as simplifications are) always wrong to a certain extent. Thus figure 9 gives only a rough impression of the main times of migration in the different parts of the world.

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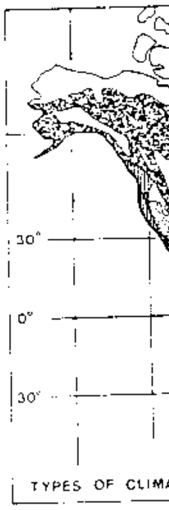
figure 7 Expanding ring echoes caused by starlings (Sturnus vulgaris) leaving their roost in successive waves.



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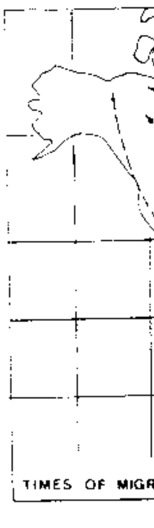

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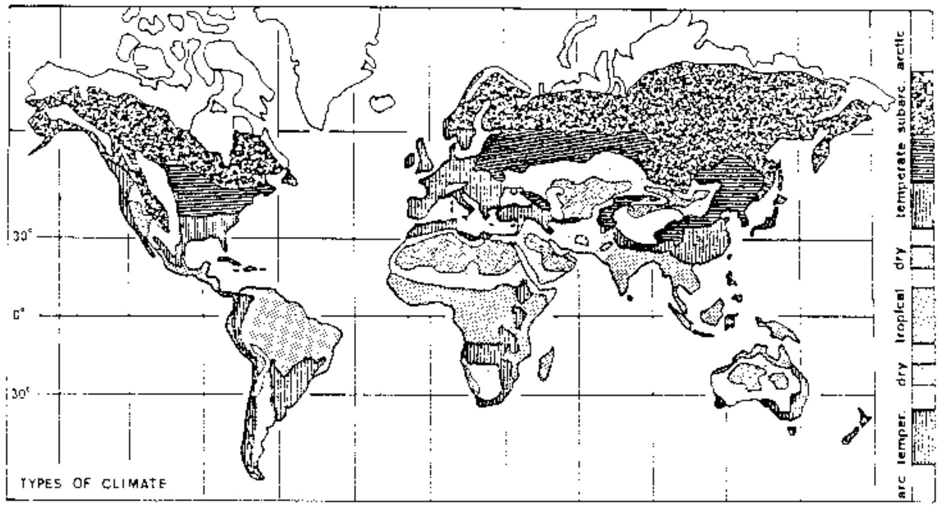


figure 8 Different climatic belts with seasonally changing food supply are the ultimate cause of bird migration.

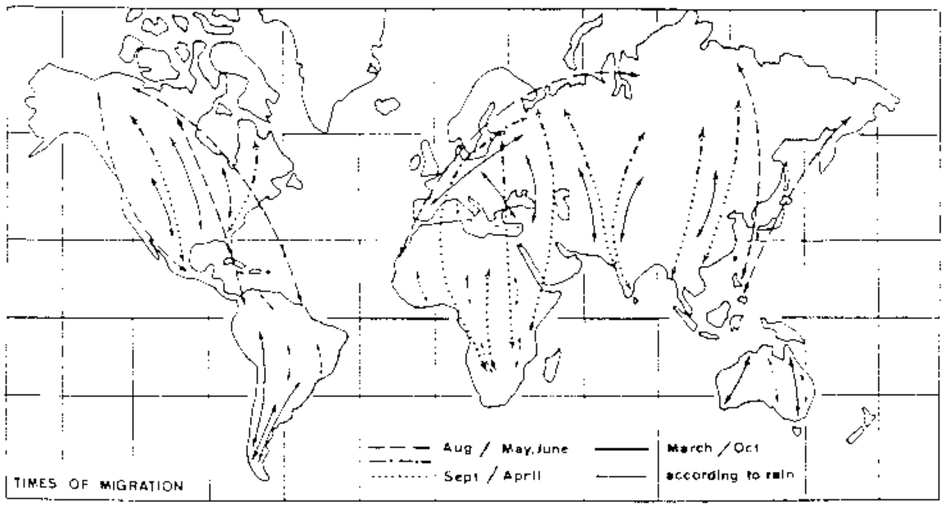


figure 9 The transitional phases between rich and poor seasons are the times of peak migration.

Diurnal cycle Short distance migrants are able to undertake their migratory flights within the course of their normal activity; most of their migration takes place in the first hours of daylight. Somewhat later in the day, when the warming effect of the sun causes thermals, large soaring birds enjoy their best time of migration. At the same time of day flocks of pigeons or rooks may be on the wing as well as swallows and martins, using suitable places for flight-hunting. During the afternoon migratory activity is reduced (figure 10). Most long distance migrants (except soaring birds and flight hunters) take off for their extended flights around dusk. The maximum intensity of night migration is usually reached towards midnight. Nocturnal migrants may continue their flight until dawn and even during the following day when at daybreak they find themselves over the ocean or other inhospitable areas. Diurnal migration usually consists of flocked birds (except birds of prey), while nocturnal migrants are more or less spaced: in passerines the nearest neighbour distances are usually larger than 50 m (figure 10).

Day to day variation and weather Migratory intensity varies day- to-day. In temperate regions this variation is mainly due to weather. Bad weather (precipitation, fog) suppresses the migratory activity of many species. If poor weather persists for several days, the number of birds physiologically ready for migration increases. A change to favourable waether may release waves of migrants. On the other hand, the number of birds ready to migrate declines when good conditions for migration persists during several days.
Peak migration usually occurs when a high-pressure area lies to the right and/or a low-pressure area to the left of the main vector of migration (figure 11). This synoptical situation is characterized by warm southerly winds in spring and by cold northerly winds in autumn. In statistical sense 50-70% of the variation in migratory intensity, as seen by radar, can be explained by correlation with combined weather factors.

2.2.3. The spatial distribution of migrants

Broad-front and concentrated bird movements Migration over areas without pronounced topographical features may consist of a flow of birds progressing on a broad-front. Its dimensions depend on the width of the breeding or assembling areas of the birds concerned. However, topographical features, such as coastlines, mountains or valleys deflect this stream to some extent and lead to local or regional concentrations. Strongest "leading-line- effects" occur by day in the lowest air layers (Buurma & Van Gasteren 1989). Because this is the part of the migratory process most easily detected by the field ornithologist there is a strong tendency to exaggerate the amount of clear routes in bird migration maps. A better approximation of the geographical shape of migratory flyways is presented in the colormap (pag 27).

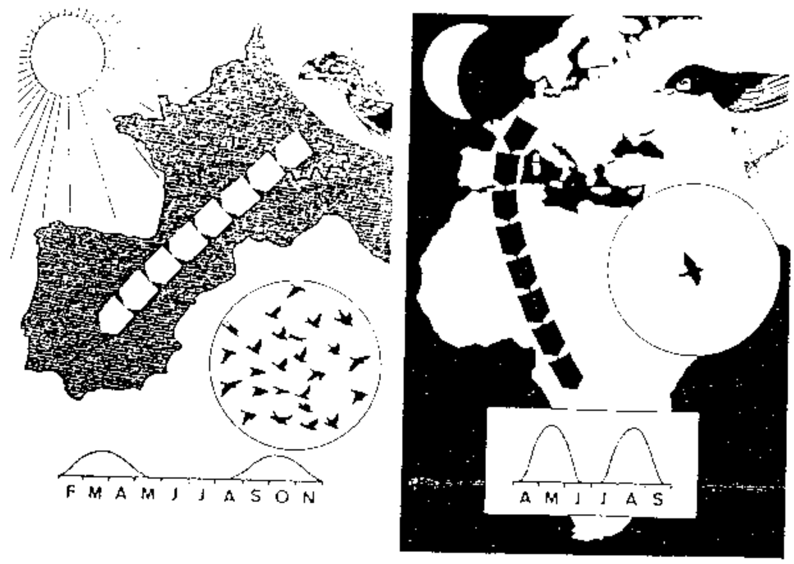
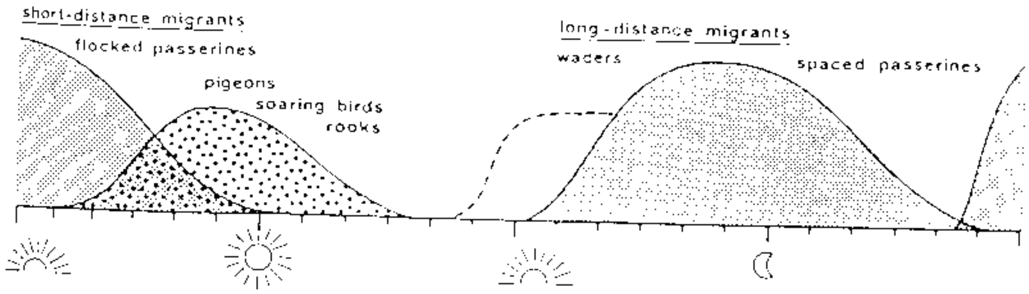


figure 10

Diurnal migration consists of: a) granivorous short-distance migrants (as finches, rooks, pigeons) migrating in flocks during the first hours of day-light, early in spring and late in autumn, b) soaring birds (as raptors and storks) migrating around noon, c) flight-hunters (as swallows, martins and swifts) and d) species perfoming long single flights like waders and geese.

Nocturnal migration consists of: a) insectivorous long-distance migrants (as warblers, flycatchers, some thrushes) migrating in loose formations or singly, late in spring and early in autumn, b) waders and most waterfowl, often already departing 1-2 hours before sunset in clear flocks that remain dense during the night.



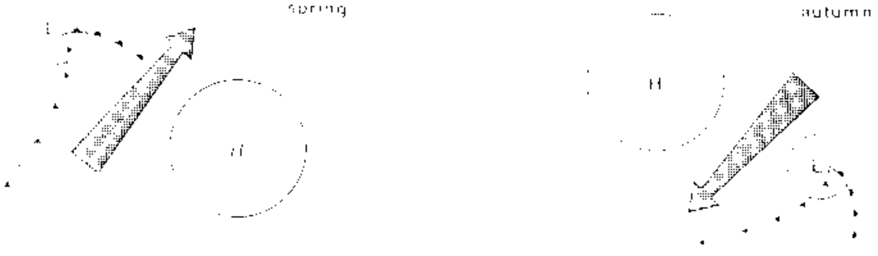
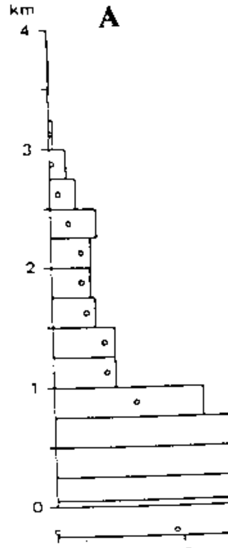


figure 11 Peak migration in relation to the simplified synoptical weather map.

The height of bird flights The overall average altitude distribution of migration above the European mainland shows highest concentrations of birds below 500 m. AGL. Above the Swiss lowlands this lowest flight level contains a mean percentage of about 60% of the day migrants and about 40% of the night migrants (fig. 12, Bruderer 1971). In eastern Holland, where the countryside is really flat, the proportion of extreem low level migration is even higher (fig. 13, Buurma, Lensink & Linnartz 1986). The birds concerned seem to seek for a compromise between flying low for contact with vegetation and conspecifics, and headwind avoidance, and rising for overview. Only about 10% of the birds fly at levels above 2000 m ASL. Highest flying birds are observed at altitudes of about 5000 m ASL. Above the Alps the upper limit of migration is slightly increased (5500 m ASL). Above the ocean, large deserts or very high mountains mean levels of migration are lifted up and highest migrants may be found at altitudes of 8000 m ASL (occasionally even higher).

In disturbed weather the altitude of migration decreases. Close to a pronounced frontal system, nearly all the birds may be concentrated within the lowest 500 m (fig. 14A). In fine weather flight levels are generally higher than in the overall mean distribution. Highest densities of birds may be found at levels up to 2500 m above flat country in central Europe. The height is primarily determined by the distribution of winds: during the first hours of the night birds seem to search for favourable flight levels. During the following part of the night they concentrate at altitudes with strongest tailwinds or weakest side- or headwinds.

The reason for the high proportion of october migrants migrating below 100 m over Holland (fig 13), and also over the northern parts of W. Germany, could be an adaptation to the frequently occurring head and side winds in that region. In flat and smooth countryside the drag of the air flow by the earth surface is less strong and more limited in height than in hilly countryside. Therefore, birds avoiding headwinds should fly extreem low. As a result, the "understream" of migrants is often badly detectable by radar.



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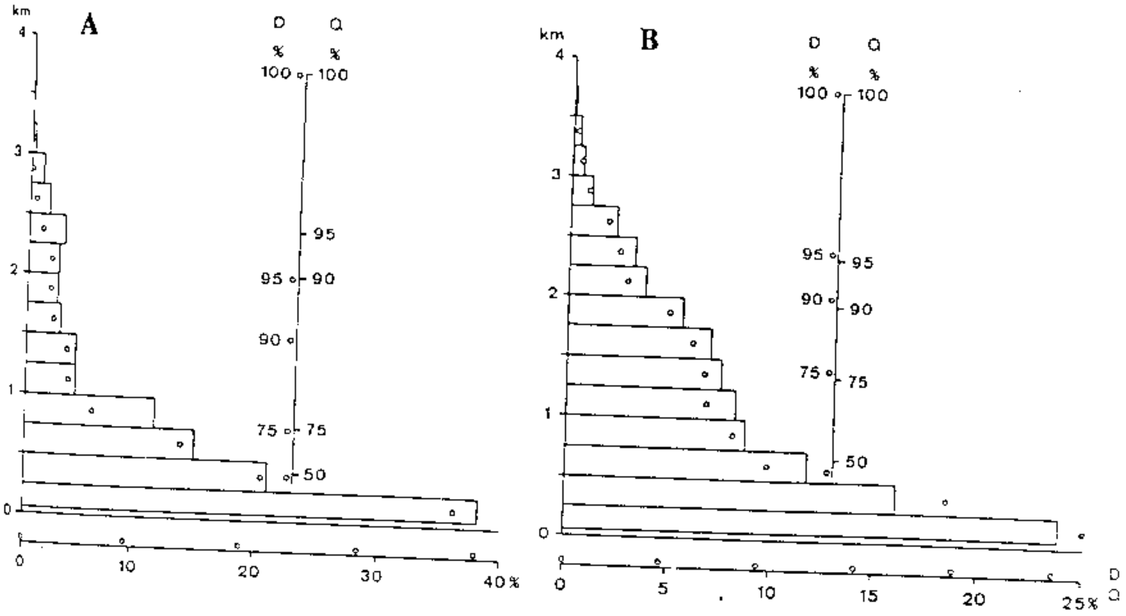

figure 12 Mean height distribution of migrating birds above the Swiss lowlands (A: by day, B: at night). D is the density of migration (birds per volume, indicated with circles), Q is the frequency or traffic rate (birds crossing a line per unit time, indicated with columns). Usually the frequency is higher than the density (as a result of the preference for tail winds, especially at high levels).

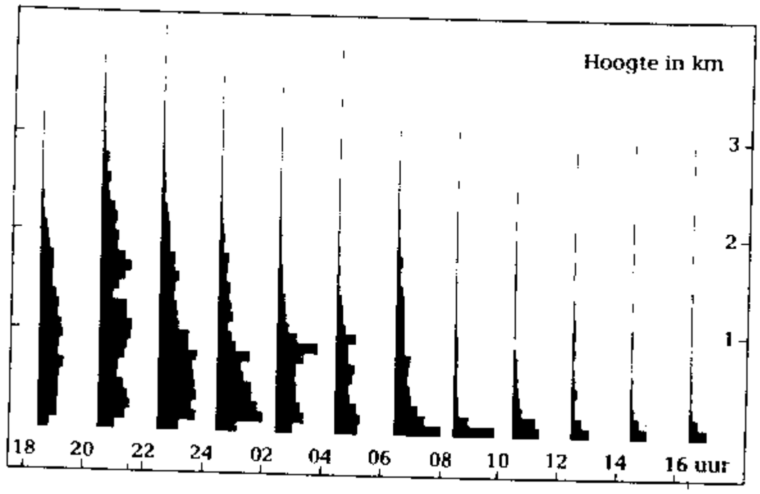

figure 13 Altitudes of bird echoes around the clock as detected by the pencil beam of an X-band Flycatcher radar scanning in a vertical plane perpendicular to the main migration stream over Eastern Holland. The samples were taken hourly from 9 till 18 oct 1985 and were averaged in two hour classes.

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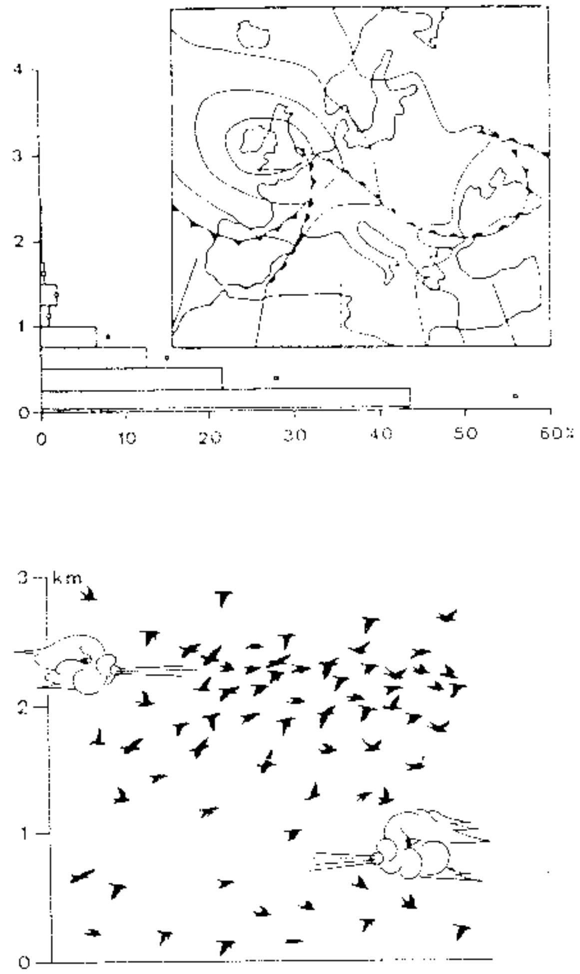

figure 14 A: migration at low levels in the neighbourhood of frontal systems. B: in fine weather birds search for the best tail wind and avoid strong head winds.

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2.3. Evaluation of bird strike risks

Aircraft speed is the major factor with respect to aircraft destruction during a bird strike. Further, the altitudinal distribution is the most important factor with respect to the chance to suffer a bird strike. The combined effect of these factors causes the evident dichotomy in fig. 15. Herein all Dutch military bird strikes have been sorted according to aircraft speed. We firstly recognize the group of bird strikes ocurring during start and landing. These low-speed flight phases constitute only a minor part of the total flying time, but the high number of local birds on the wing or scared from the ground causes a substantial amount of incidents. The opposite is true for the second group. While on average bird numbers at heigher flight levels are relatively low, the time that jet fighters spend on cruising there at high speeds constitutes the major part of the flight duration. As a result a similar amount of bird strikes was found. The relative lack of collisions at intermediate speeds mainly results from the flight envelope of the aircraft. According to fig 15 by far the highest proportion of damaging bird strikes occurs within the en route group. Low level training missions are therefore a major concern.

2.4. Reduction of bird strike risk

One may think of the following flight restrictions under bird- rich conditions:

a. no flying below a given altitude
b. flying elsewhere
c. reducing speed
d. measures near air bases

a. *Altitude restrictions* From the descriptions above it may be concluded that flight restrictions with respect to altitude should be considered first. It is however a difficult task to determine the right minimum flight level for aircraft. Depending on prevailing wind conditions the ceiling of bird activity may justify minimum flight levels of 1000, 2000, 3000 or 4000 ft, as often imposed by the German Air Force. However, this should be based on correct altitude measurements by means of radar. Such measurements are seldom performed, usually only within special ornithological studies. Operational use occurs, as far as we know, only very incidentally. As will be seen in the next chapters several suggestions for specially built radar-bird- detectors have been published.

Several West European countries not having the appropriate radars or the knowledge and/or procedures for joint use of operational equipment, confine themselves with disseminating bird warnings without altitudinal information. Usually a flight restriction of 2000 ft minimum flying height is imposed but this reduces drastically, if not completely, the value of low level training.

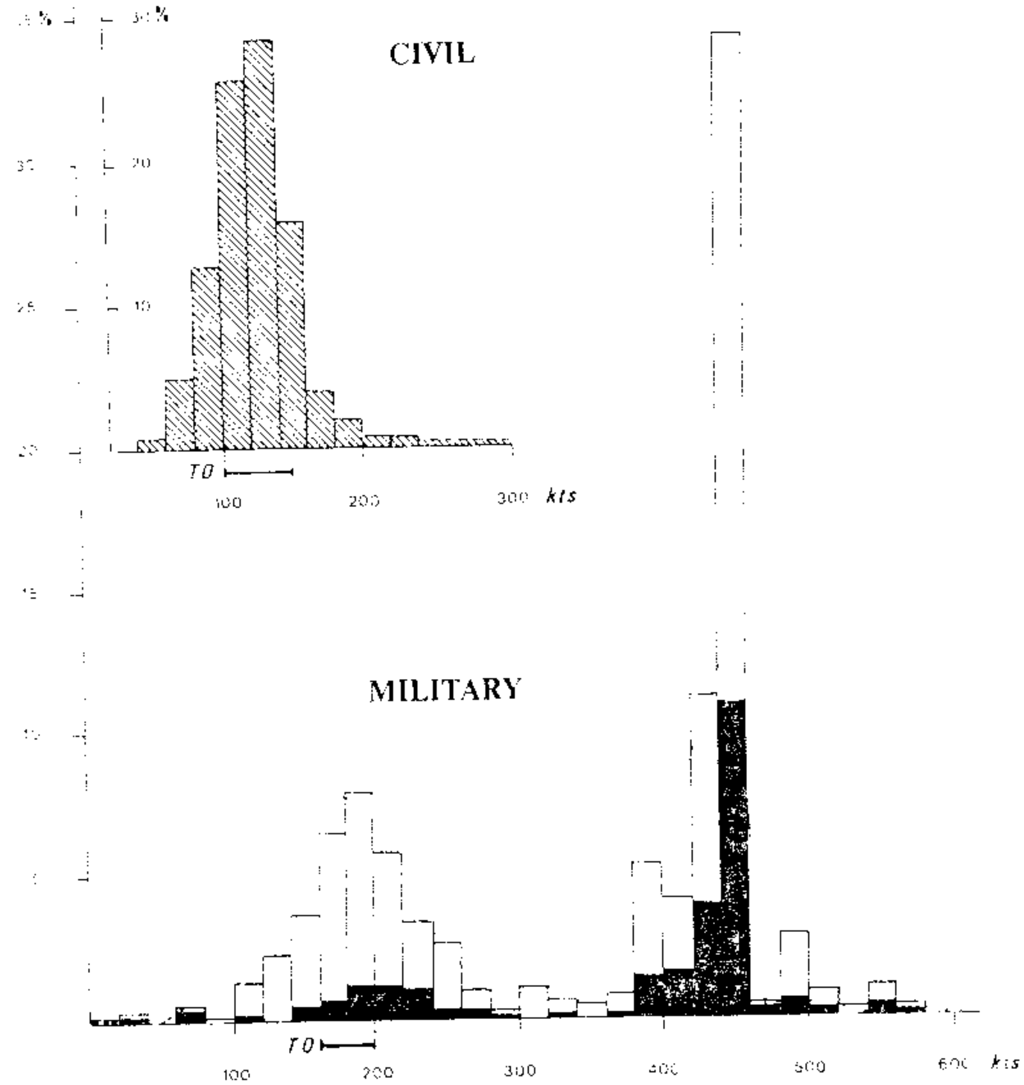

figure 15 Percentual distribution of RNLAF bird strikes over aircraft speeds (1977-1982). White parts of columns without damage, black parts with damage, total 100%. Percentual distribution of civil bird strikes taken from Thorpe 1983.

b. *Geographical flight restrictions* High level bird migration therefore may urge to reschedule flight plans. A shift towards completely other low flying areas may be a solution for large countries. The USAF operates a model helping to select the safest low flying routes and areas. However, in Europe alternatives are not available to the same extent. Germany disseminates listings of bird densities per "georef". This format has recently been adopted by NATO members.

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c. *Speed restrictions* This third option may help in two ways. First, it drastically reduces impact forces. Second, it gives the birds a better chance for succesfull evasive manouvres. One should keep in mind that a collision at 320 kts with a 4-pound bird equals a collision at 450 kts with a bird of 2 pounds. Birds over 2 pounds are 50 times more numerous than those weighing 4 pounds or more. Thus, lowering the speed by 100 kts in this example lowers the damage treshold by 50 times, all else being equal.

d. *Measures near air bases* As shown by the insert of figure 15 civil bird strikes vs aircraft speed resembles the distribution of local military ones. Both sets of data show a grouping around take-off speed, indicating the effect of the high bird densities in the lowest air layer and on the airfields. Bird strike prevention in the sense of air traffic control should in this case concentrate upon the horizontal distribution of birds at and nearby airfields, not so much on altitudes. Already 25 years ago Schaefer (1969) explained that ground radars should be used to detect birds, even when sitting on runways. Recently the possibilities for joint use of this type of equipment have increased and some firms even advertise the potential.

Prevention of bird strikes "en route", such as implemented in military low level operations with jet fighters, is also an option for "small air traffic" including sport flying and helicopter operations. Here one should try to profit from existing military bird warnings. Also low flights over bird sanctuaries and bird concentration areas mapped in the Aeronautical Information Publications should be avoided.

In summary The chance of suffering a bird strike will never be zero as long as man continues to fly. When the number of birds in the air would always and everywhere be the same, even no reduction would be attainable at all by means of avoidance plans. Fortunately, however, the presence of flying birds fluctuates to a very large extent. This makes avoidance of bird-dense parts of the air space and periods of intense bird traffic a realistic option. Consequently, the aim should be to optimize the balance between a maximum of flight safety and a minimum of flight restrictions. The more precise the presence of birds in the air can be measured, the more detailed restrictions can be disseminated, and, as a result, the smaller the impacts on operations will be. This emphasizes the need to choose appropiate detection equipment, such as certain radars, and, simultaneously, to organize an optimal "ad hoc" use of the information gathered. When such radarmeasurements are also stored and analysed, general trends and correlations will be found which might be used as parameters in a model to predict bird movements. An operational forecast system would facilitate early adaptations of flight programming. However, predictions by definition introduce uncertainties; it seems unrealistic that a forecast model at the moment would make "ad hoc" registrations superfluous. The ideal situation therefore seems to be a combination of both.

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3. GENERAL ASPECTS OF BIRD DETECTION BY RADAR

3.1. Introduction to some radar principles

Radar stands for RAdio Detection And Ranging. The equipment radiates electromagnetic waves, usually formed into pulses (packages of radio energy). By alternating pulse transmission with receiving echo returns the radar is able to range objects. Distances are calculated by using pulse return time and wave propagation speed (constant 3*10 m/sec). The bursts of microwaves are funneled into a beam, enabling the radar to measure angles. The shape of the beam depends upon the shape of the radar's antenna. Finally, certain properties of the echoes offer clues to their identification.

The range at which an object of certain size can be detected is calculated by means of the radar formula and depends on many variables and circumstances. For birds this distance may vary from a few hundred meters in small ship radars up to over 150 km in case of long range surveillance radars.

Scanning the beam through the airspace opens the possibility to build up a two or three dimensional picture of the distribution of those objects reflecting enough energy. Beam shape and scanning procedure determine how we monitor the air space. In the well-known ATC (air traffic control) radars (see cover), which rotate their beam in the horizontal plane, echoes are represented on a PPI (Plan Position Indicator). This circular monitor often includes the projection of a simple geographical reference map. Mixing map and radar video facilitates the interpretation of the live display. After having stored the radar information time- lapse on film or electronically we may get an excellent time- compressed summary of bird movement.

ATC radars have beams wide in the vertical and very narrow in the horizontal plane (fan-beams). They offer a high resolution in geographical sense, but exclude the discrimination of altitudes. Nodding height finders use the vertical type of two-dimensional scanning (cf fig. 16). A third possibility is the so-called pencil beam. Such narrow beams offer high-resolution but a large amount of scanning time is needed in order to build up a three- dimensional picture. The most simple application of pencil beams described in this booklet is mere ranging: when fixed vertically it can be used to assess the altitude distribution of birds in airspace. Its most complicated use is as a tracking beam, fixating a target during its flight and describing its three dimensional flight path.

The radar types most frequently used as bird detectors are pulse radars, which usually are classified in three or four families, according to frequency band (and therefore wavelength): table 1. They usually represent classes of equipment differing in power, size, range and resolution.

A

band	L	S	(C)	X
wave length (cm)	23	10	(5)	3
frequency (MHz)	390 - 1550	1550 - 5200		5200 - 10900
radar types	* air traffic control	* air traffic control * airport surveill. navigation		* precision approach * tracking * ship

B

wave length	N/D	counting range nM	subsaturation density (/nM2)	min.det. height ft	source
23 cm	N	20-30	0.4-1.0	600	Nisbet 1963
	D	15-25	1-2	?	Geil et al 1974
10 cm	N	30-40	ca 35	300	Buurma 1986
	D	30-40	ca 10	300	id
	N	10-20	20-25	var	Gauthreaux 1977
	D	10-20	6-8	var	id
3 cm	N	1-2	250	75	Buurma &
	D	1-2	150	75	Van Gasteren 1989

table 1 A: The old-fashion classification of radars according to wavelength. B: Diurnal (D) and nocturnal (N) "subsaturation" densities of bird echoes on the PPI of search radars and minimum detection height. Ornithologists watching over the shoulder of the radar operator might find this bird resolution in the raw video of older radars. The synthetic video of many modern radars will produce fewer bird echoes while raw video often is not available anymore. These partical experiences do not reflect theoretical possibilities which may be exploited by modern electronic (bird) echo extraction.

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Instead of simply using the echo returns, pulse doppler radars also measure the frequency modulation caused by the speed of the targets relative to the radar (radial velocity). This provides the possibility to separate moving targets from stationary objects, even though the echoes of the moving targets are very weak compared to the clutter. Radar detection of low flying birds within an obstacle rich environment is only possible when the Doppler effect is exploited. But certain limitations with respect to targets with very low speeds (song birds!), as well as the fact that only radial velocity is the selection criterion, have both serious draw-backs.

The Doppler effect is also the basis of Continuous Wave (CW) radars. Instead of rapidly switching between transmitting strong pulses and receiving weak echoes CW radars "speak" and "listen" simultaneously. In its simplest form they "hear" speeds of moving targets but do not measure distances. By applying FM and other principles CW radars can also range objects. However, multiple target detection is done easiest with pulsed radars.

3.2. Detection chance and the quantification of bird echo densities

3.2.1. The radarformula and maximum range

The maximum distance at which an object is detectable can be derived by using the radar formula:

$$R_{max} = \sqrt[4]{\frac{P\,G^2\lambda^2\sigma}{64\,\pi^3 P_{min}}}$$

Maximum range (R max) is positively correlated with transmitter power (P) and antenna gain (G, the multiplier factor due to concentration of microwave energy by the antenna; G is squared because both transmitted and received energy is concentrated), the wavelength (λ- lambda) and the echoing area (σ - sigma -, also called radar cross section) of the target. The maximum range is negatively correlated with the minimum receiver power (Pmin) required to produce a detectable signal. P, as effective power, includes the Pulse Repetition Frequency (PRF). When this PRF is chosen high, the interval time between two pulses is short. This short interval limits the maximum distance at which a target can be detected, but will never limit the maximum distance of small targets like birds. In practice we need the effective range of the radar for birds instead of the theoretical maximum range.

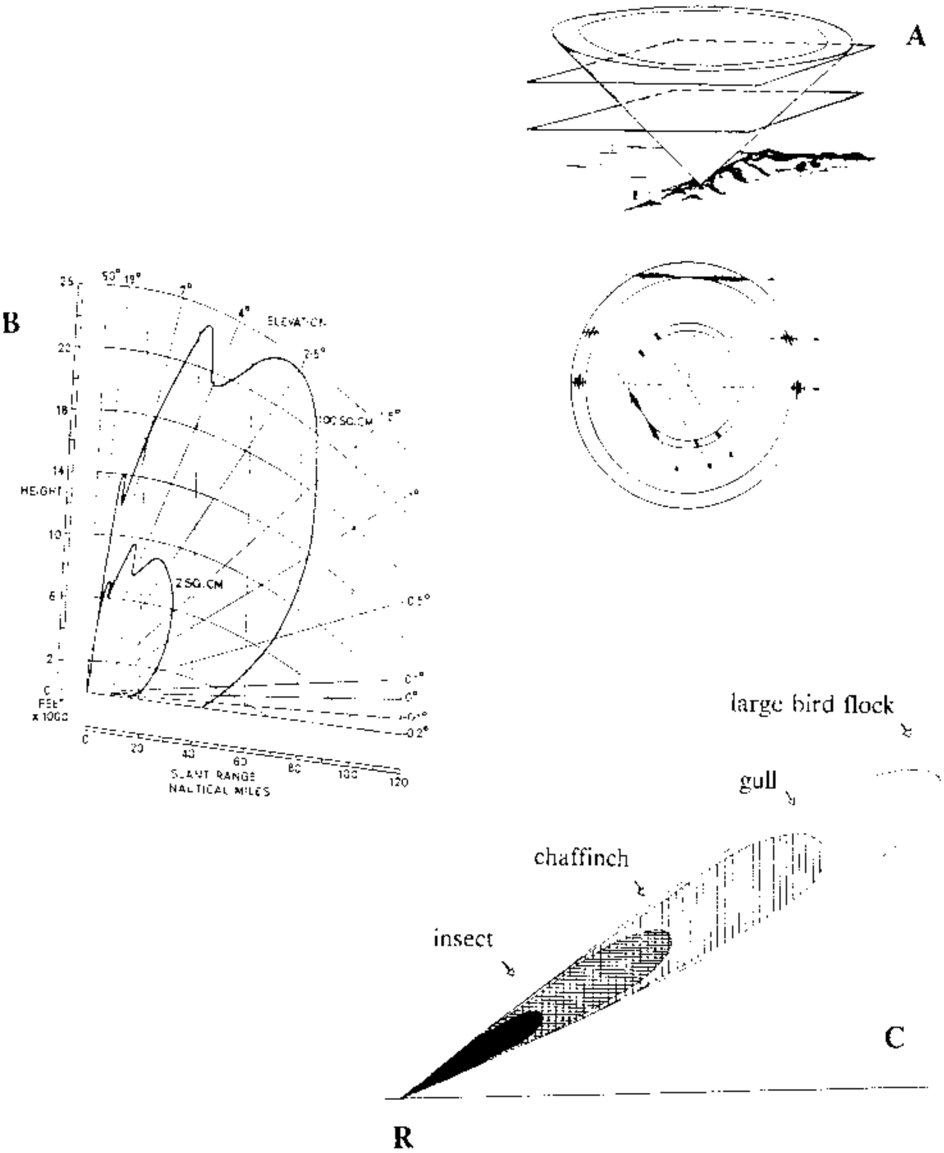

figure 16
A: conical scan of a pencil beam (upper part) and two horizontal sections (lower part) providing ringlike detection.
B: Radar performance diagram (after Eastwood 1967).
C: Relative bird ranges of a pencil beam.

figure 17

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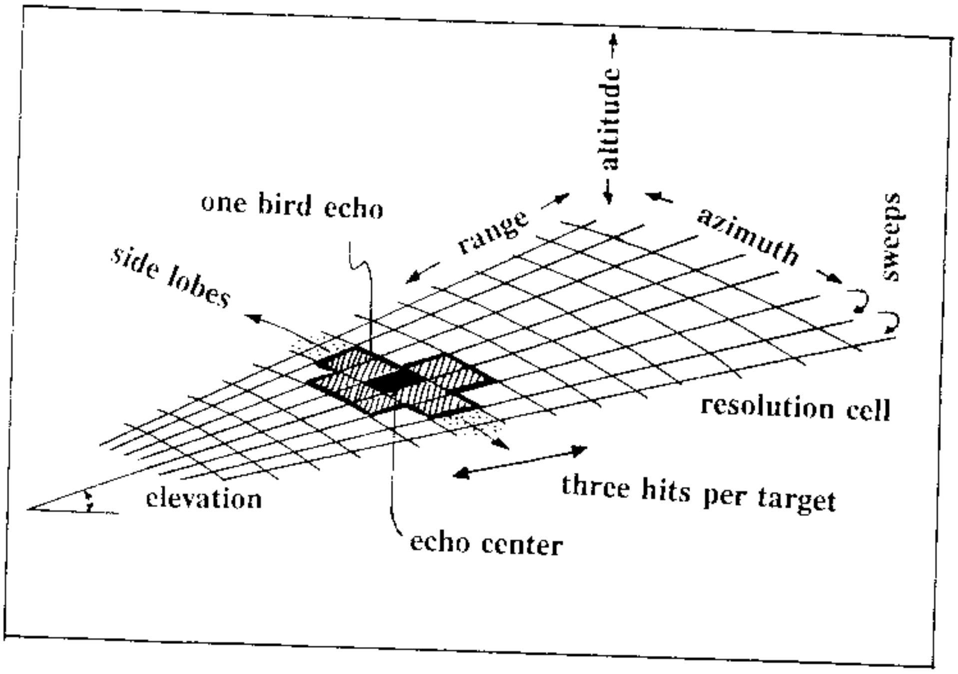

figure 17 Terms for the description of resolution and echo properties.

The pulse power of the radar, the echoing area of the target and the spreading of the electro-magnetic energy are the crucial factors limiting range. The strength of the returning echo decreases with the 4th power of the distance radar target. In other words: to double range we need a radar with 16 times more power. But also: accepting a little bit less range means a lot less power required. And if one bird has a radar cross section which is half of another's, it can be detected up to 84 % of their maximum detection range.

3.2.2. Range and resolution

Usually radars work at such large scale that they enable us neither to count birds within groups nor to recognize the shape of the flock. Even the density of flocks may be obscured when the screen of an air traffic control radar is saturated with bird echoes. The smallest volume of air that can be meaningfully measured with a radar is called "resolution cell" (fig. 17). The resolution of a pulse radar depends theoretically on pulse length and beam shape. These values are not chosen independently, and of course relate to the type of application of the radar.

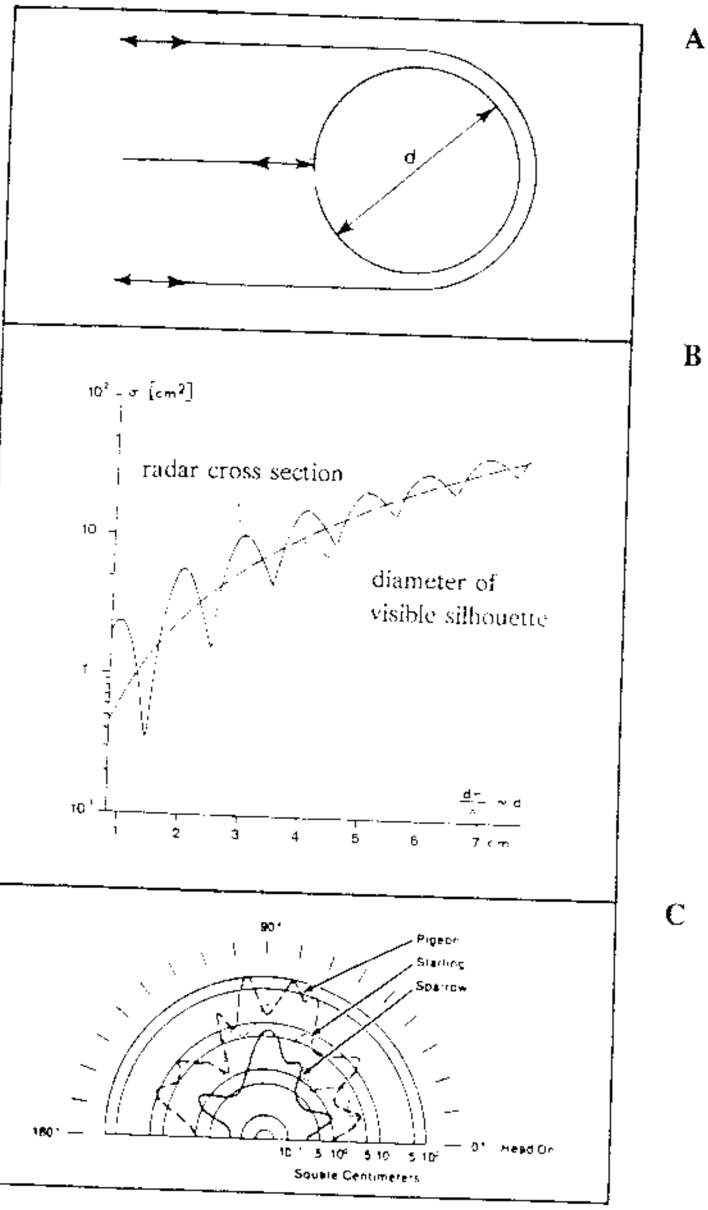

figure 18 A: Extreme simplified model to describe the relation between fluctuations in echo strength and wingbeat pattern. Directly reflected energy is supposed to interfere with energy curving around the target. Different path lengths of both energy components result in phase shifts. Because the circumference of the bird fluctuates with wing muscle contractions also the path length does so, causing the phase shift to vary.

B: Radar cross-section (σ) of targets depending on the ratio circumference - wavelength (λ). For 3 cm radars this ratio corresspnds roughly with the bird diameter in cm. As a result of the interference bird diameter and amount of reflected radar energy are by far not linear related. When the circumference of the target is a full number of wavelengths, then the echyo is strong. When the circumference is a half wavelenght shorter or longer the echo is weak. In larger targets the silhouette for radar waves and visible light shows closer correspondence.

C: Radar cross-section polar diagrams of three bird species. Observing wavelength is 3.5 cm. Linear polarization parallel with the body axis. Approximate target weights: pigeon (Columba livia) 300 g; starling (Sturnus vulgaris) 80 g; house sparrow (Passer domesticus) 27 g (from Edward & Houghton 1955).

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As can be seen in the radar formula, a long detection range can be realised easiest with long wavelength. But long waves are more difficult to funnel into a narrow beam and necessitate large antennas. Moreover, the greater the distance to cover, the slower the beam should scan. If the pulse has to travel a long distance (low pulse repetition frequency), then apart from the divergence of the beam, the increment of scan also reduce angular resolution. High resolution in range is difficult to achieve in combination with large scale operation. An extra difficulty is that a high amount of energy necessary for long distance ranging is difficult to squeeze into a very short pulse. Nevertheless, several modern (military) search radars have been equipped with pulse compress modes reducing pulse length by a factor 60, thereby enlarging range resolution.

3.2.3. radar cross section

The radar cross section is defined as "the (fictional) shadowing area of the target intercepting that amount of power which, when scattered in all directions, produces an echo equal to that of the target. The electromagnetic waves are reflected by objects having different electric and magnetic properties than the surrounding medium. The water in blood and muscles of the bird body are most reflective while bones and feathers seem to contribute only little to the echo.

The average intensity of a bird echo roughly equals the echo of a sphere of water with the same weight as that of the bird. This echo strength is half of that of a metal sphere of the same size, which offers a possibility of calibrating the radar equipment.
In the case of big targets (compared to the wave length of the radar) the reflected energy is more or less proportional to the shadowing area of the target; the known optical principles are valid. When target size is in the same order of magnitude as the wave length the echo strength does not correlate in a simple way with target surface.

Figure 18A gives a model explaining the interference of electromagnetic energy partially curving around and partially reflected directly by the sphere with a circumpherence in the same order of magnitude as the wavelength. The two energy components, travelling different distances become out of phase. The resulting echo strength may vary up to a factor 16 when the circumference of target and wavelength are more or less the same and the circumference varies by half of the wave length. Figure 18B indicates how the ratio of both results in varying radar cross sections (cm2).

Clearly a bird's body is a more complicated target than a sphere. A spheroid or a "cigar like" body may be slightly better approximation. In the case of the "spheroid-bird" the echoing area is larger in side view than in head-on or tail-on view. As explained above small differences in silhouette size may result in larger differences in echoing areas. A graphical representation of these echoing areas as "seen" under all angles with the bird's body axis is called a "polar diagram". Fig 18C gives an example. It shows

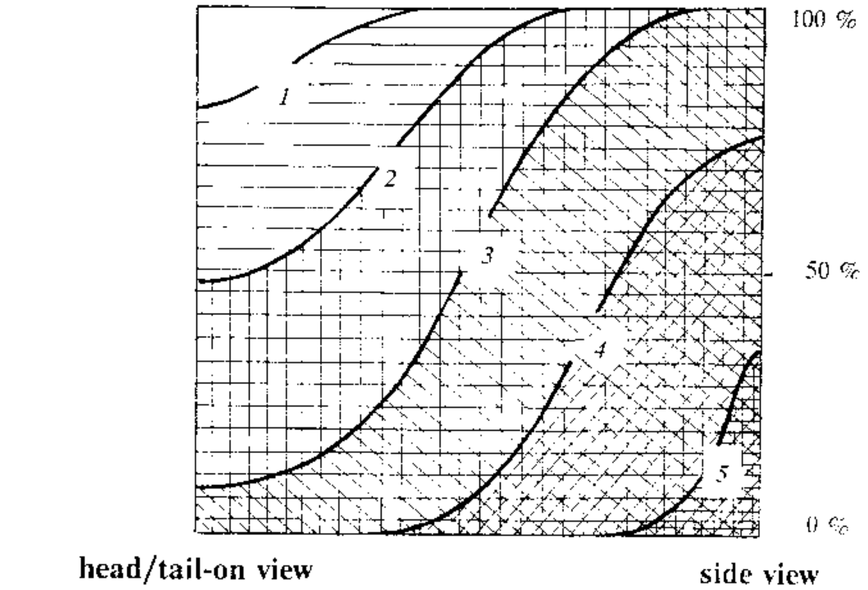

figure 19 Echo density during broad front migration at night at the PPI of a 3 cm search radar in relation to distance (1 nearby - 5 far away) and aspect (birds seen in head/tail on view - side view). Maximum density taken as 100 %.

enormous fluctuations and may give the impression that dealing quantitatively with detection probabilities is very complicated. We cannot deny this, indeed, but when processing a radar picture with hundreds or thousands of bird echoes an average bird size is taken into account. Small individual differences in size, wingbeat phase and flight direction smooth the average polar diagram of the whole cohort. As a result we will find a smooth curve representing the head/tail view - side view ratio of detection chance in statistical terms (figure 19, derived from Buurma & Van Gasteren 1989). We can use such empirical curves to correct our measurents. It is clear that we need information on the heading of the birds in relation to the angle at which we see them within the sampling window on the radar screen.

Contractions of the flight muscles influence the diameter of the bird body. This results in remarkably strong variation of received echo strength. When a tracking radar follows a single bird, its Automatic Gain Control (AGC) compensates for these fluctuations in order to get a constant signal. When we record these AGC power variations we get valuable information on the wing beat pattern (see 4.5).

3.2.4. Radar horizon

In order to detect an object above the horizon at a distance of 50 km it must be 100 m above the surface. At 100 km an object must have a height of 300 m! Loss of visibility behind the horizon does not increase linearly. Radar waves normally slightly curve behind the visual horizon but radar detection at long distances is anyway limited in the same manner as visual observation. The height/range relation is therefore graphically incorporated in the conventional Vertical Performance Diagram.

In the fictitious example of figure 20 we included the bird range of the three classes of pulse radars of table 1. Inability to detect low-flying targets behind the radar horizon is a problem, especially of long range radars. Because these radars also have the largest bird detection range, they miss many birds. Moreover, if the lowest air layers contain most flying activity, as is usually the case in the European low lands, the bird density on

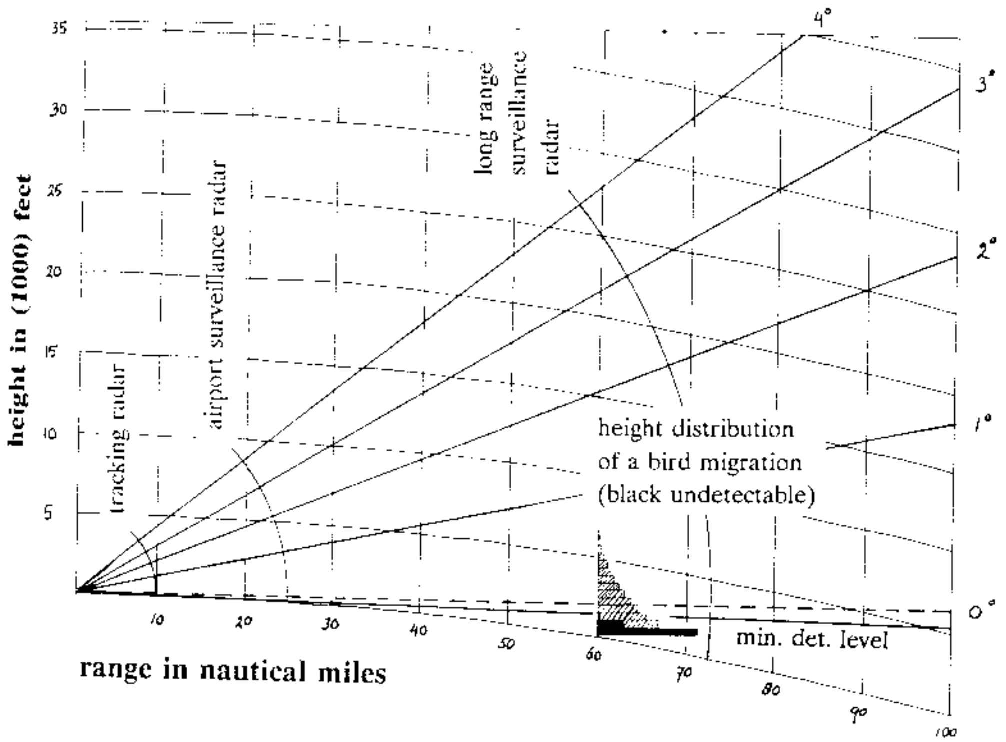

figure 20 Vertical coverage in relation to distance for three important classes of search radars depending on the width and elevation of the radarbeam.

a PPI of long range surveillance radars soon diminishes to very low values when going from center to periphery. Because at short distance echoes of objects on the ground saturate the radar display, the effective region for proper bird detection becomes very limited. Low level bird migration (say below 50 or 100 m) may be totally "overlooked", and therefore radar is usually described as complementary to the visual bird observer who will start to miss small birds at 50 m, even when they pass overhead.
As a result of the horizon effect, the thinning rate of bird echo density with range in long range radars often is not primarily caused by the decrease of sensitivity but rather by the altitudinal distribution of the birds. Therefore, samples of the bird flying activity taken by long range radars are always biased with respect to height. Provided the radar beam propagates along straight lines we can turn this in our advantage by calculating the intersected portion of the air space at several distances. Comparing the bird echo densities offers a indication of the altitudinal distribution of birds. Calibration of such indices by means of small radars and/or visual observers is needed.

A special problem with respect to 3-D measurements by means of radar is the so-called anomalous propagation (fig.21). The radar beam may be reflected against or funneled by discontinuities in air density, such as inversion layers. As a result the radar looks behind the radar horizon and the PPI is spoilt with extended fields of groundclutter. This may totally disturb an index of bird migration intensity because many more bird echoes may be received, provided they can be separated from the ground clutter. The solution to this problem is to check always whether the clutter pattern is normal and, if not, to cease measuring. Fortunately, the frequency of "anaprop" is not prohibitive. Furthermore, the phenomenon is predictable to a certain extent and is usually easy to recognize.

3.2.5. Polarization, STC, FTC and other circuits

So far, we dealt with physical effects in (bird) detection by an unfiltered radar signal. This unfiltered signal is not always sufficiently clear for operational use. Often the amount of unwanted echoes, including "bird clutter", can be so predominant that aircraft detection and tracking becomes impossible. Therefore, several techniques and filter processes have been developed to suppress unwanted echoes. We have to know their influence upon bird detection chance, especially when the radar is simultaneously being used for other purposes. The most important techniques are discussed below.

Polarization: Electromagnetic radiation is normally polarized in either the horizontal or the vertical plane. Both are said to be linearly polarized. Often radars can also be switched to circular polarization. The effect is a reduction of the reflectivity of sphere-like bodies, such as rain drops. Small birds being more or less spherical water bodies will give weaker echoes too. The reduction of recorded bird echoes is said to vary between 11 to 54 %, depending on radar and range. Small song birds are more affected by circular polarization than bigger birds. Dutch electronic counting results were corrected with a factor 1.6. Vertical and horizontal polarization also differ slightly : the chance of bird detection being somewhat better in case of horizontal polarization (1/2 unit in 0-8 scale).

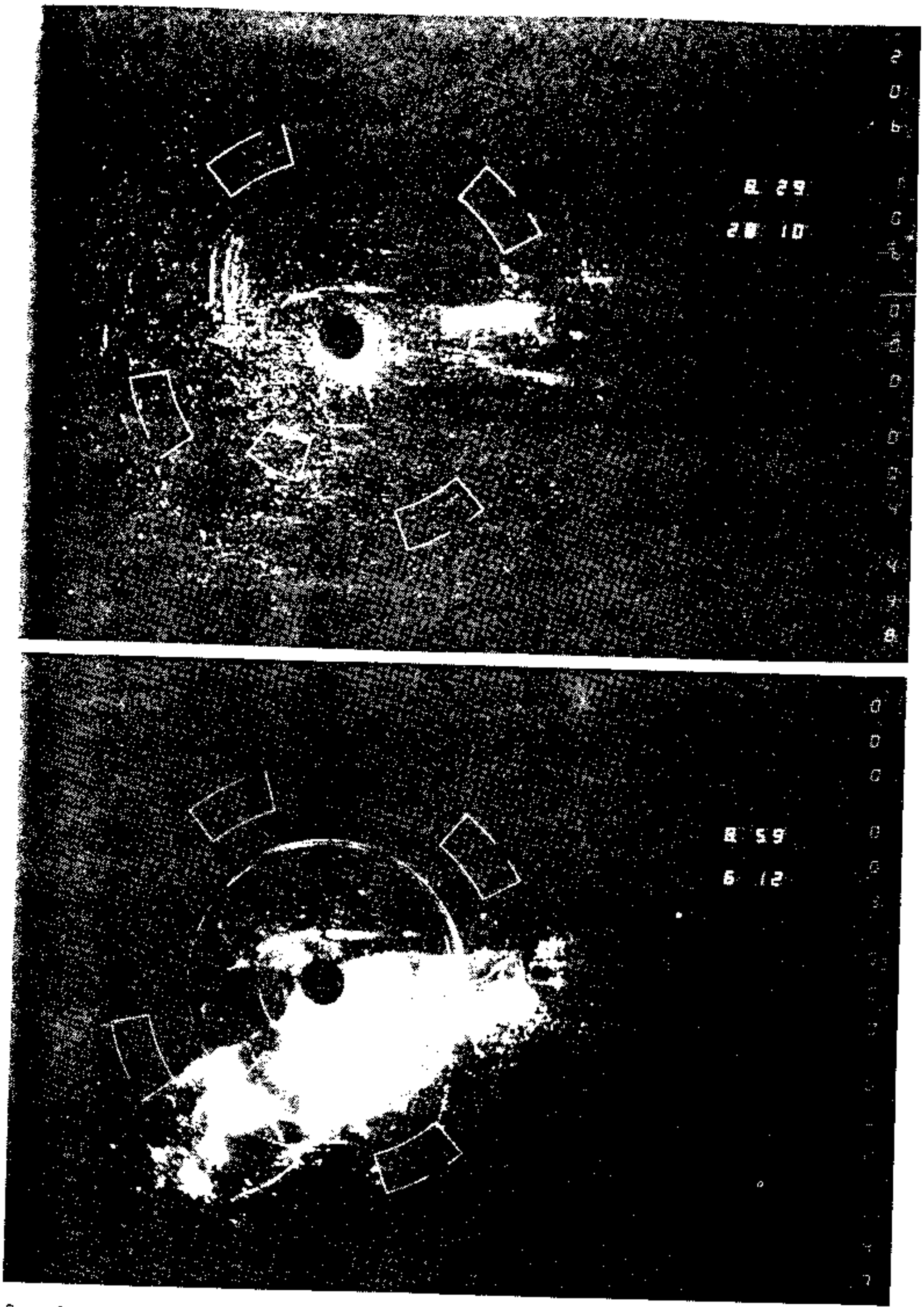

figure 21 Time exposure photos of the PPI of the S-band radar in the NW of The Netherlands (one antenna rotation, range set at 73 nM). A: Most echoes from birds. B: Massive groundclutter indicates the distribution of land (saturated with echoes) and sea (no echoes). Echoes of object on the ground were created due to energy ducted along the earth surface (anomalous propagation). Ring echoes are side lobe echoes of very strong ground echoes. The five sectors are electronic counting areas (KIEVIT system, see 5.1.). Time, date and echo counts in LED displays (right).

receiver type and noise figure: Usually video voltages within the receiver are directly proportional to the echo signal amplitudes (linear receivers). But sometimes a logarithmic or other specialized type of receiver may transform the received signals. The presented echo intensity variation should be interpreted accordingly.

Sensitivity Time Control (STC): Close to the radar, aircraft guidance may become impossible because their echoes are hidden through mass occurrence of echoes from undesired targets such as birds. STC circuitry counteracts this by reducing the gain of the IF amplifier by an amount inversely related to range. As a result the number of bird echoes may be markedly reduced, in large search radars up to distances of 20 - 30 nM. STC circuits can and should be switched off in order to detect birds.

Fast Time Constant (FTC): In contrast to aircraft and birds, large targets, such as rain showers, produce echoes of much longer duration than that of a single pulse. FTC circuitry starts to suppress such echo returns after a given amount of time. As a result only the leading edge of showers appear on the radar screen, while point echoes should remain in tact. However, bird echo's can also disappear, especially in radars with low resolution and when bird echoes occur in high densities. Preferably, FTC should be switched off. Comparable to FTC but more complex are so-called Pulse Length Discriminators (PLD's). Depending on their characteristics they may reduce the number of bird echoes according to their length in range. PLD filters may also select echoes smaller than a certain size, as was the case with an adjustable PLD in the electronic counting device KIEVIT.

Instantaneous Automatic Gain Control (IAGC) and Constant False Alarm Rate (CFAR): The gain of the IF amplifier can at any instant be related inversely to the average power received during several pulse durations prior to that instant. As a result large areas of clutter are suppressed while point echo's should remain largerly unaffected. This is what IAGC and the more sophisticated CFAR circuits do. As was the case with FTC and PLD, again high densities of bird echoes may become suppressed and therefore application of these circuits should be avoided.

3.2.6. Moving Target Indicators

Elimination of stationary targets (ground clutter) is one of the most obvious needs in radar design and under many circumstances crucial to the detection of birds. Radar detection of birds in mountainous regions is virtually impossible without special circuitry. But even in flat country, echoes from objects on the ground can cause clutter up to ca. 25 nM under normal conditions when the lower side of the radar beam is directed to the horizon. This implies that low and medium powered radars with maximum bird ranges of less than 25 nM can only resolve low flying birds when equipped with Moving Target Indicator (MTI).

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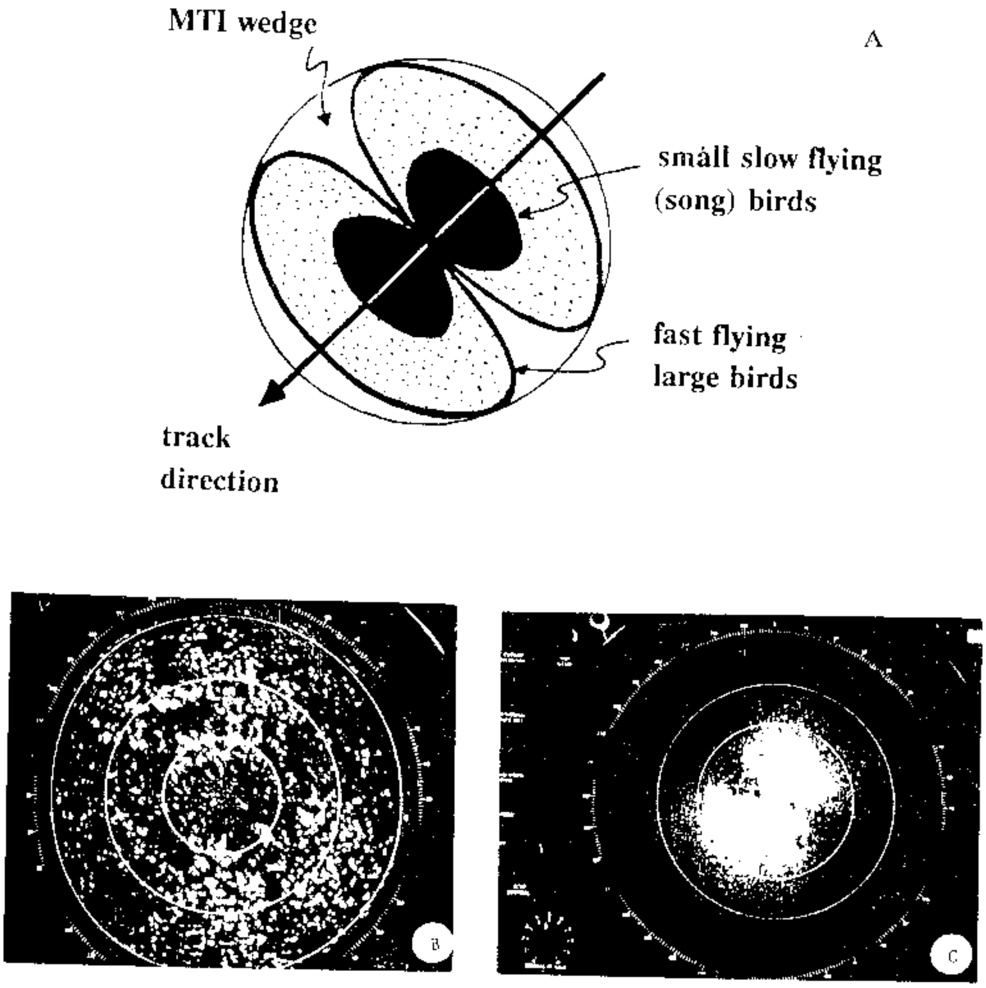
figure 22 The undetectability of birds flying more or less perpendicular to the radar beam when using MTI (moving target indecator circuitry). A: a sketch of the so-called MTI-wedges, B: a weak MTI effect during the day when bird migrate in flocks and produce strong dot echoes. Direction of movement according to the MTI wedges is SSW-ward. C: more clear MTI effect in the mass of weak echoes of nocturnal migrants flying singly to the SSW. Both photos taken from Gauthreaux 1980.



MTI's extract Doppler frequency shifted echoes by means of one or more delay-line cancelers, with or without positive feedback. The delay-line canceler acts as a filter to eliminate the DC component of fixed targets and to pass the AC components of moving targets. The video portion of the receiver is divided into two channels. One is a normal video channel. In the other the video signal experiences a time delay equal to one pulse repetition period. The output from the two channels are subtracted from one another. The fixed targets with unchanging amplitudes from pulse to pulse are canceled on subtraction. However, the amplitudes of the moving target echoes are not constant from pulse to pulse and subtraction results in an uncanceled residue. Nowadays spectral techniques are replacing the described delay-line cancelers. For a description of the priciples and many types of MTI's see the radar text books.

The diversity of MTI's results in very different rates of suppression of bird echoes. The most obvious effect is the cancellation of birds observed perpendicular to their flight path, where they move at radial velocity zero. During broad front migration this results in so-called MTI-wedges, sectors without bird echoes at the PPI (fig. 22). The azimuthal size of these bird echo free sectors differs depending on a) power output and sensitivity of the radar, b) the shape of the "velocity response curve" of each particular MTI, c) the range d) the size distribution of bird targets and e) their ground speeds. Another very unlucky aspect of MTI's is their limited dynamic range. The range of signal amplitudes which an MTI canceler can process is not as wide as the range of echo amplitudes that a radar may receive. As a result birds flying over an area from which strong ground echoes are being received are less likely to be detected than the same birds flying over an area with no ground echoes, even though the ground clutter may be completely suppressed by the MTI.

In conclusion: the rate of suppression of bird echoes by MTI's varies in time and space and with different types of equipment and their setting. In other words, careful selection of sampling areas at the ppi and calibration of measurements should be given high priority. If clutter free areas are available through horizon screening and nevertheless low altitude coverage, the use of MTI should be avoided.

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3.3. Recording technics

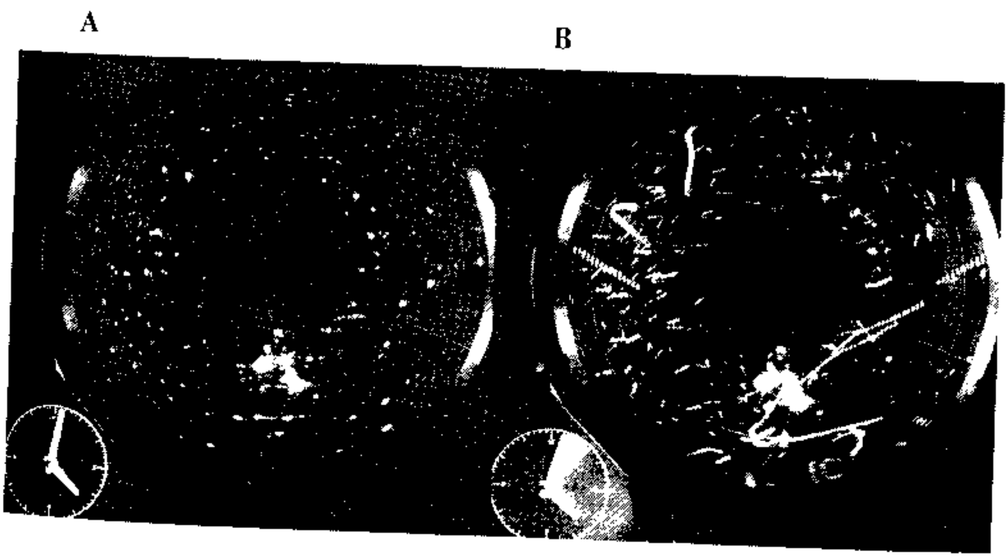
The movements of birds are difficult to follow directly on the PPI because of the large scale on which radars work (even short range radars) and because of the weakness of afterglow tails. Therefore, data have to be stored for serious analysis. Because of the electronic nature of radar equipment electronic storage seems to be the obvious approach. This however is usually a costly and complicated affair. Therefore much of the ornithological and operational work applied photographical means.

3.3.1. Photographical methods.

Two methods are frequently used: time exposure photographing and time lapse filming. For instantaneous assessment of bird migration intensity often polaroid photos are taken. A cheap method for long term studies is periodically taking time photos with a 16 mm or even an 8 mm filmcamera.

Time exposure photos of 2 to 15 minutes indicate speed and direction. Photos of the PPI taken during one revolution of the antenna yield a valuable impression of the echo density in the space covered by one sweep of the beam. The single echoes appear as dots (fig. 23A). Depending on scale and bird speeds the echoes of several antenna rotations build up shorter or longer streaks (fig. 23B). Direction suffers a 180 degrees

figure 23 Time exposure photos of one full rotation of the radar antenna (A) and the accumulation of echoes within one picture when exposed five minutes (B).



ambiguity. This has been prevented by adding one short extra exposure to each time photo after a short closure of the shutter. The point echo added to the streak indicates track direction. The obvious disadvantage of time exposure photos is the quick saturation of the image while the radar still displays single echoes (fig. 24).

Time lapse filming is a better, but more expensive technique. Radar films vividly illustrate the process of bird movements. An indication of how spectacular such films may be is provided by the series of photos in figure 25. The cognitive powers of the human eye and brains provide extreme quick pattern analysis. However, proper elaboration of the film recordings in order to reach scientifically satisfying results is very difficult. Selective extraction of the easily recognisable heavy and quick echoes may cause severe bias. Eye fitting average track directions of cohorts may obscure non-random directional variation. Weak but consistent bird cohorts or reversed movements can easily be overlooked.

A general disadvantage of photographical recording is the loss of information and addition of variation due to limitations of this extra medium: reduction of resolution, bias through a non-linear relation between brightness of echoes and sensitivity, blurring and backgound illumination of the whole picture by bright echo fields from rain, causing weak echoes to merge into the noise.

3.3.2. Electronical methods.

A first step towards more stable storage is using video instead of film. The newest CCD video cameras offer reasonable resolution and, at least theoretically, open the possibility of electronic assessment.

A more sophisticated possibility is the use of the synthetic digital radar information available at modern radar stations. This information extracted for operational purpose however, usually reduces or even excludes bird echoes. The best but also the most expensive option is to convert the analogue raw video into digital data. It enables collection and analysis of basic radar information, but also provides the possibility of extracting bird echoes at the source and/or performing pattern analysis (see chapter 5).

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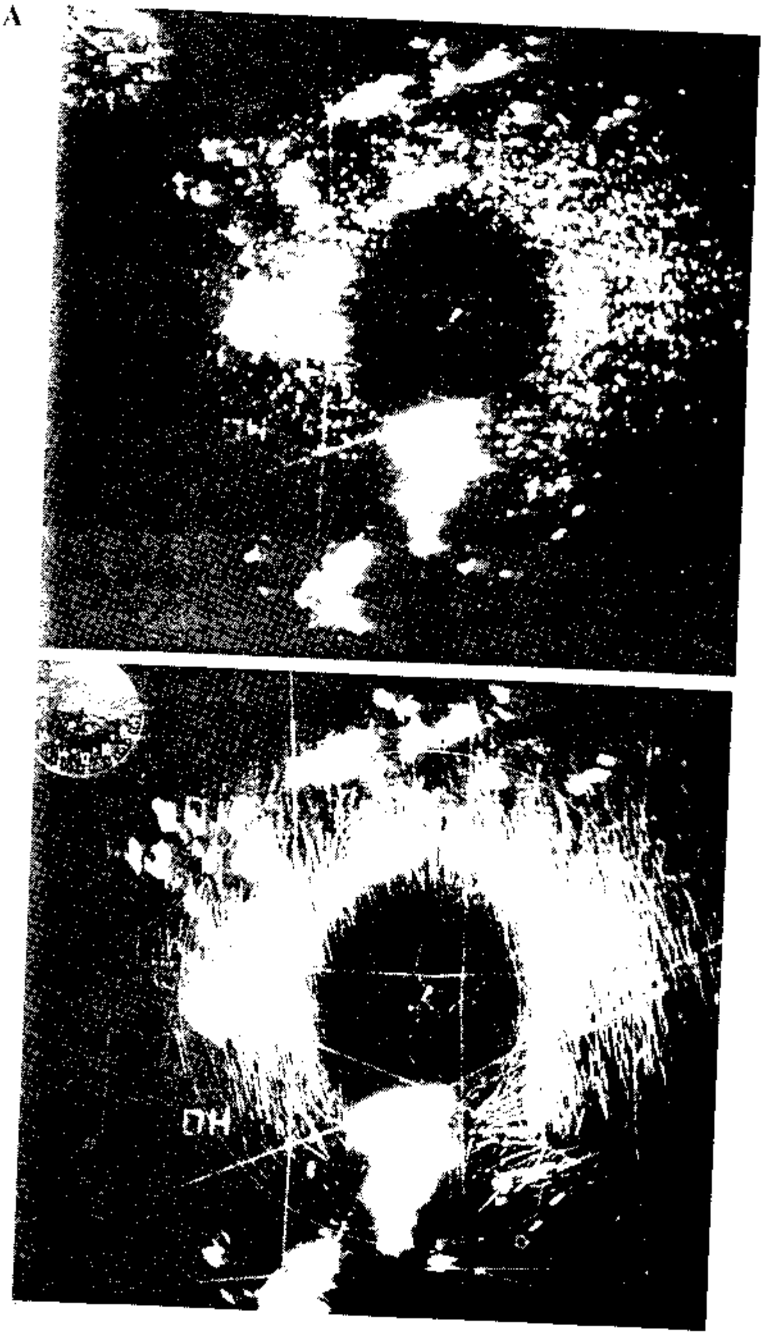


figure 24 Time exposure photos of the former L-band radar in the NW of The Netherlands showing bird echoes (point echoes), a few rain showers (small echo fields) and the normal amount of groundechoes around the station in the centre (A, one antenna rotation). The accumulation of all images of 10 minutes of antenna rotation causes bird echoes to grow into short streaks indicating direction and speed. A few much faster echoes from aircraft produce stipple lines to (or from) Amsterdam airport.

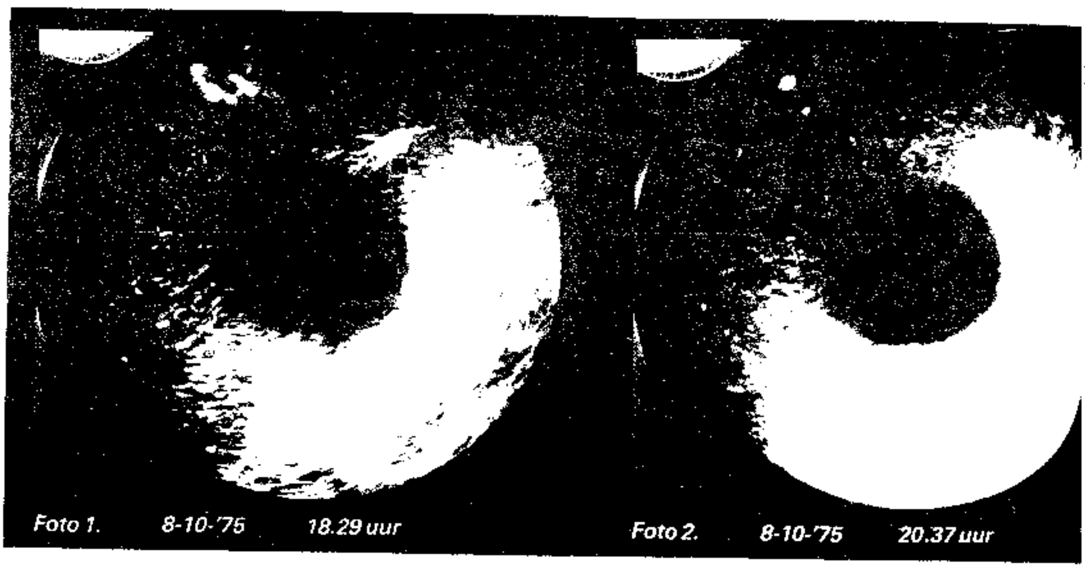


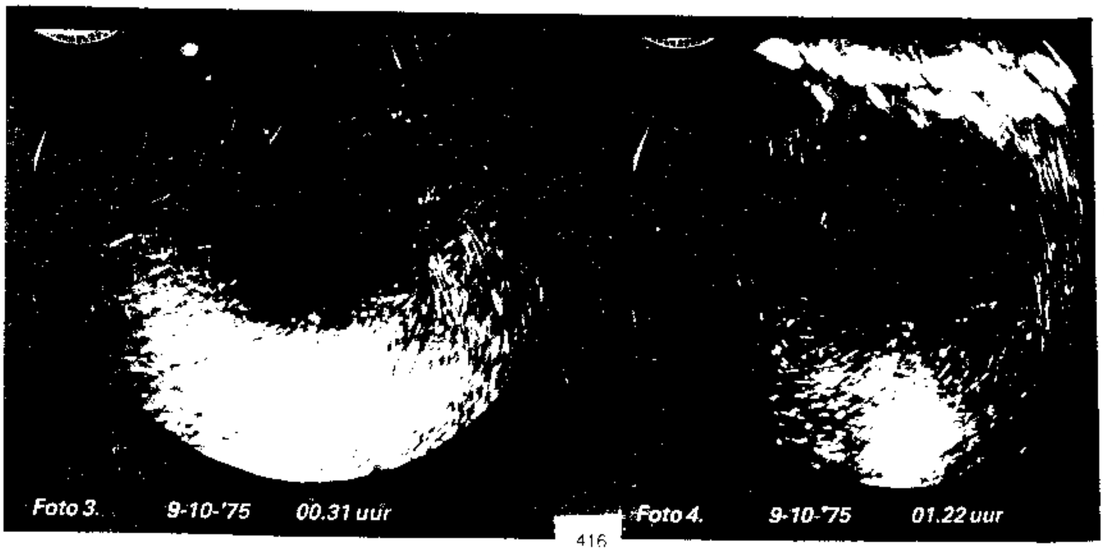
figure 25 Photo series illustrating the process of bird migration over the North Sea as seen by the former L-band radar near Den Helder in the NW of The Netherlands.

(1) Departure of nocturnal migration towards WSW. Because the echoes start above the Waddensea islands and above the mainland, we may conclude that they were produced by landbirds. The time of the year and the massality of the movement makes thrushes the most probable species.

(2) Two hours later the migration is really massive. Saturation of the PPI is extra strong because of the change in flock behaviour at dusk. At sunset the birds flew in dense flocks, but in the darkness the birds are spacing out.

(3) Shortly after midnight the intensity of westward migration has weakened. In the upper part of the screen fast bird echoes appear. They indicate migrants that left southern Norway at dusk.

(4) One hour later the southward migration is clearly visible. The birds fly with the wind as can be deduced from the movement of the front of rain showers. The bird echoes are very long as a result of the high ground speeds.



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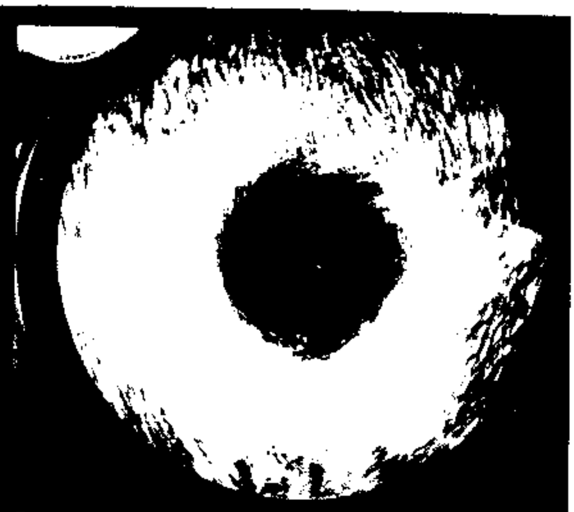

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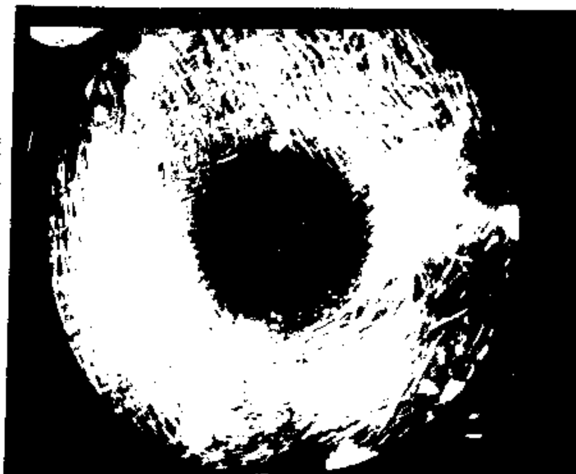
(5) Behind the rain front a huge mass of nocturnal migrants is approaching Holland. While the westward migration has ceased, the Norwegians have to proceed because the birds can not land at sea.

(6) This big arrival from the north continues far into the following day. The direction of the stream has shited to the SE. The echoes became stronger because the birds reordered into groups at dawn.

(7) At noon there is still very heavy migration over sea. Perpendicular to the flight directions of the Norwegian birds there is WSW day-time migration over land as well as over sea, as during the night before.

(8) Several days later there is W-WNW movement of very big bird echoes coming from the low parts of The Netherlands. Lapwings (Vanellus vanellus) is a good candidate to explain this type of migration. Reflections of obstacles on the ground indicate more or less the topography of The Netherlands. The centre of the PPI was artificially kept echo free.



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4. TYPES OF RADAR AND THEIR SUITABILITY FOR BIRD OBSERVATION

In this chapter we will shortly describe some examples of ornithological work for each type of radar that we consider of interest for bird strike prevention. Only studies that contributed to our understanding of the quantification problem have been included. Apart from giving some references we aim at emphasizing particular advantages and shortcomings of the different classes of radar. Radar pictures with a few results rather than extended text are chosen to support our conclusions.

4.1. Fan-beam search radars

Fan-beam search radars map the movements of air and sea traffic on PPI's. They have beams wide in the vertical and narrow in the horizontal plane. While scanning along the horizon, the beam covers a large part of the air space but discrimination between targets on the same spot at different altitudes is impossible. This third dimension of air traffic control can only be performed by additional equipment such as nodding height finders or, near airports, by precision approach radars.

Fan-beam search radars were the first and most important tools that evoked the new discipline "radar ornithology". Spectacular sequences of bird migration waves around the clock and over the seasons can be visualized by time-lapse filming. This representation of the process of bird migration is so impressive that, unfortunately, many people judged bird migration studies with simpler means to be superfluous. Fan-beam search radar still can be considered as the type of radar to be chosen for getting a general overview of migration and a rough indication of relative intensities in large areas. However, its inability to provide altitudinal information on bird movements as well as the qualitative rather than quantitative nature of its data must be emphasized.

4.1.1. Air Traffic Control (ATC) radars

These high-powered long range surveillance radars, often connected into networks, guide the flights of civil airliners outside the control zones of airports, where short or medium range airport surveillance radars (4.1.2.) take over their task. Modern civil ATC radars will usually not provide any significant bird information, because their operationally used video signals (mostly synthetic) have been cleaned up for undesired echoes. Certain video extractors may provide a figure indicating the amount of removed clutter including bird echoes, but to what extent this figures has any value to indicate bird densities remains very uncertain.

Military ATC or air defense radars are usually better suited for bird detection. Depending on their task, they should register even fairly small targets that do not respond to the radar by transmitting IFF (Identification Friend or Foe) signals. Moreover, they usually are designed to provide higher resolution.

Military ATC radars have already been used for ornithological purposes since the Fifties. Well known is the work of the British school of radar ornithologist "founded" by Lack. Also researchers in Denmark, Sweden and the USA produced papers based on military long range surveillance radars, mostly fan-beamed. Nice pictures could be taken from the PPI of the Dutch L-band radar near Den Helder (figures 24 and 25).

The radar registrations from Holland are well suited for demonstrating possibilities and restrictions. The flatness of the country provides the best low coverage one could think of. The ground clutter pattern is very regular, normally a circle with radius 20 nM around the radar. Birds can be observed far beyond 50 nM, but the filming was limited within this distance. Therefore a "donut" like annulus of 30 nM depth is available for bird detection. When fixed echoes are removed via MTI, only a central area of 10 nM radius cannot be used. Because of the wave length of 23 cm the difference in detection chance between birds observed head- or tail-on and those seen from the side is fairly small. The latter echoes exceed the noise level at longer distances. Due to the combined effect of low resolution and long wave length, saturation of the ppi by bird echoes can occur easily, especially at night. Solitary songbirds cannot be detected but when several individuals simultanously occupy one resolution cell a weak echo is received. This is clear from the daytime pictures wherein the echo of a flock of finches cannot be told from that of a single goose, apart from typical differences in speed. During the night many songbirds fly singly and remain invisible but chance may bring them within one resolution cell. As a result a very diffuse bird echo pattern emerges on the PPI. Sometimes, it resembles weather echoes and mostly it does not provide reliable directional information.

The biological significance of observations with this type of radar primarily concerns the recognition of large scale patterns of migration. The short series of time exposure photos (figure 25) may illustrate this. According to departure areas, timing and speeds several so-called cohorts (Alerstam & Ulfstrand 1972) can be identified as "songbirds", "waders", "geese", "gulls" and others. Systematic recordings offer the possibility to describe temporal patterns (circadian and circannual) and the short-term reactions to weather. Migration intensity can be scaled roughly, using the exponentional 0 to 8 values (see 5.1.), but real quantification is difficult. Apart from the saturation problem, also the invisibility of the smallest birds, even on short range, makes it impossible to select a certain sampling spot where all birds above a certain minimum altitude are detected.

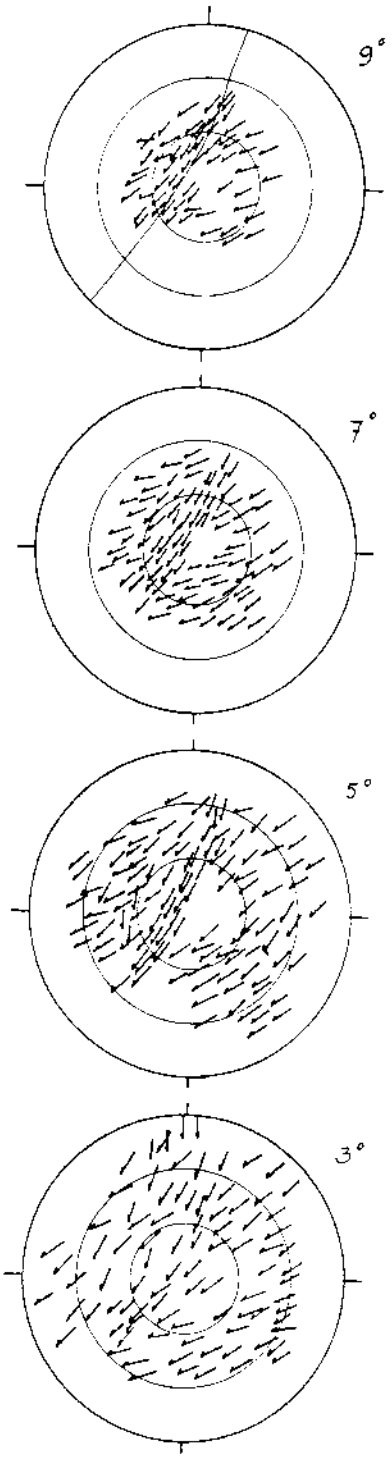

figure 26 Diurnal autumn migration (ca 10.00 hr) around the Dutch west coast, as taken from the PPI of an old airport surveillance radar at the naval base Valkenburg. Range rings were set at 5, 10 and 15 nM. The coastline is indicated in the upper figure. The elevation of the fan beam was set at 3, 5, 7 and 9 degrees, cutting off bird detection from low to high altitude.

4.1.2. Airport Surveillance Radars (ASR)

What is said about ATC radars partly applies also to ASR radars. Although airport radars work at smaller scale, they nevertheless cover such large areas that they are able to monitor large scale bird movements. Especially when several ASR radars are exploited for simultaneous registration of bird migration, geographical patterns can be studied in detail.

While most fan-beam ATC radars operate at 23 cm wavelength, ASR radars use the 10 cm (S) band. This improves the potential detection of solitary flying small songbirds, while the wave length is just long enough to avoid serious insect contamination. This makes ASR radars better for the assessment of bird numbers within a certain volume of air than ATC radars. The smaller scale increases resolution. But the inclusion of smaller birds leads to bigger numbers of echoes. Therefore, also the PPI of ASR radars can become saturated. Gauthreaux (1970) has proposed a procedure to quantify bird migration even in case of mass migration. By stepwise attenuation of the radar sensitivity the bird density will diminish. After calibration of this thinning effect by parallel observations with other means, the real densities are calculated and the drawback of saturated PPI is avoided.

Very detailed and biological reliable migration studies have been performed since the fifties at the airport radar near Zurich in Switzerland (Sutter 1957, Gehring 1963 and Hilgerloh 1981). A good analysis of the quality of ASR radars for bird detection and an extended ornithological study was performed by Richardson (1976) in Canada.

A series of sketches directly taken from the screen of an old GCA radar at Valkenburg naval base along the Dutch west coast is reproduced in figure 26. Tilting the antenna from 0-9 degrees reveals two types of bird movement: ENE-WSW broad-front migration over land as well as over sea and a narrow, concentrated stream of migrants flying parallel to the coast. Different from what most ornithologist think, the migrants following the coast perform this behaviour also at very high altitudes. They seem to use the coast as a guide line.

With respect of biological results the work at Ben Goerion airport near Tel Aviv, Israel (Leshem 1988) is very interesting. This ASR-8 radar is used without any special modification. Figure 27 shows the video normally used by the air traffic controllers. In this radar setting birds of small or medium size, flying singly or in small flocks, do not reflect strong enough to penetrate the filters. Only flocks of heavy migrants like storks, pelicans and bird of prey, soaring from thermal to thermal, produce echoes. The numbers and identity of these birds, and thereby the performance of the radar, were checked by visual observations from a motorized glider. As a result the radar can be used in its normal setting as a calibrated tool for "ad hoc" warnings to the Israeli Air Force. Broad-front migration remains undisclosed in this way, but nowadays other (more sensitive) settings are tested.

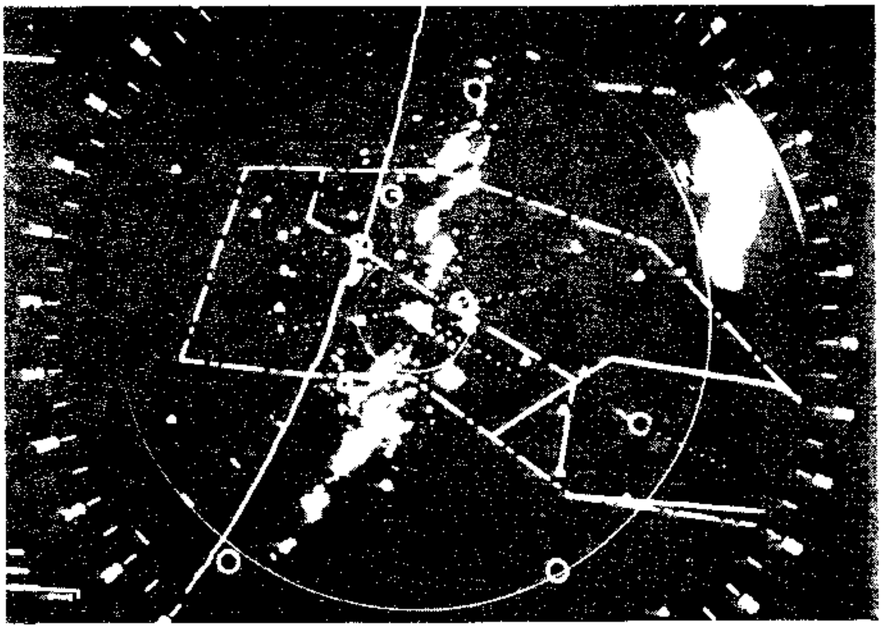

figure 27 Ben Goerion airport surveillance radar (ASR-8) on 28 sept 1986, 11.30 hr. A long line of 82 km of Lesser spotted eagles (Aquila pomarina) are visible as a row of cloudy echoes parallel to the coastline projected into the PPI. It is estimated that the echoes represent ca. 15.000 eagles.

4.1.3. Ship navigation radars

Ship navigation radars are the smallest fan-beam search radars used for bird detection (Williams et al 1972). Because of the big market of recreation vessels, these radars are cheap and easily accessible to ornithologists. However, maximum bird range is small. Songbirds cannot be seen beyond 1 km (if at all) while the detection of flocks of large birds is only possible up to 2-3 km at the most. Therefore such radars can not cover the full altitude range of bird migration. By replacing the fan beam antenna by a narrow pencil beam range can be enlarged.

The application of ship navigation radars is mostly scientific. The disadvantage of very limited range is more or less compensated by good resolution and the easy use in the field. Recently, the Danish field ornithologists Brinch Pedersen and Poulsen used a modern Furuno ship radar to study nocturnal bird movements around a windturbine. Modern types, like the Furuno, have memory functions enabling the operator to see simultaneously the latest and several earlier plots of each target. This enormously facilitates recognition and understanding of the bird movements in real time.

Gauthreaux has included a ship radar into his mobile field laboratory, which was set up for, amongst others, the study of birds colliding with electric power lines. He combined several remote sensing technics and profitted from the sometimes complementory nature of these.

Figure 28 gives an impression of the PPI of the search beam of the Flycatcher tracking radar. This component of the Dutch X-band military radar can be considered as a small-range fan-beam search radar like the ship navigation radar. However, because of the much higher power bird detection can be done at somewhat larger scale (rings indicate 5 and 10 km range). The row of echoes in the NW indicates the metal poles of an electric power line. The echo field from the center to the SW is a fairly open area wherein all single trees, farms and many smaller objects reflect radar energy. The reason for the clean PPI in all other directions is that the radar could be placed at a location surrounded by low homogeneous woods, obscuring the horizon over 270 degrees. Birds could be detected (and tracked!) down to an altitude of only 20 meters at a distance of 2-3 kilometer. Single trushes were detectable in side view up to 7 km.

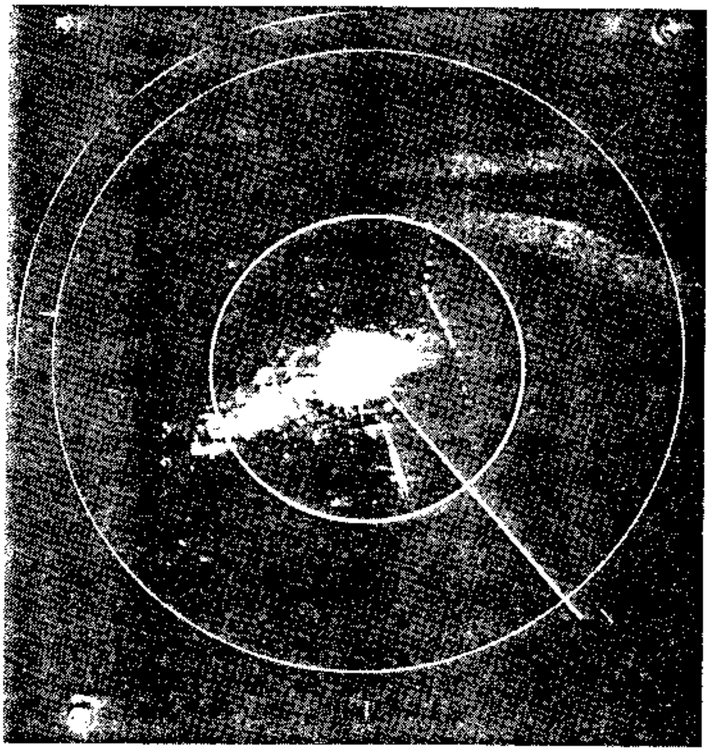

figure 28 PPI of the search beam of the Flycatcher tracking radar. Explanation in the text.

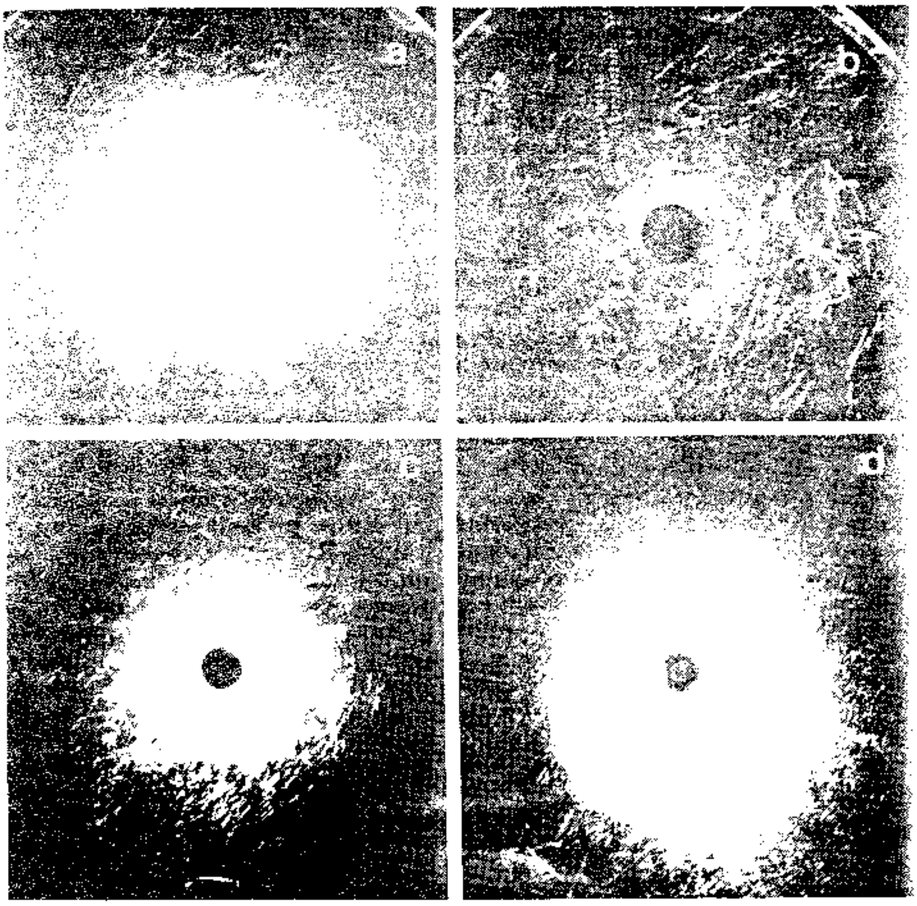

figure 29 The filtering of unwanted echoes as visualized at the PPI of the stacked beam long range surveillance radar in the NW of The Netherlands. Explanation in the text.

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4.2. Pencil beam search radars

4.2.1. Long distance (stacked beam) radars

Pencil beam antennas produce beams which are narrow in azimuth as well as in elevation. The aperture of long range radars is usually around one degree. In stacked beam radars the radar energy is divided over several wavetubes. Each radiates from a slightly different position in the focal area of the big antenna and produces it own radar beam. The beams together fill a vertical detection plane which is rotated in the horizontal, resulting in a three dimensional coverage. For bird detection only the lowest two beams are interesting. Combining the information of both beams gives a limited idea of the heigth distribution of the birds.

The S-band stacked beam radar in The Netherlands (see figure 24) offers fascinating facilities for bird detection. The raw video of this radar may be densily packed with bird echoes as a result of the perfect low level detection in very bird-rich and very flat country side. For normal operations (the guidance of aircraft), the video should therefore be cleaned. Figure 29A is a 10 min time-exposure polaroid photo of the raw video showing many bird streaks. Picture B is taken nearly at the same time and gives only that part of the video which is extracted for operational use (again acumulated over 10 minutes). Here aircraft echoes dominate the picture. North of the radar strong also echoes from ships remained visible. Those signals that were trapped by the video extractor can also be shown, albeit in reduced quality: figure 29C. The availability of this "unwanted echoes video" was accidental and proves the possibility of a dedicated bird echo extractor. A-C were day-time pictures. 29D illustrates the unwanted echoes filtered out of the signal during a night with heavy bird migration.

4.2.2. Medium distance (weather-) radars

This category of radars is not often used for bird detection. Most weather radars are fairly low powered because of the low resolution needed for detecting rain showers. Both affect the quality for radar ornithology. However, very good results were achieved with the weather surveillance radars (WSR) in the US by Gauthreaux.

4.2.3. Short distance radars

A high resolution pencil beam radar with a corresponding short range, which is nevertheless long enough to reach the highest flying birds, is ideal for bird studies as well as for future bird strike prevention (see 5.3.2.).

figure 30 Radar study along the Dutch west coast by means of the two search pencil beams of a L4/5 tracking radar. Explanation in the text.

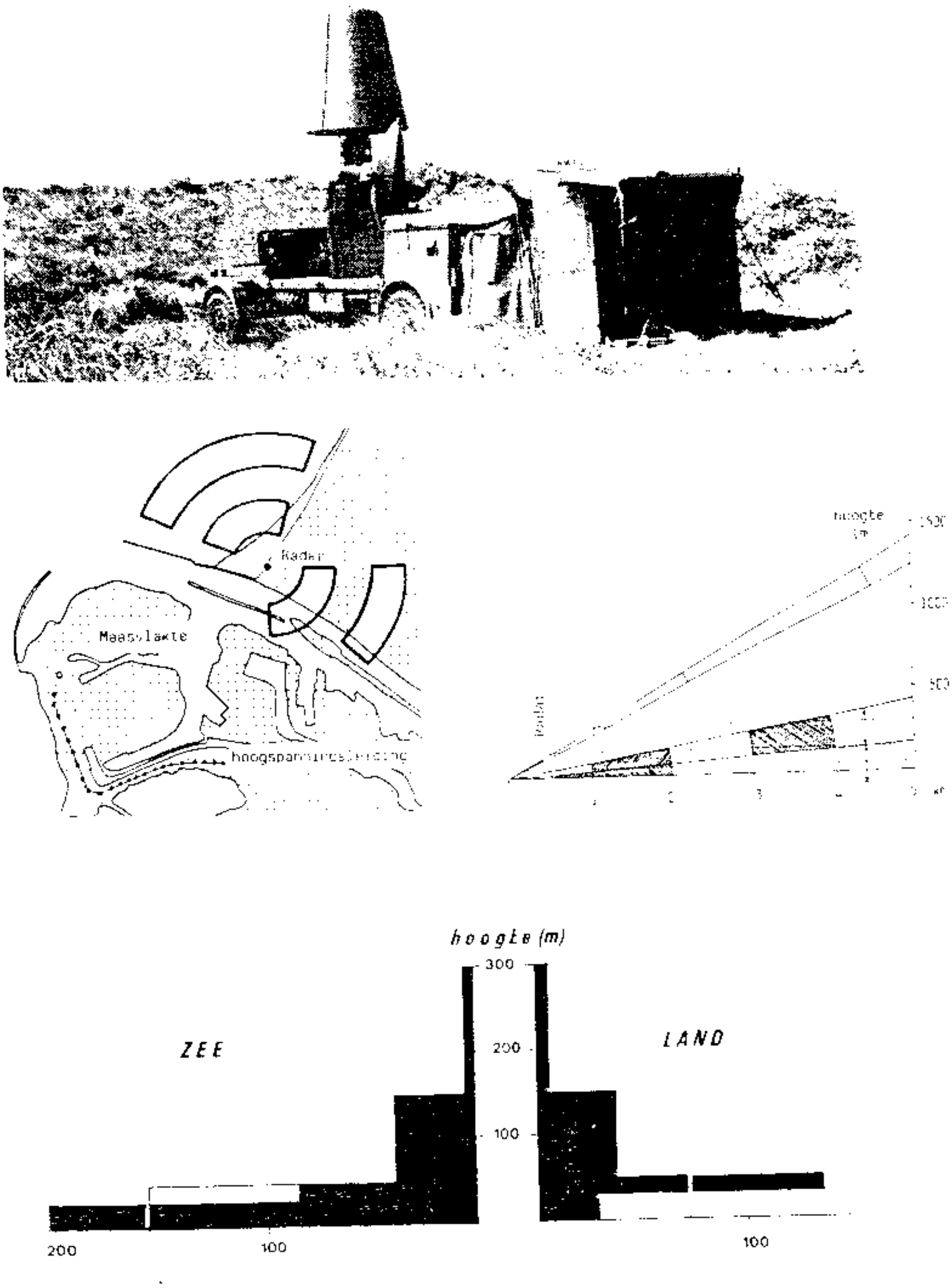

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Figure 30 presents a collage of work done in The Netherlands with the two pencil search beams of L4/5 (tracking) radar (A). The mobile system was put on top of the dunes along the Dutch west coast near Hook of Holland. The project aimed at assessing autumn bird movements during day and night at different height levels. The lowest air layers got special emphasis because of the concentrated diurnal migration parallel to the coast and the question whether this well-known movements also occur at such low levels during the night. One reason for the study was the completion of a nearby electric power line perpendicular to the coastline and to the bird stream (Buurma & Van Gasteren 1989). The two radar beams scanned in the horizontal plane under different elevation angles (C). Bird movements were filmed time- lapse hourly. Figure 30 B and C show the sampling areas chosen in the horizontal and vertical plane respectively. The results of one night (6 november) were averaged with respect of the altitude distribution of bird density (per km3) above sea and land: figure 30D. This night of intense migration shows that the birds seem to avoid the lowest meters over land but that they don't do so above sea.

4.3. Nodding height-finders

4.3.1. Height surveillance radars

These old-fashion radars complement the fan-beamed search radars by providing altitude information. In fact they are fan- beam radars of which the antenna is rotated 90 degrees around a horizontal axis. The beam, narrow in the vertical plane, is scanned up and down and the signal is displayed at a so-called Range Height Indicator (RHI). Figure 31 gives an impression of this type of presentation, although it came from a nodding pencil beam.

Riemens (1971) evaluated a large nodding height-finder (S-band) in The Netherlands, that belonged to the same radar park as the L-band long range surveillance radar, shown at the cover. He took time-exposure photos simultaneously at both stations (figure 32). The nodding height finder was used as a search radar giving a very narrow beam in the vertical plane. The results showed very meager correlation, which seems to be primarily a matter of skewed altitude distribution during daytime migration. The SSW flying bird at the L-band radar are missing at the S-band radar, probably because they flew low above the sea.

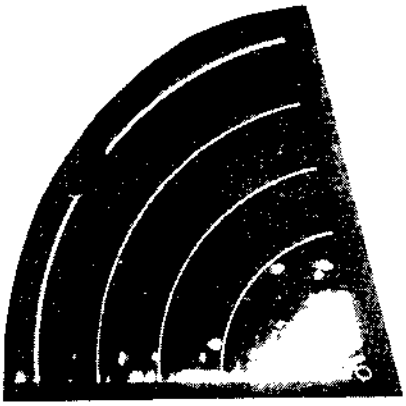
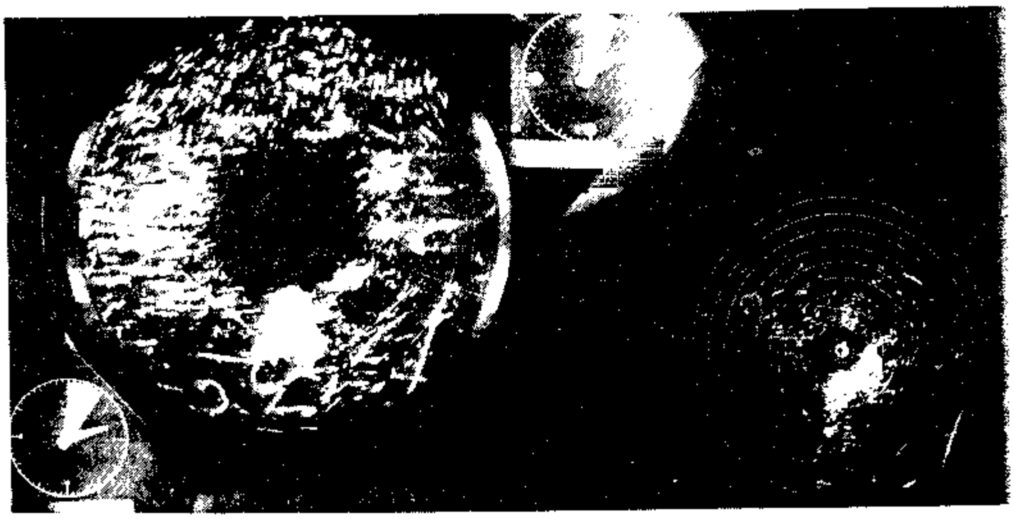


figure 31 Vertical scan of the tracking beam of the Flycatcher. Rang rings at each km indicate a maximum detection at nearly 5 km altitude. Figure 13 showed results. Dot echoes came from birds. The first km is saturated with a mixture of noise, side lobes and insect echoes. Reflections of trees etc. are visible at the bottom.

figure 32 Time exposure photos taken simultaneously from the PPI of the L-band fan beam radar near Den Helder, The Netherlands (left), and a S-band nodding height finder at the same spot (right). Both radars were scanning in the horizontal plane.



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4.3.2. Precision Approach Radars (PAR)

PAR's help landing aircraft to follow their flight path as precise as possible in the vertical plane. Mostly these radars, operating in X or C-band, have their antenna fixed in one direction. Birds passing through the scanning plane produce clear echoes, directly giving altitude information. When there are no details on flight direction and speed of the birds, it is difficult to quantify the movement. PAR's are not often used because they offer not much flexibility for ornithological use.

4.4. Tracking radars

The ultimate radar system for scientific studies on bird migration is the (military) tracking radar, especially when optimally attuned, adapted and instrumented for bird observation. For a classic study see Bruderer 1971. The tracking capacity offers the possibility of studying the flight path of individual birds. But most tracking beams offer also the (potential) possibility of being used as a scanner. During tracking fluctuations of the automatic gain control voltage appear to reflect the wing beat signature of the bird(s) tracked, enabling the researcher to identify species(groups). Bloch et al (1981) give a good overview of potential results. Figures 33 and 34 illustrate some details of the Swiss studies with Superfledermaus X-band tracking radar.

As was judged by Richardson (tabel 2) tracking radars score high in the quality of the results. This does not necessarily mean that they are very suitable for operational use in bird strike prevention. Tracking birds one by one does not easily support the needed quantitative measurements. But as explained in 5.3.2. the use of a fairly short-range tracking beam as a flexible volume scanner come close to the ideal dedicated bird radar. Tracking radar studies can support the further development of such a system.

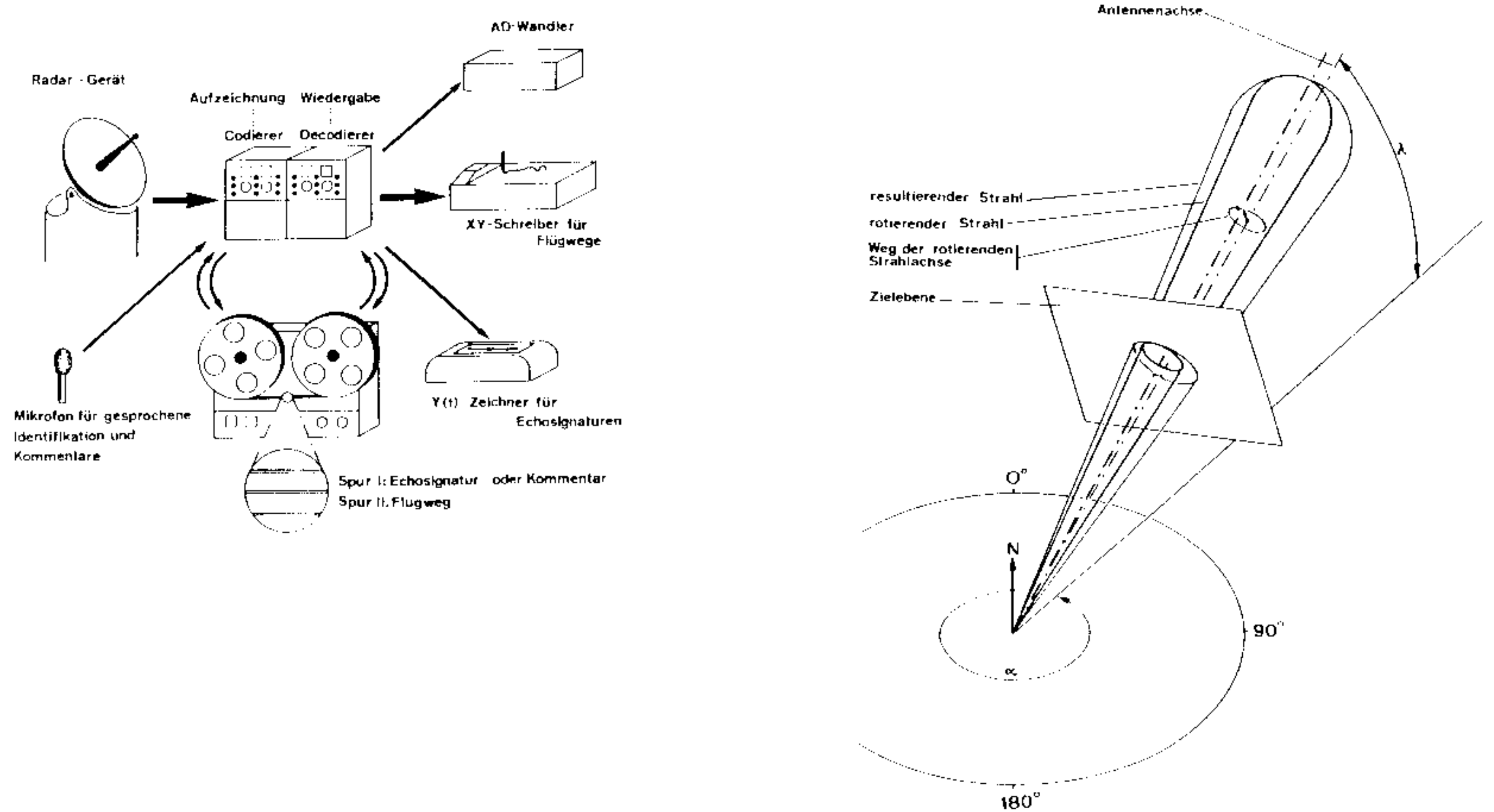

figure 33 Set-up of the Swiss migration studies by means of Superfledermaus tracking radar. Fig A illustrates the transfer of flight path data and AGC signatures from the radar via a coding device to a tape recorder, a X/Y-plotter, an Y(time) plotter and a A/D converter. Spoken text can be added. Fig B explains the rotational scan of the radar beam while tracking. The effective widened beam has an energy dip in its central axis, enabling the circuitry to fixate a target.

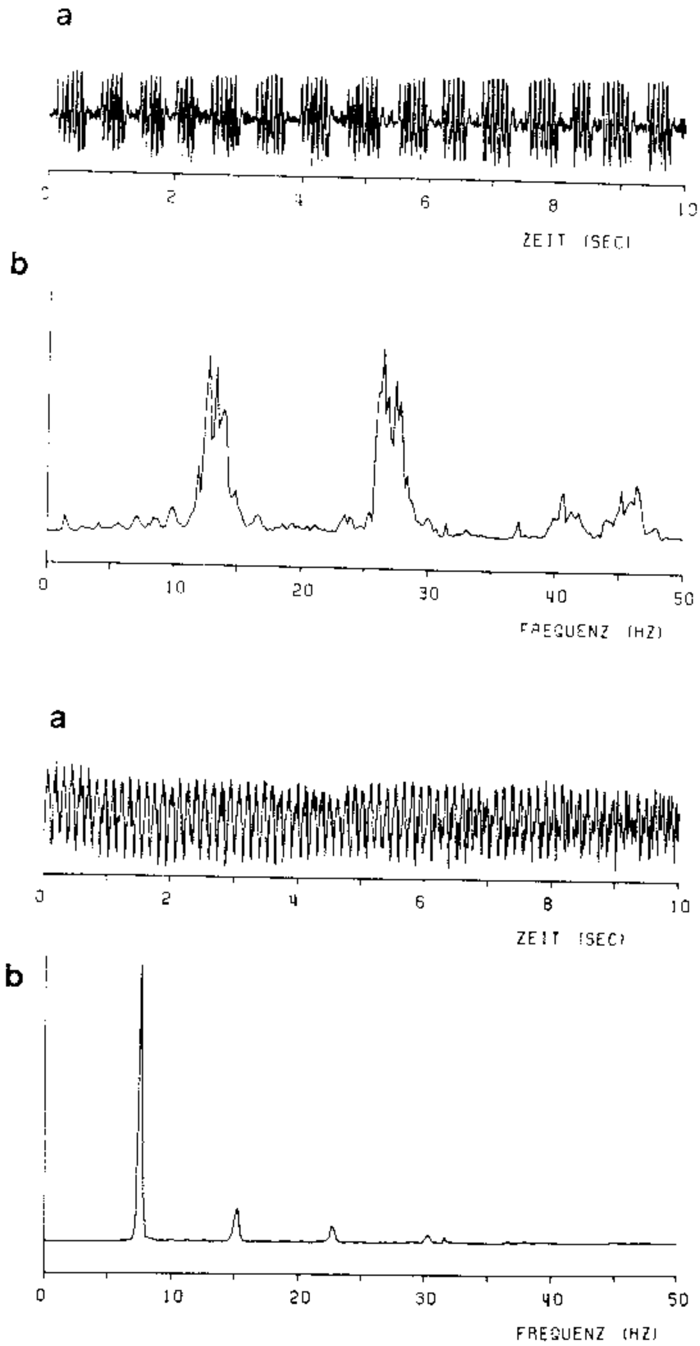

figure 34 Wing-beat patterns (AGC signals) of a passerine bird (upper figure) and a non-passerine species (lower figure). The a) parts give the pure signals, while b) represents the occurrence of each frequency within both signals. Passerine birds alternate short burst of wingflapping with short gliding phases.

Table 2 --Characteristics and applications (emphasizing bird studies) of various radar types. ++ = very suitable, + = suitable, ± = some capability (often difficult), - = unsuitable.

Radar type	Band	kW Peak Power	Range[2]	Pulse Duration[3]	Beam width[4] Horizont.	Beam width[4] Vertical	Chronology	Routes	# Flocks	# Birds	Bearing	Distance	Height	Course/Speed	Grouping	Signature
				Typical characteristics			Parameters measurable[5]									
A. FAN-BEAM SEARCH																
Ship navigation	X-S	25	S	SM	2°	20°	+	±	±	+	++	++	-	++	±	-
Airport surveil.	S	400	SM	M	1½	20	++	±	++	±	++	++	-	++	-	-
Air route; military	S,L	5,000	ML	ML	1	10	++	++	++	-	++	+	-[6]	+	-	-
B. PENCIL-BEAM SEARCH																
Weather surveil.	C,S	500	ML	ML	2	2	++	++	±	+	++	++	±	++	-	-
Mod. Ship/Airborne[7]	X	25	S	SM	2	2	+	±	-	+	++	++	+	+	±	±
Tracking (search mode)[8]	X-	40-	SM	SM	1-2	1-2	±	+	±	±	++	++	+	+	±	-
	S	5,000	ML	M	½-1	½-1	±	+	±	±	++	++	+	+	-	-
C. HEIGHT FINDERS																
Precision approach	X,C	150	S	SM	5	1	±	-	±	±	±	++	++	-	±	-
Surveillance	C,S	4,000	ML	M	3	1	±	±	±	-	±	+	+	-	-	±
D. VERTICAL BEAM	X	25	S[9]	SM	2	2	+	-	-	+	-	-	++	-	±	±
E. TRACKING[8]	X-	40-	SM	SM	1-2	1-2	-	-	-	-	++	++	++	++	±	++
	S	5,000	ML	M	½-1	½-1	-	±	-	-	++	++	++	++	+	++

[2]Usable range for biological targets; S=short (<5 km), M=Medium (5-30 km), L=Long (>30 km).
[3]Short (<½ usec), Medium (½-2 usec) or Long (>2 usec); corresponding range resolutions are <75 m, 75-300 m and >300 m.
[4]Corresponding resolutions (in km) = Range (km) x sine (Beamwidth).
[5]Parameters 1-4 concern multiple targets; 5-10 concern individual targets.
[6]Roughly measurable on multiple-beam (3 dimensional) radars.
[7]Ship navigation or aircraft weather radar with dish antenna (see Graber & Hassler 1962; Schaefer 1976).
[8]Upper and lower lines give characteristics of low and high power trackers, respectively.
[9]Range is measured vertically in this case.

table 2 Summary of characteristics and suitability for bird studies of different classes of radar according to Richardson (1979).

5. Operationa

5.1. Military sy

5.1.1. Observations b

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5. Operational use

5.1. Military systems at work

5.1.1. Observations based on polaroid time-photos

Germany, Norway, France and Belgium still succesfully apply this technique which was proposed by Gunn in Canada and has been introduced in Europe during the early sixties after a persistent BSCE/NATO campaign. As described in chapter 3.3.1. and illustrated in many photos throughout this booklet, birds appear as well recognisable streaks. By comparing the polaroid photo with a standard reference series the technician is able to estimate the bird activity nearly "ad hoc". Bird densities are expressed according to a exponential zero to eight scale. Also certain geographical information as well as rough estimates of top altitudes of bird activity can be derived from the bird echo patterns. The method is reliable and cheap provided the radar and photo equipment is set correctly and the operator has the knowledge and skill to interpret the results.

As described in chapter 3 the common difficulty in all use of radar is calibration of the quantities of bird echo returns. One cannot register more than the radar "sees", while one can loose part of the information available. Most regrettably, this usually happens in case of the photographic method. The attentuation method of Gauthreaux may ameliorate the difficulties. But not all radars offer stepwise attenuation and not all users can execute careful calibration studies. However, comparison of bird density measurements at one radar station over the seasons will provide at least a good idea of the relative variation. It depends on the amount of safety a user wishes to achieve were to put the flight restriction treshold.

5.1.2. FAUST (Denmark)

This is the first operational warning system with electronically determined echo densities. It was developed for the Danish Air Force in 1971 by Clausen, partly based on ideas from Holland (see Tengeler 1972). For several years it served as an example for the radar working group of BSCE. It was revised and is still in use. Just like the other more or less comparable systems, it does need a skilled radar observer. Separation of bird echoes and clutter is imperfect and the system does not give height information.

5.1.3. KIEVIT (The Netherlands)

Since 1978 the RNLAF has operated an electronic counting system called KIEVIT (Kast met Integrale Vogeltrek Intensiteits Tellers) at its stacked beam radar in the NW of Holland. Only the lowest two beams are used because only they detect large numbers of birds.

The system determines bird echo intensity within 5 movable windows (figure 21) provided the radar works in Pulse Compression mode (range resolution 30 m.). The raw video signal is quantified by means of two seperate thresholds, a distance dependent low bird threshold and a 16 dB higher clutter threshold. Herewith two digital video signals are produced, resp. called "bird video" and "clutter video". The clutter video selects all strong echoes which are directly fed into a clutter counter. The video first is counted by a "bruto bird counter" and confines all energy not exceeding the clutter video. The bird video also passes a combined pulse length discriminator and an "isolation filter" to eliminate weak echoes from rain and ground objects. All echoes with a certain minimal distance to their neighbours (in range) and having a certain maximum pulse length do pass the filter and are counted by the "netto bird counter". The two filters may have different settings and are usually adjusted either to the heavier, widely spaced, diurnal echoes or to the denser but weaker nocturnal echoes.

Quantification implies the calculation of the percentage occupied resolution cells within each window after subtraction of the number of clutter cells plus the difference between bruto and netto bird cells. The figures are converted to the well-known 0-8 exponential scale for bird migration warnings. The two lowest radar beams are sampled seperately per window giving a rough height indication. Furthermore, the location of the 5 adjustable windows offers the possibility to discriminate roughly between different types of bird migration over Holland and the adjacent parts of the North Sea.

The system also includes a SRT-radar screen, photographical recording facilities and a output plug delivering formatted output of counts.

KIEVIT is still in use as a back-up system. It has proven to be able to select bird echoes under most circumstances. If this is not the case the bruto bird counters indicate the potential mistake. However, due to the filter process many birds may eliminate each other when the echo density is too high. Therefore, the system still needs an experienced person to evaluate the figures (not necessarily seeing the screen), although it was intended to work automatically.

5.1.4. ROBIN (T

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5.1.4. ROBIN (The Netherlands)

ROBIN stands for Radar Observation of Bird INtensity. It is the acronym for the new Dutch system that recently replaced KIEVIT. ROBIN consists of two cooperating systems: a registration system and a presentation system, which can be separated geographically. The registration system has to be located near the radar; the presentation system can theoretically be set up anywhere.

The communication between both systems takes place via a serial line (a modem connection): commands are sent from the presentation system to the registration system; the recorded and processed images are returned to the presentation system (figure 35).

The presentation system is a standard workstation with a high resolution screen and ample data storage capacity. The system is controlled by a hierarchical menu structure in which selections can be made using a mouse.

Numeric parameters can be entered via the keyboard in various windows linked to the menus. Text and graphic output also occurs in windows.

The adjustable parameters include among others the time of acquisition, the resolution in distance and azimuth and the choice of different filters. The size and location of the acquisition area are indicated by the mouse on the map displayed on the screen. The image, compressed to allow for minimal transmission time is converted by the workstation (after decompression) from polar to cartesian coordinates.

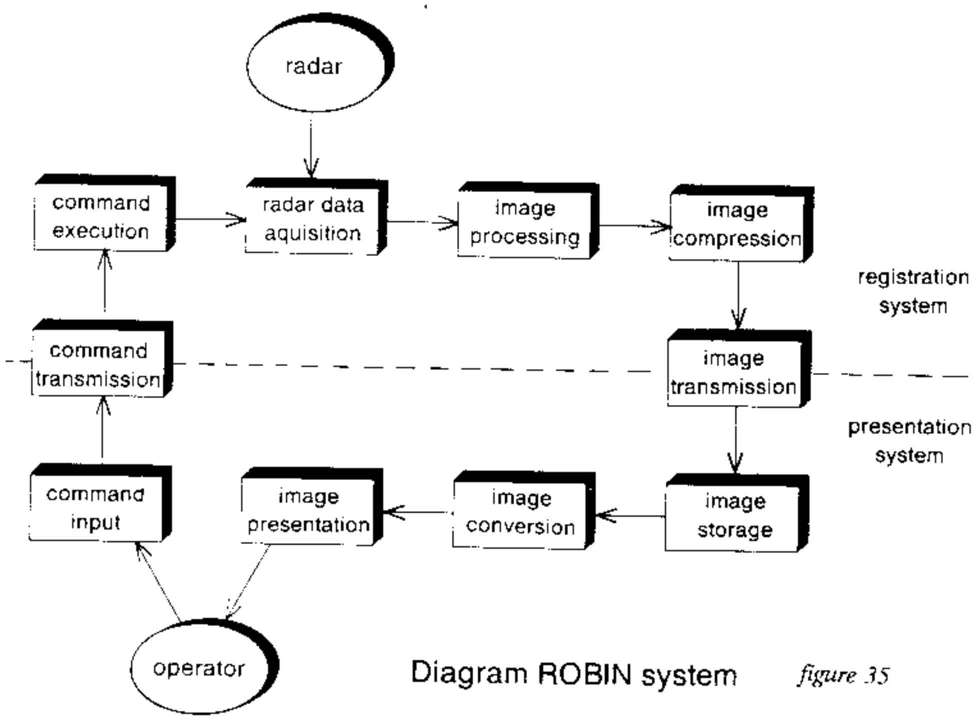

Diagram ROBIN system *figure 35*

The registration system takes care of the data acquisition and image processing without further intervention being necessary. The radar signals are recorded and processed without affecting the radas's primary operational task (Air Traffic Control, object detection etc.).

The system includes the data acquisition hardware, combined with commercial VME-bus processor modules on which software programmes for image processing, datacommunication and data acquisition control are executed. The architecture is strongly directed at het flexible implementation of signal processing algorithms in software.

The image processing aims at supporting the user in making quick, accurate and reproducible interpretations of radar images. The image processing can be divided into the following stages:

- compensation of less desired characteristics of the radar as sensor such as beam form and distance dependency;
- filtering of disturbing radar reflections (towers, etc.) and noise;
- improvement of images for visual assessment by removing insignificant details and assigning colours to different sources of echoes;
- determination of quantitative characteristics for bird migration like bird density and flight direction;
- compression of images for transport and storage;
- transformation of polar radar images for presentation on a raster oriented computer screen.

The most important aspect is to distinguish between birds or groups of birds and other reflections, such as rain showers. The criteria used are:

- size and strength of echoes;
- spatial distribution of reflections;
- movement in direction and speed.

Reflections linked to the ground can be eliminated by their correspondence in place in consecutive images.

Rain can vary in the radar image from massive echoes to finely distributed speckles. Classification as rain can be made if these characteristics occur over a connected and sufficiently wide area.

The contour of the area found in this way is depicted by the thick line in figure 36B. Potential bird echoes are identified by limits on size, strength and mutual distances. Several migrational directions may be identified in one image; further selection is possible after linking echoes in consecutive images and by grouping displacement vectors.

figure 36
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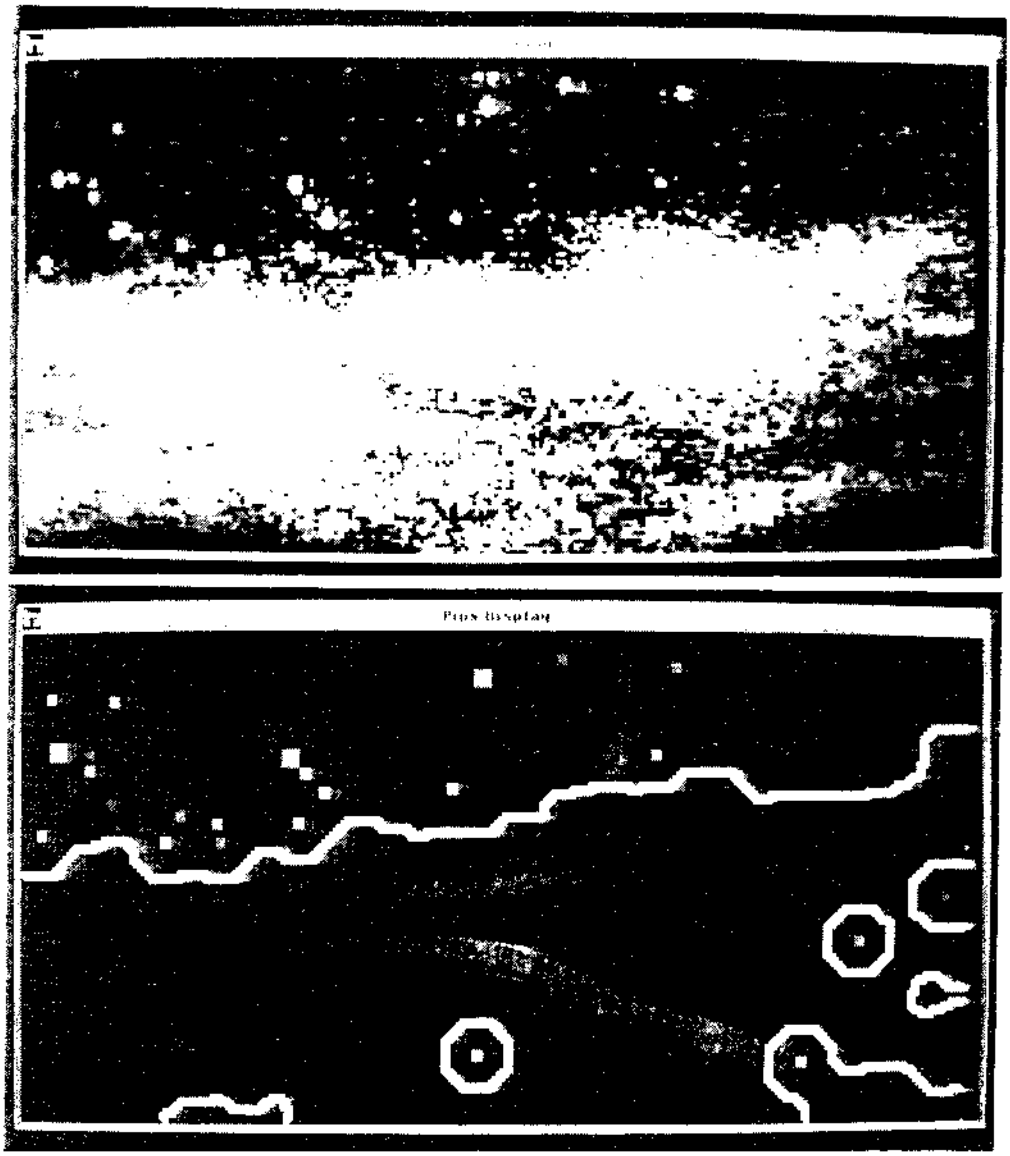

figure 36 Bird and rain echo recognition by pattern analysis within ROBIN (lower figure). The raw video signal from a window selected at the PPI was first processed into digital information (upper figure). Bird echoes are the dot-echoes consisting of several pixels. Rain consists of large fields of smaller echoes and single pixels.

5.1.5. BOSS (Belgium)

In modern phased array radars for air traffic control many "temporal" pencil beams in fixed or rotating arrays "fire" in random sequences one by one in different directions. They build up a three-dimensional picture of echoing objects. Many functions are implemented in software. Although the programming is not adjusted for optimal bird detection a smart programmer could reprogram for bird sampling. As a consequence the radar is out of normal operations for a few seconds or minutes.

During "bird scanning" the Bird Observation System Semmerzake is sampling the Belgian air space air three dimensionally like a stacked beam surveillance radar. All echo returns are extracted in the way typical for this radar. The plots are presented and counted within height classes of 2000 ft (Dupont 1986). Judging to the maximum reported echo densities the resolution and bird sensitivity is meager. It should be reminded that the system is not specifically extracting bird echoes according to their properties right from the raw video, as is done by ROBIN. Nevertheless, BOSS provides an index of real bird activity. Calibration with other (radar) sensors should reveal its value. More refined altitude information, especially within the lowest 2000 ft is highly desirable.

5.2. Civil systems in work

A few attempts have been made to apply bird warnings, obtained by radar, in civil aviation. Because the prime interest is in the prevention of local bird strikes, long range bird surveillance is not very helpful for air carriers, which quickly ascend above the heigths where the birds fly. Hunt (1974, 1975) developed a system for Winnipeg International Airport (Canada) where heavy goose migration poses a real threat also for civil aviation. His electronic counting system on the ASR radar rings a bell when bird echo densities exceed a certain threshold. There are no recent reports on the functioning of this system.

Like in the military some radar operators undoubtly warn the air traffic control tower or pilots when they discover big bird echoes in the (potential) flight path of aircraft in their local control zone. But such voluntary initiatives fully depend on the potentials of equipment and procedures and the knowledge of the operator. The crucial question is of course: how to quantify the danger. Clearly, civil aviation is awaiting a more refined and, above all, an highly reliable sensor of bird activity directly above and around the runways.

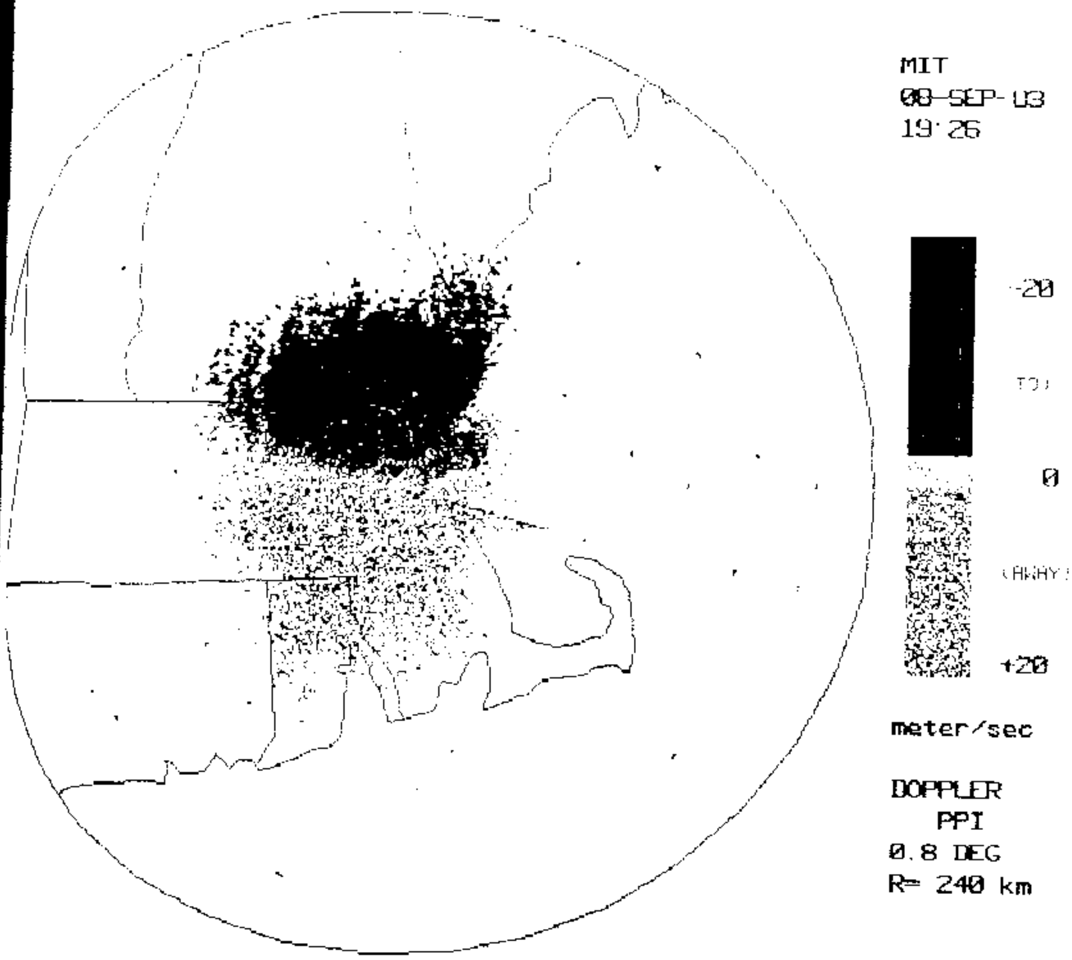

figure 37 Image of the PPI of a doppler radar. Explanation in text.

5.3. Systems proposed

5.3.1. NEXRAD software

The National Weather Service in the US may soon (1990) start spending more than a billion dollar on a radar network to improve its forecasting. The service plans to set up 135 NEXRAD (NEXt generation RADar) units (2.5 million dollar each) at airports and weather stations to cover the whole country. Larkin & Quine (1988, 1989) study the possibility of implementing bird recognition algorithms in the large S-band pulsed Doppler radars. The radars will be equiped with a narrow beam and great power (1 megawatt) and sensitivity (90 dB dynamic range). Apart from the Radar Data Acquisition Subsystem it includes a Radar Products Generation Subsystem and a Principal User Processor Subsystem. Digital NEXRAD weather data are automatically processed by large computer programs but periods without severe weather will offer considerable processing time to run special bird programs. It is expected that actual bird information will be available every 5-15 minutes.

The great sensitivity of the radar indicates that the curvature of the earth will be the limiting factor for bird detection. Calculations show that a single Herring gull would theoretically be visible as a faint target at a distance of 450 km (but, of course, never will fly high enough to ascend above the radar horizon). Songbird echoes during migration often extend out to beyond 100 km. Another limitation for scientific purpose is the low resolving capacity of the system.

The researchers expect to be able to devise algorithms allowing NEXRAD to automatically distinguish echo patterns of weather and birds according to:
1) speed of the birds (the Doppler radar directly provides speed information - see figure 37), 2) their appropiate migratory directions, 3) the timing of their flying activities, 4) their relation to topography and 5) certain echo characteristics.

The plans are to let NEXRAD radars to report bird hazards with reference to large geographical areas and to estimate the degree of hazard in different altitude strata over these regions. The USAF has the resposibility for communicating future warnings from such summaries to pilots in the air and before take off.

5.3.2. Towards a dedicated birdradar

During the 19th meeting of BSCE in Madrid (1988) the radar specialist agreed upon the rough characteristics of a "ideal" bird sensor. The plenary meeting accepted a recommendation alone the lines defined within the radar working group. This is an important step forward because the diversity of methods and types of equipment is very large, as is examplified in this booklet.

- Avoiding insect contamination requires a wave length of 5-10 cm (C or S band). Polarization should be horizontal. It should be a coherent radar, with two MTI's: separating slow and fast flying objects (birds 1-40 m/s) and rejecting ground clutter (-1 to +1 m/s). About 1500 Hz PRF would give about 10 RPM sweep rate with 25 pulses per target.

- The display should contain about 512x512 square pixels with 16 colors or more. The principal display is PPI with radar cross section color-coded. Altitude should easily be determined on the display when needed. All information from the display and pertinent housekeeping information should be available on a connector designed for computer-compatible output.

- A research version with several extra options such as manual scanning, mobility, dual polarization (hor/vert) and full doppler capability, may be desired.

An important rationale behind the above described bird radar is that it should be small enough in range to perform the three dimensional task correctly. The beams of long-range-radars cannot be shaped refined enough, and, more important, must be directed with very small elevation angles. This raises a serious problem of anomalous propagation, frequently disturbing the altitudinal coverage. Furthermore, small dedicated bird radars offer much better possibilities of international standardization of bird warnings. As a result, they will substantially promote international coordination within warning systems and procedures, which, in turn, will favour credibility.

The most important properties of a radar system, specifically assembled for bird detection, are the following:

- It should be able to detect a single herring gull (100 cm2 radar cross section) at 10 km. Thus, the system belongs to the family of (fairly) small-range-radars, like the military tracking radars discussed in 4.2.3. and 4.4.

- No full-time crew should be required. The display would be added to other instruments, available to existing personnel. Because of permanent monitoring a very high "mean time between failure" is a must.

- The system should be designed to monitor the air space three- dimensionally with a resolution in range, azimuth and elevation of 160 m at 10 km. This means that a pencil beam of 1 (max 2) degree aperture is needed, which, at C-band, requires a antenna of 2-3 m across. Volume scanning at 1 degree increments and 5 scans per elevation would cover the important air layers.

6. RESEARCH

Developments in radar and computer technology proceed very fast. In fact, several approaches described in this booklet,may seem fairly obsolete. However, biologist have very limited access to new equipment which is extreme expensive and has an operational task not allowing deviating settings. Even flight safety considerations do not open all doors as one would presume. As a result, most insight into the spatial and behavioural aspects of bird migration was gathered with low budgets, relative simple means and, in case of radar, old fashion equipment And even nowadays a lot of progress in scientific terms can be made older methods. Fundamental biological knowledge still is a limiting factor with respect of designing warningssystem and procedures.

However, operational implementation of electronic counting systems requires a sophisticated approach because modern radars don't allow simple co-use as they did in the past. Furthermore, a simple index of bird migration intensity is not enough to meet the latest requirements for operational inclusion. At least a three dimensional dataset should be provided. And further details on the species composition with respect of bird weights are also highly desirable. The information provided to the pilots and disseminated internationally should be calibrated. Thus, future applied research should concentrate upon quantitative assessment of bird numbers aloft. Automatic recognition of bird echoes by means of pattern analysis algorithms is a first step. Further improvements can be expected neural network technology. This will make echo extraction faster and less critical. Learning the neural network recognizing bird echoes by offereing examples is another potential advantage. Artificial intelligence may help to recognize temporal patterns in the process of day to day bird activity. However, all these challenges of the future should not let us forget that most decision makers don't have the slightest idea of what is going on high up in the air. Therefore, simple means should be applied when ever possible and be paralled by process of permanent education.

7. LITERA

Alerstam T. &
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Edwards J. &

Gauthreaux

7. LITERATURE

Alerstam T. & Ulfstrand S. 1972. Radar and field observations of diurnal bird migration in Southern Sweden, autumn 1971. Ornis Scandinavica 3:99-139.

Becker J. & Van Raden H. 1985. Grundlagen der radarornithologie und ergebnisse der radarvogelzugbeobachtung in Munchen 1981 - 1983. Vogel und Luftverkehr, sonderheft 1.

Bruderer B. 1971. Radarbeobachtungen uber den Fruhlingszug im schweizerischen Mittelland. Orn. Beob.68:89-158.

Bruderer B. 1988. Electronic recording of bird tracks and bird numbers by tracking radar. Madrid BSCE 19 / wp 41.

Buurma L.S. 1977. Over trekvogels tijdens de vlucht. Waddenbulletin 12:330-337

Buurma L.S. 1984. Key factors determining bird strike and risks. Int. J. of Aviation Safety Vol 2:91-107.

Buurma L.S. & Van Gasteren H. 1989. Trekvogels en obstakels langs de Zuidhollandse kust. report Prov. South Holland, 117 pp. (Eng. summary).

Buurma L.S., Dekker A. & Brom T.G. 1986. Uber die raumliche und zeitliche Verteilung der an Vogelschlagen der Niederlandischen Luftwaffe beteiligten Vogelarten. Vogel und Luftverkehr, band 6, heft 1:12-28.

Buurma L.S., Lensink R. & Linnartz L.G. 1986. Hoogte van breedfronttrek overdag boven Twente: een vergelijking van radar en visuele waarnemingen in oktober 1984. Limosa 59: 169-182. (Eng. summary).

Buurma L.S. 1987. Patronen van hoge vogeltrek boven het Noordzeegebied in oktober. Limosa 60:63-74. (Eng. summary)

Clausen P. 1973. The FAUST system. Paris. BSCE.

DeFusco R.P., Larkin R.P. & Quine D.B. 1986. Bird hazard warning using next generation weather radar. Copenhagen BSCE 18 / wp 7.

Dupont G. 1986. B.O.S.S. - Bird Observation System Semmerzake, further steps and improvements. Copenhagen, BSCE 18 / wp 16.

Eastwood E. 1967. Radar ornithology. Methuen, London.

Edwards J. & Houghton E.W. 1959. Radar echoing area polar diagrams of birds. Nature 184:1059.

Gauthreaux S.A. 1970. Weather radar quantification of bird migration. Bioscience 20:17-20.

Gehring W. 1963. Radar- und Feldbeobachtungen uber den Verlauf des Vogelzuges im Schweizerischen Mittelland: Der Tagzug im Herbst. Orn. Beob. 60:35-68.

Hunt F.R. 1974. Memorandum on radar trials: Winnipeg International Airport. Frankfurt BSCE.

Hunt F.R. 1975. Automatic warning of hazardous bird conditions. Stockholm BSCE 10 / wp 33.

Larkin R.P. & Quine D.B. 1988. Recognizing bird targets on next generation weather radar. Madrid. BSCE 19 / wp 15.

Larkin R.P. & Quine D.B. 1989. Report on bird hazard algorithm. Illinois Natural History Survey report no. 14-16-0009-87-1221.

Leshem. Y. 1988. Following soaring bird migration from the ground, motorized glider and radar at a junction of three continents. Madrid, BSCE 19 / wp 13.

Nisbet I. 1963. Quantificative study of migration with 23- centimeter radar. Ibis 105:435-460.

Ockeloen M.W. & Van de Heuvel W.C.J. 1983. Onderzoek naar de mogelijkheden tot verbetering van automatische detectie van vogeltrek uit radarbeelden. Leok rapport TR 1983-12.

Oranje J. & Blokpoel H. 1966. Fotografische registratie van vogelbewegingen via radar. rapport RNLAF WO-132.

Richardson W.J. 1979. Radar techniques for wildlife studies. Nat. Wildl. Fed. Sci. Tech. Ser. 3, pp.171-179.

Riemens R.G. 1971. Onderzoek naar de geschiktheid van de SGR-109 radar met betrekking tot de vogeltrekregistratie. rapport RNLAF WO-194.

Schaefer G.W. 1968. Bird recognition by radar; a study in quantitative radar ornithology. In: The problems of birds as pests. Murton & Wright (eds). Academic Press, London, pp. 53-86.

Schaefer G.W. 1969. An airport bird detection radar for reducing bird hazards to aircraft. World Conf. on bird hazards to aircraft, Kingston, Canada.

Skolnik M. 1980. Introduction to radar systems (2nd edition). McGraw-Hill, New York.

Thorpe J. 1983. Anbalysis of bird strikes to UK registered aircraft 1981. Safety data retrieval / analysis report nr. 83/91. CAA, UK.

Vaugn C.R. 1985. Birds and insects as radar targets: a review. Proc. IEEE Vol. 73. No 2: 205-227.

Williams T.C., Settel J., O'Mahoney P. & Williams J.M. 1972. An ornithological radar. Am. Birds 26:555-557.

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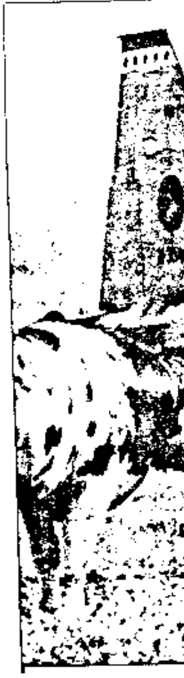

NF-5 grounded after collision with Racing pigeons, 4 may 1990, Holland.