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The European Space Agency´s FlySafe project, looking at the bird strike problem from another perspective.

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The bird strike problem is a negative side effect of the aerial mobility of both aircraft and birds. A successful prevention strategy should therefore be based on knowledge of the mobility of both parties involved. While we know all the details of aircraft mobility, surprisingly little is known about the mobility of birds.
Most bird strike prevention on-airfields assumes that birds on the airfield will at some time fly and thus are considered a threat for starting or landing aircraft. Nearly all prevention efforts are therefore aimed at reducing the number of birds on airfields. The fact that, despite increasing efforts, the bird strike ratio (bird strikes per 10.000 air traffic movements) in many countries hardly decreases anymore is an indication that new approaches are needed.
The FlySafe project of the European Space Agency is such a new approach, aimed at increasing the knowledge of bird mobility and making this knowledge available for operational use by military and civil aviation.
Between 2002 and 2005 the RNLAF, University of Amsterdam (UvA) and the Dutch Centre for Field Ornithology (SOVON) worked together to develop the Bird Avoidance Model (BAM) (Bouten et al. 2005; Shamoun-Baranes et al. in press). This resulted in a bird migration forecast model for Northern Netherlands that is used within the RNLAF (Van Belle et al. 2007) in combination with ad-hoc radar measurements of bird migration to avoid bird strikes during low-level training missions.
Inspired by the BAM project, the ESA (European Space Agency) FlySafe project is aimed at further improving flight safety across national borders through several activities which together will create an integrated bird warning system. Since bird and aircraft movements are not restricted by national boundaries it also includes facilitating international cooperation and working towards standardization. The activities include improving bird migration models, adding altitude information to them, extending the spatial coverage of models and combining them with measurements into automatically generated now casts. These then will be automatically broadcasted to the pilots as BIRDTAM´s.
FlySafe is testing different potential sensors to monitor bird movements at different scales. One of the sensors being tested is a small scale dedicated bird radar system for the detection of local bird movements around airfields. In the future this should provide warnings to air traffic control and bird control units, enabling them to take timely action. Other sensors being tested include weather radars and satellite tracking of individual birds. The project also includes efforts to calibrate bird migration information extracted from military air defence radars by the ROBIN (Radar Observation of Bird Intensity) system with that of the German BIRDI (Bird Radar Data Interface) system.
Finally all these separate information sources are merged in a system of systems to create a more complete picture of bird mobility for the user.
The nucleus of the current activities is the area of Northern France, Belgium and the Netherlands. We hope that through future expansion the system can become pan-European.
This paper gives a broad overview of the project.

OUTLINE

In 2006 the European Space Agency (ESA), in their Integrated Application Promotion program (IAP), defined the FlySafe project aimed at the prevention of bird strikes. This paper describes the extent of the FlySafe project. Using data from the European Military Bird Strike Database (Dekker & van Gasteren 2005) the nature of the bird strike problem is explained. On the one hand there is the local, on/near airfield situation which has to be dealt with by both civil and military aviation. On the other hand the low level, en-route situation is confined to altitudes which are below the normal air layers in which commercial civil aviation is concentrated and is therefore a nearly exclusive military problem.
Both parts of the problem require different approaches, which are summarized in the FlySafe objectives. From there on the paper is split into two parts. First the joint civil/military, on/near airfield situation will be dealt with while in the second part the military, low level, en-route situation is described. The paper ends with a view beyond the present FlySafe project when both approaches can cross-fertilize each other and are complemented with space based sensors.

THE NATURE OF BIRD STRIKES

Plotting the proportional distribution of bird strikes of NATO jet fighter aircraft in Europe for different speeds, using data from the European Military Bird Strike Database (Dekker & van Gasteren, 2005) reveals a typical bimodal distribution (figure 1). Low speed bird strikes predominantly occur on or near airbases (local) while high speed strikes are happening during cruise at lower altitudes (en-route). Since civil aviation normally cruises at altitudes above the bird rich air layers, the civil bird strike problem is predominantly a local one, while military aviation has to deal with the additional low-level, en-route situation for jet fighters. Because of the higher speeds, the proportion of bird strikes resulting in damage in the en-route situation (48%) is about twice as high as in the local strikes (23%). On the other hand, the chance of a local bird strike turning into a major accident is much higher, especially during take-off. (Dolbeer 2007; Dolbeer 2008).

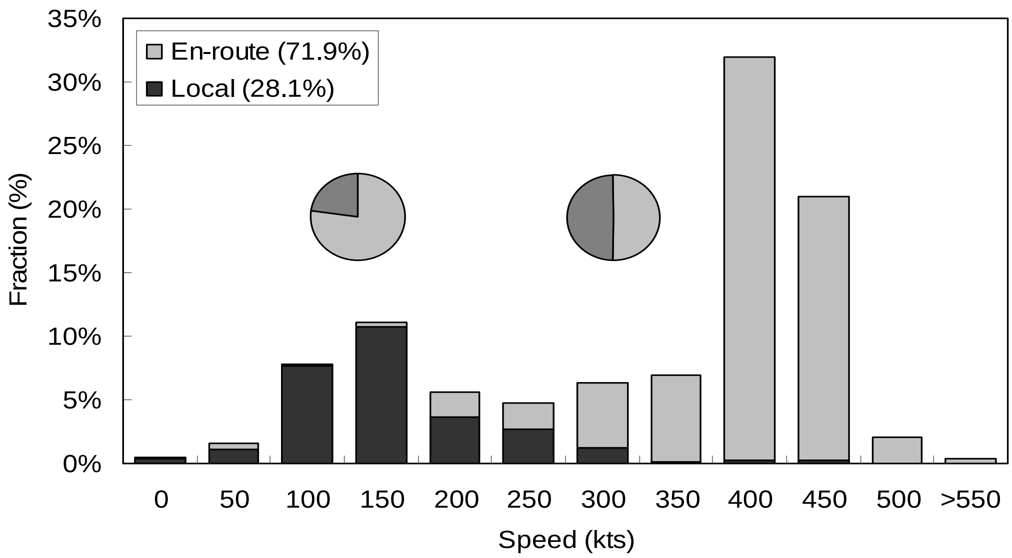

Figure 1: Proportional distribution of local and en-route bird strikes for different speeds of military fast jets (N=17,732). Proportion of damage during the two different flight phases is indicated by dark grey in the inserted circles. Data taken from the European Military Bird Strike Database.

THE OBJECTIVES OF THE FLYSAFE PROJECT

The aim of the FlySafe project is to reduce the impact of bird strikes on military aviation both locally and en-route by combining terrestrial and space based assets, with the potential of expanding services to civil aviation. In order to realize this three objectives are defined.

Airport vicinity*: Development of a small scale (mobile) radar for monitoring on-airport and airport vicinity bird movements. Such a small scale radar should have the following specifications: detection range of 6-7 km for a gull sized bird, altitudes up to 2 km, automatic bird detection and tracking facilities with the option to discriminate between small and large bird echoes as well as discrimination between birds and all other targets. Data is stored in a database to monitor hourly, daily and seasonal movements.*

Bird density measurements and now casts: *Make the existing ad-hoc BIRDTAMs*[1] *expert-independent and robust by nowcasting, provide data quality measurements, improve bird altitude information, integrate systems of neighbouring countries (calibration and validation), visualization (temporal and spatial information), development of automatic BIRDTAM generation for aviation use and data security.*

Bird intensity forecast*: Hourly forecasts of bird migration intensity (echo density) throughout the whole year (24/7) for the area of the Benelux plus Northern France. This also implies altitude information. The forecasting period is +48 hours. Forecast models for non-migratory bird movements, mainly during summer, are also developed. Not only actual meteorological forecasts are used as input for the models but also measured, calibrated radar sensor bird densities. Collection of weather information and radar data as inputs for the forecast models should be automatic. The area in-between the different (radar) sensors is interpolated over similar landscapes within the FlySafe area.*

In cooperation between ESA and the air forces of Germany, Belgium, France and the Netherlands, the basic activities of the FlySafe project started in the autumn of 2006. Initial efforts focussed on the exploration of the problems and definition of the user requirements. Since then the following preliminary work was done:

- testing of a pre-operational version of ROBIN Lite;
- construction of a centralized information system for all data needed in the project (meteorological, radar measurements (from different radar systems), landscape, GPS bird tracks);
- automatic quality assessment of radar data and development of algorithms for correction;
- testing of weather radars as extra bird sensors;
- GPS logging of individual birds (to acquire 3-D spatial information needed for modelling bird movements);
- first attempts to calibrate the German system against the ROBIN system.

Following the approval of the Integrated Application Promotion program at the next ESA Ministerial Conference (The Hague, 25-26 Nov 2008) and the approval of the FlySafe follow-on by the member states involved in this project, the second phase of the project will start in January 2009. After three years the project should yield sustainable operational services for flight safety.

The FlySafe project has a system of systems approach and encompasses four main elements: (1) sensors; (2) data collection network; (3) data storage, post-processing and modelling; and (4) data distribution and visualization in sustainable services. An overview of the FlySafe system of systems is given in figure 2.

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[1] The BIRDTAM is a message originated by military services based on a NATO standard that provides spatial information about the bird strike risk. Regulations make pilots avoid those areas that have an increased bird strike risk due to high bird densities.

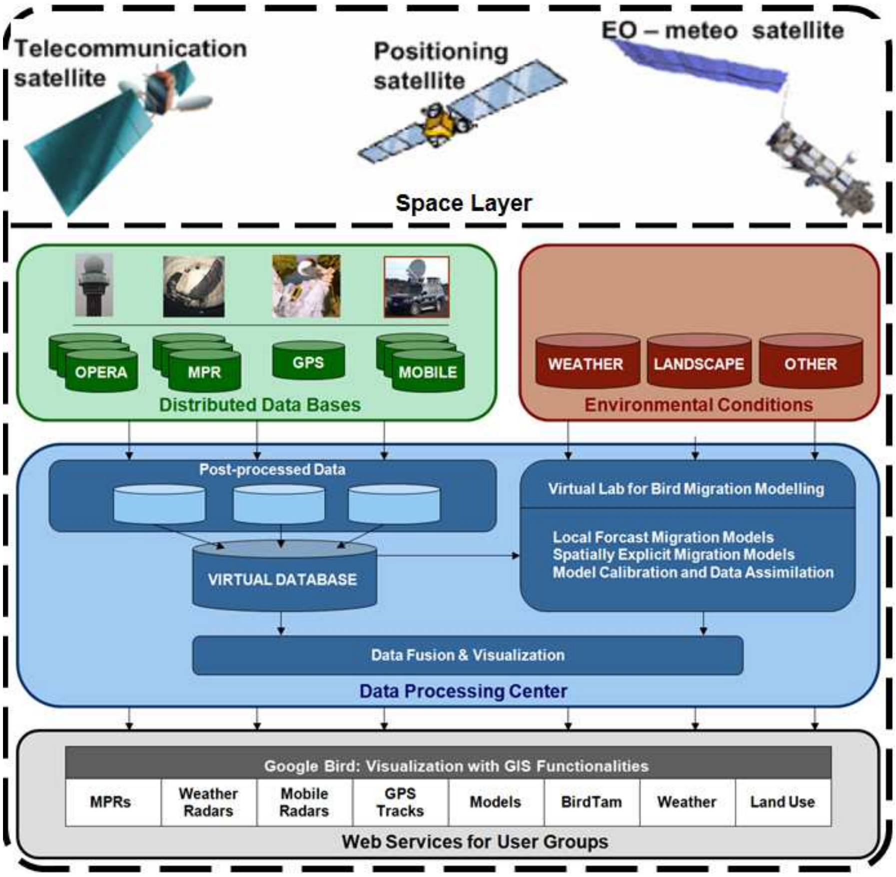

Figure 2: Flysafe system of systems overview. The Flysafe system concept exhibit four main elements: (1) sensors; (2) data collection network; (3) data storage, post-processing and modelling; and (4) data distribution and visualization in sustainable services.

LOCAL, ON/NEAR AIRFIELD BIRD STRIKE PREVENTION

The history of local bird strike prevention

The ever growing volume of civil aviation, combined with the sense that manipulating bird population on airfields is feasible, are responsible for the fact that most efforts in bird strike prevention are focussed at the local, on/near airfield situation. It has traditionally been aimed at reducing the number of birds on airfields. In the 1960´s and 1970´s this was predominantly achieved by chasing away birds from the runway environment. This reactive approach was soon followed by the more pro-active habitat management which is aimed at making an airfield and its surroundings unattractive for birds (Dekker 2000, Dekker 2003). At present, increasing emphasis is put on embedding the known measures and techniques in Safety Management Systems (SMS), legislation and audits (Anonymous 2007a; IBSC 2006). Despite the changes in techniques, and an ever more professional approach, the key strategy is unchanged and aimed at the reduction of bird numbers on airfields. This approach is frequently articulated in unrealistic, sometimes contra productive zero-tolerance policies (Dekker & Buurma 2003) which are based on the presumption that birds in the runway environment may, for whatever reason, start flying and thus interfere with aircraft movements (de Hoon & Buurma 2003).

Trends in local bird strikes

After the introduction of professionally supported bird strike prevention schemes, the number of bird strikes normally decreases considerably, resulting in decreasing bird strikes rates (number of bird strikes per 10.000 ATM (Air Traffic Movements). Despite all efforts there seems to be a lower limit to the number of birds in and around an airfield and hence the bird strike rate of an airfield. In line with the law of diminishing returns reducing the bird strike rate below this lower limit is often extremely difficult and prohibitively expensive. This lower limit does vary between airfields, due to geographical and social circumstances that influence the avifauna for the particular airfield. This means that since the last decades of the 20th century the overall bird strike rate does not show a significant decrease anymore.

During the years 2000 to 2006 bird strike rates in the UK varied between 3 and 5 per 10.000 ATM (Yearwood 2008). This is very much in line with the goal of a maximum of 4 strikes per 10.000 ATM of Amsterdam Airport Schiphol (Anonymus 2008). Although the overall bird strike rates in the United States are considerably lower than in Europe, during the years 1990 to 2007 there is a steady increase from around 0.7 per 10.000 ATM to 1.7 in 2007 (figure 3, Dolbeer & Wright 2008).

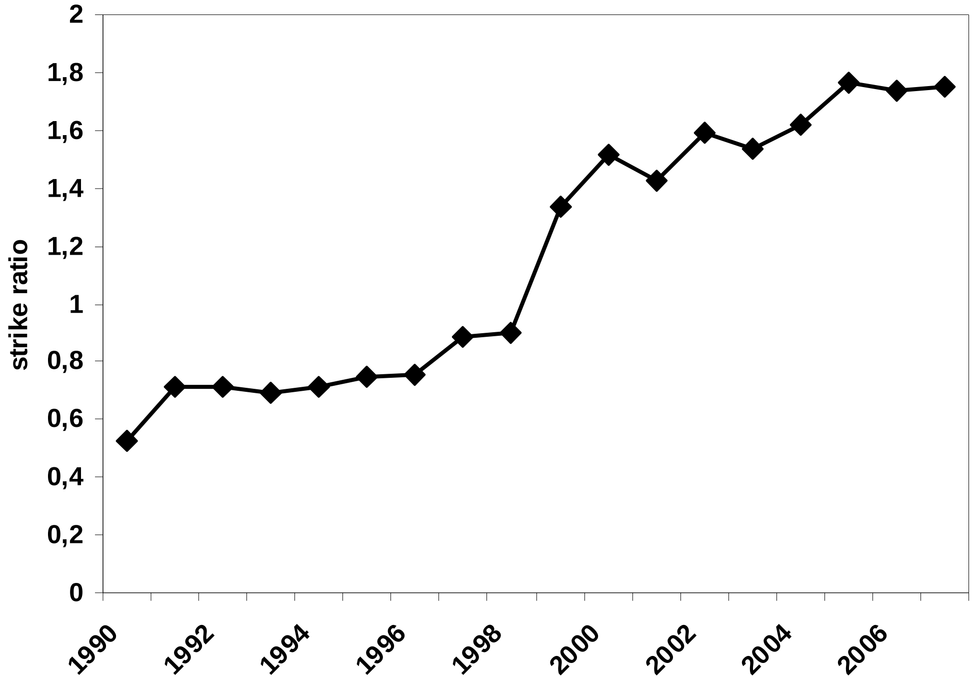

Figure 3: Wildlife strike rate (strikes per 10.000 movements) to civil aircraft, USA, 1990 – 2007, based on 79.972 bird strikes and 1.737 mammal strikes. Data taken from Dolbeer & Wright 2008.

With an expected average yearly increase of ±3% of the Air Traffic Movements for the next decade (Anonymous 2007b) and bird strike rates that are not decreasing, it is to be expected that the absolute number of bird strikes will increase. The impact a bird strike has on an aircraft is related to the speed of the aircraft (squared) and the weight of the bird involved. Aircraft speeds will not significantly change but the populations of many large, heavy bird species are growing, both in de USA (Dolbeer & Eschenfelder 2003, Gauthier et al. 2005) and Europe (Van Eerden et al. 1996; Van Eerden at al. 2005). This means that the proportion of damaging bird strikes will rise. Combined with the increasing number of bird strikes this means that, if no extra prevention efforts are made, the absolute number of damaging bird strikes will increase significantly.

New perspective for local bird strike prevention

In order to counter the expected scenario of more seriously damaging bird strikes it is necessary to re-think traditional bird strike prevention, which is simply aimed at reducing the number of birds present at airfields and their immediate surroundings. For a bird strike to happen, both aircraft and birds have to fly. So, instead of investing all prevention efforts on birds on an airfield that might start to fly, a potentially more successful strategy is aiming directly at flying birds. Air Traffic Control (ATC) controls aircraft activity from one second to the other. If more would be known of bird flight, ATC could really control the traffic in the air, taking into account the presence and trajectories of both aircraft and birds. This would mean a revolutionary change in bird strike prevention. Prevention would no longer be solely dependent on the removal of birds from a large area but precisely aimed at expected interaction of flight paths of both aircraft and birds. As a new, complimentary strategy, ATC could then facilitate bird avoidance by aircraft.

The FlySafe project and the local, on/near airfield bird strike prevention

Landing or departing aircraft always have to cross the lower air layers which might contain high bird densities due to local or regional bird flights or during periods of large scale seasonal bird migration. During starting or landing a pilot is very occupied; it is therefore very difficult to visually observe a flying bird in time to avoid it. Moreover, the relatively low speeds and complex procedures during this flight phase mostly do not allow evasive manoeuvring. Of all the local birds strikes that turned into catastrophes almost none happened during the landing phase, nearly all took place during take-off (Dolbeer 2007; Dolbeer 2008). It is therefore legitimate to state that the best way to avoid major bird related accidents would simply be not to start at those moments that birds might cross the intended trajectories of the aircraft. Often a waiting phase of some tens of seconds is sufficient to let the birds cross in front of the aircraft. If local bird strike prevention is to be precisely aimed at avoiding only those flying birds that do pose a risk to aircraft, a system is needed which measures the exact position of flying birds and projects their flight path in relation to that of the aircraft.

Such a system needs a high resolution 3D bird detection sensor, which covers the aircraft trajectories and a sufficient large area around them. Furthermore the system must be able to provide the projected flight paths of the detected birds on a (near) real-time basis and sufficiently in advance to allow ATC to take action.

Within the FlySafe project the ROBIN Lite system, developed by TNO Defence, Security and Safety, is used. The ROBIN Lite system consists of a standard (X-Band or S-Band) ship radar with the ROBIN bird extracting software that provides real-time bird tracks and densities and a vertical radar using the Frequency Modulated Continuous Wave radar (FMCW) technology providing altitude information. This transmits sweeps of radar energy with low power in stead of radar pulses. Contrary to pulse type radars, the low energy levels of FMCW radars allow this type of radar to be pointed in one direction without any restrictions. The vertical radar can be automatically operated in 3D by the horizontal radar. In effect, this makes the ROBIN Lite concept the only available (non military) search and track bird radar. As the vertical radar can track birds continuously it is also possible to measure the wing beat frequency, which is an indication of the species group. Extensive suppression of ground clutter, using dynamic filters, makes it possible to detect birds down to ground level. ROBIN Lite stores all bird information in a database. This provides the opportunity to increase the understanding of local and regional bird movements around airfields.

There are three major routes along which small scale, dedicated airfield bird radar can contribute to the reduction of the bird strike risk:

- Airport vicinity. Using such a radar as a measuring tool will facilitate a better understanding of the local/regional bird movements. This, in turn, will help to better assess the implications of changes in land use or operational procedures.
- Air Traffic Control: Reliable warnings for bird flocks that are on collision course with the flight path of departing aircraft will enable air traffic controllers to postpone starts for a short while (maximum several minutes).
- Bird Controllers: Timely spatial information on approaching bird flocks will enable bird controllers to be in the right spot at the right time. This would significantly increase their efficiency.

THE MILITARY, LOW LEVEL, EN-ROUTE BIRD STRIKE PREVENTION

The prevention of military, en-route bird strikes

Contrary to the local, on/near airfield situation, the prevention of military, low level, en-route bird strikes is based on the avoidance of birds by the aircraft. This approach is only acceptable and successful in those situations where it is possible to substantially reduce the bird strike risk with only limited operational consequences. In practice this means the avoidance of those air layers only on peak days of mass bird migration, when the bird densities are extremely high. These situations are recognized using radar to detect bird densities in the air. At present there are only a few Air Forces using a real time warning system for en-route bird strike prevention. In NW Europe, radar measurements of Denmark, Germany, Belgium and the Netherlands are combined in the so called BIRDTAM system. Different systems are used to extract the bird information from the radars:

- In Denmark, for more than two decades the Faust system is used. Since there is no insight into the techniques behind this system it is not included (yet) in the FlySafe project.
- In Germany the continually updated and modernized BIRDI[2] system in combination with the visualization tool VoVis (Vogelzug Visualisierung) is used.
- In the Netherlands the continuous use and further refinement of radar information on bird densities is based on the co-operation between RNLAF and TNO. Since 1989 the ROBIN system[3] is operational in use. In 2005 the ROBIN system was adopted by the Belgian Air Force.

Due to fundamental differences between the BIRDI system and the ROBIN system their results are not comparable on a one to one scale. Nevertheless the operational output from both systems is the NATO standardised BIRDTAM in which bird densities are presented on a logarithmic 0 to 8 scale with a resolution of 1 x 1 lat-long degree (figure 4).

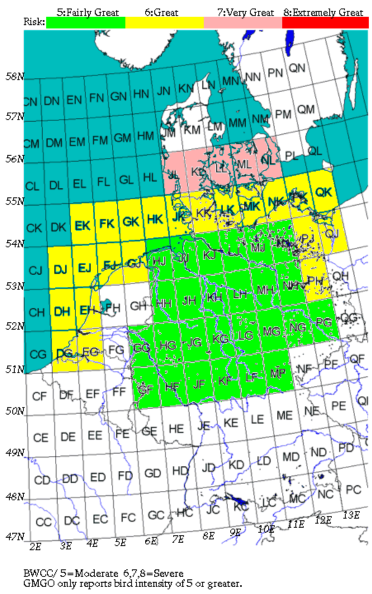

Figure 4: BIRDTAM as published on www. notams.faa.gov/common/birdtam.html. Colors indicate the bird strike risk (see top of figure)

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[2] BIRDI = Bird Radar Data Interface. This system uses processed sensor data which is automatically submitted to the BGIO (Bundeswehr Geo Information Office) in 20 minute intervals for visualization and interpretation.

[3] ROBIN = Radar Observation of Bird INtensities. The system derives the bird data almost directly from the antenna output of Air Defence Radars meaning that no information is lost due to operational filtering. It consists of a Registration System (RS) at the radar and dislocated Presentation Systems (PS) for visualization and interpretation.

Both the BIRDI and the ROBIN system need extensive expert interpretation. Due to frequent periodical radar maintenance and meteorological disturbances of the radar signal these systems are not robust enough to continually cover the whole area. Altitude information is directly available in the BIRDI system but only indirectly in the ROBIN system.

The success of en-route bird strike prevention based on radar detection of mass bird movements is beyond question. The remarkable decrease in en-route bird strike ratio in the RNLAF (figure 5) since 1990 coincided with a radical change in operations and the introduction of the ROBIN system. Although it is difficult to disentangle the contribution of both factors there are indications that the introduction of the ROBIN system considerably contributed to this decrease. The dependency of the system on human, expert interpretation, as well as interpolation (in case of non-availability of data) makes that the basis of the success is only a narrow one. The dependency of the system of the extended expertise of only a few people makes it vulnerable. Ideally the BIRDTAM system should rely on automatically generated nowcasts of the bird intensity. These nowcasts can be realised by running a bird migration model parallel to the measurement, thus filling in gaps in space and time. This also prevents conflicting BIRDTAMs along borders due to differences in interpretation and/or bird detection systems.

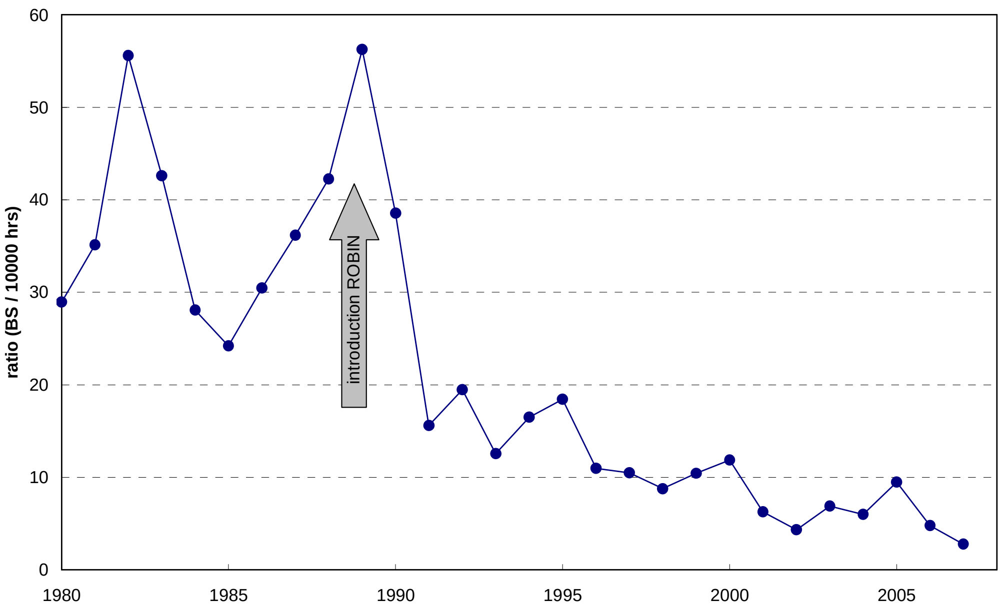

Figure 5: Bird strike ratio (strikes per 10.000 flying hours) for RNLAF fast jet fighters 1980 – 2007. The ROBIN system was introduced in 1989. Note that the decrease in bird strike ratio is a combined result from changing operations and the introduction of ROBIN.

Another badly needed operational extension of the present system is a reliable operational forecast. Present systems are based on ad-hoc measurements and generate immediate flight restrictions to pilots. This means unplanned loss of preparation time and loss of exercise opportunity that has to be compensated for at other times. In the case of planned night exercises a whole airbase is kept open for hours, the sudden cancelling of flights then results in substantial economic loss and frustration.

Between 2002 and 2005 the RNLAF, University of Amsterdam (UvA) and the Dutch Centre for Field Ornithology (SOVON) worked together to develop the Bird Avoidance Model (BAM) (Bouten et al. 2005; Shamoun-Baranes et al., in press). This resulted in a bird migration forecast model for Northern Netherlands (figure 6).

This model is used by the operators of the ROBIN system as an additional source of information on which the BIRDTAM is based (van Belle et al. 2007). The model is also used to timely inform pilots of expected bird intensity, especially for night exercises. The limited spatial area for which this model was developed as well as the course resolution in time inhibits the full operational use without expert interpretation.

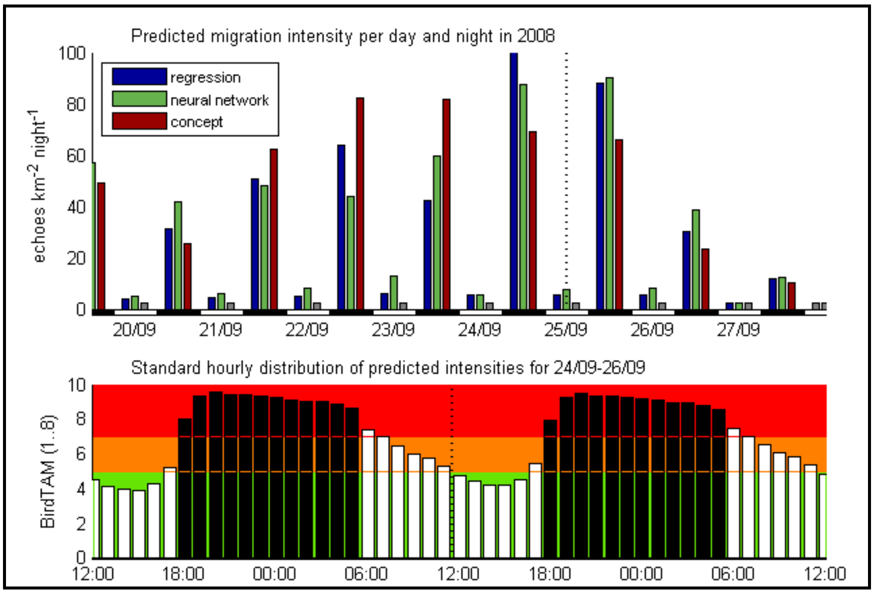

Figure 6: Bird Avoidance Model (BAM, https://www.bambas.ecogrid.nl/migration) output showing the total nightly bird densities as predicted by three different models for the past 5 and the coming three nights (top). The hourly break down for the previous and the next 24 hours (bottom) is generated by a disaggregation of the predicted total volume of night migration.

The FlySafe project and the low level, en-route military bird strike prevention

Improvements in the FlySafe project of en-route bird strike prevention by BIRDTAM´s are not primarily aimed at the further reduction of the already low en-route bird strike rates but concentrate on:

- Making the existing system automatic, person independent, robust and 24/7 operational;
- Add more reliable altitude information to the BIRDTAM´s;
- The use of more sensors to get a better geographical coverage;
- Increasing the temporal and spatial resolution of forecasts;
- Coupling the models and measurements into nowcasts.

FlySafe aims at covering the area depicted in figure 7; using ROBIN equipped Air Defence radars. The resulting nowcasts, together with measurements of the German system, will lead to more harmonized BIRDTAM´s that need far less human interpretation, are more reliable and available 24/7 (see chapter FlySafe extensions).

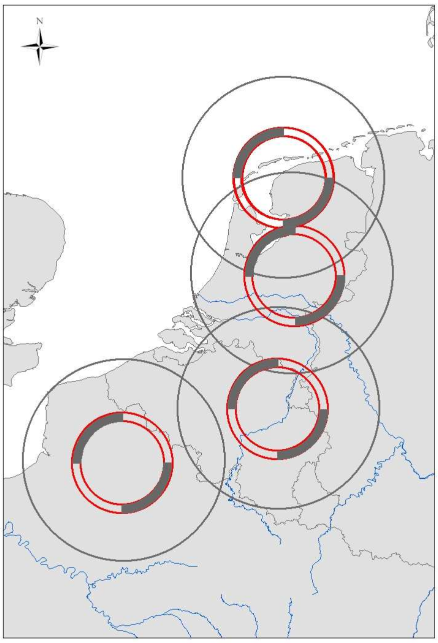

Figure 7: Area of the Flysafe nucleus. The large circles denote the maximum detection range for birds (150 km) of the four military long-range surveillance radars. Standardized measurement windows (50-60 km range, 90-180 and 270-360 degrees azimuth) for quantitative bird densities are indicated by dark grey segments.

The use of weather radars

One drawback of the present systems is that it relies on radar measurements of only a limited number of Air Defence Radars. One potential source of sensors that covers large areas of Europe is the network of weather radars (figure 8b). After a preliminary study in which data from the De Bilt weather radar was compared with ROBIN data (van Gasteren et al. 2008) the Royal Dutch Meteorological Institute (KNMI) has further explored the potential of operational C-band Doppler weather radar as a bird migration sensor. A bird migration recognition algorithm has been developed, extracting bird density, speed and direction as a function of altitude. The weather radar data have been validated against simultaneous and co-located bird density measurements by a high precision bird radar, designed for research purposes which was provided by the Swiss Ornithological Institute (SOI). This mobile tracking radar has been stationed next to weather radar sites in the Netherlands, Belgium and France during the peak bird migration season in autumn 2007 and spring 2008. The mobile tracking radar is capable of detecting and discriminating bird echoes with a high accuracy, providing additional bird species information by analysing wing beat frequencies observed in bird echoes, making it an ideal reference for validating the weather radar observations (for more details see the Liechti et al. paper from this meeting).

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The Doppler weather radar appeared highly successful in determining quantitative bird densities as a function of altitude (Holleman et al. 2008; Van Gasteren et al. 2008). A quantitative correspondence in observed bird-densities is found between the weather radar and dedicated bird radar (figure 8a). There is great potential for using the existing European weather radar network (OPERA - Operational Programme for the Exchange of weather RAdar information, consisting of over 180 radars, see http://www.knmi.nl/opera) for observing bird movements. This sensor network will open up the possibility of monitoring large scale bird movements on a continental scale, thereby greatly improving the predictability of the occurrence of large bird concentrations at specific times and locations.

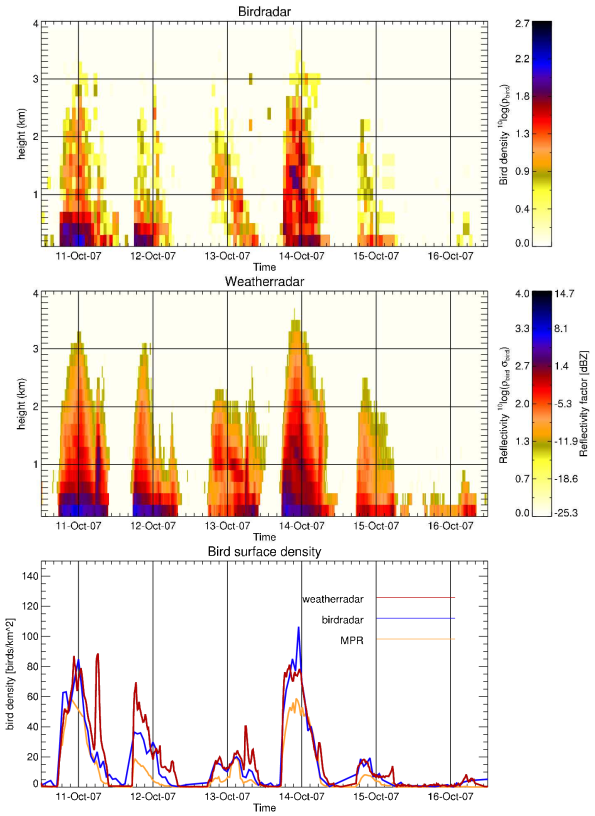

Figure 8A: (left): Comparison in time and altitude of bird echoes as detected by the dedicated bird radar of the Swiss Ornithological Institute (SOI) (top) and the weather radar (middle). The bottom graph shows the detected volume of bird migration (regardless of altitude) for the SOI bird radar, the weather radar and the ROBIN equipped Air Defence Medium Power Radar (MPR).
8B (right): The European OPERA network of weather radars.

The development of models

Models will play a central role in the FlySafe system of systems. Bird movement models play several roles in general and specifically in the context of flight safety such as:

- models provide a means to communicate system processes to a multidisciplinary team;
- models present an expectation under normal conditions and can facilitate the identification of unusual events;
- models provide a formal framework for integrating data and expert knowledge;
- measurements of bird movement are very limited in space and time and these gaps can be filled using models (nowcasts);
- models can be used to provide predictions for flight planning.

Within the context of FlySafe we will be continuing the development of forecast migration models which describe and predict the temporal dynamics of migration at different radar locations in relation to meteorological conditions. The data used to develop these models has improved since the first operational model was developed (Van Belle et al. 2007). Perhaps more importantly, data is also available for multiple radar sites. Therefore a modelling workflow will be developed and tested, enabling the relatively seamless development of new models as data becomes available for more sites. Although temporal migration patterns in the Netherlands are rather well documented over several years, little information is available on flight altitudes. Weather radar may be able to fill this gap. Therefore preliminary work will be done to model flight altitude dynamics during migration. In addition, spatially explicit agent based migration models are being developed. These models incorporate rules and external factors such as habitat quality, topography and meteorological conditions to describe migration at a continental scale. One of the important aspects of all modelling activities in FlySafe is to develop extendible modelling frameworks that can cope with new data as it becomes available. This will reduce the modelling effort needed as FlySafe expands to include new data sources and countries.

The use of NAV data for track and trace of tagged birds (ARGOS services) for modelling

If bird strike prevention is to be lifted to a new level, more knowledge on bird flight behaviour is needed and has to be included in the models for now- and forecasting. Answers to the following questions are needed:

- what proportion of their time do birds fly and how does this vary between species;
- what is the seasonal and daily fluctuation in time spent flying;
- what are the factors that make birds fly;
- at what altitudes do birds generally fly;
- what are the conditions and circumstances that determine their flight altitude and
- do birds have preferred flight routes during local movements which can be predicted?

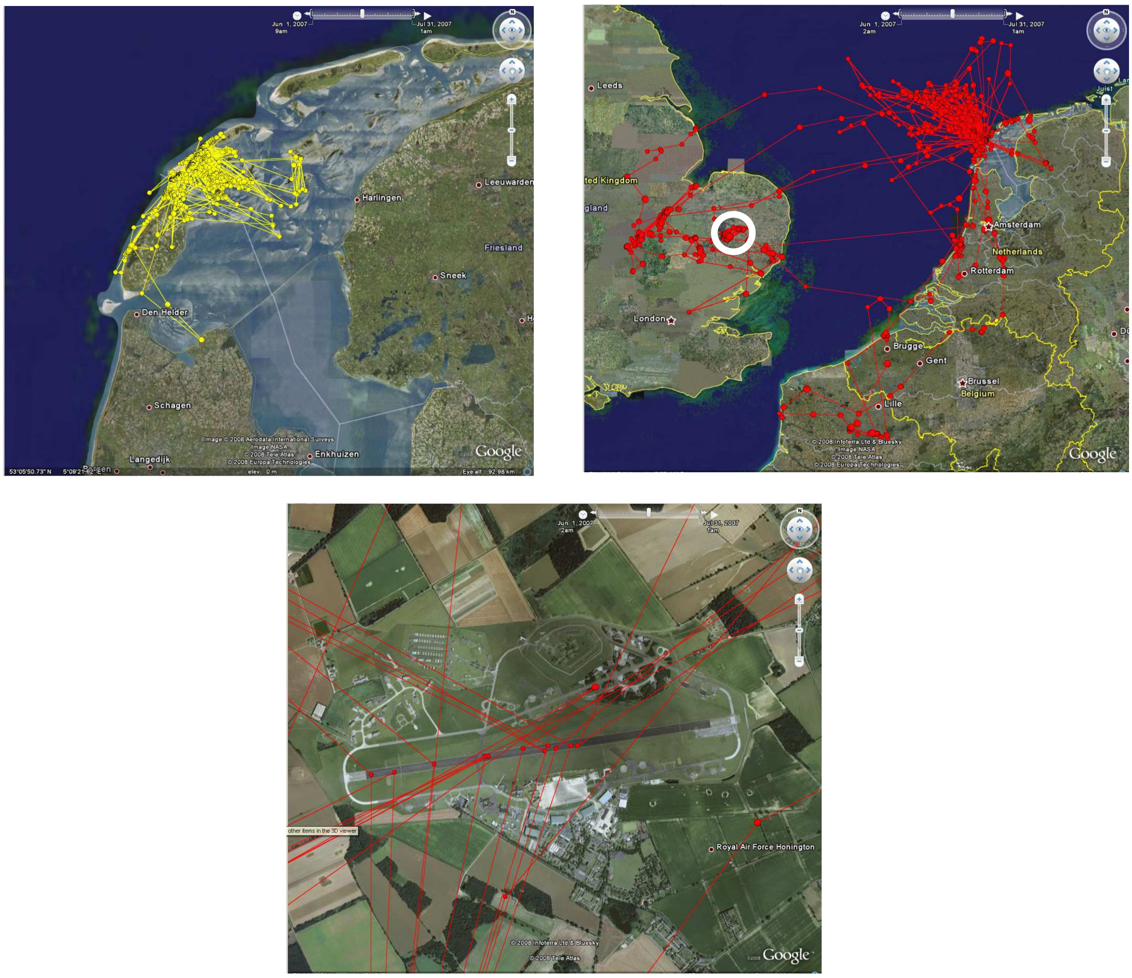

Figure 9: GPS fixes from 5 Herring Gulls (left) and 5 Lesser Black-backed Gulls (right) during June and July 2007 breeding at the Waddensea island Vlieland. The fixes in the white circle (right) are from a trip of Lesser Black-backed Gull nr. 41757 which frequented the disused Royal Air Force base Honington (bottom).

The only way to get insight in these questions is by tracking individual birds using GPS. The basic FlySafe activities therefore included explorative work (Ens et al. 2008) with GPS Platform Transmitting Terminals (PTT) transmitters attached to:

- breeding Herring Gulls (*Larus argentatus*) on the island of Vlieland (wintering in the Netherlands);
- breeding Lesser Black-backed Gulls (*Larus fuscus*) on the island of Vlieland (wintering in Spain) and
- wintering Barnacle Geese (*Branta leucopsis)* caught in the coastal area of Northern Netherlands.

Apart from a wealth of methodological experience on the capabilities and limitations of GPS PTT´s, already a lot of new insight was acquired. In the subproject in which individually tracked birds were linked to a ROBIN equipped radar in the North of The Netherlands it was found that gulls spent most of their time (78%) on the ground. Flying occurred mainly at low altitudes (only 3.7% of the GPS fixes above 75 meter). Due to these low altitudes and the decreasing radar detection with distance, only very few GPS equipped gulls could be located by the ROBIN equipped MPR radar. The main conclusion is that most of the flight activity of the gull species is not detected by this radar. Existing, solar powered GPS PTT technology was proven to provide useful species and individual information that could not be provided by any other sensor.
As an example the completely different foraging behaviour of both gull species is presented in figure 9. Herring Gulls only moved over relatively short distances and almost exclusively used the Waddensea and not the Waddensea. Lesser Black-backed Gulls on the other hand made long distance feeding flights which could last for several days and were predominantly over the North Sea, sometimes as far as inland UK.

FLYSAFE EXTENSIONS

The end products

The FlySafe project should result in a sustainable, operational, automatic, 24/7 service for the dissemination of bird migration warnings and forecasts in the core area of the FlySafe project. This service is primarily aimed at the prevention of bird strikes in military en-route, low level operations at minimum operational impact. The architecture of this service should be of such a nature that it easily allows for the extension of the covered area.
Within FlySafe the IBIS application (International Bird Information System) will be developed in which the FlySafe nowcast will be integrated with the results from the German BIRDI system.

At the end of the project there should also be an operational small scale (mobile) radar available for monitoring on-airport and airport vicinity bird movements. The use of such an instrument is not limited to military aviation but will be of importance for civil aviation.

The use of space based sensors.

Radars will never be able to cover the complete area of NW Europe for all bird activity. Due to the fact that migrating birds mostly select a specific altitude band, radar beams close to the radar site will be sampling the air layers below the flying birds while at further distance the beam is sampling above the birds (figure 10). Furthermore, the capability to detect small echoes of birds decreases with distance. Of course, with a dense network of radars the interpolation of uncovered areas can be predicted, using models. Such a network is not principally limited to one specific kind of radar but could include air defence radars, dedicated airfield bird radars and weather radars. Another approach in covering larger areas that will be explored within future FlySafe activities is the use of space based sensors that are able to detect mass bird movements. This would be a particularly beneficial information source in

areas that are not covered by radar. For instance, the detection of departing mass bird migration from Scandinavia could act as an early warning for expected bird activity in the core area of FlySafe. Within ESA an exploration of the potential of space based sensors is foreseen as part of the FlySafe project.
Another important contribution of space based sensors is to be expected from Earth Observation sensors which provide information on factors that influence bird movement. This kind of information is if great importance for the spatially explicit agent based modelling.

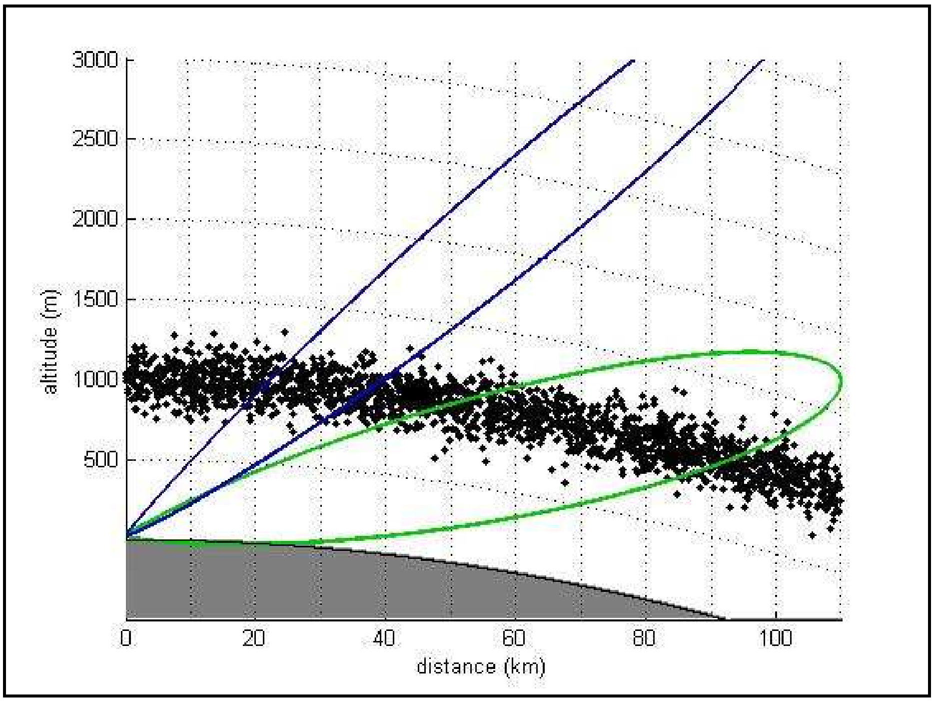

Figure 10: Radar coverage diagram showing the limited 3D coverage when birds are concentrated in specific air layers. Black dots denote birds concentrated at 1000m altitude.

Cross fertilization

At the end of the FlySafe project there will be two systems for the prevention of bird strikes. One based on a small scale, dedicated bird radar providing information on local and regional bird mobility on and near military and civil airfields. The other system is based on air defence and weather radars in combination with models and aimed at detection and forecast of large scale bird movements, mainly during the migration seasons and specifically meant for military, low level, en-route aviation. Since an airfield bird radar is also able to detect large scale bird migration it would be obvious to integrate the information from these small radars in the system that provides military, low level, en-route with BIRDTAMs. Likewise, a local, on airfield bird strike prevention system could benefit from the information on large scale movements as detected by air defence and/or weather radars as well as models of local bird movements.

With the products from the FlySafe project as a start, all the ingredients are available for the development of a sophisticated system of systems in which both approaches cross fertilize each other and thus yield a better product for both types of users. If space based detection of mass bird movements proves feasible there could even be a system in which three layers of detail are integrated.

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