SCOTTISH
NATURAL
HERITAGE

guidance

WINDFARMS AND BIRDS:
Calculating a theoretical collision risk assuming no avoiding action

Windfarms may impact on ornithological interests in a number of ways. There may be:

- loss of habitat, due to the construction of turbine bases and tracks
- displacement of birds as a result of disturbance
- potential mortality through collision.

SNH Guidance note describes a methodology for assessing in full the impact of windfarms on ornithological interests, taking account of each of these effects. The methodology includes a two-stage process for the assessment of collision risk.

More detailed prescriptions for use in the second stage of that collision risk assessment are set out here. It sets out how to estimate a 'no-avoidance risk', ie the rate of collision assuming that birds fly as if the wind turbine structures and rotors were not there and take no avoiding action whatsoever. It is assumed that if a bird is hit it is killed, whether immediately or through injury.

Avoidance

In practice, most birds do take avoiding action: they may detect either an entire wind farm array, or an entire wind turbine, and alter their flight lines such as to avoid the structures; or they may at close quarters see an oncoming blade and take emergency avoiding action. The result of a no-avoidance calculation must therefore be moderated by an 'avoidance factor' which represents the (often high) proportion of birds which are likely to take effective avoiding action. However the data available on avoidance factors is limited, and often relates to topographic and climatic conditions which differ from most Scottish windfarms, and to species not common in Scotland. The difficulties of collecting such data are also considerable. It can rarely be assumed that all collisions have been detected, because of scavenging losses, injured birds escaping from the search area, or because of rough ground or tall vegetation. A precautionary approach is recommended when basing an avoidance factor on available data. Greater significance can be attached when data from a number of comparable sites yield similar conclusions.

The remainder of this note assumes no avoiding action.

No-avoidance collision risk

The aim, normally, is to estimate the number of bird collisions over a period of time such as a year. The calculation proceeds in two stages:

Number of birds colliding per annum =
number flying through rotor (Stage 1) x
probability of bird flying through rotor being hit (Stage 2)

Stage 1: Number of bird flying through rotors

There are two standard approaches which may be appropriate depending on the species and flight behaviour. Usually the detailed method of calculation set out below will have to be modified in some way to make best use of the available data. If the flight data available is detailed, the approach below may be refined by considering separately different sectors of the wind farm area, or different seasons of the year when the flight behaviour may differ, or different scenarios such as when site-faithful birds are breeding. However, in most circumstances the following can guide the general approach.

1. Regular flights through a windfarm

The first approach is where a bird population makes regular flights through the windfarm, possibly in a reasonably defined direction. This applies for example to over-wintering geese making their twice-daily flights from roost to feeding areas, within habitually-used flight corridors; or to divers making regular feeding trips from hill lochan nest sites to the coast.

1. Identify a 'risk window' ie a window of width equal to the width of the windfarm across the general flight direction of the birds, and of height equal to the maximum height of the highest turbine (see Fig 1). The cross-sectional area W = width x height.

2. Estimate the number of birds n flying through this risk window per annum, ie flock size x frequency of flight. Make allowance in the flock size for occasions on which birds which may fly higher than this risk window and for the fact that the risk window may only straddle a proportion of the overall flight corridor used by the birds.

3. Calculate the area A presented by the wind farm rotors. Assume the rotors are aligned in the plane of the risk window as, to a first approximation, any reduction in cross-sectional area because the rotors are at an oblique angle is offset by the increased risk to birds which have to make a longer transit through the rotors. Where rotors overlap when viewed in cross-section, allow for the full cross-sectional area of separate rotors as the risk to birds is doubled if passing through two successive rotors:

   $A = N \times \pi R^2$ where N is the number of rotors and R is the rotor radius

4. Express the total rotor area as a proportion A / W of the risk window.

5. Number of birds passing through rotors = number of birds through risk window x proportion occupied by rotors = n x (A / W)

Birds using the windfarm airspace

The second approach (se Fig 2) is most appropriate for birds such as raptors which occupy a recognised territory, and where observations have led to some understanding of the likely distribution of flights within this territory.

1. Identify a 'flight risk volume' V_w which is the area of the windfarm multiplied by the height of the turbines.

2. Calculate the combined volume swept out by the windfarm rotors

   $V_r = N \times \pi R^2 \times (d + l)$ where N is the number of wind turbines, d is the depth of the rotor back to front, and l is the length of the bird.

3. Estimate the bird occupancy n within the flight risk volume. This is the number of birds present multiplied by the time spent flying in the flight risk volume, within the period (usually one year) for which the collision estimate is being made.

FIG 1: BIRDS FLYING THROUGH WINDFARM

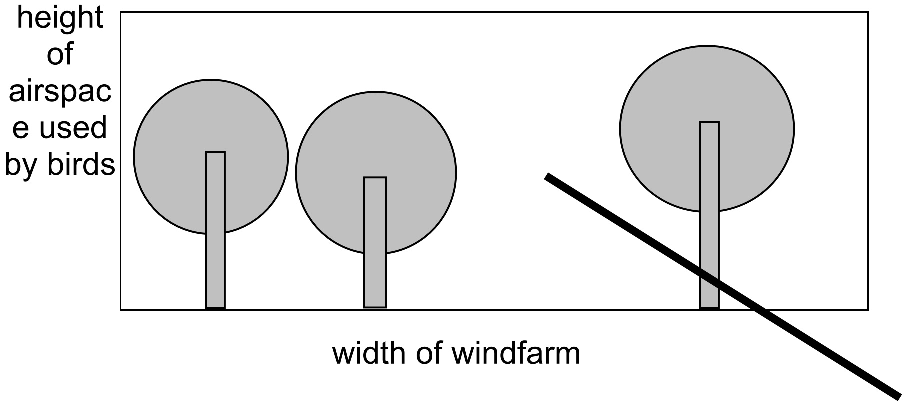
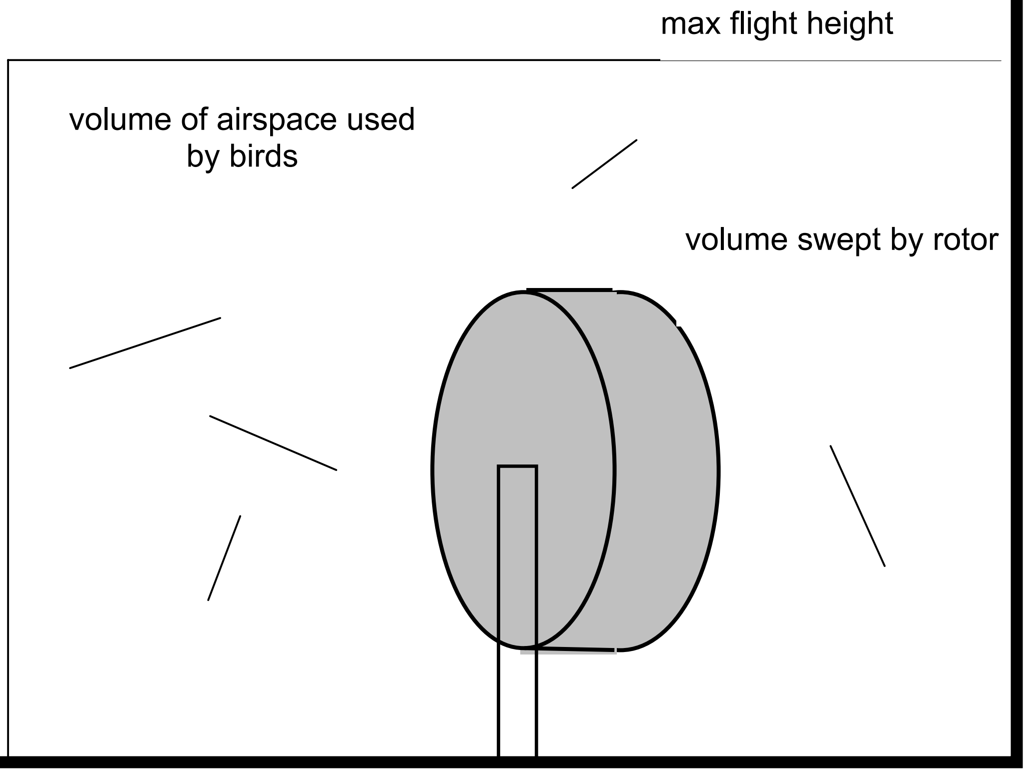


FIG 2: BIRDS USING WINDFARM AIRSPACE



For good results the data available should be based on actual observations within the area of the windfarm alone (provided the observation is done without disturbance), and the best results will be based on observational data about flight heights, such as will enable informed estimate of the proportion of flights at a level which may collide with the windfarm rotors. However, in the absence of such data, an estimate can be made knowing only the number of birds, and proportion of time flying, within the bird's territory, and using some knowledge of flight behaviour to gauge the proportion of flights at a height to be at risk.

4. The bird occupancy of the volume swept by the rotors is then

   $n \times (V_r / V_w)$ bird-secs.

5. Calculate the time taken for a bird to make a transit through the rotor and completely clear the rotors:
   $t = (d + l) / v$ where v m/sec is the speed of the bird through the rotor

6. To calculate the number of bird transits through the rotors, divide the total occupancy of the volume swept by the rotors in bird-secs by the transit time t:

   Number of birds passing through rotors = $n \times (V_r / V_w) / t$

Note in this calculation that the factor $(d + l)$ actually cancels itself out, so only assumed values need be used - it is used above to help visualise the calculation.

Both approaches yield the number of bird transits (per annum) through the rotors of the windfarm.

Stage 2: Probability of bird being hit when flying through the rotor

This stage computes the probability of a bird being hit when making a transit through a rotor. The probability depends on the size of the bird (both length and wingspan), the breadth and pitch of the turbine blades, the rotation speed of the turbine, and of course the flight speed of the bird.

To faciltate calculation, many simplifications have to be made. The bird is assumed to be of simple cruciform shape, with the wings at the halfway point between nose and tail. The turbine blade is assumed to have a width and a pitch angle (relative to the plane of the turbine), but to have no thickness.

It is best to visualise this as in Fig 3, looking vertically down on the flying bird in a frame which is moving with the bird. In this moving frame, each rotor blade is both moving from right to left (say) and also progressing towards the bird. Each blade cuts a swathe through the air which depends both on the breadth of the blade and its pitch angle. Successive blades cut parallel swathes, but progressively closer to the bird. The angle of approach of the blade α, in this frame, depends on both bird speed and blade speed. At the rotor extremity, where blade speed is usually high compared to bird speed, the approach angle α is low, ie the blades approach the bird from the side. Close to the rotor hub, where the blade speed is low and the bird is therefore flying towards a slow-moving object, the approach angle α is high.

The probability of bird collision, for given bird and blade dimensions and speeds, is the probability, were the bird placed anywhere at random on the line of flight, of it overlapping with a blade swathe (since the bird, in this frame, is stationary). It may therefore be calculated from simple geometric considerations. Where the angle of approach is shallow, it is the length of the bird, compared to the separation distance of successive swathes, which is the controlling factor. Where the angle of approach is high, it is the wingspan of the bird compared to the physical distance between blades, which is the controlling factor.

The calculation derives a probability p(r, φ) of collision for a bird at a radius r from the hub, and at a position along a radial line which is an angle φ from the vertical. It is then necessary to integrate this probability over the entire rotor disc, assuming that the bird transit may be anywhere at random within the area of the rotor disc:

Total probability

$$= (1/\pi R^2) \iint p(r, \varphi)\, r\, dr\, d\varphi$$

$$= 2 \int p(r)\, (r/R)\, d(r/R) \qquad \ldots.. \qquad \mathbf{(1)}$$

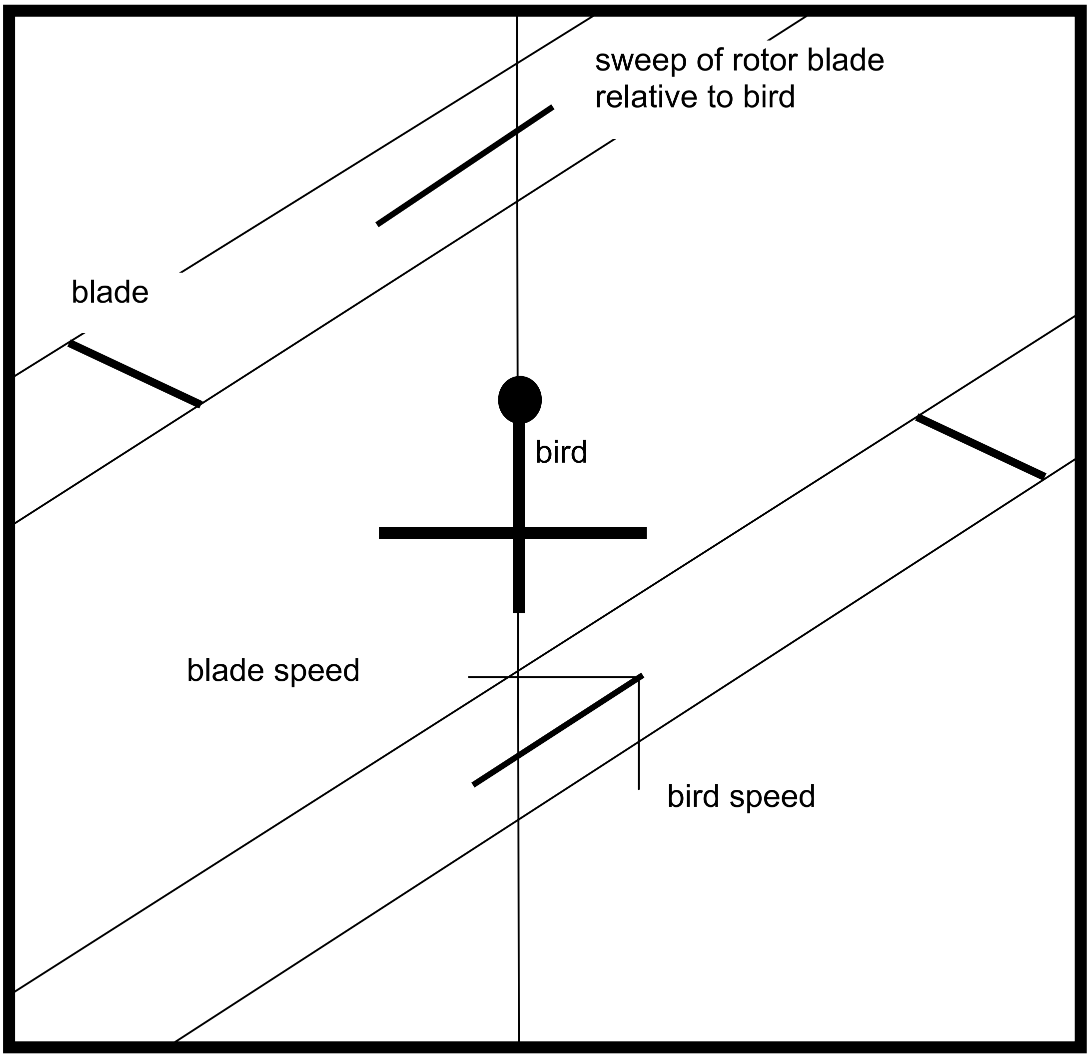
where p(r) now allows for the integration over φ.

Probability p of collision for a bird at a radius r from hub

$$p(r) = (\, b\Omega/2\pi v\,)\, \left[\, K \,|\pm c \sin\gamma + \alpha\, c \cos\gamma\,| \;+\; \begin{cases} l & \text{for } \alpha < \beta \\ w\alpha F & \text{for } \alpha > \beta \end{cases} \right] \qquad \ldots\ldots \qquad \mathbf{(2)}$$

where b = number of blades in rotor
Ω = angular velocity of rotor (radians/sec)
c = chord width of blade
γ = pitch angle of blade
R = outer rotor radius

FIG 3: COLLISION RISK FLYING THROUGH ROTOR



l = length of bird
w = wingspan of bird
β = aspect ratio of bird ie l / w
v = velocity of bird through rotor

r = radius of point of passage of bird
α = $v/r\Omega$

F = 1 for a bird with flapping wings (no dependence on φ)
= $(2/\pi)$ for a gliding bird

K = 0 for one-dimensional model (rotor with no zero chord width)
= 1 for three-dimensional model (rotor with real chord width)

The chord width of the blade c and the blade pitch γ, ie the angle of the blade relative to the rotor plane, vary from rotor hub to rotor tip. The chord width is typically greatest close to the hub and the blade tapers towards the tip. The pitch is shallowest close to the tip where the blade speed is highest. The apparent width of the blade, looked at from the front, is $c \cos\gamma$, and the depth of blade from back to front is $c \sin\gamma$.

The factor F is included to cover the two extreme cases where the bird has flapping wings ($p(r, \varphi)$ has no dependence on φ) or is gliding ($p(r, \varphi)$ is φ dependent, ie at maximum above and below hub, at minimum when wings are parallel with rotor blade). F=1 for flapping bird, F = $2/\pi$ for a gliding bird.

The sign of the $c \sin\gamma$ term depends on whether the flight is upwind (+) or downwind (-).

The factor K is included to give a simple option of checking the effect of real blade width in the result: K=0 models a one-dimensional blade with no chord width.

As α, c and γ all vary between hub and rotor tip, a numerical integration is easiest when evaluating equation (1).

For ease of use these calculations are laid out on spreadsheet (Fig 4). The spreadsheet calculates p(r) at intervals of 0.05 R from the rotor centre (ie evaluating equation (2)), and then undertakes a numerical integration from r=0 to r=R (ie evaluating equation (1). The spreadsheet is set out as follows:

1 The input parameters are in the first two columns. Bird aspect ration β is calculated.

2 Collision probabilities are then calculated for radii at intervals of 0.05 R from the hub to the tip. Each radius is represented by a row in the table, with the value of the radius r/R in the first column..

3 The second column of the table is the chord width at radius r as a proportion of the maximum chord width. The taper profile here is that of a modern Aerpac turbine blade. The taper will differ for different turbine blades.

4 Factor α is calculated.

5. The 'collide length' is the entire factor within square brackets within equation (2) above, using the upwind case.

6. p(collision) is p at radius r, as calculated by equation (2). It is however limited to a maximum value of 1.

7. 'contribution from radius r' is the integrand of equation (1) (including the factor 2) prior to integration.

8. The total risk is then the summation of these contributions.

9. The calculation is then repeated for the downwind case.

10 The spreadsheet then shows a simple average of upwind and downwind values. (Note that in a real case it may be important to add in the effect of wind to the bird's

ground speed, and flight patterns may not be such that upwind and downwind flights are equally frequent.)

The result is an average collision risk for a bird passing through a rotor.

Note that there are many approximations involved , for example in assuming that a bird can be modelled by a simple cruciform shape, that a turbine blade has width and pitch but no thickness, and that a bird's flight will be unaffected by a near miss, despite the slipstream around a turbine blade. Thus the calculated collision risks should be held as an indication of the risk - say to around ±10%, rather than an exact figure. It is also simplistic to assume that bird flight velocity is likely to be the same relative to the ground both upwind and downwind. Ideally, separate calculations should be done for the upwind and downwind case, using typical observed flight speeds.

FIG 4: CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

Only enter input parameters in blue

W Band 21/05/00

K: [1D or [3D] (0 or 1)	1	
NoBlades	3	
MaxChord	2.431	m
Pitch (degrees)	30	
BirdLength	0.82	m
Wingspan	2.12	m
F: Flapping (0) or gliding (+1)	1	
Bird speed	13	m/sec
RotorDiam	52	m
RotationPeriod	2.97	sec
Bird aspect ratioo: ?	0.39	

Calculation of alpha and p(collision) as a function of radius

			Upwind:			Downwind:		
r/R radius	c/C chord	? alpha	collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r
0.025	0.575	9.45	24.90	1.00	0.00125	23.50	1.00	0.00125
0.075	0.575	3.15	8.77	0.68	0.00511	7.37	0.57	0.00429
0.125	0.702	1.89	6.20	0.48	0.00602	4.49	0.35	0.00436
0.175	0.860	1.35	5.31	0.41	0.00723	3.22	0.25	0.00438
0.225	0.994	1.05	4.83	0.37	0.00844	2.41	0.19	0.00421
0.275	0.947	0.86	4.02	0.31	0.00860	1.72	0.13	0.00368
0.325	0.899	0.73	3.45	0.27	0.00871	1.27	0.10	0.00319
0.375	0.851	0.63	3.01	0.23	0.00878	0.95	0.07	0.00275
0.425	0.804	0.56	2.67	0.21	0.00881	0.79	0.06	0.00260
0.475	0.756	0.50	2.38	0.19	0.00879	0.80	0.06	0.00295
0.525	0.708	0.45	2.14	0.17	0.00873	0.80	0.06	0.00325
0.575	0.660	0.41	1.93	0.15	0.00862	0.79	0.06	0.00351
0.625	0.613	0.38	2.05	0.16	0.00997	1.08	0.08	0.00523
0.675	0.565	0.35	1.92	0.15	0.01009	1.09	0.08	0.00572
0.725	0.517	0.33	1.80	0.14	0.01016	1.09	0.08	0.00616
0.775	0.470	0.30	1.69	0.13	0.01019	1.09	0.08	0.00656
0.825	0.422	0.29	1.59	0.12	0.01018	1.08	0.08	0.00691
0.875	0.374	0.27	1.49	0.12	0.01011	1.06	0.08	0.00722
0.925	0.327	0.26	1.39	0.11	0.01001	1.04	0.08	0.00748
0.975	0.279	0.24	1.30	0.10	0.00986	1.02	0.08	0.00770
	Overall p(collision) =			**Upwind**	**17.0%**		**Downwind**	**9.3%**