Australian Government

NATIONAL ENVIRONMENTAL PROTECTION AGENCY



Australian Collision Risk Framework

Collision Risk Model Methodology

The Collision Risk Model (CRM) tool provided within the Australian Collision Risk Framework (ACRF) is designed for rapid understanding of collision likelihood. The CRM tool is underpinned by the **collision** R package (Stark et al. 2026), an open source, stochastic framework for modelling avian collision risk with wind turbines based on Smales et al (2013). This document is a companion to the ACRF CRM Tool User Guide which provides step-by-step instructions for using the online tool.

Overview

Context and motivation

The ACRF CRM online tool was developed to fulfil the need for an accessible collision risk model as part of the Australian Government funded Australian Collision Risk Framework (ACRF). A literature review of international assessment frameworks (Stark and Thompson 2026) found common requirements for field studies and evidence-based collision assessment, but few standards for these models.

These findings contributed to the decision to develop tools to accompany the ACRF to enable users to collate data on collision prone species (the Species Traits Tool) and to assess collision likelihood with standard inputs and outputs. The Collision Likelihood Score (CLS) provides a qualitative tool for when sufficient field data cannot be collated. The CRM provides a quantitative tool suitable for onshore and offshore applications.

What is included in the CRM tool?

The ACRF CRM tool provides a simplified interface to the open-source **collision** R package (Stark et al. 2026). This is a stochastic extension of the geometric turbine CRM previously published in Smales et al. (2013), commonly referred to as the 'Biosis model'. **Collision** updates and modifies the original model to better represent the range of resident and migratory species flight characteristics.

The ACRF CRM tool provides template forms so users can input data into the model and obtain a quantitative estimate of collision. To standardise the inputs, certain simplifying decisions were made. The online tool allows for one turbine model per calculation, assumes a uniform spatial distribution of flights and incorporates uncertainty in inputs using common distributions.

After undertaking some preliminary data analysis, the user inputs turbine, bird and survey observation inputs, in addition to recording information on the evidence sources used. The model produces an estimate of the long-term average annual collisions, and the range of plausible annual collisions expressed as the median and percentiles. The user can download a report containing a list of all model inputs, references and outputs. It is recommended this output, or its equivalent, is included in impact assessment documentation for transparency and reproducibility.

For more information on using the tool itself see the accompanying ACRF CRM User Guide, which can be accessed from within the online tool.

When should the CRM tool be used?

The tool outputs are suitable for use during data collection, for early indication of the scale of collision likelihood, and as input into population-level assessment tools. In addition to estimating average annual collisions, the range of collision outputs can be used to quantify the uncertainty in the prediction. The range of predicted fatality can inform whether the survey program is sufficient to assess risk, or if survey or modelling changes are needed.

CRMs are technical, mathematical and statistical models to predict long-term average collision of flying fauna with turbines from a combination of engineering specifications, species morphological parameters, site-collected flight data, and statistical modelling. As such it is recommended users consult ecological and collision risk modelling experts to prepare and review model inputs.

For sites with complex collision risk (e.g. multiple species, spatially complex ecological variables requiring precise micro-siting, or strong seasonal or environmental variability) modelling using the underlying collision R package (or another peer reviewed stochastic model) should be undertaken to finalise and validate the results of the online tool.

Key limitations

In general CRM will not:

- Provide a determination about the population level impacts of collision. CRM provides a quantified estimate of the annual likely number of collisions that may occur and is an input into broader impact assessments.
- Provide robust estimates for echolocating bat species. There are currently serious limitations in the ability to collect direct observations of individual bat flights over the spatial and height

scale needed for CRM. There also remains a very high level of uncertainty about the avoidance (or attraction) of echolocating bats to operational wind turbines.

- Provide robust estimates for nocturnal and very cryptic species. There is some scope to use the CRM tool with scenario or expert elicited inputs on the flight height and frequency in the absence of direct measurement. In general, qualitative methods (e.g. Collision Likelihood Score) or a custom hybrid (incorporating a mix of qualitative and quantitative inputs) will usually be more appropriate.
- Provide guidance on whether the collision output is precise "enough". The model presents the estimate and its statistical uncertainty, but the required precision is a factor of the species risk, and any project specific regulator guidance.
- Provide a direct determination of whether the input data is "sufficient" to support the modelling. The online tool provides some information to assist users to make this determination, but users are strongly encouraged to include comprehensive references in support of collisions for transparency and reproducibility. The collision distribution can be used to assess the level of uncertainty in the output; and by extension this can inform statistical confidence analysis of 'how much is enough' to obtain a desired level of certainty.

The online CRM tool has the following additional limitations to enable a standardised user interface. Some of these limitations may be addressed when using CRM R packages directly:

- Species flight behaviour. The ACRF CRM tool treats flight behaviour as spatially 'flat' for simplicity. Spatial movement can be modelled in various ways, and the choice of method should be guided by experts based on site-specific requirements. If per-turbine collision rates are needed, the site-level output can be scaled post-hoc using a custom spatial model. Alternatively, the **collision** R package allows input of flight flux at the turbine level.
- Input uncertainty. Uncertainty is modelled using standard statistical distributions: the normal distribution (default), the log-normal distribution for positive-only inputs, and a bounded beta distribution (via the R package **mc2d**), for the avoidance rate. Additionally, ACRF CRM tool assumes the covariance between the encounter rate and the effective detection width inputs is 0, this results in slightly higher variance in the collision rate distribution but a simpler user interface.
- Output interpretation. The ACRF CRM tool reports the number of movements at risk of collision, which differs from the number of individuals at risk of collision. For sites with large populations and high replacement rates, this metric provides a suitable estimate of total bird fatalities. For sites supporting small populations (e.g., a few breeding pairs or isolated populations), the number of at-risk movements and the number of at-risk individuals may not be the same and the results considered in the context of the available at-risk population.

History and other models

Despite 40 years of development and numerous published applications (Cook et al. 2025), most CRMs are based on a small number of underlying theoretical approaches (Smales 2017).

In Europe and the UK, collision risk modelling has historically been dominated by the Band Model (Band 2012). This approach estimates collision probability from instantaneous bird density and flight speed, before modelling interactions between birds and the rotor swept area. This approach is

sensitive to uncertainties in bird flight speed. Recent advancements, such as the **stochlab** R package (Caneco et al. 2022), have introduced stochasticity but remain optimised for specific survey designs and data types, such as monthly offshore bird surveys.

In Australia, the Biosis CRM (Smales et al. 2013) adopted a different approach by using direct measurements of flight flux (birds per unit area per unit time). This avoided the need to infer flight flux from bird density and flight speed estimates, reducing reliance on assumptions associated with snapshot survey methods. The model also incorporated bird movements through the turbine from any direction and accounted for collisions with the entire turbine structure.

The Biosis CRM has been applied in both onshore and offshore settings. However, its closed-source implementation limited opportunities for extension, review, and ongoing development. The **collision** R package builds on and modernises the underlying Biosis approach, providing an open source, stochastic, and peer-reviewed package.

A full comparison between the ACRF tool and the stochastic-Band model is provided at the end of this document.

Methodology

Overview

Figure 1 shows the conceptual model underpinning the ACRF CRM online tool. Field observations and survey metadata combine to estimate the number of interactions with a given turbine within a defined study period (typically one year).

Timed field observations are first converted into a flight flux expressed as movements per unit area of a vertical plane. This flux is then scaled to the turbine's rotor swept area to estimate the expected number of turbine interactions per year.

These interactions are subsequently adjusted to account for avoidance behaviour and the probability of collision given an interaction. The collision probability is derived by projecting the 3D turbine geometry onto a 2D flux plane and integrating across all possible angles of transit through the rotor-swept area.

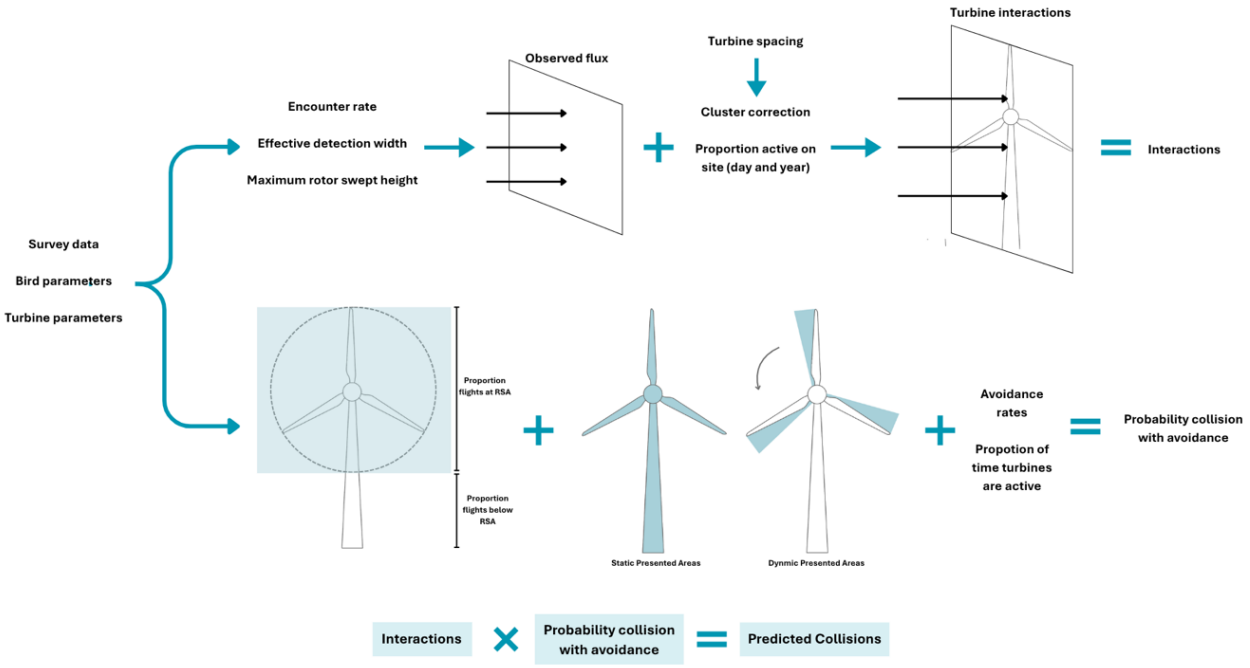


Figure 1 - Overview of the CRM model in the ACRF online tool

Inputs

The **collision** online tool requires inputs to calculate the number of turbine interactions and the probability of collision.

To estimate the number of turbine interactions:

- Observation data for flights below the maximum turbine height:
  - ***ER*** - Encounter rate (movements per minute)
- Survey metadata
  - ***EDW*** - Effective detection (half) width in metres
  - Total survey duration in minutes from timed surveys only. The duration must include any surveys with no sightings as well as positive detections
- Turbine information
  - H_{max} Maximum rotor swept height in metres
  - R_d Rotor diameter in metres
  - μ_t Average minimum distance between turbines in metres, used to calculate the Cluster Correction (***CC***)
- Bird(s) information
  - $P_{bird\text{-}day}$ Proportion of a 24-hour day active.
  - $P_{bird\text{-}yr}$ Proportion of the year active. If surveys were only conducted during seasonal activity, then this should be the proportion of the total year the species is present. If the surveys include the entire year, then this proportion should be 100%.

To estimate the probability of collision during interactions:

- Bird(s) information
  - Bird length in metres (bill tip to tail tip or outstretched legs)
  - Average flight speed in m/s
  - α_{static}, α_{dyn} Static and dynamic avoidance rate
  - Proportional split below- and at-rotor swept height
- Turbine(s) parameters
  - Number of turbines
  - Technical dimensions for the tower, blades and blade tilt, all in metres
  - Revolutions per minute (average)
  - Proportion of year turbines are operational (based on anticipated downtime due to inappropriate wind data, grid access and maintenance)

Bird and turbine parameters are taken from known values. The rest of the inputs must be calculated prior to using **collision**. An overview of these inputs is below.

Calculation

The number of interactions for a single turbine is calculated from the observed flux:

$$F_{obs} = \frac{ER}{EDW \cdot H_{max}}$$

Where *ER* = count of observations divided by the total survey duration. The observed flux is the number of individual movements through an observed 'window' in one minute. The observed flux is scaled to a 'window' of area $A_T = R_d H_{max}$ via:

$$F_{turbine} = F_{obs} \cdot CC \cdot A_T$$

The turbine flux is calculated as the number of individual movements through a turbine 'window' in one minute. The Cluster Correction (*CC*) allows for the case where the observer window is wider than the space between turbines and is discussed in further detail below. The total number of interactions for that turbine in a year is then:

$$n_{interactions} = F_{turbine} \cdot P_{bird-day} \cdot P_{bird-yr} \cdot 365.25 \cdot 24 \cdot 60$$

Finally, the collision estimate can be calculated. This uses the previously calculated yearly interactions (flights through the turbine area), and probability of collision given interaction with the expected avoidance rates. This is defined as:

$$C_{movements} = n_{interactions}(1 - \alpha_{static})P_{coll-static} \cdot \left(1 - \alpha_{dyn}\right)P_{coll-dyn}$$

Where $P_{coll\text{-}static}$ and $P_{coll\text{-}dynamic}$ are the probability of collision with the static and moving parts of the turbine respectively and accounts for turbine geometry, bird speed, flight height and proportion of turbine uptime. $C_{movements}$ is the predicted average annual number of movements (flights) ending in collision from one turbine.

To estimate the total collision for a site we sum the contributions from all turbines.

Modelling uncertainty

In practice many of the input parameters are physical values that are established within some standard deviation (e.g. bird length) or are field derived measures with an associated standard error (e.g. the encounter rate). If these error terms are input into the online collision tool, the model uses a simulation algorithm to estimate the variation in the collision estimate.

The ACRF CRM tool presents the model results as a set of related statistics:

- The mean is interpreted as the long-term annual expected collision rate and is the appropriate statistic for cumulative and long-term projection.
- The median and interquartile range (IQR; as given by the range between the 25th and 75th percentiles) provide measures of the expected variability in the number of collisions.

Model input details

In this section we provide more details on key variables needed for modelling, to guide the analyst using the ACRF CRM online tool.

Encounter rate

The encounter rate (ER) is defined as the uncorrected number of flights per survey minute. That is the average number of flights by a given species observed in each minute of the survey. For simple survey designs this is the number of observations divided by the total survey effort. For more complex designs the analyst should account for design factors like stratification when calculating this value.

As the encounter rate is used to calculate the flux of bird movements, only the flights between the ground and maximum turbine height are used to calculate the encounter rate. This means the total flights observed will be the number flying below maximum turbine height.

Effective detection half width

The effective detection half width (EDW) is defined as radius/width in which a bird detection is assumed to be perfect.

For onshore point count or vantage point surveys, this is equivalent to the effective detection radius (Buckland et al. 2001). Ideally it is calculated directly from field-measured distances. The observer estimates distance at first sighting for each observation and the effective detection radius is determined from an empirical distribution fitted to the pool of distance records. This correction factor accounts for the fact that observer efficiency will decline with distance.

Similarly, the effective detection half width for line transects surveys is equivalent to the Effective Strip (half) Width, as defined in Buckland et al. (2001). For strip transects (e.g. digital aerial transects) this is the distance from the observer to one side of the ‘strip’.

Proportion of flights at and below rotor swept height

The ACRF CRM online tool requires specification of the proportion of flights occurring below and within the rotor swept height. These two proportions must sum to 1.

To generate this input, only records occurring below the maximum rotor height should be used. From this subset, the proportion of flights within the rotor swept zone and the proportion below it are calculated.

Both proportions, along with their associated error terms, should be generated by fitting an appropriate empirical distribution to field data or by using an equivalent modelling process.

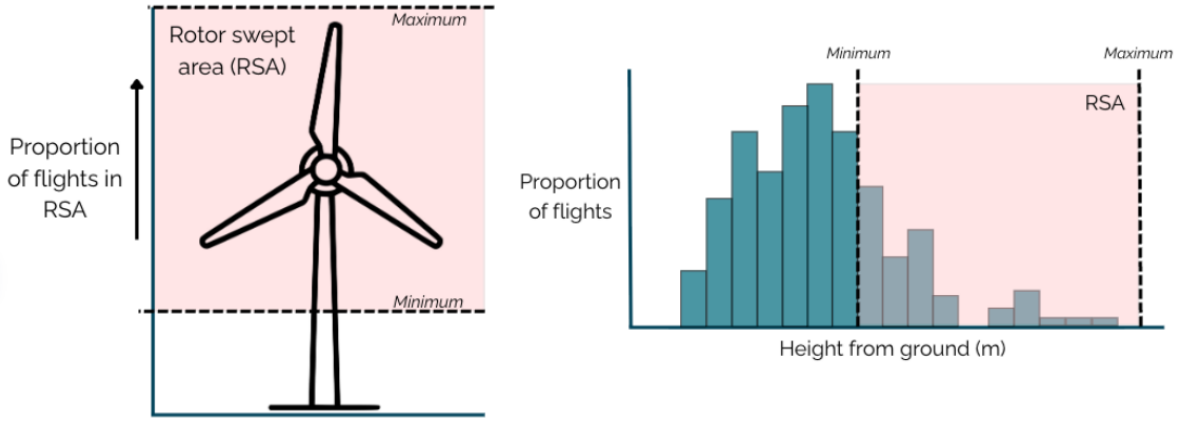


Figure 2 - Illustration of the flight height distribution (right) and the rotor swept area (left)

Cluster correction

Collision calculates flux within an observer window under the assumption that each flux is associated with a single turbine interaction. This assumption holds when observer windows do not overlap multiple turbines.

However, when observer window encompasses more than one turbine, the same flux may be attributed to multiple turbines, violating this assumption and leading to inflation of estimated interactions.

To correct for this, a cluster correction factor is applied to scale flux estimates according to turbine density. The **collision** package provides both a 2D correction using a proposed turbine layout, and a 1D correction using only the distance between turbines. For ease of use, the ACRF CRM online tool provides only the 1D correction.

In the 1D formulation, the correction factor is defined using the mean where μ_{min} is the average minimum inter-turbine distance and the effective detection half width (EDW) as defined above. This adjustment accounts for the density of turbines on the site, by reducing inflated interaction estimates where multiple turbines fall within a single observer window.

Probability of collision

Static components

The probability of collision with static turbine components is defined as the ratio of the total static presented area to the turbine plane area. Static components include the tower below rotor height, the tower within rotor height, the nacelle, hub, and rotor (stationary parts).

Dynamic components

This probability of collision with dynamic components refers to the likelihood of a bird striking moving parts of the turbine, primarily the rotor blades. This is calculated as the ratio of the dynamic

presented area to the turbine plane area, multiplied by the proportion of birds flying within rotor swept height. The calculation also accounts for turbines operational time, as collisions with moving blades can only occur when turbine is active.

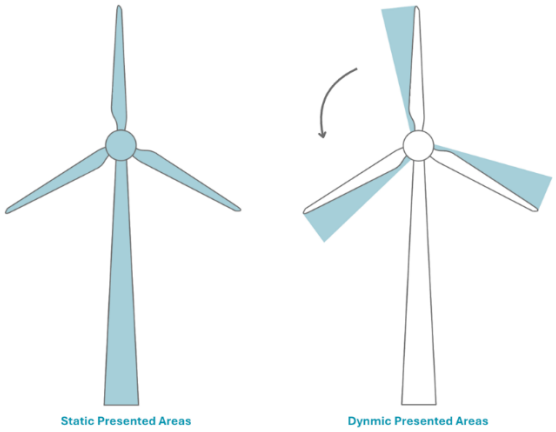


Figure 3 - Schematic of static and dynamic presented areas

Avoidance rates

A key component of CRMs is adjusting the number of flights at risk of collision by the species' ability to avoid turbines, commonly expressed as the avoidance rate.

Birds can avoid turbine collisions through behaviour at three scales (Cook et al. 2012; Smales 2017):

1) **Macro-avoidance**: Avoidance of the site as a whole.
2) **Meso-avoidance**: Alteration of flight paths within the site to avoid turbine infrastructure.
3) **Micro-avoidance**: Avoidance within the rotor-swept zone, including flying through, above, or below the blade sweep and around the tower.

In the ACRF CRM tool and underlying **collision** package, the avoidance rate represents the total avoidance at all three scales, relative to a site with no turbines.

Macro-avoidance is understood to be a major factor in lowering collision rates at offshore wind sites in the northern hemisphere (Cook 2025), but no data currently exists for Australia. Studies of terrestrial species are also limited. Behavioural observations have been conducted for the Tasmanian wedge-tailed eagle (*Aquila audax fleayi*) and the white-bellied sea-eagle (*Haliaeetus leucogaster*), providing estimates of meso-avoidance from direct flight path data (Hull and Muir 2013), and comparisons of predicted versus observed collisions (Smales et al. 2013; Smales 2023).

A range of dynamic avoidance rates can be selected from overseas studies of flight behaviour (Cook et al. 2012). When applying these values, preference should be given to studies using direct behavioural measurements rather than post-construction comparisons of model predictions, as the latter are influenced by model and estimation errors and generally carry lower confidence (Smales 2017).

The online tool allows for the dynamic avoidance rate to be entered as a maximum, minimum and expected value, enabling exploration of uncertainty in this parameter.

The static avoidance rate in the ACRF CRM online tool refers to the probability that a bird will evade collision with static turbine components. Empirical data are largely lacking, but it is generally assumed to be very high for most species (e.g. 0.9999).

Table 1: Comparison of collision risk models (ACRF CRM and collision vs stochastic Band-based models)

This table provides a non-exhaustive comparison of the key approaches between the **collision** based ACRF CRM tool and the stochastic CRM provided by stochLAB based on Masden (2015), which was an extension of Band (2012).

Model component	ACRF CRM and collision package	Band-based sCRM / stochLab
Flight flux through turbines	Derived from point, line, or strip transect surveys, using encounter rates (movements per minute), survey duration, and effective survey width (with associated uncertainty). Flux is scaled from observed movement rates to a vertical plan and then to turbine dimensions (rotor diameter and maximum height). Per-turbine estimates represent the number of flights intersecting a single turbine per year, with optional adjustment for turbine clustering.	Derived from line transect-based density estimates, which are scaled to wind farm level. Flight speed is used to estimate the time taken for a bird to pass through a wind farm, and this information is then scaled up to estimate the total number that may pass through the wind farm in a year (from Cook et al 2025). Density refers to individuals per unit horizontal area, typically estimated using methods such as Buckland et al.
Distribution of flight heights	Proportion of flights within and below rotor-swept height is estimated from empirical data (with uncertainty). These proportions are sampled during simulation and applied to static and dynamic collision.	Flight height is modelled either as a proportion at rotor height as a percentage, or using distribution (e.g. 1 m bands), integrated across the rotor-swept zone.
Spatial (per turbine) values	Supports per-turbine variation in flux via spatial modelling (e.g. Kernel Density Estimation; R package only). Assumes equal risk across turbines.	Whole of wind farm estimate only. Includes a large array correction to account for depletion of birds as they pass through successive turbine rows (Band 2012)
Daily activity	User-defined proportion of daily activity time. Seasonal variation can be incorporated via adjustment of temporal availability.	Activity typically specified as proportion of nocturnal or diurnal activity.
Seasonality	Proportion of time species is present within the study period (e.g. annual scaling or survey period adjustment).	Incorporated using monthly observation data
Bird-turbine interaction and probability of collision when in rotor space	Uses a presented-area approach incorporating static (tower, nacelle, rotor, hub) and dynamic (moving blades) components. Allows birds to traverse the turbine from any direction. Requires detailed turbine specifications	Uses a rotor-swept-area approach. Collisions are assumed to occur only within the rotor swept zone, with birds assumed to traverse from upwind or downwind directions only. Requires fewer turbine-specific inputs.
Avoidance	Separate static and dynamic avoidance rates represent macro-, meso-, and micro-scale avoidance.	Single avoidance parameter applied across all avoidance processes.
Turbine downtime	Entered as proportion of operational time over the study period.	Entered as proportion of operational time over the study period.
Uncertainty	Input uncertainty represented using user-defined distributions (normal, log-normal, beta). Simulation via monte-carlo method.	Uncertainty represented using normal or truncated normal distributions. Simulation via monte-carlo method.

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