Norfolk Boreas Offshore Wind Farm

Review of Kittiwake Flight Speed for use in Collision Risk Modelling

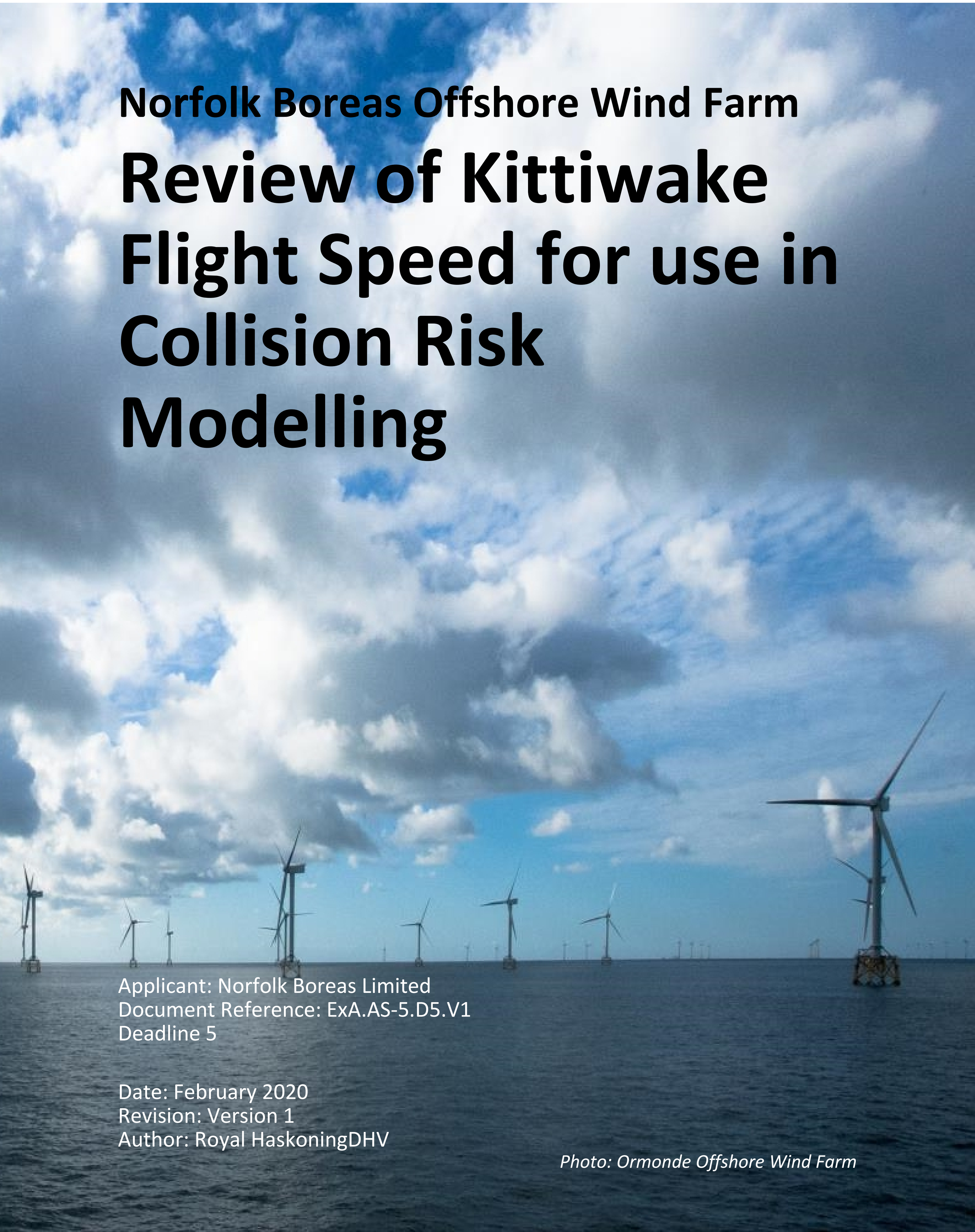

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Table of Contents

1 Kittiwake flight speed 4

1.1 Kittiwake flight speeds predicted by flight theory 5

1.2 Empirical measurements of kittiwake flight speed 5

1.3 Application to Collision Risk Modelling 13

2 References 15

Table of Tables

Table 1.1 Summary of flight speed measurements reported in the published literature 12

Glossary of Acronyms

CRM	Collision Risk Modelling
GPS	Global Positioning System
V_{mp}	Minimum power velocity
V_{mr}	Maximum range velocity
$V_{no\ wind}$	Velocity under conditions of no wind

1 Kittiwake flight speed

1. Typical flight speeds of bird species can be predicted with high accuracy from flight theory based on the particular morphometrics of each species (Pennycuick 1989). Flight theory predicts that the energy cost of flight in birds (the power requirement) is closely related to flight speed, with a U-shaped relationship indicating minimum power requirement at a particular air speed (Pennycuick 1989, Tobalske et al. 2003). The exact position of the U-shaped relationship depends on species-specific features of wing shape and body mass in particular but also on factors such as tail length and area, and mode of flight (Pennycuick 1989). Birds can therefore minimise the energy cost of flight by flying at the air speed that requires lowest power, known as the minimum power velocity, V_{mp}, which will vary among species in relation to their morphology. Where natural selection favours minimisation of energy expenditure (as is often the case), it can therefore be predicted that birds will fly at air speeds close to V_{mp}. However, natural selection may sometimes operate in relation to parameters other than energy expenditure. Where selection is in relation to distance travelled rather than energy expenditure, the optimal speed may be the velocity giving maximum range, V_{mr} rather than V_{mp}. V_{mr} can also be predicted from flight theory. V_{mr} is slightly faster than V_{mp}. In practice, and with only a very small number of exceptions, measured air speeds of birds tend to fall within the range between V_{mp} and V_{mr} and mostly close to V_{mp} (Pennycuick 1987, 1989, Alerstam et al. 1993, Pennycuick et al. 2013).

2. It is likely that optimal air speed will differ according to the status of the individual bird. For example, a migrating bird may need to optimise distance travelled rather than power output if crossing inhospitable terrain. Breeding birds that are central place foragers may need to optimise time rather than power output if chick survival and growth are at risk, so are likely to fly faster than birds that are not under such constraint. For birds not constrained by central place foraging, such as birds that are migrating or are in their nonbreeding habitat, power output minimization would be a stronger influence.

3. The conclusions from flight theory could be summarised as following: birds should fly at air speeds that are within a narrow band, mostly constrained by power costs of slower or faster flight, but the optimal air speed of birds will differ slightly depending on the ecological conditions in which the individual is operating. Optimal air speeds can be predicted for individual species based on the morphometrics of the species. However, the ground speed of a flying bird is determined by the combination of air speed with wind speed and direction relative to the bird's flight path. Therefore, ground speed is likely to vary much more than air speed, depending on the added influence of wind, and behavioural responses of the bird to the wind direction and strength.

1.1 Kittiwake flight speeds predicted by flight theory

4. Based on morphometrics of the species, Pennycuick (1987) estimated that kittiwake V_{mp} will be 8.9 m/sec, and V_{mr} will be 14.9 m/sec. Flight theory suggests that kittiwakes should avoid flying at air speeds of less than 8.9 m/sec or more than 14.9 m/sec, as the power requirements would increase, and increase at an increasing rate, beyond these limits (Pennycuick 1989, Pennycuick et al. 2013). However, the foraging method of the kittiwake may require some flight at lower speed while actively foraging, or the use of tortuous tracks to maintain optimal air speed while reducing ground speed. Alternatively, kittiwakes can switch to gliding flight if they want to reduce ground speed, as their gliding speed is lower than their flapping flight speed (Pennycuick 1987).

1.2 Empirical measurements of kittiwake flight speed

5. Flight speeds of birds can be measured in a number of ways using different tools. These can be summarised as direct observation of flight along a defined line, ‘distance and direction measurement’, tracking radar, and GPS tracking. Each method has advantages and disadvantages.

1.2.1 From vehicle speed beside flying kittiwake

6. Götmark (1980) estimated flight speed and flight heights of breeding kittiwakes commuting to and from a colony in arctic Norway, and related these to local wind speed and direction on a number of dates during the chick-rearing period. Götmark measured ground speed of kittiwakes by driving his car along a coastal road parallel to the flying birds, and estimated ground speed of the kittiwakes at 11 m/sec. Götmark showed that 100% of kittiwakes flying into a 10 m/sec headwind (n=2,320) flew at <5 m over the sea surface, as did 100% of kittiwakes flying into a 5-6 m/sec headwind (n=2,639), whereas in calm conditions 91% of kittiwakes (n=1,567) flew at 5-20 m above sea level. As a consequence of their selection of flight height, kittiwakes experienced a lower headwind than would have been the case at higher flight height due to the friction of the wind on the sea surface reducing wind speed closer to the water. Götmark estimated that the air speed of the birds was between V_{mp}, and V_{mr}, as predicted by flight theory, but Götmark did not correct wind speed estimates for the flight height of birds above the water so may have overestimated their air speed (because these kittiwakes flew low over the water into a headwind where wind speed is less due to friction with the sea surface).

1.2.2 Time taken for flocks to migrate between adjacent defined sites

7. Coulson (2011) states that he and Edward White measured flight speeds of kittiwakes in the 1950s/1960s ‘over a one-kilometre stretch of coast near a colony in north-east England’. Coulson does not give details of the methodology or sample

sizes but states that in relatively calm conditions individuals travelled at an average of 11.9 m/sec.

8. Oldén and Peterz (1985) realised that the mean flight speed of kittiwakes could be estimated by timing how long a flock took to travel from one coastal seawatching site to another further down the coast. By this method they obtained estimates of kittiwake ground speed on migration averaging 12.1 m/sec (s.d. 7.9). Based on the prevailing weather conditions, with a headwind of about 4-5 m/sec, the air speed averaged 16.7 m/sec (s.d. 4.8), results similar to the speed previously reported by Götmark (1980). However, these flight speed estimates are likely to be relatively inaccurate as the timing of birds passing a particular location in the manner done during seawatching is unlikely to be precise, and the wind speed estimates used to convert ground speeds to air speeds were also imprecise in this study, and may have overestimated wind speed at the low level over the water at which the kittiwakes were flying. Wind speed close to the sea surface is considerably less than wind speed at the height conventionally used to measure general wind speeds by meteorologists (Spear and Ainley 1997), so air speed of these birds may have been considerably less than the estimated 16.7 m/sec.

1.2.3 Distance and direction measurement

9. Pennycuick (1987) used an ‘ornithodolite’, a computer controlled instrument which estimated the position, derived from measured distance and direction, of individual birds at time intervals and reconstructing the flight track in each interval between position fixes. Pennycuick observed birds from a fixed position on a clifftop to measure ground speed of flying seabirds at sufficient distance not to be influenced by wind effects on the coast. Analysis assumes that birds moved in straight lines between successive position fixes. This is likely to be nearer to the truth the shorter the interval between position fixes. Ground speeds were converted into air speeds from wind speed data collected simultaneously at the observation site. This tool allows the user to select individuals in the field to avoid birds that are flying in a tortuous way. That will reduce the risk that measurements underestimate flight speed because of non-linear tracks, but may introduce other biases relating to selection of focal birds for measurement. Pennycuick (1987) measured flight speeds of 18 kittiwakes over the sea off Foula, Shetland. Mean air speed of these birds was 13.1 m/sec, with a range of values from 9 to 17 m/sec; there was a significant influence of wind on the ground speed (slope 0.82, $p<0.05$), with ground speed under conditions of no wind ($V_{\text{no wind}}$) estimated at 9.17 m/sec (Pennycuick 1987). These empirical data show that kittiwake ground speed varies with wind strength and direction, and that under conditions of no wind, ground speed (and air speed) was close to the V_{mp} predicted by flight theory (8.9 m/sec). Given the technology used and the care given to the methodology, these measurements are considered

likely to be accurate, and provide a strong evidence base indicating that these kittiwakes flew at speeds close to V_{mp} predicted by flight theory. The 'ornithodolite' has been updated since the pioneering work of Pennycuick (e.g. Pennycuick 1982) and still has a place as a tool to measure bird locations and flight speeds (Pennycuick et al. 2013, Cole et al. 2019).

10. Spear and Ainley (1997) used triangulation from a ship to estimate ground speed of seabirds, correcting for non-linear flight, and converting the ground speed into an estimated air speed by taking account of wind speed and direction and the relationship between bird height above sea level and wind speed. Spear and Ainley collected large amounts of data for a wide range of seabird species in order to assess allometric relationships between flight speed and size and to test for relationships between flight speed and wind direction. Although Spear and Ainley did not include kittiwake in the many seabirds they studied, the allometric relationships they derived show a close agreement with predictions from flight theory and also show the importance of wind speed and direction in influencing ground speed of seabirds (as shown also in tracking radar studies by Mateos-Rodríguez and Bruderer 2012). Spear and Ainley (1997) showed that seabirds that mainly use flapping flight (such as kittiwakes) decrease their air speed when there is a supporting tailwind, because the tailwind increases their ground speed so reduces their energy cost of travel. Seabirds with low wing loading (such as the kittiwake which has a particularly large wing area in relation to its body weight) showed a stronger response to headwinds than seabirds with a high wing loading (such as guillemots). As a result, the species with low wing loading flew with an air speed faster than V_{mr} when flying into very strong headwinds (although of course their ground speed will be lower when flying into a headwind than in absence of wind). One implication of this is that kittiwakes are likely to avoid flying into strong headwinds as much as possible because of the greatly increased energy cost of maintaining a particularly high air speed. That is consistent with Götmark (1980) observing that kittiwakes fly low over the sea surface when flying into a headwind.

11. A similar approach was used by Skov et al. (2018) who measured flight speeds of seabirds from offshore wind farm turbines using a laser rangefinder rather than an ornithodolite, assuming that birds flew in a straight line between successive position fixes obtained from the rangefinder. Skov et al. (2018) measured flight speed of a large number of kittiwakes. They report a mean ground speed for this sample of measurements (excluding extreme values) of 8.7 m/sec. However, the intervals between position estimates are not reported, so it is difficult to assess how much this estimate may underestimate true ground speed as a result of birds not flying in a straight line between position fixes. They also report a range of estimated flight speeds from <1 m/sec to 30 m/sec. These extremes are implausible, so indicate that error in position fixes is likely to have a significant influence on their individual

estimates of flight speed. Their data also lack conversions to air speeds or analysis of the influence of wind speed and direction which make comparing these with previous estimates more difficult.

12. These ‘distance and direction’ measurement methods (e.g. ornithodolite and laser rangefinder) have the advantage of being relatively inexpensive to carry out, without the need for costly and cumbersome equipment such as radar, or the need to deploy expensive GPS tags on birds. However, the ‘distance and direction’ methods may involve issues with selection of focal birds to measure (e.g. there may be a tendency to target higher flying individuals which are easier to follow), and of correcting ground speed estimates with wind speed data to give air speed.

1.2.4 Radar

13. Alerstam and Gudmundsson (1999) used a tracking radar to measure flight speeds of kittiwakes over the Arctic Ocean. 106 measurements at ten second intervals of ground speed of three kittiwakes were made, with simultaneous measurement of wind direction and speed at different heights above sea level. Ground speed of kittiwakes averaged 15.9 m/sec, with an air speed averaging 13.6 m/sec, a value also falling between predicted V_{mp} and V_{mr}. The extremes of air speed were 13.5 and 13.7 m/sec, indicating extremely consistent air speeds for these tracked birds. However, the ground speeds were much more variable, with extremes of 10.3 and 23 m/sec. The radar methodology appears to provide highly accurate measurements of ground speed of flying birds, and conversions of ground speeds to air speeds were performed by measuring wind speeds at a variety of heights above sea level by releasing balloons, so that accurate local height-specific wind strength and direction data were available.

14. Alerstam et al. (2007) used a tracking radar to measure flight speed of birds in southern Sweden and in the Arctic Ocean. Birds being tracked were identified to species by visual observation using a telescope. Data on flight speeds of individual bird species are not presented in the main paper, but are tabulated in an Annex in electronic supplementary material. Data reported in the supplementary material associated with their paper indicate sample sizes, number of seconds over which birds were tracked and the calculated air speed. Ground speeds and wind speeds used to compute air speeds are not presented. Alerstam et al. (2007) only tracked two kittiwakes, but tracked these birds for a total of 660 seconds. They calculated the mean air speed of these birds as 13.1 m/sec, with a narrow range from 12-14 m/sec. The paper does not allow ground speeds of these birds to be back-calculated from the data presented, and the ground speeds measured by radar are not provided in the paper. The radar measurements of bird flight speed appear to be among the most accurate achieved, although the published data are derived from small numbers of tracked birds.

1.2.5 GPS tracking

15. GPS tags have been deployed on kittiwakes in a number of studies. It is likely that the Marine Scotland Science report on behaviour of seabirds at sea, which was due to be published in October 2019 (although this project appears to have been delayed), will contain some new analysis of kittiwake flight speeds derived from GPS tag deployments.

16. When GPS tags are deployed to study bird behaviour it is especially important to assess whether tag effects bias data. For example, Gessaman and Nagy (1988) showed that tags weighing 5% of body weight reduced flight speed of homing pigeons by 25%, as well as increasing their flight energy expenditure by 50%. In the case of kittiwake, several studies have found tag effects, suggesting that this species is particularly strongly affected by having loads attached (Heggøy et al. 2015, Chivers et al. 2016, Christensen-Dalsgaard 2017). Vandenabeele et al. (2012) modelled the flight energy costs of carrying a tag such as a GPS tag and concluded that the energy cost increased by a higher percentage than the weight increase, and was strongly affected by whether or not the tag was streamlined. For a tag weighing 3% of body weight and not streamlined, the energy cost of flight by kittiwakes at minimum power cost was estimated to increase by about 17%. Although there are now lightweight GPS tags available on the market, those have not yet been deployed on kittiwakes to study flight speeds. Many of the GPS tags deployed on kittiwakes in previous studies have weighed between 3 and 5% of the birds' body weight. The increase in power costs for heavier tags would be at least proportionally higher. There is, therefore, concern that flight speeds suggested by GPS tags may be biased by tag effects on kittiwakes that seriously compromise their flight costs. Evaluation of data from GPS tag deployments on kittiwakes should take careful account of the weight of tags and in particular also the extent to which their design is streamlined to fit the flying bird. However, published data on kittiwake flight speeds derived from deployments of GPS tags have generally failed to consider this problem.

17. There are two ways that estimates of the ground speed of flying kittiwakes can be obtained from deployments of GPS tags on kittiwakes. Firstly, tags may provide satellite-derived 'instantaneous estimates of ground speed' associated with each individual GPS position fix. Those are derived by the satellite from measurements of parallax of the path of the tag relative to the path of the satellite. For a flying bird, the speed of tag movement is very slow compared to the speed of movement of the satellite, making such instantaneous measurements of ground speed of the bird very imprecise. As a result, most studies deploying GPS tags on birds do not use these instantaneous speed estimates to estimate flight speed. Secondly, the speed of movement of the tag between successive position fixes can be used as an estimate of ground speed of the bird if it is assumed that the bird travels in a straight line

between the two points and remains at exactly the same altitude. The shorter the interval between successive position fixes the greater the chance of the bird's flight approximating to a straight line, so estimates of flight speed are likely to be more accurate where position fixes are obtained at short intervals. Unless the interval between fixes was extremely short, the error in position fixes would be unlikely to contribute greatly to errors in estimation of ground speed, and would be likely to be random error so should add noise to, but not bias, estimated ground speed. However, any deviation from straight line flight by the tracked bird (between position fixes) will lead to ground speed being underestimated. In the extreme case, a bird flying in circles with a relatively slow fix interval could register a ground speed of zero m/sec regardless of its actual flight speed. This could also be the case with other methods of estimating flight speed, such as use of radar or ornithodolite, except that in the other cases the observer can see the flight path taken by the bird so could exclude from the data set cases where the bird deviated greatly from straight line flight. That is not possible with GPS tracking, as the actual movements of the bird are unknown and only the position fixes at intervals are available.

18. Safi et al. (2013) recommended the use of instantaneous 'on board' flight speed data from GPS tags rather than flight speed estimates derived from distances between consecutive points. They used GPS tags programmed to provide position fixes every 15 minutes. Not surprisingly with such long intervals between position fixes the estimates of flight speed over 15 minutes were considered to be unreliable; it is extremely unlikely that birds will fly in a straight line without altering altitude over a period of 15 minutes, even in the case of migration or commuting flight to a nest. For that reason, Safi et al. (2013) considered flight speed estimates derived from distance between two points determined at 15 minute intervals to be unreliable as a measure of flight speed. Elliott et al. (2014) programmed tags on kittiwakes to provide position fixes every 30 seconds. They compared instantaneous ground speed estimates provided by the tag with ground speed estimates between position fixes 30 seconds apart and found that the onboard instantaneous speed estimates were lower than the speed estimates between positions over 30 second intervals. This result is impossible, since speeds measured over time intervals will underestimate true ground speed to the extent that the actual track is longer than a straight line assumed track, so cannot give higher speed estimates than actually occur. Elliott et al. (2014) therefore considered the onboard instantaneous estimates of speed provided by the tags to be unreliable and they discounted those data in their study. Elliott et al. (2014) also plotted the estimated ground speed of kittiwakes (from measured linear track distances) against sampling interval between position fixes. Elliott et al. found a strong curvilinear relationship with estimated ground speed increasing asymptotically as the sampling interval decreased, with these data closely fitted by an exponential function. This relationship was for kittiwakes considered to

be in commuting flight, which indicates that flight speed estimates based on GPS tag data will only provide reliable estimates of ground speed if sampling interval is very short, preferably no more than 30 seconds and ideally at even shorter intervals (Elliott et al. 2014). Elliott et al. (2014) tracked ten kittiwakes using GPS tags with sampling interval of 30 seconds, and from the total sample of 58 track length measurements reported a range of ground speed estimates between 4 and 17 m/sec, with a mean ground speed of 10.6 m/sec, and an estimate of a flight speed of 10.6 m/sec in calm conditions. Ground speed showed a strong and statistically significant relationship with wind speed and direction as:

Ground speed = -0.60 x headwind + 10.6

19. Since this is a linear relationship, the reduction in ground speed due to a headwind is the same as the increase in ground speed due to a tailwind of the same strength, suggesting that birds were maintaining approximately constant air speeds. Ground speed showed a strong relationship with the strength of headwind or tailwind, but no significant relationship with strength of a crosswind. The GPS tag and accelerometer deployed by Elliott et al. (2014) together added about 4% to the normal body weight to the birds and the authors point out that this exceeded the suggested limit of 3% for devices attached to birds. The authors state ‘we assume that all birds were similarly impacted by the devices because all were equipped similarly’. However, they do not discuss to what extent flight speeds of the birds may differ from those of unimpacted kittiwakes. The reduced flight speed and increased energy cost of flight for birds carrying heavy tags (Gessaman and Nagy 1988, Vandenabeele et al. 2012) would suggest that their estimates will underestimate the flight speeds of unimpacted kittiwakes.

20. Kotzerka et al. (2010) deployed GPS tags on 14 breeding kittiwakes and obtained data from a total of 16 foraging trips by these birds. A few birds were tagged during incubation but most had small chicks. The GPS tags were programmed to obtain position fixes every five minutes. Estimates of ground speeds of flying kittiwakes were obtained assuming that birds flew in a straight line throughout the five minute interval between position fixes. The assumption of continuous straight line flight over five minute periods is likely to result in underestimation of true ground speed, as demonstrated by Elliott et al. (2014). Kotzerka et al. (2010) report a mean ground speed of these birds of 9.2 m/sec. Most estimates fell within the range 7 to 13 m/sec. No corrections were made for wind speed, so the air speeds were not estimated. The GPS tags deployed by Kotzerka et al. (2010) weighed about 3% of kittiwake body mass. The authors state that they found no evidence of the tags affecting breeding success, but the authors did not assess whether the tags had any effects on behaviour, such as flight speed.

21. Masden (2015) derived estimates of kittiwake flight speed from RSPB FAME GPS tag data, from deployments on breeding adult kittiwakes mostly while provisioning small chicks. Masden (2015) did not report how these estimates were obtained from the data, the number of birds included in the sample, or the interval between position fixes. The reported ground speed (mean 7.26 m/sec, s.d. 1.5) is considerably slower than reported in any other study of kittiwake flight speed, and is considerably less than the calculated V_{mp} (8.9 m/sec; Pennycuick 1987), which would not only make the rate of travel surprisingly slow for a breeding bird with chicks to feed, but also energetically more costly than flying faster. This suggests that the estimate presented by Masden (2015) is probably unreliable. Nevertheless, Masden’s unusually low value for kittiwake flight speed was subsequently used, without discussion of its validity, in CRM by Busch and Garthe (2017). The GPS tags used by RSPB weighed up to about 5% of kittiwake body mass (Wakefield et al. 2017). These tags were not streamlined, so may have had particularly high impacts on the flight costs of the equipped birds. Vandenabeele et al. (2012) estimated that an unstreamlined tag weighing 3% of kittiwake body mass would increase flight costs by 17%, so an unstreamlined tag weighing 5% of body mass is likely to increase flight costs by more than 25%. In two separate studies, Chivers et al. (2016), and Heggøy et al. (2015), found that tags of about 4% of body weight on kittiwakes had severe impacts on their flight behaviour, suggesting that data from such tagged birds could not be assumed to be representative of untagged bird behaviour.

22. Tag technology is advancing rapidly, and there are now ultra-lightweight GPS tags available that weigh less than 1% of kittiwake body mass and can be programmed to obtain position fixes every few seconds (for a short duration). Deployment of these new GPS tags may allow more reliable measurement of kittiwake flight speeds than was possible using the large and heavy GPS tags that have previously been deployed on kittiwakes. A summary of the published kittiwake flight studies, as discussed above, is provided in Table 1.1.

Table 1.1 Summary of flight speed measurements reported in the published literature

Reference	Method	N birds	Data sample size (n values)	$V_{no\ wind}$ m/sec	Ground speed (mean) m/sec	Air speed m/sec	Flight speed (range) m/sec
Götmark 1980	Car speedometer				11.0	15.0	
Oldén & Peterz 1985	Seawatch timing		7 flocks		12.1	16.7	s.d. 4.84
Pennycuick 1987	Flight theory					8.9-14.9	
Pennycuick 1987	Ornithodolite	18		9.2		13.1	9-17
Alerstam & Gudmundsson 1999	Tracking radar	3	1060 secs		15.9	13.6	13.5-13.7
Alerstam et al. 2007	Tracking radar	2	660 secs			13.1	12-14
Kotzerka et al. 2010	GPS	14	16 trips		9.2		
Coulson 2011	Seawatch timing			11.9	11.9		
Elliott et al. 2014	GPS	10	58 tracks	10.6	10.6		4-17

Reference	Method	N birds	Data sample size (n values)	$V_{no\ wind}$ m/sec	Ground speed (mean) m/sec	Air speed m/sec	Flight speed (range) m/sec
Masden 2015	GPS				7.26		s.d. 1.5
Skov et al. 2018	Laser rangefinder		287		8.7		s.d. 3.16
MEAN VALUES				**10.6**	**10.8**		
Standard error, mean of means					**0.9**		

1.3 Application to Collision Risk Modelling

23. Natural England has recommended that Environmental Impact Assessments for offshore wind farms should use a flight speed for kittiwake of 13.1 m/sec in collision risk modelling (Orsted 2019), citing as their source for this estimate the paper by Alerstam et al. (2007). This recommendation is despite the fact that the Alerstam et al. (2007) study reported flight speeds for only two birds, and that the 13.1 m/sec metric refers to air speed and not ground speed. It is important to recognise that the flight speed input into the Band Model is ground speed rather than air speed. Ground speed varies in relation to wind speed and direction. Masden et al. (2019) point out that the numbers of birds estimated to be killed by collision is highly sensitive to the value of ground speed used in CRM, with the estimated mortality lower when the input value for ground speed is lower. Two aspects of the calculation are affected by ground speed. The estimated flux of birds through the collision risk area increases with increased ground speed, whereas the probability of collision for a bird flying through the rotor swept area decreases with increased ground speed. The first of these two effects has the stronger influence on the estimated number of collisions. As a consequence, the estimate of mortality was 8% lower for a 10% reduction in ground speed used in CRM (Masden et al. 2019).

24. Three published estimates of the mean ground speed of kittiwakes flying under conditions of no wind (so ground speed = air speed) give estimates of 9.2, 10.6 and 11.9 m/sec, which gives a mean of means of 10.6 m/sec (Table 1.1). Eight independent measurements, using a variety of methods, of the mean ground speed of flying kittiwakes gave values that average 10.8 m/sec (Table 1.1). These empirical measurements are broadly consistent with flight theory, which predicts that kittiwakes should fly within the range of 8.9 to 14.9 m/sec, and would minimise power output by flying at speeds around the lower end of that range. Although the flight speed estimates from tracking radar studies may be more accurate than estimates from GPS tag deployments, sample sizes from the tracking radar studies were small. As a result, it is difficult to suggest that any particular estimates in Table 1.1 should be given higher weighting than the others or that particular estimates should be excluded. Therefore, if we consider all of the available data, based on the

evidence in Table 1.1, there is a case for using a mean flight speed of kittiwakes in CRM of 10.8 m/sec with a standard error of 0.9 m/sec.

25. For CRM the influence of wind on ground speed of kittiwakes will depend on the direction of flight of birds at collision risk. If birds are flying at a particular air speed but with a tailwind, the flux past a turbine will increase with the higher ground speed achieved. If birds are flying at this same air speed but with a headwind, the flux past a turbine will decrease with the lower ground speed achieved. Risk of collision for birds passing through the rotor swept area will change in the opposite direction, with a higher ground speed of birds with a tailwind reducing the risk of contact with a blade whereas birds with a lower ground speed due to a headwind will have an increased risk of contact with a blade. Therefore, if the flux of birds is equal in all directions relative to wind (and therefore relative to turbine orientation), the effects of wind on bird ground speed will cancel each other out. The risk will be the same. So for CRM, the alteration of ground speed due to wind, only becomes an issue if the flux of birds is much higher in one particular direction, so that most birds have ground speeds altered from their air speed in the same direction. That could be the case if birds were migrating consistently in one direction past an offshore wind farm and wind direction was also consistently from one direction. But under most conditions the effect of wind would cancel out between birds experiencing a headwind and birds experiencing a tailwind (setting aside any effects of wind direction on the flight heights of those birds), so that the CRM predictions would be the same as for conditions with no wind. If we took into account the fact that kittiwakes fly lower over the sea when flying into a headwind (Götmark 1980), then collision risk will decrease when birds fly into a headwind because an increased proportion fly below collision risk height, whereas birds flying with a tail wind will be likely to have a higher proportion flying at collision risk height, but will have a higher ground speed so that risk of collision will be reduced. Where CRM uses evidence-based avoidance rates from comparison of predicted and actual numbers of collisions, these effects are incorporated into the evidence-based avoidance rate. However, where CRM for offshore wind farms is based on precautionary avoidance estimates or empirical avoidance behaviour observations rather than by comparing observed and predicted numbers of collisions, standard CRM is made more precautionary in this regard because these reductions in collision risk are not included in the calculations.

26. In conclusion, it is recommended that for CRM with kittiwake as the focal species, it would be appropriate to use a flight speed of 10.8 m/sec with a standard deviation of 0.9 m/sec, based on the available evidence and range of different methods used to estimate kittiwake flight speed.

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