Understanding Flight in Birds

Wing Shapes

Developed by EM Date-Huxtable
Photo credit: Lene Parashou

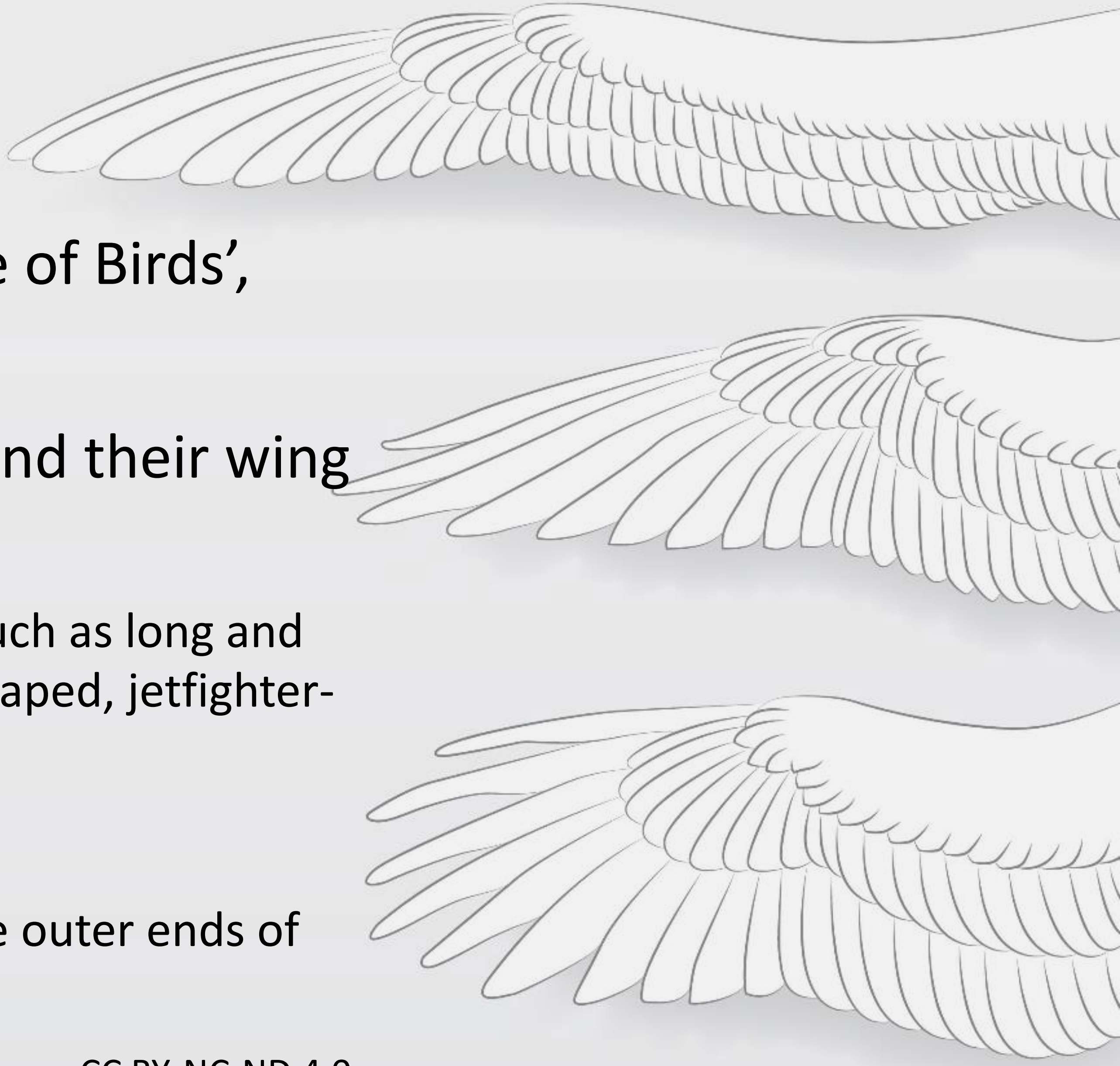
Hunter Bird Observers Club
Affiliated with BirdLife Australia

Learning Outcome:

- to accurately observe and describe wing shape and flight behaviour of some birds

Photo credit: Lene Parashou

Bird Wing Shapes



- Watch David Attenborough's 'The Life of Birds', Episode 2 'The Mastery of Flight'
- Observe the different types of birds and their wing shapes:
  - describe each bird's body size and shape, such as long and thin, short and round, large and torpedo-shaped, jetfighter-shaped, etc.
  - describe the wing shape
  - note the way the feathers are shaped at the outer ends of the wings

Bird Flight Patterns

- Describe the main flying behaviour(s), such as soaring, flapping, diving with wings partly folded, undulating or alternately flapping and gliding, high-speed flying, hovering. How do birds use their body, wings and tail to adjust their flying speed and direction?

- Observe the 'flight environment' for each different bird. Is it windy? Hot or cold weather? Are there lots of obstacles in the way like trees? Do the birds appear to use the wind and thermals?

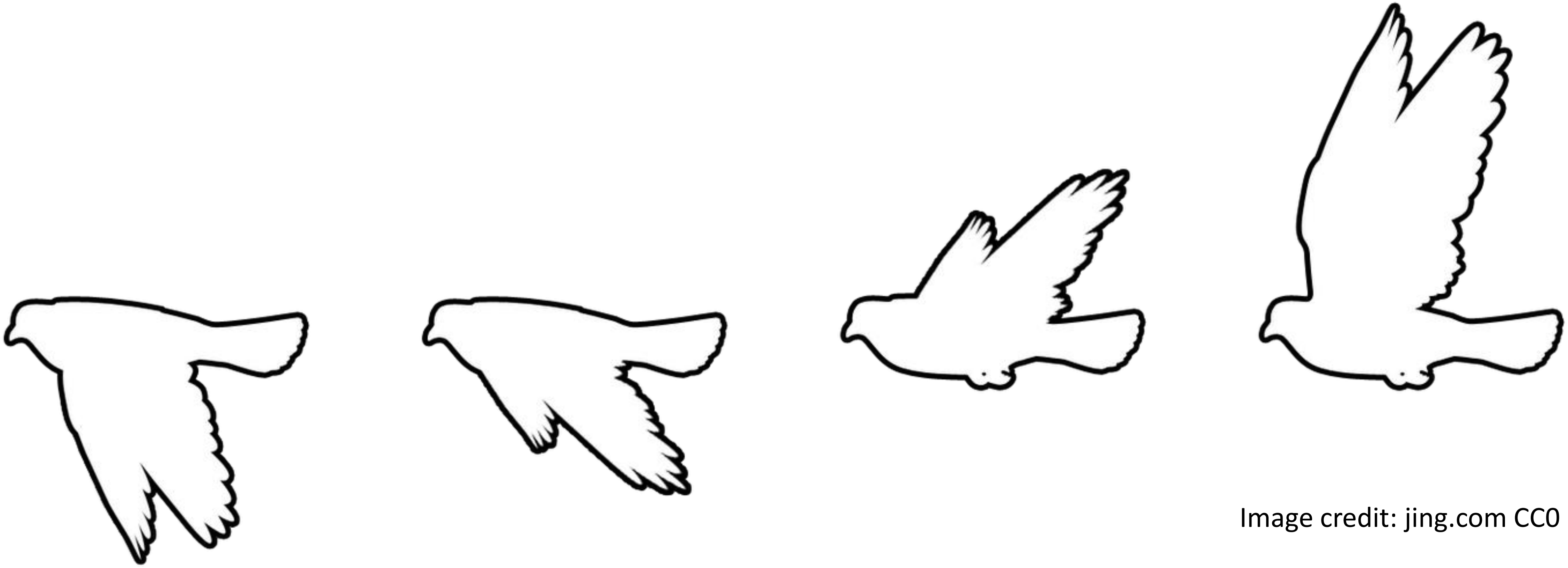


Image credit: jing.com CC0

Bird Wing Shapes and Flight Patterns

Photo credit: Lene Parashou

- Tabulate your observations (Table 1):

Species	**Body size and shape**	**Wing shape**	**Outer wing feather arrangement**	**Observed flight environment**	**Observed flight pattern**
Albatross	Large, torpedo-shaped	Long and narrow	Pointed	Very windy	Mostly soaring
…	…	…	…	…	…

Learning Outcomes:

- to use observations as evidence in explaining differences in wing shape and flight performance between birds
- to describe wing shape and flight performance quantitatively, calculating ‘Aspect Ratio’, ‘Wing Loading’, and ‘Cruising Speed’

Photo credit: Lene Parashou

Classifying Wing Shape, Predicting Flight Pattern

- Quantify the effect of a bird's wing and body proportions on flight performance, using Aspect Ratio, Wing Loading and Cruising Speed (aerodynamic variables that measure a bird's wing structure, a bird's ability to bear its own body weight on its wings during sustained flight and the minimum cruising speed of flight required to maintain lift)

- Factors that affect flight performance:
  - ➢Wing length
  - ➢Wing width and curvature
  - ➢Feather arrangement
  - ➢Body shape and mass

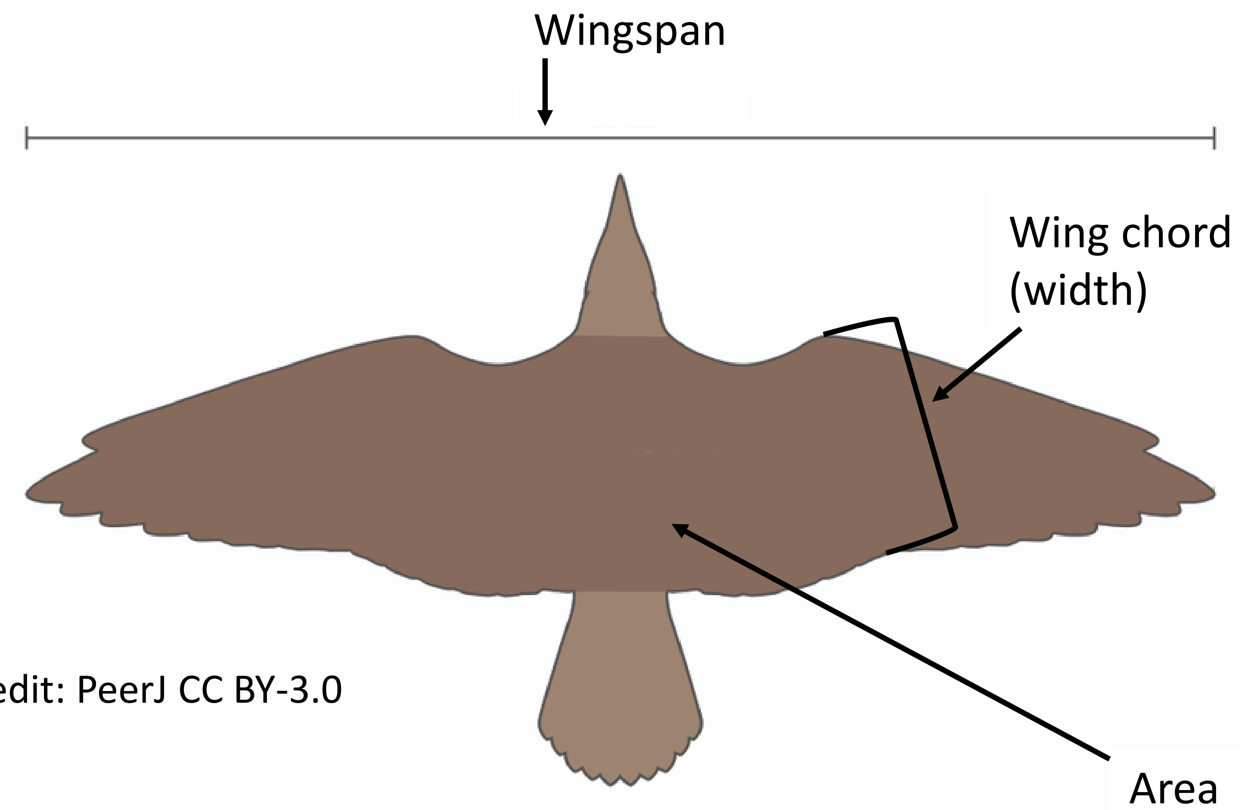
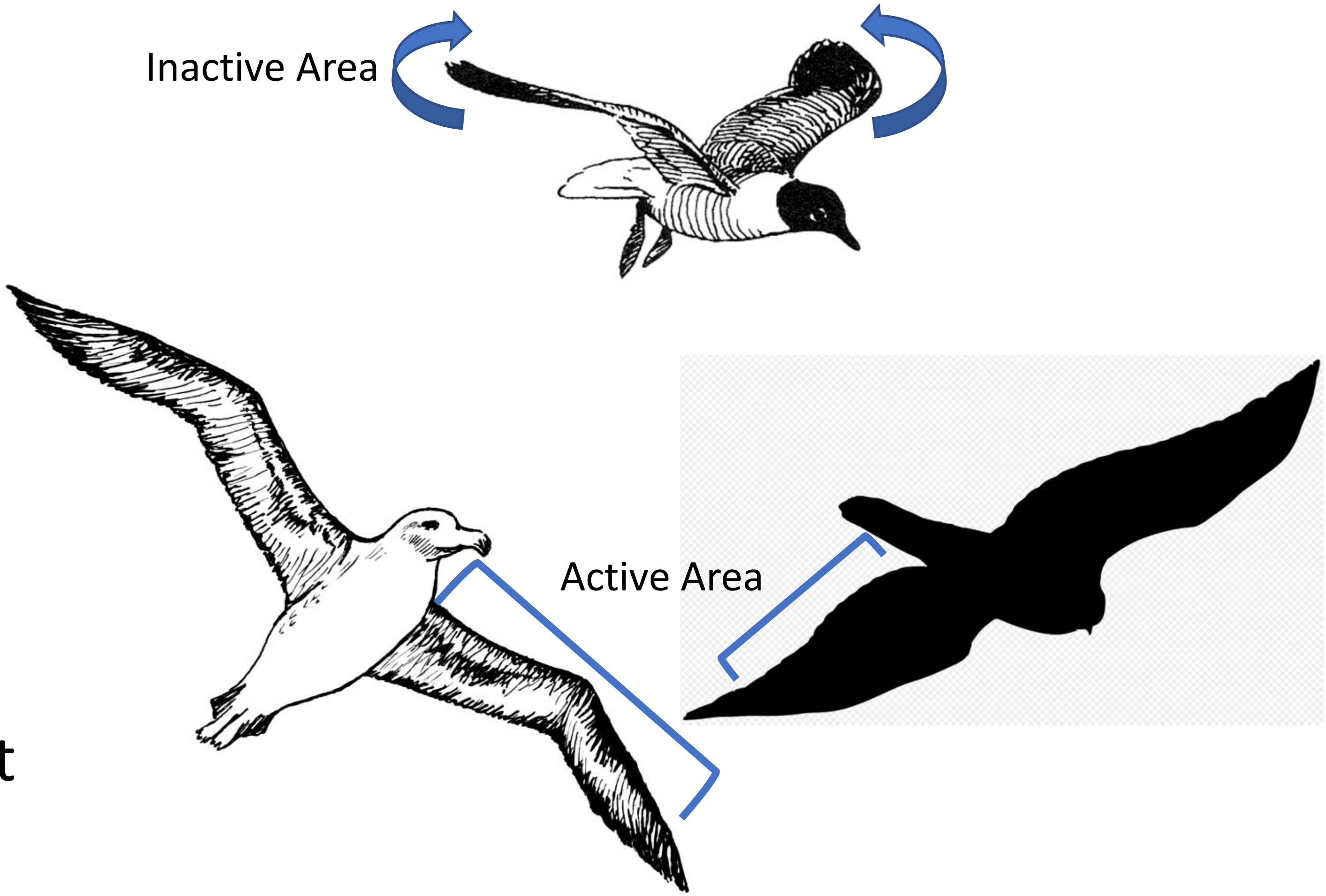


Image credit: PeerJ CC BY-3.0

Wing Length

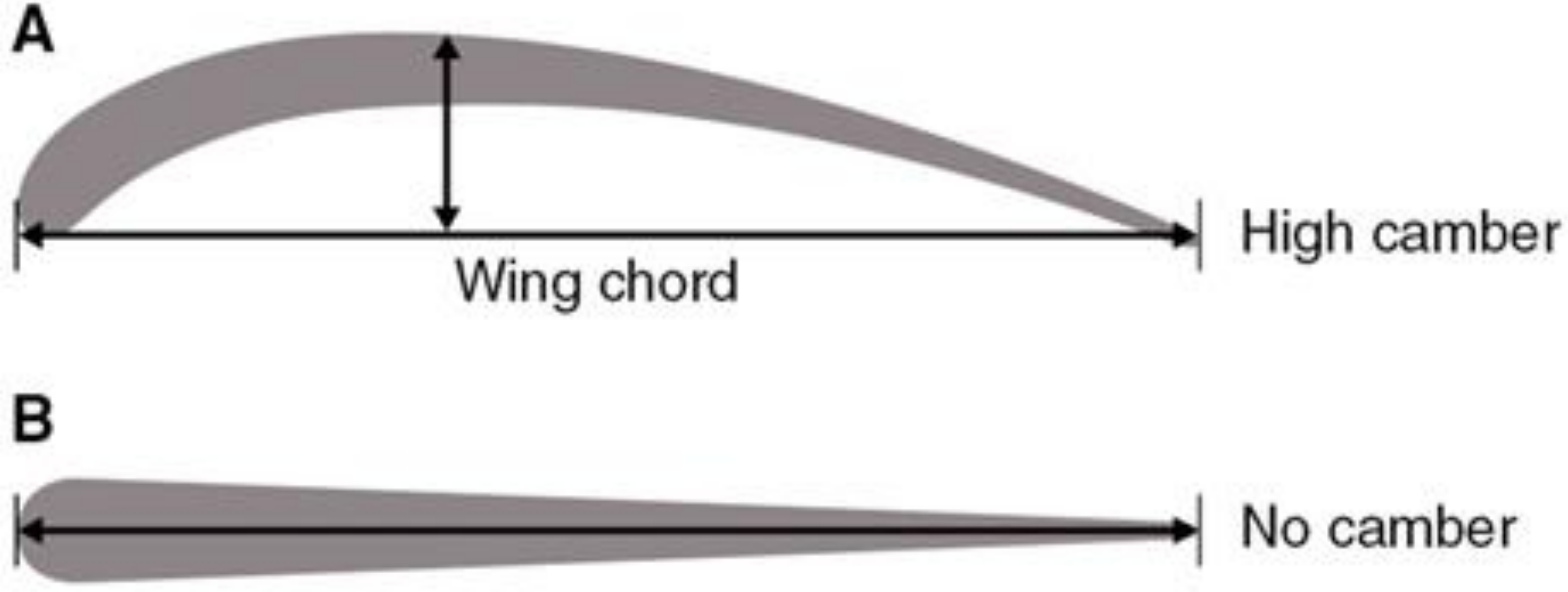
- The greater the length of the wing, the higher the lift
- Air wraps around the wings, leads to an inactive area on the tips and causes drag on the wing (top)
- Longer wings have a disproportionately larger active area which provides lift relative to the inactive areas (bottom left vs right)



Wing Width

- The greater the width or chord of the wing, the higher the lift but the greater the drag (friction acting opposite to lift and thrust)

Image credit: Lovell and Fitzpatrick (2016)



Wing Curvature

- Across its width the wing may also be curved or cambered, the greater the camber the higher the lift at low air speeds, the lower the camber the higher the frequency of flapping required for the bird to remain airborne
- Long wide wings with deep camber increase lift, short wide wings with shallow camber increase agility and maneuverability mid-flight, narrow wings with shallow camber increase flight speed

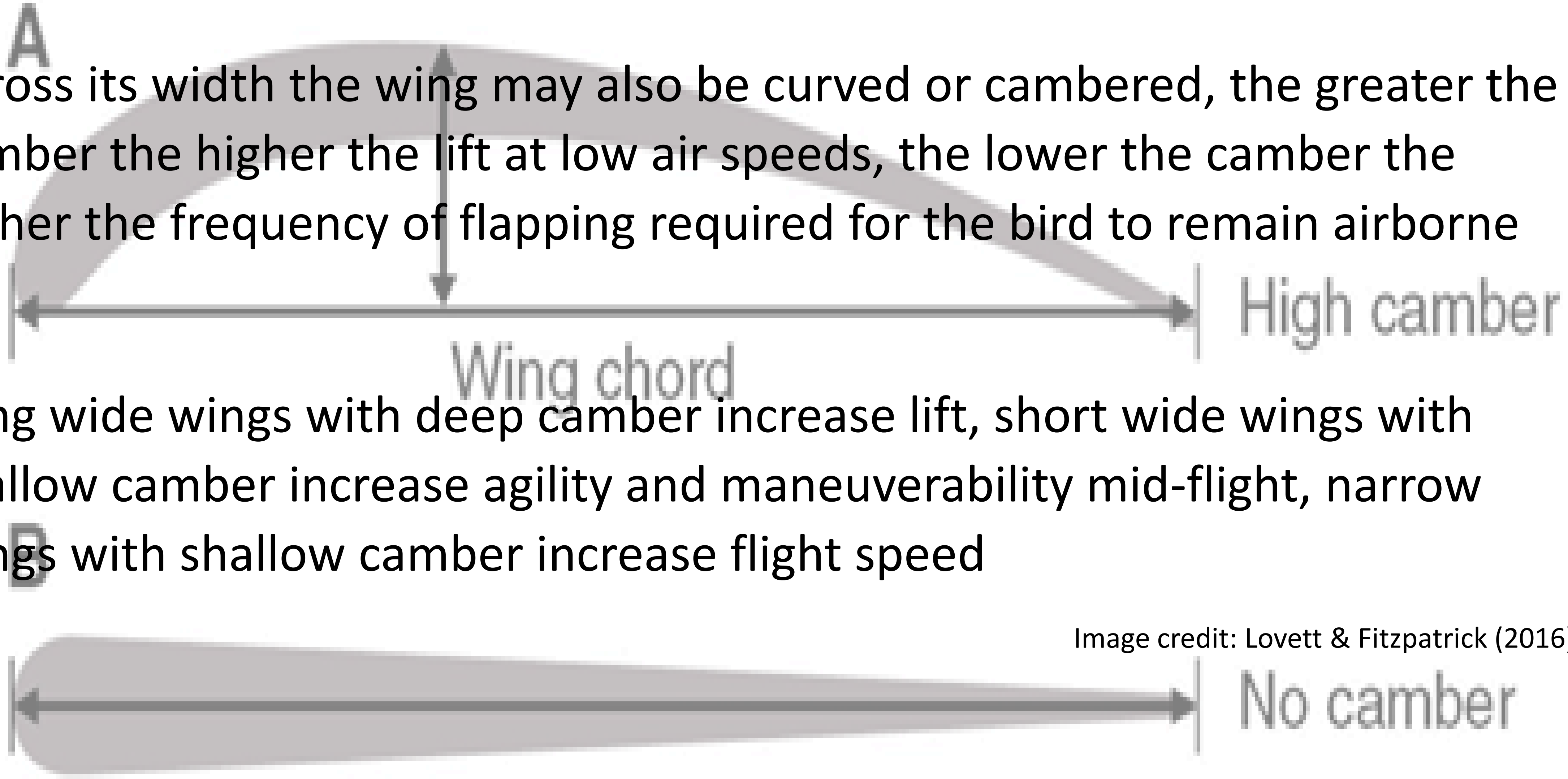


Image credit: Lovett & Fitzpatrick (2016)

Feather Arrangement

- Alula (‘winglet’), the freely moving first digit (thumb) near the ‘wrist’ that bears 3 to 5 small flight feathers
- Slots between the flight feathers at the outer end of the wing allow the bird to fly at slower speeds without stalling

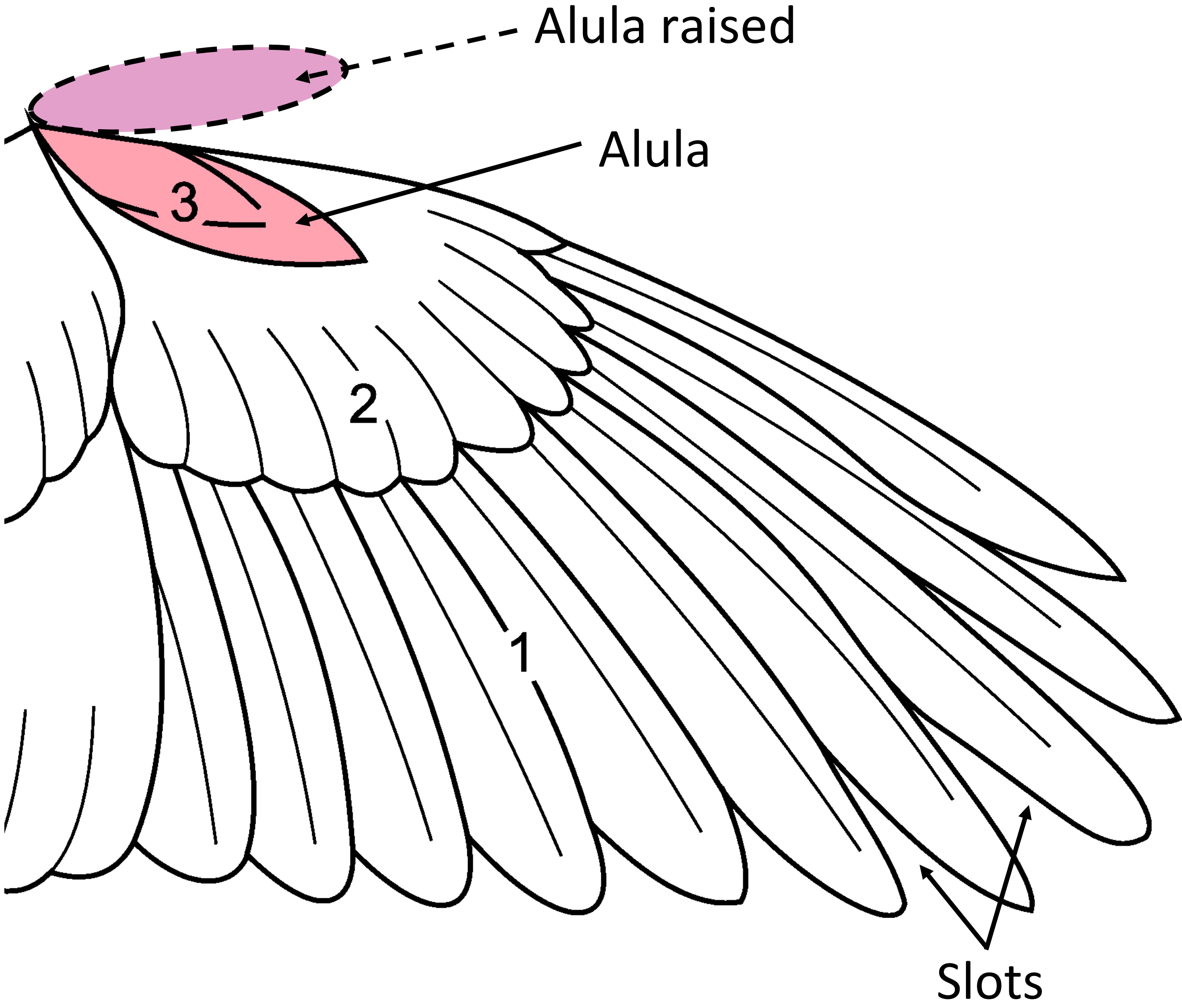
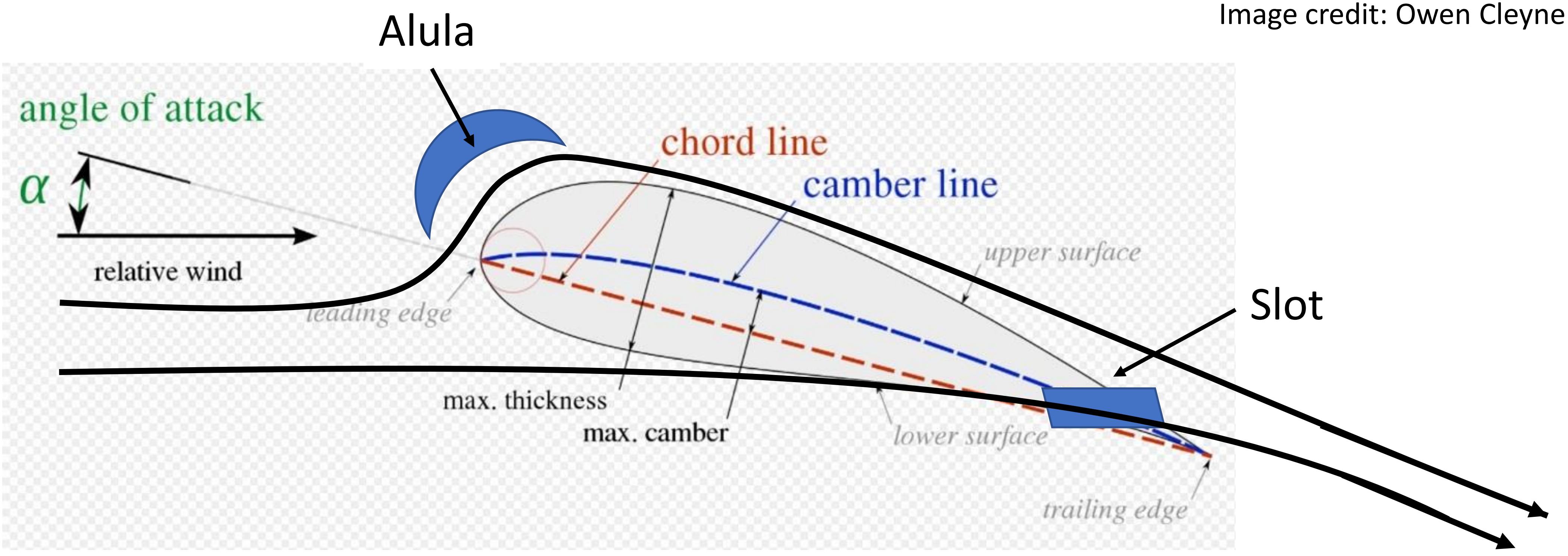


Image credit: Muriel Gottrop CC BY-SA 3.0

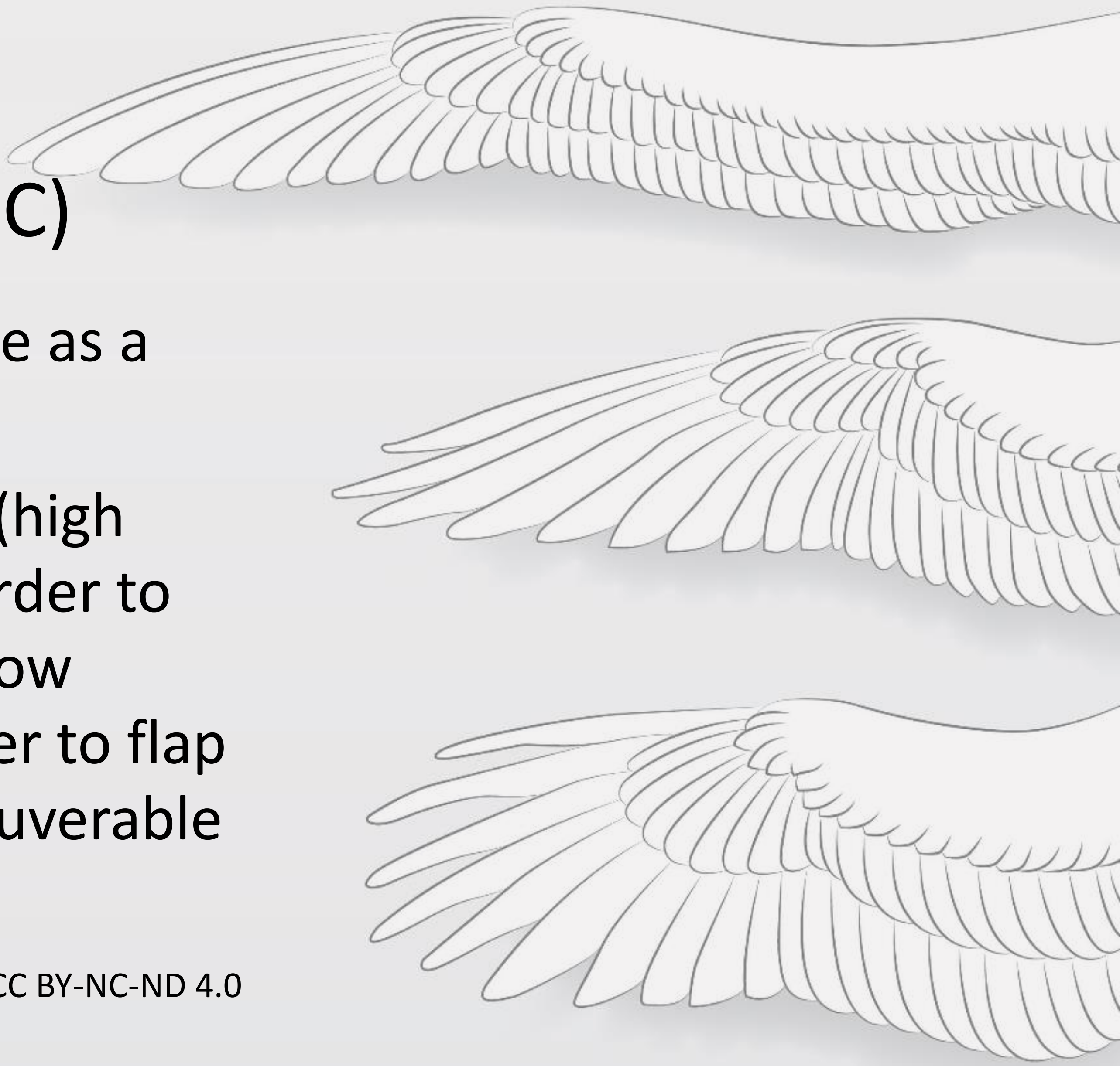
Feather Arrangement

- The alula is usually held flush against the wing, but it can be moved. When flying at slow speeds or landing, the bird moves the alula upwards and forwards, which creates a slot on the wing's leading edge; this gives the wing a higher angle of attack and lift without stalling

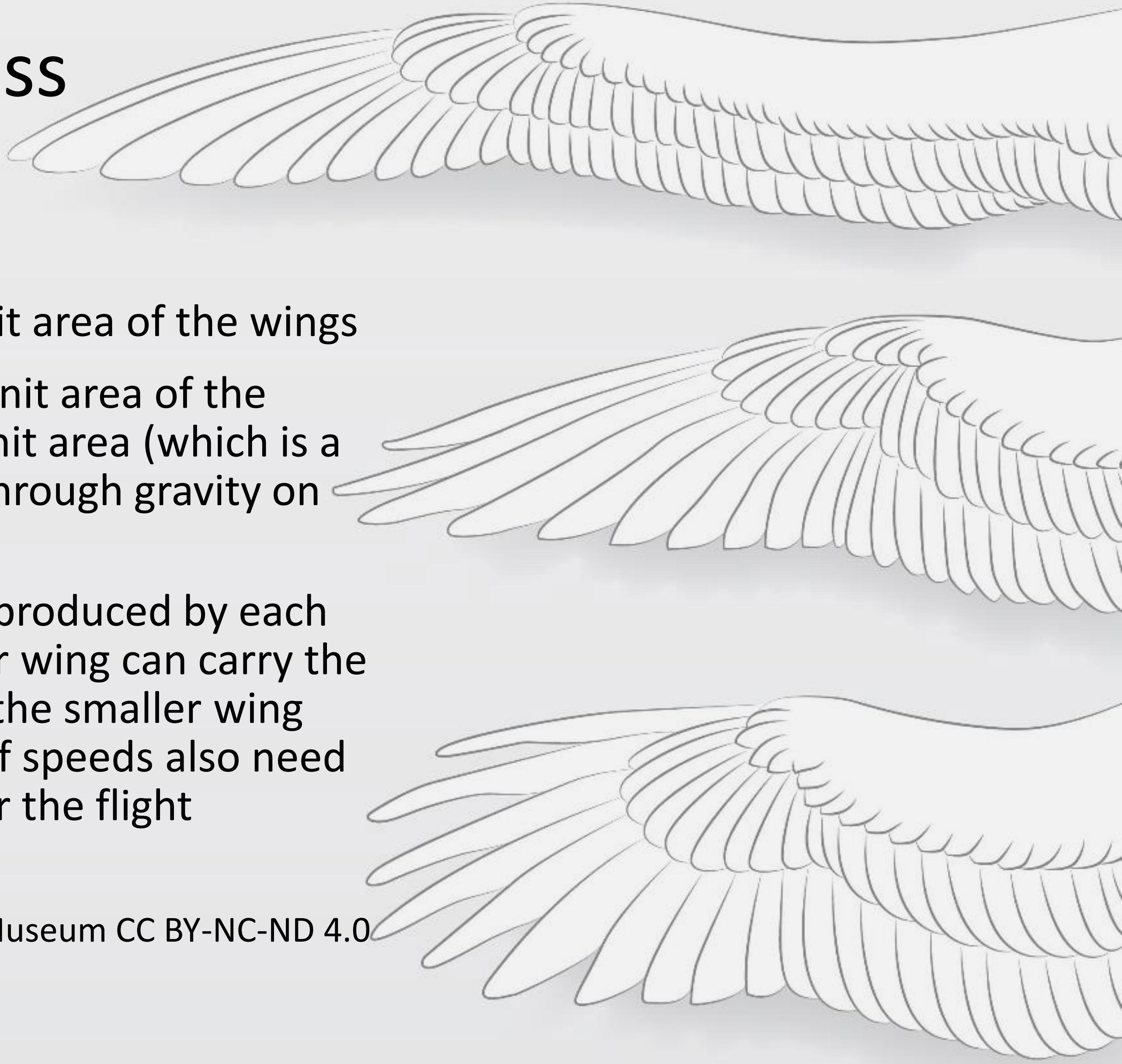


Aspect Ratio (R) =
Wingspan (S) / Wing Chord (C)

- Aspect ratio describes the wing shape as a dimensionless number
- Implications: Long and skinny wings (high aspect ratio) get more lift but are harder to flap faster. Short and stubby wings (low aspect ratio) get less lift but are easier to flap faster. Shorter wings are more maneuverable in the air and under water



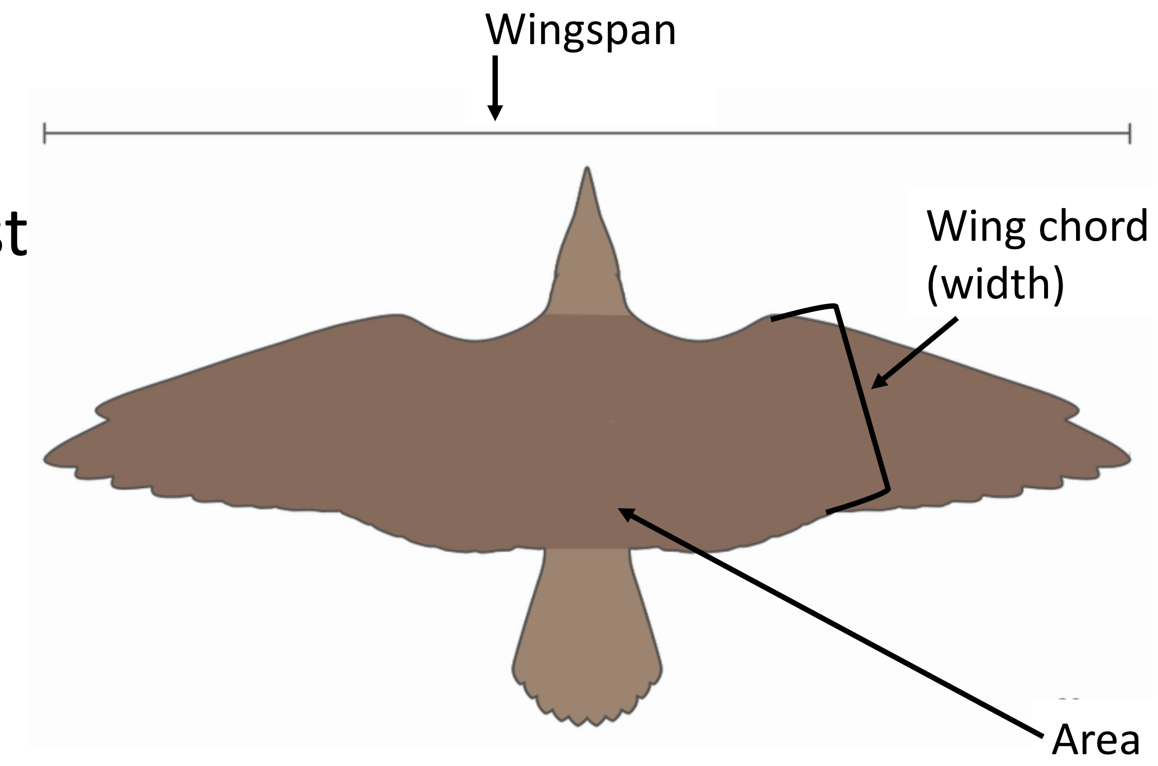
Wing Loading (L) = Body Mass (m) / Wing Surface Area (A)



- Wing loading describes the mass of the bird per unit area of the wings
- Wing loading can also be described as weight per unit area of the wings, which estimates the force in Newtons per unit area (which is a measure of the pressure that a bird's mass exerts through gravity on the wings when in flight)
- Implications: The faster a bird flies, the more lift is produced by each unit area of wing. Thus, with higher speed a smaller wing can carry the same weight as a larger wing at slower speed, i.e., the smaller wing has a higher wing loading. Correspondingly, take-off speeds also need to be higher. The higher the wing loading, the lower the flight maneuverability

Measuring a Bird's Wings and Body

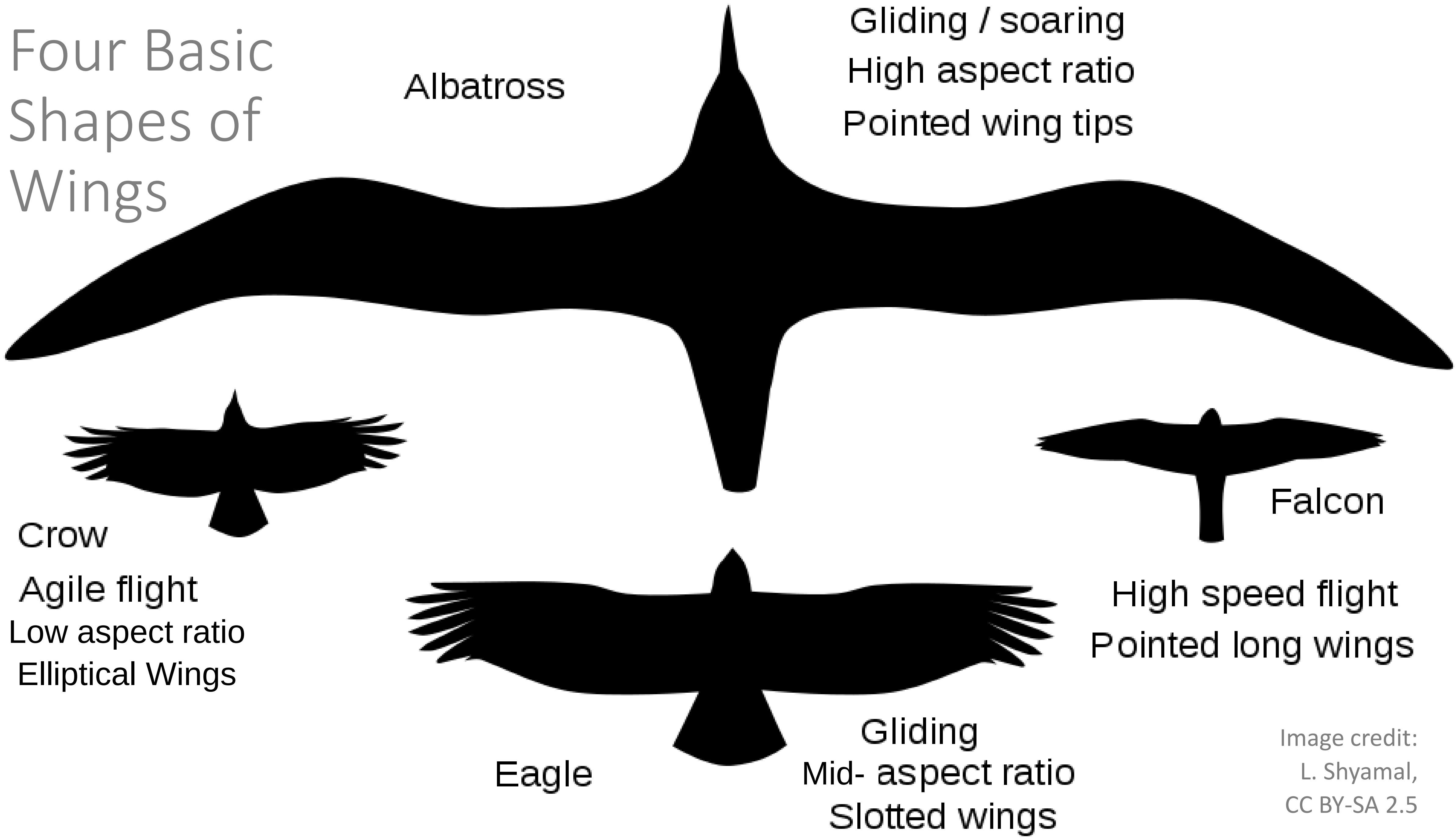
- Wingspan (S) = (wing length x 2) + body width at wings cm
- Wing chord (C) = mean wing width cm (i.e., approx. width at 'wrist' ~innermost primary feather)
- Wing shape (Aspect ratio, R) = span / chord (i.e., S / C)
- Wing loading (L) = body mass m / wing area A (i.e, m / S x C) g cm^{-2}



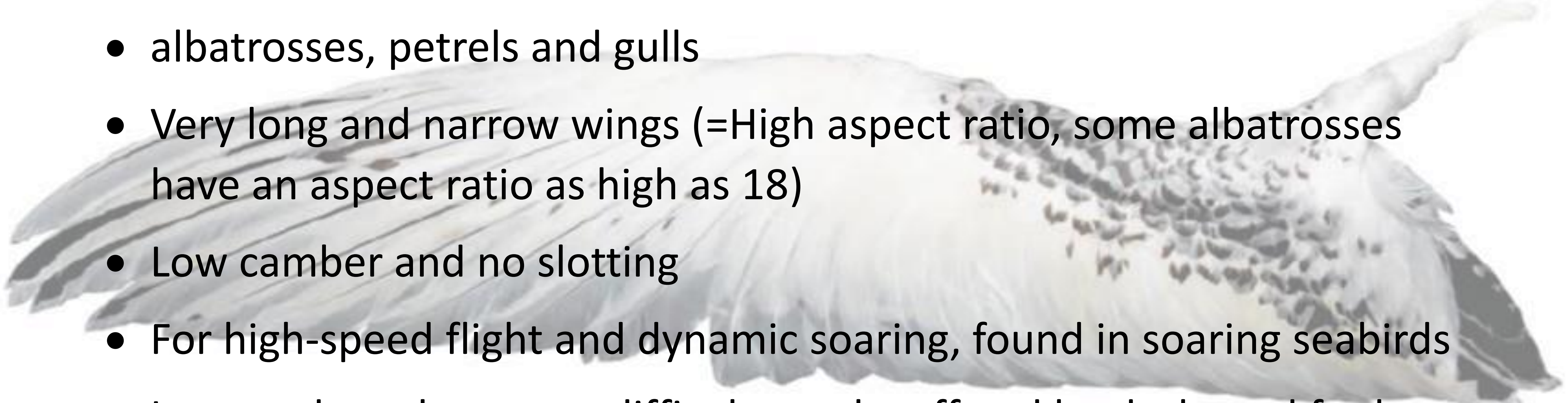
Describing bird wings with standardised measurements:

- **Aspect Ratio**: Wingspan (cm) / Wing chord (cm)
- **Wing Loading as Density:** Mass (g) / Wing area (cm^2)
- **Wing Loading as Force:** Weight (N) / Wing area (m^2) = Pressure (Pa)

Four Basic Shapes of Wings



High Aspect Ratio Actively-soaring Species



- albatrosses, petrels and gulls
- Very long and narrow wings (=High aspect ratio, some albatrosses have an aspect ratio as high as 18)
- Low camber and no slotting
- For high-speed flight and dynamic soaring, found in soaring seabirds
- Long and cumbersome, difficult to take off and land, shaped for long distance soaring with little effort

- View ‘Ocean-going Birds in Flight’ by Alwyn Simple and examine the wing shapes of these magnificent fliers: https://birds-australia.smugmug.com/Theme-Galleries-Birds/Birds-in-Flight/Ocean-Going-Birds-in-Flight/

High Speed Species

- Includes open-habitat birds, long-distance migrants and birds that feed in flight, such as swallows, swifts, falcons
- Moderate in length and narrow wings (=Moderate to high aspect ratio)
- Low camber, slender tips and no slotting
- Built for speed and require a lot of work to keep the bird airborne

Did you know…?

- Peregrine Falcons can fly as fast as 390 kph when they are hunting

Photo credit: Gary Tong

- Bar-tailed Godwits can fly non-stop over 12,000 km in 11 days at 89 kph during migration

Photo credit: Rob Palazzi

- View ‘Migrating Birds to Australia in Flight’ by Alwyn Simple and examine the wing shapes of ‘the extreme athletes of the bird world’: https://birds-australia.smugmug.com/Theme-Galleries-Birds/Birds-in-Flight/Migrating-Birds-to-Australia-in-Flight/

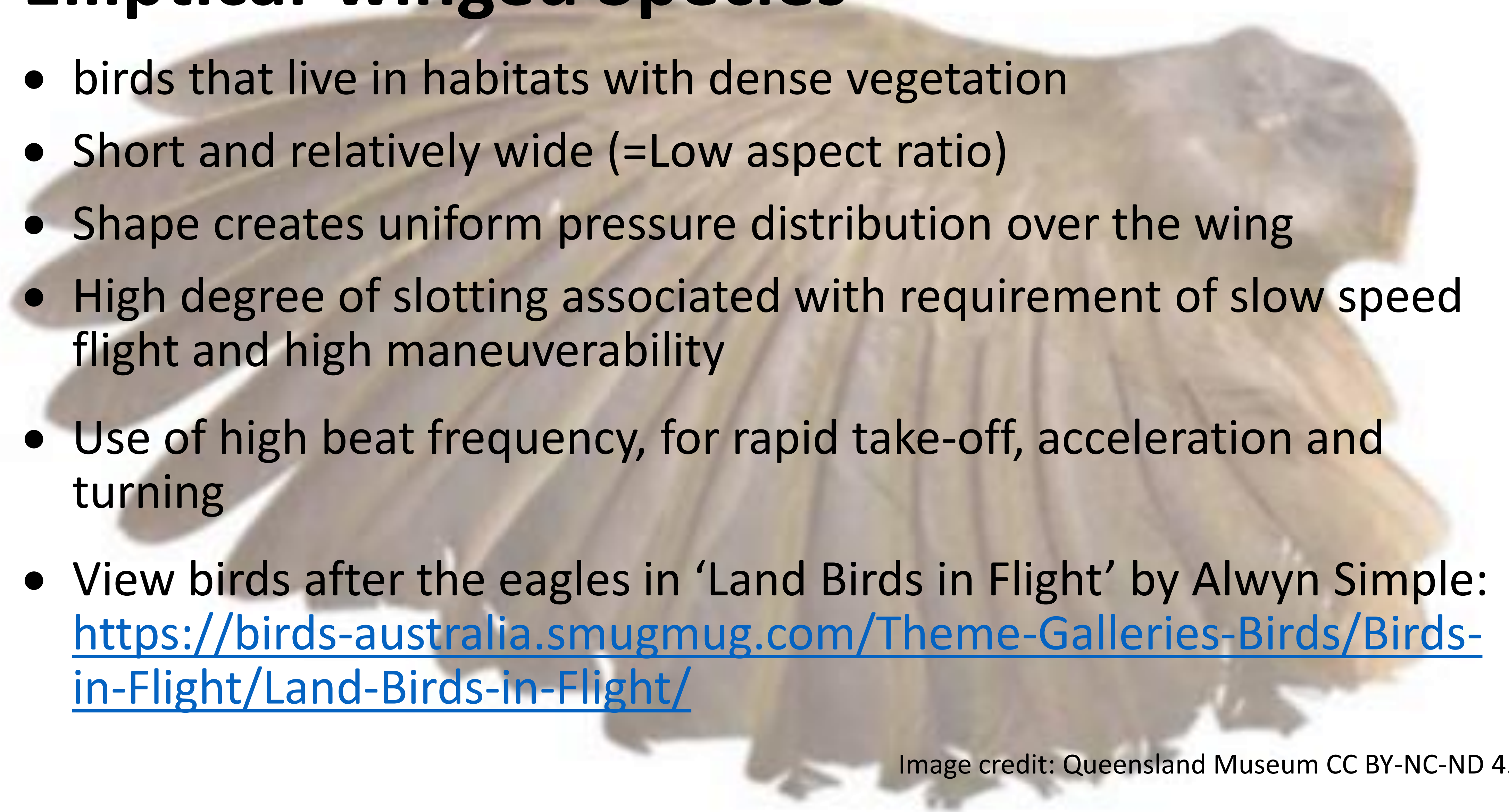
Slotted High-lift Passively-soaring Species

- hawks, eagles, swans and geese
- Long wide wings (=Moderate aspect ratio)
- Deep camber and high slotting
- Extreme notching present on outer primary feathers, called emargination
- Provide extra lift needed to keep their large bodies airborne or to carry heavy prey, capable of soaring on thermals

Image credit: Conty CC 3.0

- View the eagles in ‘Land Birds in Flight’ by Alwyn Simple: https://birds-australia.smugmug.com/Theme-Galleries-Birds/Birds-in-Flight/Land-Birds-in-Flight/

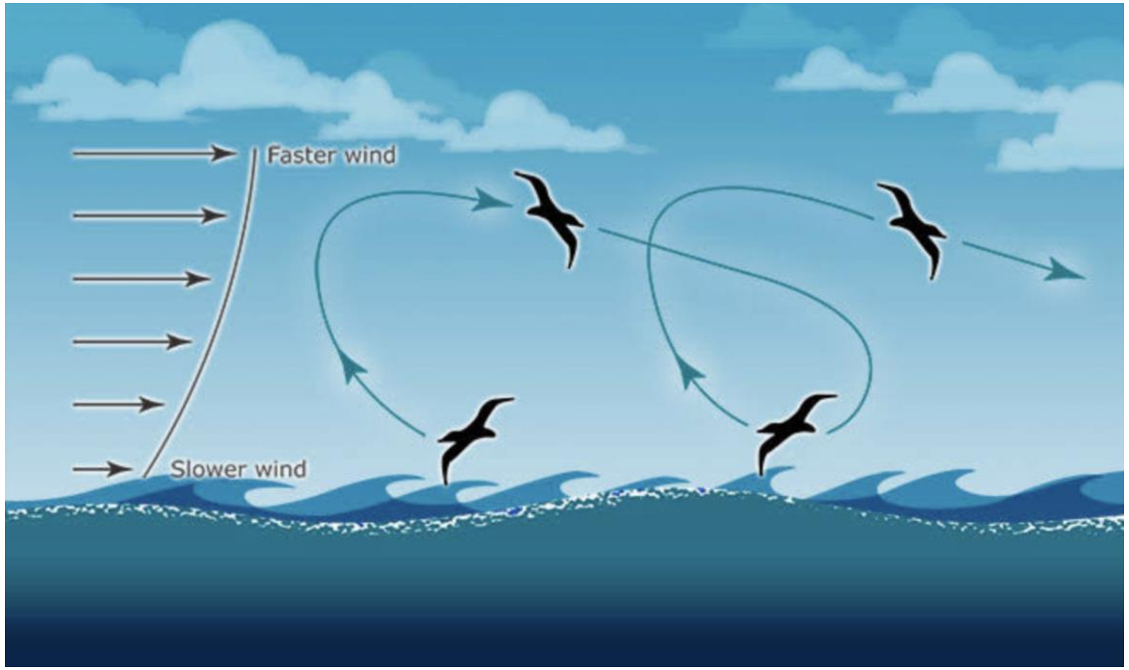
Elliptical-winged Species



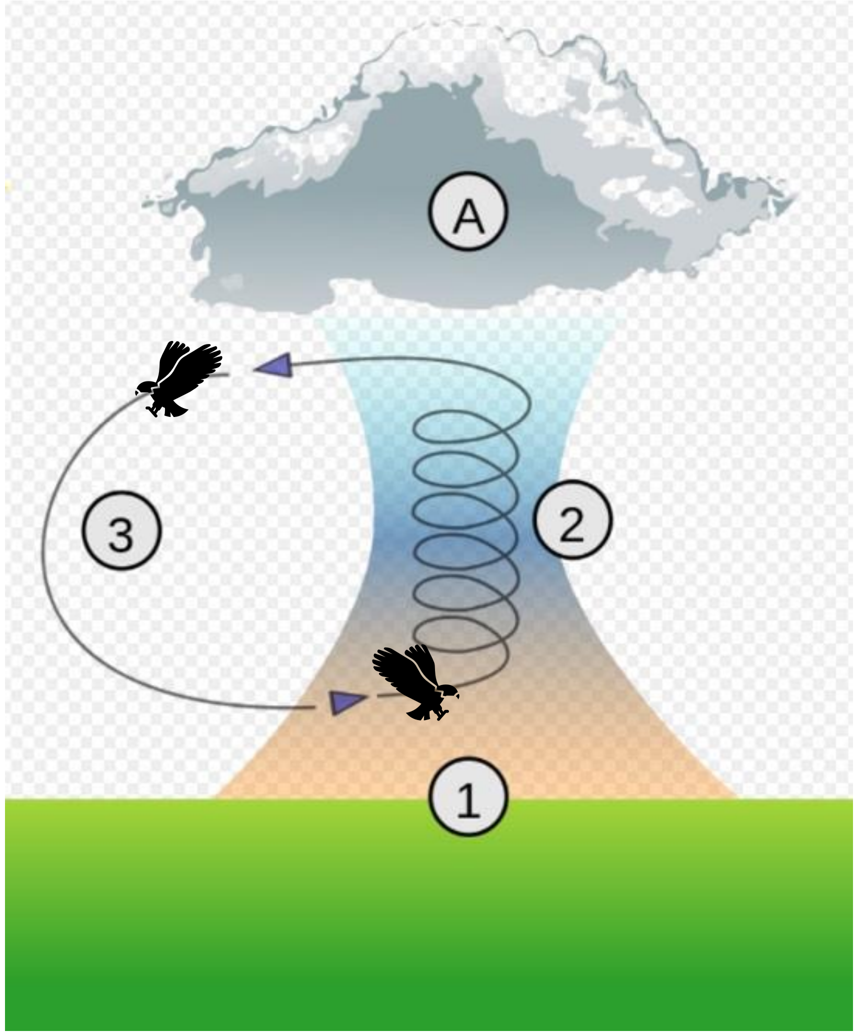
- birds that live in habitats with dense vegetation
- Short and relatively wide (=Low aspect ratio)
- Shape creates uniform pressure distribution over the wing
- High degree of slotting associated with requirement of slow speed flight and high maneuverability
- Use of high beat frequency, for rapid take-off, acceleration and turning
- View birds after the eagles in ‘Land Birds in Flight’ by Alwyn Simple: https://birds-australia.smugmug.com/Theme-Galleries-Birds/Birds-in-Flight/Land-Birds-in-Flight/

Active Soaring (left) vs Passive Soaring (right)

Watch youtube video: Staying in the Air – Bird Flight by Emma Lumley and Amy Hooper (2010), https://www.youtube.com/watch?v=F41qG_lfDwU



Active soaring over waves, above (TeAre CC BY-NC 3.0), and Passive soaring on thermals, at right (Dake CC BY-NC 2.5)



Wing Loading and Cruising Speed

How fast must a bird fly – what is the minimum speed – to maintain lift? A few factors come into play:

- weight
- wing size
- air speed and air density
- angle of attack, angle of the wings with respect to direction of flight

In this example the force (i.e., weight) produced by body mass under gravitational acceleration, which is a constant 9.8 m s^{-2}, is used to calculate wing loading (Tong & Schwab 2021).

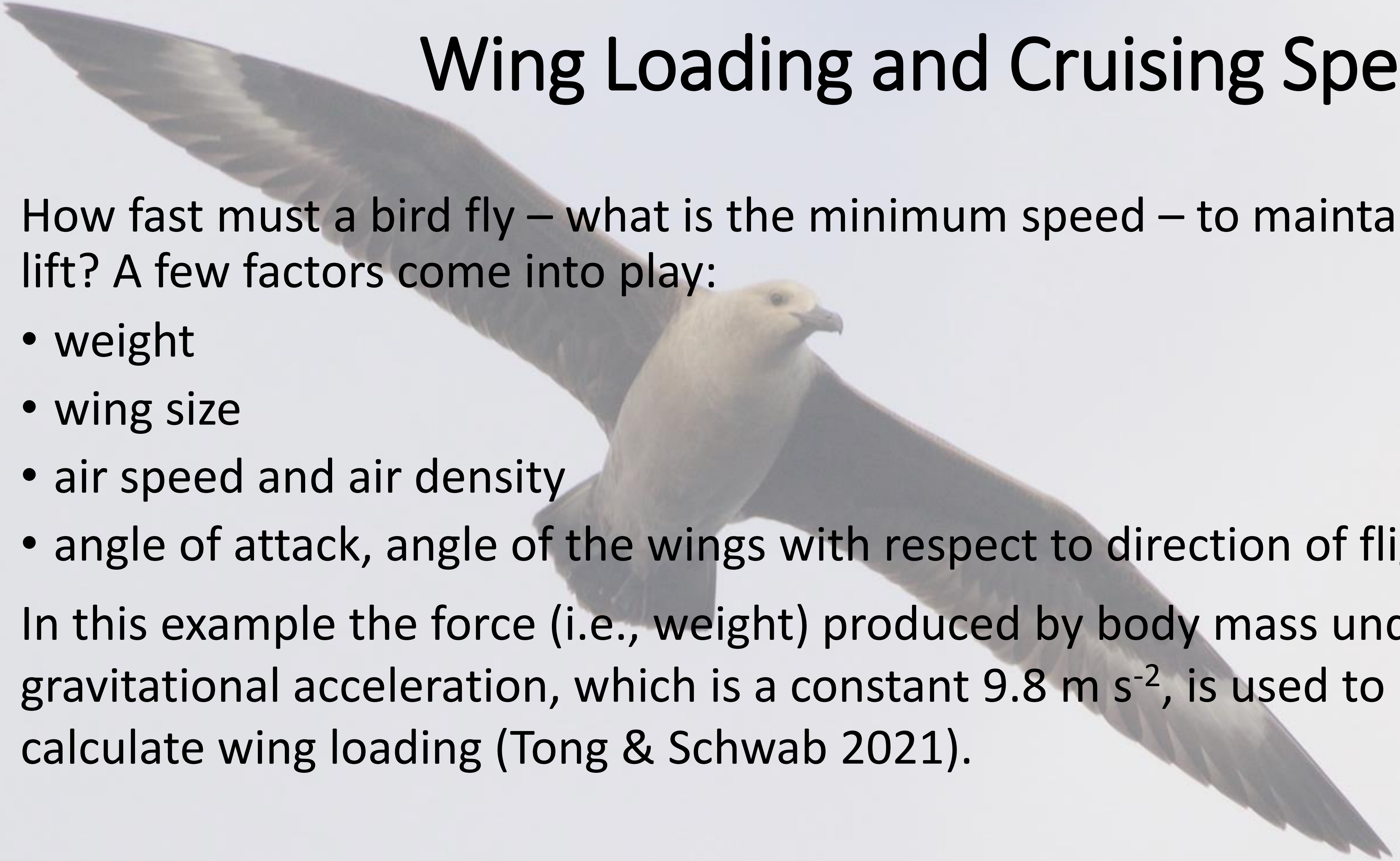
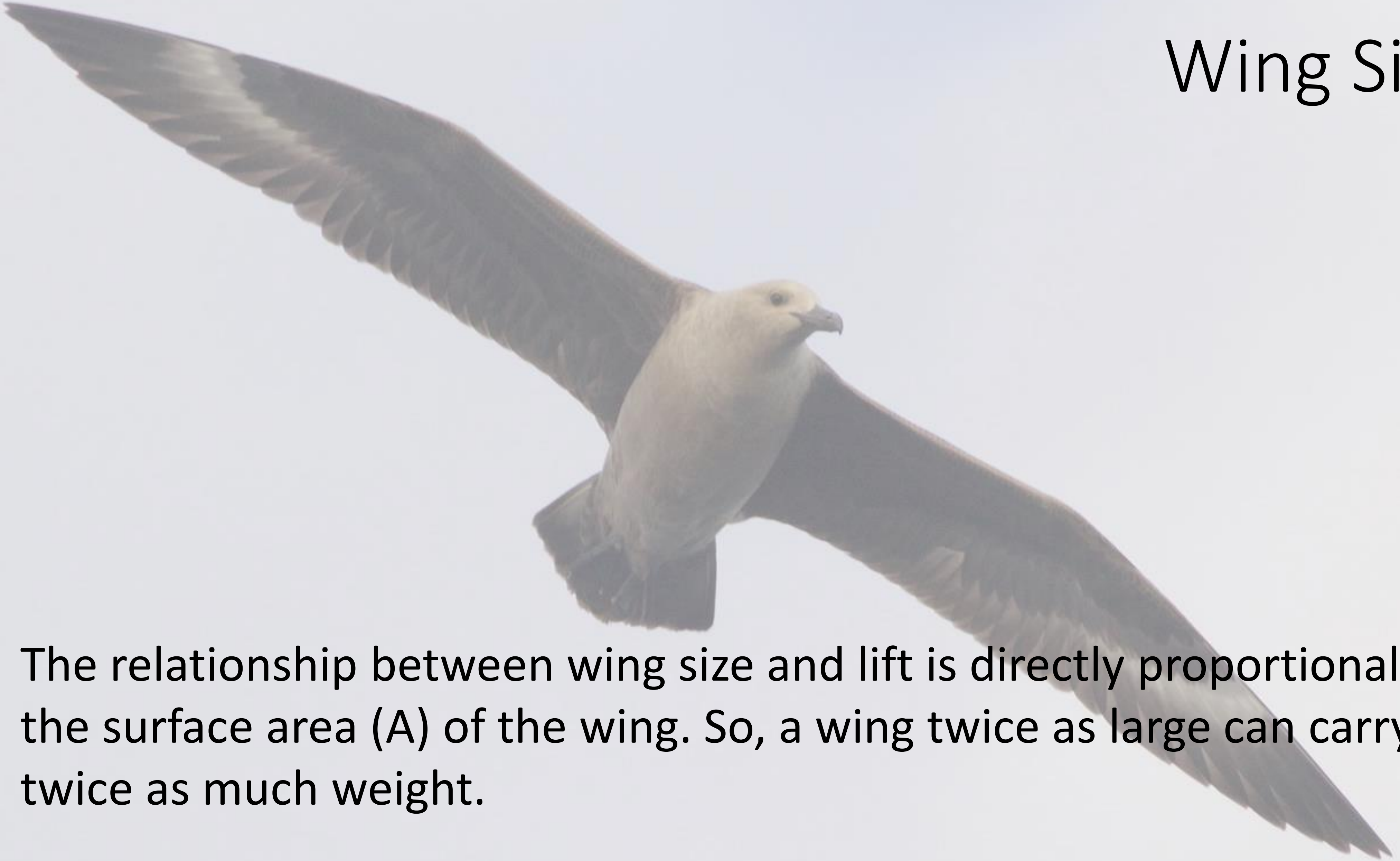


Photo credit: Mick Roderick

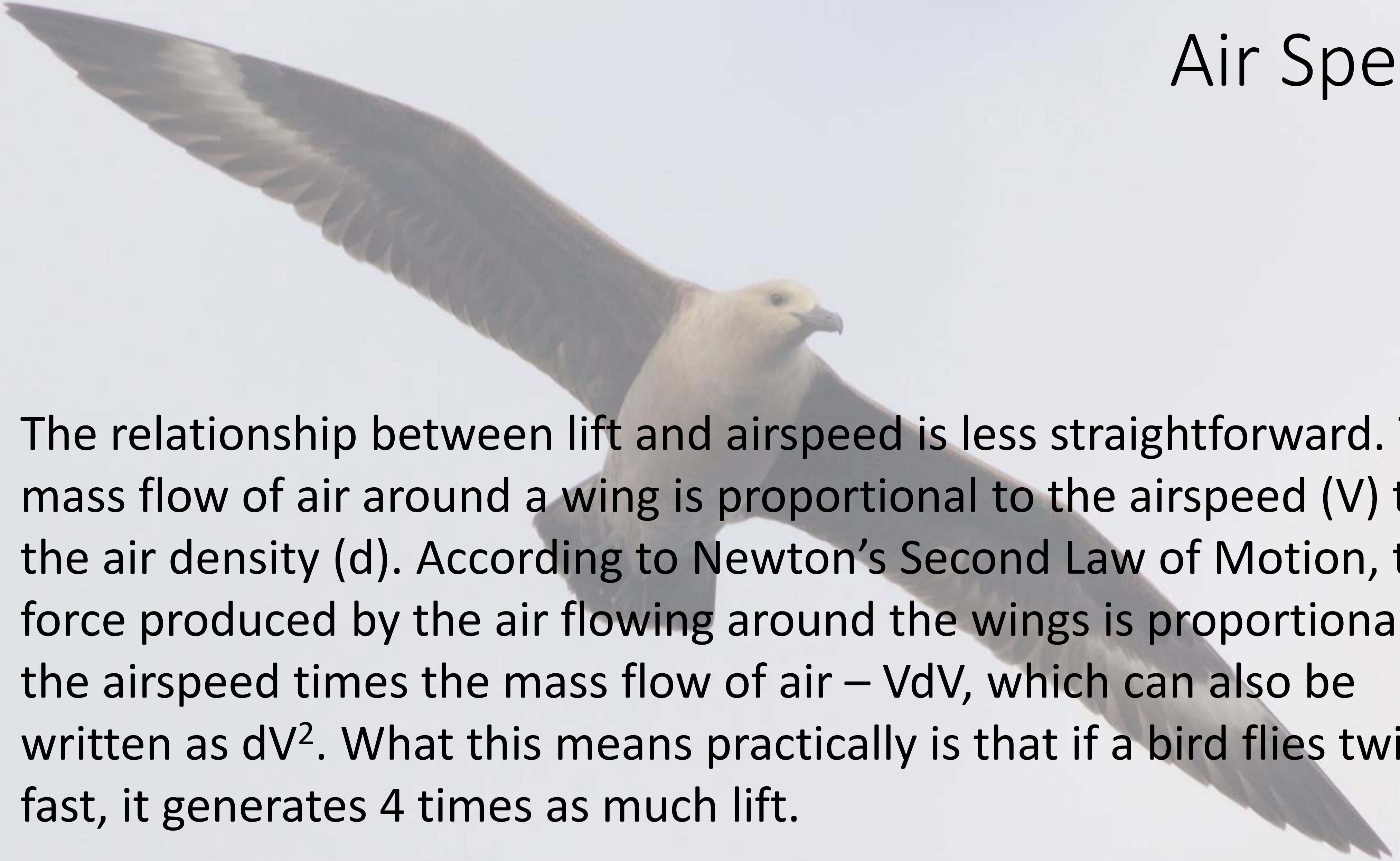
Wing Size



The relationship between wing size and lift is directly proportional to the surface area (A) of the wing. So, a wing twice as large can carry twice as much weight.

Photo credit: Mick Roderick

Air Speed



The relationship between lift and airspeed is less straightforward. The mass flow of air around a wing is proportional to the airspeed (V) times the air density (d). According to Newton's Second Law of Motion, the force produced by the air flowing around the wings is proportional to the airspeed times the mass flow of air – VdV, which can also be written as dV^2. What this means practically is that if a bird flies twice as fast, it generates 4 times as much lift.

Photo credit: Mick Roderick

Angle of Attack:

is the angle between the wing and the direction of the oncoming wind. At small angles of attack, the air flow stays close to the wing. At higher angles of attack, the air flow separates from the wing and stops flowing smoothly, causing a large loss in lift. Birds can adjust the angle of attack of their wings to suit circumstances, but for long distance flights, they hold their wings at an angle of attack of 6^o. Lift increases as angle of attack increases, but only up until a certain critical angle. At that point, stall occurs as the air stops flowing smoothly over the top surface and instead peels away, leaving a turbulent wake.

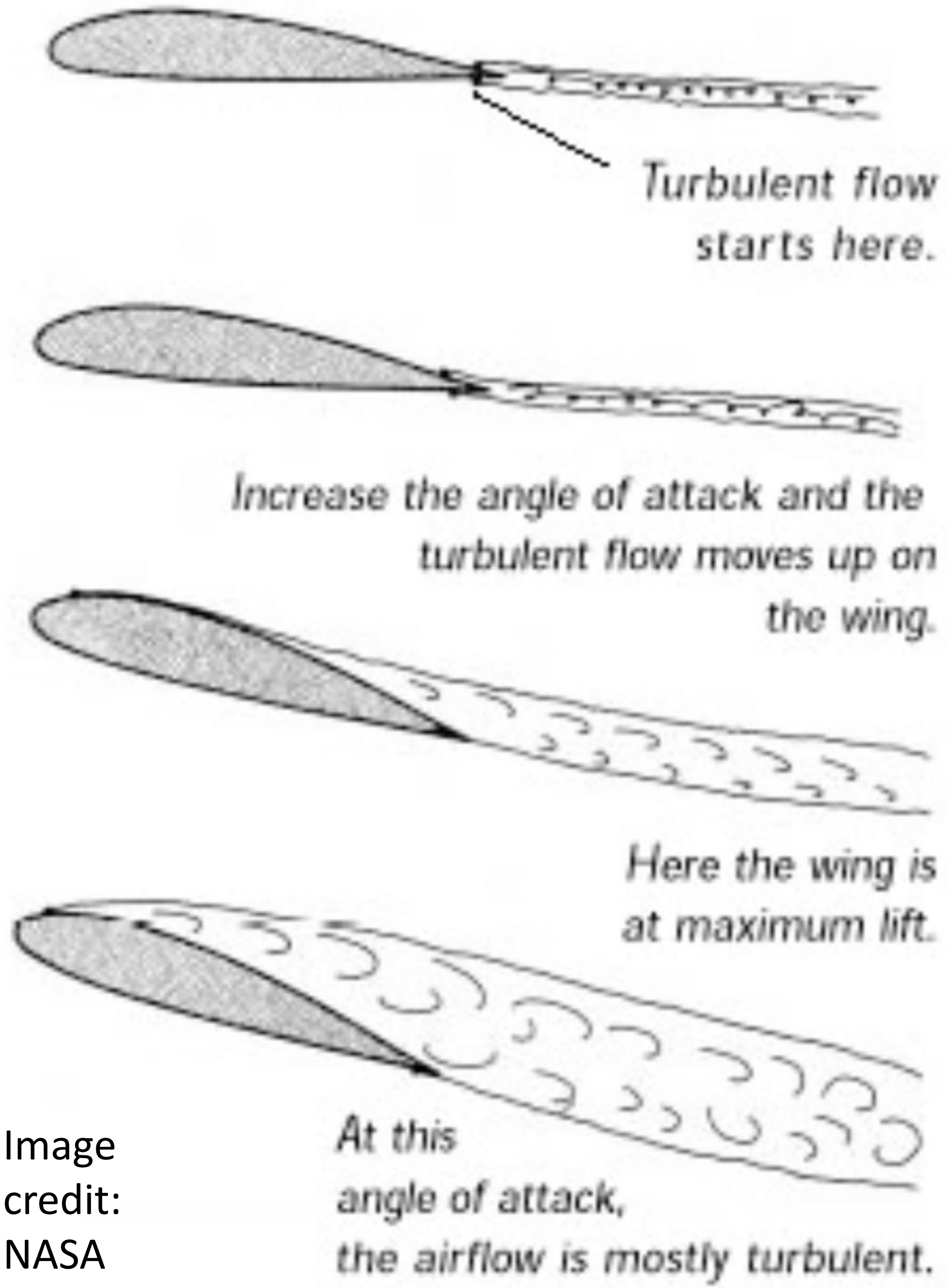


Image credit: NASA

Calculating Weight in Newtons

A bird's wings have to support its weight against the force of gravity, so lift must equal its weight W. Force of weight W equals the bird's mass m multiplied by gravitational acceleration a=9.8 m s^{-2} [W=ma=m*9.8 N]. Lift is related to the surface area of a wing A and to air speed dV^2 (0.3 is a constant related to the average value of the angle of attack for long distance flight in birds, which is 6^o), therefore:

$$W = 0.3dV^2A$$

Calculating Wing Loading in Newtons per unit area

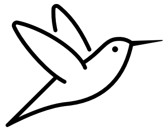
The previous equation can also be simplified and rearranged by setting d, the density of air at sea level, to be 1.25 kilograms per cubic meter. Since birds fly relatively close to sea level, it is safe to use this number in the equation. Both sides of the equation can be divided by the wing area A, leading to the new equation: W/A is the amount of weight supported by the wings divided by the surface area of the wings, the bird's wing loading (the greater a bird's wing loading, the faster it must fly):

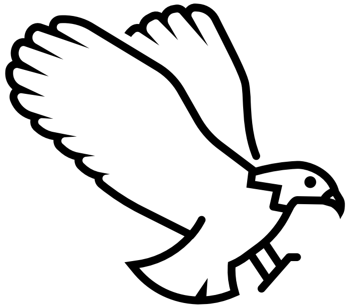
$$W/A = 0.38V^2$$

Calculating Minimum Cruising Speed

To calculate the minimum cruising speed, V, requires the previous equation to be re-arranged as:

$$V=\sqrt{2.63W/A}$$





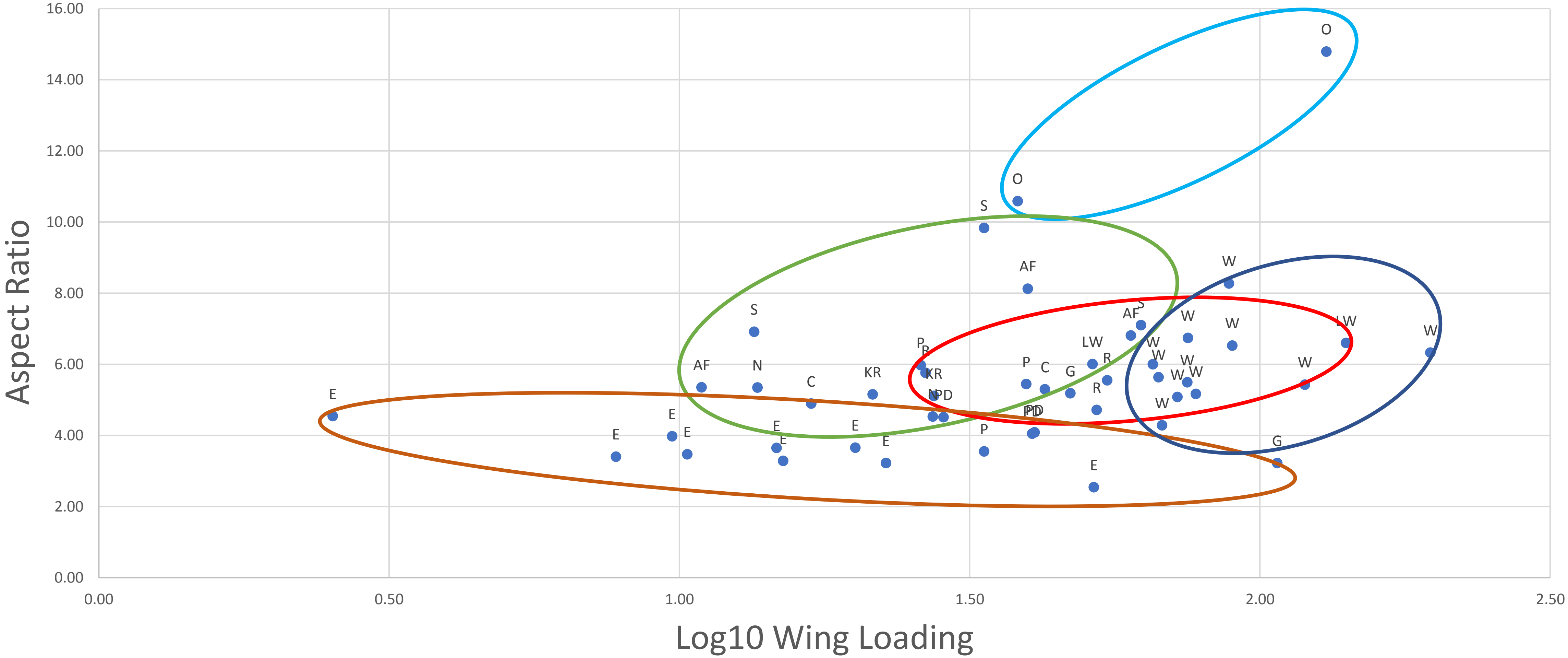
Maths Activity: Classifying Wing Shape and Flight Behaviour

- Complete Table 2 below (see also accompanying worksheet) calculating Aspect Ratio, Wing Loading (in Newtons per m^2 not grams per cm^2) and Cruising Speed for all the species listed
- Plot Aspect Ratio (y-axis) against Wing Loading (x-axis) and label the points by their Avian Order
- Plot Weight (y-axis) against Cruising Speed (x-axis) and label by Avian Order
- Compare your graphs with Norberg's (2002) and Tennekes' (2009) results
- Classify each species according to Wing Shape type and add to Table 2 (**Hint**: use reference images to assist in classifying)

Order	Species	Body Length cm	Wingspan (S) cm	Wing Chord (C) cm	Aspect Ratio (R=S/C)	Body Mass (m) kg	Body Weight (W) N [W=ma, a=9.8]	Wing Area (A=S*C) m^2	Wing Loading (L=W/A) N m^{-2}	Cruising Speed (V) m s^{-1}	Wing Shape Type

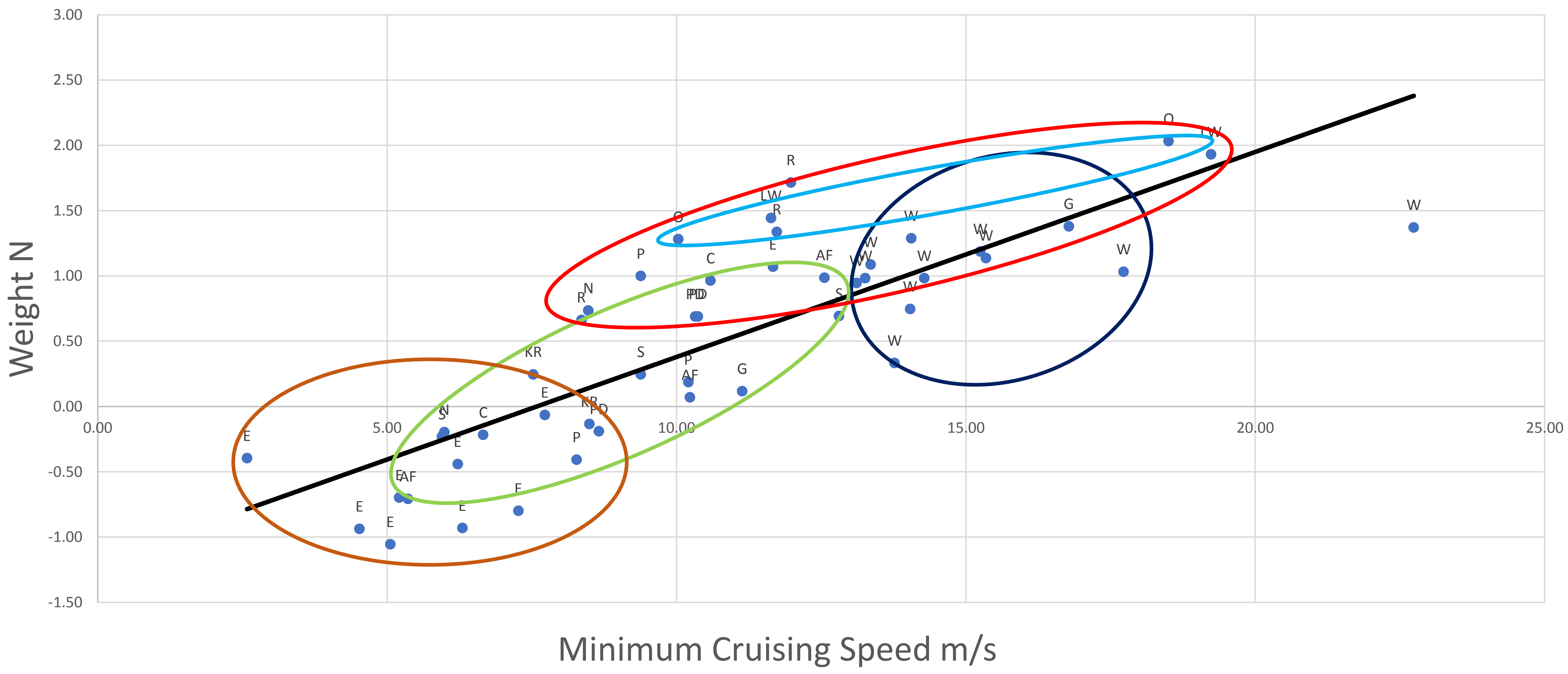
Different groups of birds have characteristic aspect ratio to wing loading patterns (compare with Norberg 2002):

Elliptical, High lift, High speed, High aspect ratio, High wing loading



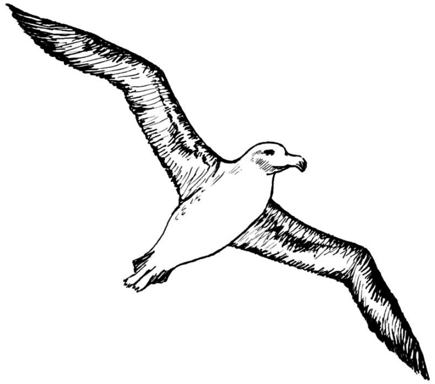
The proportional relationship between weight and cruising speed for various species of birds (compare with Tennekes 2009):

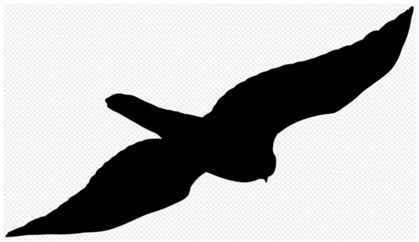
Elliptical, High lift, High speed, High aspect ratio, High wing loading

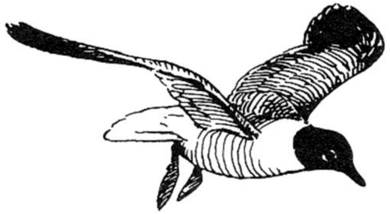


Use the results of your calculations and the position of each species relative to other species on the graphs of Aspect Ratio vs Wing Loading and Weight vs Cruising Speed to interpret the range of values of Aspect Ratio and Wing Loading that characterise each wing shape type. Explain the flight performance capable of each wing shape type using Benoulli's Principle:

- High Aspect Ratio
- High Speed
- Slotted High Lift
- Elliptical







- Do any species not fit into the four categories? How would you describe their wing shape and flight performance?

Inquiry Questions

- How does observation instigate scientific investigation?
- What are the benefits and drawbacks of qualitative and quantitative observations?
- How does the collection and presentation of primary data affect the outcome of a scientific investigation?
    - ➢ Apply conventions for collecting and recording observations to qualitatively and quantitatively analyse the primary (**‘Flight’ Experiment**) and secondary data (**Maths Activity**)
- How do conclusions drawn from the interpretation of primary data promote further scientific investigation during the planned experiment?

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