Understanding How Birds Fly

Developed by EM Date-Huxtable
Photo credit: Lene Parashou

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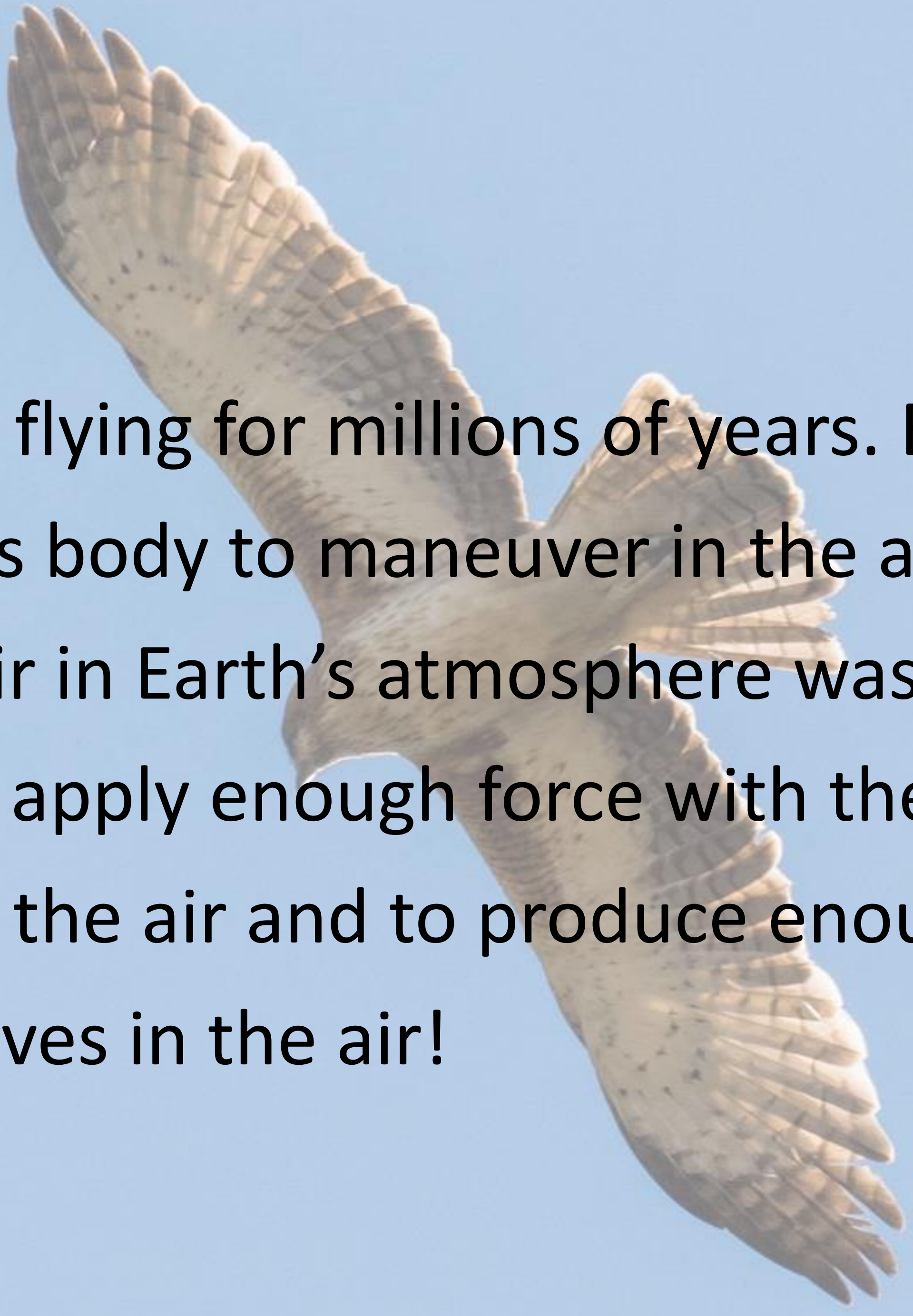
Affiliated with BirdLife Australia



Birds have been flying for millions of years. Every flying bird learns to fly by using its body to maneuver in the air. Flight might not be possible if the air in Earth’s atmosphere was less dense. Birds must instantaneously apply enough force with their wings to lift themselves into the air and to produce enough forward movement to keep themselves in the air!

Photo credit: Lene Parashou

Understanding How a Kite 'Flies'

Think about when you last flew a kite:

- What key environmental factor enabled you to 'fly' it?
- What does the kite usually do when you launch it into the air?
- What happens when there isn't enough of this key factor?

Image credit: cocoparisienne CC0

Explaining How a Kite 'Flies'

As air moves (i.e., wind) around an object, such as a kite that's in the air, it creates different pressures on that object. The air moving across the lower surface is slowed down by the kite being tilted towards the air flow, so it moves more slowly than the air moving across the upper surface. Faster air means less pressure on the upper surface of the kite. Slower air means more pressure on the lower surface. This creates a force called 'lift', which makes the kite float upwards. Therefore, the key to flight is creating pressure upwards on the kite to keep it in the air. This is called Bernoulli's Principle after Daniel Bernoulli who published it in his book *Hydrodynamica* in 1738. The principle is basically similar for a bird's wings.

Image credit: cocparisienne CC0

Understanding How a Glider ‘Flies’

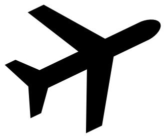
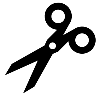
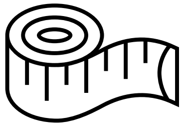
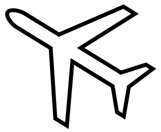
Learning Outcomes:

- To understand how changing the length and width of the glider’s wings changes its ‘flight performance’
- To explain the forces acting on the glider when it is ‘flying’

‘Flight’ Experiment

You will use a toy glider as a simple ‘bird’. Firstly, observe the shape of the glider’s wings and tail.

Experiment: Materials

1. Toy foam glider purchased from a toy or department store
2. Discarded styrofoam packaging, eg. from a new fridge or washing machine
3. Sharp knife for cutting and paring the styrofoam 
4. Discarded cardboard, eg. cereal and pizza boxes 
5. Scissors and sticky tape
6. Digital scales that measure in tenths of a gram  
7. 25m measuring tape
8. Small fan with several (at least 3) speed settings

Experiment: Methods

1. Assemble the glider by following the instructions on the box. ‘Test fly’ it and observe how far and high it glides when you launch it with different force or ‘thrust’. Now observe what happens when you launch the toy glider after you change the size and shape of its wings.

Experiment: Methods

2. Ask a parent or teacher to help you cut and pare the styrofoam to make two wings, each the same width as the originals but twice as long (see below); shape the styrofoam so that the lower surface remains relatively flat and the upper surface is curved like an airfoil (see diagram of cross-section).

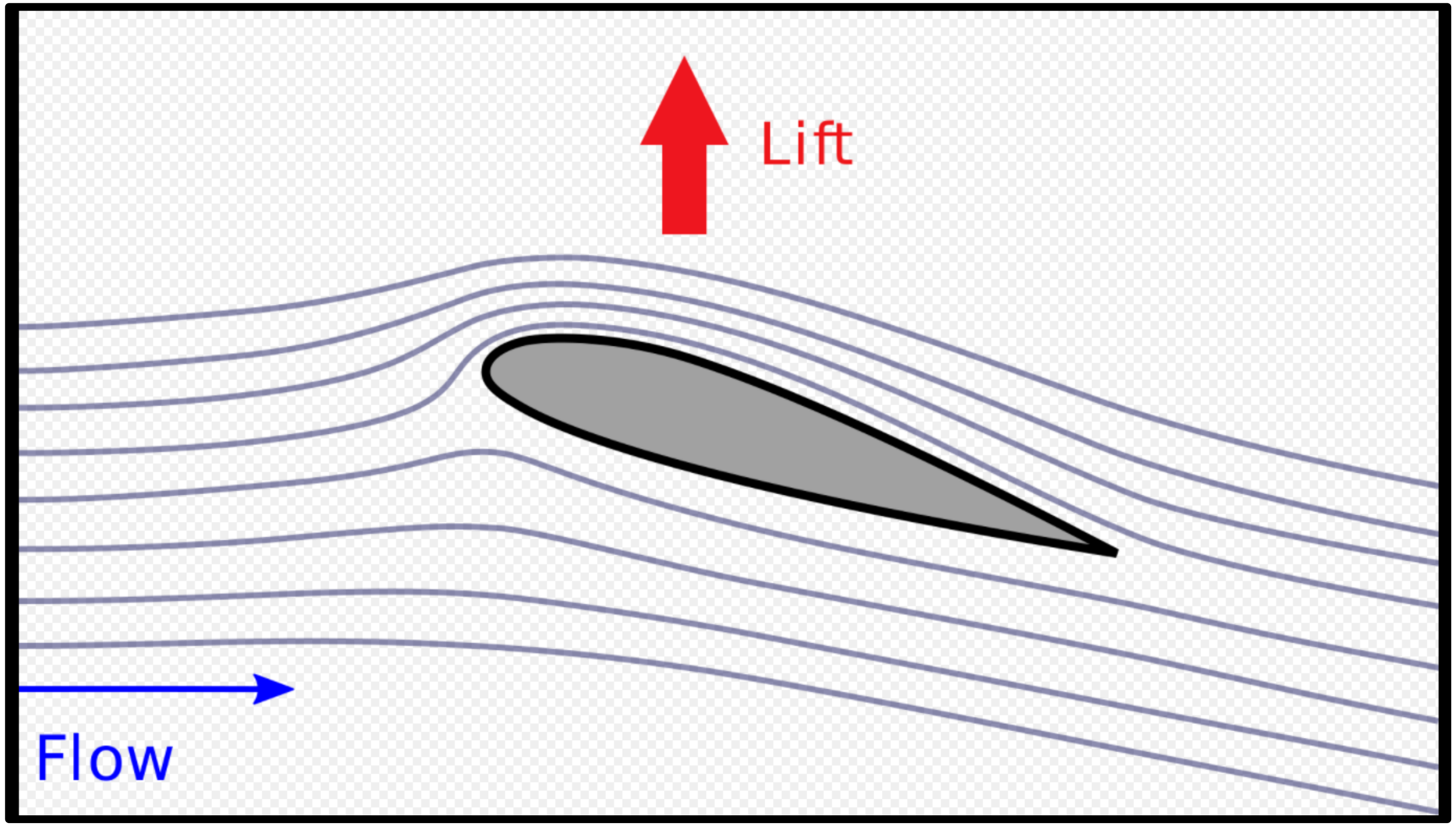


Image credit: Michael Paetzold CC BY-SA 3.0

Experiment: Methods

3. Launch the glider and measure with 25m tape how far it glides (throw ‘javelin-style’); repeat 10 times from the same point and calculate the mean distance it ‘flies’.

4. Suspend the glider so that the belly just touches the ground, point the fan at its nose and switch it on to the lowest speed, then the next fastest and so on, and record what happens to the glider.

Experiment: Methods

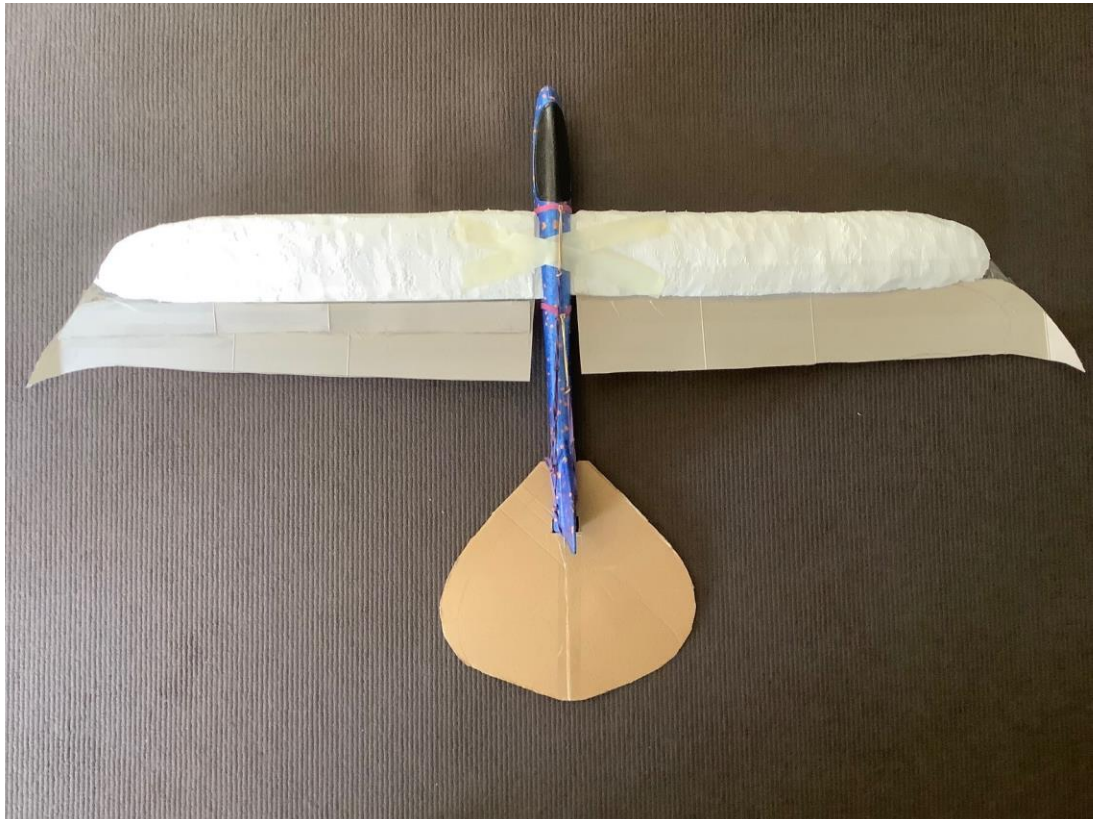
5. Trace the 2D shape of the Styrofoam wings on to cardboard, cut the cardboard ‘wing extensions’ out and attach them with sticky tape to the back edge of the Styrofoam, use the scales to decide how to adjust the weight of the wings so that they are approximately equal (within 1g difference) by adding a strip of cardboard to the lighter wing along the back edge of the Styrofoam on the upper surface.

6. Repeat steps 3. & 4.

7. What difference did you observe in the glider’s flight path between the two modifications?

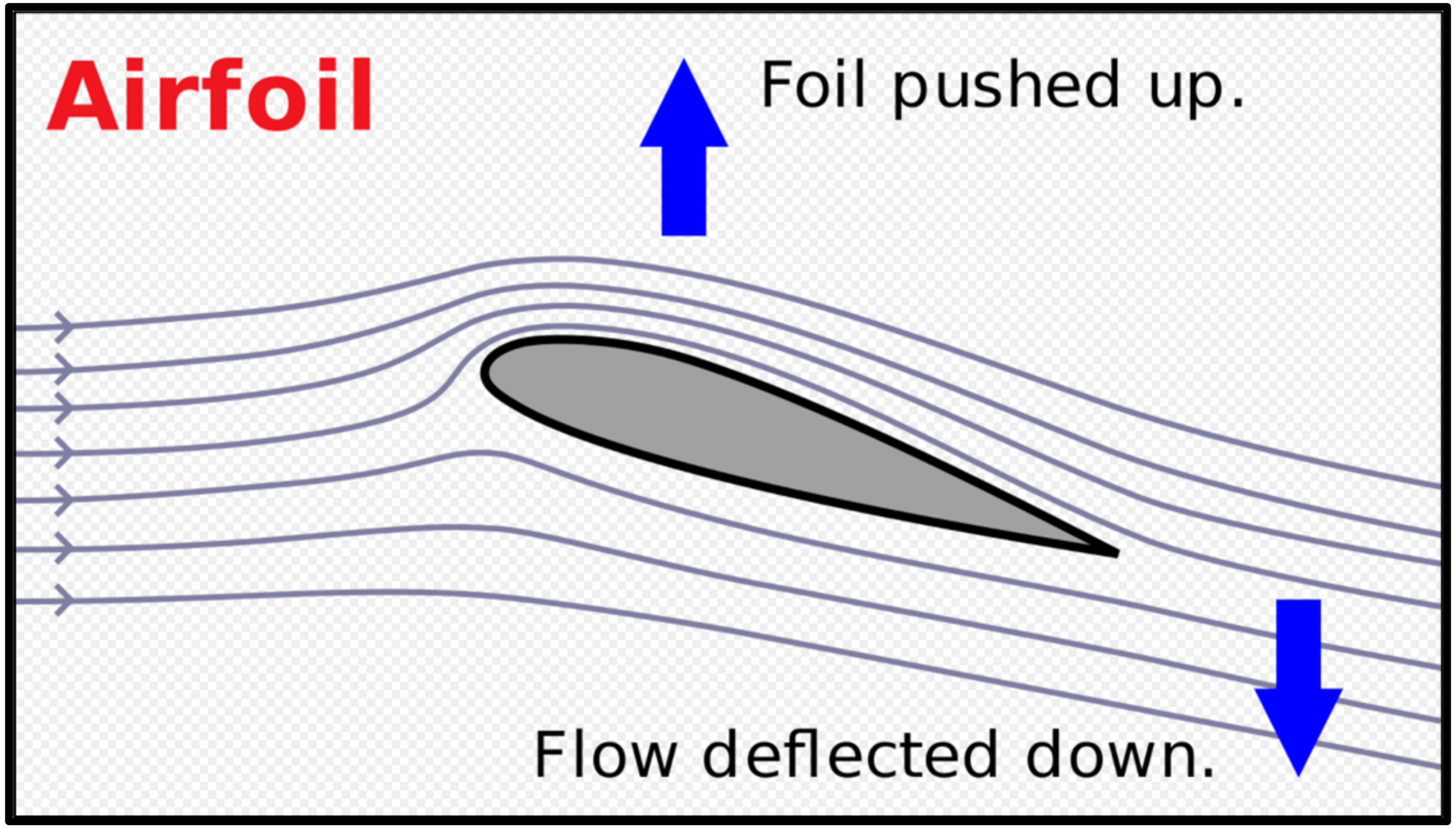
Experiment: Methods

8. Try making some tail modifications (see below) and test fly/glide again; repeat steps 3. & 4.



Explaining Flight using Science

When air flows over an airfoil (wing), the air flows faster over the top of the wing and slower under the wing. The faster flowing air exerts a lower pressure than the slower moving air. The pressure difference causes an upward force called lift, which enables the bird to fly.



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Explaining Flight using Forces

There are four main forces on a bird in flight. **Weight** is a force produced by gravity in the downward direction, and every bird has to produce **lift** with its wings to counteract weight. A wing moving through air also experiences **drag**, which slows it down, so the bird must produce a forward-moving force, called **thrust**, to oppose the force of drag. These two pairs of forces weight and lift, drag and thrust must be roughly balanced for a bird to fly (Tong & Schwab 2021).

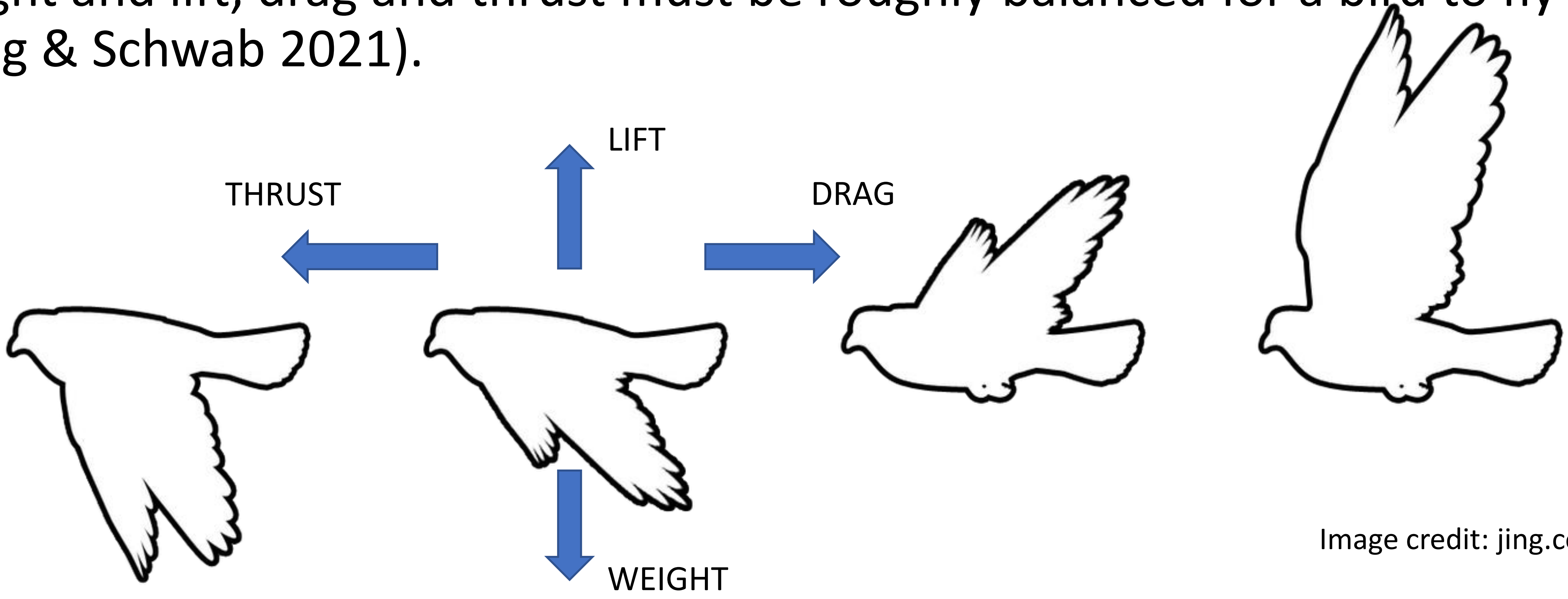


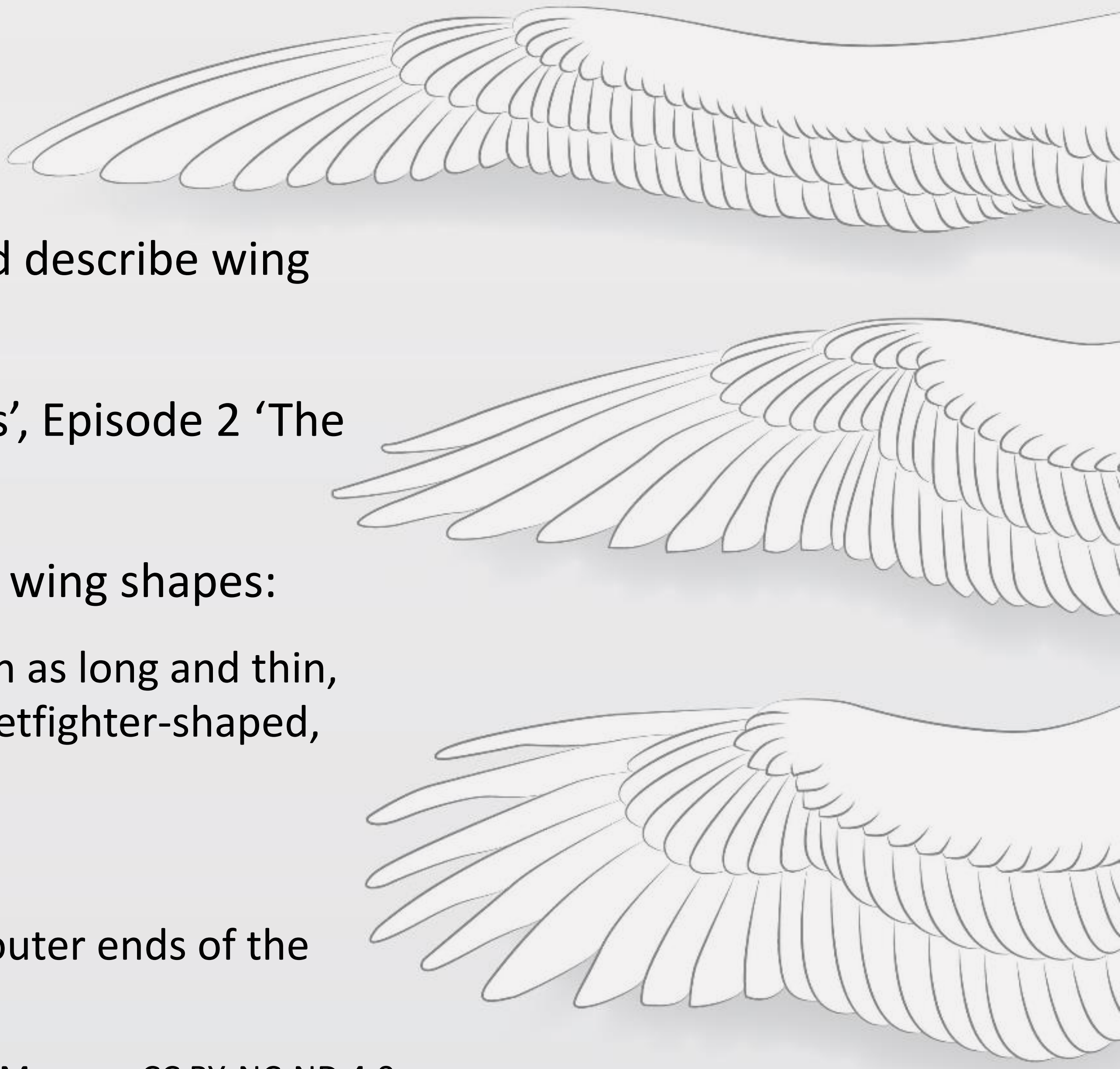
Image credit: jing.com CC0

Evaluate the Experiment:

- What was the experimental question being asked?
- Identify the variables in the experiment
- After completing the guided experiment, what can you predict about the effect of wing size and shape on flight performance?
- Do you think the experiment was a fair test of the question? Why or why not?
- Design and Plan your own Investigation

Bird Wing Shapes

- **Learning Outcome**: To accurately observe and describe wing shape and flight behaviour of some birds
- 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?

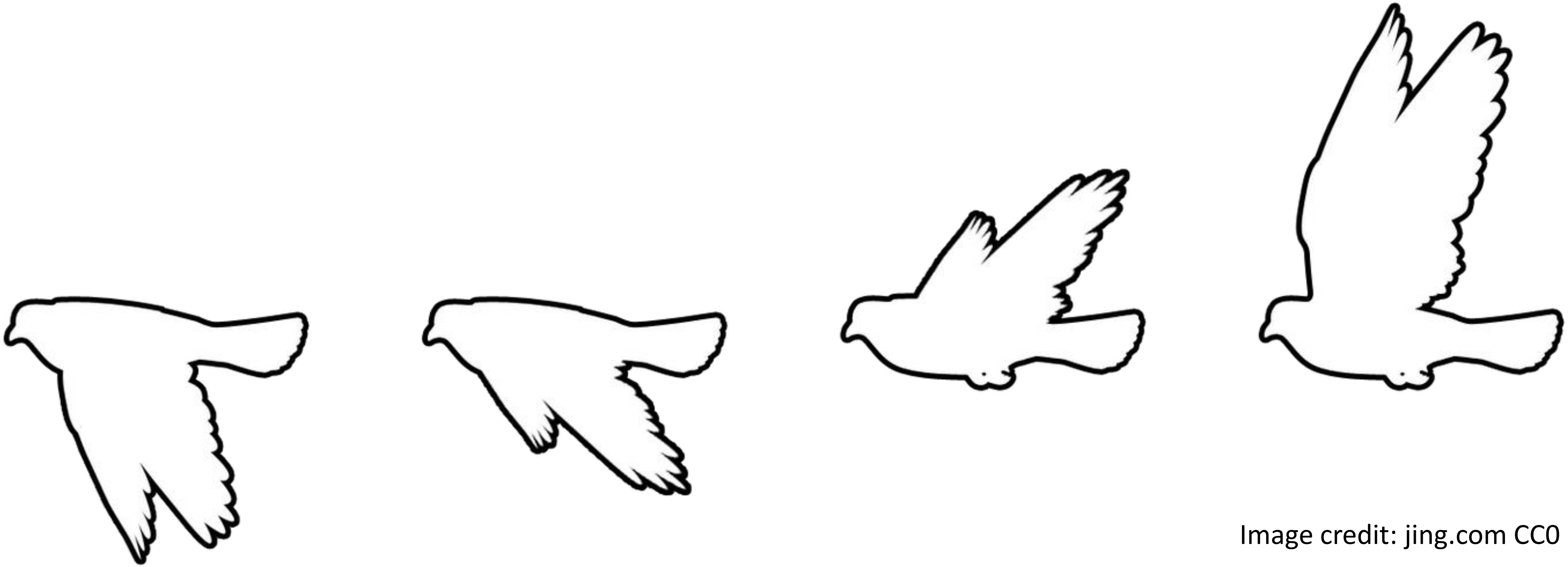


Image credit: jing.com CC0

Bird Wing Shapes and Flight Patterns

- Tabulate your observations:

Photo credit: Lene Parashou

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
…	…	…	…	…	…

Classifying Wing Shape, Predicting Flight Pattern

- **Learning Outcome**: To classify wing shape descriptively and numerically
- Factors that affect flight performance
  - ➢Wing length
  - ➢Wing width and curvature
  - ➢Feather arrangement
  - ➢Body shape and mass

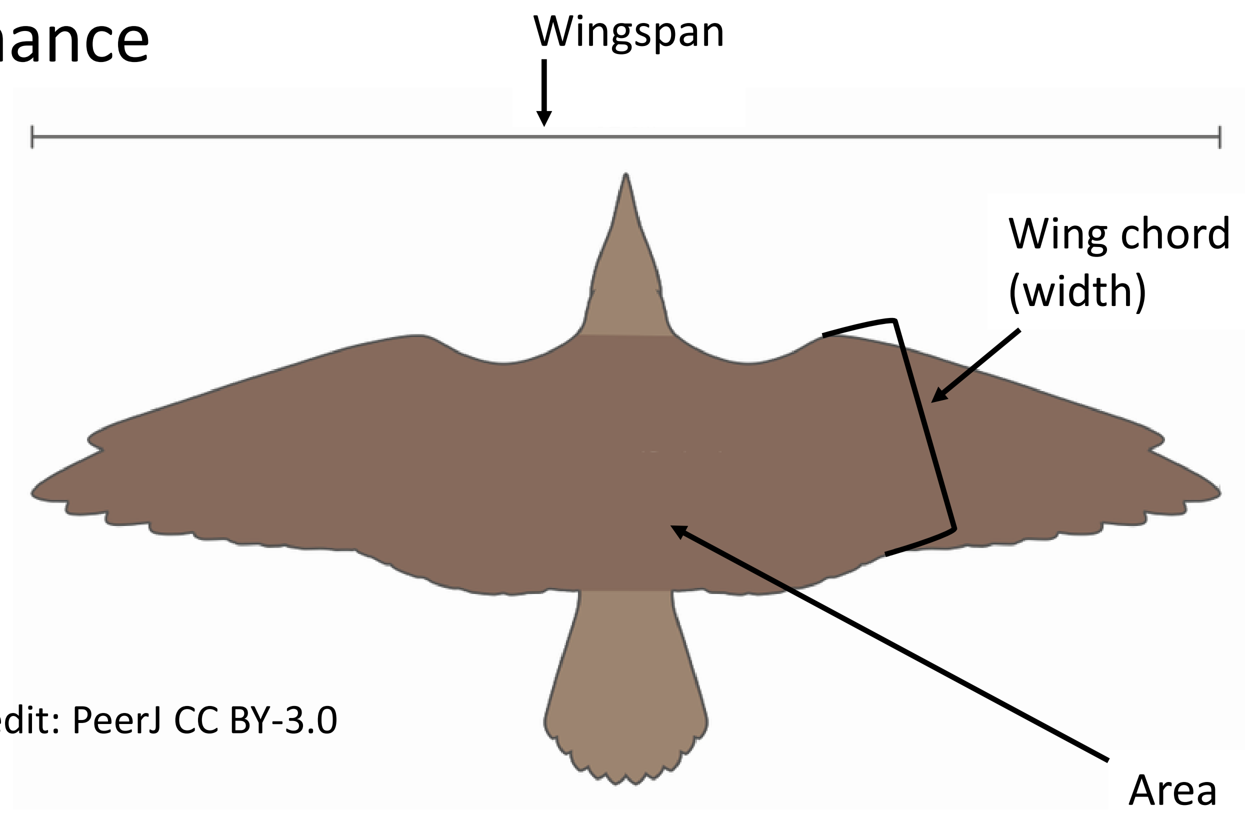
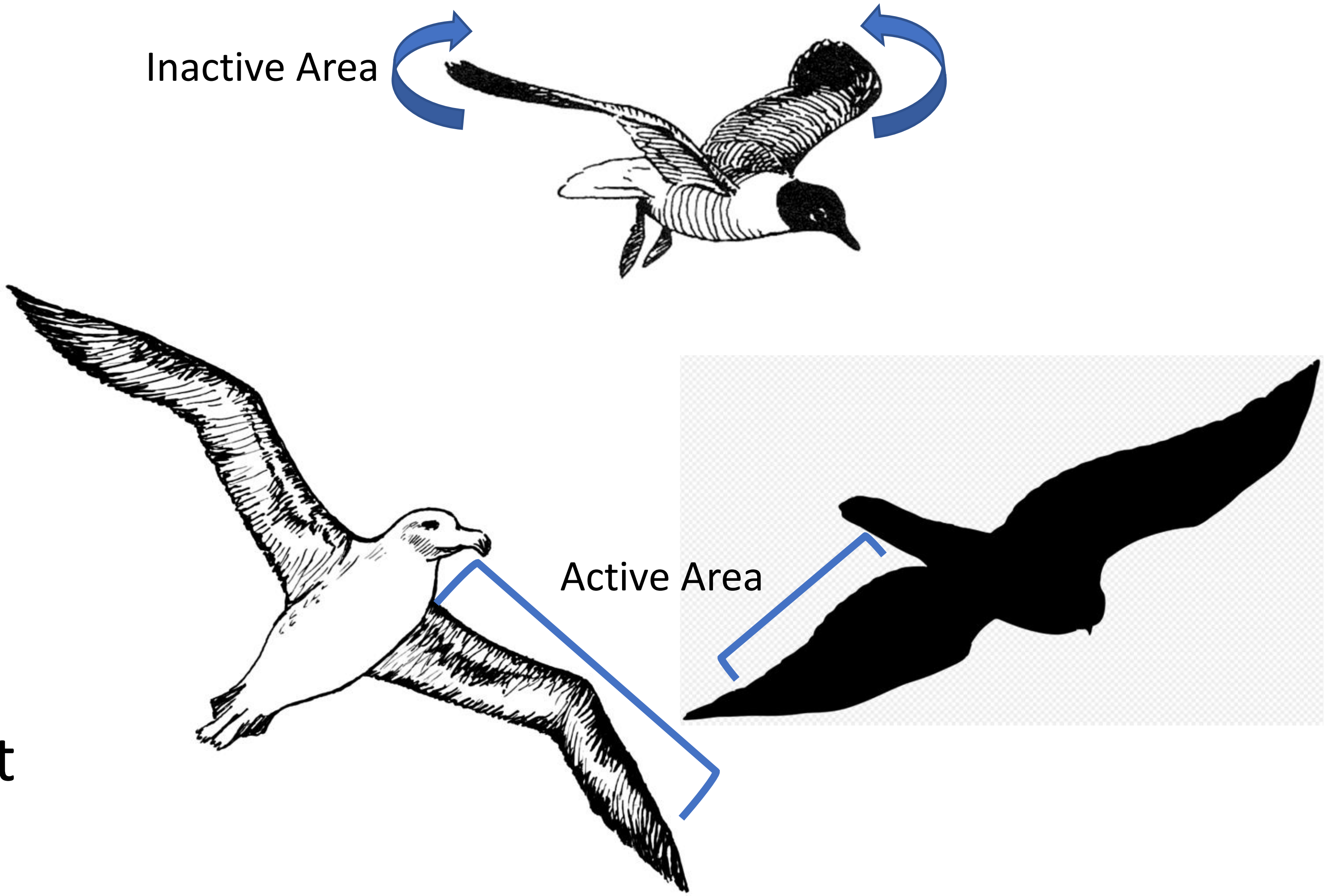


Image credit: PeerJ CC BY-3.0

Wing Length

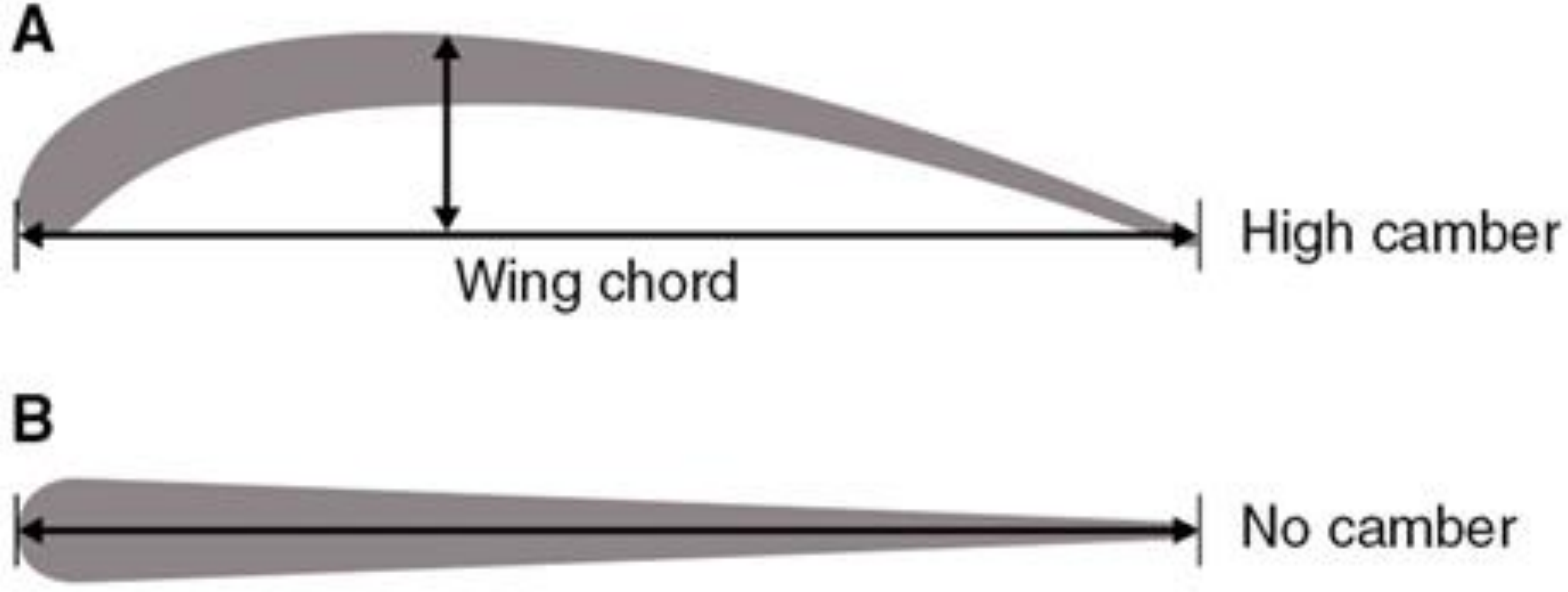
- The greater the length of the wing, the higher the lift
- Air wraps around the wings, leads to an inactive area on the tips and causes drag on the wing (top)
- Longer wings have a disproportionately larger active area which provides lift relative to the inactive areas (bottom left vs right)



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

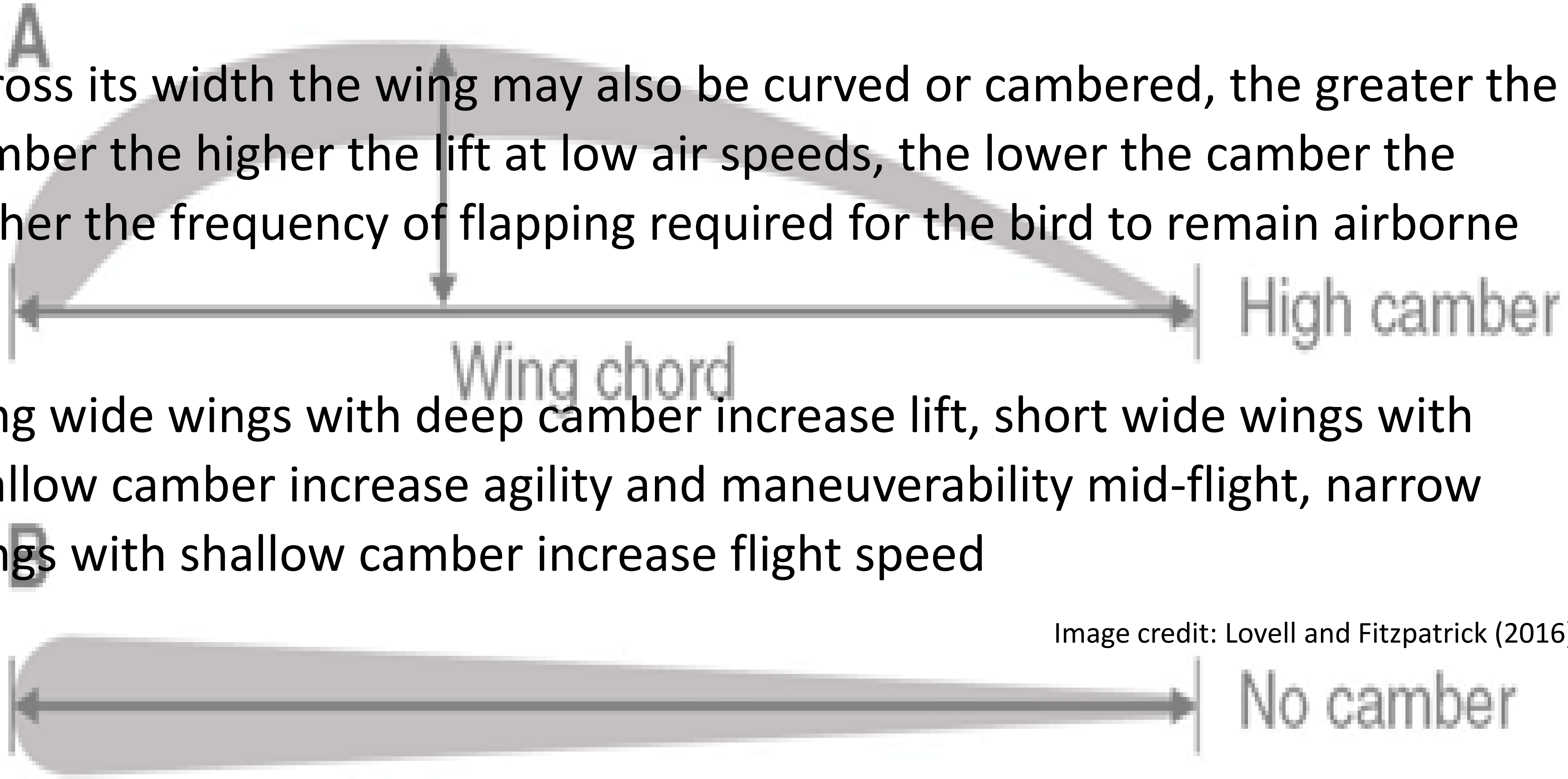
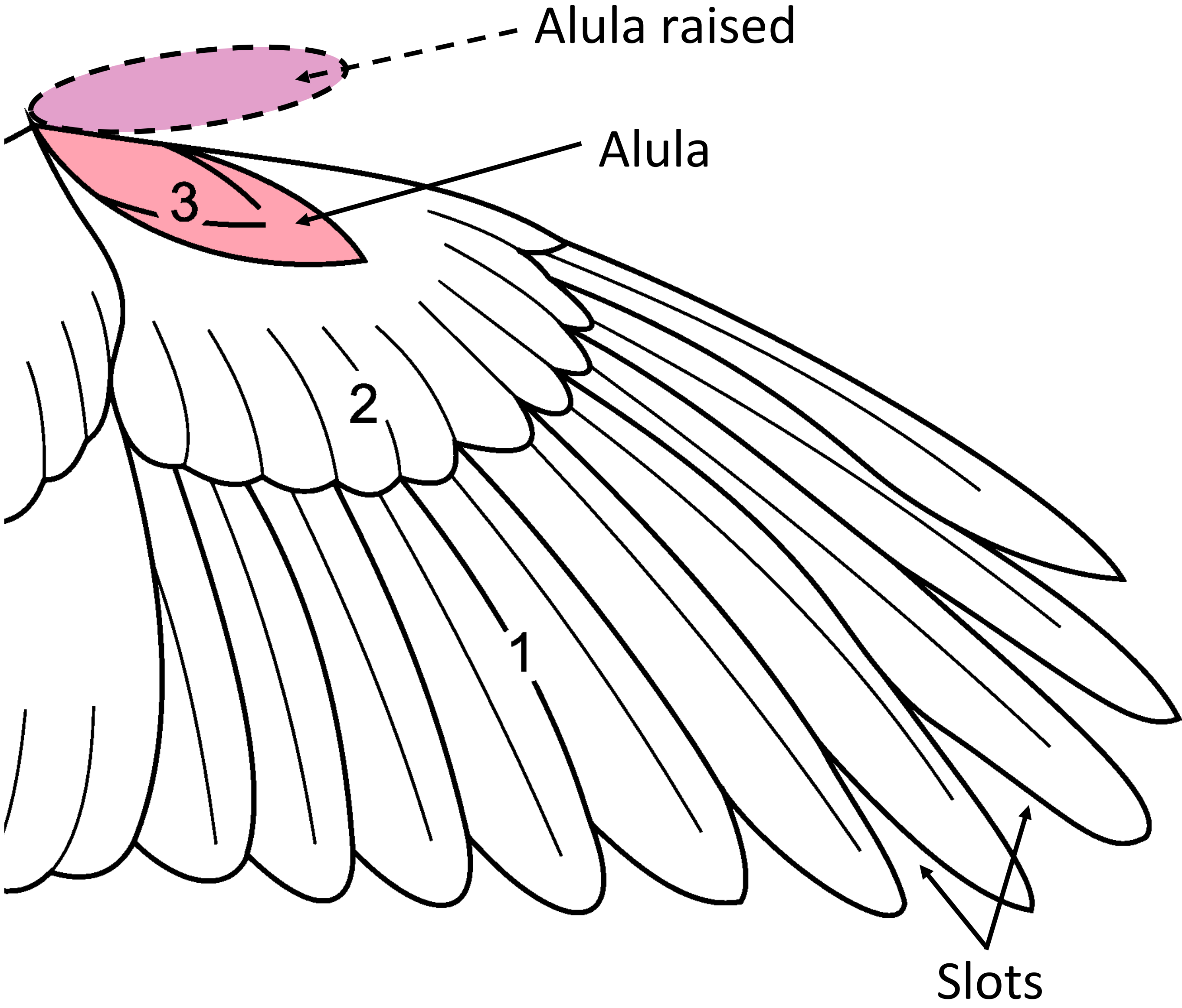


Image credit: Lovell and Fitzpatrick (2016)

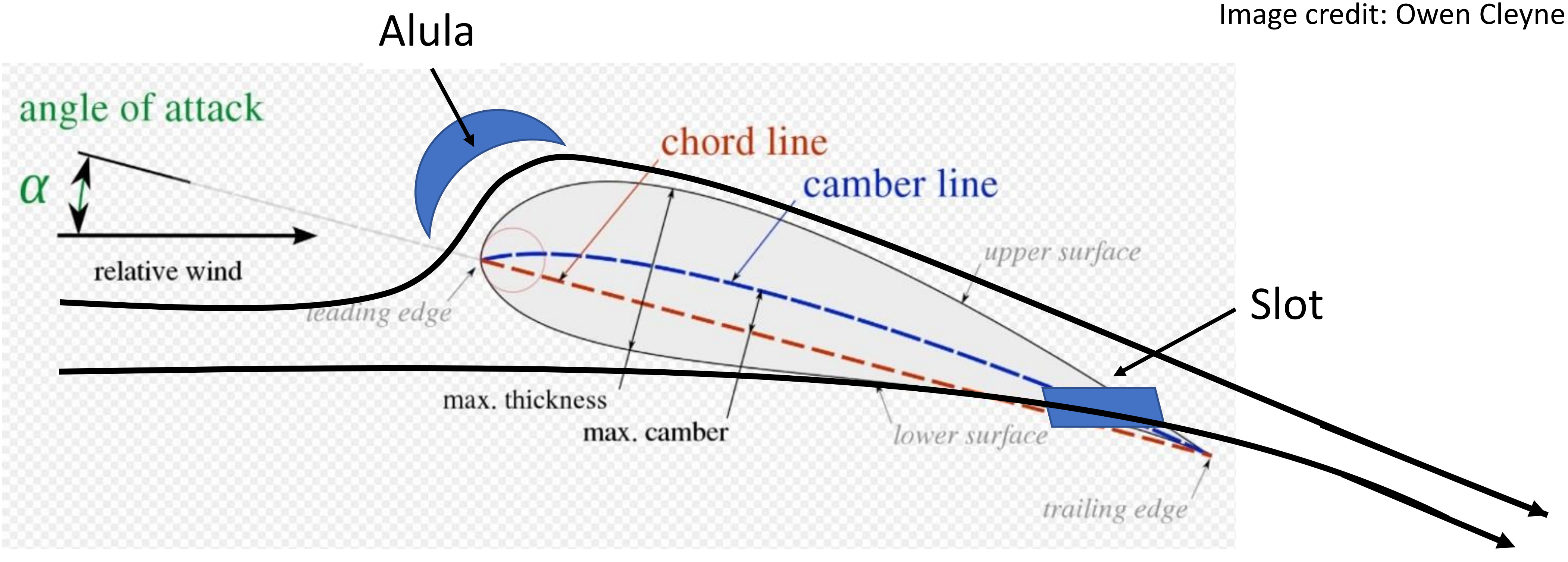
Feather Arrangement

- 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



Feather Arrangement

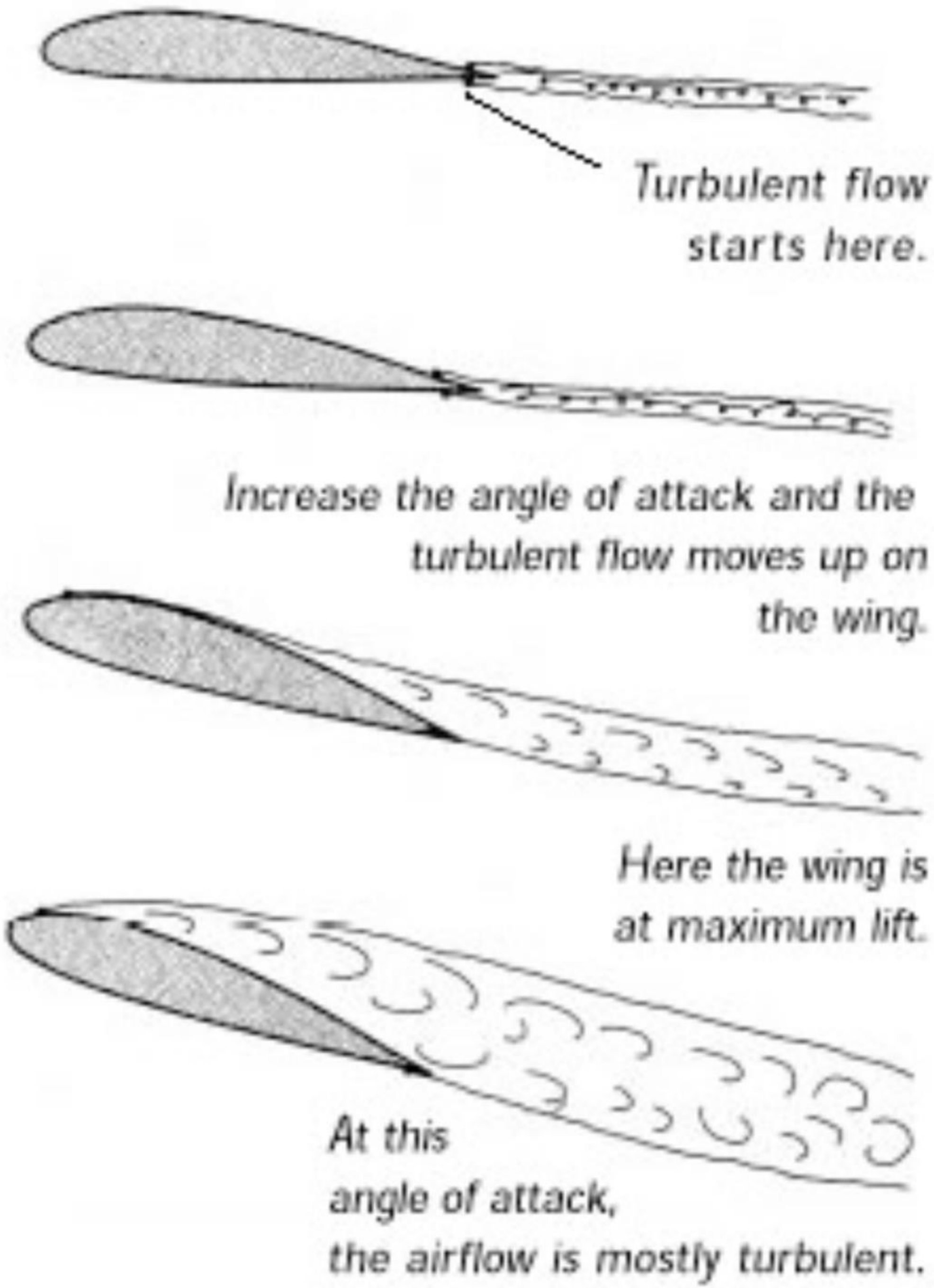
- The alula is usually held flush against the wing, but it can be moved. When flying at slow speeds or landing, the bird moves the alula upwards and forwards, which creates a slot on the wing's leading edge; this gives the wing a higher angle of attack and lift without stalling



Angle of Attack:

is the angle between the wing and the direction of the oncoming wind. Birds can adjust the angle of attack of their wings. 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. 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

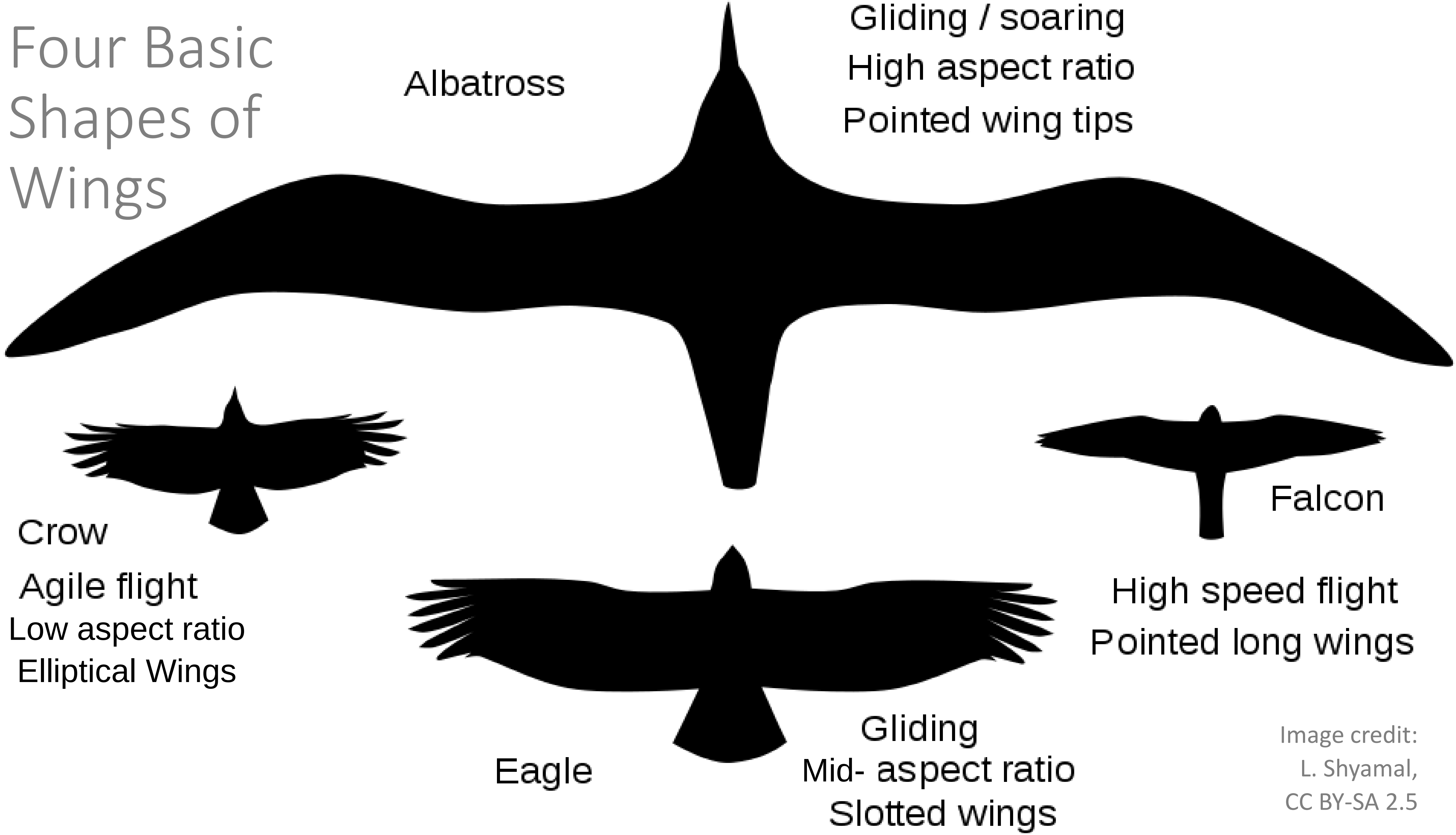


Describing Birds’ Wing Shapes:

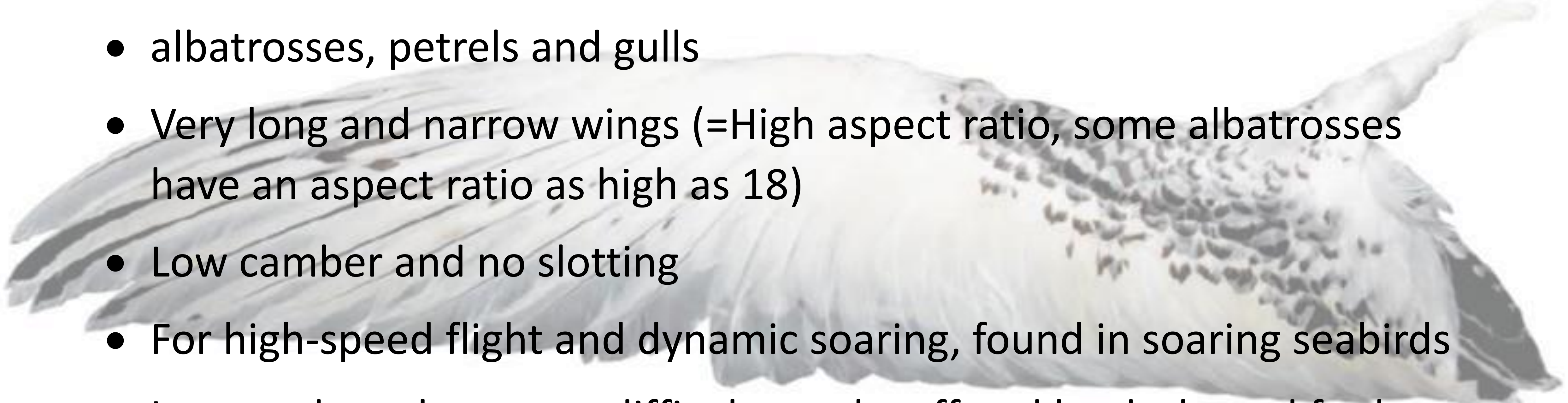
- When the ratio of length to width of a bird’s wing is large it is said to have a High Aspect Ratio (eg. Wandering Albatross)
- When a bird’s wing has a Low Aspect Ratio the ratio of length to width is small (eg. a Superb Lyrebird)

Image credit: Queensland Museum CC BY-NC-ND 4.0

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

Image credit: Auckland Museum CC BY 4.0

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

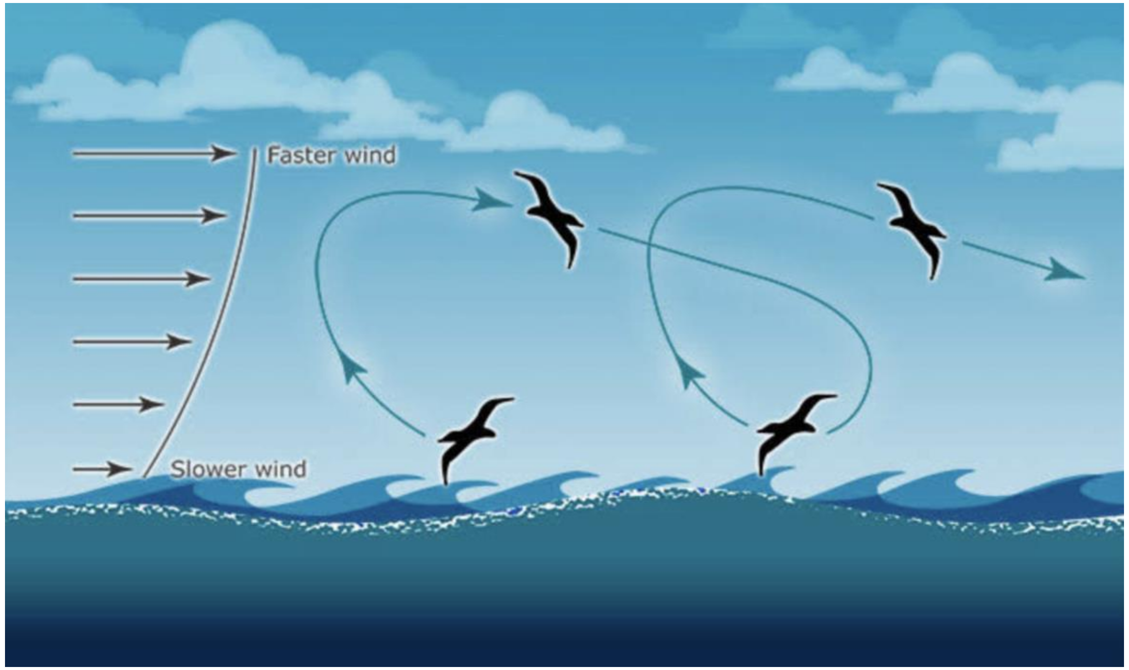
- View the eagles in ‘Land Birds in Flight’ by Alwyn Simple: https://birds-australia.smugmug.com/Theme-Galleries-Birds/Birds-in-Flight/Land-Birds-in-Flight/

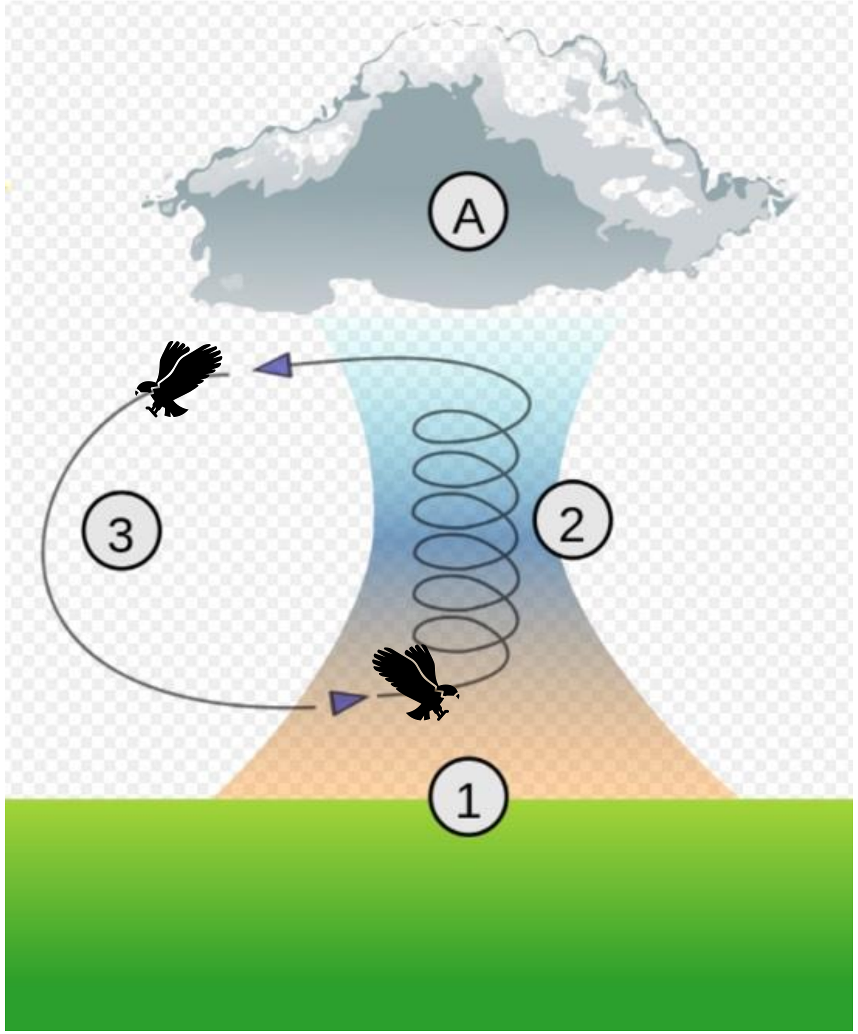
Elliptical-winged Species

- 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)

Bird Wing Shapes and Flight Patterns

Activity: Classify Wing Shapes

- Add a column called ‘Wing Shape Type’ to Table 1 from the previous activity and classify the wing shape of each species according to the four wing shapes described in this activity

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

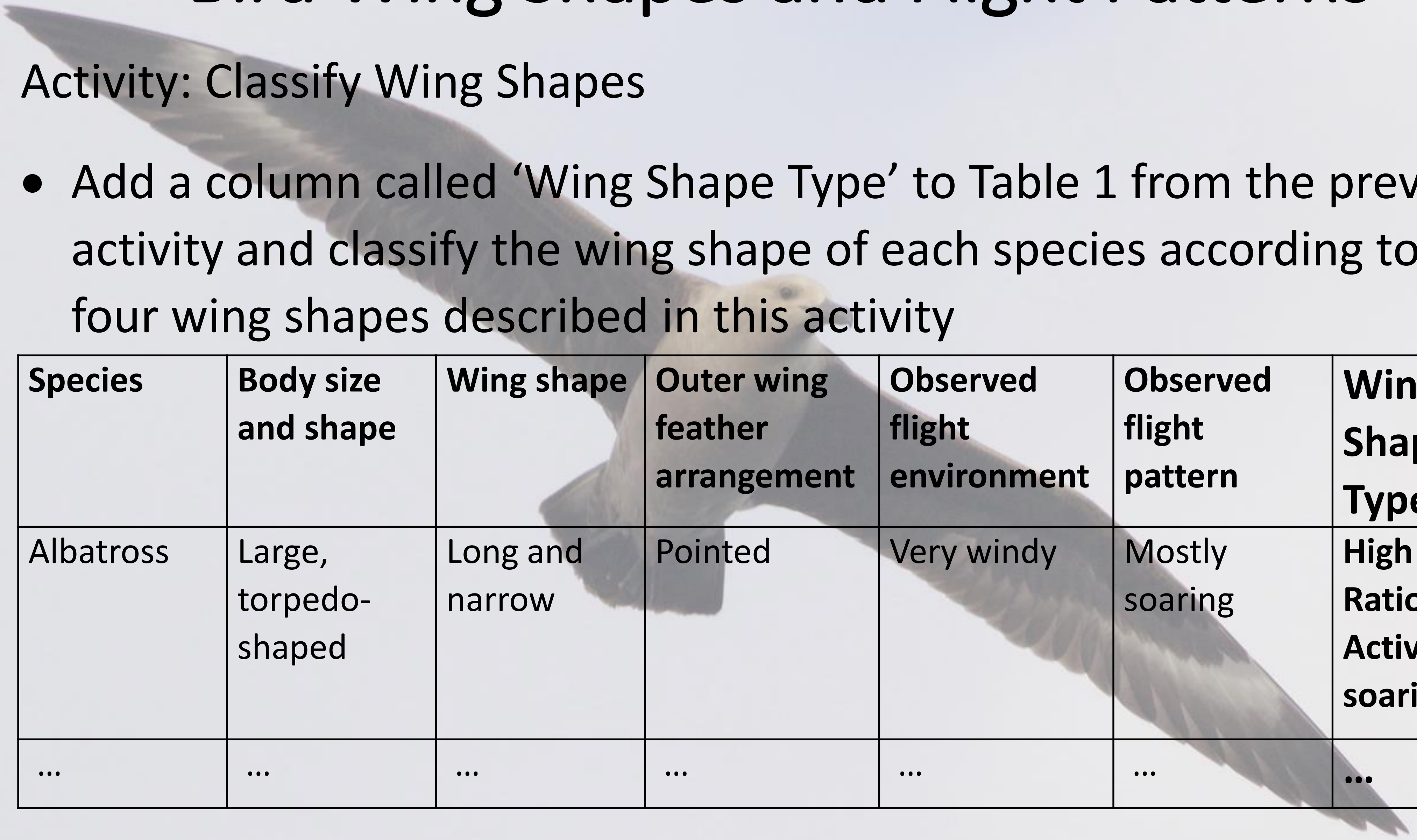


Photo credit: Mick Roderick

Bird Wing Shapes and Flight Patterns

- Plot Wingspan (y-axis) against Wing Chord (x-axis) for the Australian bird species in Table 2 (see worksheet) and label the points by their Avian Order (use codes in table)
- Classify each species according to Wing Shape type and add to Table 2 (**Hint**: use reference images to assist in classifying)
- Interpret from the graph the range of values of Wingspan and Wing Chord that characterise each wing shape type:
    - 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?
- Predict the flight pattern of each species; to inform your answer, use the position of each species relative to other species on the graph:
    - High Aspect Ratio, High Speed, Slotted High Lift, Elliptical
    - Do any species not fit into the four categories? How would you describe their flight pattern?

Photo credit: Mick Roderick

References

- Carr, S.M. (2002) Wing Types in Birds, https://www.mun.ca/biology/scarr/Bird_Wing_Types.htm
- Direct Science: Biology. *How do Birds Fly?* http://www.dynamicscience.com.au/tester/solutions1/biology/beastonlnad/birdsinflight.html
- Higgins, P. *et al*., eds. (1990-2006). *Handbook of Australian, New Zealand and Antarctic Birds.* Vol. 1-7. Birds Australia, Melbourne.
- Hyrenbach, D. 'Wing Ecomorphology Lab', Seabird Ecology and Conservation course, Hawai'i Pacific University, https://www.pelagicos.net/classes_seabirds_fa18.htm
- Lovett, I.J. and Fitzpatrick, J W. (2016). The Flight of Birds: videos. *Handbook of Bird Biology. 3rd Edn.* Cornell Univ/John Wiley & Sons, Ltd., https://academy.allaboutbirds.org/textbook/handbook-chapters/#chapter-5
- Merck, J. (2017) *The Biomechanics of Flight*, GEOL 431 Vertebrate Paleobiology, The University of Maryland, https://www.geol.umd.edu/~jmerck/geol431/lectures/d12wflight.html
- Norberg, U.M.L. (2002). Structure, form, and function of flight in engineering and the living world. *Journal of Morphology*, 252: 52-81.
- Pennycuick, C.J. (2008). Modelling the flying bird. Elsevier, Amsterdam, The Netherlands (including Computer Software For Energetic Costs of Flight).
- Rayner J.M.V. (1988). Form and Function in Avian Flight. Pp. 1-66 in Johnston R.F. (eds), *Current Ornithology, vol 5.* Springer, Boston, MA. https://doi.org/10.1007/978-1-4615-6787-5_1
- Savile, D. B. O. (1957). Adaptive evolution in the avian wing. *Evolution*, 11: 212-224.
- Tennekes, H. (2009). *The Simple Science of Flight*. MIT Press, Cambridge, MA.
- Tong, J. & Schwab, A. 'The Flight of Birds' presentation. Massachusetts Institute of Technology Open Courseware, https://studylib.net/doc/13562570/the-flight-of-birds-joanna-tong-andamp%3B-adele-schwab