Understanding Flight in Birds: Teacher's Notes

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Background: Curriculum Links

This series of activities provides a context in which students can learn about the role of observations and inferences in evidence-based scientific studies of cause and effect. It is relevant to Modules 1&2 of the Investigating Science course in the NSW Senior Science curriculum. It immerses students in making observations and inferences about primary and secondary data using inductive and deductive methodologies. It focuses on the beginning of a scientific investigation, in which inferences are drawn from observations, then questions and hypotheses generated and predictions made that allow testing of these inferences in a planned investigation. Optionally, the activities can be developed into a full investigation that can be conducted as a depth study.

The activities in this module guide students through the collection of primary data about flight performance during an experiment using toy gliders and about wing shape while watching video footage of living birds. They provide an example of processing secondary data that measure wing shape in different bird species and of making predictions about their flight performance that are derived from the data using Bernoulli's Principle (Effect). Students are asked to communicate their understanding of the scientific process and of scientifically collected results in questions that elaborate curriculum points. Ideas in the main and extension activities can be used for developing further independent investigations (depth studies).

Objective

Students:

- **develop knowledge and understanding of cause and effect**

Year 11 course outcomes

A student:

INS11-8 identifies that the collection of primary and secondary data initiates scientific investigations

Role of Observations

Inquiry question: How does observation instigate scientific investigation?

Students:

- carry out a practical investigation to record both quantitative and qualitative data from observations of **the Bernoulli effect/principle** in toy gliders and birds
- discuss and evaluate the characteristics of observations made about birds compared to inferences drawn from the practical investigation with toy gliders

Observations

Inquiry question: What are the benefits and drawbacks of qualitative and quantitative observations?

Students:

- carry out a practical activity to qualitatively and quantitatively describe wing shape and flight patterns in birds
- analyse the quantitative data from the following information sources: primary data collected during a guided 'flight' experiment and secondary data about wing shape and wing loading
- evaluate the differences between qualitative and quantitative observations and data and where these are used in making inferences about flight patterns in birds

Observations as Evidence

Inquiry question: How does primary data provide evidence for further investigation?

Students:

- use data gathered to plan a practical investigation about the effect of wing shape on flight performance to:
  - pose further questions that will be investigated
  - discuss the role of variables
  - determine the independent and dependent variables
  - formulate a hypothesis that links the independent and dependent variables
  - describe at least three variables that should be controlled in order to increase the validity of the investigation
- develop a method to collect primary data for a practical investigation about the effect of wing shape on flight performance by:
  - describing how to change the independent variable
  - determining the characteristics of the measurements that will form the dependent variable
  - describing how the data will be collected
  - describing how the controlled variables will be made consistent
  - describing how risks can be minimised
- evaluate how observation is limited by the observational tools available (tape measure vs description from visual observation)

Observing, Collecting and Recording Data

Inquiry question: How does the collection and presentation of primary data affect the outcome of a scientific investigation?

Students:

- carry out the planned practical investigation, above, to collect primary data
- apply conventions for collecting and recording observations to qualitatively and quantitatively analyse the primary data, including:
  - tabulation after collecting data about Birds' Wing Shapes from video footage

- (graphing secondary data in Maths Activity: Classifying Wing Shape [Norberg 2002] and Predicting Flight Pattern [Tennekes 2009])
- visual representations that use a toy glider as a model of a bird
- digital representations using bird flight simulators in the Extension Activities

- compare the usefulness of observations recorded in the initial practical activity with the primary data gathered in a planned practical investigation

Conclusions Promote Further Observations

Inquiry question: How do conclusions drawn from the interpretation of primary data promote further scientific investigation during the experiment planned by students?

Students:

- draw conclusions from the analysis of the primary data collected in the practical investigation
- evaluate the process of drawing conclusions from the primary data collected
- assess the findings of the scientific investigation in relation to the findings of other related investigations
- assess the need to make further observations by gathering data about other phenomena arising from the practical investigation

Objective

Students:

- **develop skills in applying the processes of Working Scientifically**

Stage 6 course outcomes

A student:

Questioning and predicting

INS11/12-1 develops and evaluates questions and hypotheses for scientific investigation

Students:

- develop and evaluate inquiry questions and hypotheses to identify a concept that can be investigated scientifically, involving primary and secondary data
- modify questions and hypotheses to reflect new evidence

Conducting investigations

INS11/12-3 conducts investigations to collect valid and reliable primary and secondary data and information

Students:

- employ and evaluate safe work practices and manage risks
- use appropriate technologies to ensure and evaluate accuracy

- select and extract information from a wide range of reliable secondary sources and acknowledge them using an accepted referencing style

Processing data and information

INS11/12-4 selects and processes appropriate qualitative and quantitative data and information using a range of appropriate media

Students:

- select qualitative and quantitative data and information and represent them using a range of formats, digital technologies and appropriate media
- apply quantitative processes where appropriate
- evaluate and improve the quality of data

Communicating

INS11/12-7 communicates scientific understanding using suitable language and terminology for a specific audience or purpose

Students:

- select and use suitable forms of digital, visual, written and/or oral forms of communication
- select and apply appropriate scientific notations, nomenclature and scientific language to communicate in a variety of contexts
- construct evidence-based arguments and engage in peer feedback to evaluate an argument or conclusion

Optional Activities:

Planning investigations

INS11/12-2 designs and evaluates investigations in order to obtain primary and secondary data and information

Analysing data and information

INS11/12-5 analyses and evaluates primary and secondary data and information

Problem solving

INS11/12-6 solves scientific problems using primary and secondary data, critical thinking skills and scientific processes

Birds and Bernoulli's Principle

The first section of the presentation provides a rationalé for studying Bernoulli's Principle in birds and standard definitions of Bernoulli's Principle in physics.

Understanding ‘Flight’ in Kites and Gliders

The next two sections introduce explanations of flight using Bernoulli’s Principle with the example of ‘flying’ a kite before exploring the ‘flight’ of a toy glider in an observational experiment.
In the ‘flight’ experiment the learning objective is to encourage students to think about the relationship between wing shape/design and glider flight performance. Based on how well the gliders perform, ask them to try to describe and compare the performances, and then to explain them using Bermoulli’s principle:

- Why do you think the glider with longer wings tends to ‘nose-dive’? (And the original glider and the one with longer and wider wings don’t?)
- What would improve its performance? (eg., greater launch speed, lighter weight or lower ‘wing loading’)
- What happens when you try to launch the glider that has longer and wider wings with more force (=thrust)?

Learning Outcomes:

- To understand the role of observing and explaining ‘flight’ in a toy glider, a simple model of a bird
- To understand how changing the length and width of the glider’s wings changes its ‘flight performance’

‘Flight’ Experiment:
You will use a toy glider as a simple ‘bird’. Firstly, observe the shape of the glider’s wings. After assembling it, ‘test fly’ the glider 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 area of its wings.

Materials required:

1. Toy foam glider purchased from a toy or department store (~$3, see below)
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. Toy catapult and 25m measuring tape
8. Small fan with several (at least 3) speed settings

Method:

1. Assemble the glider (follow the instructions on the box)
2. Cut and pare the styrofoam to make two wings, each the same width as the originals but twice as long; shape the styrofoam so that the lower surface remains relatively flat and the upper surface is curved like an airfoil (see diagram of airfoil cross-section)
3. Using the catapult, launch the glider from the same point and measure with 25m tape how far it glides (or throw ‘javelin-style’); repeat 10 times and calculate the mean distance it ‘flies’
4. Suspend the glider so that the belly just touches the ground (see below), 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
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 (see

below), 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.
    - A variation of longer wider wings made of styrofoam only was instructive as it doesn't work – it tends to 'backflip' when launched

    - The prototype with longer wider wings, note how the glider is suspended as per 4. above

7. What difference did you observe in the glider's flight path between the two modifications? Try explaining the difference using Bernoulli's principle.
8. Try making some tail modifications and test fly/glide again (repeat steps 3 & 4)

Explaining Flight using Bernoulli's Principle and Forces

This section provides a scientific explanation of applying Bernoulli's Principle to flight in birds.

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. Looking at flight from a physics point of view, there are four main forces. **Weight** is a force produced by gravity in the downward direction, and every flyer has to produce **lift** in order to counteract weight. Anything moving through air also experiences **drag**, which slows it down, so there must be a forward-moving force, called **thrust**, to oppose the force of drag. These two pairs of forces weight and lift, drag and thrust have to be roughly balanced in order for a bird to fly (Tong & Schwab 2021).

See also: Minute Physics (2012). How does a wing actually work?
https://www.youtube.com/watch?v=aFO4PBolwFg#t=60

Results and Conclusions:

In this section students are asked to record their qualitative and quantitative observations during the experiment with the toy gliders and address questions about making observations and inferences in scientific studies in the context of the 'flight' experiment.

Wing Shape/Size	Distances 'Flown'	Wing Shape/Size	'Distances Flown'

- Describe differences in flight path and lift you observed between the wing shapes/sizes:

Evaluate the Experiment:
What was the experimental question asked? Can you formulate the hypothesis that was tested?

Identify the variables in the experiment.

After completing the guided experiment, what can you predict about the effect of wing size on flight performance?

Do you think the experiment was a valid and reliable test of the question/hypothesis? Why or why not?

Design and Plan another Investigation, using the wing shapes available and/or other wing designs:
Pose further questions that can be investigated

Discuss the role of the variables used and other possible variables (those that were controlled but can be varied)

Determine the independent and dependent variables

Formulate a hypothesis that links the independent and dependent variables

Describe at least three variables that should be controlled in order to increase the validity of the investigation

Develop a method to collect primary data for a practical investigation about the effect of wing shape on flight performance:
Describe how to change the independent variable

Determine the characteristics of the measurements that will form the dependent variable

Describe how the data will be collected

Describe how the controlled variables will be made consistent

Describing how risks can be minimised

Evaluate how observation is limited by the observational tools available (eg., using a tape measure vs verbal description from observation)

Bird Wing Shapes and Flight Patterns

During this activity, encourage students to describe accurately what they see observe during the video footage about different types of birds that have differing body proportions and that show different flight behaviours. (See also 'Travelling Birds' (2003) on DVD, David Attendorough's 'Global Adventures', Episode 3 'The Rise of Nature', on ABC iView [first 23 min about evolution of flight] https://iview.abc.net.au/show/david-attenborough-s-global-adventure)

Learning Outcome: to accurately observe and describe wing shape and flight behaviour of some birds

Instructions:

- Watch David Attenborough's 'The Life of Birds', Episode 2 'The Mastery of Flight' on DVD
- Observe the different types of birds and their wing shapes. Try to describe each bird's body size and shape, such as long and thin, short and round, large and torpedo-shaped, jetfighter-shaped, etc. Try to describe the wing shape. Also note the way the feathers are shaped at the outer ends of the wings. For example, an albatross has very long wings that are relatively narrow, many flight feathers that are also short relative to wing length, and the wing feathers are pointed at the outer end: therefore, their wings are 'very long, narrow and pointed'.
- Try to 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, etc. 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 updrafts and thermals?
- Tabulate your observations

Table 1 has been completed table for reference

Species	**Body size and shape**	**Wing shape**	**Outer wing feather arrange-ment**	**Observed flight environment**	**Observed flight pattern**
Albatross	Large, torpedo-shaped	Very long and narrow	Pointed	Very windy, launch by taxiing/running, updrafts from waves/cliffs	Mostly soaring, some shallow flapping, controlled crash to land
Wedge-tailed Shearwater	Large, torpedo-shaped	Long and narrow	Pointed	Windy, launch from sloping tree	Mostly soaring, some shallow flapping
Domestic Pigeon	Medium and barrel-shaped	Medium length and width	Slightly slotted	Calm, launch by jumping and two very strong flaps	Fast flapping, some gliding
Knot	Small to medium, bullet-shaped	Medium length and narrow	Pointed	Clam to windy	Fast shallow flapping, half folded upstroke
Mallard (Duck)	Large, heavy and boat-shaped	Medium length and width	Slightly slotted	Calm to windy	Fast shallow flapping ~70kph (~40mph)
Osprey	Long and medium build	Long and wide	Slotted	Clam	Slow strong flaps, carries fish straight

Pelican	Very large and round	Very long and wide	Slotted	Calm to windy, uses thermals	Slow strong flaps, flying in formation, strong flaps to land
Griffin Vulture	Long and medium build	Very long and wide, highly curved	Slotted	Use of thermals, spiralling updrafts	Soaring, tiny movements of wing feathers and tail, lands by swooping upwards and tilting back
Mute Swan	Very large, heavy and round	Long and wide	Slotted	Landing only on water, calm	Strong flaps to land and feet out to brake
Peregrine Falcon	Medium length and thin	Medium length, narrow and back swept	Pointed	Calm or some wind	Strong flaps after 'stooping' with half folded back swept wings for maximum speed when hunting
Barn Owl	Medium length and medium build	Long, wide, curved	Rounded, fluffy margins	Calm	Strong, slow flaps and gliding when hunting
Kestrel	Small and thin	Medium length and narrow	Pointed	Gentle wind	Hovering, sometimes shallow flapping when hunting
Hummingbird	Very small and thin, hibernates every night	Short and narrow, symmetrical (not curved), create down draft, flap in any direction, steer with tail	Pointed	Mostly calm	Vertical posture, beating forwards and backwards in figure of 8 25+/sec, flicking wing over on back stroke, moves in any direction
Western Sandpiper (migrating)	Small and bullet-shaped	Medium length and narrow	Pointed	Winds from north	Fly in formation during migration
Hawks (migrating)	Medium length and build	Medium length and width	Slotted	Thermals over land	Soaring to great heights and gliding southwards repeatedly
Snow Goose (migrating)	Long and very round	Long and wide	Slotted	Any	Strong shallow flapping, flying in formation
Dicksissel (migrating)	Small and thin	Short and wide	Rounded	Any	Strong continuous flapping, flying in enormous flocks

Classifying Wing Shape and Predicting Flight Pattern

Classifying bird wing types and flight behaviours using Aspect Ratio, Wing Loading and Cruising Speed

This section of the presentation (from 'Wing Length' to 'Calculating Minimum Cruising Speed') describes how to calculate 'Aspect Ratio', 'Wing Loading', and 'Cruising Speed', aerodynamic variables that measures a bird's wing structure, its ability to bear its own body weight on its wings during sustained flight and the minimum cruising speed of flight required to maintain lift. The aim is to encourage students to start thinking quantitatively about the effect of a bird's wing and body proportions on flight performance, and the implications of Bernoulli's principle for birds.

It is adapted from David Hyrenbach's (2019) 'Wing Ecomorphology Lab', Seabird Ecology and Conservation course, Hawai'i Pacific University, https://www.pelagicos.net/classes_seabirds_fa18.htm, and Joanna Tong & Adele Schwab's 'The Flight of Birds', Massachusetts Institute of Technology Open Courseware, https://studylib.net/doc/13562570/the-flight-of-birds-joanna-tong-andamp%3B-adele-schwab

Optional: see 'Bird Flight', Visual Resources for Ornithology (2001-2015). Drexel University, http://vireo.ansp.org/bird_academy/bird_flight.html

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' (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)

Maths Activity: Classifying bird wing shapes and flight behaviours using Aspect Ratio, Wing Loading and Cruising Speed

In this section students are asked to record and interpret their quantitative observations during the analysis of data sourced from Higgins *et al*. (1990-2006) Handbook of Australian, New Zealand and Antarctic Birds (use Microsoft Excel to assist with calculations and graphs), and to address inquiry questions about making observations and inferences in scientific studies in the context of investigations using primary and secondary data.

Inquiry question: How does observation instigate scientific investigation?

- Discuss and evaluate the characteristics of observations made about birds compared to inferences drawn from the practical investigation with toy gliders

Inquiry question: What are the benefits and drawbacks of qualitative and quantitative observations?

- Analyse the quantitative data from the following information sources: primary data collected during a guided 'flight' experiment and secondary data about wing shape and wing loading
- Evaluate the differences between qualitative and quantitative observations and data and where these are used in making inferences about flight patterns in birds

Inquiry question: 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 (and secondary) data
  - tabulating **primary data** about Birds' Wing Shapes in previous activity (Table 1)
  - tabulating **secondary data** and calculating Aspect Ratio, Wing Loading (in Newtons per m^2 not grams per cm^2) and Cruising Speed for the Australian species listed (Table 2)

- graphing **secondary data** in Maths Activity: Classifying Wing Shape [Norberg 2002] and Predicting Flight
  Pattern [Tennekes 2009]
  a. Plot Aspect Ratio (y-axis) against Wing Loading (x-axis) and label the points by their Avian Order (use codes below table)
  b. Plot Weight (y-axis) against Cruising Speed (x-axis) and label by Avian Order (use codes below table)
  c. Compare your graphs with Norberg's (2002) and Tennekes' (2009) results
- Classify each species according to Wing Shape type and add to the Table 2 (**Hint**: use reference images to assist in classifying)

- Interpret from the graphs the range of values of Aspect Ratio, Wing Loading and minimum Cruising Speed that characterise each wing shape type. Explain the flight performance capable of each wing shape type using Benoulli's Principle; to inform your answer, 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:
  - 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?
  - Optional:
    - visual representations that use a toy glider as a model of a bird
    - digital representations using bird flight simulators in the **Extension Activities**

- Compare the usefulness of observations recorded in the initial practical activity with the primary data gathered in the planned practical investigation

Inquiry question: How do conclusions drawn from the interpretation of primary data promote further scientific investigation during the planned experiment?

- draw conclusions from the analysis of the primary data collected in the practical investigation
- evaluate the process of drawing conclusions from the primary data collected
- assess the findings of the scientific investigation in relation to the findings of other related investigations
- assess the need to make further observations by gathering data about other phenomena arising from the practical investigation

Extension Activity: Modelling the Flying Bird

Evaluate the authenticity of the following flight simulators:

Download: Pennycuick, C.J. (2008) *Modelling the Flying Bird*. The Netherlands: Elsevier Academic Press (https://books.google.com.au/books/about/Modelling_the_Flying_Bird.html?id=KG86AgWwFEUC&redir_esc=y) and use simulation to predict a bird species' flight mode(s) and ecological habits from its wing shape, wing loading and cruising speed (~$100)

Download and play: Scott, G. (2020) Aquila: Bird Flight Simulator https://www.aquila-bfs.com (~$10)

[Free Download still under development (watch this space): Seagull Simulator, accessed on 12th August 2021, from https://www2.unil.ch/biomapper/opengl/BirdFlight.html#Download]

Extension Activity: Engineering a Flying Bird

The Blue Jay is a small to medium-sized bird that lives in North America. The Go-Go-Bird toy (https://www.zing.toys/go-go-bird) has been engineered to fly like a Blue Jay, or has it? Evaluate the flight of the Go-Go-Bird compared with that of a real Blue Jay, using videos (Blue Jay: https://www.youtube.com/watch?v=SZgp_3SLv90; Go-Go-Bird: https://www.youtube.com/watch?v=UXqAQWi3XRM&t=63s).

What are the similarities and differences in their flight performance and maneuverability? Use estimates of Aspect Ratio and Wing Loading to assist with your evaluation and write a short report (~500 words).

Blue Jay measurements: Body length=30cm, Weight=100g, Wingspan=43cm, Wing Width=12cm

Go-Go-Bird measurements: Body length=22cm, Weight=10g, Wingspan=28cm, Wing Width=8cm

References

Anderson, J.D. (2016), Some reflections on the history of fluid dynamics, in Johnson, R.W. (ed.), *Handbook of fluid dynamics, 2nd edn.* CRC Press, Boca Raton, ISBN 9781439849576

Batchelor, G.K. (2000). *An Introduction to Fluid Dynamics*. Cambridge University Press. Cambridge, ISBN 978-0-521-66396-0.

Carr, S.M. (2002). Wing Types in Birds, accessed from https://www.mun.ca/biology/scarr/Bird_Wing_Types.htm

Clancy, L.J. (1975). *Aerodynamics*. Wiley. New York, ISBN 978-0-470-15837-1.

Higgins, P. *et al*., eds. (1990-2006). *Handbook of Australian, New Zealand and Antarctic Birds.* Vol. 1-7. Melbourne: Birds Australia.

Hyrenbach, D. (2019). 'Wing Ecomorphology Lab', Seabird Ecology and Conservation course, Hawai'i Pacific University, accessed from 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., accessed from https://academy.allaboutbirds.org/textbook/handbook-chapters/#chapter-5

Merck, J. (2017) *The Biomechanics of Flight*, GEOL 431 Vertebrate Paleobiology, The University of Maryland, accessed from https://www.geol.umd.edu/~jmerck/geol431/lectures/d12wflight.html

New South Wales Education Standards Authority. (2017). NSW Syllabus: Investigating Science: Stage 6 Syllabus, accessed from https://www.educationstandards.nsw.edu.au/wps/portal/nesa/11-12/stage-6-learning-areas/stage-6-science/investigating-science-2017

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. (2021). 'The Flight of Birds' presentation. Massachusetts Institute of Technology Open Courseware, accessed from https://studylib.net/doc/13562570/the-flight-of-birds-joanna-tong-andamp%3B-adele-schwab

APPENDIX: Table 2 (note that some species have 'hybrid' wing shapes)

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
Podicipediformes (W)	Australasian Grebe	23-25	39	7.67		0.096-0.22					
Procellariformes (O)	Wandering Albatross	110-135	250-350	23.66		6-11					
Pelicaniformes (W)	Little Pied Cormorant	55-65	85-90	14.99		0.41-0.9					
(O)	Great Frigatebird	85-105	205-230	21.72		0.95-1.95					
Ciconiiformes (W)	Straw-necked Ibis	60-70 (35-40)	100-120	14.50		1.15-1.57					
Anseriformes (LW)	Magpie Goose	70-90	125-180	29.95		2.07-2.83					
(W)	Wandering Whistling-Duck	55-60	80-90	15.96		0.45-0.98					
(W)	Musk Duck	55-66	72-87	14.41		0.99-3.12					
(LW)	Black Swan	110-140 (55-70)	160-200	30.30		4.6-8.7					
(W)	Australian Shelduck	56-72	94-132	19.57		0.99-1.98					
(W)	Maned/Wood Duck	47-48	78-80	15.48		0.66-0.98					
(W)	Pacific Black Duck	47-60 (32-40)	80-100	15.32		0.6-1.4					
(W)	Hardhead	45-60 (30-40)	65-70	12.89		0.53-1.1					
Falconiformes (R)	Wedge-tailed Eagle	85-105	185-230	41.41		2.03-5.3					
(HS)	Peregrine Falcon	35-50	80-105	15.42		0.36-0.99					
Galliformes (G)	Australian Brush-Turkey	60-70	85	26.39		1.07-2.45					
Turniciformes (G)	Painted Button-Quail	17-23	28-38	7.33		0.072-0.134					

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) m2	Wing Loading (L=W/A)	Cruising Speed (V) m s-1	Wing Shape Type
Gruiformes (W)	Purple Swamphen	44-48	70-88	20.53		0.77-1.25					
(W)	Eurasian Coot	35-39	56-64	11.65		0.52-0.57					
Charadriiformes (S)	Pacific Golden Plover	23-26	60-72	7.32		0.11-0.18					
(S)	Bar-tailed Godwit	37-39, Bill (8-10.8)	62-75	10.56		0.237-0.504					
(S)	Little Tern	20-28	45-55	7.95		0.035-0.06					
Columbiformes (PD)	Wompoo Fruit-Dove	35-45	~65-70	17.12		0.22-0.5					
(PD)	White-headed Pigeon	38-42	65-70	17.28		0.22-0.5					
(PD)	Diamond Dove	20-24	30-32	7.09		0.036-0.066					
Psittaciformes (P)	Sulphur-crested Cockatoo	48-55	103	28.99		0.5-1.02					
(P)	Rainbow Lorikeet	28-32	46	8.45		0.075-0.157					
(P)	Budgerigar	17-18	25-30	5.02		0.012-0.04					
Cuculiformes (C)	Fan-tailed Cuckoo	24-28	34-42	8.58		0.037-0.062					
(C)	Channel-billed Cuckoo	56-70	88-107	20.20		0.45-0.94					
Strigiformes (R)	Powerful Owl	50-60	110-140	29.69		0.99-2.22					
(R)	Barn Owl	29-38	70-100	17.35		0.25-0.47					
Caprimulgiformes (N)	Tawny Frogmouth	35-50	75-95	20.96		0.123-0.555					
(N)	Australian Owlet-Nightjar	19-25	34-50	9.35		0.035-0.065					

Order	Species	Body Length cm	Wingspan (S) cm	Wing Chord (C) cm	Aspect Ratio (R=S/C)	**Body Mass (m) g (NB convert to kg)**	Body Weight (W) N [W=ma, a=9.8]	Wing Area (A=S*C) m2	Wing Loading (L=W/A)	Cruising Speed (V) $m\ s^{-1}$	Wing Shape Type
Apodiformes (HS)	White-throated Needletail	20-22	49	6.03		47-120					
Coraciiformes (KR)	Sacred Kingfisher	21-23	33-37	7.24		28-75					
(KR)	Dollarbird	26-29	55-65	12.61		51-180					
Passeriformes (E)	Superb Lyrebird	78-103, Tail 25-71	68-76	29.90		721-1200					
(E)	Southern Emu-wren	13.5-19	9-19	4.78		5-9					
(E)	Yellow-faced Honeyeater	15-17.5	21.5-26	7.49		12-20.5					
(E)	Brown Thornbill	9-11.5	12.5-16	4.87		5-12					
(E)	Grey-crowned Babbler	23-26.5	35	10.86		52-88					
(E)	Golden Whistler	16-19	25-30	8.22		15-37					
(E)	Grey Fantail	14-16.5	18-22.5	6.61		5.7-11.8					
(E)	Australian Magpie	37-43	65-85	18.69		190-410					
(E)	Zebra Finch	9-11.5	12.5-17	4.65		9.4-16.2					
(HS)	Welcome Swallow	14-16	26-31	5.79		9-20					

W=waterbird, LW=large waterbird, O=ocean-going, R=raptor, AF=aerial forager, G=ground, S=shorebird, PD=pigeon/dove, P=parrot, C=cuckoo, N=nightjar, KR=kingfisher/roller, E=perching bird