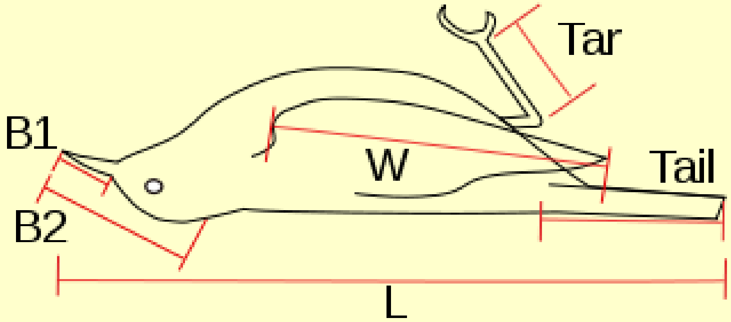
1. Check out your bird



- Where are the feet placed on the body? Measure L

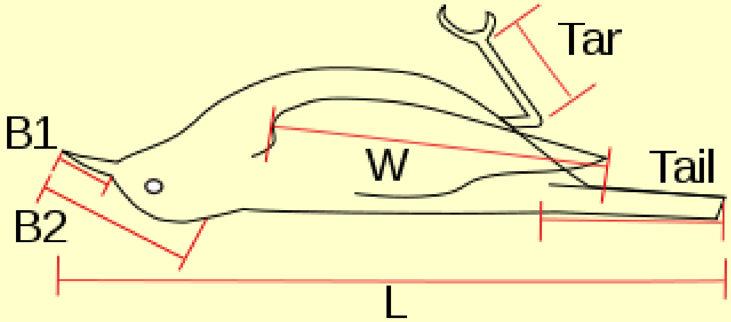
Range of values:

47% Hawaiian Petrel (Procellariidae)

to

74% Common Murre (Alcidae)

1. Check out your bird



- Where are the feet placed on the body? Measure L

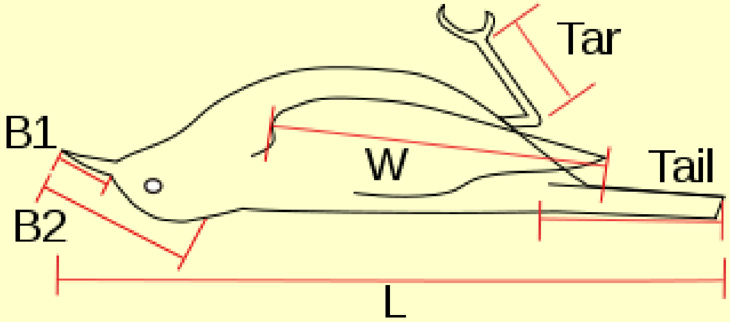
Range of values:

42% Chicken (Phasianidae)

to

100% Western Greebe (Podicipedidae)

1. Check out your bird



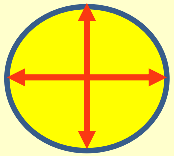
- What are the feet like ?

  Write a brief description and make a drawing

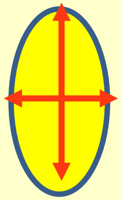
- What is the tarsus like ?
  Write a brief description of the cross-section shape
  (Note: use calipers to measure tarsus cross-section)

Tarsus Ratio = $\dfrac{\text{Parallel to leg movement}}{\text{Perpendicular to leg movement}}$

Round Tarsus



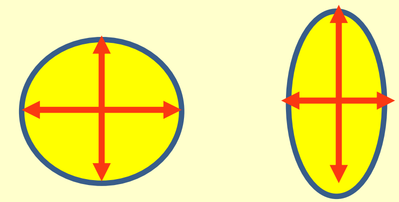
(Wood 1993)



Elliptical Tarsus

1. Check out your bird

$$\text{Tarsus Ratio} = \frac{\text{Parallel to leg movement}}{\text{Perpendicular to leg movement}}$$



Range of values:

1.00 Black-winged Petrel (Procellariidae)

to

1.50 Common Murre (Alcidae)

Values < 1.00

0.80 RFBO (Sulidae)

to

0.80 BRBO (Sulidae)

Tarso-metatarsus Section Ratio (Wood 1993)

Major and minor axes (a and b) of one tarsus per bird measured with vernier calipers at mid-point between ankle and knee.

Cross-section ratio (a / b) reflects the extent to which tarsus is laterally compressed.

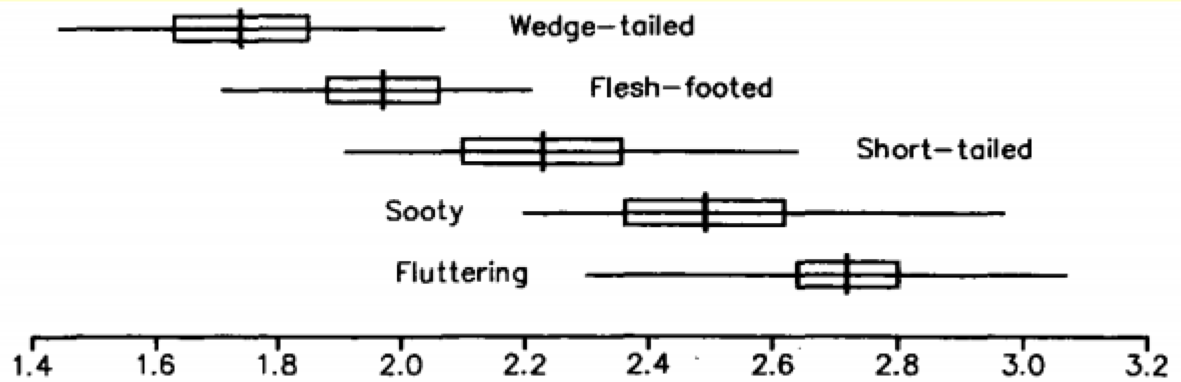


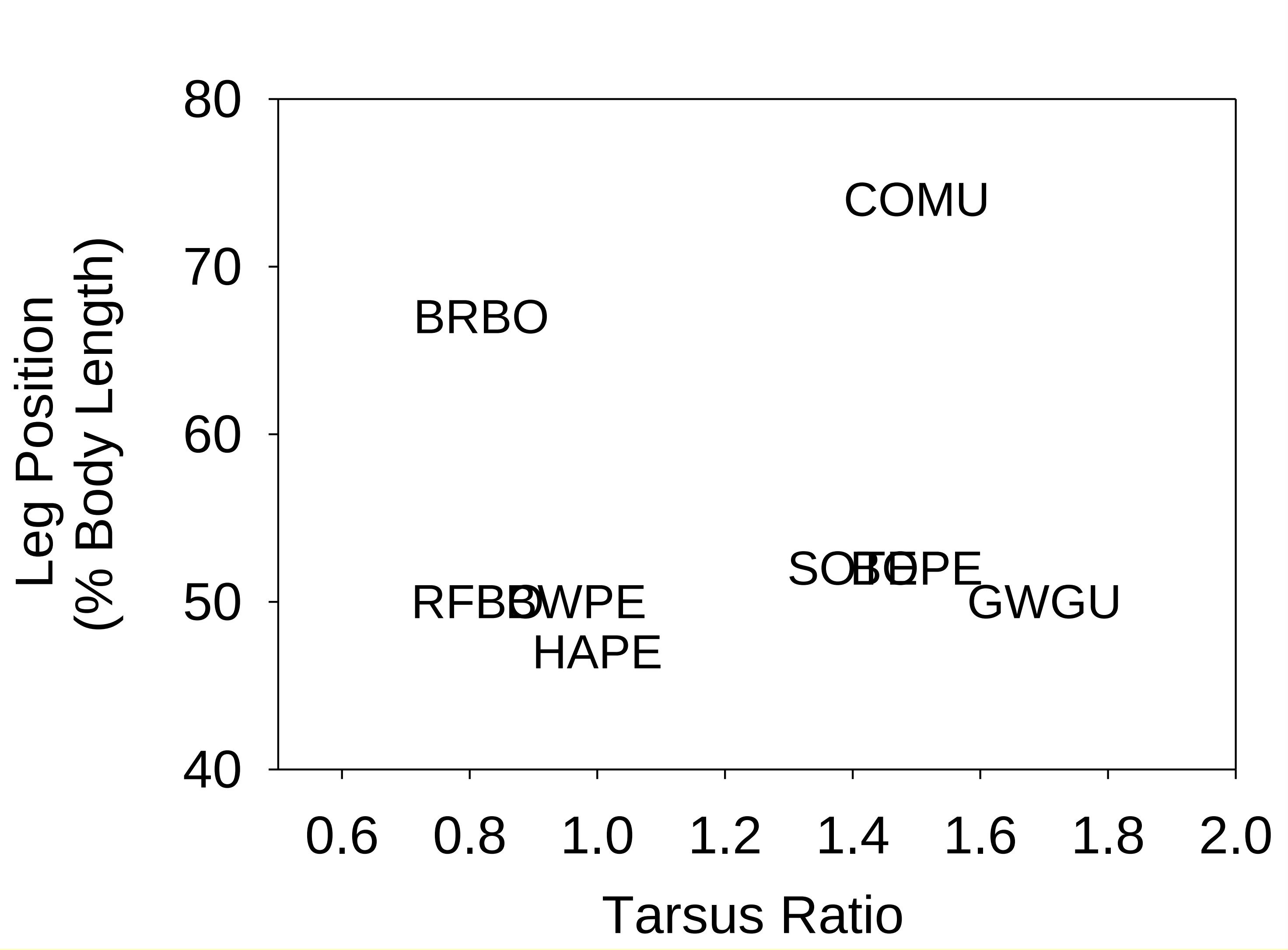
FIGURE 1 — Shearwater tarsometatarsus section ratio (a/b) indicating mean, ± 99% confidence limits of mean (rectangle) and range (horizontal line).

TABLE 1 — Scavenging techniques and offal preferences of shearwaters off Wollongong, N.S.W.

Species	Offal Type		Scavenging Technique				
	Fish	Fat	Surface Seizing	Contact Dipping	Surface Plunging	Shallow Diving	Pursuit Diving
Wedge-tailed *P. pacificus*	XX	O	XX	X	XX	O	O
Flesh-footed *P. carneipes*	XX	O	XX	X	XX	O	O
Short-tailed *P. tenuirostris*	XX	O	X	O	X	X	X
Sooty *P. griseus*	XX	O	X	O	X	X	X

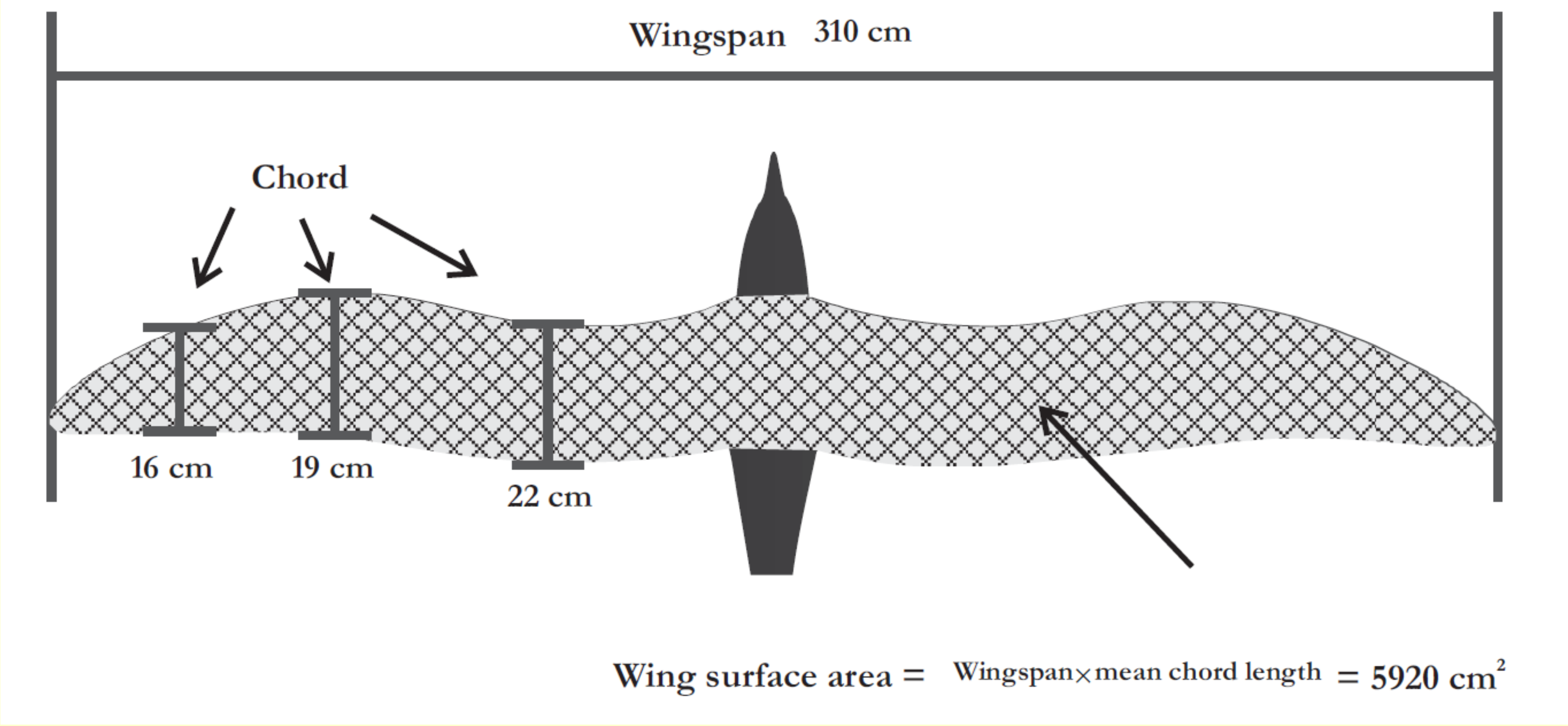
XX indicates highest preference or usage
O indicates no preference or usage

Leg Position vs Tarsus Ratio



2. Make Bird Measurements

- Weight (to the closest gram):
- Lay out bird on its back and stretch the wings out.



2. Make Wing Measurements

Wing Span =

Wing Chord =

Wing Aspect Ratio =

Wing Loading =

2. Make Wing Measurements

$$\text{Wing surface area} = \text{Wingspan} \times \text{mean chord length} = 5920\ \text{cm}^2$$

$$\text{Aspect ratio} = \frac{\text{Wingspan}}{\text{Mean chord length}} = \frac{310\ \text{cm}}{19\ \text{cm}} = 16.32$$

$$\text{Wing loading} = \frac{\text{Mass} \times \text{acceleration}}{\text{Wing surface area}} = \frac{7960_{\text{g}} \times 9.81_{\text{m/s}^2}}{5990_{\text{cm}^2}} = 13.26_{\text{N/cm}^2}$$

$$1\ \text{N} = 1\ \text{kg}\frac{\text{m}}{\text{s}^2}$$

Newtons are Kg . Convert from g.

Area units can be changed, to make WL easier to interpret.

3. Estimate Wing Area

Sample	Area_mm2	Mass_grams	perDensity_g per m2
scale1	2,500	0.17	68.00
scale2	5,000	0.34	68.00
scale3	10,000	0.68	68.00
scale3	20,000	1.35	67.50
scale5	40,000	2.70	67.50
scale6	80,000	5.40	67.50
scale7	160,000	10.80	67.50
scale8	320,000	21.60	67.50
COMU	248300	16.81	67.70
BWPE	262128	17.55	66.95
BOPE	662940	43.68	65.89
SOTE	700743	47.60	67.93
HAPE	742188	50.02	67.40
BRBO	782574	58.27	74.46
RFBO	868301	58.03	66.83
GWGU	1020704	67.04	65.68

Adjusted R2 = 0.996

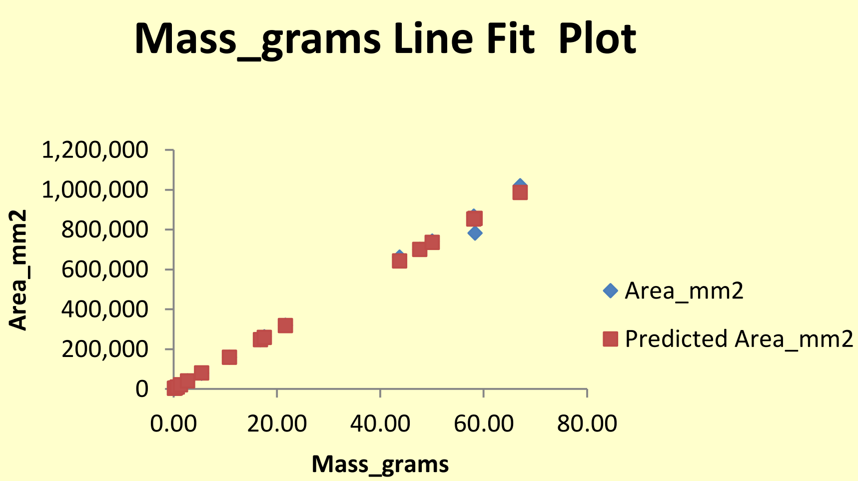
Regression Statistics	
Multiple R	0.998
R Square	0.996
Adjusted R Square	0.996

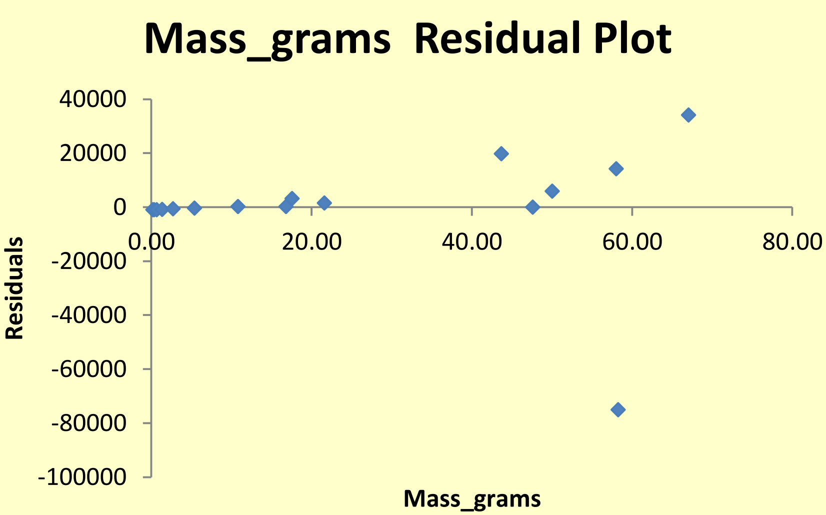
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2E+12	2E+12	3676.48	2.37229E-18
Residual	14	7.4E+09	5.3E+08		
Total	15	2E+12			

3. Estimate Wing Area

Paper_Area_mm = 917.035 + (14701.785 * Paper_Mass_g)

species	tracing_mass (g)	intercept	slope	tracing_area (mm2)	tracing_area (m2)
BOPE	3.2	917.035	14701.785	47962.7	0.048
SOTE	3.93	917.035	14701.785	58695.0	0.059
BWPE	2.61	917.035	14701.785	39288.7	0.039
GWGU	13.68	917.035	14701.785	202037.4	0.202
HAPE	5.25	917.035	14701.785	78101.4	0.078
COMU	2.47	917.035	14701.785	37230.4	0.037
RFBO	11.14	917.035	14701.785	164694.9	0.165
BRBO	10.18	917.035	14701.785	150581.2	0.151





Example: Laysan Albatross

Mass = 1307 g = 1.307 kg

Wing Area = 272209 mm2 = 0.272 m2

Wing Span = 1897 mm = 1.897 m

Mean Wing Chord =

Mean Wing Chord = Wing Area / Wing Span
= 0.272 m2 / 1.897 m = 0.143 m

Wing Aspect Ratio =

Wing Aspect Ratio = Wing Span / Wing Chord
= 1.987 / 0.143 = 13.89

4. Estimate Wing Loading

Mass = 1307 g = 1.307 kg

Wing Area = 272209.7 mm2 = 0.272 m2

Wing Loading (g / mm2) = 1307 g / 272209 mm2
Wing Loading (g / mm2) = 0.00480 g / mm2

Wing Loading (kg / m2) = 1.307 g / 0.272 m2
Wing Loading (kg / m2) = 4.805 kg / m2

4. Estimate Wing Loading

N = One newton is the force needed to accelerate one kilogram of mass at the rate of one meter per second squared in direction of the applied force.

Wing Loading (kg / mm2) = 1.307 kg / 272209 mm2
Wing Loading (kg / mm2) = 0.00000480 kg / mm2

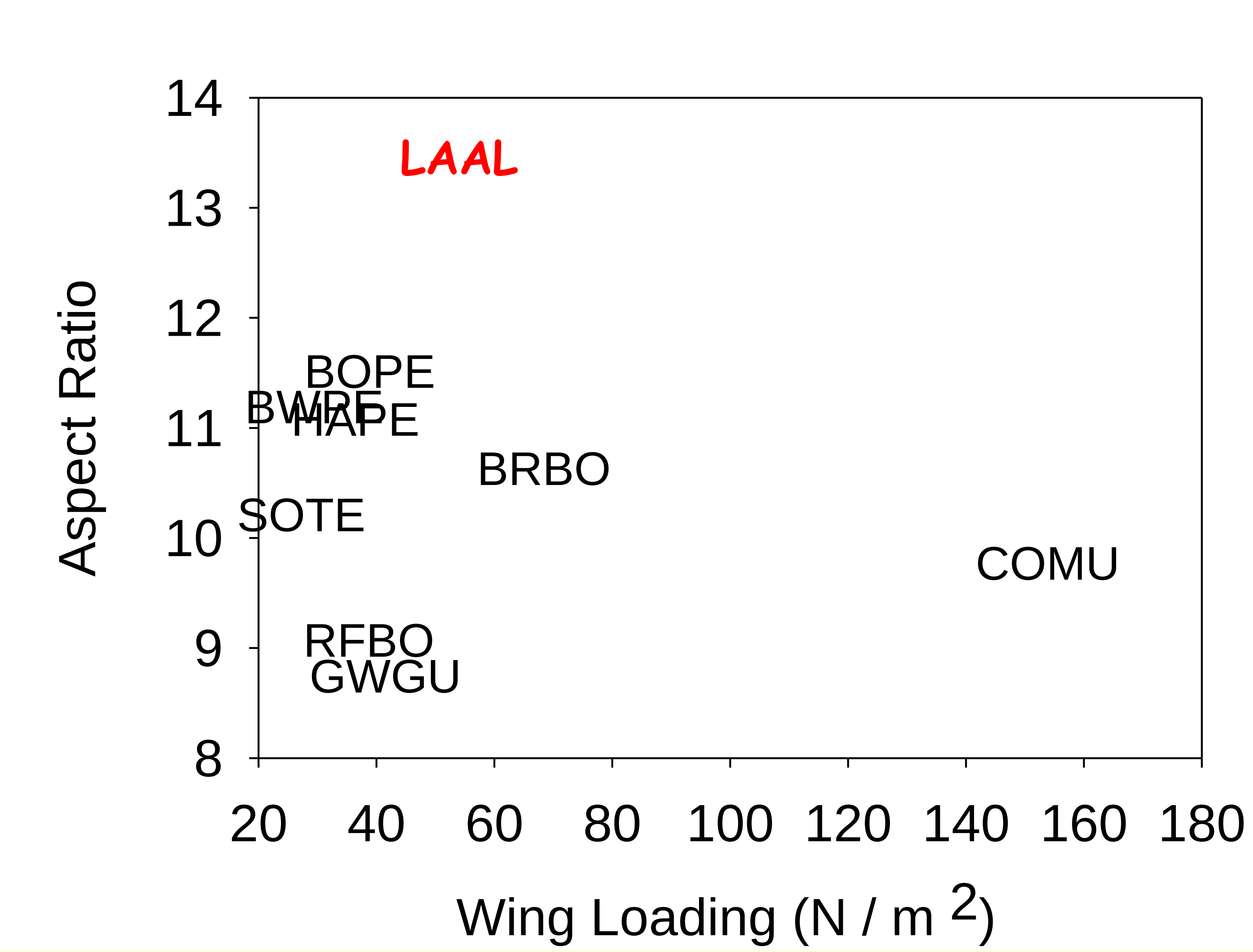
Wing Loading (N / mm2) = (1.307 kg / 272209 mm2) * *G*

Wing Loading (N / mm2) = 0.000047102 (kg/mm2) * (m/s2)

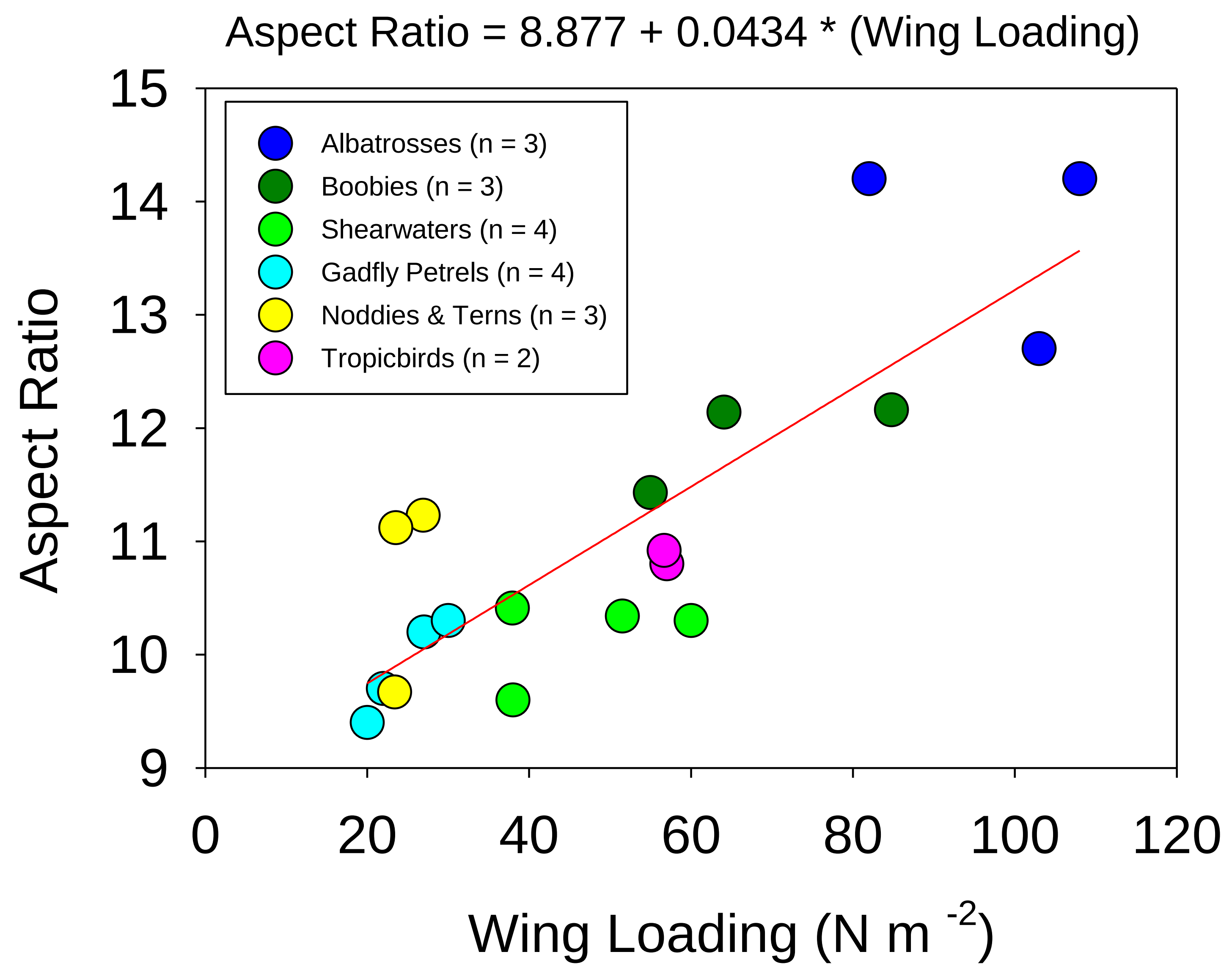
Wing Loading (N / mm2) = 0.000047102 N / mm2

Wing Loading (N / m2) = 47.102 N / mm2

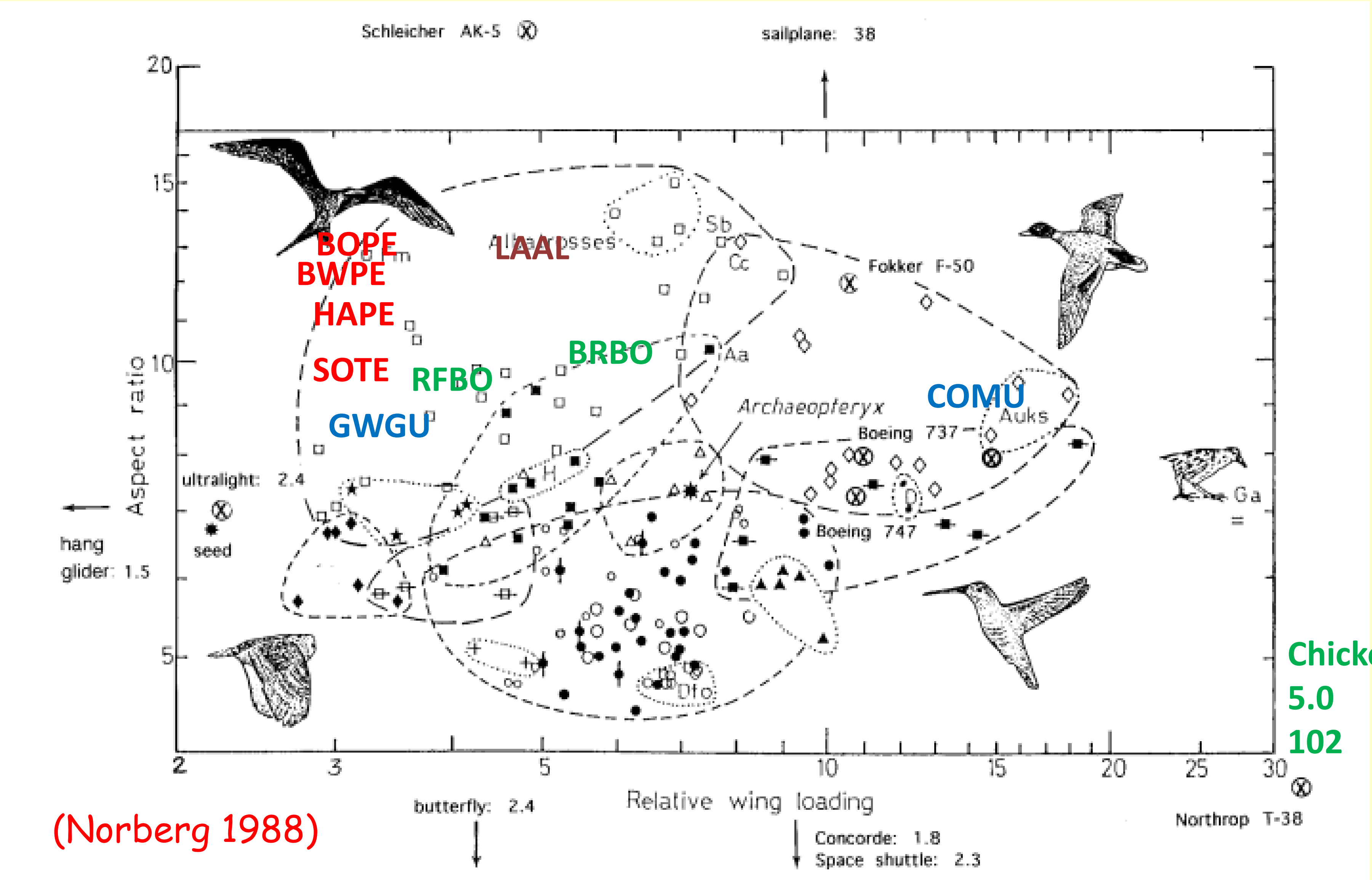
Wing Loading vs Aspect Ratio



Wing Loading vs Aspect Ratio



What does it all Mean ?



Chicken
5.0
102

(Norberg 1988)

Locomotion Costs: Flight

The shape and size of wings influence the mode of flight.

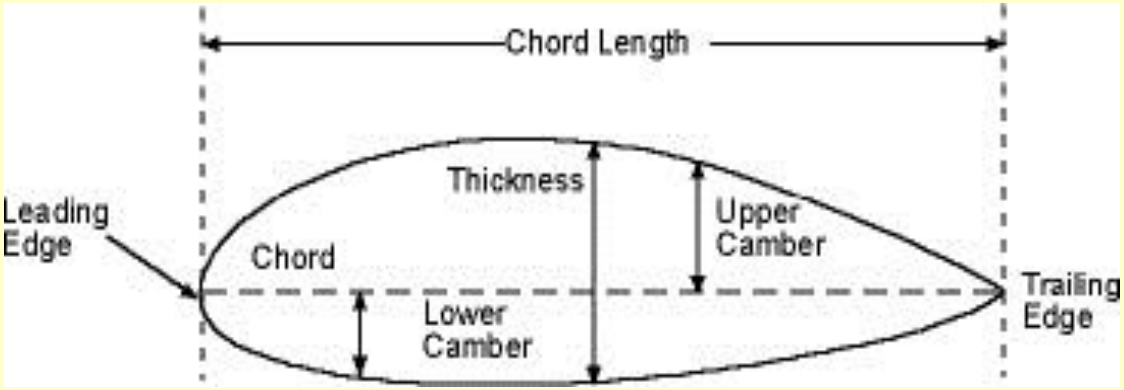
The mode of flight influences locomotion energetics.

The shape and size of wings influence the diving ability.

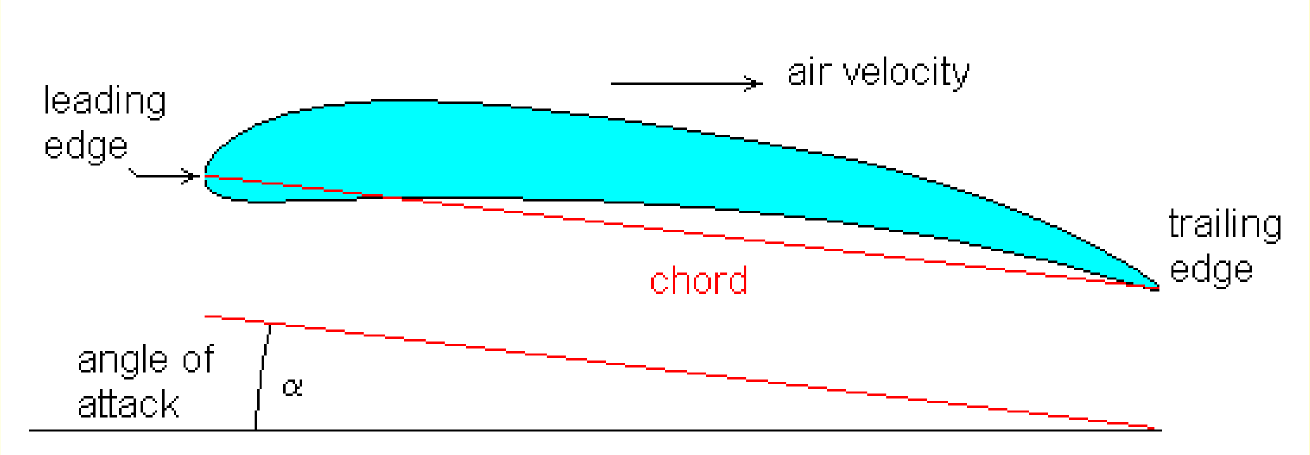
Introduction to Wings

Bird wings are asymmetric airfoils

Adapted to provide high lift at low speeds

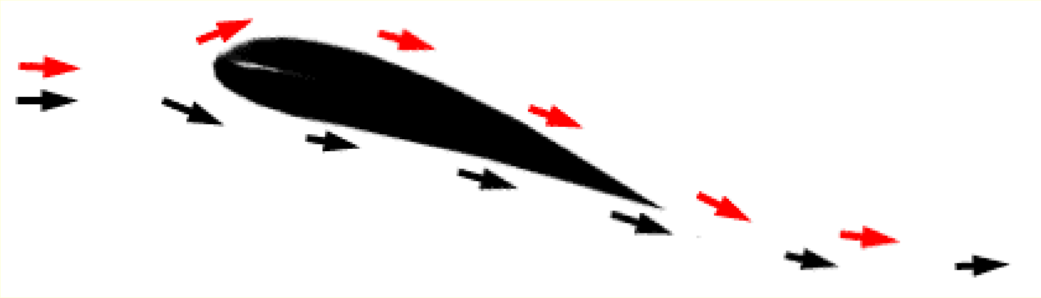


Camber:
Asymmetry between the top and bottom surfaces of an airfoil



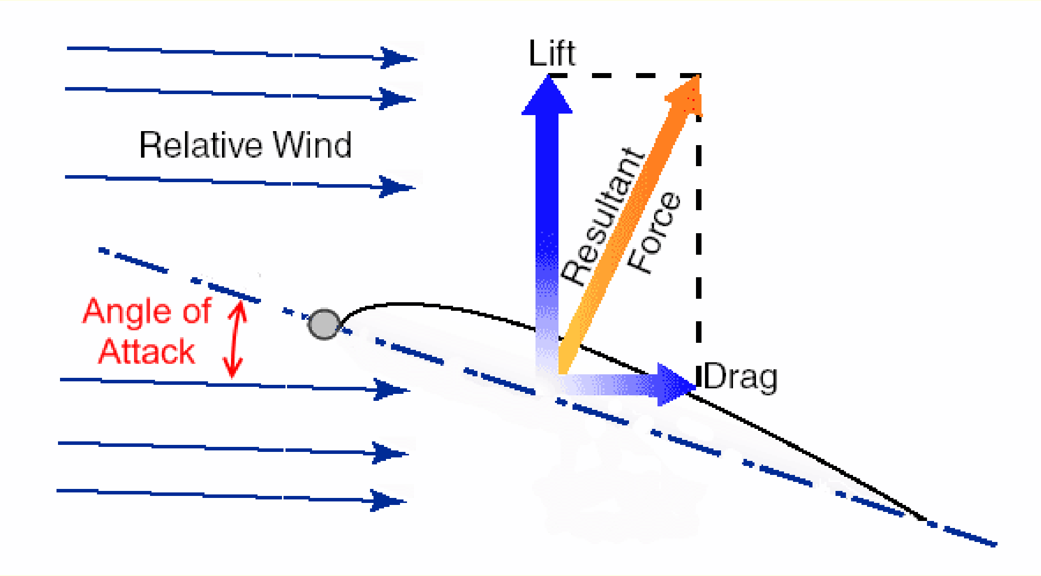
Introduction to Wings

Click image for a three minute review of the physics of wings:



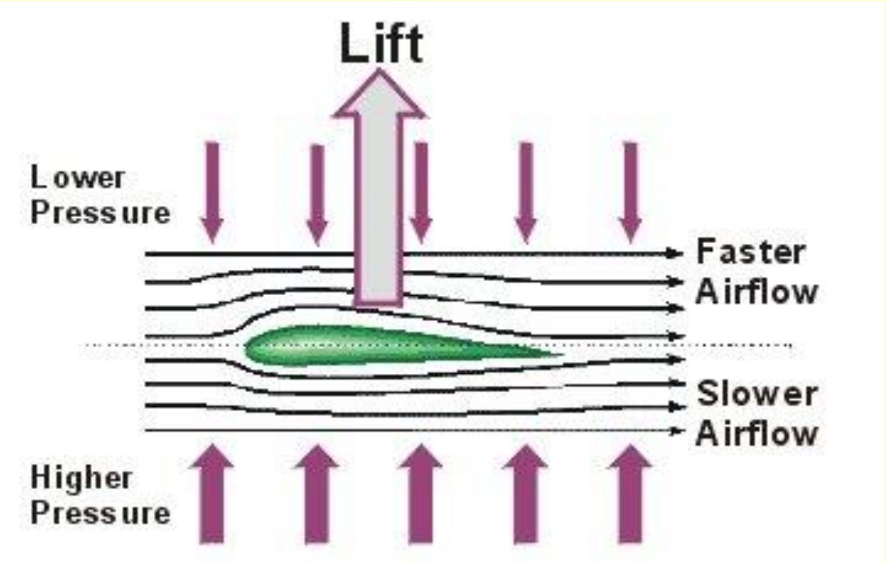
Wing is subjected to lift and drag

Shape and angle of attack critical aspects



How do wings work: Gliding Flight

Gliding birds use their weight (mass) to overcome air resistance to forward motion. This motion causes lift on the front (leading) edge of wings.



Lift is higher in longer and skinnier wings.

Because gliding requires a certain mass, only large birds can glide regularly.

How do wings work: Gliding Flight

Birds gain altitude in a variety of ways:

- Updrafts (fulmars)
- Thermals (frigates)

Gliding bird loses altitude at 'sinking speed' (V_s) while travelling forward at 'flight speed' (V).

A bird's glide ratio equals
V / V_s
(distance travelled forward divided by altitude lost).

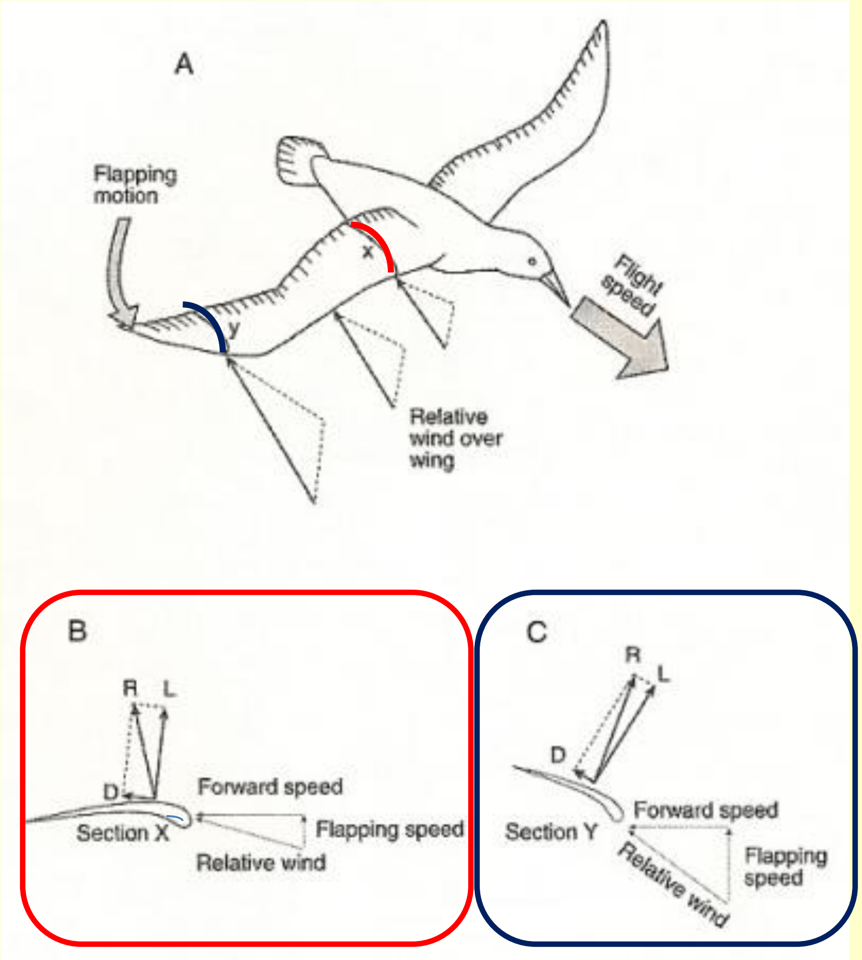
How do wings work: Flapping Flight

Flapping flight involves up-and-down movement of wings.

Different parts of the wing have different functions:

X: The proximal part of the wing (closest to body) moves through narrower arc and provides most lift to the bird

Y: The distal part of the wing moves through a wider arc and generates the thrust that propels the bird forward



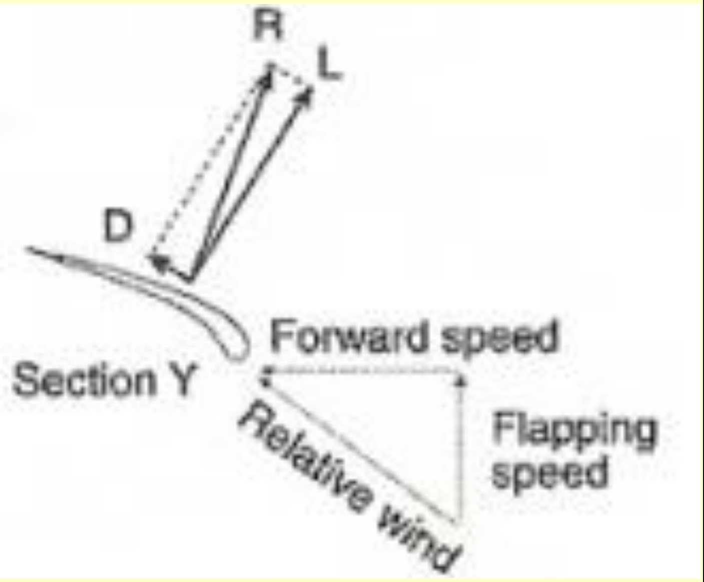
How do wings work: Flapping Flight

During downstroke (power stroke), wings moves downward and forward. As a result, the leading edge of the wing, is lower than the trailing edge

As a result, the resultant force (R) is angled forward, producing forward thrust

During upstroke (recovery stroke), the tips of primaries separate and the 'slots' allow passage of air (reducing friction as wing comes up)

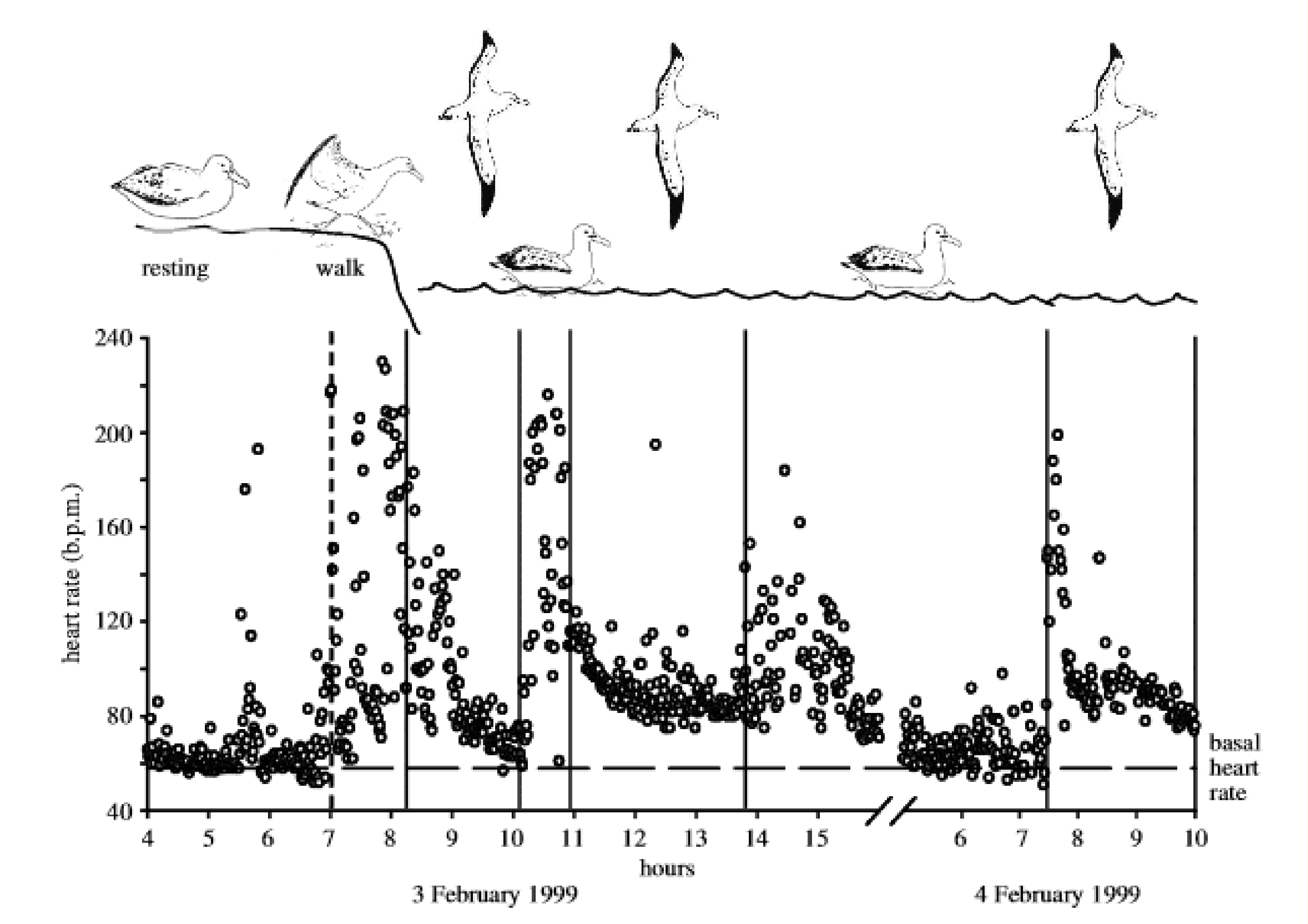
Wing folded at wrist & elbow and drawn toward body to reduce drag



Albatross Flight – Energetically Inexpensive

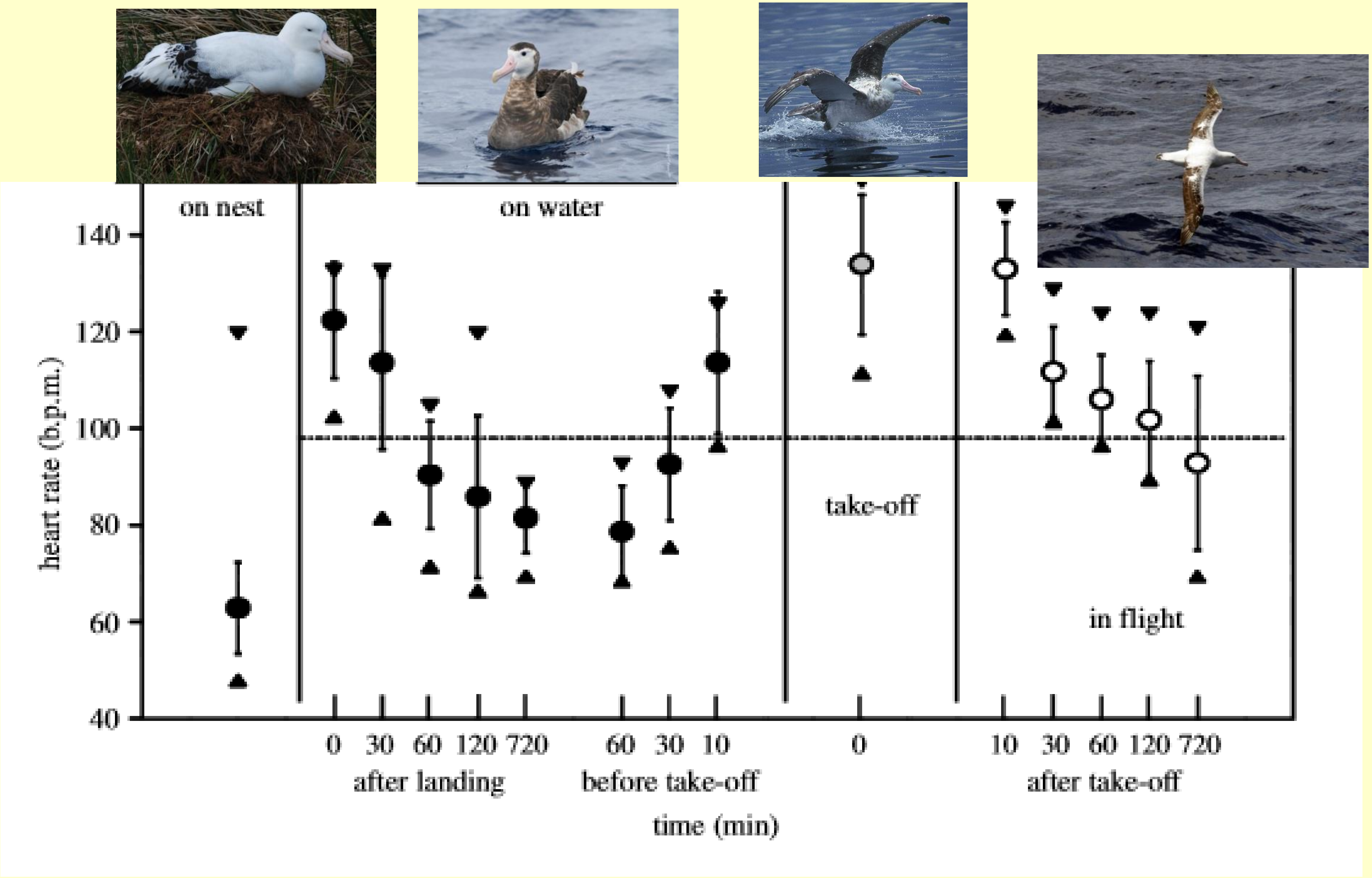
Wandering Albatross (*Diomedea exulans*): 3 m wingspan, 10 kg

Albatross Flight – Energetically Inexpensive



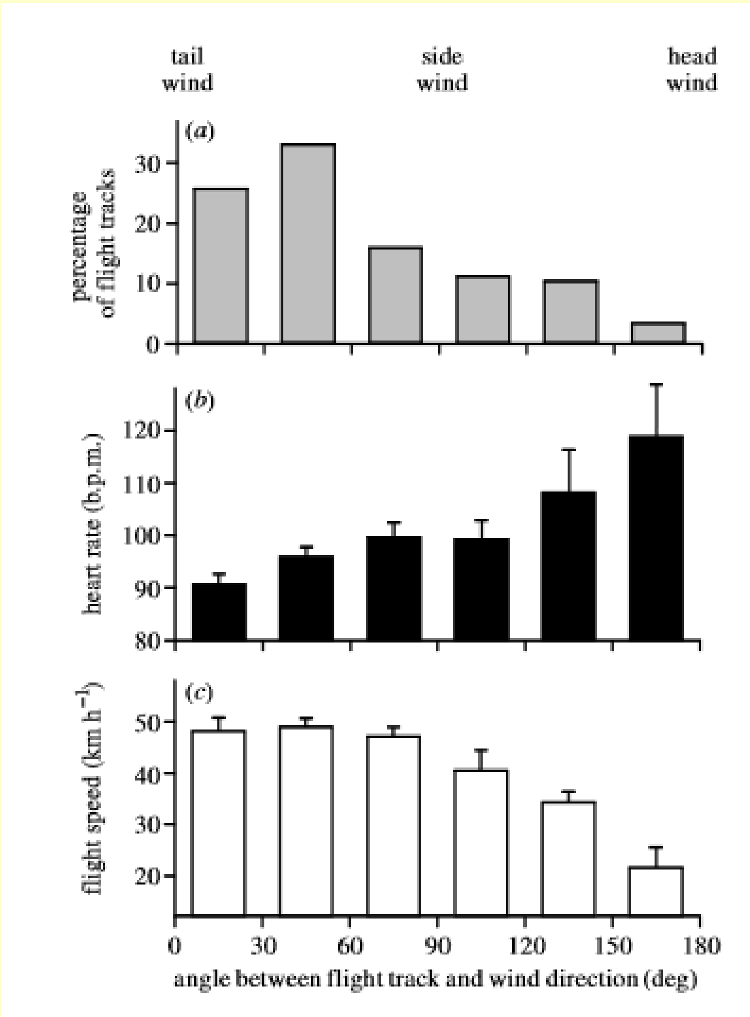
Heart-rate monitor: proxy for energetic costs (Weimerskirch et al. 2000)

Albatross Flight – Energetically Inexpensive



(Weimerskirch et al. 2000)

Albatross Flight – Energetically Inexpensive

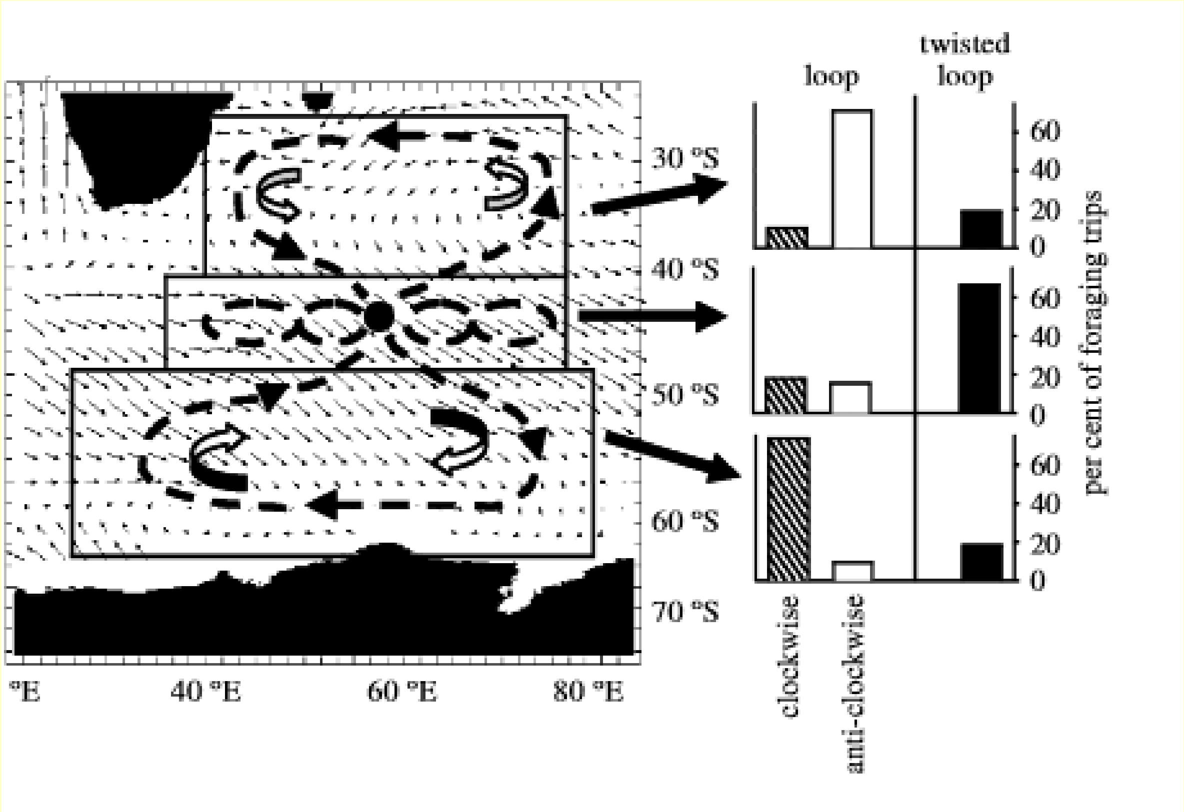


(Weimerskirch et al. 2000)

Heart rates measured at least 30 min after a take-off varied according to the angle between the wind direction and the flight direction; they increase when birds fly from tail to head winds.

Flight speeds also varied according to wind, but decreased when birds fly from tail to head winds

Albatross Flight – Energetically Inexpensive

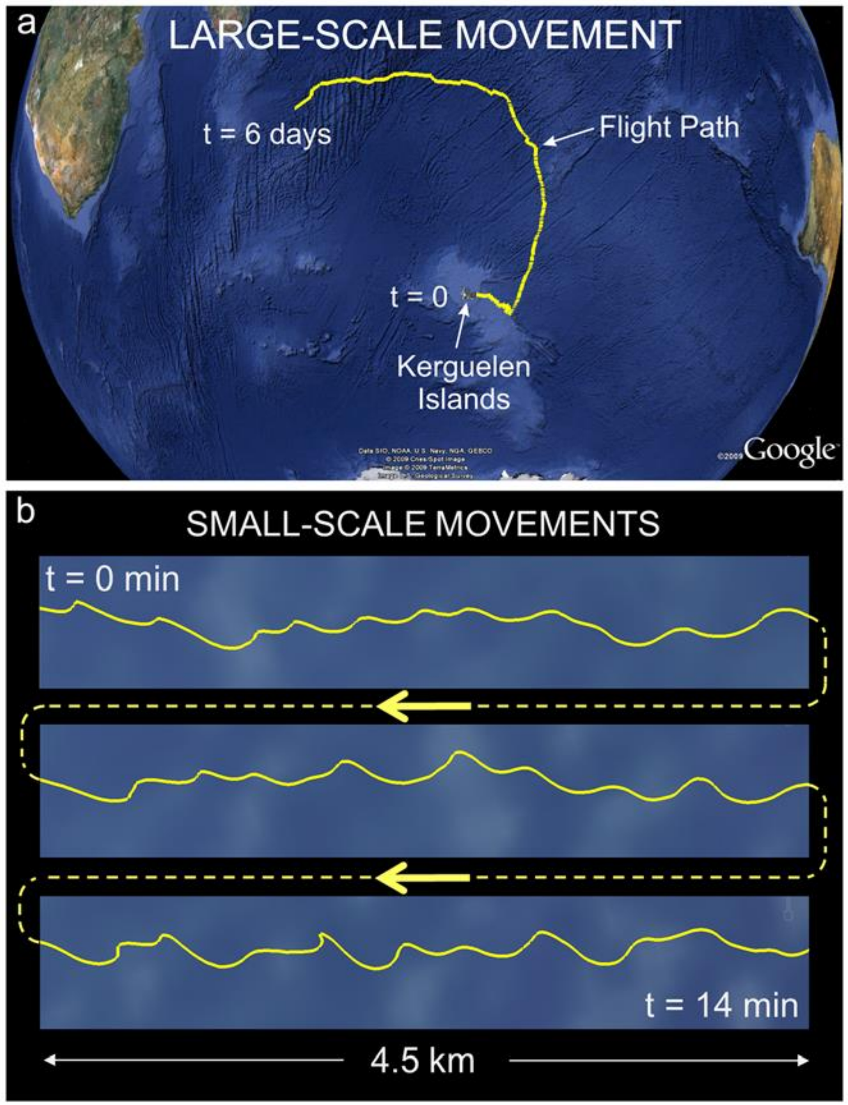


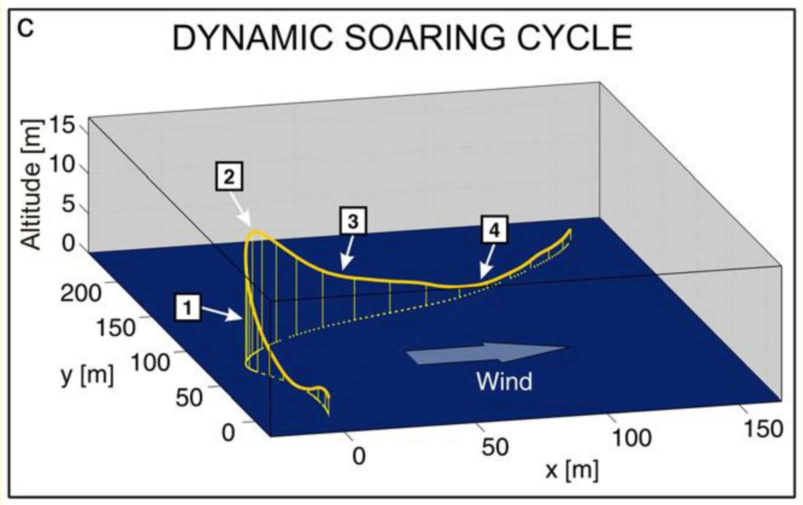
Birds follow loops to fly down-wind or cross-wind, as they complete foraging trips to / from the breeding colony

Large-scale movements driven by the meso-scale wind patterns in Southern Indian Ocean

(Weimerskirch et al. 2000)

Albatross Flight – Energetically Inexpensive





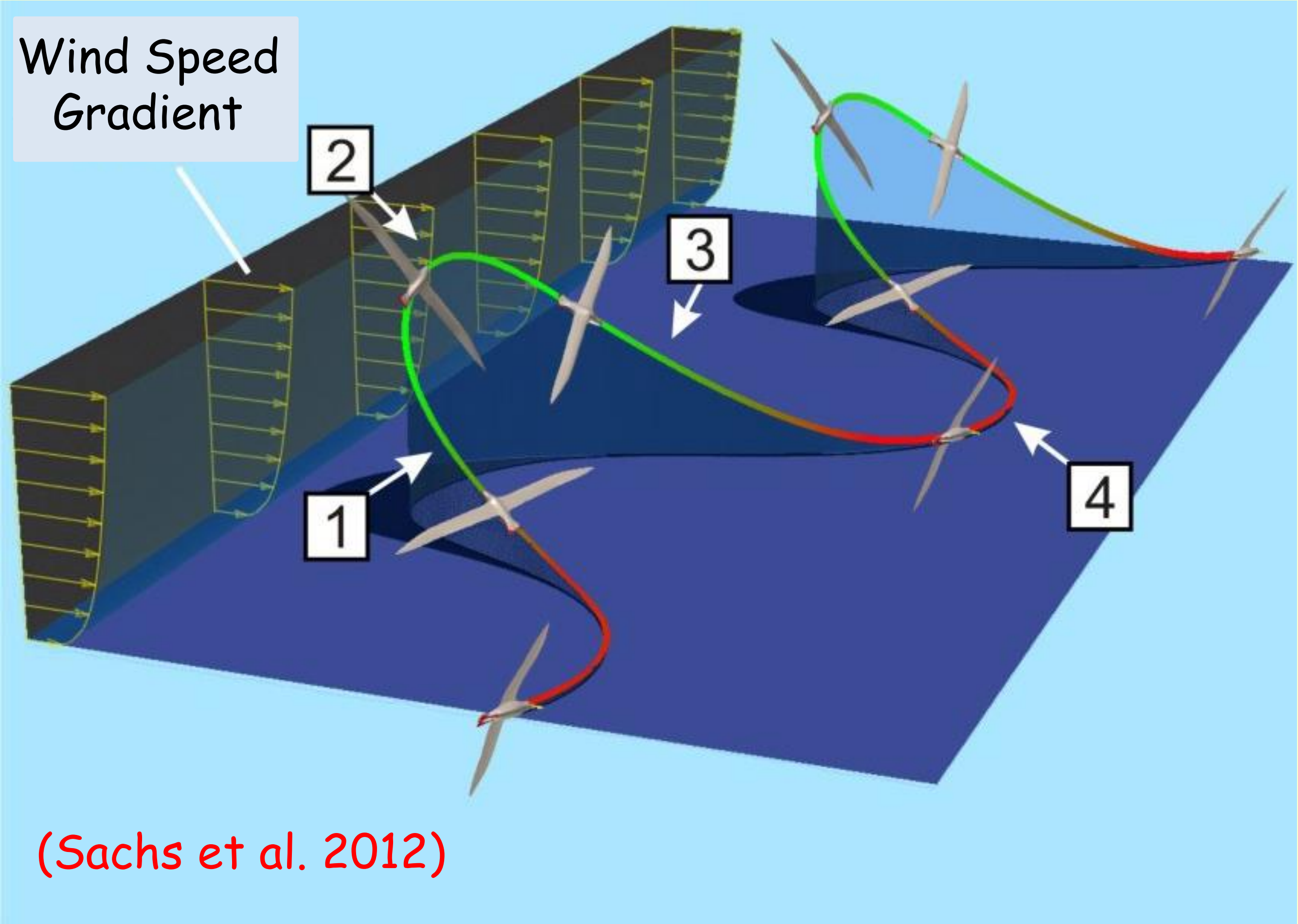
(Sachs et al. 2012)

The small-scale movements consist of dynamic soaring cycles featuring distinct motions in longitudinal, lateral, and vertical directions.

Each dynamic soaring cycle consists of (1) a windward climb, (2) a curve from wind- to leeward at upper altitude, (3) a leeward descent and (4) a curve from lee- to windward at low altitude, close to sea surface.

Albatross Flight – Energetically Inexpensive

Dynamic soaring is a technique used to gain energy by crossing boundary between air masses of different velocity.



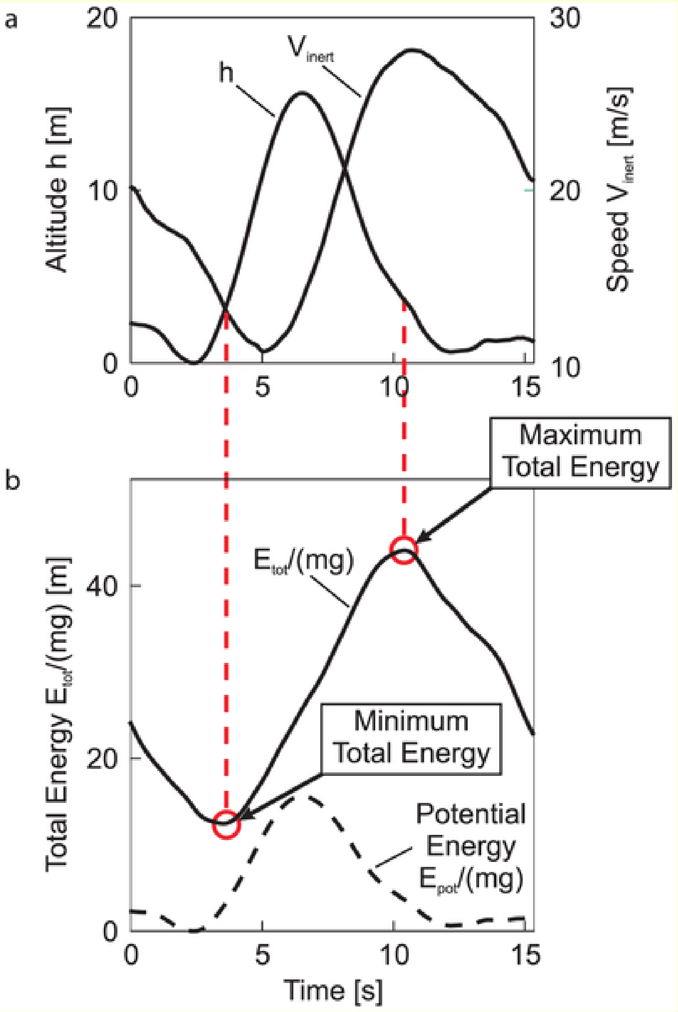
1: Bird flies into wind, lift increases its height; speeds slows down

2: When bird is about to stall, it turns downwind

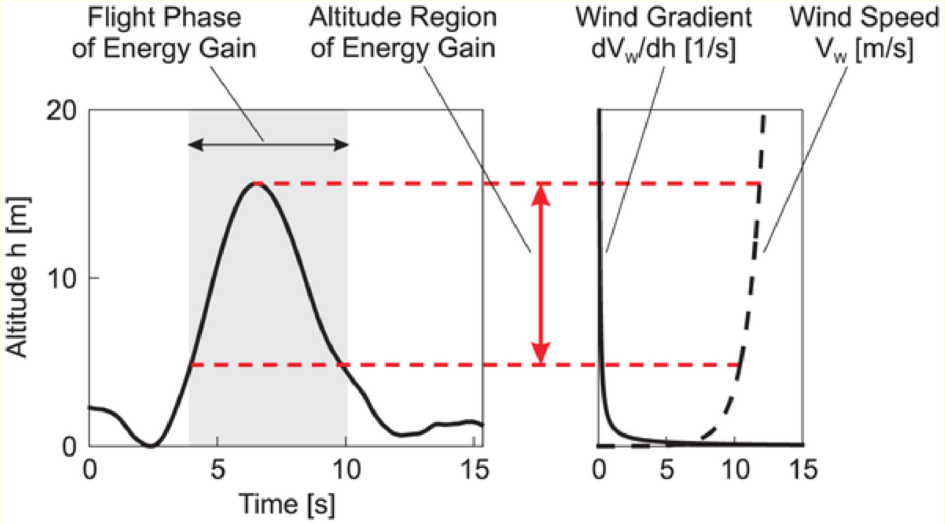
3: Bird speeds up and loses height

4: At highest speed, the bird turns into wind

Albatross Flight – Energetically Inexpensive



a. Altitude h, inertial speed (Vinert).
b. Energy: Total and Potential



Relationship between energy gain, altitude and wind gradient.

Left and right diagrams show the relationship between shear wind layer above sea surface and the altitude region where energy gain from wind is achieved during dynamic soaring cycle

(Sachs et al. 2012)

Energetic Trade-Offs – Cost of Locomotion

Main Idea: Seabird wing morphologies, foraging methods and diving capabilities are related to each other

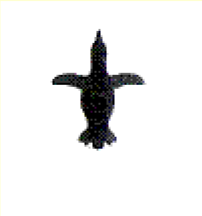
(Ainley 1977, Wahl et al. 1989, Ballance et al. 1997)

Wing Loading: Body Mass / Wing Surface Area (**kg/m^2**)

- Metric of "cost of flight" (indication of diving ability)

Frigatebird

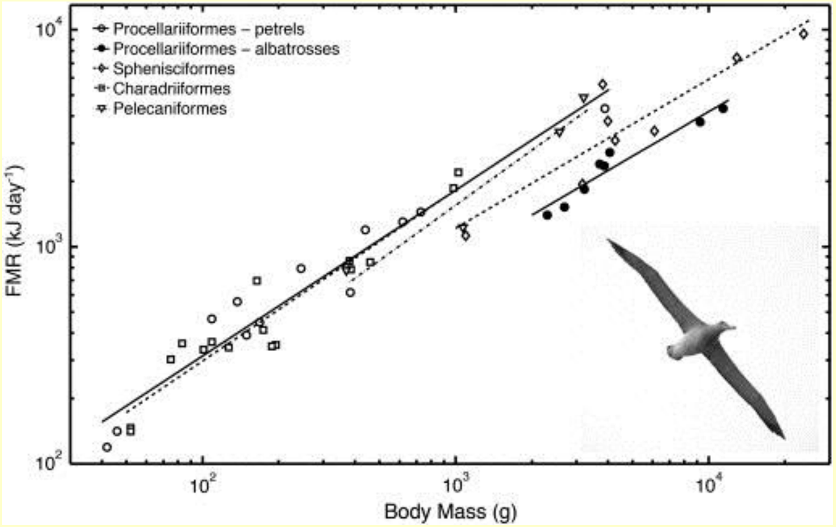
Razorbill



Penguin

Energetic Consequences for Species

Group	No. of species	Equation	R^2	s.e. Intercept	s.e. Slope
All seabirds	48	$FMR = 18.522\ M^{0.619}$	0.925	1.191	0.026
Procellariiformes	20	$FMR = 25.326\ M^{0.562}$	0.911	1.330	0.041
Albatrosses	8	$FMR = 7.933\ M^{0.681}$	0.925	1.938	0.079
Petrels	12	$FMR = 9.262\ M^{0.765}$	0.943	1.399	0.060
Charadriiformes	16	$FMR = 7.866\ M^{0.788}$	0.908	1.425	0.067
Auks	7	$FMR = 15.537\ M^{0.689}$	0.909	1.770	0.097
Non-auks	9	$FMR = 10.181\ M^{0.717}$	0.835	1.782	0.120
Pelecaniformes	4	$FMR = 4.557\ M^{0.844}$	0.940	2.999	0.151
Sphenisciformes	8	$FMR = 10.649\ M^{0.686}$	0.827	2.999	0.128



(Shaffer 2011)

Ecological implications for Seabirds:

- Spatial segregation across species:

Consummate divers forage closer; Proficient fliers forage farther away

- Differential profitability of prey patches:

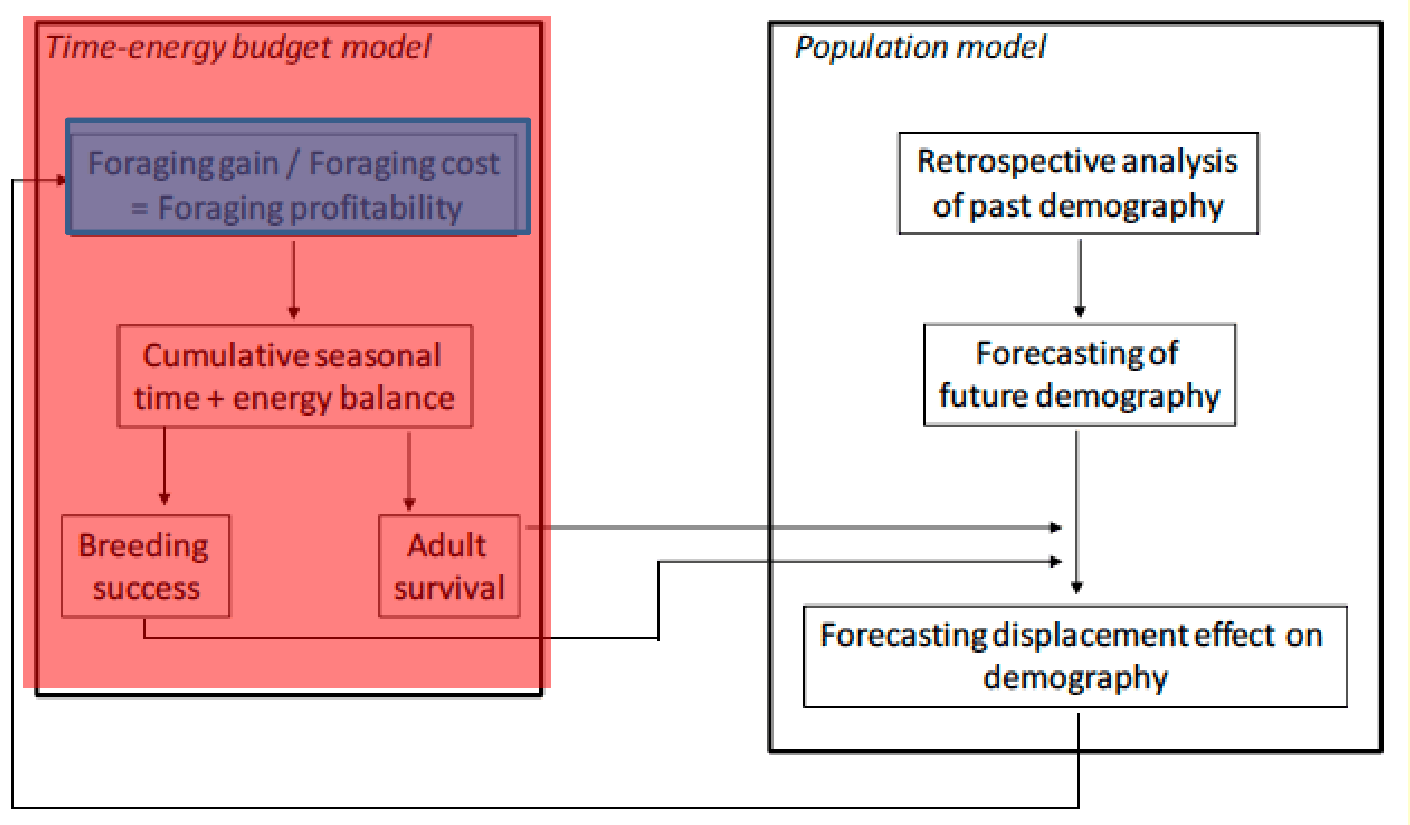
Some species can exploit small prey patches; others need dense aggregations

Energetic Trade-Offs of Foraging

- Foraging Costs:

  [Time Flying * Flying Cost]
  + [Time Diving * Diving Cost]
  + [Time Resting * Resting Cost]

- Foraging Costs: Link Individual / Population Responses



References

Wilson, R.P., Hustler, K., Ryan, P.G., Burger, A.E., and Noldeke, E.C. (1992) Diving Birds in Cold Water: Do Archimedes and Boyle Determine Energetic Costs? The American Naturalist. 140(2): 179-200.

Wood, K. W. (1993) Feeding behaviour, offal preferences and tarsus shape of *Puffinus* shearwaters off central New South Wales. Notornis. 40(2): 123-127.

Weimerskirch, H., Guionnet, T., Martin, J., Shaffer, S.A., and Costa, D.P. (2000) Fast and fuel efficient? Optimal use of wind by flying albatrosses. Proc. Biol. Soc. 267(1455): 1869–1874.

Sachs, G., et al. (2012) Flying at No Mechanical Energy Cost: Disclosing the Secret of Wandering Albatrosses. PLoS ONE 7(9): e41449. doi:10.1371/journal.pone.0041449