Lecture 22: Gliding

Biol427 – Autumn 2013 – Biomechanics

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Gliding is a form of flight that requires no input of energy from the organism beyond that required to maintain a gliding posture: the energy for movement is converted from gravitational potential energy. In this lecture, we will explore some physical aspects of gliding, and discuss various metrics of gliding performance.

How to glide

All animals, when they fall, convert gravitational potential energy into kinetic energy:

$$\begin{aligned} \Delta(\mathrm{PE}) &= \Delta(\mathrm{KE}) \quad (1)\\ mg\Delta h &= \frac{1}{2}m(\Delta v)^2 \quad (2)\\ \Delta v &= \sqrt{2g\Delta h} \quad (3) \end{aligned}$$

Eqn 3 should be familiar from physics, but it is important to note that this equation ignores resistance to the motion of the animal due to fluid forces. As the speed of the falling animal increases, the fluid forces resisting the motion of the animal will increase proportional to the square of its velocity:

$$\begin{aligned} D &= \frac{1}{2}\rho S U^2 C_D \quad (4)\\ L &= \frac{1}{2}\rho S U^2 C_L \quad (5) \end{aligned}$$

where U is the speed with which the local flow moves around the falling animal (for an animal falling in perfectly still air, $U = v$). In Eqns 4 and 5, we have split the total aerodynamic force acting on the animal into two components: drag (D), which is the component of the force parallel to the direction of the flow, and lift (L), which is the perpendicular component. The falling animal will eventually reach some equilibrium speed where the downwards gravitational force will be exactly opposed by the upwards net aerodynamic force, where the net aerodynamic force is the vector sum of the drag and lift.

All falling animals will experience drag; gliding animals are those animals which are able to use their morphology and posture to generate *controllable* lift forces and thereby effect directed horizontal motions while falling.

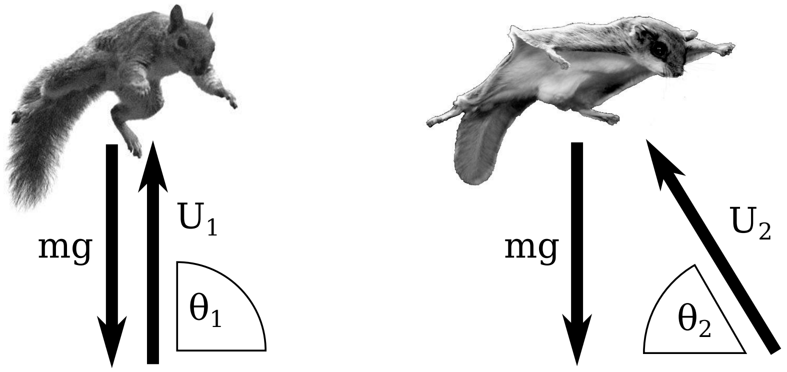

Figure 1: Falling vs flying squirrels

Exercise: Figure 1 shows two squirrels, which we will assume for simplicity have the same mass m, both of whom have fallen out of a tree. The squirrel on the left, being of the non-flying variety, falls straight downwards with a glide angle of $\theta_1 = 90°$. The flying squirrel on the right, by virtue of the patagial membrane stretched between its fore- and hindlimbs, is able to generate controllable lift forces, allowing it to achieve a glide angle of $\theta_2 < 90°$. Assume that both squirrels have fallen sufficiently far to reach their equilibrium sped, and draw a free body diagram for both squirrels showing the lift and drag vectors (L and D). Next, derive an expression for how the glide angle θ depends on the lift-to-drag ratio L/D.

An abridged tour of the gliders

Within animals, there are four known independent evolutions of powered flight: insects, bats, birds and pterosaurs. Gliding flight has evolved with a frequency at least an order of magnitude higher, with examples to be found in mammals, lizards, snakes, amphibians and arthropods. Within the vertebrate gliders, lift is achieved by stretching a membranous structure (or patagium) between bony structures to form an airfoil. In mammals, the patagium is divided into three parts: the main region is the plagiopatagium, which stretches between the fore- and hindlimbs, and all gliding mammals exhibit this feature. In some groups, there is also a propatagium anterior to the forelimbs, and a uropatagium posterior to the hindlimbs and possibly encompassing the tail.

Within reptiles, *Draco* lizards glide using a patagium stretched across collapsible extensions of the ribs, and *Chrysopelea* snakes form their entire bodies into undulating airfoils through dorsoventral flattening. In amphibians, the flying frog genus *Rhacophorus* employs

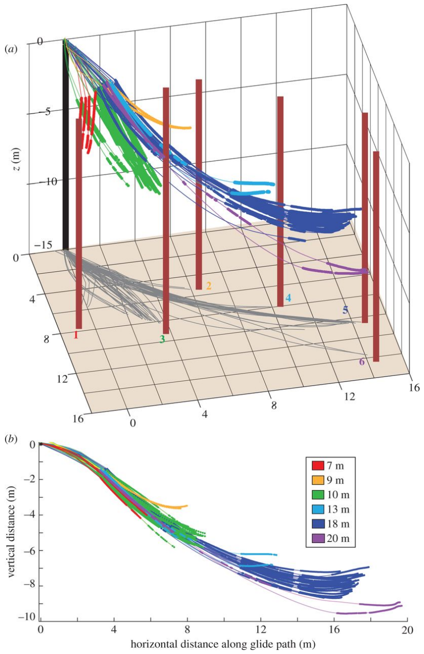

Figure 2: 3-D trajectories of flying squirrels gliding to various distributed target trees. From Bahlman *et al.* (2013).

a distributed airfoil composed of large expanses of webbing between all of its toes.

Gliding arthropods were first discovered in 2005, with the description of gliding in workers of the neotropical ant species *Cephalotes atratus*. Since this initial discovery, gliding has been discovered to be widely distributed across various lineages of wingless insects. These gliders differ in many ways from the vertebrate gliders introduced above, but perhaps most remarkably in that they have no obvious morphological adaptations for gliding. Despite this, *C. atratus* ants achieve glide angles of up to 70°, and are able to use this behavior to return the trunks of nearby trees following a fall from the canopy.

Gliding and size

> You can drop a mouse down a thousand-yard mine shaft; and, on arriving at the bottom, it gets a slight shock and walks away, provided that the ground is fairly soft. A rat is killed, a man is broken, a horse splashes. — J.B.S. Haldane, *On Being the Right Size*

Gliders tend to be small: flying squirrels, gliding snakes, and flying frogs typically weigh less than 100 g. *Draco* lizards weigh less than 20 g. The largest gliders (e.g. colugos, giant flying squirrels) can weigh over 1.5 kg, and in these animals the patagial membranes are quite conspicuous.

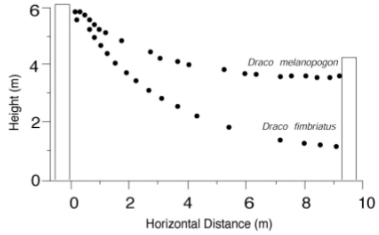

Figure 3: Trajectories for *Draco melanopogon* (2.95 g) and *Draco fimbriatus* (21.6 g), from McGuire and Dudley (2005).

Exercise: Figure 3 shows trajectories for two gliding *Draco* lizards, with the lighter of the two lizard species following a much shallower trajectory. Why do you think glide performance might decrease with increasing body size? What do you think might limit the maximum size for a glider?

Stability and control

Generating lift is not sufficient to make a glider – a glider must also be able to control its lift and remain stable in its descent. Stability and control of maneuverability are critical factors for any glider and, as it turns out, these factors are physically at odds with one another.

Equilibrium requires that that all of the forces acting on a body sum to zero. *Stability* requires that if a perturbation causes the system to leave its equilibrium state, the resultant forces act to return the system to equilibrium. If the system is unstable, the converse is true.

Exercise: You may intuitively, or perhaps based on experience, be aware that maintaining an equilibrium state while standing on top of a surfboard is hard and requires active input to stay upright, but hanging from a parachute requires no active input. Draw a free body diagram for both of these equilibrium situations. Which is stable, and which is unstable? Why?

Stability is not the sole desirable character of gliding performance; many gliders need to be maneuverable as well — and maneuverability requires that the direction of the net aerodynamic force can be modulated through change in posture.

On being a "good" glider

Traditional analyses of gliding performance have focussed on measurement of the lift-to-drag ratio, with "good" gliders featuring a high lift-to-drag ratio and "poor" gliders featuring a low lift-to-drag ratio. This may be at least partially due to an early distinction, made by Oliver, between gliders and parachuters, in which 45° was arbitrarily defined as the cutoff between the two behaviors. Recent analyses of gliding have shown that many gliders continually modulate their lift-to-drag ratio over the course of their descent, and that actual bouts of equilibrium gliding tend to be rare.

While high lift-to-drag ratios are undeniably important for some gliders (Fig 4), for the majority of animal gliders control of direction through maneuvering and modulation of impact forces upon landing may well be more biologically relevant measures of performance.


Figure 4: The gliding seed of the Javan cucumber (*Alsomitra macrocarpa*).