Flight in Birds

from www.ucmp.berkeley.edu/vertebrates/flight/flightintro.html

The Physics of Flight

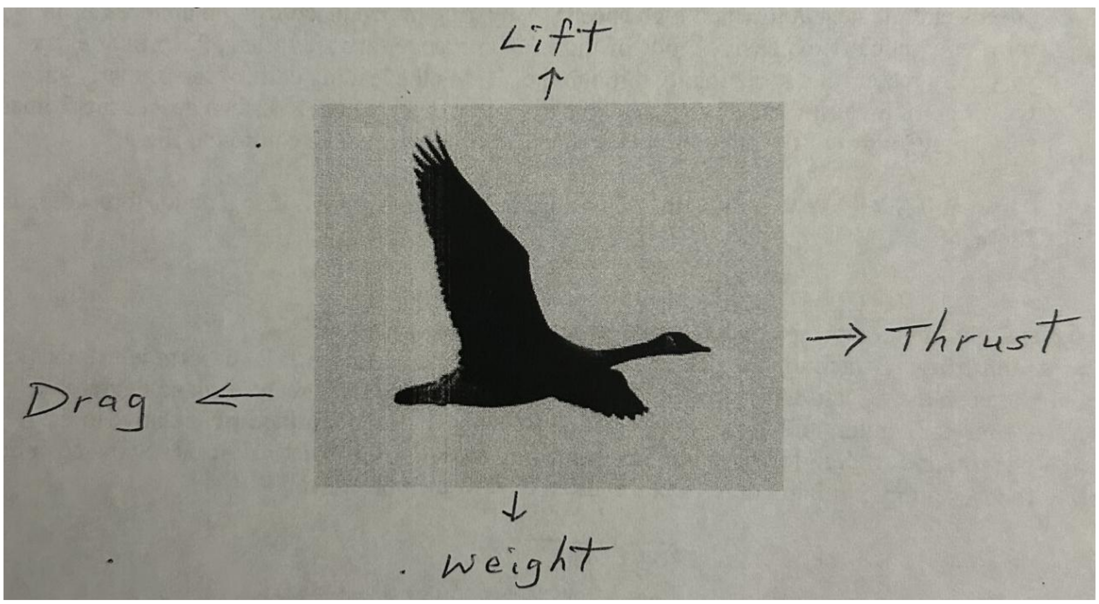
from www.ucmp.berkeley.edu/vertebrates/flight/physics.html

To comprehend the biomechanics of flight, a few simple physical principles must be kept in mind. First of all

What is the basic nature of air?

Air is a **fluid**, just like water. A fluid consists of particles that can flow and move easily, e.g., liquids and gases. Liquid particles are particles that do not separate from each other as easily as gas particles, which do change their relative position to each other more easily. Air is a fluid, but not a liquid, like water, but is called a fluid because the force needed to deform it depends on how fast it is deformed, not how much it is deformed. **Solids** are substances for which the force needed to deform the substance is dependent on the extent of deformation rather than the rate of deformation (so it takes the same amount of force to break a pencil quickly as it does to do it slowly.)

What are the four forces involved and must be in balance with each other in a particular way for sustained flight? i.e., what are the four forces represented in this diagram?



1) What is **Drag?** Drag is a force exerted on an object moving through a fluid, and Drag opposes a bird's movement through the air. Drag is oriented in the direction opposite a bird's flight. Drag occurs when a force opposes the motion of the object. Drag is higher when the surface area of the object exposed to the fluid flow is higher. Drag is higher when the object is moving faster.

a) What is **induced drag?** Induced drag is produced by turbulence of air about the airfoil that disrupts the lift-producing airstream, i.e., wind eddies on the rear edge of the wing and wing tips. Pointed wings generate less induced drag than rounded ones. Induced drag decreases with increasing airspeed.

b) What is **profile drag?** Profile drag is caused by friction between the air and a bird's body and wing surfaces. Thin leading edges of the wings, for example, minimize this form of drag. Long, narrow wings are best for fast-flying birds, because they reduce profile drag.

2) What is **Lift?** Lift is another force exerted on an object moving through a fluid. It is usually directed upward – opposing the weight of the animal that is pulling it down to earth. The angle of the wings against the flow of air – and the shape of the wing - creates a resistance that has the net effect of moving the wing and animal upward. Most of the lift is produced where the wing area is the largest. In particular,

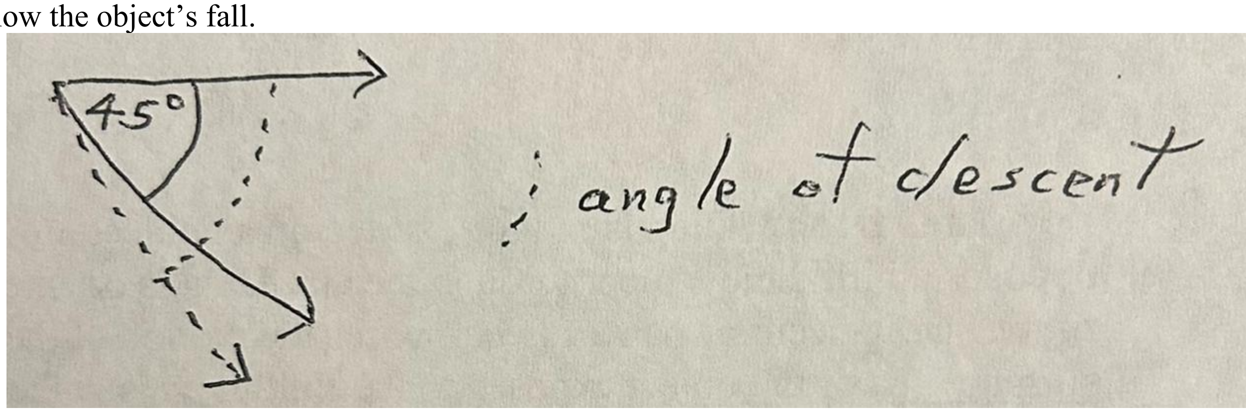
the wing acts as an **airfoil** – an asymmetrically curved structure that tapers posteriorly. Lift results in part from the different speeds at which air flows past the upper and lower surfaces of the airfoil. The speed of the air is faster over the top of the wing (because of its shape) and this causes the pressure on the top part of the wing to be less, resulting in lift. Birds adjust the angle of their wings just before landing to stall. Slots between adjacent flight feathers aid fine control of the air moving over the wing surface - and especially prevent stalling at lower air speeds. The **alula** originates from the first digit – the thumb - and moves independently of the rest of the wing tip. This ensures that the air goes closely over the back of the wing, preventing the bird from stalling.

3) What is **Thrust?** Thrust is the force that is present in true fliers and is produced by powered flight, i.e., wing flapping, especially the downbeat of the wing. Thrust opposes the drag force and is created by flapping the wings. Thrust is a force basically dependent on the **power output** of the flight muscles of the animal. The energy cost of flying is least at intermediate speeds and greatest at low and high speeds. Hovering in one place with no air speed is the most energetically expensive mode of flight. To produce forward thrust , the primaries move vertically rather than horizontally through the air. As the leading edge of the primariy slices the air column during the downstroke, the net pressure on the back surface pushes the feather forward. Control of the angle of attack of each primary results in controlled flight.

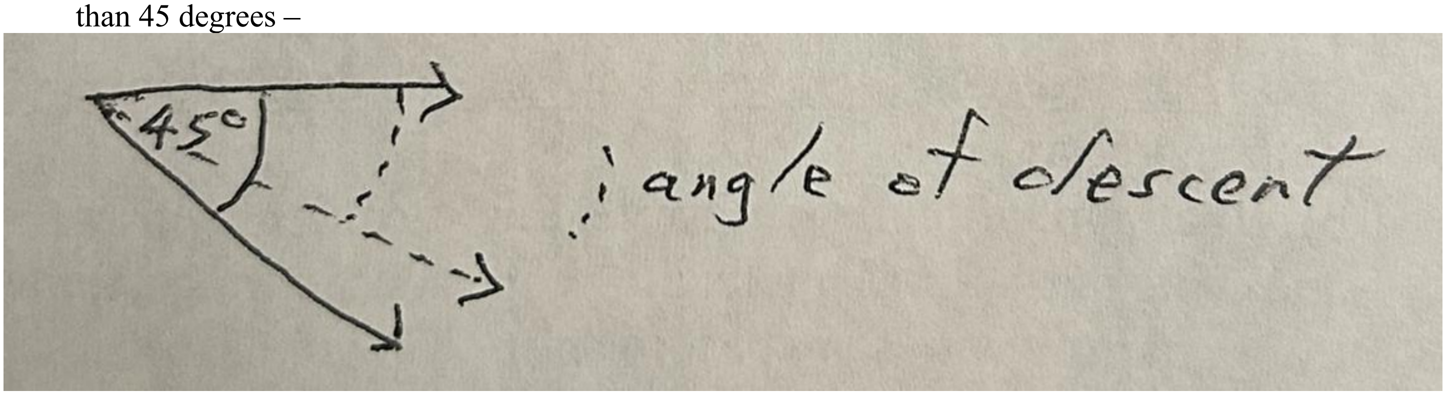
4) What is **Weight?** Weight is the downward pull of gravity and is also a major force affecting flight.

To put flight into perspective, what are the types of aerial locomotion?

1) Parachuting: Parachuting is defined as having an angle of descent, i.e., descent with an angle between the direction of parachuting and the horizontal axis, of greater than 45 degrees. Better parachuters fall more slowly, because they have a lot of surface area relative to their weight, and so drag forces are higher, which slows down the object's descent. So parachuting focuses on maximizing drag forces in order to slow the object's fall.



2) Gliding: Gliding is basically a more elaborate form of parachuting; it is when the angle of descent is less than 45 degrees –



and gliders tend to go longer horizontal distances as a result. Gliding works by having a gliding **airfoil design** that generates **lift forces** and this keeps the animal in the air longer. Streamlining is important in gliders to reduce drag forces. Gliders do not produce thrust; they do not flap their wings. Indeed, a glider might compromise its lift production and fall if it tried to flap.

Will the ratio wing length/wing breadth be higher or lower in gliders relative to flyers? Gliders have a lower **aspect ratio** (wing length/wing breadth) than flyers.

3) Flight: If an animal flaps its wings and moves, then it is **flying**. This is also called assisted aerial motion, or **true powered flight**. Each primary flight feather functions as an airfoil, as can the wing itself. True flyers have more control over their descent – they can flap their wings to produce **thrust** for added speed and lift for added height. True flyers can move horizontally or even ascend at a steady speed, unlike gliders and parachuters. True flight has only evolved three times in the vertebrates – in the pterosaurs, the birds, and bats. Drag forces are minimized for fast flight with a streamlined body. Since drag increases rapidly with flight speed, however, drag will always be limiting.
How can drag be helpful? When a flying animal is trying to slow down or land – so in that case birds spread out their wings. Body weight is critical and must be minimized.
How is Lift generated? By flapping the wings quickly or moving quickly – or by having a large wing area. Note that flyers will also use gliding and parachuting when this behavior is useful to them.
What does a bird need to produce thrust? Large flight muscles. This also means having a **keeled sternum** (breastbone), large **humerus** (upper arm bone), and a modified shoulder girdle. The forearms are more elongated than in gliders, i.e., flyers have a higher **aspect ratio** (wing length/wing breadth) than gliders.

4) Soaring: Soaring animals appear to be only gliding because they don't flap their wings. Soaring is actually very different, and requires specific physiological and morphological adaptations. Soaring uses the energy of the surrounding air (e.g., thermals = rising air) to keep the animal at a constant altitude. It is sometimes described as "falling (walking) down an up escalator." A soaring animal does not flap its wings except to take off or to land, or to make slight adjustments while soaring. Only large animals can efficiently soar. The large pterosaurs and some large birds are the only known animals to soar. Large birds would not be able to sustain true powered flight for very long, since the bird would have to flap its wings too quickly and burn too much energy to keep airborne. Large birds have **low wing loading** – i.e., the weight/wing area ratio is low, i.e. a proportionally larger wing area maximizes lift.

How is the bird skeleton adapted for flight?

- Fusions and reinforcements of lightweight bones make the avian skeleton both powerful and delicate.
- Supports the large muscles needed for flight. A large keel (carina) anchors large flight muscles.
- Cross sections of bird bones reveal light, air-filled structures unlike the dense bones of most terrestrial animals.
- Major bones of the wings are strengthened by internal struts.
- Birds have a lightweight, toothless bill, instead of a bony jaw filled with dense teeth.
- **Uncinate processes** are parts of the skeleton that that extend posteriorly from the vertical upper ribs to hook and overlap the adjacent rib and reinforce the rib cage.
- The partially fused thoracic vertebrae have limited flexibility.
- The **furcula** or "wish bone" or clavicle or collar bones resist the chest-crushing pressures created by the wing strokes during flight. It acts as an elastic spring. It may spread out up to 50% wider in a wing stroke, relative to the normal resting width – and then contract.
- The fused hand and finger bones help provide strength and rigidity in the outer wing skeleton.
- The **alula** originates from the first digit – the thumb, and moves independently of the rest of the wing tip. This ensures that the air goes closely over the back of the wing, preventing the bird from stalling.

What are the two major flight muscles?

Pectoralis muscle is the muscle that pulls the wing down in the power stroke. It is attached to the sternum keel, furcula, and humerus. The pectoralis muscles are larger than the muscles used for the recovery stroke and make up about 15% of the bird's total weight.

Supracoracoideus muscle lifts the wing on the recovery stroke. Pulley-like tendons are involved in this process.

In what bird are the supracoracoideus muscles five times the relative size than in other birds.? (answer: hummingbirds)

What is a major difference <u>in</u> the muscle <u>cells</u> between birds that are good fliers and those that are not?

Red muscle fibers with lots of <u>myoglobin</u> and mitochondria are found in good fliers. Myoglobin is the pigmented protein comparable to hemoglobin that carries oxygen within the muscle cells. Birds that do not fly well have fewer red fibers, less myoglobin, and have muscles that are not as red looking, e.g., a chicken breast versus a duck breast. White muscle fibers are also needed, however, for greater short-term power. Red fibers are not as strong but adapted for endurance. Sparrows have <u>only</u> red muscle fibers in the pectoralis muscles, while hummingbirds have only red muscle fibers in both the pectoralis and supracoracoideus muscles. Grouse have pectoralis muscles consisting mainly of white fibers and account for their ability of an explosive takeoff.

How are the tails of birds different in immature birds of some species, e.g., raptors?

Immature tails are <u>longer</u> and provide more lift. The extra lift apparently reduces the chance of injury when they strike prey and also helps them learn to master the intricacies of flight.

Birds are able to control their wings independently of each other. What is the function of this?

Wing actions that are asymmetrical enable the bird to steer, turn, and twist. For example, flapping with one wing oriented for forward flight and the other wing oriented for backward flight, the bird can make an abrupt turn.