Newtons laws explain how birds fly.

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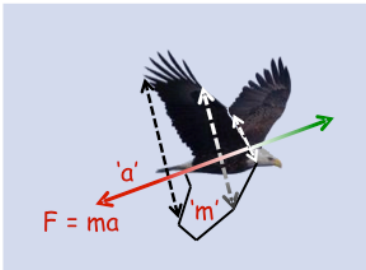
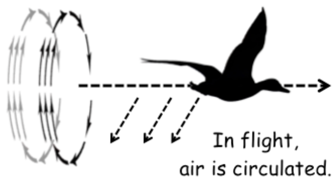
Abstract

Newtons laws of motion explain the physics for how birds fly. Specifically, the mass of air flown through ('m') by the wings is accelerated ('a') back & downwards by the bird. This action generates a force due to Newtons 2nd law of motion (Force = ma). Downward airflows are enhanced by the Coanda effect on the topside of the wings. The 'equal & opposite' forward & upward force created due to according to Newtons 3rd law of motion, provides forward motion & vertical lift. It's simple; air goes down and the bird goes up.

Birds circulate air. The air pushed down with gravity, pushes air up elsewhere against gravity. Birds only need to displace a mass of air downwards equal to their mass, to achieve buoyancy and fly. The physics is similar to how balloons float and helicopters hover.

So what? This analysis provides new insight into flight. In addition, applying Newtons laws to bird flight in this way helps explain why hovering flight is inefficient. This will help physicists to explain how all things fly, biologists to understand bird physiology, and engineers to build micro robotic vehicles. Current theories of bird flight are incomplete or false.





I. Introduction

A. The physics of bird flight are still unproven.

Most scientists appear to support the view that birds fly by pushing air downwards, and that Newtons laws of motion explain the physics involved. But scientists debate exactly how this is done and prefer theories based on flight being explained by vortices. "The only fact we can take for granted is that the mechanism of lift generation is ruled by vortices." [8] There is no scientific experiment in realistic conditions that has proved this to be true.

So, the basic proposition of this paper based on Newtons laws explaining lift is not unique. But no one has previously proposed an explanation of flight that focuses on the mass of air directly accelerated by the wings that generates buoyancy by circulating a mass of air equal to their own mass. This paper is the first to highlight the importance of the Coanda effect on the topside of wings, during the downstroke.

In particular, a key part of this paper's thesis contrasts with the accepted view that lift must equal the weight (mass x gravity) of the bird for it to fly. In turn, the argument for buoyancy is supported by: (i) Experiments on helicopter drones that show that the drone displaces a mass of air down each second at least equal to their own mass. The 'drone in a box' experiment. [10] (ii) The lift paradox, [13] where thrust-to-weight ratios are used to prove mathematically that lift must be less than the weight of the airplane in flight (lift < weight). (iii)

The observation that birds flap their wings more frequently in a hover compared to flight.

It's noteworthy that some pundits prefer theories of lift based on airflows pulling (sucking) the bird upwards. This effect is supposedly caused by air viscosity and low air pressure on top of the wings. [14] In turn, these theories are typically based on Bernoulli's principles of fluid dynamics or Navier-Stokes equations. Again, There is no scientific experiment that has proved this to be true.

B. Vortices.

The airflows around birds' wings include vortices, which this paper considers to be a consequence, not a fundamental or primary cause for lift. Vortices can boost the amount of air displaced down and thus boost lift. Vortices such as leading edge vortices, help explain many bird manoeuvers or wide amplitudes of the wing cycle.

Vortices are complicated. For example, birds and delta wing jets are thought to use leading edge vortices to allow for flight at unusually high angles of attack. Vortices can work both ways, either boosting lift or detracting from lift, depending on the circumstances.

C. The physics of itself lift are still debated.

The theory of lift remains unresolved. [11]

Broadly, there are two competing theories for lift. One camp claims that fluid flow over the topside of the bird sucks (pulls) it upwards. This is usually based on Bernoulli's principles of fluid dynamics, Navier-Stokes or similar complex equations. The other camp claims that lift is the equal and opposite force resulting from the bird pushing air downwards, based on Newtons laws of motion. This is similar to how almost every object generates forward motion.

Strangely, the physics of lift remain debated due to the lack of any conclusive evidence and realistic experiment to support any one theory. It is noteworthy that NASA [1] sits on the fence in this debate, and supports both explanations of lift. But both theories cannot both be correct, as the physics involved are completely different.

Worse, there is no universal theory of flight that easily explains how all animals and objects fly. [11]

II. Newtonian explanation of lift

A. Lift explained by Newtons laws of motion.

The theory of lift based on Newtons laws of motion provides a simple and easy to understand explanation of what is observed in reality. In summary, the bird pushes air down and backwards, the equal & opposite force pushes the bird up.

According to Newtons 2nd law of motion (F = ma), this downward force can be measured; based on a mass of static air ('m') flown through that is accelerated ('a') downwards. This requires the wings to have a positive angle-of-attack (AOA) to the direction of flight. See Fig. 2a and 2b.

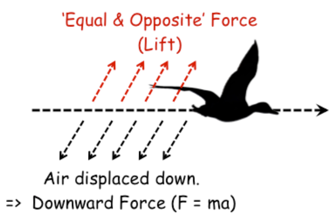


Fig 2b. Newtonian forces in bird flight

As the bird pushes air down and slightly backwards, the upward force is at an angle to the vertical direction. 'Lift' is simply the vertical component of the upward force.

Comparing the wing position at the start and end of the downstroke, it is possible too analyze the area swept by the wing. It is clear under casual observation that most of the mass of air is accelerated by the wings backwards and slightly downwards, often in line with the bird's tail. This implies that most of the bird's effort and energy in flight is used to move forwards, and only relatively little energy is used to generate vertical lift. See Fig. 2a.

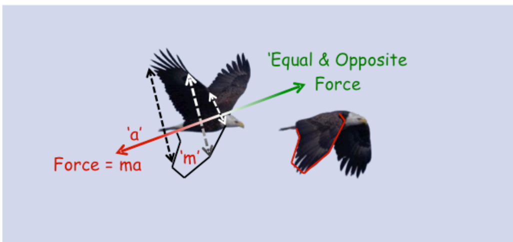


Fig 2b. Downstroke – area covered.

The Newtonian explanation of lift is consistent with the key principles in physics of the conservation of momentum, mass and energy. There is no net gain or loss of momentum, mass or energy. Momentum and energy are transferred from the bird to the air, to generate lift, by pushing the air down.

B. Dynamic and soaring flight.

In soaring flight, birds are simply pushed upwards by a rising mass of air. Here the upward lift force (F = ma) depends on the mass of air ('m') displaced by the wings each second, and the relative acceleration ('a') of the up-current compared to the bird.

In dynamic or gliding flight, birds can displace air down due to the Coanda effect on the topside of the wings and the bird's body.

C. Angle-of-attack (AOA).

Birds flying head-on into the wind will have a relatively low angle-of-attack (AOA) to the wind. This provides minimum resistance to the direction of flight. The wings move and change shape during the wing cycle and their AOA to the wind will vary during the wing cycle. See Fig 2c

Fig 2c. Wing angle of attack

D. The standard equation for lift.[1]

Lift = 0.5 x Velocity^2 x Air Density x Wing Area x Lift Cf.

Newtons laws of motion (F = ma) as applied to bird flight in this paper are consistent with the standard equation for lift. All the parameters of the standard equation for lift (Velocity, Air Density, Wing Area , & Lift Coefficient) affect the mass of air displaced ('m') and/or the velocity to which this air is accelerated ('a') downwards. This is explained in more detail in another paper; 'Newtons laws explain the equation for lift..' [6]

It should not be surprising that Newtons laws of motion can explain the physics of how birds fly.

E. Similar Newtonian explanations of lift in birds.

"To fly, wings impart downward momentum to the surrounding air and obtain lift by reaction. This is Newton´s 3rd Law, which says that action and reaction are equal and opposite to each other. The lift force, which counterbalances the weight, is obtained from Newton´s 2nd Law.

To obtain the downward momentum, we have to know the downward component of the velocity deflected by the wing and the mass flow which is proportional to the air density, the wing area and the downward component of the velocity. This velocity component depends on the flight speed and on the angle of attack. The mass flow due to the deflected wing depends on the wing area, wing curvature, and in birds also on various lift-increasing-manipulations with the feathers.

However, in principle, lift depends primarily on the angle of attack! With the only exception of a hummingbird, birds generate lift and thrust by flapping the wings. This is a complex unsteady and three-dimensional motion of the wings, changing at every instant with the new position of the wings. The aerodynamic analysis of bird flight was usually based on the quasi-steady assumption, according to which all instantaneous forces on a flapping wing in unsteady motion are assumed to be those corresponding to steady motion at the same instantaneous velocity and attitude. This assumption may be misleading (as is definitely the case when dealing with insect flight) and it is recommended to consider even the aerodynamics of the bird flight as unsteady.

….. The only fact we can take for granted is that the mechanism of lift generation is ruled by vortices. The vortices drive in the surrounding air and impart downward momentum to this air ." [8]

F. Similar Newtonian explanations of lift in airplanes.

For reference, this concept of lift based on Newtons laws of motion, is similar to that provided by the book "Understanding Flight." "In the simplest form, lift is generated by the wing diverting air down, creating the downwash." [2]. "From Newton's second law, one can state the relationship between the lift on a wing and its downwash: The lift of a wing is proportional to the amount of air diverted (down) per time times the vertical velocity of that air." [2]. ie. Lift = Downward Force = ma.

The book: "Stick and Rudder" by Wolfgang Langeweische (1944) [3], which is famous among pilots for its accurate, practical and common-sense advice on how to fly a plane well. In Chapter 1 the book states: " The main fact of heavier-than–air-flight is this: the wing keeps the plane up by pushing air down. It shoves air down with the bottom surface, and it pulls air down with the top surface. But the really important thing to understand is that the wing, in whatever fashion, makes air go down. In exerting a downward force on the air, the wing receives an upward counterforce – by the same principle, known as Newton's law of action and reaction, …. " as well as: "That's what keeps a plane up. Newton's law says that if the wing pushes the air down, the air must push the wing up."

III. The Wing Cycle

A. The wing cycle summarized.

The typical bird wing cycle used in flight and a hover, involving a downstroke and an upstroke, displaces air down and backwards overall. This is consistent with the Newtonian explanation of flight. See Fig 3a and 3b.

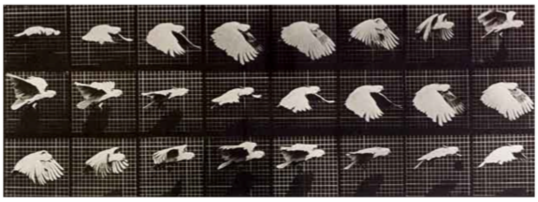


Fig 3a. Photographs of a cockatiel in flight [7]

Fig 3b. Downstroke – side view.

The downstroke and upstroke are two distinct phases of the wing cycle that are analyzed separately.

B. The downstroke.

Fig 3c. Downstroke – side view.

On the downstroke, the wings start above & slightly behind the bird's body, fully outstretched. As the wings descend, they remain fully outstretched and finish slightly in front of the bird's body. This action pushes air down and backwards. The feathers are smooth and overlap to prevent any air passing between them, and maximize the air displaced. During this process, the birds' body rises slightly in the air.

Fig 3d. Downstroke – front view.

C. The upstroke.

Fig 3e. Upstroke – side view.

On the upstroke, as the wings are pulled up, they are draw in close to the birds body. Also, the feathers delaminate and separate slightly, to allow air to pass between them. This avoids displacing air upwards as much as possible, while allowing the birds to raise its wings.

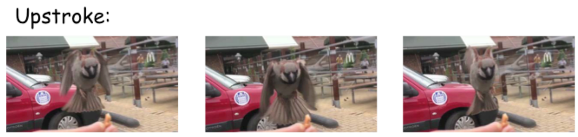


Fig 3f. Upstroke – front view.

D. Two wing airflows.

In flapping forward flight, there are two wing airflows evident on the downstroke:

(i) The underside of the bird's wing directly pushes air down. This causes high air pressure under the wing; due to the force applied directly by the wing (Pressure = Force / Area).

(ii) The curved topside of the bird's wing pulls air downwards due to a vacuum (low air pressure) created above the wing, as the wing moves downwards. Also, the Coanda effect significantly enhances the amount of air displaced down.

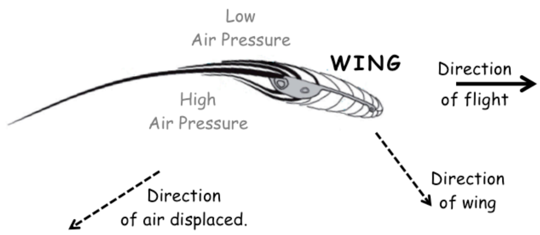


Fig 3g. Wing cross-section on the downstroke.

In a glide, especially against a head wind. The Coanda effect from both the wings and the bird's body, alone can provide sufficient lift by displacing enough air downwards for the bird to remain airborne. See the explanation of the Coanda effect in Section IV.

E. Laminar airflows.

The optimal lift generation occurs when airflow around the wing is laminar (smooth) and non-turbulent. Laminar airflow ensures that the maximum amount of air is displaced down at the greatest acceleration under the circumstances that exist (wing shape, AOA, ……). Turbulence typically arises first at the trailing edge of the wing, as this is usually the longest distance that the upper airflow has travel. So, if separation of airflow occurs (resulting in turbulence), it is usually at the trailing edge of the wing. For this reason, the 'Kutta condition' refers to the maintenance of laminar airflow at the trailing edge of the wing. See Fig 3h.

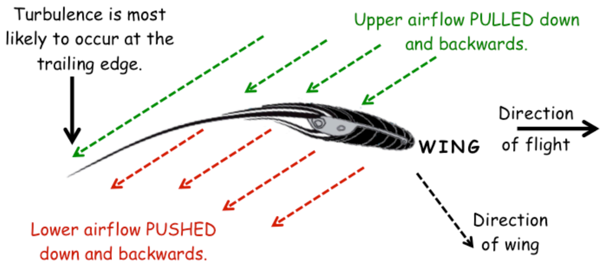


Fig 3h. Airflows in a wing cross-section.

Turbulence is complicated and hard to model and predict. It depends a lot on a variety of factors (e.g. wing shape, AOA, …..) which are often inter-dependent.

F. Birds' muscles.

A bird's muscles used for the downstroke are significantly larger and more developed than the muscles used for the upstroke. This supports the view that air is displaced down & backwards in the downstroke, to generate forward motion and lift.. See Fig 3i.

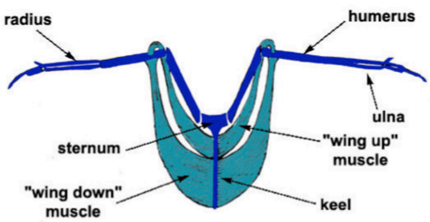


Fig 3i. Diagram of a birds muscles.

G. Wing area and amplitude.

The wings have two basic functions in lift generation; to catch a mass of air ('m'); and then to accelerate ('a') this air downwards to generate a force (F = ma). The wing area and the angles (amplitude) that the wings move through directly affects how much air mass is displaced down. A longer wingspan primarily determines how much air is 'caught' on each wing beat. The wing depth (chord) primarily determines the acceleration of this air.

The wing beats per second also determines the force generated, (the mass of air displaced and how fast this air is accelerated to).

IV. The Coanda effect

The Coanda effect has a significant impact on the physics of lift for birds. Fluid flow (airflow) naturally follows a curved surface due to the Coanda effect. Air flowing around the curved topside of a bird is similar to how falling water is re-directed by a spoon. See Fig 4a.

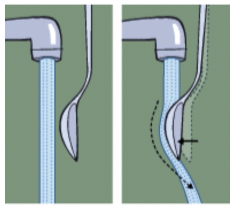


Fig 4a. Falling water being re-directed by a spoon.

The curved shape of birds' wings and bodies boosts the air displaced down. See Fig 4b.

Fig 4b. Curved shape of birds bodies and wings.

As there is a lack of appropriate data and wind tunnel experiments available for birds (with smoke to show airflows), airplane wings are used as a proxy to demonstrate the Coanda effect. See Fig 4c.

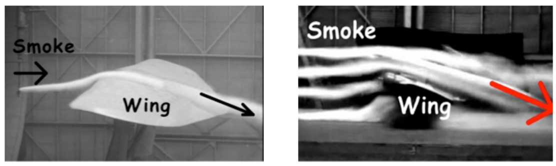


Fig. 4c. The Coanda effect on airplane wings in wind tunnels.

The Coanda effect on airplane wings shows that the amount of air re-directed depends on the maintenance of laminar (smooth) airflow. In turn this depends mostly on the AOA and shape of the wing (or bird). Any turbulence significantly reduces the amount of air displaced. See Fig 4d.

Fig. 4d. Airplane wings in a wind tunnel;
laminar and turbulent airflows.

In general, airplane wings will produce a stronger Coanda effect at lower AOA, at higher aircraft speeds and where the wings are deepest (widest). Conversely the Coanda effect is weakest at high AOA, slow aircraft speeds and where the wings are thinnest (eg. at the wing-tips).

V. Buoyancy in flight

Note: The analysis in this section is the same as provided in the paper 'Newtons laws explain insect flight.' [15]

A. Birds achieve buoyancy.

To fly, the bird has to generate a upward force sufficient to keep its weight in the air. In flight, the downward force will at least equal the weight of the air pushed down. The downward force has nowhere else to go, but to displace air down and to the sides. But air pushed to horizontally sideways will not generate any vertical lift. It will be an inefficient use of force and energy.

Birds are circulating the air in flight. Air pushed down causes air elsewhere to be pushed up; Due to the principle of conservation of mass. See Fig 5a.

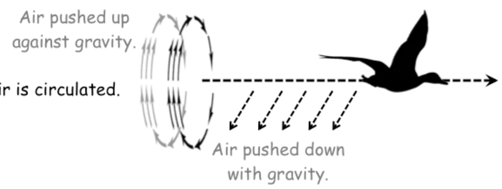


Fig 5a. Bird in flight circulating the air.

The weight (and mass) of the air pushed down with gravity, will equal the weight (and mass) of the air pushed up elsewhere against gravity. This means that the air pushed up, provides resistance to the bird pushing air down. This process is similar to how a swimmer treads water (by circulating the water). See Fig 5b.

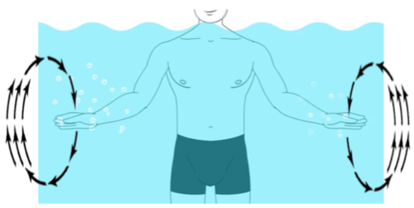


Fig 5b. Swimmer treading water.

The physics described above is summarized by the equations:

$$\text{Downward Force } (F = ma) = \text{Upward Force (lift)}$$
$$\Rightarrow \text{Weight}_{\text{AIR PUSHED DOWN}} = \text{Weight}_{\text{BIRD PUSHED UP}}$$
$$\Rightarrow \text{Mass}_{\text{AIR DOWN}} \times \text{Gravity} = \text{Mass}_{\text{BIRD UP}} \times \text{Gravity}$$
$$\Rightarrow \text{Mass}_{\text{TOTAL AIR PUSHED DOWN}} = \text{Mass}_{\text{BIRD PUSHED UP}}$$

Note that:
- Weight = Mass x Gravity [1]

As birds are circulating the air, so gravity cancels out of the equations above, which simplify to: The mass of the air displaced down, must equal the mass of the bird pushed up; for the bird to generate a sufficient force fly. i.e. The bird achieves buoyancy.

Birds are unlikely to be 100% efficient at displacing air down. Therefore birds will probably need to displace a mass of air down that slightly exceeds their own mass.

This explanation and analysis is consistent with experiments on helicopter drones (quadcopters) in a hover. [10] Experiments demonstrated that a helicopter drone in a hover displaces a mass of air downwards each second, that slightly exceeded its mass. This was confirmed by measuring the velocity of the downwash under the rotors. Like birds in a hover, the helicopter drone circulates the air. The weight (and mass) of air displaced downwards each second, equals the weight (and mass) of air displaced up. See Fig 5c.

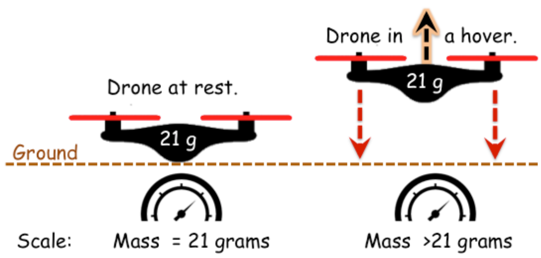


Fig 5c. Helicopter drone (quadcopter) at rest and in a hover.

B. Little force is required to fly.

In short, this analysis on buoyancy and the amount of air displaced down, supports the view that it takes relatively little effort (force & energy) for a bird to fly, as it only needs to displace a mass of air equal to its mass, not its weight (mass x gravity). This physics is not what is taught at schools.

C. Total mass of air displaced.

The air directly flown through ('m') and accelerated down ('a'); indirectly displaces more air. The total mass of air displaced includes the air directly & indirectly displaced. It is important to differentiate between the small mass of air that the bird flies through and directly accelerates with its wings; And the total mass of air that the bird's wings displace.

Total Mass of Air Displaced = Air directly Displaced + Air Indirectly Displaced.

D. Static & dynamic buoyancy.

This analysis describes the same physics that explains how balloons float in the air. Except a static balloon passively displaces air down to achieve static buoyancy and float in the air. A bird actively displaces air down to achieve dynamic buoyancy to float in the air. See Fig 5d.

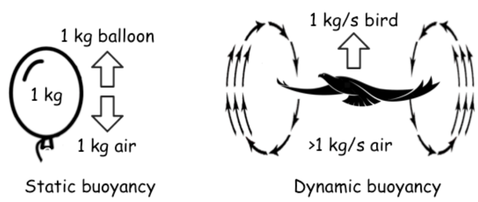


Fig 5d. Static and dynamic buoyancy.

VI. Hovering is inefficient

Note: The analysis in this section is the same as provided in the paper 'Newtons laws explain insect flight.' [15]

A. 'U' shaped power curve.

Birds are least efficient at generating lift at relatively slow or fast speeds. "Aerodynamic theory predicts that the power required for an animal to fly over a range of speeds is represented by a 'U'-shaped curve, with the greatest power required at the slowest and fastest speeds, and minimum power at an intermediate speed." [9] See Fig 6a.

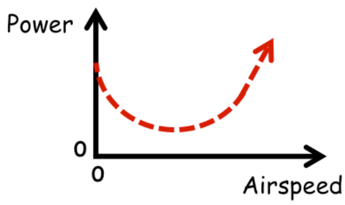


Fig 6a. Typical power – velocity profile of bird flight.

B. Why hovering is inefficient.

At first glance it is strange that birds use more power (force and energy) in a hover compared to when in flight. This implies that hovering is inefficient compared to cruise flight.

This is consistent with helicopters that have a high fuel burn in a hover compared to normal cruise flight. [12] This is also similar to a Harrier and F-35 VTOL jets, which are rumored to use at least twice as much fuel each second in an out-of-ground hover, compared to normal cruise flight.

This appears illogical because in flight fuel is needed to both generate lift to fly and to move forward. So how can fuel burn be higher in a hover if lift equals the weight of the bird, helicopter or airplane?

The explanation is that in a hover the birds are pushing air down on to itself, to circulate the air. This makes it hard to generate sufficient 'equal and opposite' upward force. It's like running on a vertical treadmill.

Whereas in cruise flight, the birds are constantly moving forwards into static (undisturbed) air. This static air is easier to push down and generate a sufficient 'equal & opposite' upward force. See Fig 6b.

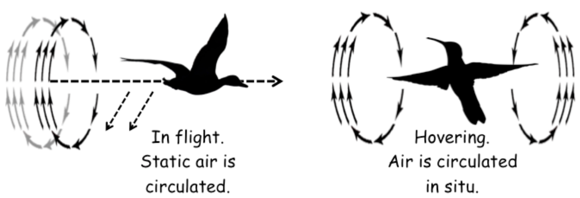


Fig 6b. Flight and hovering compared.

C. Mass flow rate.

Note that the 'mass flow rate' is the amount of air that the bird's wings come into contact with each wing beat. This is the mass of air that is accelerated downwards. The mass flow rate is derived from Newtons 2nd law of motion (F = ma):

Force = ma = m x dv/dt = m/dt x dv

Where:
'm' is the mass of air directly accelerated down by the wings.
'a' = dv/dt (acceleration)
'dv' is the change in velocity.
'dt' is the change in time (seconds).
'm/dt' is the mass flow rate; The mass of air directly accelerated down by the wings each second.

To put it another way, there are two issues that help explain why hovering is inefficient:

(i) In a hover, air is constantly moving (displaced down and circulated) by the bird; and the wings are constantly trying to maintain this circular airflow. So, in a hover the bird's wings come into contact with less air mass on each wing beat, compared to normal cruise flight. So the mass flow rate is lower overall.

(ii) In a hover, the air around the bird's wings is already moving downwards at a given velocity; the air is not static. So the wings have to use more power (beat faster and/or more aggressively), to accelerate the moving air down, to generate a sufficient downward force (F = ma); and in turn create a big enough 'equal & opposite upward force, to enable the bird to hover.

D. Lift = Mass (not weight).

The explanation for the physics of a hover above is consistent with birds, airplanes and helicopters only needing to achieve buoyancy to fly. Here the force for lift only needs to equal the mass of the object in flight, not its weight (mass x gravity).

There is a very big difference between these two concepts; whether lift must equal the object's mass or its weight. Given that gravity is about 9.8 m/s^2, then the difference between mass and weight is equal to a factor of almost 10x.

VII. Example calculation Framework

A. Overview.

It should be possible to perform calculations that show that it is feasible for a bird to generate a sufficient lift force to fly or hover, based on Newtons laws of motion (F = ma). Albeit, with some difficulty.

It was not possible to find reliable data to do these calculations for a specific bird for this paper. In particular, there is no data available of how fast birds accelerate air downwards. A lot of research in this area is on birds flying in a wind tunnel, not in a hover. Where experimentation has been done, there is a lack of data on the wing area of birds which is essential to estimate the mass of air displaced down.

In addition, exact calculations are difficult to complete as bird wings have a non-geometric shapes and morph a lot during flight. For example see fig 7a.

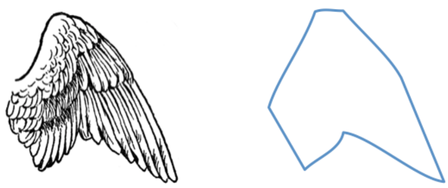


Fig 7a. Bird wing.

As a result, calculations here are limited to providing a methodology and framework for these calculations.

It is worth noting that experiments have been done on helicopter drones that demonstrate that a helicopter achieves buoyancy in a hover. [10]

B. Data and assumptions.

Data and assumptions:

- A adult house sparrow with a 30 g mass.
- Each wing has a 25 cm wingspan and xx cm wing depth (chord).
- 75 cm^2 total wing area.
- The wings pass each wing cycle, at an angle of xx°.
- On each wing cycle the wings cover a distance of xx mm.
- xx wing cycles a second.
- Standard air density of 1.2 kg/m^3 (0.0012 g/cm^3).
- The bird is 100% efficient at generating lift. That all the air displaced down is converted into lift.

It is assumed that the upstroke displaces a mass of air upwards that is 20% of the downstroke. This 20% is simply a guess at this stage based on intuition and analysis of the wing cycle from slow motion videos of birds in a hover. The actual figure requires some detailed research and experimentation to calculate accurately.

So, the downstroke must displace a mass of air that is 120% of the birds mass for this Newtonian theory of flight to be correct. For the 30 g sparrow in this example, 36 g (36g = 1.2 x 30g) of air must be displaced of the sparrow to fly.

C. Methodology.

The net mass of air displaced downward by the bird in a hover is estimated and then compared to the mass of the bird. This is the mass of air net of the downstroke and upstroke.

Taking a hypothetical adult male house sparrow with a 30 g mass, where each wing was 25 cm wingspan and a 75 cm^2 total wing area.

The net mass of air displaced in a hover is estimated using:

1. The volume of air displaced during one wing cycle; based on the total wing area, wingspan, wing depth (chord), angle of movement of the wings.

If on each wing cycle, the sparrow flaps its wings through an angle of 110°, it will displace a volume of air of xx cm^3 on each downstroke of the wing cycle. See Fig 7b.

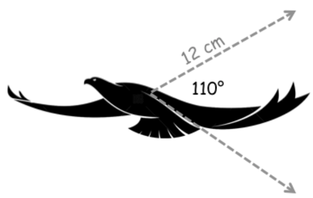


Fig 7b. Volume of air displaced.

2. The number of wing cycles each second.

   If the sparrow flaps its wings 10 times each second in a hover, and displaces xx cm^3 on each flap; then this is xx cm^3/s of air displaced down.

   xx cm^3/s = 10 wing cycles/s x xx cm^3 per wing cycle

3. The standard air density is used to convert volume of air displaced each second, to the mass of air displaced each second.

   xx g/s = xx cm^3/s x 0.0012 g/cm^3

4. Then the mass of air displaced each second ('m/dt') is compared to the mass of the bird; to provide the acceleration of the air ('a') required to achieve buoyancy (displace a total mass of air the equals the bird's mass).

   This air mass only needs to be accelerated down at an average velocity of about xx cm/s (about xx km/hr); to displace a total mass of air of 36 g/s, which is equal to the birds mass, to achieve buoyancy and fly.

   36 g cm/s^2 = xx g/s x xx cm/s
   = 36 N
   (which will accelerate 36 g mass at 1 cm/s^2)

5. Then the data is reviewed for reasonableness. Is it feasible that the bird achieves buoyancy?

D.Summary.

In summary, the downward force (F = ma) is sufficient to displace a total mass of air (directly and indirectly) down each second, that equals the mass of the bird. A critical uncertainty for which there is limited data, is the velocity at which the bird accelerates the air downwards.

VIII. Discussion of Results

This analysis provides significant into how birds fly that has not been provided previously. It should not be surprising that Newtons laws of motion can explain how a birds fly. This helps to resolve the debate regarding the physics of lift.

Applying Newtons laws of motion to flight allows the application of the standard equation for kinetic energy, to estimate the kinetic energy used by a bird to fly:

$$\text{Kinetic Energy} = 0.5\, mv^2 \quad [1]$$

Where:
m = Mass of air displaced.
v = Velocity of the air displaced.

IX. Conclusions

Newtons laws of motion explain the physics of how a bird flies. In particular, Lift (Force = ma) is equal to the mass of air displaced ('m') and the velocity to which this air is accelerated ('a'). This Newtonian explanation for flight fits best with what is observed in reality. In particular, this theory provides insight as to exactly why hovering flight is inefficient.

This paper helps provide a universal theory of flight for all objects and animals, based on Newtons laws of motion.

As buoyancy determines whether a bird can float in the air, then the force required to fly only needs to be enough to circulate a mass of the bird. Lift does not need to equal the bird's weight (mass x gravity). There is a very big difference between these two concepts, given that gravity is about 9.8 m/s^2. The difference between mass and weight is equal to a factor of almost 10x.

It should be possible to perform calculations that confirm that it is feasible for a birds in a hover to displace a mass of air downwards each second, that is equal to its mass.

X. Additional Information

Website: Short explanatory video on birds.

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