PLANES AND BIRDS: MINIMIZING ENERGY

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Introduction

Technology advancements in nature's flyers and in aircraft include by necessity multiple sequenced developments – weight-reducing, power-increasing, and aerodynamic adaptations.

The "survival of the fittest" selection process for nature implies that each subsystem is in itself an optimum solution within the confines of the overall optimized system.

Expanded view of the evolution of flight:

VFD (Visual Flight Dynamics – birds, seeds & bugs)

KFD (Knowledge of Flight Dynamics)

UFD (Understanding Flight Dynamics)

Early flight concepts & attempts

Mathematicians

Wright Brothers initial flights:

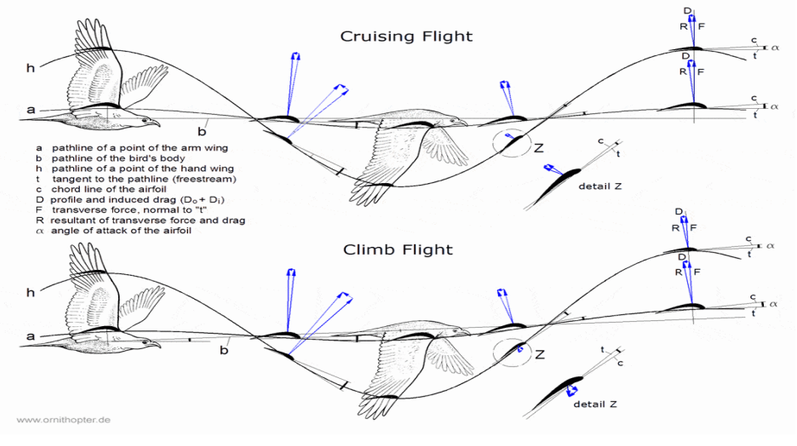
Pettigrew, 1874;

Lilienthal, 1889;

Chanute, 1894;

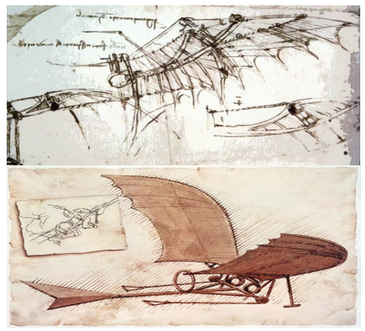
Moedebeck, 1903

Bernoulli's principle states the faster moving air reduces the air pressure over the top wing surface, lifting the wings.

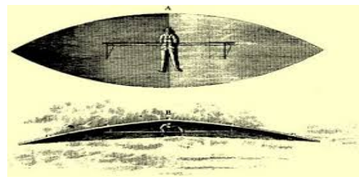


History of Flight

Man's concepts of the nature and the physics of avian flight gradually developed from endless hours of observing the flight of birds over centuries of time. The main concern will always be the optimization of energy use during flight.

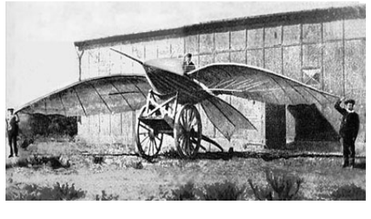


1. Leonardo Da Vinci's well-known sketches of bird flight from about 1500 also show his interpretation of the characteristics of the flow around the bird as well as how a bird was able to control its flight path.



2. Carl Meerwein was the first to estimate the size of a wing surface necessary to support the weight of a man using as a basis, the weight and corresponding wing area of ducks in 1789.

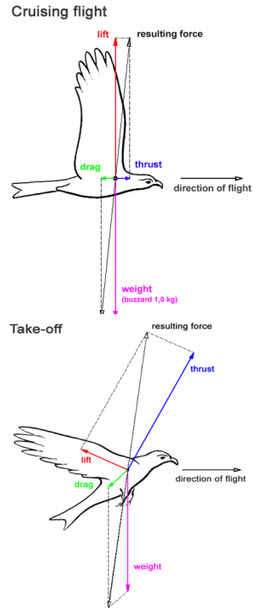
3. George Cayley designed the earliest known idea for flight with fixed wing geometry as in today's airplanes in 1799 aircraft.



4. Le Bris built a glider which was inspired by the shape of the albatross. The glider consisted of a wood frame and was covered in cloth. This invention, which he patented in 1857 was the first flight control concept.

5. Chanute-Herring biplane concept became mentor of the Wright brothers, in 1896.

Important Equations



1. Find out what speed will minimize the power required to propel a fixed-wing aircraft forward: $P = Av^3 + \frac{BL^2}{v}$

Where P is power, A and B are constants specific to the aircraft, and L is lift. In reality, L is proportional to v, according to Bernoulli's principle. Differentiating, we have:

$$v = \sqrt[4]{\frac{BL^2}{3A}}$$

2. We can find the optimal speed for minimizing energy consumption given the equation: $E = \frac{P}{v}$

By substitution: $v = \sqrt[4]{\frac{BL^2}{A}}$

3. To apply this equation to bird flight, we split it into two parts:

P_{flap} for the bird's body and P_{fold} for its wings. We designate the power needed over an entire flight cycle as:

$$\overline{P} = x P_{flap} + (1-x) P_{fold} = A_b v^3 + x A_w v^3 + \frac{Bm^2 g^2}{xv}$$

To find the optimal time a bird should spend flapping, differentiate and find the minimum.

4. Value of x which minimizes P would be: $x = \sqrt{\frac{Bm^2 g^2}{A_w v^4}}$

Therefore, we can conclude that the faster the bird is flying, the less time it should spend in the flapping phase.

5. If the average energy over a cycle is $\overline{E} = \frac{\overline{P}}{v}$, then the value of x which minimizes E would be: $x = \sqrt{\frac{Bm^2 g^2}{A_w v^4}}$

References

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James Stewart *"Calculus: Early Transcendentals."* Eighth Edition, *Cengage Learning, 2015*.