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A4_4_Getting into a flap

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Abstract
Mankind has strived to achieve flight for millennia. This report explores the logistics of flying using only the hands for propulsion. It is hypothesised that simply twisting of the hand and flapping is enough to achieve the necessary net movement of air. It is found that the arms would have to flap at a frequency of 223Hz in order to maintain flight. A lower limit to the required power is calculated to be 1.3kW.

Introduction

Since the dawn of time man has struggled to achieve flight, with popular accounts such as that of Icarus dotted throughout history.

This report explores the requirements for a person to fly using only their arms and hands.

Discussion

The first point to consider is the force due to gravity which must be overcome in order for the person to float. This force F_w is simply the weight of the body and is given by

$$F_w = Mg, \quad (1)$$

where M is the mass of the body and g is the acceleration due to gravity.

The motion of the arm should now be considered. Whilst moving down it will displace a specific volume of air, imparting momentum onto said air. Whilst returning to its initial position it will again displace a similar volume or air. By twisting the hand 90° on the return stroke a net displacement downward can be achieved. According to Newton's third law an equal reaction will then be experienced by the body, propelling it upward. As the change in area of the actual arm due to twisting of the hand is negligible, this contribution to the force will cancel with each stroke and thus can be ignored.

This net displacement can be found by considering the surface area of the face of the hand relative to the side of the hand. A simple and reasonable approximation would be to say that the area of the face of the hand is approximately five times greater than the area of the side of the hand. From Bernouilli's equation [1] the pressure exerted ΔP is found to be

$$\Delta P = \frac{1}{2}\rho v^2, \quad (2)$$

where ρ is the density of air and v is the hand's velocity. As the pressure is the force exerted over the area of the hand A, the force $F_\uparrow$ experienced pushing the body upward is given by

$$F_\uparrow = \frac{1}{2}\rho A v^2 \ . \quad (3)$$

The downward force $F_\downarrow$ is found by the same method calculated with a fifth of the area, resulting in

$$F_\downarrow = \frac{1}{2}\rho \frac{A}{5} v^2 = \frac{1}{10}\rho A v^2. \quad (4)$$

The average force over time F_{av} due to the up and down movement of the hand is then given by

$$F_{av} = \frac{F_\downarrow - F_\uparrow}{2} = \frac{\frac{1}{2}\rho A v^2 - \frac{1}{10}\rho A v^2}{2} = \frac{1}{5}\rho A v_{av}^2, \quad (5)$$

where v_{av} is the average velocity.

The combined effect of two hands producing this force must overcome the force acting on the body due to gravity, as described by equation 1. Equating these components as shown in

$$Mg = \frac{2}{5}\rho A v_{av}^2 \, , \qquad (6)$$

before rearranging for v_{av} shows the necessary velocity, as described by

$$v_{av} = \sqrt{\frac{5Mg}{2\rho A}}. \qquad (7)$$

By considering the distance *D* as half the total distance over which the hand must travel at this velocity, the resulting period taken *T* is then given by

$$T = \frac{2D}{v_{av}} \, . \qquad (8)$$

As frequency is the inverse of period, this finally provides the frequency of flap f_{flap} which the person must perform, as described by

$$f_{flap} = \frac{1}{T} = \frac{v_{av}}{2D} = \sqrt{\frac{5Mg}{8\rho A D^2}} \, . \qquad (9)$$

By estimating the mass of the person to be 60kg, estimating the face of their hand to have an area of 150cm^2 and the range of motion of their arm to be 70cm results in a frequency estimate of 223Hz. Using these same values with equation 7, the average velocity required to achieve this frequency is found to be 156ms^{-1}.

An expression for the resulting power *P* can also be obtained by simply finding the product of the average velocity of the hand and the average force it is experiencing, as shown by

$$P = \frac{1}{5}\rho A v_{av}^2 * v_{av} = \frac{1}{5}\sqrt{\rho A}\left[\frac{5Mg}{2}\right]^{\frac{3}{2}} . \qquad (10)$$

In order to find a lower limit to the power, the arm is approximated as a thin rod with negligible mass and area. Hence, the power required for motion of the arm is zero. Once again using the same values as for the previous estimates a value for the average power required to move the hand is found to be 1.3kW.

Conclusion

In conclusion, a calculation has been made to determine the mechanics of generating lift using only the body. It has been shown that flying without wings is dependent on flapping of the arms at a frequency of 223Hz. This is considerably greater than the frequency at which a hummingbird flaps it's wings, which has been observed at around 50Hz [2]. This is not a viable proposition. Further, a lower limit to the required power output has been found to be 1.3kW.

References

[1*] http://www.princeton.edu/~asmits/ Bicycle_web/Bernoulli.html*, accessed on the 6th November

[2] T. L. Hendrick, "Morphological and kinematic basis of the hummingbird flight stroke: scaling of flight muscle transmission ratio", 2011