Journal of Special Topics

P1_3 The Aerodynamics of Pterodactyl Flight

R.A Boadle, E Wigfield, A.S Dulay
Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH.
October 22, 2009

Abstract
This article discusses the aerodynamic feasibility of pterodactyl flight. The different situations of gliding and flapping are covered, and the perils of a stalling wing introduced. It is concluded that, assuming a similar build to a modern wandering albatross, the pterodactyl could have glided through the air if the relative wind speed was greater than 14.1ms^{-1}, but based on the article's assumptions, would have fallen if required to flap its wings in a gentle wind.

Introduction

The behaviour of dinosaurs is an area of much contention amongst palaeontologists, given that in many cases fossils have been found which could support several different theories. In 2008 Prof. Katsufumi Sato presented a study into the flight of large birds, concluding that pterodactyls were too heavy to fly [1]. Naturally many people were unwilling to accept this claim.

The shape of a pterodactyl, with its long but narrow wings, is reminiscent of a modern day wandering albatross, a comparison used by Sato in his work. Large birds often fly long distances using dynamic soaring, a form of gliding where the bird changes direction repeatedly in order to stay airborne. However, when the wind drops off the bird must flap its wings otherwise it will be dragged downwards by its own weight. This article seeks to assess whether a large pterodactyl would have been able to support itself in the air, both through gliding and flapping.

Gliding

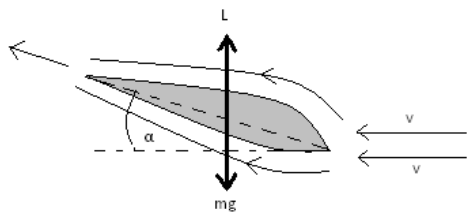

Figure 1: Forces on a wing

This model assumes a rigid wing, in a frame of reference where the wing is stationary and the air moves around it (see figure 1). The vertical forces acting upon it are lift, *L*, and the weight *mg*. The horizontal forces of thrust and induced drag are included in the velocity of the air *v*, so only the vertical forces are considered here. Lift is generated to air velocity differences as it flows around the asymmetric wing; it is strongly dependent upon the velocity of the air and the angle of attack α. From aerodynamic theory there is a critical angle of attack, α_c, [2] (0.26rads for air), above which the air detaches from the wing creating turbulent motion known as 'stalling'. This decreases the amount of lift generated by the wing; the maximum lift is produced when $\alpha = \alpha_c$. To remain airborne, the pterodactyl's wings must produce a minimum lift given by:

$$L = mg,$$

$$\frac{1}{2} C_L A_w \rho v^2 = mg \quad (1)$$

where C_L is the coefficient of lift, A_w is the wing area, ρ is the density of air, v the velocity of the air over the wing, m the mass of the pterodactyl and g the acceleration due to gravity. Substituting the appropriate equation for C_L for a bird shaped wing, valid only when $\alpha \leq \alpha_c$, [2] into (1), the mass of a pterodactyl that could be supported by such wings can be calculated:

$$m = \frac{\left(\frac{2\pi\alpha}{\left(1 + {}^{2}/_{AR}\right)}\right) A_w \rho v^2}{2g} = 781kg \quad (2)$$

where the aspect ratio, *AR,* is defined by $AR = (wing\ span)^2/wing\ area$ and assuming that the pterodactyl had a wing span of 15m [1] with an aspect ratio equivalent to a wandering albatross of 16 [3], the wing area is 14.06m^2. The velocity *v* was assumed to match the albatross's average cruising speed of $25ms^{-1}$ [4], α was the critical angle, α_c, of 0.26rads, the density of air ρ=$1.2kgm^{-3}$ and g=$9.81ms^{-2}$. Given that the largest pterodactyls are estimated at 250kg, from the above calculation it seems feasible that they could have glided easily. However, this assumed a large relative air velocity of $25ms^{-1}$, given a mass of 250kg, working back from (2) the minimum relative air velocity must be at least $14.1ms^{-1}$ for the pterodactyl to remain airborne.

Flapping

When the wind dies down the pterodactyl would need to support itself in the air by flapping its wings, generating lift only on the down stroke. The previous calculations assumed that none of the wing would make an angle greater than the critical angle with the air flow; this is valid given a perfectly rigid wing. Birds (including this model pterodactyl) rotate their wings at the shoulder to flap meaning that the angle of attack along the length of the wing is a minimum at the shoulder and a maximum at the wing tip. A recent study [5] showed that most birds have a Strouhal number, σ, a dimensionless number relating the amplitude of wing strokes, their frequency and the forward speed, of 0.2. If the wing moves up and down with a speed of $2A_0f$ (where A_0 is the amplitude of each stroke and f their frequency), and $\sigma = 0.2$, then the angle the wing tip makes with the air flow is:

$$\theta = tan^{-1}\left(\frac{2A_0f}{v}\right) = tan^{-1}(2\sigma) = 0.38rads \quad (3)$$

where $\sigma = A_0f/v$ and v is the forward velocity. This is larger than the critical angle ($\alpha_c = 0.26rads$), so lift would be lost as the wing tip stalls. To compensate, most birds angle their bodies when flapping their wings; this increases the angle of attack on the down stroke and decreases the angle on the upstroke safeguarding against stalling.

From a reformulation of the left hand side of (1) to include the up and down strokes (assuming the wing is once again rigid), the mean lift generated by flapping is

$$Mean\ Lift, L_M = {}^1/_4\, C_L(\beta)A_w\rho v^2 \ < \ mg \quad (4)$$

where $C_L(\beta)$ is the coefficient of lift with the same form as used in (2) but with β, the angle the body (not the wing) makes with the oncoming air flow, replacing α. Given that the relative air velocity is now assumed to be below the minimum needed for the pterodactyl to glide, the amount of lift provided by the flapping wings is not sufficient to hold it in the air.

Conclusion

This article has discussed the lift that a pterodactyl could generate through gliding and flapping, comparing these to the minimum necessary levels. The effect of stalling on the lift has been presented and the solution incorporated into the flapping problem. It is found that whilst the pterodactyl would easily glide at relative wind speeds in excess of $14.1ms^{-1}$, it would not have been able to support itself whilst flapping in less ideal wind conditions. These calculations seem to support theories that any flight ability pterodactyls may have had was extremely dependent upon the wind conditions. This model assumed similar physical characteristics to the modern wandering albatross; pterodactyls may have had different physiologies allowing them to fly. For example, they may have been able to generate the necessary minimum relative wind speeds by building up momentum whilst on the ground, or could have used thermal air currents not considered here. In addition, this article has assumed that atmospheric conditions during the Cretaceous were similar to modern conditions, higher wind speeds or air density could have made it easier for pterodactyls to fly.

References

[1] R Alleyne, *Pterodactyls were too heavy to fly, scientist claims,* The Telegraph, 01/10/2008
[2] JO Linton, *The Physics of Flight: II. Flapping Wings,* Physics Ed. 42(4) pp358-364
[3] M Denny, *Dynamic Soaring: Aerodynamics for Albatrosses,* Eur. J. Phys. 30(2009) pp 75-84
[4] http://www.sailnet.com/forums/seamanship-articles/19247-amazing-albatross.html
[5] GK Taylor, RL Nudds, ALR Thomas, *Flying and Swimming Animals…,* Nature 425 pp707-11