Journal of Physics Special Topics

A2_5 Rotation Aviation

J. A. Farrow, J. Hue, R. Miller and C. Checklin

Department of Physics and Astronomy, University of Leicester. Leicester, LE1 7RH.

November 13, 2014.

Abstract
This paper investigates the feasibility of an aircraft flying using the Magnus effect by replacing its conventional wings with cylindrical wings that rotate. It is found that if the wings were to maintain roughly their current size, the minimum angular frequency required to create enough lift at take-off is 37.69 rad/s and at cruising speed is 8.58 rad/s.

Introduction

The Magnus effect is the effect often seen in which a spinning ball (such as a football) curves away from its original trajectory. This effect also occurs when a cylinder spins while moving through a liquid and has already been used to create motion in rotor ships. People have also tried to capitalise on the Magnus effect to create flying machines such as the Fettner aeroplane. Although there is a record of at least one of these such aeroplanes being built, there is no evidence that it has ever flown. [1] This paper looks at the feasibility of creating a commercial aircraft that utilises this effect and the rate at which the the cylinders would have to rotate in order to attain and maintain flight.

Discussion

As a cylinder rotates while moving through the air it also spins a boundary layer of air which clings to the surface. On one side of the cylinder the boundary layer will be spinning in the opposite direction to movement so the air will collide with the boundary layer and cause a deceleration. This creates a high-pressure area on one side of the cylinder. On the other side the boundary layer will be moving in the same direction as motion causing the air to collectively move faster. This leads to a low-pressure area creating a pressure differential across the cylinder which produces a lift force (as seen in Fig.1 as Magnus force). This causes the cylinder to move in the direction of the pressure differential and is known as Kutta-Joukowski lift.

In order to determine whether it is possible for this force to be used to enable a plane to fly instead of using conventional aerofoils we take the aircraft in question to be of the same size and weight as a Boeing 757-200. For this type of aircraft its maximum take-off weight is 115680kg, its wingspan is 38.05m, and its body is 3.7m wide. [5] Using these values we take the cylinders used to have the same total length as the wings which is 34.35m and we assume that the mass of the cylinders would be the same as that of the conventional wings meaning that the total mass remained the same, although this would actually change as the radius of the cylinder changed. In order to aid comparisons later, the average width of the conventional wing was calculated by taking the total wing area of 185.3m^2 [3] and dividing by the wing length, as calculated earlier of 34.35m, to get an average width of 2.70m. Therefore we will use the radius of our cylinders to be half of this, 1.35m.

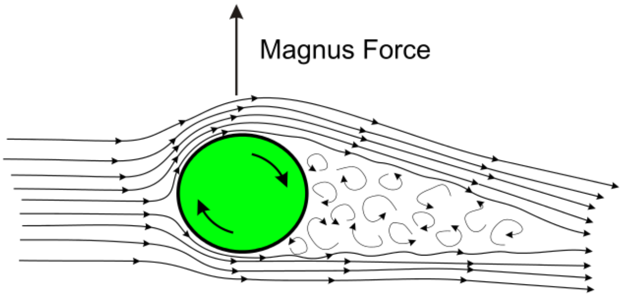

Fig. 1: Diagram illustrating the Magnus effect. [2]

The lift generated by a revolving cylinder can be calculated by [2],

$$F = \rho v G L, \tag{1}$$

where; ρ is the density of the fluid, in this case air taken to be 1.225 kg/m^3 [4] (although in reality this would change with altitude), v is the forward velocity of the plane, L is the length of the cylinder, and G is the vortex strength as defined in Eqn.(2).

$$G = 2\pi\omega r^2, \tag{2}$$

where; ω is angular frequency of the cylinder and r is the radius of the cylinder.

Two different situations were considered; take-off and then cruising. For take-off a 757-200 will be travelling at roughly 140mph (62.59ms^{-1}) and it will cruise at a speed of Mach 0.8 (274.4ms^{-1}) [5]. In order for an object to lift off the ground the upward force must exceed the force due to gravity. In this situation this leads to,

$$ma < 2\pi\rho v L\omega r^2, \tag{3}$$

where; m is the mass of the aircraft and a is the acceleration due to gravity, taken to be 9.81ms^{-2}. Meaning that,

$$\omega > \frac{mg}{2\pi\rho v L}\frac{1}{r^2}. \quad (4)$$

For the situation at take-off a graph was plotted to determine the relationship between the angular frequency and the radius of the cylinder that would be needed to create enough lift. The result of this is shown in Fig.2. Here it is clear to see the $\frac{1}{r^2}$ relationship between the angular velocity and the radius of the cylinder. This means that for a radius of 1.35m, the minimum angular frequency would be 37.69 rad/s. If you were to use a larger radius this would lead to a lower angular frequency needed but there would be a threshold size to actually fit on the aircraft.

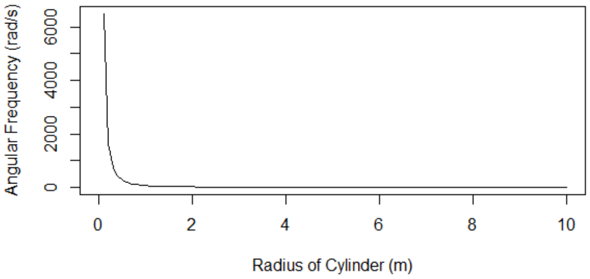

Fig. 2: Graph showing the relationship between angular velocity and radius of the cylinder at take-off.

The second situation that was tested was the relationship between the radius of the cylinder and the angular frequency to enable the aircraft to stay airborne at its cruising altitude. A Boeing 757-200 cruises at roughly 274.4ms^{-1} meaning that overall the angular frequency and radius of the cylinder required to maintain altitude will in fact be less than needed to take off. This is shown in Fig.3 and is due to the fact that, as shown in Eqn.(4), $\omega \propto \frac{1}{v}$. If the radius of the cylinder was again taken to be that of the average width of a conventional wing, 1.35m, then the minimum angular frequency required would be 8.58 rad/s.

Conclusion

Although it has been shown that it is possible to create enough upward force to maintain flight in a plan this is probably highly improbable to happen. Both results for the angular frequency seem low but this is expected as most of the lift comes from the high forward velocity. This is one of the reasons that this situation is unlikely to occur as it would likely be far less efficient than using a conventional aerofoil as you would still need some way to power the forward motion while also powering the rotation of the cylinders. This paper does not take into consideration how the forward motion would be achieved, how the rotating wings would in fact be powered, or what effect the inertia of these rotating cylinders would have on the situation. It may also be of interest to calculate the extra drag that would be created due to the larger area cutting through the air and how this would effect of the speed of the aircraft. These are all possible areas of expansion by future papers.

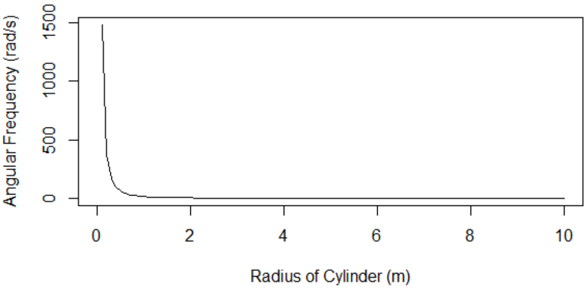

Fig. 3: Graph showing the relationship between angular velocity and radius of the cylinder at cruising speed.

References

[1] `http://en.wikipedia.org/wiki/Flettner_airplane` accessed 05/11/2014

[2] `http://en.wikipedia.org/wiki/Magnus_effect` accessed 04/11/2014

[3] `http://www.airliners.net/aircraft-data/stats.main?id=101` accessed 12/11/2014

[4] `http://en.wikipedia.org/wiki/Density_of_air` accessed 12/11/2014

[5] `http://www.boeing.com/boeing/commercial/757family/pf/pf_200tech.page` accessed 05/11/2014