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P5_8 A Mechanised Mitigation of a Mayonnaise Mess-Up

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Abstract

In this paper, an analysis is carried out of an aviation propeller strapped to an office chair as a life-saving device. If one were to find themselves in trouble, this device would be able to hold a human atop a mayonnaise surface, averting disaster. The rotational speed necessary for the propeller was calculated in this paper via consideration of the coefficient of thrust. The rate required was found to be 6.58 rad $\cdot$ s^{-1}.

Introduction

Due to a worrying spike in drownings at the Mayonnaise's factory, a new piece of life saving equipment is being developed. This will consist of an aviation propeller and combustion engine, strapped to an ergonomic office chair from the HR department. This paper aims to investigate the rotational rate required of the propeller, in order to allow the employee to float atop of the vat of mayonnaise.

Theory

Firstly, the masses of each constituent part of the life-saving propulsion device must be considered individually, in order to find the mass of the whole system. For the propeller, a Hartzell 3-blade propeller was decided upon. This has a mass of $m_{prop} = 19.1$ kg [1]. The engine used in this contraption, a Lycoming O-320, has a mass of $m_{eng} = 111$ kg [2]. Additionally the chair used was assumed to be $m_{chair} = 12.5$ kg [3]. Finally, the mass of an average human is $m_{hu} = 70.8$ kg [4]. Summing all of these masses together:

$$m_{tot} = m_{prop} + m_{eng} + m_{hu} + m_{chair}, \qquad (1)$$

a value of 213.35 kg was obtained.

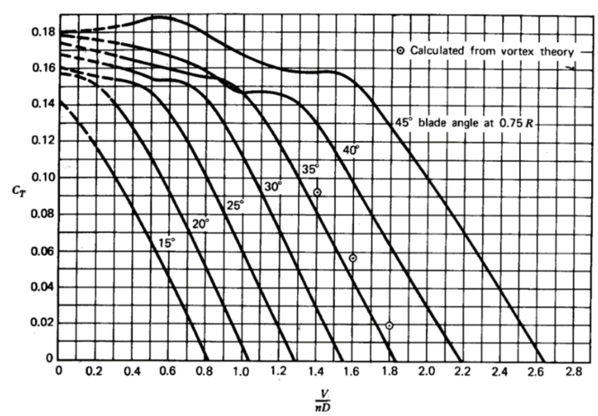

Figure 1: A plot showing typical thrust coefficient relations to the quantity V/nD, where D is the diameter of the propeller, V is the speed at which the system is moving with respect to the stationary fluid. Figure adapted from [5]

Next in order to calculate the thrust required to elevate a human above the mayonnaise, the following equation was employed

$$T = \kappa_T \rho n^2 D^4 \qquad (2)$$

where κ_T is the coefficient of thrust, an empirical value, ρ is the bulk density of the fluid, n is the rate of rotation and D is the diameter of the propeller [5]. This equation was then equated to the vertical force of gravity acting on the human and life-saving device:

$$\kappa_T \rho n^2 D^4 = m_{tot} g \tag{3}$$

where $g = 9.81$ ms^{-2} is the gravitational acceleration. This balance of forces models the scenario where the upwards thrust of the propeller is equal to the downwards force of gravity and the human is therefore in equilibrium above the mayonnaise.

To use this equation, the coefficient of thrust, κ_T, must be determined. This was done using a standard chart [5], shown in figure 1, relating the coefficient of thrust to the advance ratio $J = V/nD$, which is the distance that the propeller moves per rotation, divided by the diameter in order to make it a dimensionless quantity. Here V is the speed of the craft with respect to the fluid. Using a value of $V = 0$, as the craft is stationary resting on the surface of the mayonnaise, J will also become zero. Assuming a blade angle of 30°, the constant κ_T can be found to be 0.168. Next, rearranging equation 2 for the rotational rate n will give

$$n = \sqrt{\frac{m_{tot} g}{\kappa_T \rho D^4}}. \tag{4}$$

Inputting into this equation values of $\kappa_T = 0.168$ along with a value of 910 kgm^{-2} for the bulk density of mayonnaise [6] and a value of $D = 1.88$ m for the diameter of the propeller [1], gives a value of $n = 1.05$ full rotations per second for the required rotational rate of the propeller.

Conclusion

When investigating this concept as a life-saving device, the forces of thrust and gravity upon a craft were assessed at a point of equilibrium atop the surface of the mayonnaise. This allowed the blade speed necessary for this equilibrium to be calculated. The rate obtained after calculations, $n = 1.05$ rotations per second or 6.58 rad·s^{-1}, was obtained assuming that mayonnaise is a Newtonian fluid. However, mayonnaise has thixotropic properties meaning that the viscosity decreases at higher sheering rates. This implies that the rate of rotation required may be higher than previously calculated. The inclusion of a correction for this factor would provide a more accurate result.

References

[1] *Experimental composite 3- blade propellers.* URL: `https://hartzellprop.com/products/top-prop/other/experimental-composite-3-blade-propellers/` (visited on 10/25/2022).

[2] *Federal Aviation Administration.* URL: `https://web.archive.org/web/20090304122724/http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgMakeModel.nsf/0/B8D9638EAC0BE96786257085006EBBA3?OpenDocument&Highlight=320` (visited on 10/25/2022).

[3] *Staples.* URL: `https://www.staples.co.uk/office-furniture/office-chairs/desk-chairs/ff-first-medway-mesh-high-back-operator-chair-black-ch2803tc4ch/` (visited on 10/26/2022).

[4] *Biomed Central.* URL: `Biomed%20Central://bmcpublichealth.biomedcentral.com/articles/10.1186/1471-2458-12-439` (visited on 10/26/2022).

[5] B W McCormick. *Aerodynamics, aeronautics and flight mechanics.* en. Nashville, TN: John Wiley & Sons, Nov. 1979.

[6] *Engineers Toolbox.* URL: `https://www.engineeringtoolbox.com/foods-materials-bulk-density-d_1819.html` (visited on 10/26/2022).