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A5_1 Exploration of Dune's Ornithopters

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Abstract

The film Dune utilises ornithopters with a unique eight winged design. In this paper we investigated the requirements needed for such a design to function. It was found that merely hovering would require the wings to beat 1.78 times a second, while requiring 182 horsepower each.

Introduction

The 2021 film Dune utilises ornithopters (winged helicopters) as a primary mode of transport [1]. Despite ornithopters existing in reality, the ones used in this film stand apart due to a unique eight winged design and their ability to carry entire groups of people. In this paper, we investigate how effective this propulsion system would be when applied in reality by comparing it's requirements to those of the AW109 [2], a helicopter capable of carrying the same number of people as the ornithopter.

Assumptions

Within the film, it is shown that when hovering the wings beat exclusively up and down. We therefore assumed that all lift while hovering comes from the drag force exerted on the wings as they move downward.

To maintain constant lift we assumed that wings beat in alternating groups of four, and that they rise with the same velocity they descend with.

To generate any net lift, we assumed that as the wings rise they are tilted vertically, and that due to the thin and streamlined shape the drag they experience while being raised is negligible.

We assumed the cylindrical rod connecting the wing to the pivot point will generate no net drag.

No official specifications for the ornithopter could be found, the dimensions and behavior of the wings were therefore estimated based on comparisons to the actors in the film.

Method

From [3] the force of drag is shown to be,

$$F = \frac{1}{2}\rho C_d A v^2 \tag{1}$$

Where ρ is air density of 1.225 kgm^{-3}, C_d is the dimensionless drag coefficient which, as the wing is assumed to be rectangular, is 1.17 from [3]. A is the area (m^2) and v is the velocity (m/s). The wing is estimated to have a length 20 m including the connecting rod of length 2 m and a width of 2.5 m. Eq. (1) cannot be used directly due to the fact that while flapping the wing rotates around an angle of $\sim 20°$. This means different parts of the wing experience different velocities. To correct for this, we rearranged the equation to find the force per unit length. We also changed the variables to show each of their dependence's on the length, and the constant angular velocity

ω (rad/s). This gave the following equation.

$$dF = \frac{1}{2}\rho C_d W dr^2 \omega^2, \quad (2)$$

Where $r\omega$ is equivalent to v, with r being the radial distance (m) from the center of rotation. Wdr is equivalent to small unit of area A with W being the width of the wing (m).

The total force of drag on each wing required to provide the necessary lift can be found using.

$$F = \frac{ma}{4} \quad (3)$$

Where m is the mass to be lifted (kg), which we took to be the maximum carry weight of the AW109 that being 3000 kg [2]. a is the acceleration due to gravity of 9.81 m/s^2. The factor of 1/4 comes from the fact that in this system four wings will be beating at once. This means each wing only needs to provide 1/4 the required lift.

Integrating (2) over the wings length and rearranging for ω using F from (3), we found the necessary angular velocity to be 1.24 rad/s. Over the 20° of wing rotation this obtains an angular frequency of 3.55 Hz. As the two sets of four wings alternate between ascending and descending, this results in 1.78 flaps per second per wing.

We found the torque experienced by each wing due to the drag force using,

$$\tau = rF sin\theta \quad (4)$$

Where τ is the torque (N.m). θ in this equation is the angle between the force and radial vectors. As drag always acts against the direction of motion this angle is always 90°. We substituted F with dF from (2). This allowed us to find the torque per unit length, which can be integrated across the length to find the total torque experienced by the wing due to the drag force. We found this to be 110 kN.m.

The power P (W) needed to overcome this torque was found using,

$$P = \tau\omega \quad (5)$$

We found this to be 136 kW, which is equivalent to 182 horsepower (hp). Across all eight wings this totals to 1460 hp.

Discussion

Initially, this power requirement seems reasonable in comparison to the two 560 hp engines used in the AW109[2]. However, as will be explained, this is a considerable underestimate of the power that would actually be needed for an ornithopter of this design.

The first reason for this relates to the weight of the wings and motor system needed to run them. Although their exact weight is unknown, based on the increased wing thickness, wing surface area and number of wings it is clear that they would weigh more than the rotor blades of the AW109. This would add extra weight to the 3000 kg it needs to be capable of lifting, which would require more force from each wing.

The second is that 1460 hp is what is required simply for the ornithopter to overcome its own weight, while the AW109 uses its horsepower for full flight. Flying the ornithopter would require significantly more power in order to accelerate its at least 3000 kg load and to change the direction of the wing during each flapping motion.

Conclusion

To summarise, by finding the drag force experienced by each wing we estimated that they would each need to flap at least 1.78 times per second using 182 hp. This makes it clear that this ornithopter would require significantly more power than a helicopter to lift an equivalent load. We have therefore decided that it is not an effective propulsion system to use in reality.

References

[1] Feature Film: Dune: Part One [Released 22 October 2021]

[2] `https://www.globalair.com/aircraft-for-sale/specifications?specid=965` [Accessed 11 October 2022]

[3] `https://www.engineeringtoolbox.com/drag-coefficient-d_627.html` [Accessed 10 October 2022]