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P5 3 Iron Man: I Am ... Powered?

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Abstract

Iron Man's suit is capable of sustained flight using compact repulsors located in the hands and feet. In this paper, we investigate the power required for Iron Man's suit to hover. This is done using a simplified physical model which applies thrust balance and actuator-disc momentum theory. We treat the four repulsors as discs of radius r = 0.03 m and take a combined mass of the suit and wearer as 85.2 kg. Using the combined mass, we show that hovering requires a thrust of 836 N, an ideal power of 145 kW and an input power of 290 kW, at an assumed efficiency of 50%. Reducing the outlet area significantly increases the power required, thus smaller outlets are shown to be very costly. Hovering with small outlets increases the difficulty of achieving sustained flight with a compact, wearable propulsion system.

Introduction

In the Marvel Cinematic Universe, Tony Stark (aka Iron Man) uses a high-tech suit, which grants the user with super-strength, the ability to fly and various other powers. Throughout the films, we see that Iron Man is able to fly using repulsors in the palms of his hands and the soles of his feet. Despite the outlets being small, they have the capability to hold Iron Man in the air, posing the question of how much power is required to accomplish this.

A previous PST paper, *Windswept*, studied these thrusters as weapons, whereas here we consider the energy required for sustained flight compared to the bursts of power discussed in [1]. We ask the question: how much power is required for the Iron Man suit to hover continuously? To answer this, we use actuator-disc momentum theory, adapting suit parameters from [1].

Theory

For steady hovering, the upward thrust produced by the suit must equal its weight,

$$T = mg, \tag{1}$$

where m is the combined mass of the suit and its wearer and g is the acceleration due to gravity. Taking m as 85.2 kg, the required thrust force is $T \approx 836N$. The four repulsors are modelled as identical discs of radius r = 0.03 m [1], resulting in a combined area:

$$A = 4\pi r^2. \tag{2}$$

The air passes through the disc with an initial velocity, v_i, and leaves far downstream with a final velocity, v_f. From Newton's Second Law of Motion, the aerodynamic forces on an aircraft (lift and drag) are directly related to the change in momentum of a gas with time [2]. Hence, the mass flow rate can be expressed as

$$\dot{m} = \rho A v_i, \tag{3}$$

where ρ is the air density. Therefore, thrust can be defined as momentum given to the air per second

$$T = \dot{m} v_f = \rho A v_i v_f. \tag{4}$$

The corresponding ideal hover power is the thrust multiplied by the initial velocity, which must equal the kinetic energy given to the air:

$$T v_i = \frac{1}{2} \dot{m} v_i^2 = \frac{1}{2} \rho A v_i v_f^2. \tag{5}$$

Rearranging and substituting Eq(4) into Eq(5) gives $v_f = 2v_i$. From the actuator-disc momentum theory [3], Eq(4) becomes:

$$T = 2\rho A v_i^2. \tag{6}$$

Therefore, the ideal power is:

$$P_{ideal} = T v_i = \frac{T^{3/2}}{\sqrt{2\rho A}}. \tag{7}$$

Real propulsion systems require more input power than the ideal limit. This is represented by an overall efficiency, η. To find the input power:

$$P_{input} = \frac{P_{ideal}}{\eta}. \tag{8}$$

As seen from Eq(7), for a fixed thrust, a smaller area means air must leave the outlet quicker. Since kinetic energy is also dependent on v^2, the power rises. This is reinforced through the relationship between power and area: $P \propto A^{-1/2}$.

Quantity	**Value**
Thrust, T	$836N$
Outlet Area, A	$0.0113m^2$
Initial Velocity, v_i	$174ms^{-1}$
Final Velocity, v_f	$347ms^{-1}$
Ideal Power, P_{Ideal}	$145kW$
Input Power, P_{Input}	$290kW$
Assumed Efficiency, η	0.5

Table 1: Hovering Requirements for $r = 0.03m$, $m = 85.2kg$.

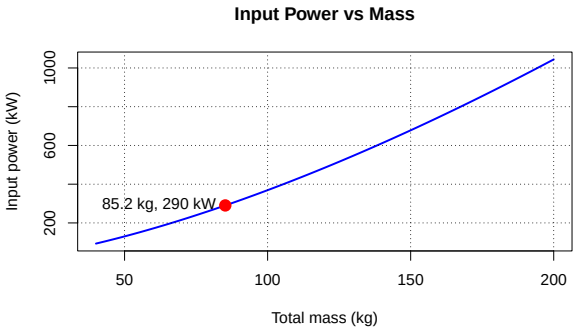


Figure 1: Input Power vs Mass for 50% Efficiency

Results

As seen above, Table 1 lists the results using the equations mentioned. The input power is approximately equal to 290 kW. Hovering at this rate for one minute would require around $17MJ$ of energy.

Additionally, Figure 1 shows how power changes with total mass. The red point on the figure marks the parameters from [1].

Discussion and Conclusion

The model estimates an input power of approximately 290 kW, reflecting the small outlet area. As shown in Table 1, the final air velocity is approximately $347ms^{-1}$, approaching the speed of sound. The result depends strongly on assumptions: the mass and outlet dimensions are taken from [1], air density is set to $1.225kgm^{-3}$ [4], and an efficiency of 50% is assumed. Uniform airflow is also assumed, neglecting drag and manoeuvring. Therefore, although the model cannot prove that the suit is impossible to power, it demonstrates the substantial power required for hovering.

Using thrust balance and actuator-disc momentum theory, the model predicts that an 85.2 kg suit-and-wearer system with four outlets of radius 0.03 m requires approximately 290 kW to hover at 50% efficiency. Despite the model's limitations, the results highlight the significant challenge of achieving sustained flight with a compact, wearable propulsion system.

References

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