Take-Home Project
for IIT Madras Course - Fundamentals of Aerospace

Report: Helicopter Hover Challenge – Earth vs. Mars

by ARNAV VENKATESH | Grade 11 | NHVPS B'lore

Objective:

- To compute and compare the rotor speeds required to hover helicopters and small drones on Earth and Mars.

- To understand why hovering is harder on Mars despite lower gravity.

- To compare theoretical results with NASA's Ingenuity drone.

Background / Equations:

- Hover condition: Lift = Weight $T = W = mg$

- Rotor thrust (two rotors): $T = 2\, C_T\, \rho\, A\, (\omega R)^2$

- Solve for rotor angular velocity: $\omega = \frac{1}{R}\sqrt{\frac{W}{2 C_T \rho A}}$

- Constants used :

$C_T = 0.008,$

$R = 0.6m,$

$\rho_{earth} = 1.225,$

$\rho_{mars} = 0.020,$

$g_{earth} = 9.81,$

$g_{mars} = 3.71.$ all in their SI Units

Results Table:

Mass (kg)	**Planet**	**Weight (N)**	**ω (rad/s)**	**rpm**
1500	Earth	14715	1357.92	12967
1500	Mars	5565	6535.52	62410
1	Earth	9.81	35.06	335
1	Mars	3.71	168.75	1611
1.8 (Ingenuity)	Mars	6.68	226.40	2162

Comparison to NASA Ingenuity:

- Ingenuity rotor span 1.2 m → radius 0.6 m
- Reported Mars rotor speed: ≈2400 rpm
- Model predicts 2162 rpm (≈10% lower)
- Difference due to simplified thrust model, idealized constant C_T, and ignoring aerodynamic/operational margins.

Discussion / Conceptual Questions:

1. Why is hovering harder on Mars, even though gravity is weaker?

Ans: Hover requires **lift = weight**: $T = mg$.

On Earth, air density is $\rho \approx 1.225\, kg/m^3$. But on Mars, it is $\rho \approx 0.020\, kg/m^3$ $(\approx 60\times\ thinner)$

So, for the same rotor size and mass, much higher ω is needed if ρ is small.

Even though Mars' gravity is only ~0.38g, the *thin atmosphere* dominates and the required rotor speeds are impractically high.
Therefore, hovering is harder on Mars because the air is too thin to generate sufficient lift without extremely high rotor speeds, despite lower gravity.

2. How does Newton's Third Law explain the need for a tail rotor?

Ans: Newton's Third Law states that "Every action has an equal and opposite reaction." The main rotor pushes air downward and an equal reaction spins the helicopter fuselage in the opposite direction (torque).

To counteract this reaction torque, a tail rotor applies an opposing thrust sideways, stabilizing yaw.
Therefore, without a tail rotor, the fuselage would spin uncontrollably opposite to the rotor's direction; so the tail rotor provides an opposing force to balance this reaction torque.

3. Could autorotation (engine-off descent) work on Mars? Why or why not?

Ans: Autorotation is the principle wherein engine-off descent on Earth, upward airflow through the rotor keeps blades turning, generating lift and allowing a controlled glide down.
On Mars, air density is ~1.6% of Earth's, so very little upward airflow momentum is there.
Rotor blades would not capture enough kinetic energy from such thin air to sustain rotation.
Therefore, autorotation would be ineffective on Mars, because the thin atmosphere cannot provide sufficient upward airflow to keep the rotor spinning, so controlled engine-off descent is essentially impossible.

Conclusion:

- Hovering is feasible in theory on Mars but requires much higher rotor speeds than Earth.

- Small drones like Ingenuity are designed with high rpm margins to compensate for low atmospheric density.

- The course model provides a good first approximation but real-world rotorcraft need additional considerations (blade aerodynamics, induced velocity, operational margins).
