7 On April 19, 2021, ***Ingenuity***, a small robotic helicopter operating on Mars as part of NASA's Mars 2020 mission completed the first powered controlled flight by an aircraft on Mars. The controlled flight consisted of taking off vertically, hovering and landing. The first takeoff happened at 07:15 Coordinated Universal Time (UTC). The whole event was livestreamed from a video camera on the Perseverance rover, which subsequently transmitted the footage over electromagnetic waves over 200 million kilometres back to Earth. Ingenuity carries a piece of fabric from the wing of the 1903 Wright Flyer, the Wright Brothers' airplane used in the first flight on Earth. (Source Wikipedia)

The project is solely a demonstration of technology; it is not designed to support the Mars 2020/Perseverance mission, which is searching for signs of ancient life and collecting samples of rock and sediment in tubes for potential return to Earth by later missions. (Source NASA)

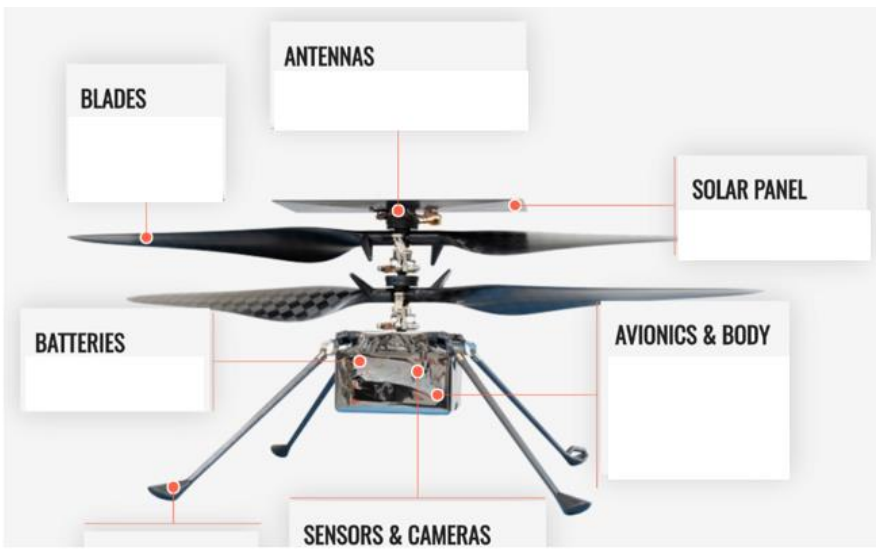

Fig 7.1 Side view of Ingenuity with labelled parts (Source adapted from Wikipedia)

<u>The testing phase</u>

In 2019, preliminary designs of the 1.8 kg Ingenuity with a rotor span (diameter) of 1.2 metres were tested on Earth in simulated atmospheric and gravity conditions corresponding to those on Mars. For flight testing, a large vacuum chamber was used to simulate the very low pressure of the atmosphere of Mars – filled with carbon dioxide to approximately 0.60% of standard atmospheric pressure at sea level on Earth. The density of air on Earth at sea level is 1.225 kg m^{-3} while the density of air on Mars is 0.020 kg m^{-3}. In order to simulate the gravity field of Mars (38% of Earth's), 62% of Earth's gravity was offset by a line pulling upwards during flight tests. (Source NASA: edited)

Fig. 7.2 and **Fig. 7.3** show the flight data for a flight on Mars.

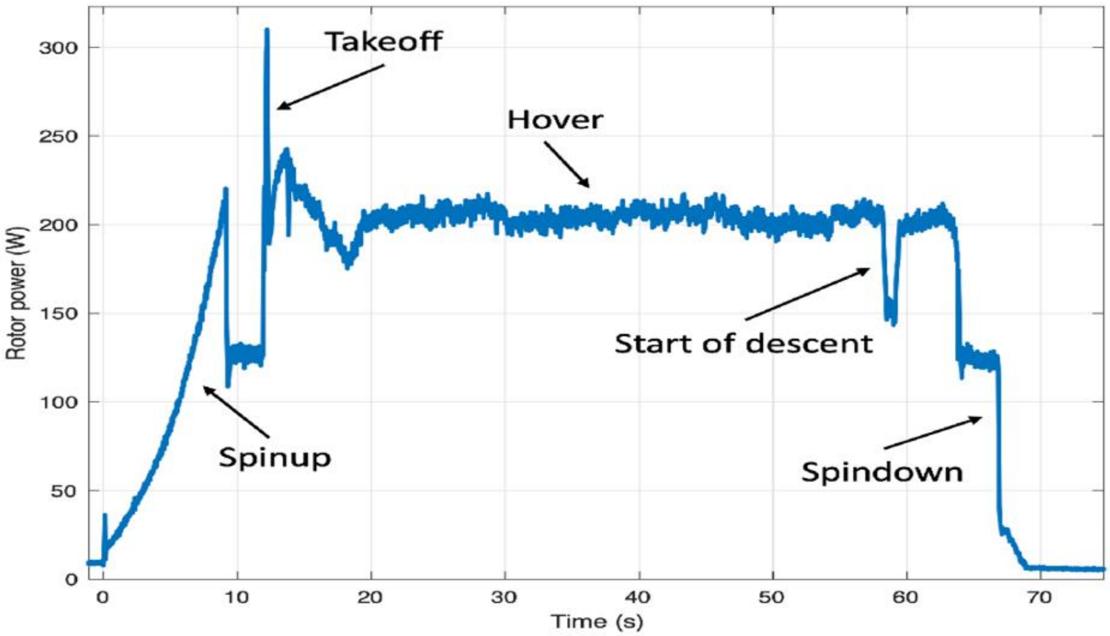

Fig. 7.2 (Source: NASA)

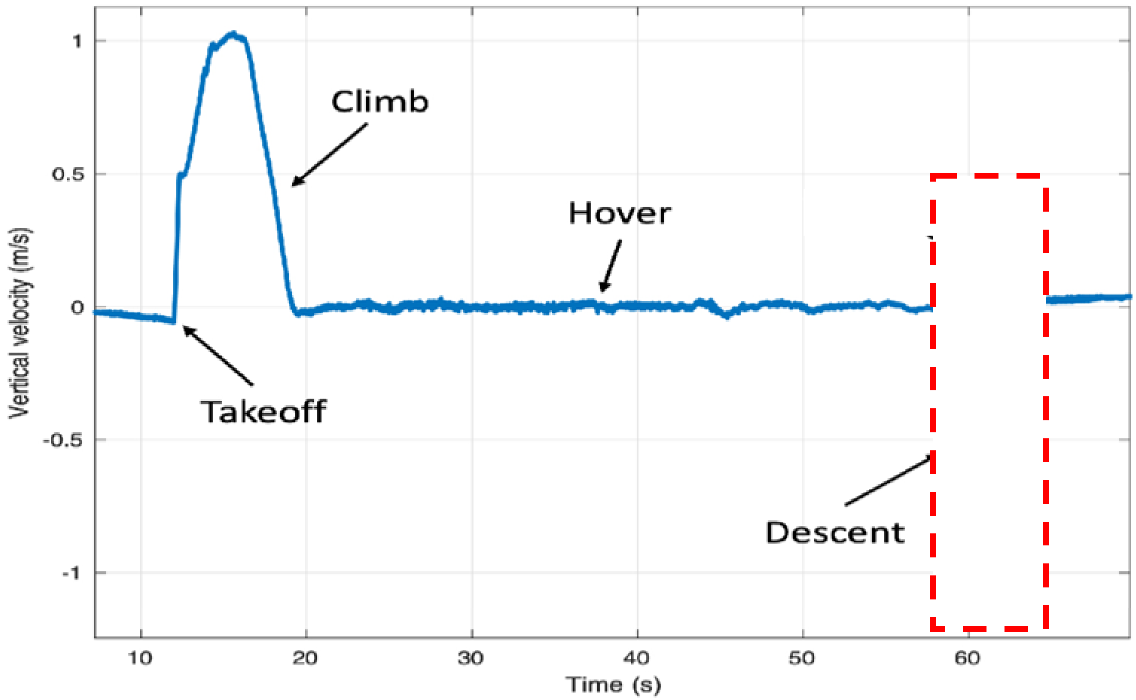

Fig. 7.3 (Source: NASA)

(a) “The first takeoff happened at 07:15 Coordinated Universal Time (UTC).” Calculate the time it would take for the take-off on Mars to be seen on Earth.

Time = ………………min [2]

(b) **(i)** The conditions on the surface of Mars are different from those on Earth. State and explain one condition that makes it easier to fly a helicopter on Mars and one condition that makes it harder.

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(b) **(ii)** By considering the momentum of air particles due to the blades and using Newtons' Laws, show that the lift force F_L generated by the rotor blades is given by $\rho A v^2$, where ρ is the density of air on the surface of Mars, A is the circular area swept by the blades and v is the downward velocity of air below the blades.

[3]

(iii) Calculate the velocity of air below the blades to allow Ingenuity to hover on the surface of Mars.

Velocity = ... m s^{-1} [3]

(iv) In a simple model, the velocity of air below the blades v can be assumed to be proportional to the rate of rotation of the rotor blades f. Using data in the passage and the expression in **(b)(ii)**, calculate the ratio of the rate of rotation of the rotor blades required for Ingenuity to hover on Mars to the rate of rotation on Earth.

[3]

(c) Make reference to **Fig 7.2** and **Fig. 7.3** for the following questions.

(i) State the approximate power required by Ingenuity to hover.

Power = ... W [1]

(ii) With reference to **Fig. 7.3**, estimate the height that Ingenuity hovered at.

Height = ……………………. m [2]

(iii) Explain why during the descent phase starting from around 58 s, the motor power dipped to around 150 W for approximately 1 second then spun up to 200 W again.

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(iv) Complete the diagram in **Fig. 7.3** (within the dotted lines) to show approximately how the velocity-time graph of ingenuity should look like during the descent phase from approximately 58 s to 64 s. [2]

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