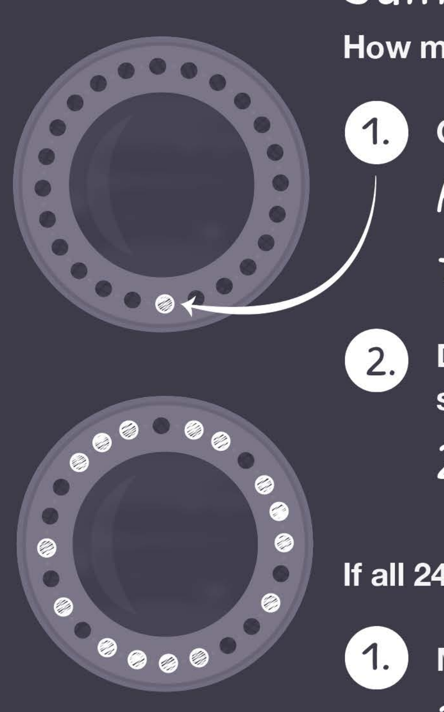
Jet Propulsion Laboratory
California Institute of Technology
Education

π IN THE SKY 8

Answer Key

Sample Science

How many pads needed to make contact with Bennu's surface to meet the mission requirement?



1. **Compute the area of each sample pad.**
   $A = \pi r^2$
   $\pi(0.75\ cm)^2 \approx 1.8\ cm^2$

2. **Divide the mission requirement for contact with Bennu's surface by the area of the sample pad.**
   $26\ cm^2 \div (1.8\ cm^2/pad) \approx$ **15 pads**

If all 24 pads contacted Bennu, how much asteroid surface area would the contact pads sample?

1. **Multiply the number of pads by the surface area contacted by one pad.**
   $24\ pads \cdot (1.8\ cm^2/pad) \approx$ **$43\ cm^2$**

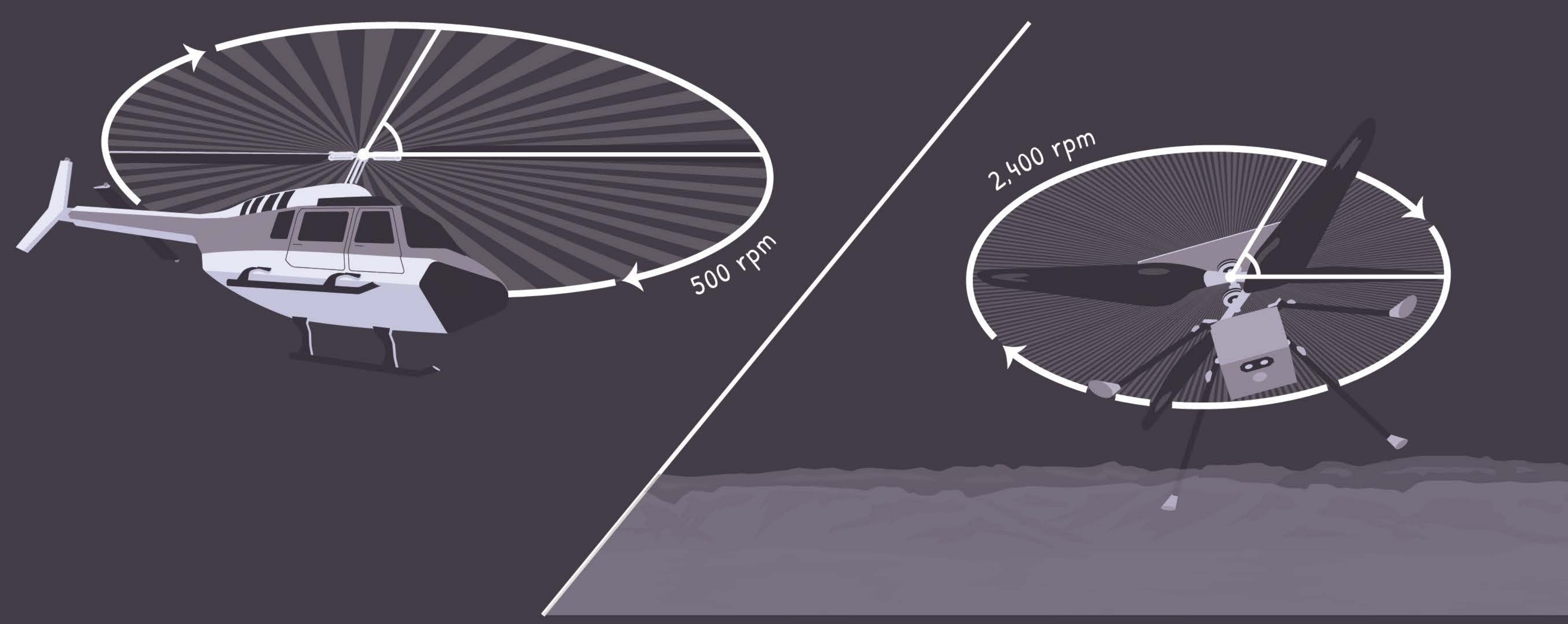
Whirling Wonder

How fast, in rotations per minute, do Ingenuity's blades spin?

1. **Convert radians to rotations per minute (1 rotation = 2π radians).**
   $(250\ rad / sec) \cdot (60\ sec / 1\ min) \cdot (1\ rotation / 2\pi\ radians)$
   $\approx$ **2,400 rpm**

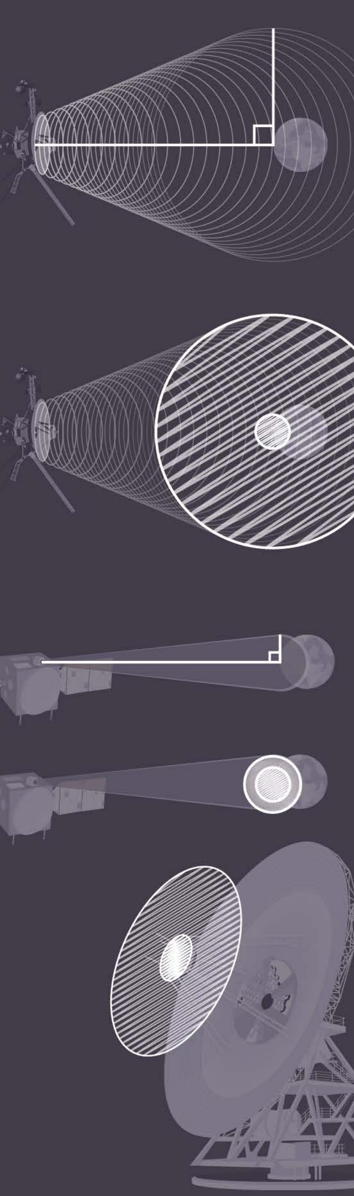
How does that compare to a typical helicopter on Earth?

1. **Divide Ingenuity rotations per minute by Earth helicopter rotations per minute.**
   $2{,}400\ rpm / 500\ rpm = 4.8$
   Ingenuity's blades spin **~ 5 times faster**



Signal Solution

What fraction of Voyager's original signal is received by a 70 meter antenna on Earth?



1. **Convert astronomical units to meters.**
   $124\ AU \cdot (150{,}000{,}000\ km / 1\ AU) \cdot (1{,}000\ m / 1\ km) = 1.86 \cdot 10^{13}\ m$

2. **Find the beam radius at Earth using tangent and the distance between Earth and Voyager.**
   $\tan 0.25^\circ \approx x / (1.86 \cdot 10^{13}\ m) \rightarrow 8.12 \cdot 10^{10}\ m$

3. **Find the ratio of the antenna area (radius of 35 m) to the signal area.**
   $\pi(35\ m)^2 / \pi(8.12 \cdot 10^{10}\ m)^2 \approx 1.9 \cdot 10^{-19}$

4. **Find the ratio of received signal versus the sent signal.**
   $1.9 \cdot 10^{-19} \cdot 12.5\ W \approx$ **$2.3 \cdot 10^{-18}\ W$ or $1.8 \cdot 10^{-20}\ \%$**

What fraction of the signal from a DSOC-equipped spacecraft is received?

1. **Follow the same process as above with the values for the DSOC-equipped spacecraft.**
   $24\ AU \cdot (150{,}000{,}000\ km / 1\ AU) \cdot (1{,}000\ m / 1\ km) \approx 1.86 \cdot 10^{13}\ m$
   $\tan 0.00045^\circ \approx x / (1.86 \cdot 10^{13}\ m) \rightarrow 1.46 \cdot 10^{8}\ m$
   $\pi(35\ m)^2 / \pi(1.46 \cdot 10^{8}\ m)^2 \approx 5.7 \cdot 10^{-14}$
   $5.7 \cdot 10^{-14} \cdot 4\ W \approx$ **$2.3 \cdot 10^{-13}\ W$ or $5.8 \cdot 10^{-14}\ \%$**

By what factor is DSOC more effective?

1. **Divide the received wattage of the DSOC spacecraft's signal by that of Voyager's.**
   $2.3 \cdot 10^{-13} / 2.3 \cdot 10^{-18} =$ **10^5 or 100,000 times more effective**

Force Field

What force does a hydrogen ion at π/4 radians from the equator observe? What about at the North Pole (π/2 radians)?

1. **Convert microteslas to teslas and kilometers per second to meters per second.**
   $60\mu T = 6 \cdot 10^{-5}\ T$
   $400\ km/s = 4 \cdot 10^{5}\ m/s$

2. **Enter the known values into the Lorentz force equation and compute.**
   $F = (1.602 \cdot 10^{-19}\ C) \cdot (4 \cdot 10^{5}\ m/s) \cdot (6 \cdot 10^{-5}\ T) \cdot \sin(\pi/4)$
   $F \approx$ **$3 \cdot 10^{-18}\ N$**
   $F = (1.602 \cdot 10^{-19}\ C) \cdot (4 \cdot 10^{5}\ m/s) \cdot (6 \cdot 10^{-5}\ T) \cdot \sin(\pi/2)$
   $F \approx$ **$4 \cdot 10^{-18}\ N$**

Does the relative magnetic field agree or disagree with what you'd expect about the location of auroras?

1. **Agrees.** A larger Lorentz force occurs at the North Pole where the formation of auroras is more common.