Space Careers Wayfinder

Communicating in Space

There are many challenges associated with space exploration whether it be retrieving data collected by satellites or communicating with astronauts aboard a rocket bound for the Moon. Just one of these is the rate/speed at which we are able to carry out these tasks.

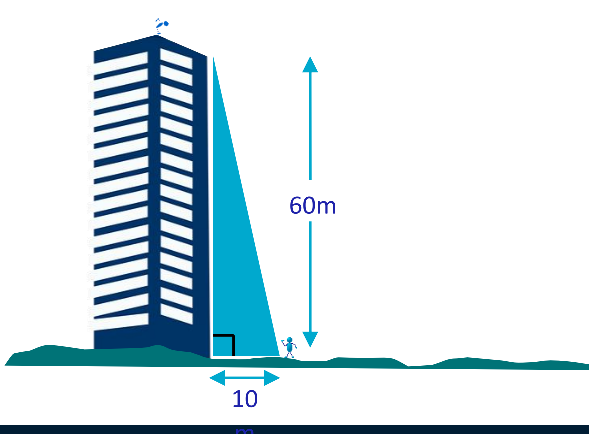
To give some idea of this challenge here are a few simple calculations to perform.

1. Carpenter Joe forgot to take his claw hammer up to the roof of the 17-storey apartment block he's working on with his daughter Jill. Joe shouts down to Jill who is outside on the ground level to bring up his hammer when she joins him on the roof

If Joe shouts down to Jill from the same side of the building on which she is stood, and the building is 60 m high, with Jill stood 10 m out from the side of the building.

How long after Joe shouts down to Jill will she get the message to bring up the hammer?

NOTE the speed of sound in air = 343 m/s



$$c^2 = a^2 + b^2$$

$$c = \sqrt{(a^2 + b^2)}$$

$$= \sqrt{(10^2 + 60^2)}$$

$$= \sqrt{3700}$$

$$= 60.83 \text{ m}$$

$\therefore$distance from Joe to Jill = 60.83 m

time = distance/speed

= 60.83/343

= 0.18 s (approximate value, time will be affected by air pressure, temperature etc)

2. If Joe had taken the UHF radio with him to communicate his request to Jill, how long would the message take in this instance. Assuming the message is travelling the same distance and the radio wave travels at the speed of light

NOTE speed of light ~300 000 000 m/s

time = distance/speed

= $60.83/3.0 \times 10^8$

= 2.0×10^{-7} s

3. Radio waves travel at the speed of light (3.0×10^8 m/s), but they have different frequencies. Frequency is measured in Hertz (Hz) where 1 Hz is 1 cycle (or wavelength) per second. 1 kHz is 1000 cycles per second.

The wavelength (λ) is the distance that a wave repeats itself.

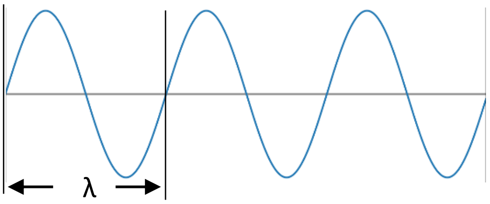
How many wavelengths can you see on the diagram below? 3 wavelengths (or cycles)

The wavelength of a radio wave can be calculated if we know the frequency of the wave (Hz).

Use the formula: $v = f\lambda$

Where λ = wavelength, v = velocity, F = frequency.

If Joe's radio has a frequency of 477 MHz, calculate the wavelength of the radio.



$v = f\lambda$

$\lambda = v/f$

= 300 000 000/477 000 000 (or $3.0 \times 10^8/4.77 \times 10^8$)

= 0.629 m

4. The Deep Space Network (DSN) is made up of ground-based antennae located in Australia, America and Spain. DSN is used to communicate with space craft and does so using gigahertz (GHz) frequencies.

a) What would Joe's 477 MHz frequency be if converted to Hz in scientific notation.

b) Convert this to gigahertz (GHz) or billions of Hertz.

a) 477 MHz = 477 000 000 Hz

= 4.77×10^8 Hz

b) 1 GHz = 1 000 000 000 Hz

∴ 477 MHz = $4.77 \times 10^8/1 \times 10^9$

= 0.477 GHz

5. If radio signals used for communication do travel at the speed of light (~ 300 000 000 m/s) how long would it take to get a message to the following:
    i. International Space Station, mean distance from Earth 400 km
    ii. The Moon, mean distance from Earth 384 400 km
    iii. Mars, when 225 000 000 km distance from Earth

Where t = d/v, t = time(s), d = distance (m), v = speed of light (m/s)
All 'km' have been converted 'm' below.

i. t_{ISS} = 400 000/300 000 000
= 0.001 s (or $4.0 \times 10^5/3.0 \times 10^8 = 1.0 \times 10^{-3}$ s)

ii. t_{Moon} = 384 400 000/300 000 000
= 1.28 s (or $3.844 \times 10^8/3.0 \times 10^8 = 1.28$ s)

iii. t_{Mars} = 225 000 000 000/300 000 000
= 750 s (or $2.25 \times 10^{11}/3.0 \times 10^8 = 750$ s)

NOTE these times are based on mean distances from Earth

Robots or remote-control units on other planets?

Robots can use sensors and make predetermined decisions based on these inputs **without any further input from people.** They have automatic responses in many respects. Remote control units have information that can be sent to people but will not deviate in speed or pathway unless **instructions are sent to the unit by people on Earth.** They are manual units and not automatic.

A *remote-control* Mars unit is travelling at maximum speed (4.2 cm/s) in a straight line. If ordered to halt immediately, it can stop within a negligible distance. Scientists on Earth watching from an onboard camera notice a deep ravine exactly 50 metres ahead and immediately send a 'stop' message.

a) Assuming it takes one second for humans to react and send the 'stop' message, how far will the unit move before it stops? Would you recommend using robots or remote control for Mars vehicles?

    Hint – Factor in the time it takes for the camera footage to travel from Mars to Earth. Use the result from 5 iii.

b) Compare this with the time delays with communications between the Earth and the moon.

a) $T_{total} = t_{MarstoEarth} + t_{Reaction} + t_{EarthtoMars}$
= 750 + 1 + 750
= 1501 s (or 25 min 1s)

v = 4.2 cm/s
= 0.042 m/s

d = vt
= 0.042 x 1501
~63 m It crashes into the ravine before it receives a signal to stop.

As it takes on average a total of 25 minutes for scientists to receive input from Mars and the time to send instructions, it is not possible or remotely likely to control units/vehicles on Mars by remote control. For Mars, the autonomous robotic nature is crucial.

b) 5 ii) shows a one-way time of 1.28 s to the moon, so the total two-way time of travel from Moon ➔Earth ➔ Moon of 2.56 s is more potentially manageable should something need to be controlled by remote control.

6. As we explore the outer reaches of space and NASA plan a return to the Moon and beyond, scientists are looking at ways they can accommodate the ever-increasing amount of data being collected. Traditionally the data has been beamed back to Earth using radio waves. Now agencies such as NASA are actively investigating the use of lasers to perform this task.

Using the internet and other sources compile a table comparing the radio wave communication with laser communication. Your table should include any advantages and disadvantages of each system, any challenges and possible solutions to the challenges.

Radio communication	Laser (optical) communication
Low frequency	Higher frequency
6 Mbps to 300 Mbps download	Around 1Gbps download (predicted to increase)
Moderate to high security	High security
Can be affected by RF broadcast congestion	Not affected by other optical broadcasts
Not badly affected by cloud cover	Signal can be disrupted by clouds
RF waves spread as they leave source	Infrared used in laser is narrow and focused
Less accuracy required during data download	Laser must be accurate for data download
Large ground-based dish needed to capture RF waves	Small ground station facility
Antenna occupies large space	Minimal space required
Antenna adds to weight	Much lighter than RF instrumentation

NASA's Laser Communications Relay Demonstrator https://youtu.be/KcBQclXOj7Y

7. Scientists predict the increased likelihood of climate change and the impact this might have on the environment. One of the real and ever-present dangers in Australia is the devastation and threat to life of large bushfires. Various proposals have been put forward which aim to address the issue or at least provide sufficient warning of a potential issue.

   The majority of these proposals include the use of satellites. One such proposal from Professor Carl Pennypacker, UC Berkeley incorporates the use of a satellite telescope normally used for detecting bright spots across the universe, along with on-ground cameras to confirm the satellite images.

The creators of the system claim they have the ability to notify emergency services within one to three minutes of the fire starting[1].

Satellites orbiting the Earth tend to be located in one of three orbital heights, Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Earth Orbit (GEO). Which of the three orbital heights would you most likely find the UC Berkeley system and why?

The telescope will be installed in a satellite which will be placed in GEO. Placing the satellite out at distance of around 36 000 km in GEO allows continual observation of specific areas on the Earth's surface. Satellites in GEO also cover a large area of Earth so as few as three equally spaced satellites can provide near global coverage. Although image resolution from a satellite in LEO or MEO is likely to be much clearer. The issue with placing the telescope here is the orbital period. A satellite orbiting Earth in LEO or MEO would take around 90 minutes to orbit the Earth and might not cover the area of interest in the following orbit.

The approximate period of a satellite orbiting at 550 km can be calculated using the following formula:

$$T^2 = 4\pi^2 r^3/GM$$

Where:

T = Period

r = radius of the Earth plus the distance to satellite (6.382×10^6 m)

G = Gravitational constant (6.673×10^{-11} N m^2 kg^2)

M = Mass of the Earth (5.972×10^{24} kg)

[1] https://www.innoosamagazine.com.au/new-fire-technology-will-help-save-lives/

Australian Curriculum

Mathematics

Recognise that the real number system includes the rational numbers and the irrational numbers, and solve problems involving real numbers using digital tools (AC9M9N01)

Solve problems involving very small and very large measurements, time scales and intervals expressed in scientific notation (AC9M9M02)

Solve spatial problems, applying angle properties, scale, similarity, Pythagoras' theorem and trigonometry in right-angled triangles (AC9M9M03)

Solve practical problems applying Pythagoras' theorem and trigonometry of right-angled triangles, including problems involving direction and angles of elevation and depression (AC9M10M03)

trigonometry to solve right-angled triangle problems (ACMMG224), (ACMMG245)

Science

Use wave and particle models to describe energy transfer through different mediums and examine the usefulness of each model for explaining phenomena (AC9S9U04)

Investigate how advances in technologies enable advances in science, and how science has contributed to developments in technologies and engineering (AC9S9H02), (AC9S10H02)

Examine how the values and needs of society influence the focus of scientific research (AC9S9H04), (AC9S10H04)

Write and create texts to communicate ideas, findings and arguments effectively for identified purposes and audiences, including selection of appropriate content, language and text features, using digital tools as appropriate (AC9S9I08), (AC9S9I08)

Design and Technologies

Analyse how people in design and technologies occupations consider ethical, security and sustainability factors to innovate and improve products, services and environments (AC9TDE10K01)

Analyse the impact of innovation, enterprise and emerging technologies on designed solutions for global preferred futures (AC9TDE10K02)

Analyse and make judgements on how characteristics and properties of materials, systems, components, tools and equipment can be combined to create designed solutions (AC9TDE10K06)