Space Careers Wayfinder

Pulling it Together

Background

Space exploration by humans has occurred since the 1960s and many technological advances have been made since. The International Space Station (ISS) is the first and only orbiting station that has a full-time crew year-round. Although on a small scale, the ISS clearly demonstrates that survival off Earth's surface is achievable.

The ISS needs to be stocked with things like freeze dried foods, and astronauts especially prize fresh produce when it is occasionally available. These foods can only be provided by visiting missions https://www.nasa.gov/feature/space-station-20th-food-on-iss. One of the major aspects that needs to be overcome in pushing exploration boundaries further is the need for sustainable survival over extended and permanent timeframes.

What features are essential in enabling, sustainable survival to occur without reliance on deliveries of resources from Earth?

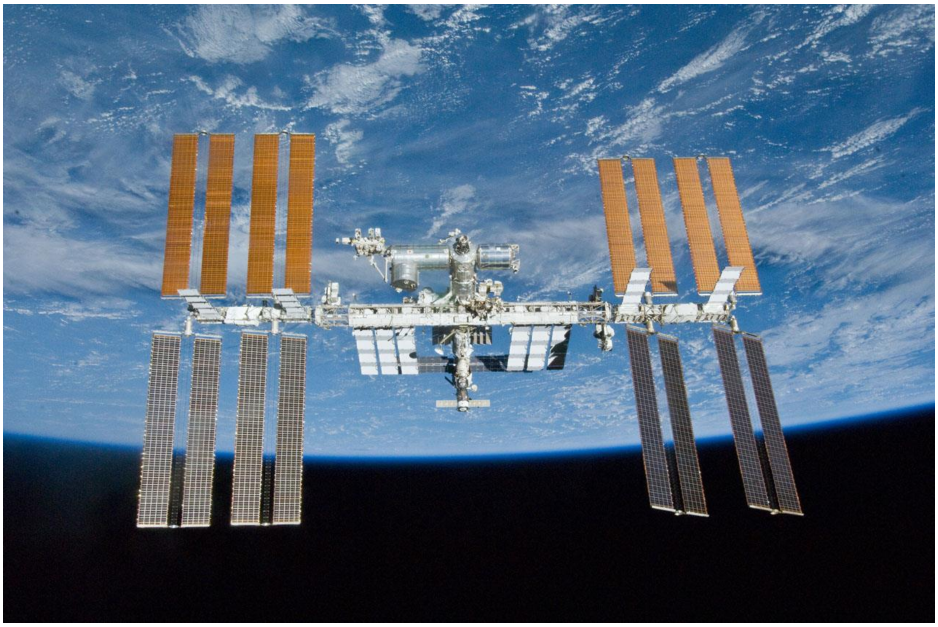


Photo credit https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-the-iss-58.html

The Brief

In the future, there may be a permanent base on the Moon and then eventually a base on Mars. For these settlements to be sustainable, many life support systems need to be integrated. It may be possible for a long-term orbital space station, once it is launched, to be completely severed from resources required from the Earth. How could this be achieved?

Maintaining a permanent orbit requires calculations based on well-known physics principles. If the orbital speed is too slow, the space station will spiral towards the surface and be destroyed through burning up due to friction in the Earth's atmosphere and possible ground impact. If the speed is too fast, then the space station may escape the Earth's gravitational pull and stop orbiting our planet altogether. The effect of gravity alters dependent on the altitude. It is only 9.8 m/s^2 when close to the Earth's surface.

Your team will:

1. Design life support systems for a long-term orbital station and then integrate them with each other.
2. Calculate the required orbital velocity at a specific altitude.

NASA - Long-Term Challenges to Human Space Exploration
https://www.nasa.gov/centers/hq/library/find/bibliographies/Long-Term_Challenges_to_Human_Space_Exploration

NASA Education – Escape velocity https://www.nasa.gov/audience/foreducators/k-4/features/F_Escape_Velocity.html

The Student Activity

Part A – Space Systems Engineering (team task)

Three systems perpetually necessary for immediate life support are:

- water supply
- food supply
- constant internal atmosphere, especially regarding replenishing oxygen and removal of carbon dioxide

These cannot be continually shipped in from Earth, so it is crucial they are self-sustainable for long term survival.

In your groups, each person will:

a) Individually research and design one of the three different life support aspects listed above. Each of them needs to be designed at least once by a group member. Show specific details for each system. For example, if considering water:
   - Where will the water be necessary?
   - What system of pipes are shown in your plans?
   - How will the water be moved from place to place?
   - What energy source may be used to move or pump the water?
   - How will the water be recycled?
   - How are wastes removed from it?
   - How can the wastes be made useful? Note – some aspects may lead to combining beneficially with other systems.

b) Act as a Space Systems Engineer on a team to show how the three systems *designed by your team members* can be integrated effectively. Include a detailed 'floor' plan drawing including passageways, piping, wiring etc. This may include modifying any of the support systems from part a).

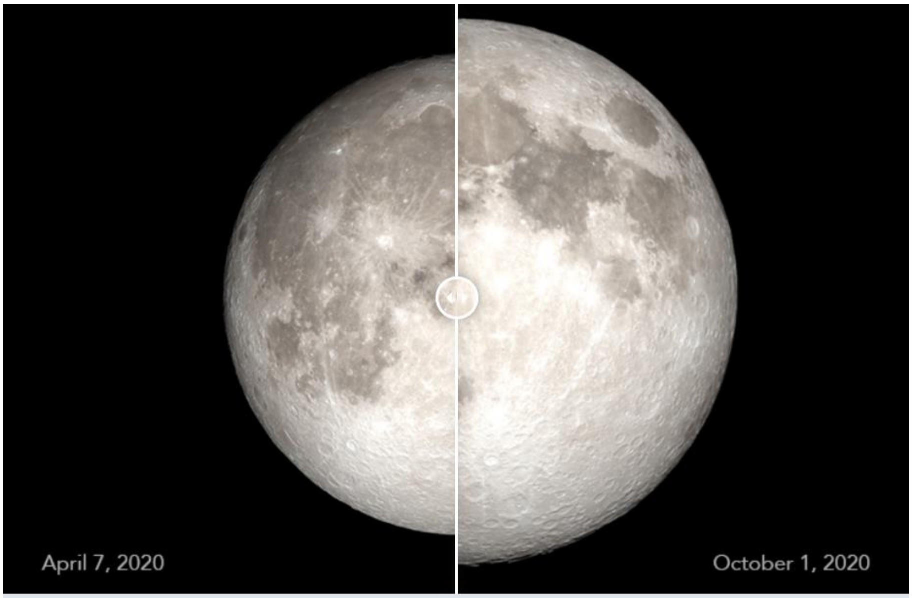
What other essential systems need to be designed? Think especially of what is needed to make the other three systems above work properly. Name at least two other systems that are essential to missions and/or sustaining the wellbeing of someone living in space for years at a time. Incorporate this aspect into your design simply as distinct modules that are added at certain locations, justifying the placement with reasons where possible.

Think of energy supply, communications, lighting etc.

Part B – Satellite Orbit

The pathway of a satellite orbit is the shape of an ellipse. The Earth is not necessarily the centre of the ellipse. Therefore, there is a location when a satellite is at its closest (perigee) to Earth or farthest (apogee) from Earth.

The Moon for example, has a difference in distance of more than 42,000 km between these two locations. Use the animation and slider bar comparison at https://moon.nasa.gov/moon-in-motion/phases-eclipses-supermoons/supermoons/ to see how 'supermoons' form. In the following activity you will calculate the orbital height by finding the average between the perigee and apogee distances.



Not-So-Super Moon vs. Supermoon

Credit: NASA's Scientific Visualization Studio

There are three broad categories of orbital altitudes:

Category	Altitude ranges (km)
Low Earth orbit (LEO)	200 – 2,000
Middle Earth orbit (MEO)	2,000 – 35,586
Geostationary Earth orbit (GEO)	35,586 – 35,986

It is essential to maintain a stable, perpetual orbit. We can examine data to calculate optimal speeds at different altitudes. Satellites need to go fast enough at their specific altitudes to counter the effect of gravity from Earth.

Open the Database (Excel format) of the following website
https://www.ucsusa.org/resources/satellite-database

Note: The relevant parts for this section are columns A, I, L, M, P and R.

Find the satellite ABS-4 (ABS-2i, MBSat, Mobile Broadcasting Satellite, Han Byul)

1. Calculate the:
   a) estimated altitude in *metres* by taking the average between the perigee and apogee figures
   b) Circumference (C) of orbit in metres, using C = 2πr (where radius = radius of the earth + the altitude of the satellite)
   c) period (T) of the satellite in *seconds*
   d) speed (v) of the satellite in m/s using v = C/T
2. Repeat step 1 again but using the data from any LEO satellite
3. What can you infer about how the altitude of the satellite determines the orbital speeds required?

Calculation sample

1a) The average radius of the Earth is 6,371 km.

Estimated altitude = (35780 + 35793)/2
= 35 786.5 km
= 35 786 500 m

1b) Radius (r) = altitude + radius of the Earth
= 35 786 500 + 6 371 000
= 42 157 500 m

C = 2πr
= 2π x 42 157 500
= 264 883 385 m

1c) T = 1436.1 x 60
= 86166 s

1d) v = distance/time
= C/T
= 2 640 883 385/86 166
= 3 074 m/s

3. The higher the altitude the slower the orbital speed. A Low Earth Orbit satellite (ISS) would have an average orbital period of around 90 minutes. Whereas a satellite in Middle Earth Orbit (Navstar) would have an average orbital period around 9 hours.

Compare your value to using the Earth Orbit Calculator application below https://www.omnicalculator.com/physics/earth-orbit. Select ‘Speed of the satellite’ and enter the value of 35,786.5 km for ‘Height’ (do not include any spaces) that was our estimated altitude.

4. Calculate the percentage error based on the following calculation. Use real velocity as the value found on the Earth Orbit Calculator and the calculated velocity from your calculations above.

$$\% \text{ Error} = \frac{(\text{real velocity} - \text{calculated velocity})}{\text{real velocity}} \times 100$$

$$= [(3075 - 3074) \div 3075] \times 100$$

$$= 0.03\ \%$$

How close is your calculated value to the Earth Orbit Calculator?

Very close, as the percentage error was only 0.03%

Most GEO satellites have a period range between 1436 and 1437 minutes regardless of mass. Whereas most LEO satellites have a period range between 92 and 99 minutes.

Examine rows 8 and 63, comparing satellites with 'dry' mass that have a difference of more than 1000 kg. The altitude difference is negligible compared to the ~35 800 km orbital altitudes.

What can you infer about the effect of mass on satellite orbit speeds?

Mass has little to no effect on the orbit speed.

Calculating apparent gravity

We can use the orbital speed to calculate the effect of Earth's gravity on the satellite at different altitudes.

At ground level, gravity on Earth is 9.81 m/s^2. As altitude is increased, gravity decreases. Apparent gravity can be calculated based on the formula

$g_{app} = v^2 \div r$ where

g_{app} = apparent gravity

v = orbital speed (m/s)

r = distance from the centre of the Earth (m)

5. Calculate the apparent gravity of a satellite orbiting at 35 786.5 km above Earth's ground level. Use Earth radius = 6371 km.

$g_{app} = v^2 \div r$
$= 3074^2 \div (6\,371\,000 + 35\,786\,500)$
$= 0.22$ m/s^2

Compare your value to using the 'Gravity Acceleration by Altitude' application below https://www.vcalc.com/wiki/KurtHeckman/Gravity+Acceleration+by+Altitude

Enter 35 786 500 (without spaces) for the altitude. Then click on the field located at the website (image only shown below) to get a result.

Note: The calculation used in the app (see website) uses a different formula to the one you used, which uses the orbital velocity calculated earlier.

Research Tasks

1. Find out what chemical can be used to determine the presence of carbon dioxide and write a word equation for the reaction.

   How can this be useful in preventing the build-up of too much carbon dioxide?

   Define the term precipitate.

2. Green plants need light to photosynthesise to produce food and oxygen by using water and carbon dioxide. On Earth, we can grow plants outdoors in the sunlight.

   In space, there are harmful types of radiation besides light and heat that are dangerous to life.

   a) Research the names of these types of radiation and the effect they would have on humans and plants.

   b) If glass and plastic are unable to block the harmful rays, what alternatives can you think of to provide light for plants to grow?

3. Other than STEM based careers, research other careers that exist in the space industry. For example, lawyers and communications experts. Talk to your careers advisor for ideas.

Australian Curriculum

Science

Model the rearrangement of atoms in chemical reactions using a range of representations, including word and simple balanced chemical equations, and use these to demonstrate the law of conservation of mass (AC9S9U07)

Identify patterns in synthesis, decomposition and displacement reactions and investigate the factors that affect reaction rates (AC9S10U07)

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)

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)

Apply the exponent laws to numerical expressions with integer exponents and extend to variables (AC9M9A01)

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

Use mathematical modelling to solve practical problems involving direct proportion, rates, ratio and scale, including financial contexts; formulate the problems and interpret solutions in terms of the situation; evaluate the model and report methods and findings (AC9M9M05)

Design Technologies

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)