Introduction

Who is this course for?

This is a course for young people who are learning science, mathematics, engineering and technology (STEM) in a way that combines both practical and theoretical elements. It teaches some fundamental ideas in maths and science through the story of a space agency and each lesson students must solve a problem and complete a practical exercise.

What will you learn?

Lesson 1:

- Rockets
- Gravity
- Energy
- Fuel
- The important role of minimization in engineering problems
- Composite materials
- The new space economy

Lesson 2:

- Aerofoils
- The atmosphere
- Aeroplanes
- Speed/distance/time

Lesson 3:

- Forces on a rocket
- Hydrogen
- Combustion
- Averages
- Vacuum of space

Lesson 4:

- Orbits
- Earth’s size and shape
- Speed/distance/time
- Circumference of a circle
-

Lesson 5:

- What do humans need to survive?
- Gases
- Space suits and space stations
- The future of space

Why will you learn it?

The real world isn't split up into simple subjects like school is. In school we break up science from maths, languages from arts to make them easier to understand and teach. However, in this class we want to teach you some important mathematical, scientific and technological concepts but also show you how they are linked together. We also want to set off a fascination with space and aerospace. 120 years ago the first planes were being built and tested, but could only transport one or two people a few hundred metres, at a height of a few metres above the ground. On top of that, they would often crash. Now there are often more than 1 million people in the sky in almost 10,000 planes. Some people today predict the same thing is going to happen with space. Now there are simply a few people that occasionally visit space, maybe in 100 years there will be hundreds of spaceships taking off and landing every day. We want you to have the best chance to be part of this exciting new development in human technology - and this course is perhaps your first step.

Explanation of course structure

The course is made up of six lessons, which each involve a practical activity, watching a video and a written or theoretical exercise. The final lesson involves students using their imagination to write their own chapter in the future of space. Each lesson starts with a problem, and ends with its solution.

Premise for students:

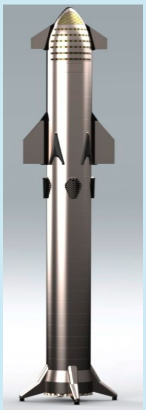
The year is 2035, and you have just started your dream job as a rocket scientist at the Phoenix Space agency. A lot has happened in the progress of space travel in the last decade - many people live in space in orbit around earth, and some people even live permanently on far away Mars and on the Moon. The Phoenix Space agency is a organisation that was inspired by the dream of the Lebanese Rocket Society in the 1960s - to give the Levant its own independent space agency. We're planning to run the world's first space hotel and you are part of the team that will design and test parts of the mission. In the space hotel guests can view the earth, take part in scientific experiments, and get prepared for journeys into deeper space.

During this experience of planning the journey and experience in space, you will learn what a scientist and engineer really does - a mixture of problem-solving, investigation and constant learning. At the end, you will present your mission plan and explain the solutions to each of the problems you have faced along the way.

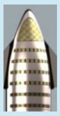
Lesson 1 : Getting off the ground

Introduction

Over the last hundred years, human beings have tried a number of ways to get close to space: balloons, guns, planes, but so far the only real way we have found to reach far beyond earth is the rocket. We will use a rocket to travel far from earth to reach outer space and move around the earth in a circular path called an orbit. Reaching orbit comes with a major difficulty: the amount of fuel that is required to get something flying that quickly to escape earth is absolutely huge. Space isn't that far away, it's probably closer than the distance to the capital city of your country, but it takes so much fuel to go straight up - think about how much more tiring walking up 100 steps is compared to walking forwards 100 paces. The best rocket at the moment - the SpaceX Starship - has a total mass of 5,000,000kg, but the bit of the rocket which actually makes it to orbit but the **payload** is only 150,000kg.



Rocket



Payload

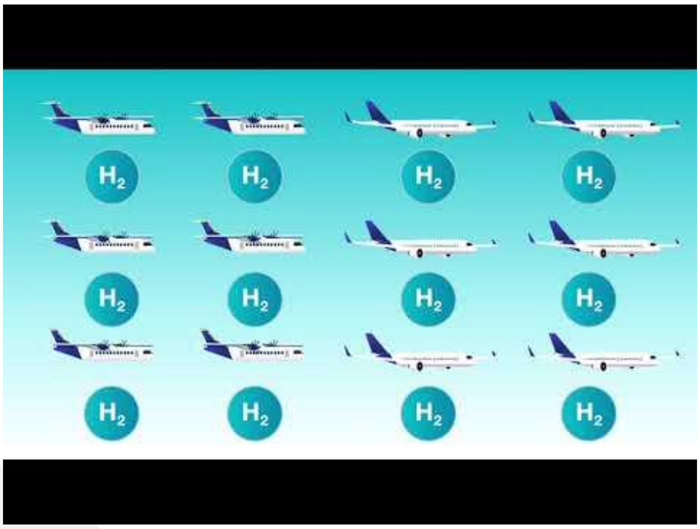
All of the rest is fuel and engines!

Almost all the rocket is fuel and engines. To make the most of our trip, we want to carry as many people and things up to the space hotel as possible, and we do this by saving weight - trying to make everything: the rocket, the spacesuits, the wings, the fuel, the engines etc. **as light as possible.**

Problem

Every kilogram takes an enormous amount of fuel to get to orbit and we want to lift as many adventurers and as much material to our new hotel as possible. What materials can we use so that our payload is as light as possible?

Composites Materials



1. Watch the video

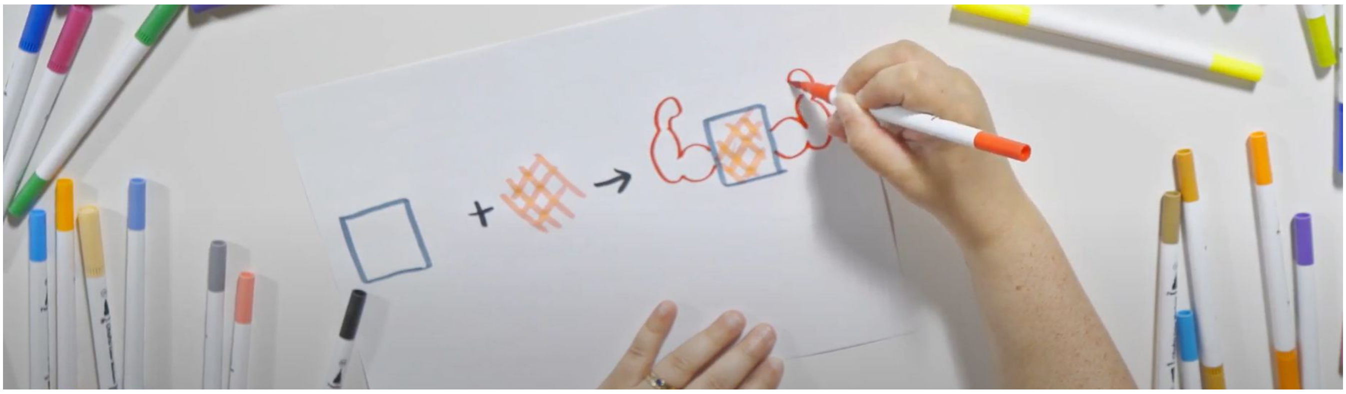
Students will watch the video and take notes and write down questions for the teacher, and will fill out the question sheet below:

1) What is a composite material?
2) What were the components of the composite material in the video?
3) How are composite materials useful to us?
4) What do you think you could use a composite material for?
5) Could a composite material have more than two materials in it?
6) What else would you like to know about composite materials or their uses?

2. Activity! Making Composite Materials

Students can also make their own composite materials: these can be pykrete, plastic ice, mud bricks, honeycomb structures.

What are composites?



The science question in this video

This video deals with composite materials. Starting with questions about the materials used to make aeroplanes, we find out about composites and try to make some.

Composite materials are used in car chassis, aeroplanes, wind turbine blades… In fact, they're pretty much everywhere!
There are many different types of composites, some of which are adapted to industrial scale manufacture while others are reserved for cutting-edge technology and so on.
One major area of application is aeronautics because, by combining two different materials, you can produce a strong and lightweight composite.

The principle is always the same. Combine two different materials in such a way as to create a new material with properties that none of the originals had on their own.

A composite consists of (at least) two materials:

- The **reinforcement**: the 'skeleton' of the composite material e.g. rods or fibres arranged in a specific manner.
- The **matrix**: the material around the skeleton e.g. resin, concrete or metal.

Some examples!

Reinforced concrete: Concrete (the matrix) is poured around metal rods (the reinforcement).

Cob: Used to make walls and fences. The matrix is subsoil clay mixed with water, while the reinforcement consists of natural fibres such as straw, hay and horsehair.

Related experiments: Paper is stranger than you think!

First experiment

You will need:

- Several sheets of paper.

Most sheets of paper are rectangular, so have a long edge and a short edge.

1) Tear a sheet from the middle of a short edge and watch how it tears.
2) Now tear another sheet from the middle of a long edge and watch again.

You may have noticed that in one direction (usually when tearing from the short edge) the tear runs straight, while from the other edge it curves as though unable to go straight.

Second experiment

You will need:
- several sheets of paper;
- a pair of scissors.

Take a sheet of paper and cut out two rectangular strips, each measuring 10 cms long by 2 cms wide (approx. 4 in x 1 in).
1) Cut the first strip parallel to the long edge.
2) Cut the second strip parallel to the short edge.
3) Place the two strips precisely on top of one another and hold them together, horizontally, by pinching the short edges between your thumb and index finger. Watch what happens.
4) Turn your wrist 180 degrees so that the top strip becomes the bottom strip and vice versa. Watch what happens.

You will probably notice something changes!

One way, the bottom strip separates completely from the top one by bending downwards.
The other way, the bottom strip doesn't separate from the top one and the two strips bend downwards together.

What do you think happened?

Paper consists of fibres, which generally run in one specific direction. So each sheet of paper will tend to tear along the fibres (first experiment) and will bend more easily in one direction than the other (second experiment).

Challenge!

Can you name five living things that have provided the source of inspiration for new materials?

If you need help, search the internet for:
- biomimicry;
- biomimetic materials.

3: Extension problem

This optimization problem, again about making maximum use of the mass we have saved by using composite materials. Optimisation problems are ones we face every day: given some constraint(s), how do we maximise another value? Explain how this is an essential problem in almost all aspects of practical life: you have a constraint (money available to spend, time, personnel, space, power etc.) and you want to maximise some other quantity (money earned, time, attendants, distance, efficiency).

Our rocket is going to head to the space hotel. Many people, guests and staff, in the hotel want different items, and each of these items takes up mass in the rocket. It has been decided that each item comes with a given 'utility', although you can call this 'value, usefulness etc.'.

The goal is simple: given a set of items, which of them will you take to maximise utility while staying below the mass?

Simple version (Only four items, only 1 allowed of each, maximum mass allowed 390kg)

Item Name	Mass	Utility
Extra spacesuits	250kg	3
CO2 Recycler	200kg	4
Robotic telescope camera	180kg	2
Milkshake maker	170kg	1

Optimum solution (for teachers):

You bring a CO2 recycler and a telescope - this gives a total utility of 4 + 2 = 6, with a total mass of 200 + 180kg = 380kg, which is below the total mass.

Harder version (more items, more mass, for some items multiple items allowed):

Mass 700kg

Item Name	Mass	Utility	Number allowed
Home cinema system	400kg	10	1
Solar panels	250kg	30	1
CO2 Recycler	200kg	42	1
Robotic telescope camera	180kg	23	2
Extra spacesuit	250kg	11	unlimited
Helper Robot	500kg	5	unlimited
Radiation monitor	200kg	2	unlimited

Optimum solution (for teachers):

CO2 Recycler + 2 Telescopes + (42 + 46) = 560kg with 88 utility

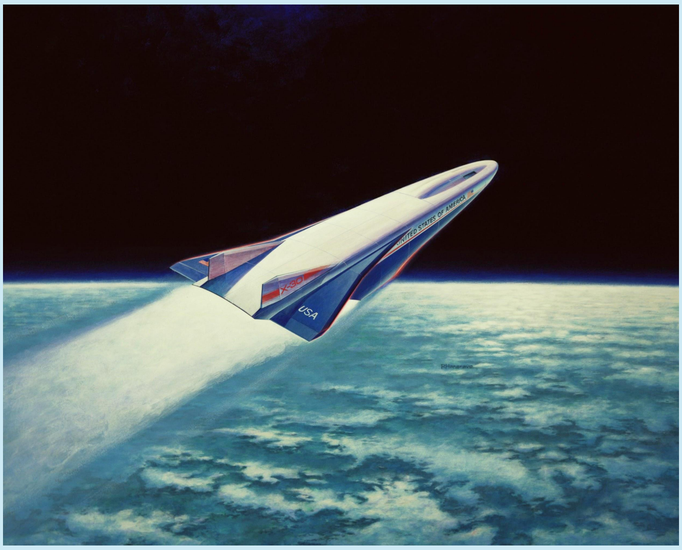
Solution and review:

Students should review the idea that we can use composite materials which are incredibly strong for their mass to make sure our rocket can have as much mass left over for the payload. By choosing correct materials we can make all sorts of things possible. Students should also understand that engineers are always trying to solve problems that involve maximizing one quantity while minimizing another. Students should understand that mathematics is crucial to understanding the modern world of science and engineering.

Lesson 2: Scraping the sky

Introduction

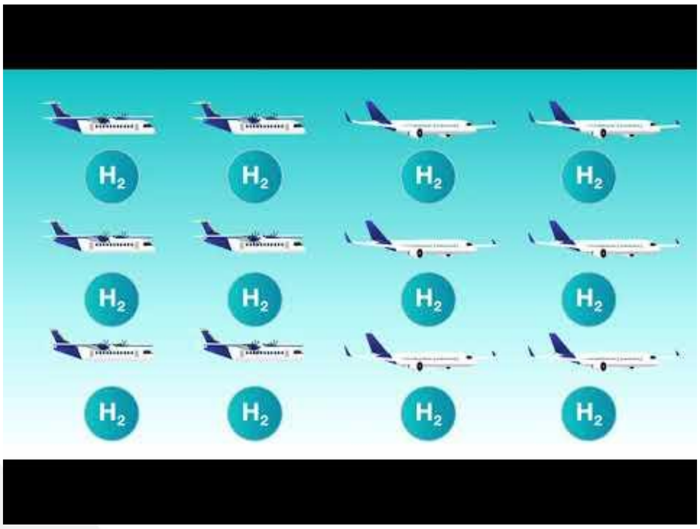
As you already know, it takes a lot of fuel to carry something straight up to space, and we tried to use composite materials to make our spacecraft as light as possible. What if we could carry our payload closer to space without turning on the rocket motor? At some point we have to turn on the rocket motor because the wings will stop working when the atmosphere becomes too thin. The official starting point of space is 100km. The trick is to combine a rocket and a plane into one vehicle: a space plane.



Problem

We need to understand how planes stay in the sky at the edge of the atmosphere, and how can we get it as high as possible to save fuel on the rocket?

Aerofoil



1. Watch the video

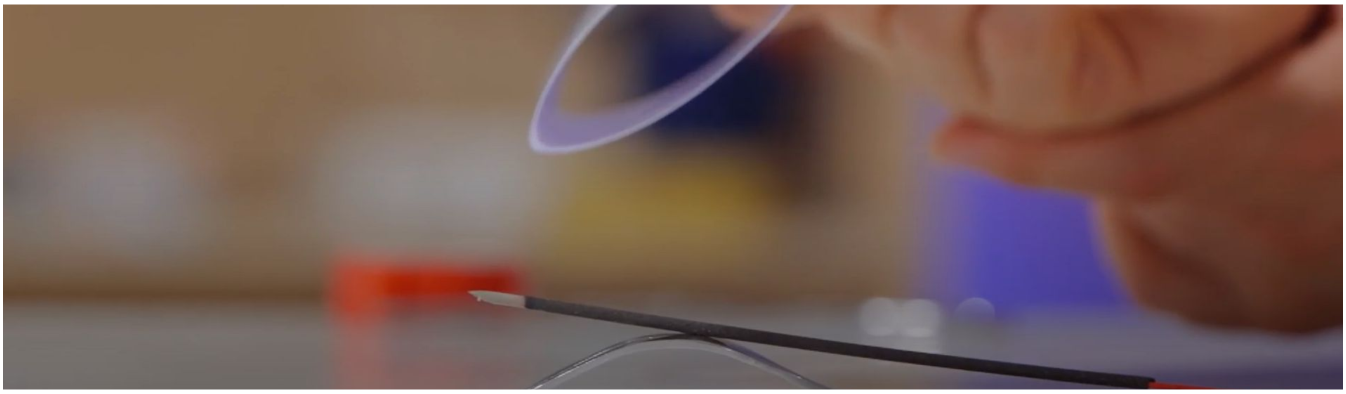
Students will watch the video and take notes and write down questions for the teacher, and will fill out the question sheet below:

1) Why wouldn’t an aerofoil work in space?
2) Draw the shape of an aerofoil from the side.
3) How can we make it easier to see the flow of air?
4) How does the shape of an object affect how air flows around it?
5) How do wings push objects upwards?
6) Would an aerofoil also work in a liquid, like water?

2. Activity!

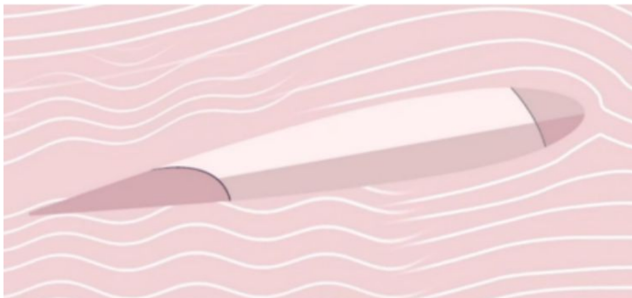
Making an aerofoil and viewing the airflow

How does air flow around a wing?



The science question in this video

This video studies the following diagram:



It's the standard diagram used to show how air flows around an aeroplane wing. The aim of the video is to test the diagram experimentally.

It may seem strange at first that the air flowing in from the right and passing over the wing is deflected to follow the shape of the wing, as though 'stuck' to it.

But if you check, using an incense stick and a wing shape made out of paper, you'll see that's exactly right.

If you look closely above the wing, the diagram shows two zones:

- one zone above the first half of the wing, where the airflow follows the wing shape;
- an ensuing zone where the air appears to become 'unstuck' and starts to get a bit more turbulent.

These are two crucial types of flow to be considered in wing airflow.
The first is called **laminar flow**. Aeroplanes are designed to create as much as possible of this type of airflow, since it ensures maximum lift and safety. Laminar flow is where the air follows the wing contours.
The second is called **turbulent flow**. While turbulent flow cannot be eradicated, we generally try to reduce it as much as possible. This kind of flow causes the air to become turbulent and may create vortices that greatly limit an aircraft's ability to fly.

An aeroplane's ability to fly is closely related to these flow types. Firstly, through the concept of **lift** (the upwards force exerted on the wing that 'carries' the aeroplane) and secondly through the concept of **drag** (the force that opposes an aeroplane's motion through the air).

If an aeroplane gradually increases its pitch (points its nose upwards), at a given point the airflow will become purely turbulent and the aeroplane will stall and stop flying.

Whether the airflow over a wing or other obstacle is laminar or turbulent depends mainly on the shape of the obstacle. This explains why a lot of studies, calculations and experiments are done to determine the best possible wing shape.

Related experiment: The flying ping pong ball

You will need:
- a ping pong ball.

You're going to have to blow vertically, straight up!
So:
- Put your head back so that you're looking straight up.
- Hold the ping pong ball between your thumb and index finger and position it a centimetre (half an inch) away from your mouth.
- Start blowing. Imagine that you want to produce a very fine, powerful, vertical and constant stream of air.
- Once you've started blowing, let go of the ball.

With a bit of practice, you should be able to keep the ball in the air for several seconds (until you run out of breath!)

If you have trouble, you can try using a hairdryer instead.

What do you think happened?

If you watch the ball's movements closely, you will notice that it seems to be stuck in the airstream coming from your mouth. It looks like it's trying to escape to one side before being brought back to the centre, and then to the other side where it is brought back to the centre again, and so on. It wobbles from one side to the other but stays in the airstream, provided the flow is constant.

What is interesting about this experiment is the fact that the ball is continually brought back to the centre of the airstream. When it moves to one side, the air is much faster on the airstream side than on the other side of the ball. This difference in speed is the reason why the ball returns to the centre of the airstream.

Challenge!

Is it possible to make objects fly or levitate using different methods from those used by aeroplanes?

If you need help, search the internet for:
- levitation;
- acoustic levitation;
- magnetic levitation;
- electrostatic levitation.

3: Extension problem

As this lesson deals with the movement of air, and aeroplanes through the atmosphere, it is important to introduce a mathematical way of describing the movement of objects: speed.

$$1)\quad Speed = \frac{distance\ travelled}{time\ taken} = distance\ travelled \div time\ taken$$

This gives us a number that we can use to accurately compare how quickly things are moving. This equation can also be rearranged to make the following two equations (you may want to give this as an exercise to the students).

$$2)\ Distance\ travelled = speed \times time\ taken$$

$$3)\ time\ taken = \frac{distance\ travelled}{speed} = distance\ travelled \div speed$$

Use these formulae to answer the following questions:

Easy question:

Q) What is the speed of a plane that moves 200m in 5 seconds?
A) 40m/s

Medium question:

Q) Which is faster, a plane that travels 2.3km in 42 seconds, or one that travels 2600m in one minute?
A) 2.3km in 42 seconds.

Hard question:

Q) A spaceplane speeds up as it turns on its engines. In the first second, it travels at 1m/s, in the second second it travels at 2m/s, at the 3rd second it travels at 3m/s. After how many seconds will it have travelled 10,000m?
A) Approximately 140 seconds.

Solution and review:

We now know that by adding wings to our rocket we can turn it into a spaceplane. Wings have a shape known as an aerofoil and this causes air to flow around it and be pushed downwards. This leads to an aerofoil being pushed upwards ‘lifting’ the plane. This can help us save on fuel as the engines required to lift a plane slowly to the edge of space (100km) do not need as much fuel - remember everything is about saving mass.

We also learned that scientists and engineers describe how things move by using the mathematical description of speed.

$$Speed = \frac{distance\ travelled}{time\ taken} = distance\ travelled \div time\ taken$$

If things have **high speed,** this means they travel a **long way in a short amount of time.**

Lesson 3: Ignition!

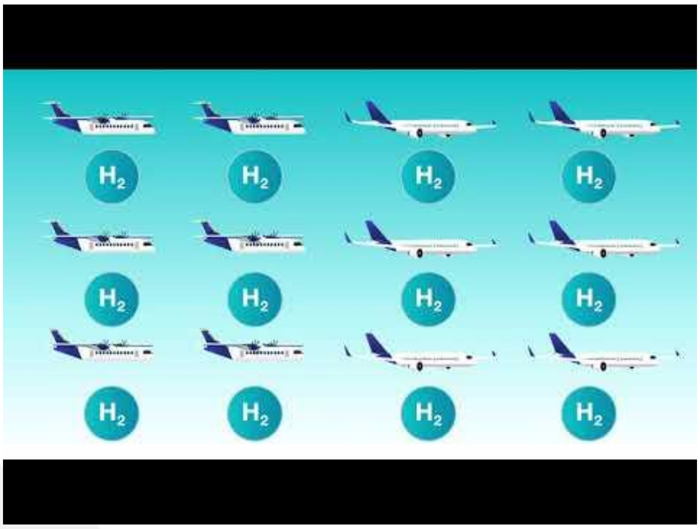
Introduction

So far we've been talking about saving fuel - but we haven't actually explained what fuel our rocket needs. Many vehicles and machines use different fuels: the fires in some of our homes use wood, old trains use coal, ships use thick oil, our stoves can use natural gas, and our cars use a flammable liquid called gasoline. We've carried our rocket to the edge of the atmosphere using aerofoil wings, but now we need a fuel that can release all of its energy quickly (in only a few minutes) to get the payload into space. We need to choose the best fuel.

Problem

Our team has suggested we use a **flammable gas called hydrogen** like the rocket in the picture above. We need to understand out of all the fuels, why is hydrogen the best fuel?

Hydrogen



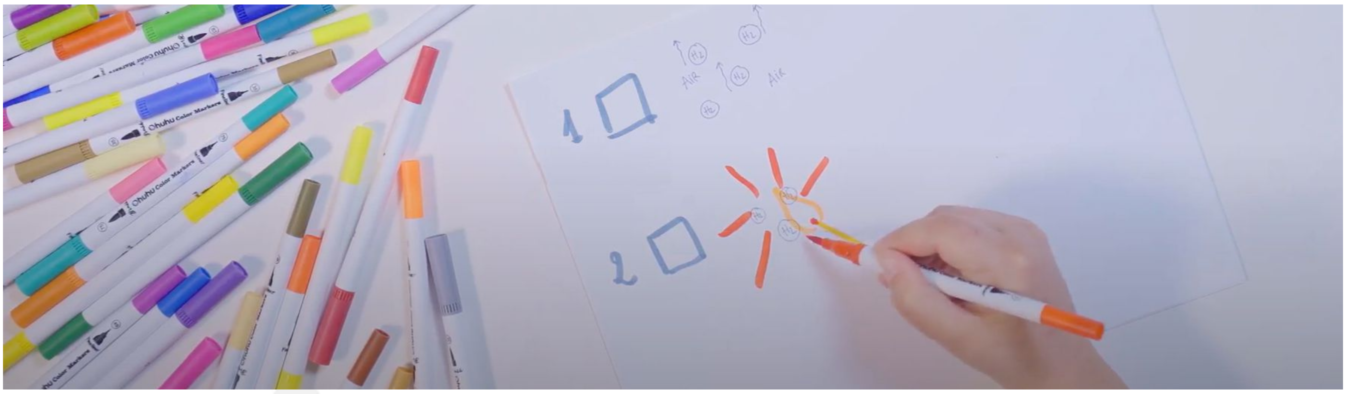
1. Watch the videos

Students will watch the video and take notes and write down questions for the teacher, and will fill out the question sheet below:

1) Does hydrogen burn?
2) What raw materials can hydrogen be made out of?
3) How can we test if a gas is hydrogen?
4) What are some of the uses of hydrogen?
5) Hydrogen is a chemical - does that make it poisonous?
6) How many atoms in a hydrogen molecule?
7) What does hydrogen need to be mixed with to burn?

2. Activity! Making hydrogen fuel

How do you produce hydrogen?



The science question in this video

In this video, Paul realises that hydrogen gas can be used to power vehicles and discovers how to produce this gas and what its characteristics are.

By putting a battery in water, Paul unwittingly creates a chemical reaction known as water electrolysis. The water (H20) molecules are split by the electric current as it passes through the water, resulting in the formation of two distinct gases at each end of the battery: dihydrogen (H2 or hydrogen gas, commonly known as hydrogen) at one end, and dioxygen (O2) at the other. Twice as much dihydrogen is produced as dioxygen, which explains why the hydrogen bubbles are so much easier to see and collect. This same principle is used on a massive scale in special power stations, to produce large quantities of dihydrogen.

The reverse process is used in hydrogen-powered vehicles. The reaction created by combining dihydrogen with dioxygen powers the engine and drives the vehicle, emitting only water vapour.

Paul then conducts a simple experiment to check the two main characteristics of dihydrogen:
- Because it is less dense than air, it rises, allowing it to be collected inside a small container.
- It is highly inflammable, so capable of generating an explosion.

Related experiment: Another way to produce oxygen

Careful! This experiment uses hydrogen peroxide, a liquid that can burn the eyes and skin. Always have an adult present for this experiment and, if possible, wear safety goggles and gloves when handling things!

You will need:

- a bowl;
- an empty bottle;
- a packet of instant yeast;
- concentrated hydrogen peroxide, ideally 6% (dangerous product, please use with care!);
- washing-up liquid;
- a funnel;
- water;
- a mixing ustensil;
- a basin to conduct the experiment in.

1) Pour three tablespoons of lukewarm water and half a packet of instant yeast into a bowl and mix well until combined.
2) Pour about 15 cL of hydrogen peroxide into the empty bottle along with a small amount of washing-up liquid and mix gently without creating too many bubbles.
3) Place the bottle containing the hydrogen peroxide and washing-up liquid in the basin.
4) Using a funnel, pour the water and yeast mixture into the bottle.
5) Watch what happens. A large quantity of bubbly foam should form very rapidly. Be careful not to touch the foam because it is very hot!

Always get an adult to clean the equipment, and wash your hands thoroughly afterwards.

What do you think happened?

This experiment produces another chemical reaction that results in the production of large quantities of dioxygen (the gas inside the foam).
An enzyme (large molecule) in the yeast called catalase causes the hydrogen peroxide (H2O2) to split into two separate molecules:

- water (H2O), which remains in the liquid mixture;
- gaseous dioxygen (O2), which tries to escape but stays trapped inside the soap bubbles.

The catalase in this reaction plays a similar role to that of the electric current in water electrolysis. Both make it possible to split one molecule into two. This is known as disproportionation.

Challenge !

Can you make a vehicle that moves a short distance by itself without fuel or electricity?

If you need help, search the internet for:

- rubber band car;
- gas propulsion.

You can also watch the Propulsion video for more ideas!

How do you propel an object upwards?

The science question in this video

In this video, Maxime and Clementine try to understand different types of propulsion using things they already know about: helicopters and space rockets.

Their experiments show them there are several ways to propel an object to make it take off.

The first method they look at is **reaction propulsion**, which is used in both propeller systems and rocket launch systems. Reaction propulsion is based on **the law of action-reaction** or Newton's third law, which states that: "Any object A that exerts a force on object B is subjected to a force of equal magnitude in the opposite direction by object B."
→ As a propeller turns, it pushes the air downwards (action), which then propels it back upwards (reaction).
→ The gas ejected from a rocket pushes downwards (action), which then propels the rocket upwards (reaction).

This fundamental law also applies to other systems such as jet aeroplanes and propeller-driven boats, for example, enabling them to move forwards.

The second experiment explores another principle… If you increase the pressure applied to an object, that object will suddenly start moving due to thrust. So when the gas in a bottle is put under pressure, it pushes on the cork and ejects it upwards.

Related experiment: The water rocket

An adult must be present!

For more details on this experiment, see the following tutorial:
https://www.instructables.com/Pump-Rocket/
(Author: mikeasaurus sur le site Instructables ; License CC BY-NC-SA 4.0)

You will need:

- a rigid plastic bottle (ideally a soda bottle);
- a cardboard;
- scissors;
- a cork;
- a bicycle pump adapted for inflating footballs/basketballs.

1) Cut out three or four fairly large, identical rocket fins from the cardboard.
2) With the bottle pointing downwards, sticky tape your fins to the base, making sure they're placed perfectly symmetrically. The fins should extend beyond the bottle neck so that you can use them as a stand for your rocket (which will rest on them).
3) Stick the bicycle pump needle into a cork that is the same size as the bottle cap.
4) Pour some water into the bottle.
5) Push the cork with the needle into the neck of the bottle.
6) Taking the pump with you, move as far away from the bottle as possible (and certainly don't stand over it!)

SAFETY CHECK:
We're now going to start pumping up the bottle, which will take off without warning! It is therefore vital that:

- **an adult is present;**
- **the rocket is vertical;**
- **everyone present stays at least 1 m/3 ft away from the bottle and watches it all the way from take off to landing.**

7) Pump air into the bottle to build up pressure until it takes off all by itself! (Careful, you may get sprayed as it leaves!)

Now you can start again, varying how much water you pour into the bottle until you find the right amount to take your rocket as high as possible!

What do you think happened?

This experiment uses the principle of reaction propulsion. The air in the bottle is put under pressure using the bicycle pump. When the pressure reaches a certain level, the friction of the cork against the bottle neck is no longer enough to hold it. All of the air and water inside the bottle are suddenly ejected downwards, which propels the water rocket upwards.

Challenge!

Try to find a way of propelling a ping pong ball as high as possible, without using muscular force!

Got any ideas? Then go ahead and test them!

3: Extension problem

Mixing fuels problems:

Q: What happens if we try to burn hydrogen fuel without enough oxygen?
A: Fuels need to burn, or react, with oxygen to release heat and power things. Without oxygen the burning will stop.

To burn hydrogen, just like any other fuel, we need oxygen. For every 1 m^3 of hydrogen we need 3 m^3 volume of liquid oxygen.

Easy
a) What is the total volume of fuel and oxygen in a rocket that carries 300 m^3 of hydrogen?
A: 300 m^3 of hydrogen + 900 m^3 of oxygen = 1200 m^3 of fuel in total.

Medium
b) If 1 m^3 of hydrogen has a mass of 70kg, and 1 m^3 liquid oxygen has a mass of 1100kg, what is the maximum volume of hydrogen that can be completely combusted onboard a rocket with a maximum fuel mass of 40,000kg?

1 m^3 + 3 m^3 → 70kg + 1100kg = 1170kg. 40,000kg/1170kg = 34.2

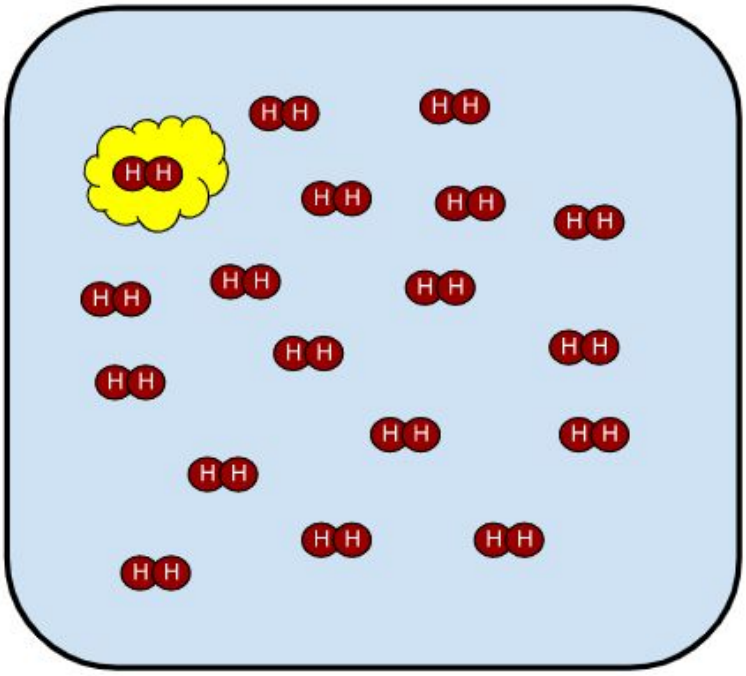
The answer is 34.2 m^3 of hydrogen.

How many 9V batteries to fill the tank?

We can also do a simple estimation for our engineers - often experiments don't start off very fancy or complicated: we do a simple experiment first to test if something works, or is practical. Place a glass over a 9V battery in the salt water and try to work out how long it takes for some easy fraction of the entire glass to fill up. Our rocket tanks are really big - the size of over 1,000,000 glasses. Work out how long it takes to fill up an entire tank.

Chain reactions

When the hydrogen gas pops, it actually undergoes a chain reaction - this means that the heat released from one small explosion causes the gas around it to explode, this carries on the reaction in a chain. Let's imagine we have a container with 1000 particles of hydrogen in it, mixed with oxygen. When each hydrogen molecule burns, it releases enough energy to set the other hydrogen molecules reacting and burning with the oxygen molecules around them. This is why it spreads so quickly like an explosion from a tiny spark. If each molecule of hydrogen causes three more hydrogen molecules to react, how many steps will it take to set off all 1000 particles of hydrogen? Let's begin this process together and you can finish this off.



Step number	Number of hydrogens ignited	Total burned
1	1	1
2	3	4
3	9	13
4		
5		
6		
7		

Solution and review:

Hydrogen is an excellent fuel to choose for our rocket. It can be produced from water and electrical energy, it releases a lot of energy very quickly and because it is a liquid or gas it can be pumped to our rocket.

Students should review the ideas that designing a rocket requires a lot of fancy calculations to do with fuels and ensuring a good balance, they should understand that fuels need oxygen to burn with them, and that chain reactions spread very quickly.

Lesson 4: Blast off!

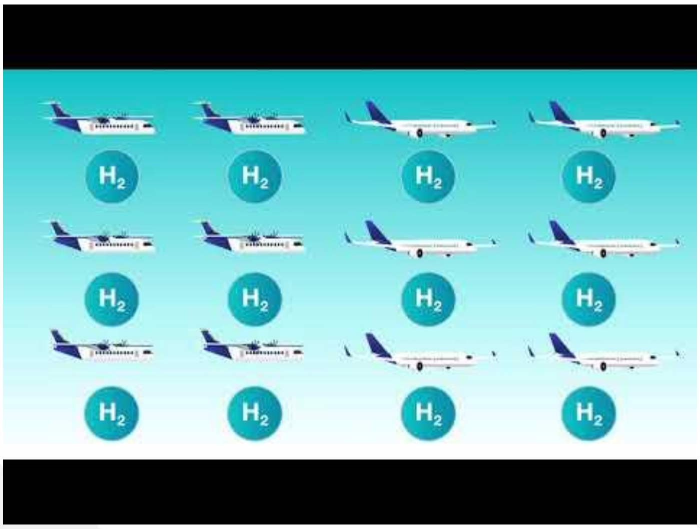
Introduction

The hydrogen fuel in our test rocket has begun burning and is releasing lots of energy. The rocket is speeding up and flying beyond the edge of the atmosphere into the vacuum of space - there is no air. If we are to control our space plane in space, we need to understand how rockets work, and how they are different from wings and normal engines.

Problem

How do rockets work even when there isn't an atmosphere?

Rockets



1. Watch the videos

Students will watch the video and take notes and write down questions for the teacher, and will fill out the question sheet below:

1) Why can rockets still work in space?
2) What is the name of the force that pushed rockets forwards?
3) Is gas inside the rocket higher or lower pressure?
4) Can rockets work in the atmosphere?
5) Are rockets always very large?

2. Activity! Making a rocket

How is fire used for rocket propulsion?

The science question in this video

In this video, Paul, Maxime and Clementine try to understand how fire is used for rocket propulsion. They experiment with a single flame before attempting to create a more directed flame that they think might be more effective.

The experiment in this video demonstrates that producing a flame is not enough to propel an object. The conditions to be met are actually far more complex. A rocket is first and foremost propelled into space by ejecting large amounts of gas downwards, which push it in the opposite direction. This is thanks to the law of action-reaction and is known as reaction propulsion.

The gas is produced by an explosion in the rocket engine and ejected at high velocity to produce very high thrust… and an impressive takeoff!

Related experiment: The match rocket

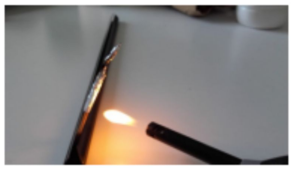
Careful, this experiment uses fire! It must be done with an adult present and outdoors, after checking that the match is not facing anything inflammable. Most importantly, make sure that no one walks in front of the match!

To better understand this experiment, search for 'match rocket' on the internet.

You will need:
- a match;
- a square of tin foil;
- a glass bottle;
- a lighter.

1) Wrap the top two-thirds of the match in tin foil, wrapping it around at least four times. The foil should sit tightly around the match with as little air inside as possible. It should also extend beyond the match head at the top.
2) Twist the foil that extends beyond the match head in order to seal it at the top. The foil should cover all of the match head.
3) Place the match on a fireproof surface (e.g. in the neck of a glass bottle), with the foil-wrapped head pointing upwards and towards an open space.

At this stage, make sure there's nothing inflammable in front of you and that nobody's about to walk past!



1) Bring the flame of a lighter under the tip of the match (where you would have liked to light the match).
2) Wait a few seconds, and watch the rocket go!

What do you think happened?

When the flame is brought near, the match head heats up and releases a large quantity of combustion gas which tries to escape. Since the only exit is out the bottom, when the gas suddenly manages to escape downwards, it propels the match upwards.

Challenge!

Can you make a rocket or propulsion system without using fire?

If you need help, search the internet for:
- Fireless propulsion
- Homemade rocket
- Fireless rocket

You can also watch the Propulsion video for more ideas!

3: Extension problem

Making DIY rockets

Equipment list:
-Safety matches
- Aluminium foil
- Cigarette lighter
- Bamboo skewer of similar
- Projector

Description:
Note, most of these rockets won't launch unless carefully constructed. Building them is very easy, but the wrapping part must be done properly and tightly.

Instructions:
Students should follow the video and instructions using the foil template included below. Once they make the matchstick rockets they should fire them, with adult supervision, in a place with no flammable material.

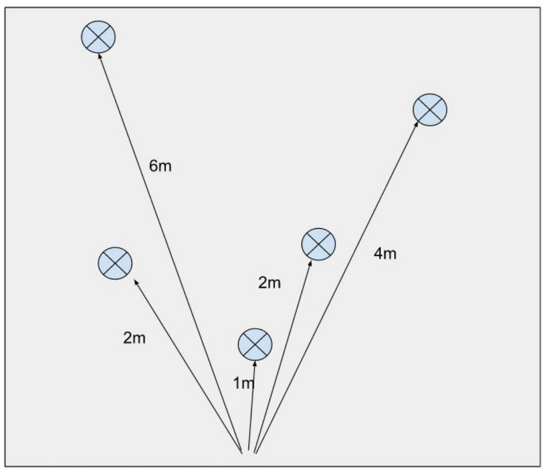
This requires a bit more supervision and discretion as the students will be playing with small amounts of flammable material. They should understand the science behind the chemical reaction producing a hot gas which is forced from the back of the rocket. These are not very difficult to make and don't really require the fins, but from experience I have found that the most important factor is to wrap the aluminium foil tightly properly.

https://www.youtube.com/watch?v=WFyKgmnCF-8
Matchstick rocket guide.pdf - see in Appendix 1

Rocket Maths activity

If several rockets are launched, students will notice that they don't always travel the exact same distance. We need a way to measure the distance that we could expect a random rocket to travel. Scientists do this all the time to make sure they can sum up and communicate all the information they collect. Students can make and launch at least three of their own rockets, or measure results from a teacher's demonstration.

The students can calculate two statistics: the mean, and the range.



Solution and review:

Students should understand that rockets work by pushing hot gases out one end, which pushes the rest of the rocket in the other direction.

Space is a vacuum - there is no air so rockets need to carry their own fuel.

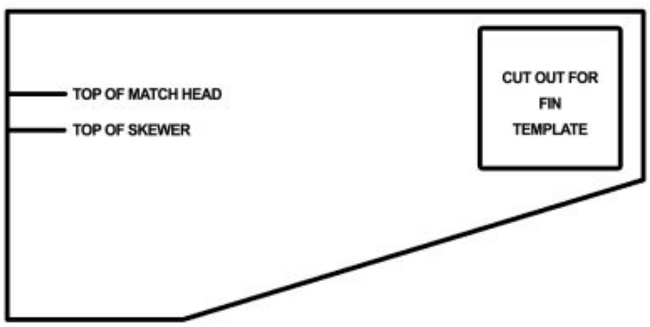
Rockets can be used for peace or for war

Averages help scientists to combine lots of data, and communicate them.

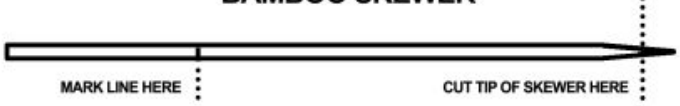
Appendix 1

MATCH BOX ROCKETS
(COMPONENTS TEMPLATE)

ALUMINUM FOIL FOR ROCKET BODY



BAMBOO SKEWER



NOTES:

Lesson 5: Hello World!

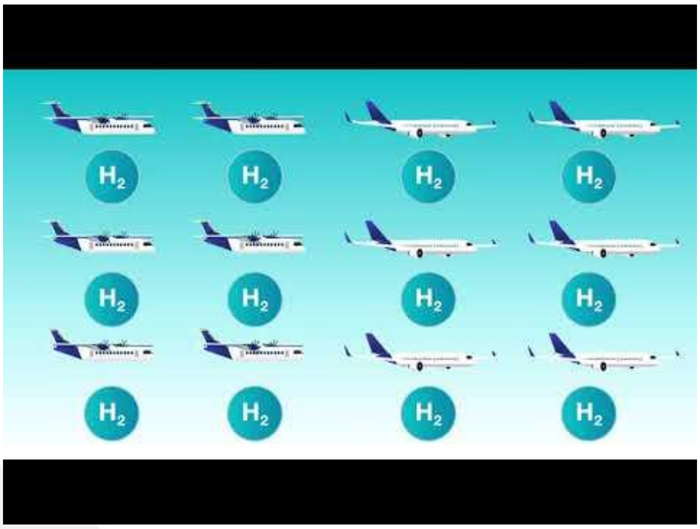
Introduction

Our test space plane has got enough speed and height to reach the space hotel, and now the burning hydrogen in the engines has stopped. But won't the earth pull it back down? We learn early on in life that what comes up must come down, but is this always actually true, and if not…

Problem

…why doesn't our space station just fall back to earth?

Orbits



1. Watch the videos

Students will watch the video and take notes and write down questions for the teacher, and will fill out the question sheet below:

1) How many kilometres an hour does a satellite in low earth orbit travel?
2) What force causes objects to fall?
3) What do we call the circular path that objects travel around under objects due to gravity in space?
4) If objects are too slow, will they orbit? If not, where will they end up?
5) If objects are too fast, will they orbit? If not, where will they end up?
6) Are there any natural objects that orbit the earth?

2. Activity! Making own orbit

How are satellites launched?

The science question in this video

This video looks at how satellites launched from the Earth are then placed into orbit around the Earth.
First, it's worth pointing out that the word 'satellite' doesn't refer solely to artificial satellites. Our moon, for example, is a satellite of the Earth!

Satellites in orbit
When a satellite approaches the Earth, it is affected by its gravity. The further away from Earth it is, the weaker the gravitational pull.
If a satellite moves too far away, it will be unable to remain in orbit.
But it's not just about gravity! If so, the satellite would fall back to Earth (provided it wasn't too far away), just like us when we jump off a diving board, for example.
So something else is required… Speed!
Imagine a salad spinner. When you turn it, the water is projected to the sides.
A similar thing happens with satellites. They must be launched at high speed to avoid falling back down and in order to orbit the Earth. But launch them too quickly and they go too far and drift off into space.
So for a satellite to orbit the Earth, you need to find the right balance between height and speed.

Possible orbits
It's this balance between a satellite's speed and its altitude that determines its movement around the Earth.
If a satellite exceeds the speed limit of 11.2 km/7 miles per second then, regardless of its altitude, the Earth's gravitational pull will no longer be enough to hold it and it will escape into space.
For any given altitude, there is a very specific speed or velocity that enables a satellite to orbit the Earth in a circle. It is at this velocity that the satellite must be launched to obtain a circular orbit.
For example, a satellite placed in circular orbit at an altitude of 300 kms/186 miles needs to have a velocity of nearly 8 km (5 miles) per second! Any faster or slower and its orbit will no longer be circular but elliptical!

Orbiting satellites
So how are satellites orbited?
It's the launcher/rocket that:
- takes off;
- climbs to the exact altitude where the satellite is to be orbited;
- starts orbiting the Earth at the velocity required by the satellite;
- finally, releases the satellite at precisely the right altitude and velocity!

Related experiment: The winner's pool table

Fancy making a pool table that lets you win every time?

You will need:
- a piece of cardboard;
- two thumbtacks;
- a piece of string;
- a pencil;
- two marbles;
- a shoelace.

1) On the sheet of cardboard, mark two points about 20 cms/8 in apart.
2) Cut a piece of string 28 cms/11 in long.
3) Tack each end of the string to the points drawn. The resulting attached string should hang loose unless you make it taut by stretching it out to the side.

We will now use this device to draw something called an ellipse.

4) Use the tip of your pencil to pull the string out to one side until taut.
5) You can now start drawing. Keeping the string taut with the tip of your pencil, draw an ellipse by moving the pencil and going around the thumbtacks (at one point you will need to lift and reposition your pencil).
6) Once you've drawn your ellipse, you can remove the string and thumbtacks.

And there you have it! A pencil-drawn ellipse. Now for the sides of the pool table.

7) Glue a shoelace onto the cardboard, following the outline of the ellipse.

Your pool table is ready!

Next:
8) Place a marble on each thumbtack hole.
9) Launch one of the marbles in a straight line in any direction.
10) Watch what happens!

You will undoubtedly notice that, whichever direction you launch the marble in, it always bounces off the shoelace and hits the other marble.

What do you think happened?

Satellites have an elliptical trajectory (with a circle actually being a specific kind of 'unflattened' ellipse).
When an object is launched in any direction from one of an ellipse's construction points, it automatically passes through the other construction point!

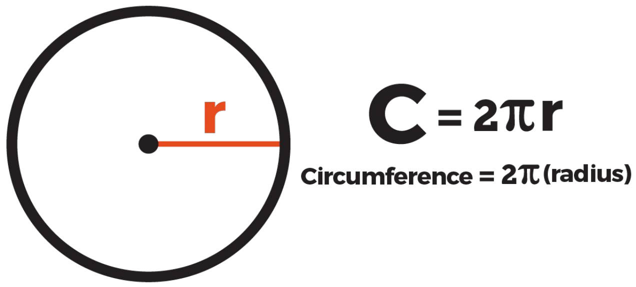
Challenge!

Of all the objects sent into space by humans, which are your 'top three' in terms of weirdness?

If you need help, search the internet for:
- objects sent into space;
- what we've sent into space.

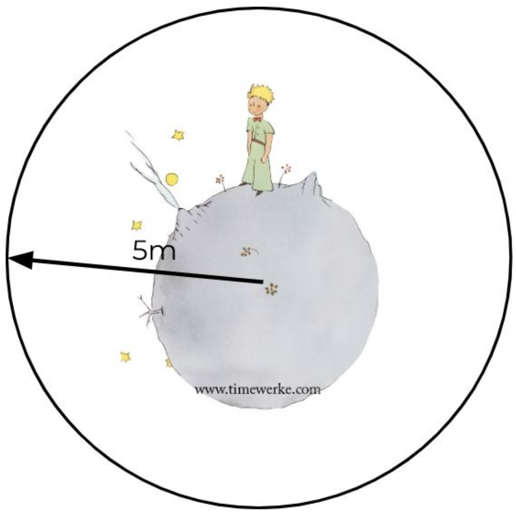
3: Extension problem

Students can learn to calculate the size of an orbit by using the formula for the circumference of a circle: C = 2 x pi x r.   To make things simple or for those without calculators, we can say that pi ~ 3. For those more advanced, they can use pi =~ 3.14.



Easy problems:

For this tiny planet, what is the length of the circular orbit going around it?



A: 5 x 2 x π ~ 31.4 m

Medium problems:

1) The radius of the earth is 6400km. Draw a diagram and calculate the length of the orbit around earth at 400km above the surface of the earth, in km.
2) Calculate the speed of something which takes an 1.5 hours to travel around the earth. This is the speed of our space hotel.

Tricky problem:

The Apollo lander travels around the moon at 1600 m/s, at a height of 1,800,000 metres from the centre of the moon. How many orbits of the moon will it complete in one earth day?

Solution and review:

Gravity is an attractive force which keeps objects pulled towards each other. Really heavy objects like the earth pull everything towards them very strongly, which is why us, the oceans, the plants and animals and the atmosphere don't just float away into space. Objects with enough speed can keep continuously falling by always avoiding the earth. Its speed keeps it from hitting the earth. To do this they have to move in a circular* path.

Right now there are multiple objects, natural (like the moon), or artificial (like the space station or satellites) which are orbiting.

The length of a circular path can be calculated using the formula $C = 2 \times pi \times r$

*or eliptical

Lesson 6: Walking in Space

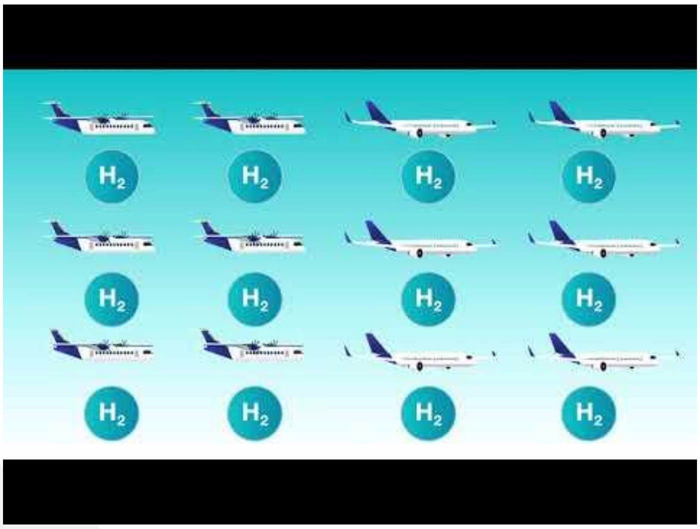
Introduction

We've reached the space station, and some of our passengers want to experience what floating in space is really like.

Problem

How can we protect our passengers from outer space?

Vacuum



1. Watch the videos

Students will watch the video and take notes and write down questions for the teacher, and will fill out the question sheet below:

1) What is a vacuum?
2) What liquid makes up most of the human body?
3) What would happen to our blood if we went out into space without a vacuum?
4) What happens to gas bubbles in a rarefied atmosphere or vaccum?
5) How do spacesuits prevent the harmful effects of a vacuum?
6) Space itself is very cold, but can sometimes be very hot due to the strength of unfiltered sunlight. How else do you think space suits protect astronauts?

2. Activity! Effects of vacuum

What happens to the human body in a vacuum?

The science question in this video

In this video, Clementine, Maxime and Paul are inspired by Maxime's question of what would happen if a human found themselves in space without a spacesuit.
This gets them thinking about the concept of a 'vacuum' and how to create one.

In physics, a 'vacuum' refers to the absence of all matter. But it's not possible to create a space that contains ZERO atoms and ZERO molecules.
When we talk about the 'interstellar vacuum' or 'space vacuum', we actually mean an environment containing far fewer molecules than there are around us here on Earth.

Imagine, for example, a small cube of air measuring 1 cm on each side (1 cm3), floating above the palm of our hand:
- on Earth, that cube of air would contain approximately 20 quintillion (20 billion billion) molecules (20 000 000 000 000 000 000);
- if we were in one of the 'emptiest' parts of the universe, though, that same cube may contain a single molecule! In such cases, we describe the air as 'rarefied'.

There are devices that enable us to obtain a near vacuum by rarefying the molecules. Vacuum pumps, for example, suck as much air as possible out of a container. But they're not powerful enough to extract it all!

Another way to rarefy molecules is suggested in the video. Trap a volume of air in a jar, then expand the container (but without letting any air in or out!) The result is nowhere near a vacuum but it can still produce an effect.

We see this in the video when the air bubbles expand slightly. The molecules in the air of the jar are 'rarer' than those in the bubbles. So the latter tends to push against the surface of the bubbles from the inside, making them expand slightly.

The final experiment in this video shows how to use a syringe to further reduce the number of molecules in each cm3 of air inside. The water inside the syringe becomes surrounded by very ‘rare’ air and boils much more easily than in the conditions we’re used to, thereby filling this ‘rare’ air with water vapour. If you rarefy the air enough, the water will boil at room temperature!

N.B. The video never mentions pressure, but the experiments and resulting observations (‘aspirated’ balloon, expanding bubbles, boiling water) can provide a starting point for this concept!

Related experiment: The cold balloon

You will need:

- a balloon;
- a sharp object (to pierce the balloon).

1) Inflate the balloon.
2) Place the balloon on the ground and sit on it carefully (it shouldn’t burst :-))
3) While still sitting on the balloon, pierce it with the sharp object.
4) What’s the sensation around your bottom? Touch the balloon – how does it feel?

You should feel a cool sensation just after the balloon bursts.

What do you think happened?

When you burst the balloon, the air inside which was very ‘constricted’ or under pressure is suddenly released and starts to fill up far more space than just before. It’s a bit like the experiment in the video where they pull on the jar top, except that here it’s much quicker.
When air very suddenly fills up much more space, it gets colder!
It’s this coldness that you can feel around your bottom or when you touch the burst balloon that has been cooled by the air.

Challenge!

Can you find three living things (plants or animals) able to survive in space without protection?

If you need help, search the internet for:

- an animal that survives in space;
- a plant that survives in a vacuum.

3: Extension problem

Measuring the volume of a breath.

How to measure the volume of one breath:

Use a balloon and stretch it several times to make sure it inflates easily. Fill it up with an exhalation from a normal breath and use a ruler to measure the diameter, from which the radius can be determined. This can be substituted into the equation.

$$V = \frac{4}{3}\pi r^3$$

Please note r must be given in metres, though it will probably be measured in centimetres.

Step 1: Measure the volume of one breath three times. Find an average and record it.
Step 2: Count the amount of time for one breath. Introduce an important technique for measuring things correctly with poor equipment: Count the number of breaths in one minute and then divide that number by 60 to find the breaths per second.

Now can you calculate what volume of air would be required for the average person in a spacesuit for 3 hours?

Maths problem on spacesuit use:

In each 24-hour cycle at our space hotel, we organise spacewalks that last for three hours. The table below shows how many people are spacewalking during each time period.

0-3 hours	3-6 hours	6 - 9 hours	9 - 12 hours	15-18 hours	18 - 21 hours	21-24 hours
3 people	7 people	8 people	2 people	11 people	5 people	6 people

- Each spacesuit takes 30 minutes to retrieve, put on, check, and the same amount of time to take off, check and store.
- After each spacewalk, each spacesuit needs to be sprayed with a disinfectant and left to dry. This can only be done to one space suit at a time and takes 20 minutes to complete.
- There must always be at least two spacesuits cleaned and ready to be put on in case of an emergency.
- After three uses, a space suit must undergo an expert safety check which takes 15 minutes.
- After four uses, a spacesuit must undergo a thorough clean which takes 2 hours.

Given all these constraints, what is the smallest number of spacesuits you could carry aboard the space hotel?

Solution and review:

To summarise, the students should understand that we use spacesuits to protect ourselves from the harsh temperatures, radiation and vacuum of space. Without them, our blood would boil, our outer layers would freeze and we would be unable to breath.

We they should understand how to estimate the volume of their normal breathing, use the formula for the volume of a sphere and understand that even seemingly simple tasks like finding the number of spacesuits can become increasingly difficult to manage as the numbers become larger

Lesson 7 (Optional): Presenting your findings

Introduction

You and your engineering team have solved all the major problems faced in the development of your space plane:

- How can we make our spaceship as lightweight as possible?
- What fuel shall we use?
- How can we get to the edge of space without turning on our rocket engineer?
- How can we make and use hydrogen fuel?
- Why won't our space hotel fall back to earth?
- And why are spacesuits needed for the spacewalk?

But remember, not everyone at the organisation is working on the same projects as you, so you need to **share and explain your ideas with others**. This is a really important part of being a rocket scientist: not only do you need to calculate, investigate, experiment and problem solve, you need to tell others about it!

Problem

Can you come up with a clear presentation which explains the choices you've made, and go into some detail explaining why?

Students should include visual aids, and prepare clear and concise answers. The focus should be on proper verbal delivery instead of having flashy slides. This is why we have included a template for students to fill in.

Extension problem

Once students have explained their choices and solutions to problems, they can then use their imaginations to create a new aspect of the space mission - maybe a moon base, a robotic probe, a new section to the space hotel etc. etc. but they must explain what technologies are required to make it possible.
This will demonstrate the student has made the strong link between imagination, scientific technique and technological progress, as well their progress.