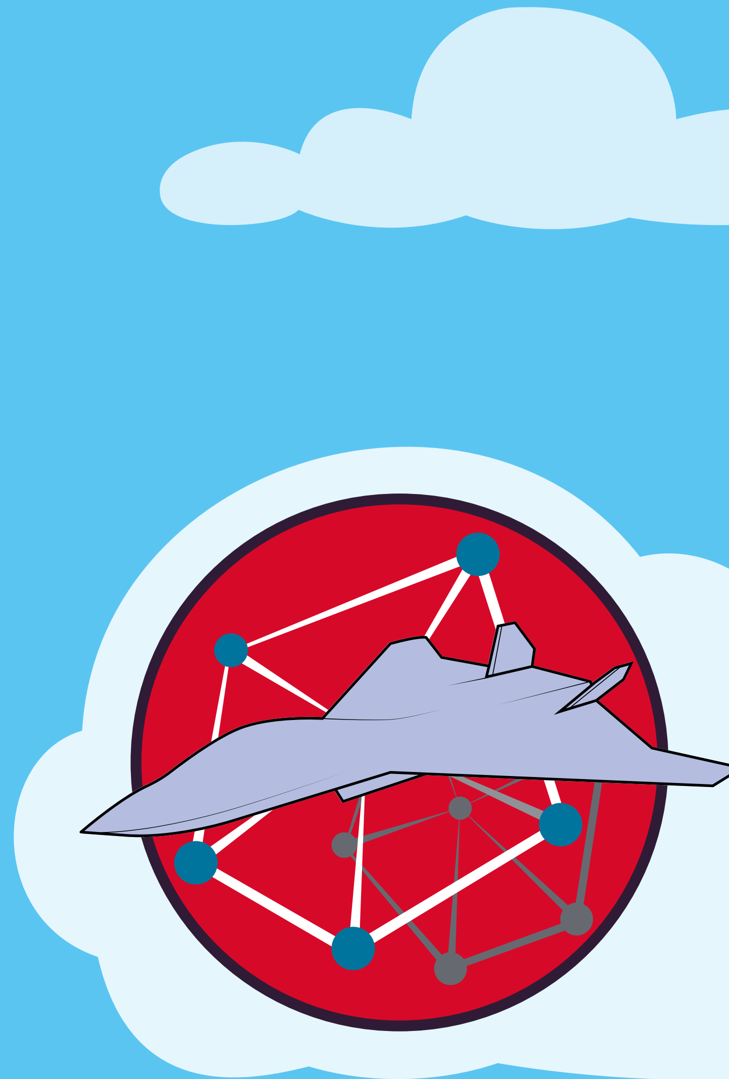
Future of flight:

Materials



Royal Academy of Engineering

THIS IS ENGINEERING

TEAM TEMPEST

Introduction

Next generation aircraft need to be more advanced than ever before, be able to go further, react faster, carry more advanced sensor and communication systems or produce less carbon dioxide.

Considering advanced materials and their different properties including; Density, Conductivity, Hardness etc, will impact the weight, efficiency/ sustainability, cost and suitability of the aircraft.

With modern technology, using radio waves to communicate and locate aircraft, stealth aircraft design needs to also consider how to best utilise the latest smart materials that can disrupt these signals to camouflage the aircraft, while enabling onboard sensors to still communicate effectively.

Case study

Andrew Frost

Craft composite apprentice at Leonardo

I have been a massive fan of Formula 1 since I've been able to walk! I now build and repair helicopter rotor blades at Leonardo in Yeovil, using cutting-edge composite materials, which are both strong and lightweight. The work I do is essential to make sure military helicopters continue to be reliable when they are in-service.

I joined the composite engineering apprenticeship aged 18 after finishing my A levels in maths, design technology and PE. For my A-level project, I combined my main hobby of sailing with learning about composites to design a hydrofoil to make a boat lift up out of the water.

Although I am a qualified blade manufacturer, I want to be able to help with the advancement of future composite and aerodynamic projects whether they are aircraft related or not. To do this, I'm continuing to learn and understand as much as I can about the sector I work in and I plan on completing a degree to support this.

I've found that it's really important you do a job that is close to something you are passionate about, as it allows you to take into work that same feeling you have about your passion, so that you can pass it on to the work you do.

"I thoroughly enjoy my job, and it's really exciting when I see helicopters flying around the area knowing that I have been part of the journey to get the aircraft up there. Not many people can say that!"

Choosing materials

Choosing the right material is extremely important in any engineering and design process, and aircraft design is no exception.

Aircraft need to withstand extreme forces such as temperature and G-force, and choosing the correct materials means that they can function safely and efficiently.

Time to reflect

What do we mean when we say materials?

In small groups, make a list of 20 kinds of materials. Write each different material on a post-it note.

- What are the most important materials to you?
- How could you group these materials?

Move the material post-it note to the appropriate group. There are several ways you could do this.

Materials have some properties that are different and some that are the same.

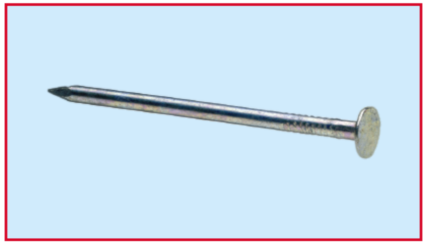
Use the material cards on page 3 to create a material chain, linking images and descriptive words.

Place one of the descriptive words down, followed by an image of an object that fits that description. Find another descriptive card that also describes that object. See the example (right).

Create the longest chain you can.

- Are there any words you don't recognise? Look these up and create a mini glossary.
- What other words can you add?
- What other materials can you add?

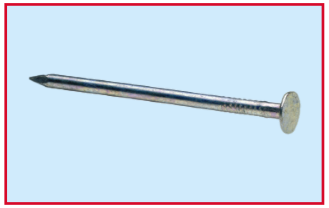
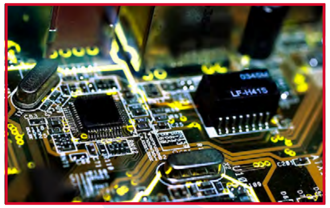
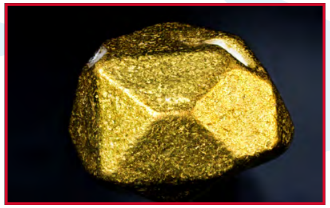
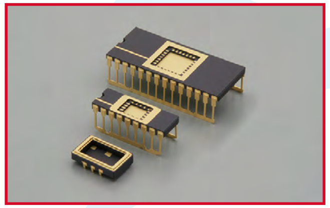
Metal



Rigid

Objects and their material description

Cut out the description and object cards. Create a chain linking objects and descriptions.

Brittle		**Good insulator**		**Elastic**	
Wood		**Ceramic**		**Metal**	
Polymer		**Composite**		**Conductor**	
Absorbent		**Malleable**		**Ductile**	
Porous		**Natural**		**Textile/ fabric**	

Managing temperatures

The materials chosen for different aircraft not only need to withstand extreme temperatures, but also regulate the temperature of both people and equipment.

Time to design

Design, make, test, and evaluate a freeze-shield that will keep 200ml of water from increasing in temperature.

Equipment

- Fridge
- Thermometer
- Water
- Adhesive
- Scissors

Materials you could use as your cold shield

- Foil
- Polystyrene
- Newspaper
- Different plastics
- Cardboard
- What other materials do you think would work?

The water represents the people, equipment and tools you are trying to protect from extreme weather conditions.

- What materials could you choose? Why?

You will be looking for materials that are good **insulators**. An insulator is a material that does not let heat or electricity travel through it easily.

- What is the opposite of a material that is a good insulator?

Testing your freeze-shields

When you are ready to test your freeze-shield, put your water in a container and measure the temperature.

Place the freeze-shield ideally in a fridge for a set amount of time (approx. ½ hour). Measure the temperature of the water again after this time.

- What happened to the temperature?
- Did the materials change over time?
- How could the design be improved?

Manufacturing polymers

One way we could group materials is natural vs synthetic. Would your materials fit into these categories?

Enhancing and designing new materials for next-generation aircraft, clothing for pilots and general future aerospace is a central part to the development of the Tempest aircraft. Many of the innovative materials that have been and continue to be developed are known as **synthetic materials**.

Time to make your own bouncy ball

Synthetic materials are developed to have specific and unique properties, often very different to the materials used to create the synthetic material.

Make your own bouncy ball by mixing two different polymers.

Materials – for one bouncy ball

- Three tablespoons PVA glue
- ¼ teaspoon bicarbonate of soda
- Two teaspoons of water
- Plastic container
- Stirring rod
- One drop of food colouring (optional)

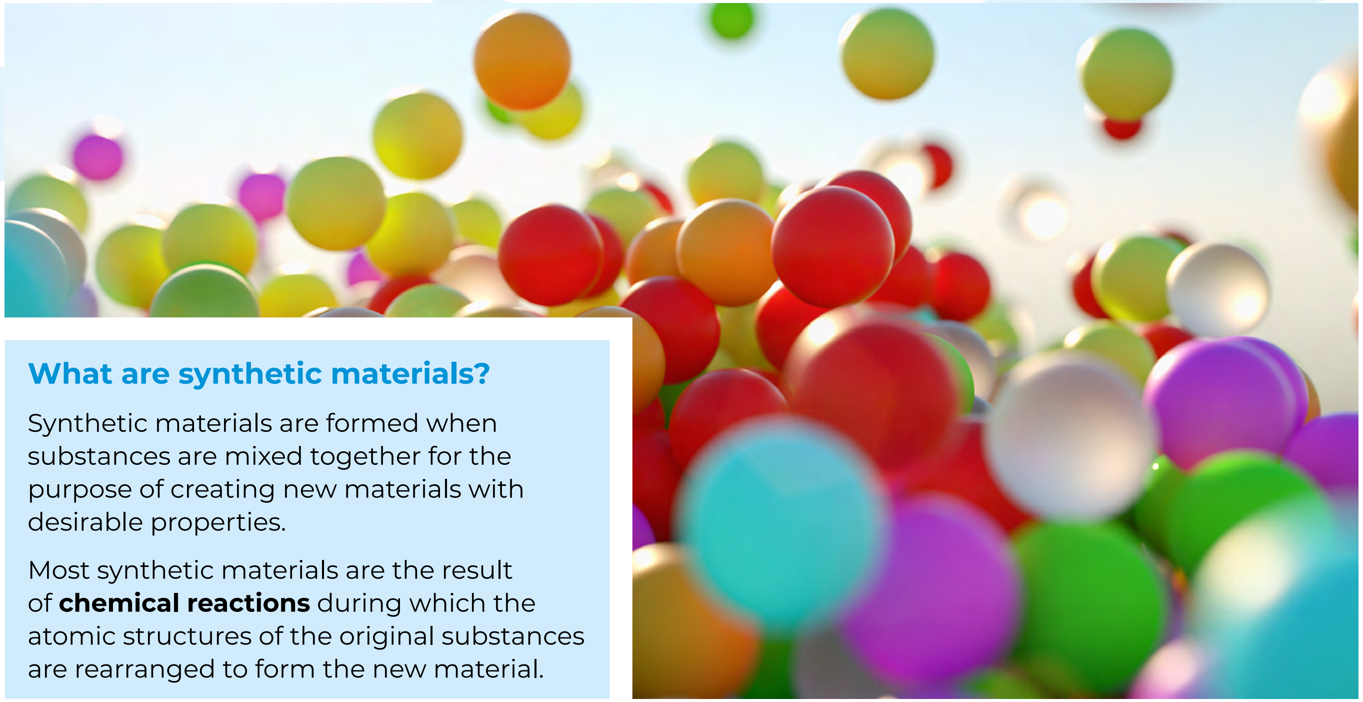
Method

1. Put ¼ teaspoon of bicarbonate of soda in a plastic container
2. Add two teaspoons of water and mix well – add more drops of water if it is not mixing well
3. Squeeze about three tablespoons of PVA glue into a different plastic container
4. Add one (approx.) drop of food colouring (optional) to the PVA
5. Stir your water and baking soda mix into the glue
6. Mould your bouncy ball
7. Let it dry for 24 hours

Compare your ball with others in your group.

- How well does your ball bounce?
- What do you think impacts how well each ball bounces?

Keep your balls in a plastic bag to stop them from drying out.



What are synthetic materials?

Synthetic materials are formed when substances are mixed together for the purpose of creating new materials with desirable properties.

Most synthetic materials are the result of **chemical reactions** during which the atomic structures of the original substances are rearranged to form the new material.

Strength in numbers

Composites are extremely important in aerospace and defence applications as materials need to be able to withstand severe environments.

Hypersonic flight applications, building construction, material-processing equipment, energy and energy production industries are a few applications that use composite materials because of their unique property combinations. Such composites include metal, ceramic, fibre, and polymers.

Within each of these vastly different material systems, material scientists have found unique property behaviours.

These material behaviours revolve around the shape, orientation, size distribution, strength, and toughness.

Materials engineers and scientists explore these quantities and rank them for performance following experiments.

What are composites?

Composite structures are a general class of materials that include two or more materials combined into one: a **matrix** and a **filler** or **reinforcement**.

For example, concrete is made using cement as the matrix and aggregate (sand, gravel) as the filler/reinforcement. In general, engineering materials for specific applications involve making composites out of metal and ceramic, ceramic and ceramic, polymer and metal, and polymer and polymer combinations.

Depending on the application and properties needed, engineers select different types of composite.

Composites allow engineers and scientists to achieve unique property combinations that individual materials cannot provide.

Make and test your own composite beams

Create your own composite beams. Try two different investigations: one where you change the filler you use and one where you change the amount of filler you use.

Materials

For the mould

- Cardboard
- Aluminium foil (optional)
- Masking tape

For the composite filler

- Water
- Flour
- Bulgur wheat (or something similar)
- Dry spaghetti
- Chickpeas
- Large mixing bowls

Testing

- Hook
- Weights

Health and safety: We suggest that you wear eye protection when carrying out this activity.

Making the mould

You will need to make several moulds that you will fill with your composite mix. A template for the mould can be found on page 8.

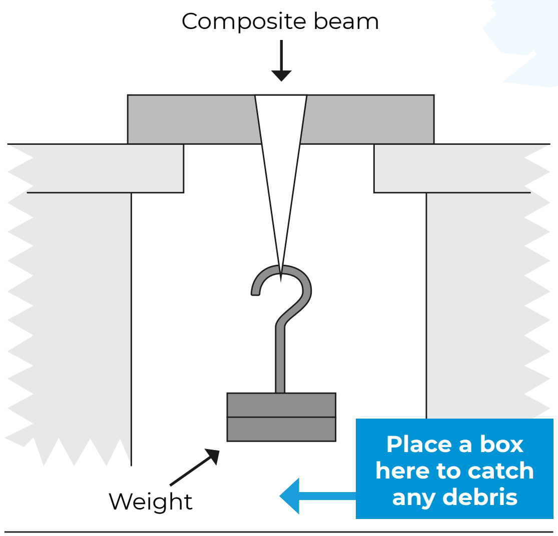
Testing your composites

For each challenge you will be testing the strength of your beam with different composite mixes.

Set up a testing station using a hook and weights. You will need to be able to increase the weights in a controlled way so you can measure the breaking point. The diagram shows one way you can test your beam.

- How else could you test your beams?

You will need to let your composites set after they have been mixed. Ideally have a 48-hour gap between adding the composites to your mould to create the beams and testing the beams.



Which filler to use?

Different fillers have different properties. Create a plaster substitute as your matrix and test how it behaves with different fillers.

Your matrix is actually a composite itself. You will create plaster by mixing water and flour.

Using the table (right), in a mixing bowl create four mixes, each with a different filler.

Once the mix has set, you can carefully cut the mould and lift the mould out.

Test each of the samples in turn.

- Which is the strongest?
- Which is the weakest?
- Why do you think that this is case?

Mix	Matrix		Filler
A	125ml warm water	125g flour	None
B	100ml warm water	100g flour	40g bulgur wheat
C	100ml warm water	100g flour	40g spaghetti
D	100ml warm water	100g flour	40g chickpeas

How much filler to use?

How do you know the right amount of filler to add to give a strong composite? Is it possible to add too much?

Changing the proportions not only affects the properties of the final material, but also affects the overall cost and can affect how easy the material is to work with.

Using the table (right) in a mixing bowl create three mixes, each using a different amount of the same filler (we have chosen bulger wheat).

Once the mix has set, you can carefully cut the mould and lift the mould out.

Test each of the samples in turn.

- Which is the strongest?
- Which is the weakest?
- Why do you think that this is case?

Mix	Matrix		Filler
A	100 cm^3 warm water	200 cm^3 flour	25 cm^3 bulgur wheat
B	100 cm^3 warm water	200 cm^3 flour	50 cm^3 bulgur wheat
C	100 cm^3 warm water	200 cm^3 flour	75 cm^3 bulgur wheat

This activity has been adapted from activities found in 'Composites: Designing materials for the future from the Science Enhancement Programme'.

Making your plaster

- Mix your flour and warm water (approx. 40°C if you have a thermometer – this could even be from tap)
- Stir the mixture with a spoon or spatula until there are no lumps. You are aiming for a thick white paste. If it seems too thick, add more water. If it is too runny, add more flour
- The plaster will start to solidify as you work with it. At this point, add your filler if you are using one
- Once you have mixed your filler with the plaster, pour into your mould
- Let the plaster set for 48 hours

Too much filler?

Create some plaster and slowly add in filler.

Is there a point when the amount of filler makes it too difficult to stir?

Stretch and challenge – volume fraction

Scientists and engineers often refer to the ‘volume fraction’ of filler in a composite.

- What was the volume fraction of the strongest sample?

$$\text{Volume fraction} = \frac{\text{Volume of filler}}{\text{Volume of filler + matrix}}$$

Based on your results, how does the ‘volume fraction’ of filler affect the strength of the composite?

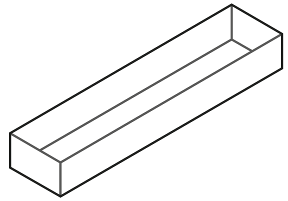
Mould template

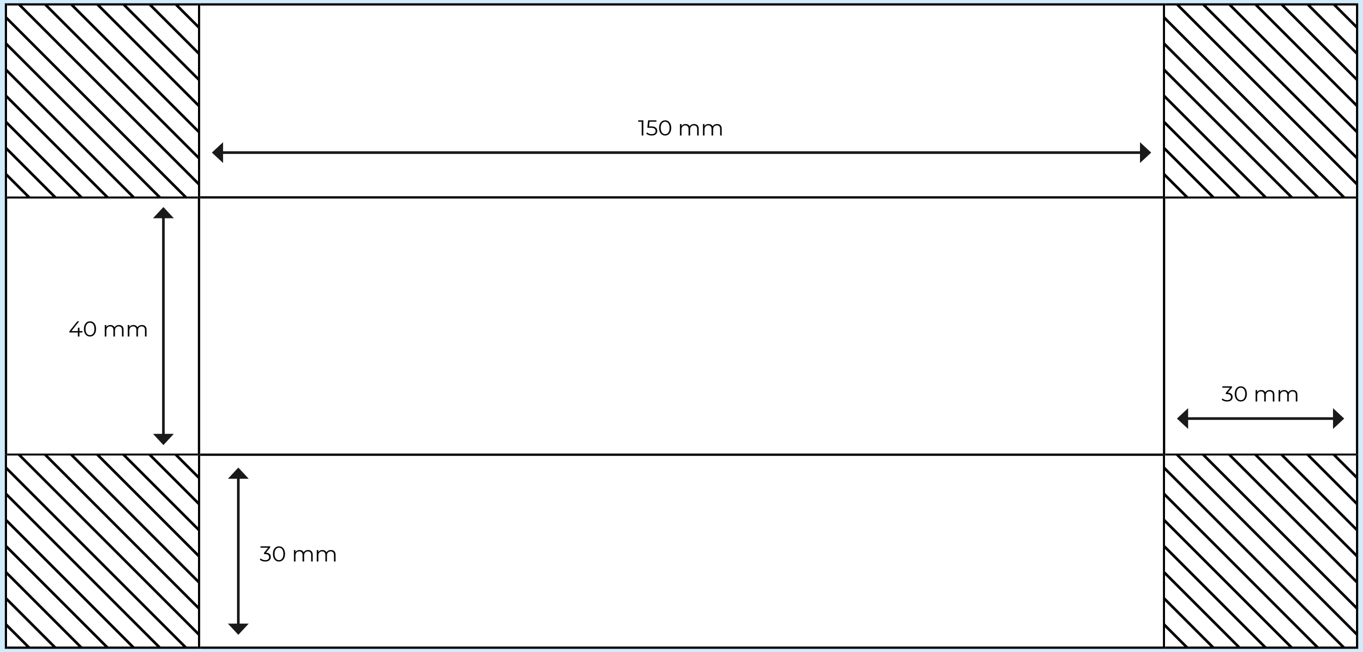
The template below is for one mould. You can get several moulds from one sheet of corriflute or corrugated cardboard.

Cut along solid lines and discard the shaded areas. Fold along the dashed lines. (It may help to score the material along the line first.)

Hold the sides of the mould in place with adhesive tape round the outside of the mould.

The assembled mould should look like this:





Note: Mould template not to scale, please see support sheet for 100% scale version.

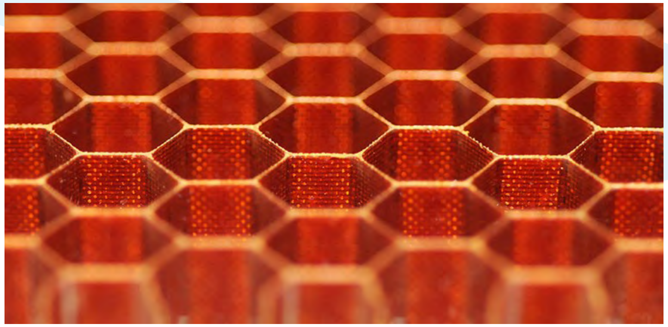
What is the volume of the mould?

Biomimicry – in materials

When developing new materials, engineers have turned to nature for ideas and inspiration.

Learning from nature through biomimicry encourages a more sustainable approach to engineering and design as well as innovative and forward-thinking design. For example, the honeycomb design plays an important role in flight technology and is still being used to influence the development of new materials such as the strong and lightweight carbon aluminium honeycomb.

Honeycomb materials resemble the hexagonal wax cells built by honey bees in their nests to contain their larvae and stores of honey and pollen.



In fact, the team at BAE Systems values the work that honeybees do so much that it has formed a bee colony at one of its bases that will be home to approximately 60,000 bees! Find out more about the project.

Time to reflect

- Why the hexagon? And why honeycomb?
- What do you think make the properties of the honeycomb design so great?

Time to tessellate

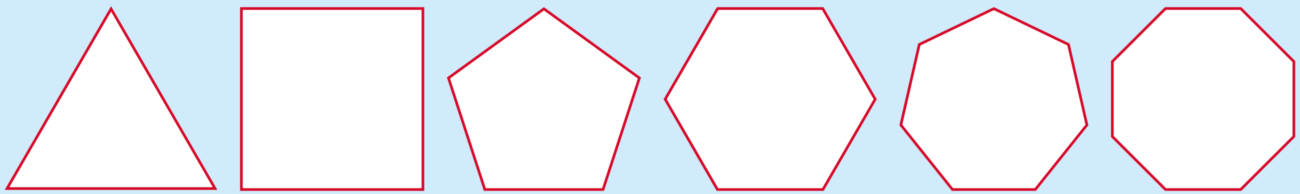
The honeycomb is a **tessellation** of hexagons with hundreds of bees working together to repeat the pattern simultaneously.

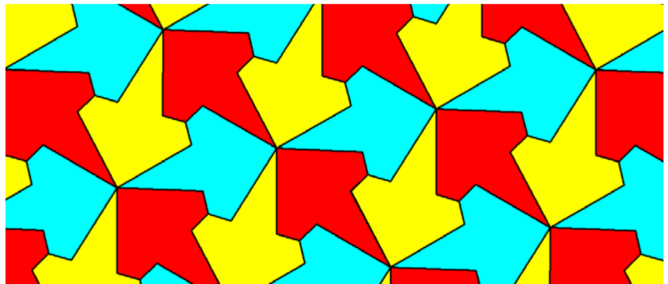
Only **three regular polygons** tesselate. A regular polygon is a 2D shape where all interior angles and sides measure the same.

Experiment to find the three regular polygons that tesselate.

- Why do you think the bees use the hexagon and not the other two shapes?

Experiment to find the three regular polygons that tesselate.





A non-regular polygon tessellating pattern.

All about the angles

Why do you think that these are the only regular polygons that tessellate?

Using the table, investigate the interior and exterior angles of each regular polygon and use this information to explain which regular polygons will tessellate.

Stretch and challenge

Finding the volume between space in material is an important part of the design and planning process.

Using what you know about area and volume, formulate an equation for the volume of liquid one hexagon cell can hold.

- What about for a number of cells?
- Does this equation hold true regardless of the size of the individual cells within the space?

Time to build

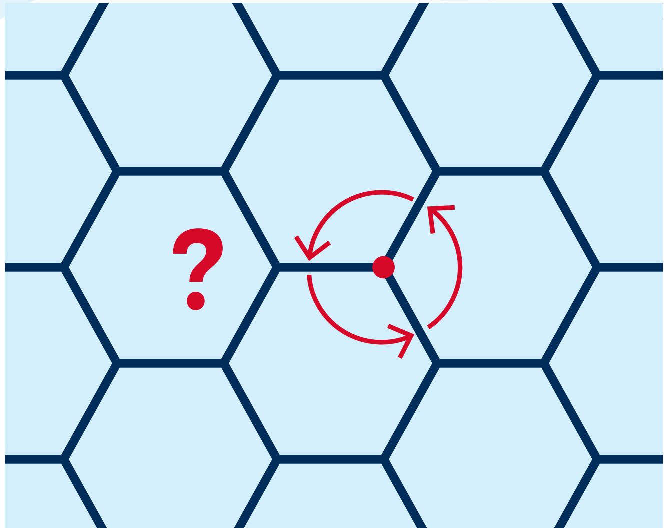
Build a honeycomb structure that can hold 3kg.

Suggested materials

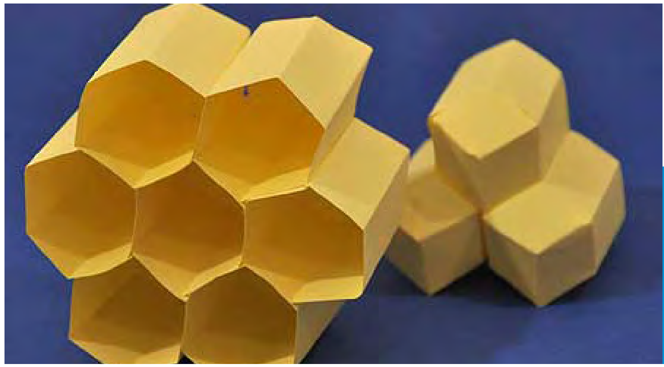
Newspaper, cardboard, tape, different types of paper, toothpicks, glue.

Get creative. What can you **reuse and recycle** from around your school or home?

Regular polygon	Size of each exterior angle	Size of each interior angle	Divide by 360°	Does this polygon tessellate?
Triangle				
Square				
Pentagon				



For a shape to tessellate, what is the sum of the angles around a point?



Example of a honeycomb structure.

Can you create a similar tessellation structure using different shapes? What happens to the strength and stability of your structure?

Image courtesy of https://www.cutoutfoldup.com/

Royal Academy of Engineering

The Royal Academy of Engineering is harnessing the power of engineering to build a sustainable society and an inclusive economy that works for everyone.

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