You work for an airline. Your company is running a course for nervous flyers. Your team will use science to reassure passengers. You will plan a presentation to:

- Describe the forces acting on an aeroplane
- Explain how a turbofan jet engine works

**Task 1 – the basics**

As a group, tackle the tasks below.

1. Draw and label four force arrows on the aeroplane when it is moving at constant velocity and level flight. Choose from the forces in the list:
   - thrust
   - drag
   - weight
   - lift

2. Circle the one correct sign in each equation or inequality below. Remember **Newton’s first law** – an object continues to be stationary, or to move at a steady speed in a straight line, unless a force acts on it.
   - a) When an aeroplane is accelerating in level flight: $	ext{thrust} = \pi \text{drag}$
   - b) When an aeroplane is slowing down in level flight: $	ext{thrust} = \pi \text{drag}$
   - c) When an aeroplane is travelling at a steady velocity in level flight: $	ext{thrust} = \pi \text{drag}$

3. Blow up a balloon. Do not tie a knot in it. Let it go, and watch what happens. Copy the diagram below, and add two force arrows as it accelerates. Use these labels to annotate your arrows:
   - thrust moves the balloon forwards
   - air leaves the balloon from the back

A jet engine works like the moving balloon. It pushes gases out of the back of the engine. An equal and opposite force pushes the engine, and the aeroplane, forwards. This is **Newton’s third law** – if object A exerts a force on object B, then object B exerts an equal but opposite force on object A.

**Task 2 – inside a jet engine**

A turbofan jet engine operates in four stages:

- **Fan** – takes in huge amounts of air and pushes it backwards
- **Compressor** – squashes air to very high pressures
- **Combustor** – burns fuel with air from the compressor
- **Turbine** – extracts energy from hot gases to drive the fan and compressor

Now allocate one jet engine part to each person in your group. Give each person one briefing sheet. Read your sheet and use the web site below to answer the questions. www.rolls-royce.com/interactive_games/journey03/

Take turns to teach the others in your group what you have learnt.

Now plan your presentation for nervous flyers. Decide what each person will say. Make a poster or PowerPoint presentation to illustrate your talk.

Finally, give your presentation to one other group. They will use the peer assessment sheet to assess your presentation.
Peer assessment

Listen to another group give their presentation. Then complete this form.

<table>
<thead>
<tr>
<th>Question</th>
<th>Did the group answer this question?</th>
<th>How clear is the information? 1 = not clear 3 = very clear</th>
</tr>
</thead>
<tbody>
<tr>
<td>What does the fan do?</td>
<td></td>
<td></td>
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<tr>
<td>What does the compressor do?</td>
<td></td>
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<tr>
<td>What happens in the combustor?</td>
<td></td>
<td></td>
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<tr>
<td>What does the turbine do?</td>
<td></td>
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</tbody>
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1. What were the two best things about the other group’s work?
   ☺
   ☺

2. Suggest one improvement.

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Key Stage 4 - Jet
Suck-squeeze-bang-blow

Briefing sheet 1 – Fan

What the fan does

The fan draws air into the engine. A typical fan draws in 1,500 kg of air every second – the mass of a large car. Around 90% of this air is bypass air. This is the air that does not enter the combustion chamber. The fan module compresses this air, and sends it out through a nozzle at the back of the engine. The bypass air provides around 75% of the thrust of the engine.

1 One engine takes in 1,500 kg of air every second. An aeroplane has four engines. Calculate the total mass of air the engines take in every second.

2 Estimate the total mass of bypass air for the four engines.

3 One engine produces 350 kN (350,000 N) of thrust in total. Estimate the thrust provided by the bypass air.

Fan safety

To make an efficient engine, the fan must be as large and light as possible. It must also be extremely strong, since it is one of the most exposed parts of the engine.

Engineers design and test fan blades to ensure that they can withstand impact by birds and other objects.

Switch on your fan. Feel the airflow it makes.

Now imagine a fan at the front of a turbojet engine. Its blades have a diameter of 3 metres. The fan blades rotate 3,300 times every minute. The tips of the blade move at a speed of 1,000 mph.

See for yourself

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**Briefing sheet 2 – Compressor**

![Diagram of compressor components](image)

**See for yourself**

Image: K. Aainsqatsi, Wikimedia Commons

1. For a fixed mass of gas, the equation below shows the relationship between pressure, volume, and temperature. A constant is a number in an equation that stays the same even when the other variables change.

\[
\frac{PV}{T} = R \quad (where \ R \ is \ the \ universal \ gas \ constant)
\]

2. Write down in words what the equation means.

3. Use the data below to calculate a value for the constant in the equation:

- pressure = 70,000 Pa
- volume = 1 m³
- temperature = 280 K

4. Now calculate the temperature of the gas if its pressure increases to 400 000 Pa and the volume decreases to 0.55 m³. You will need to use the rearranged version of the equation below. Give your answer in kelvin (K).

\[
T = \frac{PV}{R}
\]

5. Now work out the temperature of the gas in °C. Use the equation below:

\[
temperature \ in \ kelvin – 273 = temperature \ in \ °C
\]

Most of the hot air from the compressor now enters the combustor at high pressure. Some of it is diverted to cool the exhaust section of the engine.

**Compressor safety**

The temperature in the compressor can reach 700 °C. Its components are made from a material that melts between 1,260 °C and 1,340 °C. The material does not corrode and is very strong.
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Briefing sheet 3 – Combustor

See for yourself

Use a fan to create moving air. Now try to light a candle in the moving air. What happens? Can you explain your observations?

How could you make it easier to light the candle?

What the combustor does

Air from the compressor enters the combustor. It mixes with kerosene fuel, and the fuel burns. Carbon dioxide and water are formed. They are in the gas state. During burning, energy is transferred as heat, sound, and light.

One of the compounds in kerosene is dodecane. The equation shows its burning reaction:

\[ 2 \text{C}_{12}\text{H}_{26} + 37 \text{O}_2 \rightarrow 24 \text{CO}_2 + 26 \text{H}_2\text{O} \]

1. The fuel is a store of chemical energy. When it burns, does the total amount of energy increase, decrease, or stay the same? Explain how you know.
2. In the combustor, the transfer of energy to sound and light is not useful. Explain why.

When the fuel burns, the heat released makes the particles move faster. They spread out, and the mixture of gases fills a greater volume. The moving particles push their way through the turbines, transferring kinetic energy as they do so.

As the gas expands, it cools. This means that, overall, heat released from the burning fuel is converted to useful work. We know that work is done because a force is making something move.

3. Some of the heat released when the fuel burns is not transferred as kinetic energy. Suggest what happens to this heat.

No aeroplane is 100% efficient. Engineers use computer models and experimental simulations to test design changes that might improve efficiency. You can use this equation to calculate the efficiency of an engine:

\[ \text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \]

4. In one second, burning fuel in an aeroplane (aeroplane A) transfers 215,000 kJ of energy as heat. In this time, the aeroplane does 87,500 kJ of work as it moves forwards. Calculate the efficiency of the engine.

5. In another aeroplane (aeroplane B) a smaller amount of energy is transferred as heat to make an aeroplane do 87,500 kJ of work. Which aeroplane is more efficient, plane A or plane B? Explain your answer.

Combustor safety

Temperatures in the combustor can rise to 2,100 °C. Its walls are cooled with cooler air that has come directly from the compressor. Its inside is coated with a ceramic material that can withstand very high temperatures.
See for yourself

Switch on an electric fan. What energy transfers take place?

Now tie a small object to a piece of string. Whirl the string around above your head. **Keep away from other people when you do this.**

The inward force needed to make the object move in a circle is the centripetal force. How does the size of the force change if the object turns more quickly?

**What the turbine does**

The combustor delivers a mixture of hot gases to the turbine. The turbine is made up of discs of blades. The gases push against the turbine blades at high speed, typically 1,000 m/s (about 2,000 miles per hour.) The turbine gains energy, and turns like a windmill.

As the mixture of gases moves through the turbines it expands and cools. It is this expansion that gives the turbine enough energy to drive the fan and compressor.

Overall, heat released from the burning fuel is converted to useful work. We know that work is done because a force is making something move.

**Turbine safety and testing**

The turbine blades experience huge forces as they turn. The faster they turn, the greater the centripetal forces that act on them:

\[ F \alpha (\text{velocity})^2 \]

(the symbol \( \alpha \) means ‘is proportional to’)

1. A turbine blade rotates about 10,000 times every minute. Predict what happens to the force on the blade if it spins more slowly. Does the force increase, decrease, or stay the same? Explain your answer.

The gases enter the turbines at around 1,600 °C. This is above the melting point of the turbine blade material, nickel super alloy. Scientists and engineers have developed complex systems to cool the turbine blades. Each turbine blade has a network of cooling holes inside it. Cooler air travels through these holes. The blades are coated by an insulating layer of cooler air.

2. Explain why turbine blades do not melt.

Scientists and engineers improve turbine design. They use computer models to help predict the effects of design changes. But the air flow through the turbines is too complicated for computer models to accurately simulate what happens. Scientists and engineers need to test real components.

The Oxford Turbine Research Facility allows scientists to test the effects of design changes on turbine efficiency and heat transfer.

3. Explain why scientists and engineers need to test real engine components rather than use computer models alone.