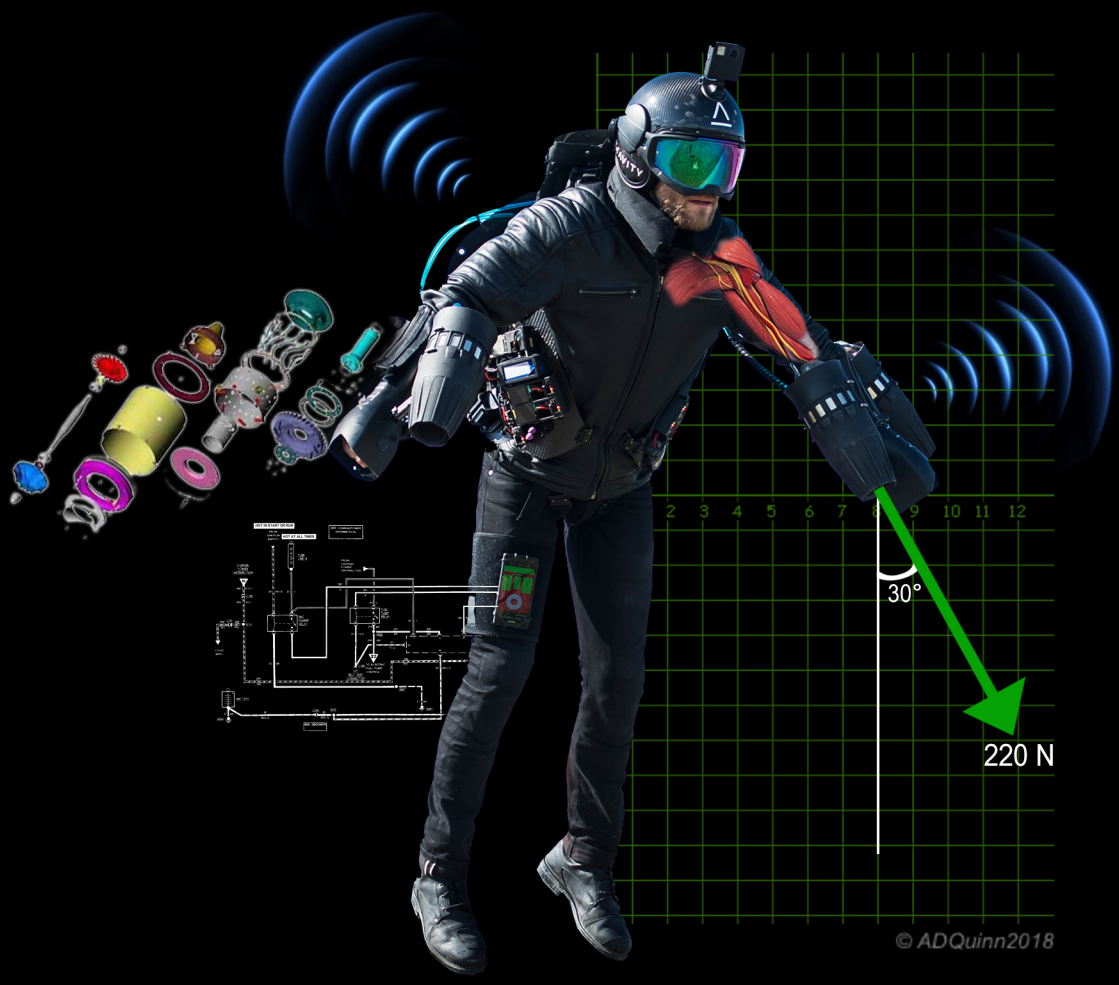
GRAVITY®

STEM



KEY STAGE 3 AND 4
RESOURCE PACK

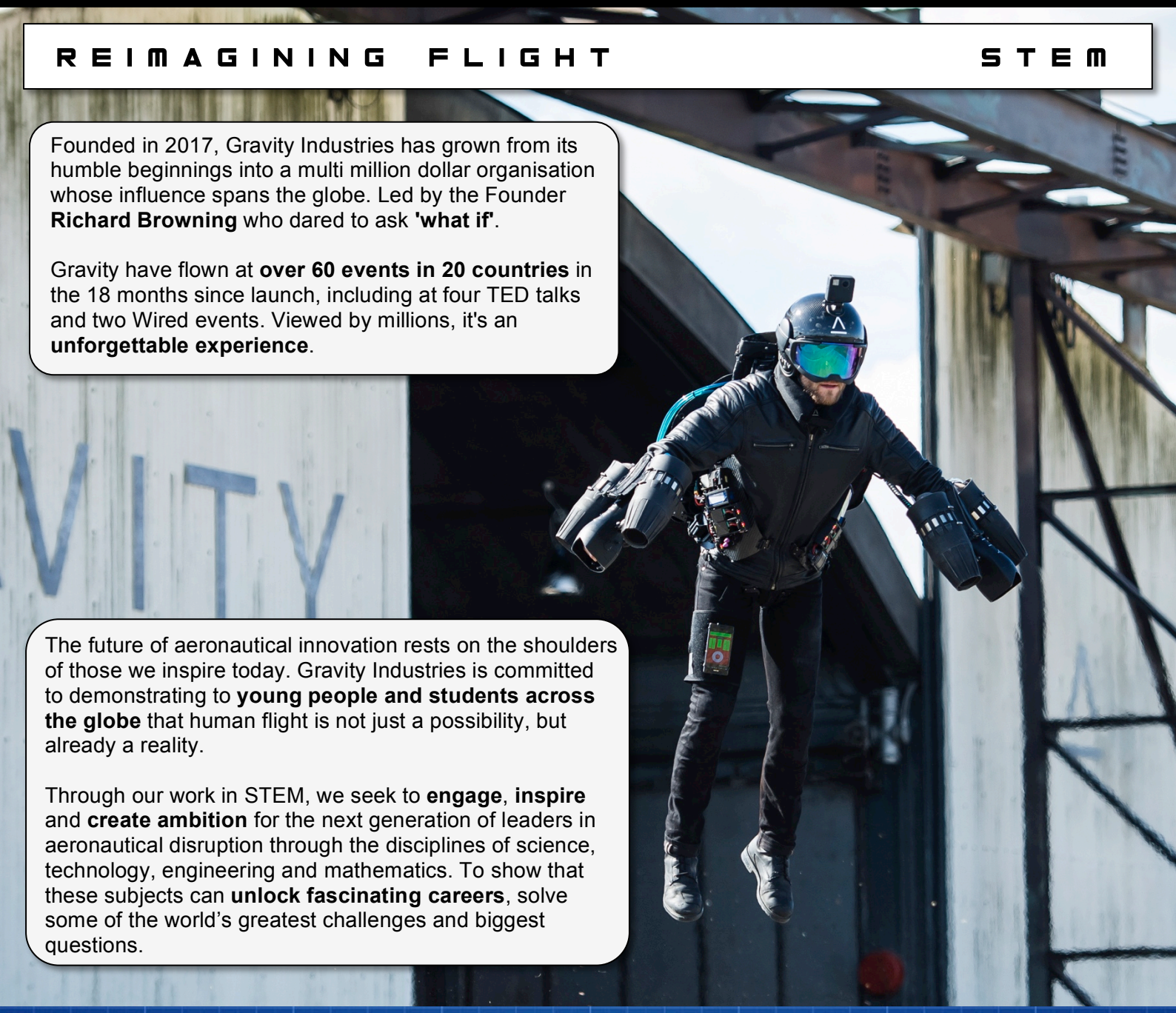
THANKS TO GCSE BBC BITESIZE AND
CGP REVISION AND PRACTICE GUIDES

GRAVITY

REIMAGINING FLIGHT STEM

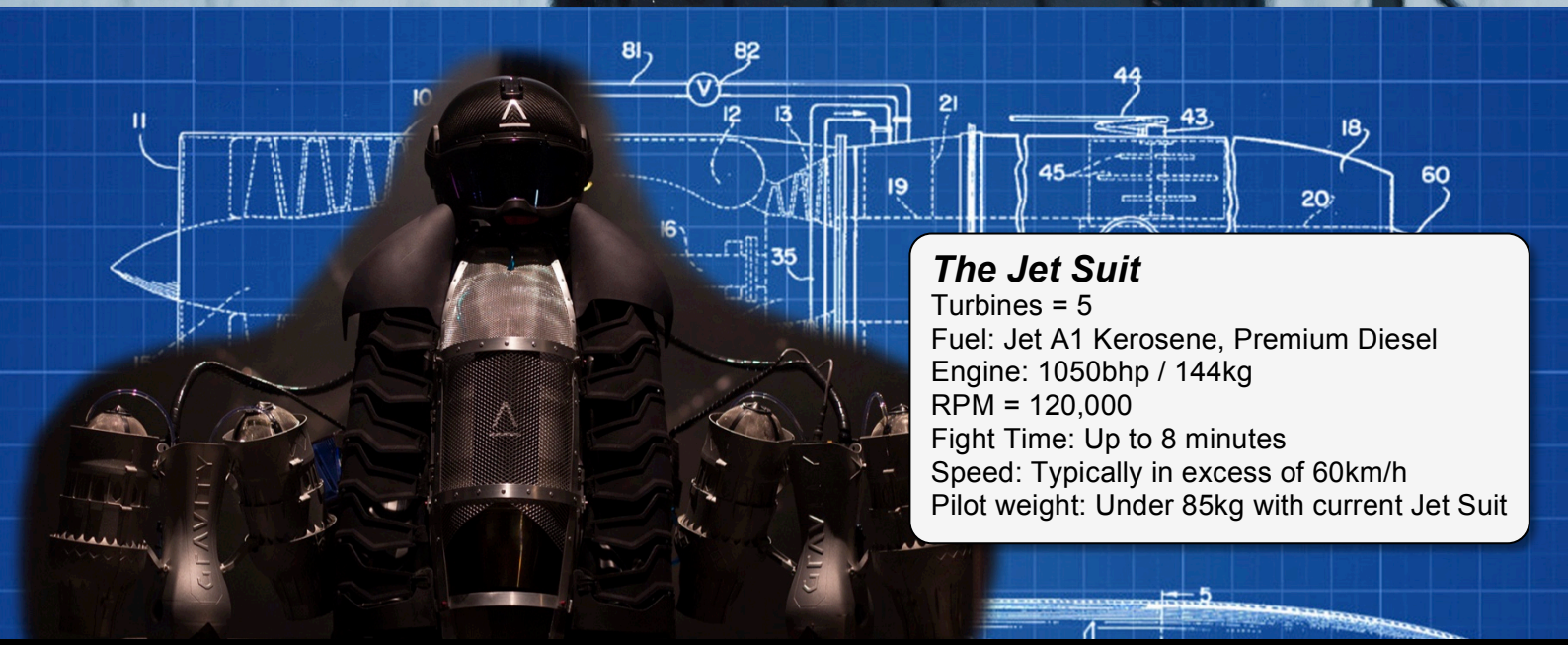
Founded in 2017, Gravity Industries has grown from its humble beginnings into a multi million dollar organisation whose influence spans the globe. Led by the Founder **Richard Browning** who dared to ask **'what if'**.

Gravity have flown at **over 60 events in 20 countries** in the 18 months since launch, including at four TED talks and two Wired events. Viewed by millions, it's an **unforgettable experience**.



The future of aeronautical innovation rests on the shoulders of those we inspire today. Gravity Industries is committed to demonstrating to **young people and students across the globe** that human flight is not just a possibility, but already a reality.

Through our work in STEM, we seek to **engage**, **inspire** and **create ambition** for the next generation of leaders in aeronautical disruption through the disciplines of science, technology, engineering and mathematics. To show that these subjects can **unlock fascinating careers**, solve some of the world's greatest challenges and biggest questions.



The Jet Suit

Turbines = 5
Fuel: Jet A1 Kerosene, Premium Diesel
Engine: 1050bhp / 144kg
RPM = 120,000
Fight Time: Up to 8 minutes
Speed: Typically in excess of 60km/h
Pilot weight: Under 85kg with current Jet Suit

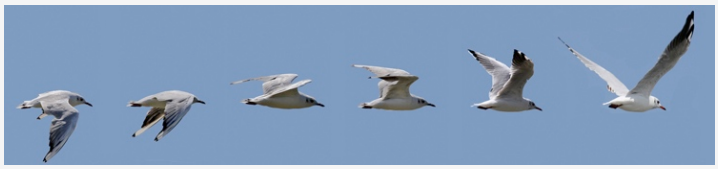
AERODYNAMICS

STEM

Aerodynamics is the branch of physics that deals with the dynamics of air as it interacts with solid objects, such as aircraft wings. Anything that flies, such as aeroplanes, helicopters, and birds, utilise the principles of aerodynamics to move through the air.

Aircraft are able to fly because of two key effects. The first effect is the "push" given by the engines which propel the aircraft through the air. The second effect is the movement of air over the wings which creates the lifting force required to keep it up in the air. In simple terms, the wings of an aircraft generate **lift** force and the engine creates the **thrust** to propel the aircraft through the air.

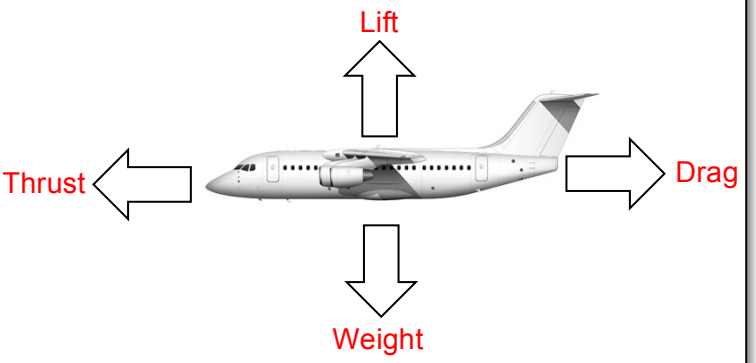
For birds and other flying animals, the flapping motion of their wings creates both lift and thrust.



If the wings of an aircraft could flap they would also propel it through the air and maintain lift, and so an engine wouldn't be needed. It would be an extreme engineering challenge to design an aircraft with flapping wings, which is why aircraft are designed to keep the source of lift (the wings) and thrust (the engine) separate.

Text source: https://www.real-world-physics-problems.com/aerodynamics-for-kids.html

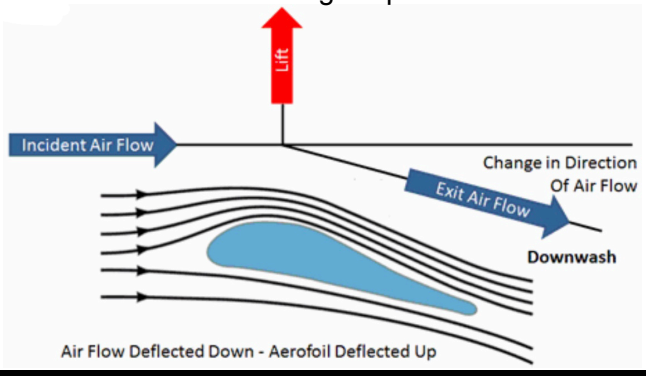
To gain an understanding of the **aerodynamic forces** necessary for flight, consider the image below showing an aircraft flying through the air.

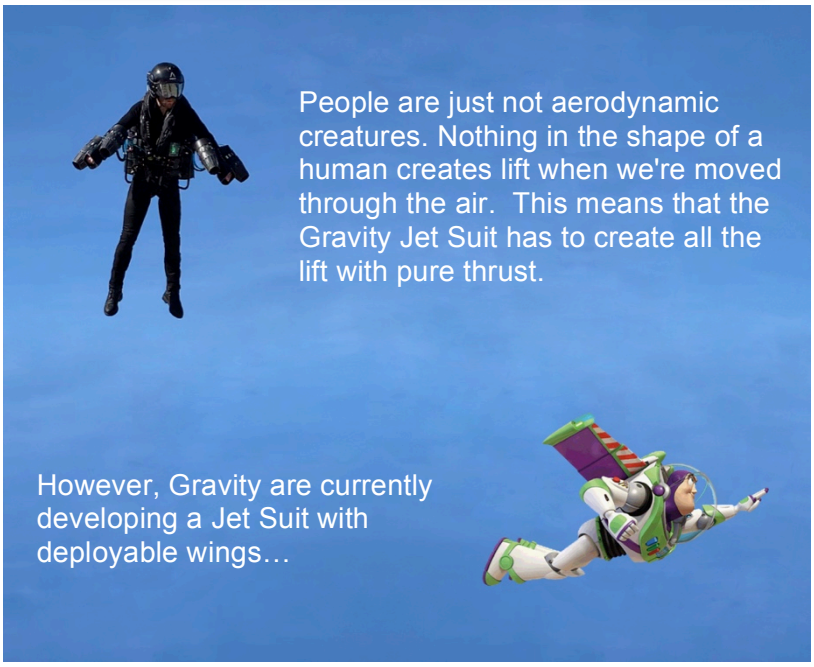


If the aircraft is moving at constant velocity with no acceleration, the forces shown in the image must balance.

This means that the lift force (L) generated by the aircraft wings must equal the aircraft weight (W) due to gravity. Similarly, the thrust force (T) generated by the aircraft engines must equal the drag force (D) caused by air resistance.

Wings are also called **aerofoils** and their shape generates **lift**. The lift on an aerofoil is primarily the result of its angle of attack and shape. When oriented at a suitable angle, the aerofoil deflects the oncoming air resulting in a force in the direction opposite to the deflection. This force is known as aerodynamic force and can be resolved into two components: lift and drag. This "turning" of the air around the aerofoil results in lower pressure on one side and higher pressure on the other.





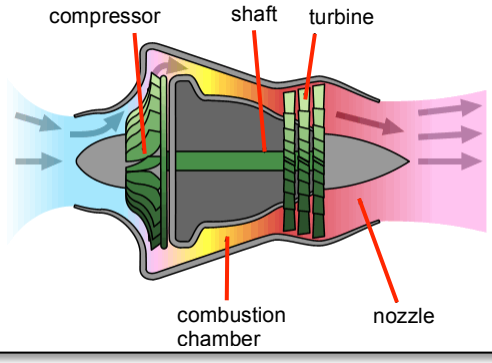
GAS TURBINE / JET ENGINE STEM

A **gas turbine** (or jet engine) is a machine that converts energy-rich, **liquid fuel** into a powerful pushing force called **thrust**. Five small gas turbine engines provide enough thrust to allow Gravity Jet Suit pilots to fly and manoeuvre in the air.

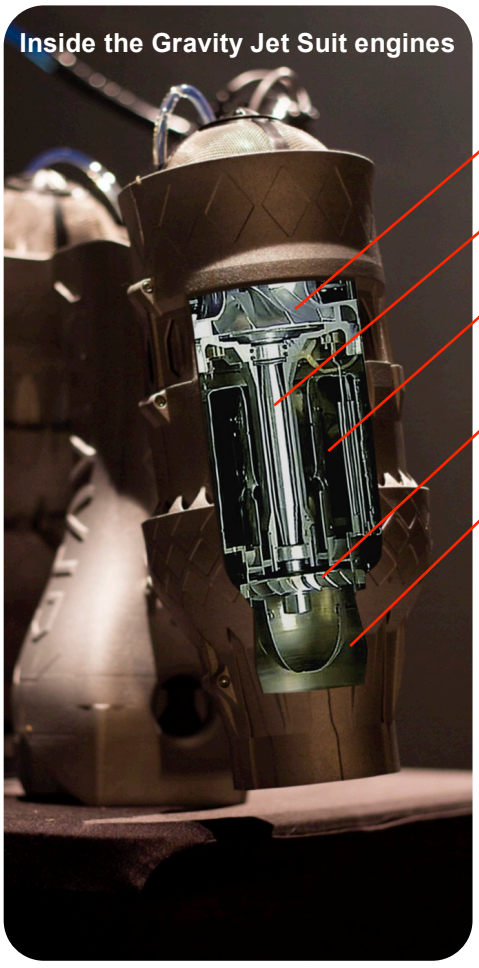
A jet engine uses the same scientific principle as a car engine: it burns fuel with air in a **chemical reaction** called **combustion**. This releases **energy**. A gas turbine is designed to hoover up huge amounts of air and burn it with vast amounts of fuel (roughly 50 parts air to 1 part fuel), so the main reason why it makes more power than a car engine is because it can **burn more fuel**.

Because intake, compression, combustion, and exhaust all happen simultaneously, a jet engine can produce maximum power all the time. However, this is bad for mechanical reliability of the engine.

- The blades of the compressor spin at high speed and compress or squeeze the air.
- The compressed air is then sprayed with fuel and an electric spark lights the mixture in the combustion chamber.
- The burning gases expand and blast out through the nozzle at the back of the engine.
- **As the jet of gas shoots backward, the engine is thrust forward.**



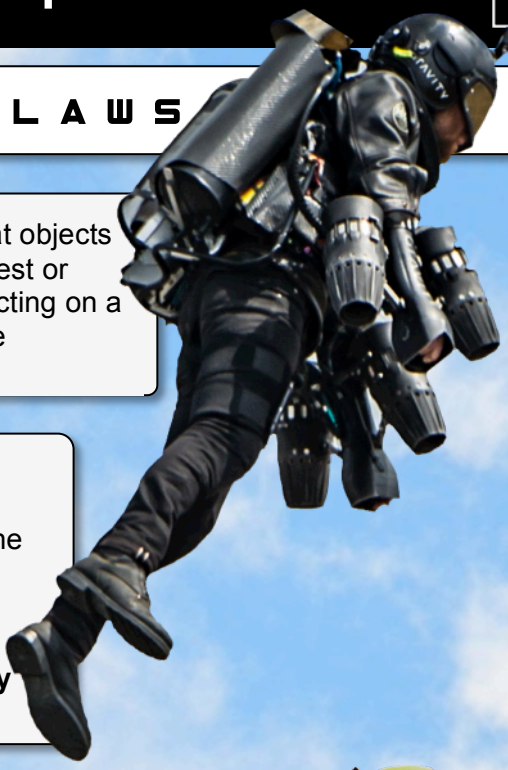
Boyle's Law Boyle says Pressure x Volume is proportional to Temperature **(PV = nRT)**. As the temperature rises rapidly in the combustion chamber, (typically to over 1000°C) the volume of the gases flowing through the engine increases, both with the chemical reaction of the combustion of fuel, but also due to the temperature rise, producing a big increase in the flow of hot gases. The pressure of the gases then drops rapidly in passing through the turbine blades, dropping the exhaust temperature (to around 500°C).



Each main part of the engine does a different thing to the air or fuel mixture passing through:

- **Compressor**: Dramatically increases the pressure of the air (and, to a lesser extent) its temperature.
- **Combustion chamber**: Dramatically increases the temperature of the air-fuel mixture by releasing heat energy from the fuel.
- **Shaft**: An axle that runs the length of the engine and connects the **turbine** blades to the compressor fan. So, as the turbine blades spin, they also turn the compressor fan sucking more air into the engine
- **Exhaust nozzle**: Dramatically increases the velocity of the exhaust gases, they also allow the Gravity Jet Suit pilot to accurately adjust thrust vectors to manoeuvre during flight.

FORCES AND NEWTON'S LAWS



Newton's First Law of Motion states that objects with **balanced forces** acting on them will stay at rest or stay in constant motion. This means that forces acting on a Jet Suit pilot can change his or her **speed**, and the **direction** in which he or she is moving.

Newton's Second Law of Motion states that when an **unbalanced force** acts on an object:

- the direction of the object's **acceleration** is the same as the direction of the unbalanced force
- the **magnitude** of the object's acceleration varies in direct proportion with the size of the unbalanced force
- the magnitude of the object's acceleration varies **inversely** with the mass of the object

The unit of force is called the **newton (N)**

1 newton is defined as that unbalanced force which produces an acceleration of 1 m/s^2 when it acts on a mass of 1kg.

Newton's Second Law of Motion can be written as the following relationship:

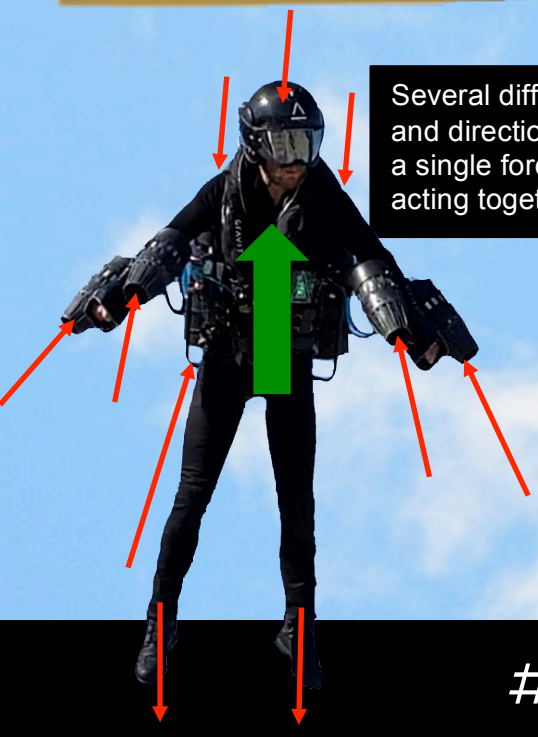
$$F = ma$$

where: F = unbalanced force
m = mass
a = acceleration

Weight and Mass

Weight is not the same as mass. In physics, the term weight has a specific meaning - which is the force that acts on a mass due to gravity. **Weight is measured in newtons. Mass is measured in kilograms.**

Weight is the result of **gravity**. The gravitational field strength of Earth is 10 N/kg (ten newtons per kilogram). This means a pilot weighing 82kg would be attracted towards the centre of the Earth by a force of 820 N. To accelerate away from the Earth and **fly**, the Jet Suit has to have thrust of more than 820 N



Several different forces act on a Jet Suit pilot; these forces have different strengths and directions. But they can be added together to give the **resultant force**. This is a single force that has the same effect on the Jet Suit pilot as all the individual forces acting together.

Types of Forces

A force is any influence that causes an object to undergo a specific change. Related concepts include:

thrust - increases the **velocity** of an object
air resistance - decreases the velocity of an object
torque - changes the **rotation** of an object.

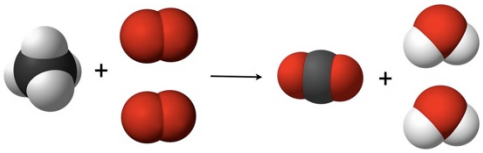
COMBUSTION STEM

Combustion is the scientific word for burning. In a combustion reaction, a **substance reacts with oxygen** from the air. Combustion reactions happen at high temperatures, and **transfer energy** to the surroundings as **light and heat**. This is why you see flames when things burn.

The most common form of combustion is fire. Most forms of combustion happen when oxygen joins with another substance. For example, when wood burns, oxygen in the air joins with carbon in wood. Many common substances can undergo combustion - for example, paper, cloth, and natural gas. Combustion begins when the substance reaches a temperature called its **ignition point**.

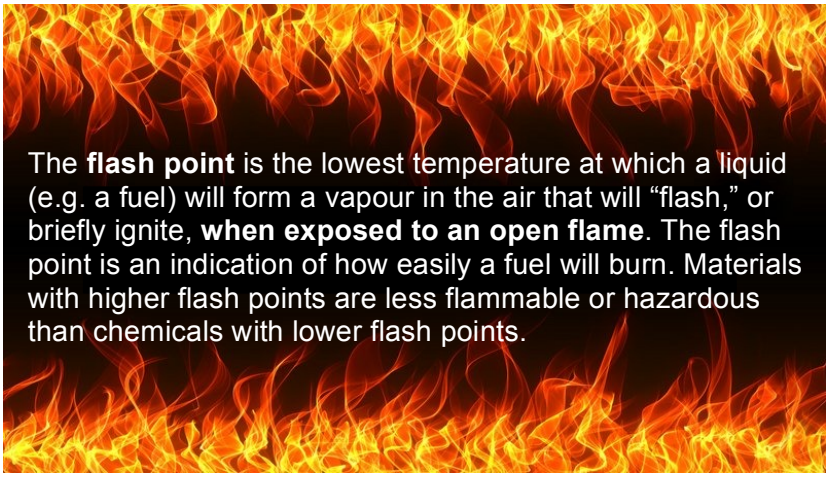
One important combustion reaction is that of methane. Methane reacts with oxygen from the air and produces either a hot blue or an orange flame. The energy that the reaction produces can be used to heat water, cook food, generate electricity or even power vehicles.

The products of combustion reactions are compounds of oxygen, called **oxides**. Since methane is made up of atoms of carbon and hydrogen, the products of its combustion reaction are oxides of carbon and hydrogen. The names of these oxides are **carbon dioxide and water**.



$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

The fuel used in the Gravity Jet Suit is called kerosene, or Jet A1 fuel. Like methane, this fuel contains hydrogen and carbon molecules. The chemical formula is a bit more complicated than for methane but the process is the same. The combustion inside the gas turbines causes hot gases to blast out of the exhaust nozzles.

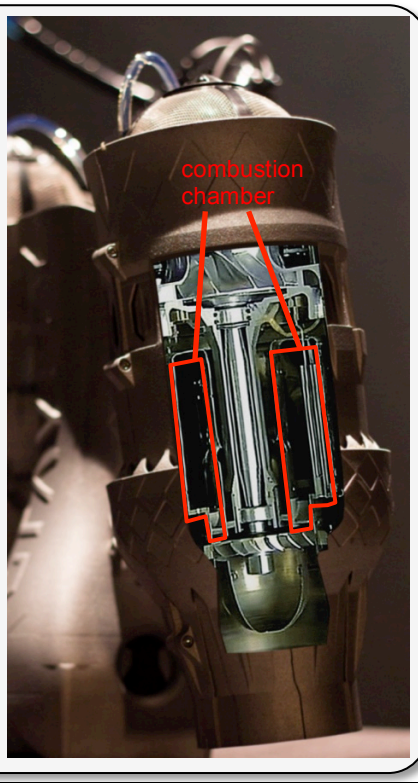


The **flash point** is the lowest temperature at which a liquid (e.g. a fuel) will form a vapour in the air that will "flash," or briefly ignite, **when exposed to an open flame**. The flash point is an indication of how easily a fuel will burn. Materials with higher flash points are less flammable or hazardous than chemicals with lower flash points.

*The flash point is not the same as the **auto-ignition temperature**. This is the minimum temperature required to ignite a gas or vapor in air without a spark or flame present. For example if it touches hot metal.*

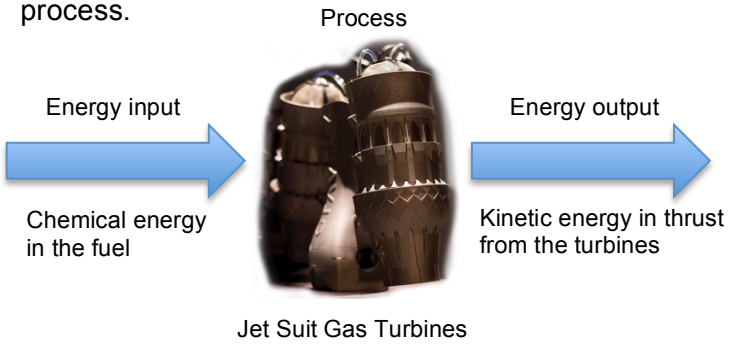
The combustion inside the Gravity Jet Suit engines combines fuel and compressed air. The large amount of air compressed into the small combustion chamber provides lots of oxygen molecules to produce a combustion reaction with the hydrogen and carbon molecules in the vapour of the kerosene or Jet A1 fuel.

Jet A1 fuel has a much higher flash point than petrol for a car engine. This is an important safety feature because the risk of a fire is low for general use, or in the event of an accident.



ENERGY TRANSFER STEM

There are several different **types of energy** which can be **transferred** from one type to another. **Energy transfer diagrams** show these transfers in process.



Jet Suit Gas Turbines

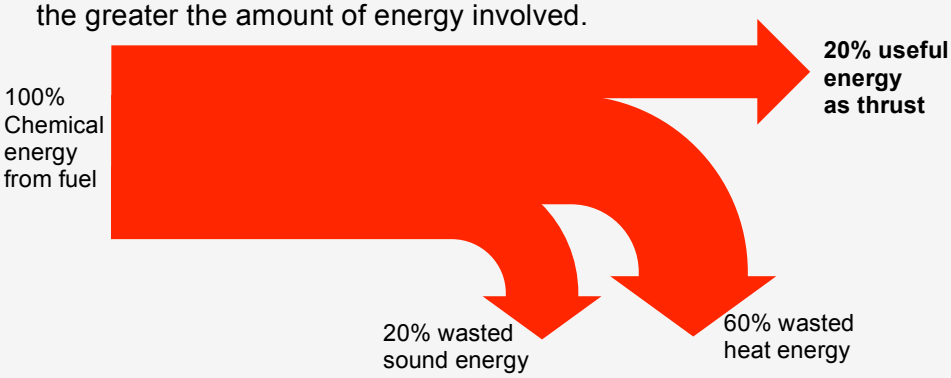
More efficient devices transfer the energy supplied to them into a greater proportion of useful energy.

Types of Energy

- **Magnetic** - Energy in magnets and electromagnets
- **Kinetic** - The energy in moving objects.
- **Heat** - Also called thermal energy.
- **Light** - Also called radiant energy.
- **Potential** - Stored energy in raised objects.
- **Chemical** - Stored energy in fuel, foods and batteries.
- **Sound** - Energy released by vibrating objects.
- **Electrical** - Energy in moving or static electric charges.
- **Elastic Potential** - Stored energy in stretched or squashed objects.
- **Nuclear** - Stored in the nuclei of atoms.

Energy can be **transferred** usefully, stored or dissipated. **It cannot be created or destroyed**. The chemical energy transferred from the fuel to kinetic energy in thrust of the Jet Suit pilot is the useful transfer; the rest is **'wasted'** as sound energy and heat energy.

Sankey diagrams summarise the main energy transfers taking place in a process. The thicker the line or arrow, the greater the amount of energy involved.



This thermal image of a Gravity Jet Suit pilot shows the amount of energy wasted in heat.

In this example, the efficiency of the engine is 20%. How efficiently an engine converts fuel into useable energy is a key commercial factor.

When a **force** causes a body to move, work is being done on the object by the force.
Work is the measure of energy transfer when a force (F) moves an object through a distance (d).
When work is done, **energy** has been transferred from one energy store to another,
and so: ***energy transferred = work done***

Energy transferred and work done are both measured in **joules (J)**.
The amount of work done when a force acts on a body depends on two things:

the size of the force acting on the object
the distance through which the force causes the body to move in the direction of the force

The equation used is: **work done = force × distance**

$$W = F \times d$$

work done (*W*) is measured in joules (J)
force (*F*) is measured in newtons (N)
distance (*d*) is in the same direction as the force and is measured in metres (m)

So, for the Gravity pilot in the picture whose Jet Suit is delivering a total of 1,430N of thrust:

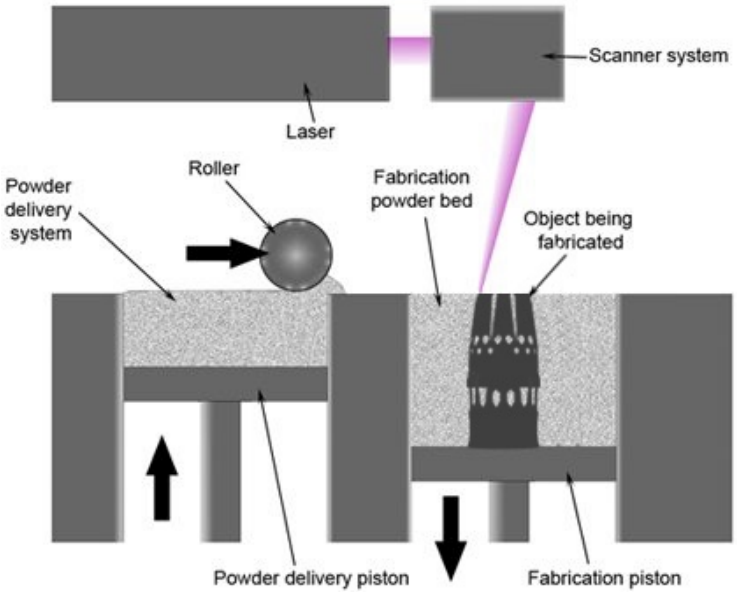
W = 1,430 x 3 = 4,290 J

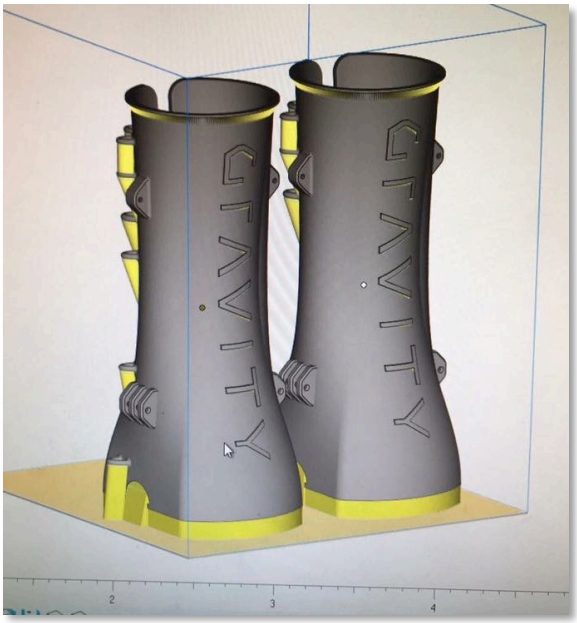
3D PRINTING

STEM

Three dimensional (3D) printing, or **additive manufacturing**, is a process in which a mechanical device can make a three-dimensional object out of digital information. The process involves depositing materials **layer by layer** in accordance with the digital model on a computer. 3D printing is often cheaper, faster and more customizable than traditional manufacturing processes.

For the Gravity Jet Suit parts, a process called **Direct Metal Laser Sintering (DMLS)** was used. This method of 3D printing uses a laser to melt or 'sinter' metal powder. A precision laser moves across a bed of atomised aluminum powder to melt it into hard metal; the bed is lowered a tiny distance; a roller pushes more metal powder into the bed and then the laser melts the next layer of the object. The new layer fuses to the previous layer with the heat from the laser. This continues until every layer is complete and the object is built.





Just like a document printer needs a digital document (a PDF, a Word file or a JPEG) to print, 3D printers require a **digital design file** containing the three-dimensional geometry of the object.

These digital files are designed using **CAD (Computer Aided Design)** software.

The digital design file is then put through **3D slicer software**. This specialist software prepares the design for 3D printing by 'slicing' it into individual layers of data which correspond to each individual layer of the physical object.

RESULTANT FORCES

STEM

When multiple **forces** act on an object, they can add together or subtract from each other until there is the equivalent of just one force acting in a single direction. This is the **resultant force**.

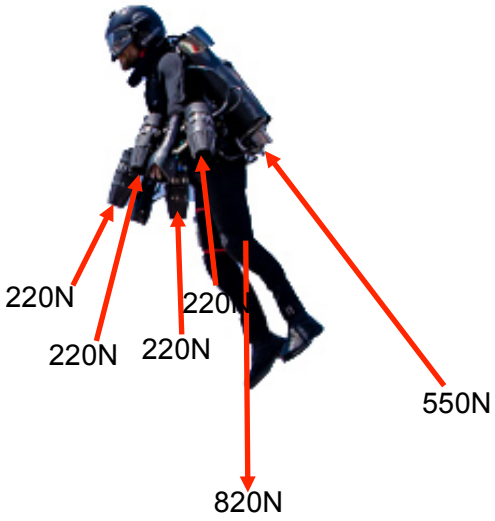
Free Body Diagrams show all the forces acting on an object.

The sizes of the arrows show the relative magnitudes of the forces and the directions show the directions of the forces acting on the object.

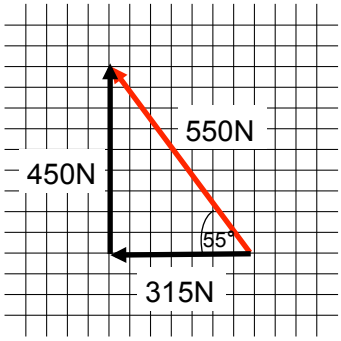
An object is in **equilibrium** in the forces on it are **balanced**.

Vectors have magnitude and direction	
Vector quantities	**Scalar quantities**
force velocity displacement acceleration momentum	speed distance mass temperature time

Not all forces act horizontally or vertically - some act at awkward angles.



To make these easier to deal with, they can be split into two **components** at right angles to each other. You can **resolve** a force split into components by drawing it on a scale diagram.



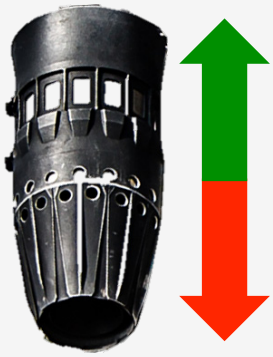
Horizontal component = 315N
Vertical component = 450N

Newton's Third Law

When two objects interact, the forces they exert on each other are **equal and opposite**.

In the Gravity Jet Suit, the 5 turbine engines produce hot exhaust gases. As the burning gasses expand and blast out through the nozzle down towards the ground, the pilot is thrust upwards.

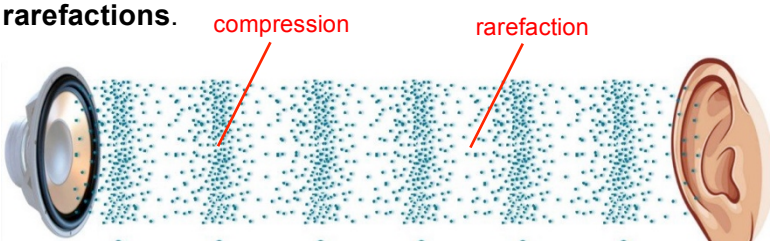
The downwards force equals the force pushing the turbines and the pilot upwards.



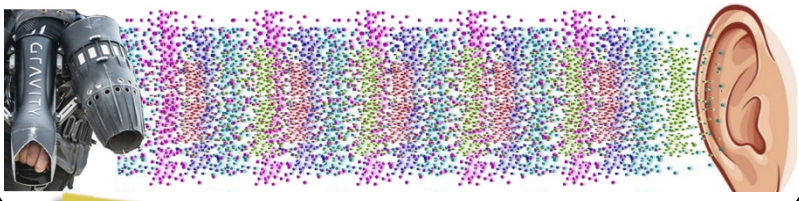
SOUND WAVES

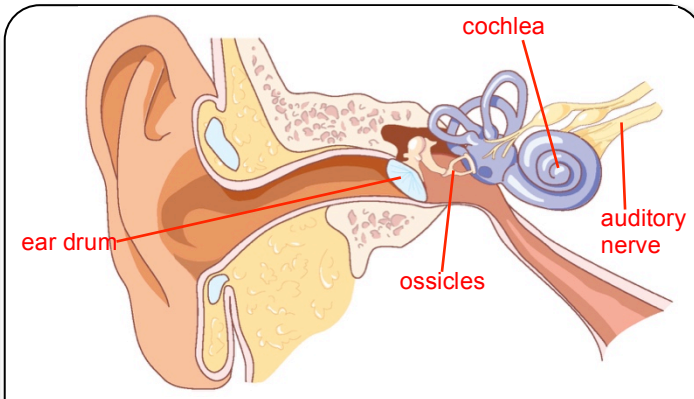
STEM

Sound waves are **longitudinal waves** caused by vibrating objects. These vibrations are passed through the surrounding medium as a series of **compressions** and **rarefactions**.



The gas turbine engines in the **Gravity Jet Suit** create a huge amount of turbulence of the air rushing out of each exhaust nozzle. This rushing of exhaust gases transmits pressure waves haphazardly through the air resulting in very powerful sound waves.





The human ear detects sound. Sound waves enter the ear canal and cause the **eardrum** to vibrate. Three small bones called **ossicles** transmit these vibrations to the **cochlea**. This produces electrical signals which pass through the **auditory nerve** to the brain, where they are interpreted as sound.

High pressure sound waves can permanently damage parts of the ear and so **Jet Suit pilots** and spectators wear earplugs to stop the most powerful vibrating air enter the ear canal.

When sound travels through a solid it causes the particles to vibrate.

Sounds generally travel faster in solids than in liquids, and faster in liquids than in gases.

Sound can't travel in space because it's mostly a vacuum and there are no particles to move or vibrate.

Speed of sound in air is about 330 metres per second (m/s)

The **amplitude** of sound is how loud it is.

The **frequency** of sound is how high pitched it is. High frequency sound waves are high pitched.

Sound waves will be **reflected** by **hard flat surfaces**. Echoes are reflected sound waves.

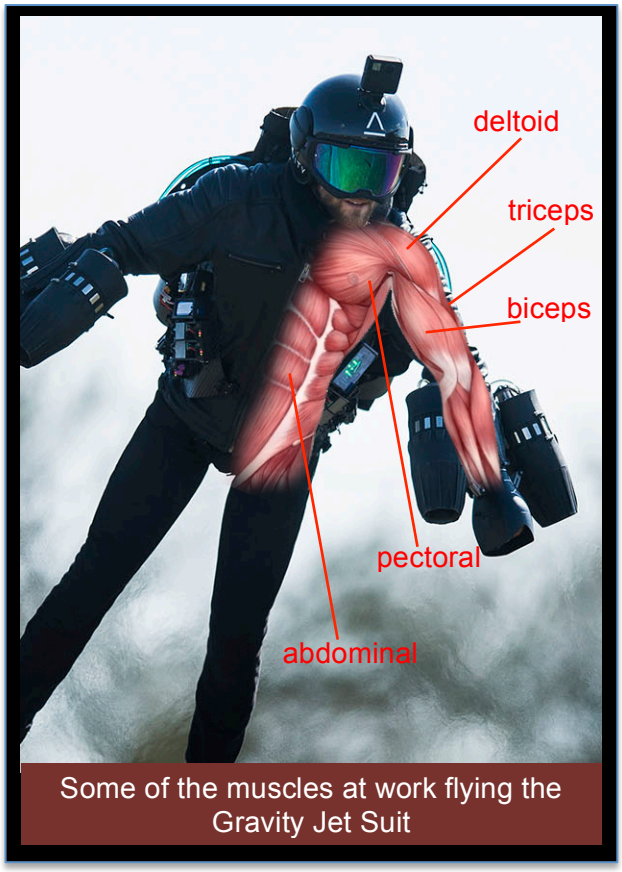
BIOMECHANICS

STEM

Some bones in the skeleton are joined rigidly together and cannot move against each other. Bones in the skull are joined like this. Other bones are joined to each other by flexible joints. Muscles are needed to move bones attached by **synovial joints.**

Skeletal muscles work in pairs to move the body. When you move your arm, the bicep contracts while the triceps muscle relaxes. The bicep pulls the bones together, bending the arm. The reverse happens when the arm straightens.

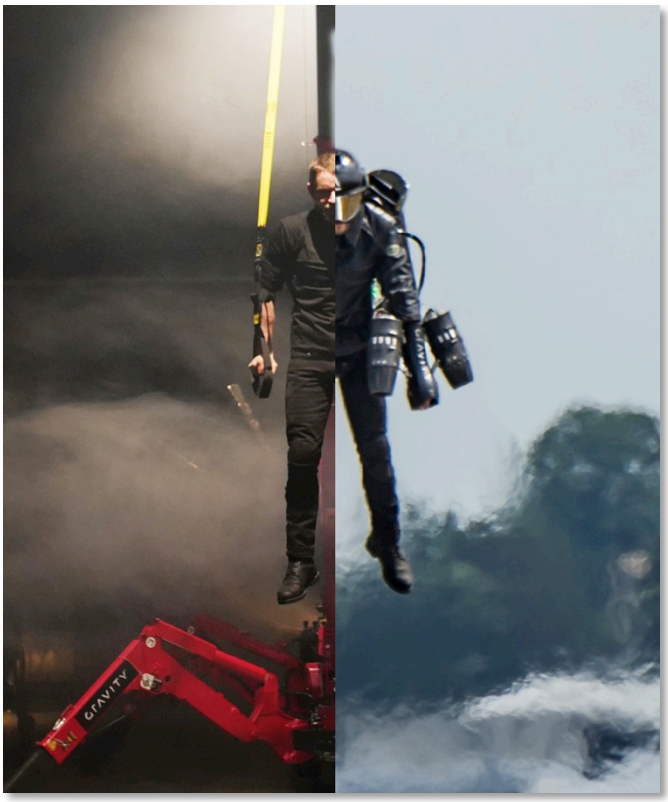
Muscles can only contract and pull bones - they never push them.



Some of the muscles at work flying the Gravity Jet Suit

Different types of **synovial joint** allow different types of movement. The table below describes two types of joint:

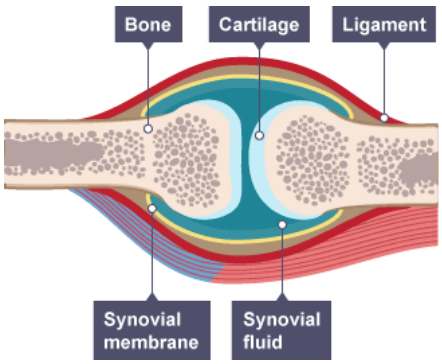
Type of joint	Examples	Movement allowed
Hinge joint	Knee, elbow	The same as opening and closing a door, with no rotation (turning)
Ball and socket joint	Hip, shoulder	Back and forth in all directions, and rotation



The way in which muscles and bones work together to exert forces is called

biomechanics.

If two bones just moved against each other, they would eventually wear away. To stop this happening, the ends of the **bones** in a joint are covered with a tough, smooth substance called **cartilage**. This is kept slippery by a liquid called **synovial fluid**. Tough **ligaments** join the two bones in the joint and stop the joint falling apart.



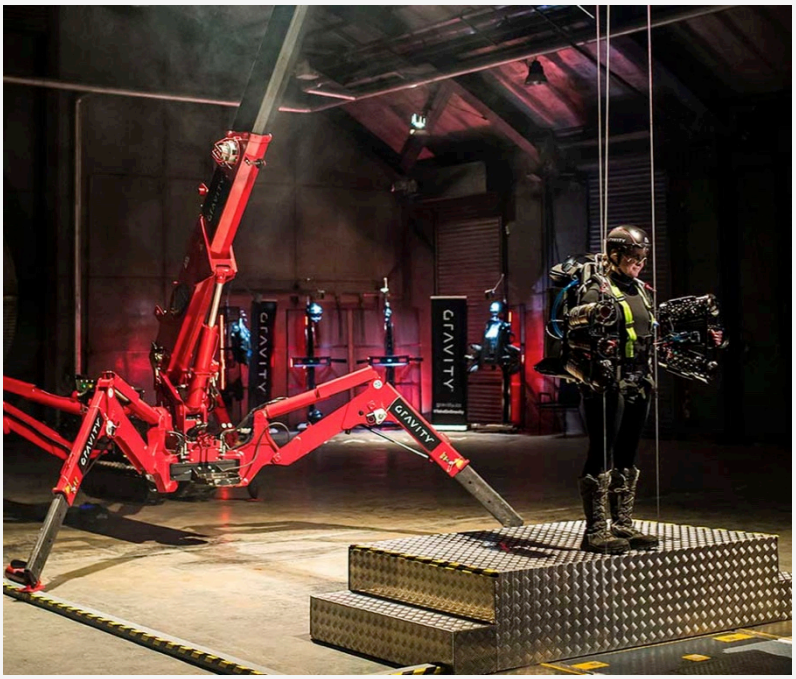
Muscles exert a force on bones when they contract. This happens for example when you lift or hold an object, or when you move a part of your body. If you hold an object weighing 10 N, keeping it still and with your forearm horizontal and your upper arm vertical, you would be exerting an upwards force of 10 N on the object. You could work out the force exerted by the biceps muscle to do this using the idea of moments.

HUMAN BALANCE

STEM

Your balance system helps you stand, walk, run, and move without falling. Your eyes, **inner ear**, and muscles and joints send signals to your brain. These signals help you stay balanced. This system of signals is your **vestibular system**.

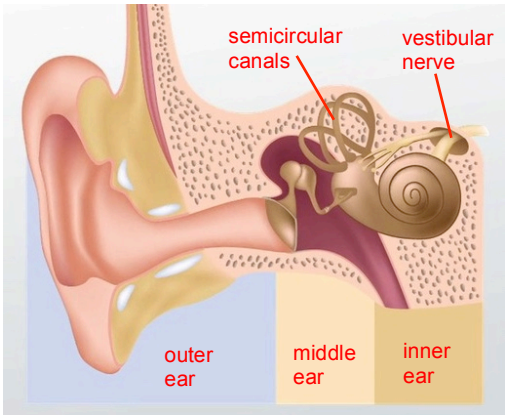
Flying the Gravity Jet Suit relies on the pilot's ability to balance and demands a complex interaction of different parts of the brain, inner ear, muscles, joints and visual system.



Gravity Jet Suit flying training takes time for the pilot's vestibular system to learn the new muscle movements required to balance. With enough practice, flying a Gravity Jet Suit becomes as natural as walking and running.

The Inner Ear

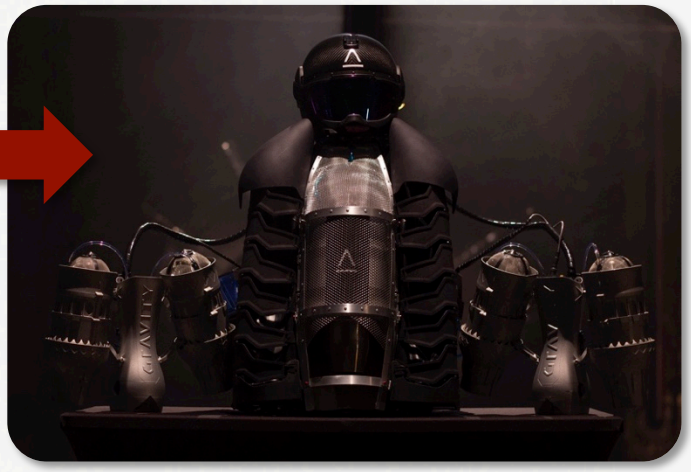
There are three loops in your **inner ear**, called **semicircular canals**. One canal senses up-and-down movement. Another canal senses side-to-side movement. The third canal senses tilting movements. Each canal has **hair cells** and **fluid** inside. When you move, the fluid and hair cells move. The hair cells send messages to your brain through the **vestibular nerve**. Your brain uses this information to help you know where you are in space. You use this information, along with what you see and feel, to keep your balance. Inner ear trouble can lead to balance problems.



Some text sourced from: www.asha.org; Ear diagram: study.com

SCIENTIFIC METHOD STEM

An empirical method of acquiring knowledge.
First, formulate a question based on an **observation**. Then create a **hypothesis** based on knowledge that can explain the observation. Next, make a **prediction** then **test** that prediction, and finally **analyse** your results.



Empirical = based on, or verifiable by, observation or experience rather than theory or pure logic.

OBSERVE
Humans can fly

HYPOTHESIS
Jet engines strapped to a human and pointed down could produce enough lift to keep a person airborne.

PREDICT
4 jet engines will create enough thrust (it actually takes a 5th engine for stability but Gravity started with a different prediction).

TEST
Create an experiment to see if your prediction is true.

ANALYSE
This is done through the senses (did it work?), but also through analysing the data collected.

REPEAT...FAIL...REPEAT...FAIL...
REPEAT...**SUCCEED!!**

This is a process and almost always includes many failures…which is good. Each failure is a lesson that allows you to change aspects of your approach.

BEWARE

BEWARE OF YOUR BIASES

Biases are perceptions that we bring to our approach that can influence the way we interpret information.
We all have biases, but being aware of and understanding them will help us evaluate information objectively.

Main Biases

Confirmation Bias: agree with people who agree with us. The often unconscious act of referencing only those perspectives that match our pre-existing views, while at the same time ignoring or dismissing opinions - no matter how valid - that threaten our world view.
Gambler's Fallacy: putting a tremendous amount of weight on previous events, believing that they will somehow influence future outcomes.
Negativity Bias: Paying more attention to bad news. For example, crime, violence, war, and other injustices are steadily declining, yet most people would argue that things are getting worse
Bandwagon Effect: Built-in desire to fit-in and conform. Though we're often unconscious of it, we love to go with the flow of the crowd.
Projection Bias: We tend to believe that people not only think like us, but that they also agree with us.