A-Level mechanics in mechanical, aerospace, and automotive engineering

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IMA Festival of Mathematics & its Applications

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A-Level Mechanics in Mechanical, Aerospace, and Automotive Engineering

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Department of
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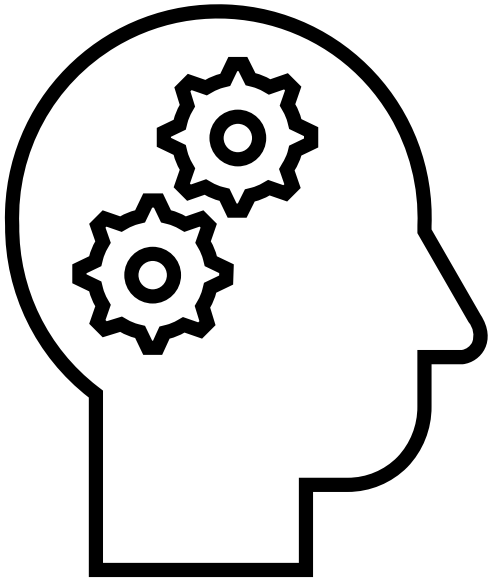
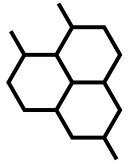
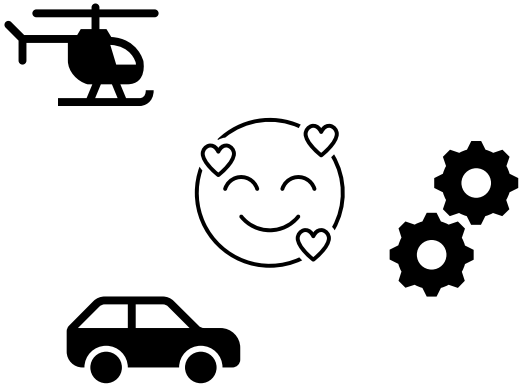


Why Mechanics?

Mathematics - Physics is the anatomy of almost all types of Engineering

Chemistry is very important too, for example, when studying Materials Engineering or Chemical Engineering



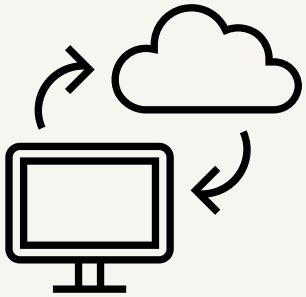


Mechanics is at the heart of Aerospace, Automotive, and Mechanical Engineering

Maths provides a very useful toolkit to study Engineering

So, if you like your maths it certainly helps to ‘fix’ engineering. That is not to say you need to be brilliant at maths.

What you need is **a passion for maths**, a reasonable working knowledge in maths, a lot of **imagination**, and an **inquisitive mind** about how maths can be used in different engineering applications.



As Engineering has now moved into the digital era, in later years of study, there is a lot of **simulation and modelling**. As all of you are “digital wizards”, you will begin to enjoy engineering studies more and more as you master the **skills** to handle engineering software, and gradually move away from complex maths **.....**

. **.....** if that is the way you like your engineering to be.

Manufacturing, Rail, Maritime, Automobile, Aerospace, Biomedical, Renewable Energy **.....**

However, to make the most of future opportunities, you will still need a good early **foundation knowledge** of core mathematics and engineering principles.

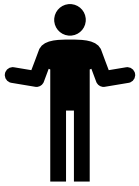
So, what you are currently studying in A-Levels will be a very useful starting point.

The transition from A-Levels to university early engineering studies will be an exciting stage in your development**.....**

..... once you enter the university, it is in your own hands to make the journey happen!

The study of **‘Mechanics’** within Maths and Physics is a major part of this base knowledge.

What really is Mechanics?



It could mean different things to different people?

In Engineering, we mainly talk about two main types of Mechanics:

- Mechanics of Solids
- Mechanics of Fluids

Possible Definitions?

- Mechanics is the area of study in physics and mathematics that examines how forces affect a body and its motion. It deals with the movement of physical objects and the relationship between force, mass, and motion. Mechanics studies include stationary objects, where the forces acting over them are in equilibrium.

- Mechanics is that branch of Physics dealing with the study of behaviour of bodies and their motion when subjected to forces, and the subsequent effects of the bodies on their environment.

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The key name associated with Engineering Mechanics is,

Sir Issac Newton
1642 - 1727

- Newtonian Mechanics
- Classical Mechanics

Deals with macroscopic bodies

Newton's 1st Law

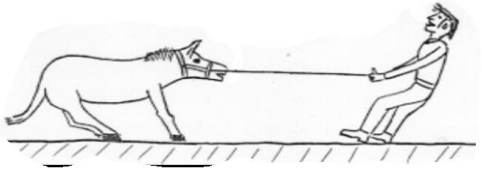
"Every object persists in a state of rest or uniform motion in a straight line unless it is compelled to change that state by force impressed on it"

Newton's 2nd Law

"The resultant force on an object is equal to the rate of change of momentum (mV)"

Newton's 3rd Law

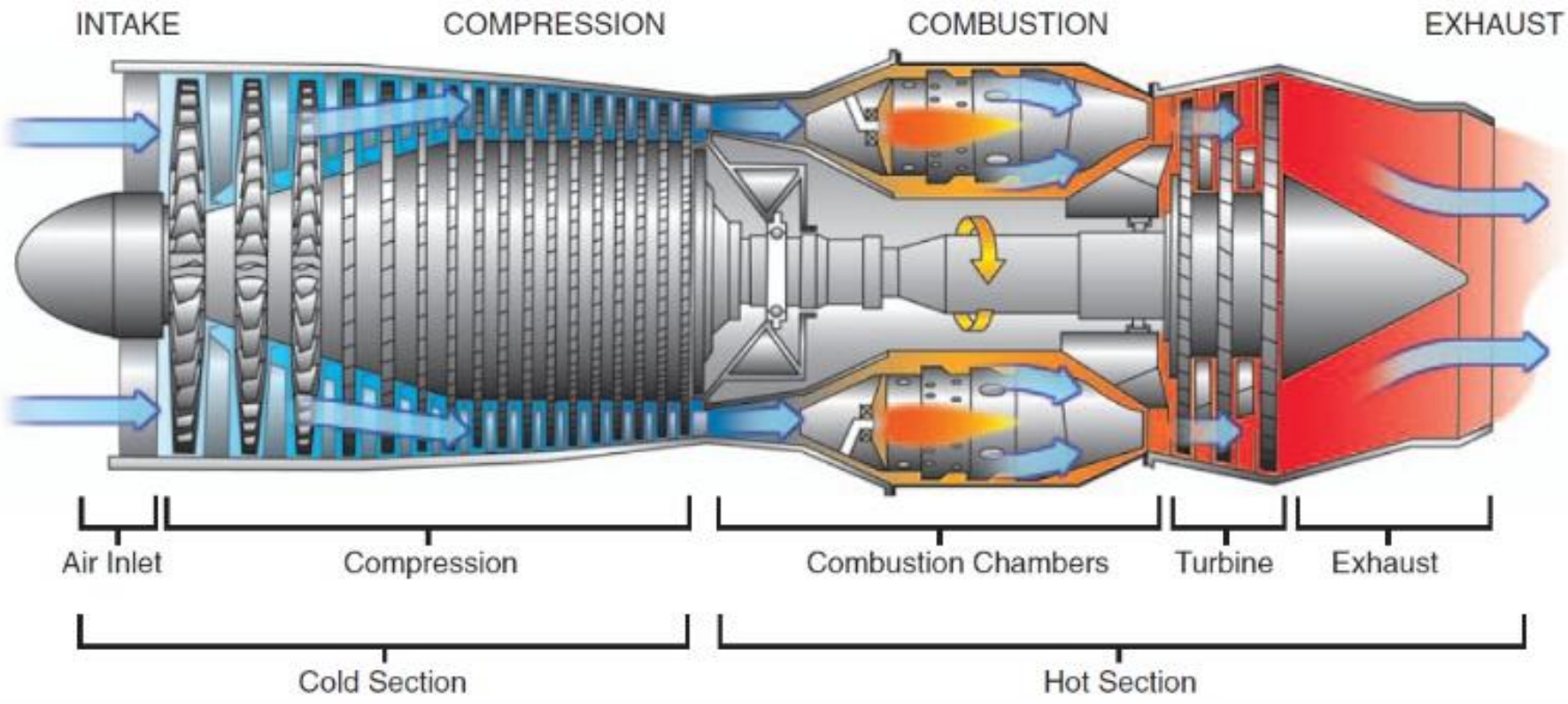
"For every action, there is an equal and opposite reaction"



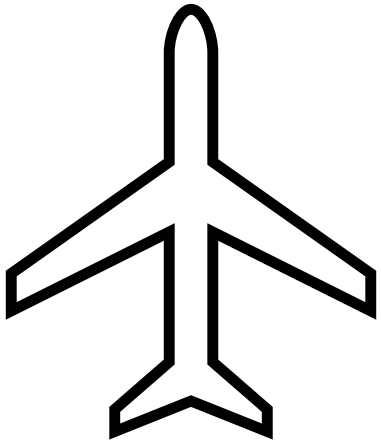
..... a bit of mathematics

What is this? Which company makes these?

Components of a gas turbine engine



Four sections: intake, compression, combustion, and exhaust

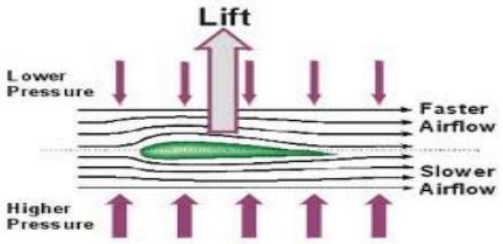


How does the aircraft fly?
Fluid Mechanics principles!

It has to accelerate along the runway, take off at high speed, gain height, gather speed, cruise at high altitude, overcome turbulent weather, decelerate, descend, and land **safely.**

$$p + \frac{1}{2}\rho v^2 = \text{Constant}$$

Bernoulli's principle



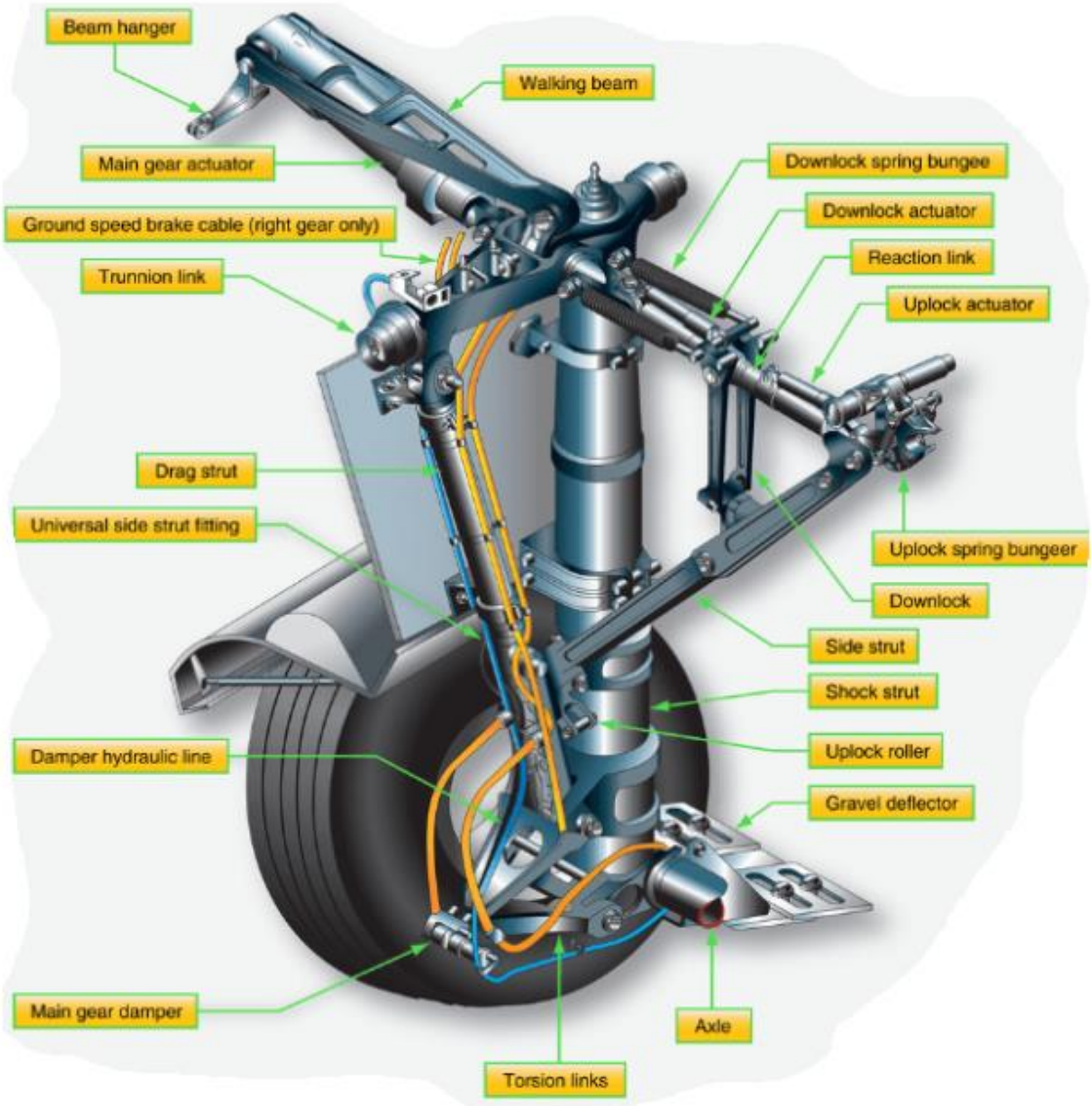
Pressure + $\frac{1}{2}$ density x (speed)^2 is constant

Apart from the Aerodynamics, how does the aircraft land smoothly and safely?

The landing gear on an Airbus A380. Photo: arpingstone via Wikimedia

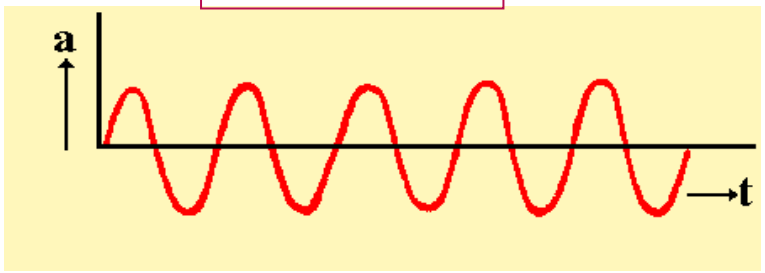
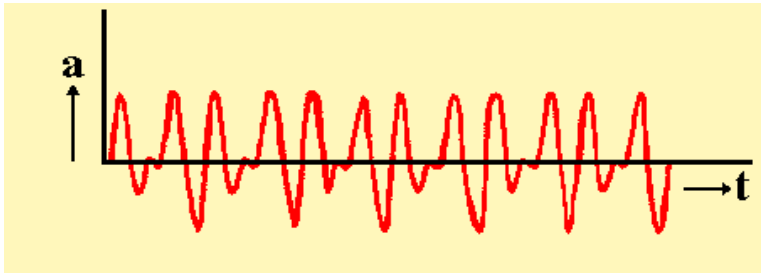
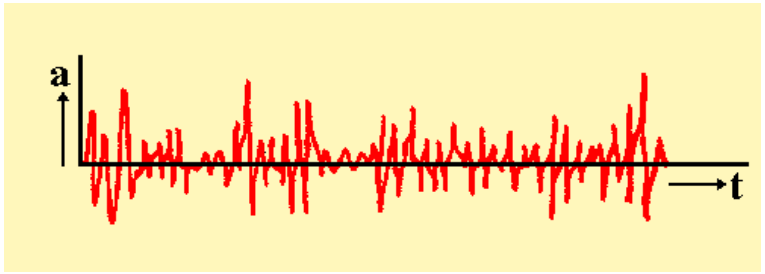
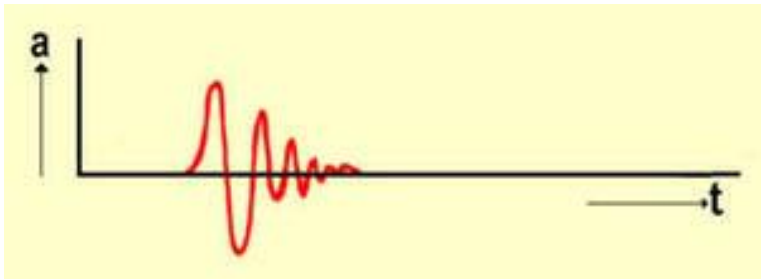
The primary function of the landing gear is to absorb the force of landing and, of course, prevent the fuselage from hitting the ground. This force absorption happens in several ways.

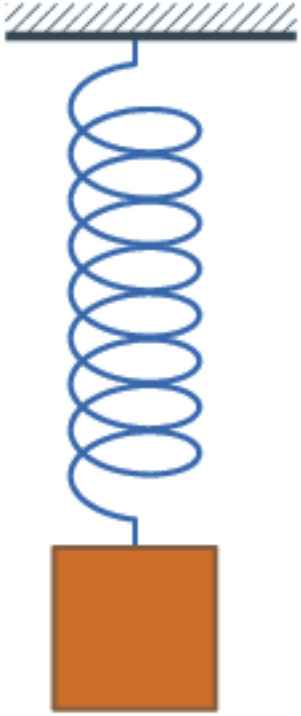
Firstly, the main landing gear strut has a shock absorption system, using compressible fluids. Secondly, the landing force is spread over a number of wheels.


Beam hanger
Walking beam
Main gear actuator
Downlock spring bungee
Downlock actuator
Ground speed brake cable (right gear only)
Reaction link
Trunnion link
Uplock actuator
Drag strut
Universal side strut fitting
Uplock spring bungeer
Downlock
Side strut
Shock strut
Damper hydraulic line
Uplock roller
Gravel deflector
Main gear damper
Axle
Torsion links

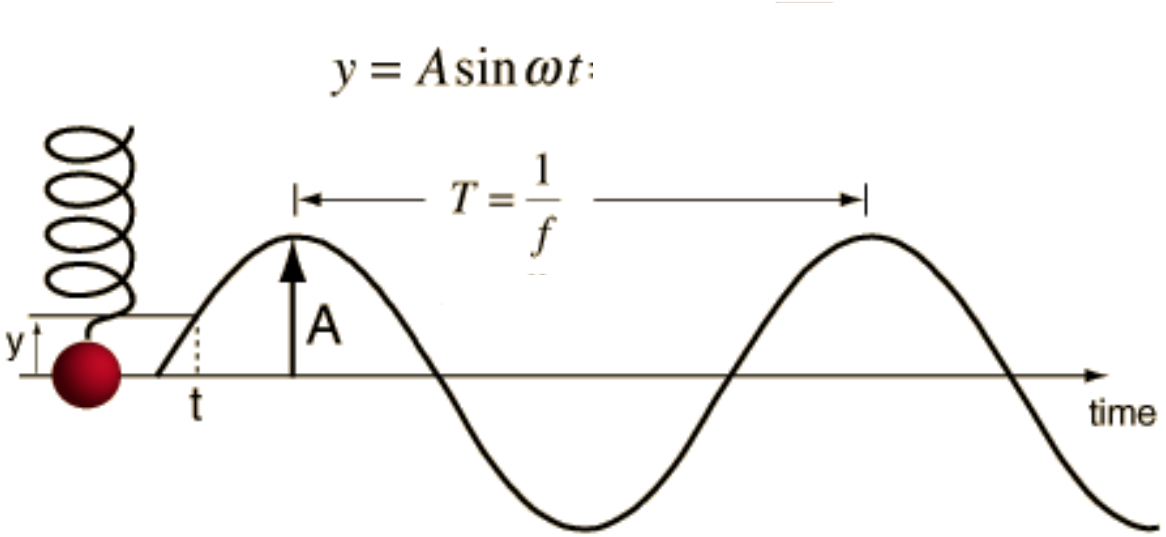
Let’s look at a familiar example.
The Automotive shock absorber.

Types of Vibration Signature with Automotive Applications

Wave Form		Application
	Harmonic	Suspensions All signals formed from this, i.e. Fourier Analysis
	Periodic	Rotary nature of engine means this is of the form of engine vibration/noise
	Random	Road surface Flow noise
	Transient	Door slam Pot hole

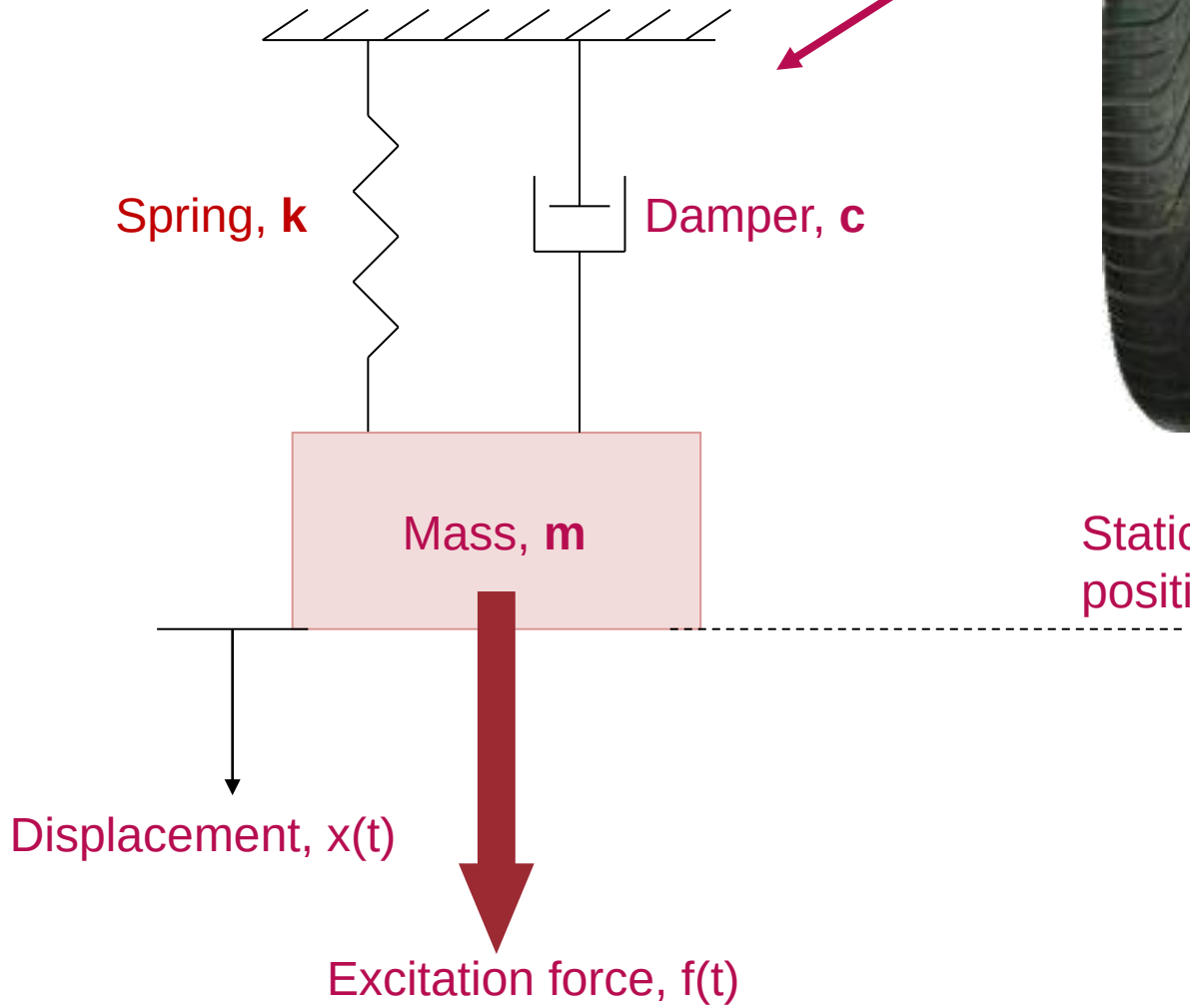


Un-damped Mass on Spring - SHM

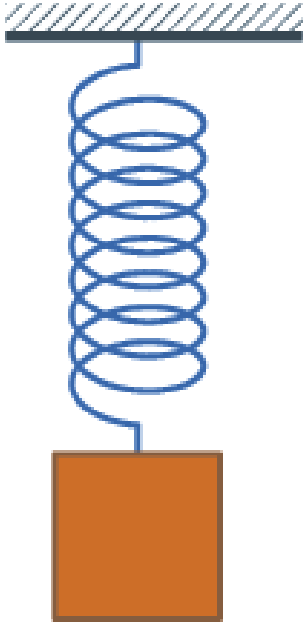


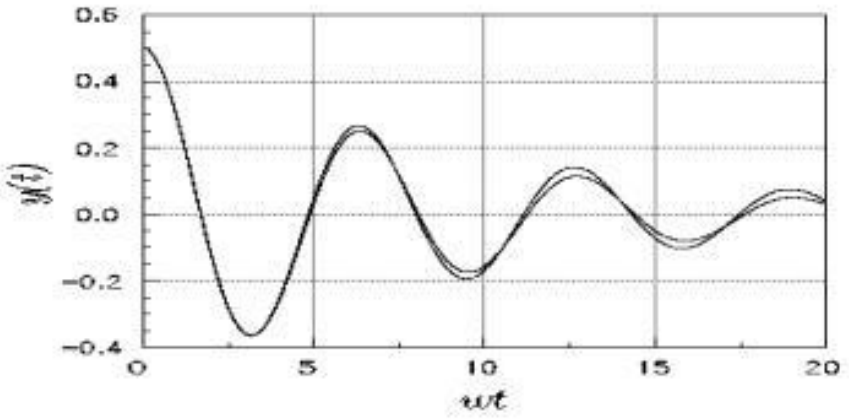
Basic Concepts / Terminology

Idealised elements of a Vibrating System
"Lumped Parameter System"



Damped Mass on Spring - SHM





Damping takes energy out of the system allowing the mass to decay to rest.

Let’s look at another exciting example of Mechanics in action!

All kinds of Mechanics, and engineering knowledge and skills, will come into play here.

Remember - **Safety first** is always an underlying theme in Engineering.

Conservation of energy

$\Delta E_p = mg\Delta h$ $E_k = \frac{1}{2}mv^2$

Circular motion

$\omega = \frac{v}{r} = 2\pi f$ $a = \frac{v^2}{r} = \omega^2 r$ $F = \frac{mv^2}{r} = m\omega^2 r$

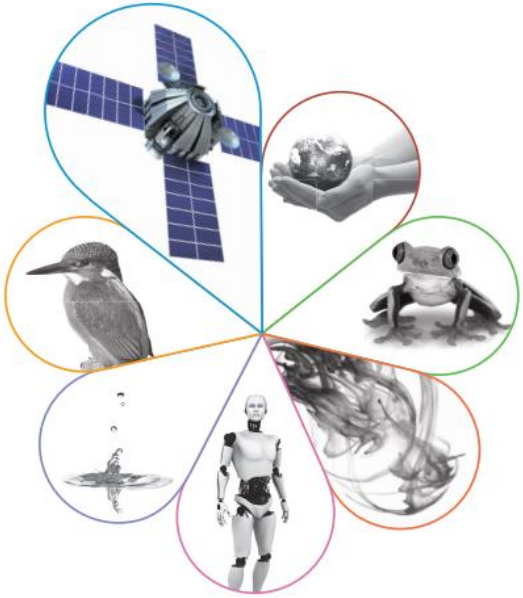
The formal study of Mechanics begins with GCSE Physics

AQA
Realising potential

GCSE
PHYSICS
(8463)

Specification
For teaching from September 2016 onwards
For exams in 2018 onwards

Version 1.1 30 September 2019



2.1 Subject content

1. Energy (page 17)
2. Electricity (page 23)
3. Particle model of matter (page 32)
4. Atomic structure (page 36)
5. Forces (page 43)
6. Waves (page 59)
7. Magnetism and electromagnetism (page 67)
8. Space physics (physics only) (page 72)

4.1 Energy

4.1.1 Energy changes in a system, and the ways energy is stored before and after such changes

4.1.1.1 Energy stores and systems

4.1.1.2 Changes in energy

Kinetic Energy $E_k = \frac{1}{2} m v^2$

Elastic Potential Energy $E_e = \frac{1}{2} k e^2$

Gravitational Potential Energy $E_p = m g h$

4.1.1.3 Energy changes in systems

4.1.1.4 Power

$P = \frac{E}{t}$ $P = \frac{W}{t}$

4.1.2 Conservation and dissipation of energy

4.1.2.1 Energy transfers in a system

4.1.2.2 Efficiency

4.5 Forces

4.5.1 Forces and their interactions

4.5.1.1 Scalar and vector quantities

4.5.1.2 Contact and non-contact forces

4.5.1.3 Gravity $W = m g$

4.5.1.4 Resultant forces

4.5.2 Work done and energy transfer $W = F s$

4.5.3 Forces and elasticity

Force $F = k e$

Elastic potential energy $E_e = \frac{1}{2} k e^2$

4.5.4 Moments, levers, and gears

Moment of a force $M = F d$

4.5.5 Pressure and pressure differences in fluids

4.5.5.1 Pressure in a fluid

$$p = \frac{F}{A} \qquad p = h \rho g$$

4.5.6 Forces and motion

4.5.6.1 Describing motion along a line

$$s = v t \qquad a = \frac{\Delta v}{t} \qquad v^2 - u^2 = 2 a s$$

4.5.6.2 Forces, accelerations, and Newton's Laws of motion $F = m a$

4.5.6.3 Forces and braking

4.5.7 Momentum $p = m v$

4.5.7.1 Momentum is a property of moving objects

4.5.7.2 Conservation of momentum

4.5.7.3 Changes in momentum $F = \frac{m \Delta v}{\Delta t}$

AQA

AS AND
A-LEVEL
PHYSICS

AS (7407)
A-level (7408)

Specifications
For teaching from September 2015 onwards
For AS exams in May/June 2016 onwards
For A-level exams in May/June 2017 onwards

Version 1.3 June 2017

The study of Mechanics topics continue in A-Level Physics

.1 Subject content

ore content

Options

3.4 Mechanics and materials

3.4.1 Force, energy, and momentum

3.4.1.1 Scalars and vectors

3.4.1.2 Moments

3.4.1.3 Motion along a straight line

$$v = \frac{\Delta s}{\Delta t} \qquad a = \frac{\Delta v}{\Delta t}$$

$$v = u + at$$

$$s = \left(\frac{u + v}{2}\right)t$$

$$s = ut + \frac{at^2}{2}$$

$$v^2 = u^2 + 2as$$

3.4.1.4 Projectile motion

3.4.1.5 Newton's laws of motion

3.4.1.6 Momentum

Force

$$F = \frac{\Delta (mv)}{\Delta t}$$

Impulse

$$F\Delta t = \Delta (mv)$$

3.4.1.7 Work, energy, and power

$$P = \frac{\Delta W}{\Delta t} = Fv$$

3.4.1.8 Conservation of energy

$$\Delta E_p = mg\Delta h \qquad E_k = \frac{1}{2}mv^2$$

3.4.2 Materials

3.4.2.1 Bulk properties of solids

Density $\rho = \frac{m}{V}$

Hooke's law, elastic limit
Tensile strain and tensile stress
Elastic strain energy, breaking stress

3.4.2.2 The Young modulus

$$Young\ modulus = \frac{tensile\ stress}{tensile\ strain}$$

3.6 Further mechanics

3.6.1 Periodic motion

3.6.1.1 Circular motion

$$\omega = \frac{v}{r} = 2\pi f \quad a = \frac{v^2}{r} = \omega^2 r \quad F = \frac{mv^2}{r} = m\omega^2 r$$

3.6.1.2 Simple harmonic motion (SHM)

3.11 Engineering physics

3.11.1 Rotational dynamics

3.11.1.1 Concept of moment of inertia

$$I = \Sigma mr^2$$

3.11.1.2 Rotational kinetic energy

$$E_k = \frac{1}{2} I\omega^2$$

3.11.1.3 Rotational motion

$$\omega_2 = \omega_1 + \alpha t, \quad \theta = \left(\frac{\omega_1 + \omega_2}{2}\right)t$$

$$\theta = \omega_1 t + \frac{\alpha t^2}{2}, \quad \omega_2^2 = \omega_1^2 + 2\alpha\theta$$

3.11.1.4 Torque and angular acceleration

$$T = Fr \qquad T = I\alpha$$

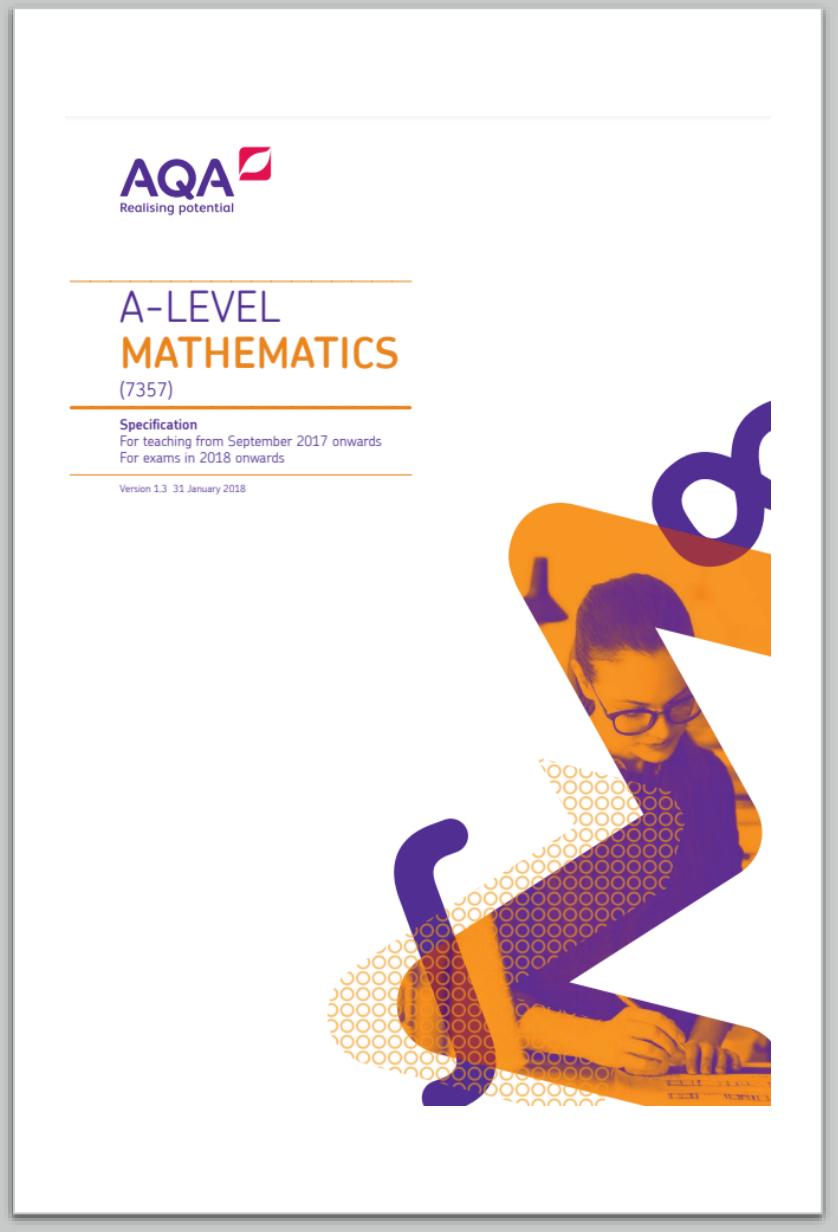
3.11.1.5 Angular momentum

$$angular\ momentum = I\omega$$

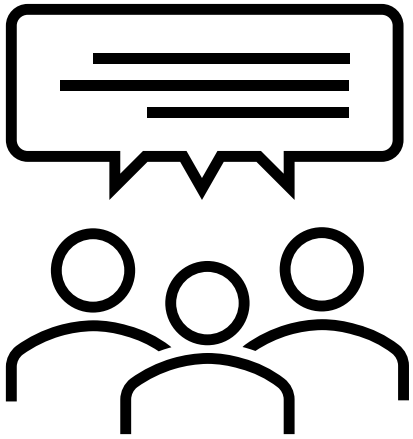
3.11.1.6 Work and power e

$$W = T\theta; \; P = T\omega$$

Let’s look at
A-Level Maths



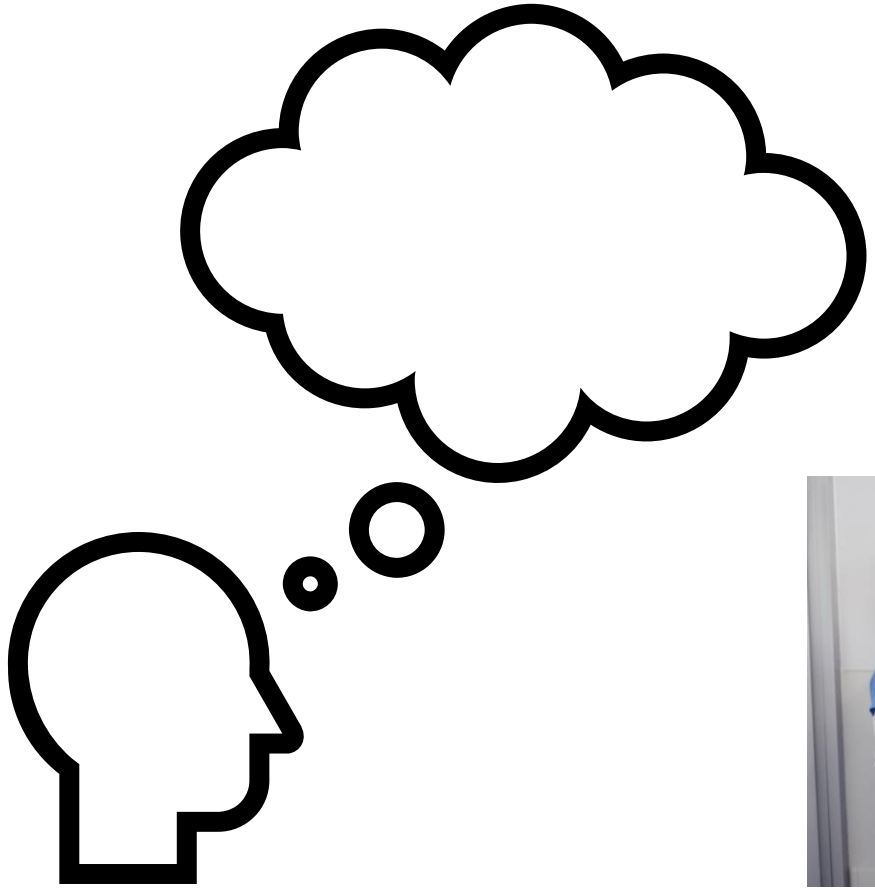
2.1 Subject content



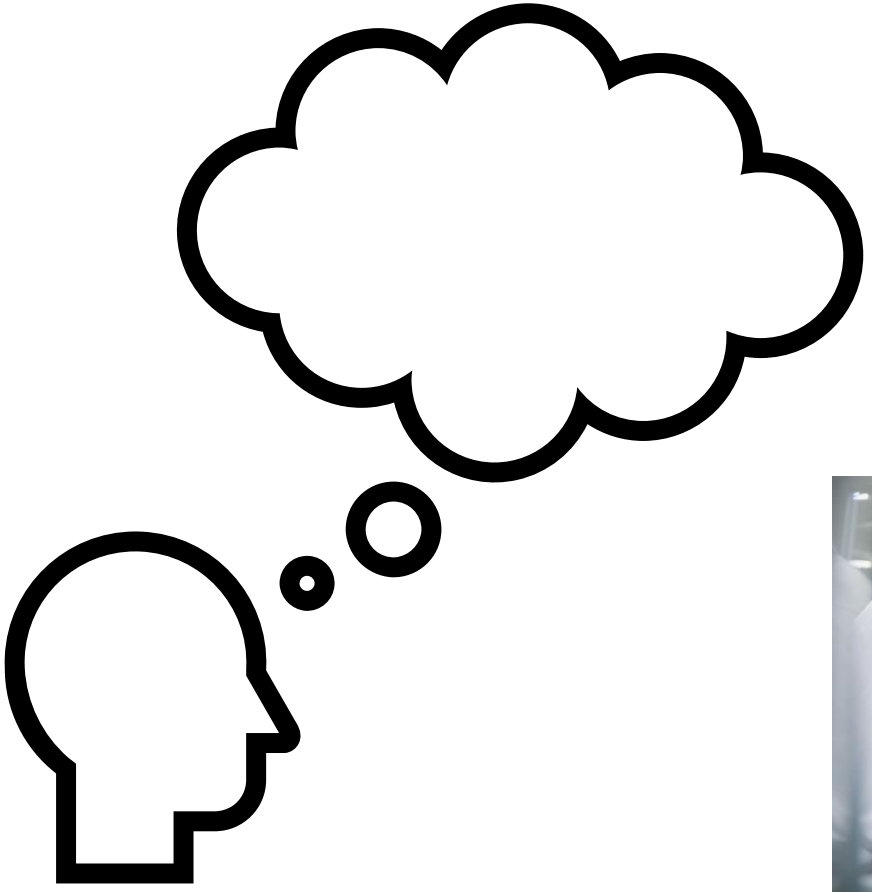
Question Time!

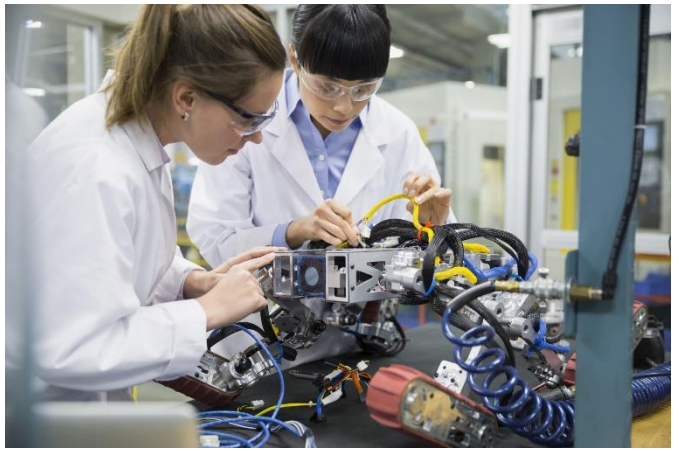
..... well, thinking time?

Who is an Engineer?



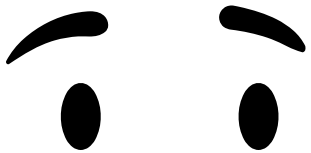
Are men good at Nursing?





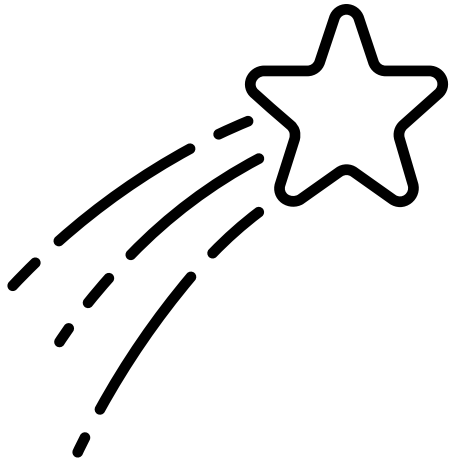
Are women good at Engineering?

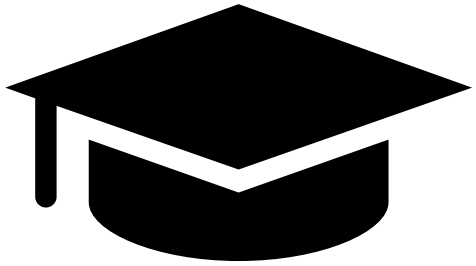
What am I good at?



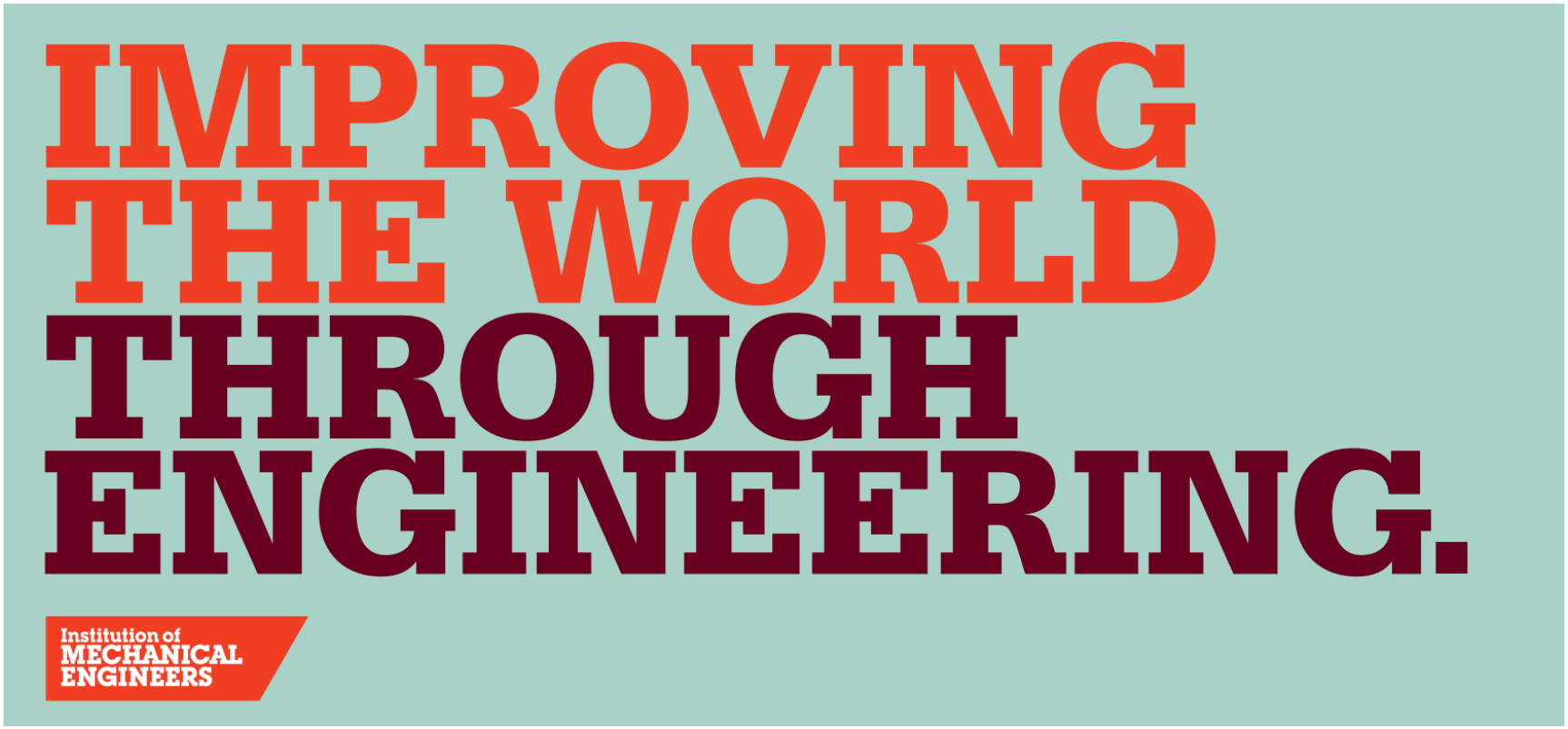
Hurrah!

Our Aerospace, Automotive, and Mechanical Engineering MEng and BEng Degrees have been re-accredited by the Institution of Mechanical Engineers for another 5 years up to 2025-2026





Engineering Council accredited degree


IMPROVING
THE WORLD
THROUGH
ENGINEERING.
Institution of
MECHANICAL
ENGINEERS

Thank you!


MATHS &
ENGINEERING