

INTRODUCTION to THERMO-FLUIDS (THER103)

Thermo-Fluids is a 'composite' subject where we shall look at two aspects of engineering science:

Thermodynamics: – (literally 'heat' 'movement') the study of the interrelationship between energy in the form of heat and work and in particular how one is converted to the other; and

Fluid Mechanics: – the study of how fluids (liquids and gases) behave when they move (fluid dynamics) and when they don't move (fluid statics).

The two subjects are quite closely related. Arguably Fluid Mechanics is a sub-set of Thermodynamics, but in the design or analysis of engineering machines such as engines or gas turbines both subjects are needed.

However, some devices need mainly one discipline or the other so they also have a distinctiveness of their own: so in Stage 2 they have modules of their own! (THER205 & HYFM218)

Because thermodynamics deals with energy conversion (heat to work) it often concerns gases. Gases expand a lot when heated so they are ideal for converting heat to work, but the conversion of liquids to vapours is also used (steam engines & turbines). Fluid mechanics deals with pumps, turbines and the flow of both gases and liquids.

Solid Mechanics deals with the effect of forces on solid materials – also very important to engineers! (MECH108)

In any discipline we have to use names to describe what we are talking about. Sometimes we use 'everyday' words used in ordinary conversation, but within a discipline they may have a very specific meaning.

Words such as 'system', 'heat', 'hot', 'cold' etc. need to be used carefully!

We shall look at:

SYSTEMS

MASS

FORCE

MOMENTUM

ENERGY

COMPRESSIBLE

INCOMPRESSIBLE

Systems

A **system** is a part of the universe defined by a **boundary**.

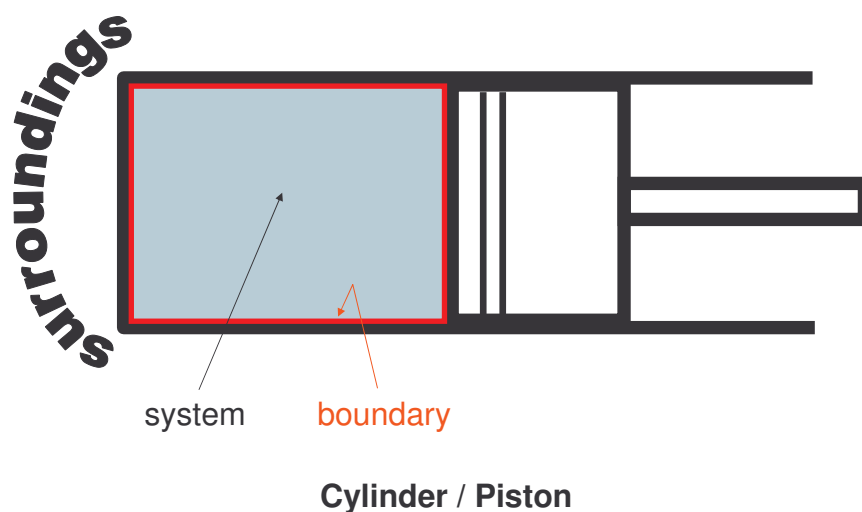
A boundary may be an actual physical boundary, or it may be 'imaginary'.

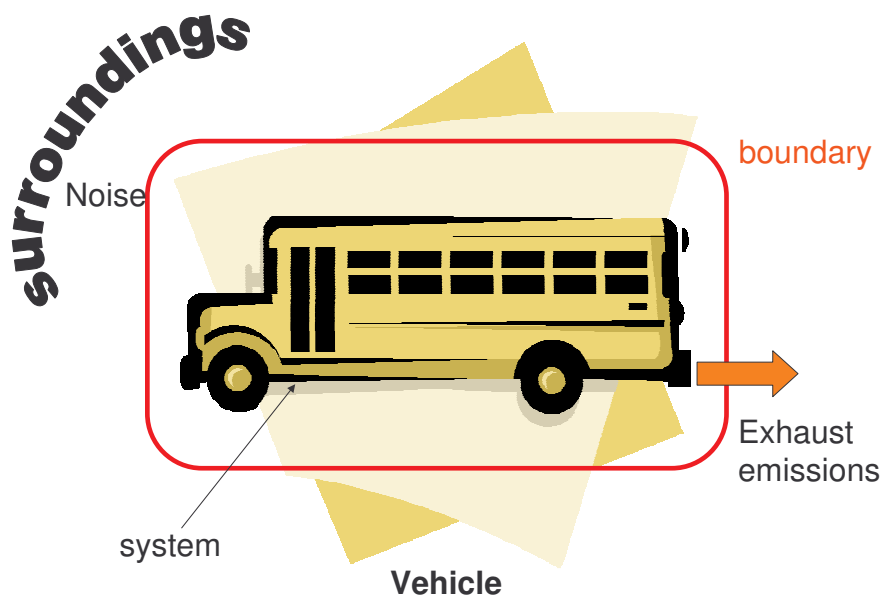
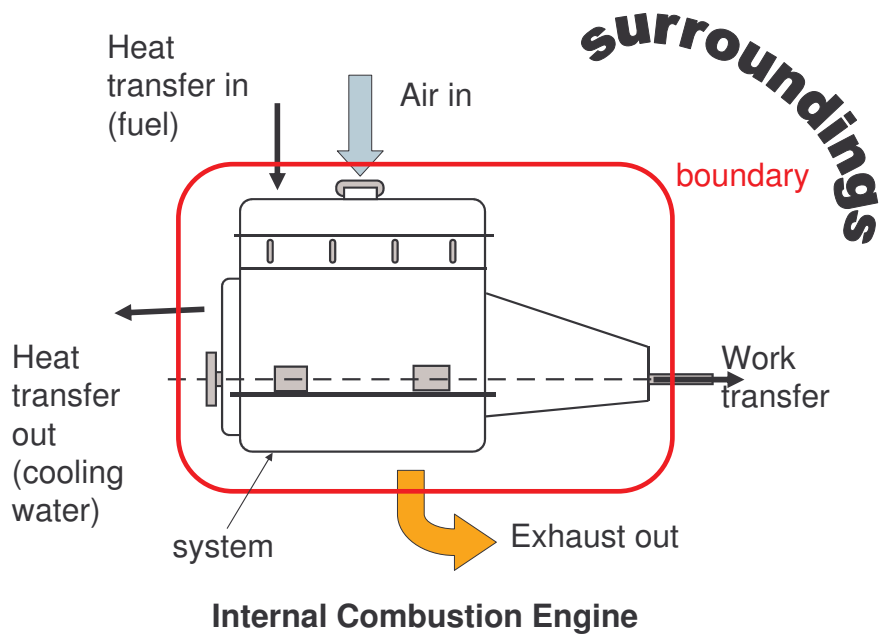
The boundary may be fixed (and we may then call the system a '**control volume**' - often used in Fluid Mechanics) or it may be allowed to move.

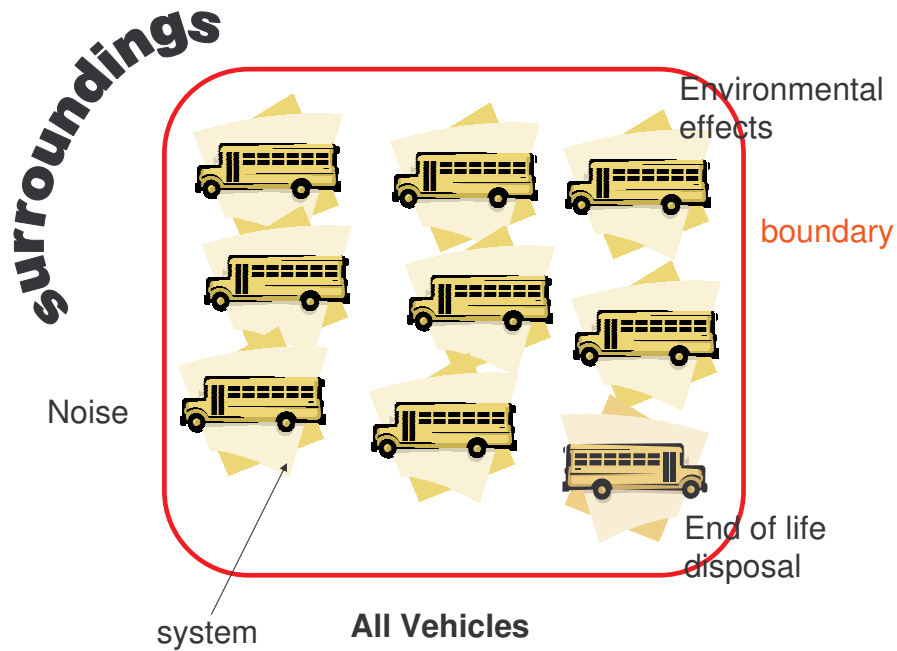
It is important to know what is **inside** the boundary and what is not.

What is **outside** the boundary is often simply called the system's 'surroundings'.

Examples of systems and boundaries







A System may be **CLOSED** or **OPEN**.

A **CLOSED** system is one where **mass** does **not** cross the boundary.... (but energy in the form of heat and/or work can enter or leave the system by means of heat transfer or work transfer).

MASS is defined as the quantity of material.

It is normally measured in one of two ways:

1. By counting the number of atoms or molecules; or
2. By measuring the force (weight) with which the amount of material is attracted to the centre of the earth and converting it mass.

If Method '1' is used the numbers involved are extremely large so we normally measure in 'batches' of atoms or molecules where the number in a batch is defined as the number of atoms in 12g of C_{12} . This number of atoms or molecules is called a 'mole' (or 'mol' for short) and is around 6.023×10^{23} . (Avogadro's number)

If Method '2' is used we need to use a conversion factor '**g**' the gravitational constant:

$$W = mg \quad \text{SO} \quad m = \frac{W}{g} \quad g = 9.81 \text{ m/s}^2$$

Note that the conversion factor is usually built in to weighing machines so their readout is in kg. Also note that mass remains constant whereas force (weight) may not... because of variations in '**g**' on the earth or a different '**g**' on the moon.

A System may be **CLOSED** or **OPEN**.

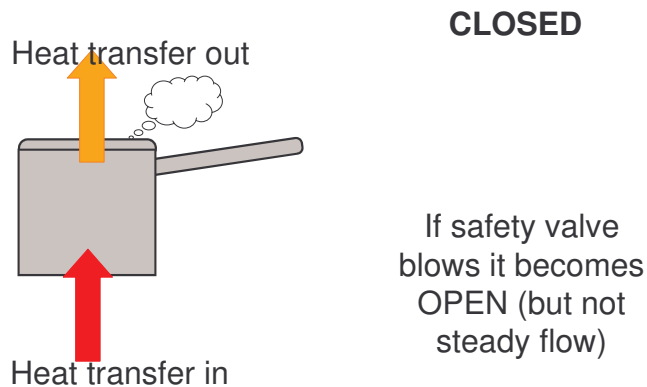
A **CLOSED** system is one where **mass** does **not** cross the boundary.... (but energy in the form of heat and/or work can enter or leave the system by means of heat transfer or work transfer).

An **OPEN** system is one where **mass** may enter or leave the system.

The **OPEN** systems we will study will be those where mass enters and leaves at the same rate. i.e. the system is not accumulating mass, or being depleted of mass.

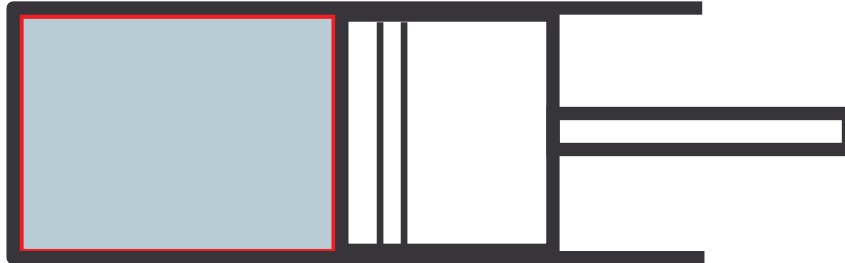
Such a system is said to be a 'steady flow' system.

It is important to be able to identify whether a system is **OPEN** or **CLOSED**:



Pressure cooker

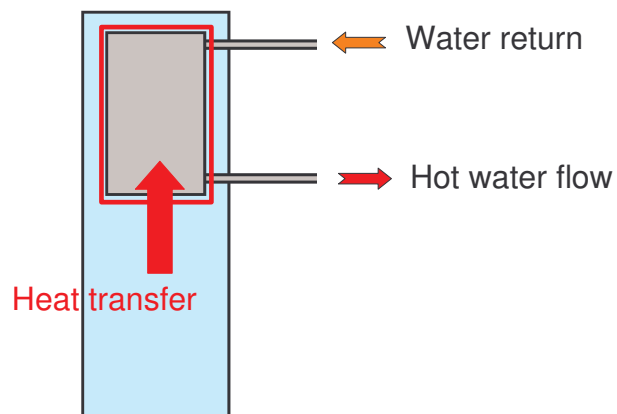
CLOSED
assuming no
leakage past the
piston seals



Cylinder / piston

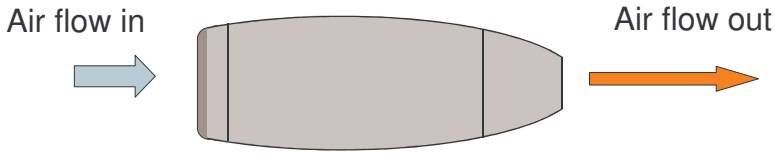
but the system
may change
shape

OPEN



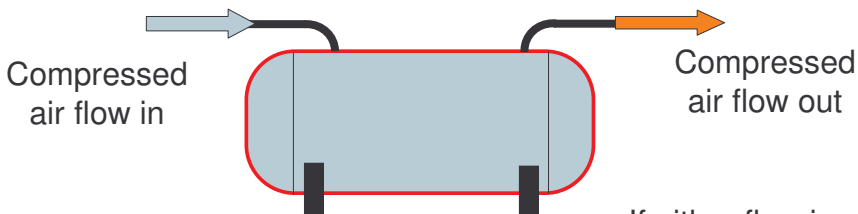
Heat exchanger in a central
heating boiler

OPEN



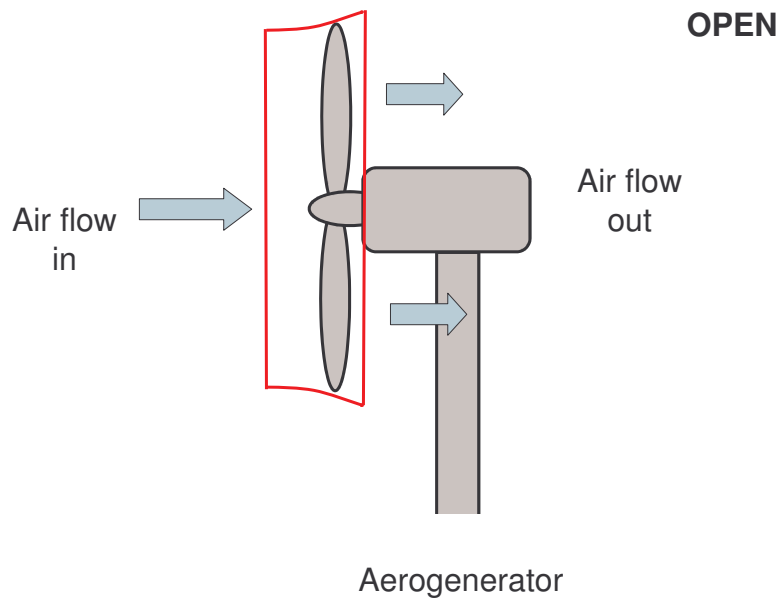
Jet engine

OPEN



If either flow is zero it remains OPEN (but not steady flow)

Compressed air receiver



Force

A **force** is that which moves or tends to move a body (mass) from a state of rest or uniform motion in a straight line.

The measurement of **force** arises from Newton's second law: 'The rate of change of momentum of a body is proportional to the force acting on it.'

Momentum is the product of mass and velocity.

It follows that: $F \propto \frac{d}{dt}(mv)$

and since we use a constant of proportionality equal to 1.

$$F = \frac{d}{dt}(mv)$$

If the mass is constant: $F = m \frac{dv}{dt} = ma$

If there is a steady mass flow rate: $F = v \frac{dm}{dt} = \dot{m}v$

Energy

Energy is often defined as ‘the potential to do work...’
but what is work?

Well, work is a form of energy!!

Energy is a **useful concept** that helps us make sense of the universe and the way it behaves.

Energy manifests itself in different ways – but it is all essentially the same thing – it is an entity that characterises systems and helps in our understanding of them.

Work is ‘done’ (or energy is transferred) when a force moves its point of application through a distance coinciding with the direction of the force. Therefore anything that can essentially or potentially do the same is also a form of energy.

It has not always been obvious that such a connection exists!

$$W = Fx$$

For example: a moving body ‘contains’ energy:

If a body of mass m travelling in a straight line with velocity u is brought to rest by uniformly decelerating it by applying force F for time t .

The deceleration a is given by: $a = \frac{v-u}{t} = -\frac{u}{t}$

The distance s required to bring it to rest is found from: $s = ut + \frac{1}{2}at^2$
 $s = ut + \frac{1}{2}\left(-\frac{u}{t}\right)t^2 = \frac{ut}{2}$

The force F applied during the deceleration is given by:

$$F = ma = m\frac{u}{t}$$

The work done in bringing the body to rest is therefore:

$$W = Fs = \left(m\frac{u}{t}\right)\left(\frac{ut}{2}\right) = \frac{1}{2}mu^2$$

Which we recognise as being the **KINETIC ENERGY** of a moving body.

Other forms of energy are:

POTENTIAL ENERGY (the work required to move a body subject to a force field)

Therefore within the earth's gravitational field:

$$\text{POTENTIAL ENERGY} = F \times \text{vertical distance moved} = mgz$$

THERMAL ENERGY = *heat energy that when transferred to a substance raises its temperature (or causes it to change phase)*

energy transmitted to a substance that only raises its temperature is often referred to as 'sensible heat' (i.e. able to be sensed with a temperature detecting device)

energy transmitted to a substance that only causes a phase change is often referred to as 'latent heat' (i.e. 'hidden', not able to be sensed with a temperature detecting device)

The 'sensible heat' 'contained' by a substance is typically a function of temperature and given by: $mc\Delta T$

where c is the specific heat capacity of the substance;

and ΔT is the temperature change .

Note that c itself may vary with temperature but normally a reasonable average can be used over moderate temperature ranges.

Work Energy

WORK ENERGY is typically transferred by either linear or rotary motion.

by linear motion: $W = Fx$ F =force (N); x = distance (m)

by rotary motion: $W = \tau\theta$ τ = torque (Nm); θ = angle (radians)

It follows that if work is being done continuously - the **rate** of work transfer is found by dividing each of the above equations by time to give (power):

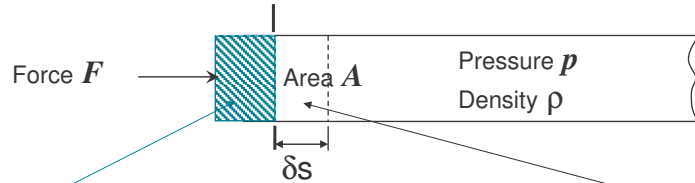
$$\dot{W} = F \frac{x}{t} = Fv \quad v = \text{velocity (m/s);}$$

$$\text{and } \dot{W} = \tau \frac{\theta}{t} = \tau\omega \quad \omega = \text{angular speed (radians/sec)}$$

$$\omega = \frac{RPM \times 2\pi}{60}$$

Pressure-Volume Energy

If a fluid under pressure is being 'forced' **in** to (or **out** of) a system it transfers work (energy) to (or by) that system by virtue of entering (or leaving) it.



The **fluid upstream** may be imagined as a piston acting on the fluid downstream, moving it a distance δs .

$$\text{Force } F = p \times A$$

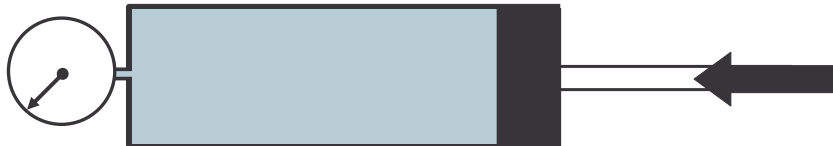
$$\text{Work done} = F \times \delta s = p \times A \times \delta s \quad \text{but } A \times \delta s = \text{volume entering } V$$

$$\text{therefore Work done} = p \times V$$

$$\text{by definition: } \rho = \frac{m}{V} \quad \therefore V = \frac{m}{\rho} \quad \text{therefore Work done} = p \frac{m}{\rho}$$

This is the work required to operate a pneumatic or hydraulic piston and we shall encounter it again when we formulate the steady flow energy equation.

Compressible and Incompressible Fluids



If the volume of a fluid changes significantly when it is pressurised it is called a **compressible fluid**. Compressible fluids are typically gases.



If the volume of a fluid does not change significantly when it is pressurised it is called an **incompressible fluid**. Incompressible fluids are typically liquids – but gases may also be treated as incompressible provided the pressure changes are small. (Low speed aerodynamics typically treats air as incompressible.)