Defence School of
Aeronautical Engineering

Aerosystems Engineer & Management
Training School

Academic Principles Organisation

MATHEMATICS

BOOK 2
SI Units

KEY LEARNING POINTS

KLP	Description
MA2.1	Define and use the base SI units of measurement
MA2.2	Define and use the base Imperial units of measurement
MA2.3	Convert compound and named derived units into base SI units.
MA2.4	Convert imperial units into base SI units.

PHYSICAL UNITS

1. When studying physical science, we are looking at the way in which ‘physical’ systems respond to various kinds of change. For example, this could be response to a force or to pressure or an increase in temperature. In order to quantify any change or response an agreed system of ‘measurement’ has to be used so that all Scientists, Engineers and Technicians understand each other’s figures. Various agreed systems exist and aircraft technicians need to be aware of two: The Imperial system and the Système Internationale d’Unités or ‘SI’ system.

2. All changes in physical systems can be reduced to changes in just seven ‘base’ units. These can be thought of as building blocks, from which any other type of measurement can be built. They are:

- Physical length
- Mass
- Time
- Electrical current
- Temperature
- Amount of substance
- Luminosity

3. In Aerospace engineering we are interested in the first five. In the SI system the units of measure for these five are:

Unit	**Measure**	**Symbol**	
Physical length	Metre	m	
Mass	Kilogram	kg	
Time	Second	s	
Electrical current	Ampere	A	
Temperature	Kelvin	K	(Note: do not use a ° symbol)

4. The SI base units can be combined as required to measure any non-base quantity. For example, an area is not a base unit but can easily be measured as length x width for a rectangle which is a length x a length. This gives us *SI derived* units of:

Area = length x length
Area = m x m = m^2 (or metres squared)

Volume = length x length x length
Volume = m x m x m = m^3 (or metres cubed)

If we consider measuring the speed of an object this is defined as the distance travelled divided by time taken. This gives *compound SI derived* units of:

Speed = distance travelled / time taken
Speed = m/s (or ms^{-1}) i.e. metres per second

Acceleration is similarly the change in speed divided by the time taken:

Acceleration = change in speed / time taken

Acceleration = (m/s)/s = $\frac{m}{s} \cdot \frac{1}{s} = m/s^2$ (metres per second squared)

Force is defined as a push or a pull, which moves or tries to move an object.
Force can be calculated as mass x acceleration for simple objects.

Force = mass x acceleration (*explained in Science*)
Force = kg x m/s^2 (Kilogram metre per second squared)

The unit of Force is used so frequently and complex that a shorthand method is adopted to ease confusion. Force is a *compound SI derived* unit however a shorthand method to refer to force is the Newton and it is more commonly used in its *named* unit form.

Named Unit		Compound SI derived Unit
1Newton	=	$1kg \cdot m \cdot s^{-2}$

5. Further examples of compound SI derived units:

Pressure is defined as force acting per unit area:

Pressure = Force / area
Pressure = N/m^2 (Newtons per metre squared)

Torque is the turning force multiplied by perpendicular distance to the pivot.

Torque = Force x distance
Torque = Nm (Newton metres of torque)

Work is found by the force acting multiplied by the distance moved.

Work = Force x distance (NB: distance is not perpendicular this time)
Work = Nm (To distinguish from ‘torque’ we write J for Joules)
Work = J (Joules)

Density is defined as the mass per unit volume of a substance.

Density = mass / Volume
Density = kg/m^3 (Kilograms per metre cubed)

Note. A quantity raised to a power appears on the bottom of an expression as in kg/m^3, it can also be expressed as a negative power on the top of the expression from indice law 5; therefore, the unit of density may also be expressed as kgm^{-3}

Engineering Prefixes

6. When writing very large or very small measurements, a mathematical method is used to prevent having to record too many decimal places or trailing zeros. The method is to use prefixes to the units to count in large or small bundles. This is to improve accuracy and ease of use.

Prefix	Symbol	Multiplying factor	Prefix	Symbol	Multiplying factor
tera	T	1,000,000,000,000 = 10^{12}	milli	m	0.001 = 10^{-3}
giga	G	1,000,000,000 = 10^{9}	micro	μ	0.000 001 = 10^{-6}
mega	M	1,000,000 = 10^{6}	nano	n	0.000 000 001 = 10^{-9}
kilo	k	1,000 = 10^{3}	pico	p	0.000 000 000 001 = 10^{-12}

Examples:

a) When we write 210 GN/m^2,

this means 210 x 10^9 N/m^2.
Written in full: 210,000,000,000 N/m^2

b) When we write 110 μm,

this means 110 x 10^{-6} m.
Written in full: 0.000110 m

7. As indicated in the examples above, it is usual to combine these specified engineering prefixes with SI units.

Examples: MN (meganewton), GW (gigawatt), μs (microsecond), kV (kilovolt), mm (millimetre), pF (picofarad)

Power of 10	Name	Symbol	Example of use
10^{-12}(0.000000000001)	Pico	p	A capacitor has value 12 pF
10^{-9} (0.000000001)	Nano	n	The wavelength of this light is 400nm
10^{-6} (0.000001)	Micro	μ	The circuit took 20 μs to switch on.
10^{-3} (0.001)	Milli	m	The wire was 0.46 mm in diameter
10^{3} (1,000)	Kilo	k	The Volvo had a mass of 1500 kg
10^{6} (1,000,000)	Mega	M	The fuel contains 1 MJ of energy
10^{9} (1,000,000,000)	Giga	G	A hydraulic pump produced 3GN/m^2
10^{12} (1,000,000,000,000)	Tera	T	The power station produced 1.2 TW

One problem exists with this system, how to represent 1000 kg? The issue here is that the unit name 'kilogram' has one of the prefixes embedded in it. If we use the above system with this value we would get: 1000 kg = 1k·kg
Instead the term 'tonne' (t) is used to represent 1000kg

8. There are a number of units in common usage, which technically do not fall into the SI system. These include: the gram (g), milligram (mg), microgram (μg), 'kilometre per hour' (kph), centimetres (cm, centi is not a preferred prefix), revolutions per minute (rpm). These will be dealt with in detail as they are encountered.

Imperial units

9. Although the SI is the accepted system of engineering and scientific units in the UK, the Imperial system may well be encountered when working with American aircraft or the older types of British aircraft.

10. Imperial units in common use include:

- Length — feet (ft) or inches (in), [′ or ″]. (Note: 1 ft = 12 in)
- Mass — pounds (lb)
- Time — minutes (min), hours (hr), days etc
- Temperature — degrees Fahrenheit (°F) (See note 1 below)
- Speed — miles per hour (mph)
- Pressure — pounds per square inch (psi)
- Volume — gallons (gal) (See note 2 below)
- Torque — pounds force feet (lbf.ft) or pounds force inches (lbf.in)

Note 1: The Fahrenheit temperature scale is based on the melting point of ice being at 32°F and normal body temperature at 96°F. It is rapidly falling out of general use.
Note 2: The Imperial (UK) gallon is defined as 4.54609 L and is different from the US liquid gallon which is defined as 3.785411784 L.

11. Some problems exist with the Imperial system. There can be different definitions for the same unit name (American US gallons and Imperial UK gallons are not the same size for example). Great care has to be taken when safety critical measurements are involved. A good example to bear in mind here is the fuelling of an aircraft where conversions between Imperial UK gallons, American US gallons, litres, kilograms or pounds of fuel may be necessary.

Note: An important measurement unit is the litre (L or l) which is technically a 1000 cubic centimetres or one thousandth of a cubic metre.

Conversion factors

12. To convert between SI and Imperial units there are two common methods. The first is to use conversion tables. The second method is to use conversion factors. Examples of other conversions are covered in the mathematical element of this unit.

13. The following conversion factors will be used in this module (any others will be introduced as necessary):

SI Units		**Imperial Units**
1 metre (m)	=	3.2808 feet (ft)
1 kilogram (kg)	=	2.2046 pound (lb)
0.3048 metre (m)	=	1 foot (ft)
0.4536 kilogram (kg)	=	1 pound (lb)
60 seconds (s)	=	1 minute (min)

Examples:

14.

a) An imperial mile is approximately 1609 m. A runner completes 5 miles in 30 minutes. What is his average speed in SI units?

SI distance ran = 5 x 1609 = 8045 m
SI time taken = 30 x 60 = 1800 s
Average speed = distance / time
= 8045 / 1800
= 4.469 m/s

b) A car has a mass of 2.2 tonnes. What is this in pounds?

1 tonne = 1000 kg
so, 2.2 tonnes = 2200 kg
1 kg = 2.2046 lbs (from the list above)
So, 2.2 tonnes = 2200 x 2.2046
= 4850 lbs

Exercise 1

1. What are the five SI units and their symbols commonly used in aircraft engineering?

2. What are the base units of the British imperial system?

3. What is the volume of a cuboid shaped garage, which measure 3m long, 2m high and 2.5m wide?

4. A ship is 234 m long. How many feet is this?

5. An aircraft has wingspan 153 ft. What is this in metres?

6. A vehicle has mass 5000lb. What is its mass in SI units?

7. A bullet's velocity is 290m/s. What is this in ft/s?

8. Using the conversion factors listed in the notes to convert the following:

    a. 5.5 feet into metres.

    b. 1.74m into feet

    c. 75kg into pounds

    d. 1000 lb into kilograms

    e. 23 minutes into seconds

Check your answers on page 8

Answers

Exercise 1

1.

Length	metre	m
Mass	kilogram	kg
Time	second	s
Temperature	Kelvin	K
Electrical current	Ampere	A

2.

Length	feet: inch
Mass	pound: ounce
Time	minute: hour
Temperature	Fahrenheit

3. 15 m^3

4. 767.71ft

5. 46.63m

6. 2268kg

7. 951.4ft/s

8.
   a. 1.676m
   b. 5.708ft
   c. 165.34lb
   d. 453.6kg
   e. 1380s