Aerodynamic Lift Introduction

A Level

P P P

This question introduces equations and quantities that are not typically covered in Physics A Level, but they are explained so that the question can be attempted by A Level students.

The lift force from a wing (or other aerofoil) is given by the formula

$$L = \frac{1}{2} C_{\mathrm{L}} \rho S v^n$$

where

- C_{L} is the co-efficient of lift
- ρ is the density of air
- S is the area of the wing
- v is the speed of the wing through the air, and
- n is an integer.

The co-efficient of lift C_{L} depends on the design of the wing itself, and also on the angle made by the wing to the oncoming air. In this question, you may always assume that the lift force points vertically upwards.

This is a shortened form of a question which explores lift in more detail. Here is a link to the full question.

Part A The power n

The force L is measured in newtons where $1\,\mathrm{N} = 1\,\mathrm{kg\,m\,s^{-2}}$. Given that the co-efficient of lift has no units (it is a pure number), that the density will be measured in $\mathrm{kg\,m^{-3}}$, the area in $\mathrm{m^2}$ and the speed in $\mathrm{m\,s^{-1}}$, work out the missing power n in order for the units in $L = \frac{1}{2} C_{\mathrm{L}} \rho S v^n$ to agree.

Part B Co-efficient of lift at cruise speed

A loaded aircraft with a mass of $758\,\mathrm{kg}$ and a wing area of $13.9\,\mathrm{m^2}$ is flying in air of density $1.21\,\mathrm{kg\,m^{-3}}$. If the aircraft is flying horizontally at a steady speed of $45.0\,\mathrm{m\,s^{-1}}$, calculate the co-efficient of lift to three significant figures. Take $g = 9.81\,\mathrm{N\,kg^{-1}}$.

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Introducing Dimensional Analysis

GCSE A Level

The dimensions of physical properties do not depend on specific units; here we use length L, time T and mass M as our fundamental dimensions. In any equation relating physical properties the dimensions must be the same on both sides.

For example force $=$ mass $\times$ acceleration.

Obviously mass has dimensions M. To deduce the dimensions of acceleration recall that acceleration $=$ change in velocity over time; velocity ($=$ change in displacement over time) has dimensions of LT^{-1} so acceleration has dimensions $(LT^{-1})(T^{-1}) = LT^{-2}$.

Thus force has dimensions MLT^{-2}.

Part A Dimensions of kinetic energy

The kinetic energy of a body of mass m moving with speed v is equal to $\frac{1}{2}mv^2$.

Find the dimensions of (kinetic) energy. Recall that the factor of $\frac{1}{2}$ in the expression is dimensionless.

The following symbols may be useful: `L, M, T`

Part B Planck unit

One type of "Planck unit" is defined as:

$$h^{\frac{1}{2}} G^{\frac{1}{2}} c^{-\frac{5}{2}}$$

where h is Planck's constant (dimensions ML^2T^{-1}),
G is the universal constant of gravitation (dimensions $M^{-1}L^3T^{-2}$) and
c is the speed of light (dimensions LT^{-1}).

Find the dimensions of this "Planck unit".

The following symbols may be useful: `L, M, T`

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Essential Pre-Uni Physics A2.7

GCSE A Level

Express the following derived unit in terms of the SI base units. As an example, the first row ($\mathrm{m\,s^{-2}}$) has been done for you:

Derived Unit	in Base Units	Power of each base unit			
		m	s	kg	A
$\mathrm{m\,s^{-2}}$	$\mathrm{m\,s^{-2}}$	1	-2	0	0
$\mathrm{N\,C^{-1}}$		(a)	(b)	(c)	(d)

Part A Power of m

What is the power of m?

Part B Power of s

What is the power of s?

Part C Power of kg

What is the power of kg?

Part D Power of A

What is the power of A?

Essential Pre-Uni Physics A2.9

GCSE A Level

Express the following derived units in terms of the unit specified and base units. The first one has been done for you.

Part A The ohm

a) Express the ohm in terms of the volt and base units.

Part B The joule

b) Express the joule in terms of the newton and base unit(s).

- $\mathrm{N\,m}$
- $\mathrm{m\,N^{-1}}$
- $\mathrm{N\,m^{-1}}$

Part C The pascal

c) Express the pascal in terms of the joule and base unit(s).

- $\mathrm{J\,m^{2}}$
- $\mathrm{J\,m^{-3}}$
- $\mathrm{J\,m^{3}}$
- $\mathrm{J\,m^{-2}}$

Part D Pressure

d) The answer to part (c) means that pressure in effect measures an amount of energy per unit ...?

- Volume
- Length
- Mass
- Area

Part E $\mathrm{V\,m^{-1}}$

e) Express the $\mathrm{V\,m^{-1}}$ in terms of the joule and base unit(s).

- $\mathrm{J\,m^{-1}\,s^{-1}\,A}$
- $\mathrm{J\,m\,s^{-1}\,A^{-1}}$
- $\mathrm{J\,m^{-1}\,s^{-1}\,A^{-1}}$
- $\mathrm{J\,m^{-1}\,s\,A^{-1}}$

Part F The unit of density

f) Express the unit of density in newtons and base unit(s).

- $\mathrm{N\,m^{-4}\,s^{2}}$
- $\mathrm{N^{-1}\,m^{-4}\,s^{2}}$
- $\mathrm{N\,m^{-4}\,s}$
- $\mathrm{N\,m^{-3}\,s^{2}}$

Powerful Stuff

A Level

P P P

Which of the following is a unit of power?

- $\mathrm{N\,m}$
- $\mathrm{N\,s}$
- $\mathrm{kg\ m\,s^{-1}}$
- $\mathrm{N\,m\,s^{-1}}$
- $\mathrm{N\ m\,s^{-2}}$

Used with permission from UCLES, AO Level Physics, June 1989, Paper 1, Question 1.

Rayleigh Scattering

A Level

P P P

Part A Intensity decay

Intensity decays as you move further away from the source, due to the diverging of rays. Indeed, if I is the intensity and r is the distance from the source, then $I \propto r^n$ for what value of n (to 1 significant figure)?

Part B Exponent of wavelength

Rayleigh scattering is an effect that causes many optical phenomena around us. It is caused by the scattering of light by small particles, such as the molecules that make up air in the atmosphere.

If a beam of intensity I_0 and wavelength λ interacts with one of these particles then the intensity of the light scattered at an angle θ is proportional to $I_0 \lambda^m r^n \alpha^6 \left[1 + \cos^2 \theta\right]$, where r is the distance from the scattering particle and α is the diameter of the scattering particle. The relationship of the intensity of the scattered light (for a given wavelength) with distance from the scattering particle is the same as for a point source.

By considering the dimensions of the quantities involved, what is m to 1 significant figure?

Part C Colour of sky

What colour would you expect to see most of in the sky, if the colour is caused by the scattering of light from the sun, which you assumed was to be of uniform intensity for all wavelengths?

- violet
- red
- indigo
- green
- blue
- orange
- yellow

Adapted with permission from UCLES, Scholarship Paper, June 1954, Paper 3, Question 5

Step up to GCSE Dimensional Analysis - algebra with units 48.3

Year 9 P P P
A Level C C C

Given the units of specific heat capacity $[c] = \mathrm{J/kg^\circ C}$, and density $[\rho] = \mathrm{kg/m^3}$, what quantity could $c\rho AL$ represent if L is a length and A an area?

- Specific heat capacity ($\mathrm{J/kg^\circ C}$ or $\mathrm{m^2/s^2\,{}^\circ C}$)
- Heat capacity ($\mathrm{J/{}^\circ C}$ or $\mathrm{kg\ m^2/s^2\,{}^\circ C}$)
- Energy (J or $\mathrm{kg\ m^2/s^2}$)
- Temperature change ($\mathrm{{}^\circ C}$)

Step up to GCSE Dimensional Analysis - algebra with units 48.4

Year 9 P P P A Level C C C

Complete the table below, giving each named unit in terms of kilograms (kg), metres (m), seconds (s) and amps (A). Use the equations given as hints, and use previous answers as stepping-stones. The page reference for each formula is given in brackets next to it.

Quantity	Unit	Useful formula	Unit in $\mathrm{kg, m, s, A}$
Energy E	joule (J)	$\Delta E = F \Delta s$	(a)
Power P	watt (W)	$\Delta E = P \Delta t$	(b)
Pressure P	pascal (Pa)	$F = PA$	(c)
Charge Q	coulomb (C)	$\Delta Q = I \Delta t$	(d)
Voltage V	volt (V)	$E = VQ$	(e)
Resistance R	ohm (Ω)	$V = IR$	(f)

Part A Energy E

Quantity	Unit	Useful formula	Unit in $\mathrm{kg, m, s, A}$
Energy E	joule (J)	$\Delta E = F \Delta s$	(a)

- $\mathrm{kg\ m/s^2}$
- $\mathrm{kg\ m^2/s}$
- $\mathrm{kg\ m^2/s^2}$
- $\mathrm{kg\ m/s}$

Part B Power P

Quantity	Unit	Useful formula	Unit in $\mathrm{kg, m, s, A}$
Power P	watt (W)	$\Delta E = P\Delta t$	(b)

- ○ $\mathrm{kg\ m^2/s^2}$
- ○ $\mathrm{kg\ m^2/s^4}$
- ○ $\mathrm{kg\ m^2/s^3}$
- ○ $\mathrm{kg\ m/s^2}$

Part C Pressure P

Quantity	Unit	Useful formula	Unit in $\mathrm{kg, m, s, A}$
Pressure P	pascal (Pa)	$F = PA$	(c)

- ○ $\mathrm{kg/m^2\,s^2}$
- ○ $\mathrm{kg/s^2}$
- ○ $\mathrm{kg/m\,s^2}$
- ○ $\mathrm{kg\,m/s^2}$

Part D Charge Q

Quantity	Unit	Useful formula	Unit in $\mathrm{kg, m, s, A}$
Charge Q	coulomb (C)	$\Delta Q = I\Delta t$	(d)

- ○ $\mathrm{A/s}$
- ○ A
- ○ $\mathrm{A\,s^2}$
- ○ $\mathrm{A\,s}$

Part E Voltage V

Quantity	Unit	Useful formula	Unit in kg, m, s, A
Voltage V	volt (V)	$E = VQ$	(e)

- $\mathrm{kg\,m/A\,s^3}$
- $\mathrm{kg\,m^2/A\,s^3}$
- $\mathrm{kg\,m/A\,s}$
- $\mathrm{kg\,m^2/A\,s^2}$

Part F Resistance R

Quantity	Unit	Useful formula	Unit in kg, m, s, A
Resistance R	ohm (Ω)	$V = IR$	(f)

- $\mathrm{kg\,m/A\,s^2}$
- $\mathrm{kg\,m^2/A^2\,s^3}$
- $\mathrm{kg\,m^2/A\,s^3}$
- $\mathrm{kg\,m^2/A^2\,s}$

Physics. You work it out.

Step up to GCSE Dimensional Analysis - algebra with units 48.7

Year 9 P P P A Level C C C

Aerodynamicists often calculate $\frac{1}{2}\rho v^2$ where ρ is the density of air and v is the speed of an aircraft. Which of the quantities given in question 4 could it give?

- Charge
- Pressure
- Power
- Voltage
- Resistance
- Energy

Waving Along

A Level

P P P

Ripples on the surface of deep water have a speed of propagation v given by $v = \sqrt{\frac{2\pi\gamma}{\lambda\rho}}$.

where γ = the coefficient of surface tension, λ = the wavelength of the ripples and ρ = the density of water.

Part A Wave speed

If the speed of the waves of wavelength $10\,\mathrm{mm}$ is $0.22\,\mathrm{m\,s^{-1}}$, calculate the speed of waves of wavelength $2.5\,\mathrm{mm}$.

Part B Wave frequency

What is the frequency of these $2.5\,\mathrm{mm}$ waves?

Part C Units

What are the units of γ?

- W
- $\mathrm{W\,m^{-2}}$
- $\mathrm{N\,m^{2}}$
- kg
- $\mathrm{J\,m^{-2}}$

Adapted with permission from UCLES, A Level Physics, June 1981, Paper 1, Question 8