Part 1
The Preliminaries

1 Basic Principles

1.1 The Atmosphere

The Earth's atmosphere is the layer of air that surrounds the planet and extends five hundred miles upwards from the surface. It consists of four concentric gaseous layers, the lowest of which is the troposphere in which all normal aviation activities take place. The upper boundary of the troposphere is the tropopause, which separates it from the next gaseous layer, the stratosphere. The next layer above that is the mesosphere and above that is the thermosphere.

The height of the tropopause above the surface of the earth varies with latitude and with the season of the year. It is lowest at the poles being approximately 25 000 feet above the surface of the Earth and 54 000 feet at the Equator. These heights are modified by the season, being higher in the summer hemisphere and lower in the winter hemisphere.

Above the tropopause the stratosphere extends to a height of approximately one hundred thousand feet. Although these layers of the atmosphere are important for radio-communication purposes, because of the ionised layers present, they are of no importance to the theory of flight.

Since air is compressible the troposphere contains the major part of the mass of the atmosphere. The weight of a column of air causes the atmospheric pressure and density of the column to be greatest at the surface of the Earth. Thus, air density and air pressure decrease with increasing height above the surface. Air temperature also decreases with increased height above the surface until the tropopause is reached above which the temperature remains constant through the stratosphere.

1.2 The Composition of Air

Air is a mixture of gases the main components of which are shown in Table 1.1.

Water vapour in varying quantities is found in the atmosphere up to a height of approximately 30 000 ft. The amount in any given air mass is dependent on the air temperature and the passage of the air mass in relationship to large areas of water. The higher the air temperature the greater the amount of water vapour it can hold.

1.2.1 The Measurement of Temperature

Centigrade Scale. The Centigrade scale is normally used for measuring the air temperature and for the temperature of aero-engines and their associated equipment. On this temperature scale water freezes at 0° and boils at 100° at mean sea level.

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Table 1.1 Gas Components of the Air.

Element	Volume	Weight
Nitrogen	78.09%	75.5%
Oxygen	20.95%	23.1%
Argon	0.93%	1.3%
Carbon Dioxide	0.03%	0.05%

Note: For all practical purposes the atmosphere is considered to contain 21% oxygen and 79% nitrogen.

Kelvin Scale. Often for scientific purposes temperatures relative to absolute zero are used in formulae regarding atmospheric density and pressure. Temperatures relative to absolute zero are measured in Kelvin. A body is said to have no heat at absolute zero and this occurs at a temperature of –273.15 °C.

1.2.2 Air Density

Air density is mass per unit volume. The unit of air density is either kg per m^3 or gm^{-3} and the symbol used is ‘ρ’. The relationship of air density to air temperature and air pressure is given by the formula:

$$\frac{p}{T\rho} = \text{constant}$$

where ρ is the density, p is pressure in hPa and T is the absolute temperature.

The Effect of Air Pressure on Air Density. If air is compressed the amount of air that can occupy a given volume increases. Therefore, both the mass and the density are increased. For the same volume if the pressure is decreased then the reverse is true. From the formula above if the air temperature remains constant then the air density is directly proportional to the air pressure. If the air pressure is doubled so is the air density.

The Effect of Air Temperature on Air Density. When air is heated it expands so that a smaller mass will occupy a given volume and provided that the air pressure remains constant then the air density will decrease. Thus, the density of the air is inversely proportional to the absolute temperature. The rapid decrease of air pressure with increased altitude has a far greater effect on the air density than does the increase of density caused by the decrease in temperature for the same increased altitude. Thus, the overall effect is for the air density to diminish with increased altitude.

The Effect of Humidity on Air Density. Until now it has been assumed that the air is perfectly dry; such is not the case. In the atmosphere there is always some water vapour present, albeit under certain conditions a miniscule amount. However, in some conditions the amount of water vapour present is an important factor when determining the performance of an aeroplane. For a given volume the amount of air occupying that volume decreases as the amount of water vapour contained in the air increases. In other words, air density decreases with increased water-vapour content. It is most dense in perfectly dry air.

1.3 The International Standard Atmosphere

The basis for all performance calculations is the International Standard Atmosphere (ISA) which is defined as a perfect dry gas, having a mean sea level temperature of +15 °C, which decreases at the rate of 1.98 °C for every 1000 ft increase of altitude up the tropopause which is at an altitude of 36 090 ft above which the temperature is assumed to remain constant at –56.5 °C. The mean sea level (MSL) atmospheric pressure is assumed 1013.2 hPa (29.92 in. Hg). See Table 1.2.

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Table 1.2 International Standard Atmosphere (Dry Air).

Pressure	Temperature		Density	Height		Thickness of 1 hPa layer	
hPa	°C	°F	gm^{-3}	m	ft	m	ft
1013.2	15.0	59.0	1225	0	0	8.3	27
1000	14.3	57.7	1212	111	364	8.4	28
950	11.5	52.7	1163	540	1773	8.8	29
900	8.6	47.4	1113	988	3243	9.2	30
850	5.5	41.9	1063	1457	4781	9.6	31
800	2.3	36.2	1012	1949	6394	10.1	33
750	–1.0	30.1	960	2466	8091	10.6	35
700	–4.6	23.8	908	3012	9882	11.2	37
650	–8.3	17.0	855	3591	11 780	11.9	39
600	–12.3	9.8	802	4206	13 801	12.7	42
550	–16.6	2.1	747	4865	15 962	13.7	45
500	–21.2	–6.2	692	5574	18 289	14.7	48
450	–26.2	–15.2	635	6344	20 812	16.1	53
400	–31.7	–25.1	577	7185	23 574	17.7	58
350	–37.7	–36.0	518	8117	26 631	19.7	65
300	–44.5	–48.2	457	9164	30 065	22.3	75
250	–52.3	–62.2	395	10 363	33 999	25.8	85
200	–56.5	–69.7	322	11 784	38 662	31.7	104
150	–56.5	–69.7	241	13 608	44 647	42.3	139
100	–56.5	–69.7	161	16 180	53 083	63.4	208

1.3.1 ISA Deviation

It is essential to present performance data at temperatures other than the ISA temperature for all flight levels within the performance-spectrum envelope. If this were to be attempted for the actual or forecast temperatures, it would usually be impracticable and in some instances impossible.

To overcome the presentation difficulty and retain the coverage or range required, it is necessary to use ISA deviation. This is simply the algebraic difference between the actual (or forecast) temperature and the ISA temperature for the flight level under consideration. It is calculated by subtracting the ISA temperature from the actual (or forecast) temperature for that particular altitude. In other words:

ISA Deviation = Ambient temperature − Standard Temperature

Usually, 5 °C bands of temperature deviation are used for data presentation in Flight Manuals to reduce the size of the document or to prevent any graph becoming overcrowded and unreadable.

1.3.2 JSA Deviation

As an alternative to ISA deviation some aircraft manuals use the Jet Standard Atmosphere (JSA) Deviation that assumes a temperature lapse rate of 2°/1000 ft and that the atmosphere has no tropopause, the temperature is, therefore, assumed to continue decreasing at this rate beyond 36 090 ft.

1.3.3 Height and Altitude

Three parameters are used for vertical referencing of position in aviation. They are the airfield surface level, mean sea level (MSL) and the standard pressure level of 1013.2 hPa. It would be convenient if the performance data could be related to the aerodrome elevation because this is fixed and published in the Aeronautical Information Publication.

However, this is impractical because of the vast range that would have to be covered. Mean sea level and pressure altitude are the only permissible references for assessing altitude for the purposes of aircraft performance calculations, provided that the one selected by the manufacturers for the Flight Manual is used consistently throughout the manual. Alternatively, any combination of them may be used in a conservative manner.

Table 1.3 ISA Height in Feet above the Standard Pressure Level.*

Pressure (hPa)	0	2	4	6	8
1030	–456	–509	–563	–616	–670
1020	–185	–240	–294	–348	–402
1010	+88	+33	–22	–76	–131
1000	+363	+308	+253	+198	+143
990	640	584	529	473	418
980	919	863	807	751	695
970	1200	1143	1087	1031	975
960	1484	1427	1370	1313	1256
950	1770	1713	1655	1598	1541
940	2059	2001	1943	1885	1828
930	2351	2293	2235	2176	2117
920	2645	2587	2528	2469	2410
910	2941	2882	2823	2763	2704
900	3240	3180	3120	3060	3001
890	3542	3482	3421	3361	3300
880	3846	3785	3724	3663	3603
870	4153	4091	4029	3968	3907
860	4463	4401	4339	4277	4215
850	4777	4714	4651	4588	4526
840	5093	5029	4966	4903	4840
830	5412	5348	5284	5220	5157
820	5735	5670	5606	5541	5476
810	6061	5996	5930	5865	5800
800	6390	6324	6258	6192	6127
790	6722	6656	6589	6523	6456

*Enter with QFE to read Aerodrome Pressure Altitude. Enter with QNH to read the correction to apply to Aerodrome/Obstacle Pressure Altitude.

Using MSL avoids the problem of the range of heights and would be ideal from a safety viewpoint; but again this would be too variable because of the temperature and pressure range that would be required.

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The only practical datum to which aircraft performance can be related is the standard pressure level of 1013.2 hPa. See Table 1.3.

1.3.4 Pressure Altitude

In Aeroplane Flight Manuals (AFMs) the word **altitude** refers strictly to **pressure altitude**, which can be defined as the vertical distance from the 1013.2 hPa pressure level. Therefore, aerodrome and obstacle elevations must be converted to pressure altitude before they can be used in performance graphs. Many large aerodromes provide the aerodrome pressure altitude as part of their hourly weather reports.

To correct an aerodrome elevation to become a pressure altitude if Table 1.3 is not available use the following formulae:

$$\textbf{A/F Pressure Altitude} = \textbf{Aerodrome elevation in ft} + [(\textbf{1013.2 hPa} - \textbf{QNH}) \times \textbf{27 ft}]$$

$$\textbf{Aerodrome Pressure Altitude} = (\textbf{1013.2 hPa} - \textbf{QFE}) \times \textbf{27 ft}$$

To correct an altitude for the temperature errors of the altimeter use the following formula:

$$\textbf{Altitude Correction} = \textbf{4} \times \textbf{ISA Deviation} \times \textbf{Indicated Altitude} \div \textbf{1000}$$

1.3.5 Density Altitude

The performance data for small piston/propeller-driven aeroplanes is calculated using *density altitude*, which is pressure altitude corrected for nonstandard temperature. It is the altitude in the standard atmosphere at which the prevailing density occurs and can be calculated by using the formula:

$$\textbf{Density Altitude} = \textbf{Pressure Altitude} + (\textbf{118.8} \times \textbf{ISA Deviation})$$

1.4 The Physical Properties of Air

Air is a compressible fluid. It can therefore, flow or change its shape when subjected to very small outside forces because there is little cohesion of the molecules. If there was no cohesion between the molecules and therefore no internal friction then it would be an ‘ideal’ fluid, but unfortunately such is not the case.

1.4.1 Fluid Pressure

The pressure in a fluid at any point is the same in all directions. Any body, irrespective of shape or position, when immersed in a stationary fluid is subject to the fluid pressure applied at right angles to the surface of that body at that point.

1.4.2 Static Pressure

The pressure of a stationary column of air at a particular altitude is that which results from the mass of air in the column above that altitude and acts in all directions at that point. The static pressure decreases with increased altitude as shown in Table 1.3. The abbreviation for the static pressure at any altitude is P.

1.4.3 Dynamic Pressure

Air in motion has energy because it possesses density (mass per unit volume) that exerts pressure on any object in its path. This is dynamic pressure, which is signified by the notation (q) and is proportional to the air density and the square of the speed of the air. A body moving through the air has a similar force exerted on it that is proportional to the rate of movement of the body. The energy due to this movement is kinetic energy (KE), which is equal to half the product of the mass and the square of the

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speed. Bernoulli's equation for incompressible airflow states that the kinetic energy of one cubic metre of air travelling at a given speed can be calculated from the following formula:

$$\mathbf{KE = {}^1/_2\rho V^2 \text{ joules}}$$

Where ρ is the air density in kg per m^3 and V is the airspeed in metres per second.

Note: 1. A joule is the work done when the point of application of a force of one Newton is displaced by one metre in the direction of the force.

Note: 2. A Newton is that force that when applied to a mass of one kg produces an acceleration of 1 metre per second per second.

If a volume of air is trapped and brought to rest in an open ended tube the total energy remains constant. If such is the case then KE becomes pressure energy (PE), which for practical purposes is equal to ${}^1/_2\rho V^2$ Newtons per m^2. If the area of the tube is S square metres then:

$$\mathbf{S\ (dynamic + static\ pressure) = {}^1/_2\rho V^2\ Newtons}$$

The term ${}^1/_2\rho V^2$ is common to all aerodynamic forces and determines the load imposed on an object moving through the air. It is often modified to include a correction factor or a coefficient. The term is used to describe the dynamic pressure imposed by the air of a certain density moving at a given speed and that is brought completely to rest. Therefore, $q = {}^1/_2\rho V^2$.

Note: Dynamic pressure cannot be measured on its own because static pressure is always present. This total pressure is known as pitot pressure.

1.5 Newton's Laws of Motion

1.5.1 Definitions

It is essential to remember the following definitions regarding the motion of a body:

a. **Force**. That which changes a body's state of rest or of uniform motion in a straight line is a force, the most familiar of which is a push or a pull.
b. **Inertia**. The tendency of a body to remain at rest or, if moving, to continue in a straight line at a constant speed is inertia.
c. **Momentum**. The product of mass and velocity is momentum.

1.5.2 First Law

Newton's first law of motion, the law of inertia, states that every body remains in a state of rest or uniform motion unless compelled to change its state by an applied force. Bodies at rest or in a state of steady motion are said to be in equilibrium and have the property of inertia. Where motion results from an applied force, the force exerted is the product of mass and acceleration. Mathematically:

$$\mathbf{F = ma}$$

where F = Force; m = mass; a = acceleration.

1.5.3 Second Law

Being the product of mass and velocity, momentum is a vector quantity that involves motion in the direction of the velocity. If the body is in equilibrium then there is no change to the momentum, however, if the forces are not in equilibrium Newton's second law of motion states that the rate of change of momentum, the acceleration, is proportional to the applied force in the direction in which that force acts and inversely proportional to the mass of the object. By transposing the formula for Newton's First Law then:

$$\mathbf{a = F/m}$$

1.5.4 Third Law

Newton's third law of motion states that for every action there is an equal and opposite reaction. A body at rest on a surface applies a force to that surface and an opposite force is applied by the surface to the body. A free falling body is acted on by gravity the force (F) is measured in Newtons and is calculated as:

$$\mathbf{F = mg}$$

where F = Force in Newtons; m = mass in kg; g = acceleration due to gravity of 9.81 m/s^2.

1.6 Constant-Acceleration Formulae

A constant acceleration is when the velocity of a body is changing at a constant rate. Four formulae can be derived using the abbreviations **v** = the final velocity; **u** = the initial velocity; **a** = the acceleration; **t** = the time interval over which the acceleration took place; **s** = the distance travelled during the period of motion.

a. **The Final Velocity (1)**. The final velocity of a body is equal to the initial velocity plus the acceleration made during the time interval during which the acceleration took place and can be determined at any time by the formula:

$$\mathbf{v = u + at}$$

b. **The Distance Travelled (1)**. The distance travelled during the period of motion is equal to the mean velocity multiplied by the time over which the acceleration took place and can be calculated by using the formula:

$$\mathbf{s = {}^1/_2(u + v)t}$$

c. **The Distance Travelled (2)**. By substitution in the formulae a and b a second method of calculating the distance travelled can be derived as follows:

$$\mathbf{s = ut + {}^1/_2at^2}$$

d. **The Final Velocity (2)**. Similarly, a formula for the final velocity can be derived by substitution as follows:

$$\mathbf{v^2 = u^2 + 2as}$$

$$\mathbf{or\ v = \sqrt{(u^2 + 2as)}}$$

1.7 The Equation of Impulse

The impulse of a force is the change in momentum (final momentum – initial momentum) of force acting on a body and is usually identified by the initial **J**. It is the product of that force and time. The SI unit of impulse is the Newton second (N s) **NOT** Newtons per second (N/s).

Using substitution in the formula for Newton's first law of motion and the formula for the final velocity (1) the following formula can be derived:

a. F = ma
b. By dividing by m then a = F/m.
c. v = u + at
d. By transposition becomes v = u + t(F/m)
e. By multiplication by m and transposition becomes: Ft = mv − mu
f. Therefore, the value of the impulse of the force **J = mv − mu or**

$$\mathbf{J = m(v - u)\ \text{or Impulse} = \text{mass} \times \text{speed change}}.$$

1.8 The Basic Gas Laws

There are three basic gas laws regarding the relationship between pressure (**P**), volume (**V**) and temperature (**T**) of the gas, which were formulated in the past. They are:

1.8.1 Boyles Law

This law states that if the mass of gas is fixed and the temperature of the gas remains constant then the volume of the gas is inversely proportional to the pressure. In other words, if the volume of a given mass is halved then its pressure will be doubled provided the temperature does not change. Mathematically then:

$$\mathbf{P_1V_1 = P_2V_2\ \text{or}\ PV = \text{constant}}.$$

1.8.2 Charles' Law

This law states that if a fixed mass of gas is at a constant pressure its volume will increase by 1/273 of its volume at 0 °C for every 1 °C rise in temperature. Alternatively it can be stated that the volume of a fixed mass of gas is directly proportional to its absolute temperature provided the pressure remains constant. Mathematically then:

$$\mathbf{\frac{V_1}{T_1} = \frac{V_2}{T_2}\ \text{or}\ \frac{V}{T} = \text{constant}}$$

1.8.3 Pressure Law

This law states that for a fixed mass of gas at constant volume the pressure increases by 1/273 of its volume at 0 °C for every 1 °C rise in temperature. Thus, provided the volume of a mass of gas does not change the pressure is directly proportional to its temperature. Mathematically then:

$$\mathbf{\frac{P_1}{T_1} = \frac{P_2}{T_2}\ \text{or}\ \frac{P}{T} = \text{constant}}$$

1.8.4 The Ideal Gas Equation

If the formulae in each of the gas laws a, b and c above are combined into a single equation it provides the equation for the ideal gas. Mathematically then:

$$\mathbf{\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}\ \text{or}\ \frac{PV}{T} = \text{constant}}$$

1.9 The Conservation Laws

Bernoulli's principle is for the conservation of energy and the continuity equation is for the conservation of mass; both have equations that are directly related to the conservation laws.

1.10 Bernoulli's Theorem

Bernoulli stated that moving gas has four types of energy:

a. potential energy due to its height
b. kinetic energy due to movement
c. heat energy due to its temperature
d. pressure energy due to its compression

Bernoulli's theorem states that that the sum of the energies within an ideal gas in a streamline flow remains constant. It is the same principle as that of the conservation of energy. However, it does not account viscosity, heat transfer or compressibility effects. Below 10 000 ft and 250 kt airspeed compressibility effects can be safely ignored and the flow density is assumed to be constant.

Conventionally, airflow at speeds less than 0.4 Mach are considered to be an ideal gas because it is not compressed and the friction forces are small in comparison with the inertial forces, this is referred to as an inviscid flow. The sum of all forms of mechanical energy, that is the sum of kinetic energy and potential energy remains constant along a streamline flow and is the same at any point in the streamline flow. *This principle does not apply to the boundary layer* because mechanical and thermal energy is lost due to the skin friction, which is an effect of viscosity.

Bernoulli's theorem when applied to the airflow past an aerofoil at less than Mach 0.4 shows that the total pressure is equal to the sum of the dynamic pressure (the pressure caused by the movement of the air) and the static pressure (the pressure of the air not associated with its movement) and can be expressed as the following equation:

Total Pressure (pt) = Dynamic Pressure (q) + Static Pressure (ps)

The total pressure is constant along a streamline flow. Therefore, if static pressure decreases then dynamic pressure increases and vice versa. Air that is flowing horizontally flows from high pressure to low pressure. The highest speed occurs where the pressure is lowest and the lowest speed is where the pressure is highest.

In a freestream airflow, a *favourable pressure gradient* is one in which the static pressure decreases with distance downstream. An *adverse pressure gradient* is one in which the static pressure increases with distance downstream. A freestream airflow will accelerate in a favourable pressure gradient and decelerate in an adverse pressure gradient.

It is this principle that is utilised in the construction of the airspeed indicator. The dynamic pressure is the difference between the stagnation pressure and the static pressure. The airspeed indicator is calibrated to display the indicated airspeed appropriate to the dynamic pressure.

The flow speed can be measured in a pipe in which the tube diameter is restricted. The reduction in diameter increases the speed of flow and simultaneously decreases the pressure of the flow. This is referred to as the 'Venturi effect.'

1.10.1 Viscosity

Viscosity is a measure of the degree to which a fluid resists flow under an applied force. A fluid or liquid that is highly viscous flows less readily than a fluid or liquid that has low viscosity. The internal

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friction of the gas or liquid determines its ability to flow or its fluidity. Viscosity for air is the resistance of one layer of air to the movement over a neighbouring layer. When considering the effects of scale in wind-tunnel tests this fact is of great importance in the determination of aerofoil surface friction. The greater the friction or viscosity of a gas or liquid the greater is its resistance to flow. Temperature affects the viscosity but unlike liquids, air becomes more viscous as ambient temperature increases and is less able to flow readily. The viscosity of air is not affected by changes of air density that are not caused by temperature.

1.11 The Equation of Continuity

Mass cannot be created or destroyed. Air mass flow is steady and continual. The equation of continuity states that for an incompressible fluid flowing in a cylinder the rate at which the fluid flows past any given point is the same everywhere in the cylinder. In other words, the flow rate is equal to the mass flowing past divided by the time interval. Because the air density remains constant then the flow rate is constant throughout the cylinder. The product of the air density, the velocity and the cross-sectional area, the mass flow, is always constant.

$$\textbf{Mass Flow} = \rho \textbf{AV} = \textbf{constant}$$

where ρ = air density; A = cross-sectional area of the cylinder; V = flow velocity.

The equation of continuity applies equally to a cylinder that has a variable diameter know as a Venturi tube. If the inside diameter of the cylinder decreases it causes the inside of the cylinder to have a neck. Because the flow rate is constant anywhere in a cylinder through which there is streamline airflow then for the equation of continuity to remain valid, because the air pressure decreases and the air density remains constant, then the speed of the airflow must increase to ensure the same quantity of air passes any given point in the neck of the Venturi. Because the speed of the air increases and the static pressure decreases the streamlines move closer together and vice versa.

Therefore, it is true to say that as the diameter of a stream tube decreases the stream velocity increases and to maintain a constant mass flow the static pressure decreases, the dynamic pressure increases but the total pressure remains constant. The air density is the same after the change has occurred as it was before the event.

If the temperature of streamline airflow changes, the air density will alter. Increased temperature will decrease the air density and if the stream speed remains constant then the mass flow past any point decreases and vice versa. The drag experienced in a stream tube is directly proportional to the air density of the flow. If the air density is halved then the drag is also halved.

1.12 Reynolds Number

Reynolds, a 19^{th}-century physicist, discovered from experiments that a sphere placed in a streamline flow of fluid caused the flow to change from a smooth flow to a turbulent flow. Furthermore, he found that the transition point from smooth to turbulent flow in all cases occurred at the maximum thickness of the body relative to the flow. It was also ascertained that the speed at which the transition from smooth to turbulent flow occurs is when the flow velocity reaches a value that is inversely proportional to the diameter of the sphere. Thus, turbulence occurs at a low speed over a large sphere and at a high speed over a small sphere.

Since then it has been established that the airflow pattern over an exact model of an aeroplane is precisely the same as the airflow over the actual aeroplane. Thus, the laws of aerodynamics are true and there is no error due to scale effect when based on Reynolds principles. These state that the value of velocity $\times$ size must be the same for both the model and the full-size aeroplane.

It has been determined that the similarity of flow pattern is the same for both the model and the full size aeroplane if the value of the following formula remains constant:

$$\frac{\textbf{density} \times \textbf{velocity} \times \textbf{size}}{\textbf{viscosity}}$$

For every wind-tunnel test there is one Reynolds number (R), which is always published in the results of any test. The ratio between the inertial and viscous (friction) forces is the Reynolds number. It is used to identify and predict different flow regimes such as laminar or turbulent flow. It can be calculated by the formula:

$$\textbf{Reynolds Number (Re)} = \frac{\rho VL}{\mu} = \frac{\textbf{Inertial Forces}}{\textbf{Viscous Forces}}$$

where ρ is density in kg per m^3; V is the velocity in metres per second; L is the chord length and μ is the viscosity of the fluid.

A ***small*** *Reynolds number* is one in which the *viscous force is predominant* and indicates a steady flow and **smooth** fluid motion. A ***large*** *Reynolds number* is one in which the *inertial force is paramount* and indicates random eddies and **turbulent** flow.

1.12.1 Critical Reynolds Number (Re_{crit})

The change from smooth laminar flow to turbulent flow is gradual. There is a range during which the transition from smooth to turbulent flow takes place the Critical Reynolds number occurs approximately half way through this range. Its value is determined experimentally and is dependent on the exact flow configuration.

To determine the airflow around an aeroplane a scale model is tested in a wind tunnel using the same Reynolds number as the actual aeroplane to determine the airflow behaviour. The results are directly proportional to the size of the model in relation to the size of the actual aeroplane. For example, the flow velocity and behaviour of a quarter size model has to be increased fourfold for use with the actual aeroplane. This is called ‘dynamic similarity’ and is significant when determining the drag characteristics of an aeroplane.

1.13 Units of Measurement

Item	S.I. Units	Description
Wing Loading M/S (mass per unit area)	N/m^2	Force in Newtons divided by the wing area in square metres.
Dynamic Pressure (q)	N/m^2	Force in Newtons divided by the area in square metres.
Power	N m/s	This is the measure of the work done in a specific time period. It is the force in Newtons multiplied by speed in metres per second.
Air Density	g/m^3	Mass in kilograms divided by volume in cubic metres.
Force (Newton)	$kg\ m/s^2$	Mass multiplied by acceleration in metres per second per second.
Pressure	N/m^2	Force in Newtons divided by the area in square metres. In the USA they use psi as a measure of pressure (pounds per square inch).

Self-Assessment Exercise 1

Q1.1 Which formula or equation describes the relationship between force (F), acceleration (a) and mass (m)?
- (a) a = F.m
- (b) F = m/a
- (c) F = m.a
- (d) m = F.a

Q1.2 Bernoulli's equation can be written as:
(pt − total pressure, ps = static pressure, q = dynamic pressure)
- (a) pt = q − ps
- (b) pt = q + ps
- (c) pt = ps – q
- (d) pt + ps = q

Q1.3 If the continuity equation is applicable to an incompressible airflow in a tube at low subsonic speed, if the diameter of the tube changes the air density after the change:
- (a) will be greater than it was before
- (b) will be less than it was before
- (c) is dependent on the change
- (d) will be the same as before the change

Q1.4 If the continuity equation is applicable to an incompressible airflow in a tube at low subsonic speed, if the diameter of the tube increases the speed of the flow:
- (a) increases
- (b) becomes sonic
- (c) decreases
- (d) remains the same

Q1.5 In the SI system kg. m/s^2 is expressed as a:
- (a) Joule
- (b) Watt
- (c) Newton
- (d) Pascal

Q1.6 The unit of wing loading (i) M/S and (ii) dynamic pressure q are:
- (a) (i) N/m; (ii) kg
- (b) (i) N/m^2; (ii) N/m^2
- (c) (i) N/m^3; (ii) kg/m^3
- (d) (i) kg/m; (ii) N/m^2

Q1.7 The total pressure is:
- (a) static pressure plus dynamic pressure
- (b) static pressure minus dynamic pressure
- (c) $^1/_2\rho V^2$
- (d) measured parallel to the local stream

Q1.8 The static pressure of the flow in a tube:
- (a) decreases when the diameter decreases
- (b) is total pressure plus dynamic pressure
- (c) is the pressure at the point at which the velocity is zero
- (d) increases when the diameter decreases

Q1.9 Bernoulli's equation can be written as:
(pt = total pressure; ps = static pressure; q = dynamic pressure)
- (a) pt = ps/q
- (b) pt = ps + q
- (c) pt = ps – q
- (d) pt = q – ps

Q1.10 The unit of power measurement is:
(a) kg m/s^2
(b) PA/m^3
(c) N/m
(d) N m/s

Q1.11 Static pressure acts:
(a) perpendicular to the direction of flow
(b) in the direction of the total pressure
(c) in all directions
(d) in the direction of the flow

Q1.12 Which of the following statements regarding Bernoulli's theorem is correct?
(a) The total pressure is zero when the stream velocity is zero
(b) The dynamic pressure is maximized at the stagnation point
(c) The dynamic pressure increases as the static pressure decreases
(d) The dynamic pressure decreases as static pressure decreases

Q1.13 The units of measurement used for air density (i) . . . . and its force (ii) . . . . are:
(a) (i) N/ kg; (ii) kg
(b) (i) kg/m^3; (ii) N
(c) (i) kg/m^3; (ii) kg
(d) (i) N/m^3; (ii) N

Q1.14 The units used to measure air density are:
(a) kg/cm^3
(b) Bar
(c) kg/m^3
(d) psi

Q1.15 The unit of measurement used for pressure is:
(a) lb/gal
(b) kg/dm^2
(c) psi
(d) kg/m^3

Q1.16 Which of the following formulae is correct?
(a) $a = M \div F$
(b) $F = M \times a$
(c) $a = F \times M$
(d) $M = F \times a$

Q1.17 The product kg and m/s^2 is:
(a) the Newton
(b) psi
(c) the Joule
(d) the Watt

Q1.18 The units used to measure wing loading (i) and dynamic pressure (ii) are:
(a) (i) N/m^2; (ii) N/m^2
(b) (i) N m; (ii) N m
(c) (i) N; (ii) N/m^2
(d) (i) N/m^2; (ii) Joules

Q1.19 Bernoulli's theorem states:
(a) dynamic pressure increases as static pressure increases
(b) dynamic pressure increases as static pressure decreases
(c) dynamic pressure is greatest at the stagnation point
(d) dynamic pressure is zero when the total pressure is greatest

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Q1.20 Bernoulli's theorem states:
(a) The sum of all the energies present is constant in a supersonic flow.
(b) The sum of the pressure and the kinetic energy is a constant in a low subsonic streamline flow.
(c) Air pressure is directly proportional to the speed of the flow.
(d) Dynamic pressure plus pitot pressure is a constant.

Q1.21 If the temperature of the air in a uniform flow at velocity V in a stream tube is increased the mass flow:
(a) remains constant and the velocity increases
(b) increases
(c) remains constant and the velocity decreases
(d) decreases

Q1.22 If the continuity equation is applicable to an incompressible airflow in a tube at low subsonic speed, if the diameter of the tube decreases the speed of the flow:
(a) increases
(b) becomes supersonic
(c) decreases
(d) remains the same

Q1.23 The equation for power is:
(a) N/m
(b) N m/s
(c) Pa/s^2
(d) $kg/m/s^2$

Q1.24 If the temperature of streamline airflow in a tube at constant speed is increased it will:
(a) increase the mass flow
(b) not affect the mass flow
(c) increase the mass flow if the tube is divergent
(d) decrease the mass flow

Q1.25 If the air density in a stream tube flow is halved, the drag is decreased by a factor of . . . .
(a) 8
(b) 4
(c) 6
(d) 2

Q1.26 Regarding a Venturi in a subsonic airflow, which of the following statements is correct?
(i) The dynamic pressure in the undisturbed airflow and the airflow in the throat are equal.
(ii) the total pressure in the undisturbed airflow and in the throat are equal.
(a) (i) correct; (ii) correct
(b) (i) correct; (ii) incorrect
(c) (i) incorrect; (ii) incorrect
(d) (i) incorrect; (ii) correct

Q1.27 If the velocity in a stream tube is increased, the streamlines:
(a) remain the same
(b) move further apart
(c) move closer together
(d) are not affected by the velocity

Q1.28 As subsonic air flows through a convergent duct, static pressure (i) . . . . and velocity (ii) . . . .
(a) (i) increases; (ii) decreases
(b) (i) increases; (ii) increases
(c) (i) decreases; (ii) decreases
(d) (i) decreases; (ii) increases