Basic Air Movement
Fan Principles & Types

Woods
AIR MOVEMENT

What will we cover in this Introduction

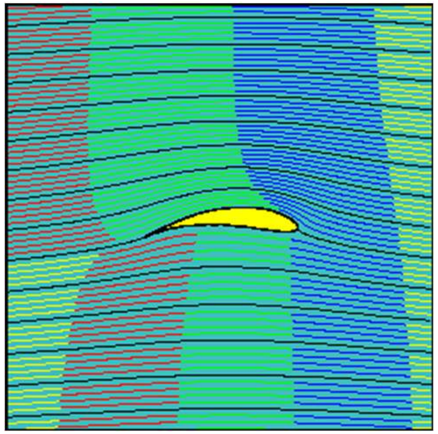
- Basic principles of air movement applied to fans
- Key air qualities and associated units,
- Measurements and how we use the results
- Fan characteristics, Volume, Pressure, Power
- Power and how we size motors
- Fan types and basic characteristic
- Background to the Fan selector

WHY DOES AIR FLOW?

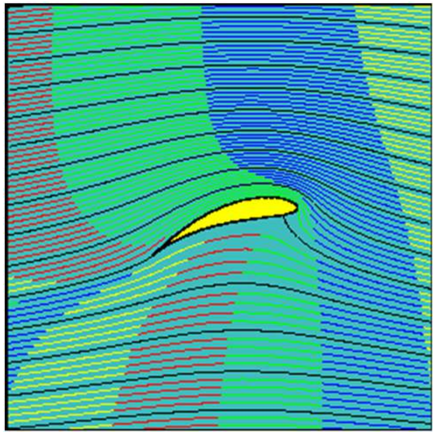
Air Naturally Flows From High Pressure to Low Pressure

Create a Pressure Differential and an Airflow Will Result

A Fan Creates a Pressure Differential Causing Air Movement



Aerofoil section blade creates pressure differential



Increased angle creates greater pressure differential

Metres / second

KM/Hour

Miles per Hour

SI Unit m/sec

CM per Minute

Feet per Minute

Velocity is an important design feature, specific velocities are required in processes like drying and conveying.

To conserve energy systems can be specified as having a maximum velocity through the fan outlet.

Some specifications will limit fan outlet velocity, to control pressure losses

For ventilation systems the volume of air is the dominant factor,

Typically Air changes per hour in a space will be the basis of calculating the required volume flow.

Litres / second

Kg / Hour

SI Unit - m^3/ sec

Cubic Feet / Minute

Metres^3/ Hour

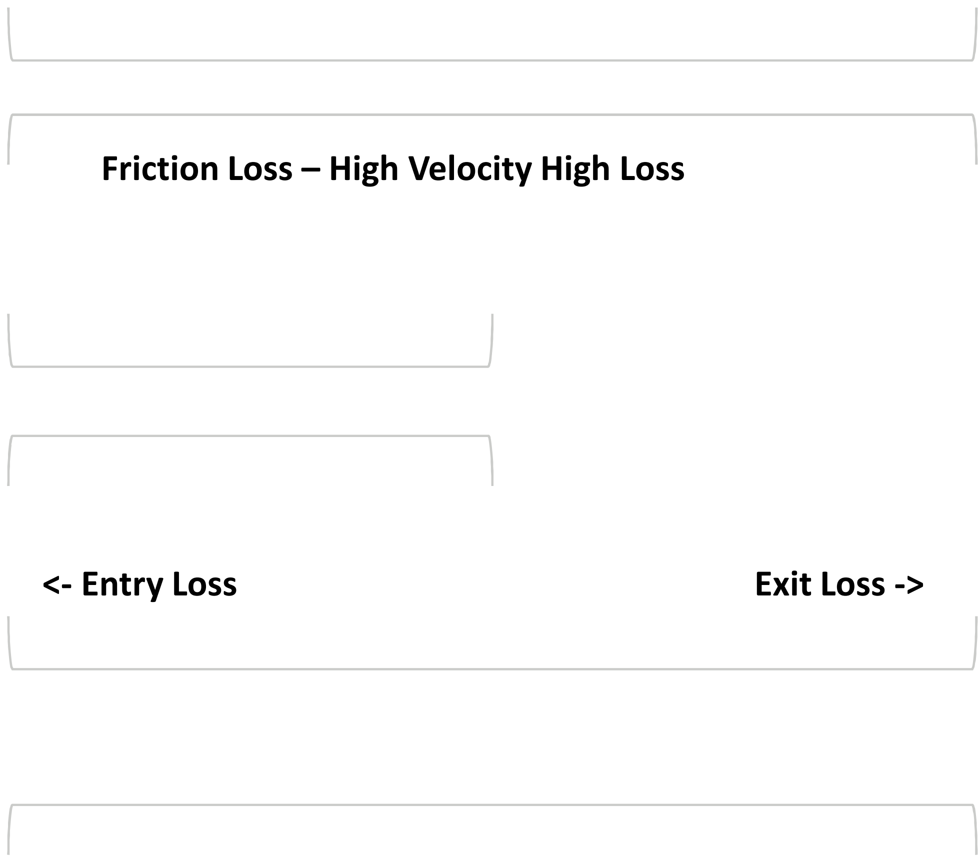
In a duct if the Velocity is known (m/sec) and the area is known (m^2) , Volume = m/sec * m^2 = m^3/sec

Static pressure for a system reflects the resistance that the fan has to overcome to deliver the volume flow required.

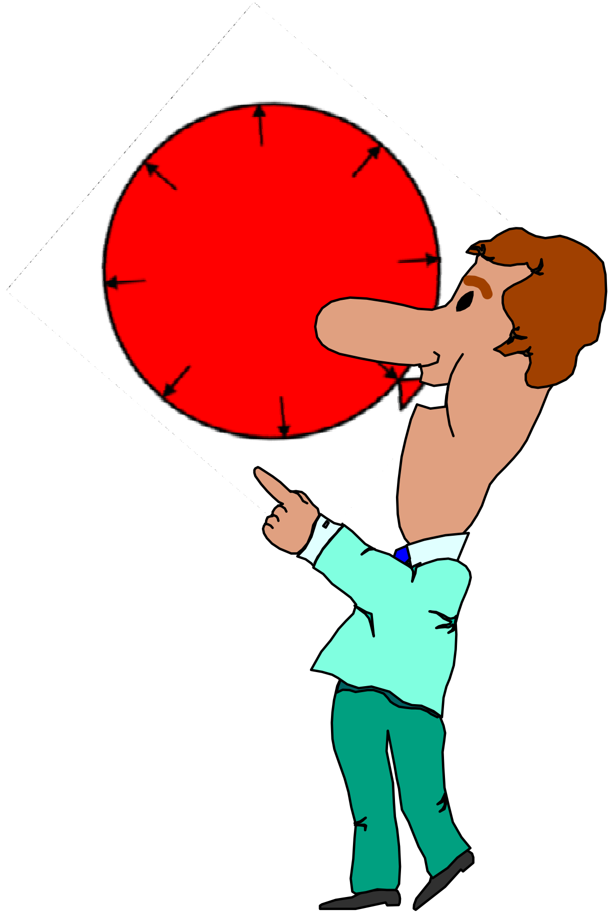
Static Pressure Is the Pressure Which Acts Equally in All Directions and Is the Pressure required in the form of work from the fan to Maintain Air Movement Against a Resistance in the system.

Units	Pa (N/m^2)
Formula	$p_{sF} = p_F - p_{dF}$

STATIC PRESSURE



STATIC PRESSURE



It is the static pressure that maintains a balloons shape

STATIC PRESSURE

It is the static pressure that inflates the flexible ducting when ventilating mine working faces and tunnel drilling faces, to ensure fresh air is delivered to the workplace

Total Pressure is the sum of the Dynamic & Static pressure of a fan.

Total Pressure Is the Measure of the Energy Level in the Air

Units Pa (N/m^2)

Formula $p_F = p_{sF} + p_{dF}$

Once any 2 of the pressures are known then the 3rd can be derived mathematically.

These pressures are characteristics of both a Fan and of the system

Total = Static + Dynamic

$$p_F = p_{sF} + p_{dF}$$

Static = Total - Dynamic

$$p_{sF} = p_F - p_{dF}$$

Dynamic = Total - Static

$$p_{dF} = p_F - p_{sF} \qquad p_{dF} = 0.5 * \rho(\text{density}) * v(\text{velocity})^2$$

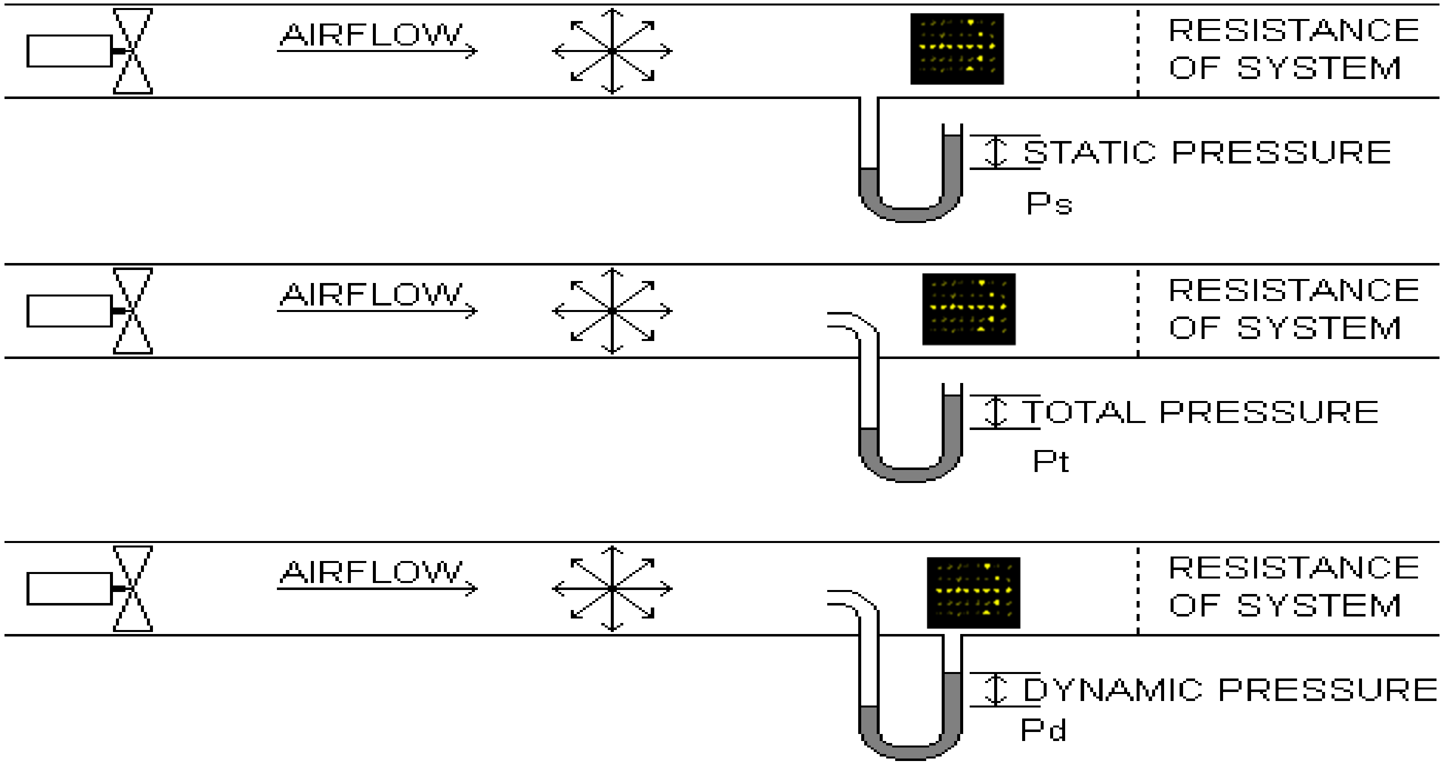
A fan is described by the performance that it gives

- Fan Total, Static and Dynamic pressures form the basis of how we determine the fan Aerodynamic performance.

- The International fan test standards rely on the accurate measurement of pressures within a standardised duct (Test) system to be the basis of calculated fan performance

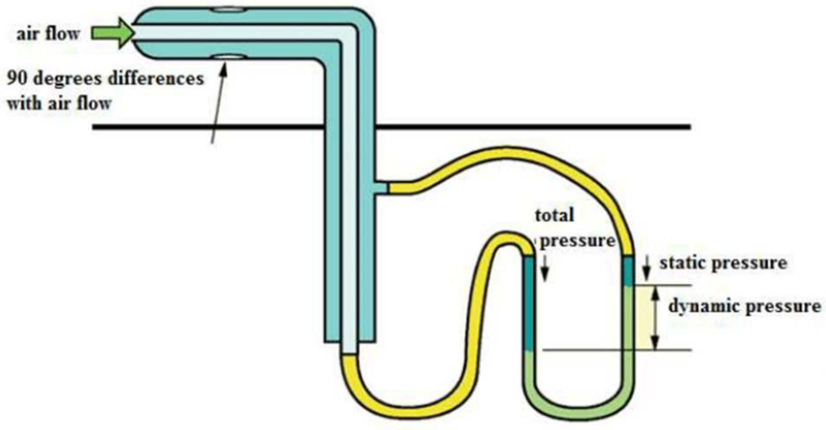
- Understanding of measurement of pressures at site will give the best possible site based performance figures

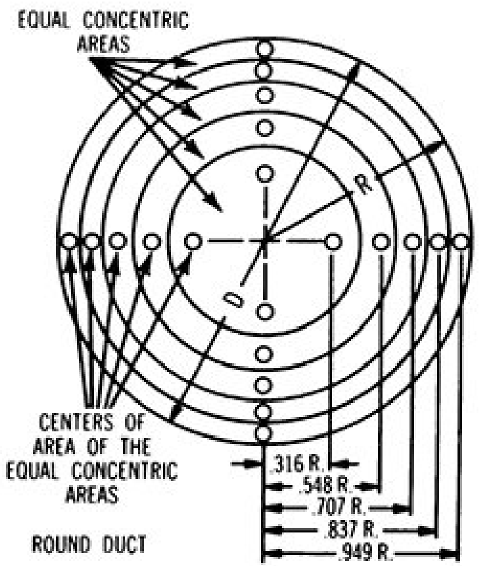
The figures below show typical duct system layouts and typical ways in which pressures are measured.

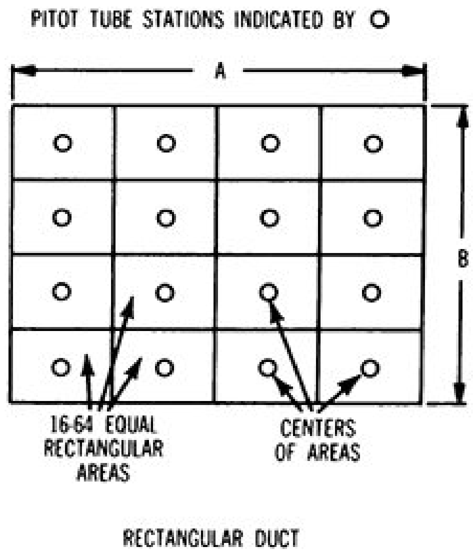


PRESSURE – Measurement

The most common pressure measuring device is the pitot tube as this has the capibility to measure both Total and Static pressure directly and Dynamic pressure as a difference. Readings are taken on a Manometer (pressure gauge) .







Many readings are required over a test section to establish reliable and accurate performance

Of increasing importance in an energy conscious market is the importance of the power our products consume.

With Fans when we talk about Power we talk about 2 specifically as detailed below, we consider both for safe and reliable installation

Duty Absorbed Fan Power - Absorbed Power

- The Power Absorbed by the Fan at the specific selection Duty

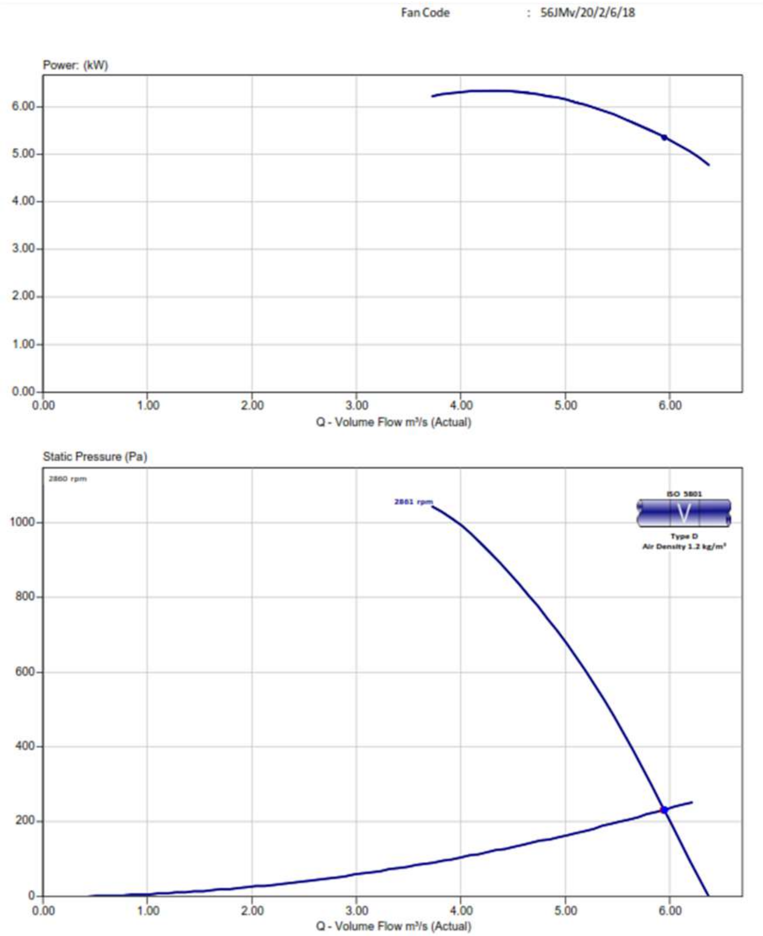
Peak Fan Power - Peak Power

- The Peak Power (the Maximum) the Fan Absorbs at the selected duty pitch angle, anywhere on the selected angle curve. For an Axial Fan we mean the selection Pitch Angle curve for a centrifugal fan this is the constant speed curve.

Sizing Motors on Peak Power – Why and Risks

Duty Shaft Power	5.37 kW
Max Shaft Power	6.48 kW

The risk of sizing motors on absorbed power +% is that if the site installation is poor or the system calculation is wrong the fan could fail prematurely



Sizing motors on Absorbed power for example +10 % would give a motor size of 5.91 kW.

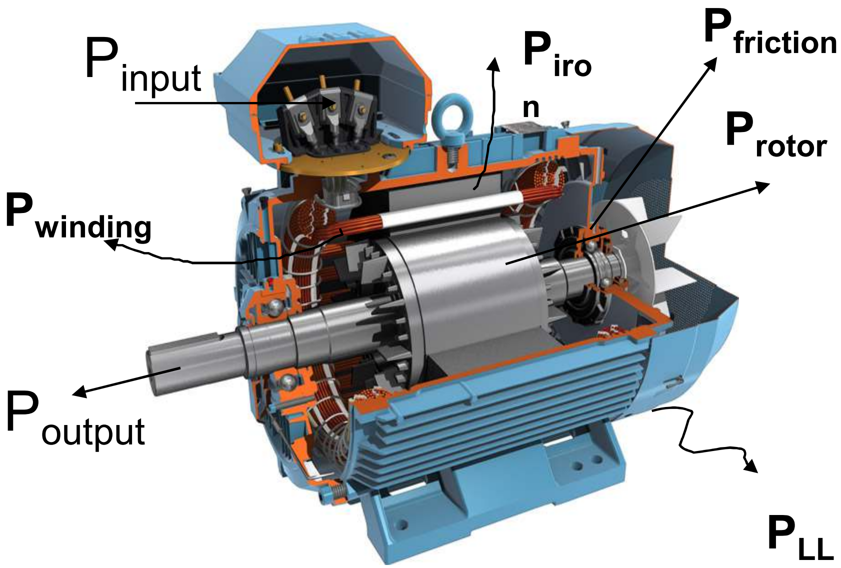
If the pressure increased above 530Pa then the motor would start to overload.

Motor failure occurs when motors overheat through load.

Failure is not immediate but will be earlier than good selection

Motor Power

- The Power Input to the Motor is used when we have to calculate ErP (Energy Related Products Legislation).
- **The Power output from the motor is the useable power available what we need for driving the fans.**
- The Ratio of Motor Input Power to Motor Output Power Is the *Motor Efficiency*.



Motor Output Power

- The Power Output by the Motor.
- On a Direct Drive Fan, This Is Equal to the Fan Absorbed Power as a minimum, preferably the peak absorbed power.
- On a Belt Drive Fan, The Motor Output Power must cover the Fan Absorbed Power and must include the additional Drive Loss.

Motor Rated Power

- The Nameplate Rating. The Maximum Permissible Output Power of the Motor. This will be nominated at specific test conditions for fan manufacturers these are
  - **IEC Rating using Forced Cooling There is a cooling fan on the fan to give cooling IEC411**
  - **Woods use IFM (Integrated Fan Motor) rating IC418 and can obtain approximately 20% extra output**

The Efficiency of a Machine Is the Ratio of the Output Power Over the Input Power. Usually Expressed As a Percentage.

$$\text{Efficiency} = \text{Power Out} / \text{Power In}$$

$$\text{Fan Efficiency} = \frac{\text{Air Power}}{\text{Fan Absorbed Power}}$$

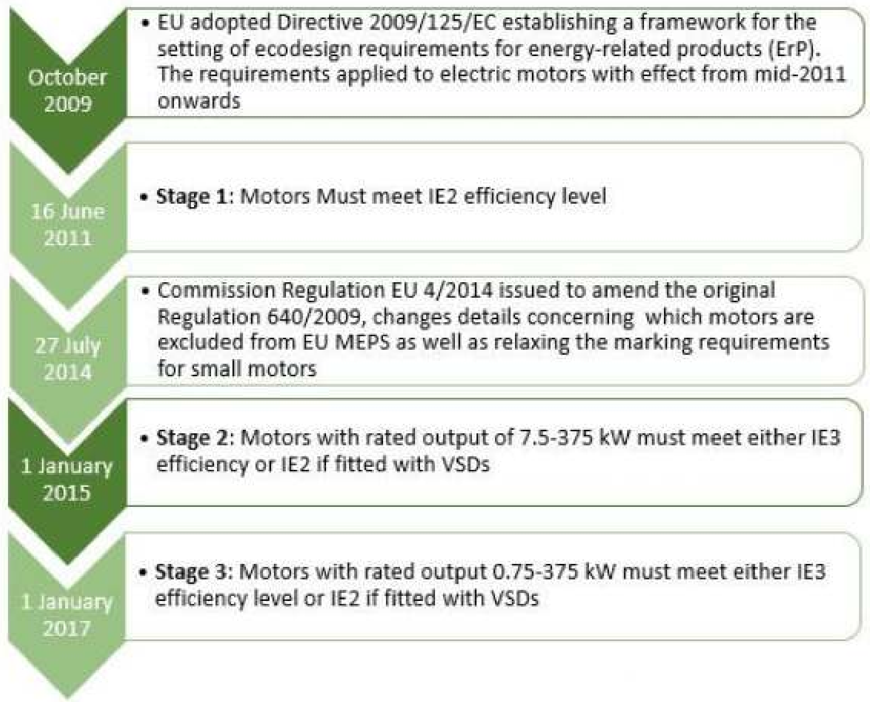
$$\begin{aligned}\text{Air Power} &= \text{Volume Flow x Total Pressure}\\ &= m^3/s \,.\, N/m^2\\ &= Nm/s\\ &= \text{Watts}\end{aligned}$$

MOTOR EFFICIENCY REGULATIONS

Motor efficiency is becoming a very important aspect of fan build, the changes to higher efficiency motors across the global markets mean that the older low efficiency motors will no longer be acceptable.

$$\text{Motor Efficiency (\%)} = \frac{\text{Output Power} \times 100}{\text{Input Power}}$$

Motors that are built into equipment such as Fans that cannot be tested without additional parts are not included in the Efficiency criteria, but ErP has to be passed when territory needs.



Ecodesign implementation timeline.

The focus on Power actual used by the Fan operator has become critical.

OVERALL Fan Efficiency Is a Term Used to describe the Combined Efficiency of the Fan and Motor, this is the driver for the ErP (Energy related Products) regulations.

Combined Efficiency = Fan Efficiency x Motor Efficiency

- If Fan efficiency is 80%
- Motor Efficiency is 90%
- Combined Efficiency is , 0.8 * 0.9 * 100 = 72%

<u>Global energy efficiency changes drive fan and system efficiency improvement</u>

Fan Performance Data Is Given at STANDARD AIR. The idea for that is so that a common reference is established.

Standard Air Is Any Air That Has an AIR DENSITY of 1.2 Kg/m^3

An Example Is Air at 16°C, a Barometric Pressure of 1013 Mb and a Relative Humidity of 68% RH.

TEMPERATURE & AIR DENSITY (2)

Air Density Varies Proportionally to the Temperature (the Absolute Temperature).

The Colder the Air, the Higher the Air Density - The Warmer the Air, the Lower the Air Density.

If the Air Temperature Changes From 16°C to 50°C the Ratio Between the Two Temperature in Absolute Terms,

(273+16)/(273+50) =

289/323 = .895 = 0.9, Is the Factor Which Applies to Air Density.

Density = 0.9 * 1.2 = 1.08 kg/m^3

Volume Flow $q'_v = q_v\,(N'/N)$

Total Pressure $p'_F = p_F\,(N'/N)^2\,(\rho'/\rho)$

Impeller Power $P' = P\,(N'/N)^3\,(\rho'/\rho)$

N = Original Speed
N^1 = New Speed
ρ = Original Density
ρ' = New Density

Note That the Volume Flow Does Not Change With the Density but Pressure & Power Both Vary Proportionally.

FANS ARE CONSTANT VOLUME MACHINES – MASS FLOW CHANGES WITH DENSITY

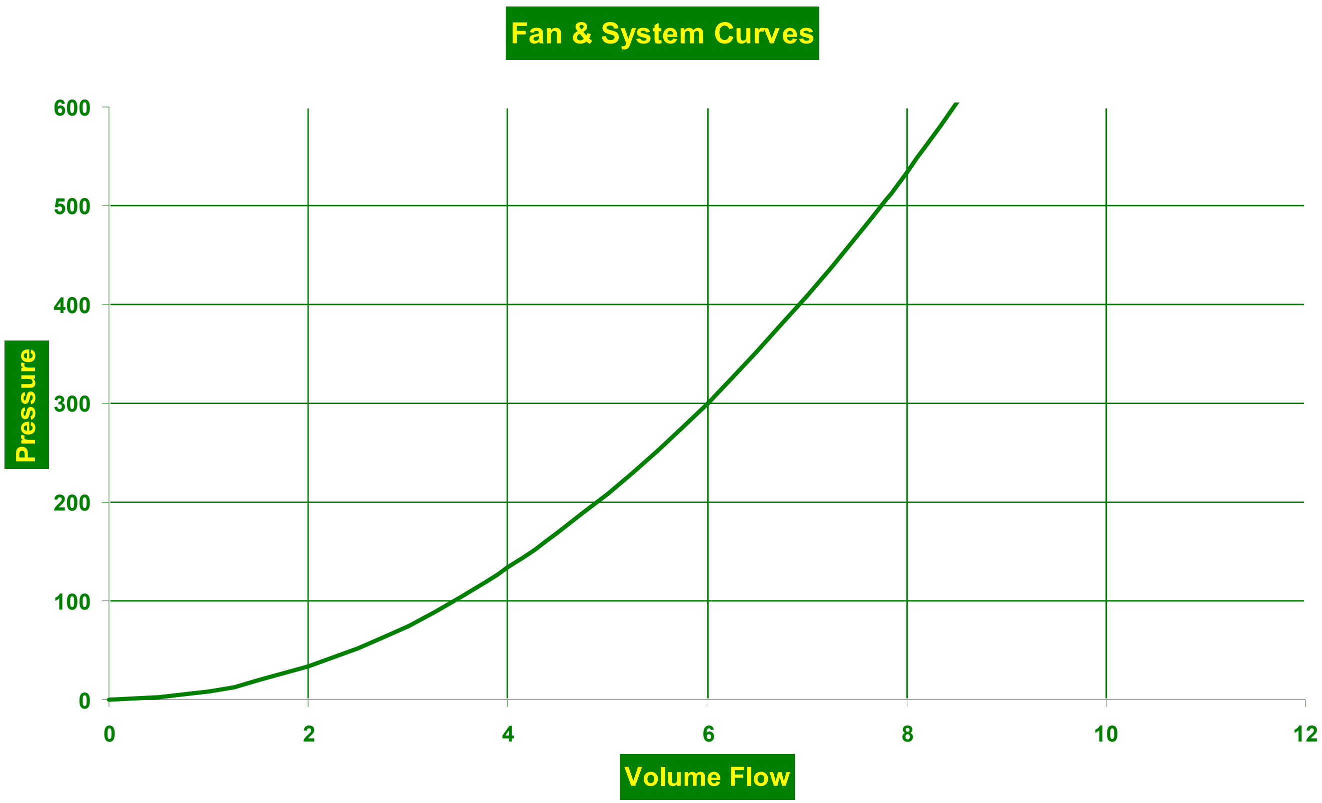
The Relationship Between Volume and Pressure Detailed in the Fan Laws Also Apply to Systems

If the Volume Halves, the Pressure Reduces by a Quarter

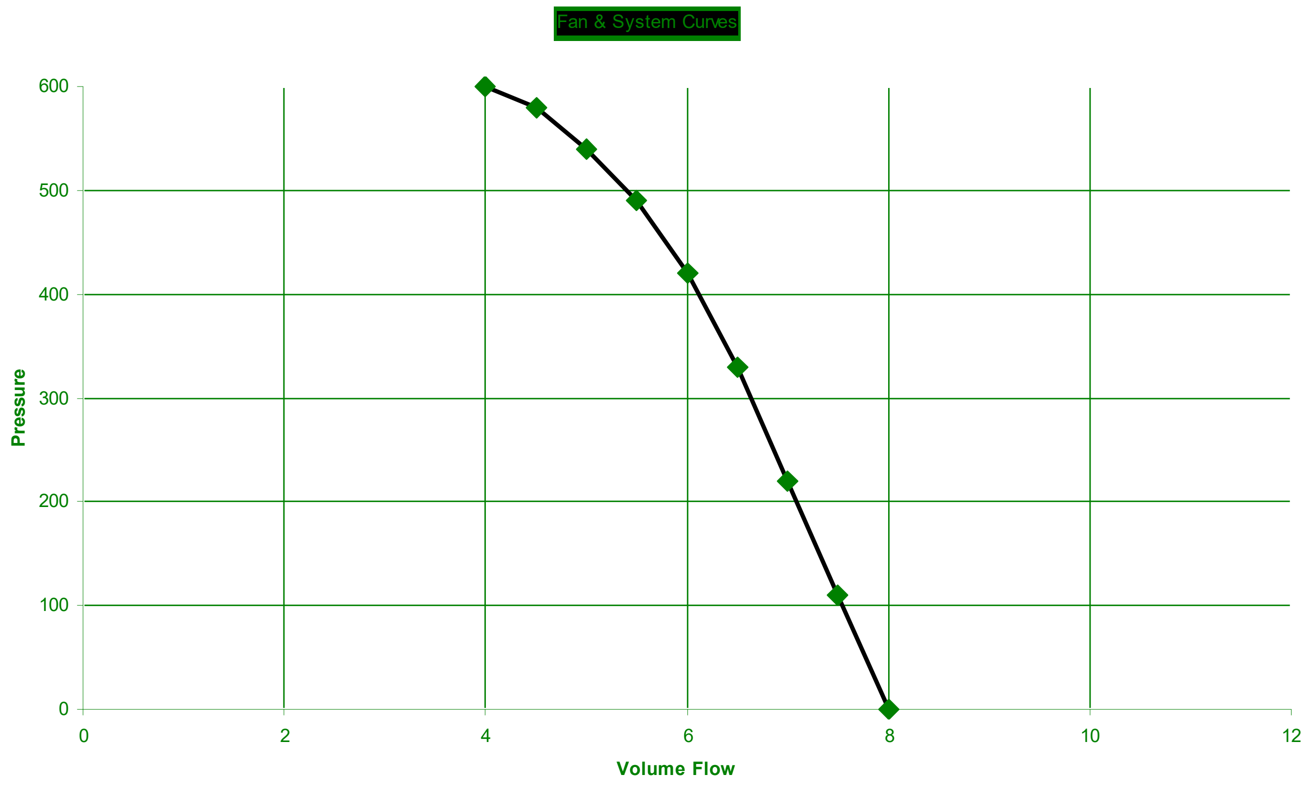
If the Volume Is Doubled, the Pressure Increases Fourfold

FAN DUTY IS THE POINT AT WHICH THE SYSTEM LINE CROSSES THE FAN PERFORMANCE CURVE

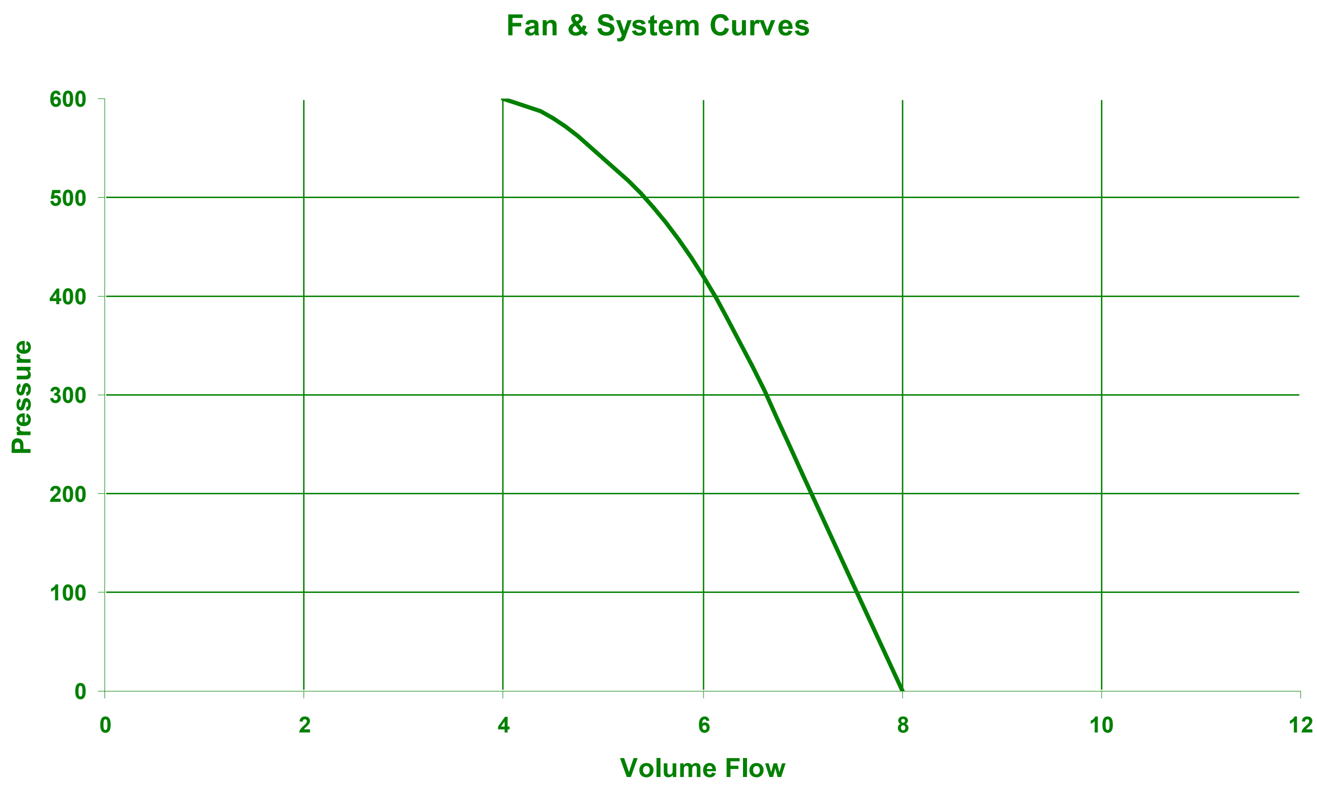
A System Curve = Design Resistance



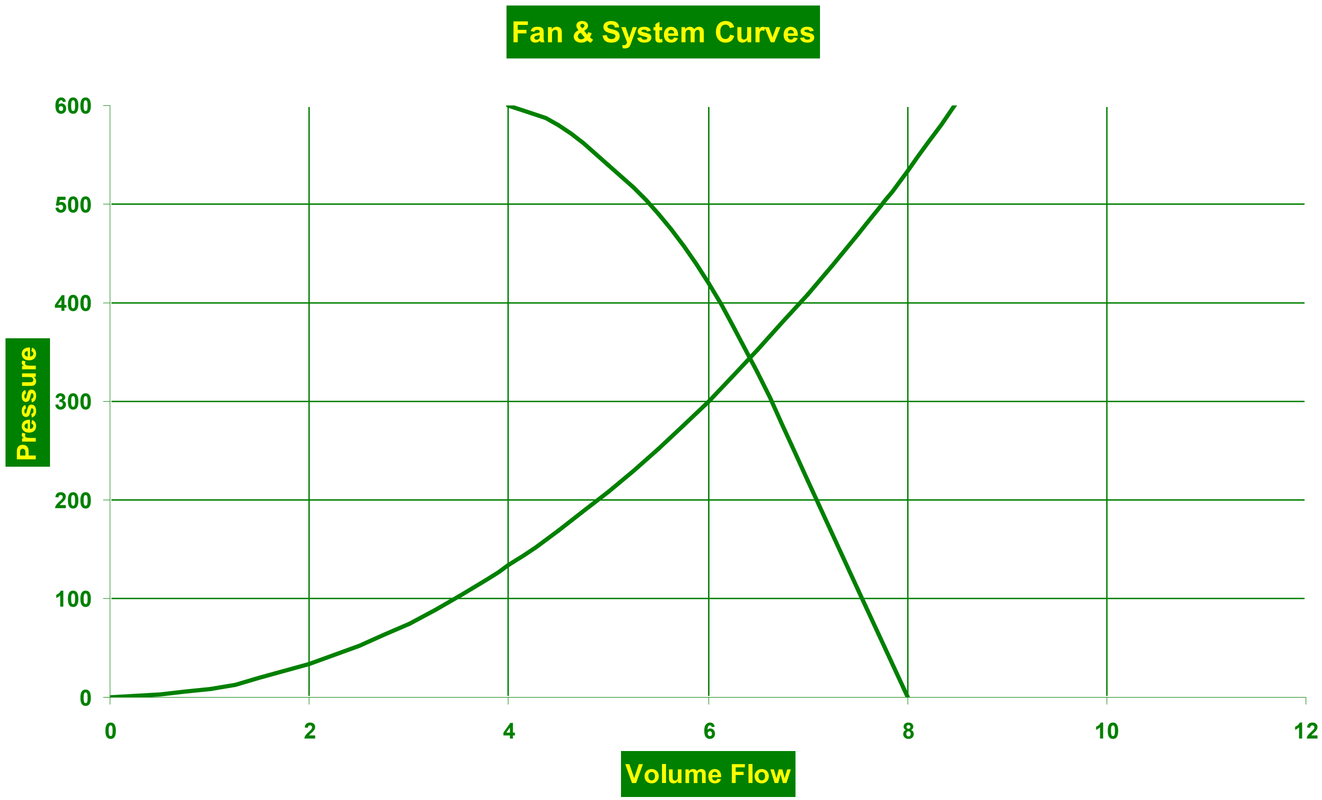
Fan Curve are Test Points On a Line



Catalogue Curve is smoothed and no Points Marked



Where System Curve Crosses Fan Curve = Duty



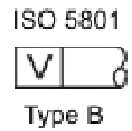
FANS ARE ALL TESTED UNDER STANDARDISED CONDITIONS

ISO 5801 (formally known as BS 848 pt 2)

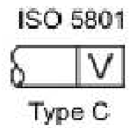
Type A – No duct fitted on inlet or outlet – plate mounted condenser fan

Most commonly used in OEM applications

Type B – Duct fitted on outlet – supply fan fitted at start of duct system

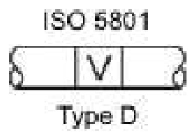


Type C – Duct fitted on inlet – exhaust fan fitted at end of duct system

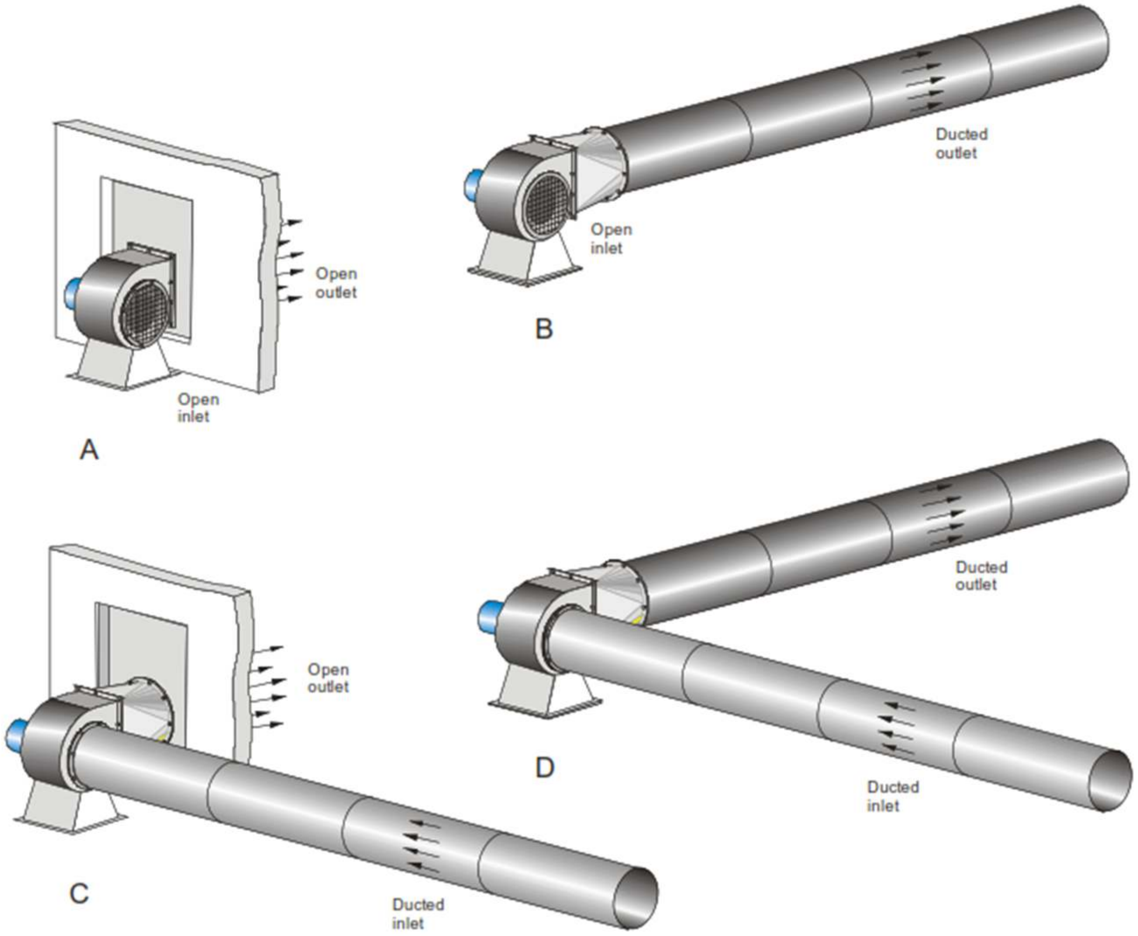


Type D – Duct fitted on both the inlet and outlet
fully ducted supply or extract fan

Most commonly used in Axial applications



Installation Categories



FAN DUTY VARIATIONS

There are a number of ways that we can vary the duty that the customer requires.

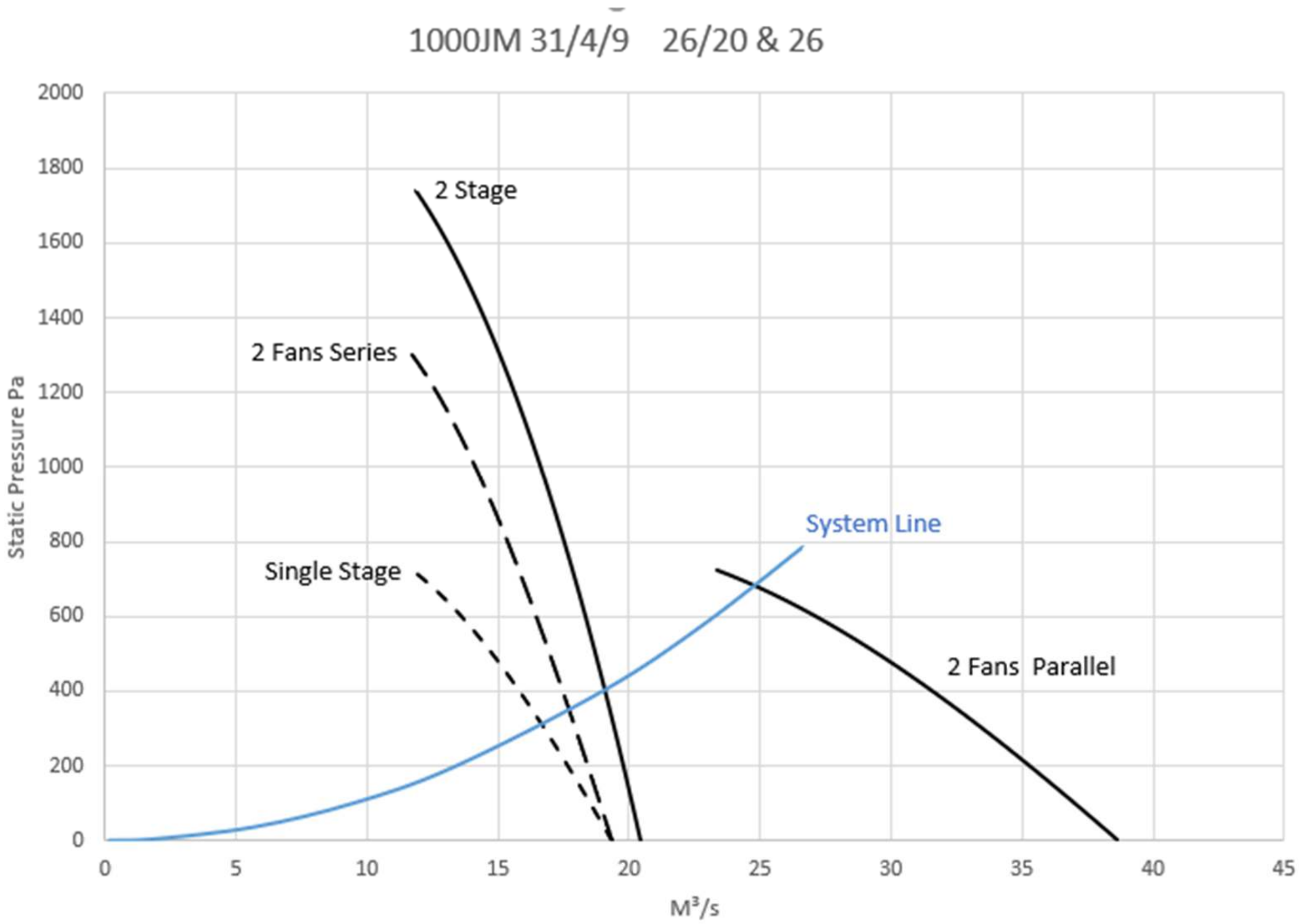
We can have multiple fans either in series or as multistage fans, in this case we can gain pressure but the volume capacity will not increase

We can have fans in parallel, in this case we can increase the volume flow but we cannot gain any pressure

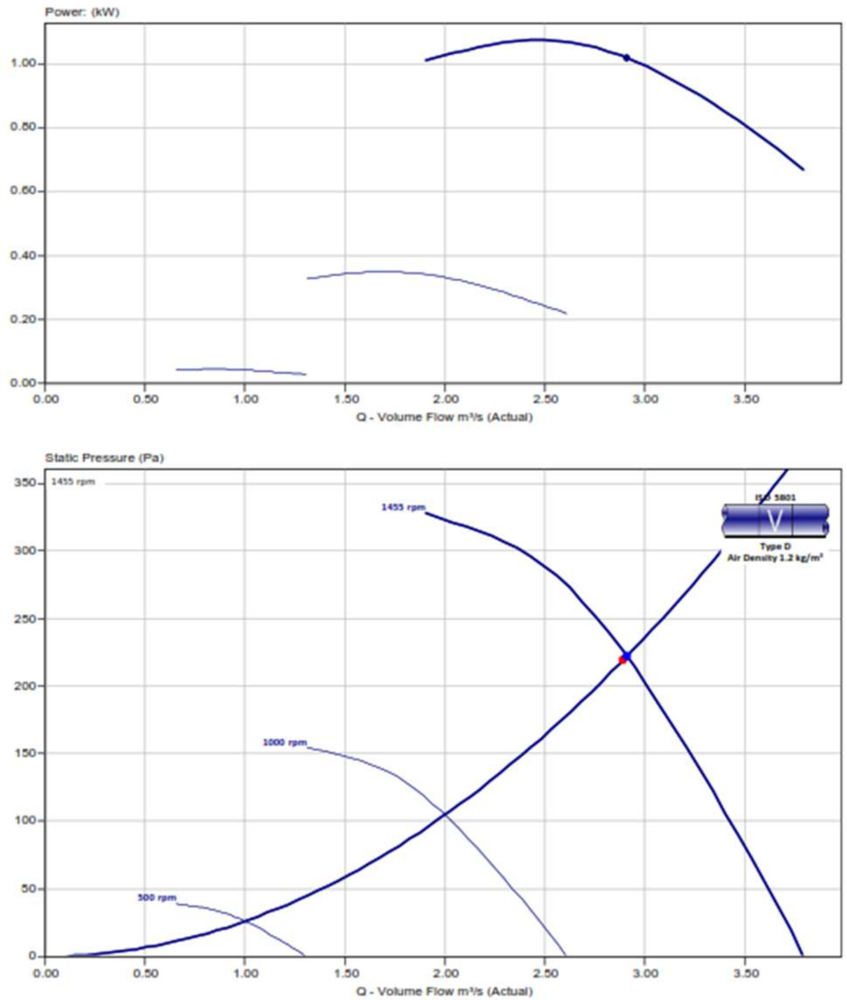
We can vary the speed of the fans, performance will change as the fans laws we looked at earlier

How does this interact with the design system line ??

Duty Variation by Fan Combination



Speed Control by Inverter



The example of speed control on a system line shows the huge gains in terms of power reduction.

Powers are Fan absorbed power and do not include any addition losses

Curves shown are at full, 2/3 and 1/3 Speed

Speed control has become the dominant control method due to accuracy, simplicity .

Operation point in the curve is at the same relative position.

20% minimum turndown recommended.

Inverter Drive - The Big Issues

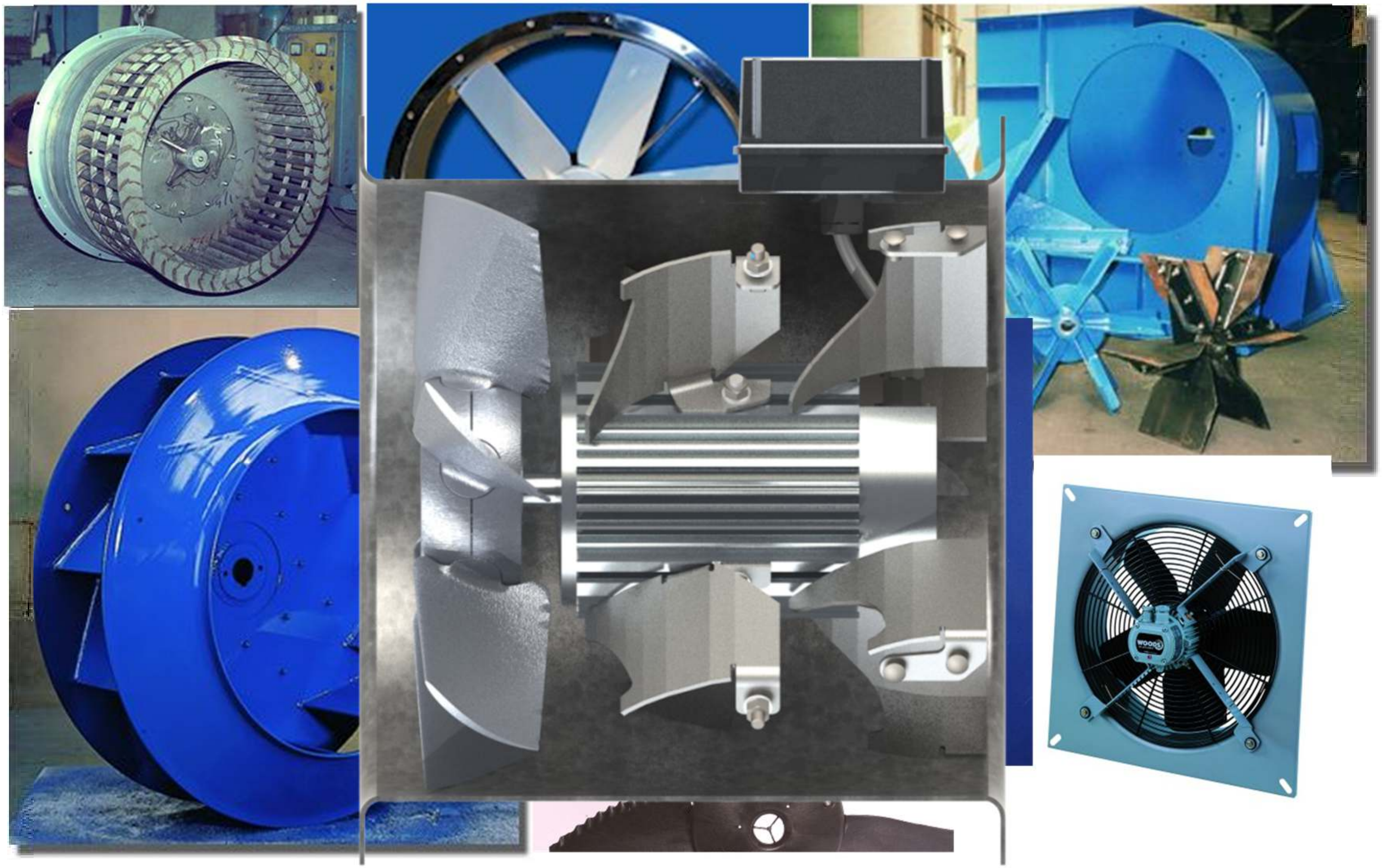
- Inverter drive offer a fantastic range of features to support, there are pros and Cons
    - Cable Runs over 50m from drive to motor may need additional filters
    - Correct cabling must be used at all times
    - Sensitive areas for EMC interference may need additional filters
    - Normal limit of turn down 20% without additional consideration to motor losses
    - On large motors 280 Frame and above , insulated bearings to prevent re circulating currents
    - Total flexibility in fine tuning site operation
    - Control of more than 1 fan from a single drive or piggy backed
    - Use of sensors connected directly to the drive, pressure, temperature etc
    - Fire Mode operation, if not tested with a drive then Inverter is switched out
    - Woods have tested the HT fan range with Inverter drive meaning more output can be used
    - Proven reliability of the best specification Drives (Danfoss FC range is the base for comparison)
    - Easy integration with existing control systems and logic
    - Eliminates the need for multi speed, low efficiency motors (IE1 Typical) and complicated switchgear

SYMBOLS & UNITS

η	Fan Efficiency	%
p_F	Fan Total Pressure	Pa
p_{sF}	Fan Static Pressure	Pa
p_{dF}	Fan Dynamic Pressure	Pa
P	Power	kW
q_m	Mass Flow	kg/s
q_v	Volume Flow	m^3/s
ρ	Air Density	kg/m^3
T	Thrust	N
v	Fan Outlet Velocity	m/s

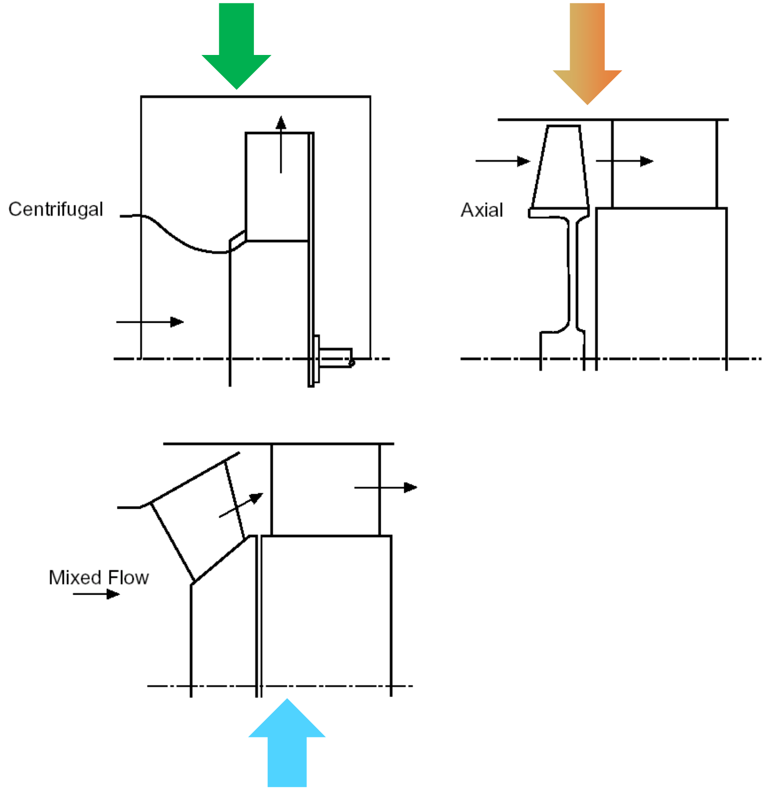
Basic Fan Types
Characteristics and Key Points

Basic Fan Types

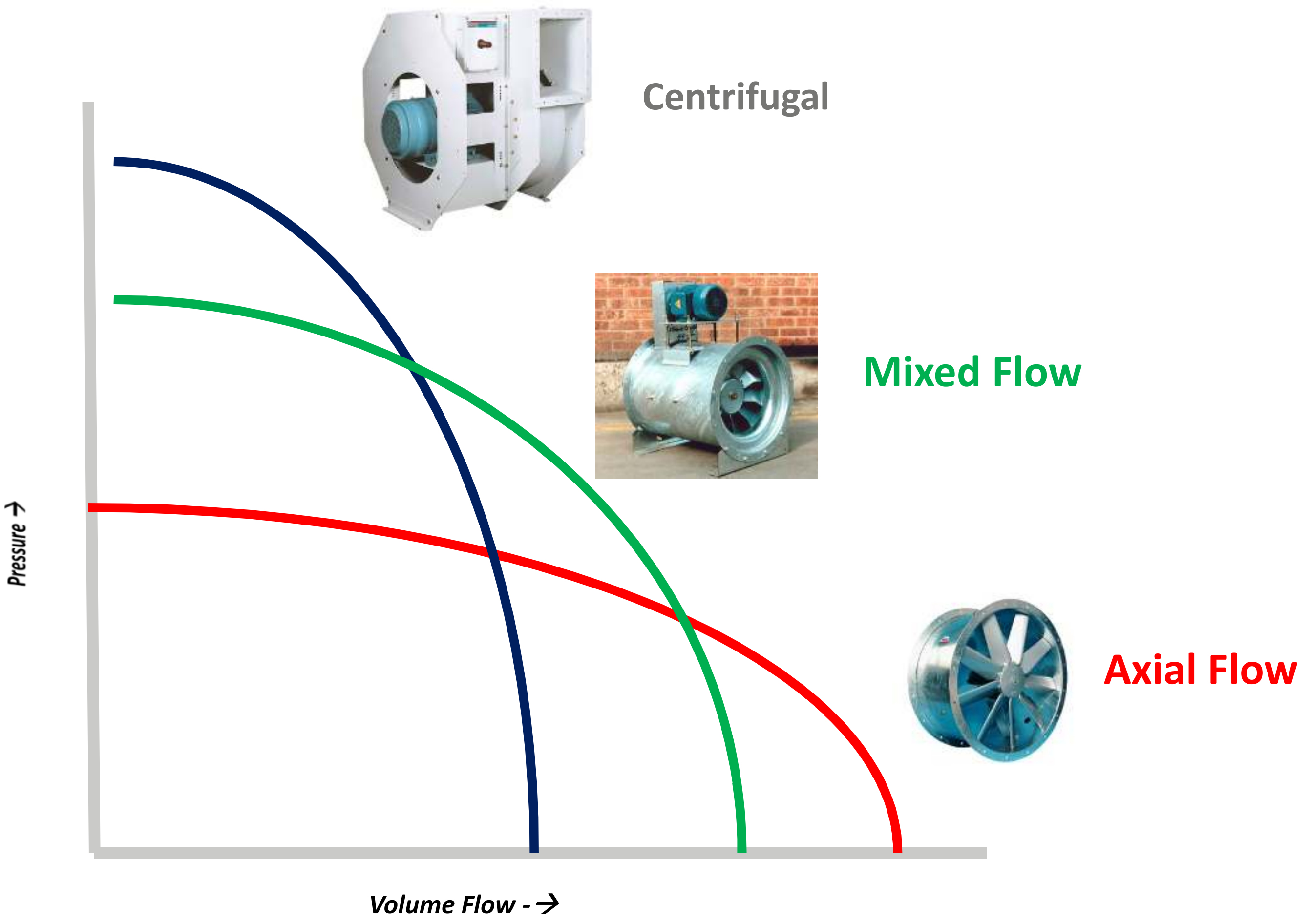


Basic Fan Types

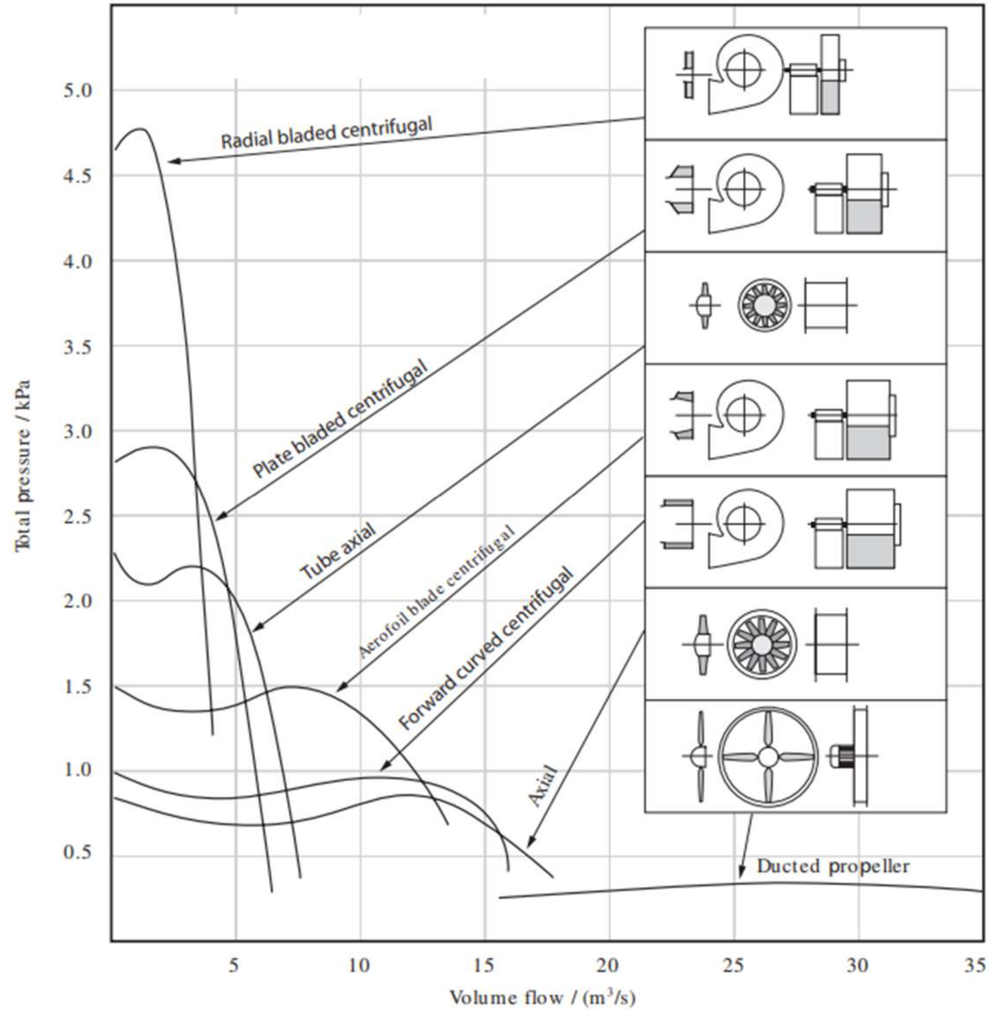
- Axial Flow
  - Airflow is in line with the axis of the fan. Work is done by the rotation and aerofoil section on the air to produce lift, therefore flow.
- Centrifugal
  - Airflow is radial to the axis of the inlet, work is tangential to rotation
- Mixed Flow
  - Airflow at an angle through the fan, guide vanes help flow development and pressure



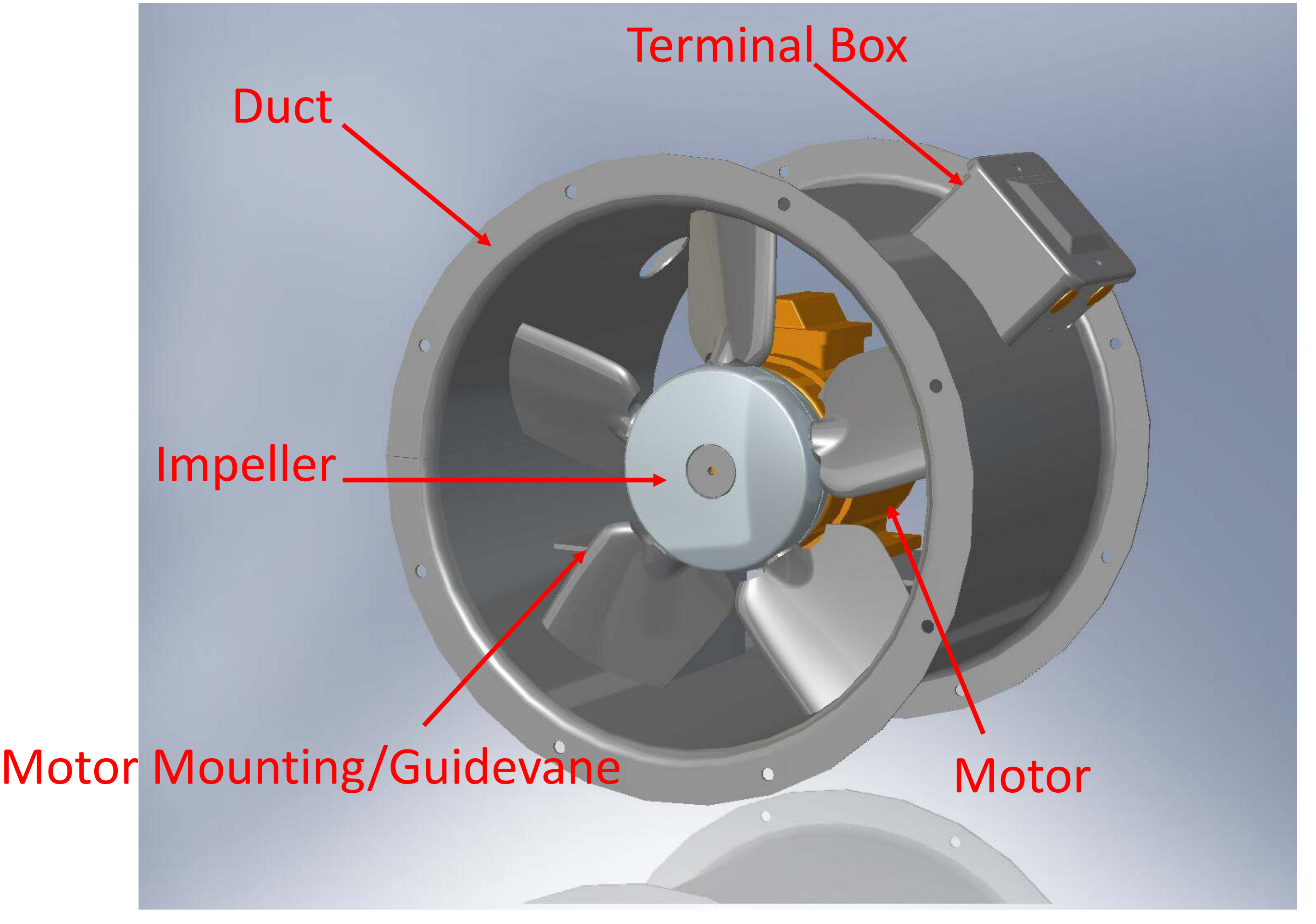
Basic Fan Types – Performance Layout



10kW Absorbed Power Comparison



Basic Fan Types – Axial Flow



Basic Fan Types – Axial Flow – Long Case

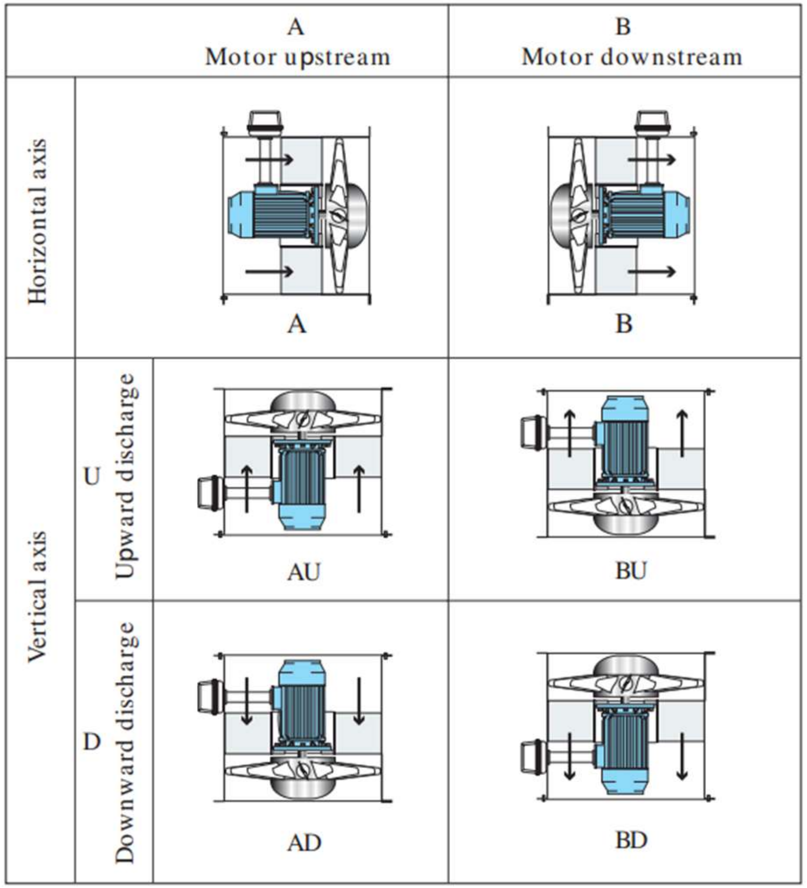
Duct Covers the Fan Motor

Basic Fan Types – Axial Flow – Short Case

Motor Extends from Casing

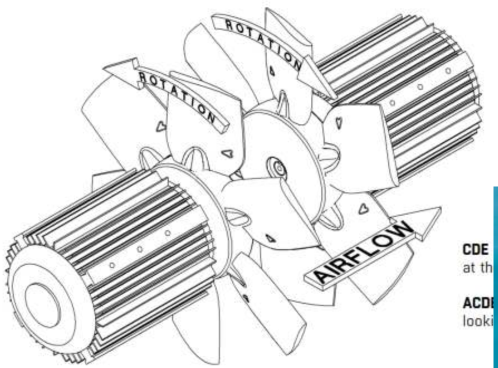
Fan Types – Plate Mounted Axial

Basic Fan Types – Axial Form of Running

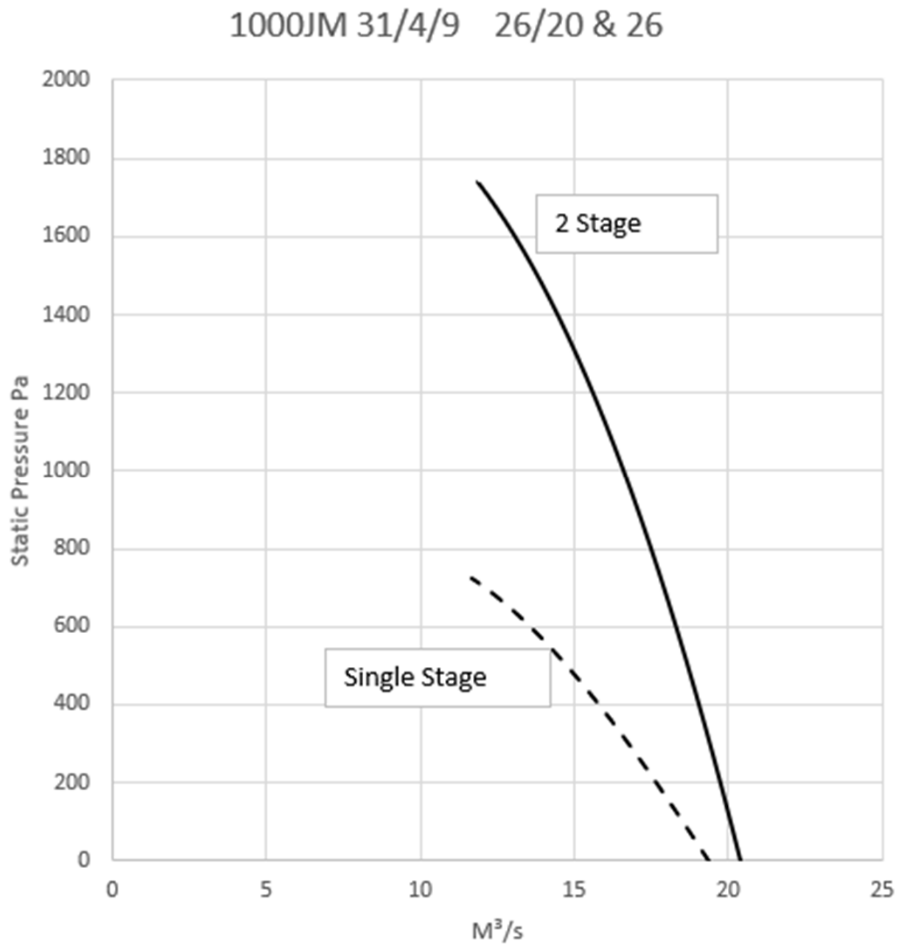


Standard running Form B - Form A – 3dB Quieter

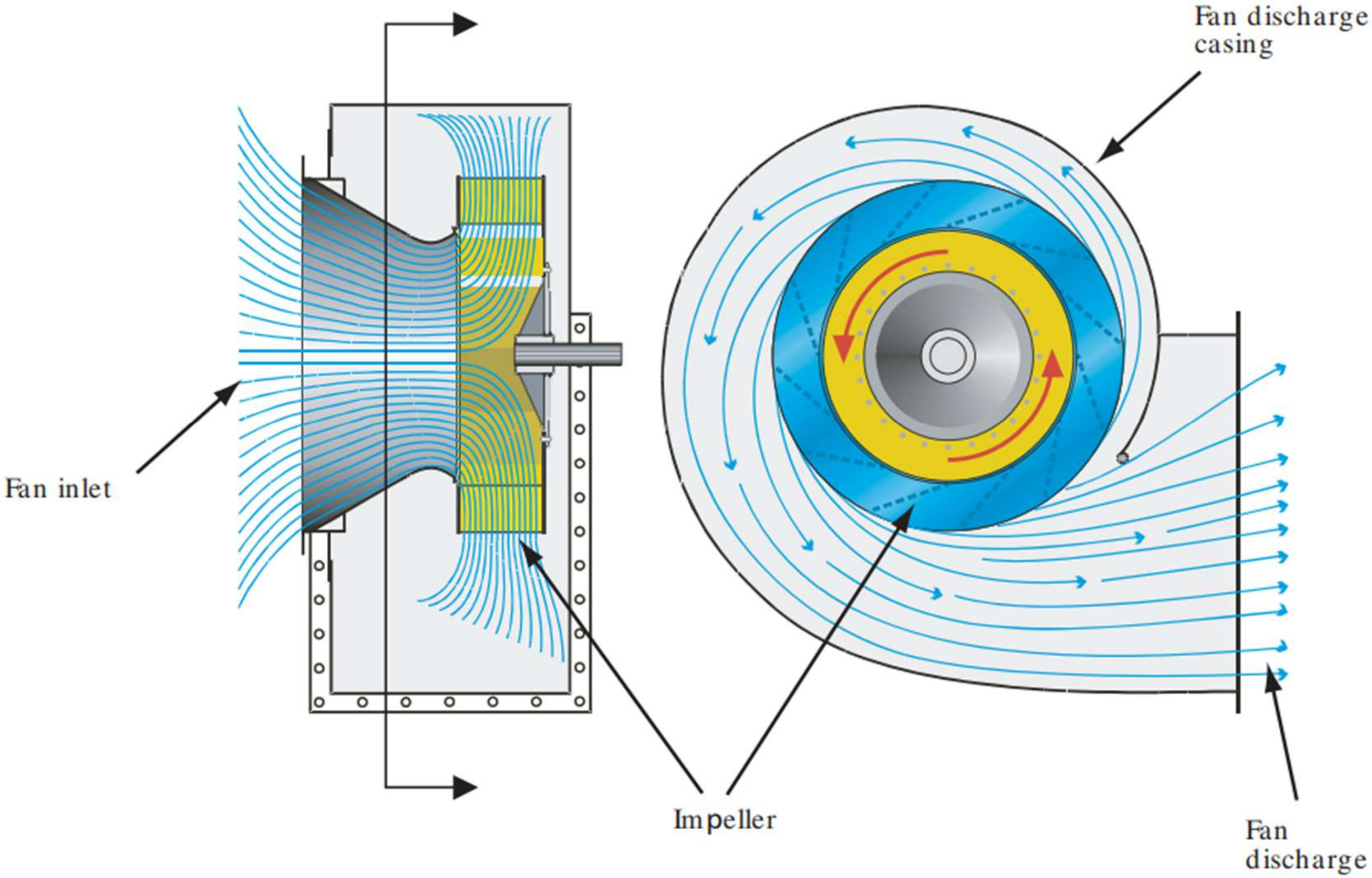
Basic Fan Types – Multistage Axials



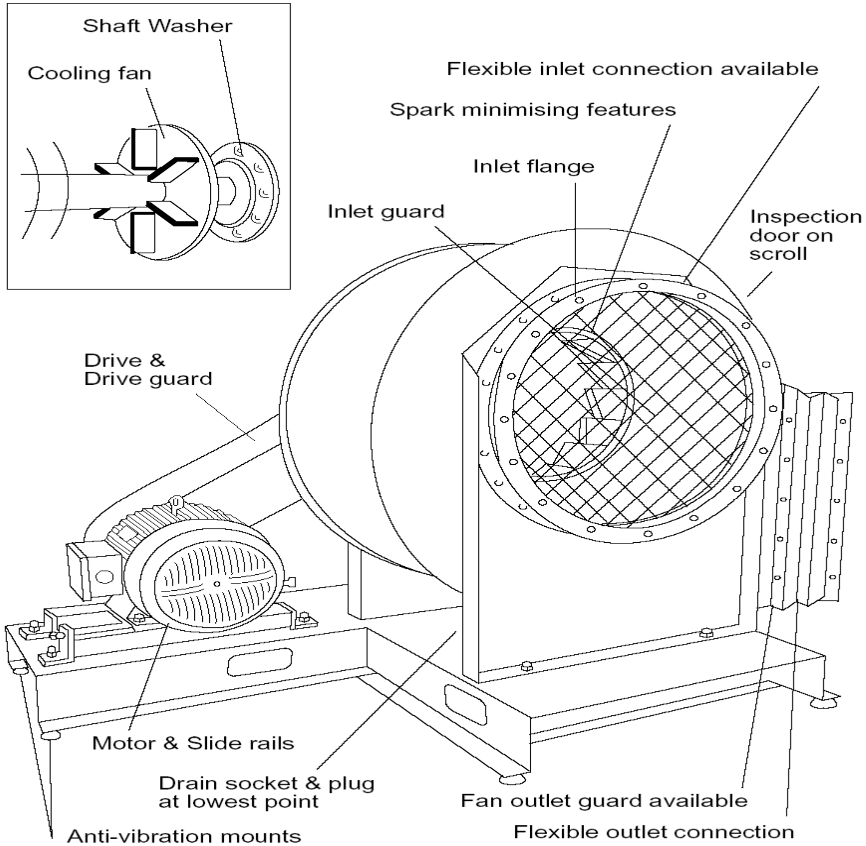
Fans Contra Rotating
2.7 times the single fan pressure
Efficiency up to 85%
Low swirl discharge
Increased Noise levels



Basic Fan Types – Centrifugal Parts



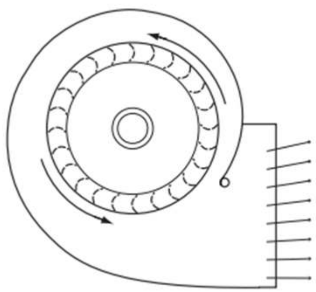
Basic Fan Types – Centrifugal Fans



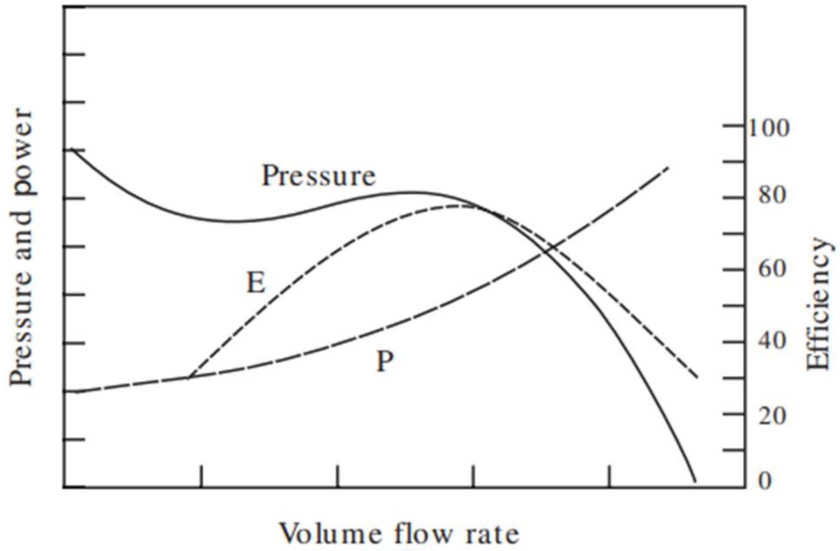
Inlet mating flange &
Outlet mating flange,
also available.

Basic Fan Types – Forward Curve Centrifugal

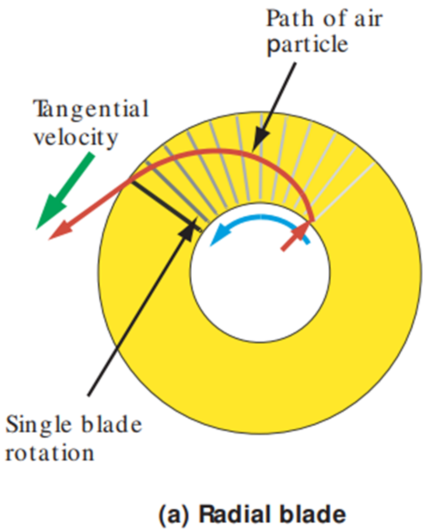
Forward curved



- *Very common usage*
- *Small air handling units*
- *Air Curtains etc.*



Fan Types – Centrifugal - Paddle Blades with Backplate



- Easy Clean Design
- Robust Industrial Design
- Material choice allows harsh handling materials

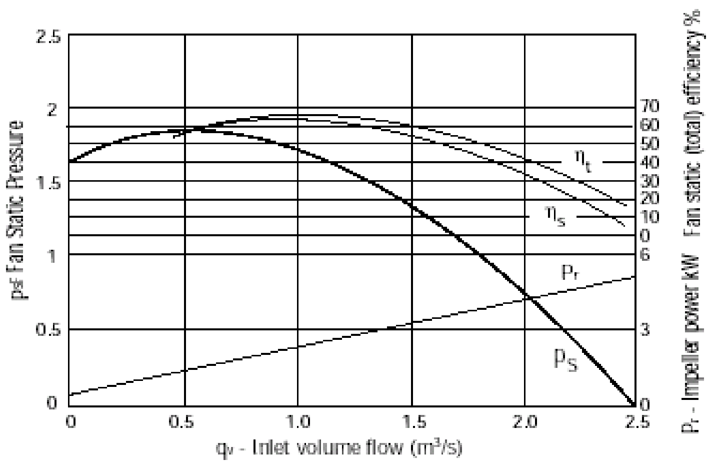
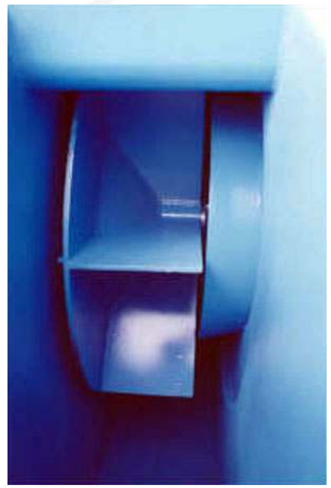
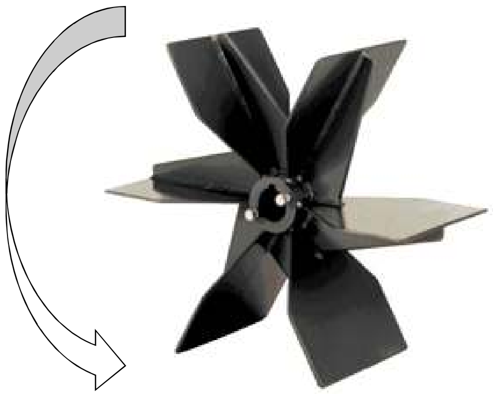


Fig 4 630mm Series 284 fan with Type 4 shrouded radial 8-blade impeller at 1500 rev/min handling air 1.2kg/m³ density.



Fan Types – Centrifugal - Heavy Paddle Blades



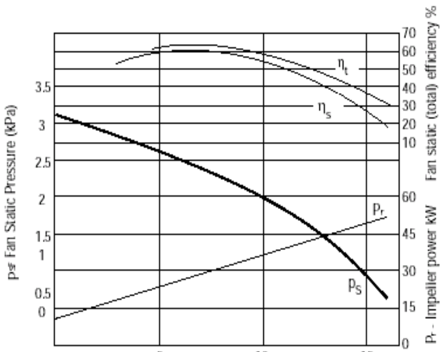
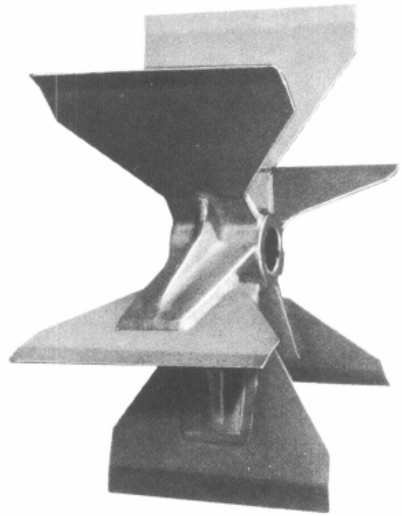
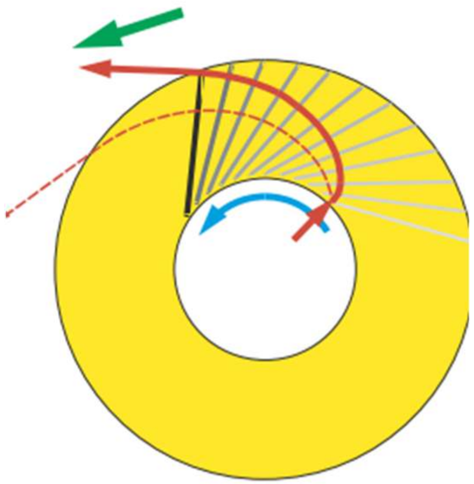


Fig 5 900mm Series 288 fan with Type 5 open paddle 6-blade impeller at 1450 kg/min³



- *Heavy Dirty Applications*
- *Material Handling*
- *Replaceable blades*
- *Self Cleaning Blades*

Fan Types – Centrifugal – Backward Inclined Blades



(b) Backward inclined blade

- *Easy to manufacture*
- *Can handle some level of contamination*
- *Reasonable efficiency*
- *Very common usage for Industrial and HVAC*

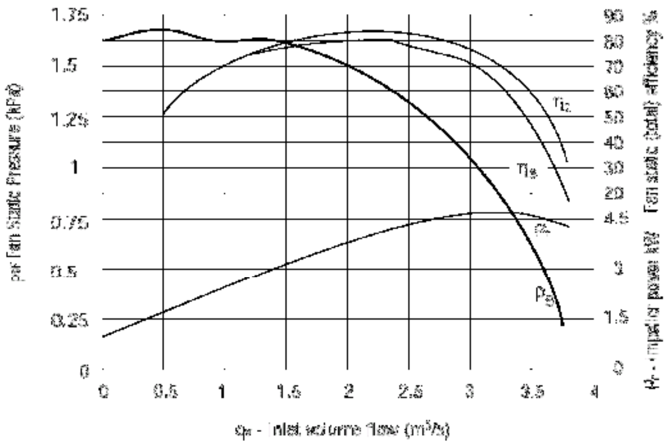
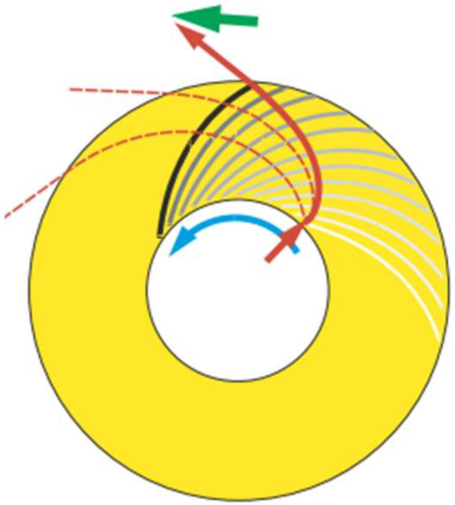


Fig 1   630mm Series 28 fan type with backward inclined 12-blade impeller at 1500 rev/min handling air 1.2kg/m³ density

Fan Types – Centrifugal – Backward Curved Blades



(c) Backward curved blade

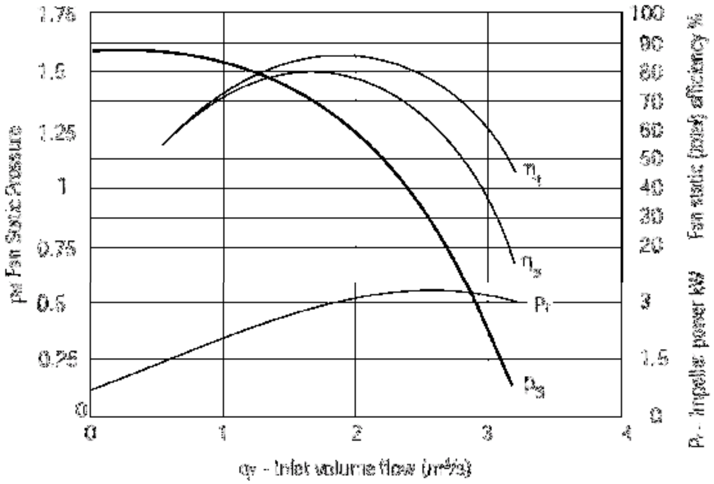
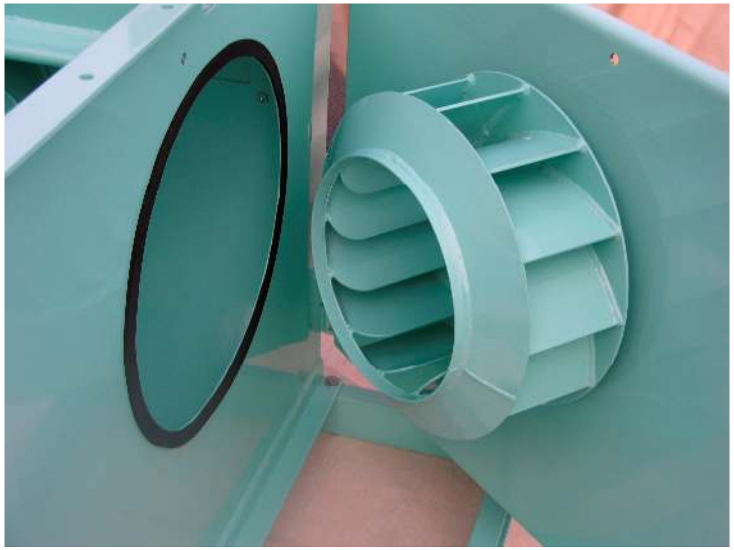


Fig 2 630mm 2BS fan with type 2 backward curved 10-blade impeller at 1500 rev/min handling air 1.2 kg/m³ density

- Most Common Fan in Current use for Industrial and heavy HVAC

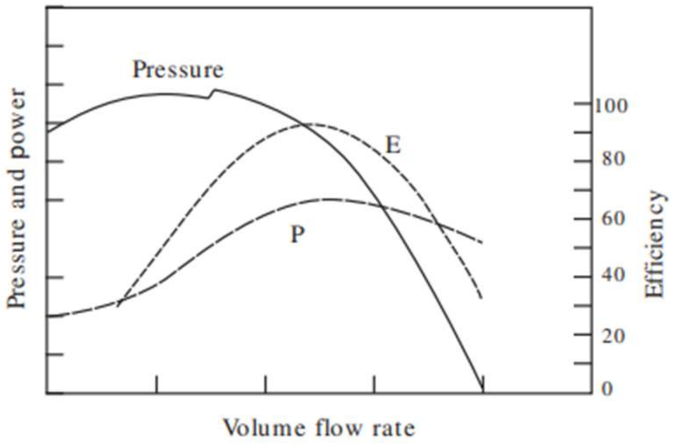


Backward Curved Impeller Centrifugal Fan Use

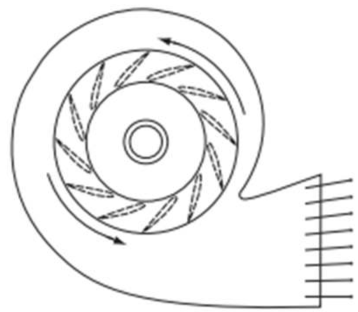
- From Air Handling Units to Power Station Inlet Draft Fans.
- Plug fans are a very important item in AHU design

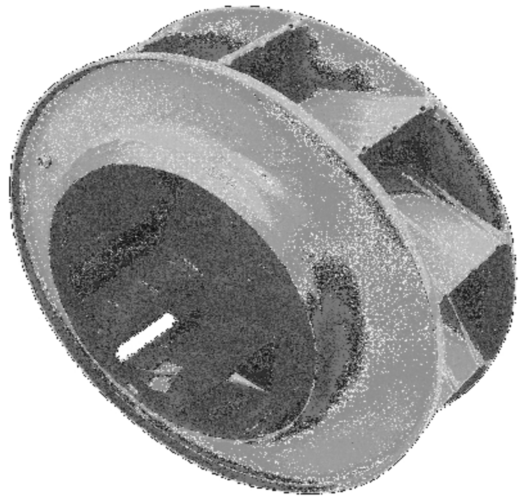
Basic Fan Types – Aerofoil Section Fans

- *Complex to manufacture*
- *Only used in very clean air applications.*
- *Highest efficiency fan available from standard ranges*



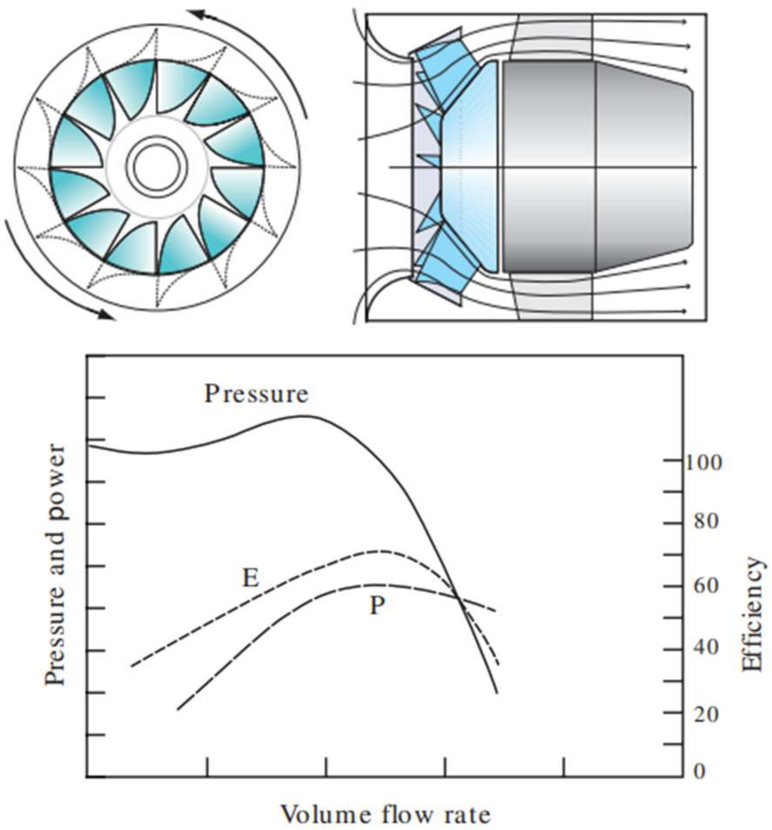
Centrifugal aerofoil

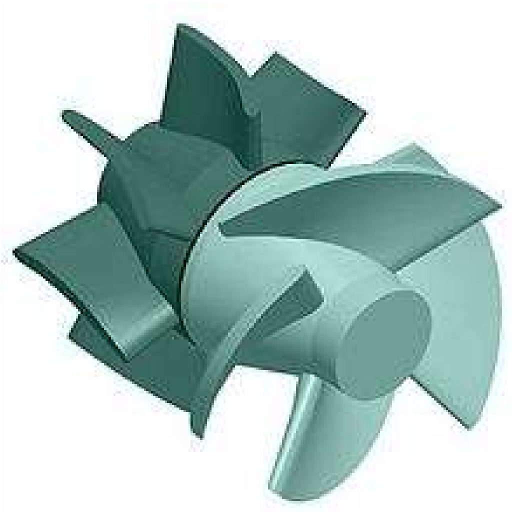




Basic Fan Types – Mixed Flow Fans

Mixed flow axial discharge





- Specialist Duties
- Off Shore
- Marine
- Transport

Basic Fan Types – Construction Details

- Direct Drive
  - Low Losses
  - Remove from system to replace
  - Not preference for Industrial users

- Belt Drive
  - High losses 5-25% of Drive Power
  - Low repair time for Motor
  - Additional set of bearings so reduced reliability
  - Industrial preference for processes
  - Complicates ErP Compliance

- Coupling Drive
  - Low Losses
  - Complex to set up and maintain
  - Motors replaced with fan installed

Centrifugal Fan Characteristics

- Centrifugal
  - Large Footprint
  - Motor change with fan in place
  - Efficiencies up to 88%
  - Direct & Belt & Coupling
  - Low Frequency Noise
  - Fixed geometry
  - Med Volume –High Pressure
  - High Temperatures Possible

Axial Fan Characteristics

- Axial
  - Small Footprint
  - Easy Installation & Removal
  - No Change of duct direction
  - Efficiencies up to 85%
  - Direct & Belt & Coupling
  - High Frequency Noise, easy attenuation
  - Adjustable geometry
  - High Volume –Medium Pressure
  - Limited operating temperature Axial (aluminium)

Basic Fan Types – Technical Applications

FläktWoods

- ATEX Fans for Hazardous Areas
- HT Fans for emergency smoke ventilation

EN 12101_3_2015
HT Fan & VSD

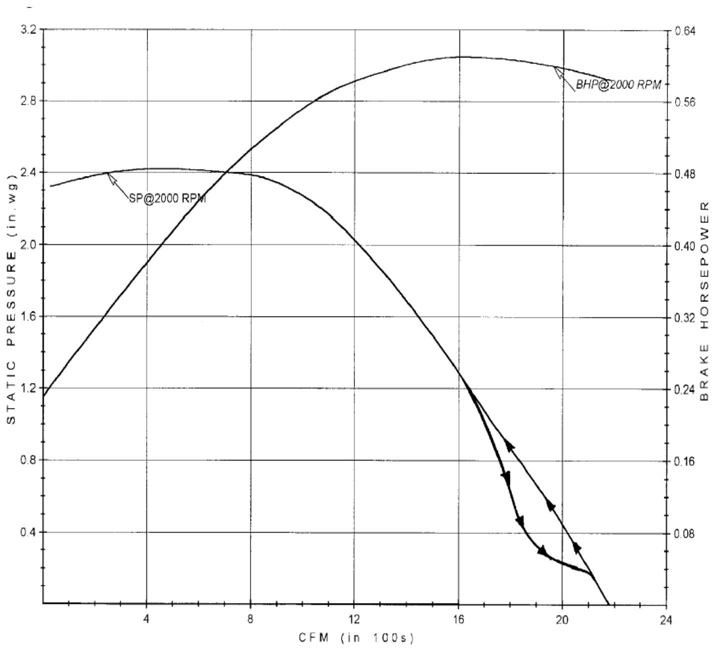
ATEX

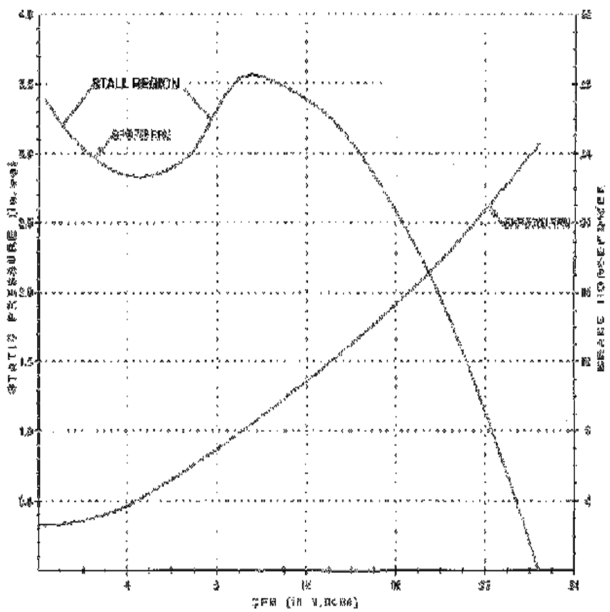
BS EN 14986: 2017

Fan Stall

The most dangerous operating condition on any fan is when the fan runs in the stall

This can be seen on the graphs below for both Axial & Centrifugal Fans





Fan Stall – What Does it Mean

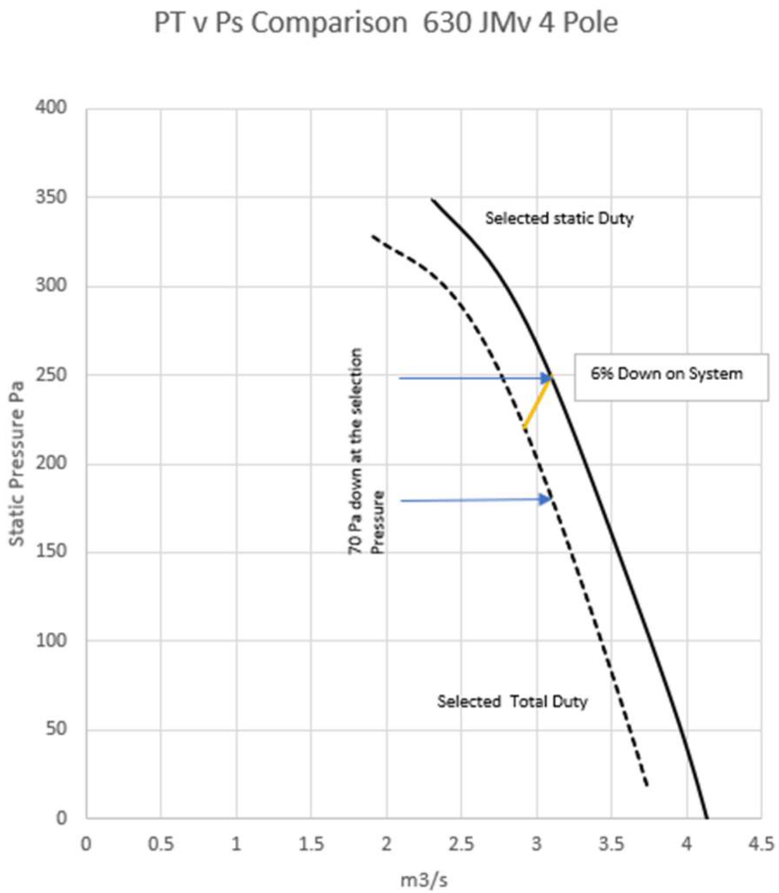
- The most common problem of fan installation is operation in the stall, this gives –
- Increased Noise, Low frequency- Ears!

- Unstable pulsating Air – Hands!

- Unstable power consumption – Eyes!

- Potential Mechanical Failure – Run!!!!
- **<u>Avoid selections close to the curve peak , or ask !!!!</u>**

The Static v Total Pressure Selection



Duties are treated as static pressure if it is not made clear.

Duties that are calculated in Total but quoted static will over perform

Duties quoted total that are really static will under perform as shown across

There will not always be the additional motor power to increase angles

Total Pressure Calculation will be atmosphere to atmosphere and should include the calculated fan diameter.

Always ask if your not clear.

Thank you.