# 23ME505 : Steam Power & Jet Propulsion

## Topic: Steam Power Plant

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# Steam Power Plant
# Rankine Cycle

# Ideally

1) For steam boiler

- constant pressure heating process of water to form steam

2) For the turbine

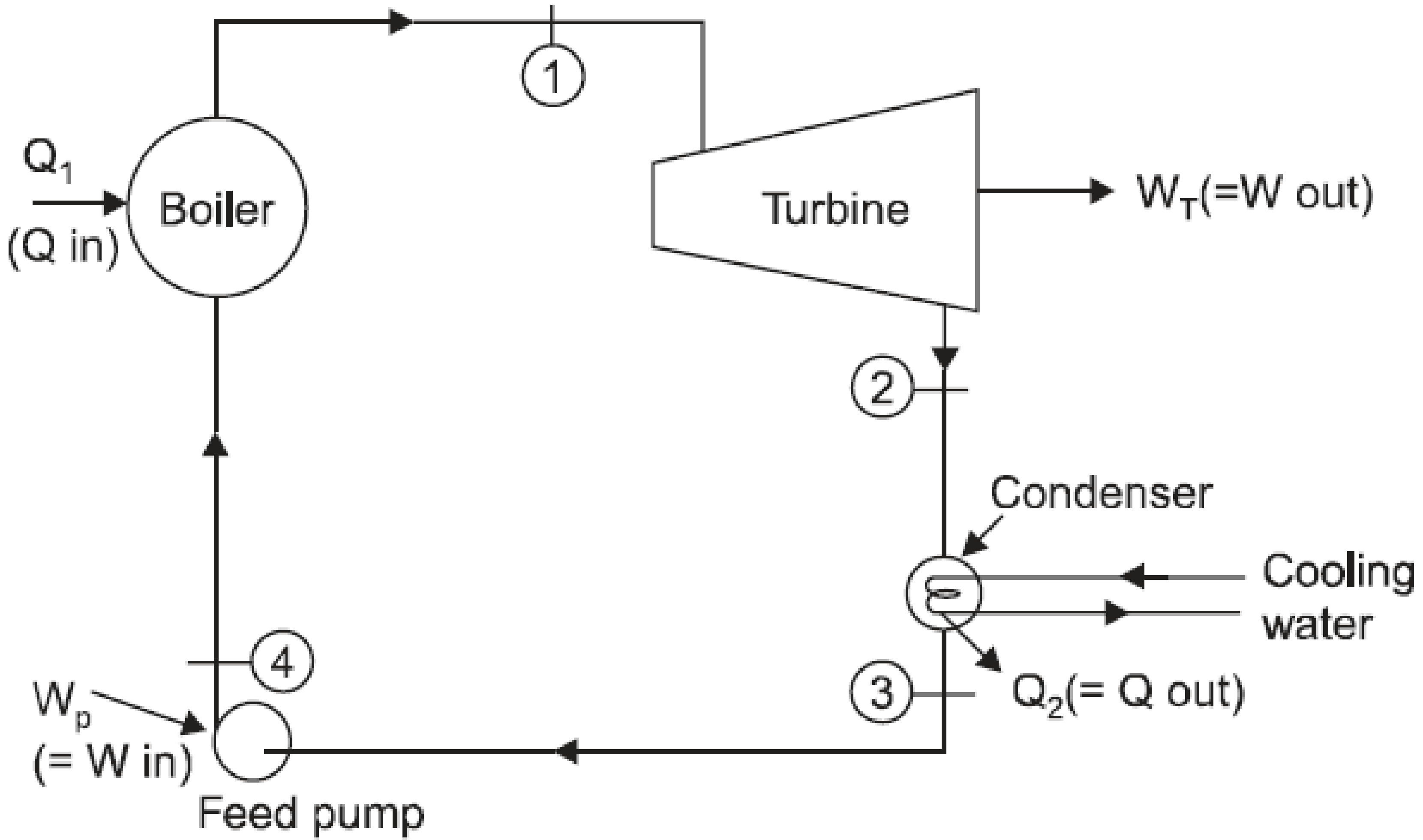
- Reversible adiabatic expansion of the steam (or isentropic)

3) For the condenser

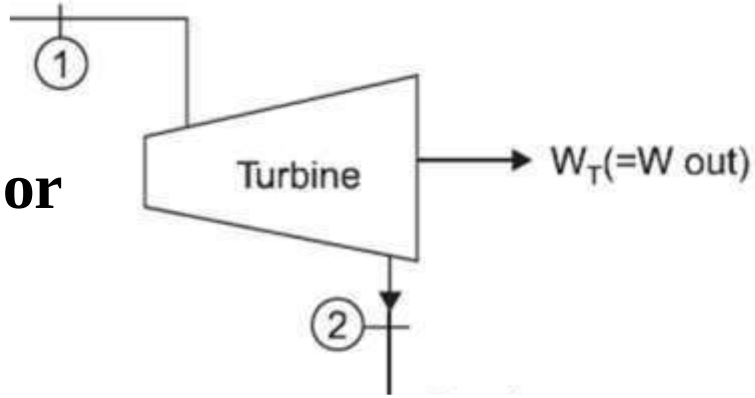
- Reversible constant pressure heat rejection as the steam condenses till it becomes saturated liquid

4) For the Pump

- Reversible adiabatic compression of this liquid ending at the initial pressure


1
$Q_1$
(Q in)
Boiler
Turbine
$W_T$(=W out)
2
Condenser
Cooling
water
$Q_2$(= Q out)
3
4
$W_p$
(= W in)
Feed pump

# Process 1–2




**At 1: dry saturated or superheated steam**
**At 2: wet steam**

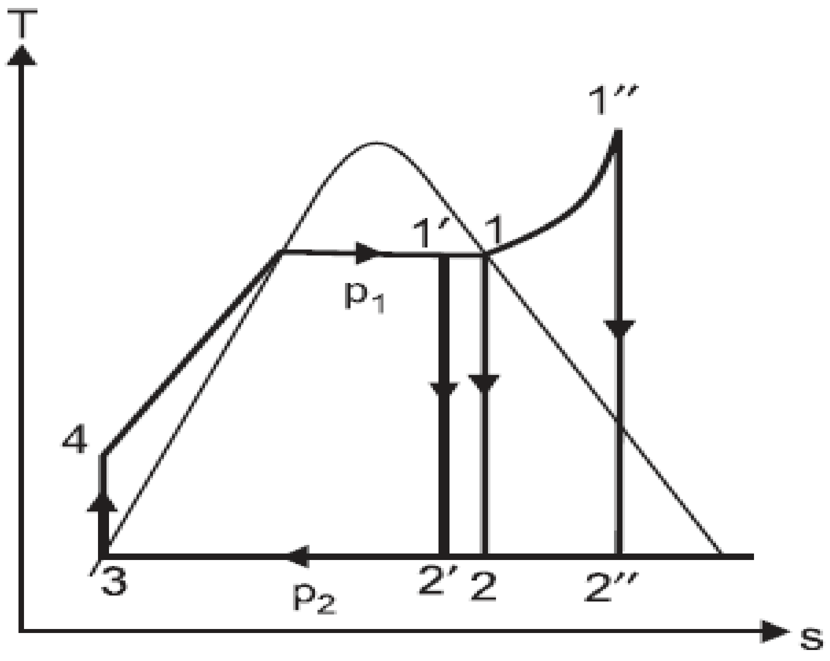
$$h_1 = W_T + h_2, \text{ where } W_T = \text{turbine work}$$

$$W_T = h_1 - h_2$$

***Assumption***:

process is adiabatic , reversible and isentropic Turbine does not absorb heat.

***Here 1-2 represents the saturated steam at boiling point entering the turbine and leaving as wet steam on B.P but on Different pressure at 2***
***As ideally process (in case of turbine)***
*is adiabatic so*
*Entropy is same*




*But in actual case due to friction and heat transfer*

$$W_T = h_1 - h_2$$

$h_2$ *increases so that turbine work and efficiency decreases*

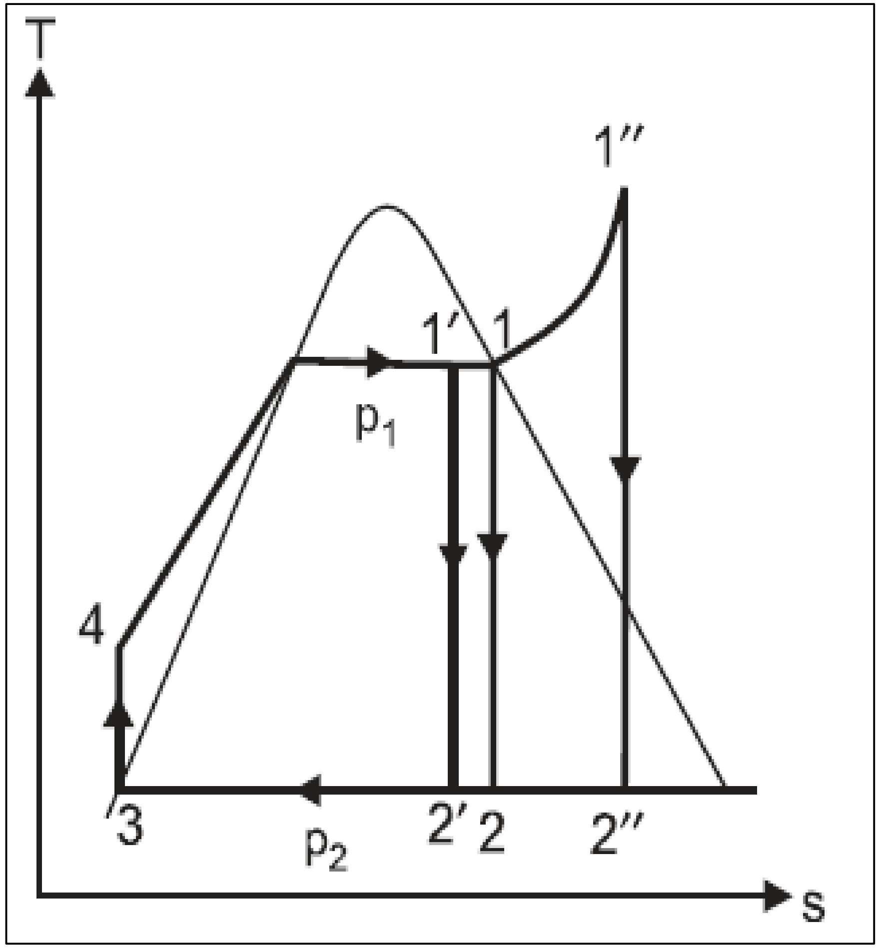
And equation becomes

$W_T = h_1 - h_2$-heat loss

And the graph for process 1-2 shifts towards right (i.e. curvature instead of straight line)
As in real case
Entropy change is positive for irreversible feasible process

- If we consider losses only due to friction the point 2 will shift on the right side as H2 is more than the ideal value.

- if there is heat loss to the surrounding , h2 will decrease, accompanied by a decrease in entropy. If heat loss Is large the end state may shift towards left.

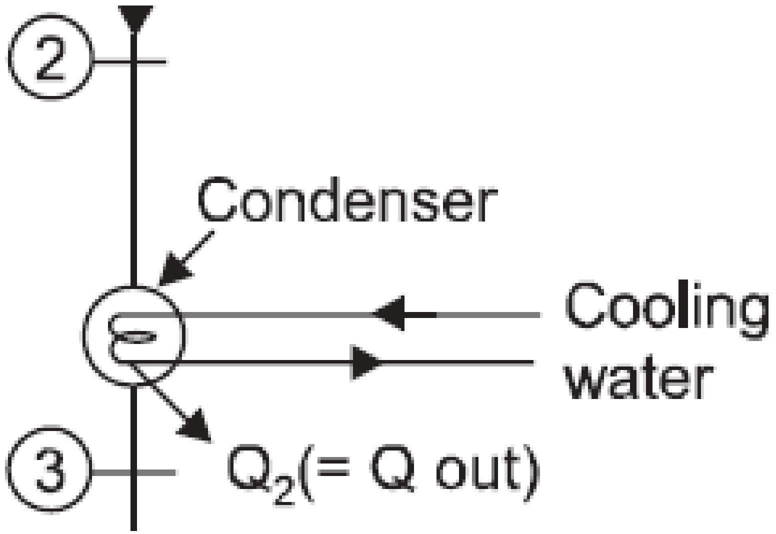


- It may so happen that the entropy increase due to frictional effects just balances entropy decrease due to heat loss so that initial and final entropies of steam in the expansion process are equal.

**Since heat loss is generally negligible so entropy change is accompanied by zero or positive change generally**

# Process 2-3

# Condenser




*Here we say the condenser is rejecting heat at constant pressure. According to the graph the condenser is only absorbing the latent heat and at constant pressure converting wet steam into liquid state without change in temperature (at saturation temperature)*

# losses

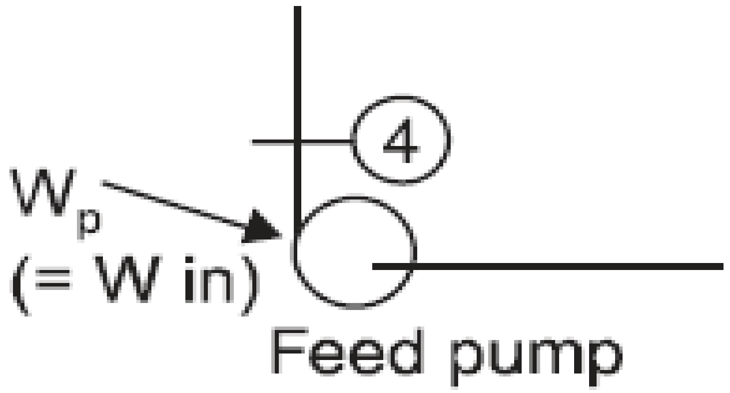
- The losses in the condenser are usually small.
- These include the loss of pressure and the cooling of the condensate below saturation temperature.

For condenser, we get

$$h_2 = Q_2 + h_{f_3}$$

$$Q_2 = h_2 - h_{f_3}$$

# *Process 3-4*




*First we should know* ***how feed water pump works*** *and* ***why it is necessary.***

- *We know that pressure inside the boiler is very high and so we need feed water pump*

***This process is to increase the pressure and ideally pressure at 4 is equal to pressure inside the boiler***

# PUMP LOSSES

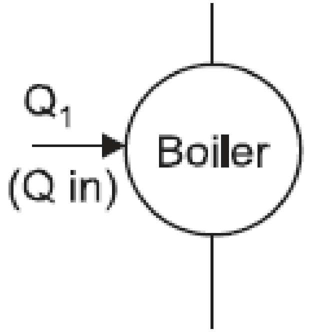
- The losses in the pump are similar to those of the turbine and are primarily due to irreversibility associated with fluid friction.
- Heat transfer is usually negligible

**For the feed pump**, we get

$$h_{f_3} + W_p = h_{f_4}, \qquad \text{where, } W_p = \text{Pump work}$$

$$W_p = h_{f_4} - h_{f_3}$$

# Process 4-1




## Boiler

*<u>This process in thermodynamics is ideally considered as constant pressure heat addition</u>*

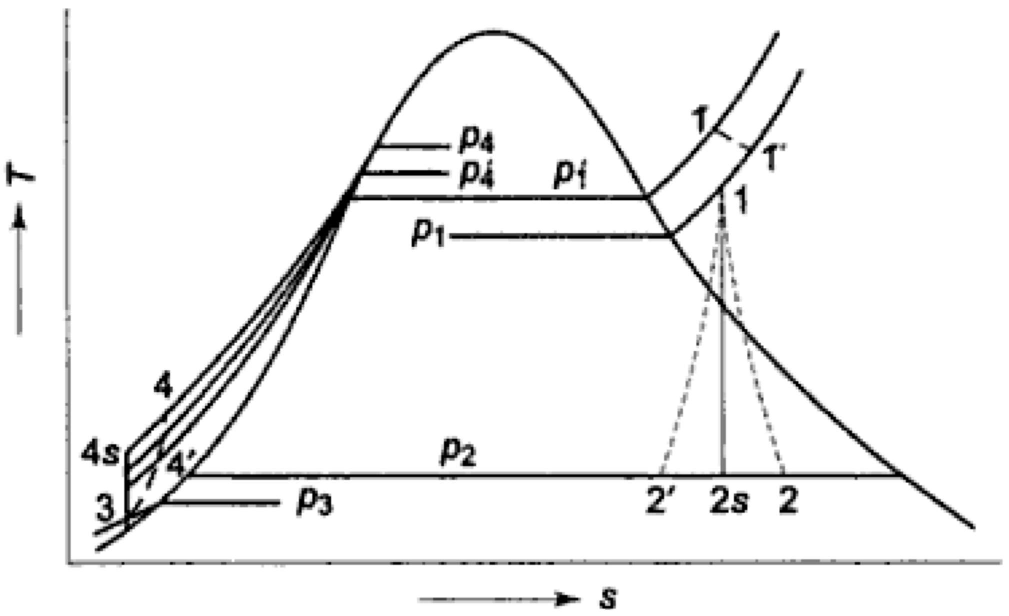
Heat addition can be studied in three parts

1) Heating till boiling point
2) Heating till saturation
3) Superheating

# *Piping losses*

Pressure drop due to friction and heat loss to the surrounding are the most important piping losses.

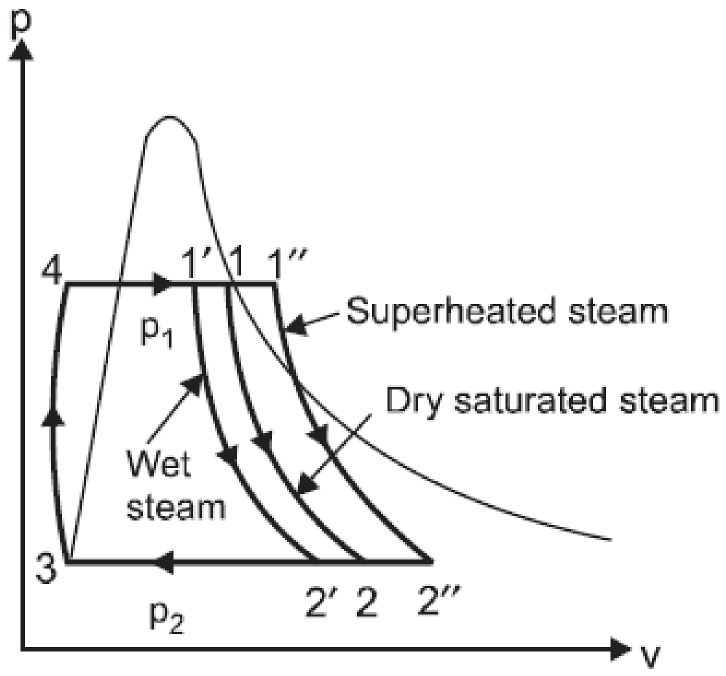
1’ and 1 represents the state of the steam leaving and entering the turbine respectively
The dotted line represents the frictional losses and Other constant pressure heat loss to the surrounding

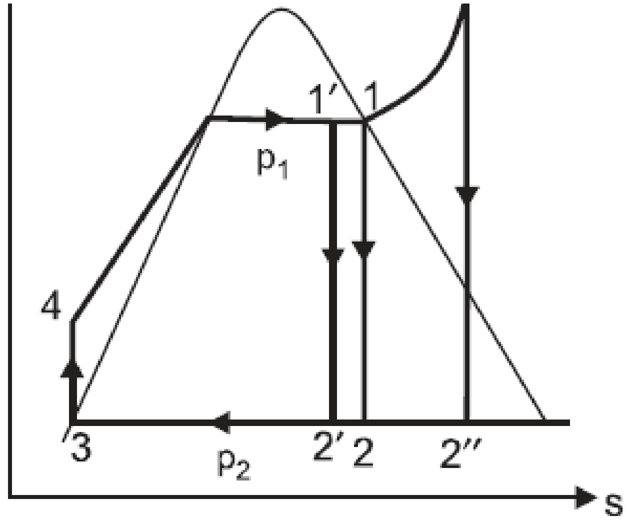


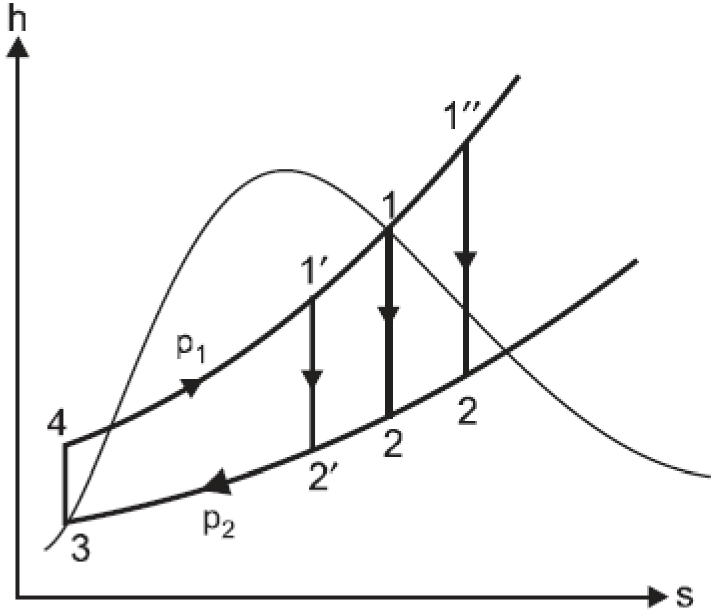
- Pressure drop in the boiler and also in the pipeline (as in fluid mechanics)from the pump from the boiler.

- Due to pressure drop in the boiler, water entering the boiler must be pumped to a much higher pressure than the desired steam leaving the boiler and this requires additional pump work.

**Process 1-2 :** Reversible adiabatic expansion in the turbine (or steam engine).
**Process 2-3 :** Constant-pressure transfer of heat in the condenser.
**Process 3-4 :** Reversible adiabatic pumping process in the feed pump.
**Process 4-1 :** Constant-pressure transfer of heat in the boiler.



| S. No. | Location | Pressure | Quality/temp. | Velocity |
|---|---|---|---|---|
| 1. | Inlet to turbine | 6 MPa (= 60 bar) | 380°C | — |
| 2. | Exit from turbine inlet to condenser | 10 kPa (= 0.1 bar) | 0.9 | 200 m/s |
| 3. | Exit from condenser and inlet to pump | 9 kPa (= 0.09 bar) | Saturated liquid | — |
| 4. | Exit from pump and inlet to boiler | 7 MPa (= 70 bar) | — | — |
| 5. | Exit from boiler | 6.5 MPa (= 65 bar) | 400°C | — |
| | Rate of steam flow = 10000 kg/h. | | | |

*Calculate :*

(i) *Power output of the turbine.*

(ii) *Heat transfer per hour in the boiler and condenser separately.*

(iii) *Mass of cooling water circulated per hour in the condenser. Choose the inlet temperature of cooling water 20°C and 30°C at exit from the condenser.*

Inlet superheated steam Exit wet steam

(*i*) **Power output of the turbine, P :**

***At 60 bar, 380°C*** : From steam tables,

$$h_1 = 3043.0 \text{ (at 350°C)} + \frac{3177.2 - 3043.0}{(400 - 350)} \times 30 \text{ ... By interpolation}$$

$$= 3123.5 \text{ kJ/kg}$$

***At 0.1 bar :***

$$h_{f_2} = 191.8 \text{ kJ/kg}, \; h_{fg_2} = 2392.8 \text{ kJ/kg (from steam tables)}$$

$$x_2 = 0.9 \text{ (given)}$$

$$\therefore \quad h_2 = h_{f_2} + x_2 \, h_{fg_2} = 191.8 + 0.9 \times 2392.8 = 2345.3 \text{ kJ/kg}$$

Power output of the turbine = $m_s \, (h_1 - h_2)$ kW,

[where $m_s$ = Rate of steam flow in kg/s and $h_1$, $h_2$ = Enthalpy of steam in kJ/kg]

$$= \frac{10000}{3600} (3123.5 - 2345.3) = 2162 \text{ kW}$$

Hence power output of the turbine = **2162 kW.** **(Ans.)**

(*ii*) **Heat transfer per hour in the boiler and condenser :**

*At 70 bar :* $h_{f_4} = 1267.4$ kJ/kg

*At 65 bar, 400°C :* $h_a = \dfrac{3177.2\,(60 \text{ bar}) + 3158.1\,(70 \text{ bar})}{2} = 3167.6$ kJ/kg

......(By interpolation)

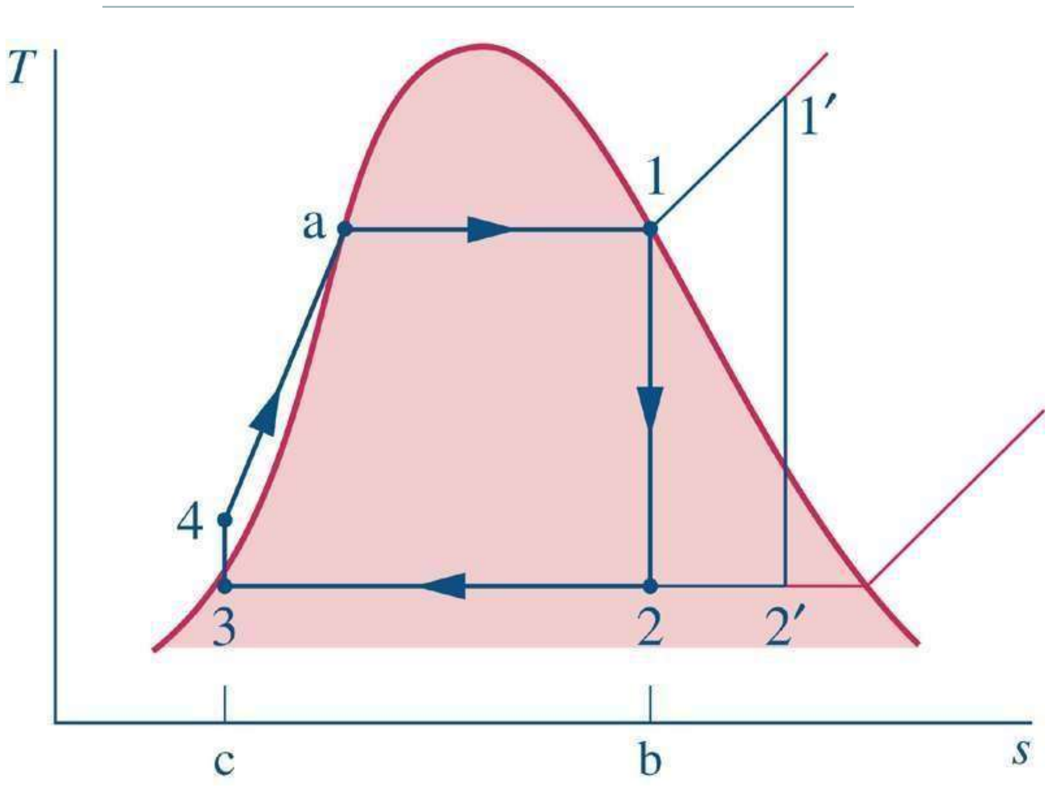
∴ *Heat transfer per hour in the boiler,*

$$Q_1 = 10000\,(h_a - h_{f_4}) \text{ kJ/h}$$

$$= 10000\,(3167.6 - 1267.4) = \mathbf{1.9 \times 10^7 \text{ kJ/h.}} \quad \textbf{(Ans.)}$$

***At 0.09 bar :*** $h_{f_3} = 183.3$ kJ/kg

# Ideal Rankine cycle with and without superheat




The maximum temperature of superheat is limited by metallurgical considerations (current state of the art allows about 700 $^{O}$C).

# Superheating: summary

- *Superheating improves both efficiency and the turbine exit quality ($T\uparrow \Rightarrow \eta\uparrow, x\uparrow$).*
- *However, the maximum temperature of superheat is limited by metallurgical considerations (current state of the art allows about 700 $^{o}C$).*

## Limitations of Carnot Cycle

Though Carnot cycle is simple (thermodynamically) and has the *highest thermal efficiency* for given values of $T_1$ and $T_2$, yet it is *extremely difficult to operate in practice* because of the following *reasons* :

1. It is difficult to compress a wet vapour isentropically to the saturated state as required by the process 3-4.

2. It is difficult to control the quality of the condensate coming out of the condenser so that the state '3' is exactly obtained.

3. The efficiency of the Carnot cycle is greatly affected by the temperature $T_1$ at which heat is transferred to the working fluid. Since the critical temperature for steam is only 374°C, therefore, if the cycle is to be operated in the *wet region*, the maximum possible temperature is severely limited.

4. The cycle is still more difficult to operate in practice with superheated steam due to the necessity of supplying the superheat at constant temperature instead of constant pressure (as it is customary).

- *In a practical cycle, limits of pressure and volume are far more easily realised than limits of temperature so that at present no practical engine operates on the Carnot cycle, although all modern cycles aspire to achieve it.*

# (Steam Generators)

# ***Factors to be considered for selection of good boiler***

1) The working pressure and quality of steam required
2) Steam generation rate
3) Floor area available
4) Accessibility for repair and inspection
5) Comparative initial cost
6) Erection facilities
7) The portable load factor
8) The fuel and water available
9) Operating and maintenance costs

# Requirements of an efficient boiler

1. The boiler should generate maximum amount of steam at a required pressure and temperature and quality with minimum fuel consumption and expenses
2. Steam production rate should be as per requirements
3. It should be absolutely reliable
4. It should be light in weight
5. It should not occupy large space.
6. It should be capable of quick starting
7. It should conform to safety regulations.
8. The boiler components should be transportable without difficulty
9. The installation of the boiler should be simple
10. It should have low initial cost, installation cost and maintenance cost.
11. It should be able to cope with fluctuating demands of steam supply.
12. All parts and components should be easily accessible for inspection, repair and replacement.
13. The tubes of the boiler should not accumulate soot or water deposits and should be sufficiently strong to allow for wear and corrosion
14. The water and gas circuits should be such as to allow minimum fluid velocity (for low frictional losses)

# Classification of boilers

¬*Relative position of hot gases and water*

- Fire tube boilers (Cochran, Lancashire, Cornish, Locomotive)
- Water tube boilers (Babcock and Wilcox boiler, Stirling boiler)

¬*Method of firing*

- Internally fired boilers ( Lancashire, Locomotive)
- Externally fired boilers (Babcock and Wilcox boiler)

¬*Pressure of steam*

- High pressure boilers(>80 bars-Cochran,Lancashire,Cornish, Locomotive)
- Low pressure boilers (<=80 bars-Babcock and Wilcox boiler, Lamont boiler)

¬*Method of circulation of water*

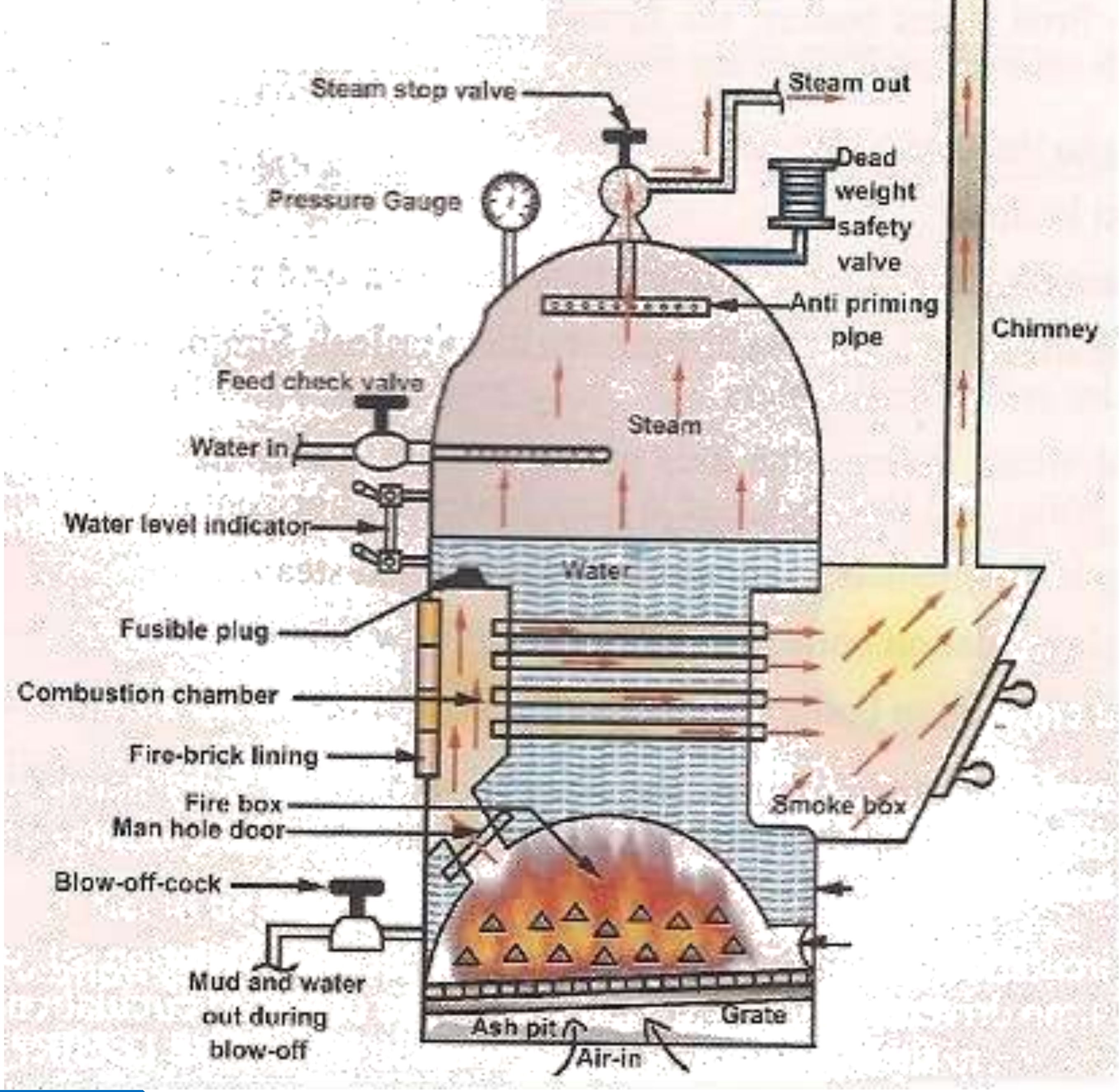
- Natural circulation boilers (Lancashire, Locomotive, Babcock & Wilcox boilers)
- Forced circulation boilers (Two large fire tubes Lancashire boiler, Single large fire tube Cornish boiler, Cochran boiler, Many small tubes Locomotive boiler, Babcock Wilcox water tube boiler)

¬*Nature of service to be performed*

- Land boilers
- Mobile boilers (or) Portable boilers

- *Once through boilers*
- *Position and number of drums*
  - Single drum boilers
  - Multi-drum boilers(Longitudinal or crosswise)
- *Design of gas passages*
  - Single pass boilers
  - Return pass boilers
  - Multi-pass boilers
- *Nature of draught*
  - Natural draught boilers
  - Artificial draught boilers
- *Heat source*
  - Combustion of solid, liquid or gaseous fuels
  - Electrical and nuclear energy
  - Hot waste gases of other chemical reactions
- *Fluid used*
  - Steam boilers
  - Mercury boilers
  - Special boilers for heating special chemicals
- *Material of construction of boiler shell*
  - Cast iron boilers
  - Steel boilers

# Cochran Boiler



# *Advantages & Disadvantages of COCHRAN* **BOILER**

**Advantages**

*1)Cochran* Boiler occupies less floor space.

2)Construction cost of *Cochran* Boiler is Low.

*3)Cochran* boiler is semi-portable and hence easy to install and transport.

4)Because of self contained furnace no brick work setting is necessary.

**Disadvantages**

1)The capacity of the *Cochran* boiler is less because of the vertical design.

*2)Cochran* Boiler requires high head room space.

3)Because of the vertical design, it often presents difficulty in cleaning and inspection.

# BABCOCK & WILCOX BOILER

***Features of Babcock & Wilcox boiler:***

1)Horizontal, Straight & Stationary

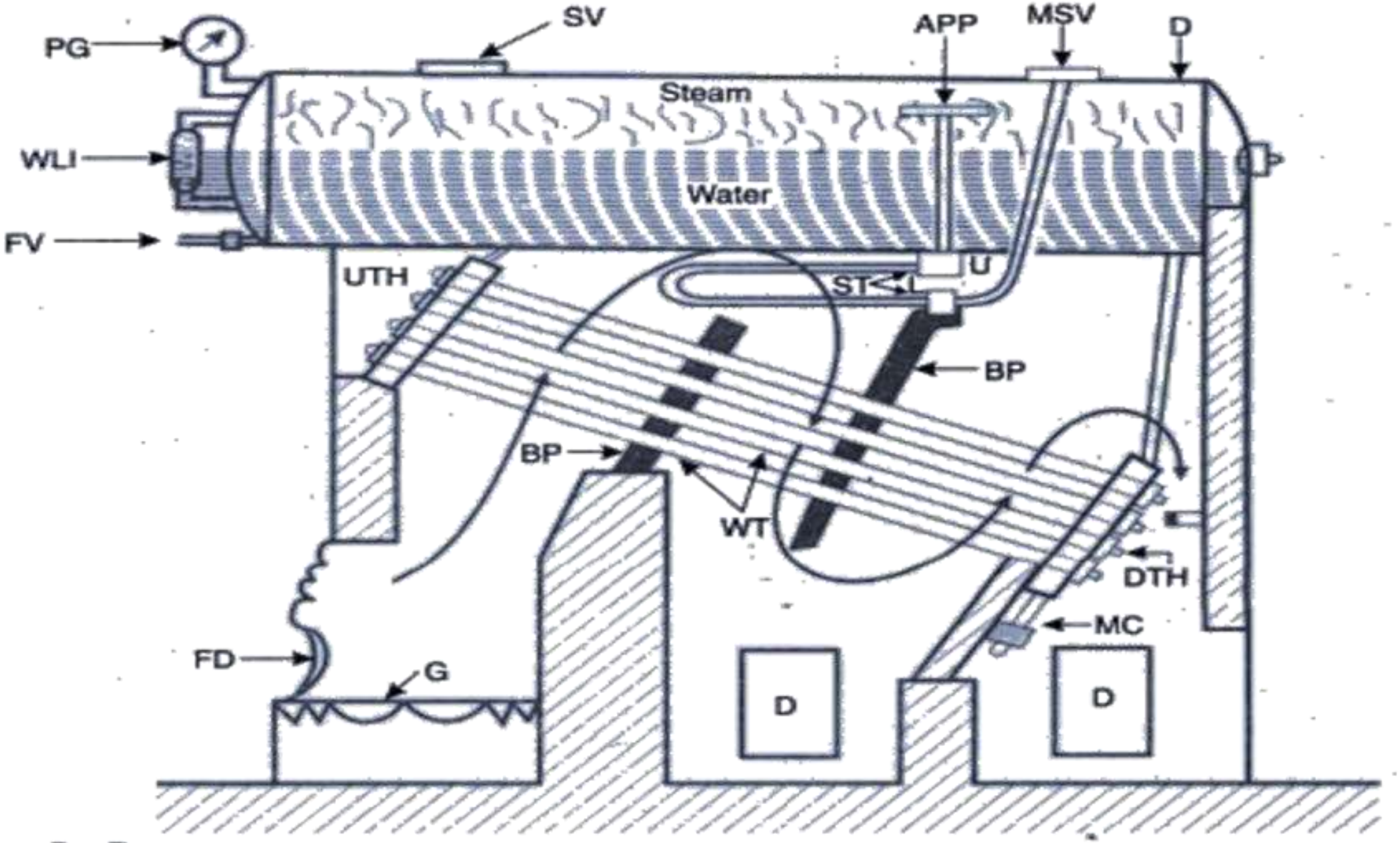
2)Externally fired

3)Natural circulation

4)Water tube boiler

5)Minimum steam pressure of 10 bar

6)Minimum evaporative capacity of 7000 kg of steam per hour.




*D* = Drum
*DTH* = Down take header
*WT* = Water tubes
*BP* = Baffle plates
*D* = Doors
*G* = Grate
*FD* = Fire door
*MC* = Mud collector
*WLI* = Water level indicator

*PG* = Pressure gauge
*ST* = Superheater tubes
*SV* = Safety valve
*MSV* = Main stop valve
*APP* = Antipriming pipe
*L* = Lower junction box
*U* = Upper junction box
*FV* = Feed valve

**Babcock and Wilcox Boiler**

# BOILER MOUNTINGS

1) **Pressure gauge**
2) *Fusible plug*
3) *Steam stop valve*
4) *Feed check valve*
5) *Blow off cock*
6) *Man and mud(sight)holes*
7) *Two safety valves*
8) *Two water level Indicators*

# Thank you

D

# UNIT-II

# STEAM NOZZLES

# INTRODUCTION

## What is a steam nozzle????

A nozzle is a device designed to control the direction or characteristics of a fluid flow (especially to increase velocity) as it exits (or enters) an enclosed chamber or pipe.
A nozzle is often a pipe or tube of varying cross sectional area, and it can be used to direct or modify the flow of a fluid (liquid or gas). Nozzles are frequently used to control the rate of flow, speed, direction, mass, shape, and/or the pressure of the stream that emerges from them.Finally the goal of a nozzle is to increase the kinetic energy of the flowing medium at the expense of its pressure and internalenergy.

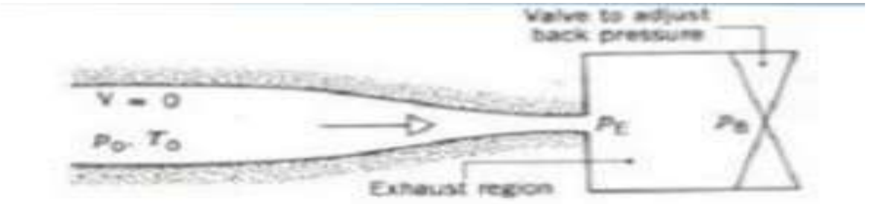
# Types of nozzles

<u>Three types of nozzles:-</u>

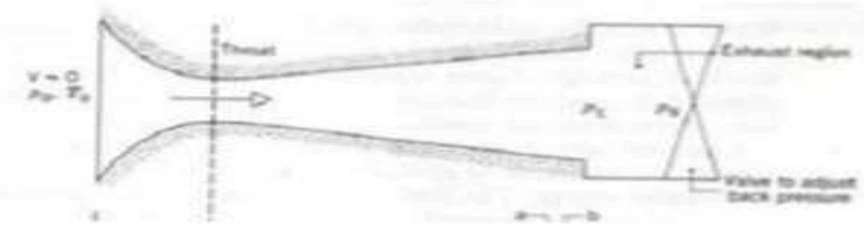
- **Convergent**:- The cross section of nozzle tapers to a smaller section allow for changes which occur due changes in velocity, specific volume dryness fraction – as the flow expands, it has lower expansion ratio and hence lower outlet velocities.

- **Convergent-----Divergent**:- The nozzle which converges to throat and diverges afterwards. It has higher expansion ratio – as addition of divergent portion produces steam of higher velocities.Eg- De-Laval Nozzle

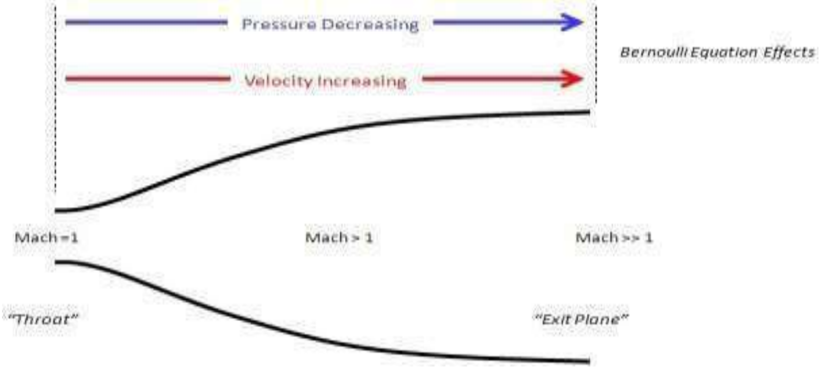
- **Divergent**:- A nozzle whose cross section becomes larger in the direction of flow is known as divergent nozzle.




CONVERGENT NOZZLE



CONVERGENT-DIVERGENT NOZZLE




DIVERGENT NOZZLE

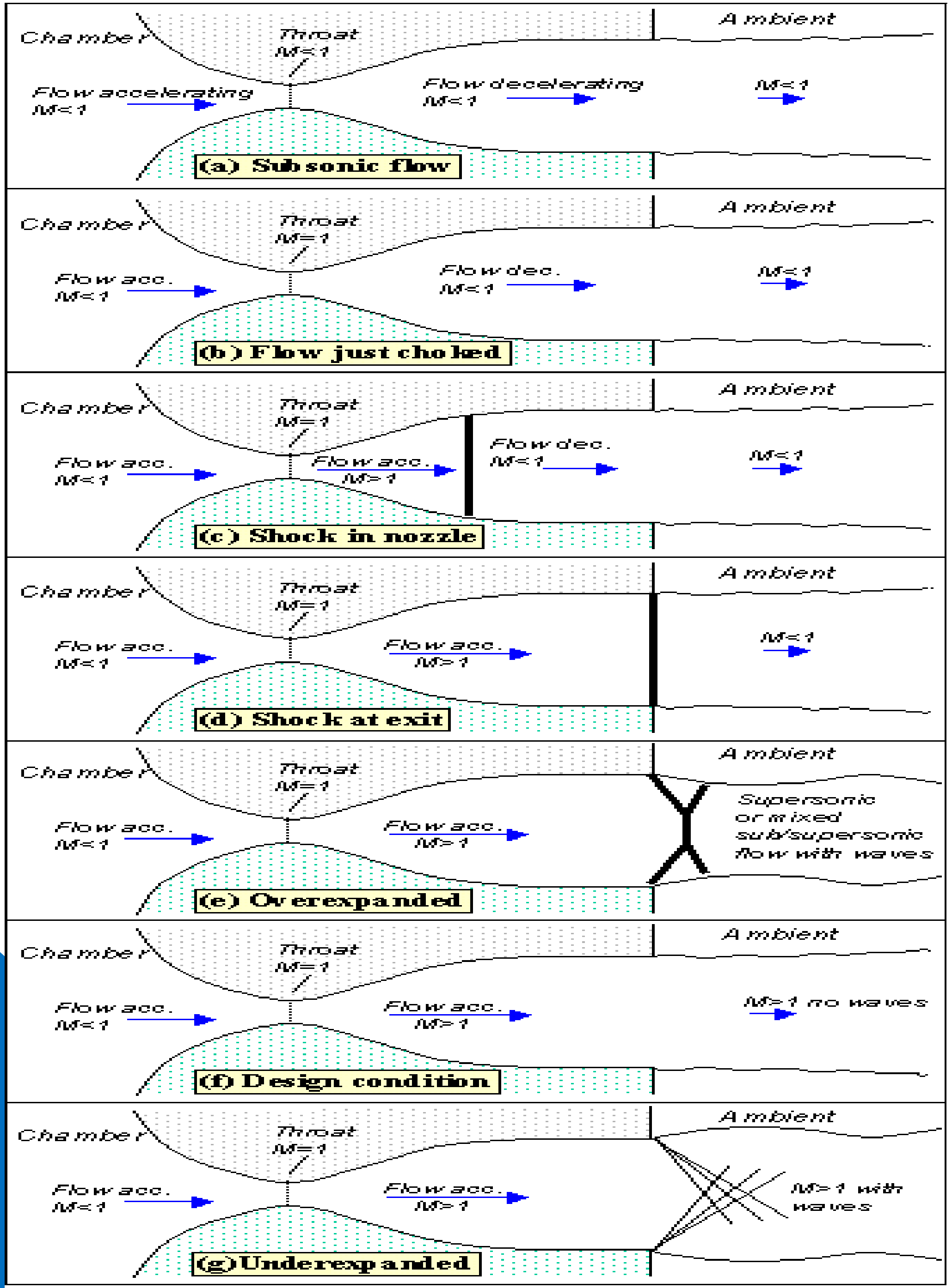



**Figure 3.** Flow patterns

**A further lowering of the back pressure changes and weakens the wave pattern in the jet. Eventually we will have lowered the back pressure enough so that it is now equal to the pressure at the nozzle exit. In this case, the waves in the jet disappear altogether (figure 3f), and the jet will be uniformly supersonic.**
**This situation, since it is often desirable, is referred to as the**
**'design condition'.**

**Finally, if we lower the back pressure even further we will create a new imbalance between the exit and back pressures (exit pressure greater than back pressure), figure 3g. In this situation (called 'underexpanded') what we call expansion waves (that produce gradual turning and acceleration in the jet) form at the nozzle exit, initially turning the flow at the jet edges outward in a plume and setting up a different type of complex wave pattern.**

# CRITICAL PRESSURE RATIO

For a perfect gas undergoing an adiabatic process the index - $n$ - is the ratio of specific heats - $k = c_p / c_v$. There is no unique value for - $n$. Values for some common gases are

- Steam where most of the process occurs in the wet region : $n = 1.135$
- Steam superheated : $n = 1.30$
- Air : $n = 1.4$
- Methane : $n = 1.31$
- Helium : $n = 1.667$

## Example - Air Nozzles and Critical Pressure Ratios

The critical pressure ratio for an air nozzle can be calculated as

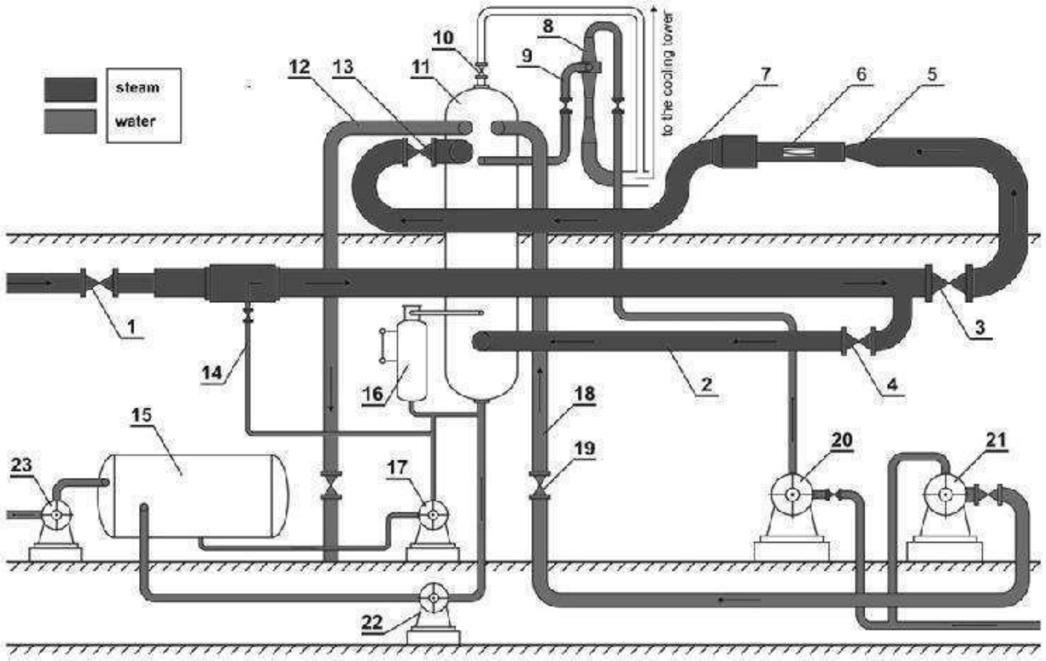
$$p_c / p_1 = ( 2 / (1.4 + 1) )^{1.4 / (1.4 - 1)}$$

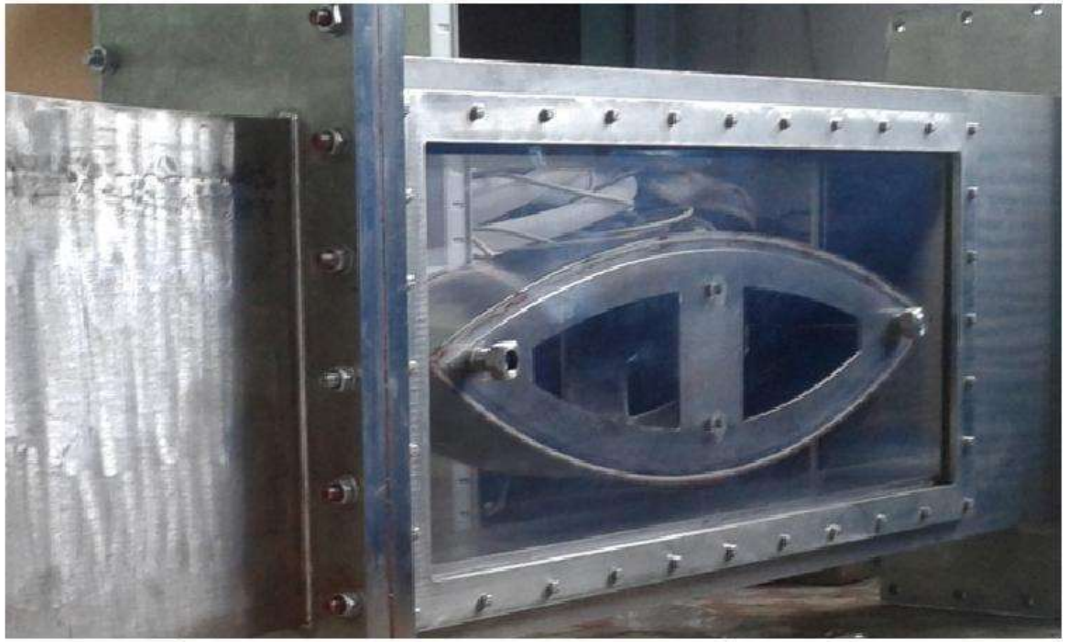
$$= \underline{0.528}$$

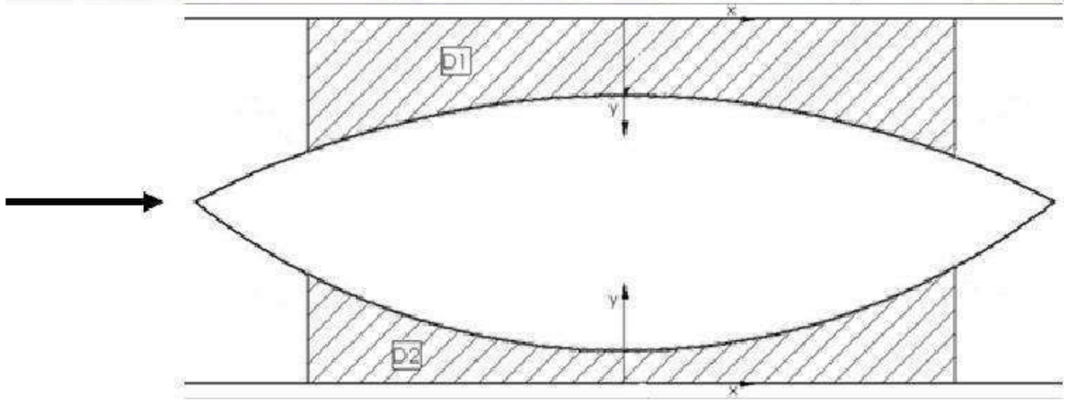
Critical pressures for other values of - $n$:

| $n$ | 1.135 | 1.300 | 1.400 | 1.667 |
|---|---|---|---|---|
| $p_c / p_1$ | 0.577 | 0.546 | 0.528 | 0.487 |

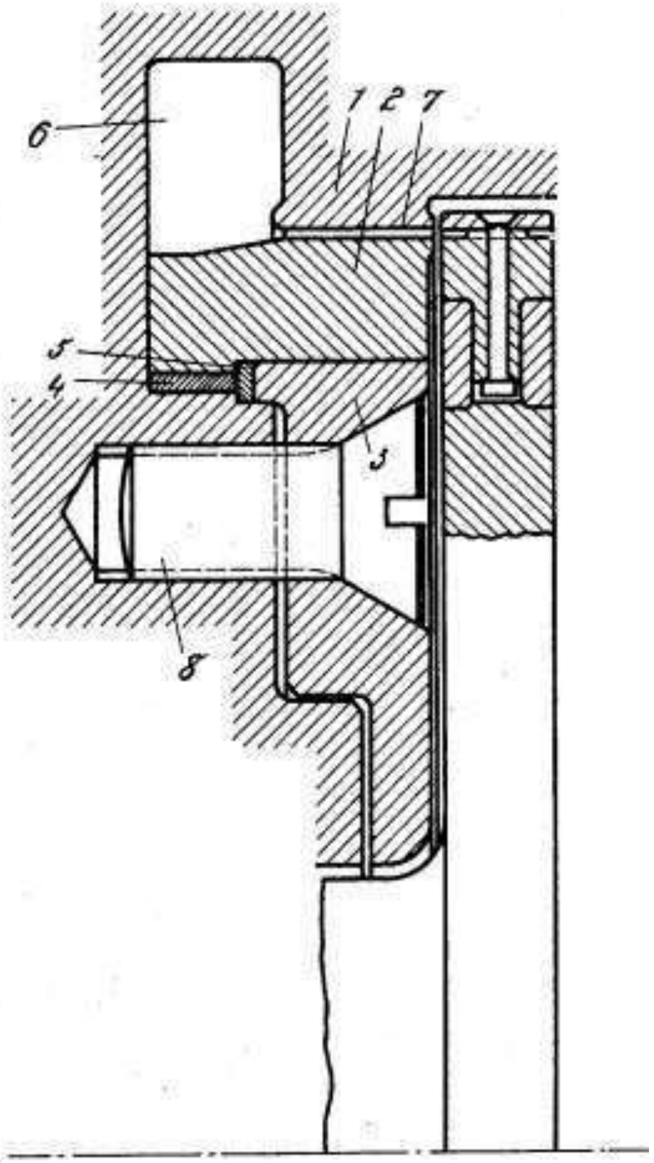
# steam transonic flows in Laval nozzles





# Construction of steam nozzle




**The flow nozzle was constructed based on the following specifications and dimensions;**
**Throat Diameter60mm**
**The diameter of the duct pipe 140mm The length of the up stream pipe 200mm The thickness of the nozzle3.8mm**
**The length of the down stream pipe 200mm The height of the nozzle820mm**
**The length of the nozzle690mm**
**The size of the pressure valves ½ inch**
**Furthermore, the selection of materials for the construction of this flow nozzle was based on the factors which includes; ductility, malleability, fabricability, mechanical strength and stability, availability, corrosion resistance and lastly cost factor.**

**Various modifications and changes may be made.**

# Effects of friction on nozzle efficiency

For stream flowing through a nozzle, its final velocity for a given pressure drop is reduces to:

- Friction between nozzle surface and stream
- Internal friction of stream itself.
- Shock losses.

Most of the frictional losses occur between the throat and exit in nozzle, producing following effect.

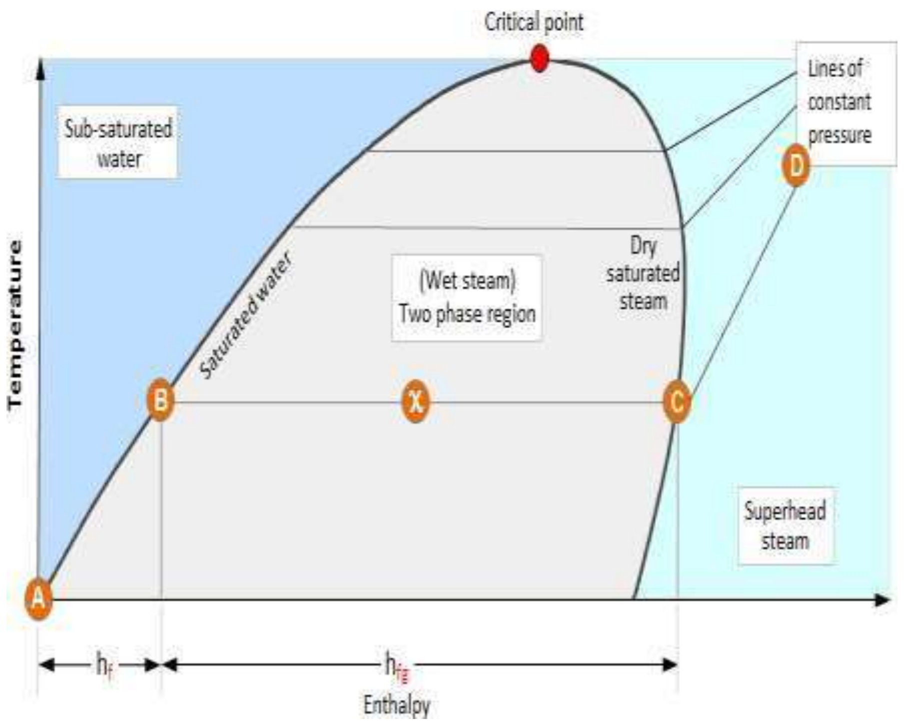
- Expansion is no more isentropic.
- Enthalpy drop is reduced.
- Final dryness fraction of steam increases.(kinetic energy- heat, due to friction and gets absorbed.)
- Specific volume of steam increases.(steam becomes more dry due to friction reheating)

# Parameters of steam nozzle

- Foundation
- Rotor or shaft
- Cylinder or Casing
- Blades
- Diaphragm
- Steam Chest
- Coupling
- Bearings
- Labyrinth seal
- Front pedestal
- TSI
- D-EHC(governor)
- MSV(main steam stop value)
- CV(control value)
- IV(intercept value)
- CRV(combined reheat value)
- Turbine Turning Gear
- Turbine Bypass and Drains
- Lube oil system
- EHC oil system
- Gland steam systems
- Condenser
- Steam jet Ejector
- Vacuum Breaker

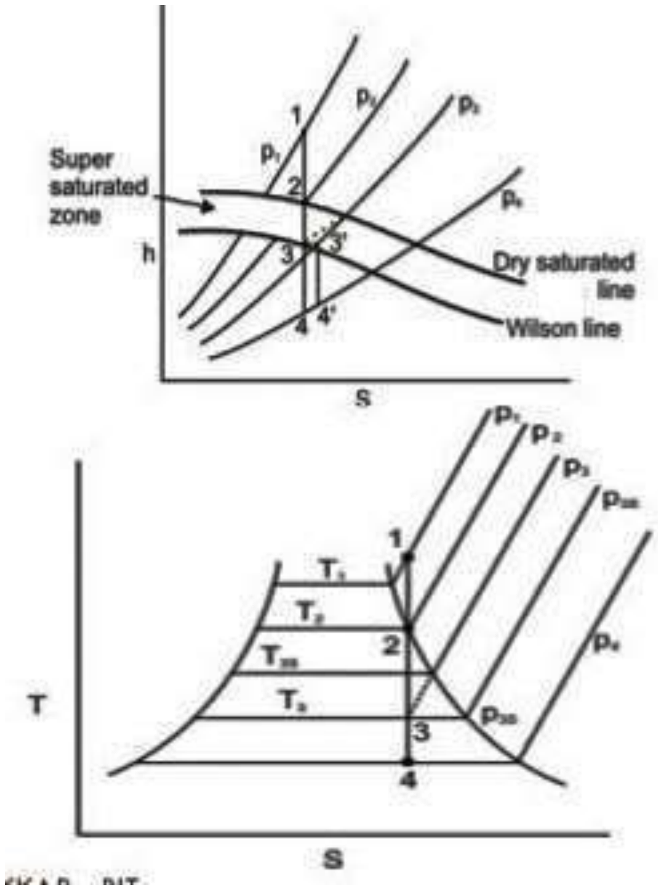
# SUPER SATURATED FLOW

When dry and saturated steam is caused to expand in a nozzle, the actual measured steam flow is found to be greater than the theoretical calculated flow. This is due to the time lag in the condensation of steam and the steam remains in dry state instead of wet. Such a steam is called supersaturated steam. This time lag is caused due to the fact that, the converging part of the nozzle is too short and the steam velocity is too high that the molecules of steam have insufficient time to form droplets.



# EFFECTS OF SUPERSATURATE

- ✓ Final dryness fraction increases.
- ✓Density of supersaturated steam is more than that for equilibrium conditions(As no condensation during supersaturated expansion => supersaturation temperature < saturation temperature corresponding to the pressure).
- ✓Thus , measured discharge (=>mass) is greater than that theoretically calculated.



# MACH NUMBER

Mach number is the ratio of flow velocity passed the boundary to the local speed of sound.

It is a dimensionless quantity:-

M=u/c  Where,

M= Mach Number.

u= Local flow velocity with respect to  the boundaries.

c= Speed of the sound in the medium.

If ,

M>1, the flow is supersonic  M<1, the flow is subsonic  M=1, the flow is sonic

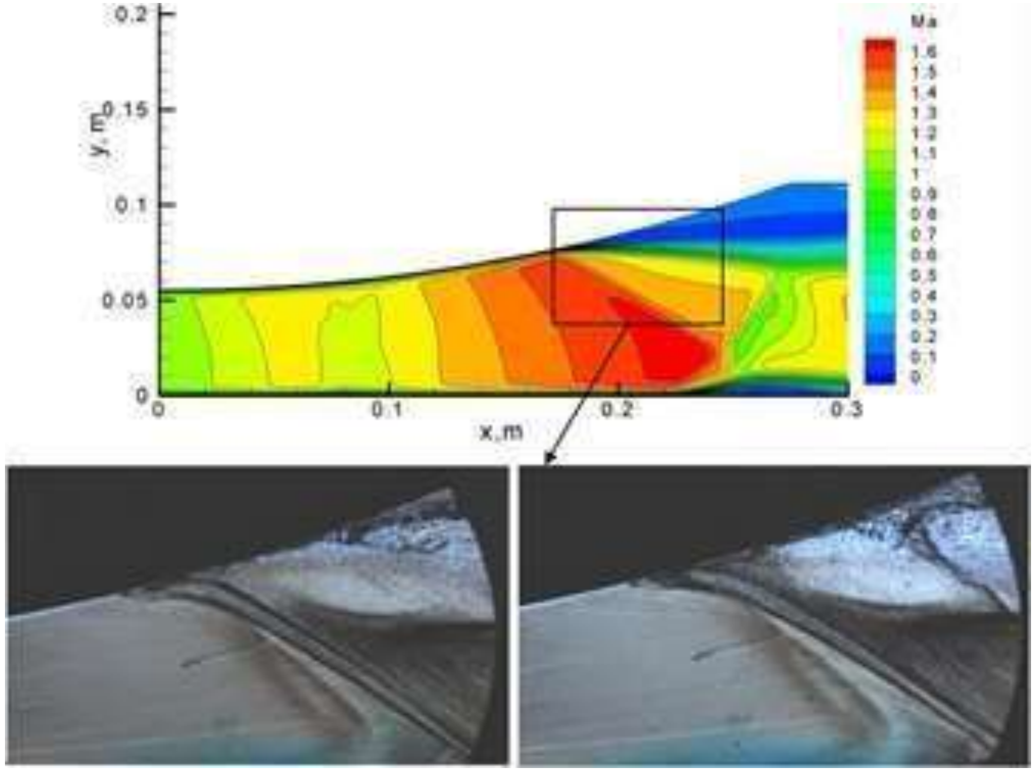



Figure 4: Calculated Mach number distribution (top) and  Schlieren pictures from experiment for D1

# APPLICATIONS OF STEAM NOZZLE

- To rotate steam turbine.
- Thermal power plant.
- Steam nozzle are also used for cleaning purpose.
- To produce a very fine jet spray.

THANK YOU

# UNIT-3
# STEAM TURBINES

## ***DEFINITION***

A ***steam turbine*** is a *prime mover* in which the *potential energy* of the steam is transformed into *kinetic energy* and later in its turn is transformed into the *mechanical energy* of rotation of the turbine shaft.

# Classification of steam turbines

***According to the action of steam:***

- *Impulse turbine:* In impulse turbine, steam coming out through a fixed nozzle at a very high velocity strikes the blades fixed on the periphery of a rotor. The blades change the direction of steam flow without changing its pressure. The force due to change of momentum causes the rotation of the turbine shaft. Ex: De-Laval, Curtis and Rateau Turbines
- *Reaction turbine:* In reaction turbine, steam expands both in fixed and moving blades continuously as the steam passes over them. The pressure drop occurs continuously over both moving and fixed blades.
- *Combination of impulse and reaction turbine*

## *ACCORDING TO THE NUMBER OF PRESSURE STAGES:*

- *Single stage turbines:* These turbines are mostly used for driving centrifugal compressors, blowers and other similar machinery.
- *Multistage Impulse and Reaction turbines:* They are made in a wide range of power capacities varying from small to large.

## *According to the type of steam flow:*

- *Axial turbines:* In these turbines, steam flows in a direction parallel to the axis of the turbine rotor.
- *Radial turbines:* In these turbines, steam flows in a direction perpendicular to the axis of the turbine, one or more low pressure stages are made axial.

## *ACCORDING TO THE NUMBER OF SHAFTS:*

- *Single shaft turbines*
- *Multi-shaft turbines*

## *According to the method of governing:*

- *Turbines with throttle governing:* In these turbines, fresh steam enter through one or more (depending on the power developed) simultaneously operated throttle valves.
- *Turbines with nozzle governing:* In these turbines, fresh steam enters through one or more consecutively opening regulators.
- *Turbines with by-pass governing:* In these turbines, the steam besides being fed to the first stage is also directly fed to one, two or even three intermediate stages of the turbine.

## *ACCORDING TO THE HEAT PROCESS:*

- *Condensing turbines with generators:* In these turbines, steam at a pressure less than the atmospheric is directed to the condenser. The steam is also extracted from intermediate stages for feed water heating). The latent heat of exhaust steam during the process of condensation is completely lost in these turbines.
- *Condensing turbines with one or more intermediate stage extractions:* In these turbines, the steam is extracted from intermediate stages for industrial heating purposes.
- *Back pressure turbines:* In these turbines, the exhaust steam is utilized for industrial or heating purposes. Turbines with deteriorated vacuum can also be used in which exhaust steam may be used for heating and process purposes.
- *Topping turbines:* In these turbines, the exhaust steam is utilized in medium and low pressure condensing turbines. These turbines operate at high initial conditions of steam pressure and temperature, and are mostly used during extension of power station capacities, with a view to obtain better efficiencies.

***According to their usage in industry:***

- *Stationary turbines with constant speed of rotation:* These turbines are primarily used for driving alternators.
- *Stationary turbines with variable speed of rotation:* These turbines are meant for driving turbo-blowers, air circulators, pumps, etc.
- *Non-stationary turbines with variable speed*: These turbines are usually employed in steamers, ships and railway locomotives.

# *ADVANTAGES OF STEAM TURBINES OVER STEAM ENGINES*

1. The thermal efficiency is much higher.
2. As there is no reciprocating parts, perfect balancing is possible and therefore heavy foundation is not required.
3. Higher and greater range of speed is possible.
4. The lubrication is very simple as there are no rubbing parts.
5. The power generation is at uniform rate & hence no flywheel is required.
6. The steam consumption rate is lesser.
7. More compact and require less attention during operation.
8. More suitable for large power plants.
9. Less maintenance cost as construction and operation is highly simplified due to absence of parts like piston, piston rod, cross head, connecting rod.
10. Considerable overloads can be carried at the expense of slight reduction in overall efficiency.

# METHODS OF REDUCING ROTOR SPEED (COMPOUNDING OF TURBINES)

- If high velocity of steam is allowed to flow through one row of moving blades, it produces a rotor speed of about **30000** rpm which is too high for practical use.

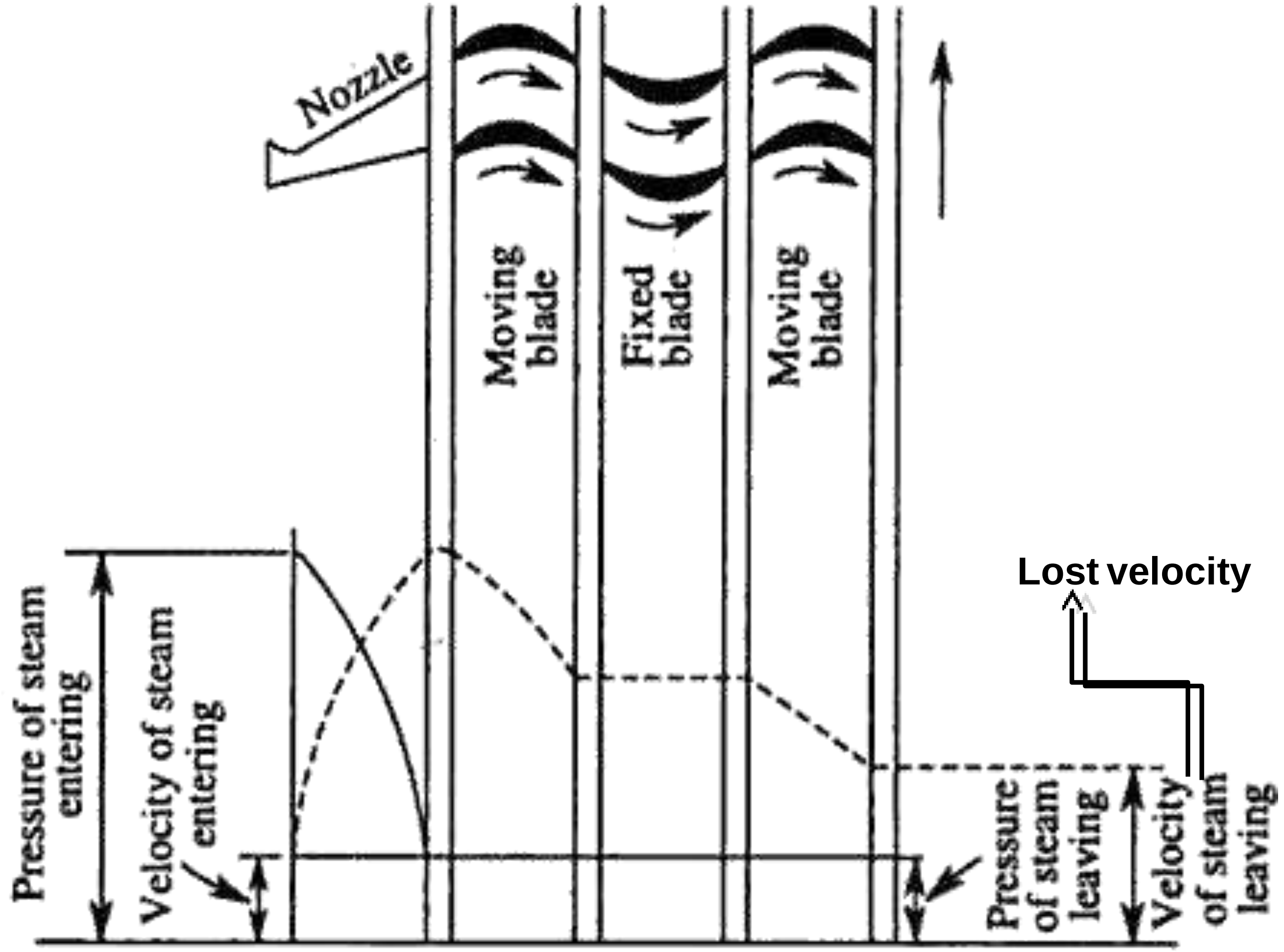
- It is therefore essential to incorporate some improvements for practical use and also to achieve high performance.

- This is possible by making use of more than one set of nozzles, and rotors, in a series, keyed to the shaft so that either the steam pressure or the jet velocity is absorbed by the turbine in stages. This is called *compounding of turbines*.

- The high rotational speed of the turbine can be reduced by the following methods of compounding:

1) Velocity compounding
2) Pressure compounding, and
3) Pressure-Velocity compounding

# VELOCITY COMPOUNDING




**Velocity compounding**

- It consists of a set of nozzles and a few rows of moving blades which are fixed to the shaft and rows of fixed blades which are attached to the casing.
- As shown in figure, the two rows of moving blades are separated by a row of fixed blades.
- The high velocity steam first enters the first row of moving blades, where some portion of the velocity is absorbed.
- Then it enters the ring of fixed blades where the direction of steam is changed to suit the second ring of moving blades. There is no change in the velocity as the steam passes over the fixed blades.
- The steam then passes on to the second row of moving blades where the velocity is further reduced. Thus a fall in velocity occurs every time when the steam passes over the row of moving blades. Steam thus leaves the turbine with a low velocity.
- The variation of pressure and velocity of steam as it passes over the moving and fixed blades is shown in the figure. It is clear from the figure that the pressure drop takes place only in the nozzle and there is no further drop of pressure as it passes over the moving blades.
- This method of velocity compounding is used in Curtis turbine after it was first proposed by C.G. Curtis.

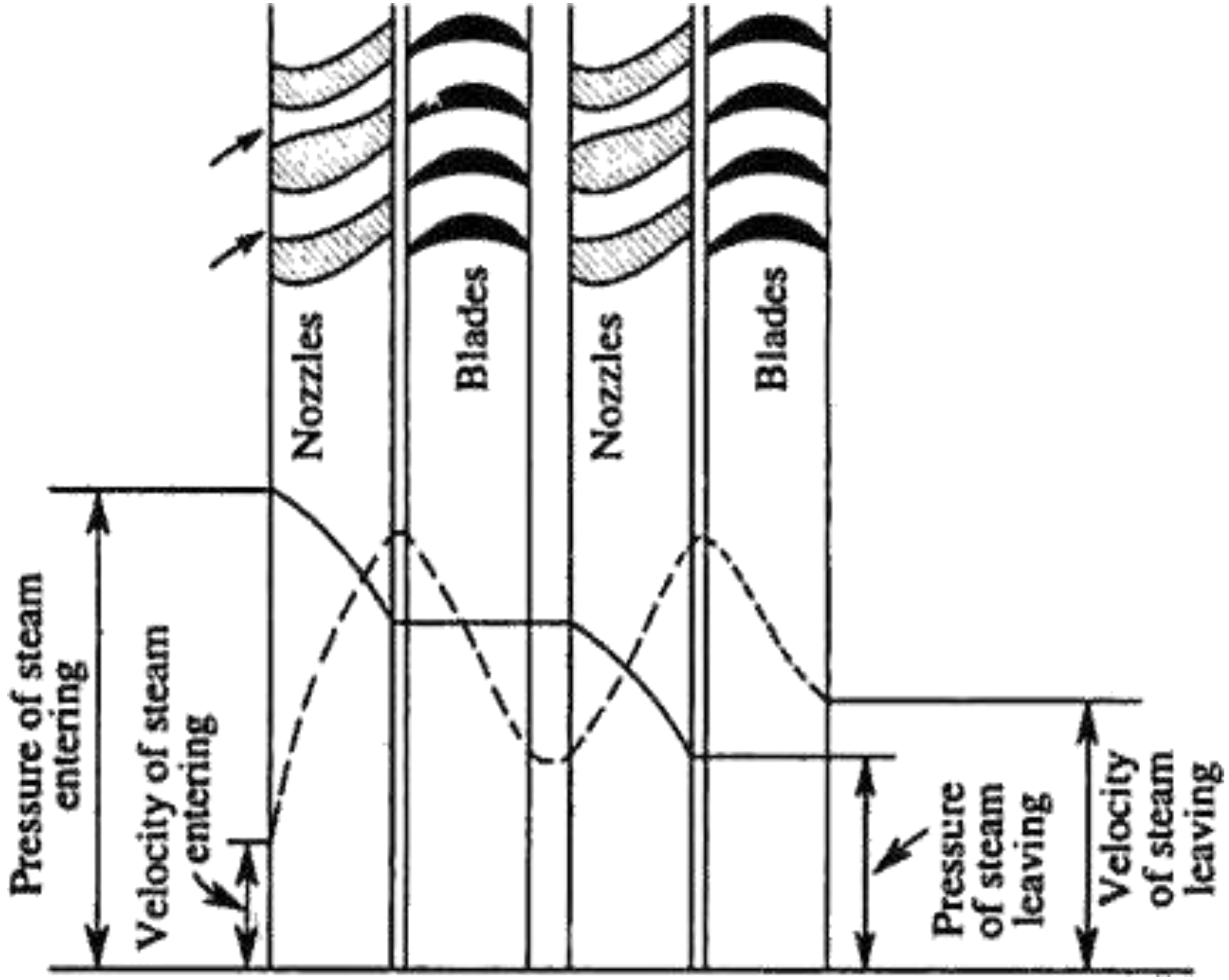
## Advantages

1) The arrangement has less number of stages and hence less initial cost
2) The arrangement requires less space
3) The system is reliable and easy to operate
4) The fall of pressure in the nozzle is considerable, so the turbine itself need not work in high pressure surroundings and the turbine housing need not be very strong.

## Disadvantages

1) More friction losses due to very high velocity in the nozzles
2) Less efficiency because ratio of blade velocity to steam velocity is not optimum
3) Power developed in the later rows is only fraction of first row. Still all the stages require same space, material and cost.

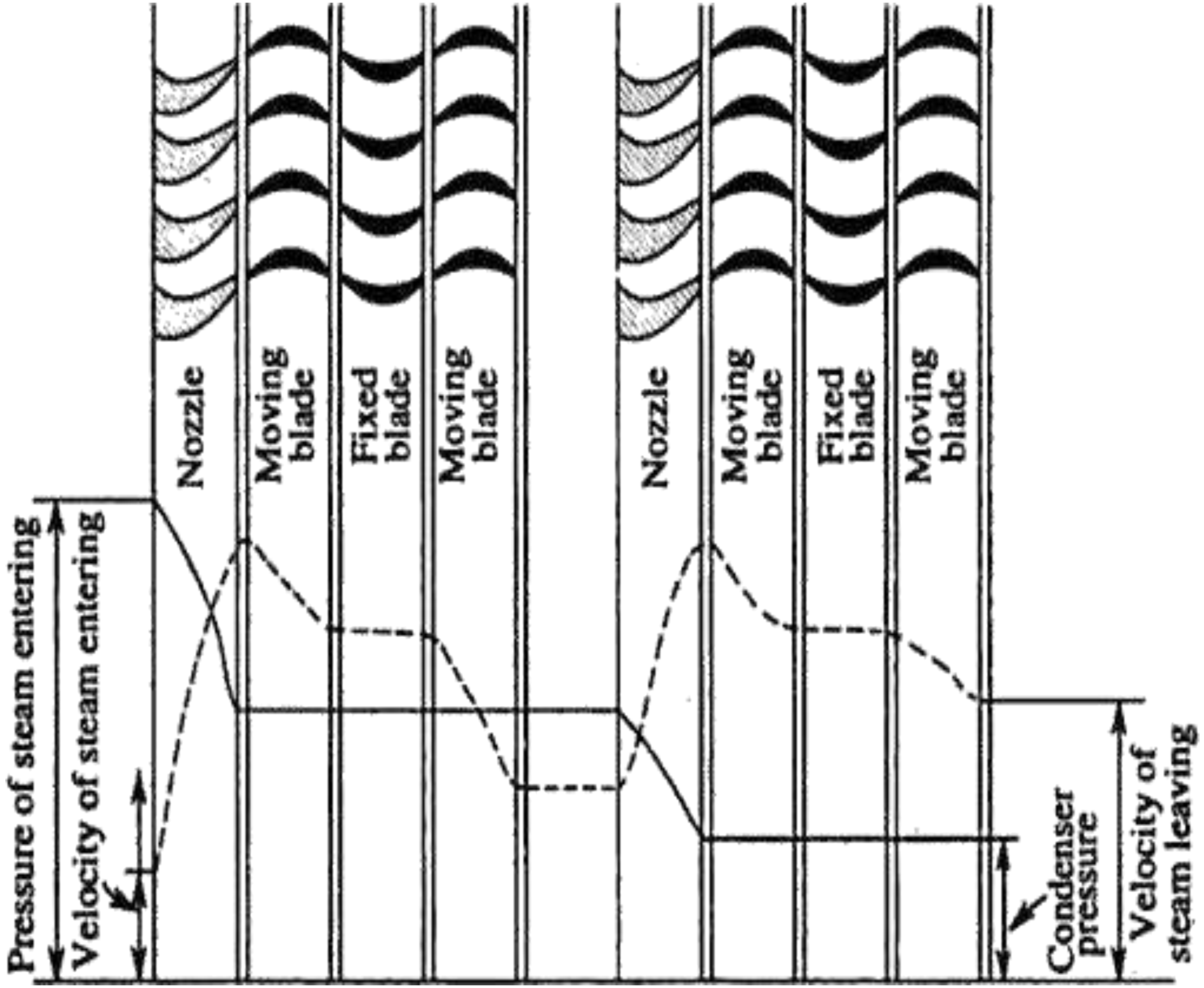
# Pressure compounding



- It consists of a number of fixed nozzles which are incorporated between the rings of moving blades. The moving blades are keyed to the shaft.
- Here the pressure drop is done in a number of stages. Each stage consists of a set of nozzles and a ring of moving blades.
- Steam from the boiler passes through the first set of nozzles where it expands partially. Nearly all its velocity is absorbed when it passes over the first set of moving blades.
- It is further passed to the second set of fixed nozzles where it is partially expanded again and through the second set of moving blades where the velocity of steam is almost absorbed. This process is repeated till steam leaves at condenser pressure.
- By reducing the pressure in stages, the velocity of steam entering the moving blades is considerably reduced. Hence the speed of the rotor is reduced. Rateau & Zoelly turbines use this method of compounding.

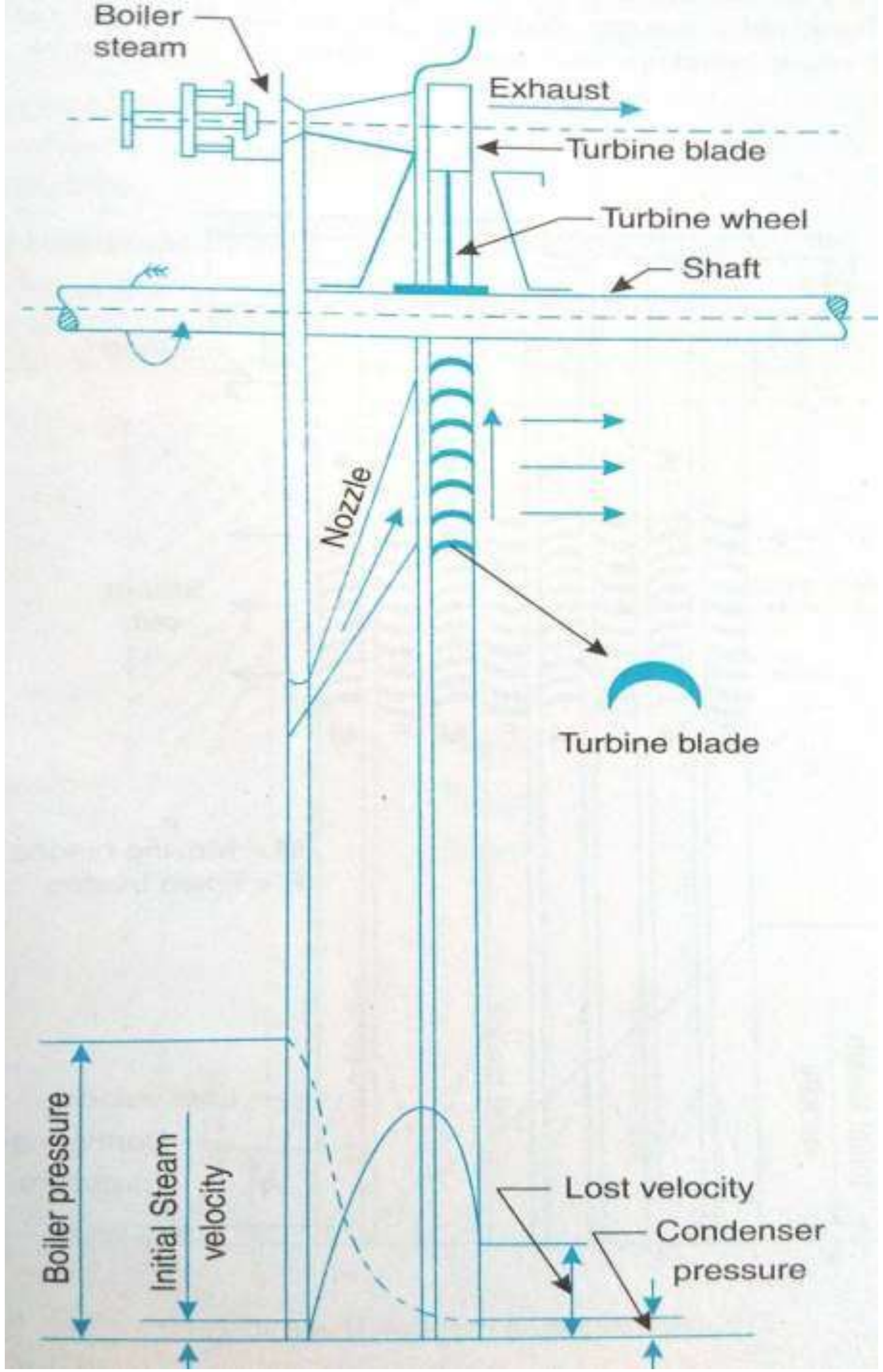
1) In this method of compounding, both pressure and velocity compounding methods are utilized.
2) The total drop in steam pressure is carried out in two stages and the velocity obtained in each stage is also compounded.
3) The ring of nozzles are fixed at the beginning of each stage and pressure remains constant during each stage.
4) This method of compounding is used in *Curtis* and *More* turbines.

# PRESSURE-VELOCITY COMPOUNDING



# Simple impulse principle

- It primarily consists of a nozzle or a set of nozzles, a rotor mounted on a shaft, one set of moving blades attached to the rotor and a casing.
- A simple impulse turbine is also called De-Laval turbine, after the name of its inventor
- This turbine is called *simple* impulse turbine since the expansion of the steam takes place in one set of nozzles.



# Basics of impulse turbine

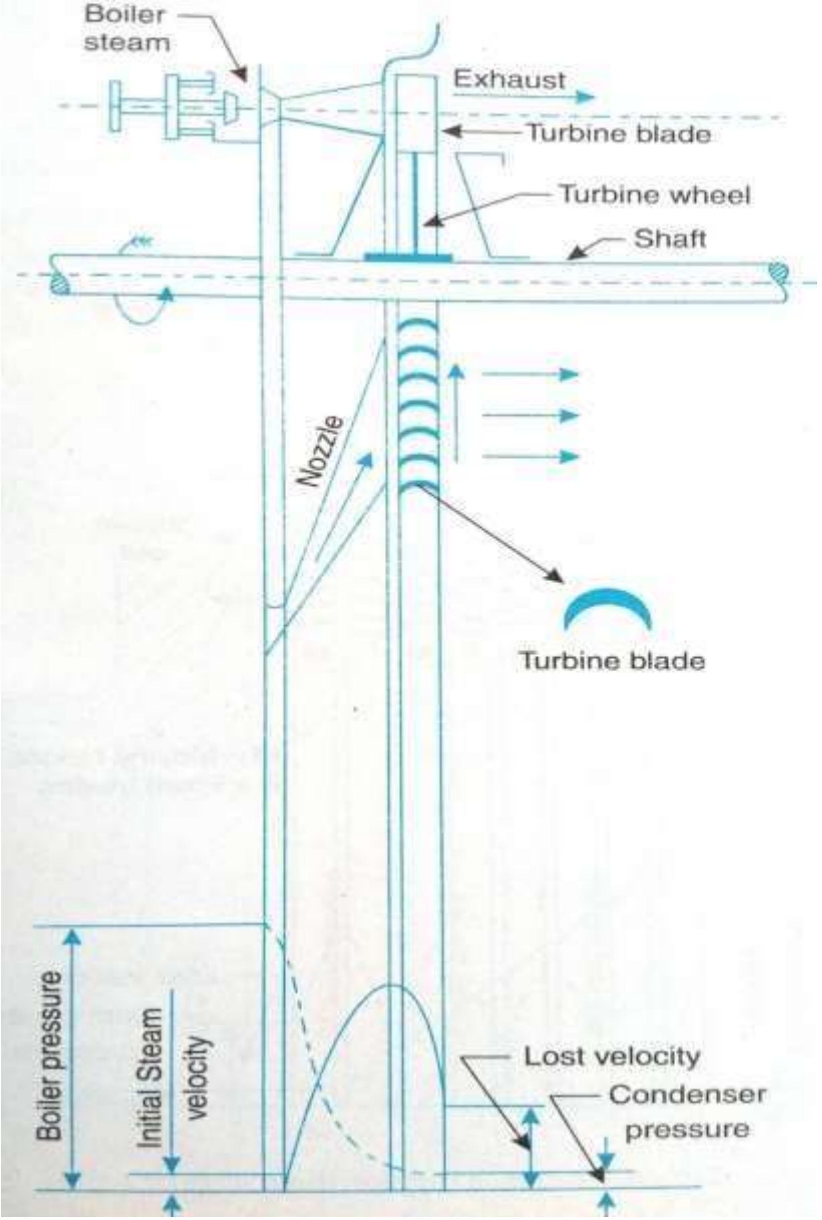
- In impulse turbine, steam coming out through a fixed nozzle at a very high velocity strikes the blades fixed on the periphery of a rotor.
- The blades change the direction of steam flow without changing its pressure.
- The force due to change of momentum causes the rotation of the turbine shaft.
- Examples: De-Laval, Curtis and Rateau turbines.

- The impulse turbine consists basically of a rotor mounted on a shaft that is free to rotate in a set of bearings.
- The outer rim of the rotor carries a set of curved blades, and the whole assembly is enclosed in an airtight case.
- Nozzles direct steam against the blades and turn the rotor. The energy to rotate an impulse turbine is derived from the kinetic energy of the steam flowing through the nozzles.
- The term impulse means that the force that turns the turbine comes from the impact of the steam on the blades.

- The toy pinwheel can be used to study some of the basic principles of turbines. When we blow on the rim of the wheel, it spins rapidly. The harder we blow, the faster it turns.
- The steam turbine operates on the same principle, except it uses the kinetic energy from the steam as it leaves a steam nozzle rather than air.
- Steam nozzles are located at the turbine inlet. As the steam passes through a steam nozzle, potential energy is converted to kinetic energy.
- This steam is directed towards the turbine blades and turns the rotor. The velocity of the steam is reduced in passing over the blades.
- Some of its kinetic energy has been transferred to the blades to turn the rotor.
- Impulse turbines may be used to drive forced draft blowers, pumps, and main propulsion turbines.

# Construction and working of impulse turbine

- The uppermost portion of the diagram shows a longitudinal section through the upper half of the turbine.
- The middle portion shows the actual shape of the nozzle and blading.
- The bottom portion shows the variation of absolute velocity and absolute pressure during the flow of steam through passage of nozzles and blades.
- The expansion of steam from its initial pressure (steam chest pressure) to final pressure (condenser pressure) takes place in one set of nozzles.
- Due to high drop in pressure in the nozzles, the velocity of steam in the nozzles increases.

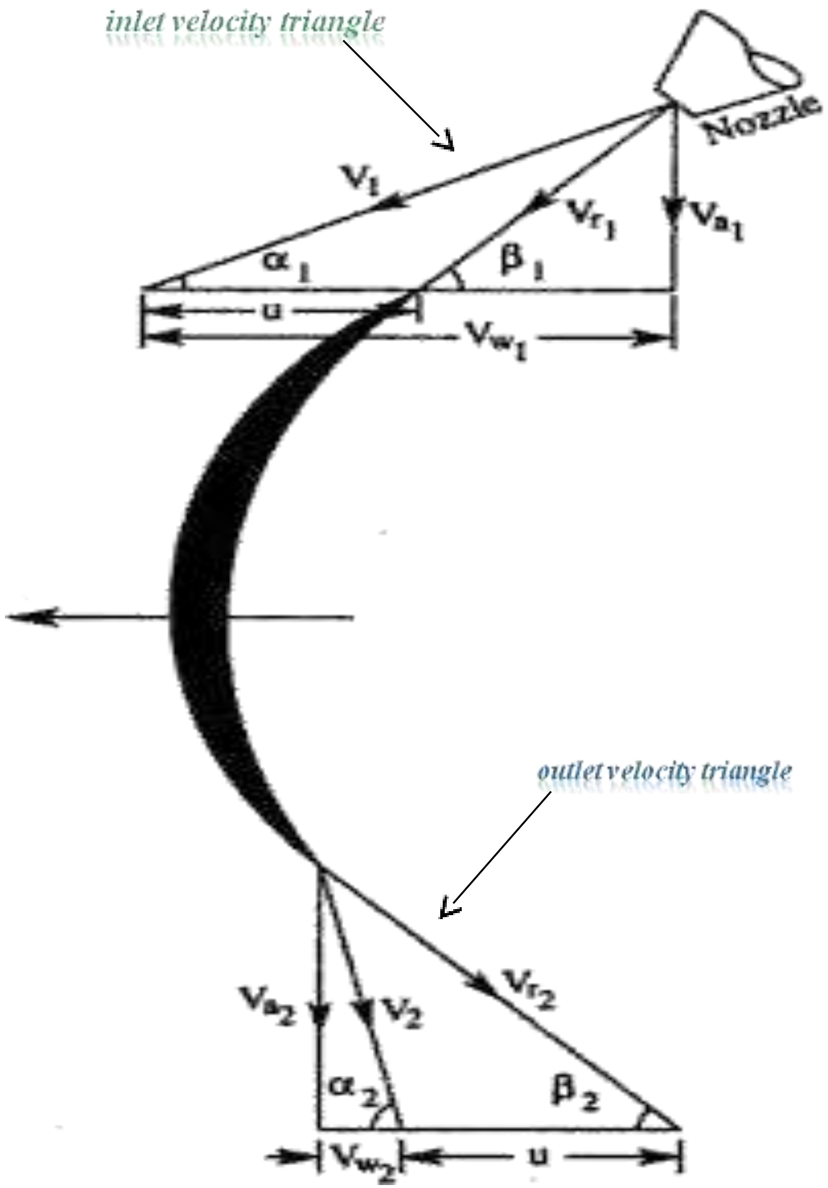


- The steam leaves the nozzle with a very high velocity and strikes the blades of the turbine mounted on a wheel with this high velocity.
- The loss of energy due to this higher exit velocity is commonly known as *carry over loss* (or) *leaving loss.*
- The pressure of the steam when it moves over the blades remains constant but the velocity decreases.
- The exit/leaving/lost velocity may amount to 3.3 percent of the nozzle outlet velocity.
- Also since all the KE is to be absorbed by one ring of the moving blades only, the velocity of wheel is too high (varying from 25000 to 30000 RPM).
- However, this wheel or rotor speed can be reduced by adopting the method of compounding of turbines.

# Disadvantages of impulse turbine

1. SINCE ALL THE KE OF THE HIGH VELOCITY STEAM HAS TO BE ABSORBED IN ONLY ONE RING OF MOVING BLADES, THE VELOCITY OF THE TURBINE IS TOO HIGH I.E. UP TO 30000 RPM FOR PRACTICAL PURPOSES.
2. The velocity of the steam at exit is sufficiently high which means that there is a considerable loss of KE.

# Velocity diagram / velocity triangle




$V_1$ = Absolute velocity of steam at inlet in $m/s$

$\alpha_1$ = Nozzle inlet angle

$u$ = Blade velocity in $m/s$

$V_{r1}$ = Relative velocity of steam at inlet in $m/s$

$V_{w1}$ = Tangential velocity of steam at inlet in $m/s$

$V_{a1}$ = Axial velocity of steam at inlet in $m/s$

$\beta_1$ = Blade inlet angle

$\beta_2$ = Blade outlet angle

$V_{r2}$ = Relative velocity of steam at outlet in $m/s$

$V_{w2}$ = Tangential velocity of steam at outlet in $m/s$

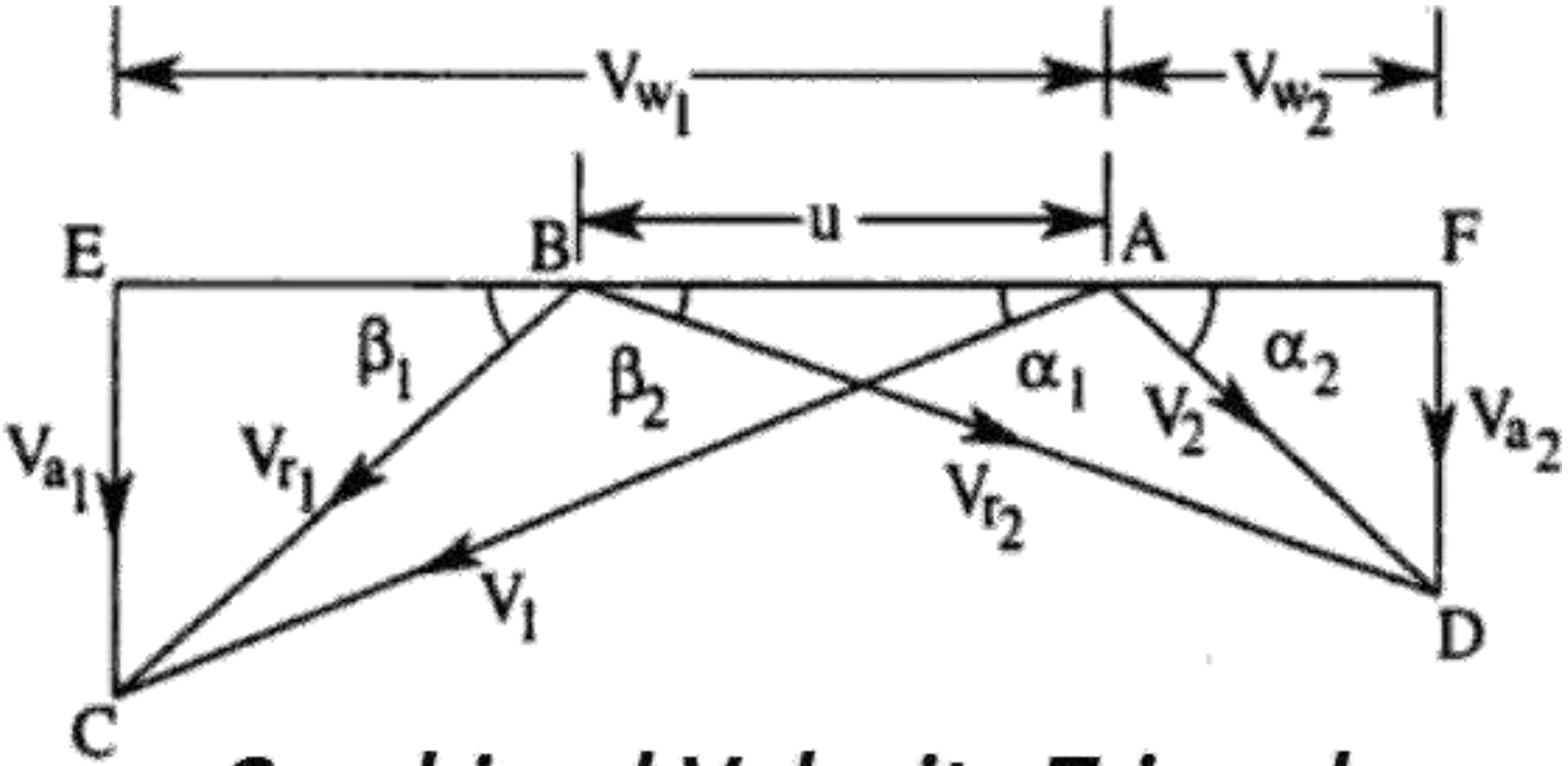
$V_{a2}$ = Axial velocity of steam at outlet in $m/s$

$K$ = Blade velocity coefficient $= \dfrac{V_{r2}}{V_{r1}}$

$V_2$ = Absolute velocity of steam at outlet in $m/s$

$\alpha_2$ = Angle made by absolute velocity $V_2$ with the tangent of the wheel at outlet

# Combined velocity triangle




**Combined Velocity Triangle**

# WORK OUTPUT, POWER, BLADE EFFICIENCY & STAGE EFFICIENCY

Force in the tangential direction = Rate of change of momentum in the tangential direction.

= Mass per second × change in velocity Newtons

$$= m\left(V_{w1} \pm V_{w2}\right) \text{Newtons}$$

Force in the axial direction = Rate of change of momentum in the axial direction.

(axial thrust) $= m\left(V_{a1} - V_{a2}\right)$ Newtons

$$\text{Work done by steam on blades} = m\left(V_{w1} \pm V_{w2}\right)u \quad \text{N - m/s}$$

$$\text{Power developed by the turbine} = \frac{m\left(V_{w1} \pm V_{w2}\right)u}{1000} kW$$

$$\text{Blade efficiency} = \frac{\text{Work done on the blade(s)}}{\text{Energy supplied to the blade(s)}} = \frac{m\left(V_{w1} \pm V_{w2}\right)u}{\frac{1}{2} m V_1^2} = \frac{2u\left(V_{w1} \pm V_{w2}\right)u}{V_1^2}$$

$$\text{Energy lost due to blade friction} = \frac{1}{2} m\left(V_{r1}^2 - V_{r2}^2\right) \quad \text{N - m/s}$$

$$\text{Stage efficiency} = \frac{\text{Work done on the blade(s)}}{\text{Total energy supplied per stage}} = \frac{m\left(V_{w1} \pm V_{w2}\right)u}{m\left(H_1 - H_2\right)} = \frac{\left(V_{w1} \pm V_{w2}\right)u}{H_d}$$

where $H_d = H_1 - H_2$ = Heat drop in the nozzle ring

# MAXIMUM WORK & MAXIMUM DIAGRAM EFFICIENCY

From the combined velocity triangle (diagram), we have

$$V_{w1} = V_1 \cos\alpha_1 = V_{r1}\cos\beta_1 + u \quad \text{and} \quad V_{w2} = V_2\cos\alpha_2 = V_{r2}\cos\beta_2 - u$$

$$\therefore V_{w1} + V_{w2} = V_{r1}\cos\beta_1 + V_{r2}\cos\beta_2 = V_{r1}\cos\beta_1\left[1 + \frac{V_{r2}\cos\beta_2}{V_{r1}\cos\beta_1}\right] = V_{r1}\cos\beta_1(1+KC)$$

where $K = \dfrac{V_{r2}}{V_{r1}}$ and $C = \dfrac{\cos\beta_2}{\cos\beta_1}$

(or) $\quad V_{w1} + V_{w2} = (V_1\cos\alpha_1 - u)(1+KC)$

Rate of doing work per kg of steam per second = $(V_1\cos\alpha_1 - u)(1+KC)u$

$\therefore$ Diagram efficiency, $\eta_b = \dfrac{(V_1\cos\alpha_1 - u)(1+KC)}{V_1^2}$

Let, $\rho = \dfrac{u}{V_1}$ = Bladespeed ratio

Then, Diagram efficiency, $\quad \eta_b = 2(\rho\cos\alpha_1 - \rho^2)(1+KC)$

# MAXIMUM WORK & MAXIMUM DIAGRAM EFFICIENCY

From the above equation, it is evident that *diagram efficiency* depends on the following factors:

1) Nozzle angle, $\alpha_1$
2) Blade speed ratio, $\rho$
3) Blade angles, $\beta_1$ & $\beta_2$
4) Blade velocity coefficient, $K$

- If the values of $\alpha_1$, $K$ and $C$ are assumed to be constant, then diagram efficiency depends only on the value of blade speed ratio, $\rho$

- In order to determine the optimum value of for maximum diagram efficiency, $\frac{\partial \eta_b}{\partial \rho} = 0$

- Then, $\rho$ becomes, $\rho = \frac{\cos\alpha_1}{2}$

# MAXIMUM WORK & MAXIMUM DIAGRAM EFFICIENCY

aximum diagram efficiency =

$$(\eta_b)_{max} = 2(1+KC)\left[\frac{\cos\alpha_1}{2}.\cos\alpha_1 - \frac{\cos^2\alpha_1}{4}\right] = (1+KC)\frac{\cos^2\alpha_1}{2}$$

*Note:* If the blade is symmetrical & friction is absent, then, we have $\beta_1 = \beta_2$ and $K = C = 1$

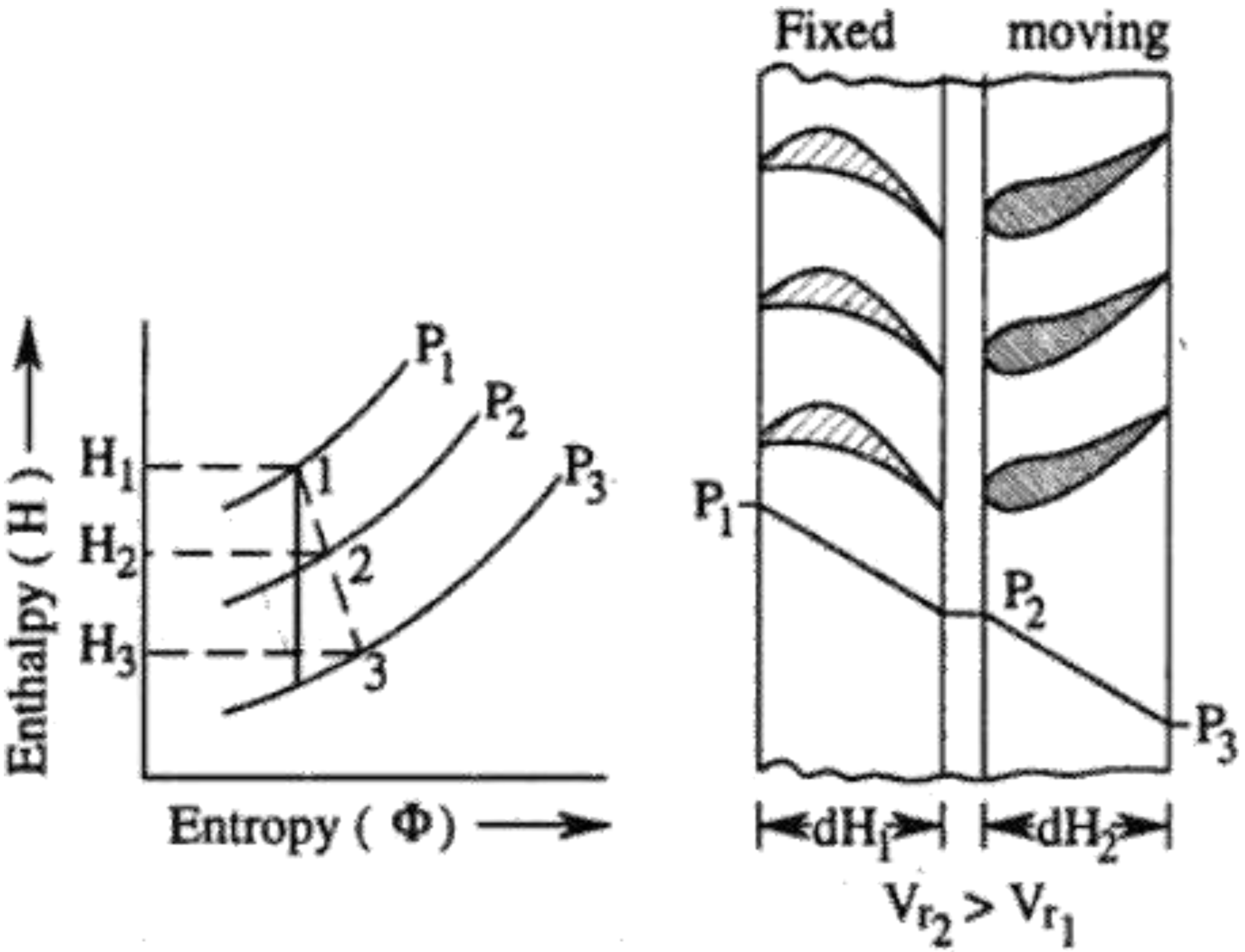
Then, maximum diagram efficiency, $(\eta_b)_{max} = \cos^2\alpha_1$

Work done/kg of steam/second = $(V_1\cos\alpha_1 - u)(1+KC)u$

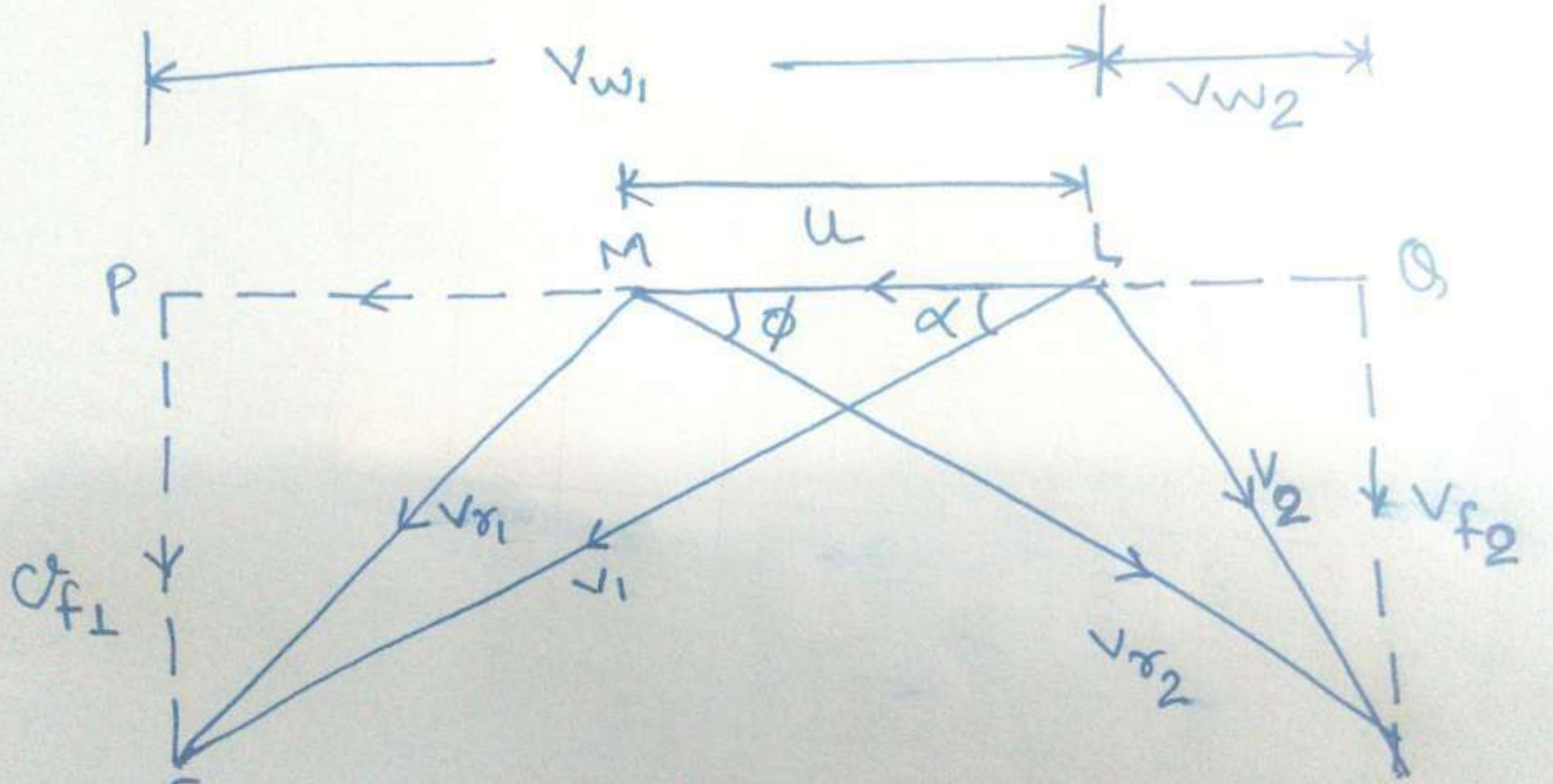
Then maximum rate of doing work/kg of steam/second $= 2u^2$

# 2. REACTION TURBINE

- A turbine in which steam pressure decreases gradually while expanding through the moving blades as well as the fixed blades is known as *reaction turbine.*
- It consists of a large number of stages, each stage consisting of set of fixed and moving blades. The heat drop takes place throughout in both fixed and moving blades.
- No nozzles are provided in a reaction turbine. The fixed blades act both as nozzles in which velocity of steam increased and direct the steam to enter the ring of moving blades. As pressure drop takes place both in the fixed and moving blades, all the blades are nozzle shaped.
- The steam expands while flowing over the moving blades and thus gives reaction to the moving blades. Hence the turbine is called *reaction turbine*.
- The fixed blades are attached to the casing whereas moving blades are fixed with the rotor.
- It is also called *Parson's reaction turbine.*




*Isentropic expansion in Reaction Turbine*




velocity diagram for Reaction turbine blade

# Work output & power in reaction turbine

The work done per kg of steam in the stage (per pair) =

$$u\left(V_{w1}+V_{w2}\right)N-m$$

The work done per kg of steam per second in the stage (per pair) =

$$mu\left(V_{w1}+V_{w2}\right)N-m/s$$

where, $m$ = mass of steam flowing over blades in $kg/s$

Power developed (per pair) = $\dfrac{mu\left(V_{w1}+V_{w2}\right)}{1000}kW$

$$Efficiency,\eta = \frac{work\ done\ per\ kg\ of\ steam\ in\ the\ stage\ per\ pair}{Enthalpy\ drop\ in\ the\ stage\ per\ pair}$$

$$\therefore\ Efficiency,\eta = \frac{u\left(V_{w1}+V_{w2}\right)}{1000H}$$

where, $H$ = Enthalpy drop in the stage per pair in $kJ/kg$

# DEGREE OF REACTION

DEGREE OF REACTION

The degree of reaction is defined as the ratio of isentropic heat drop in the moving blades to the isentropic heat drop in the entire stage of reaction turbine. It is denoted by $R$.

$$R = \frac{Enthalpy\,drop\,in\,the\,moving\,blade}{Enthalpy\,drop\,in\,the\,stage} = \frac{dH_2}{dH_1 + dH_2}$$

Where, $dH_1$ = Enthalpy drop in the fixed blade per kg of steam $= \dfrac{V_1^2 - V_2^2}{2} kJ/kg = H_1 - H_2$

$dH_2$ = Enthalpy drop in the moving blade per kg of steam $= \dfrac{V_{r2}^2 - V_{r1}^2}{2} kJ/kg = H_2 - H_3$

Also, $dH_1 + dH_2$ = Enthalpy drop in the stage per kg of steam

= $H_1 - H_3$

= Work done by the steam in the stage

= $u(V_{w1} + V_{w2})$

$$\boxed{\therefore Degree\ of\ Reaction, R = \frac{V_{r2}^2 - V_{r1}^2}{2u(V_{w1} + V_{w2})}}$$

*Note-1: In Pearson's turbine, the degree of reaction, R=0.5, then,* $\alpha_1 = \beta_2$ *and* $\alpha_2 = \beta_1$*. This means that moving blade and fixed blade have the same shape.*

*Note-2: If degree of reaction, R=0, then the turbine is a simple impulse turbine.*

*Note-3: If degree of reaction, R=1, then the turbine is a pure reaction turbine.*

# WORK DONE & EFFICIENCY IN REACTION TURBINE

BLADE EFFICIENCY AND STAGE EFFICIENCY

The condition for maximum efficiency is calculated considering the following assumptions:

- The degree of reaction, R = 0.5, i.e. $\alpha_1 = \beta_2$ and $\alpha_2 = \beta_1$
- The fixed and moving blades are symmetrical, i.e. $V_1 = V_{r2}$ & $V_2 = V_{r1}$

The kinetic energy supplied to the fixed blade per kg of steam = $\dfrac{V_1^2}{2}$

The kinetic energy supplied to the moving blade per kg of steam = $\dfrac{V_{r2}^2 - V_{r1}^2}{2}$

Total energy supplied in the stage per kg of steam = $\dfrac{V_1^2}{2} + \dfrac{V_{r2}^2 - V_{r1}^2}{2}$

Since blades are symmetrical, $V_1 = V_{r2}$ & $V_2 = V_{r1}$ & from velocity triangles, $V_{r1}^2 = V_1^2 + u^2 - 2 \cdot V_1 \cdot u \cdot \cos\alpha_1$

Therefore, total energy supplied in the stage per kg of steam = $V_1^2 - \dfrac{V_1^2 + u^2 - 2 \cdot V_1 \cdot u \cdot \cos\alpha_1}{2}$

Work done per kg of steam is given by,

$$
\begin{aligned}
\text{Work Done} &= u(V_{w1} + V_{w2}) \\
&= u(V_1\cos\alpha_1 + V_{r2}\cos\beta_2 - u) \\
&= u(2V_1\cos\alpha_1 - u) \quad (\because \alpha_1 = \beta_2 \text{ and } V_1 = V_{r2})
\end{aligned}
$$

# WORK DONE & EFFICIENCY IN REACTION TURBINE

$$\text{Diagram efficiency,} \quad = \eta_d = \frac{\textit{Work done per kg of steam}}{\textit{Total energy supplied per kg of steam}}$$

$$= \frac{u(2V_1\cos\alpha_1 - u)}{V_1^2 - \dfrac{V_1^2 + u^2 - 2\cdot V_1\cdot u\cdot\cos\alpha_1}{2}}$$

$$= \frac{2u(2V_1\cos\alpha_1 - u)}{V_1^2 - u^2 + 2\cdot V_1\cdot u\cdot\cos\alpha_1}$$

$$= \frac{2uV_1\left(2\cos\alpha_1 - \dfrac{u}{V_1}\right)}{V_1^2\left(1 - \dfrac{u^2}{V_1^2} + 2\cdot\dfrac{u}{V_1}\cdot\cos\alpha_1\right)}$$

$$= \frac{2\dfrac{u}{V_1}\left(2\cos\alpha_1 - \dfrac{u}{V_1}\right)}{\left(1 - \dfrac{u^2}{V_1^2} + 2\cdot\dfrac{u}{V_1}\cdot\cos\alpha_1\right)}$$

$$\boxed{\therefore \eta_d = \frac{2\rho(2\cos\alpha_1 - \rho)}{(1 - \rho^2 + 2\cdot\rho\cdot\cos\alpha_1)}}$$

$$\text{where } \rho = \frac{u}{V_1} = \text{Blade speed ratio}$$

The efficiency is maximum when the term $\left(1-\rho^2+2\cdot\rho\cdot\cos\alpha_1\right)$ is minimum or when $\dfrac{d\eta_d}{d\rho}=0$

$$\frac{d}{d\rho}\left(1-\rho^2+2\cdot\rho\cdot\cos\alpha_1\right)=0$$

(or) $\left(-2\rho+2\cos\alpha_1\right)=0$

(or) $\boxed{\rho=\cos\alpha_1}$

Therefore efficiency is maximum when $\boxed{\rho=\cos\alpha_1}$

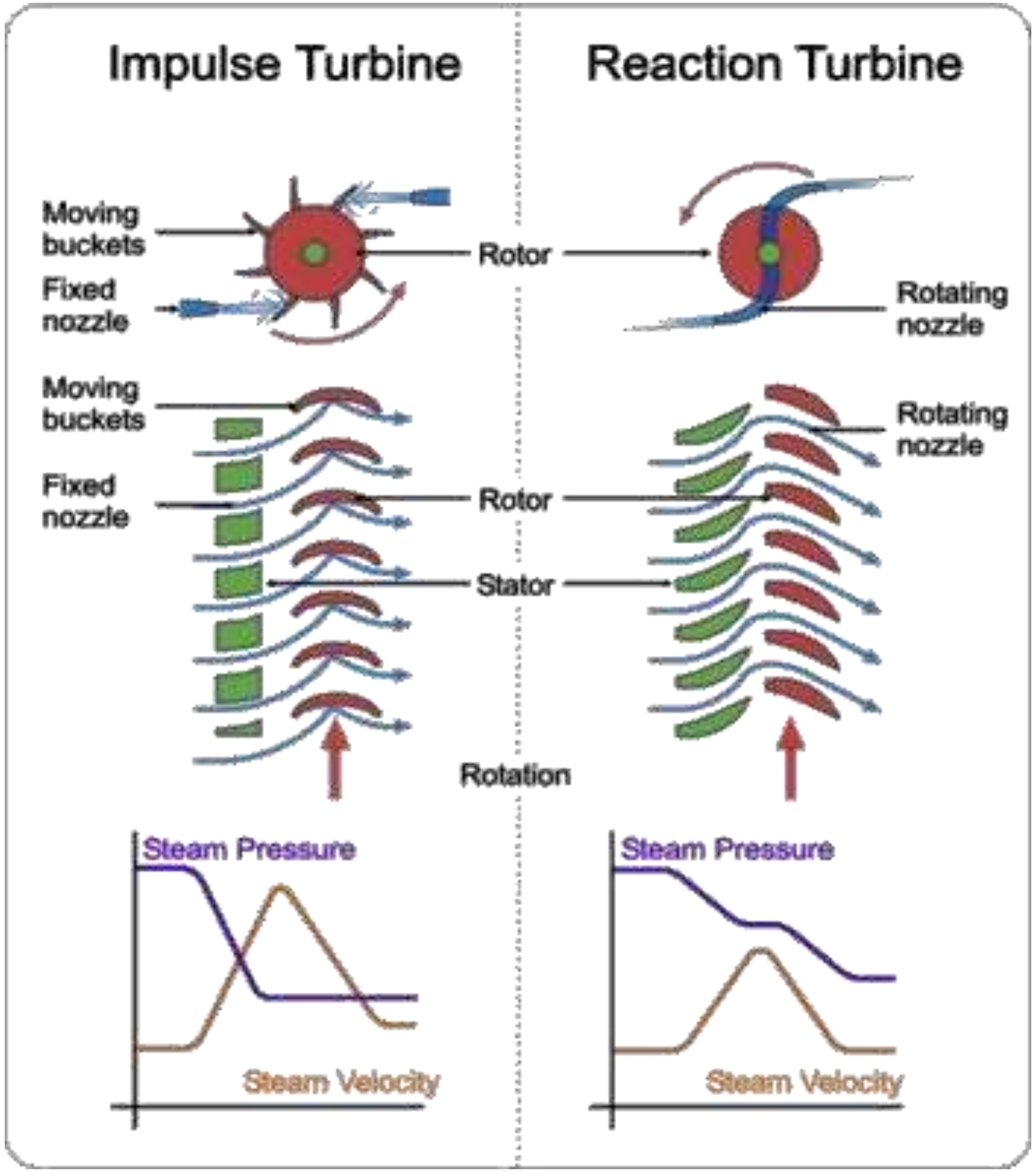
Then, $\therefore\left(\eta_d\right)_{max}=\dfrac{2\cos\alpha_1\left(2\cos\alpha_1-\cos\alpha_1\right)}{\left(1-\cos^2\alpha_1+2\cdot\cos\alpha_1\cdot\cos\alpha_1\right)}=\dfrac{2\cos^2\alpha_1}{\left(1+\cos^2\alpha_1\right)}$

$$\boxed{\therefore\left(\eta_d\right)_{max}=\frac{2\cos^2\alpha_1}{\left(1+\cos^2\alpha_1\right)}}$$

# IMPULSE TURBINE VS REACTION TURBINE

| Impulse turbine | Reaction turbine |
|---|---|
| The steam completely expands in the nozzle and its pressure remains constant during its flow through the blade passages | The steam expands partially in the nozzle and further expansion takes place in the rotor blades |
| The relative velocity of steam passing over the blade remains constant in the absence of friction | The relative velocity of steam passing over the blade increases as the steam expands while passing over the blade |
| Blades are symmetrical | Blades are asymmetrical |
| The pressure on both ends of the moving blade is same | The pressure on both ends of the moving blade is different |
| For the same power developed, as pressure drop is more, the number of stages required are less | For the same power developed, as pressure drop is small, the number of stages required are more |
| The blade efficiency curve is less flat | The blade efficiency curve is more flat |
| The steam velocity is very high and therefore the speed of turbine is high. | The steam velocity is not very high and therefore the speed of turbine is low. |

# IMPULSE TURBINE VS REACTION TURBINE



# GOVERNING OF TURBINES

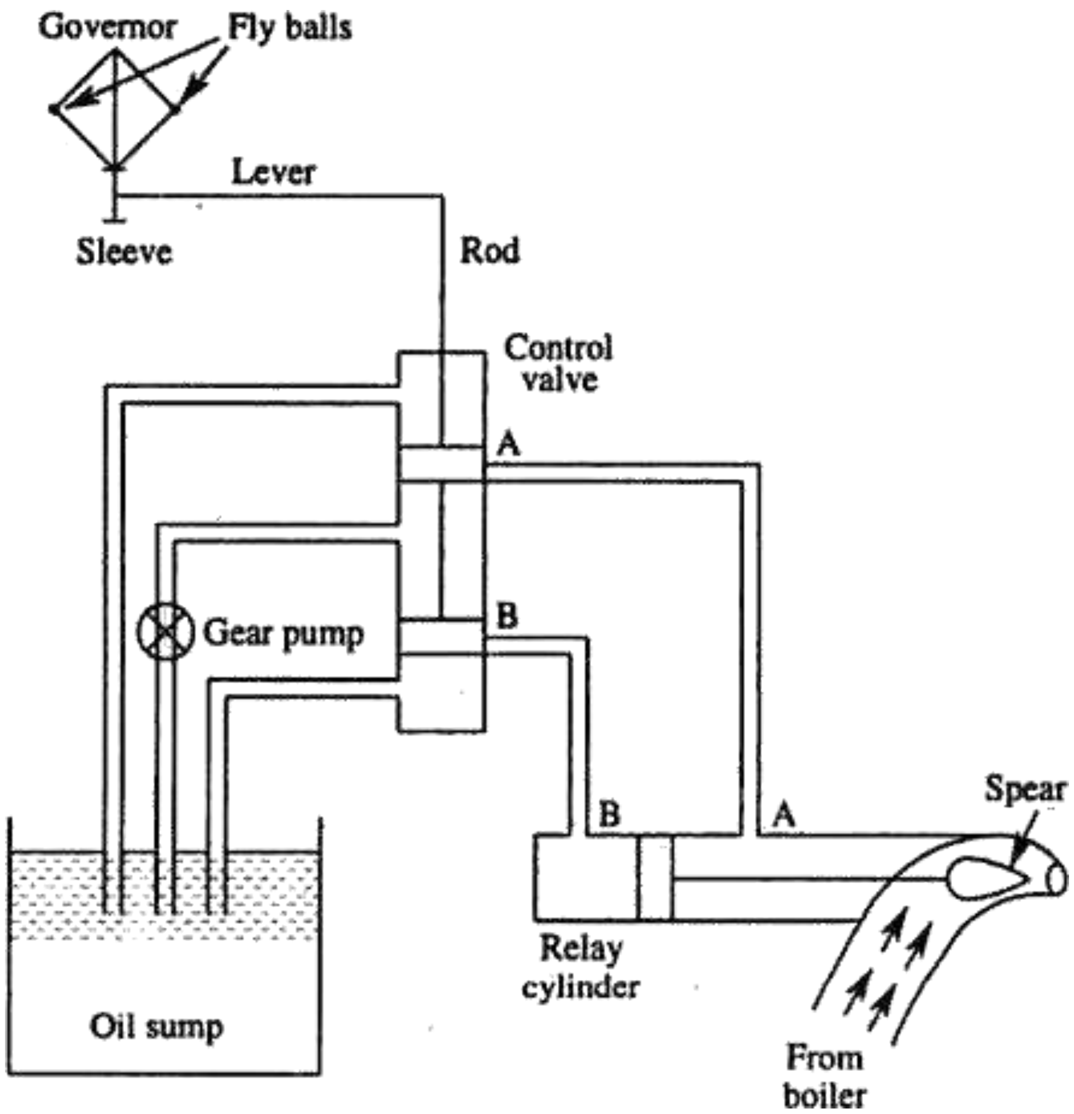
¬*Governing* is the method of maintaining the speed of the turbine constant irrespective of variation of the load on the turbine.

¬A *governor* is used for achieving this purpose which regulates the supply of steam to the turbine in such a way that the speed of the turbine is maintained as far as possible a constant under varying load conditions.

¬The various methods of governing of steam turbines are:

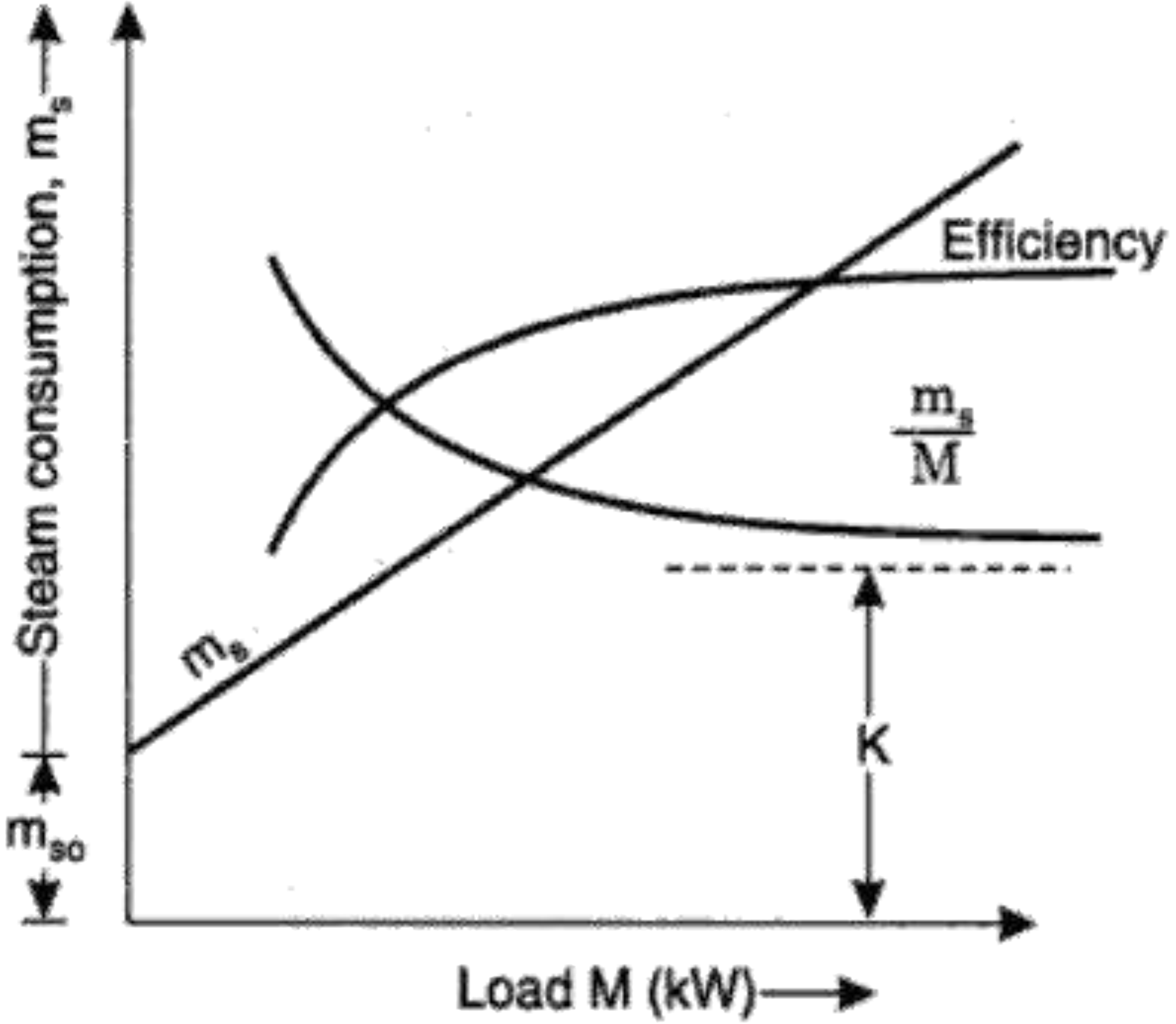
1) Throttle governing
2) Nozzle governing
3) By-pass governing
4) Combination of (1) & (2) or (2) & (3)

# THROTTLE GOVERNING

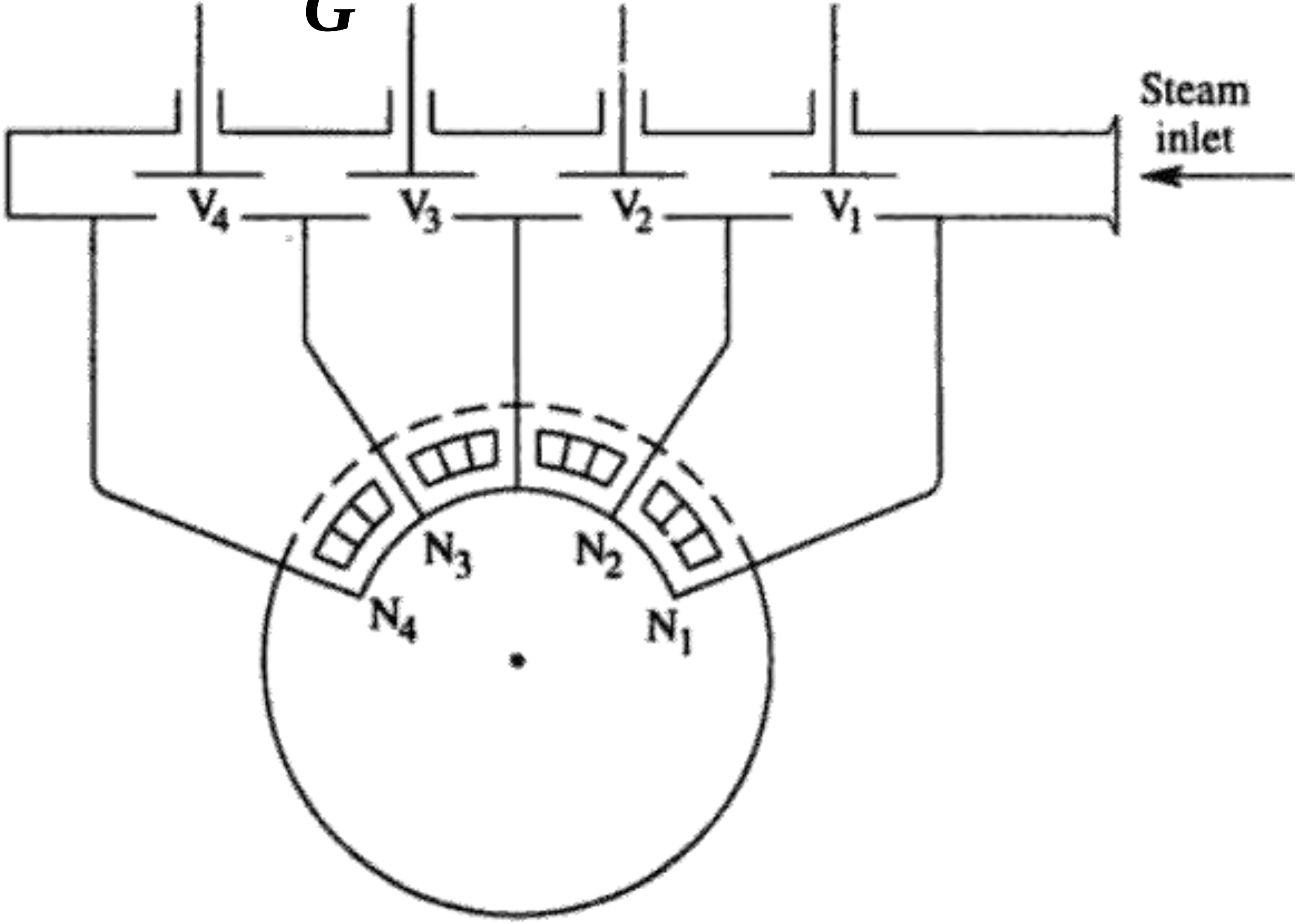


# THROTTLE GOVERNING

## WILLIAN'S LINE

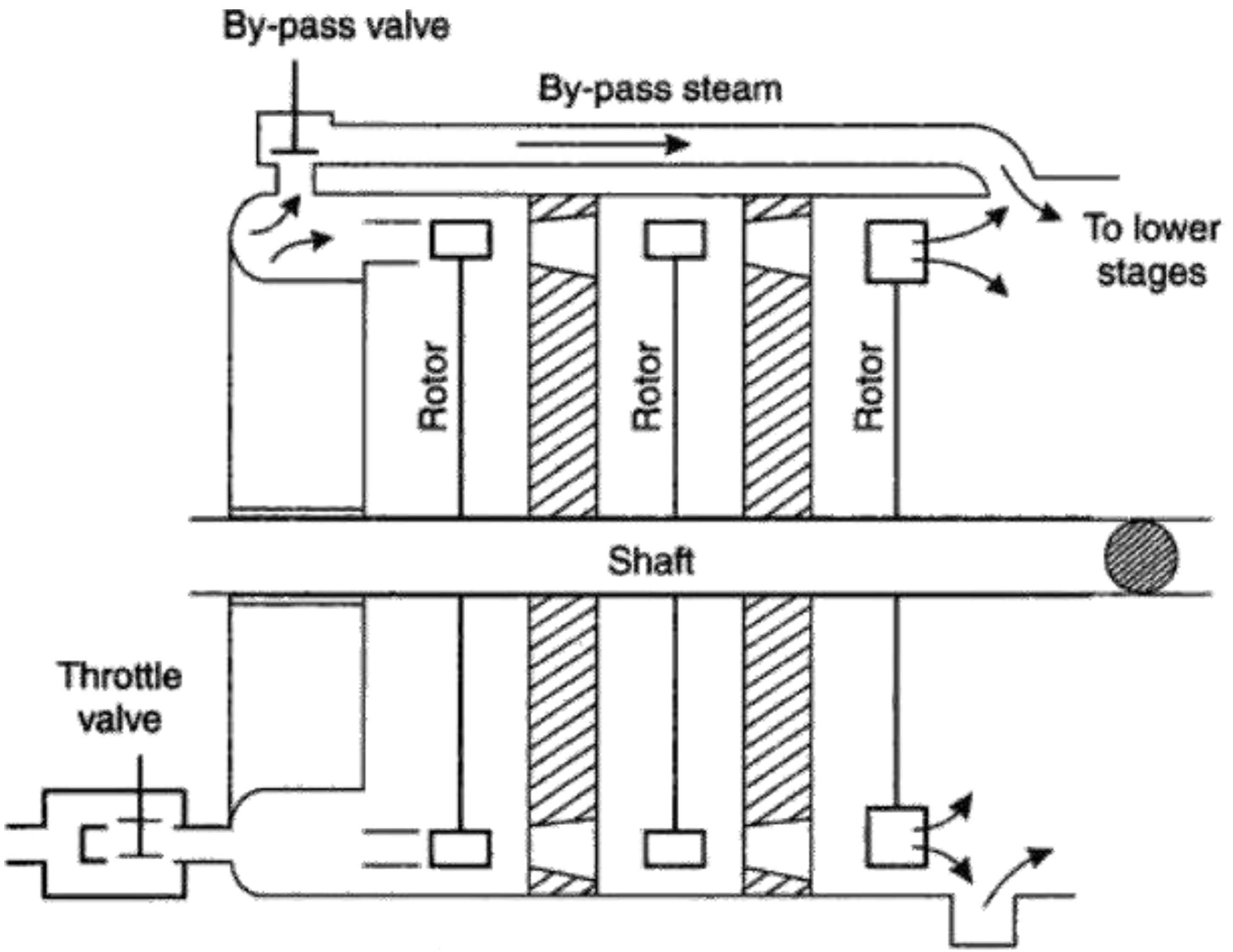


# 2. NOZZLE *GOVERNING*




***Nozzle Control governing***

# 3. BY-PASS GOVERNING

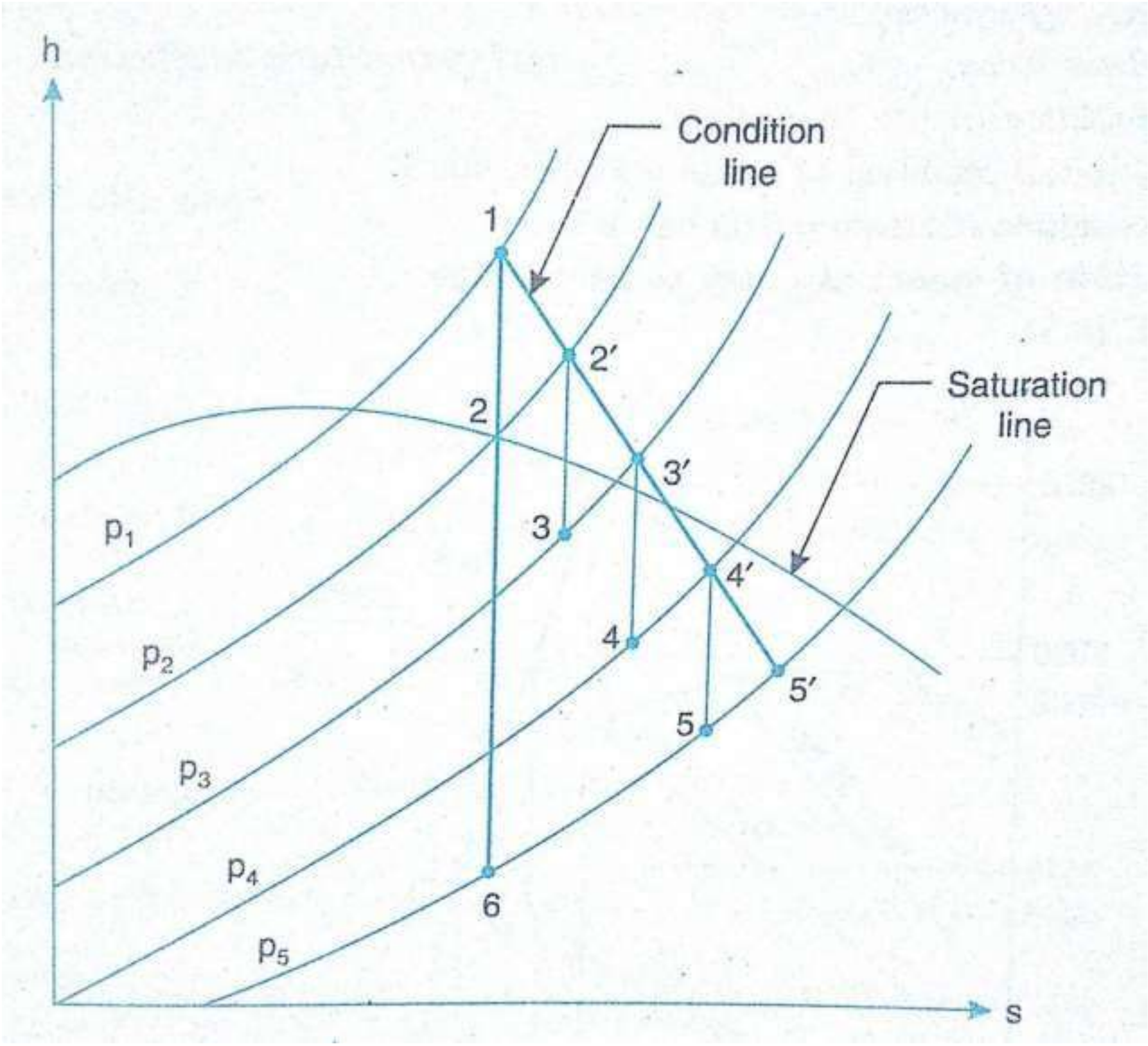



By-Pass Governing

# LOSSES IN STEAM TURBINES

¬ Residual velocity loss
¬ Losses in regulating valves
¬ Loss due to steam friction in nozzle
¬ Loss due to leakage
¬ Loss due to mechanical friction
¬ Loss due to wetness of steam
¬ Radiation loss

# EFFECT OF BLADE FRICTION IN STEAM



# OVERALL EFFICIENCY & REHEAT FACTOR

***Reheat factor:***

It is defined as the ratio of cumulative heat drop to the adiabatic heat drop in all the stages of the turbine. The value of reheat factor depends on the type and efficiency of the turbine, the average value being 1.05.

$$\text{Reheat factor} = \frac{\text{Cumulative heat drop}}{\text{Adiabatic heat drop}} = \frac{A_1B_1 + A_2B_2 + A_3B_3}{A_1D}$$

***Overall efficiency:***

It is defined as the ratio of total useful heat drop to the total heat supplied.

$$\text{Overall efficiency} = \frac{\text{Total useful heat drop}}{\text{Total heat supplied}} = \frac{A_1C_1 + A_2C_2 + A_3C_3}{H_{A1} - h_D}$$

# UNIT-IV GAS TURBINES

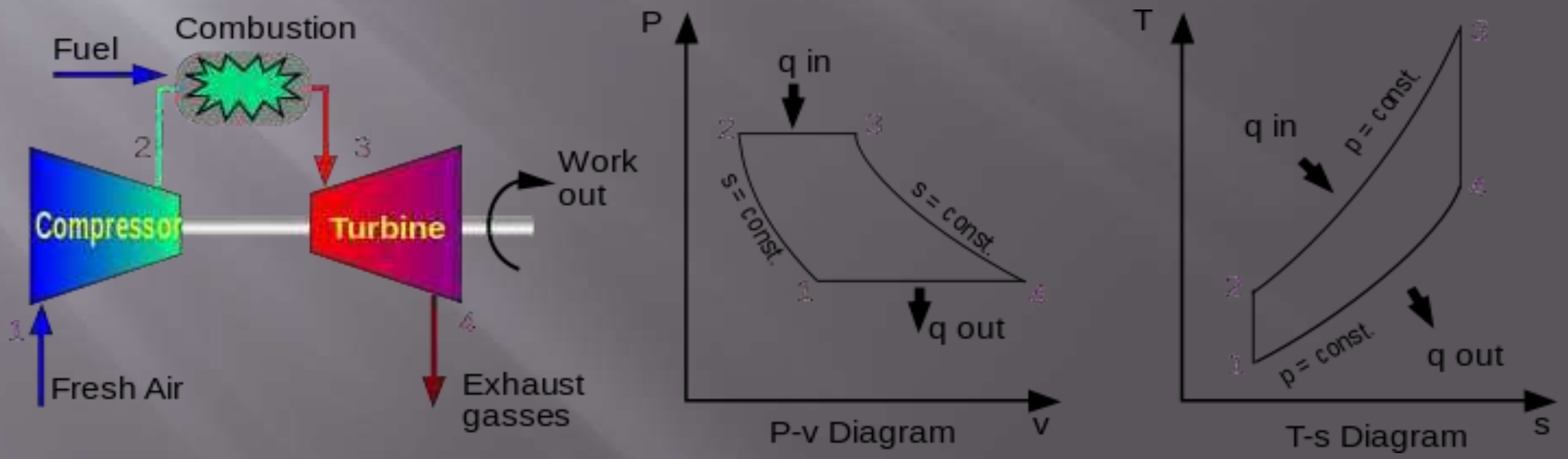
# Gas Turbines?

- Gas turbines also called combustion turbines, a type of IC engine in which burning of an air-fuel mixture produces hot gases that spin a turbine to produce power.
- It is the production of hot gas during fuel combustion, not the fuel itself that the gives gas turbines the name.
- Combustion occurs continuously in gas turbines, as opposed to reciprocating IC engines, in which combustion occurs intermittently.

# Working ?

They Work On Brayton Cycle.

- Air is compressed(squeezed) to high pressure by a compressor.
- Then fuel and compressed air are mixed in a combustion chamber and ignited.
- Hot gases are given off, which spin the turbine wheels



General View of a Gas Turbine

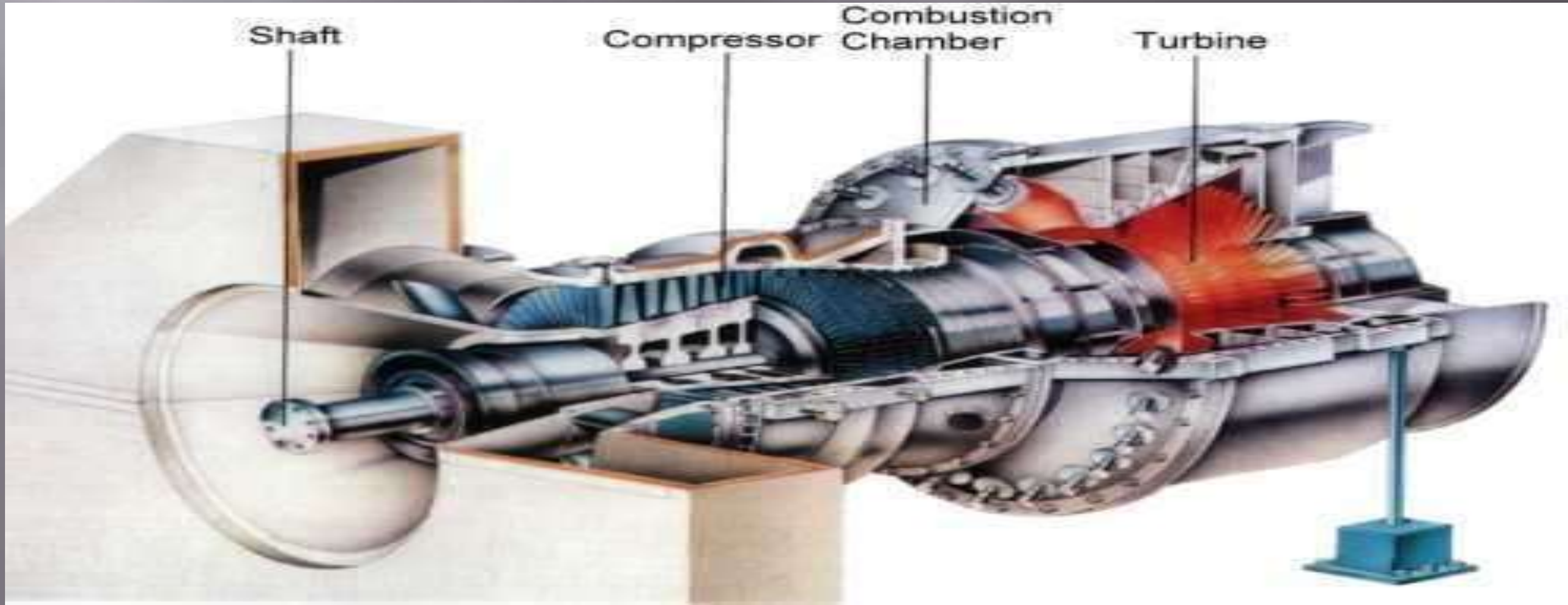
# Components Of Gas Turbine?

Gas turbines have three main parts:

i) Air compressor

ii) Combustion chamber

iii) Turbine



# Air compressor:

- The air compressor and turbine are mounted at either end on a common shaft, with the combustion chamber between them.
- Gas turbines are not self starting. A starting motor is used.
- The air compressor sucks in air and compresses it, thereby increasing its pressure.

# Combustion chamber:

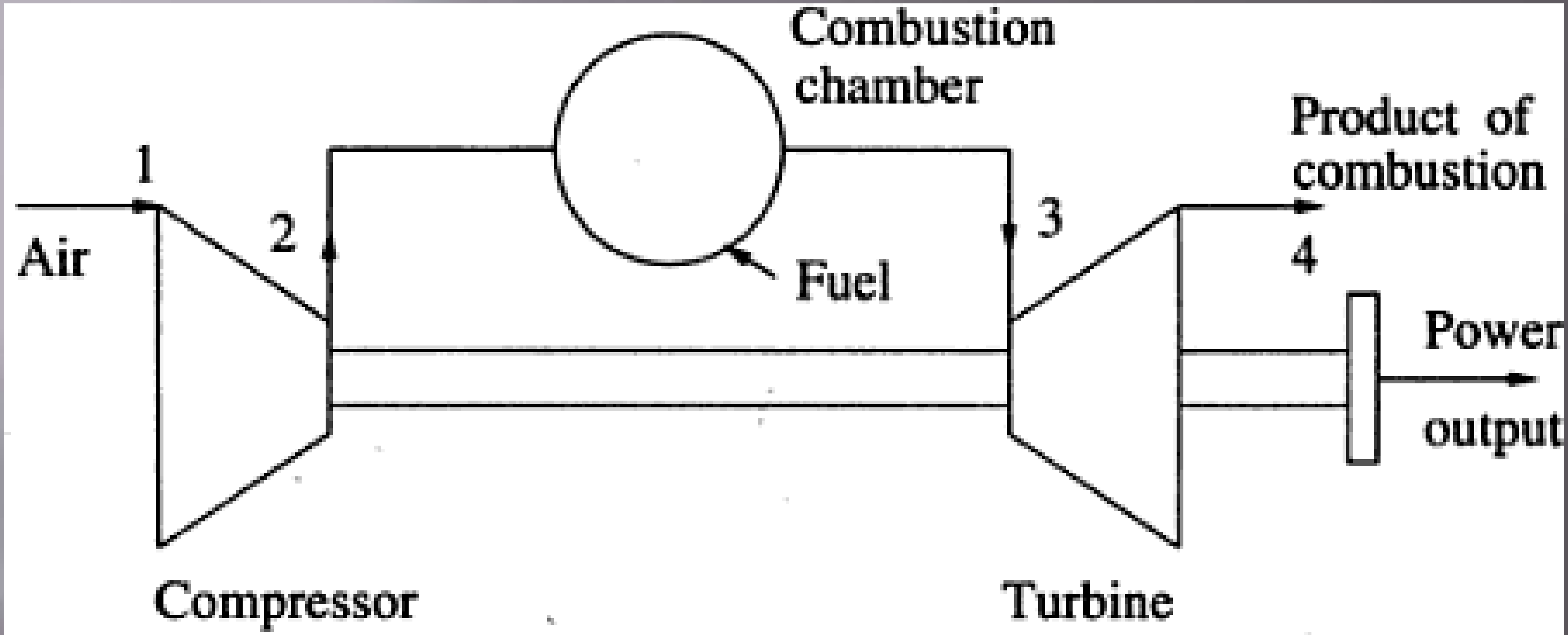
- In the combustion chamber, the compressed air combines with fuel and the resulting mixture is burnt.
- The greater the pressure of air, the better the fuel air mixture burns.
- Modern gas turbines usually use liquid fuel, but they may also use gaseous fuel, natural gas or gas produced artificially by gasification of a solid fuel.

# Turbine:

- Hot gases move through a multistage gas turbine.
- Like in steam turbine, the gas turbine also has stationary and moving blades.
- The stationary blades
  - ✓ guide the moving gases to the rotor blades
  - ✓ adjust its velocity.
- The shaft of the turbine is coupled to a generator.

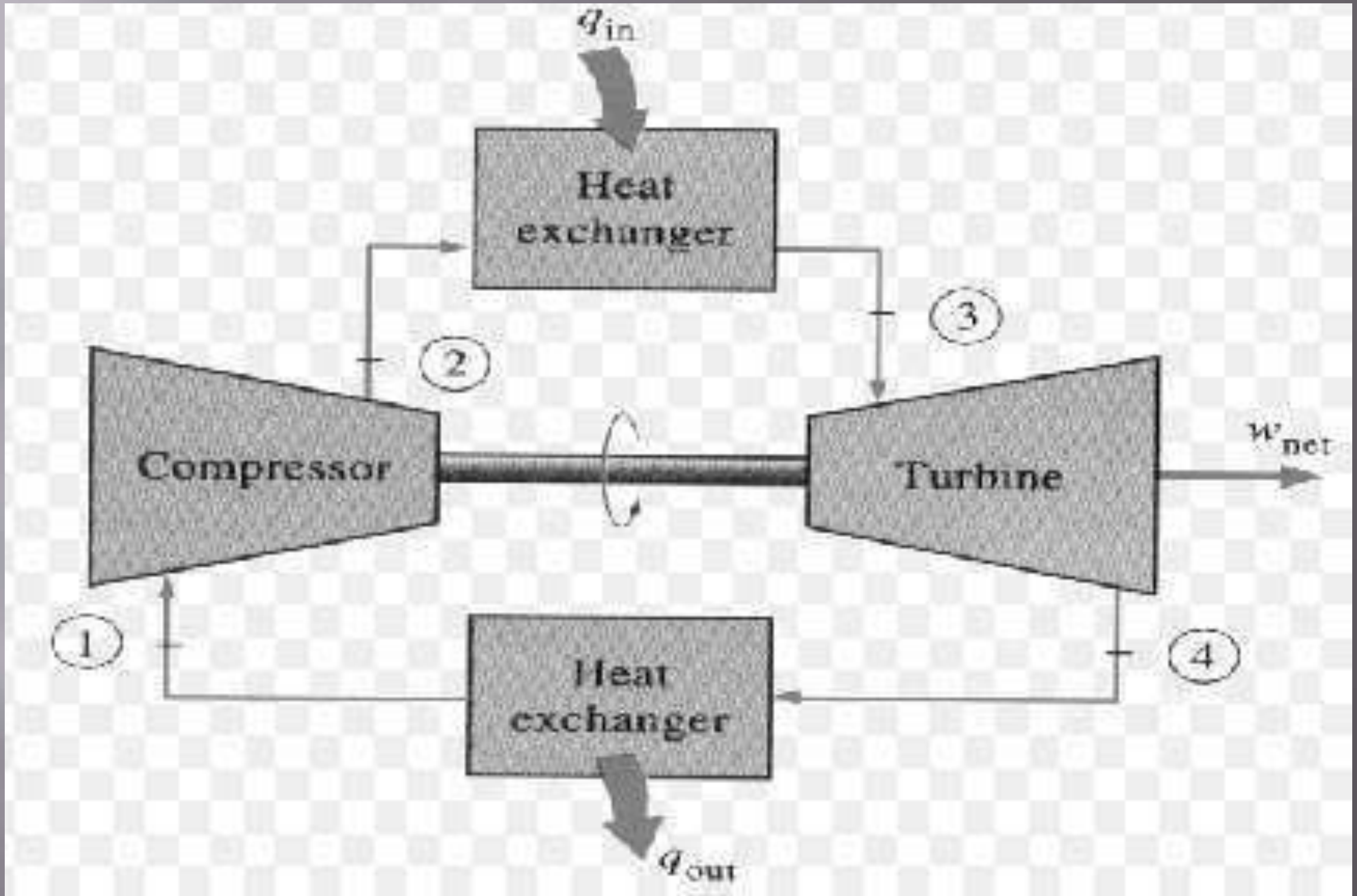
# Types ?

- OPEN CYCLE GAS TURBINE- It consists of a compressor, combustion chamber and a turbine. The compressor takes in ambient air and raises its pressure. Heat is added to the air in combustion chamber by burning the fuel and raises its temperature.
- The heated gases coming out of combustion chamber are then passed to the turbine where it expands doing mechanical work.




OPEN CYCLE GAS TURBINE

- CLOSE CYCLE GAS TURBINE-It uses air as working medium. In closed cycle gas turbine plant, the working fluid (air or any other suitable gas) coming out from compressor is heated in a heater by an external source at constant pressure.
- The high temperature and high-pressure air coming out from the external heater is passed through the gas turbine.
- The fluid coming out from the turbine is cooled to its original temperature in the cooler using external cooling source before passing to the compressor.
- The working fluid is continuously used in the system without its change of phase and the required heat is given to the working fluid in the heat exchanger.



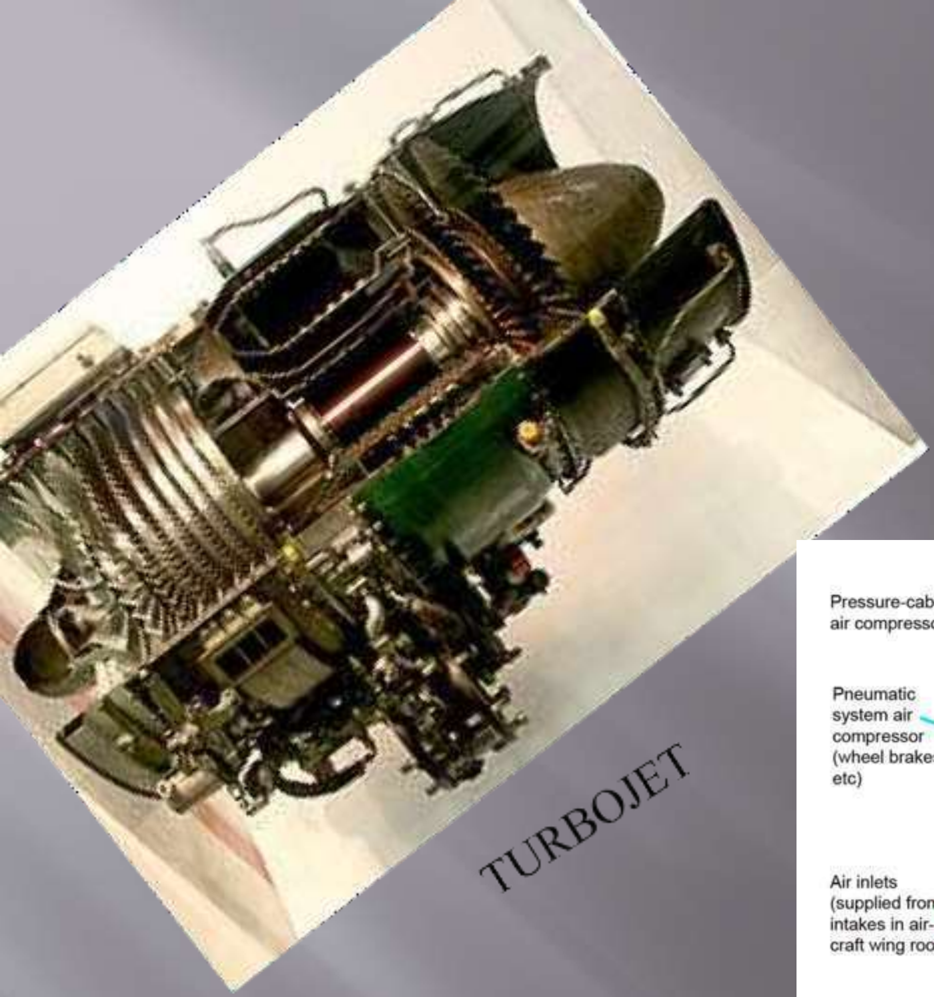

CLOSED CYCLE GAS TURBINE

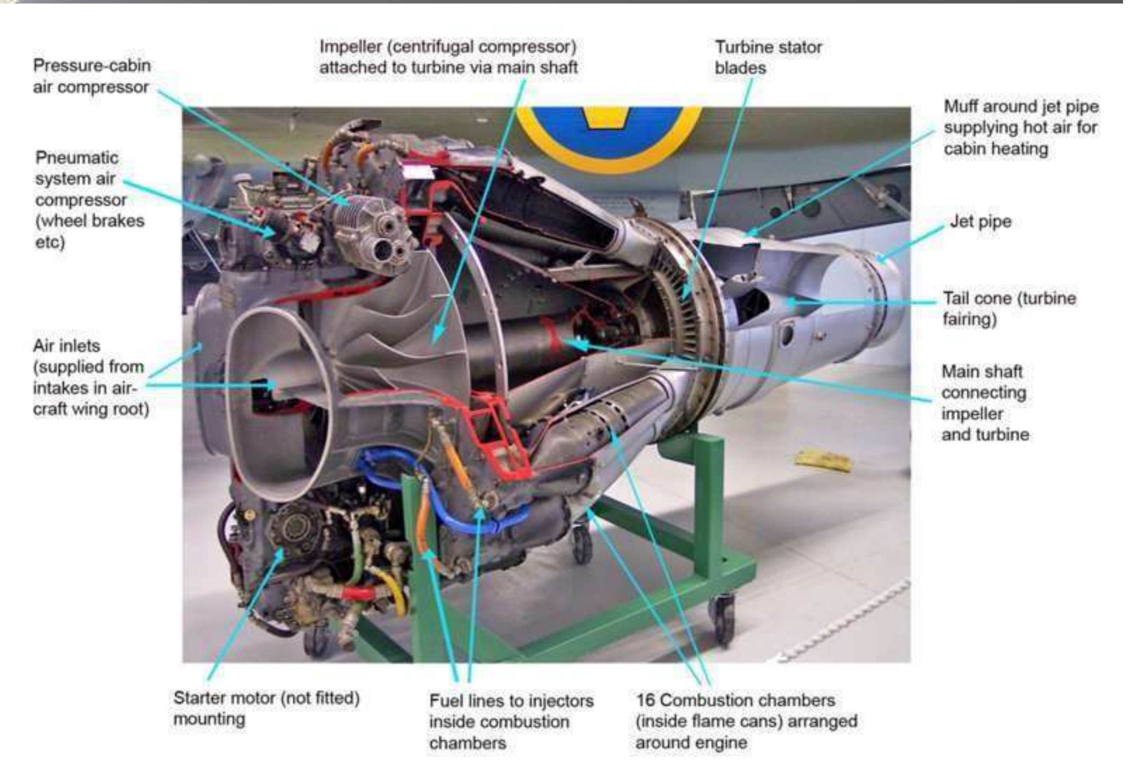
- AERODERIVATIVE GAS TURBINES- Aeroderivatives are also used in electrical power generation due to their ability to be shut down, and handle load changes more quickly than industrial machines. They are also used in the marine industry to reduce weight. Ex- General Electric LM2500, General Electric LM6000.
- SCALE JET ENGINES- Also known as miniature gas turbines or micro-jets. Kurt Schreckling, produced one of the world's first Micro-Turbines, the FD3/67.
- This engine can produce up to 22 newtons of thrust, and can be built by most mechanically minded people with basic engineering tools, such as a metal lathe.

AUXILLARY POWER UNIT- APUs are small gas turbines designed to supply auxiliary power to larger, mobile, machines such as an aircraft. They supply:

- compressed air for air conditioning and ventilation,
- compressed air start-up power for larger jet engines,
- mechanical (shaft) power to a gearbox to drive shafted accessories or to start large jet engines, and
- electrical, hydraulic and other power-transmission sources to consuming devices remote from the APU.

- JET ENGINES- Air breathing jet engines are gas turbines optimized to produce thrust from the exhaust gases, or from ducted fans connected to the gas turbines. Jet engines that produce thrust from the direct impulse of exhaust gases are often called turbojets, whereas those that generate thrust with the addition of a ducted fan are often called turbofans or (rarely) fan-jets.




Scale Jet Engines

# ADVANTAGES?

- Storage of fuel requires less area and handling is easy.
- The cost of maintenance is less.
- It is simple in construction. There is no need for boiler, condenser and other accessories as in the case of steam power plants.
- Cheaper fuel such as kerosene , paraffin, benzene and powdered coal can be used which are cheaper than petrol and diesel.
- Gas turbine plants can be used in water scarcity areas.
- Less pollution and less water is required.

# DISADVANTAGES?

- 66% of the power developed is used to drive the compressor. Therefore the gas turbine unit has a low thermal efficiency.
- The running speed of gas turbine is in the range of (40,000 to 100,000 rpm) and the operating temperature is as high as 1100 – $1260^{0}$C. For this reason special metals and alloys have to be used for the various parts of the turbine.
- High frequency noise from the compressor is objectionable.

# APPLICATIONS?

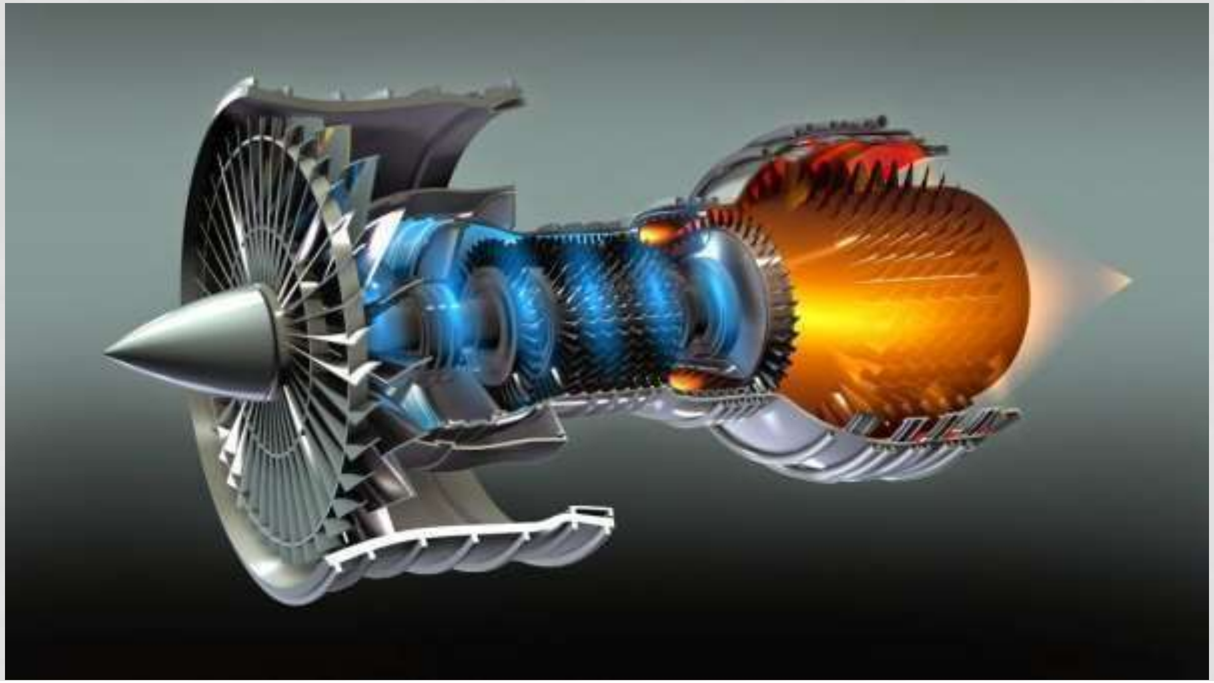
- drive pumps, compressors and high speed cars.
- aircraft and ships.
- Power generation (used for peak load and nd-by unit).

# THANK YOU!!

# JET ENGINES

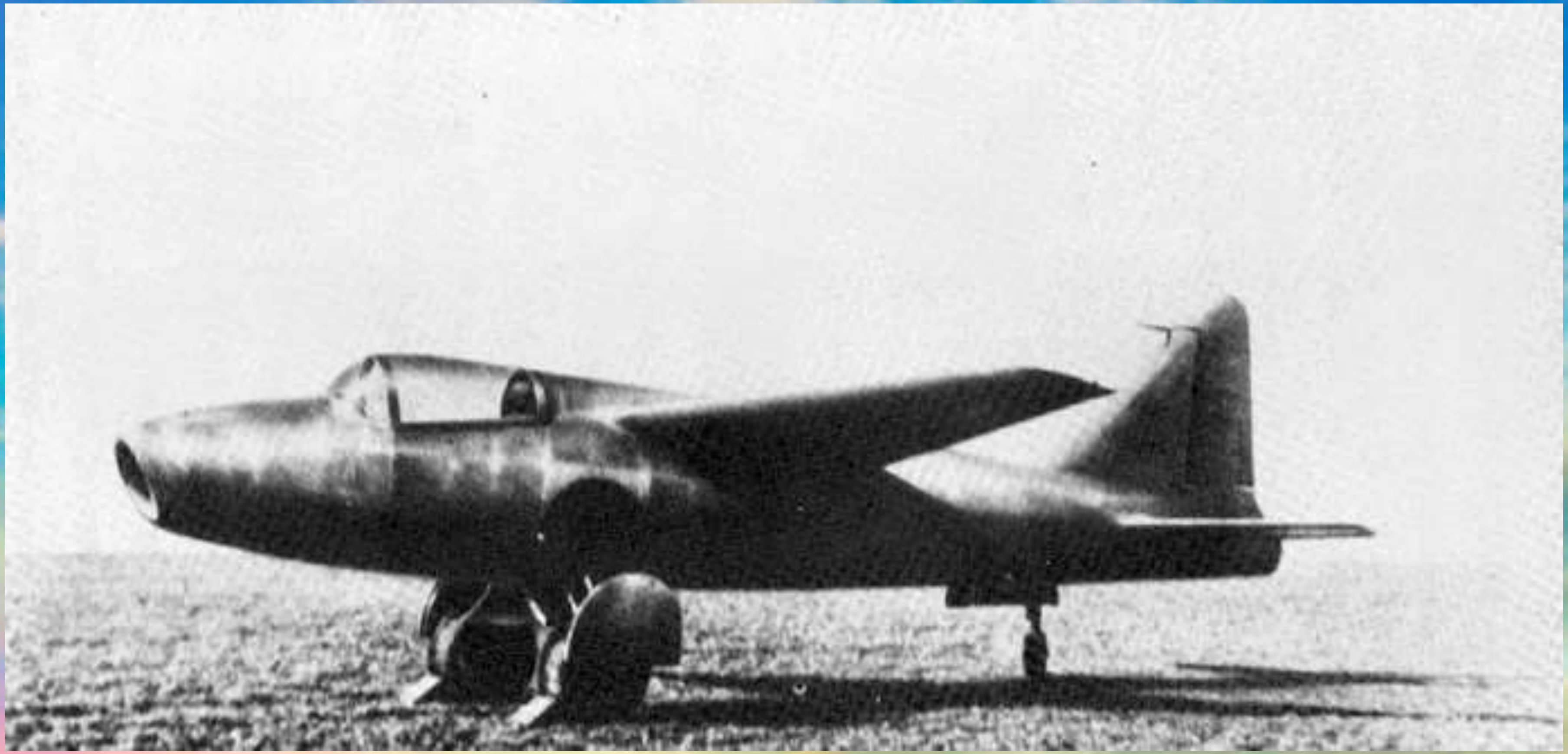
# INTRODUCTION

- A jet engine is a reaction engine that discharges a fast moving jet which generates thrust by jet propulsion in accordance with Newton's laws of motion. This broad definition of jet engines includes turbojets, turbofans, rockets, ramjets, and pulse jets. jet engine is nothing but a Gas Turbine.



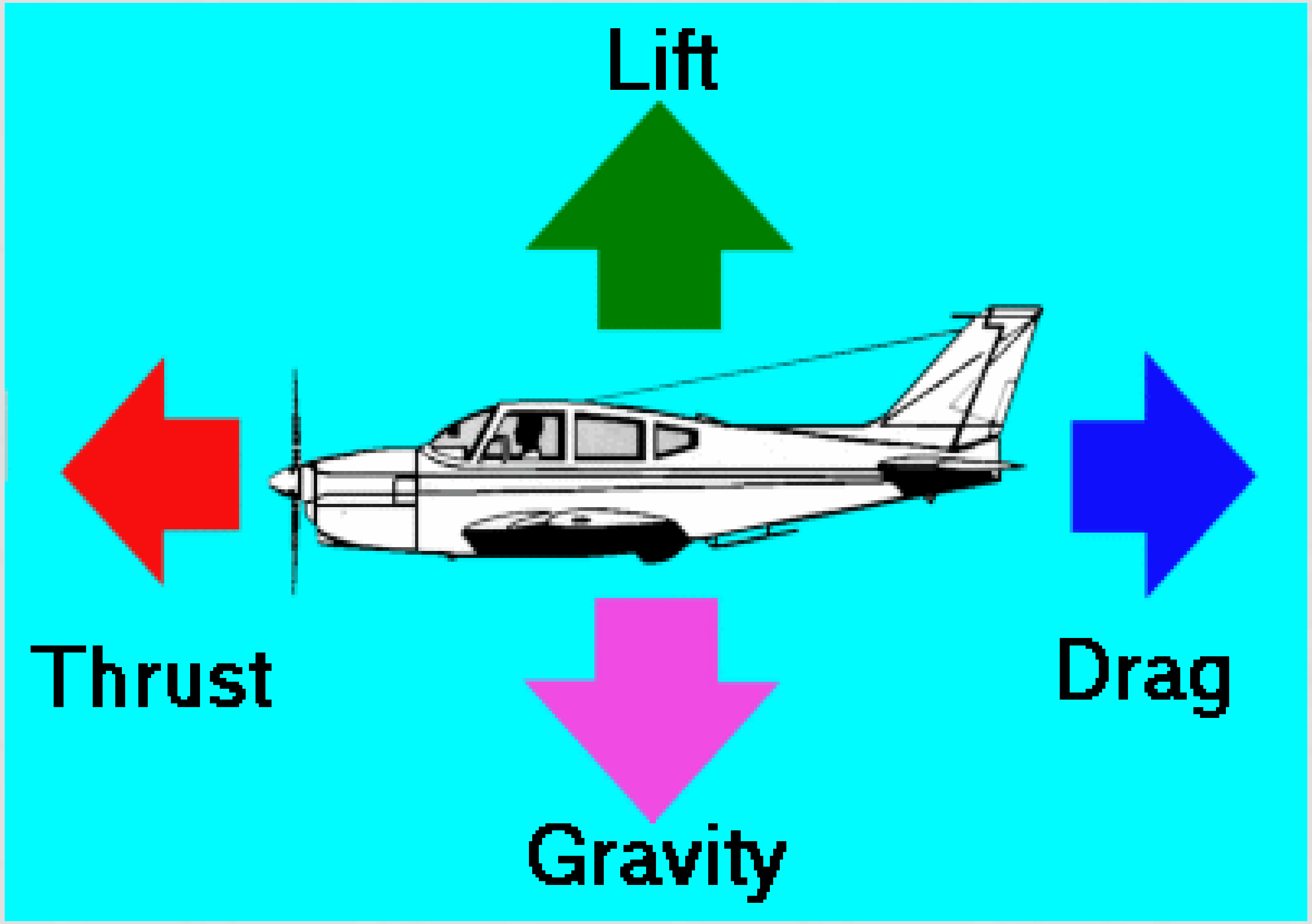
# HISTORY OF JETENGINE

- The first jet engine was built by Egyptian scientists during 100 B.C
- This device was known as Aeolipile.
- Jet propulsion only took off with the invention of the gunpowder-powered rocket by the Chinese in the 13th century.



Heinkel He 178, the world's first aircraft to fly purely on turbojet power

# HOW DOES AN AEROPLANE FLY



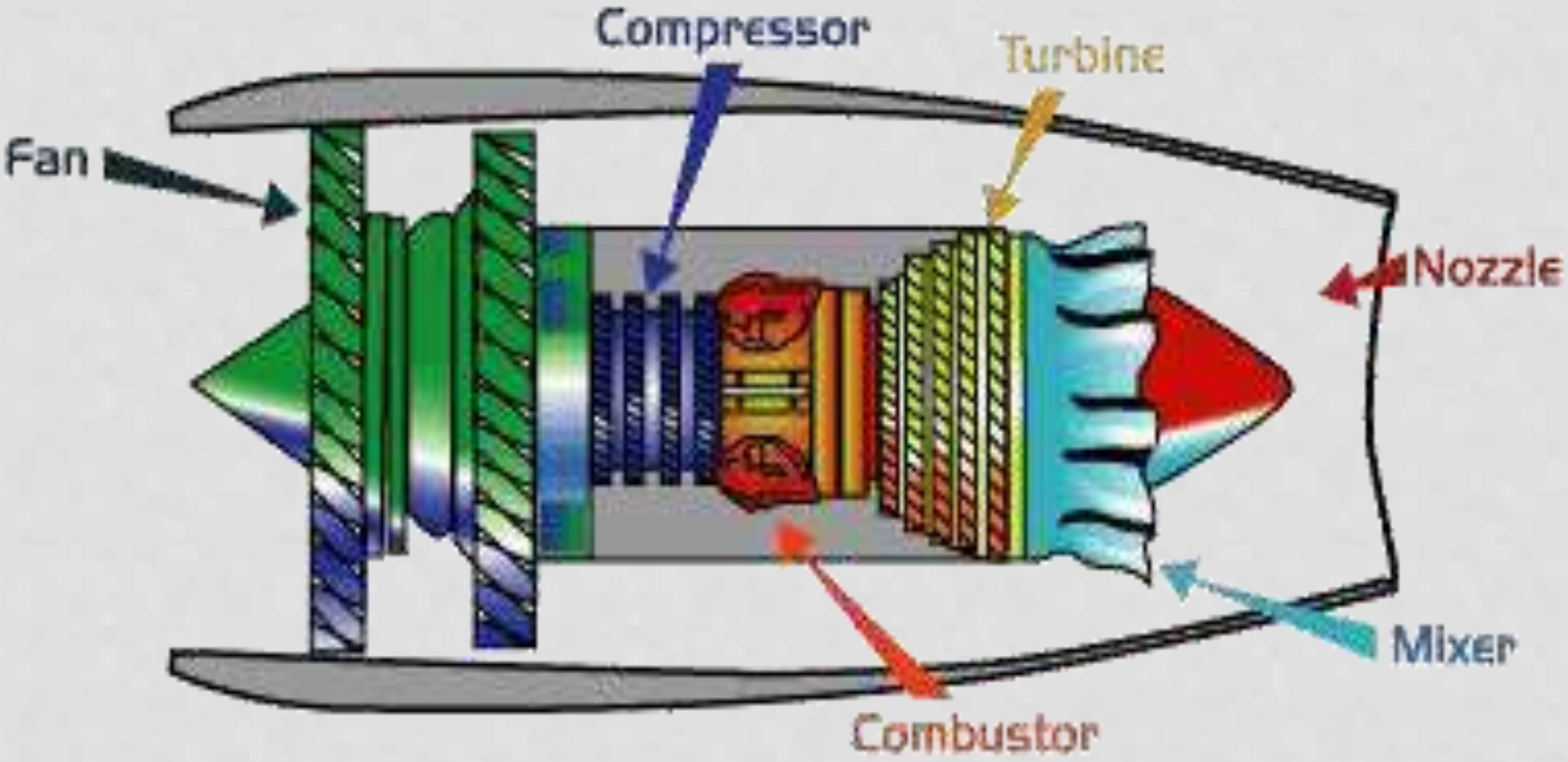
# PRINCIPLE OF JET ENGINE :

- Principle of jet engine is based on Newton's second and third law of motion.

- Second law states that the rate of change of momentum in any direction is proportional to the force acting in that direction.

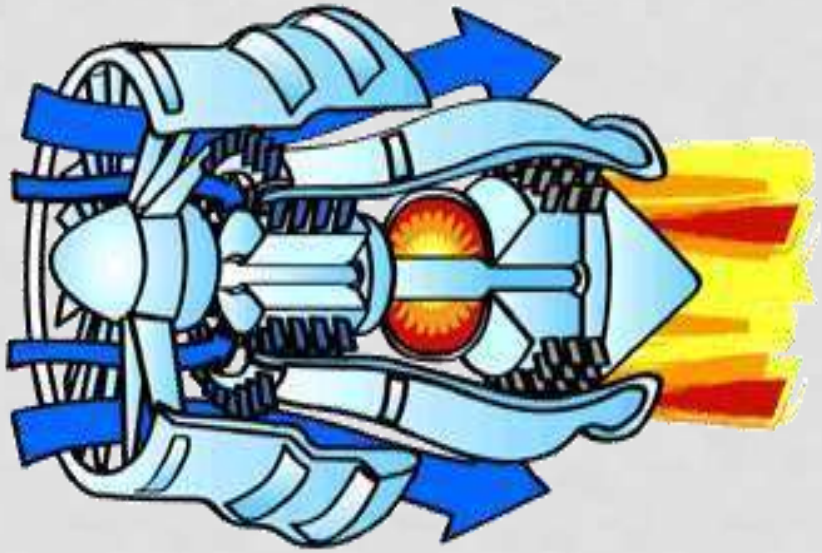
- Third law states that for every action there is an equal and opposite reaction.

# WORKING OF JET ENGINE



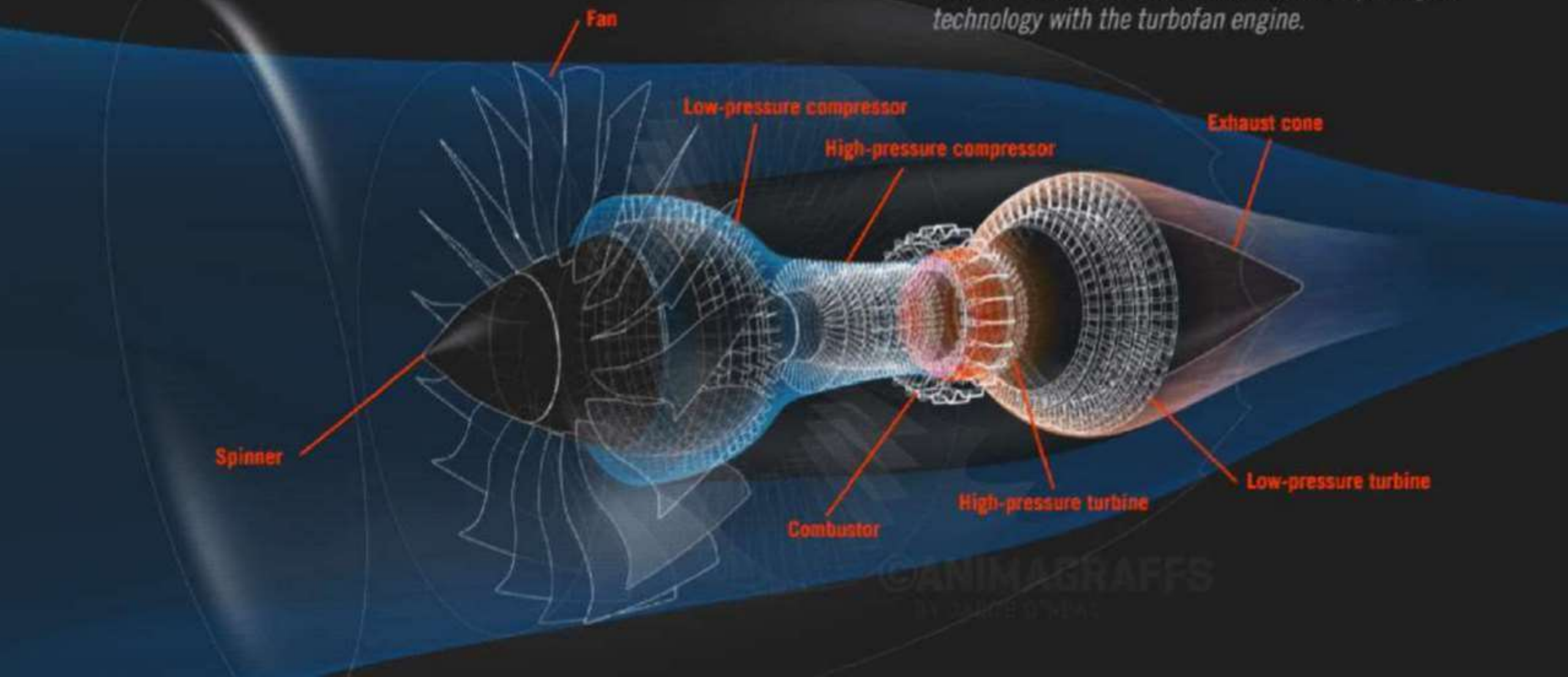
# WORKING OF JET ENGINE

- Sucks in air from front with fan
- A compressor raises the pressure of the air
- Then the compressed air is ignited
- Gas expends and comes out nozzle
- Engine/Aircraft thrusts forward

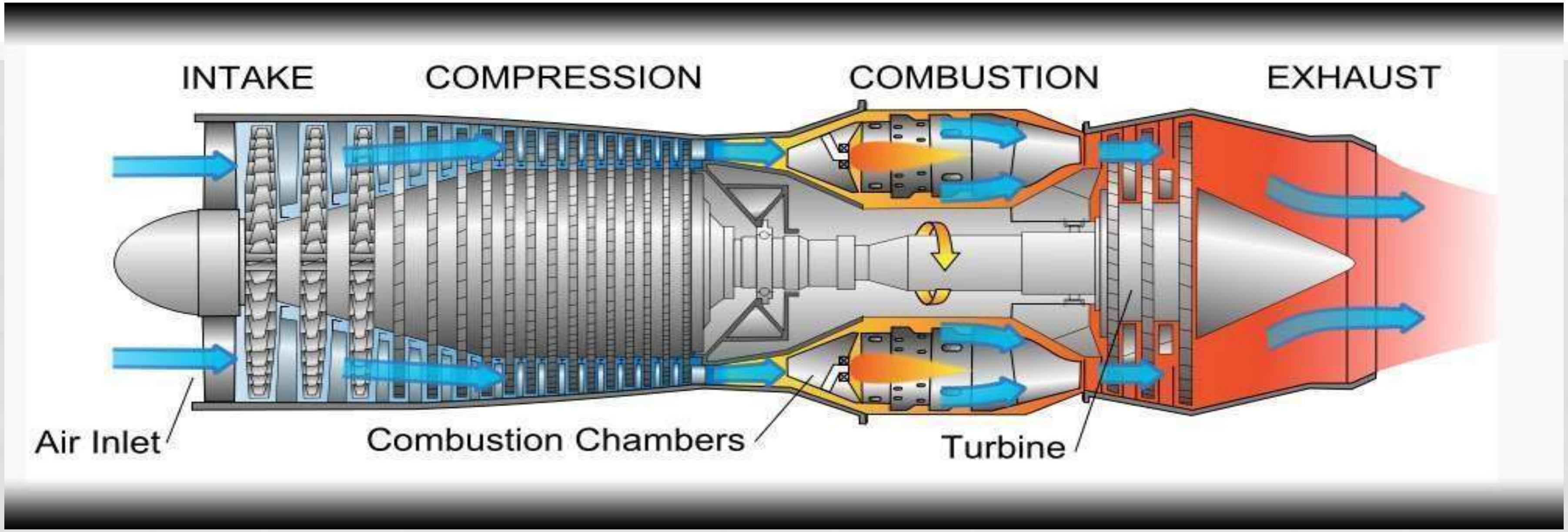


# JET ENGINE

At takeoff, a jetliner engine can move 1.25 tons of air per second. That's enough power to suck all the air out of the largest American football stadium in less than a minute! Here's a basic look at incredible jet engine technology with the turbofan engine.

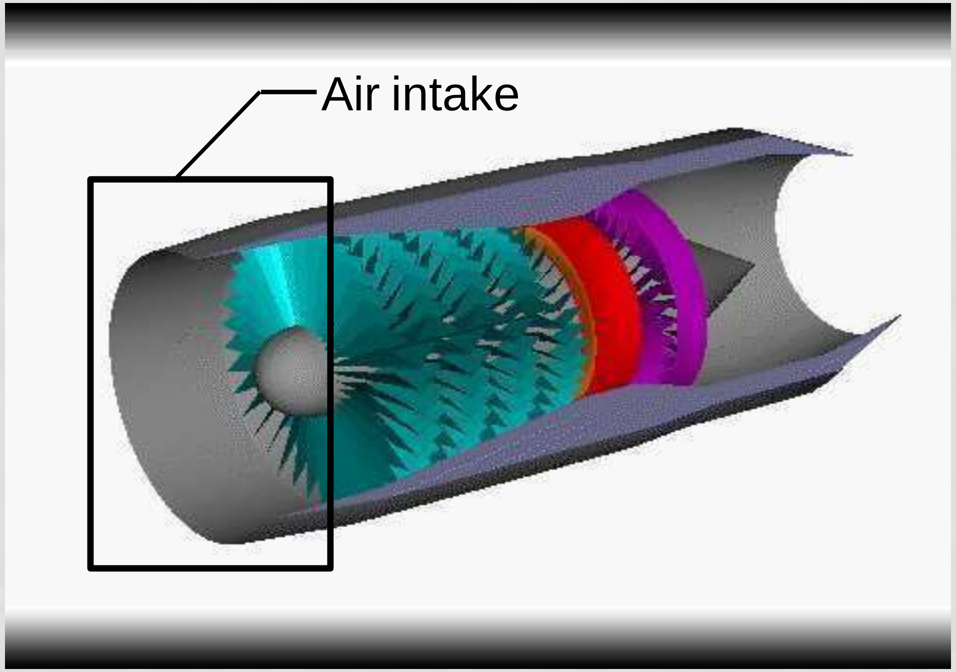


# PARTS OF JET ENGINE

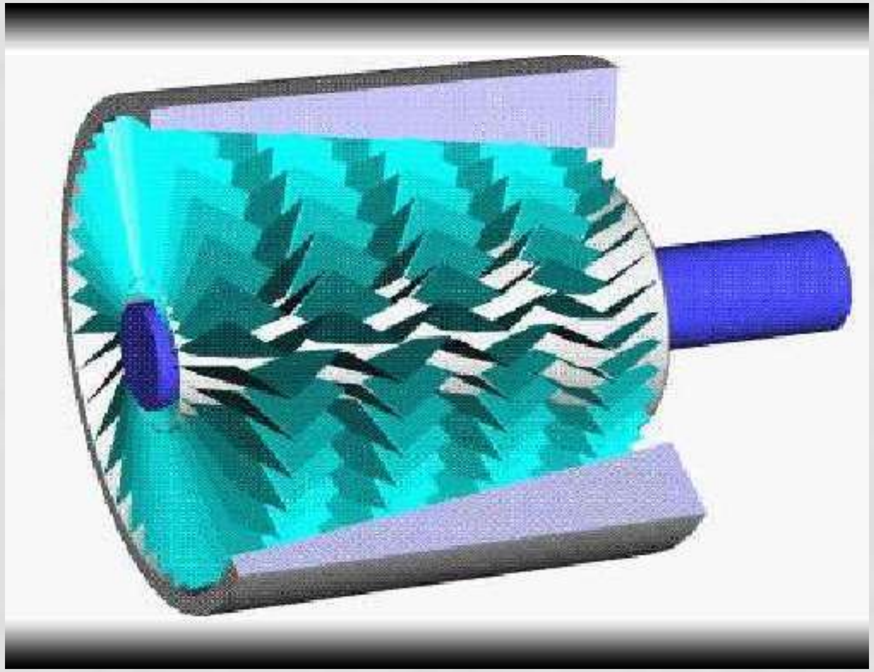



- Air intake (Fan)
- Compressor
- Combustion chamber
- Turbine
- Nozzle

# PARTS OF JET ENGINE

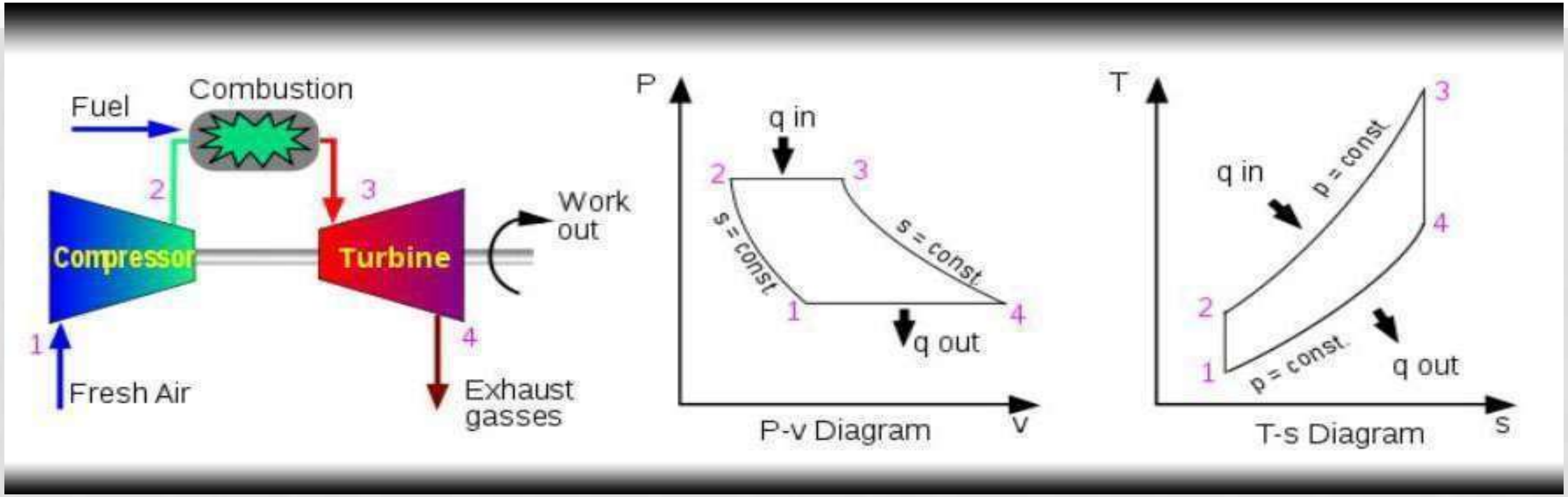



Air intake (Fan)



compressor

# BRAYTON CYCLE

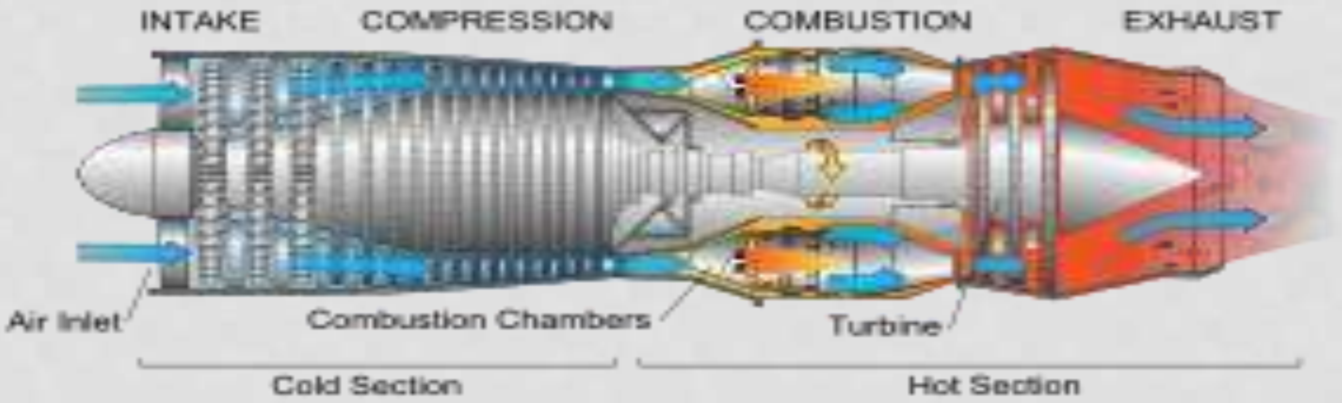



Ideal thermodynamic cycle divided into following process:

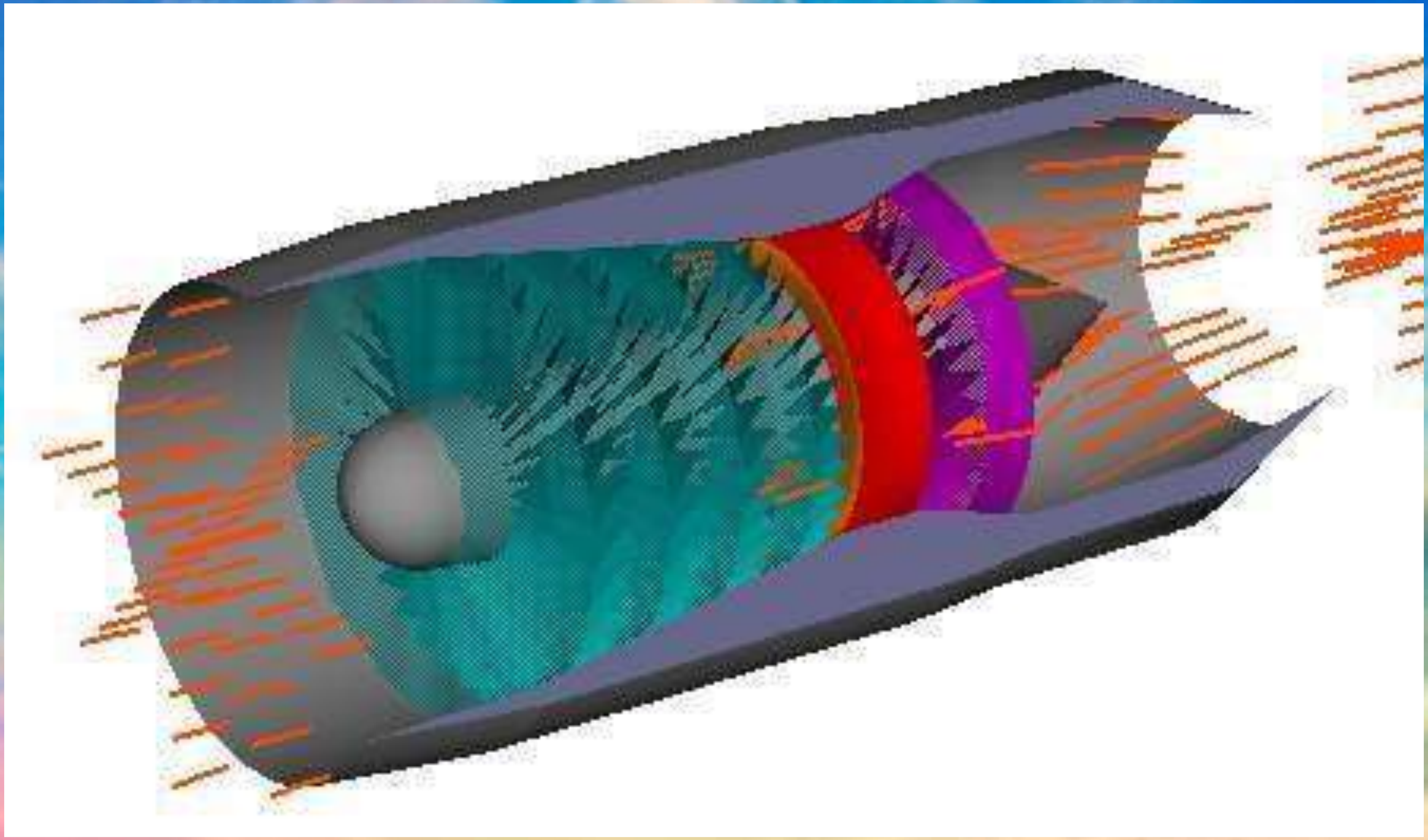
- Isentropic compression process
- Isobaric heat addition process
- Isentropic expansion process
- Isobaric heat rejection process

# TYPES OF JET ENGINE

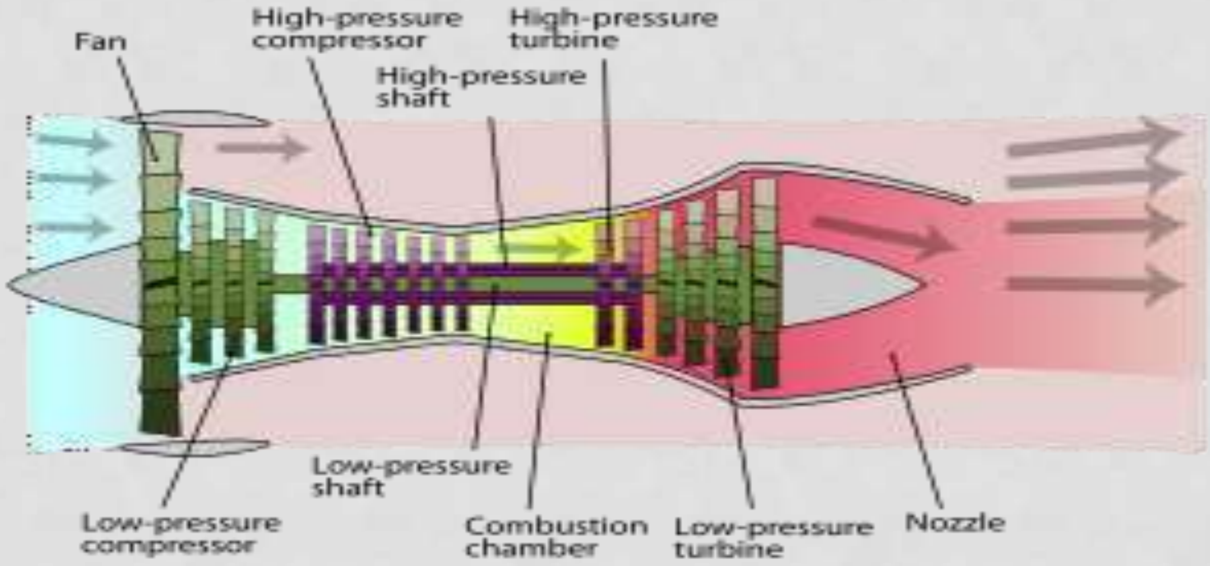
- TURBOJET ENGINE




The turbojet is an airbreathing jet engine, usually used in aircraft. It consists of a gas turbine with a propelling nozzle. The gas turbine has an air inlet, a compressor, a combustion chamber, and a turbine (that drives the compressor).

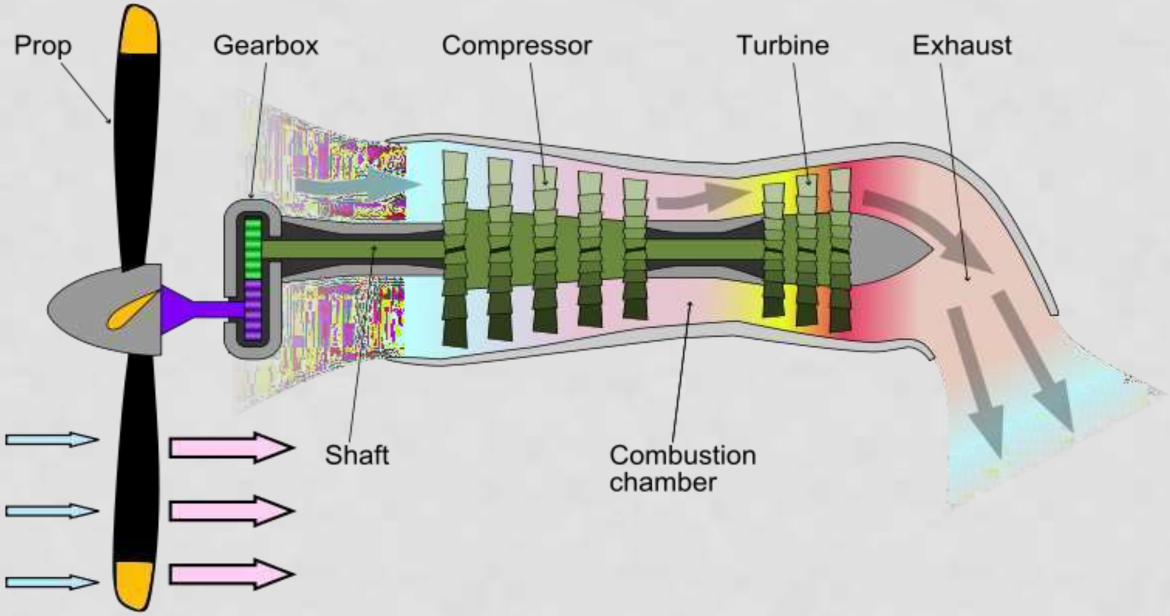


# TURBOFAN



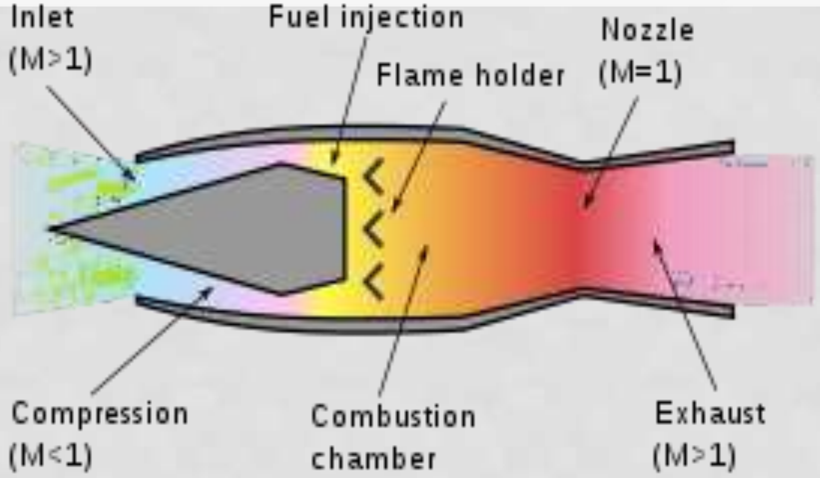

The word "turbofan" is combination of "turbine" and "fan": the turbo portion refers to a gas turbine engine which takes mechanical energy from combustion, and the fan, a ducted fan that uses the mechanical energy from the gas turbine to accelerate air rearwards.

# TURBO PROP




A turbprop engine is a turbine engine that drives an aircraft propeller. In contrast to a turbojet, the engine's exhaust gases do not contain enough energy to create significant thrust, since almost all of the engine's power is used to drive the propeller.

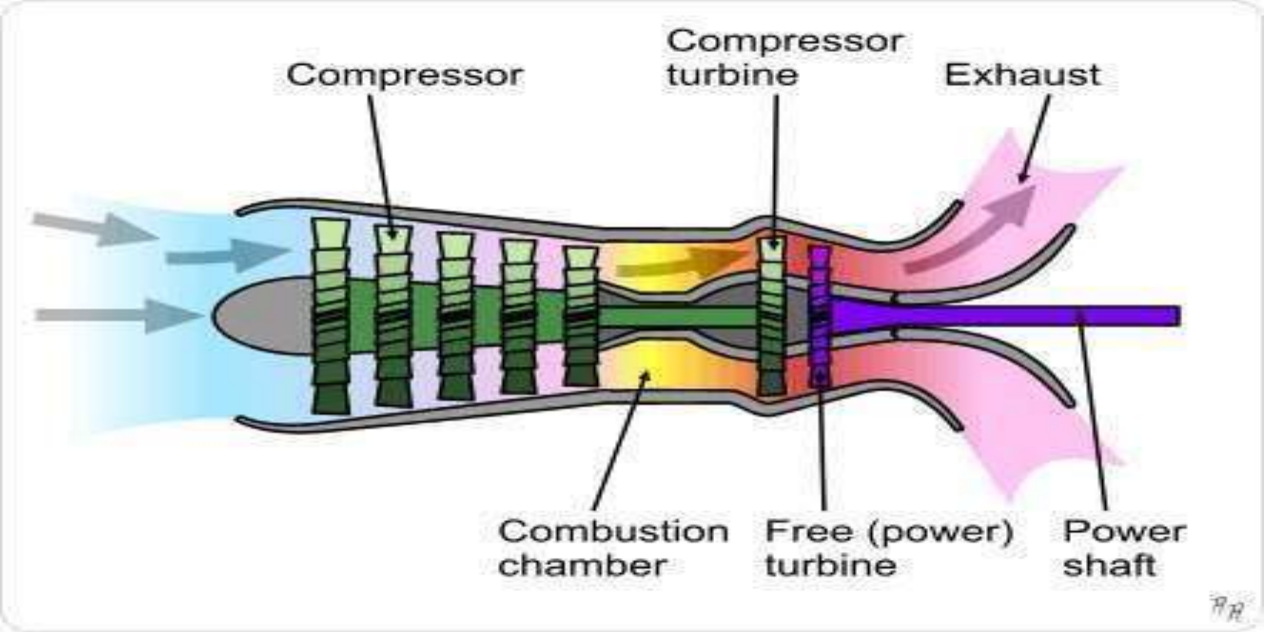
# RAMJET




Ramjets cannot produce thrust at zero airspeed; they cannot move an aircraft from a standstill. A ramjet-powered vehicle, therefore, requires an assisted take-off like a rocket assist to accelerate it to a speed where it begins to produce thrust. Ramjets work most efficiently at supersonic speeds around Mach 3

IT IS A FORM OF AIRBREATHING JET ENGINE THAT USES THE ENGINE'S FORWARD MOTION TO COMPRESS INCOMING AIR WITHOUT AN AXIAL COMPRESSOR.


# TURBO SHAFT




A turboshaft engine is a form of gas turbine which is optimized to produce shaft power rather than jet thrust. They are even more similar to turboprops, with only minor differences, and a single engine is often sold in both forms.

# MERITS & DEMERITS

## Merits of Jet engine over IC engine

- Mechanical efficiency of jet engine is high as compared to IC engine.
- Speed of jet engine per HP developed is higher than IC engine.
- Ignition and lubricating systems are much simpler in jet engine than IC engine.

# DEMERITS OF JET ENGINES OVER IC ENGINE

- Thermal efficiency of Jet engine is low compared to IC engine.
- Difficult to start.
- Turbine blades need a special cooling system due high temperature.

# APPLICATION OF JET ENGINE

- The industry they're most prominent in is in the transport industry, where they are used to propel aircraft, boats, and in some one of creations such as a turbojet powered truck.
- The first use of the jet engine was to power military aircraft.
- Normal type of jet engine is used for domestic purpose i.e. Traveling, carrying goods etc.
- As industrial gas turbine for power generation , natural gas , oil pumps etc.

# LATEST AND FASTEST JET ENGINE

***North American X-15***

This aircraft has the current world record for the fastest manned aircraft. Its maximum speed was mach 6.70 (about 7,200 km/h) which it attained on the 3rd of October 1967


THANK YOU