Introduction to Turbomachines

Session delivered by:

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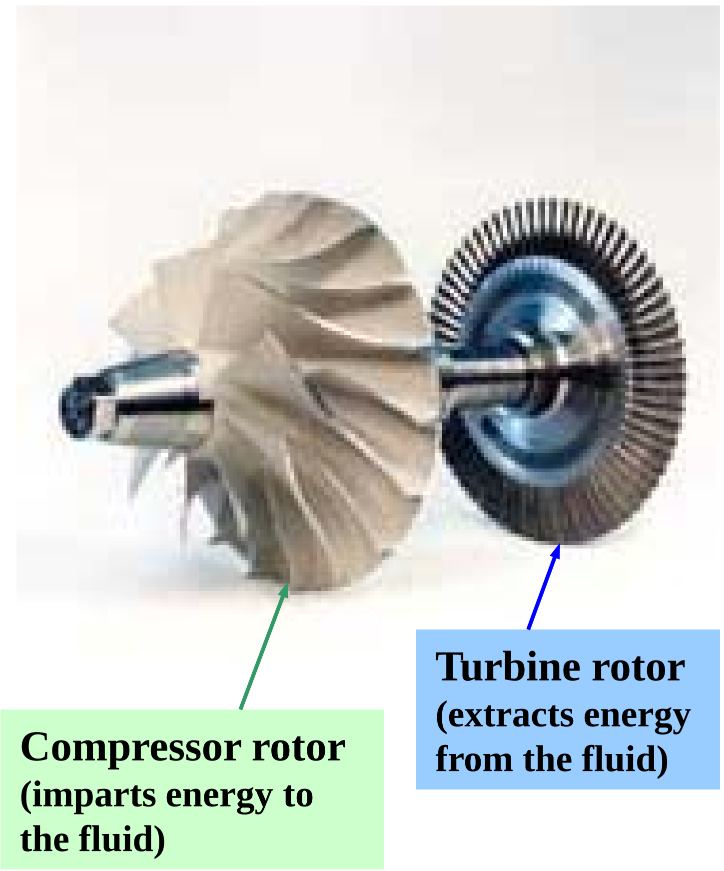
Session Objectives

This session is intended to introduce the following:

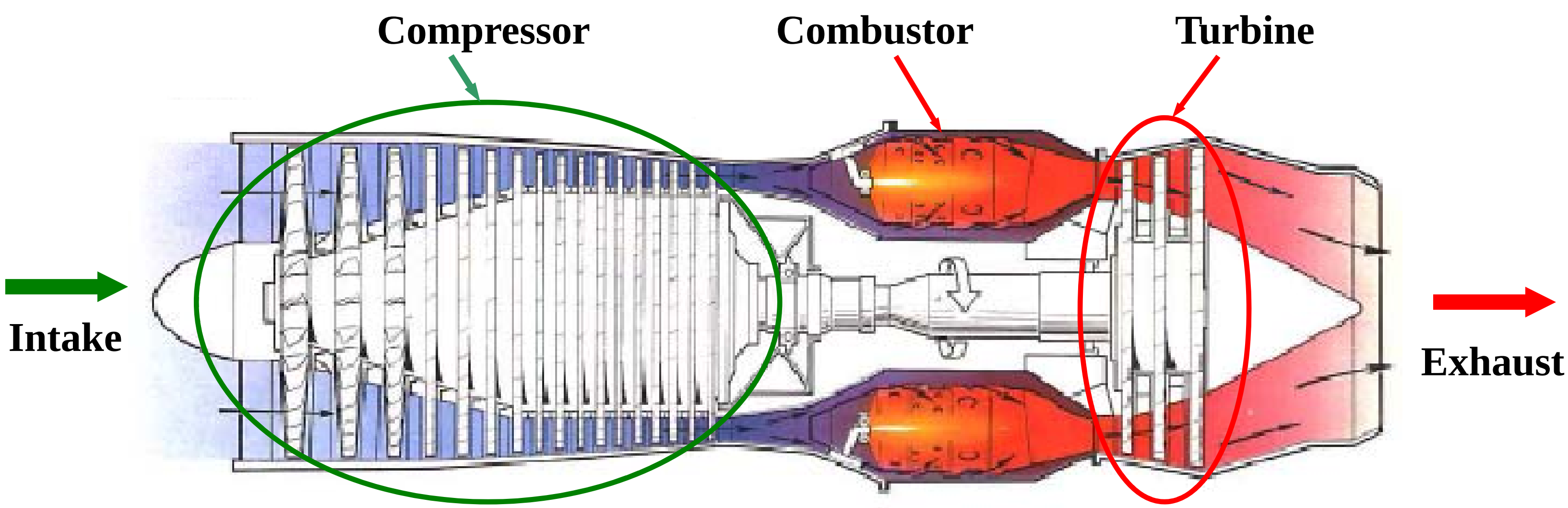
- Turbomachinery and their application
- Types of turbomachines
    - power producing and power absorbing machines
    - axial and radial flow turbomachines
    - single stage and multistage turbomachines
    - thermal and hydro turbomachines

Introduction to Turbomachinery

- A turbomachine is basically a rotating machine
- The rotating wheel is called a rotor / runner / impeller
- The rotor will be immersed in a fluid continuum
- The fluid medium can be gas / steam / water / air
- Energy transfer takes place either
  - ➢ from rotor to fluid, *or*
  - ➢ from fluid to rotor

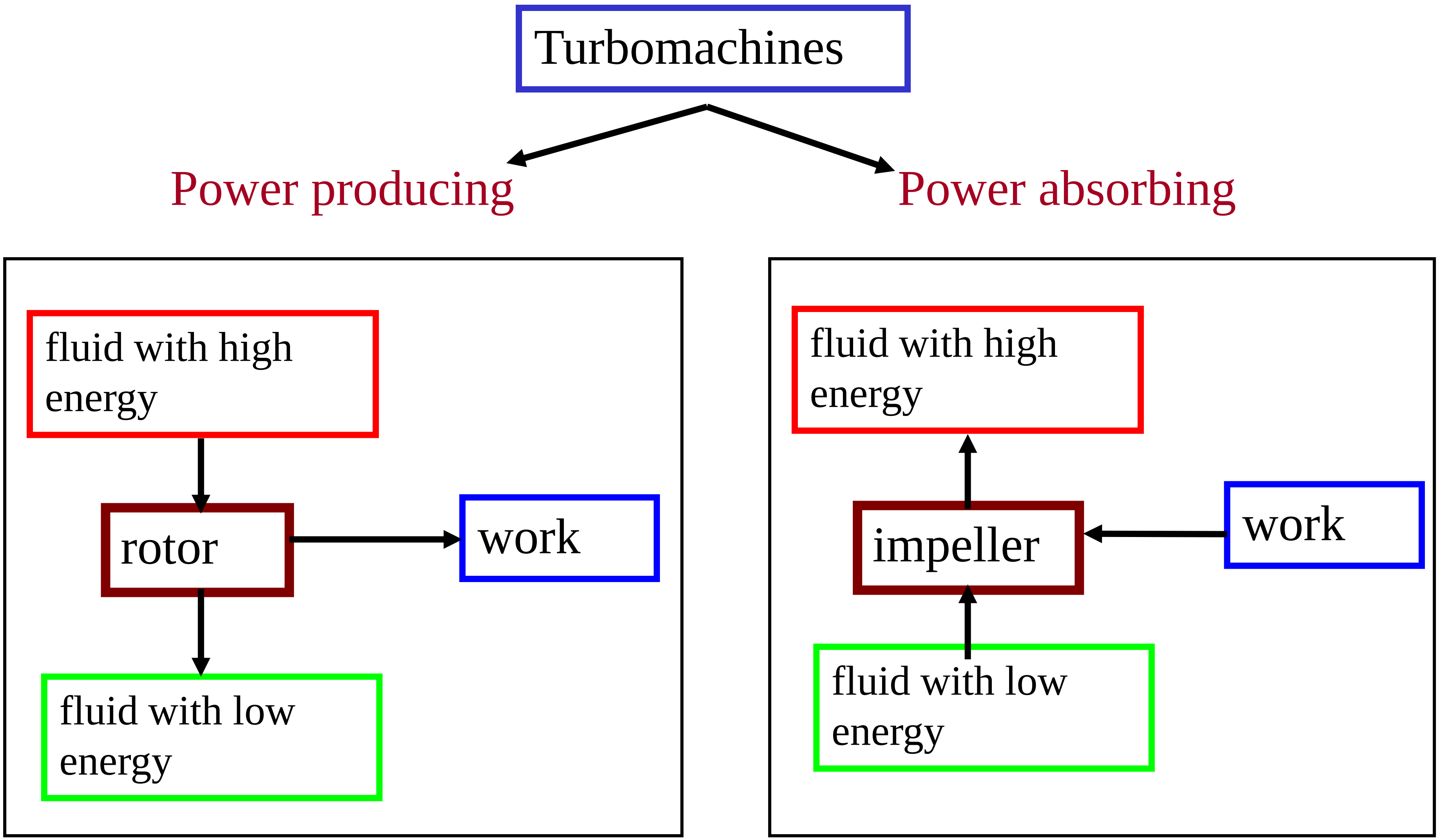


Turbomachine - Definition



- A turbomachine is a device where mechanical energy in the form of shaft work, is transferred either *to* or *from* a continuously flowing fluid by the dynamic action of rotating blade rows.
- The interaction between the fluid and the turbomachine blades also results in fluid dynamic lift.
- A turbomachine produces change in enthalpy of the fluid passing through it.

Turbomachine - Classifications



Turbomachine - Classification

Turbomachines may also be classified as:

- Turbines, compressors, pumps, fans , blowers
- Incompressible or compressible
- Axial-flow, mixed-flow or radial-flow geometry
- Single stage or multi-stage
- Turbo-pump, turbo-compressor or torque-converter
- Impulse, reaction or impulse-reaction

Power Absorbing Turbomachines

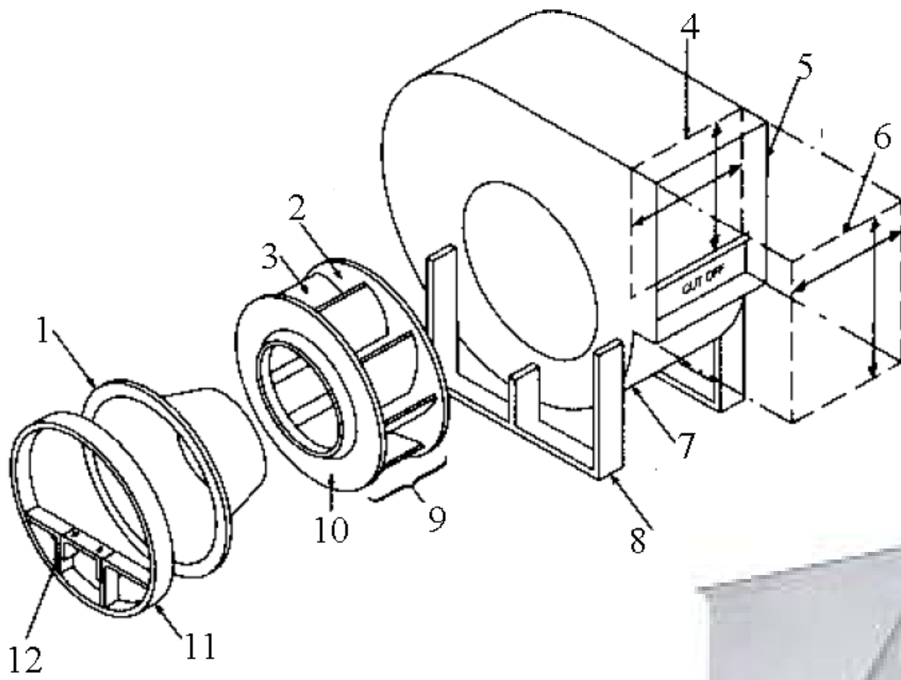
- Fans - air is the working medium
  - **axial flow**
  - **radial flow (centrifugal)**
- Blowers - air is the working medium
  - **axial flow**
  - **radial flow (centrifugal)**
- Propellers and Ducted Fans- air is the working medium
- Compressors - air is the working medium
  - **reciprocating**
  - **rotary**
    - **axial flow**
    - **radial flow (centrifugal)**
    - **mixed flow**
- Pumps - water is the working medium
  - **reciprocating**
  - **rotary**
    - **axial flow**
    - **radial flow (centrifugal)**
    - **mixed flow**

Power Producing Turbomachines

- Gas turbines – air and combustion gas is the working medium
  - axial flow
  - radial flow
- Steam turbine – steam is the working medium
  - impulse turbine
  - reaction turbine
- Hydraulic turbines – water is the working medium
  - impulse turbine
  - reaction turbine
    - **mixed flow**
    - **axial flow**
- Wind turbines – air / wind is the working medium
  - vertical axis
  - horizontal axis

Parts of Centrifugal Fan / Blower

1. Inlet
2. Back plate
3. Blade
4. Blast area
5. Discharge
6. Outlet area
7. Scroll
8. Frame
9. Impeller
10. Rim / shroud
11. Inlet collar
12. Bearing support

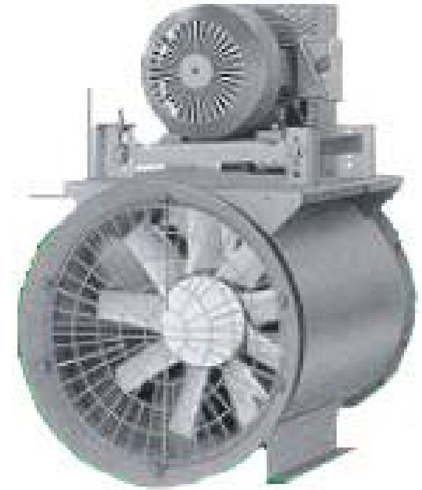


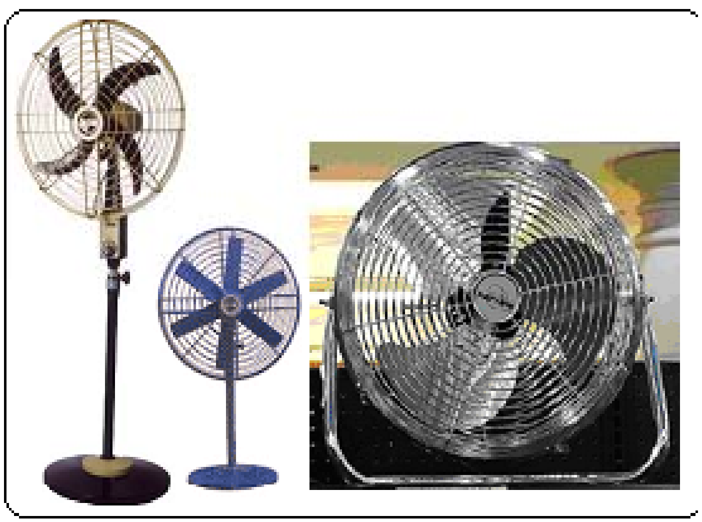
Axial Fan / Blower

Propeller type axial fans / Blowers

Tube axial fans / blowers

Vane axial fans / blowers

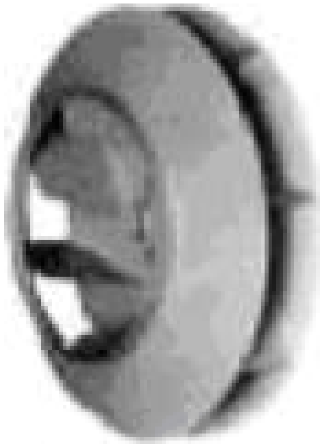




Horizontal mounted axial fans

Mixed flow fans / blowers

Types of Blower Impellers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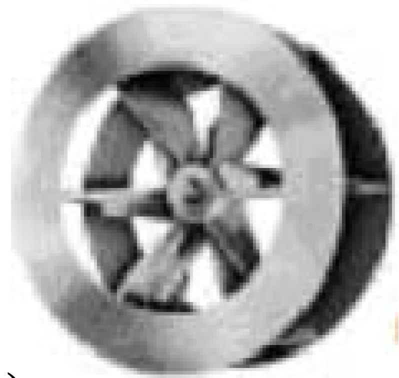
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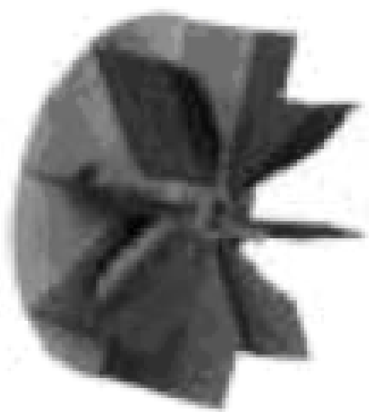
(c)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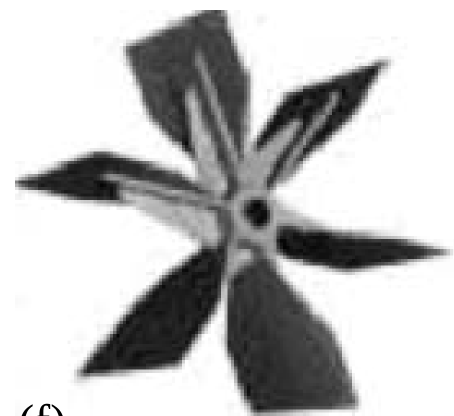

(f)

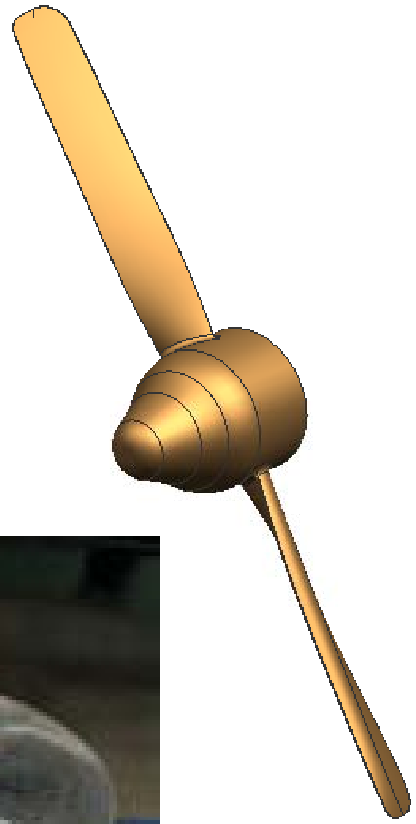
a) Air handling wheel
b) Open rim material handling wheel
c) Backplate material handling wheel
d) Backwardly inclined flat bladed
e) Backward inclined airfoil bladed
f) Open material handling wheel

Specification for Fan / Blower

	Ceiling fan	HVAC	Ducted blower
Tip diameter	1200 mm	1170 mm	400 mm
Bore diameter	50 mm	54 mm	32 mm
Speed	340 rpm	1440 rpm	1675 rpm
Number of blades	3	38	23
Type	axial flow fan	axial flow fan	centrifugal blower
Pressure rise	-NA-	0.04 bar (g)	0.15 bar (g)
Mass flow rate	3.75m^3/s	33.98 m^3/s	1.5 m^3/s
Power	68 W	712 W	140 W
Feature	-NA-	adjustable pitch	Variable speed

* The values are examples

Propellers



- ✓ A propeller is a device which transmits power by converting it into thrust for propulsion of a vehicle though a fluid by rotating two or more twisted blades about a central shaft, in a manner analogous to rotating a screw through a solid.
- ✓ The blades of a propeller act as rotating wings and produce force through application of Newton's third law, generating a difference in pressure between the forward and rear surfaces of the airfoil-shaped blades.

Air propeller

Marine propeller

Propellers

Slip Stream Theory

Continuity equation

$$\dot{m} = \rho_1 A_1 V_1 = \rho_4 A_4 V_4$$

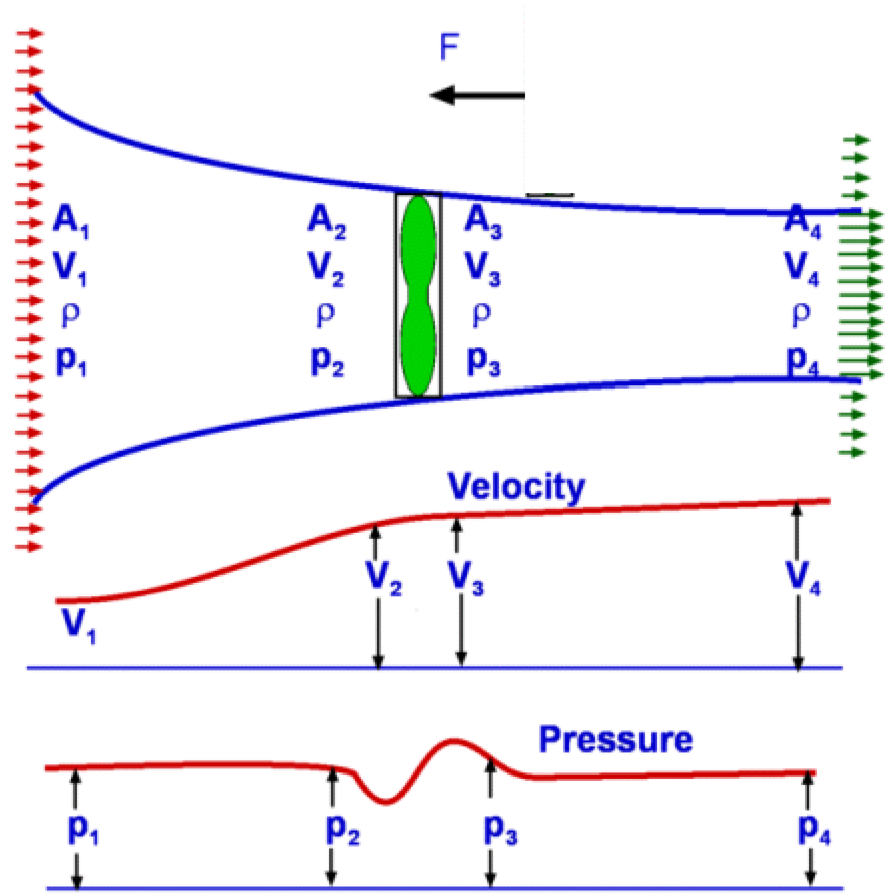
Thrust generated

$$T = \dot{m}\, \Delta V_1$$

Power required

$$P = T V_1$$

m = mass flow rate in kg/s
T = thrust in N
P = power in W
A = area in m
V = velocity in m/s
ρ = density in kg/m^3



Froude analysis of propeller

Propeller Specification

	Aircraft Application	MAV Application
Gross weight	1300 kg	75g
Power loading	7.5 kg/kW	-NA-
Datum height	1.22 m	75 mm
Thrust	1624 N	1 N
Cruise speed	85.4 m/s	25 m/s
Climb speed	35 m/s	15 m/s
Power input	-NA-	4 W

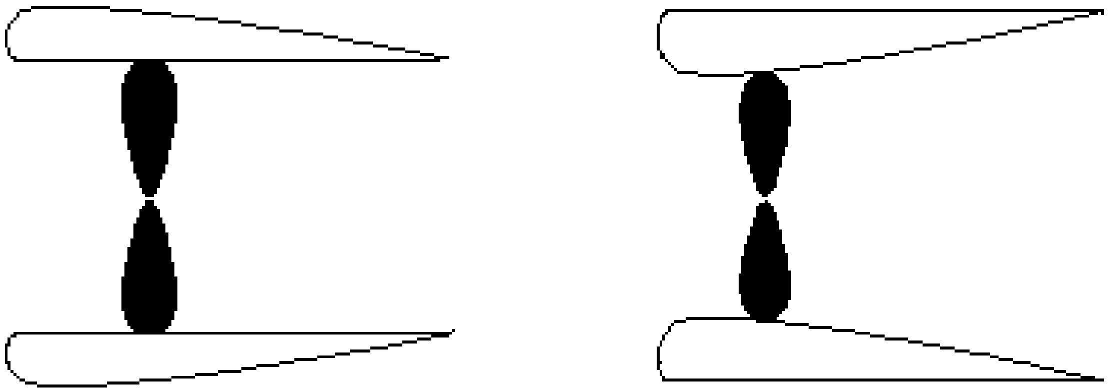
* The values are examples

Ducted Fan

- ✓ A ducted fan is a propulsion arrangement, whereby a propeller is mounted within a cylindrical shroud or duct.
- ✓ The duct prevents losses in thrust from the tips of the propeller and if the duct has an airfoil cross-section, it can provide additional thrust of its own.
- ✓ Ducted fan propulsion is used in aircraft, airboats and hovercraft.
- ✓ In aircraft application, ducted fans normally have shorter and more number of blades than propellers, and thus, can operate at higher rotational speeds.
- ✓ The operating speed of an unshrouded propeller is limited since tip speeds approach the sound barrier at lower speeds than an equivalent ducted propeller.

Ducted Fan

Duct Shapes



Accelerating shroud **Decelerating shroud**

decelerating shroud ➡ noise reduction.
accelerating shroud ➡ low speed heavily loaded propellers (improves efficiency)

Ducted fans are favoured in VTOL and other low-speed designs for their high thrust-to-weight ratio.

Centrifugal Compressor

- ✓ The flow enters a three dimensional impeller axially through an inlet duct. The impeller *may be* preceded by a row of inlet guide vanes.
- ✓ The impeller, through its blades, imparts velocity and pressure to the gas, which flows in radial direction.
- ✓ The rise in pressure takes place due to the centrifugal action of the impeller and diverging passages of the downstream diffuser and / or volute.
- ✓ Vaned or vaneless diffuser with volute are provided to convert kinetic energy at impeller exit into static pressure at compressor discharge.
- ✓ Centrifugal compressors are used to produce large pressure ratios.
- ✓ A single stage centrifugal compressor may have typical pressure ratio of about 4:1. Some test compressors are designed for pressure ratio up to 8:1.
- ✓ Centrifugal compressors are suitable for low specific speed, high pressure ratio per stage and low mass flow rate applications.
- ✓ Based on application, the centrifugal compressors can be either single stage or multistage type.

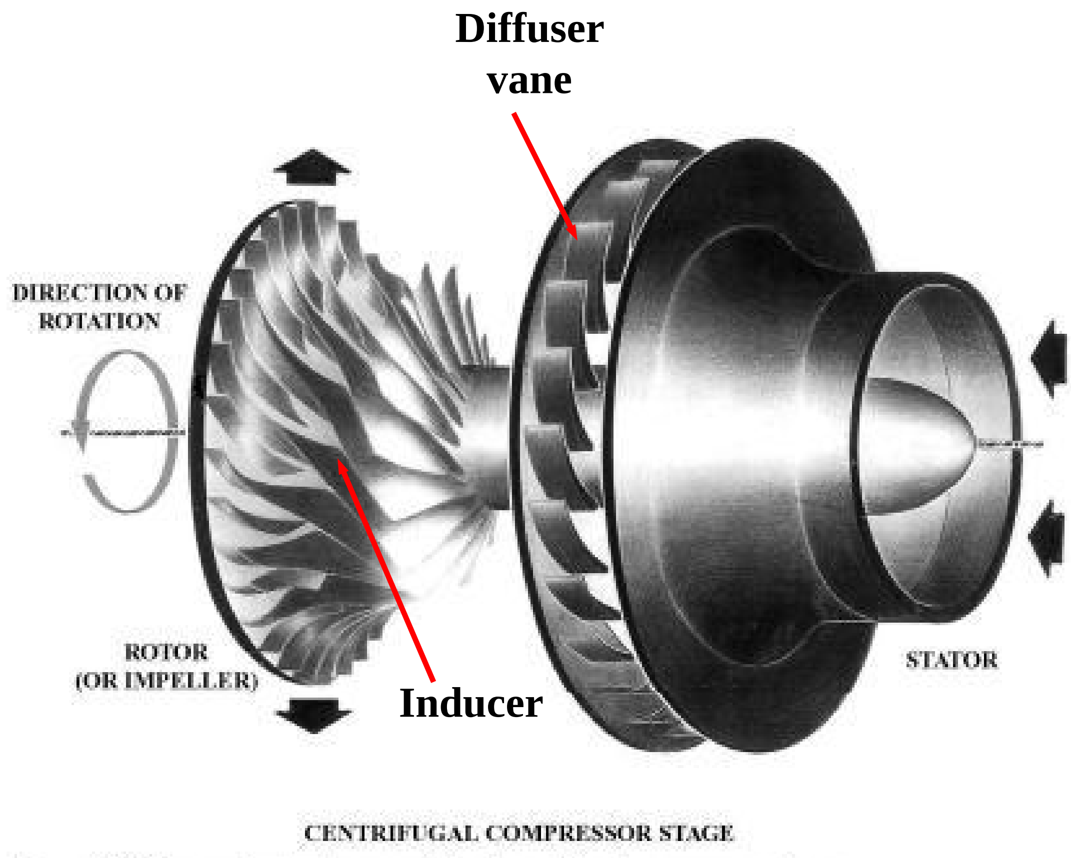
Centrifugal Compressor

Components of a centrifugal compressor

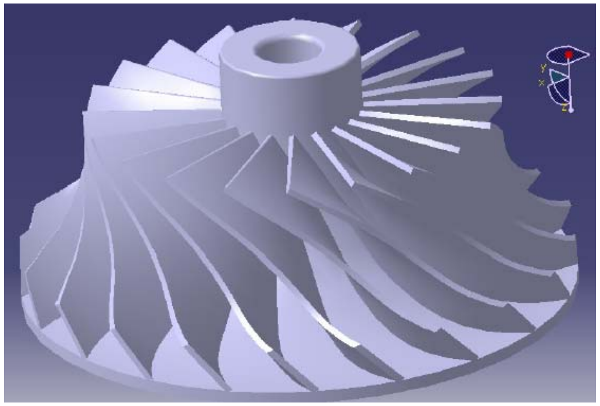
- Impeller
- Diffuser
- Casing
- Shaft

Application of centrifugal compressor

- Gas turbine
- Turbocharger
- Process industry
  - Gas compression
  - Oxygen plants
  - Instrument air

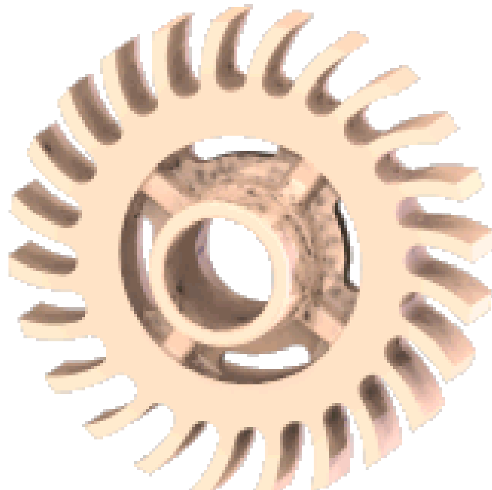


Types of Centrifugal Compressor Impeller



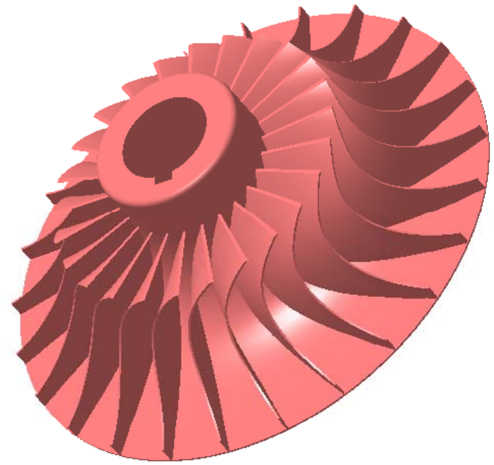
Back swept impeller

$\beta_2 =< 90^0$



Forward swept impeller

$\beta_2 => 90^0$



Radial exit impeller

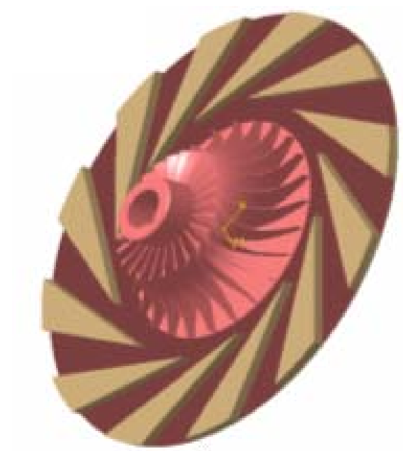
$\beta_2 = 90^0$

Forward sweep $\Rightarrow V_\theta < U_2$

Radial exit $\Rightarrow V_\theta = U_2$

Backward sweep $\Rightarrow V_\theta > U_2$

Impeller with splitter blades



Impeller with diffuser

Centrifugal Compressor Specification

	(a)	(b)	(c)
Inducer hub diameter	8mm	22 mm	0.870 m
Inducer tip diameter	12mm	65 mm	0.434 m
Impeller tip diameter	25mm	87 mm	1.524 m
Number of vanes	6+6	9+9	20
Speed	400000 rpm	81000 rpm	1918 rpm
Inlet pressure	101.325 bar	0.98 bar	101.325 bar
Inlet temperature	295K	303 K	288.1 K
Pressure ratio	4.0	2.32	1.14
mass flow rate	0.12kg/s	0.25kg/s	30 kg/s
backsweep angle	32 deg	30 deg	55 deg

(a) Micro-compressor
(b) Turbo-compressor
(c) Low Speed Centrifugal Compressor

* The values are examples

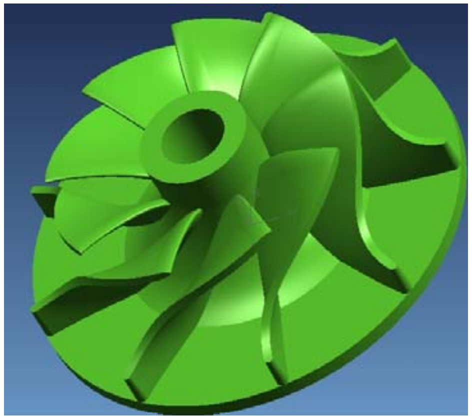
Radial Turbine

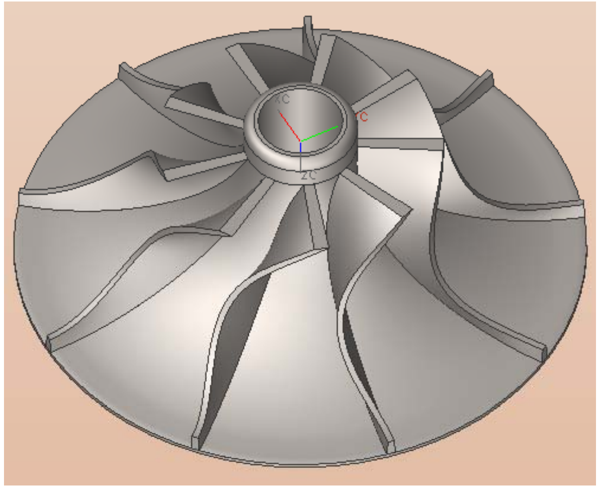
- ✓ Flow enters the impeller radially and exits axially. These machines are termed as inward flow turbines.
- ✓ A radial turbine stage consists of volute, nozzle guide vanes and impeller.
- ✓ High pressure gas passes through the volute and / or nozzle guide vanes, increasing its kinetic energy. The high velocity gas transfers its energy to the impeller shaft by flowing radially inward through the impeller.
- ✓ The nozzles with adjustable vanes provide highest efficiency.
- ✓ Radial turbines employ a relatively higher pressure drop per stage with low mass flow rate.
- ✓ The specific speed and power range of the radial turbines are low.
- ✓ Since rotors / impellers are made of single piece construction, they are mechanically strong and are more reliable.

Radial Turbine

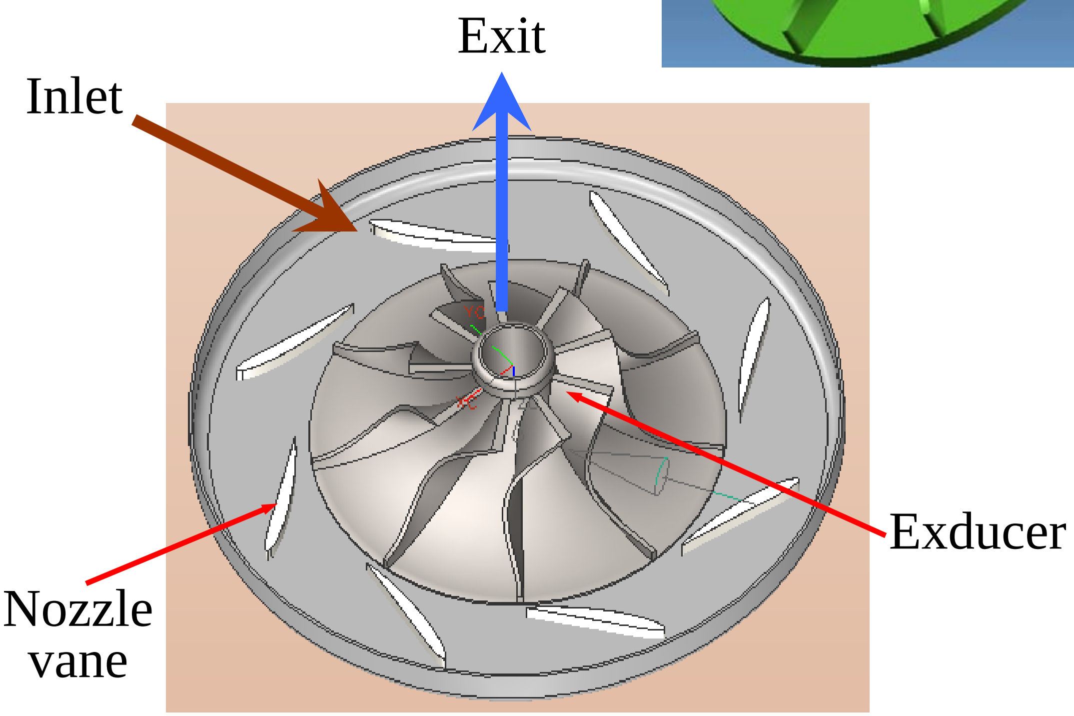
Applications of Radial Turbine

- Gas turbine
- Turbocharger
- Process industry





Impeller



Impeller and nozzle

Radial Turbine Component

Radial turbine impeller

Radial turbine volute casing

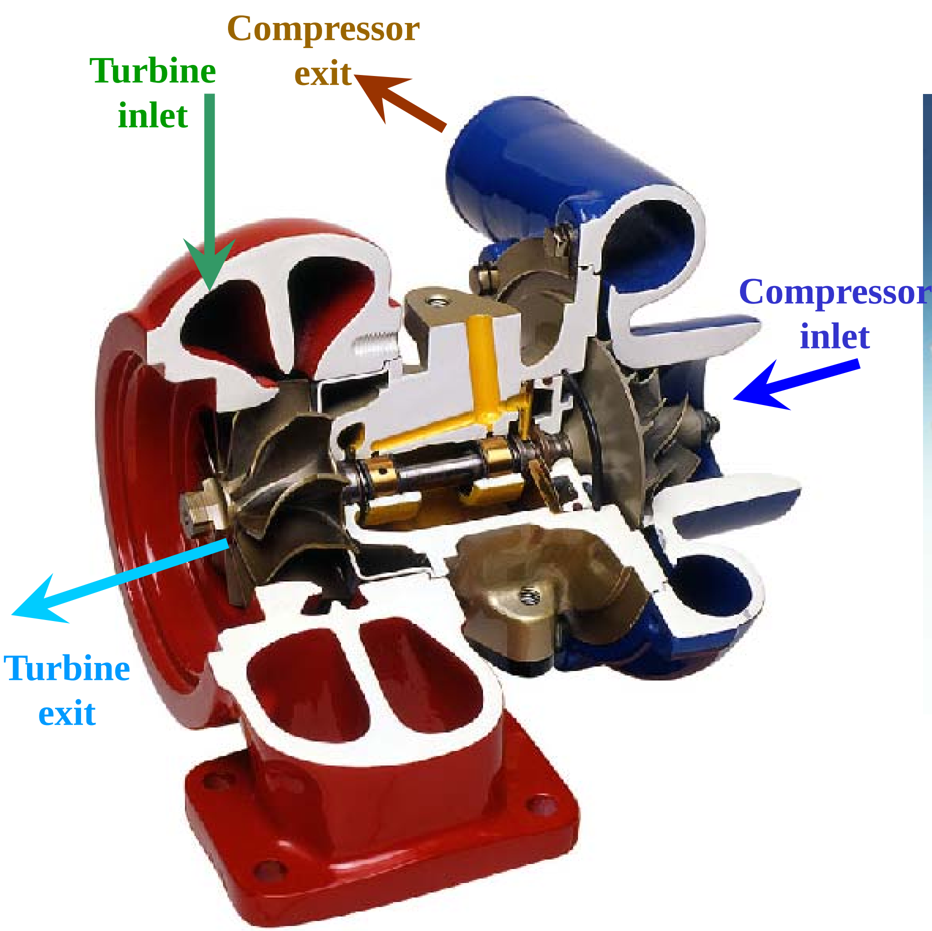
Radial Turbine Specification

	Micro Turbine	Power Turbine
Exducer hub diameter	14 mm	58 mm
Exducer tip diameter	40 mm	238 mm
Impeller tip diameter	80 mm	366 mm
Stator outer diameter	100 mm	392 mm
Stator inlet diameter	130 mm	493 mm
Number of impeller vanes	14	13
Number of stator vanes	18	15
Speed	150000 rpm	20000 rpm
Inlet total pressure	3 bar	4.05 bar
Inlet total temperature	1100 K	1533 K
Mass flow rate	0.147 kg/s	2.07 kg/s
Nozzle flow angle	70 deg	73 deg
Power / thrust	10 kW	300 kW

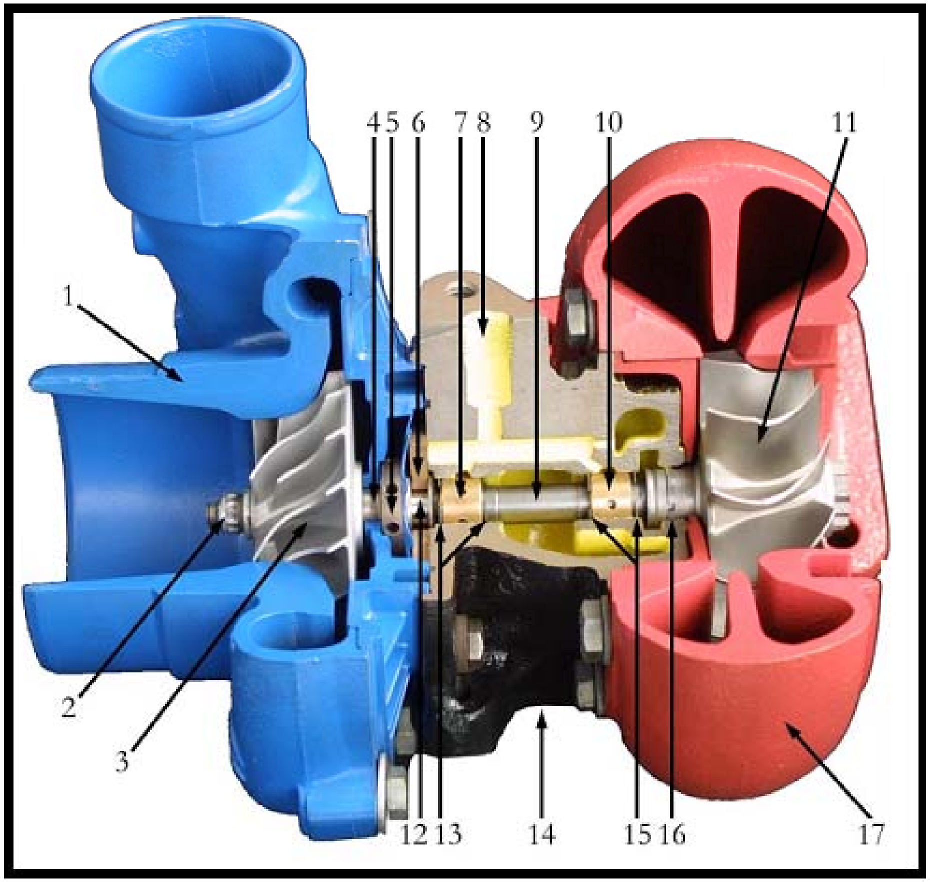
* The values are examples

Turbocharger

A turbocharger is an exhaust gas driven compressor used to increase the power output of an internal combustion engine by compressing air that is entering the engine, thus increasing the amount of available oxygen.



Parts of a Turbocharger



1. Compressor Housing
2. Compressor Wheel Lock Nut
3. Compressor Wheel
4. Piston Ring / Seal Ring
5. Oil Slinger
6. Thrust Bearing
7. Floating Journal Bearing
8. Oil Feed
9. Shaft
10. Floating Journal Bearing
11. Turbine Wheel
12. Thrust Collar
13. Retaining Rings
14. Core (Centre Housing Rotating Assembly)
15. Retaining Rings
16. Piston Ring / Seal Ring
17. Exhaust Housing

Specification of a Turbocharger

Typical Specifications

Compressor wheel diameter	170 mm
Turbine wheel diameter	106 mm
Rated flow capacity	12 m^3/s
Max. power rating	284kW
Compressor A/R ratio	0.7
Optimum boost level	0.55 – 0.7 bar
Boost pressure	0.7 bar
Turbine A/R ratio	0.5
Bearing type	full-floating bearing
Maximum recommended boost	0.96 bar
Power rating	194 kW @ 0.8-0.96 bar (at wheels)
Exhaust control	waste gate

* The values are examples

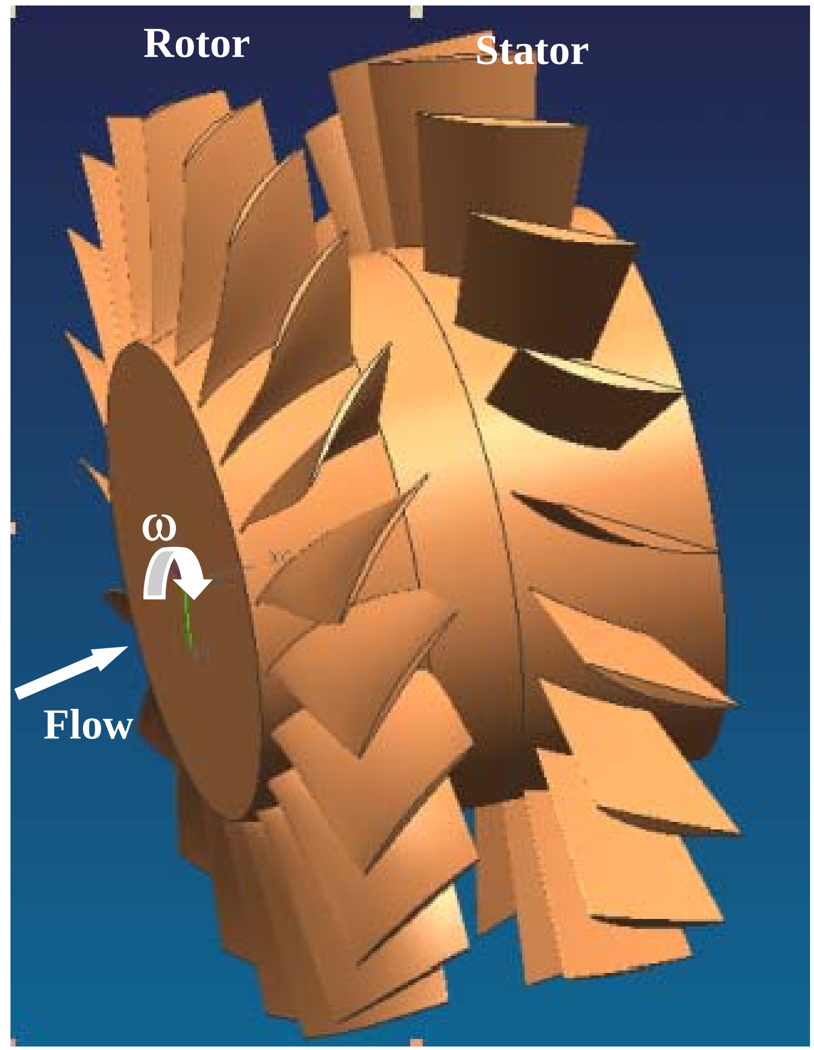
Axial Compressor

- ✓ An axial compressor consists of a row of rotor blades followed by a row of stator blades and the working fluid traverses through these without significant change in radius.
- ✓ The energy level of the fluid flowing through it is increased by the action of the rotor blades, which exert a torque on the fluid supplied by an external source.
- ✓ An axial compressor is a relatively low pressure ratio turbomachine with higher mass flow rate as compared to a centrifugal compressor.
- ✓ The flow stream lines passing through the bladings are nearly parallel to the shaft axis.
- ✓ Flow enters axially and discharges almost axially.
- ✓ The blade passages diverge from inlet to exit, and hence the flow decelerates
- ✓ Due to density variation from inlet to exit, the compressor end walls have flare with flow area reducing from inlet to exit.

Single Stage Axial Compressor

Components of Axial Compressor

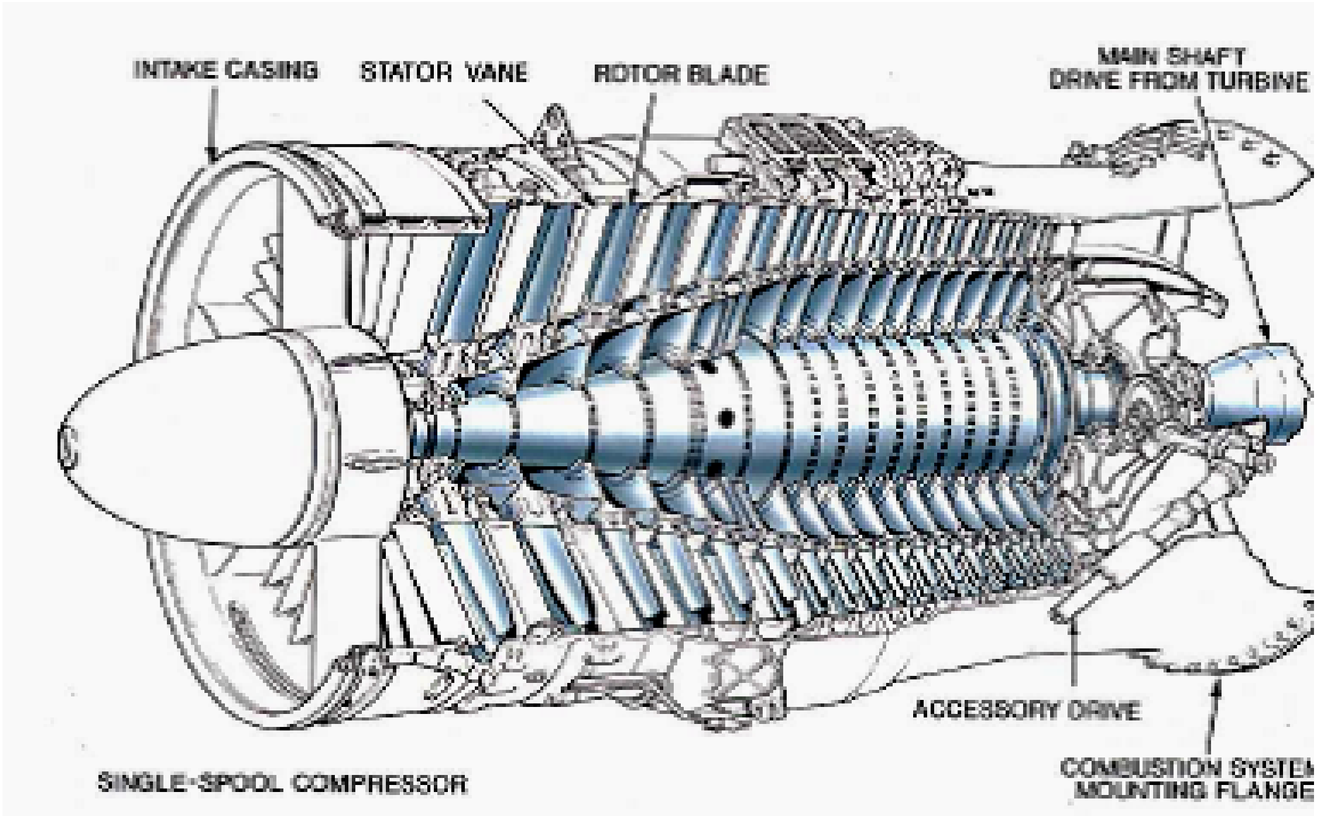
- Rotor
- Stator
- Casing
- Shaft



Applications of axial compressor

- Gas turbine
- Turbocharger
- Process industry

Multistage Axial Compressor



Transonic and Subsonic Axial Compressors

Transonic Compressor

- ✓ Flow is supersonic in some part of rotor blade span and subsonic elsewhere.
- ✓ Inlet Mach numbers are high.
- ✓ The blades are thin. Max. thickness to chord ratio is about 4%.
- ✓ The blade profiles are designed / generated and seldom chosen from a standard family of profiles. Multiple Circular Arc (MCA), Arbitrary Mean Camber Line (AMCL) and Controlled Diffusion (CD) bladings are used.
- ✓ Shock waves are formed at leading end or within the blade passages.

Subsonic Compressor

- ✓ Flow throughout the rotor blade span is subsonic.
- ✓ Inlet Mach numbers are low.
- ✓ The blades are relatively thicker. Max. thickness to chord ratio lies between 5% to 15%.
- ✓ Blade leading edge is thicker than the trailing edge.
- ✓ Standard blade profiles, such as NACA-65 or C series, are available. Double Circular Arc Aerofoils (DCA) need to be generated.
- ✓ Shock waves are not formed during normal operation.

Axial Compressor Specification

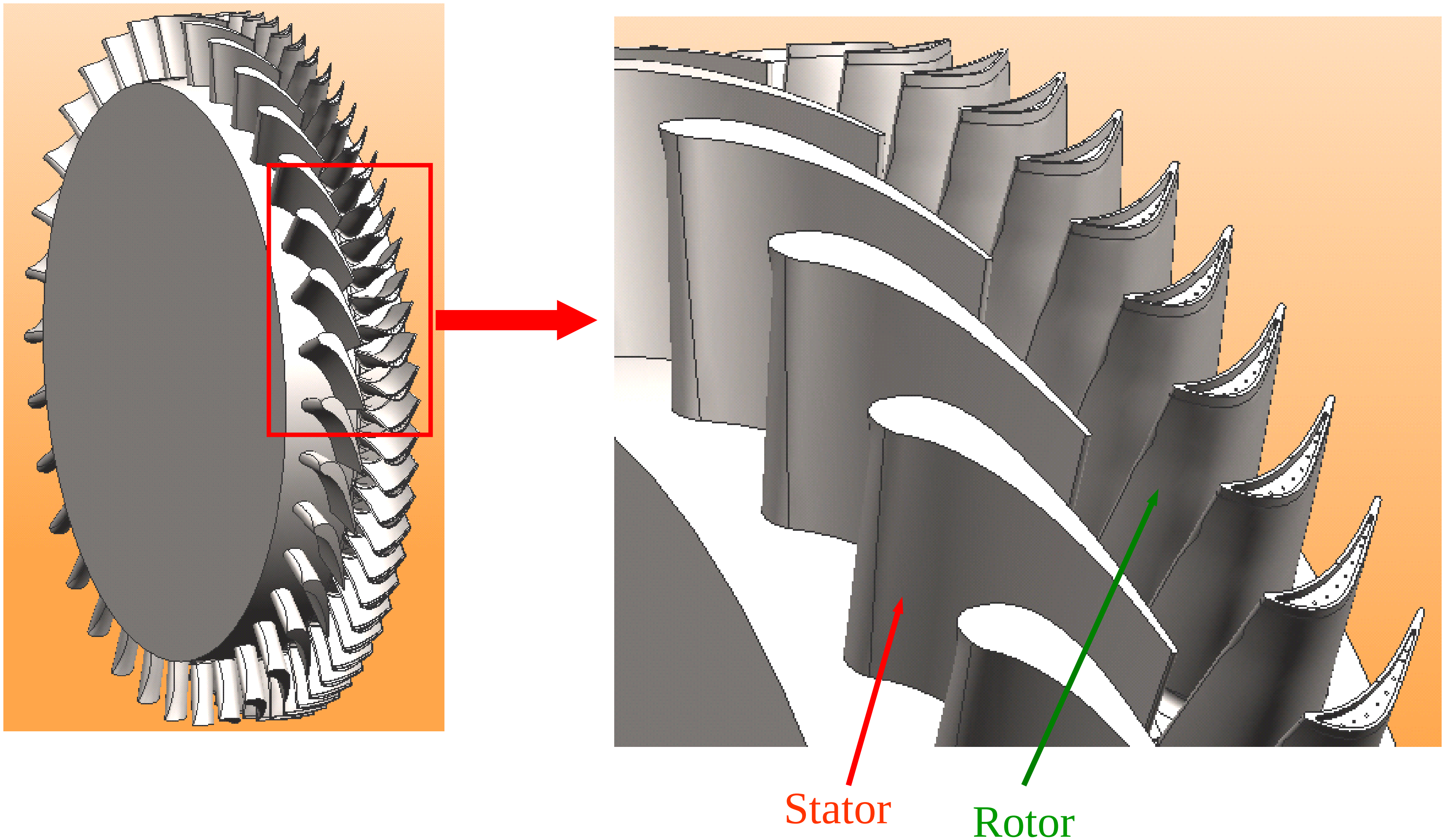
	Transonic Compressor (NASA Rotor 67)	**Subsonic Compressor** (RWTH Aachen (Germany))
Pressure ratio	1.63	1.187
Mass flow rate	33.25 kg/s	20 kg/s
Isentropic efficiency	93%	88% (stage)
Rotational speed	16043 rpm	12000 rpm
Rotor tip speed	429 m/s	264.5 m/s
Inlet tip relative *M*	1.38	0.778
Axial Mach No. (mean)	- NA -	0.49
Rotor tip diameter (inlet)	0.514 m	0.421 m
Rotor blade height (inlet)	-NA-	128 mm
No. of rotor blades	22	16

* The values are examples

Axial Turbine

- ✓ The kinetic energy of combustion gas is converted to mechanical power by the its impulse or reaction with a series of blades arranged around the circum-ference of a wheel or cylinder.
- ✓ Stationary blades / guide blades act as nozzles and they convert fluid pressure into kinetic energy. The following rotating blades convert kinetic energy into useful work.
- ✓ Axial turbines have low pressure drop per stage and higher mass flow rate compared to radial turbines.
- ✓ The flow stream lines through the bladings are nearly parallel to the shaft axis.
- ✓ Flow enters axially and discharges almost axially.
- ✓ The blade passages converge from inlet to exit, and hence the flow accelerates.
- ✓ Blade profile is thicker at the inlet and thinner at the exit.
- ✓ Due to density variation from inlet to exit, the turbine end walls have flare with flow area increasing from inlet to exit.

Axial Turbine



Axial Turbine Stage

Multistage Axial Turbine

- A series of stages form multistage turbine.
- The energy transfer in a stage is limited by the blade speed.
- If more energy transfer per unit mass is required, then more number of stages are arranged one after the other.

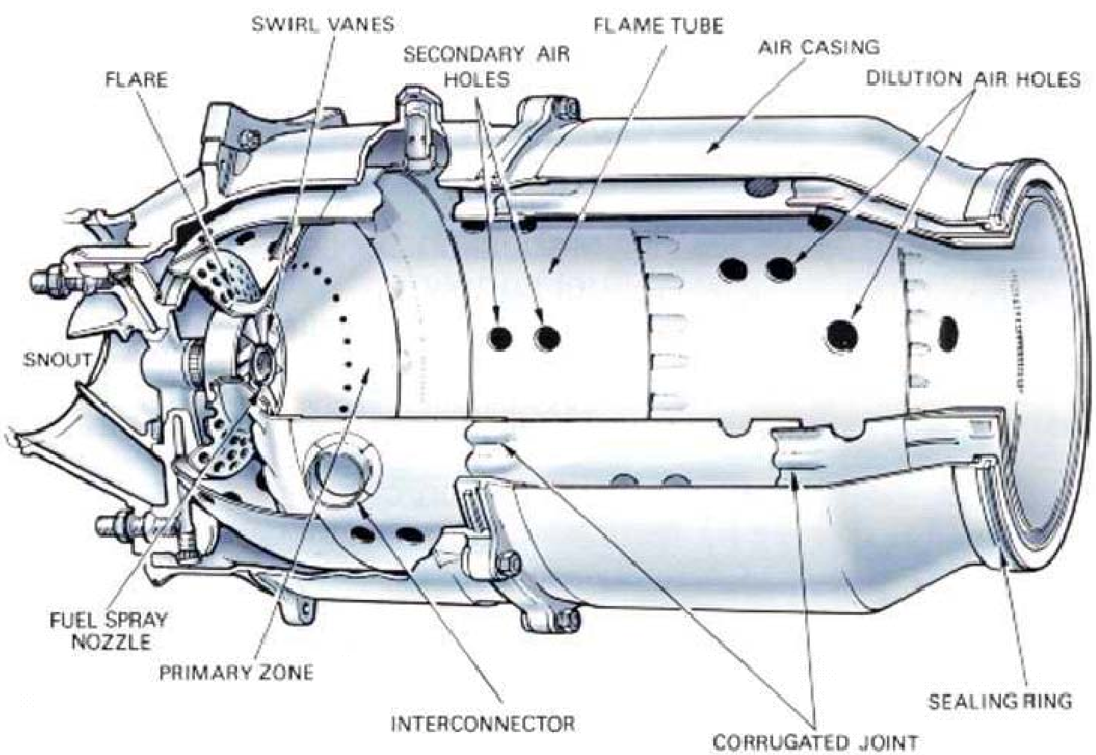
Axial Turbine Specification

	Typical	Kaveri GTX35VS
Mass flow rate	21 kg/s	73.5 kg/s
Isentropic efficiency	90%	-NA-
Inlet temperature	1500 K	1700 K
Temperature drop	700 K	1200 K
Inlet pressure	4.0 bar	29.55 bar
Rotational speed	10500 rpm	16028 rpm
Diameter	0.75 m	0.57 m
Blade height	0.12 m	0.063 m
Power/Thrust	60 MW	90 kN (thrust)

* The values are examples

Combustor

- ✓ Combustion takes place in a combustor, which is located between the compressor and the turbine.
- ✓ Combustor design requires low velocity airflow in the combustion zone, where the fuel and air are mixed and ignited. The flame holder in the combustion zone allows a stable flame front to be established and maintained.

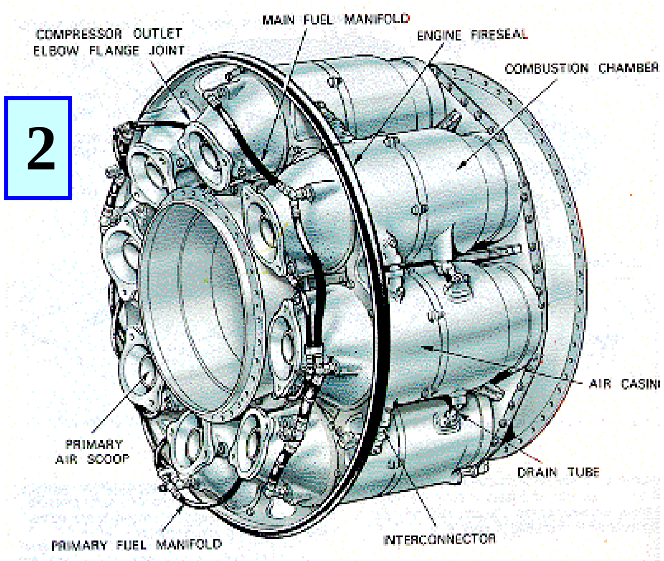


Types of Combustor

There are three types of combustors:

1. Annular
2. Can
3. Can-annular

2



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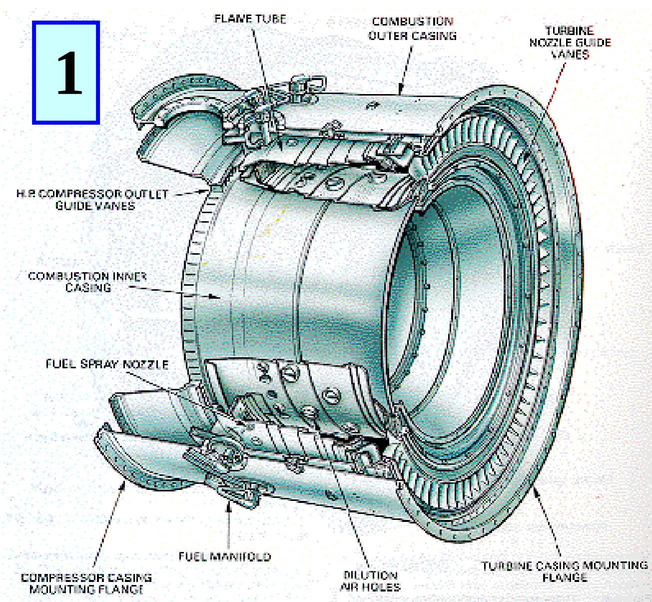

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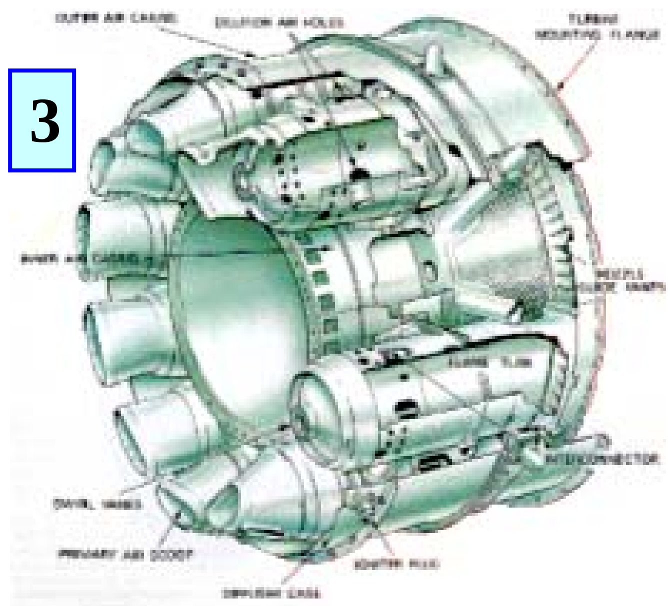
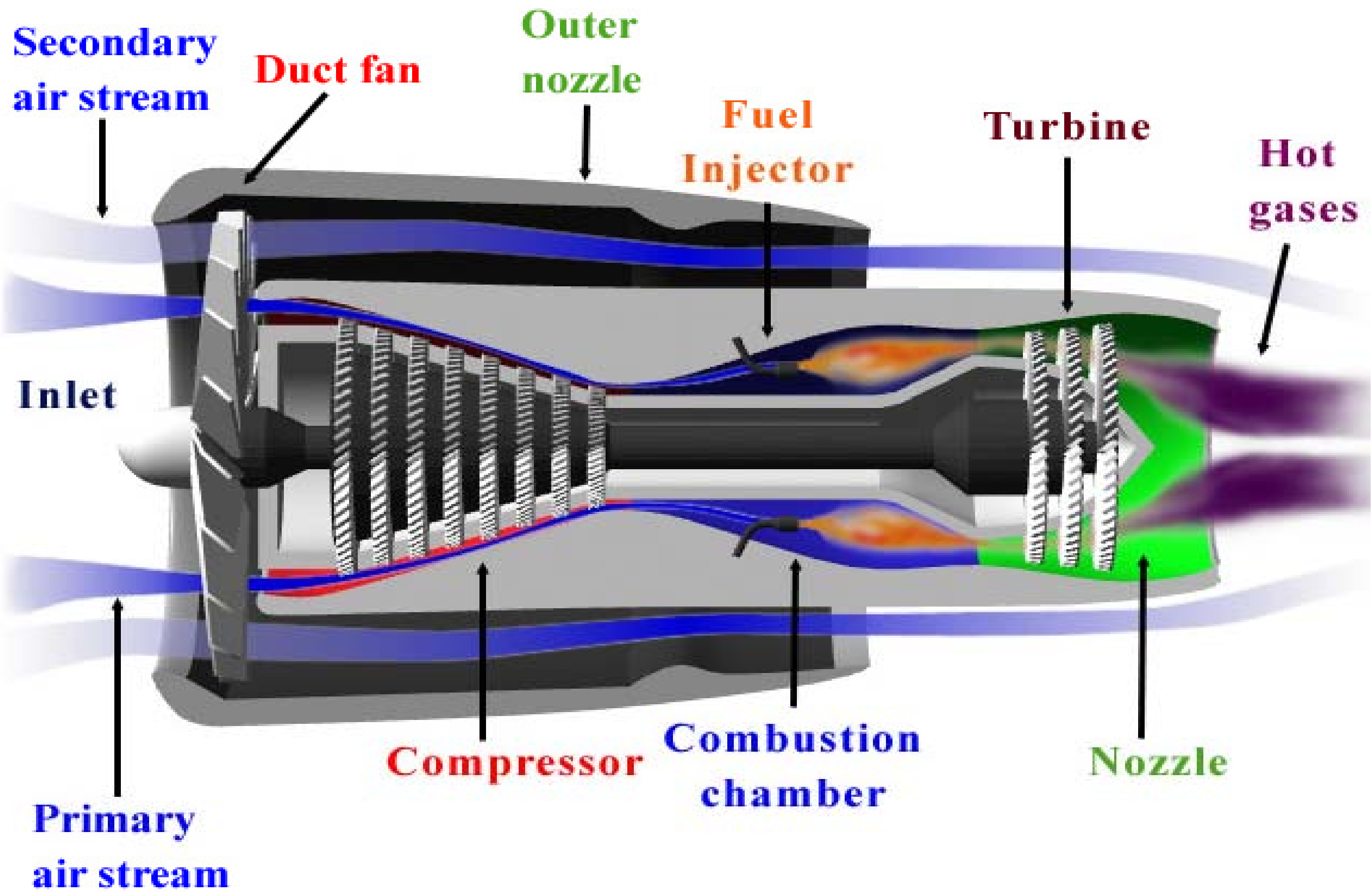


Combustor Specification

Diameter	36 mm
Pressure at Combustor Inlet	3.9 bar
Mass Flow rate	0.012 kg/s
Temperature at Combustor Inlet	500 K
Temperature required at Combustor Exit	1200 K
Fuel	Natural gas
Specific Fuel Consumption	0.0077 kg/kW/hr

(The values are examples)

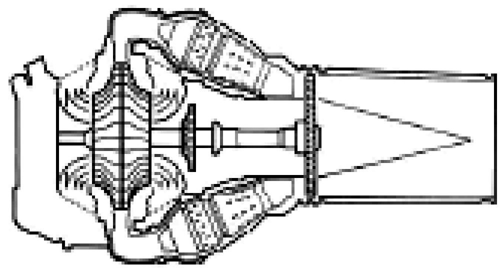
Gas Turbine


Secondary
air stream
Duct fan
Outer
nozzle
Fuel
Injector
Turbine
Hot
gases
Inlet
Compressor
Combustion
chamber
Nozzle
Primary
air stream

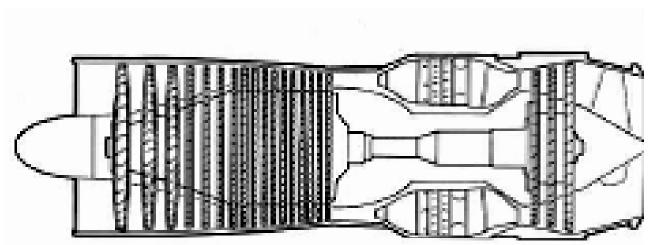
Gas Turbine

- ✓ Gas turbine unit mainly comprises compressor module, turbine module, combustor and many auxiliary components.
- ✓ Gas turbines find wide application as aeroengines and in power generation.
- ✓ In power application, all the power developed by the turbine is used to drive the compressor, generator and the auxiliary systems of the power plant.
- ✓ In aeroengines, the turbine develops power only to drive the compressor and the remaining energy of the combustion gas is used to generate thrust for aircraft propulsion.
- ✓ Gas turbines are available in a range of sizes from micro scale to very large units.
- ✓ Gas turbine units have high power to weight ratio, small frontal area and high efficiency.

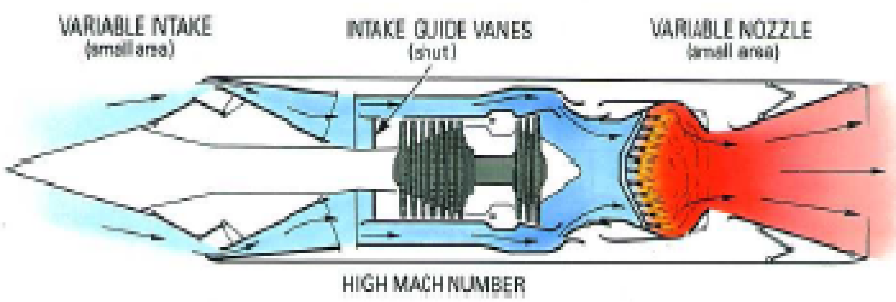
Gas Turbine Engine – Aero Application

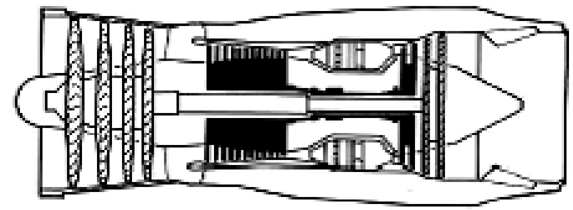


DOUBLE-ENTRY SINGLE-STAGE CENTRIFUGAL TURBO-JET

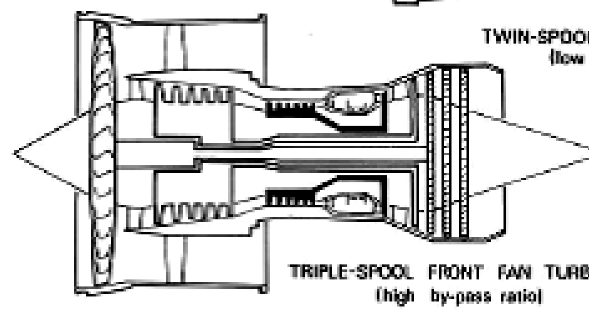


SINGLE-SPOOL AXIAL FLOW TURBO-JET

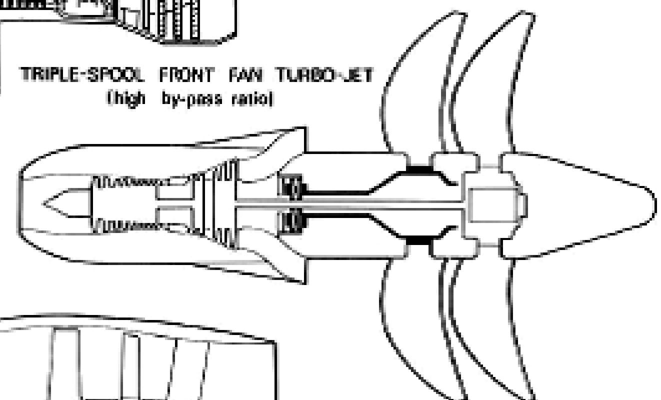




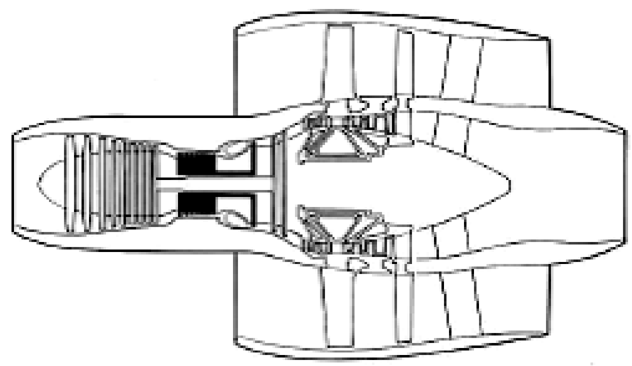
TWIN-SPOOL BY-PASS TURBO-JET (low by-pass ratio)



TRIPLE-SPOOL FRONT FAN TURBO-JET (high by-pass ratio)

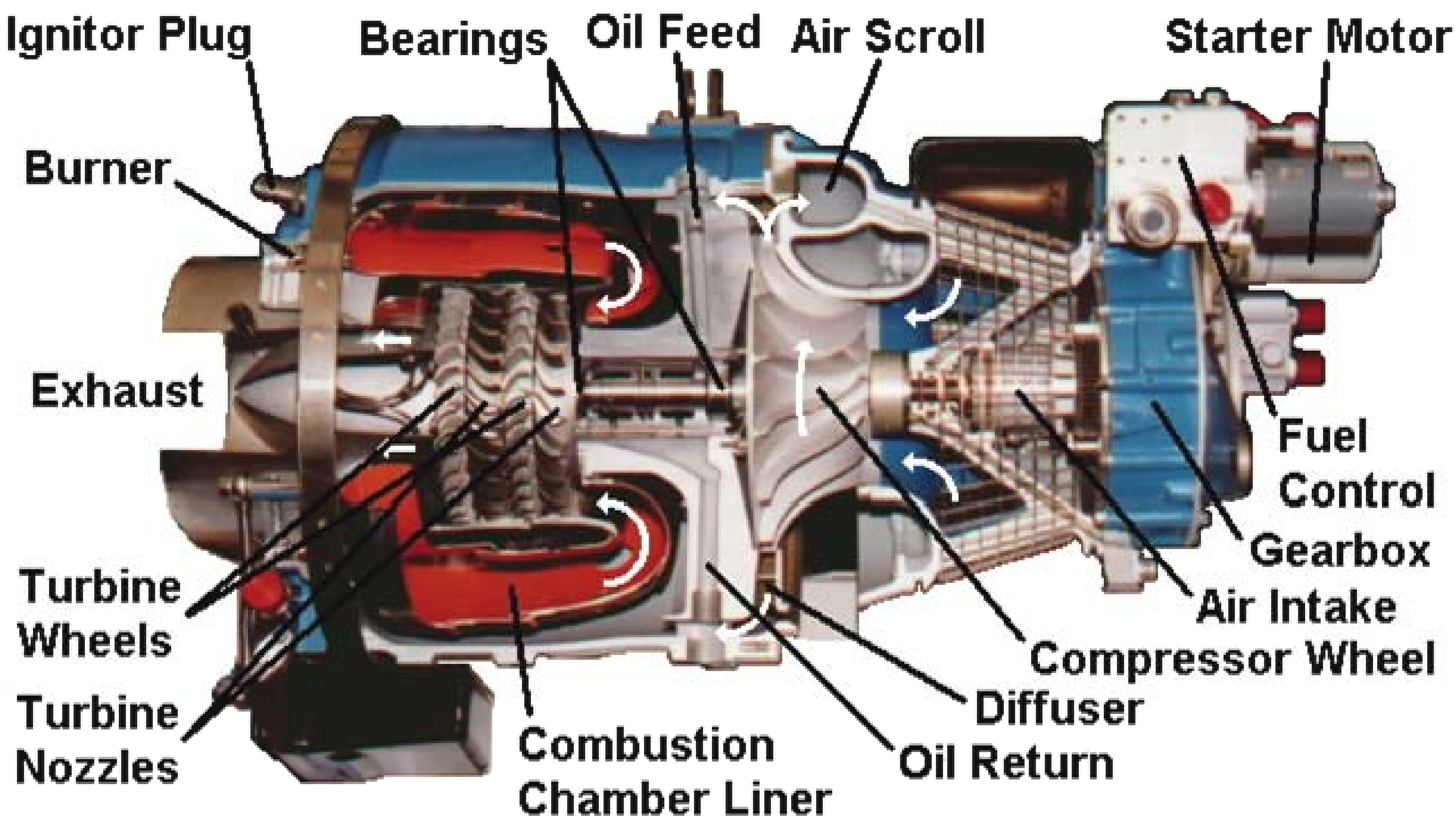


PROP-FAN - CONCEPT



CONTRA-ROTATING FAN - CONCEPT (high by-pass ratio)

Small Gas Turbine



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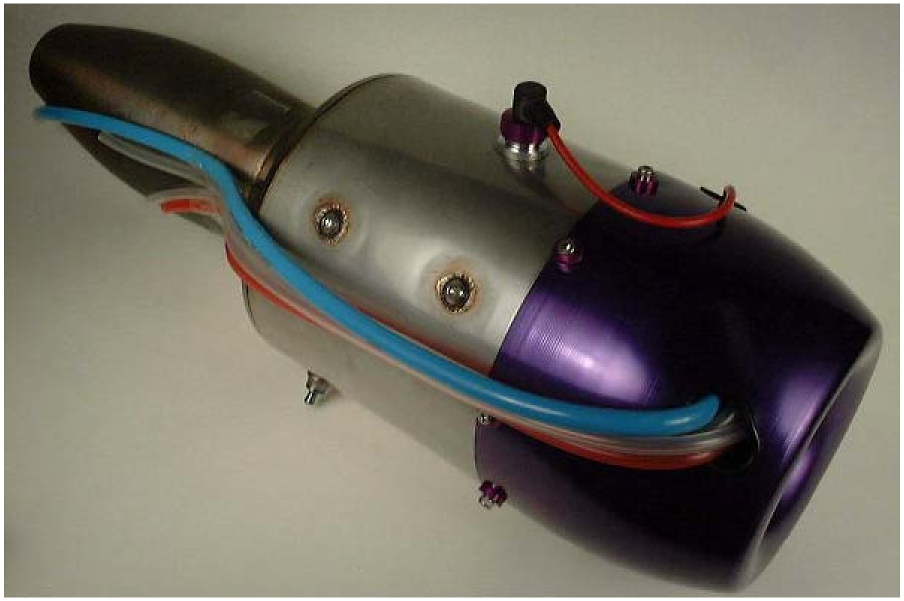
Micro Gas Turbine



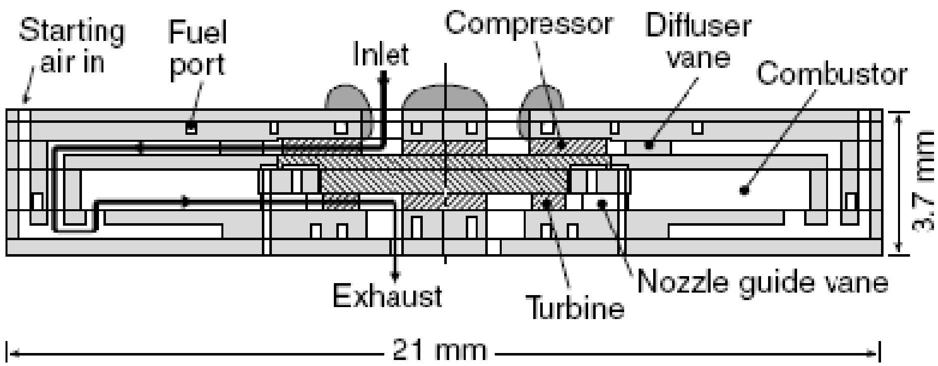
SMALL SCALE TURBO JET ENGINE

Penn State Univ., USA

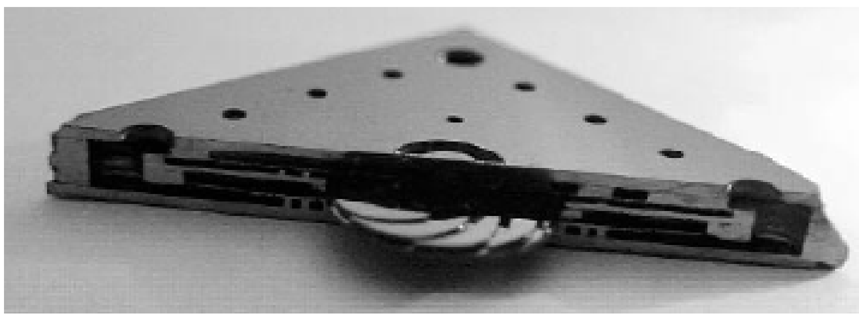
Thrust = 84.5 N   Weight = 1.4 kg

TET = 1073 K   Flow = 270 cc/min

MEMS Scale Gas Turbine



A demo engine with conduction-cooled turbine constructed from six silicon wafers



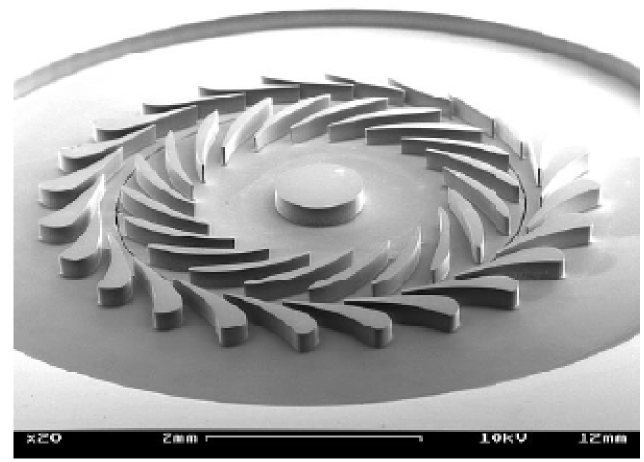
Cutaway demo gas turbine chip

Rotational speed : 1.2 Mrpm

Air flow rate : 0.36 grams/sec

Power : 11 gm (0.108 N) thrust or 17 watts power

A 500 m/s tip speed, 8 mm dia centrifugal compressor



A 4:1 pressure ratio, 4 mm rotor dia radial inflow turbine stage

Gas Turbine – Specification

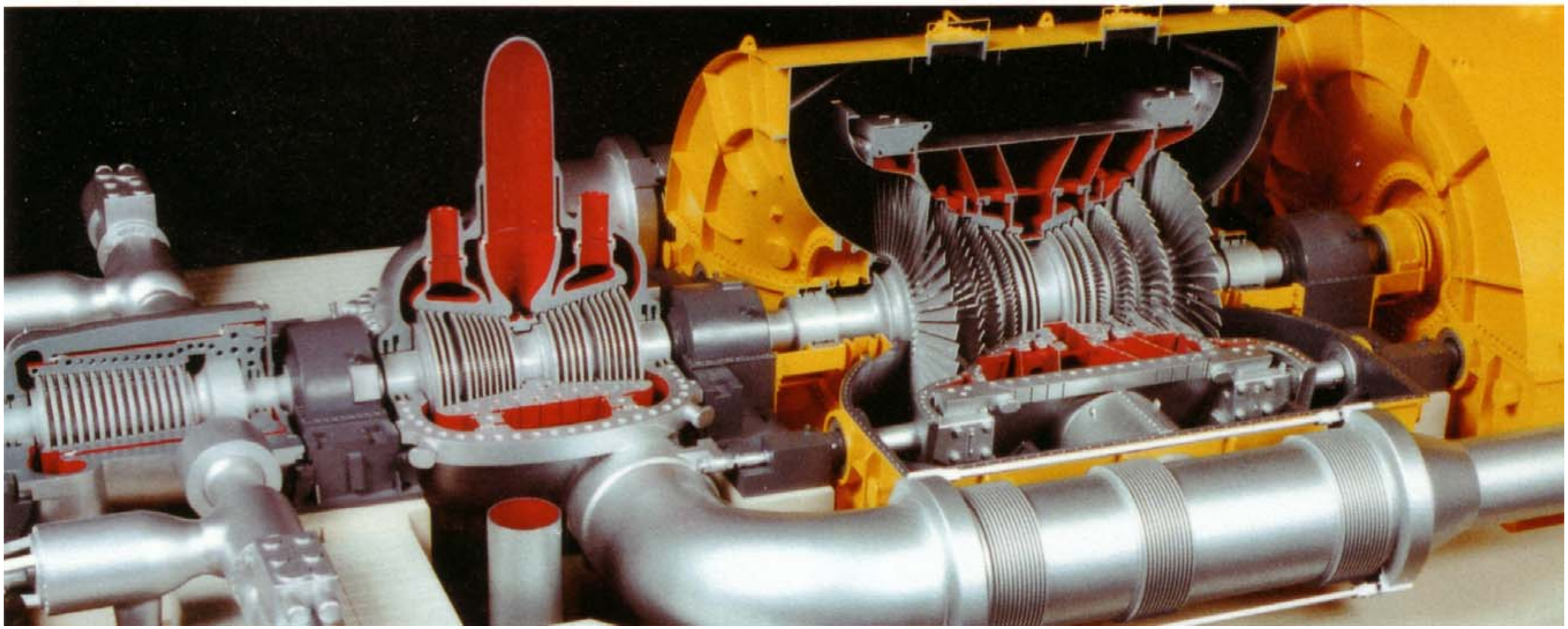
	'Cobra' Micro Gas Turbine	Power Gas Turbine#
Thrust/Power	163N	270 MW
Weight	3.1 Kg	-NA-
Pressure ratio	3.0	4.5:1
Speed	105,000 rpm	3000 rpm
Max exhaust gas temp	640 degrees C	-NA-
Mass flow	0.31 kg/s	651 kg/s
SFC (Propane)	0.8 Kg/N/Hr	-NA-
Overall length	444 mm	-NA-
Maximum width	197 mm	-NA-
No. of compressor stages	1	16
No. of turbine stages	1	4
Turbine inlet temperature	1200 K	1673 K
Combustor type	annular	Multi-can annular
No. of combustors	1	16

#Mitsubishi 701F

(The values are examples)

Steam Turbine

- The motive power in a steam turbine is obtained by the rate of change of momentum of a high velocity jet of steam impinging on a curved blade, which is free to rotate.
- The steam from the boiler is expanded in a nozzle, resulting in the generation of a high velocity jet. This jet of steam impinges on the moving vanes or blades, mounted on a disc / drum.



Steam Turbine Stage

- ✓ A turbine stage consists of stationary stator row (guide vanes or nozzle ring) and rotating rotor row.
- ✓ In the guide vanes, the high pressure, high temperature steam is expanded, resulting in high flow velocity.
- ✓ The guide vanes also direct the flow to the rotor blades at an appropriate angle.
- ✓ In the rotor, the flow direction is changed and kinetic energy of the working fluid is absorbed by the rotor shaft producing mechanical energy.

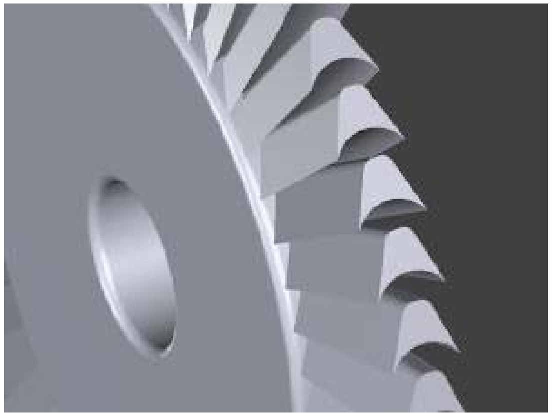
Steam Turbine Principle

- ✓ Process of complete expansion of steam takes place in stationary nozzle and the velocity energy is converted into mechanical work on the turbine blades.

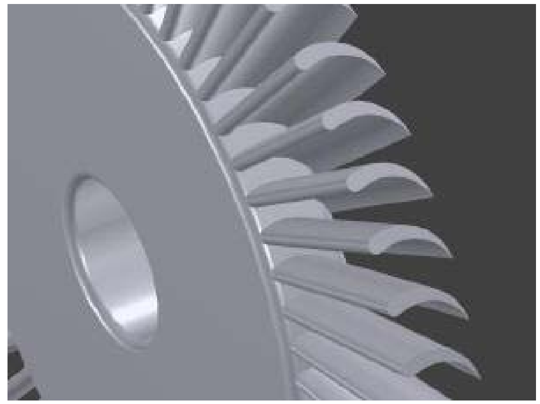
- ✓ Pressure drop with expansion and generation of mechanical energy takes place in the moving blades.

- ✓ Pressure drop may be partly effected in nozzles and partly in moving blades which are so designed that expansion of steam takes place in them. High velocity jet from nozzle produces an impulse on the moving blade and the jet coming out at still higher velocity from moving blades produces a reaction.

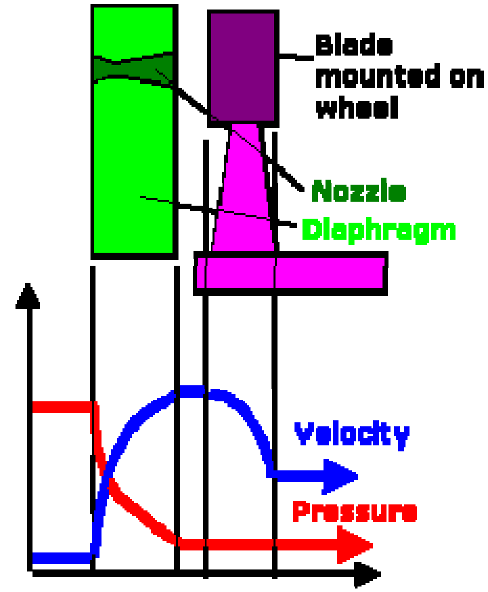
Steam Turbine Compounding

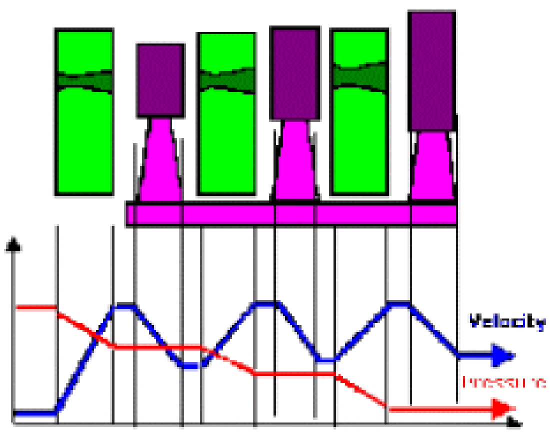


Impulse Turbine

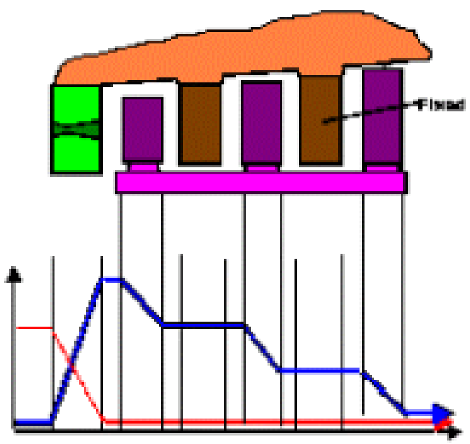


Reaction Turbine

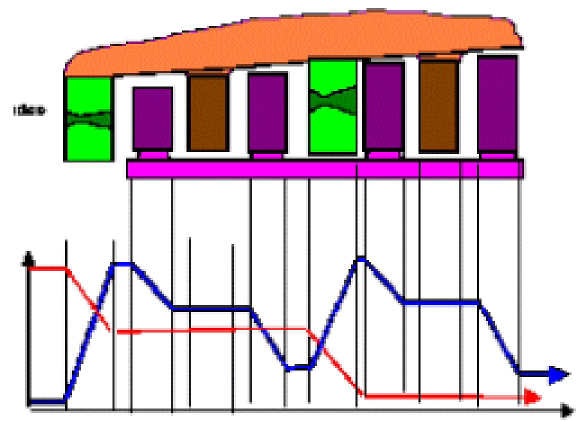




Pressure Compounding

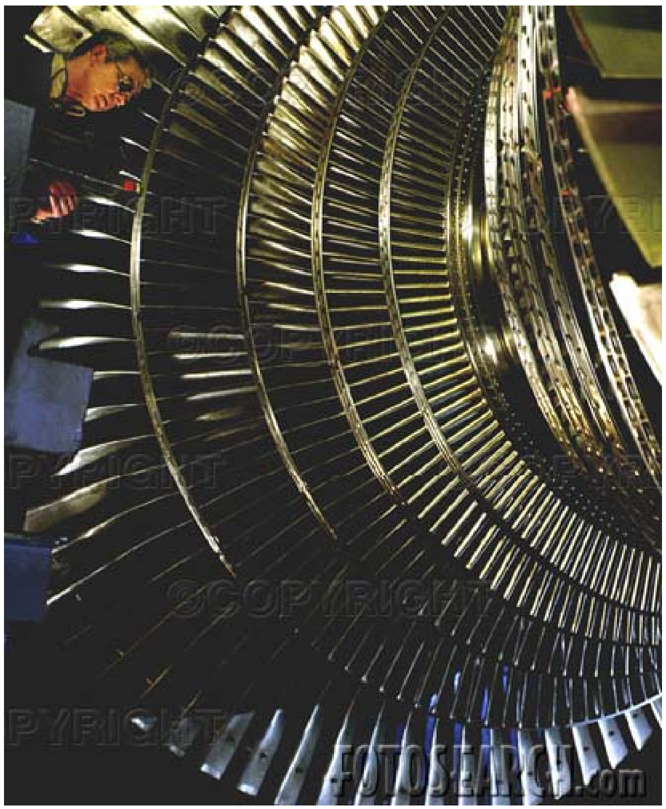


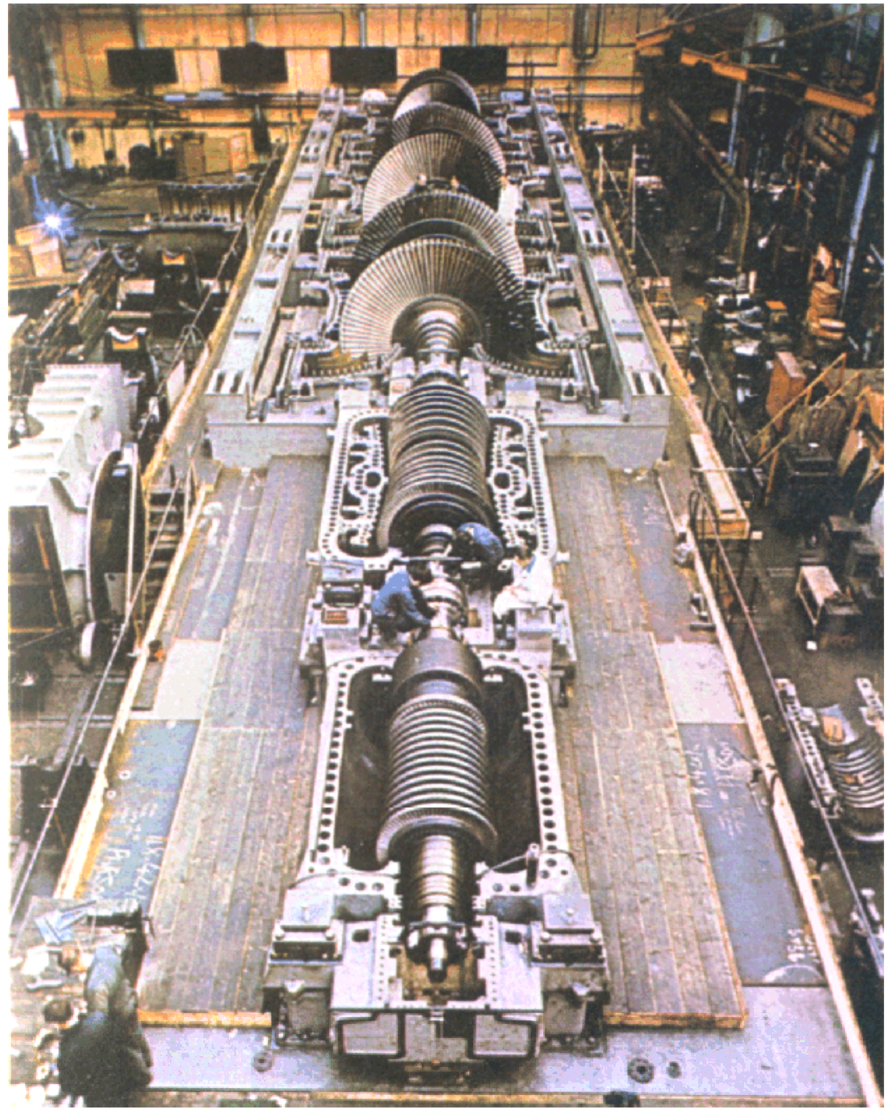
Velocity Compounded



Pressure-Velocity Compound

Steam Turbine Blades and Stages





Steam Turbine Specification

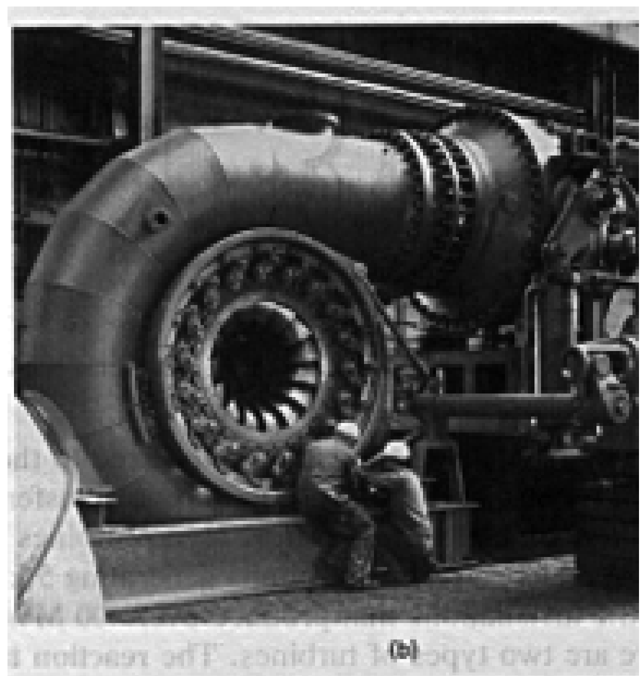
	Process industry	Power plant
Speed	9500 RPM	3000 rpm
Power output	15000 kW	130 MW
Steam inlet temperature	425 ºC	537 ºC
Steam inlet pressure	45 bar abs	126 bar abs
Condenser Vacuum pressure	0.07 bar abs	0.09 bar abs
Steam Rate	100 TPH	415 TPH
Exhaust	Condensing	Condensing
No. of Extraction	1	5 (3 LP ; 2 HP)
Extraction 1 temperature	140 °C	420 °C / 345 °C **(HP)**
Extraction 1 pressure	1.9 bar abs	35 bar abs
Extraction 2 mass flow	50.0 TPH	98 TPH
Cooling water Temperature	36 °C	38 °C

* The values are examples

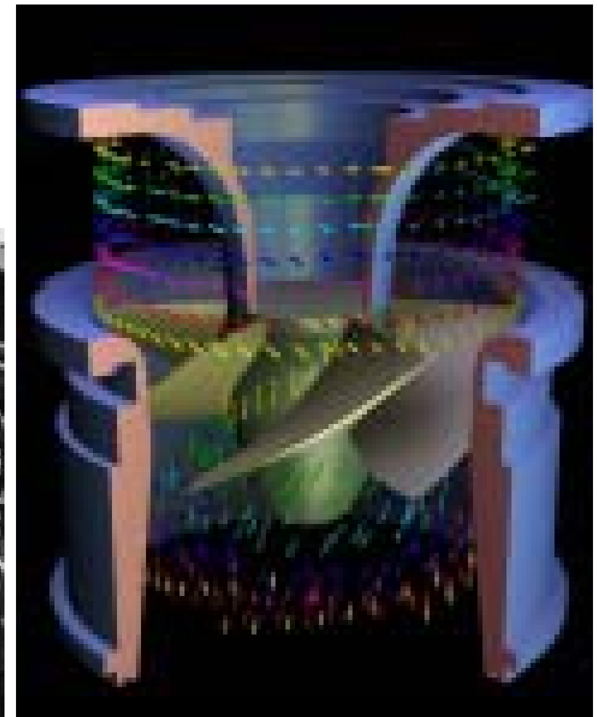
Hydraulic Turbines

Types of Hydraulic Turbines

Pelton turbine



Francis turbine

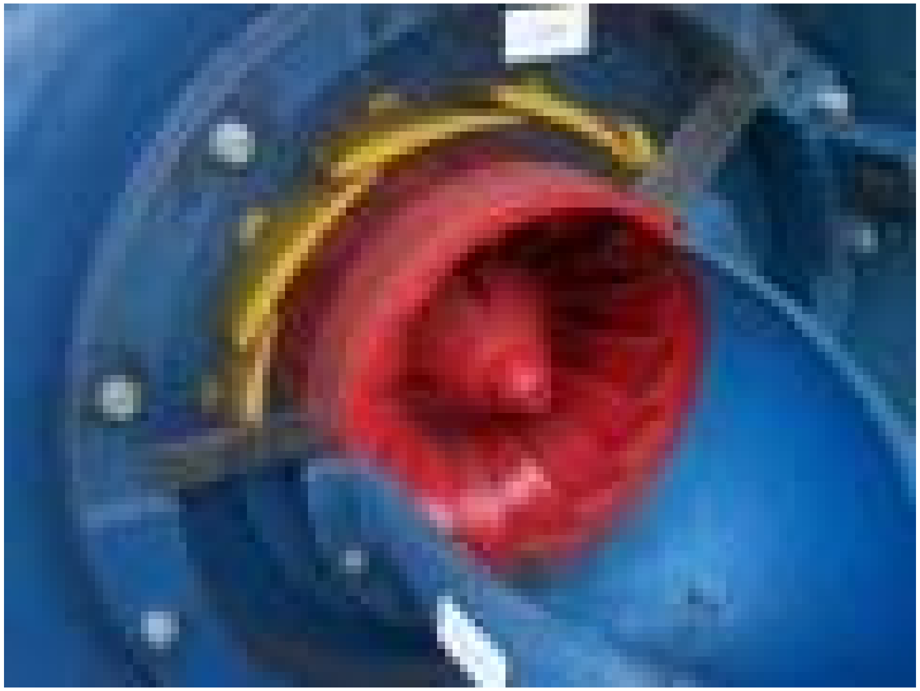


Kaplan turbine

Pelton Turbine

- The **Pelton turbine** is a tangential flow impulse turbine.
- It is most efficient in high head applications.
- Pelton turbines in power plants operate with net heads ranging from 656 to 4,921 ft (200 to 1,500 m).

Francis Turbine



- The **Francis turbine** is a reaction turbine, which means that the working fluid changes pressure as it moves through the turbine, giving up its energy.
- The inlet is spiral shaped. Guide vanes direct the water tangentially to the runner. The radial flow acts on the runner vanes, causing it to spin.
- The guide vanes (or wicket gates) are adjustable in order to allow efficient turbine operation for a range of water flow conditions.
- Power plants operate with net heads ranging from 66 to 2,461 ft (20 to 750 m).

Kaplan Turbine

- The **Kaplan turbine** is a propeller-type water turbine that has adjustable blades. It was developed in 1913 by the Austrian professor, Viktor Kaplan.
- The Kaplan turbine was an evolution of the Francis turbine. Its invention allowed efficient power production in low head applications that was not possible with Francis turbines.
- Kaplan turbines are now widely used throughout the world in high flow, low head power production.
- Power plants operate with net heads ranging from 33 to 230 ft (10 to 70 m).

Hydraulic Turbine Specification

	Francis+	Kaplan#	Pelton*
Power	47.1 MW	59 MW	18.6 MW
Total head	454 m	24.7 m	1748 m
Flow coefficient	0.25		-NA-
Blade diameter to width ratio	0.20		-NA-
Hydraulic losses	20%		-NA-
Jet velocity	-NA-		177 m/s
Speed	750 rpm	94.7 rpm	500 rpm
Pitch diameter of wheel	-NA-		3.319 m
Jet diameter	-NA_		94.2 mm

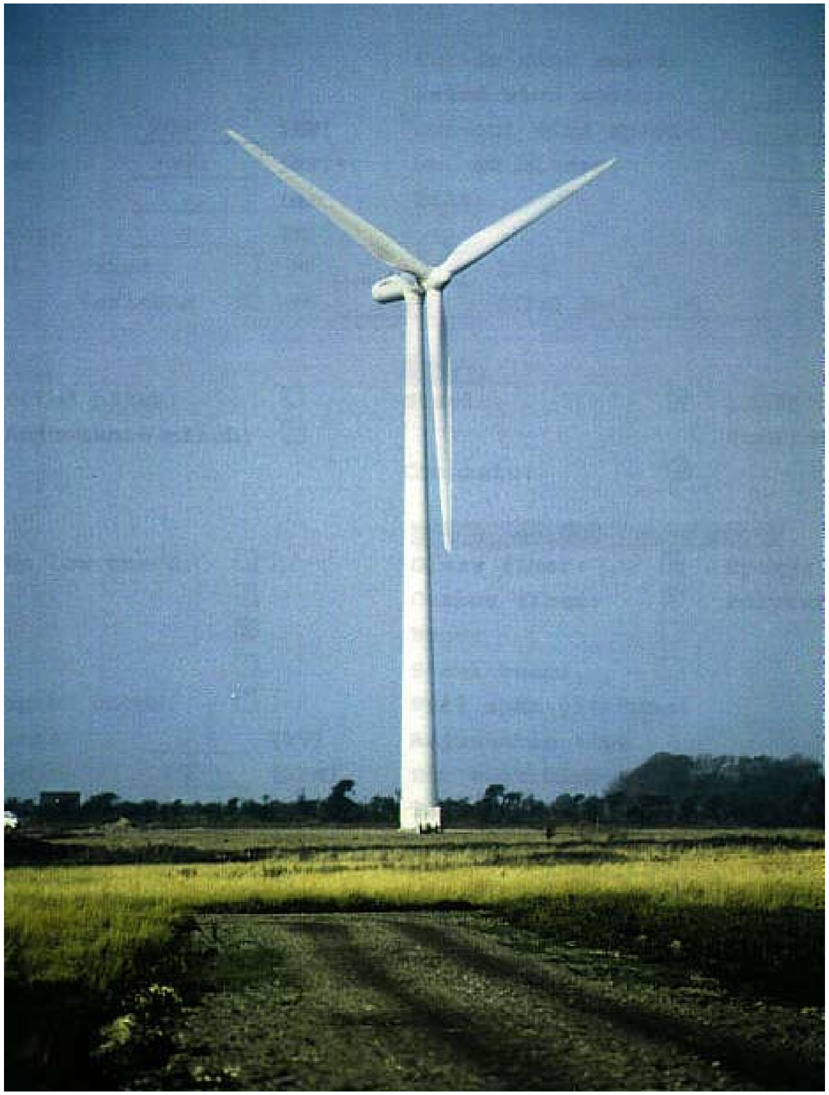
 # St. Lawrence Power Dam

+ Fionnay, Switzerland

*** Dixence, Switzerland**

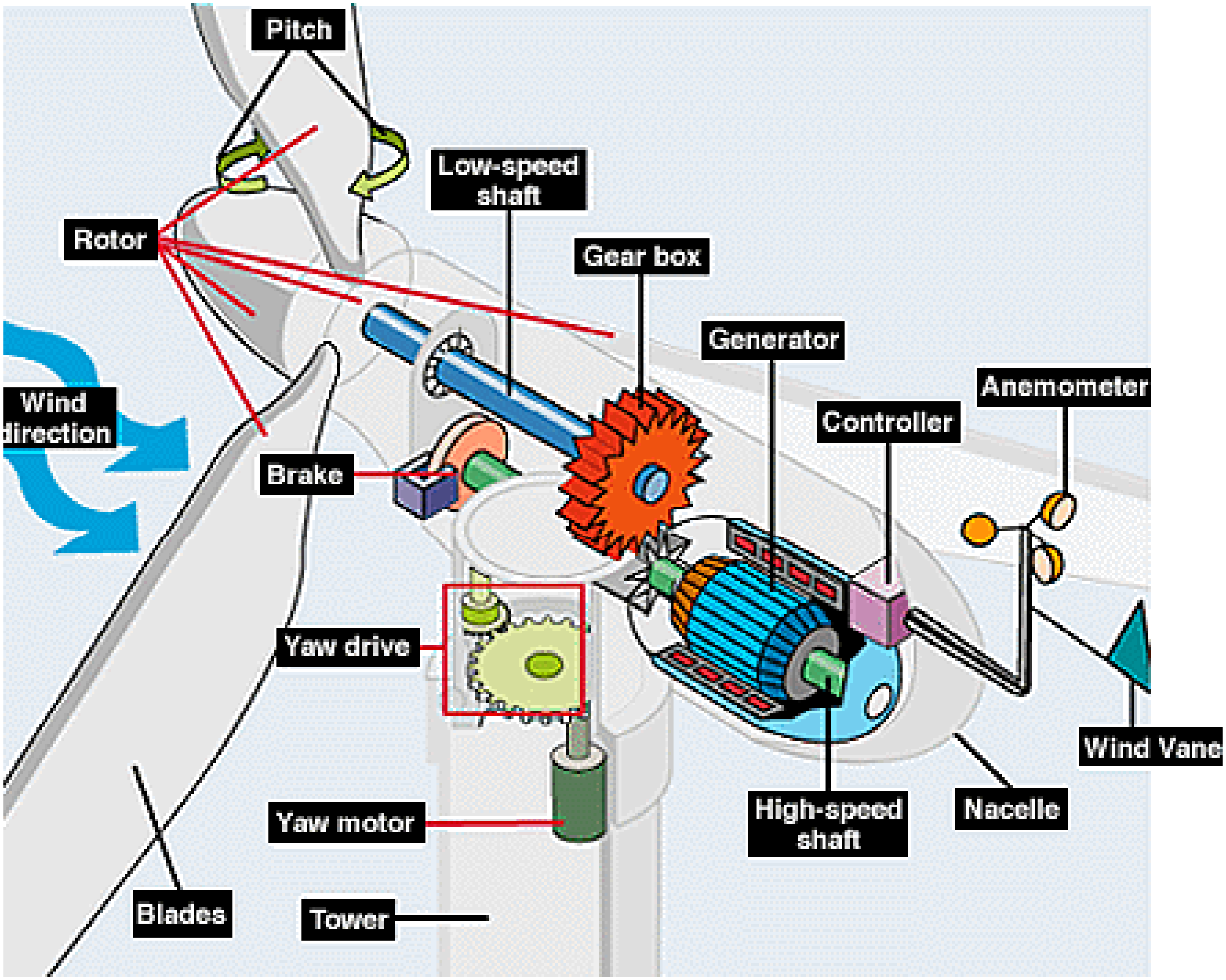
(Note: The values are examples)

Wind Turbines



- A wind turbine is a machine for converting the kinetic energy in wind into mechanical energy.
- If the mechanical energy is used directly by machinery, such as a pump or grinding stones, the machine is usually called a windmill.
- If the mechanical energy is converted to electricity, the machine is called a wind turbine.
- Wind turbines are broadly classified as horizontal axis or vertical axis.

Components of a Wind Turbine



Wind Turbine Specification

		GE 1.5 MW	VestasV42-600
Diameter	100 m	77 m	42 m
Speed	18.5 rpm	10.4 to 20.5 rpm **(variable)**	30 rpm
Power output	3 MW	1.5 MW	0.6 MW
Airfoil	NACA 0015	-NA-	NACA634XX
Axle height	100 m	100 m	40 m
Wind velocity	11.8 m/s	12 m/s	16 m/s
Operating limits	-20 to 40^{0}C	-20 to 40^{0}C	-20 to 40^{0}C

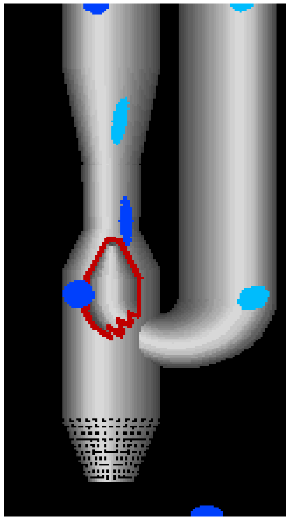
* The values are examples

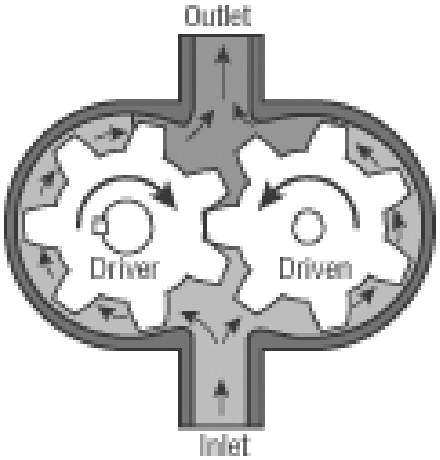
Pumps

Pump Classification

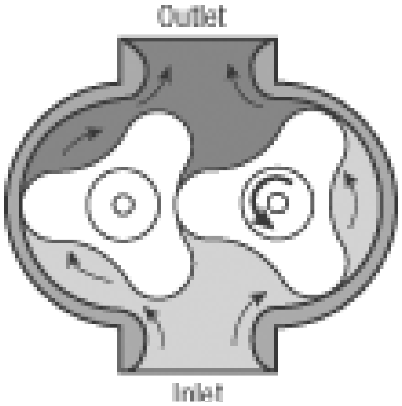
- ✓ Centrifugal pumps
- ✓ Electromagnetic pumps
- ✓ Jet pumps
- ✓ Screw pumps
- ✓ Gear pumps
- ✓ Lobe pumps
- ✓ Sliding vane pumps

Jet pump

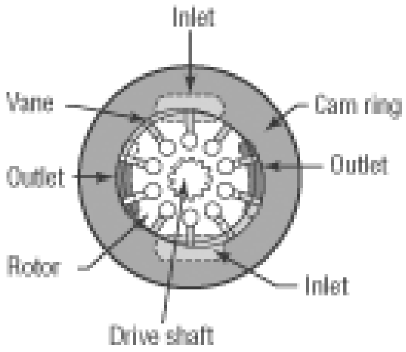




Gear pump



Lobe pump



Vane pump

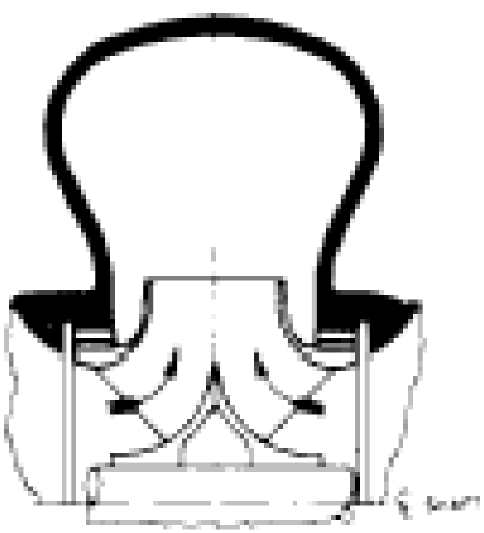
Types of Pumps

- Axial Flow Pumps
  - single stage or multistage
    - ✓ open impeller
      - fixed pitch
      - variable pitch
    - ✓ closed impeller
- Radial Flow Pumps
  - single suction or double suction
    - ✓ self priming or non priming
    - ✓ single stage or multistage
      - open impeller
      - semi open impeller
      - closed impeller
- Mixed Flow Pumps
  - single suction or double suction
    - ✓ self priming or non priming
    - ✓ single stage or multistage

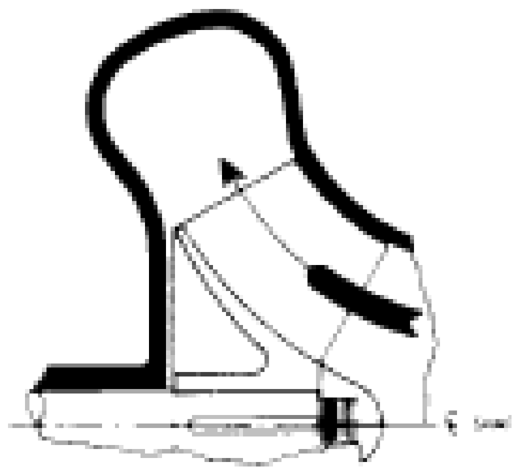
Types of Pumps (… contd.)

- Accelerate flow by imparting kinetic energy
- Decelerate flow (diffuse) in stator
- Results in increase in fluid pressure

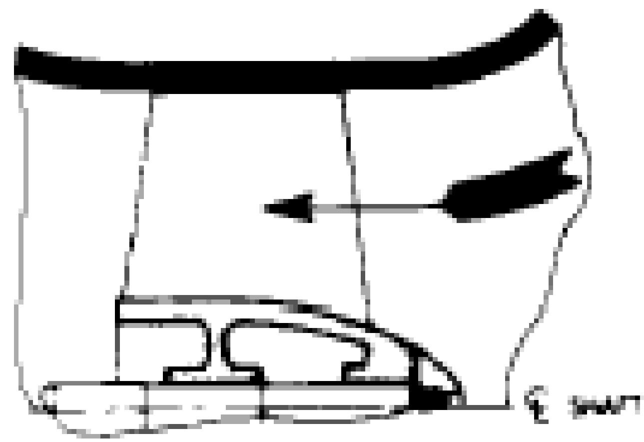
Impeller profiles



Radial flow



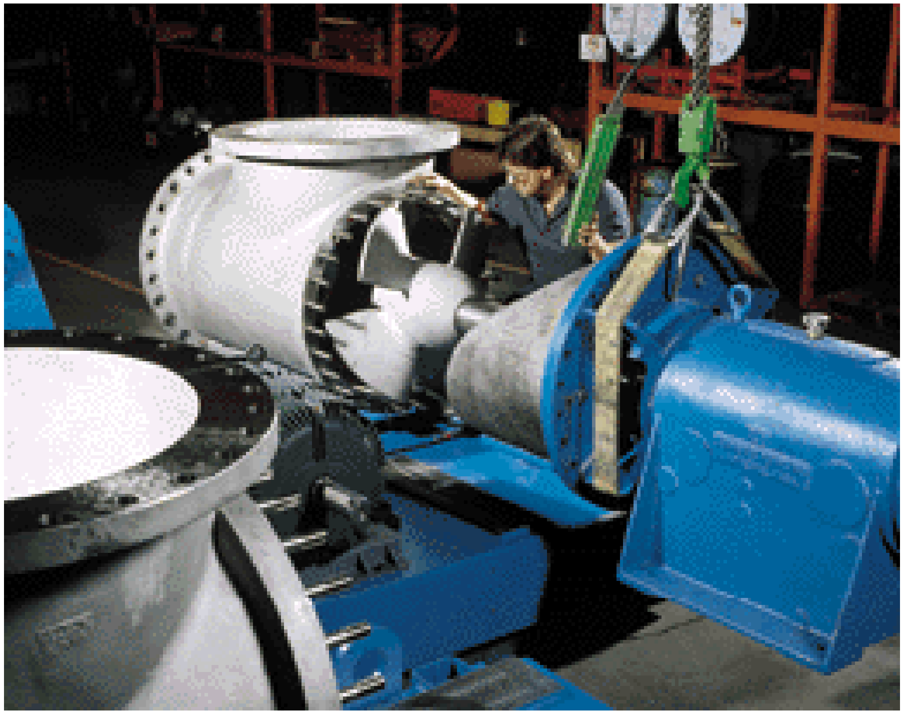
Mixed flow



Axial flow

Axial Flow Pumps

- An axial flow pump essentially consists of a propeller in a tube.
- The propeller can be driven directly by a sealed motor in the tube or by a right-angle drive shaft that pierces the tube.
- The main advantage of an AFP is that it can easily be adjusted to run at peak efficiency at low-flow/high-pressure and high-flow/low-pressure by changing the pitch of the propeller.



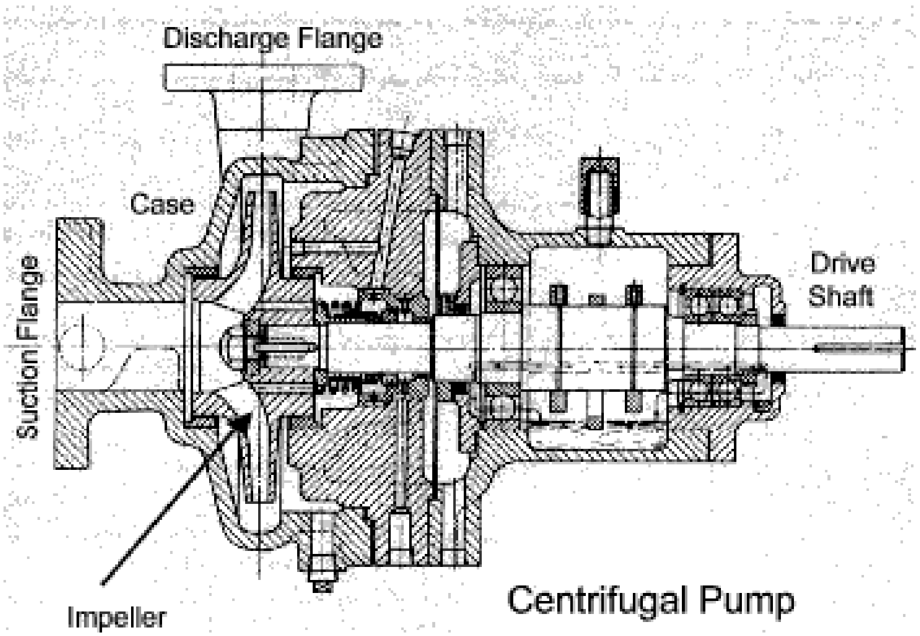
Application of axial flow pump

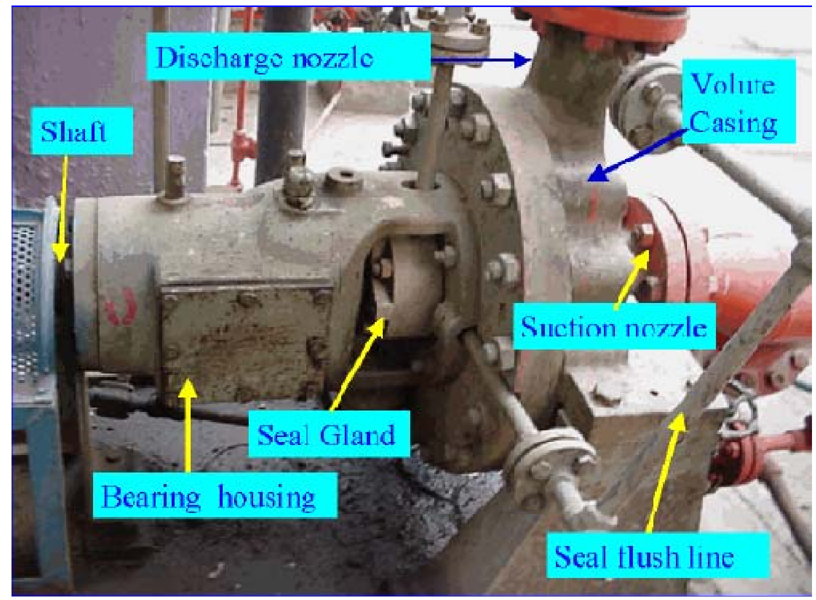
- Evaporators and crystallizers
- Waste-water handling
- Sludge transfer
- Flood control
- Flume recirculation
- Irrigation
- Regeneration
- Heat recovery
- High-volume mixing.

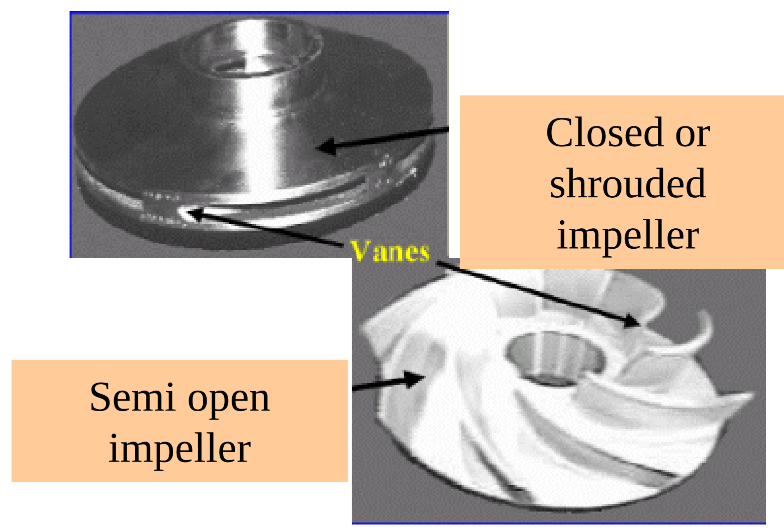
Centrifugal Pumps

- ‘Centrifugal’ means directing or moving away from the axis.
- Centrifugal pumps use an impeller and a volute to create partial vacuum and discharge pressure necessary to move water through the casing.
- Radial flow and mixed flow pumps are commonly referred to as centrifugal pumps.
- The rotating element of a centrifugal pump is called impeller.
- An open impeller consists of a hub to which vanes are attached, while a closed impeller has plates or shrouds on each side of the vanes.
- The open impeller is less efficient compared to closed one but suited to handle liquids containing solids.
- Radial pumps are provided with a spiral casing, often referred as a volute casing, which guides the flow from the impeller to the discharge pipe.
- A gradually increasing cross section around the casing tends to maintain a constant flow velocity within the casing.
- Some pumps have diffuser vanes between impeller exit and volute casing.
- Some pumps are double suction type.
- Higher the pressure drop or head, lower is the flow rate.

Centrifugal Pumps

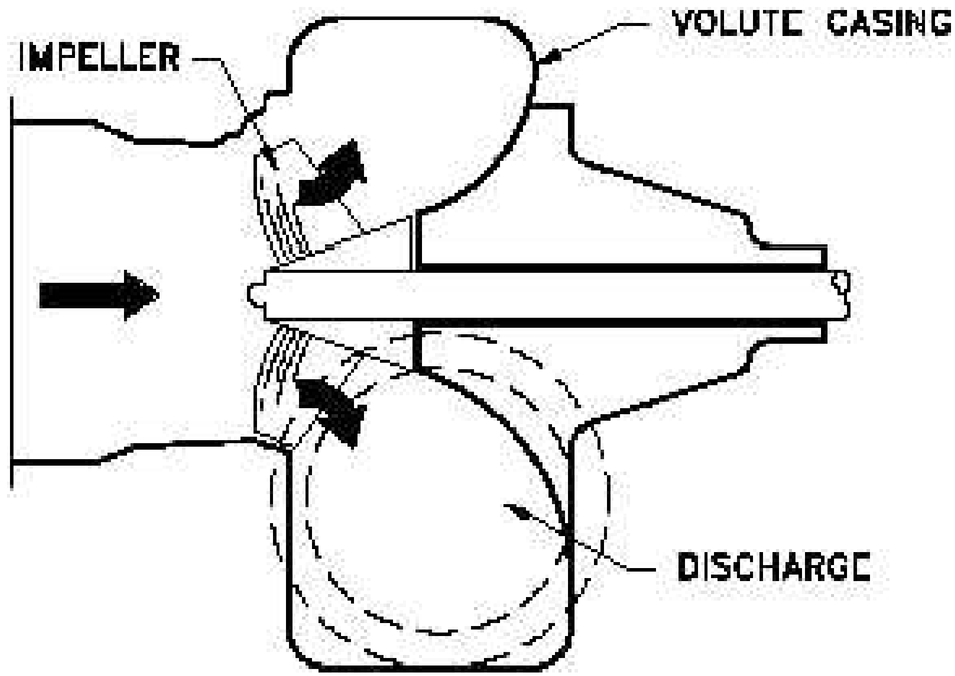


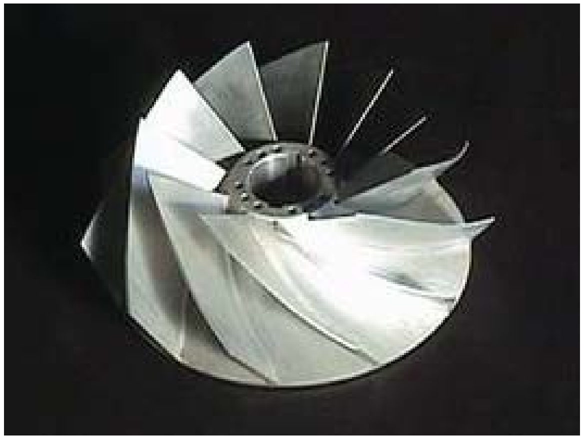


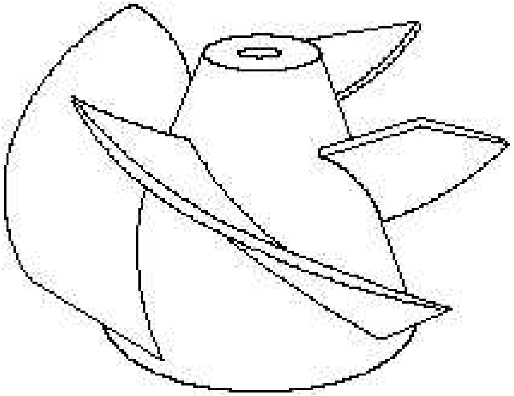


Mixed Flow Pumps

Mixed flow pumps are in-line pumps, used for applications requiring high volume flow with a low discharge pressure. One application that has used this technology in recent years, is high-performance jet-ski propulsion, where the pumps are used to power the water crafts with an outgoing stream of high speed water.







Pump Specification

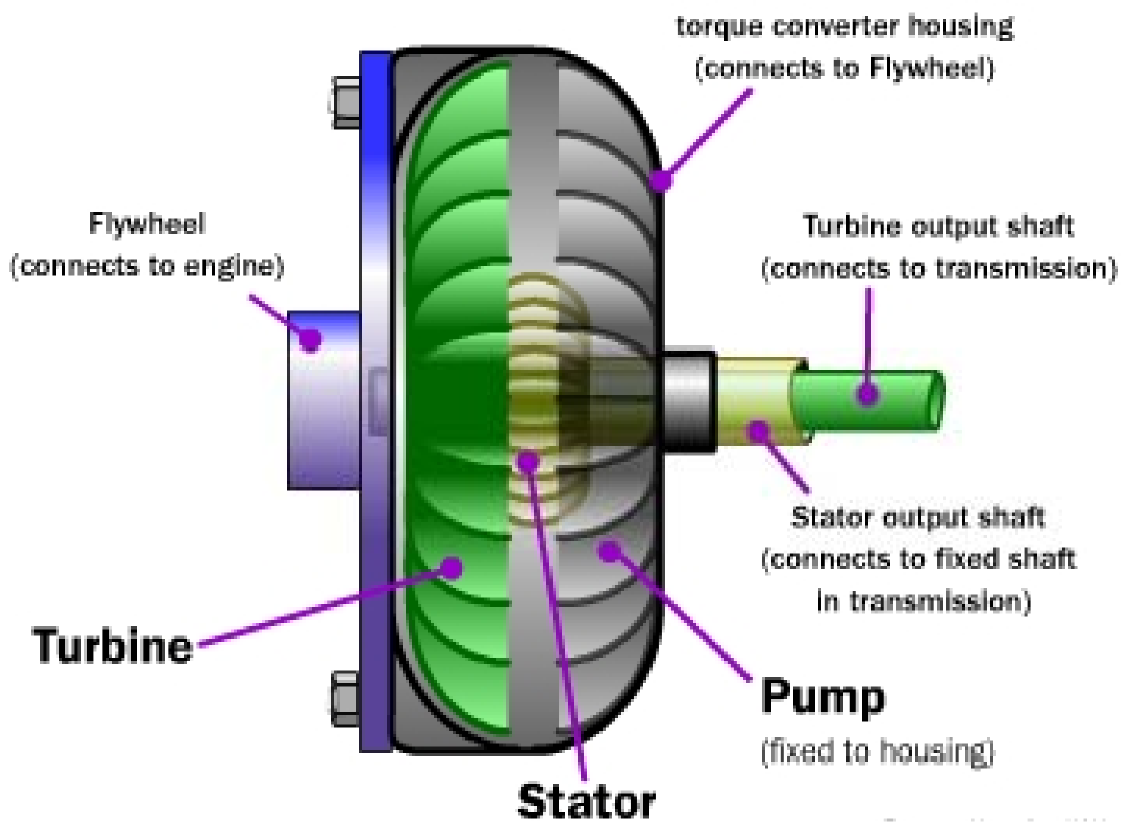
	Booster pump	Condensate extraction pump
Suction pressure	5.59 bar	0.09 bar abs
Volume flow rate	250 m^3/h	160m^3h
Discharge pressure	9.16 bar	2.6 bar abs
Power input	36.3 kW	46.5 kW
Speed	6000 rpm	4800 rpm
NPSH	22 m	-NA-
Efficiency	81%	-NA-
Fluid handled	Boiler feed pump	Condensate
Specific gravity of fluid	0.9130	-NA-
Temperature of fluid	426 K	315 K

* The values are examples

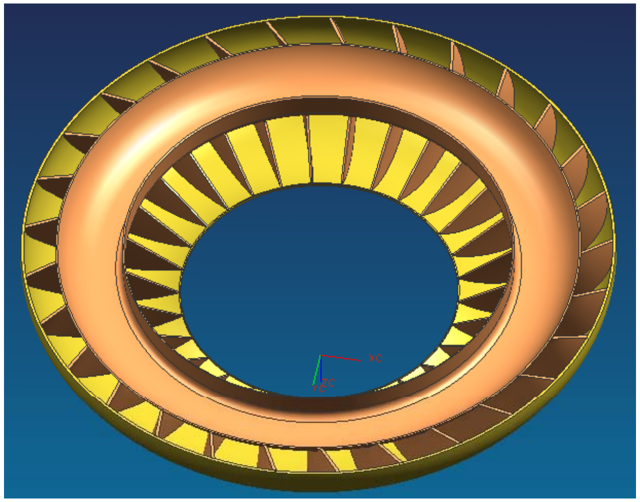
Torque converter

Principle : Engine torque + reaction torque= Output turbine torque

Oil is used as working fluid

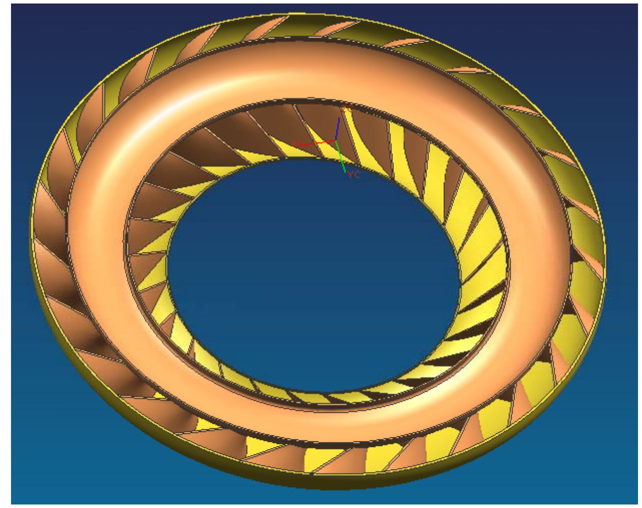


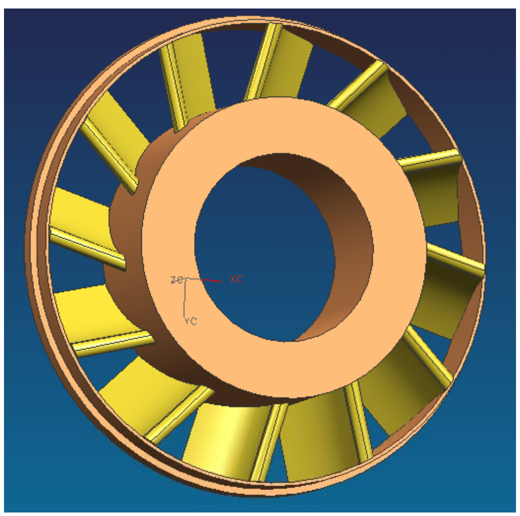
Components of a Torque Converter



Pump

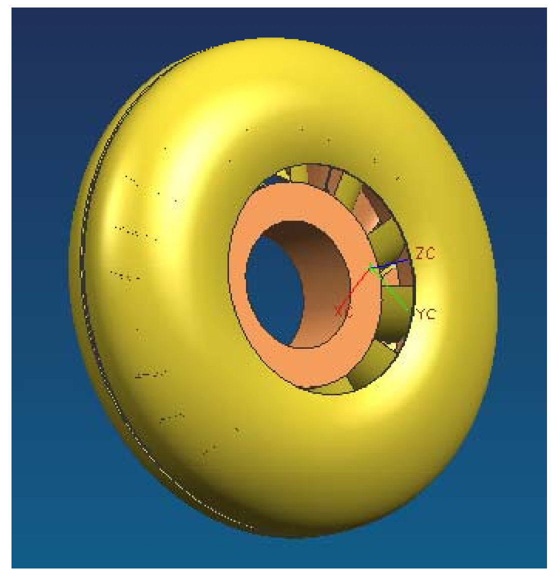
Turbine





Stator

Assembly



Torque Converter Specification

Diameter	240 mm
Axial length	75 mm
Number of pump blade	29
Number of turbine blade	25
Number of stator blade	12
Input power	125 to 200 bhp
Maximum input torque	743 Nm
Maximum input speed	3300 rpm

(Note: The values are examples)

Session Summary

- Turbomachinery has been defined.
- Classification of turbomachinery has been dealt with.
- Various turbomachinery components have been explained.
- Applications of different turbomachinery have been explained.
- Typical specifications for various turbomachinery have been discussed.