Gas Turbine and Jet Propulsion (PE-IV)

Course Code: 23BTMEL405

B. Tech - VII Semester

Prepared by:

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Teaching and Evaluation Scheme

Course Title: **Gas Turbine and Jet Propulsion**										
Semester	VII	Teaching Scheme				Evaluation Scheme				
						Theory			Practical	
Term	Odd	Th	Tu	Pr	Credits	TAE	CAE	ESE	INT	EXT
Course Category	PEC4	4 Hrs	-	-	04	10	15	50	-	-
Course Code	23BTMEL405									
Teaching Mode	Offline	4 Hrs.			Total	75			-	
Duration of ESE	2.5 Hrs.					75				

Course Objectives and Outcomes

Course Objectives	1. To use thermodynamic cycle analysis of Gas Turbine for Jet propulsions and Rockets.
	2. To understand analysis of Gas turbine and Jet Propulsion.
	3. To determine the performance of various propellants used in rockets.
Course Outcomes	Upon successful completion of this course, student shall be able to:
	CO 1. Define the basic principles of gas turbine used in propulsion devices.
	CO 2. Explain the details of gas turbine components used in jet propulsion.
	CO 3. Categorize the jet propulsion system based on their performance.
	CO 4. Compare various types of rocket propulsion system.
	CO 5. Select various fuels and propellants for rockets and jet propulsion.

Mapping of Course Outcomes with Program Outcomes and Program Specific Outcomes:

Course Outcomes	Program Outcomes and Program Specific Outcomes														
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO 10	PO11	PO 12	PSO 1	PSO 2	PSO 3
CO1	3	2	2	2	-	2	1	1	-	-	-	2	3	2	2
CO2	3	2	2	2	-	2	1	1	-	-	-	2	3	2	2
CO3	3	2	2	3	-	2	1	1	-	-	-	2	3	2	2
CO4	3	2	2	3	-	2	1	1	-	-	-	2	3	2	2
CO5	3	2	2	3	-	2	1	1	-	-	-	2	3	2	2

Syllabus

Unit	Contents
Unit 1	Introduction to Gas Turbine Cycle: Gas Turbine Cycle: Brayton Cycle, open and closed cycles, Layout of Gas turbine cycle , advantages and disadvantages of a GT plant, Analysis of a Gas turbine plant, Effect of Regeneration on Cycle Efficiency, Effect of Irreversibility's in Turbine and Compressor, Effect of Pressure Ratio on the Cycle, Effect of Intercooling and Reheating on Cycle, Ideal Regenerative Cycle with Intercooling and Reheat
Unit 2	Components of a Gas Turbine Plant: Construction and operation of the components of a gas turbine plant, types of compressor used, Combustion Chamber and its type, Gas Turbine Fuels, Gas Turbine Materials and its properties, Materials for Turbine Rotor Discs, Turbine Rotor Blade, Combustion Chamber, Compressor, nozzles
Unit 3	Principle of Jet Propulsion Classification of Jet Propulsion Engines, Turbojet Engine, Turbojet engine with afterburner ,Turbofan Engine, ATHODYDS- Ramjets and Pulse Jets, Valveless Pulsejets, Scramjet, Analysis of ramjet and scramjet engines, Performance of Jet Propulsion Engines, Energy balance of a propulsion system, Thrust power, Propulsive power, Propulsive efficiency, Thermal efficiency, Overall efficiency, Jet efficiency

Syllabus

Unit	Contents
Unit 4	Rocket Propulsion: Principle of Rocket Propulsion, Theory of Rockets, Non-Air-breathing Engines, Solid Propellant Rockets, Restricted burning , Unrestricted burning, Liquid Propellant Rocket Engines, Pressure feed, bipropellant rocket systems, Nuclear Rockets, Hybrid Rocket Engines, Hybrid rocket with a solid fuel and a liquid oxidizer, ducted rocket, ejector rocket-ramjet and integral ram rocket.
Unit 5	Fuels and Propellants Thermodynamic Requirements, Mechanical Properties of Solid propellants, homogeneous and heterogeneous, Liquid propellants and its classifications, Monopropellants and Bipropellants. Hypergolic (self-igniting), or non- Hypergolic, and Storable or Cryogenic. Polymeric Fuels for Composite Propellants, Double base Propellant Manufacture, burning rate and its affecting parameters, method of measurement of burning rate of propellants, Polymeric Fuels for Composite Propellants, Ignition Composition, Combustion Mechanism of Solid Propellants and liquid propellants, Geometric Aspects of Solid Propellants.

Study Material

Text Books	1.	Understanding Aerospace Chemical Propulsion, Prof. H. S. Mukunda, Interline Publishing, Bangalore, 2003.
	2.	Basic and Applied Thermodynamics, P K Nag, Second Edition Tata McGraw Hill Education, 2010.
	3.	Applied Thermodynamics, Onkar Singh, New Age International (P) Ltd., Third Edition, 2009
	4.	Jet Propulsion, Nicholas Cumpsty and Andrew Heyes, 3rd ed., Cambridge University Press, 2015
E-Books	1.	Fundamentals of Aircraft and Rocket Propulsion, Ahmed F. El-Sayed, https://doi.org/10.1007/978-1-4471-6796-9
	2.	Rocket Propulsion Elements, George P. Sutton, y John Wiley & Sons,2017
Reference Books	1.	Elements of Gas Turbine Propulsion, J. D. Mattingly, McGraw Hill Publications, 1996.
	2.	Fundamentals of Jet Propulsion with Applications, R. D. Flack, Cambridge University Press, 2005.
	3.	Aircraft Propulsion: Cleaner, Leaner, and Greener ,Farokhi, S. ,John Wiley & Sons.(2021)
Online Material	1.	Rocket Propulsion Elements.Sutton, G. P., and O. Biblarz, 7th ed. Wiley Interscience, 2000. ISBN: 9780471326427.
	2.	Aircraft Propulsion, Prof. Vinayak N. Kulkarni,https://archive.nptel.ac.in/courses/112/103/112103281/
	3.	Introduction to Aerospace Propulsion -Video course ,Prof. A M Pradeep https://archive.nptel.ac.in/courses/101/101/101101001/

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Unit 1

GAS TURBINE



- Invented in 1930 by Frank Whittle
- Patented in 1934
- First used for aircraft propulsion in 1942 on Me262 by Germans during second world war
- Currently most of the aircrafts and ships use GT engines
- Used for power generation
- Manufacturers: General Electric, Pratt &Whitney, SNECMA, Rolls Royce, Honeywell, Siemens – Westinghouse, Alstom
- Indian take: Kaveri Engine by GTRE (DRDO)



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GAS TURBINE

The gas turbine can handle a larger gas flow than that of the reciprocating internal combustion engines, because it utilizes a continued combustion.

- The gas turbine is suitable as the high power engine.
- The gas turbine for airplanes (called a jet engine) makes use of this advantage.

Generally speaking gas turbine is divided into two categories as follows:

(a) Open cycle gas turbine
(b) Closed cycle gas turbine

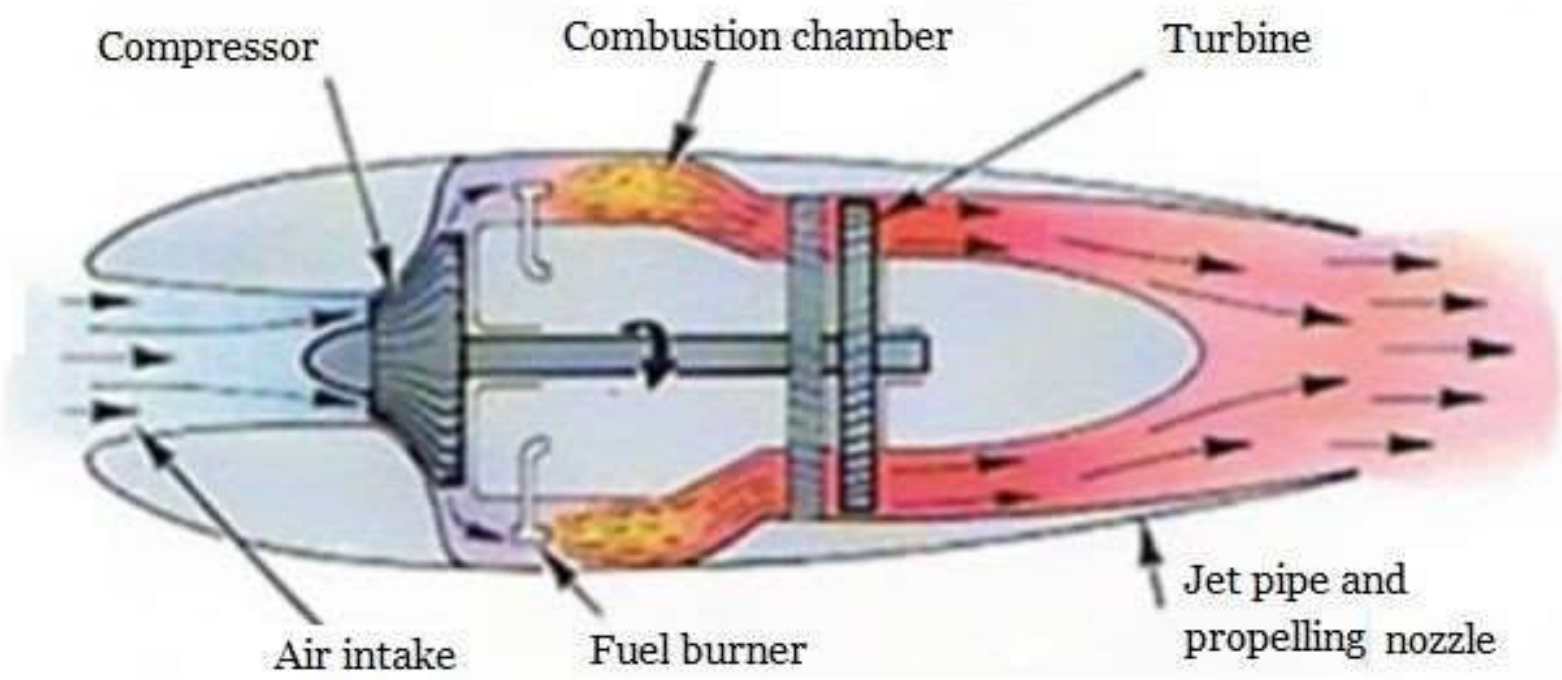


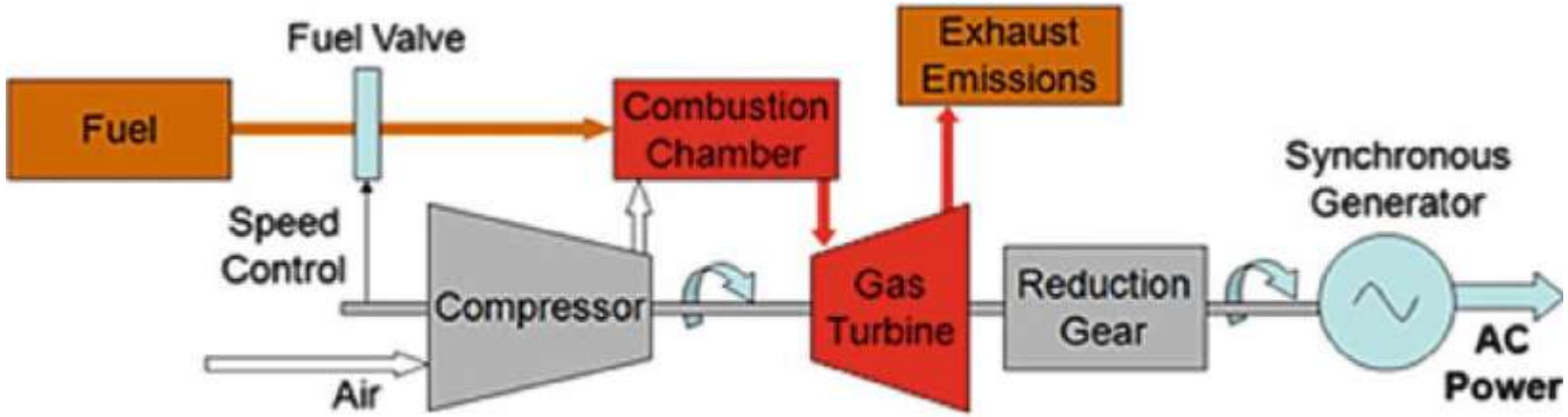
Uses of gas turbine

1. Jet engines
2. Marine
3. Power generation
4. Oil & gas industry

GAS TURBINE

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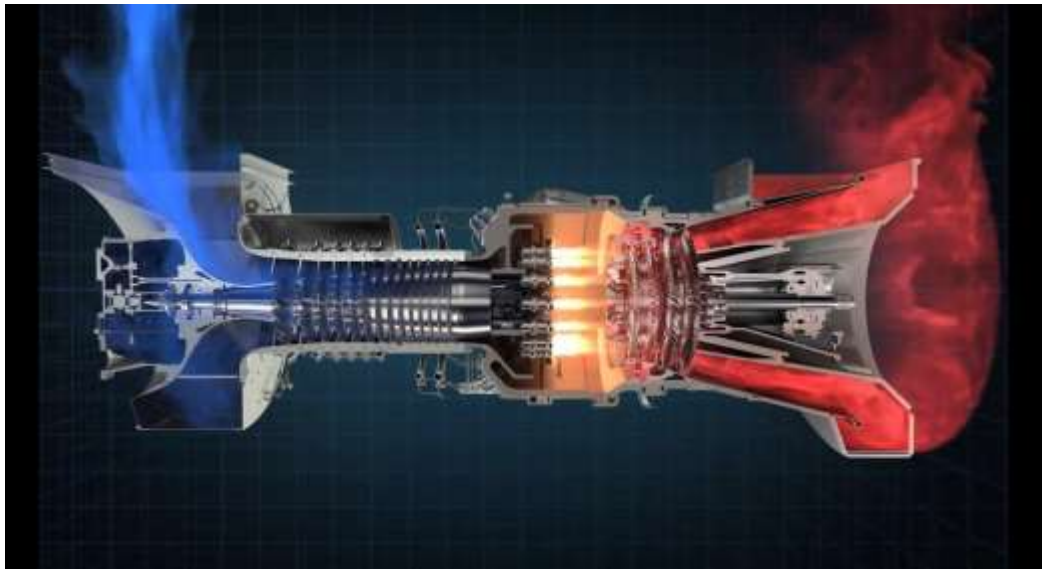
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Advantages

- Relatively small size (power to size ratio)
- Light weight for output (power to weight ratio)
- Require no cooling water
- Rapid startup and loading
- Good thermal efficiency
- Low maintenance
- Runs unattended
- Long life

Disadvantages

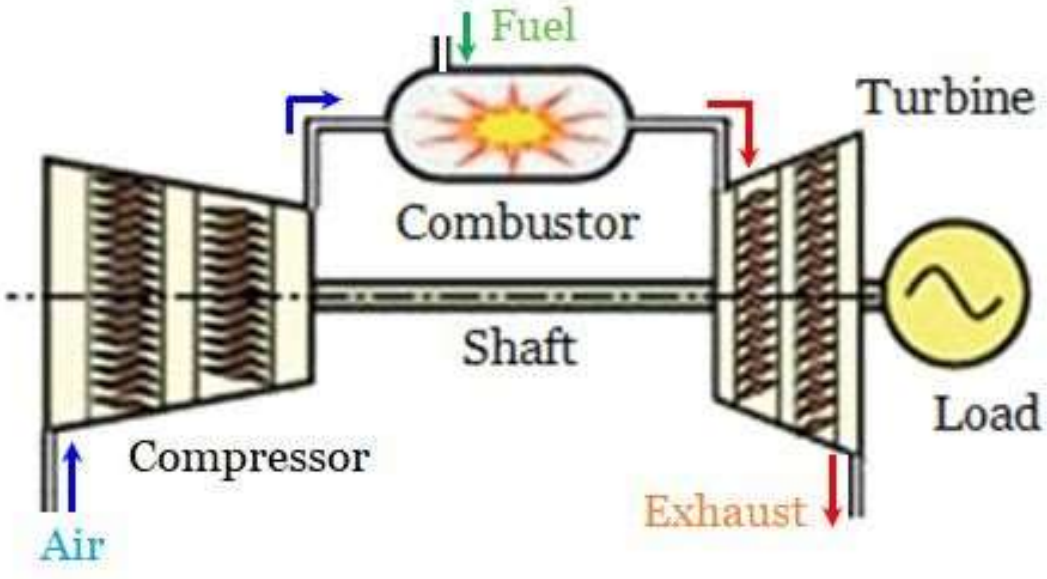
- Expensive
- Require clean fuel
- Not efficient at part load
- Use more fuel than IC engine



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(a) Open cycle gas turbine:



Working Principle

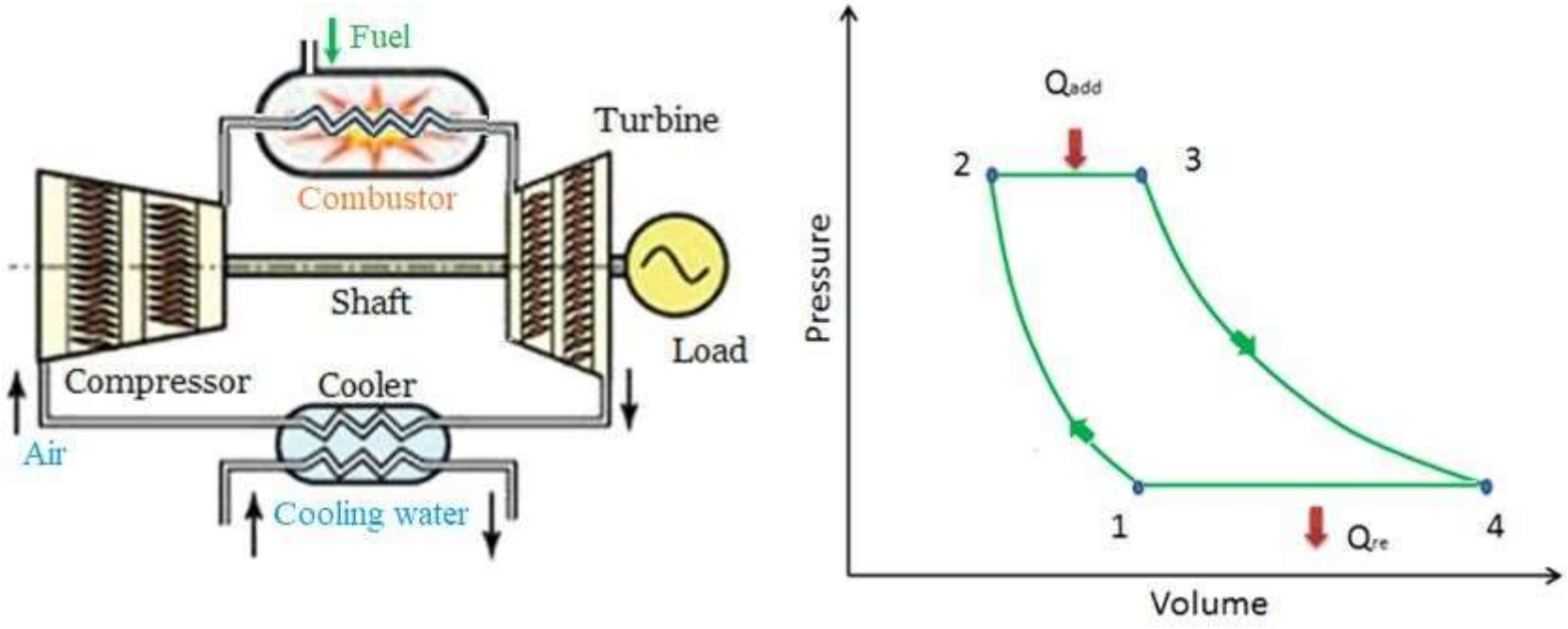
- Fresh air enters the compressor at ambient temperature where its pressure and temperature are increased.
- The high pressure air enters the combustion chamber where the fuel is burned at constant pressure.
- The high temperature (and pressure) gas enters the turbine where it expands to ambient pressure and produces work.

Features:

- Gas-turbine is used in aircraft propulsion and electric power generation.
- High thermal efficiencies up to 44 %.
- High power to weight ratio, high reliability, long life
- Fast start up time, about 2 min, compared to 4 hr for steam-turbines

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(b) Brayton Cycle or Closed cycle gas turbine:



The Brayton ideal cycle is made up of four internally reversible processes:
1-2 isentropic compression (in compressor)
2-3 const. pressure heat-addition (in combustion chamber)
3-4 isentropic expansion (in turbine)
4-1 const. pressure heat rejection (exhaust)

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Advantage of closed cycle gas turbine:

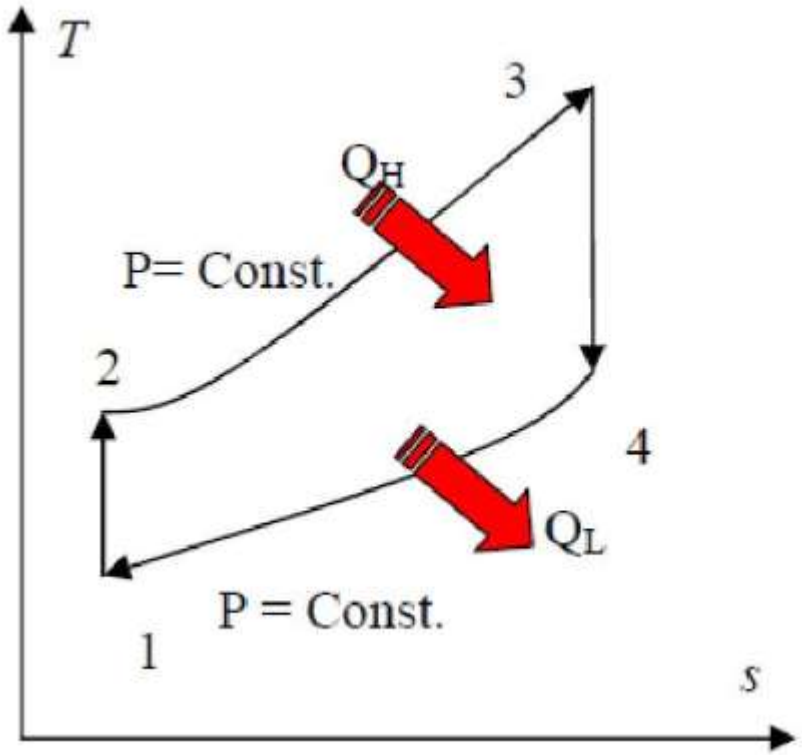
- Due to externally fired, cheaper fuel such as coal can be used
- Products of combustion is not in direct contact with turbine blades, hence fouling of the blade can be avoided
- Part load efficiency is improved by changing the pressure ratio and varying the quantity of working fluid keeping as cycle temperature constant and at constant speed
- High operating pressure causes low specific volume for the working fluid reducing the size of machines, heat exchangers and piping
- Heat transfer coefficients are higher which reduces the heat exchanger size

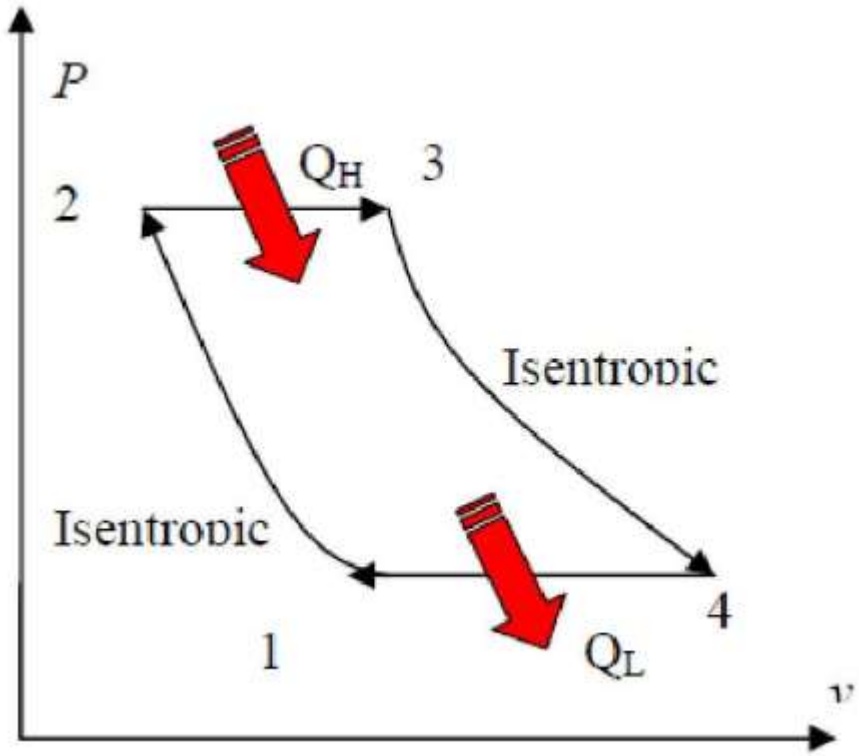
Disadvantage of closed cycle gas turbine:

- More complicated and costly system
- Air heaters alone represent over 30% of total mass and cost
- System is not sufficiently strong to resist high pressure

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Thermal efficiency for the Brayton cycle is:

$$\eta_{th,Brayton} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma} = \left(\frac{P_3}{P_4}\right)^{(\gamma-1)/\gamma} = \frac{T_3}{T_4} \qquad \frac{T_4}{T_1} = \frac{T_3}{T_2} \qquad r_P = \frac{P_2}{P_1} = \frac{P_3}{P_4}$$

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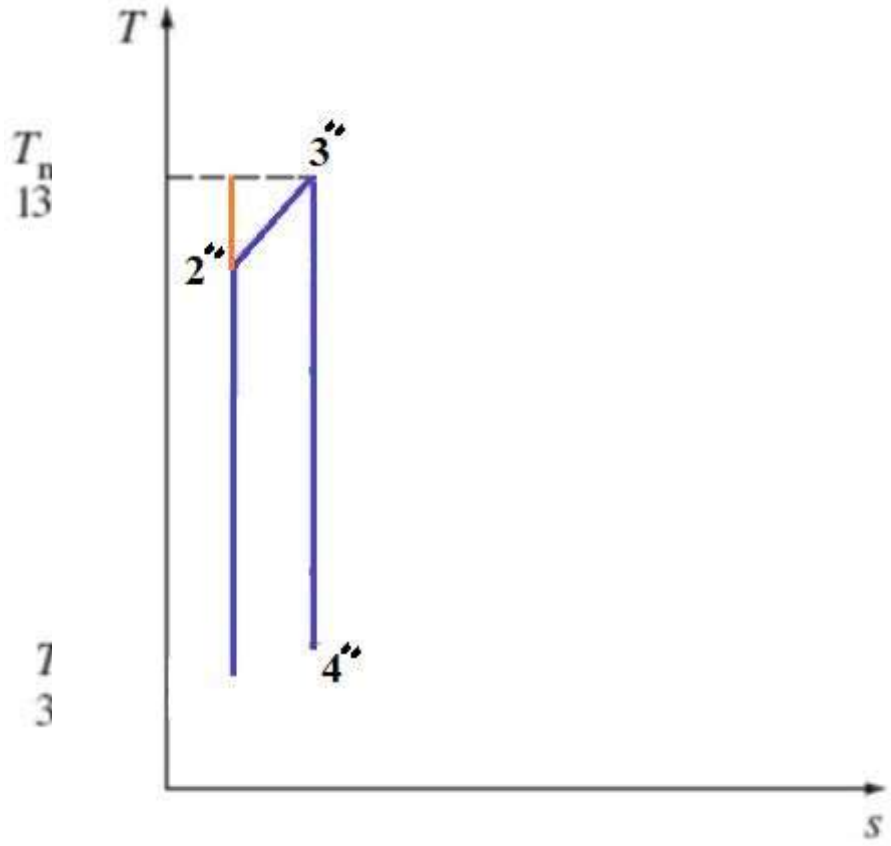
Thus, $$\eta_{th,Brayton} = 1 - \frac{1}{r_P^{(\gamma-1)/\gamma}}$$

where r_P is the pressure ration and $\gamma = c_p / c_v$ is the specific heat ratio.

Maximum Pressure Ratio

Given that the maximum and minimum temperature can be prescribed for the Brayton cycle, a change in the pressure ratio can result in a change in the work output from the cycle.

The maximum temperature in the cycle T_3 is limited by metallurgical limits because the turbine blades cannot sustain temperatures above 1300 K. The minimum temperature is set by the air temperature at the inlet to the engine.



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The specific work output w, upon which the size of plant for a given power depends, is found to be a function not only of pressure ratio but also of maximum cycle temperature T_3.

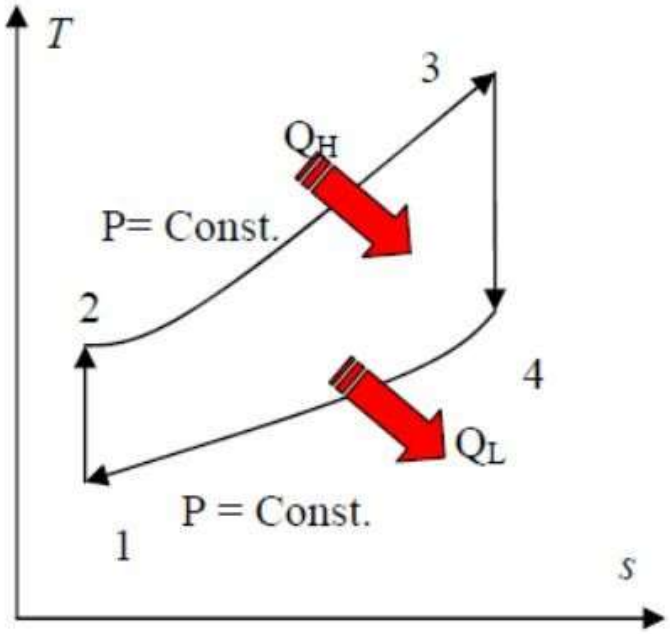
Thus, the specific work output is,

$$W = C_p(T_3 - T_4) - C_p(T_2 - T_1)$$

$$= C_p T_1\left[\frac{T_3}{T_1}\left(1 - \frac{T_4}{T_3}\right) - \left(\frac{T_2}{T_1} - 1\right)\right]$$

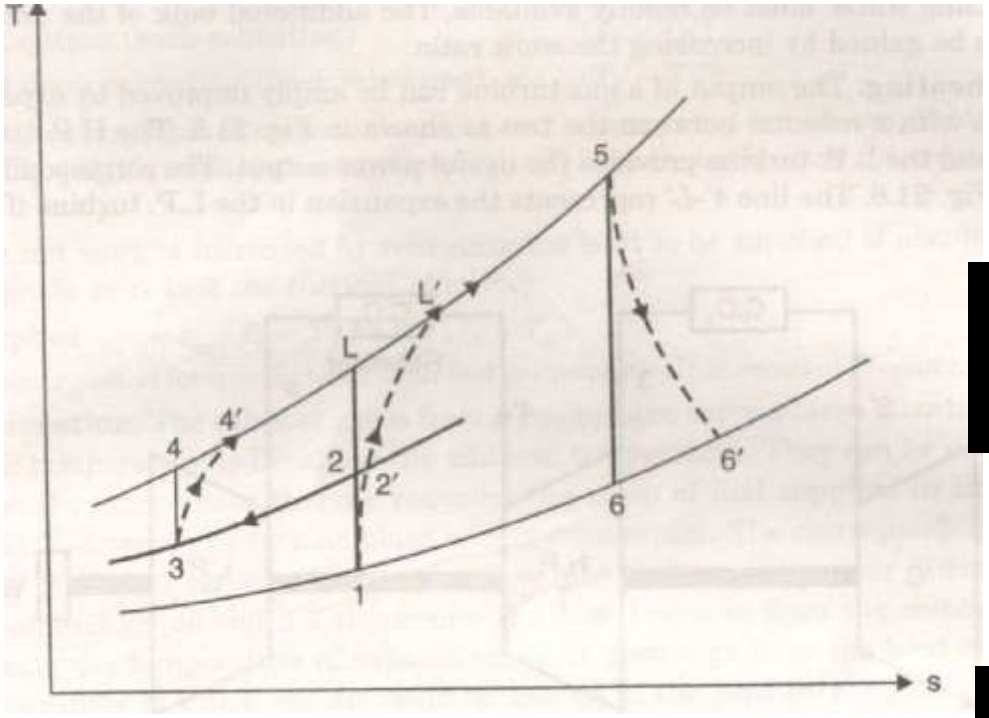
$$= C_p T_1\left[\frac{T_3}{T_1}\left\{1 - \frac{1}{(R_p)^{\gamma-1/\gamma}}\right\} - \left\{(R_p)^{\gamma-1/\gamma} - 1\right\}\right]$$

$$W_{net,max} \Rightarrow \quad r_p = \left(\frac{T_3}{T_1}\right)^{\frac{\gamma}{2(\gamma-1)}}$$



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Intercooling



Now, work input (*with intercooling*)

$$= C_p(T'_2 - T_1) + C_p(T'_4 - T_3)$$

Now, work input (*without intercooling*)

[redacted]

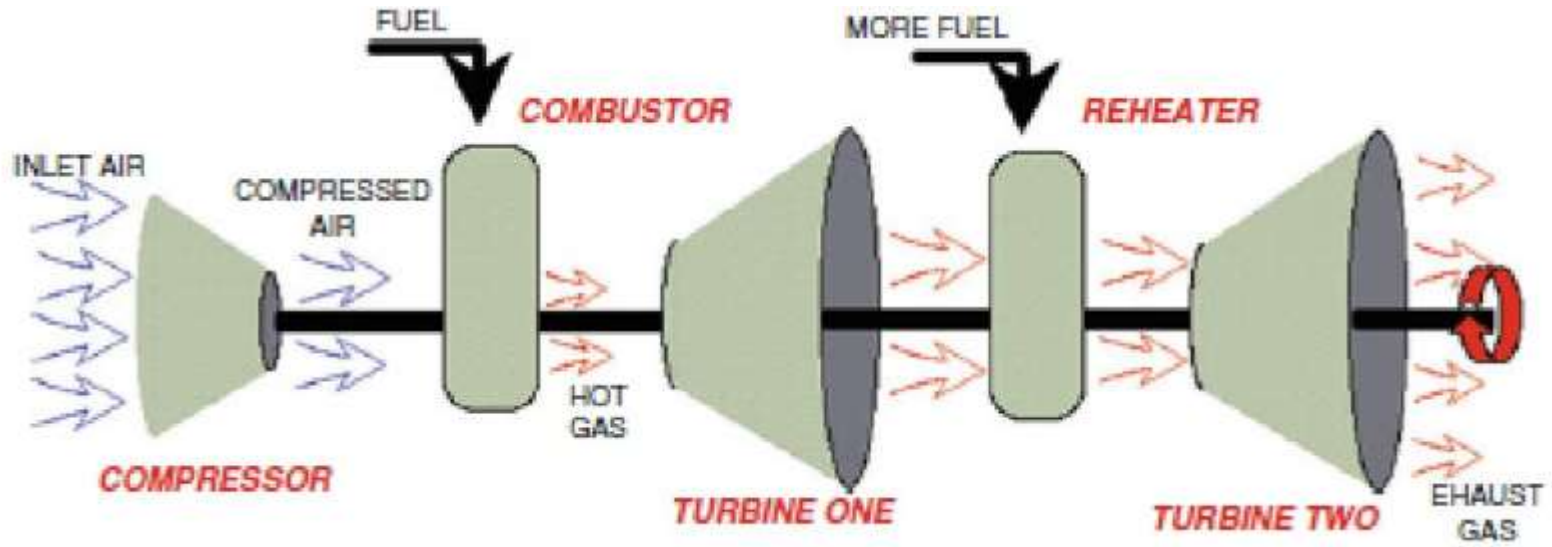
Since the pressure lines diverge to the right on T-S diagram

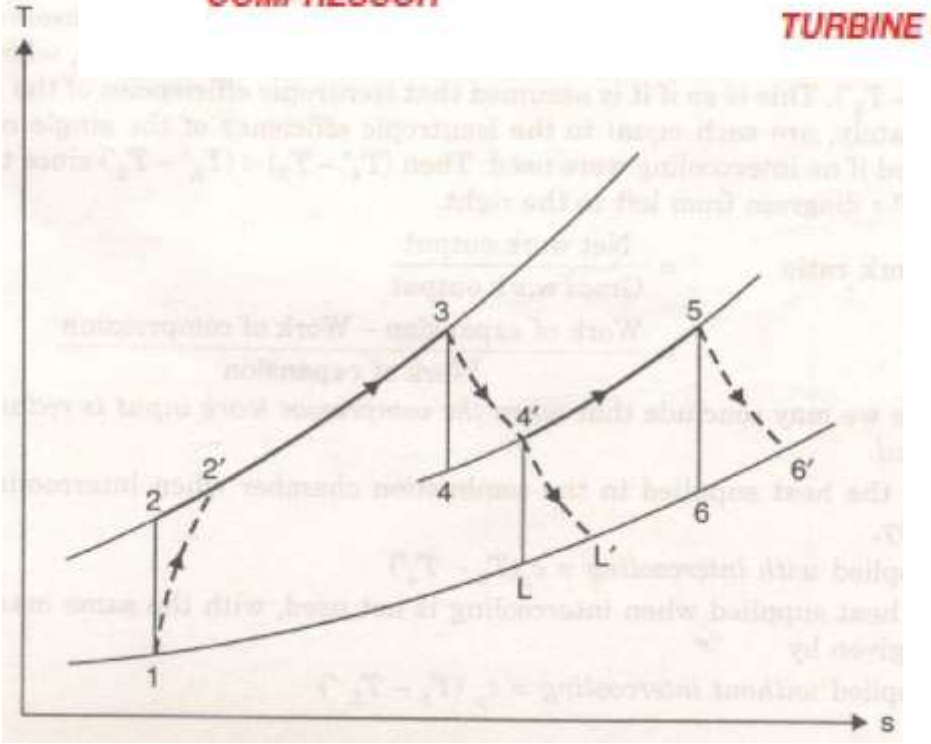
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Reheating



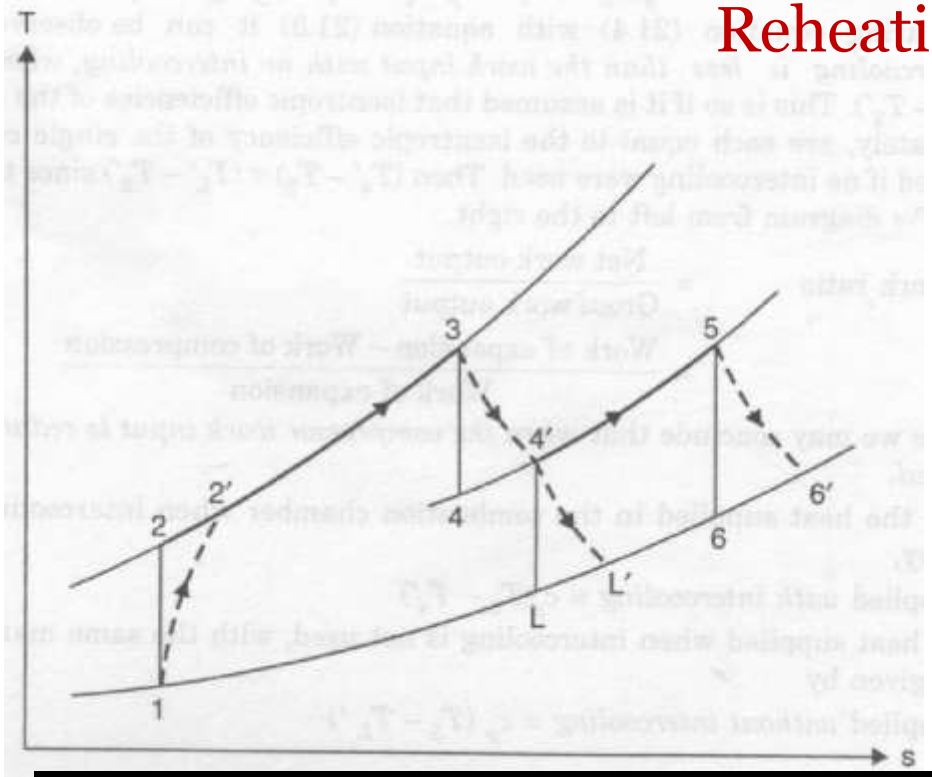


- The output of gas turbine can be improved by expanding the gases in two stages with a re-heater between the two.
- The HP turbine drives the compressor and the LP turbine provides useful power output.

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Reheating

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[redacted]

[redacted]

Now, work input (*net output*) of LP turbine is given by,

[redacted]

[redacted]

Now, work input (*without reheating*)

[redacted]

Since the pressure lines diverge to the right on T-S diagram

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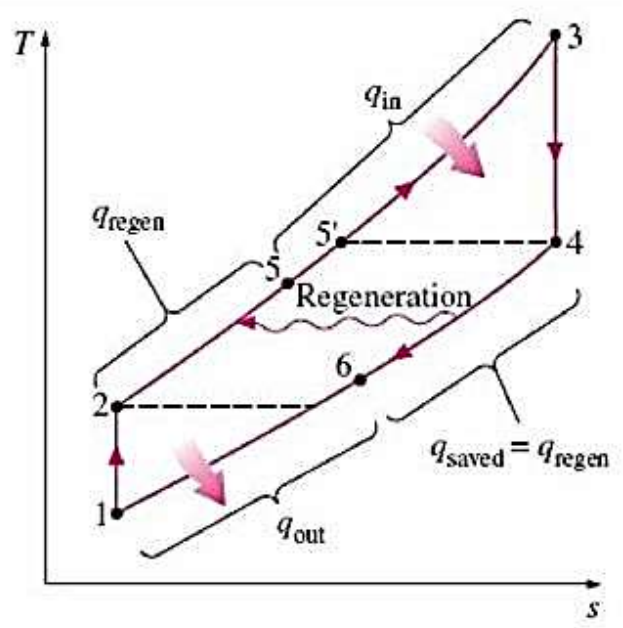
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Brayton Cycle With Regeneration

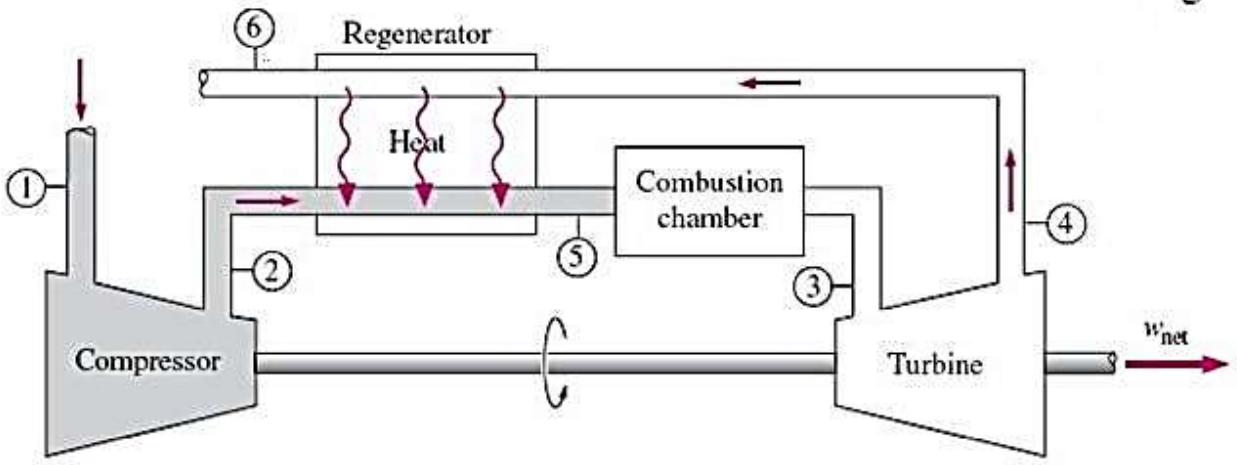
Temperature of the exhaust gas leaving the turbine is **higher** than the temperature of the air leaving the compressor.

The air leaving the compressor can be heated by the hot exhaust gases in a **counter-flow** heat exchanger – a process called **regeneration**.

The thermal efficiency of the Brayton cycle **increases** due to regeneration since less fuel is used for the same work output.



T-s diagram of a Brayton cycle with regeneration.



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Effectiveness of the Regenerator

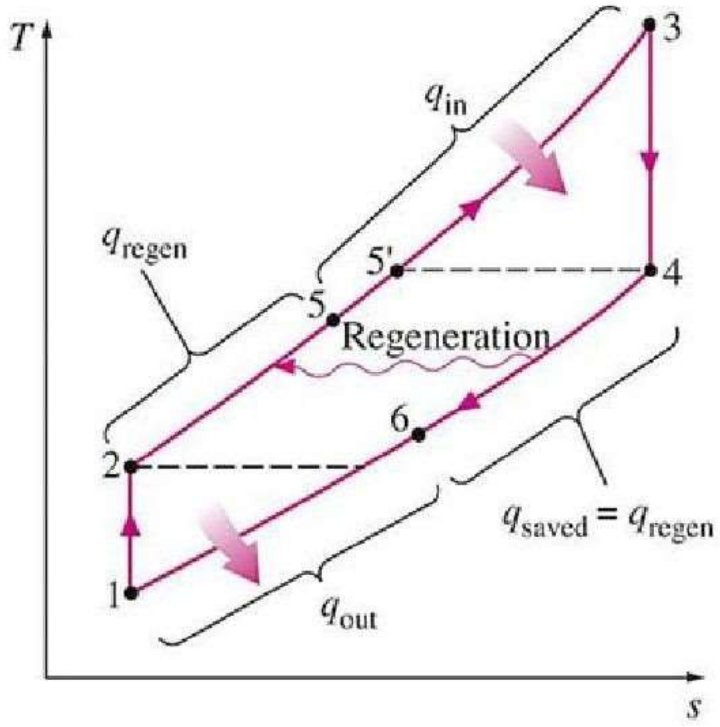
Assuming the regenerator is well insulated and changes in kinetic and potential energies are negligible, the **actual** and **maximum heat transfers** from the exhaust gases to the air can be expressed as

$$q_{\text{regen,act}} = h_5 - h_2$$

$$q_{\text{regen,max}} = h_{5'} - h_2 = h_4 - h_2$$

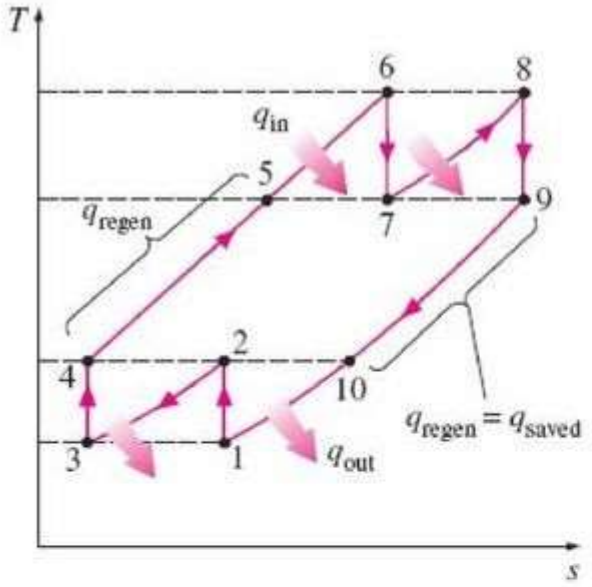
Effectiveness of the regenerator,

$$\epsilon = \frac{q_{\text{regen,act}}}{q_{\text{regen,max}}} = \frac{h_5 - h_2}{h_4 - h_2}$$

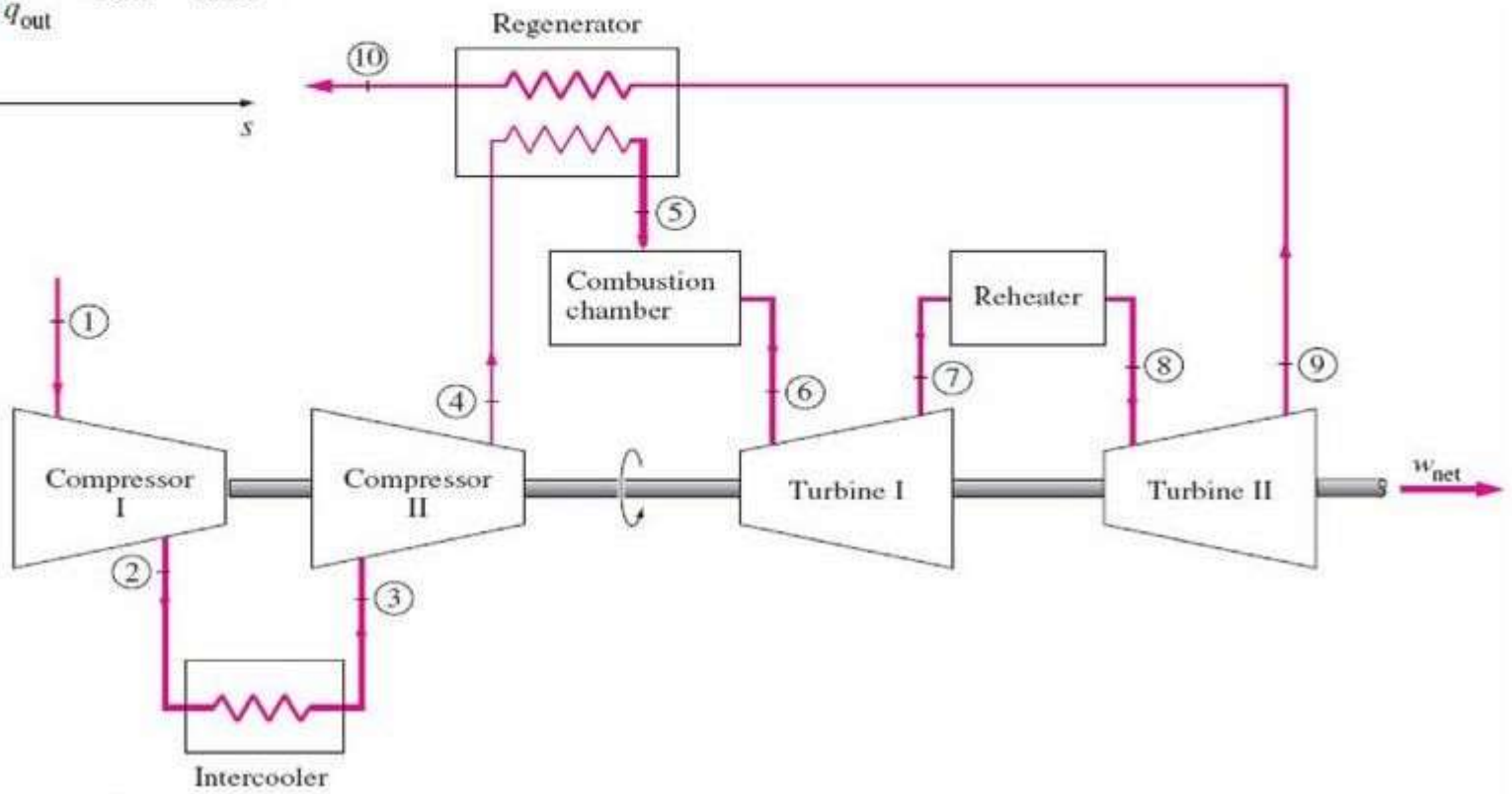


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Physical arrangement of an **ideal two-stage** gas-turbine cycle with intercooling, reheating, and regeneration.

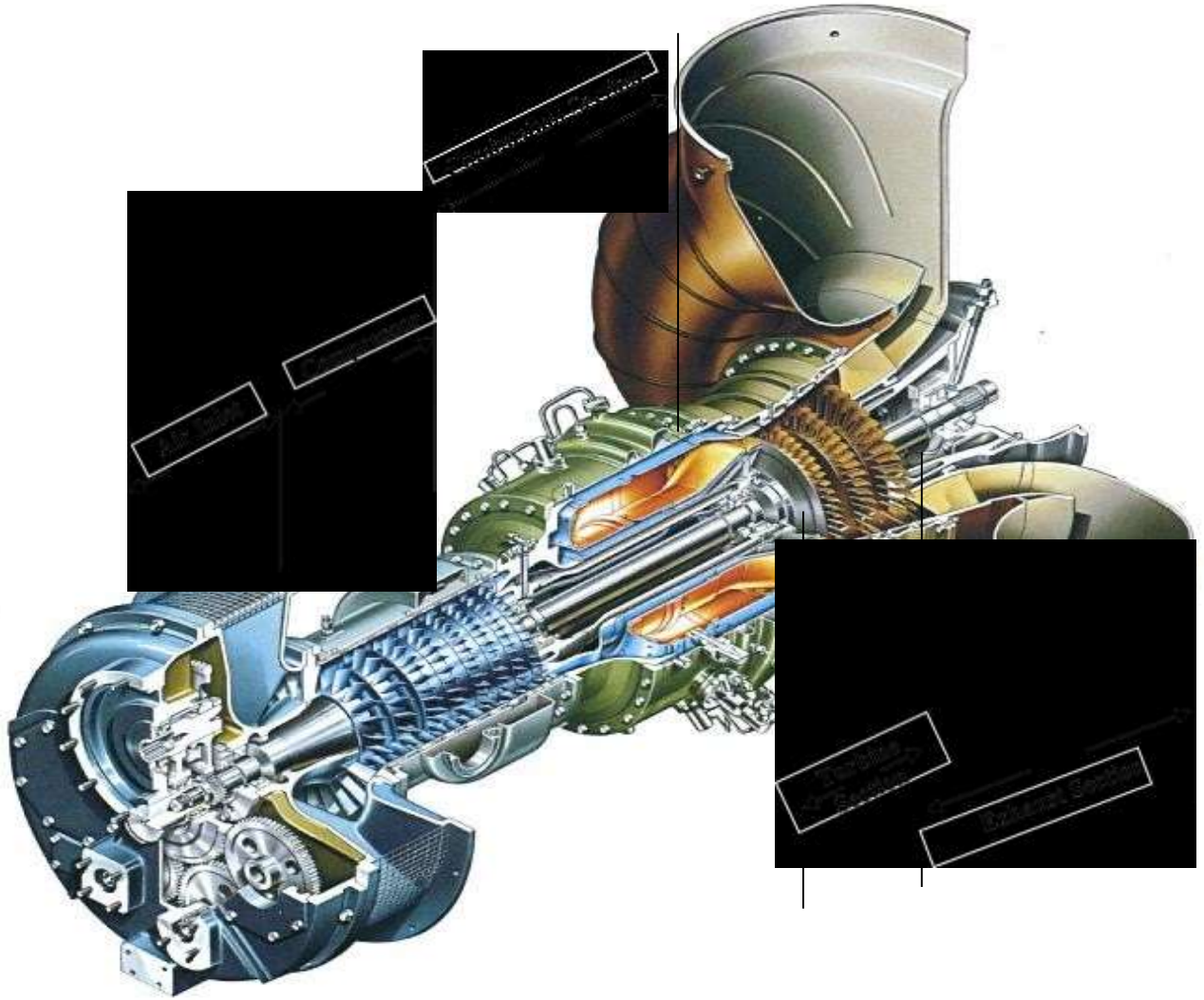


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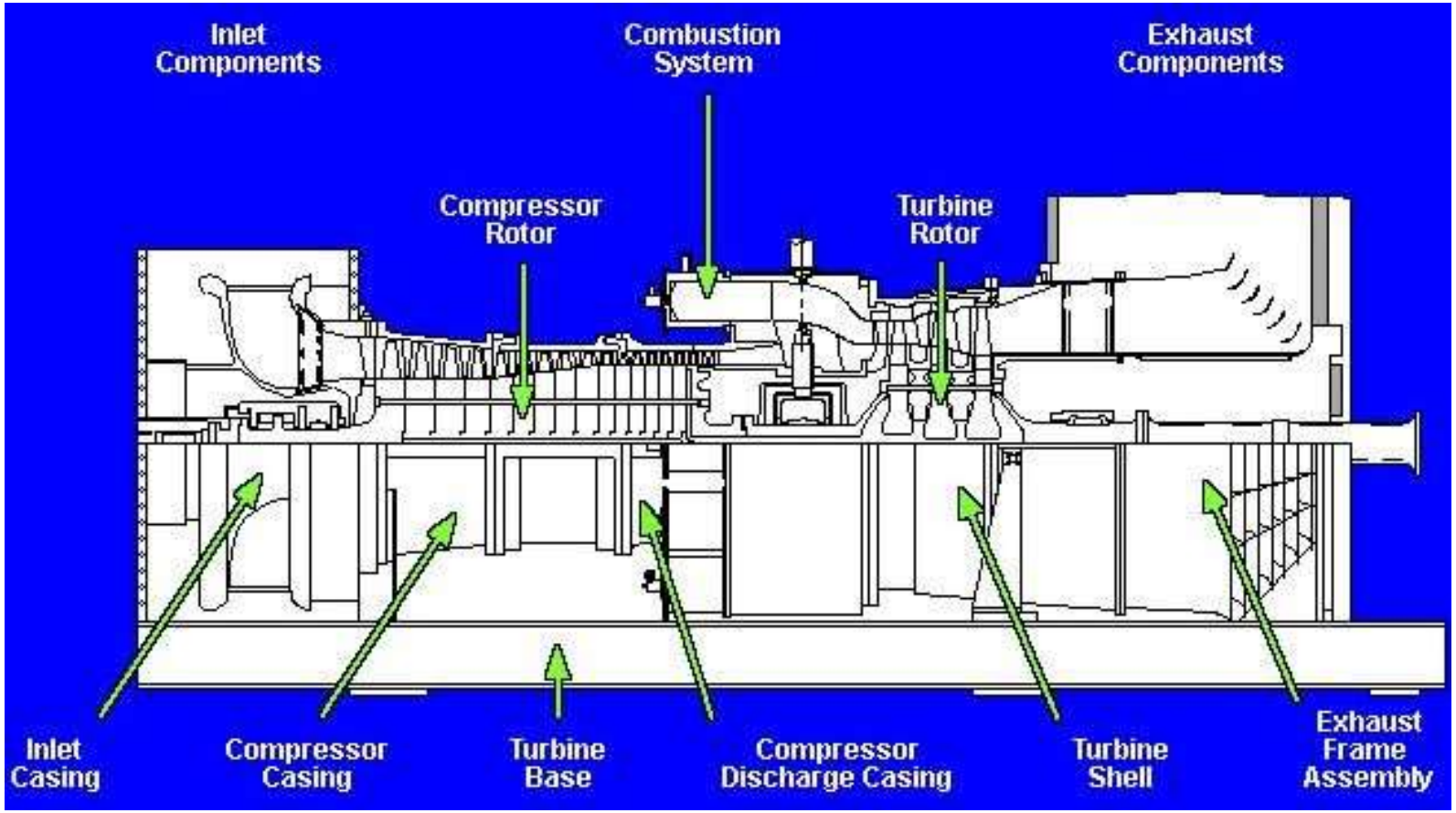
Unit 2

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Basic Gas Turbine

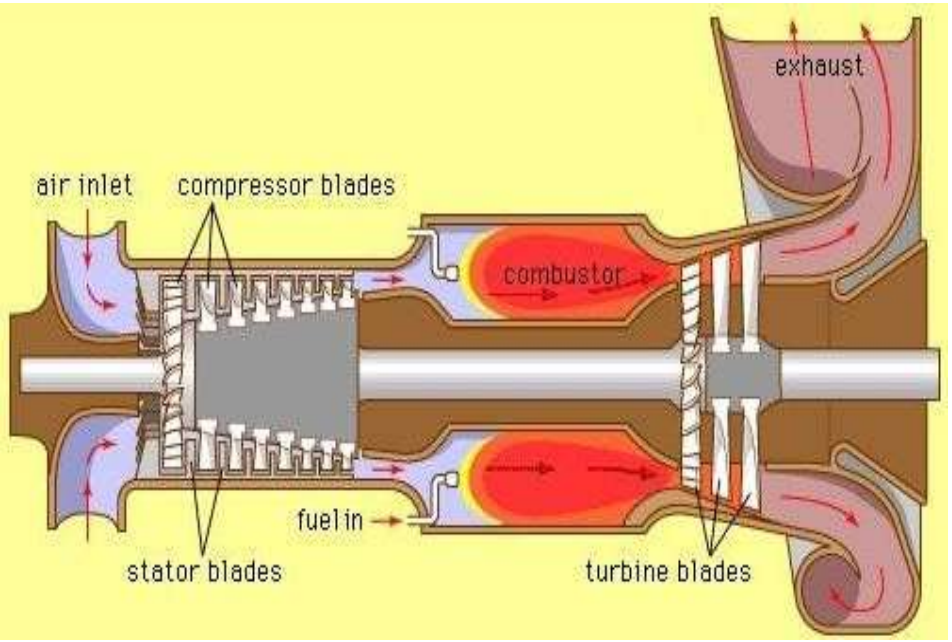


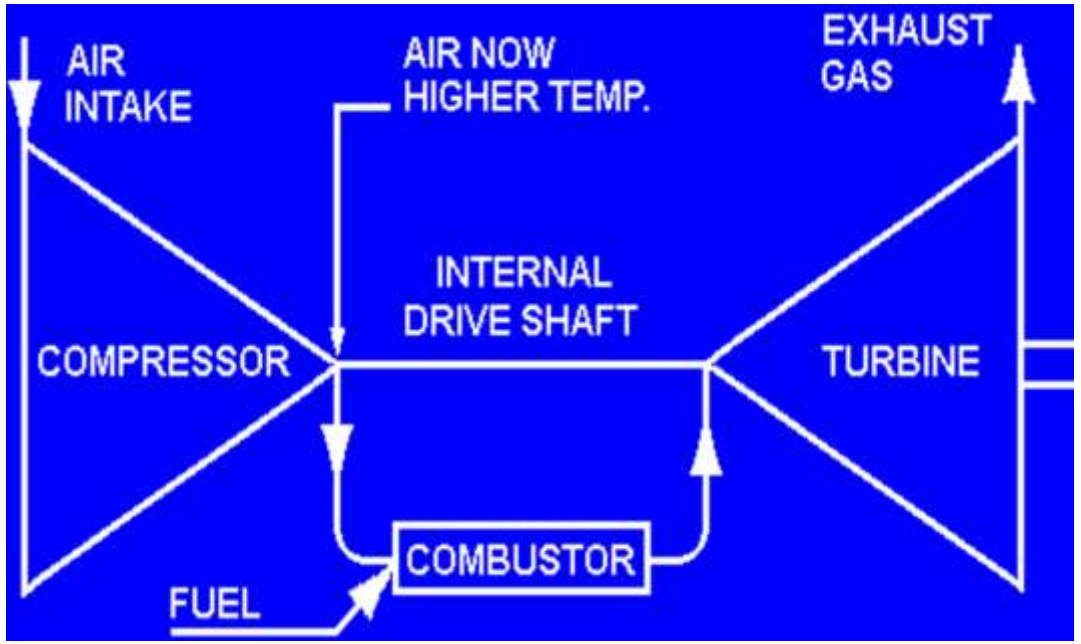
Components of Gas Turbine

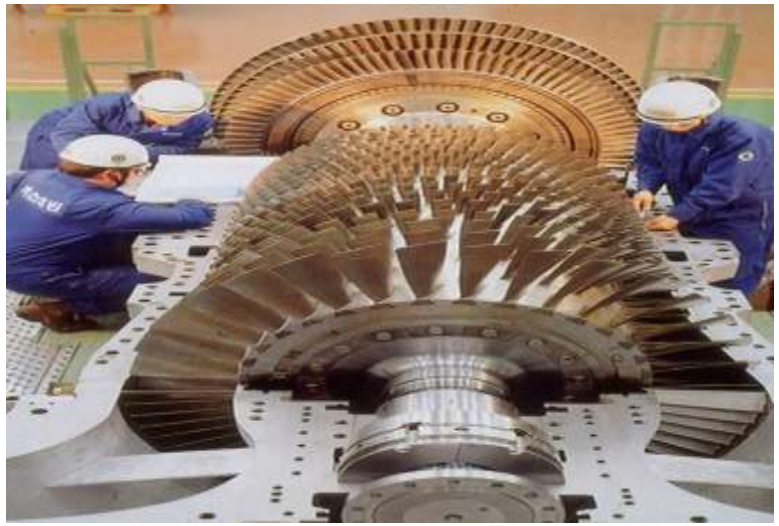


Working Principle of Gas Turbine

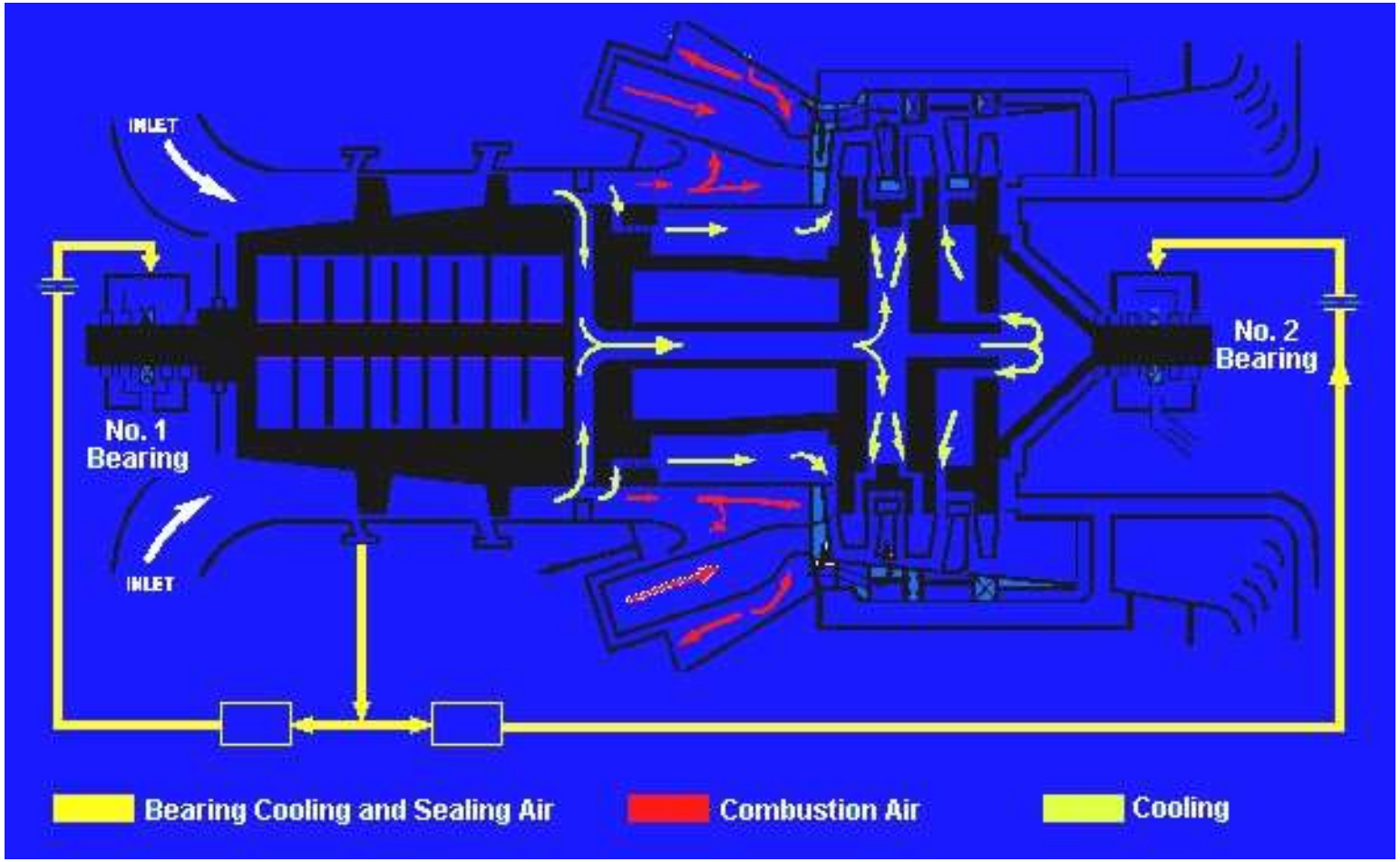
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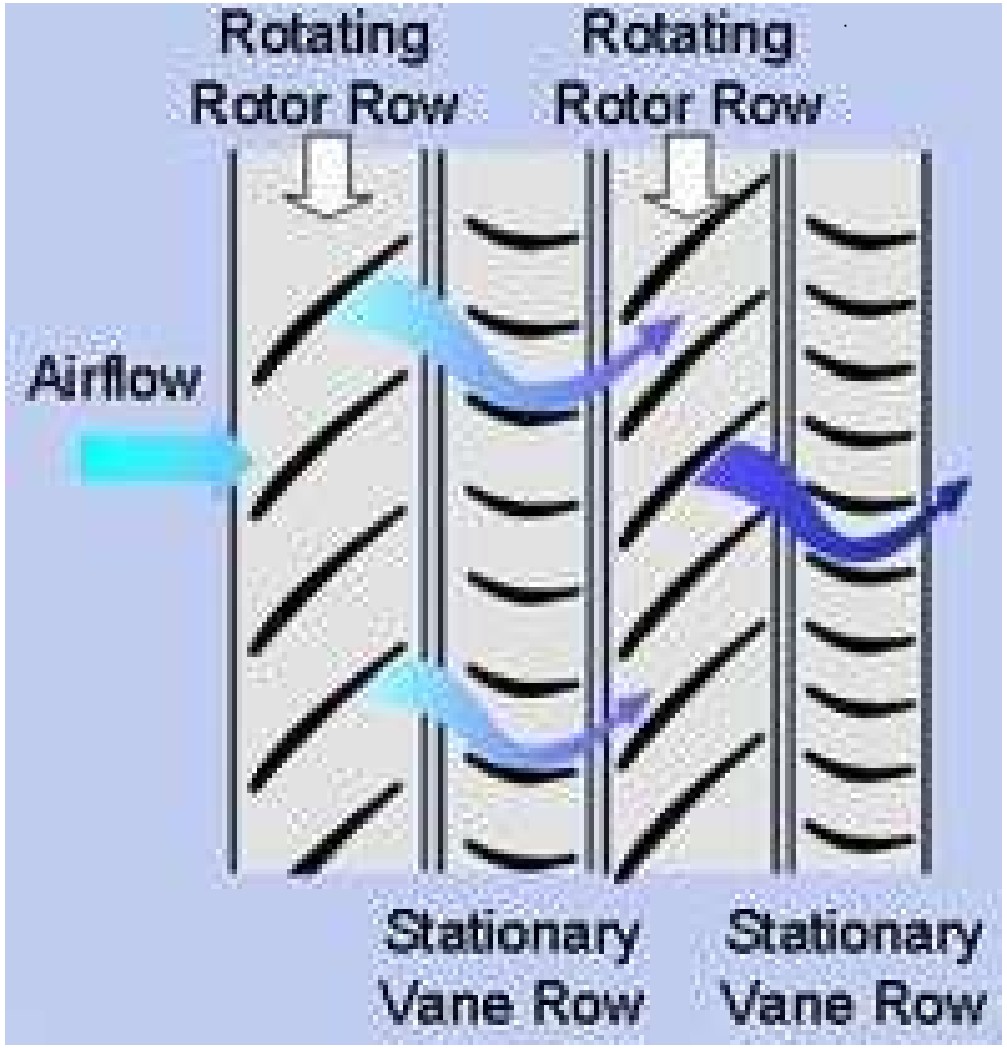


Role of Air Compressor in a Gas Turbine



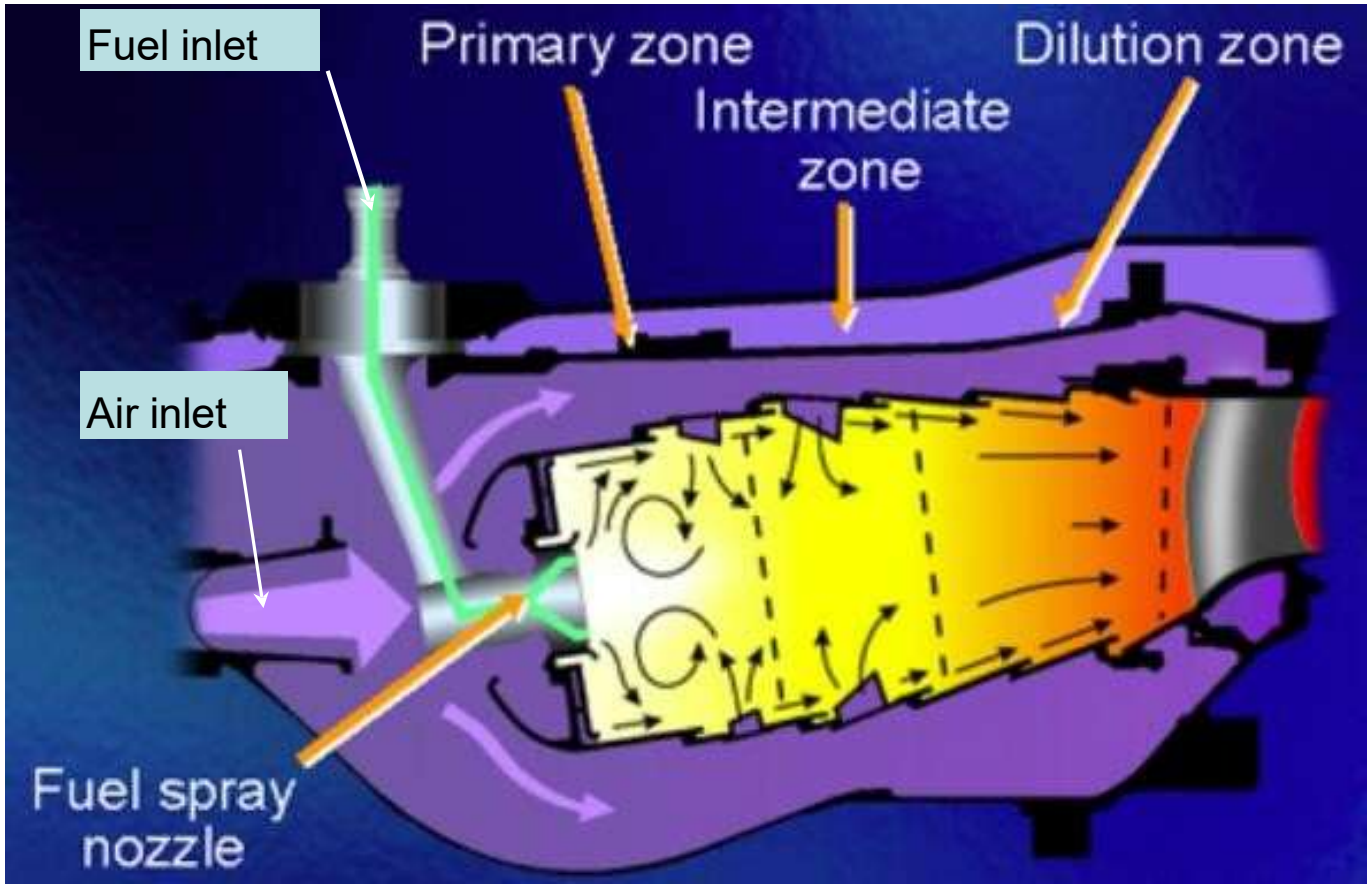
Turbine components-Axial Flow Compressor

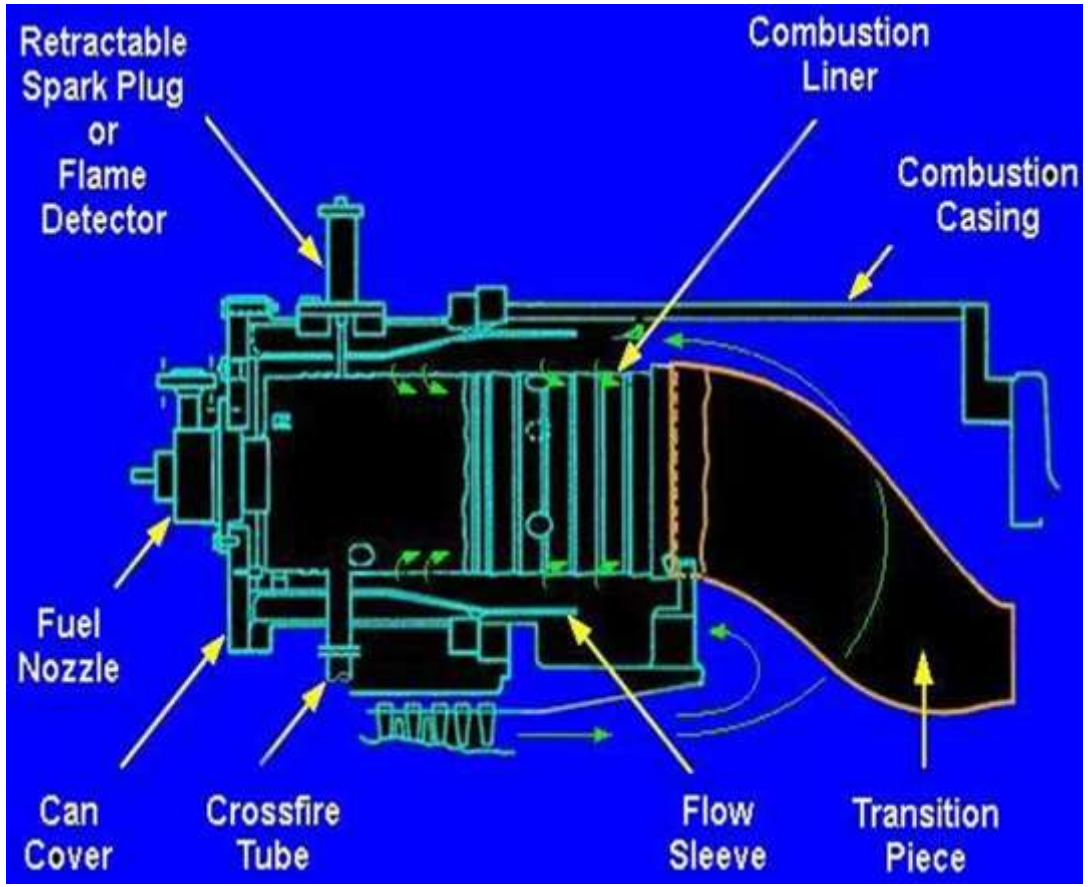




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Turbine components- Combustion Chamber





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The function of Spark Plug and Crossfire Tubes

What is the function of spark plug?

- To start the ignition of the combustible mixture in the combustion chamber on the beginning, then fire will continue without spark plug.

What is the function of crossfire tubes?

- Transfer the fire from one combustion chamber to all other combustion chambers.

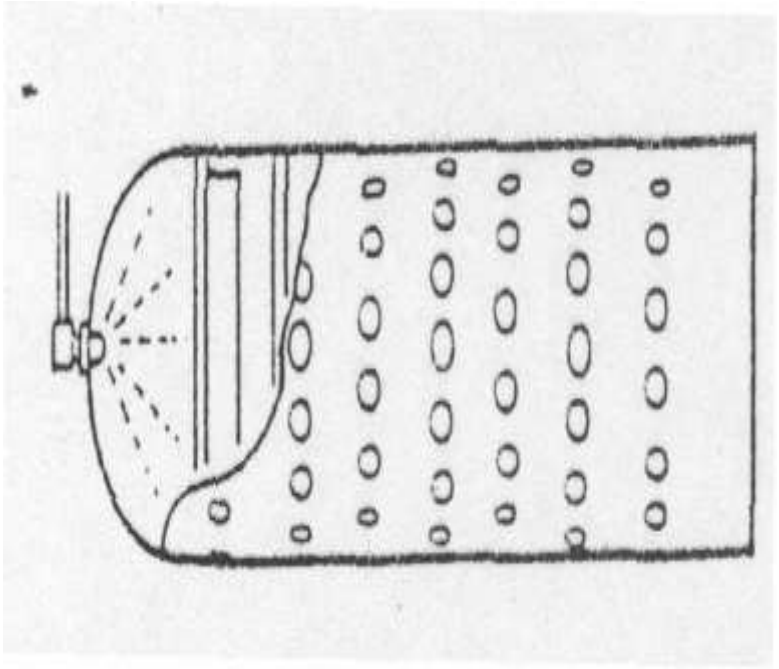
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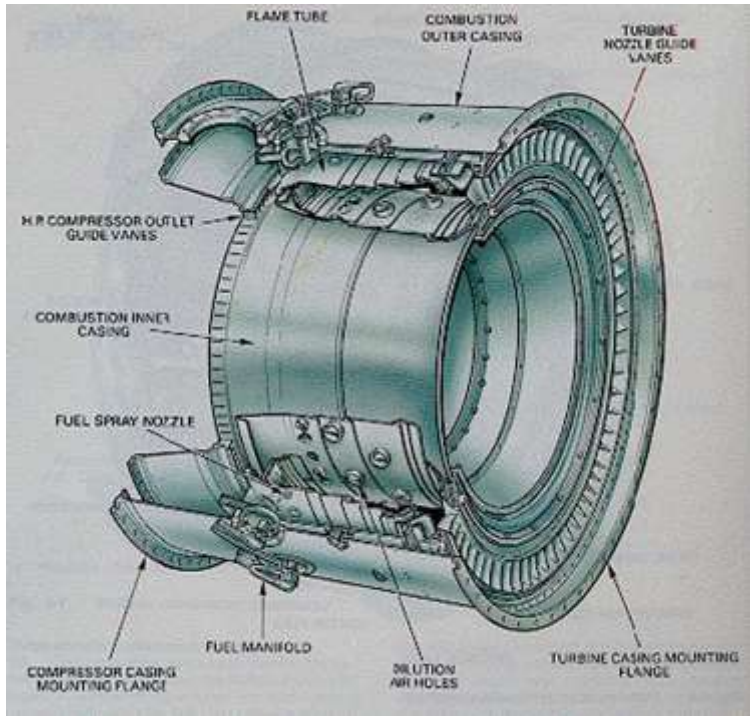
Types of combustion chambers

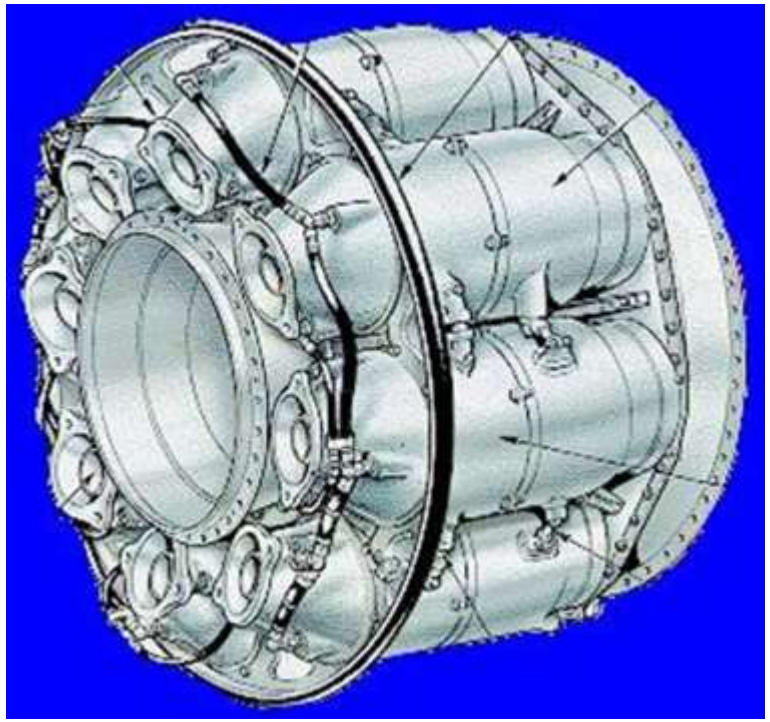
Three types of combustion chambers:

1. Single combustion chamber
2. Annular combustor
3. Can annular combustor (several combustion chambers)

Single-Combustion and Annular-Combustor Chamber (Multi-Cans)

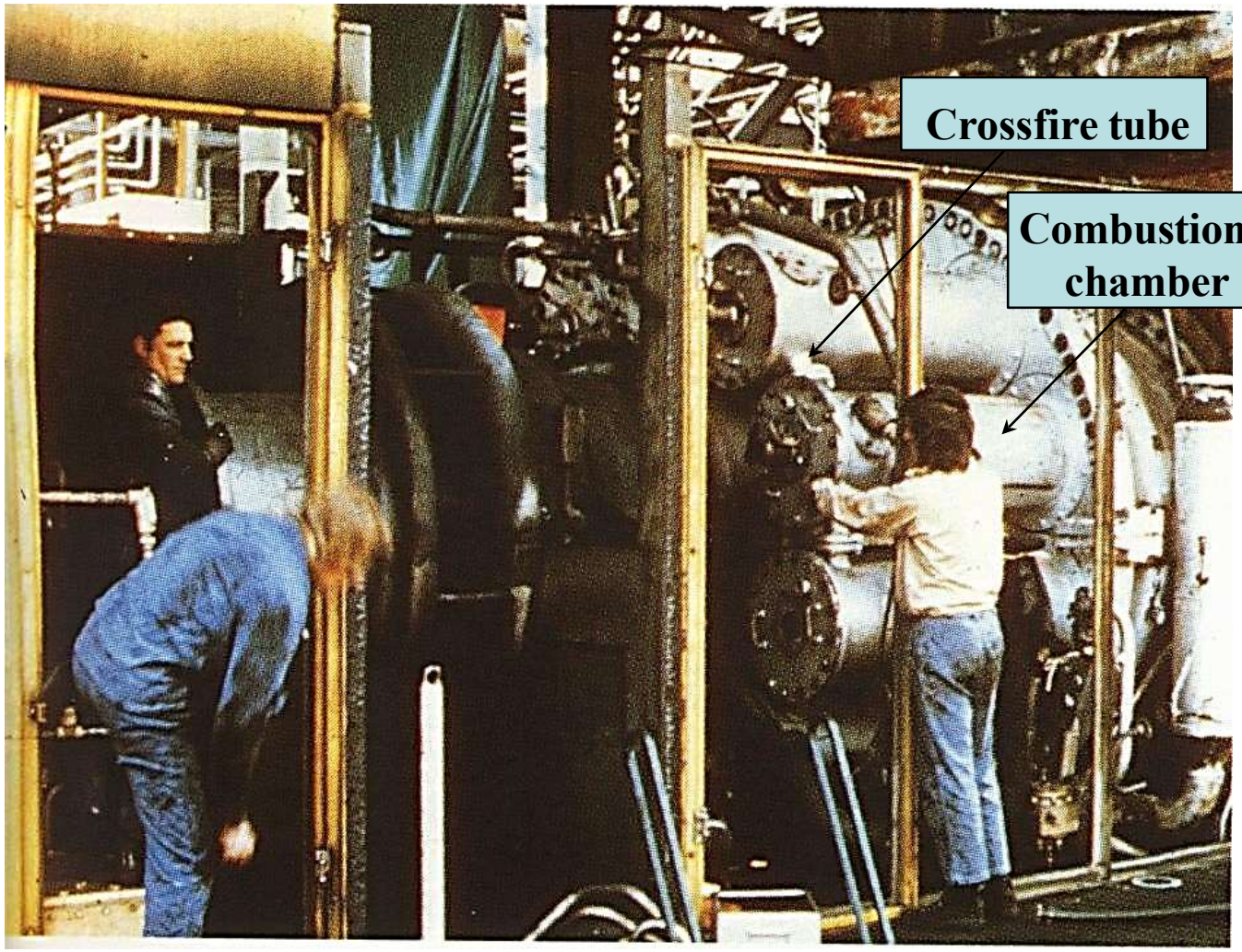


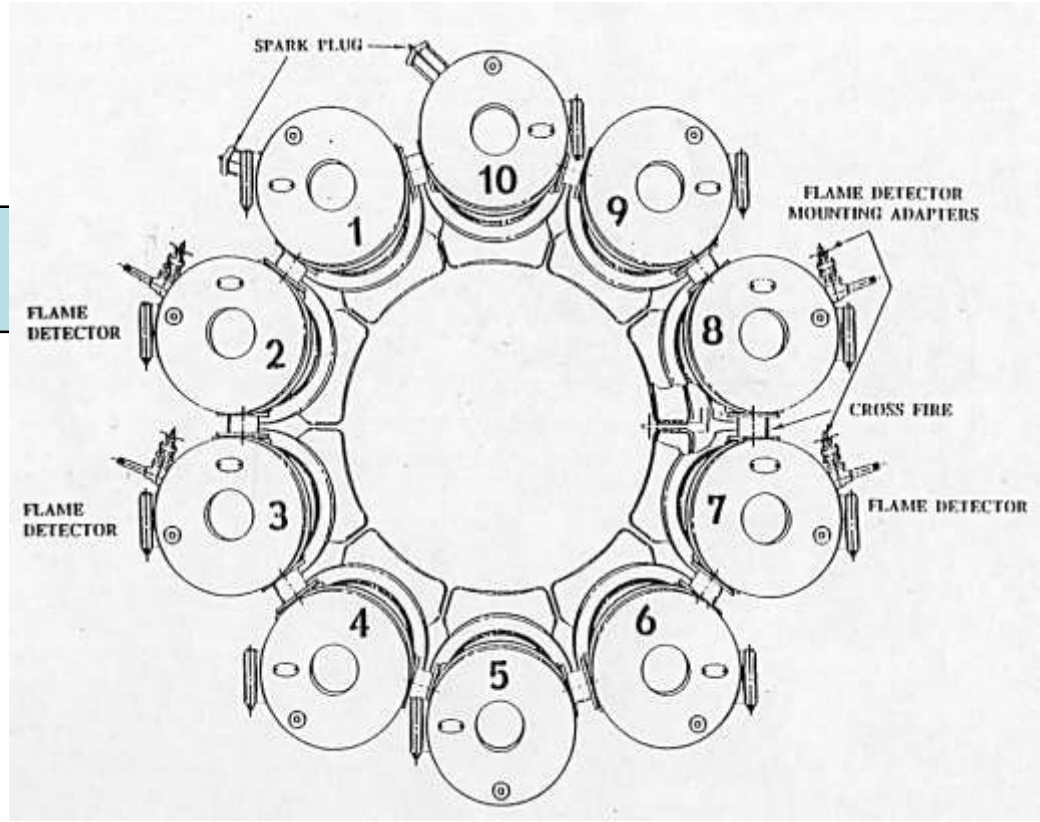




Can- Annular Combustion Chambers in Turbine

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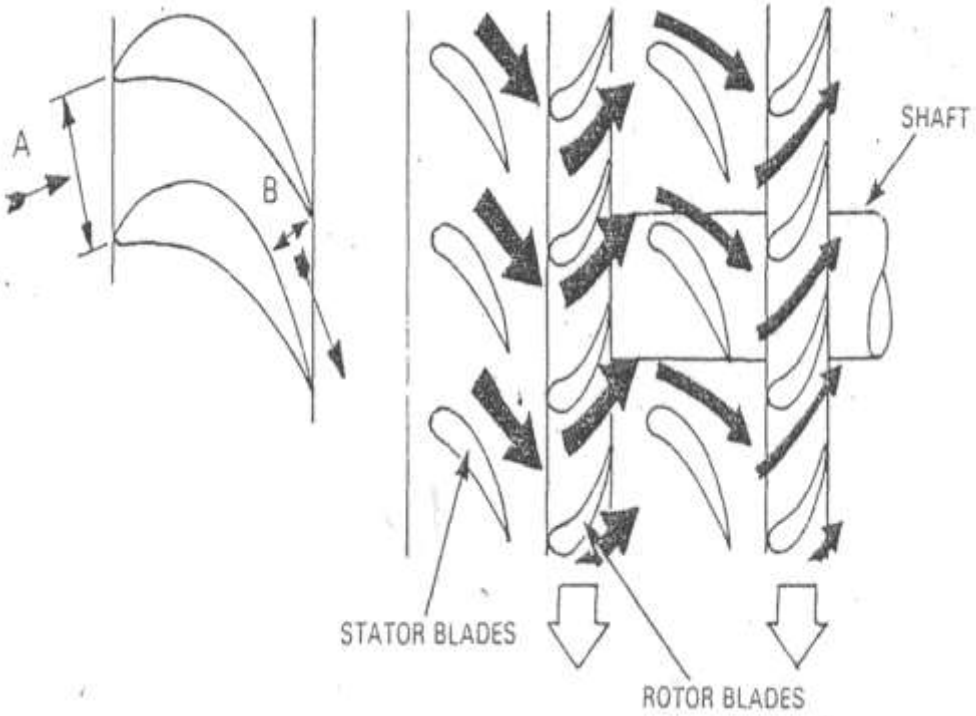


Distribution of Combustion Chamber in Turbine

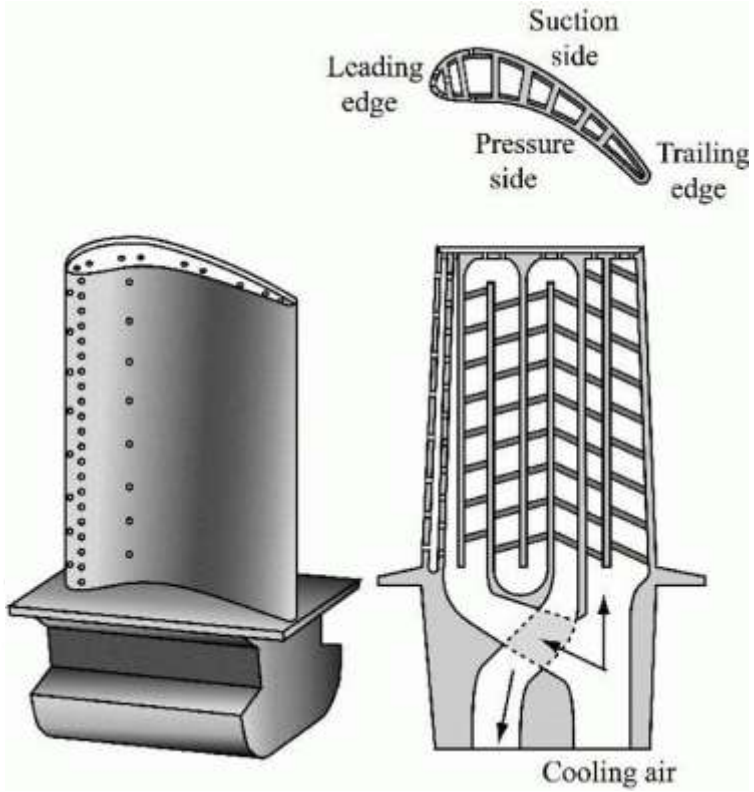
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Turbine Fixed Nozzles in Turbine Stator





Hot Gases flow through Turbine



Turbine Blades Cooling System

Surge Control

What is the surge?

1. Surge is the phenomenon of momentary, periodic fluctuation in the discharge pressure of compressor.
2. It occurs during acceleration, at a point when the compressor begins to discharge air faster than it can suck air in.
3. This condition causes low-pressure pockets to form inside the compressor.
4. The discharge air will flow back into the compressor to fill the low-pressure pockets.

What is the effect of surge?

1. As discharge air flows back into the compressor, it gains more heat during the second pressurization. If this repeated, air temperature would rise to destructive levels.
2. Surge will cause sever axial movement of the rotor in both directions (i.e. axial vibration). This condition will cause rapid failure in the thrust bearing

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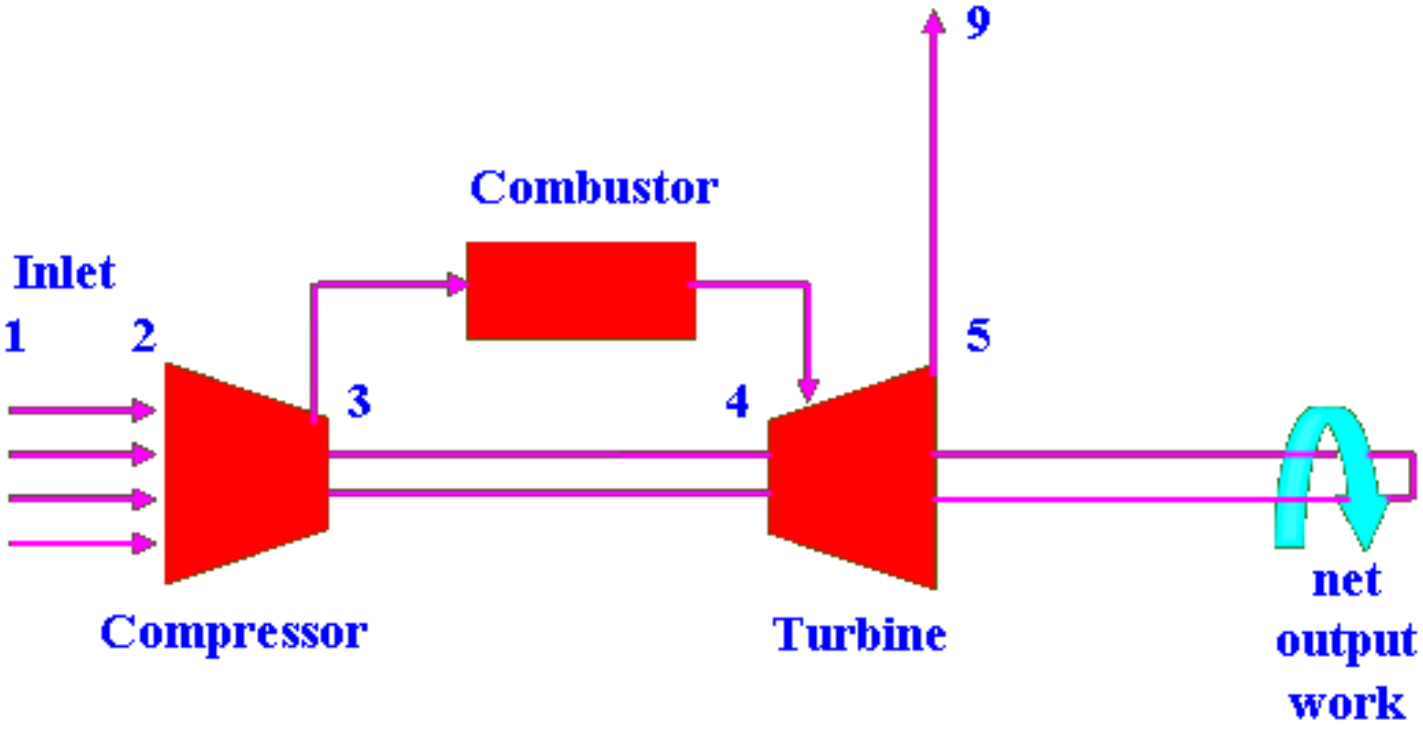
Gas Turbine Configuration

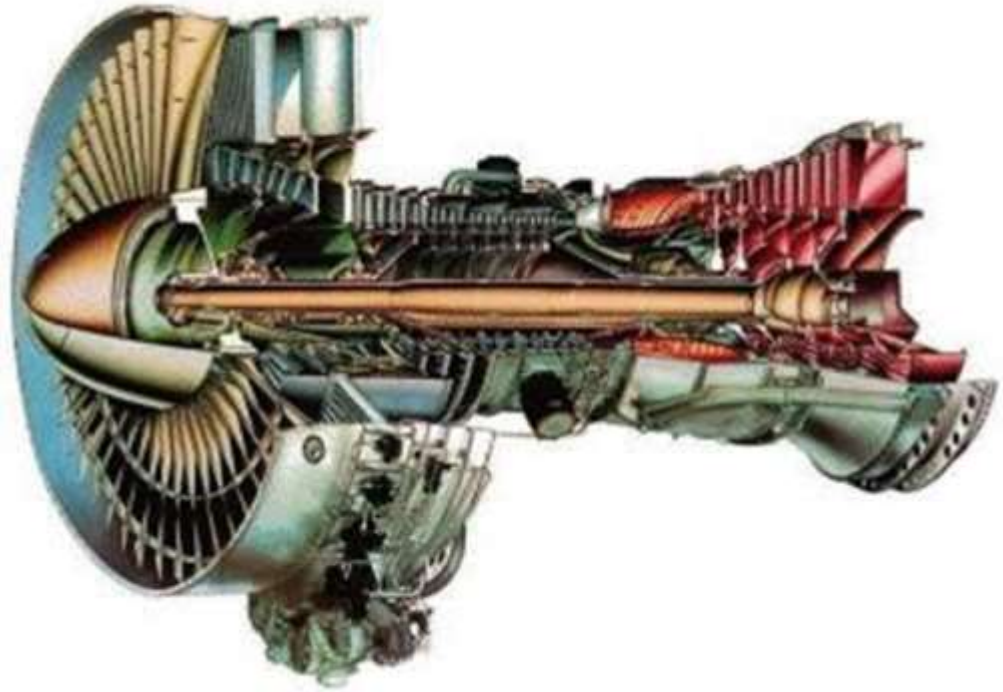
There are three common designs:

1. Single shaft arrangement (one rotor)
2. Split shaft arrangement (two rotors)
3. Twin-spool engine (triple shaft turbine)

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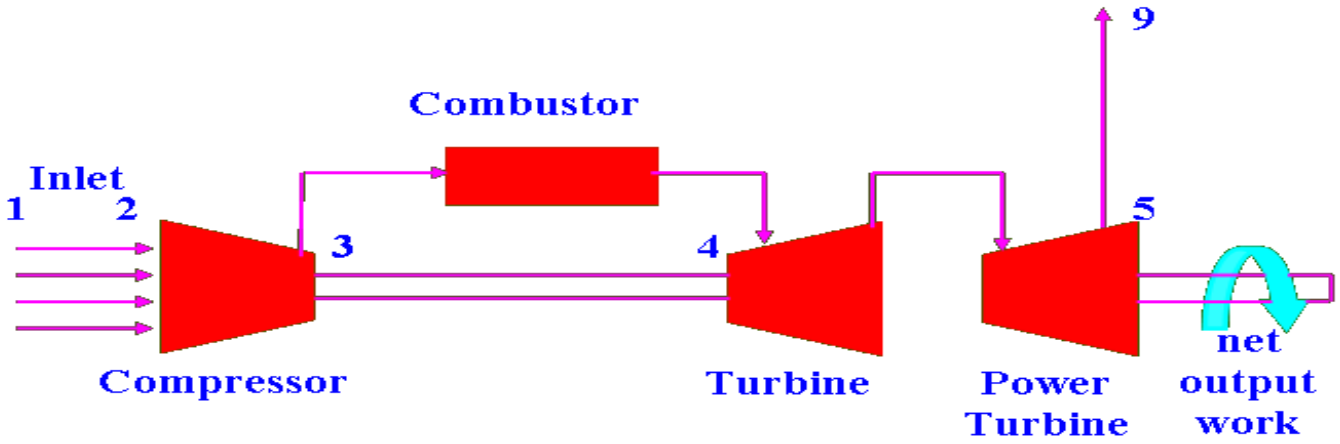
Single Shaft Rotor (One Rotor)

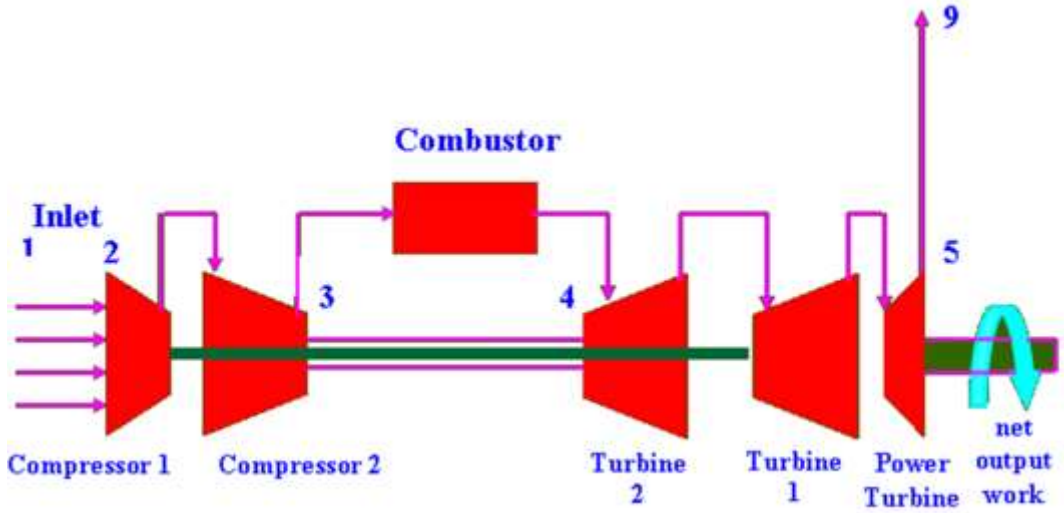




Jet Engine

Split Shaft Arrangement (Two Rotors) & Twin-Spool Engine (Triple Shaft Turbine)





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Turbine Support Systems

These systems are:

1. **Oil Lubrication System**
2. **Fuel System**
3. **Air Intake System and Inlet Air Filtration**
4. **Seal Oil System**
5. **Control system**

Oil-Lubrication System

The function of Oil Lubrication system : To provide clean, high-grade lubricating oil with suitable pressure and temperature.

Components of the system:

1. Oil tank
2. Oil pumps
3. Oil filters& strainer
4. Oil cooler
5. Oil heater
6. Control valves and protection devices

Fuel System and Air-Intake System

The function of fuel system

Fuel system supplies clean, pressure- regulated natural gas (or liquid fuel) to the combustion chambers.

There are two fuel systems:

1. Natural gas fuel system
2. Liquid fuel system

There is a relationship between the amount of fuel and the turbine RPM.

What is the function of air intake system?

Air system provide the required air for:

1. Combustion
2. Reduce the temperature of combustion products to certain limit (accepted temp.)
3. Turbine rotor cooling
4. Seal lubrication system
5. Operate the control system

Unit 3

JET Propulsion

The principle of jet propulsion involves imparting momentum to a mass of fluid in such a manner that the reaction of imparted momentum provides a propulsive force.

The propulsion system may be classified as follows;

1.Air stream jet engines (*Air breathing engines*)

a)Steady combustion system; (*continuous air flow*)

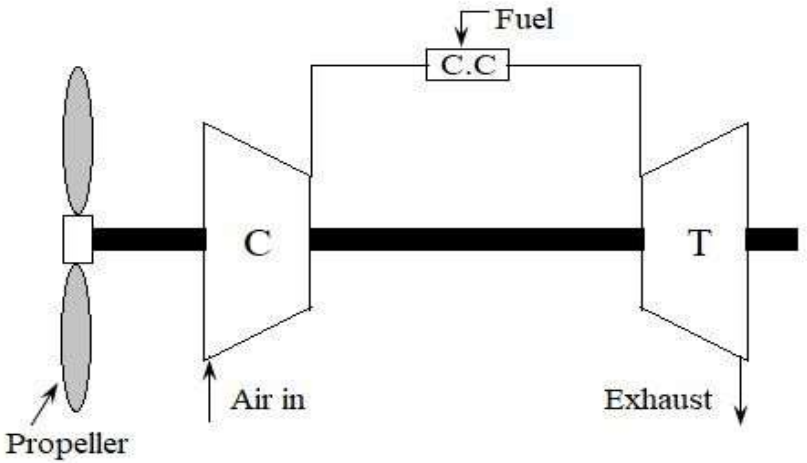
i. Turbo-jet
ii. Turbo-prop
iii. Ram Jet

b)Intermittent combustion system (*intermittent air flow*)

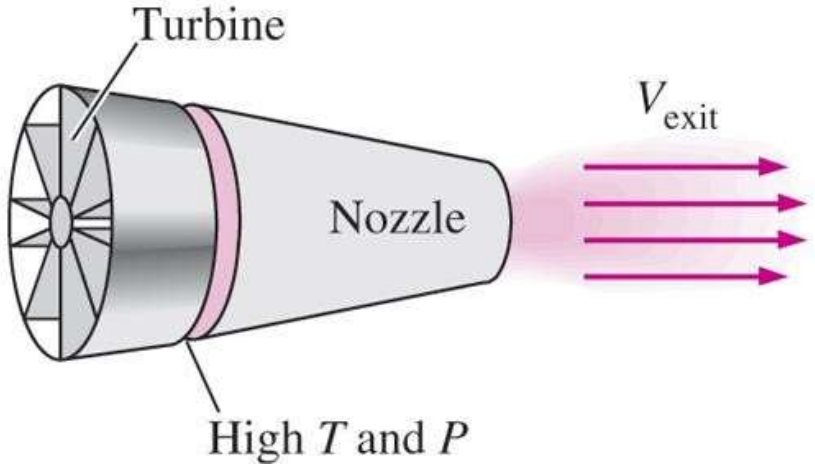
i. Pulse jet or flying bomb.

2.Self contained rocket engines (*Non-air breathing engines*)

- An engine that burns fuel and uses the expanding exhaust gases to turn a turbine and/or produce thrust
- The concept of thrust is based on the principle of Newton's Third Law



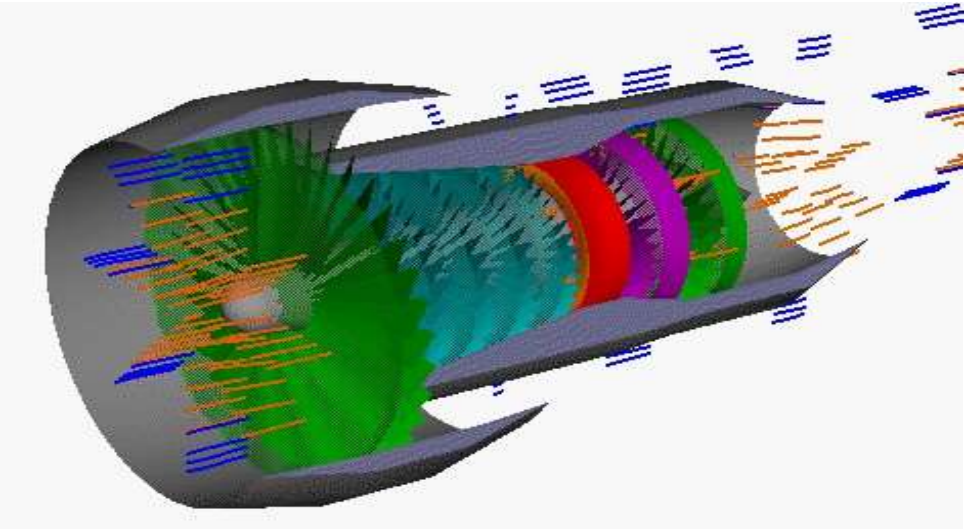
In jet engines, the high-temperature and high-pressure gases leaving the turbine are accelerated in a nozzle to provide thrust.

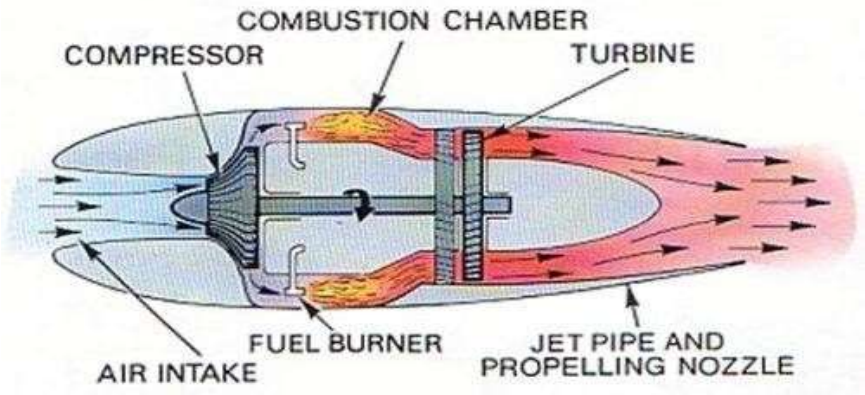


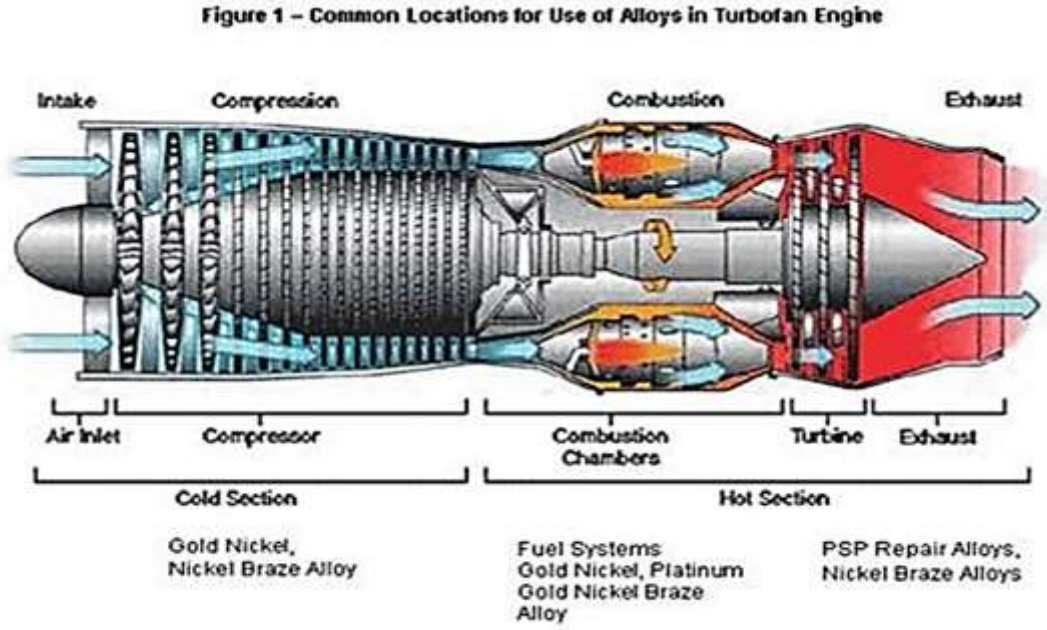
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Types Of Jet Engines

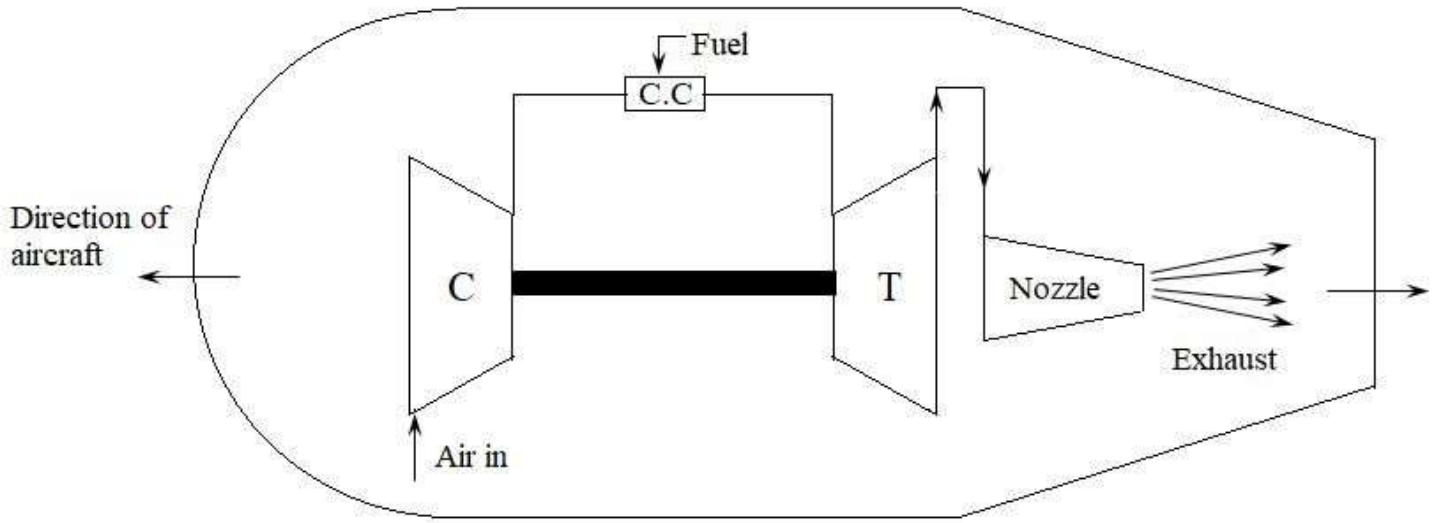
- Turbo jets
- Turbo fans
- Ramjets
- Rockets

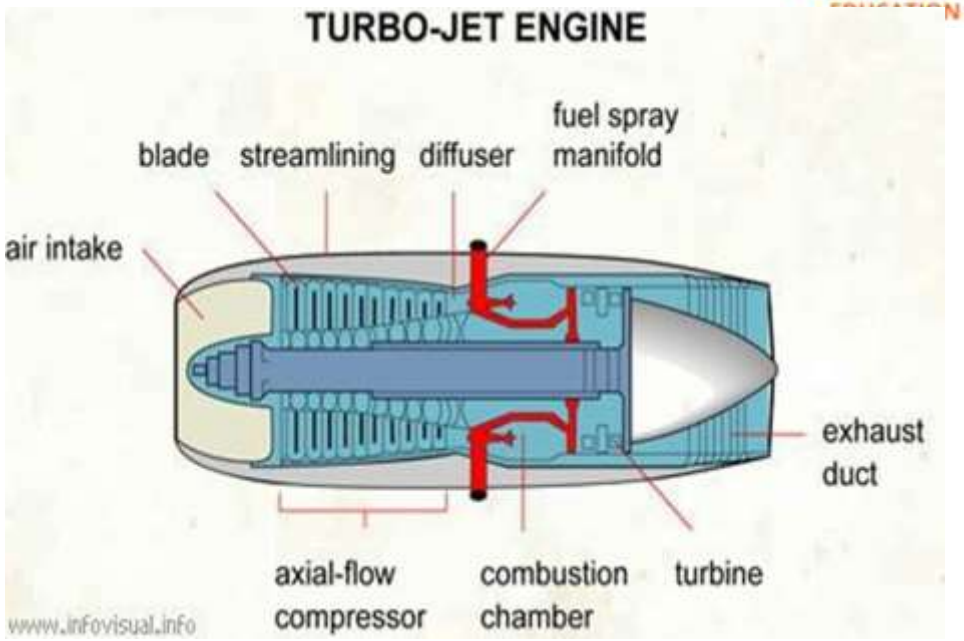






Turbo-Jet

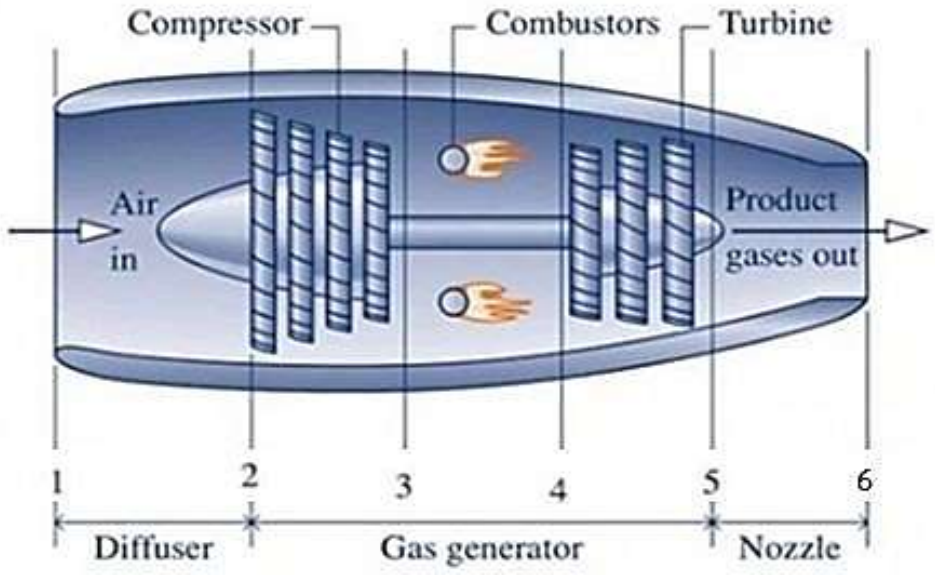


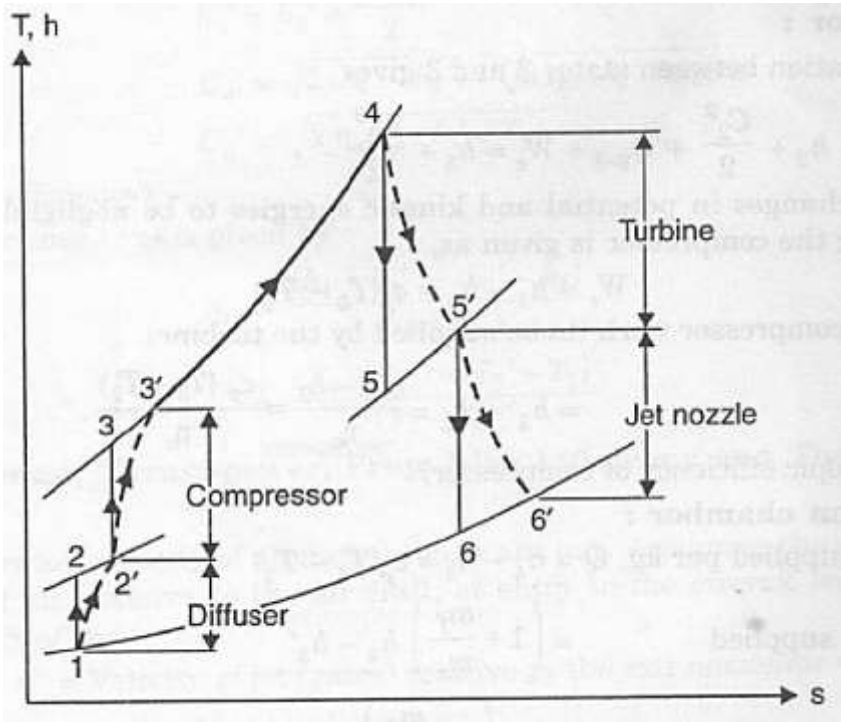


- *It consists of a diffuser at entrance which slows down the air (entering at velocity equal to the aircraft speed), convert the kinetic energy of the air stream to pressure; this type of compression is known as Ram compression.*
- *The air is then further compressed to a pressure of 3 to 4 bar in a rotary compressor (usually axial flow compressor).*
- *The compressed air then enters the combustion chamber, where the combustion of fuel provides heat to raise the temperature rapidly.*
- *The hot gases expands in the turbine partially to provide power to compressor.*
- *The hot gas then expands in the nozzle to provide a high velocity jet which gives rise a forward thrust to the aircraft.*

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Turbo-Jet Engines



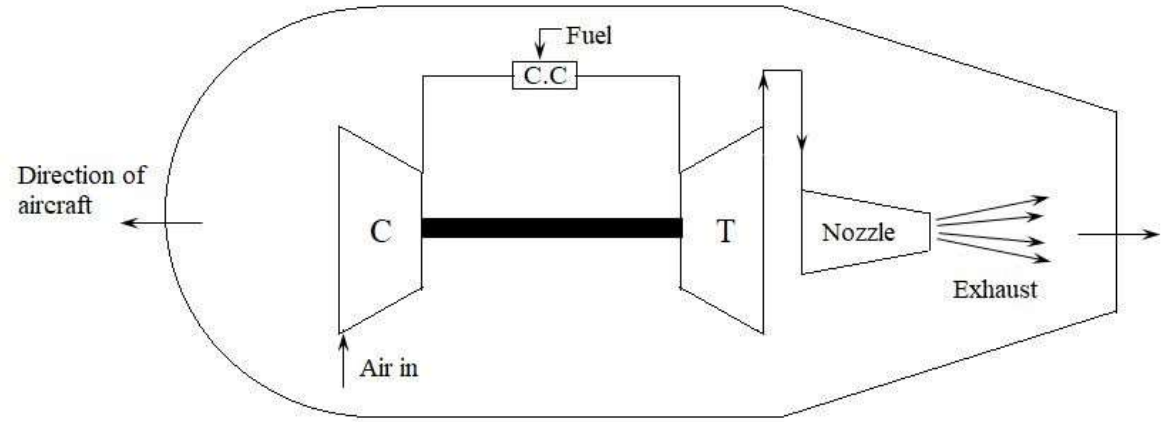


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*

Advantages of Turbo-jet engines

- Construction is much simpler
- Engine vibrations absent
- Much higher speed possible (more than 3000 km/h achieved)
- Power supply is uninterrupted and smooth
- Weight to power ratio superior
- Requirement of major overhauls less frequent
- Frontal area smaller



Disadvantages of Turbo-jet engines

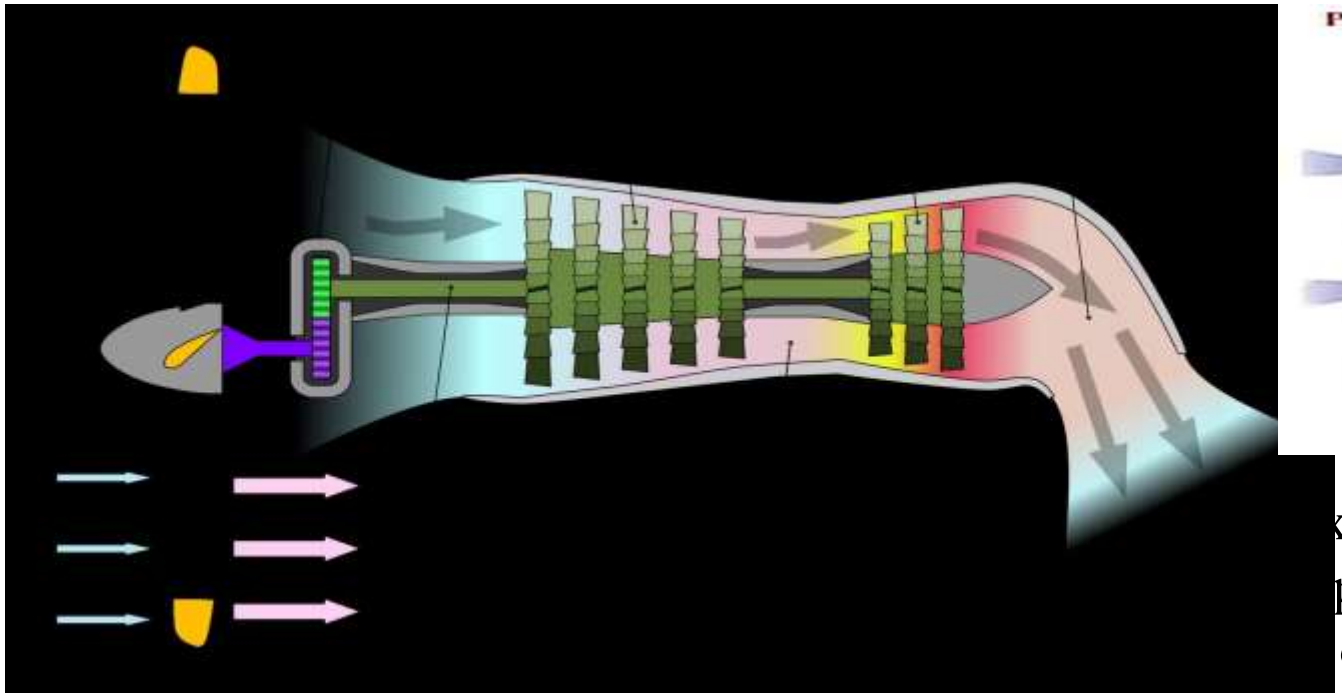
- Less efficient
- Life of the unit comparatively shorter
- The turbo-jet becomes inefficient below 550 km/h
- More noisy
- Material required are quite expensive
- Require longer strip to take off

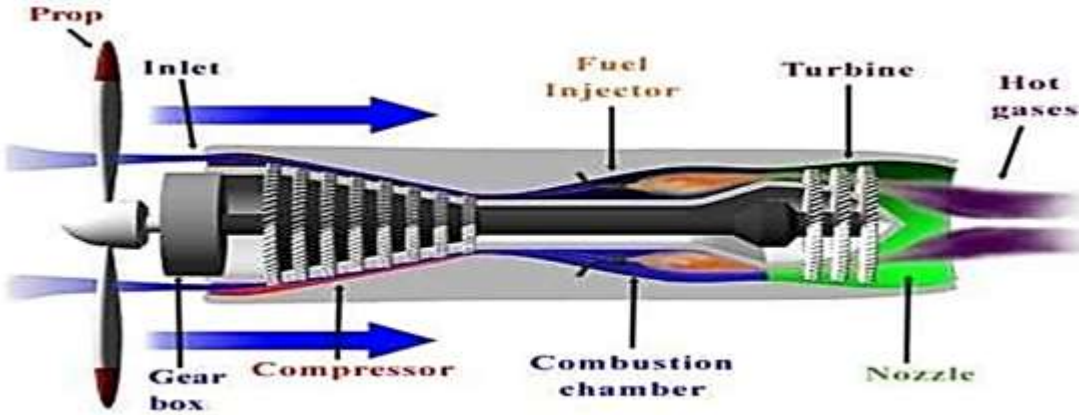
Turbo-Prop Engine

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In a jet engine, the turbines add kinetic energy to the flow, and this flow is then expelled out of the exhaust to generate the thrust. However, in a turboprop engine, the turbines are connected to a propeller shaft and thus almost all the energy extracted by the turbines is used to rotate the propeller. Due to a turboprop being in effect a turbine engine, a small amount of jet thrust is generated (about 5%).

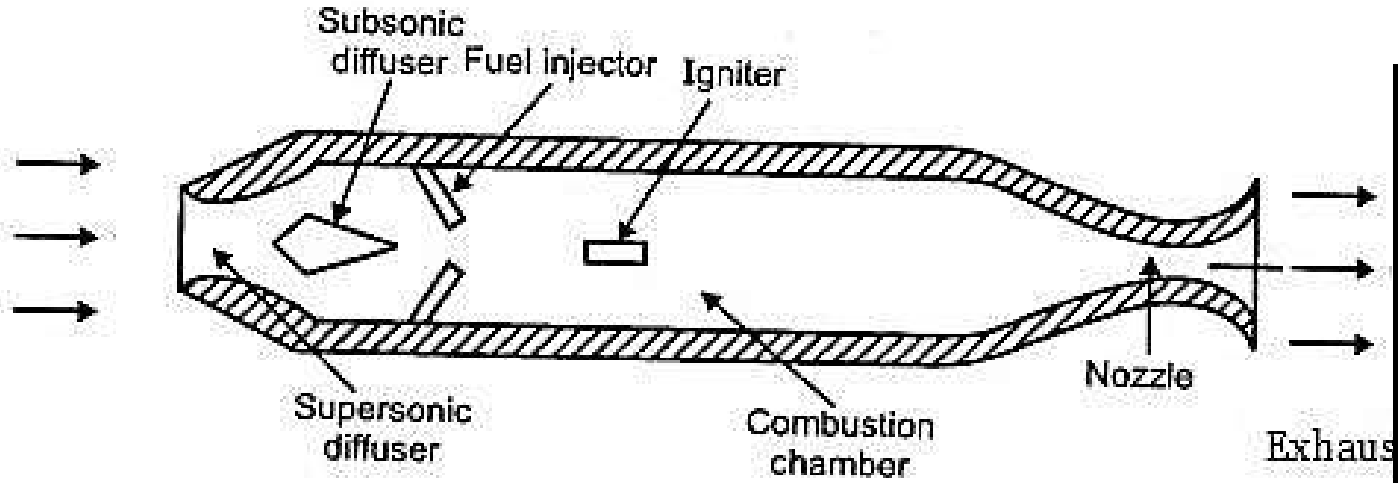


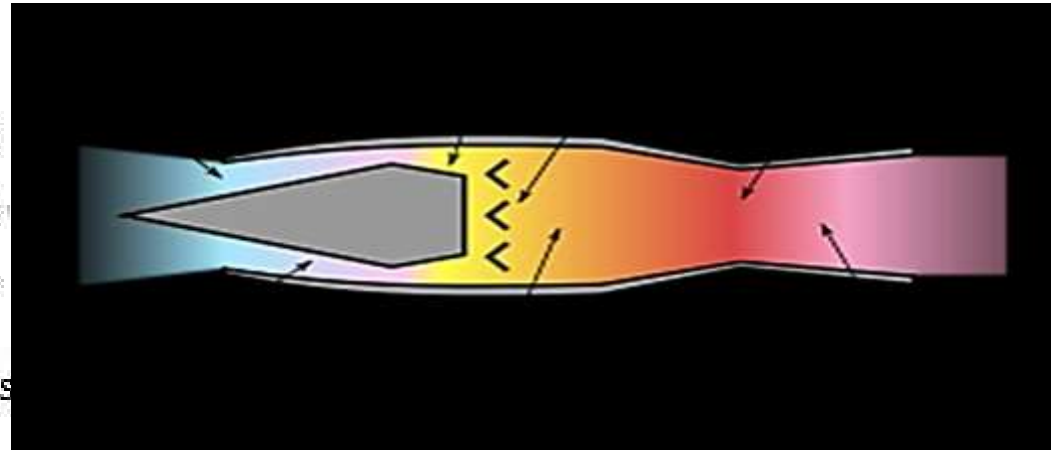


ximately 80 to 90% of the thrust is produced by peller and 10 to 20% of thrust is produced by of the exhaust gases.

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Ram –Jet Engine





Ram jet is also called athodyd, Lorin tube or flying stovepipe.

Working:- The air entering into ram jet with supersonic speed is slowed down to sonic velocity in the supersonic diffuser, increasing air pressure. The air pressure is further increase in the subsonic diffuser increasing also the temperature of air. The fuel injected into combustion chamber is burned with help of flame igniter. The high pressure and high temperature gases are passed through the nozzle converting into pressure energy into kinetic energy. The high velocity gas leaving the nozzle provide required forward thrust.

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Ram -jet



Advantages

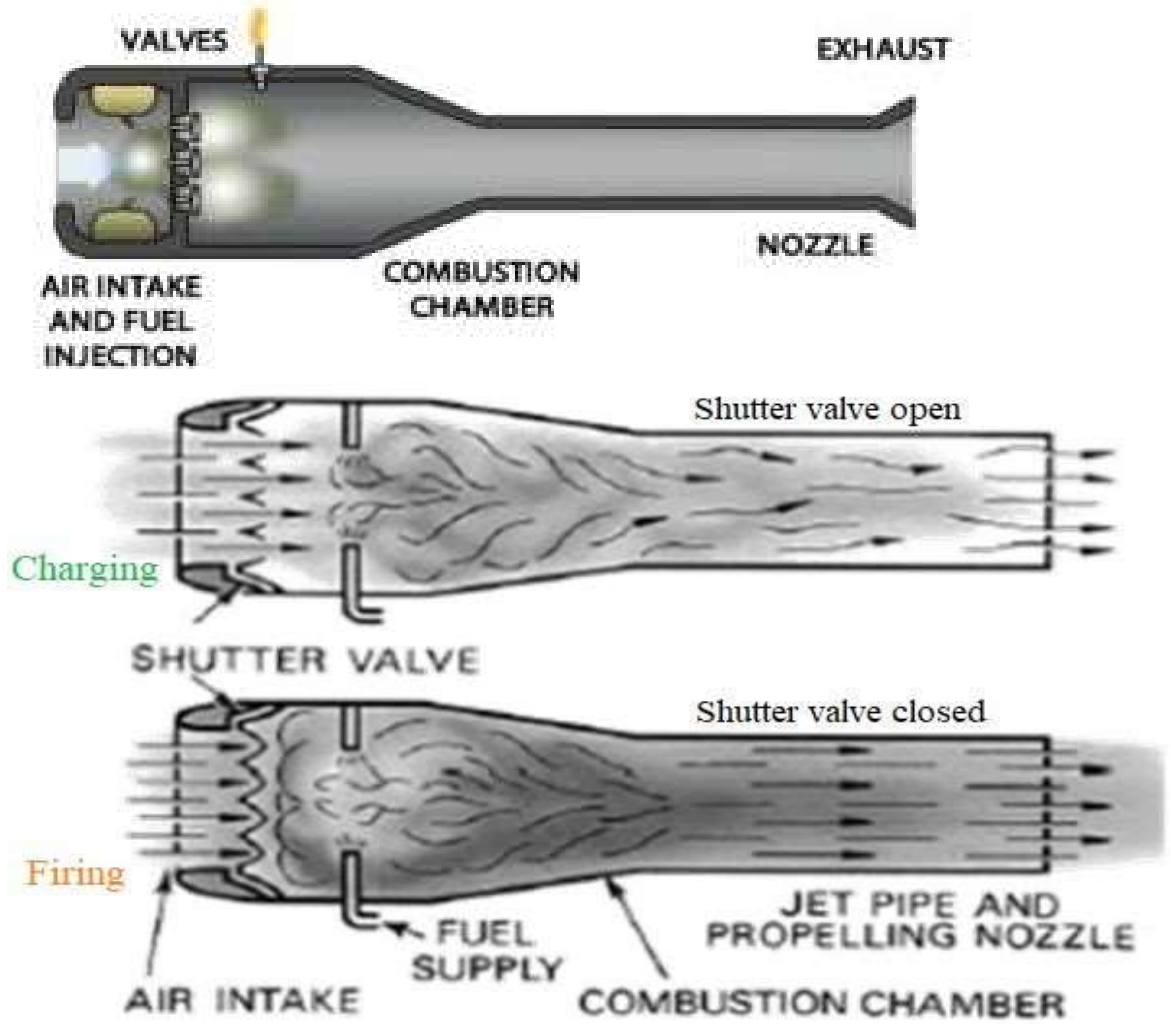
1. No moving parts
2. Light in weight
3. Wide variety of fuels can be used

Disadvantages

1. It can not be started of its own
2. The fuel consumption is too large at low and moderate speed
3. For successful operation diffuser need to be designed carefully.

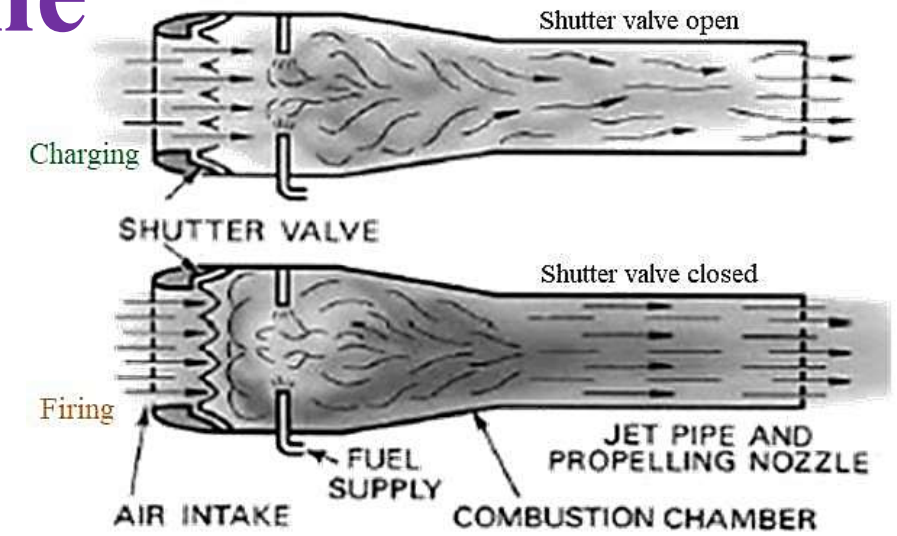
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Pulse –Jet Engine



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Pulse –Jet Engine



Operation:

- Compressed air is forced into the inlet which opens the spring loaded flapper valves.
- The air that enters the engine passes by the fuel injector and is mixed with the fuel, it is ignited by a spark plug.
- The combustion takes place, thus causing a very rapid rise in pressure, the increase in pressure forces the flapper valves shut and propels the charge of burned gases out of the tail pipe.
- The momentum of the gases leaving the tailpipe causes the air to continue to flow out even after the pressure within the engine has reached atmospheric pressure.
- The pressure within the engine is therefore evacuated to below atmosphere.

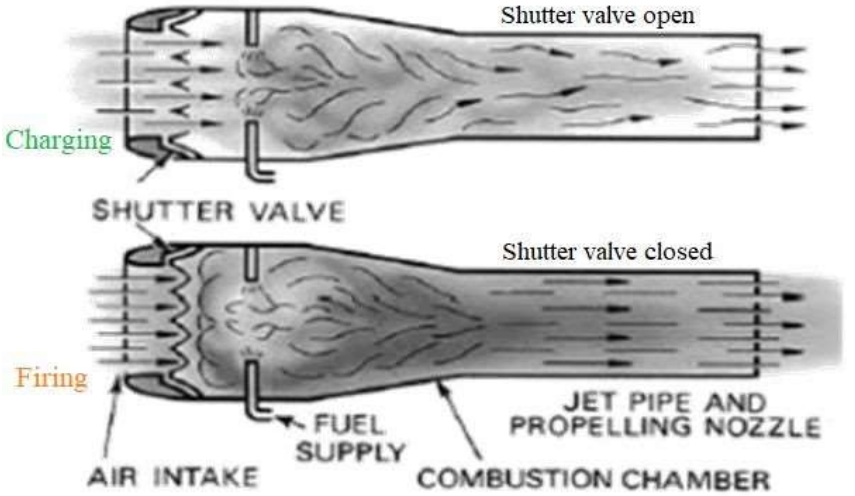
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Pulse –Jet Engine

Advantages:

•Simple in construction, very inexpensive compared to turbo jet engine, well adapted to pilotless aircraft

•Capable of producing static thrust and thrust in excess of drag at much low speed.



Disadvantages:

•High intensity of noise.

•Severe vibrations.

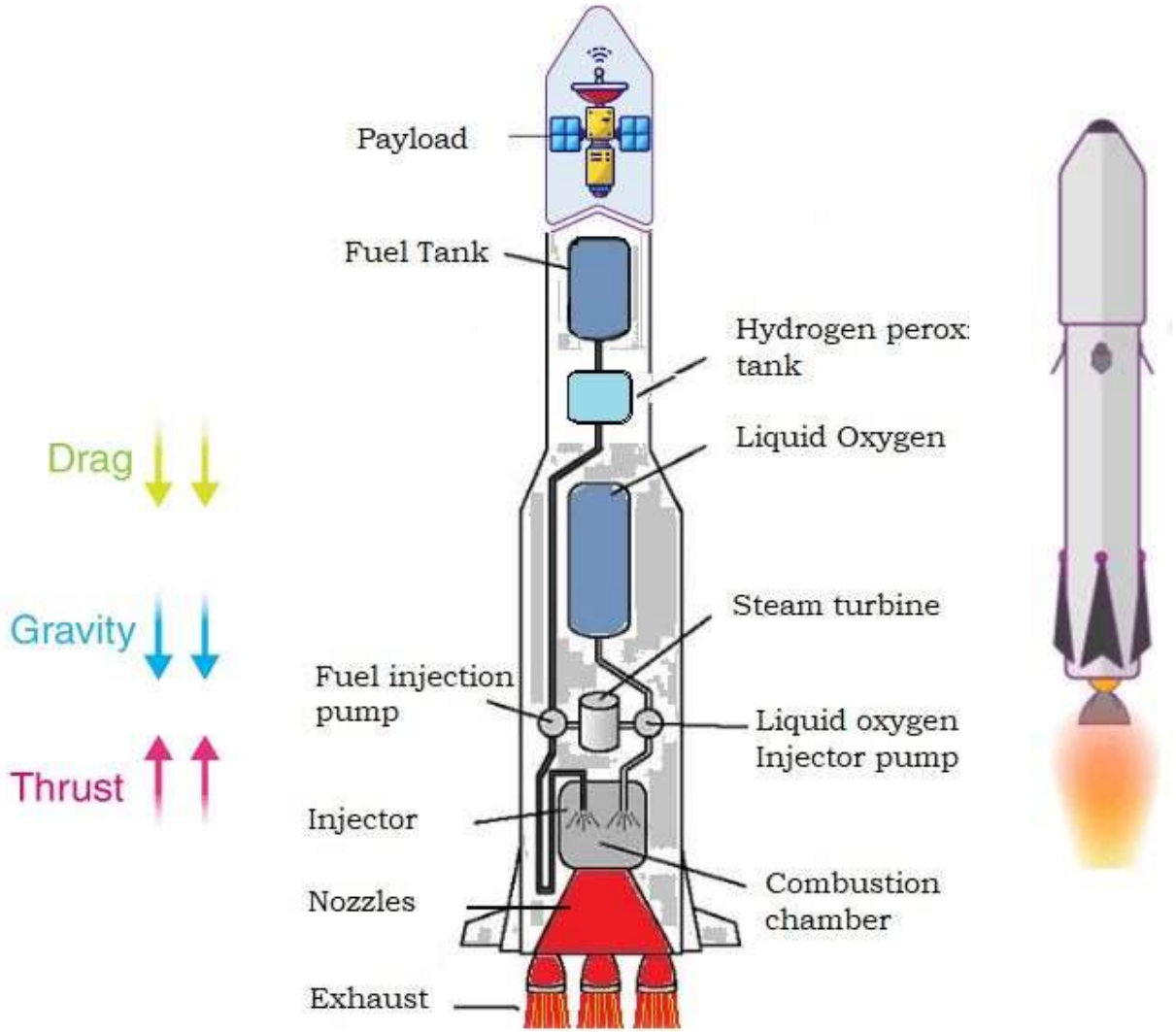
•High rate of fuel consumption and low thermodynamic efficiency.

•The operating altitude is limited by air density consideration.

•Serious limitation to mechanical valve arrangement.

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Rocket Engine



In a liquid-fuel rocket, the following things are found:

- A liquid rocket fuel such as liquid hydrogen, An oxidizer,
- Hydrogen peroxide tank,
- Pumps to carry the fuel and the oxidizer
- A combustion chamber where the two liquids mix and burn
- A Nozzle

An ideal rocket propellant should have the following characteristics

- A high heat value
- Highest possible density so that it occupies less space
- Stability and ease of handling and storing
- Low toxicity and corrosiveness
- Reliable and smooth ignition

Applications:

- Long range artillery
- Lethal weapons
- For satellites
- For spaceships
- Jet assisted takeoff

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Rocket Principles

- Rocket *thrust* is the reaction force produced by expelling particles at high velocity from a nozzle opening.

- High pressure/temperature/velocity exhaust gases provided through combustion and expansion through nozzle of suitable fuel and oxidizer mixture.

- A rocket carries both the *fuel* and *oxidizer* onboard the vehicle whereas an *air-breather* engine takes in its oxygen supply from the atmosphere.

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Solid Propellant Rocket Engine



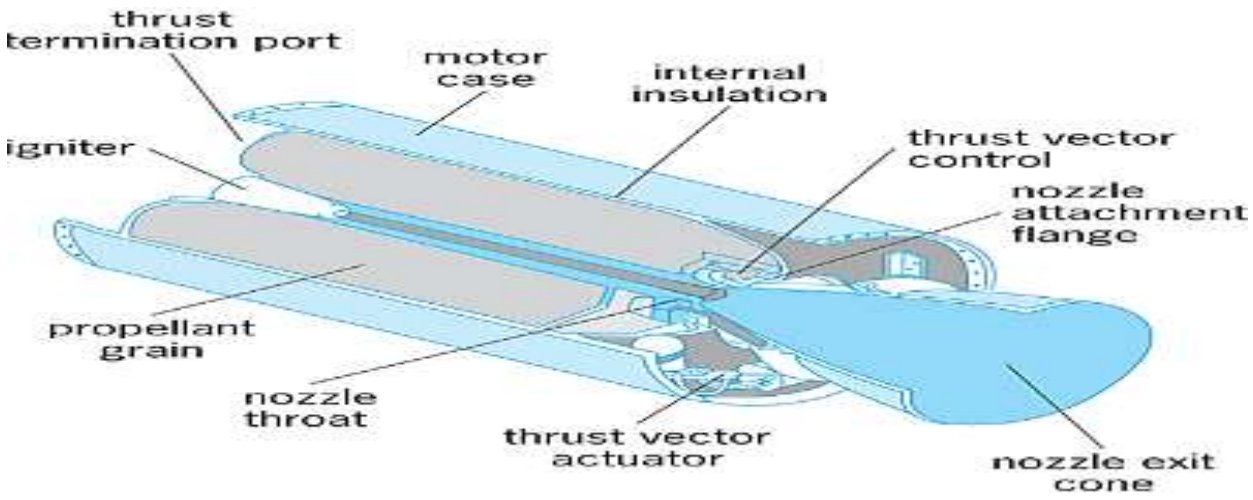
- In the solid-chemical rocket, the fuel and oxidizer are intimately mixed together and cast into a solid mass, called a *grain*, in the combustion

- The propellant grain is firmly cemented to the inside of the metal or plastic case, and is usually cast with a hole down the center. This hole, called the *perforation*, may be shaped in various ways, as star, gear, or other more unusual outlines, The perforation shape and dimension affects the burning rate or number of pounds of gas generated per second and, thereby, the thrust of the engine.

- After being ignited by a pyrotechnic device, which is usually triggered by an electrical impulse, the propellant grain burns on the entire inside surface of the perforation. The hot combustion gases pass down the grain and are ejected through the nozzle to produce thrust.

Types of Solid Propellant

a) Restricted Burning



- A restricted-burning charge is usually in the shape of a solid cylinder.
- It completely falls the combustion chamber and burns only on its end.
- The thrust developed is proportional to the cross-sectional area of the charge
- The restricted-burning charge provides a low thrust and long burning time.

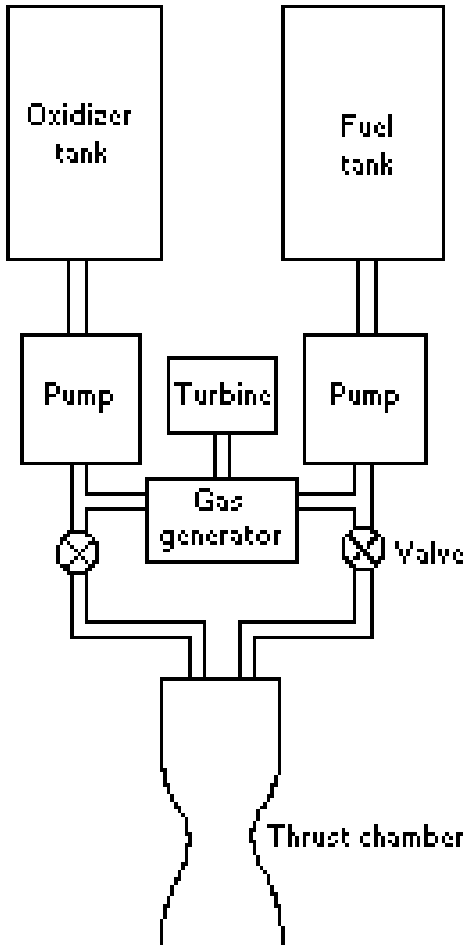
Types of Solid Propellant

b) Unrestricted Burning

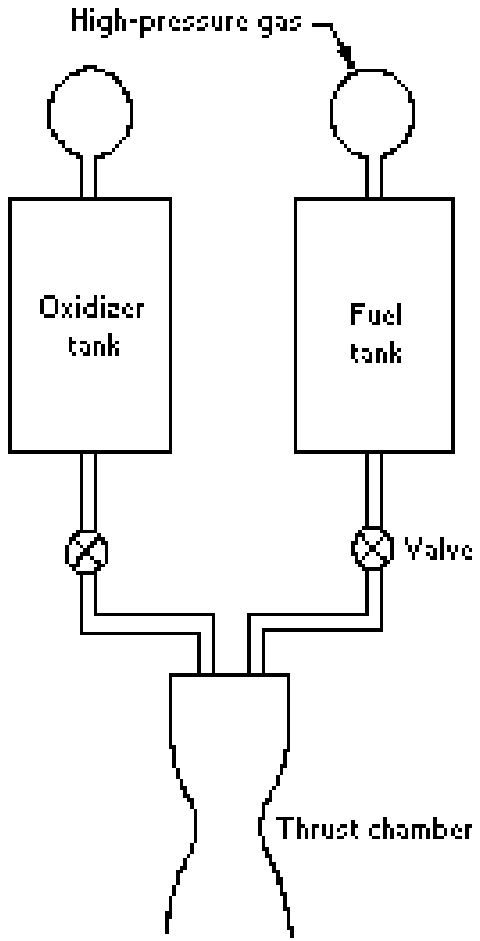
- It is essentially free to burn on all surfaces at the same time.

- The restricted burning propellant delivers a small trust for a relatively long period while unrestricted type delivers relatively large thrust for short period.
- It's application is in aircraft rockets, antiaircraft rockets and boosters etc.

Liquid Propellant Rocket Engine



(a) Pump-fed rocket



(b) Pressure-fed rocket

Liquid Propellant Rocket Engine

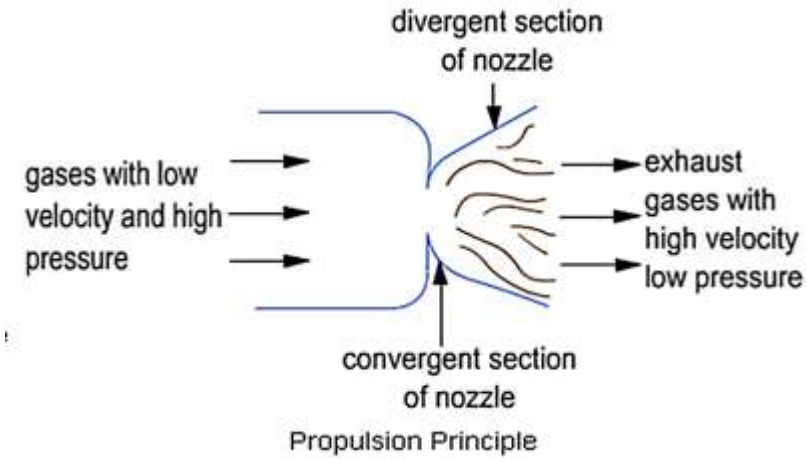
- The common liquid rocket is bipropellant; it uses two separate propellants, a liquid fuel and liquid oxidizer
- These are contained in separate tanks and are mixed only upon injection into the combustion chamber
- They may be fed to the combustion chamber by pumps or by pressure in the tanks

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Unit 4

PRINCIPLE OF ROCKETS

- THE PRINCIPLE OF ROCKET PROPULSION DEPENDS ON THE FOLLOWING TWO LAWS: -
  - (I) NEWTON 'S THIRD LAW OF MOTION
  - (II)LAW OF CONSERVATION OF MOMENTUM

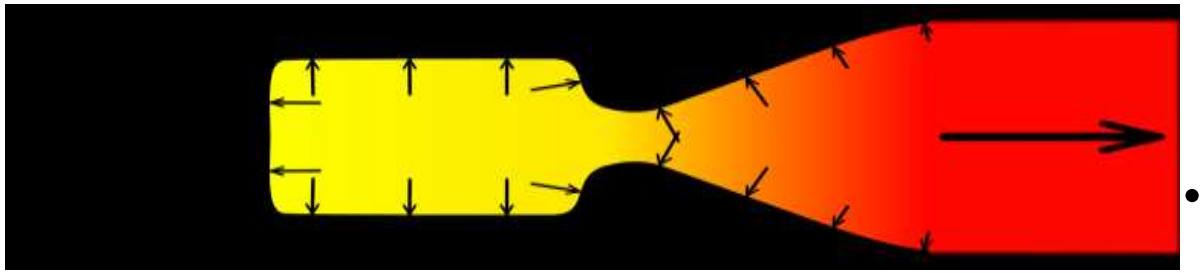


Propulsion Principle

- THE ROCKET EXPELS A JET OF HOT GASES FROM ITS TAIL. THIS IS SAY, AN ACTION FORCE. THE JET OF HOT GASES EXERTS A FORCE ON THE ROCKET, PROPELLING IT FORWARD; THIS IS THE REACTION FORCE.
- PROPULSION PRINCIPLE FROM THE MOMENTUM POINT OF VIEW, THE HOT GASES ACQUIRE MOMENTUM IN THE BACKWARD DIRECTION & THE ROCKET ACQUIRES AN EQUAL AMOUNT OF MOMENTUM IN THE FORWARD DIRECTION.

OPERATION OF ROCKETS

Rocket thrust is caused by pressures acting in the combustion chamber and nozzle. From Newton's third law, equal and opposite pressures act on the exhaust, and this accelerates it to high speeds.



- ROCKET ENGINES PRODUCE THRUST BY THE EXPULSION OF A HIGH-SPEED FLUID EXHAUST.
- THIS FLUID IS NEARLY ALWAYS A GAS WHICH IS CREATED BY HIGH PRESSURE (10-200 BAR) COMBUSTION OF SOLID OR LIQUID PROPELLANTS, CONSISTING OF FUEL AND OXIDISER COMPONENTS, WITHIN A COMBUSTION CHAMBER.
- THE FLUID EXHAUST IS THEN PASSED THROUGH A SUPERSONIC PROPELLING NOZZLE WHICH USES HEAT ENERGY OF THE GAS TO ACCELERATE THE EXHAUST TO VERY HIGH SPEED, AND THE REACTION TO THIS PUSHES THE ENGINE IN THE OPPOSITE DIRECTION.

APPLICATIONS OF ROCKETS

- TO CARRY THE PAYLOADS TO THE GEOSTATIONARY ORBITS
- TO INVESTIGATE OTHER PLANETS
- TO CARRYOUT SPACE STATION WORKS

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ROCKET ENGINE

- THE ROCKET ENGINE CARRIES BOTH ITS FUEL AND OXIDIZER AND ITS COMPLETELY INDEPENDENT OF THE ATMOSPHERE FOR ITS COMBUSTION
- ROCKETS CAN OPERATE IN VACUUM OF THE SPACE
- FUEL AND OXIDIZER ARE SPRAYED INTO THE COMBUSTION CHAMBER WHERE THEY BURN CREATING A HIGH-PRESSURE HIGH-TEMPERATURE MIXTURE OF COMBUSTION PRODUCTS
- THE MIXTURE VELOCITY IS ESSENTIALLY ZERO
- THE PRODUCTS OF COMBUSTION EXPAND TO SUPERSONIC SPEEDS THROUGH THE CONVERGENT-DIVERGENT ROCKET NOZZLE LEAVING AT A VELOCITY.
- THE EXIT VELOCITY IS EVEN MORE FOR JET ENGINES
- ROCKET ENGINES PRODUCE HIGHER THRUST BUT EFFICIENCIES ARE LOWER

ROCKET ENGINE

- THE COMPARATIVE EFFICIENCY OF DIFFERENT ROCKET ENGINES CAN BE OBTAINED FROM SPECIFIC IMPULSE ISP.
- SPECIFIC IMPULSE IS DEFINED AS THE THRUST PER UNIT WEIGHT FLOW AT SEA LEVEL
- NECESSARY CONDITION TO HAVE A HIGH IMPULSE IS

  A) COMBUSTION TEMPERATURE SHOULD BE HIGH

  B) MOLECULAR WEIGHT OF FUEL SHOULD BE LESS

  SPECIFIC IMPULSE IS THE NUMBER OF SECONDS AFTER WHICH 1 POUND OF PROPELLANTS WILL PRODUCE 1 POUND OF THRUST

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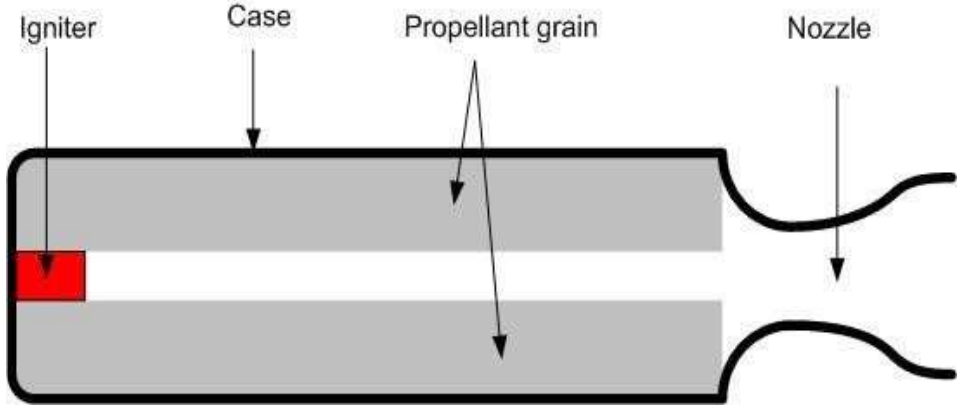
ROCKET PROPELLANTS

- THE FUEL AND THE OXIDIZER TOGETHER ARE CALLED AS ROCKET PROPELLANTS

- **CLASSIFICATION OF PROPELLANTS**
  - SOLID PROPELLANTS
  - LIQUID PROPELLANTS

SOLID PROPELLANT

IN SOLID PROPELLANTS, THE FUEL AND OXIDIZER COMPONENTS ARE PREPARED SEPARATELY AND ARE THEN MIXED TOGETHER. THIS IS BECAUSE THE OXIDIZER IS IN POWDER FORM AND THE FUEL IS A FLUID OF VARYING CONSISTENCY.



- IN ADDITION TO FUEL AND OXIDIZER, SOME OTHER COMPOUNDS ARE ADDED TO INCREASE THE EFFICIENCY OF THE PROPELLANTS
- **CATALYST**- TO INCREASES RATE OF COMBUSTION, EG: IRON OXIDIZER POWDER (0.07 %).
- **BINDER** - HOLDS MIXTURE TOGETHER, EG: POLYBUTADIENE,
- **AN EPOXY-CURING AGENT**

THE BINDER AND EPOXY ALSO BURN AS THE FUEL BURNS,

THUS CONTRIBUTING TO THE THRUST PRODUCED.

SOLID PROPELLANTS

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ADVANTAGES

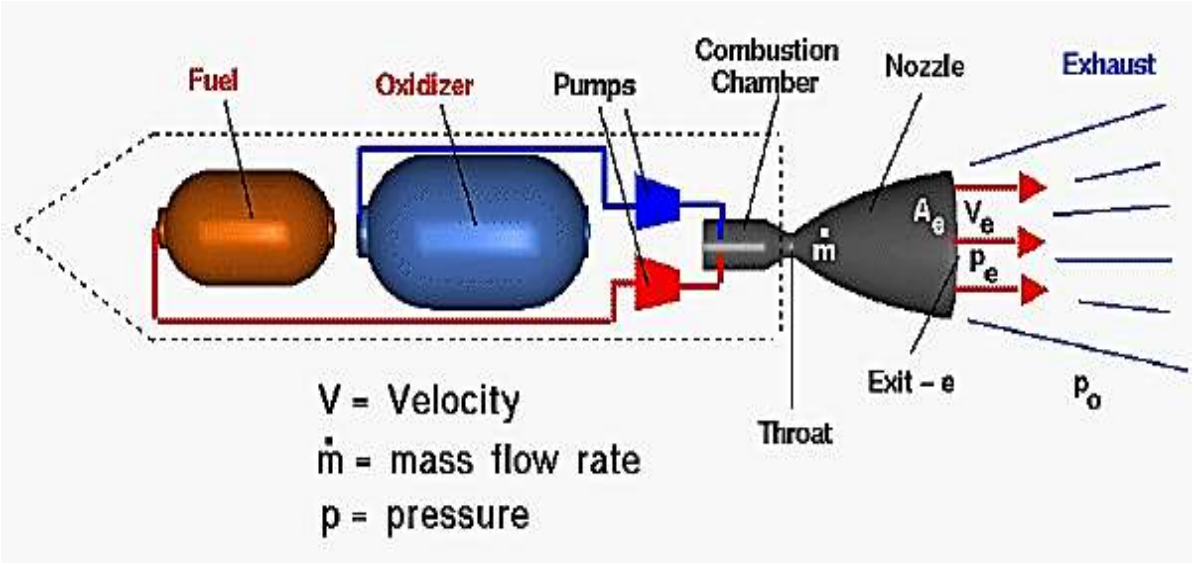
- THEY ARE STABLE AND EASILY STORABLE.
- THEY DO NOT REQUIRE TURBO PUMPS OR COMPLEX PROPELLANT FEEDING DEVICES.

- **DISADVANTAGES**

- THE SOLID PROPELLANT MOTOR CANNOT BE SHUT DOWN. THE FUEL
- ONCE IGNITED BURNS TILL THE END.
- THE PROPELLANT IS TEMPERATURE SENSITIVE.

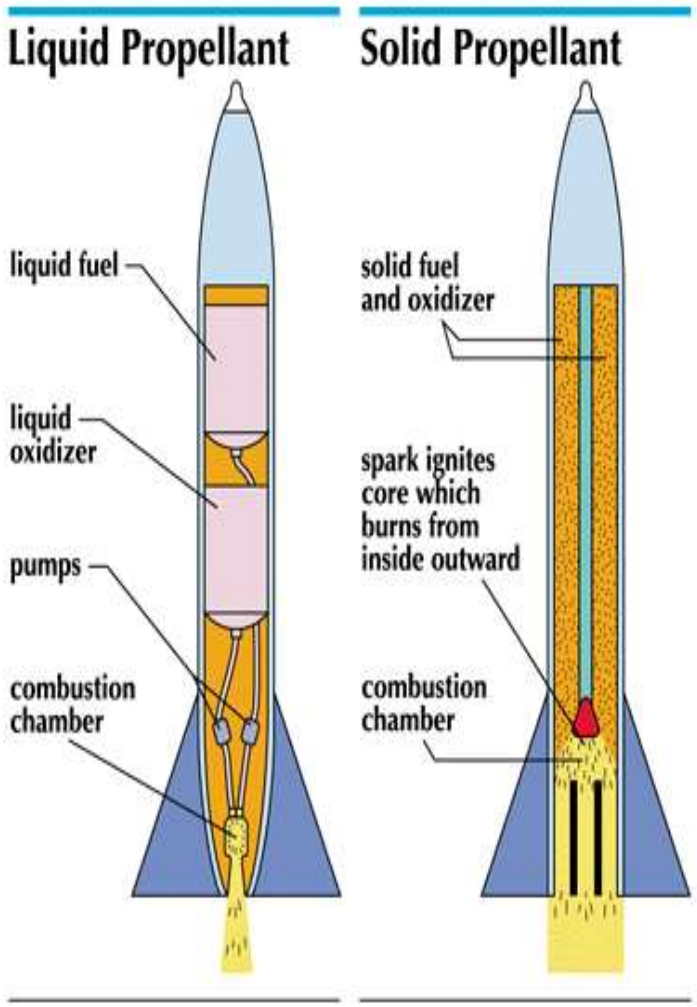
LIQUID PROPELLANTS

- BOTH THE FUEL AND OXIDIZER ARE CARRIED ONBOARD THE ROCKET IN LIQUID FORM AND THEY ARE INJECTED UNDER PRESSURE AS A SPRAY INTO THE COMBUSTION CHAMBER.



- THE PROPELLANTS ARE FED AT EXTREMELY HIGH PRESSURES AROUND 440 ATM.
- THERE ARE 2 APPROACHES : **1. PUMP-FED SYSTEM 2. PRESSURE-FED SYSTEM**

SOLID AND LIQUID PROPELLANTS



CRYOGENIC PROPELLANTS

- IN A CRYOGENIC PROPELLANT THE FUEL AND THE OXIDIZER ARE IN THE FORM OF VERY COLD, LIQUEFIED GASES.
- THESE LIQUEFIED GASES ARE REFERRED TO AS SUPER COOLED AS THEY STAY IN LIQUID FORM EVEN THOUGH THEY ARE AT A TEMPERATURE LOWER THAN THE FREEZING POINT.
- THUS WE CAN SAY THAT SUPER COOLED GASES USED AS LIQUID FUELS ARE CALLED CRYOGENIC FUELS.
- THESE PROPELLANTS ARE GASES AT NORMAL ATMOSPHERIC CONDITIONS. BUT TO STORE THESE PROPELLANTS ABOARD A ROCKET IS A VERY DIFFICULT TASK AS THEY HAVE VERY LOW DENSITIES. HENCE EXTREMELY HUGE TANKS WILL BE REQUIRED TO STORE THE PROPELLANTS.
- THUS BY COOLING AND COMPRESSING THEM INTO LIQUIDS, WE CAN VASTLY INCREASE THEIR DENSITY AND MAKE IT POSSIBLE TO STORE THEM IN LARGE QUANTITIES IN SMALLER TANKS.
- NORMALLY THE PROPELLANT COMBINATION USED IS THAT OF LIQUID OXYGEN AND LIQUID HYDROGEN, LIQUID OXYGEN BEING THE OXIDIZER AND LIQUID HYDROGEN BEING THE FUEL

CRYOGENIC PROPELLANTS

DRAWBACKS

- SINCE THESE PROPELLANTS ARE IN EXTREMELY LOW TEMPERATURE CONDITIONS THEY ARE VERY HARD TO HANDLE. THEY MUST BE PROTECTED FROM HEAT SO AS TO PREVENT BOILING OF GASES.
- WHEN LIQUID PROPELLANTS ARE STORED AT TEMPERATURES ABOVE THEIR BOILING POINT THEY VAPORIZE. IF THESE VAPORS ARE CONTAINED IN A TANK, THEN THE PRESSURE INCREASES WITH TEMPERATURE.
- CRYOGENS ARE HIGHLY CONCENTRATED GASES AND HAVE A VERY HIGH REACTIVITY.
- LIQUID OXYGEN, WHICH IS USED AS AN OXIDIZER, COMBINES WITH MOST OF THE ORGANIC MATERIALS TO FORM EXPLOSIVE COMPOUNDS. SO LOTS OF CARE MUST BE TAKEN TO ENSURE SAFETY.

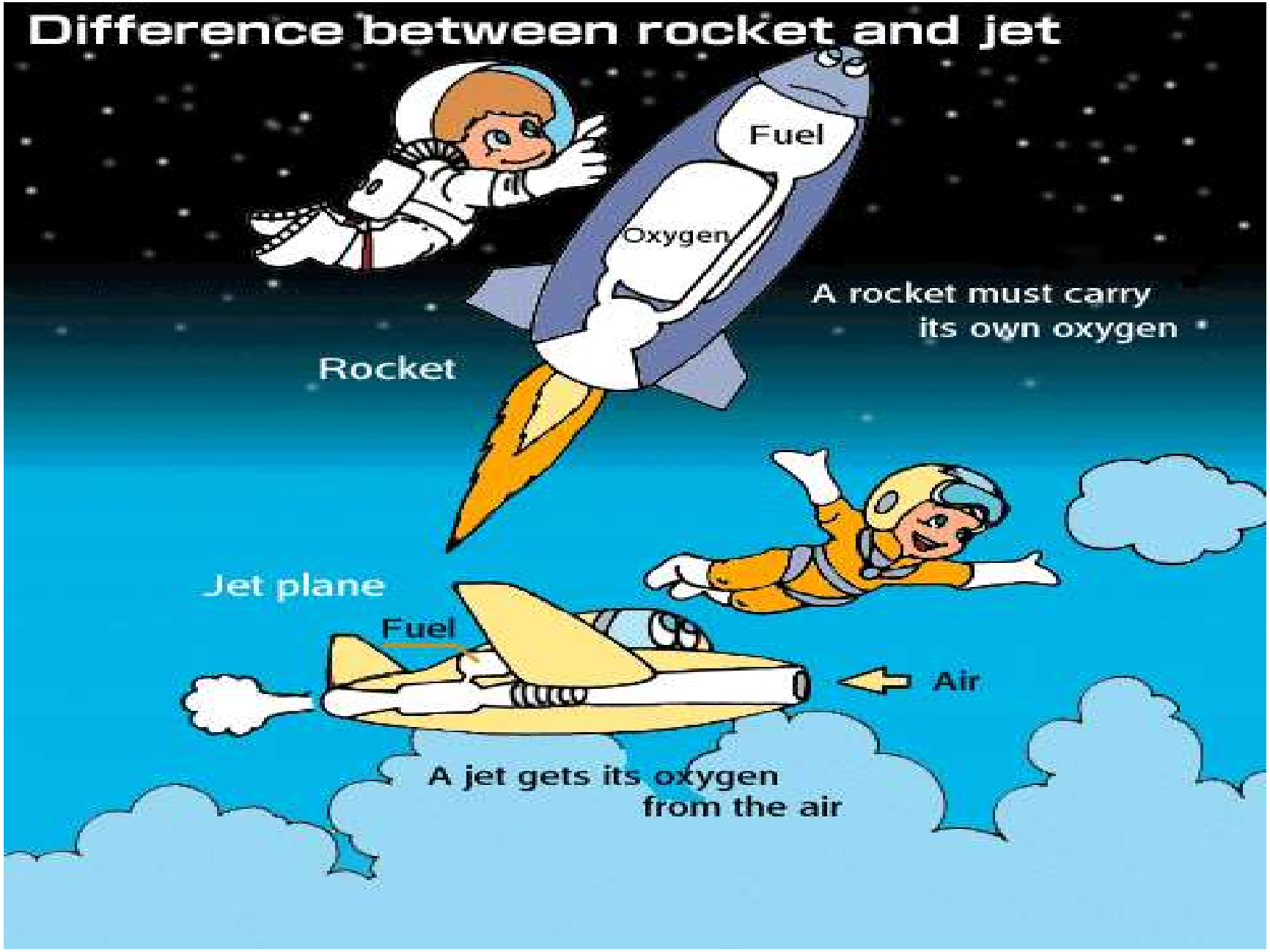
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HYPERGOLIC PROPELLANTS

- A HYPERGOLIC PROPELLANT IS COMPOSED OF A FUEL AND OXIDIZER THAT IGNITE WHEN THEY COME INTO CONTACT WITH EACH OTHER.
- THERE IS NO NEED OF AN IGNITION MECHANISM IN ORDER TO BRING ABOUT COMBUSTION.

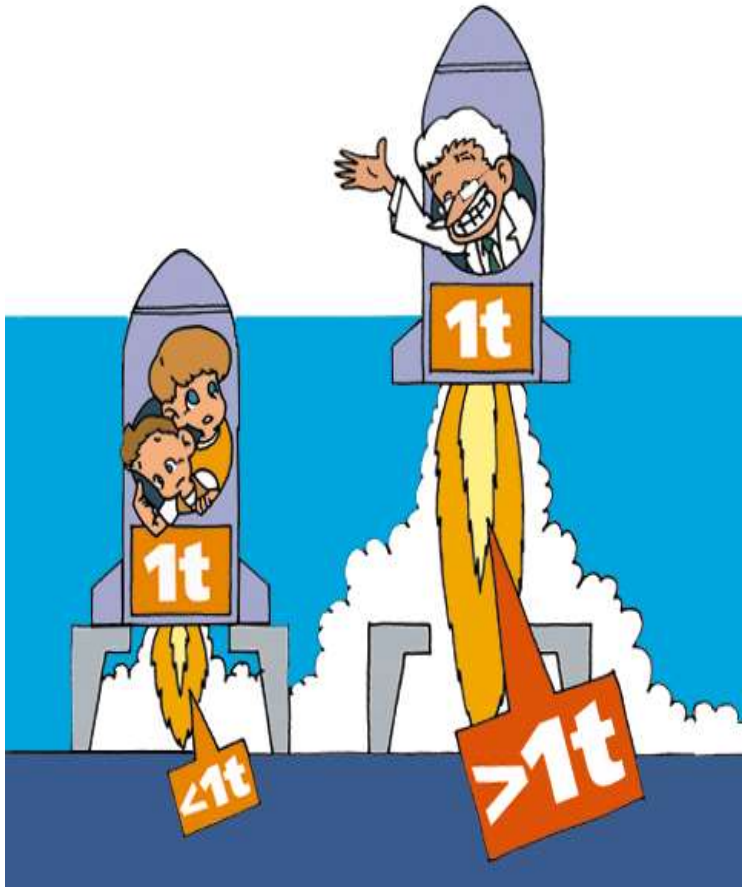
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Unit 5


Difference between rocket and jet
Fuel
Oxygen
A rocket must carry its own oxygen
Rocket
Jet plane
Fuel
Air
A jet gets its oxygen from the air

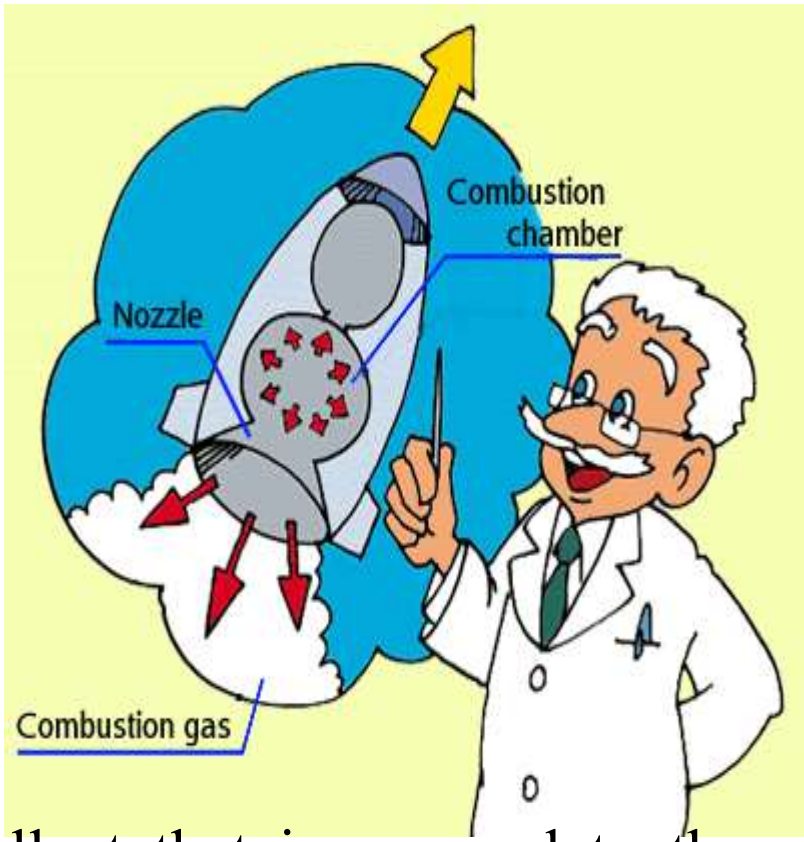
ROCKET THRUST

- Thrust indicates how much cargo a rocket can lift .
- A rocket flies faster than a rifle bullet
- A rocket must travel at a speed of 7.9 km per second to put a satellite into orbit.
- To leave the earth's gravity for a trip to the moon or a planet requires a speed of 11.2 km per second.
- The relationship between the speed of ejected combustion gas and what is called "mass ratio" is a vital factor in achieving such high speeds.



Basics Principle of Rockets

- Rocket Motion is very much like the motion of an air-filled balloon which is set free.
- Rockets generate large amounts of high-pressure combustion gas in their engines, and this gas is ejected rearwards at high-speed providing the force that drives the rocket forward.
- To burn fuel in space where no air exists, an oxidizer is necessary.





- Surface area is the amount of propellant that is exposed to the combustion chamber for burning and is directly related to thrust.
- An increase in surface area will increase thrust but will reduce burn-time since the propellant is being consumed at an accelerated rate.

ROCKET PROPELLANTS

- Unlikely the jet engines, the rockets cannot draw oxygen into their engines from the surrounding air and they must carry oxygen with them into space where there is no air.
- **Specific Impulse** is basically the efficiency of the rocket propellant and is measured in seconds. It indicates how many pounds (kg) of thrust is obtained by consuming 1 kg (1 pound) of propellant in one second.
- The specific impulse of a rocket propellant is a rough measure of how fast the propellant is ejected out from the back of the rocket. A rocket with higher specific impulse does not need as much fuel as a rocket with low specific impulse.

Higher the specific impulse, higher will be the push to move rocket forward

- More is the specific impulse the faster the rocket burns and more is the thrust that pushes it upward and so a great care is needed in solid fueled rockets as once the propellant is ignited it can't be stopped ***(very difficult to stop)***

FUEL MEASURING

- **Fuel measuring** i.e the amount of fuel that goes into space is important to get the required amount of thrust that a rocket should have.
- As each drop of fuel and oxidizer that goes into space adds up to the mass and weight of the spacecraft, so the scientists will carry the exact amount of fuel and nothing extra.
- Scientists also know about the chemical reactions that will result when the fuel and the oxidizer combines and so they know what would be the proportion of the two.
- In order to get the right proportions, they use the molecular formula of rocket fuels to calculate the no. of moles needed and once they know it they can calculate the right amount of fuels.

COMPOSITION

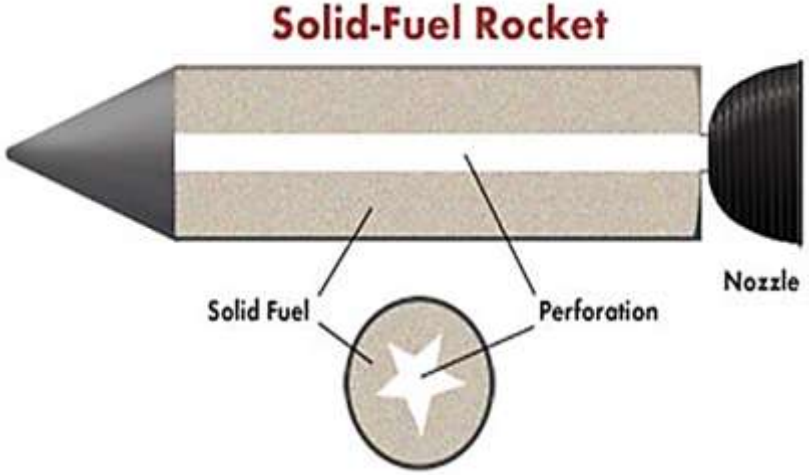
- The gun powder has the composition as:

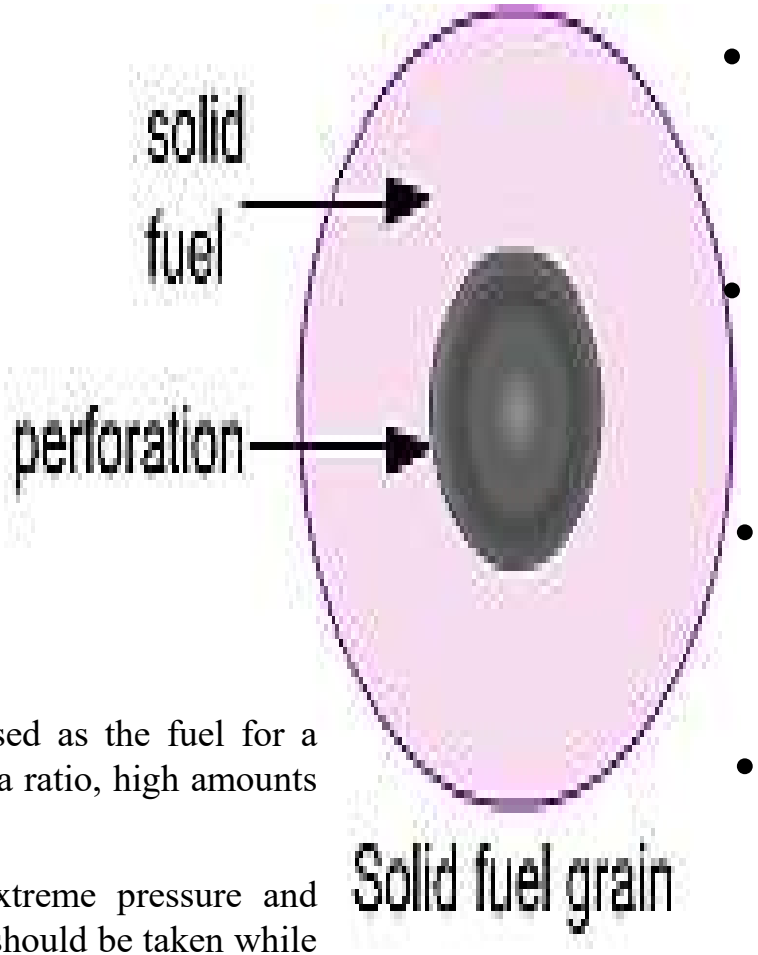
  75% nitrate 15% carbon 10% sulphur

- The casing is made up of steel containing fuel and the oxidizer which burns at a rapid rate expelling hot gases from the nozzle to produce thrust.
- The casing that contains the propellant opens to a combustion chamber at one end.
- Most rocket casings are cylindrical but some are spherical as well.
- The solid mass of the propellant is called **"charge or grain".**
- The propellant grain is an important factor in determining a rocket's performance and the variables that are important to judge the rocket's performance are **surface area and specific impulse.**

COMPOSITION

- By changing the shape and size of the perforation we can control the rate and duration of burning and thus control the thrust .





- To increase the thrust a hole is made when the propellant is cast. It is called as perforation.
- More the thrust required, larger will be the perforation but the fuel will burn for a smaller time.
- Lesser the thrust required, smaller will be the perforation but the fuel will burn for a very long time.
- The burning period and the thrust depends upon the type of perforation in the fuel.

- If a propellant with high specific impulse is used as the fuel for a rocket whose grain design has a high surface area ratio, high amounts of thrust will be produced.
- If the engine grain casing cannot bear the extreme pressure and temperature it will just explode. So, a great care should be taken while making the grain ratio of both the variables i.e specific impulse and surface area.

FAMILIES

➢There are two families of solid fueled propellants.

- **Homogeneous propellants**
- **Composite propellants**

Double Based Propellants

- Initial solid fueled rockets include gun powder and mixtures containing ***nitroglycerine*** and ***nitrocellulose*** which were also called ***double based propellants***
- Double based propellants are the combination of two propellants.

Homogeneous Propellants

- Simple based or double based (uses a single or double propellant).
- Simple homogeneous propellants consist of a single compound (nitrocellulose) and double based propellant consist of two compounds (nitrocellulose and nitroglycerine with a plasticizer added to it).

Composite Propellants

- Modern composite propellants are heterogeneous mixtures.
- The oxidizer normally uses is called ammonium perchlorate and the fuel used is aluminium.
- Additional compounds e.g catalyst is added to increase the burning rate.

Synthetic Rubber & Additives

- These oxidizers are often mixed, in making composite propellants, with synthetic rubbers such as polystyrenes & polysulfides.
- Additives are also added to composite propellants.
- *Additives have binders that hold the fuel together and increases its specific impulse.*

Boosters & Sustainers

- Booster rockets (huge rockets) need a large amount of thrust in a short time and they use chemicals to increase the burning rate.
- Also there are other rockets that need to produce less thrust over a longer period of time and they use chemicals to decrease the burning rate. Such longer burning rockets are called **“sustainers”**

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IGNITIORS

i. The ignition of solid propellants use different types of ignitors:

ii. Initially fire arrows were used as ignitors but they were not considered to be safe as they exploded.

iii. Now the safe method used is the electric current which heats up a specific wire inside the rocket. It results in increasing the temperature of the propellant inside the combustion chamber.

iv. Some ignitors use a chemical that ignites itself first and then ignites the propellant.

v. For large rockets the ignitors are the rocket engines themselves. The engines inside the rocket blasts a stream of flames and hot gases rush down from the top of the rockets igniting the entire surface of propellants within a fraction of second.

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ADVANTAGES OF SOLID PROPELLED ROCKETS

i. Simple in design.

ii. Require little pre-flight checkup.

iii. Use that propellant that do not leak/spill.

iv. Indefinite storage (5-30) years and used at high level in the military.

v. Instant ignition without fuelling operations.

DISADVANTAGES OF SOLID PROPELLED ROCKETS

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i. Exhaust gases are usually toxic.

ii. Once ignited cannot be shut down easily so they are designed for a specific mission.

iii. Re-start requires a separate ignition system.

iv. Once ignited cannot change their thrust.

v. Manufacturing of solid propelled rockets may get expensive due to separate ignition system(id re-start needed)

vi. Cracks may develop in the solid propellant that increases the exposed surface area and the propellant burns faster than the planned rate.

LIQUID FUELED ROCKETS

- Liquid fueled rockets provide greater specific impulses than solid fueled rockets.
- Engineers can control combustion in liquid fueled rockets by changing the rate at which the pumps move the liquid propellant to the combustion chamber vai valves.
- Combustion can be stopped and re-started by stopping the fuel pumps completely. This stopping and re-starting combustion is very useful in space missions as in space the course correction *(trajectory)* may needs to be changed that require short bursts from the rocket.
- Liquid fueled rockets are more complex to handle than solid fueled rockets as in liquid propellants the fuel and the oxidizer are stored in different tanks.
- Simplest liquid fueled rockets use nitrogen gas ***(high pressurized and non-reactive gas)*** which forces the propellant into the combustion chamber.

LIQUID FUELED ROCKETS

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- Liquid fueled rockets use different types of fuels and oxidizers like:

i. Fuels (alcohols, kerosene)

ii. Oxidizer (liquid oxygen)

A good liquid fueled rocket is the one that ejects high speed gases at a brisk rate which gives high combustion temperature.

FAMILIES

- Liquid propellants are classified into three families:

i. Petroleum

ii. Crogenics

iii. Hypergolics

PETROLEUM

i. *They are the fuels refined from crude oil and are the mixtures of hydro carbons.*

ii. *Petroleum fuel used as rocket fuel is kerosene.*

iii. *Used in combustion with liquid oxygen (oxidizer).*

CRYOGENICS

i. Liquid H_2 and liquid O_2 also power the upper stages of Saturn V and Saturn 1B rockets and also the second stage of Atlas launch vehicle .

ii. Due to these low temperatures of liquid crogenic propellants cannot be stored for longer periods of time and due to this reason they are less desirable to be used in military rockets which might require the rocket to be ready at launch for months.

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HYPERGOLICS

i. *They are the fuels and the oxidizers which came to in contact with each other and ignite at once without any ignition source.*

ii. *They have the easy start and re-start capability.*

iii. *Remain liquid at ordinary temperature and so no storage problem.*

- *Typical Oxidizers= Nitrogen Tetra Oxide (N_2O_4) or Nitric acid (HNO_3).*

ADVANTAGES

i. *Higher specific impulse*

ii. *Can be stopped and re-started*

iii. *Accurately controllable thrust*

iv. *Can be stored for longer periods*

v. *Can be reused after service and checking*

DIS-ADVANTAGES

i. *Complex in design*

ii. *Crogenic propellants cannot be stored for longer periods of time*

iii. *Propellant spills could be toxic and dangerous*

iv. *Combustion instability is difficult to control*

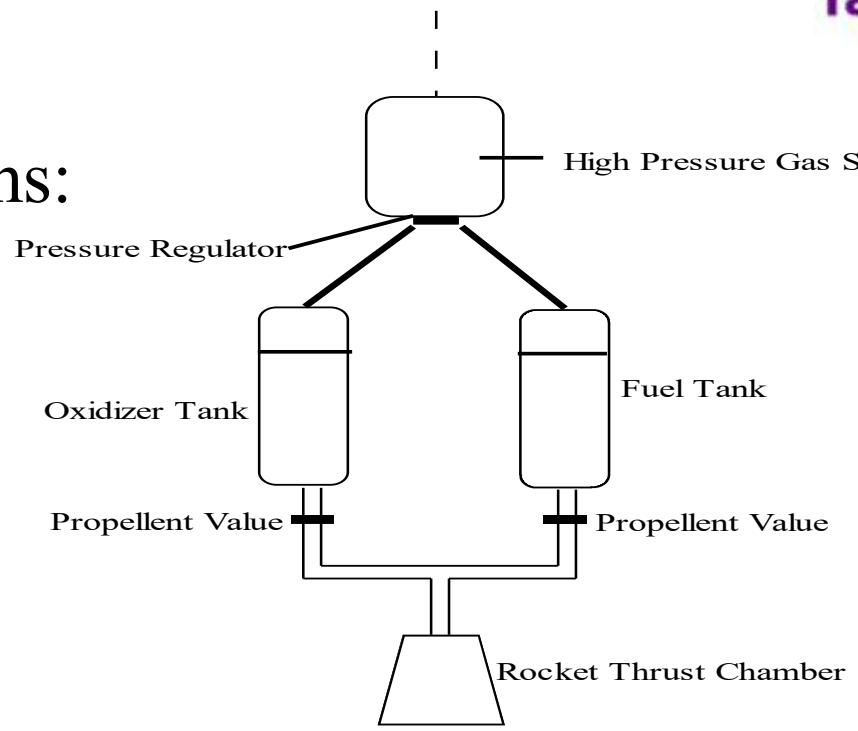
v. *Non-hypergolic fuels need an ignition system*

TYPES

- There are two types of liquid propelled systems:

i. *Gas Pressure Feed System.*

ii. *Turbo Pump Feed System.*



Schematic Diagram of Gas-Pressure Feed System

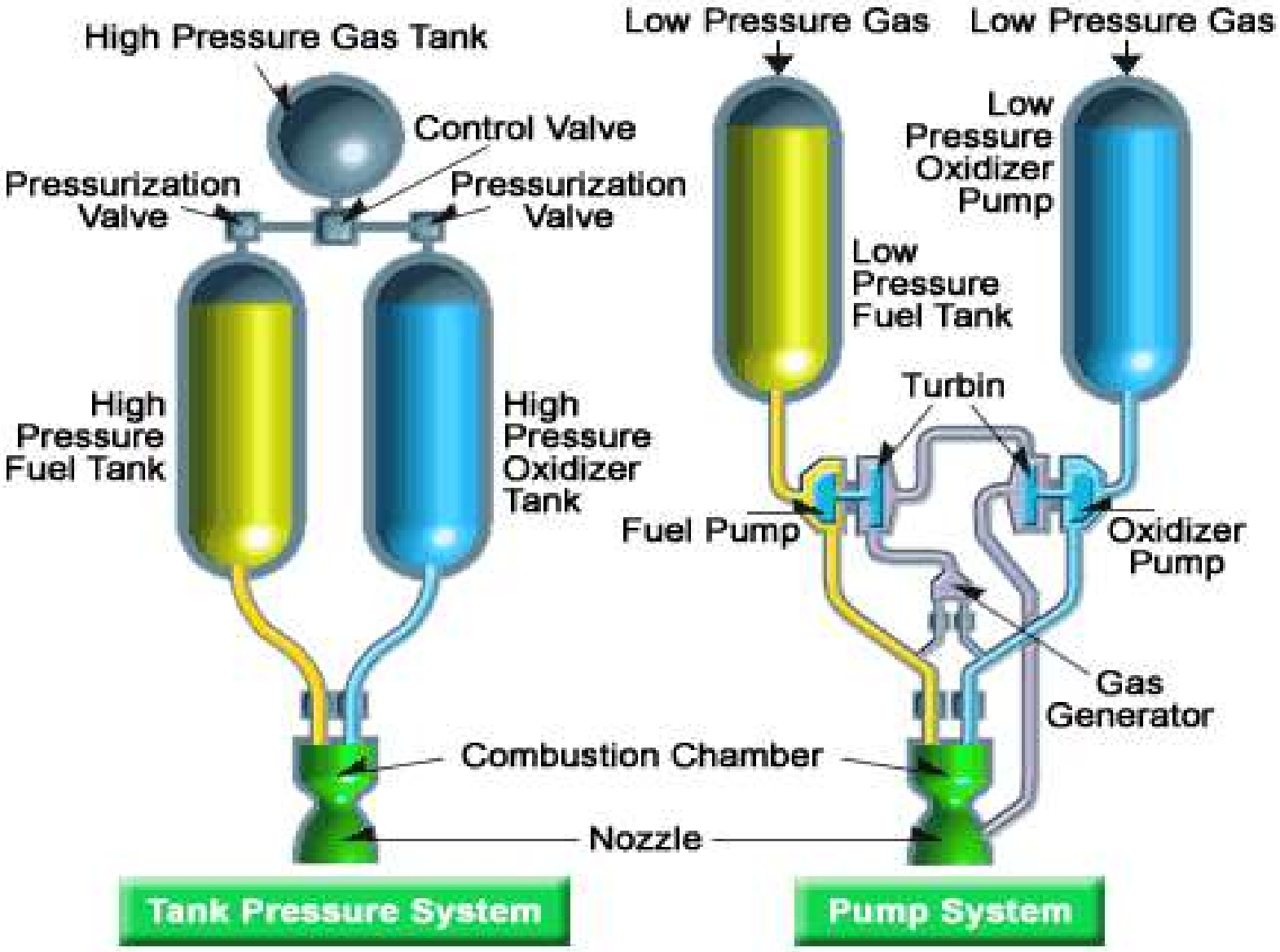
Gas Pressure Feed System

- In this type of propellant, a high-pressure gas under a pressure regulator displaces the propellant in the combustion chamber.
- It is used to produce low thrust and short duration.

Turbo Pump Feed System

- In this type the propellant is pressurized by pumps driven by gas turbine and finally displaced into the combustion chamber.
- *Combination of pumps and turbine is called* ***turbo pump.***

COMPARISON


High Pressure Gas Tank
Control Valve
Pressurization Valve
Pressurization Valve
High Pressure Fuel Tank
High Pressure Oxidizer Tank
Tank Pressure System
Low Pressure Gas
Low Pressure Gas
Low Pressure Oxidizer Pump
Low Pressure Fuel Tank
Turbin
Fuel Pump
Oxidizer Pump
Gas Generator
Combustion Chamber
Nozzle
Pump System