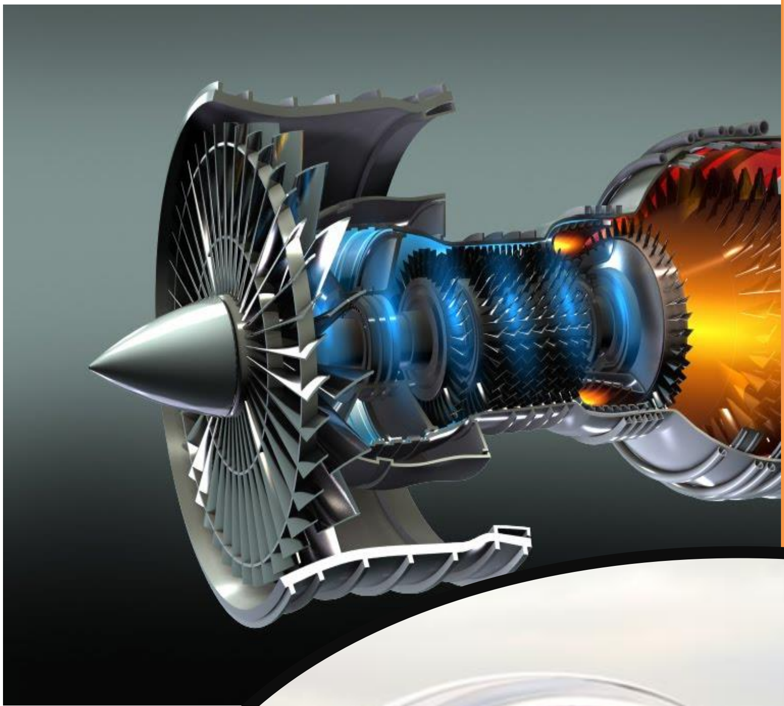
11

Jet Propulsion



Course Contents

11.1 Introduction

Jet propulsion, similar to all means of propulsion, is based on Newton’s Second and Third laws of motion.

The jet propulsion engine is used for the propulsion of aircraft, missile and submarine (for vehicles operating entirely in a fluid) by the reaction of jet of gases which are discharged rearward (behind) with a high velocity. As applied to vehicles operating entirely in a fluid, a momentum is imparted to a mass of fluid in such a manner that the reaction of the imparted momentum furnishes a propulsive force. The magnitude of this propulsive force is termed as thrust.

For efficient production of large power, fuel is burnt in an atmosphere of compressed air (combustion chamber), the products of combustion expanding first in a gas turbine which drives the air compressor and then in a nozzle from which the thrust is derived. Paraffin is usually adopted as the fuel because of its ease of atomization and its low freezing point.

Jet propulsion was utilized in the flying Bomb, the initial compression of the air being due to a divergent inlet duct in which a small increase in pressure energy was obtained at the expense of kinetic energy of the air. Because of this very limited compression, the thermal efficiency of the unit was low, although huge power was obtained. In the normal type of jet propulsion unit a considerable improvement in efficiency is obtained by fitting a turbo-compressor which will give a compression ratio of at least 4 : 1.

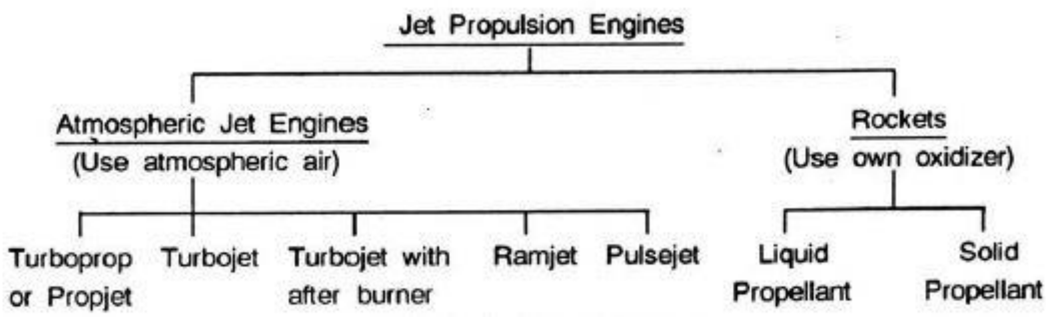


Figure 11.1 Classification of Jet propulsion Engines

11.2 Turbojet Engine

The turbojet engine is similar to the simple open cycle constant pressure gas turbine plant, except that the exhaust gases are first partially expanded in the turbine to produce just sufficient power to drive the compressor. The exhaust gases leaving the turbine are then expanded to atmospheric pressure in a propelling (discharge) nozzle. The remaining energy of gases after leaving the turbine is used as a high speed jet from which the thrust is obtained for forward movement of the aircraft

The essential components of a turbojet engine are:

An entrance air diffuser (diverging duct) in front of the compressor, which causes rise in pressure in the entering air by slowing it down. This is known as ram. The pressure at entrance to the compressor is about 1-25 times the ambient pressure.

A rotary compressor, which raises the pressure of air further to required value and delivers to the combustion chamber. The compressor is the radial or axial type and is driven by the turbine.

The combustion chamber, in which paraffin (kerosene) is sprayed, as a result of this combustion takes place at constant pressure and the temperature of air is raised.

The gas turbine into which products of combustion pass on leaving the combustion chamber. The products of combustion are partially expanded in the turbine to provide necessary power to drive the compressor.

The discharge nozzle in which expansion of gases is completed, thus developing the forward thrust.

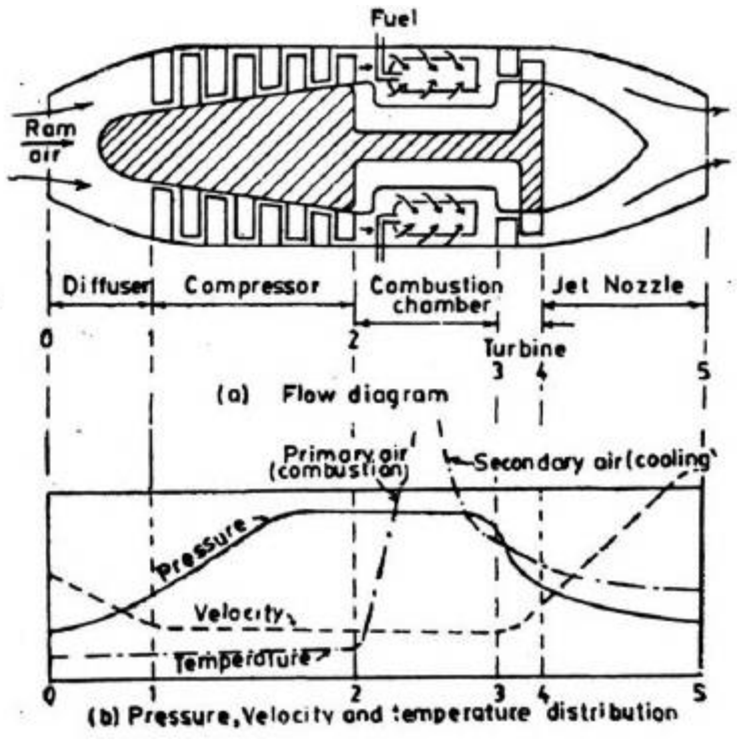


Figure 11.2 Turbojet engine

Working Cycle:

Air from surrounding atmosphere is drawn in through the diffuser, in which air is compressed partially by ram effect. Then air enters the rotary compressor and major part of the pressure rise is accomplished here. The air is compressed to a pressure of about 4 atmospheres.

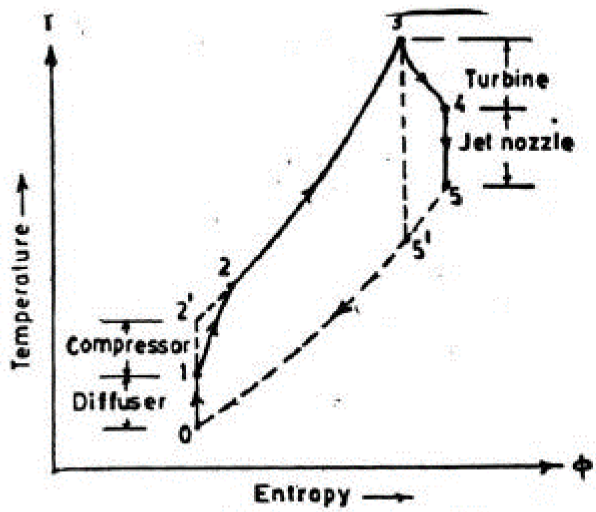


Figure 11.3 T-S diagram of turbojet engine

From the compressor the air passes into the annular combustion chamber. The fuel is forced by the oil pump through the fuel nozzle into the combustion chamber. Here the fuel is burnt at constant pressure. This raises the temperature and volume of the mixture of air and products of combustion.

The hot gases from the combustion chamber then pass through the turbine nozzle ring. The hot gases which partially expand in the turbine are then exhausted through the discharge (propelling nozzle) by which the remaining enthalpy is converted into kinetic energy. Thus, a high velocity propulsion jet is produced.

11.3 Thrust power, propulsive efficiency and thermal efficiency

The jet aircraft draws in air and expels it to the rear at a markedly increased velocity. The action of accelerating the mass of fluid in a given direction creates a reaction in the opposite direction in the form of a propulsive force. The magnitude of this propulsive force is defined as thrust. It is dependent upon the rate of change of momentum of the working medium i.e. air, as it passes through the engine. The basis for comparison of jet engines is the thrust. The thrust, T of a turbojet engine can be expressed as,

$T = m (Vj - Vo)$

Where,
M = mass flow rate of gases, kg/sec
V_i = exit jet velocity, m/sec
Vo = vehicle velocity, m/sec

The above equation is based upon the assumption that the mass of fuel is neglected. Since the atmospheric air is assumed to be at rest, the velocity of the air entering relative to the engine, is the velocity of the vehicle, Vo. The thrust can be increased by increasing the mass flow rate of gas or increasing the velocity of the exhaust jet for given Vo. Thrust power is the time rate of development of the useful work achieved by the engine and it is obtained by the product of the thrust and the flight velocity of the vehicle. Thus, thrust power TP is given by

$$TP = Tv_0 = m\,(v_j - v_0)\,v_o \text{ Nm/s}$$

The kinetic energy imparted to the fluid or the energy required to change the momentum of the mass flow of air, is the difference between the rate of kinetic energy of entering air and the rate of kinetic energy of the exist gases and is called propulsive power. The propulsive power PP is given by,

$$PP = m\frac{(v_j^2 - v_o^2)}{2} \text{ Nm/s}$$

Propulsive efficiency is defined 'as the ratio of thrust power and propulsive power and is the measure of the effectiveness with which the kinetic energy imparted to the fluid is transformed or converted into useful work. Thus, propulsive efficiency is given by,

$$\eta_p = \frac{TP}{PP} = \frac{m\,(v_j - v_o)}{1} \times \frac{2}{m\,(v_j^2 - v_o^2)}$$

Thermal efficiency of a propulsion is an indication of the degree of utilization of energy in fuel (heat supplied) in accelerating the fluid flow and is defined as the increase in the kinetic energy of the fluid (propulsive power) and the heat supplied. Thus,

$$\text{Thermal efficiency} = \eta_T = \frac{Propulsive\ power}{heat\ supplied} = \frac{Propulsive\ power}{Fuel\ flow\ rate \times C.V.of\ fuel}$$

The overall efficiency is the ratio of the thrust power and the heat supplied. Thus, overall efficiency is the product of propulsive efficiency and thermal efficiency. The propulsive and overall efficiencies of the turbojet engine are comparable to the mechanical efficiency and brake thermal efficiency respectively, of the reciprocating engine.

11.4 Ramjet engine

A french engineer, Rane Lorin invented and patented the first ram jet in 1913. It is a steady combustion or continuous flow engine. It has the simplest construction of any propulsion engine consisting essentially of an inlet diffuser, a combustion chamber, and an exit nozzle or tailpipe.

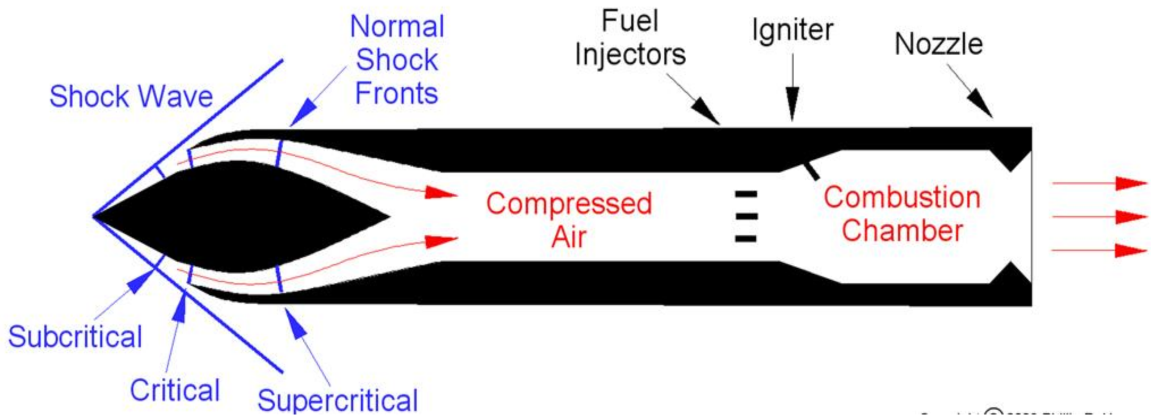


Figure 11.4 Ramjet engine

Since the ram jet has no compressor, it is dependent entirely upon ram compression. Ram compression is the transformation of the kinetic energy of the entering air into pressure energy. After the ram jet is boosted, the- velocity of the air entering the diffuser is decreased and is accompanied by an increase in pressure. This creates a pressure barrier at the after end of the diffuser. The fuel that is sprayed into the combustion chamber through injection nozzles is mixed with the air and ignited by means of a spark plug.

The expansion of the gases toward the diffuser entrance is restricted by the pressure barrier at the after end of the diffuser; consequently, the gases are constrained to expand through the tail pipe and out through the exit nozzle at a high velocity. Sometimes, the pressure barrier is not effective and that there are pulsations created in the combustion chamber which affect the air flow in front of the diffuser.

The cycle for an ideal ram jet, which has an isentropic entrance diffuser and exit nozzle, is the Joule cycle as shown by the dotted lines in fig.

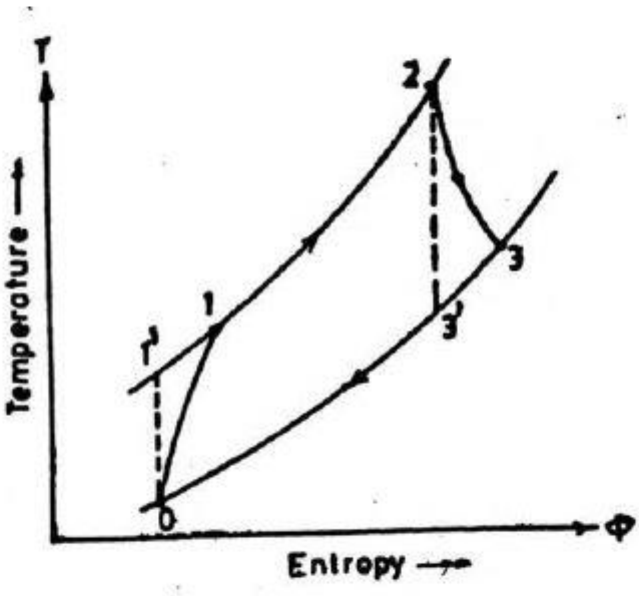


Figure 11.5 T-S diagram of ramjet engine

The difference between the actual and ideal jet is due principally to losses actually encountered in the flow system. The sources of these losses are:

- Wall friction and flow separation in the subsonic diffuser and shock in the supersonic diffuser.
- Obstruction of the air stream by the burners which introduces eddy currents and turbulence in the air stream.
- Turbulence and eddy currents introduced in the flow during burning.
- Wall friction in the exit nozzle.

11.5 Pulsejet engine

Paul Schmidt patented principles of the pulse jet engine in 1930. It was developed by Germany during World-War-II.

The pulse jet engine is somewhat similar to a ram jet engine. The difference is that a mechanical valve arrangement is used to prevent the hot gases of combustion from flowing out through the diffuser in the pulse jet engine.

The turbojet and ram jet engines are continuous in operation and are based on the constant pressure heat addition (Bryton) cycle. The pulse jet is an intermittent combustion engine and it operates on a cycle similar to a reciprocating engine and may be better compared with an ideal Otto cycle rather than the Joule or Bryton cycle.

The compression of incoming air is accomplished in a diffuser. The air passes through the spring valves and is mixed with fuel from a fuel spray located behind the valves. A spark plug is used to initiate combustion but once the engine is operating normally, the spark is turned off and residual flame in the combustion chamber is used for ignition. The engine walls also may get hot enough to initiate combustion.

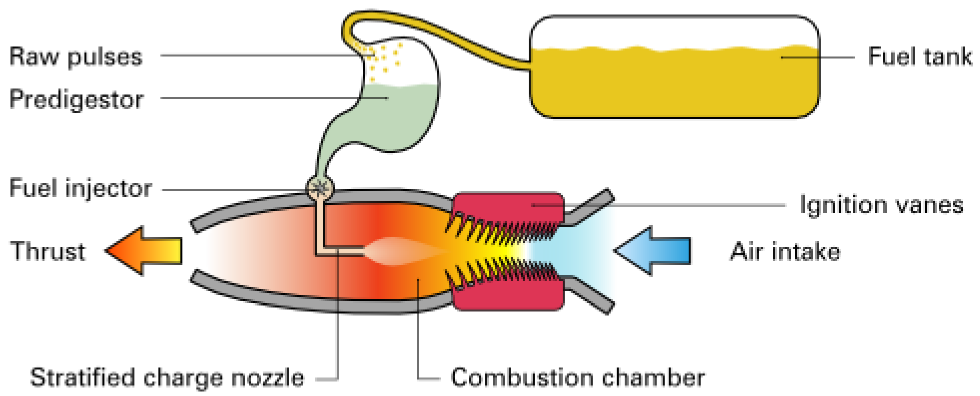


Figure 11.6 Pulsejet engine

The mechanical valves which were forced open by the entering air, are forced shut when the combustion process raises the pressure within the engine above the pressure in the diffuser. As the combustion products cannot expand forward, they move to the rear at high velocity. The combustion products cannot expand forward, they move to the rear at high velocity. When the combustion products leave, the pressure in the combustion chamber drops and the high pressure air in high pressure air in the diffuser forces the valves open and fresh air enters the engine.

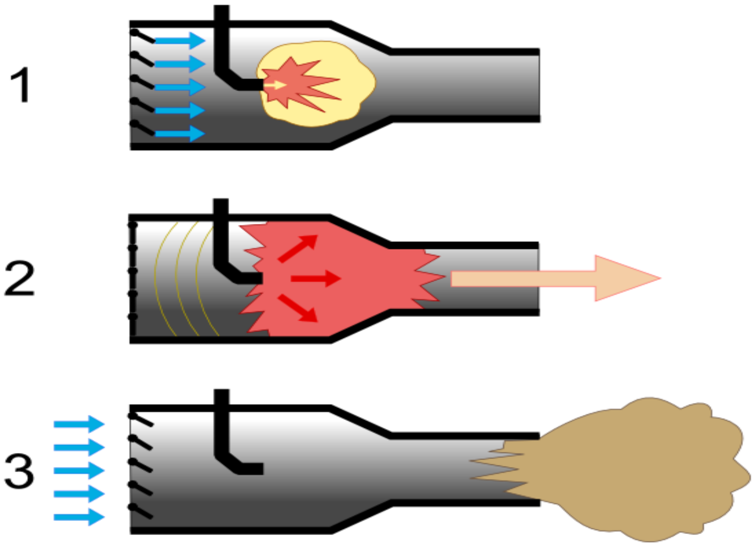


Figure 11.7 Valves position for Pulsejet engine

Since the products of combustion leave at a high velocity there is certain scavenging of the engine caused by the decrease in pressure occasioned by the exit gases. There is a stable cycle set up in which alternate waves of high and low pressure travel down the engine. The alternating cycles of combustion, exhaust, induction, combustion, etc. are related to the acoustical velocity at the temperature prevailing in the engine.

Despite the apparent noise and the valve limitation, pulse jet engines have several advantages when compared to other thermal jet engines.

- The pulse jet is very inexpensive when compared to a turbojet.
- The pulse jet produces static thrust and produces thrust in excess of drag at much lower speed than a ram jet.
- The potential of the pulse jet is quite considerable and its development and research may well bring about a wide range of application.

11.6 Rocket engine

A rocket engine is a type of jet engine that uses only stored rocket propellant mass for forming its high speed propulsive jet. Rocket engines are reaction engines, obtaining thrust in accordance with newton's third law. Most rocket engines are internal combustion engines. Vehicles propelled by rocket engines are commonly called rockets.

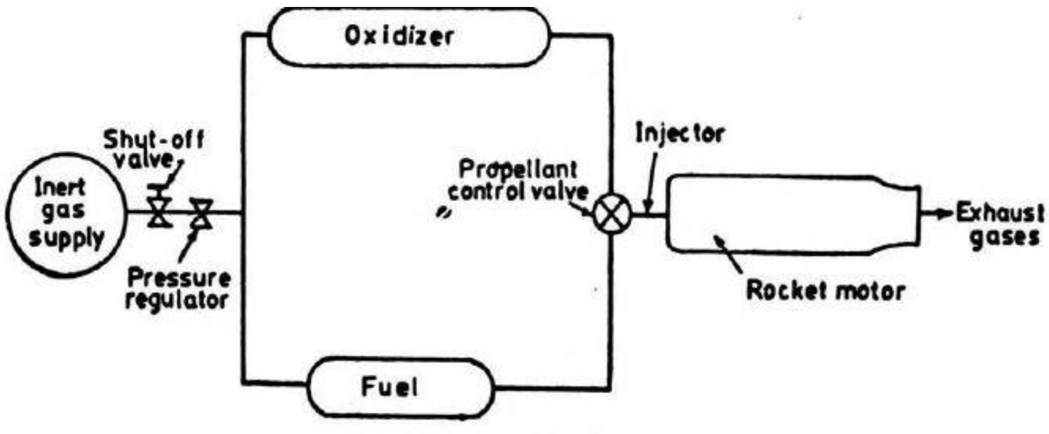


Figure 11.8 Pressure feed rocket jet

Principle of operation:

Rocket engines produce thrust by the expulsion of an exhaust fluid which has been accelerated to a high speed through a propelling nozzle. The fluid is usually a gas created by high pressure combustion of solid or liquid propellants, consisting of fuel and oxidiser components, within a combustion chamber. The nozzle uses the heat energy released by expansion of the gas to accelerate the exhaust to very high (supersonic) speed, and the reaction to this pushes the engine in the opposite direction.

Propellant

Rocket propellant is mass that is stored, usually in some form of propellant tank, or within the combustion chamber itself, prior to being ejected from a rocket engine in the form of a fluid jet to produce thrust. Chemical rocket propellants are most commonly used, which undergo exothermic chemical reactions which produce hot gas which is used by a rocket for propulsive purposes.

Rocket engines are classified as to the type of propellant used in them. Accordingly, there are two major groups: One type belonging to the group that utilizes liquid type propellants and other group that uses solid type propellants. The basic theory governing the operation of rocket motor is applied, equally to both the liquid and the solid propellant rocket.

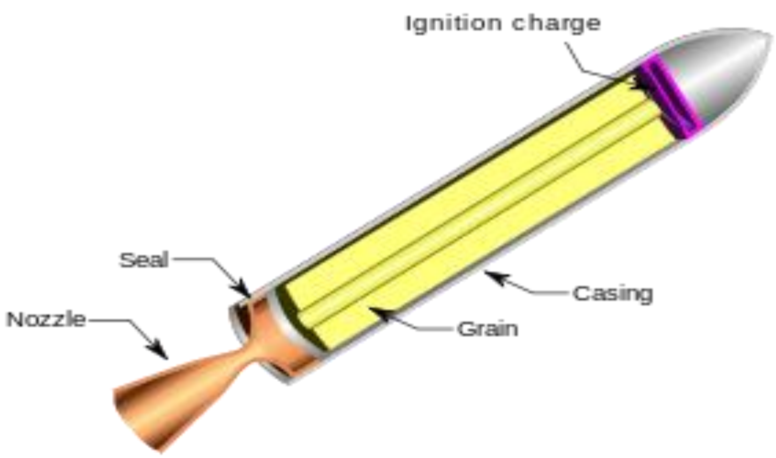


Figure 11.9 Rocket motor

The particular **advantages** of the rocket are,

- Its thrust is practically independent of its environments
- It requires no atmospheric oxygen for its operation.
- It can function even in a vacuum.
- It appear to be the simplest means for converting the thermochemical energy of a propellant combination (fuel plus oxidizer) into kinetic energy associated with a jet flow gases.

Applications:

- Artillery barrage rockets
- Anti-tank rockets
- All types of guided missiles
- Aircraft launched rockets
- Jets assisted take-off for airplanes
- Engines for long range, high speed guided missiles and pilotless aircrafts
- Main and auxiliary propulsion engines on transonic airplanes

Despite its apparent simplicity, the development of a reliable rocket system must be light in weight and the rocket motor must be capable of sustained operation in contact with gases at temperature above 2800° C and at appreciable pressures. The -problem of materials in consequently a major one. Furthermore, owing to the enormous energy releases involved, problem of ignition, smooth start up, thrust control, cooling etc. arise.

A major problem of development of rocket is selection of suitable propellant to give maximum energy per premium total weight (propellant plus containing vessels) and convenience factors such as a safety in handling, dependability, corrosive tendencies, cost, availability and storage problems. In general, it can be stated that there is a wide variety of fuels that are satisfactory for rocket purpose, but choice of oxidizers is at present distinctly limited.