AIRBREATHING PROPULSIVE DEVICE OF AN AIRCRAFT

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Abstract: This paper is about air-breathing propulsion used mostly in airborne vehicles. In this paper, the basic mechanics and applicability of laws of physics in aircraft propulsion is explained in brief. Aircraft propulsion uses a specific type of propulsive technology which is entirely different in comparison to the technology used in ground vehicles. Utilisation of atmospheric air for combustion of fuel and further production of thrust in a specific direction makes the aircraft move forward is the basic fundamental concept of aircraft propulsion.

Keywords: Aircraft, Propulsion, Thrust, Air-breathing, Efficiency, Reverser, Vectored, Augmentation.

I. INTRODUCTION

By seeing the birds flying in air, human being also developed a dream to fly. It started in reality from the experiment of Icarus wax glued feathered wings and thereafter sketches of Leonardo the Vinci's flying machines led to the invention of Lighter than air balloons. The theory for flying got revolutionised by the development of concrete scientific concepts in 1799 by Sir George Cayley, the father of aerodynamics and presented the concept of fixed wing flying machine (not flapping wings as birds have) by describing the basic four forces – lift, drag, weight and thrust and designing the first successful glider carrying human being in it. Later, on December 17, 1903, Wright brothers successfully tested the first controlled powered flight. Successful experimentation on various technical glitches by Scientists gifted a fully comfortable driven transport flying machine to this world. Propulsion is one of the major areas of concern as it provides power to the engine for making the aircraft to move forward and thereby generate lift force for becoming airborne.

II. PROPULSIVE DEVICES FOR AIRCRAFT PROPULSION

Aircraft propulsion is generally called air breathing propulsion. Air breathing propulsion means the engine utilises atmospheric air for combustion of fuel whereas in case of non air-breathing propulsion, oxygen is carried separately along with fuel for combustion and atmospheric air is not utilised at all. The advantage of this type of propulsion is that it can work even in vacuum or space. For example – Rocket engine. Two types of air-breathing propulsive devices - Piston engines and jet engines are used in aircraft.

III. RECIPROCATING ENGINE OR PISTON ENGINE

Generally in small aircrafts, piston engine propulsion is used. In this type of propulsion, piston or reciprocating engines similar to used in ground vehicles such as cars, scooters etc. is used to provide necessary thrust power to the aircraft for its forward movement. The thrust produced is not so large to achieve high speed and hence its use is restricted to small aircraft flying at lower altitude.

Except some additional components and accessories like propeller, inverted oil kit, magnetos, flow dividers etc., same components used in all internal combustion engines like crankcase, cylinders, piston, crankshaft, camshaft, inlet and outlet valves, connecting rod etc., are employed to generate power.

The reciprocating engine works on the thermodynamic principle of constant volume cycle and conversion of heat energy to mechanical energy by following the sequence of events of 4-Stroke engines. The reciprocating motion of the piston is converted to rotary motion by crankshaft and the same is delivered to the propeller which in turn produces thrust for moving the aircraft forward.

The aerodynamically designed blades of propeller creates a difference in force in front and back side of the propeller blade, thereby developing rate of change of momentum and as per Newton's third law of motion, a pair of equal and opposite action and reaction force is produced which generates a forward thrust force.

IV. CLASSIFICATION OF PISTON ENGINES

A. On the basis of arrangement of cylinders with respect to position of crankshaft, piston engines are classified as:

(**a) Radial Engine** **(b) V-Engines (c) Inline Engines** **(d) Horizontally Opposed Engines**

The first three engines are primitive engines and are not used nowadays.

Figure 1. Radial Engine

Figure 2. V - Engine

Figure 3. Inline Engine

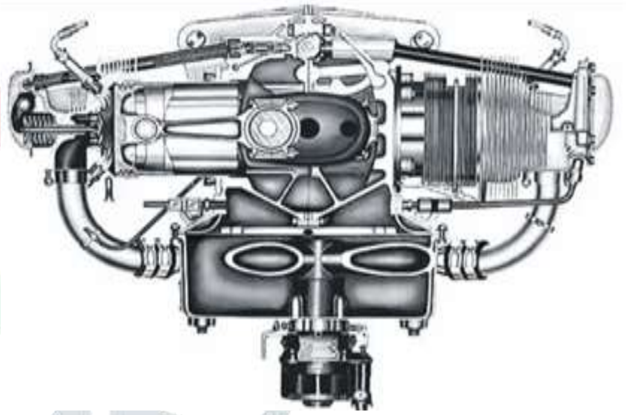

Figure 4. Horizontally Opposed Engine

B. On the basis of combustion:

(a) External Combustion (EC) Engines: In this type of engine, the power produced by the engine is transferred to the location where the power is converted into useful work.

(b) Internal Combustion (IC) Engines: In this type of engine, the power is produced in the same place where the power is converted into useful work.

C. On the basis of ignition system used in cylinders:

(a) Spark Ignition (SI) Engines: In this type of engine, a high intensity electrical spark produced by spark plug is used for igniting air fuel mixture in cylinder.

(b) Compression Ignition (CI) Engines: In this type of engine, air is compressed in the cylinder to attain self ignition temperature of fuel which is injected at the end of compression stroke. This engine doesn't use spark plug for igniting air fuel mixture in cylinder.

D. On the basis of distance travelled in degrees by the piston (stroke) in cylinders:

(a) 2 - Stroke Engines: In this type of engine, power is produced in every complete revolution i.e. 360^0 movement of the crank shaft. This type of engine produces more power in comparison to four stroke engines but requires frequent maintenance due to high heat generated as effective cooling of the engine is not achieved.

(b) 4 - Stroke Engines: In this type of engine, power is produced in every two revolutions i.e. 720^0 movement of the crank shaft. This type of engine produces less power in comparison to two stroke engines but requires less maintenance due to less heat generated, effective cooling and cleaner operation.

E. On the basis of transportation system of fuel to cylinders

(a) Carburetion Engines: In this type of engine carburetor is used which supplies air-fuel mixture to the cylinder as per the demand of the engine and throttle opening.

(b) Direct Injection Engines: In this type of engine injector is used which injects only fuel through nozzle to the cylinder as per the demand of the engine and throttle opening.

F. On the basis of type of fuel used:

(a) Petrol or Gasoline Engines: This type of engine uses petrol as fuel. In aircrafts especially, aviation gasoline (AVGAS) is used. These engines are generally spark ignition engines.

(b) Diesel Engines: This type of engine uses diesel as fuel. These engines are generally compression ignition engines.

G. On the basis of cooling system used:

(a) Air Cooled Engines: In this type of engine, air is used for cooling the engine during its operation. Small less powered engines are generally air cooled.

(b) Liquid Cooled Engines: In this type of engine, liquid is used for cooling the engine during its operation. Large high powered engines are generally liquid cooled. In most of the engine nowadays, combination of both cooling system is used.

V. JET ENGINE

In this type of propulsion, necessary thrust power is produced by using jet engine which works on the thermodynamic principle of constant pressure cycle and conversion of heat energy to mechanical energy.

In Jet engine, atmospheric air is breathed in through specially designed air intake by suction force created by compressor. The pressure of incoming air is increased to the considerable level where complete atomization and combustion of fuel is achieved in a smooth manner.

The high pressure airflow is not only utilized for combustion but also bled for cooling hot zone components and further get mixed with exhaust gases and goes out of the engine. Almost at constant pressure, combustion of fuel takes place in combustion chamber and hot exhaust gases with high velocity are directed to create an impact force on turbine blades where extraction of power and conversion of energy takes place. The mechanical energy extracted by turbine from high velocity hot exhaust gases is utilized to drive mainly compressor which is the main load of engine and even other components through accessory gear box.

The exhaust gases after imparting momentum to the turbine as per Newton's Second Law of Motion loses considerable amount of energy and move out of the engine through nozzle which due to its design reduces pressure and increases velocity.

This high velocity gases in turn generate thrust force for forward movement of aircraft as per Newton's Law of third motion.

VI. COMPONENTS OF A JET ENGINE

The main components of a jet engine are as follows:

(a) **Air Intake** – An air intake is the first part of aircraft and is being designed and manufactured by aircraft manufacturer as per the specification provided for the particular engine. The main role of an air intake is to provide ram compression to the incoming air and also to provide a smooth entry of air to the compressor in a specific direction.

(b) Compressor – It is the second major rotary component of aircraft engine which ensures delivery of high pressure air to the combustion chamber.

Two types of compressors are used to achieve high compression. Centrifugal compressor is used generally in small engine and axial flow compressor is used in large engine. In some engines, both compressors are used simultaneously. Spooling of compressor by using low pressure and high pressure compressor separately coupled with low pressure and high pressure turbine respectively is also done to reduce size and load on one compressor and to produce increase in pressure.

(c) **Diffuser -** This component provides attachment points for compressor and combustion chambers on either side of it. It receives high pressure air with considerable velocity which is reduced and further increase in pressure takes place. The same high pressure air is delivered to the combustion chamber.

(d) Combustion Chamber – It provides space for combustion of fuel in a pre-determined order. Fuel is injected on high pressure air stream, gets atomized and an electrical spark ignites the fuel air mixture and combustion takes place at approximately constant pressure.

In a jet engine, combustion is continuous unlike in a piston engine where electrical spark or combustion is timed for a particular position of piston in its compression stroke, and hence non-continuous.

Three types of combustion chambers, **Annular, Can and Can-Annular,** are used in jet engines and are arranged around the compressor and turbine shaft. Combustion chambers are also called as burners.

(e) Turbine - It is the major component which extracts power from hot exhaust gases produced in burners. The gases having high pressure and high kinetic energy moves at high velocity through the blades of turbine and conversion of heat energy to mechanical energy takes place. Gases exert an impact force on the turbine resulting in rotary motion and the transfer of drive takes place to the high pressure compressor.

(f) Exhaust Nozzle – The nozzle forms the last part of aircraft engine. Similar to an air intake, this is also a part of an aircraft and is manufactured by aircraft manufacturer. The nozzle due to its design converts high pressure of exhaust gases to high velocity. The high velocity exhaust gases moving out of the engine generates a reactive force on the structure of the engine called thrust.

VII. TYPES OF JET ENGINE

Jet Engines are classified in various categories depending on the special component involved for production of thrust in addition to basic components of a jet engine.

(a) **Turbojet** – Thrust is produced purely by exit velocity of exhaust gases. This type of propulsive device is used in all high speed aircraft especially designed for flying at both subsonic and supersonic speed along with manoeuvring or aerobatics capability.

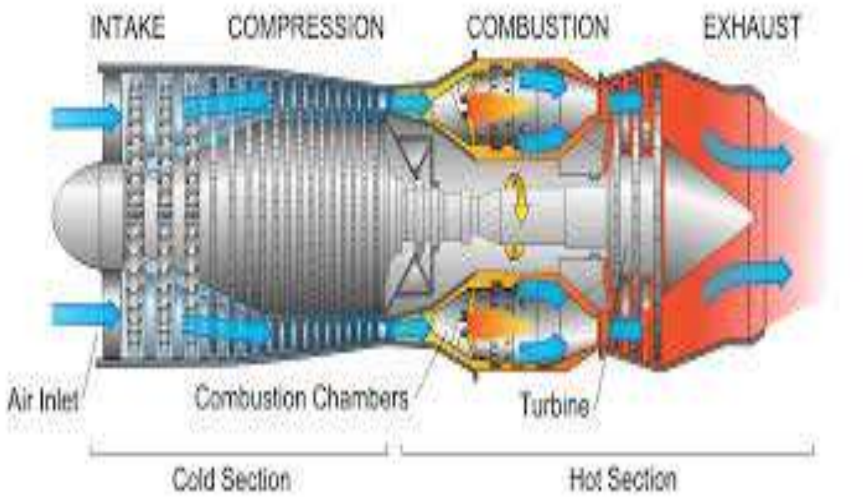

Figure 5. Turbojet Engine

(b) **Turboprop** – In addition to basic components of a jet engine like air-intake, compressor, combustion chamber, turbine and exhaust nozzle, an additional thrust producing component called propeller is used which is directly coupled with compressor through accessory gear box and a separate reduction gear mechanism for limiting the maximum speed of propeller beyond which performance of propeller will drastically reduce.

Major component of thrust is produced by propeller and less amount by exhaust gases as maximum energy of hot gases are utilized to drive compressor and propeller.

This type of engine is used to lift heavy load and are used generally in cargo or passenger aircrafts which does not fly at high speed.

Figure 6: Turboprop Engine

(c) **Turbofan** – In this type of jet engine, a fan bigger in diametric size in comparison to compressor is used either in front of compressor or at the back of engine. The fan split the incoming airflow into two flows – one passing through core of the engine and takes part in combustion and the other bypasses the core of the engine and move to the rear of the engine as cold flow and gets either mixed with hot flow before exit or move out separately and contributes in the production of thrust. The bypassed flow may be a ducted flow or un-ducted flow.

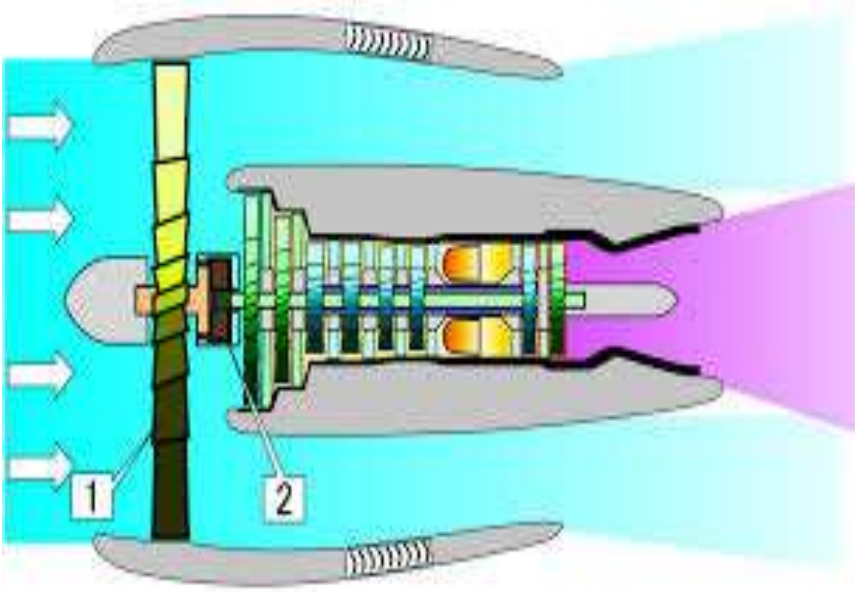

Figure 7: Turbofan Engine

Based on bypass ratio, the engines are classified as low by-pass and high by-pass. A turbojet engine is a zero percent by-pass engine.

This type of engine is more suitable for high subsonic aircraft flying at or above 0.6 Mach but not suitable for supersonic aircrafts. In high speed, the fan loses its efficiency and thereby the amount of thrust generated is reduced.

(d) Turbo shaft - This type of engine is used in helicopter. The engine works similar to a turbojet engine with a design difference of placing an additional free turbine which is absolutely and independently driven by the exhaust gases passing over the blades. The drive from this turbine is transferred to the gear box through which further drive transfer takes place to main rotor and tail rotor assembly for their operation.

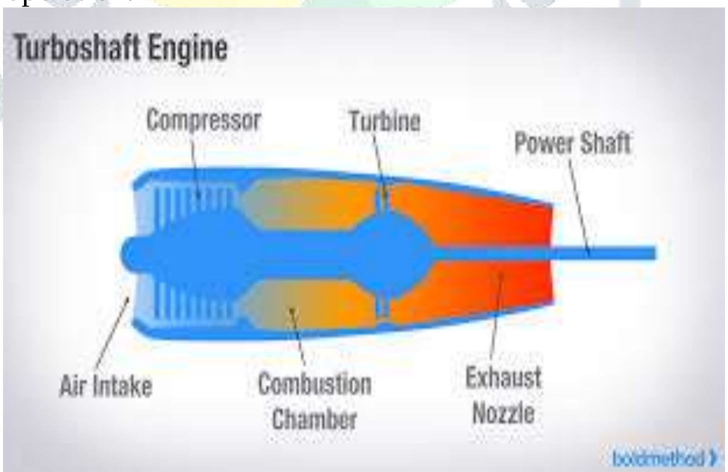

Figure 8: Turboshaft Engine

(e) Ramjet and Scramjet – This type of engine starts working only at supersonic speed as they use shock waves for necessary compression and pressure rise. These engines do not have any rotary components like compressor and turbine and makes them simpler in construction. The use of this engine is limited to high speed operation and cannot be used for take-off and landing of an aircraft. This engine is used in addition with conventional turbojet engines. When the aircraft attains supersonic speed, this engine starts producing thrust and conventional turbojet engine is switched off. Again during landing phase of aircraft, the ramjet or scramjet engine is switched off and turbojet engine is restarted.

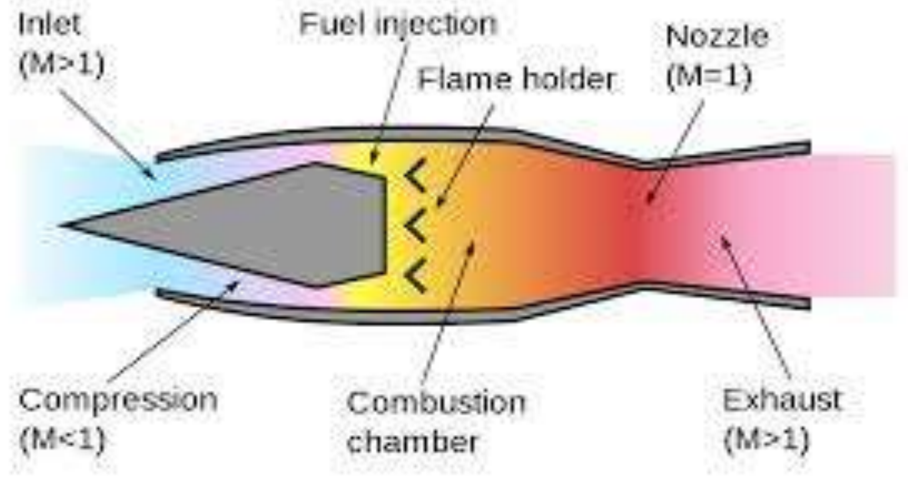

Figure 9: Ramjet Engine

Ramjet and Scramjet engine works on the same principle and their components are also similar except some design changes in air inlets. The air inlet in ramjet engine is designed to produce series of normal and oblique chocks in such a way that the air flow entering to the combustion chamber is reduced from supersonic to subsonic. In Scramjet engine, the air flow mach number entering to the combustion chamber is reduced to low supersonic in comparison to incoming air flow which is high supersonic. In ramjet engine, the combustion takes place at subsonic speed whereas in scramjet engine, it occurs at supersonic speed.

This type of engine is of vital interest now-a-days and a major area of research in aerospace propulsion especially for space mission due to its high efficiency. Choosing a suitable fuel for this engine is another area of research as fuel residence time in combustion chamber is very low due to which long combustion chamber is required for complete combustion. Hydrogen, being a cryogenic fuel is considered a suitable fuel.

VIII. PERFORMANCE PARAMETERS

(a) Thrust: It is the action force exerted on structure of jet engine as per Newton's third law of motion in reaction to high velocity exhaust gases moving out of the nozzle. The forward motion of aircraft is achieved due to net change in momentum.

Net Thrust $F = (\dot{m}_a + \dot{m}_f)\, V_e - \dot{m}_a V_a$ *where* F – Thrust Force (in N)

$\dot{m}_a$ – Mass flow rate of air (in kg/s)

$\dot{m}_f$ - Mass flow rate of fuel (in kg/s)

V_e - Velocity of exhaust gases (in m/s)

V_a - Velocity of Aircraft (in m/s)

(b) Thermal Efficiency (η_{th}): It is the ratio of the total power (propulsive power and loss in kinetic energy) produced by the engine to the power supplied to the engine in the form of heat energy by actual combustion of fuel.

$\eta_{th} = P_T / (\dot{m}_f \times H_f)$ *where* P_T - Total Power Produced by the Engine (in Watt)

H_f - Calorific value of Fuel (in Joule per Kg)

(c) Propulsive Efficiency (η_p): It is the ratio of the propulsive power (power converted to thrust) to the total power (propulsive power and loss in kinetic energy) produced by the engine.

$\eta_p = P_{thrust} / P_T$ *where* P_T - Total Power Produced by the Engine (in Watt)

P_{thrust} - Thrust or propulsive power (in watt).

$$\eta_p = 2\, V_a / (V_e + V_a)$$

(d) Overall Efficiency (η_o): It is the ratio of the propulsive power (power converted to thrust) to the power supplied to the engine in the form of heat energy by actual combustion of fuel.

$$\eta_o = \eta_{th} \times \eta_p$$
$$\eta_o = P_{thrust} / (\dot{m}_f \times H_f)$$

IX. VECTORED THRUST

The direction of thrust can be changed by altering the direction of exhaust gases. In order to have vertical take – off and reduce landing run, the angular movement of exhaust nozzle changes the direction of exhaust gases and provide a vectored thrust in a desired direction which even produces necessary lift force for vertical take – off and landing (VTOL) and short take-off and landing (STOL).

Figure 10: Vectored Thrust

X. REVERSE THRUST

Application of mechanical brake during landing run of an aircraft has resulted in many fatal accidents. In order to avoid these accidents, thrust force can also be used to provide a aero braking effect to the aircraft by creating a mechanical blockage to the exhaust gases moving out of the nozzle and deflecting it in opposite direction resulting in considerable reduction in speed of aircraft.

Figure 11: Thrust Reverser

XI. THRUST AUGMENTATION

Thrust augmentation is a method used especially in fighter aircraft to provide a sudden increase in amount of thrust enabling the aircraft to go for sudden climb and other aerobatic manoeuvres. Two types of thrust augmentation methods – after burner and liquid injection are generally used. In order to avoid complexity of additional components to be installed for liquid injection, after burner which is also called reheat system is used more. In this system, additional fuel is injected in the exhaust stream in the nozzle itself. The temperature in exhaust gases is sufficient to ignite fuel and no additional ignition system is required. The additional fuel produces a high amount of thrust in short duration which is utilized by pilot to change the aircraft's attitude. As the fuel is burned after combustion chamber and the high temperature generated is not affecting combustion chamber and turbine in their metallurgical limitations, the system is called after burner system. A variable area propelling nozzle is used in combination with reheat system.

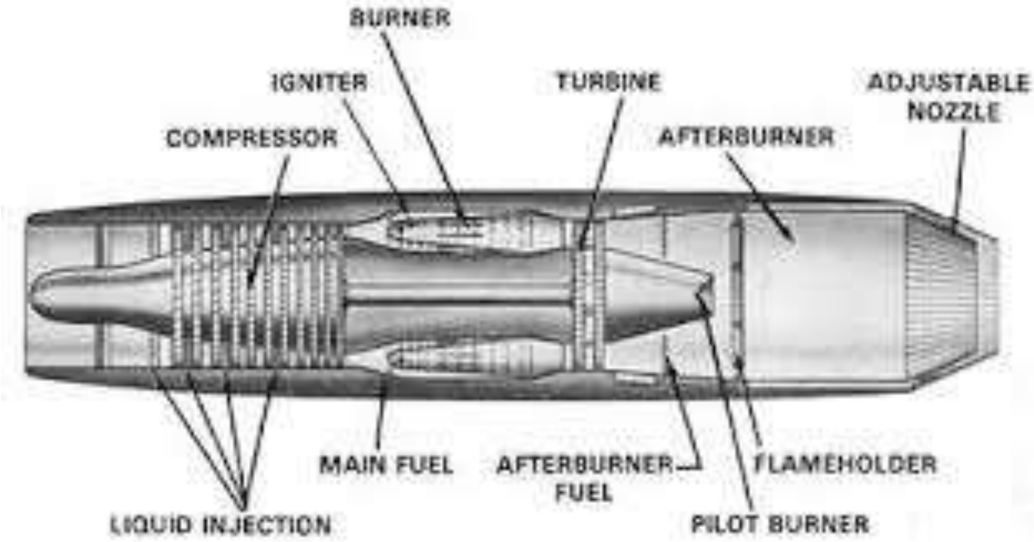

Figure 12: Thrust Augmentation (Reheat or After Burner)

XII. CONCLUSION

Propulsion system in an aircraft is similar to heart in human body. If the heart stops functioning, the body will stop working. Similar condition exists for an aircraft. An aircraft without propulsive device is like a stone which doesn't change its state of its own. Experimentation by researchers in this area has brought revolution in enhancing speed to hypersonic level. Still there are many challenging areas which need to be investigated for increasing efficiency.

Future work involves problems to be investigated in the areas of combustion instability, shock waves related problems, improving metallurgical limitations of materials etc.

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