Classifications of Aircraft Engines

An aircraft engine (or aero engine) is a propulsion system for an aircraft. Aircraft engines are the key module or the heart in aviation progress.

Aero engines must be:

1. Reliable, as losing power in an airplane, is a substantially greater problem than in road vehicles.
2. Operate at extreme temperature, pressure and speed.
3. Light weight as a heavy engine increases the empty weight of the aircraft and reduces its payload.
4. Powerful, to overcome the weight and drag of the aircraft.
5. Small and easily streamlined to minimize the created drag.
6. Field repairable to keep the cost of replacement down. Minor repairs should be relatively inexpensive and possible outside of specialized shops.
7. Fuel efficient to give the aircraft the range and maneuverability the design requires.
8. Capable of operating at sufficient altitude for the aircraft.
9. Generate the least noise.
10. Generates the least emission.

Aero engines may be classified based on input power into three main categories, namely, internal combustion engines, external combustion engines, and other power sources (Fig. 1-1).

1.1 <u>External Combustion</u>

External combustion engines are steam, stirling, or nuclear engines. In these types, all heat transfer takes place through the engine wall. This is in contrast to an internal combustion engine where the heat input is by combustion of a fuel within the body of the working fluid.

1.1.1 <u>Steam Engines</u>

Steam aircraft are aircraft that are propelled by steam engines. They were unusual devices because of the difficulty in producing a power plant with a high enough power to weight ratio to be practical.

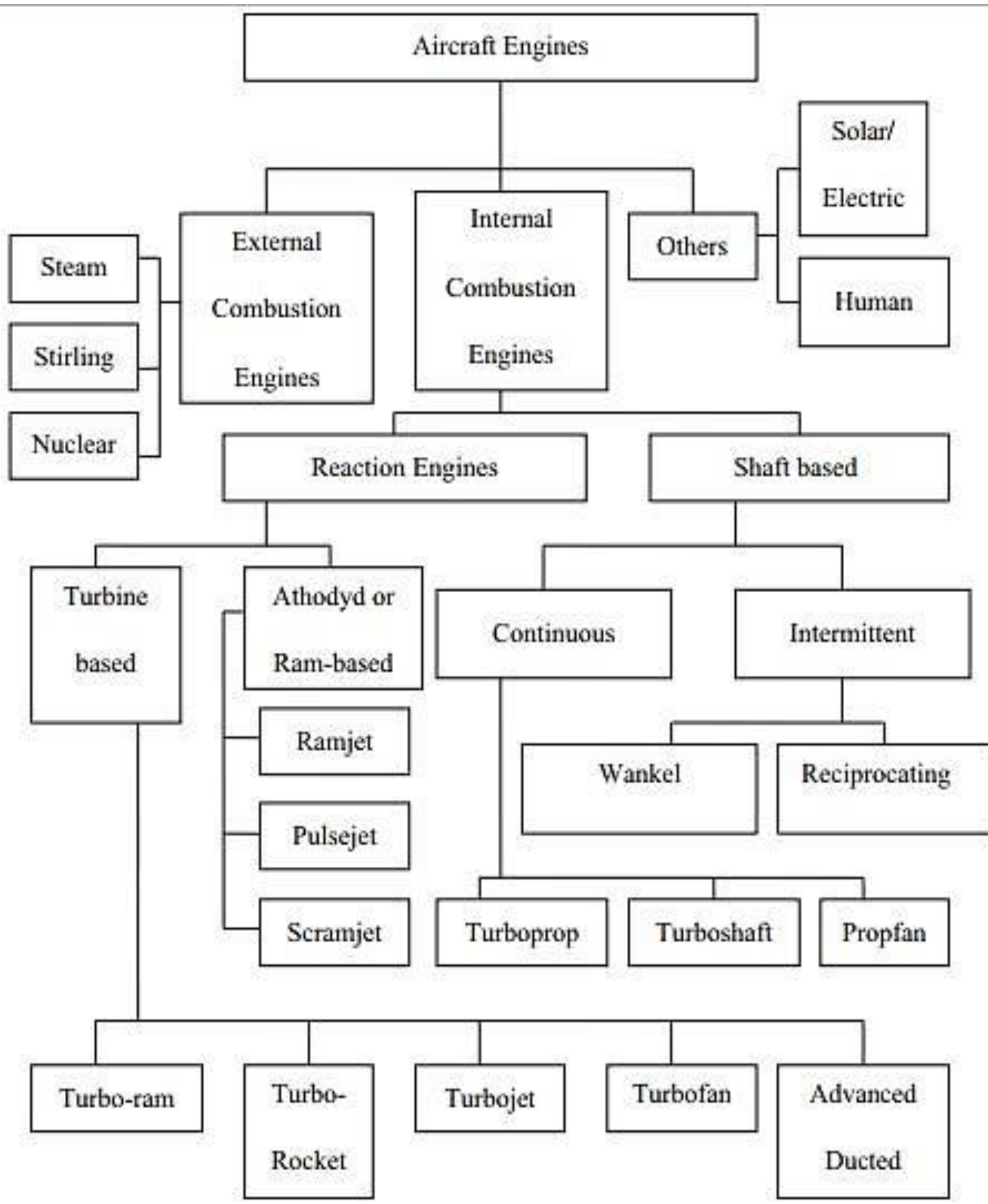


Figure (1-1): Classification of propulsion systems

1.1.2 Stirling Engines

A stirling engine is a heat engine having either air or other gas as a working fluid. It operates by cyclic compression and expansion of the working fluid, at different temperature levels such that there is a net conversion of heat energy to mechanical work.

Stirling engines have many advantages like:

2 High power density

3 Low cost

4 Quieter

5 Less polluting
6 Gain efficiency with altitude due to lower ambient temperatures
7 More reliable due to fewer parts and the absence of an ignition system
8 Produce much less vibration (airframes last longer) and safer
9 Less explosive fuels may be used
10 They have low power density compared to the commonly used piston engines and gas turbine. This issue made them critical for use as aircraft engines.

1.1.3 Nuclear Engines

A nuclear aircraft is an aircraft powered by nuclear energy. Research into them was pursued during the Cold War by the United States and the Soviet Union as they would presumably allow a country to keep nuclear bombers in the air for extremely long periods of time, a useful tactic for nuclear deterrence. Neither country created any nuclear aircraft in production numbers. One design problem, never adequately solved, was *the need for heavy shielding to protect the crew from radiation sickness*. Also, *in consideration, was the ecological impact of a crash during operations. Should one of these aircrafts were to crash in a populated area, the radiation fallout could have been disastrous*.

As described above, the three external combustion engines are not appropriate for employment in aviation field for different reasons.

- Steam engines are only appropriate for small aircrafts while large ones need heavy boilers, piping and other accessories.
- Stirling engines generate also low power which is also improper for present aircrafts.
- Nuclear engines have two drawbacks regarding shielding of flight crew and passengers versus radiation, as well as the risk of crash in residence areas leading to catastrophic situation.

1.2 Internal Combustion engines

Internal combustion engines have two broad categories *shaft* and *reaction* engines.

1 Shaft engines are either of the *intermittent* or *continuous* types.

Intermittent combustion engines may be either of the *reciprocating* or the *Wankel (rotary design)* types.

Continuous combustion engines, which may also be identified as *turbine shaft engines*, are next categorized as *turboprop*, *turboshaft* and *propfan* engines.

2 The reaction engines. This engine group is either of the *athodyd (where athodyd stands for Aero THermODYnamic Duct)* or *turbine* types.

Athodyd group includes *ramjet*, *pulsejet* and *scramjet* engines, while turbine engines includes *turbojet*, *turbofan*, *turbo ramjet*, *turbo rocket* and *advanced ducted fan* engines.

1.2.1 *Shaft engines*

Based on type of combustion are classified into two subgroups *intermittent combustion* and *continuous combustion*.

1.2.1.1 Intermittent combustion

Intermittent combustion engines are either *Wankel* or *Reciprocating* engines.

1.2.1.1.1 Wankel engines.

The Wankel engine invented by German engineer Felix Wankel in 1950, is a type of internal combustion engine which uses a rotary design to convert pressure into a rotating motion.

Figure 1.2 illustrates Diamond DA20 aircraft powered by Wankel engine. Its four-stroke cycle takes place in a space between the inside of an oval like epitrochoid-shaped housing and a rotor that is similar in shape to a Reuleaux triangle but with sides that are somewhat flatter.

Wankel engines operate at a relatively high rotational speed with relatively low torque, thus, propeller aircraft must use a Propeller Speed Reduction Unit (PSRU) to keep conventional propellers within the proper speed range.

1.2.1.1.2 Piston Engine.

A Piston engine, also often known as a reciprocating engine, is a heat engine that uses one or more reciprocating pistons to convert pressure into a rotating motion.

Piston engines may be classified into five groups as shown in Figs. 1.3, 1.4. These are *in-line*, *rotary*, *V-type*, *radial*, and *opposed*. These engines are coupled to a propeller to furnish the forward flight of airplanes.

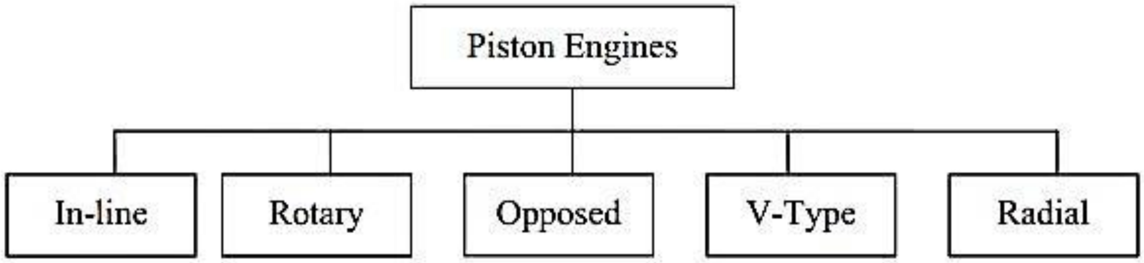


Figure (1-3): Classification of piston engines

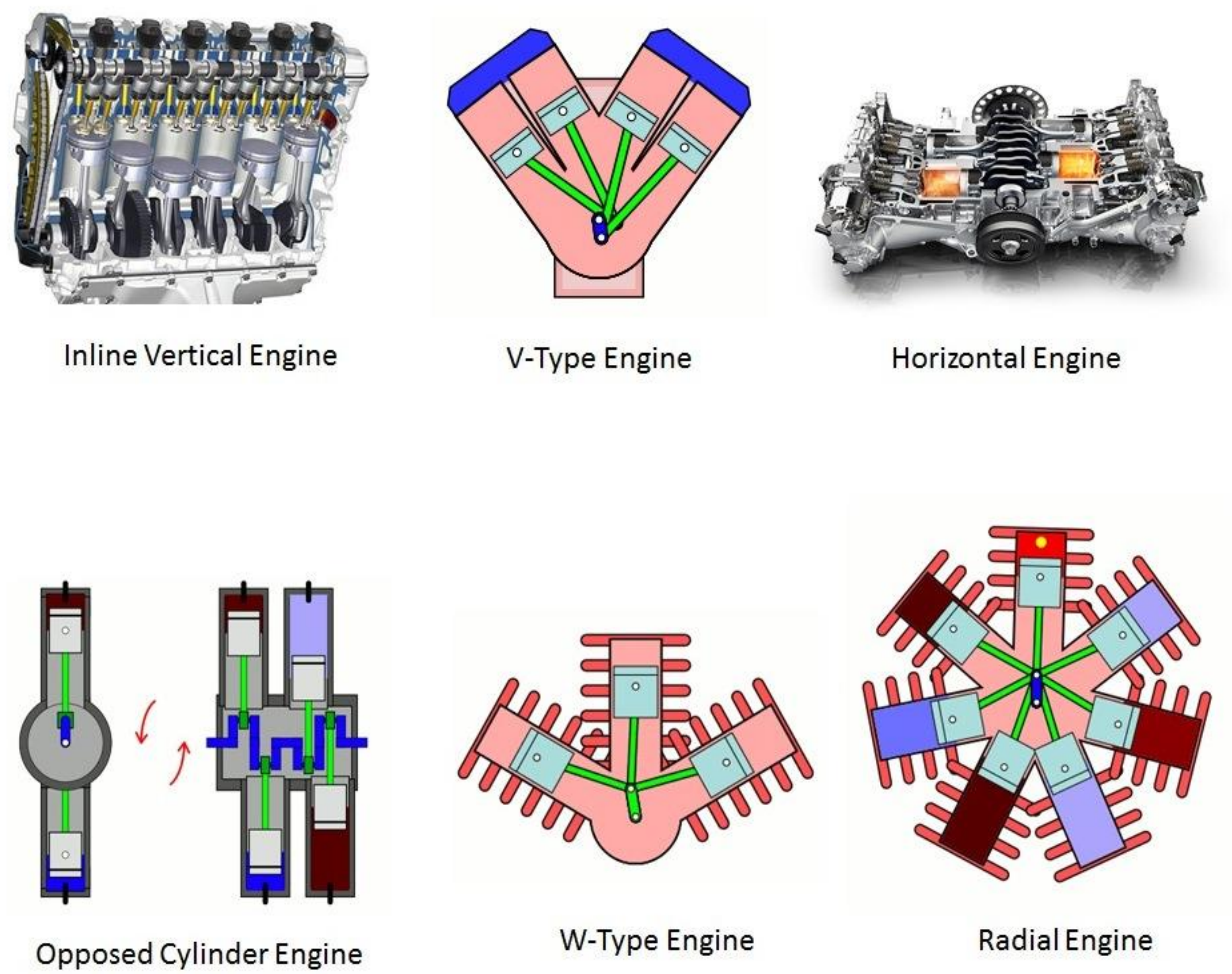


Figure (1-4): Classification of piston engines due to arrangement of cylinders.

1.2.1.2 Continuous Combustion Engines

Continuous combustion engines are mainly turbine shaft engines. It includes *turboprop turboshaft* and *propfan* engines.

They are featured with rotating elements known as turbomachines, as sub-modules. These modules may be *fan*, *compressor*(s), and *turbine(s)* as well as propellers/propfans.

1.2.1.2.1 Turboprop Engine

Turboprop engines powers both civil and military transport aircrafts with a cruise speed less 450 mph (700 km). It is composed of a gas generator (compressor, combustion chamber and turbine) as well as a propeller.

The turbine drives both compressor and propeller. Because gas turbines optimally spin at high speed, a turboprop features a gearbox to lower the speed of the shaft so that the propeller tips do not reach supersonic speeds.

An alternative to the above turboprop engines, a second turbine is added which drives only the propeller either directly or via a gearbox. The first turbine in this case drives the compressor only. Thus it is free to rotate at its own best speed (referred to as a free- or power-turbine). The other turbine is identified as compressor-turbine.

Recent turboprop engines generate thrust force from both propeller and exhaust jet stream. A fraction of 10–20 % of thrust is generated from jet stream. Consequently, some people classify turboprop as jet engine or reaction engine. Figure 1.5 illustrates two turboprop engines; the left is a single-shafted one with propeller coupled to compressor-turbine shaft and the right one is of the free turbine type.

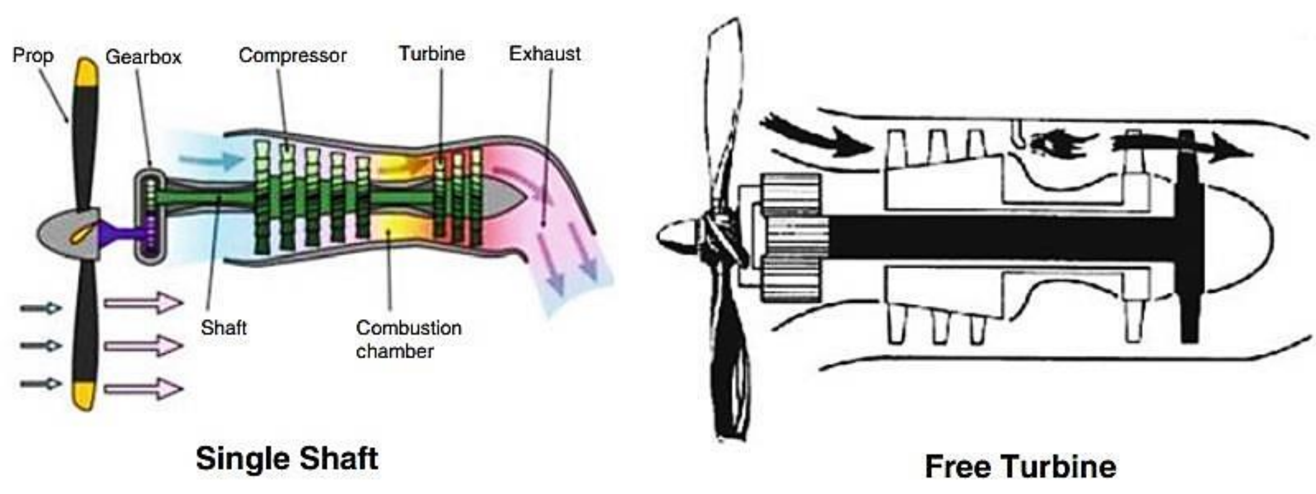
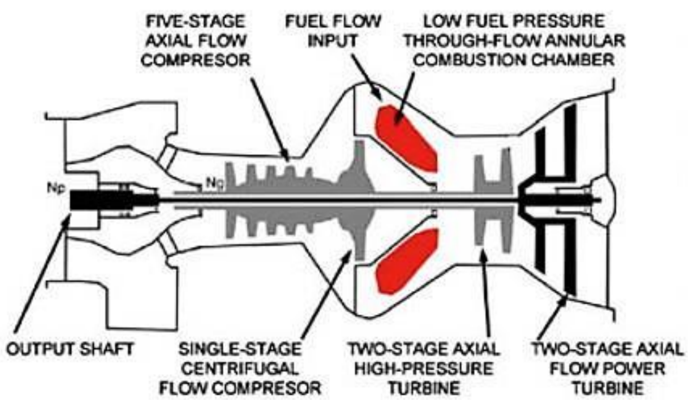


Figure (1-5): Types of turboprop engine.

1.2.1.2.2 Turboshaft Engine

Turboshaft engines are used primarily for helicopters and auxiliary power units. A turboshaft engine is very similar to a turboprop, with a key difference: In a turboprop the propeller is supported by the engine, and the engine is bolted to the airframe. In a turboshaft, the engine does not provide any direct physical support to the helicopter's rotors.

The rotor is connected to a transmission, which itself is bolted to the airframe, and the turboshaft engine simply feeds the transmission via a rotating shaft. The distinction is seen by some as a slim one, as in some cases aircraft companies make both turboprop and turboshaft engines based on the same design. An example for turboshaft engine is GE T700, which powers Seahawk helicopter (Fig. 1.6).



GE T700 Turboshaft Engine

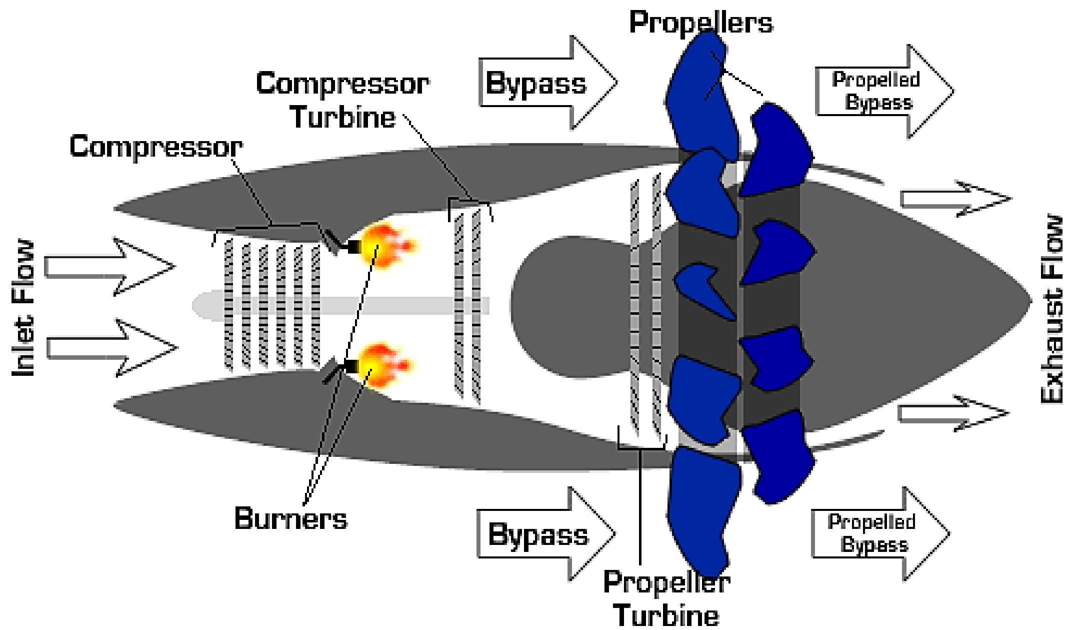
SeaHawk Helicopter

Figure (1-6): GE T700 Turboshaft engine powering Seahawk helicopter.

1.2.1.2.3 Propfan

A propfan or an unducted fan (sometimes denoted in former Soviet Union as turbopropfan) is a modified turbofan engine, with the fan placed outside of the engine nacelle on the same axis as the compressor blades.

Propfans are also known as ultra-high bypass (UHB) engines and, most recently, open rotor jet engines. The design is intended to offer the speed and performance of a turbofan, with the fuel economy of a turboprop. The propfan concept was developed to deliver better fuel efficiency than contemporary turbofans. However, this achievement has noise penalty.



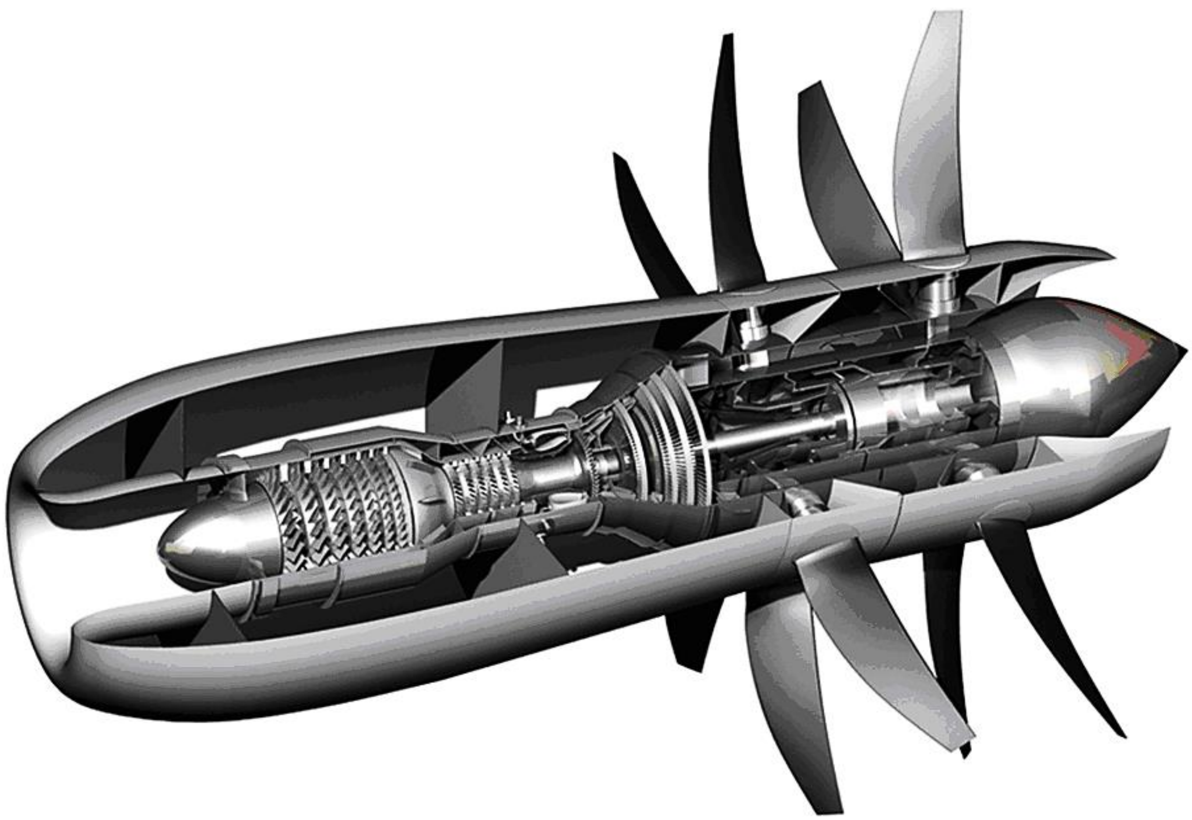


Figure (1-7): Propeller fan Engine.

1.2.2 Reaction Engines

The other main group of internal combustion engines, namely, the reaction engines.

All reaction engines develop its propulsive force as a reaction to the jet exhaust gases. Three essential modules are seen in all reaction types, namely

1 An entry duct (sometimes identified as inlet duct or intake).
2 A combustion chamber or burner, and an exhaust nozzle.
3 The exhaust nozzle (s) accelerate air/gases to greater speeds than flight speed, thus create thrust that pushes the aircraft forward.

1.2.2.1 Athodyd Types

Athodyd stands for Aero THermODYnamic Duct. Athodyd group includes ramjet, pulsejet, and scramjet engines, which do not have any major rotating elements or turbomachinery.

1.2.2.1.1 Ramjet Engine

A ramjet, sometimes referred to as a stovepipe jet, is a form of jet engine using the engine’s forward motion to admit and compress incoming air, without a rotary compressor.

Ramjets cannot produce thrust at zero airspeed and thus cannot move an aircraft from a standstill. It is composed of three modules: inlet duct, burner or combustor, and nozzle.

It has two types: namely liquid- and solid-fuel ramjets. Ramjet engines may be subsonic or supersonic (Fig. 1.8).

Subsonic ramjets do not need a sophisticated inlet since the airflow is already subsonic and a simple hole is usually used. For supersonic ramjets, supersonic flow is decelerated to subsonic speeds at the inlet through one or more oblique shock wave(s), terminated by a strong normal shock.

Thus air attains subsonic speeds at the entrance of combustion chamber. The combustor adds heat and mass to the compressed air by burning a fuel. The combustion chamber includes flame holders that stop the flames from blowing out.

A ramjet combustor can safely operate at stoichiometric fuel to air ratios, which implies a combustor exit stagnation temperature of the order of 2400 K for kerosene. Products of combustion leaving the combustion chamber are reaccelerated through a nozzle, to supersonic speeds via a convergent-divergent nozzle to produce thrust. For a ramjet operating at a subsonic flight Mach number, exhaust flow is accelerated through a converging nozzle. Supersonic ramjet engines work most efficiently at speeds around Mach 3 and can operate up to speeds of at least Mach 5.

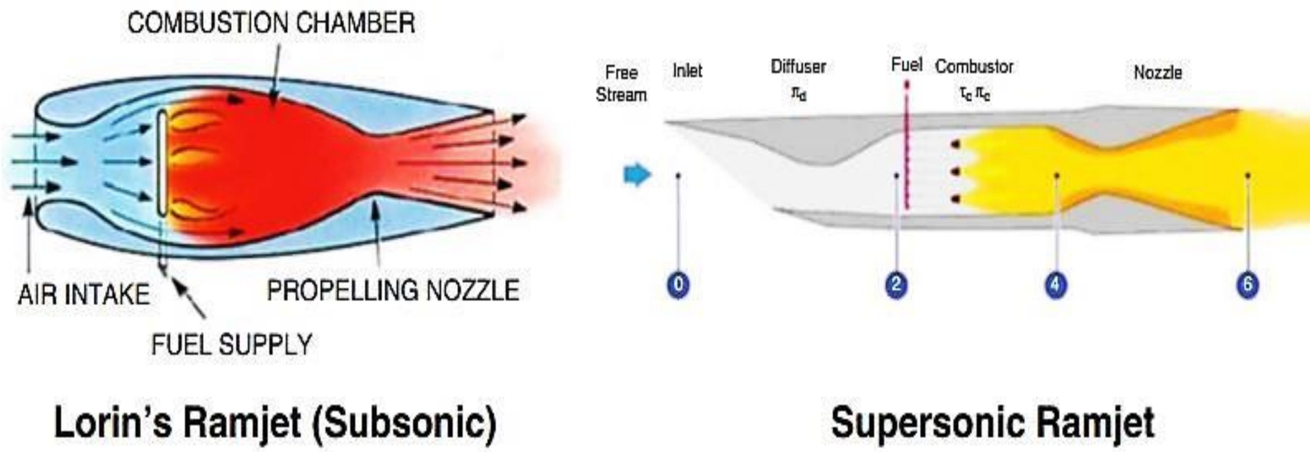


Figure (1-8): Lorin's and supersonic ramjet engines

1.2.2.1.2 Pulsejet Engine

A pulse jet engine (or pulsejet) is a very simple type of jet engine in which combustion occurs in pulses. Pulsejets use an intermittent combustion while ramjets employ a continuous combustion process.

Pulsejet engines are a unique type of jet engine, able to operate statically with few or no moving parts. They are very simple and cheap to construct. They feature an excellent balance of cost and function, as could run on any grade of petroleum and the ignition shutter system.

Their accompanying noise is unacceptable by modern standards. They have both a higher efficiency and very high thrust-to-weight ratio compared to other jet engines. Pulsejet engines may be produced in many sizes with different outputs ranging from a few pounds to thousands of pounds of thrust. There are two main types of pulsejet engines: *Valved* (Fig. 1.9) and *Valveless* (Fig. 1.10).

Both types use resonant combustion and harness the expanding combustion products to form a pulsating exhaust jet, which produces thrust intermittently

1- Valved

Valved engines use a mechanical one-way valve, which is a simple leaf-spring type of shutter. With the valve open, a fresh charge of air is admitted. The air mixes with the fuel and then an explosion takes place, which shuts the valve and forces the hot gas to go out the back of the engine through the tailpipe only, and allow fresh air and more fuel to enter through the intake (Fig. 1.9). The superheated exhaust gases exit through an acoustically resonant exhaust pipe.

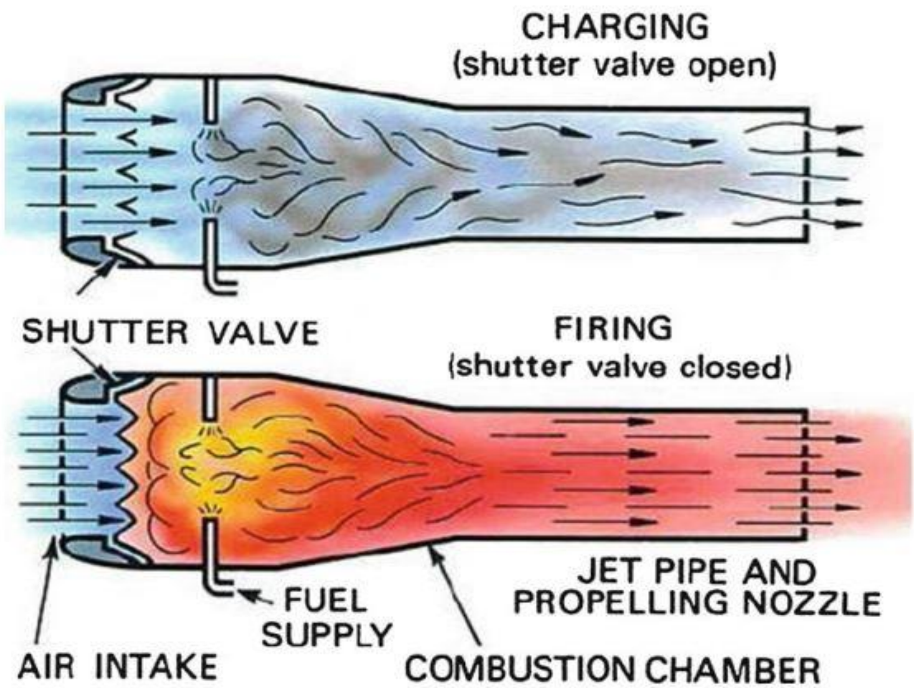


Figure (1-8): Valved pulsejet operation

2- Valveless

Valveless pulsejets have no moving parts and use only their geometry to control the flow of exhaust out of the engine (Fig. 1.10).

Valveless engines expel exhaust out of both the intakes and the exhaust, most try to have the majority of exhaust go out the longer tail pipe, for more efficient propulsion. The valveless pulse jet engine operates on the same principle as valved type. Combustion process creates two shock wave fronts, one travelling down the upper long pipe (tube) and the other down the short lower tube. By properly "tuning" of the system, a resonating combustion process can be achieved, which yields considerable thrust. Fuel consumption is very high and noise level is also unacceptable.

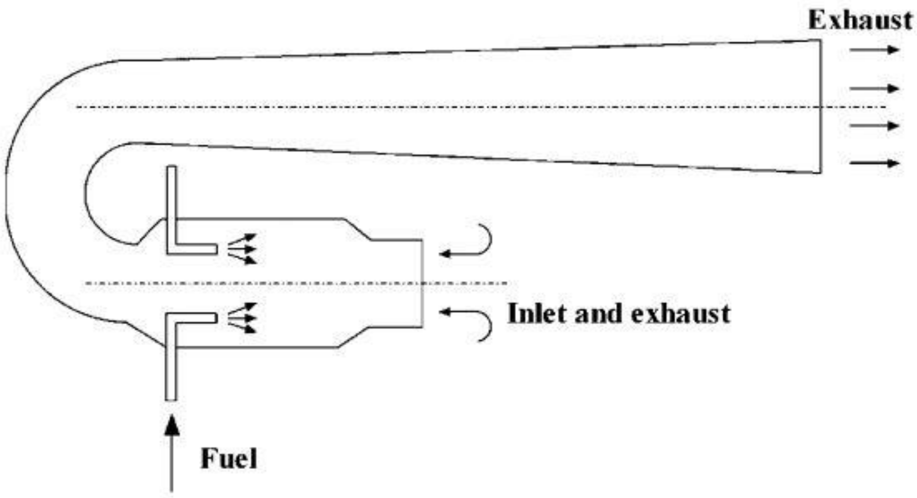


Figure (1-9): Valveless pulsejet operation

1.2.2.1.3 Pulse Detonation Engine (PDE)

The pulse detonation engine (PDE) marks a new approach towards non-continuous jet engines and promises higher fuel efficiency compared even to turbofan jet engines, at least at very high speeds.

1.2.2.1.4 Scramjet Engine

Scramjet is an evolution of the ramjets that are able to operate at much higher speeds than ramjets or any other kind of air-breathing engines. It is an acronym for Supersonic Combustion Ramjet, or in other words combustion of fuel and air occurs in a supersonic flow relative to engine. Scramjets start working at speeds of at least Mach 4 and have a theoretical maximum speed of Mach 17.

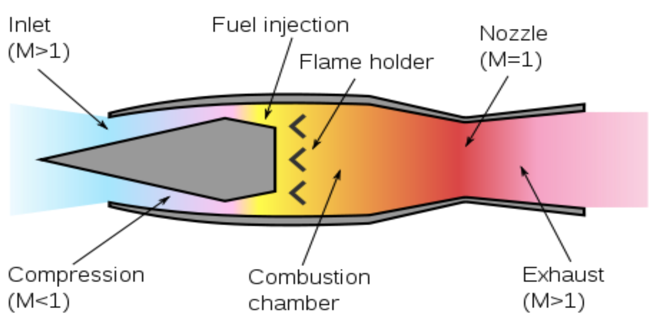


Figure (1-10): Ramjet Engine

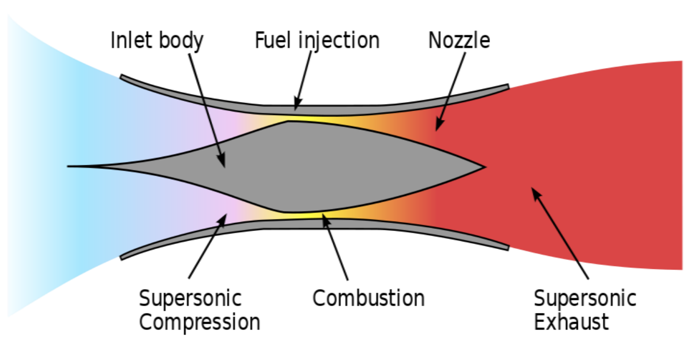


Figure (1-11): Scramjet Engine

1.2.2.2 Turbine Engine

Turbine engine or turbine based engine can be classify to five types, namely, turbojet, turbofan, turbo-ramjet, turbo-rocket, and advanced ducted fan engines.

1.2.2.2.1 Turbojet Engine

A turbojet is a type of gas turbine engine that was co-invented by Frank Whittle (in UK) and von Ohain (in Germany) in the thirties. It is the simplest of all aircraft gas turbines.

It features one or more compressors to draw air in and compress it, a combustion section which adds fuel and ignites it, one or more turbines that extract power from the expanding exhaust gases to drive the compressor(s) and provide power to aircraft systems, as well as an exhaust nozzle which accelerates the exhaust out the back of the engine to create thrust. Each compressor is connected by a shaft to a turbine.

When turbojets were introduced, the top speed of fighter aircraft equipped with them was at least 100 miles per hour faster than competing piston-driven aircraft.

When the afterburner is turned on, additional fuel is injected, which burns and produces additional thrust. Thus additional thrust is gained but much more fuel is burnt. When the afterburner is turned off, the engine performs like a basic turbojet. Afterburners are only used on fighter planes and the supersonic airliner, Concorde. Figure (1-11).

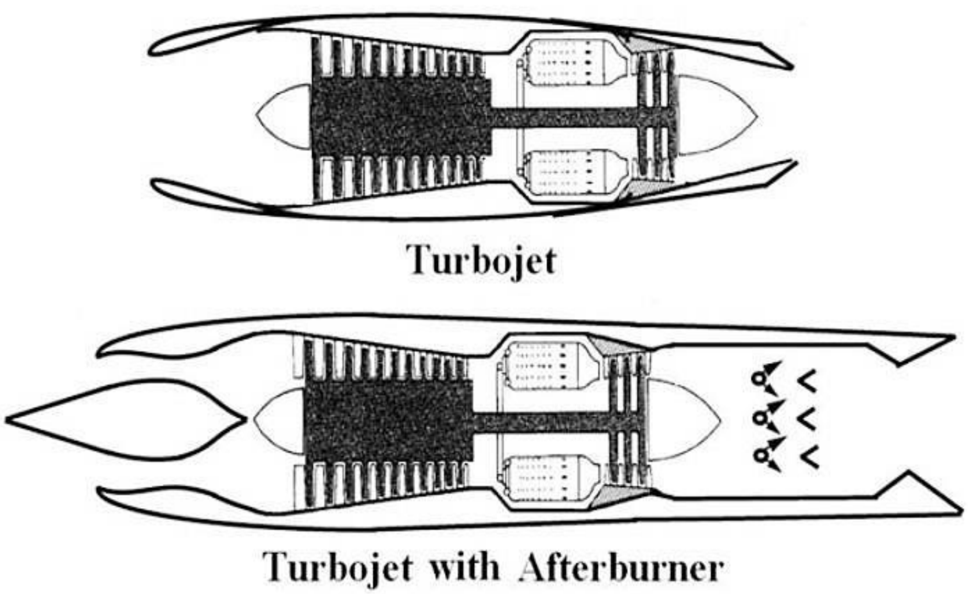


Figure (1-11): Subsonic and supersonic turbojet engines

1.2.2.2.2 Turbofan Engine

Most modern airliners, troop, and cargo transports as well as military aircrafts use turbofan engines because of their high thrust and good fuel efficiency. As with other gas turbines, there is a core engine similar to a turbojet engine, which is surrounded by a fan in the front (or rear for aft turbofan engines) and an additional turbine at the rear.

The fan and fan turbine are composed of many blade rows and are connected to an additional shaft. As with the core compressor and turbine, some of the fan blades turn with the shaft and some blades remain stationary. The fan shaft passes through the core shaft for mechanical reasons. This type of arrangement is called a two spool engine (one “spool” for the fan, one “spool” for the core).

Some advanced engines have additional spools for even higher efficiency. The incoming air is captured by the engine inlet. Some of the incoming air passes through the fan and continues on into the core compressor and then the burner, where it is mixed with fuel and combustion occurs.

The hot exhaust passes through the core and fan turbines and then out the nozzle, as in a basic turbojet. The rest of the incoming air passes through the fan and bypasses, or goes around the engine, just like the air through a propeller. The air that goes through the fan has a velocity that is slightly increased from free stream. So a turbofan gets some of its thrust from the core and some of its thrust from the fan.

The ratio of the air that goes around the engine to the air that goes through the core is called the bypass ratio. Engines with bypass ratios of 1–2 are generally termed low bypass ratio turbofans. High bypass turbofans found on most current transport aircraft, where bypass ratio is continuously increasing and reached 10 or more in some turbofan engines. Figure 1.12 illustrates high and low bypass ratio turbofan Engines

Because the fuel flow rate for the core is changed only a small amount by the addition of the fan, a turbofan generates more thrust for nearly the same amount of fuel used by the core. This means that a turbofan is very fuel efficient.

In fact, high bypass ratio turbofans are nearly as fuel efficient as turboprops. Since the fan is enclosed by the inlet and is composed of many blades, it can operate efficiently at higher speeds than a simple propeller. That is why turbofans are found on high speed transports and propellers are used on low speed transports. Low bypass ratio turbofans are still more fuel efficient than basic turbojets.

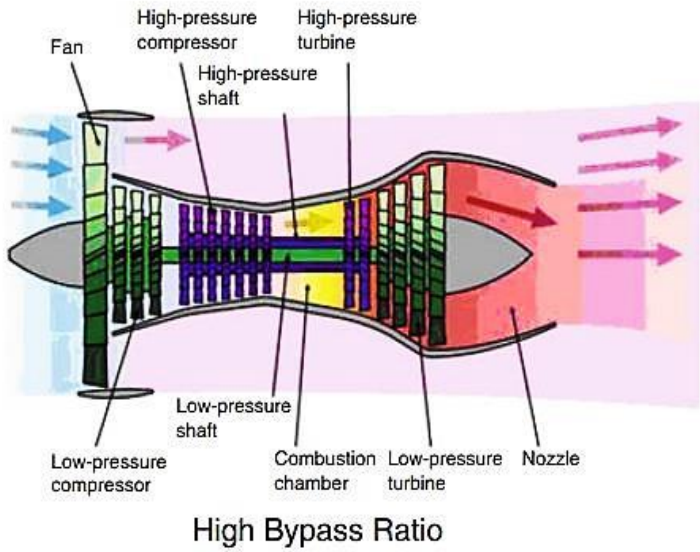


Figure (1-12): High and low bypass ratio turbofan engines

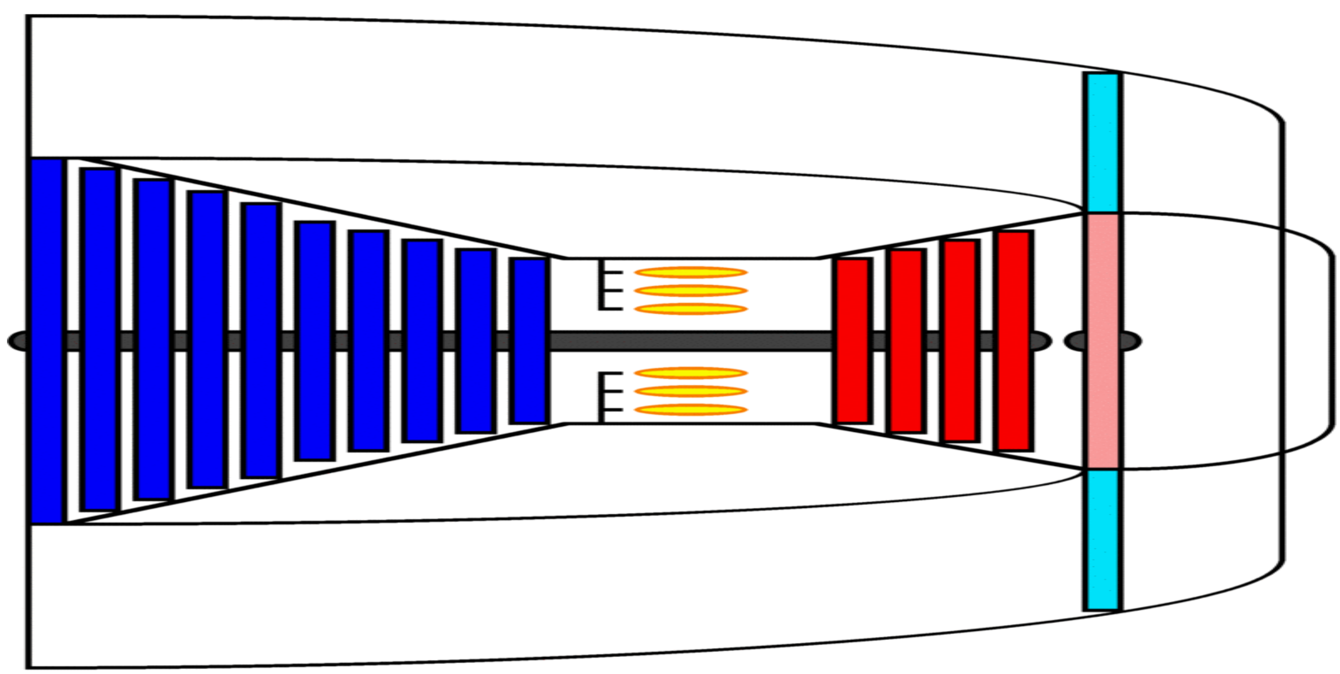


Figure (1-13): Aft Fan Turbofan Engine

Table 1.1 Turbofan engines

Company	Engine	Thrust range lbf	Aircraft
Rolls-Royce (RR)	FJ44	1900–2400	Saab SK-6
RR	RB211-535	37,400–43,100	1. Tupolev Tu 204-120 2. Boeing 757-200, -300
RR	Trent 800	75,000–95,000	Boeing 777-300, -200, -200ER
RR, MTU, Avio, ITP	EJ200	13,500 lbf (Non-Reheated) 20,000 lbf (Reheated)	Eurofighter Typhoon
GE	F101	30,000 lbf thrust class	B-1
GE & SNECMA	CFM56	22,000–24,000 LBF	Super 70 DC-8, Boeing 737-300,-400 and -500, Airbus a340
GE	CF6-80	48,000–61,500	Boeing 767, 747-400, Airbus A300,A310, A330, MD-11
GE	GE90	76,000–115,540	Boeing 747, Boeing 777-300ER
GE	GEnx	53,000–75,000	Boeing 747-8, Boeing 787-8, -9
Pratt & Whitney (P&W)	JT8D	14,000–17,400	Boeing 727, Boeing 737, DC-9, C-1 Transport
P&W	JT9D	45,800–53,000	Boeing 747, 767, Airbus A300, A310, McDonnell Douglas DC-10
P&W	F100	25,000	F-15, F-16
P&W	PW2000	37,000–43,000	Boeing 757, Ilyushin Il-96 M, C-17 Globemaster III
P&W	PW4000	52,000–99,040 lbf	Airbus A300, A310, A330, Boeing 747-400, 767, 777, McDonnell Douglas MD-11
P&W	F119	35,000 lbf class	F-22 Raptor
International Aero Engines *IAE*	V2500	23,500–28,000	Airbus A319, Airbus A320, MD-90-30
General Electric, Pratt & Whitney	GP7000	76,500–81,500 lbf	Airbus A380

Figure (1-14): Turbofan Engines

1.2.2.2.3 Turbo Ramjet Engine

Turbo ramjet is a combination engine that can operate as a turbojet or ramjet engine. It is a type of jet engine intended for high speed flight. The turbo ramjet engine (Fig. 1.15) combines the turbojet engine for speeds up to Mach 3 with the ramjet engine, which has good performance at high Mach numbers.

The engine is surrounded by a duct that has a variable intake at the front and an afterburning jet pipe with a variable nozzle at the rear. During takeoff and acceleration, the engine functions as a conventional turbojet with the afterburner lit while at other flight conditions up to Mach 3, the afterburner is inoperative.

As the aircraft accelerates through Mach 3, the turbojet is shut down and the intake air is diverted from the compressor, by guide vanes, and ducted straight into the afterburning jet pipe, which becomes a ramjet combustion chamber.

This engine is suitable for an aircraft requiring high speed and sustained high Mach number cruise conditions where the engine operates in the ram jet mode.

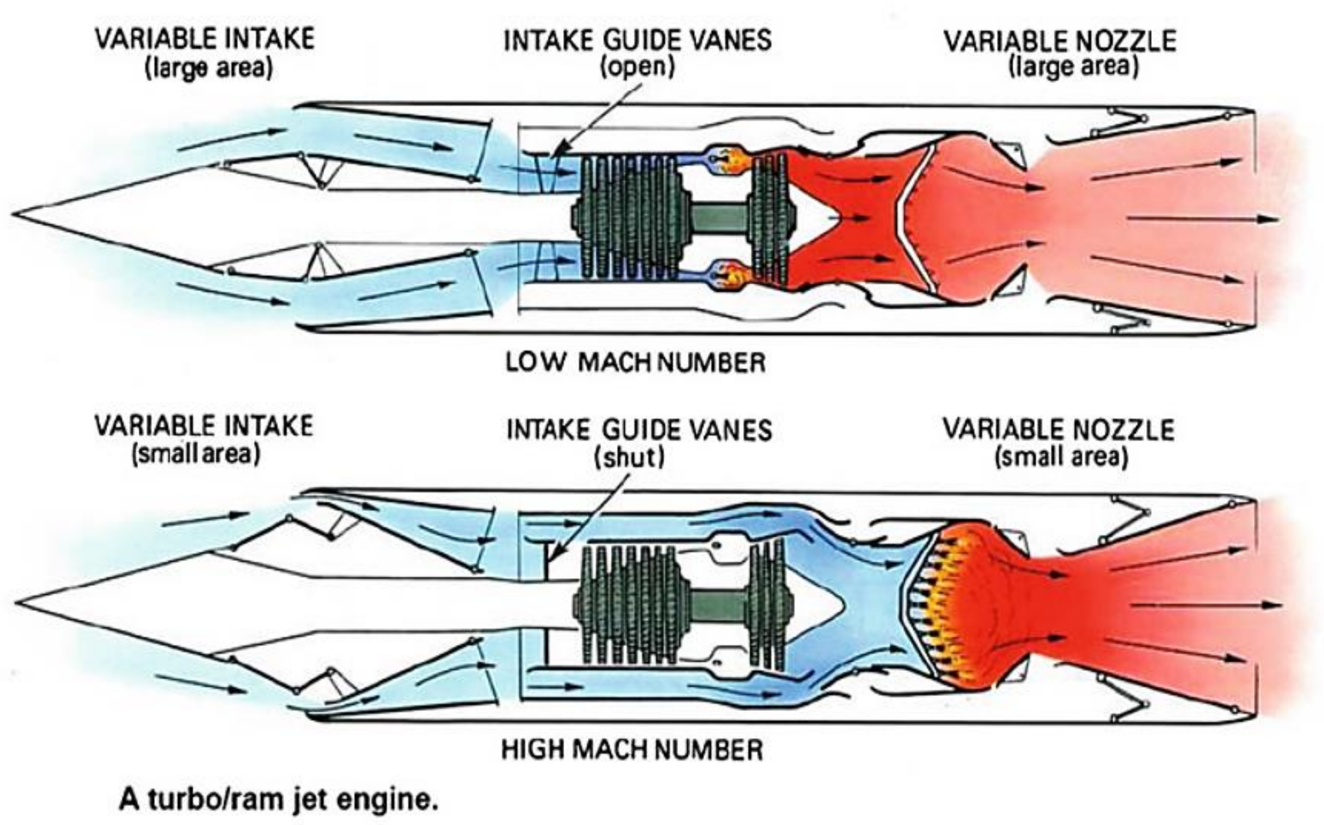


Figure (1-15): Aft Fan Turbofan Engine

1.2.2.2.4 Turborocket Engine

The turbo-rocket (or air turbo-rocket) engine (Fig. 1.16) is a type of air breathing engine combining elements of a jet engine and a rocket, which is also known by its acronym as the ATR.

The ATR belongs to a general class of propulsion engines known as Turbine-Based Combined-Cycle, or TBCC, engines. It could be considered as an alternative engine to the turbo ramjet. However, it has one major difference in that it carries its own oxygen to provide combustion at high speed.

The engine has a low pressure compressor driven by a multi-stage turbine; the power to drive the turbine is derived from combustion of kerosene and liquid oxygen in a rocket-type combustion chamber. Since the gas temperature will be in the order of 3500 ̊C, additional fuel is sprayed into the combustion chamber for cooling purposes before the gas enters the turbine.

This fuel-rich mixture (gas) is then diluted with air from the compressor and the surplus fuel burnt in a conventional afterburning system. It is finally exhausting through a convergent-divergent propelling nozzle. In some ATRs, the hot gas can be produced by burning of a solid propellant. Although the engine is smaller and lighter than the turbo ramjet, it has higher fuel consumption. This tends to make it more suitable for an interceptor or space launcher type of aircraft that requires high speed and high altitude performance and normally has a flight plan that is entirely accelerative and of short duration.

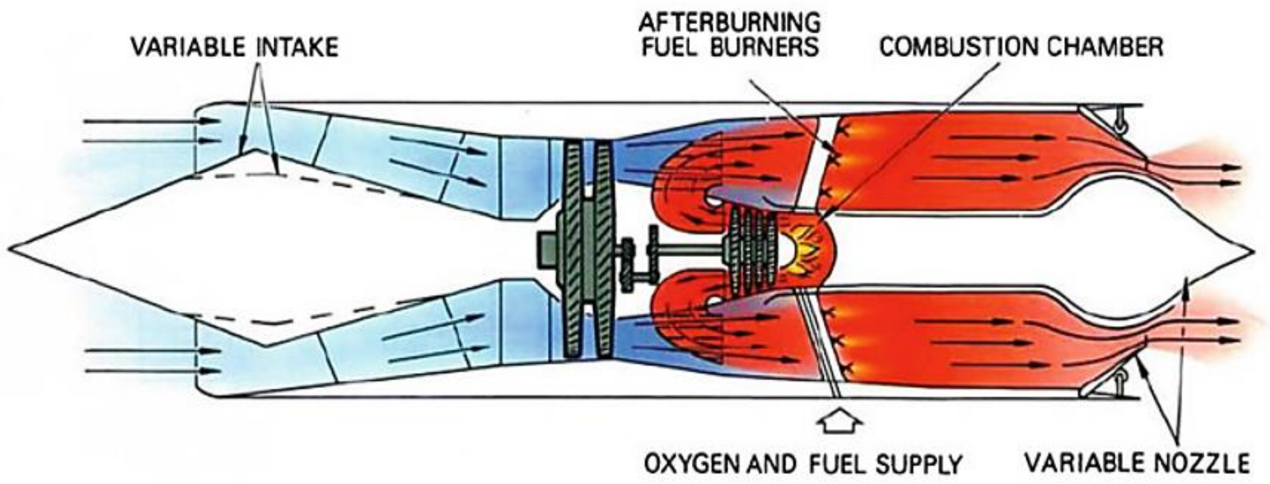


Figure (1-16): Turbo-rocket engine

1.2.2.2.5 Advanced Ducted Fan

Advanced ducted fan are essentially turbofans with large swept fan blades that have pith control and reduction gearing similar to propfans, but the fans are enclosed in ducts like turbofan engines. Bypass ratio for advanced ducted fan is from 15:1 to 25:1. There are two basic types: one with geared, variable pitch, single propeller fan, and the other with counter-rotating blades.

Extensive work has been done in some aero engine manufacturing companies like Pratt & Whitney, MTU, and Fiat Avio for the design of this type of engines. A thin-lip, slim-line nacelle is required to give such a high bypass ratio.

1.3 Other Power Sources

This third and last group of aircraft engines (identified as others) is subdivided into human- and electric-powered engines.

1.3.1 Electric-Powered Aircraft

An electric aircraft is an aircraft that runs on electric motors rather than internal combustion engines, with electricity coming from fuel cells, solar cells, ultra capacitors, power beaming, and/or batteries.

The advantages of electric aircraft include increased safety due to decreased chance of mechanical failure, such as from volcanic ash, less risk of explosion or fire in the event of a collision, less noise, and no emissions and pollution.

The main disadvantage of electric aircraft is decreased range. The range can be increased by adding solar cells to the aircraft’s body to create a solar airplane. However, the plane’s surface area must be large compared to its weight to have a significant impact on range.

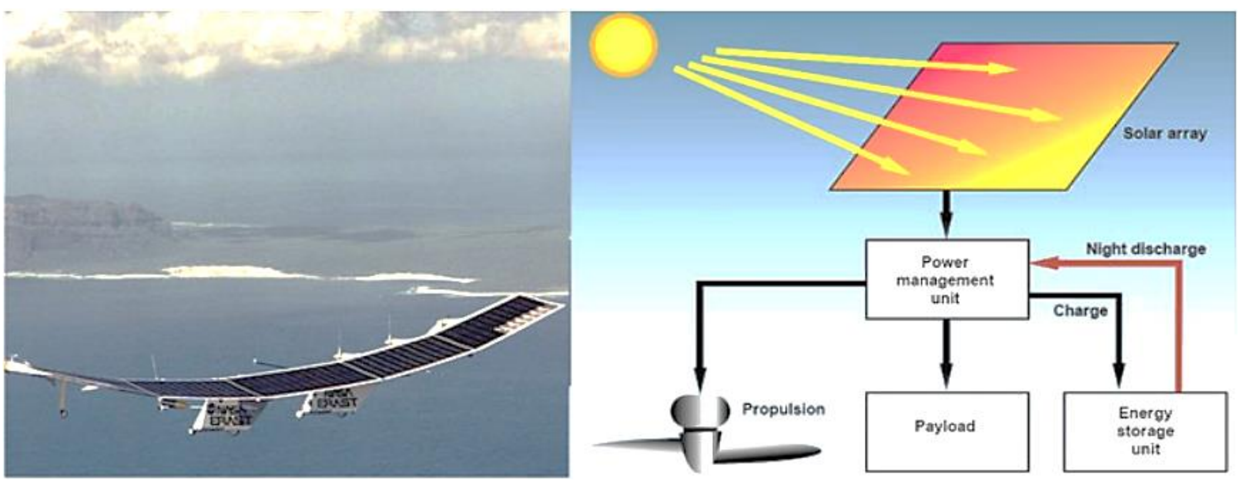


Figure (1-17): Electric-Powered Aircraft

1.3.2 Human-Powered Aircraft (HPA)

A human-powered aircraft (HPA) is an aircraft capable of sustained, controlled flight by human power alone through an act of pedaling, which activates a mechanism for turning a propeller for thrust (Fig. 1.82).

HPA inevitably experience assist from thermals or rising air currents. Pure HPA do not use hybrid flows of energy (solar energy, wound rubber band, fuel cell, etc.) for thrust.

Figure (1-18): Human-Powered Aircraft (HPA)