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DEPARTMENT OF AEROSPACE ENGINEERING

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UNIT I - INTRODUCTION TO AIRCRAFT PROPULSION

Types of Aircraft Engine

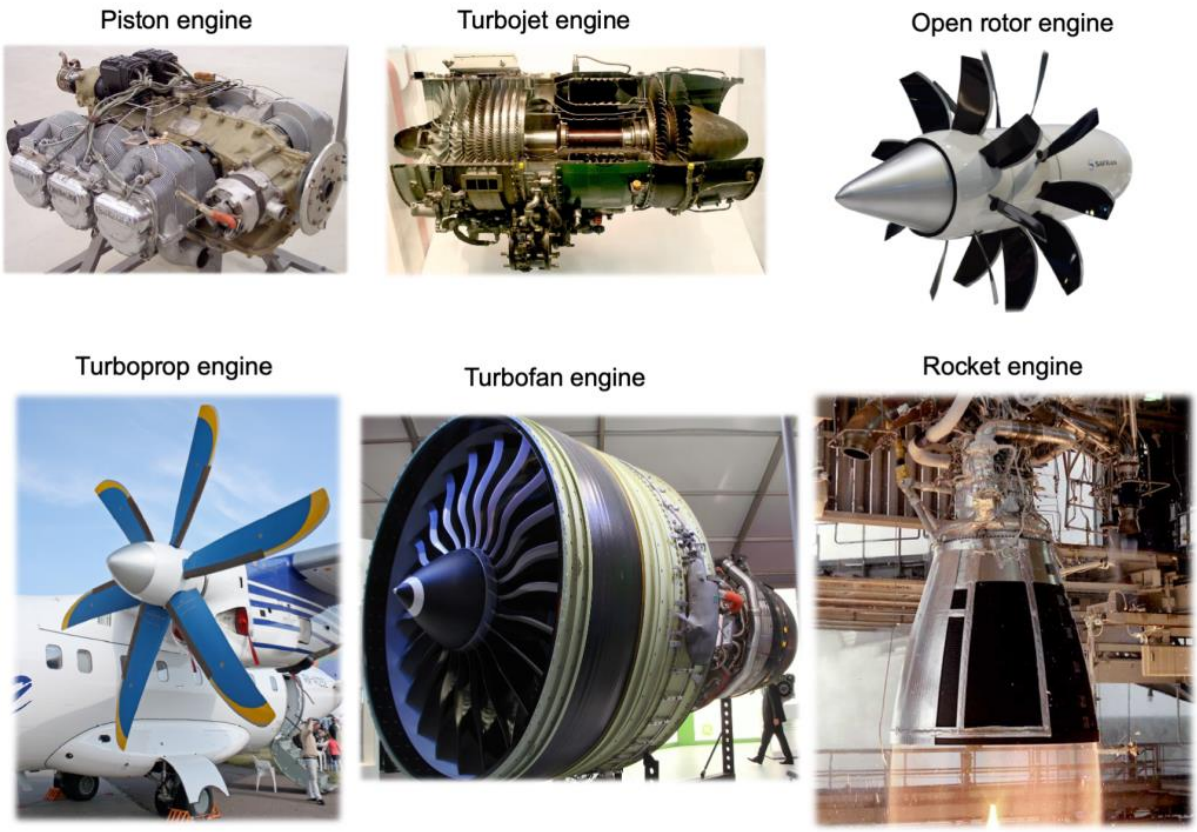
<u>Types of Propulsion Systems</u>

Not all flight vehicles are created equally, and they will require different propulsion systems. An aircraft propulsion system must produce at least enough thrust to balance the drag of the airplane when in flight and drive the aircraft forward at the required flight velocity; drag is typically an order of magnitude less than the aircraft's weight. However, the thrust produced must exceed the drag of the airplane for it to accelerate to a higher airspeed and/or to climb to a higher altitude. Therefore, an aircraft propulsion system must have at least some *excess* thrust (or power) capability for takeoff, etc., and more than that required for straight-and-level flight. Likewise, the rocket engine(s) on a launch vehicle must create enough thrust to overcome the entire weight of the vehicle initially, then progressively build up enough excess thrust as fuel is burned off for the rocket to reach an orbital velocity and altitude.

The needed propulsion on a flight vehicle can be achieved using at least one of the following systems, as shown in the images below.

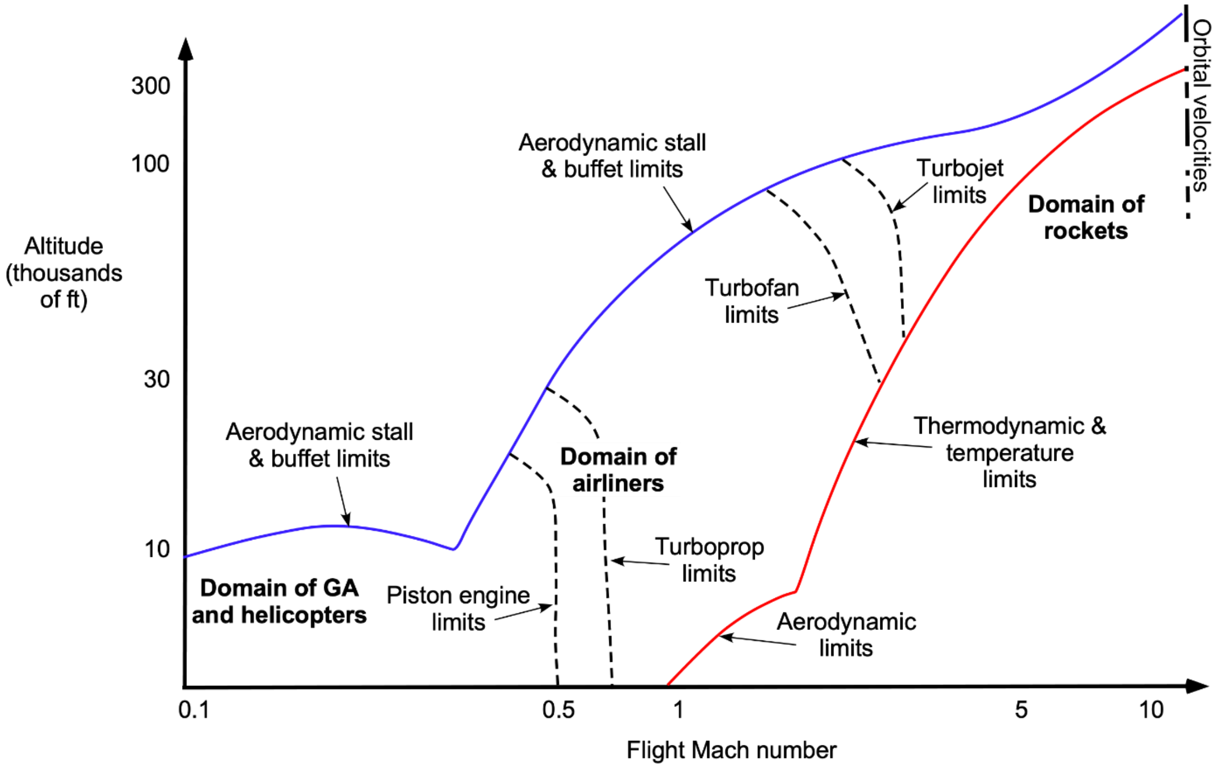
- Propeller and engine combination, such as a reciprocating (piston) engine.
- A turbojet is a basic jet engine that produces pure jet thrust.
- A turbofan is a jet engine with a bypass fan that directs a significant mass flow rate around the engine's core.

- A turboshaft in which all shaft power goes to a reduction gearbox and transmission system, such as the one used on helicopters.
- A turboprop is a turboshaft engine driving a propeller from a power turbine with little jet thrust.
- The rocket engine, which, unlike the preceding types, is not air-breathing.



Examples of different propulsion systems used for flight vehicles.

Each propulsion system is different in terms of its functional design, but the purpose in each case is to convert fuel into a propulsive power and force to propel a flight vehicle. This goal is crucial because, to a large extent, any flight vehicle's performance capabilities are determined by the thrust from the propulsion system and the quantity of fuel it takes to produce that thrust. As the figure below suggests, the propulsion system for a given aircraft design depends primarily on the vehicle's intended airspeed or Mach number.



Altitude and Mach number operational ranges for different flight vehicles and propulsion systems.

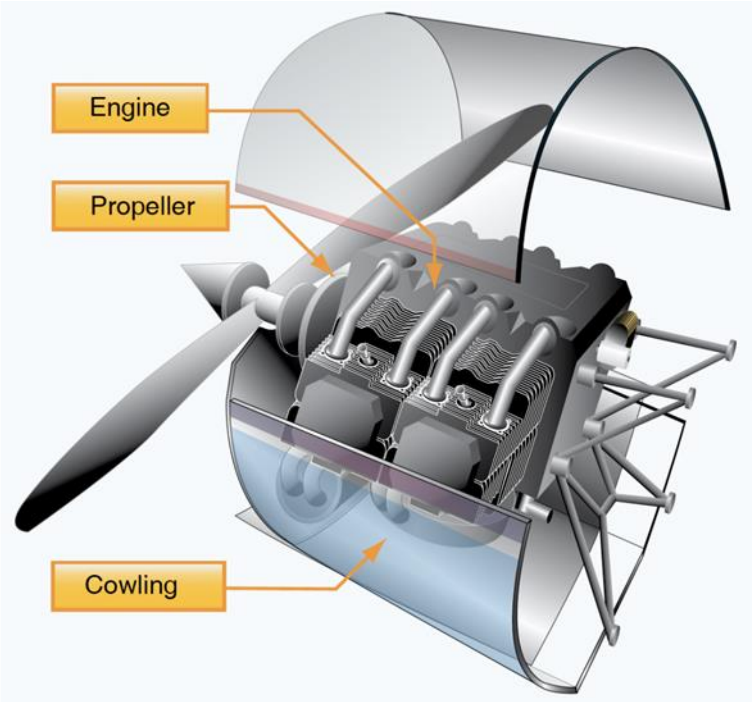
For example, a propeller, engine combination, or turboprop might power a low-speed transport aircraft. In contrast, a turbojet may power a fighter jet capable of supersonic flight. A piston engine and propeller combination will likely power smaller general aviation airplanes. Turboshaft engines usually power helicopters, but some smaller helicopters may have piston engines. Airliners spend most of their flight time at cruise operating at one airspeed, and almost constant engine thrust; the high efficiency and relatively low fuel burn of turbofan engines are attractive for these types of airplanes.

For higher supersonic speeds and flight Mach numbers, turbojets are attractive. Military airplanes need significant amounts of excess thrust to accelerate quickly, such as during combat maneuvers, and to overcome the high drag associated with operations at transonic and supersonic flight speeds. For this reason, military aircraft must have significant margins of excess thrust. They may also employ afterburners (also called reheat) to create a lot of excess thrust, at least for short amounts of time. Compared to air-breathing engines, rockets also typically operate at very high thrust levels as well as high pressures and temperatures, but for relatively short amounts of time.

Piston Engines

A reciprocating piston internal combustion engine driving a propeller is often used to power low- to moderate-performance airplanes. The propeller is attached directly to the engine's crankshaft, which spins and produces forward thrust, as shown in the figure below. The propeller may be of the fixed-pitch type for low-performance airplanes and the variable-pitch (or constant speed) type for higher-performance airplanes.

A piston internal combustion engine driving a propeller is relatively simple and robust. It is often used to power relatively low-performance general aviation aircraft.

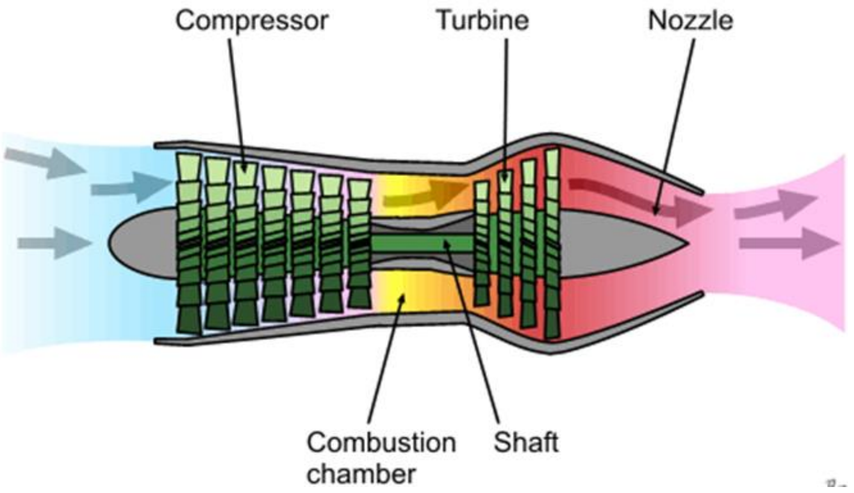


The advantages of this propulsion system are that it is robust and relatively inexpensive while also providing reasonable propulsive efficiency in terms of combined engine and propeller efficiency. *Supercharging* or *turbocharging* may be used to increase the power of a piston engine and maintain its power output to higher flight altitudes.

A modern propeller has excellent propulsive efficiency and relatively low noise. However, a piston engine and propeller combination become increasingly heavy for larger power outputs and higher altitude operations above 15,000 ft. If a propeller aircraft design is still desired, a turboprop is usually preferred.

Turbojet, Turbofans & Turboshaft Engines

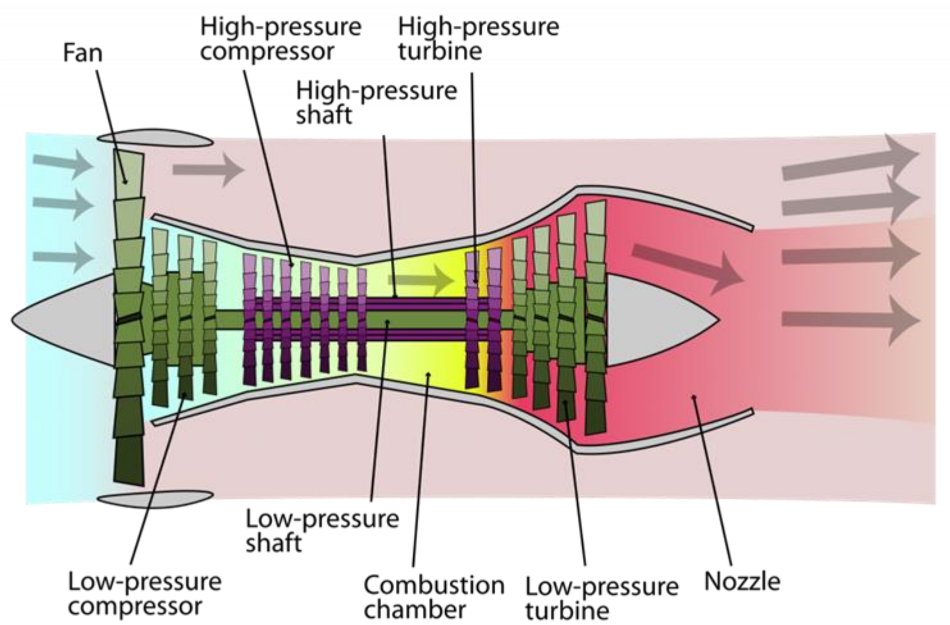
Out of all the engine types used on aircraft, the turbojet, turbofan, and turboshaft are the most frequently confused. In a turbojet engine, as shown in the schematic below, the exhaust gases are expended at high velocity through a nozzle at the rear of the engine; this process produces all of the thrust by changing the momentum of the flow through the engine. The compressor stage is driven by the turbine stage, which brings the intake air to the pressures and temperatures needed to support combustion. In a turbojet engine, all thrust is produced by expelling the hot gases out of a nozzle at high "jet" velocity.



Turbofan

In a turbofan engine, one or more large fans are mounted at the front, as shown in the schematic below. The fan increases the net mass flow through the engine, which gives more thrust, but the fan also expels the flow at a lower exit or jet velocity, which is a more efficient way of producing this thrust. In a turbofan engine, the fan makes much of the net thrust from the engine, perhaps as much as 70%, the remainder from the jet thrust developed through the engine's core and exit nozzle.

In a turbofan engine, the fan at the front produces much of the thrust, which gives better thrust-producing efficiency than a pure turbojet.



About turbofan engines, the term "bypass ratio" or BPR is often used, a higher bypass ratio being attractive in terms of thrust-producing efficiency. The bypass ratio (BPR) is the area or mass flow through the fan divided by the area or mass flow through the core itself, i.e.,

$$\text{BPR} = \frac{\text{Mass flow rate of bypass stream}}{\text{Mass flow rate of flow through core}}$$

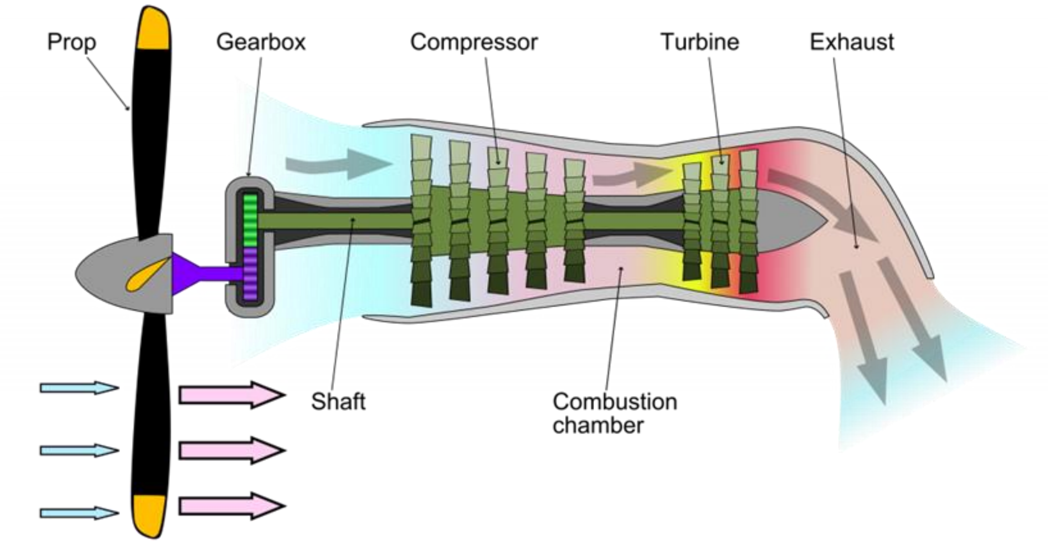
A BPR of 5, for example, means that five units of mass per unit time of air goes through the "cold" bypass stream for every one unit going through the "hot" engine core.

Typical BPR values on a modern turbofan engine range from 8 to 11 and have progressively increased over the last three decades through improvements in turbofan engine design. The purpose is clear: it is much more efficient to create thrust by accelerating a large mass flow of air through the fan and expelling it at a lower velocity versus accelerating a lower mass flow of air at a high velocity. For this reason, turbofan engines are more commonly used today than turbojets, e.g., on commercial airliners, because of their better efficiency and lower fuel consumption.

Turboprops

Turboprops are closely related to turbofans in terms of operational principle because both transfer energy from a power turbine to do work on a bypass flow stream. As shown in the schematic below, with a turboprop, the turbine stage delivers power to a shaft that drives a propeller. The propeller is often coupled through a gearbox to reduce the propeller speed and keep the tips of the propeller blade from becoming supersonic. As a result, there is little energy in this type of engine's exhaust, so little or no jet thrust is produced.

In a turboprop, the turbine stage delivers power to a shaft to drive a propeller that produces nearly all the thrust; the jet thrust is almost zero.



With a turboprop engine, the energy of the hot gasses is used to drive a turbine and then a shaft to which a propeller is attached. A turboprop is a very efficient way of producing propulsive thrust on an aircraft because it has a very high effective bypass ratio. Nevertheless, the propulsive characteristics of the propeller itself must be carefully considered relative to the overall system performance, which is usually limited to flight Mach numbers of less than 0.5.

Turboshafts

Turboshaft and turboprop engines are very similar in that both are designed to deliver nearly all of their power to a shaft rather than producing jet thrust, although some small jet thrust may still be produced at the exhaust. The main difference in their design is at the power or compressor turbine stage.

Although in most turboshaft designs, the compressor turbine (gas generator) and power section are mechanically separate, referred to as a *free power turbine*, as shown in the schematic below, the advantage is that they can rotate each at different speeds appropriate to the conditions of use. Turboshaft engines are often used to power helicopters but have also been used on tanks and ships.

A turboshaft engine is designed to produce power at a shaft, which could be used to drive a helicopter rotor.