Ideal Jet-Propulsion Cycle

Gas-turbine engines are widely used to power aircrafts because of their light-weight, compactness, and high power-to-weight ratio. Aircraft gas turbines operate on an open cycle called jet-propulsion cycle. Some of the major differences between the gas-turbine and jet-propulsion cycles are:

- gases are expanded in the turbine to a pressure where the turbine work is just equal to the compressor work plus some auxiliary power for pumps and generators i.e. the net work output is zero
- since the gases leave at a high velocity, the change in momentum that the gas undergoes provides a thrust to the aircraft
- the fluid passes through a diffuser first where it is decelerated (gas pressure increases)
- typically operate at higher pressure ratios, often in the range of 10 to 25

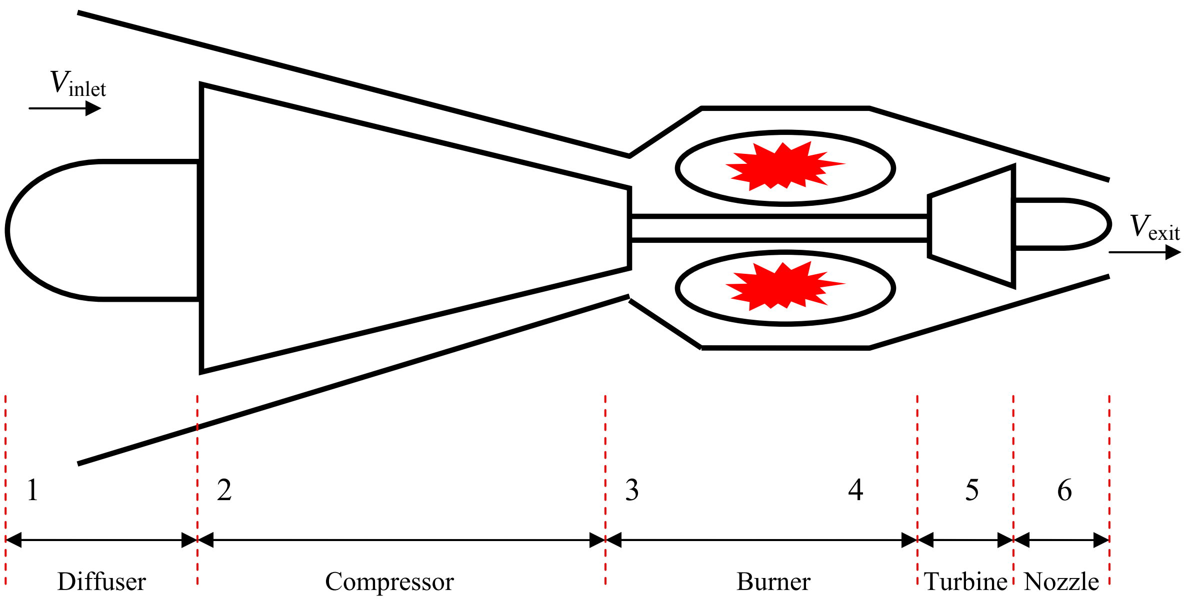


Fig.1: Schematic of a turbojet engine.

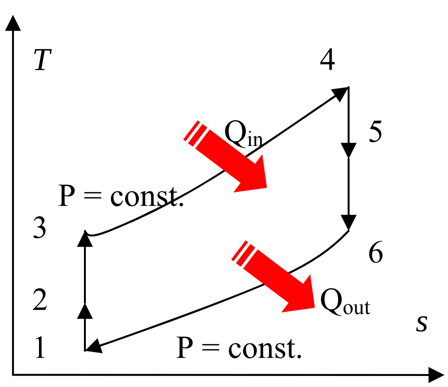


Fig. 2: T-s diagram for ideal turbojet cycle.

Diffuser (1-2)

- decelerates the incoming flow relative to the engine
- a pressure rise known as a ram effect occurs, V (↓), P (↑). It can be explained through the Bernoulli's equation:

$$P + \frac{1}{2}\rho V^2 + \rho g h = \text{Const.}$$

Compressor, Burner and Turbine (2-5)

2-3: isentropic compression

3-4: constant pressure heat addition

4-5: isentropic expansion through the turbine during which work is developed

- turbine power just enough to drive the compressor
- air and fuel are mixed and burned in the combustion chamber at constant pressure
- air velocity leaving the turbine is small and can be neglected

Nozzle (5-6)

- isentropic expansion through the nozzle, air accelerates and the pressure deceases
- gases leave the turbine significantly higher in pressure than atmospheric pressure
- gases are expanded to produce a high velocity, $V_e >> V_i$ results in a thrust

The pressure at the inlet and the exist of a turbojet engine are identical (the ambient pressure); thus the net thrust developed by the engine is:

$$F = \left(\dot{m} V\right)_{exit} - \left(\dot{m} V\right)_{inlet} = \dot{m}\left(V_{exit} - V_{inlet}\right) \qquad (N)$$

For an aircraft cruising in still air, V_{inlet} is the aircraft velocity. The power developed from the thrust of the engine is called the *propulsive power*:

$$\dot{W}_P = F V_{aircraft} = \dot{m}\left(V_{exit} - V_{inlet}\right) V_{aircraft} \qquad (kW)$$

The thermal efficiency is defined based on the propulsive power. This then becomes a measure of how efficiently the energy released during the combustion process is converted to propulsive energy.

$$\eta_P = \frac{\text{Propulsive power (Benefit)}}{\text{Input energy (Cost)}} = \frac{\dot{W}_P}{\dot{Q}_{in}}$$

Afterburner

Afterburner is popular in military aircrafts and it is used whenever a need for extra thrust arises, such as for short takeoffs or combat conditions. Afterburner is similar to a reheat device; it is located after the turbine and before the nozzle. It produces a higher temperature (and pressure) at the nozzle inlet, results in an increase in velocity (and thrust).

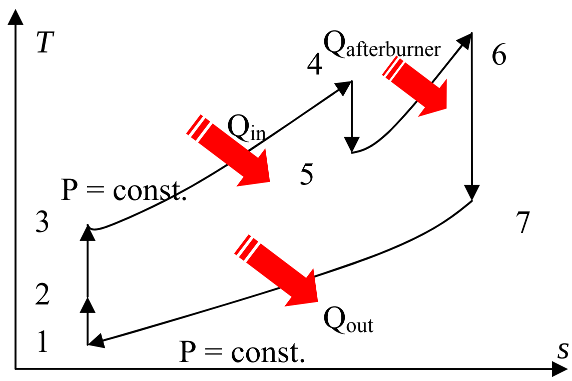


Fig. 3: T-s diagram for an ideal turbojet with afterburner cycle.

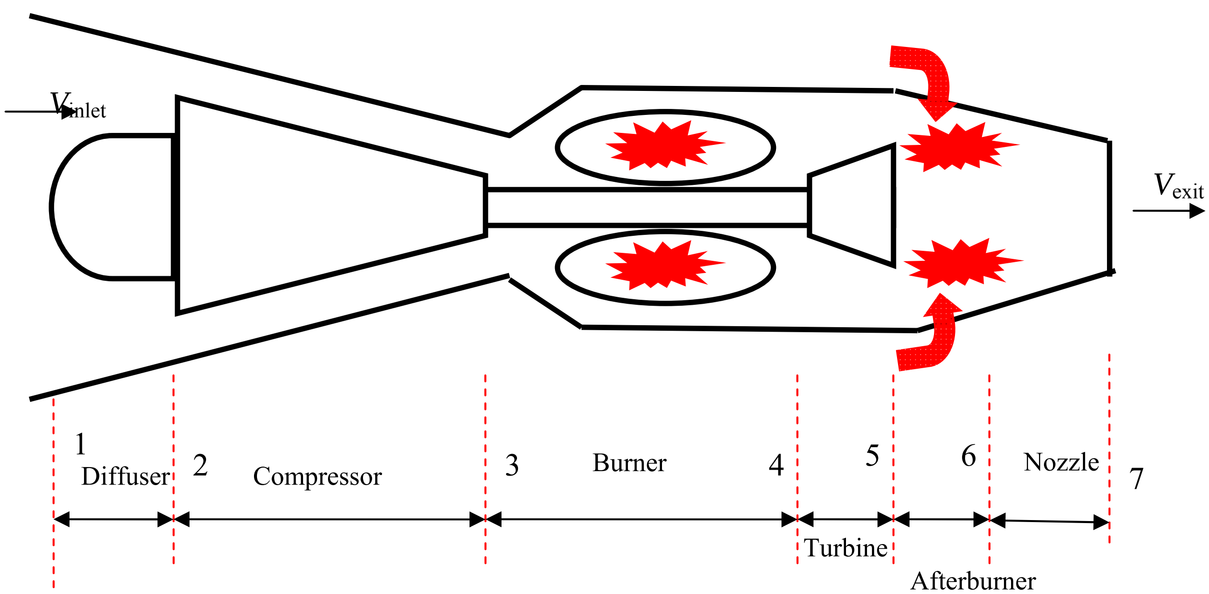


Fig. 4: Schematic diagram for a turbojet engine with afterburner.

Turboprop

- gas turbine drives the compressor and the propeller
- most of the thrust is from the propeller
- works by accelerating large volumes of air to moderate velocities
- propellers are best suited for low speed (less than 500 mph) flight
- by-pass ratio of 100:1 or more

$$\text{Bypass ratio} = \frac{\text{mass flow bypassing the combustion chamber}}{\text{mass flow through the combustion chamber}}$$

Turbofan

The most popular engine in aircrafts is the turbofan (or fanjet) where fan driven by the turbine forces a considerable amount of air through a duct (cowl) surrounding the engine.

- best choice for fuel economy and speed
- high speed exhaust gases are mixed with the lower speed air in the by-pass resulting in a considerable noise reduction
- by-pass ratio can be adjusted
- by-pass provides thrust for takeoff the core provides thrust for cruising
- typically used for speeds up to 600 mph
- typical by-pass ratios are 5-6

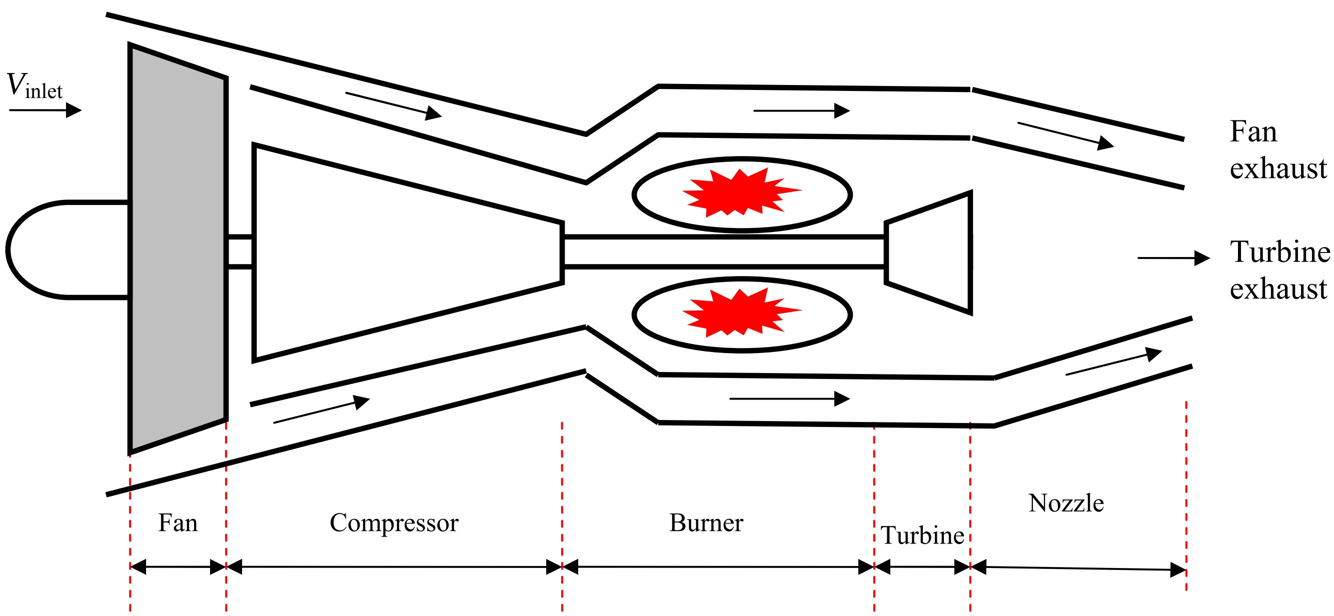
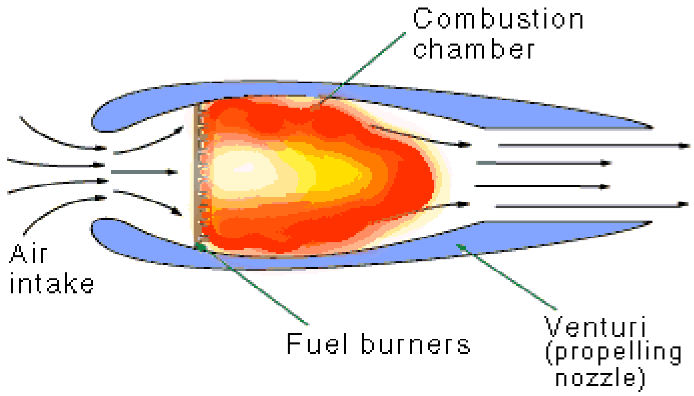


Fig. 5: Schematic of a turbofan engine.

Ramjet

A ramjet is properly shaped duct with no compressor or turbine. It is used for high-speed propulsion and missiles. Compression is achieved by decelerating the high-speed incoming air in the diffuser aircraft must already be in flight at a high speed. Ramjet is typically used in aircraft flying above Mach 1.


Combustion chamber
Air intake
Fuel burners
Venturi (propelling nozzle)