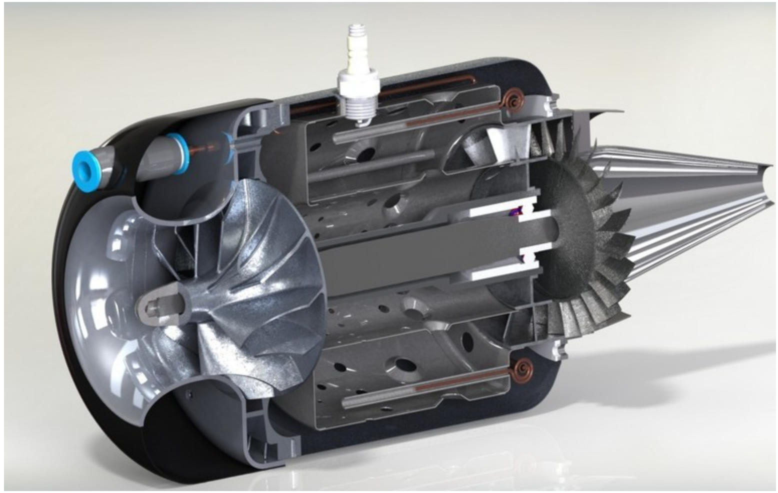
2. Gas Turbine Engine Configurations

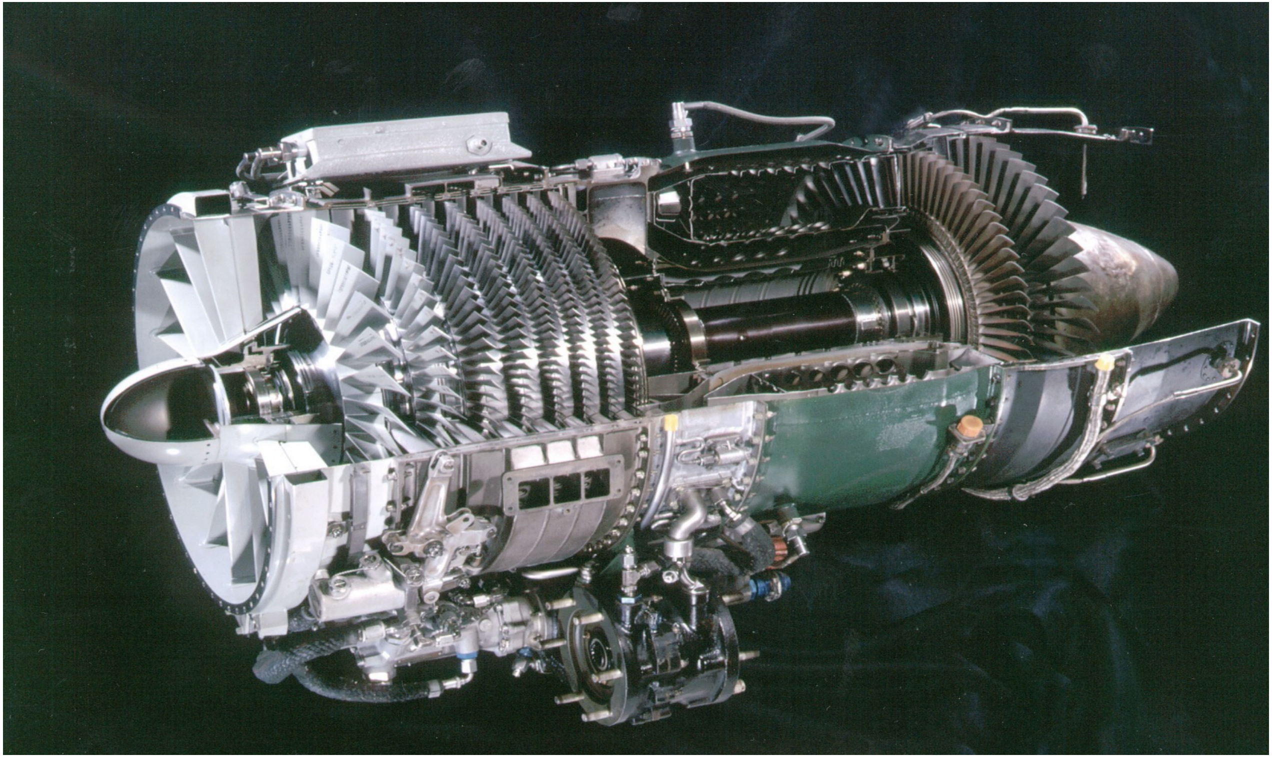
A gas-turbine engine (GTE) is an internal combustion engine, which includes following basic components:

- Air Intake;
- Compressor;
- Combustion System;
- Gas turbine;
- Exhaust System.



The gas turbine engine workflow consists of compression of the working fluid in the air intake and the compressor, the supply of heat in the combustion chamber, expansion in the turbine and the exhaust system.

Conventional turbojet



Ambient air passes from free stream to the **intake** leading edge. The air accelerates from free stream if the engine is static, whereas at high flight Mach number it diffuses from the free stream (ram conditions). It then passes to the compressor resulting a small loss in total pressure.

The **compressor** then increases both the pressure and temperature of the gas. Work input is required to achieve the pressure ratio; the associated temperature rise depends on the efficiency level. Depending upon complexity the turbojet compressor pressure ratio ranges from 4 up to 25.

The compressor exit diffuser passes the air to the **combustor**. Here, fuel is injected and burnt to raise exit gas temperature to between 1100K and 2000 K, depending upon engine technology level. The diffuser and combustor both impose a small total pressure loss.

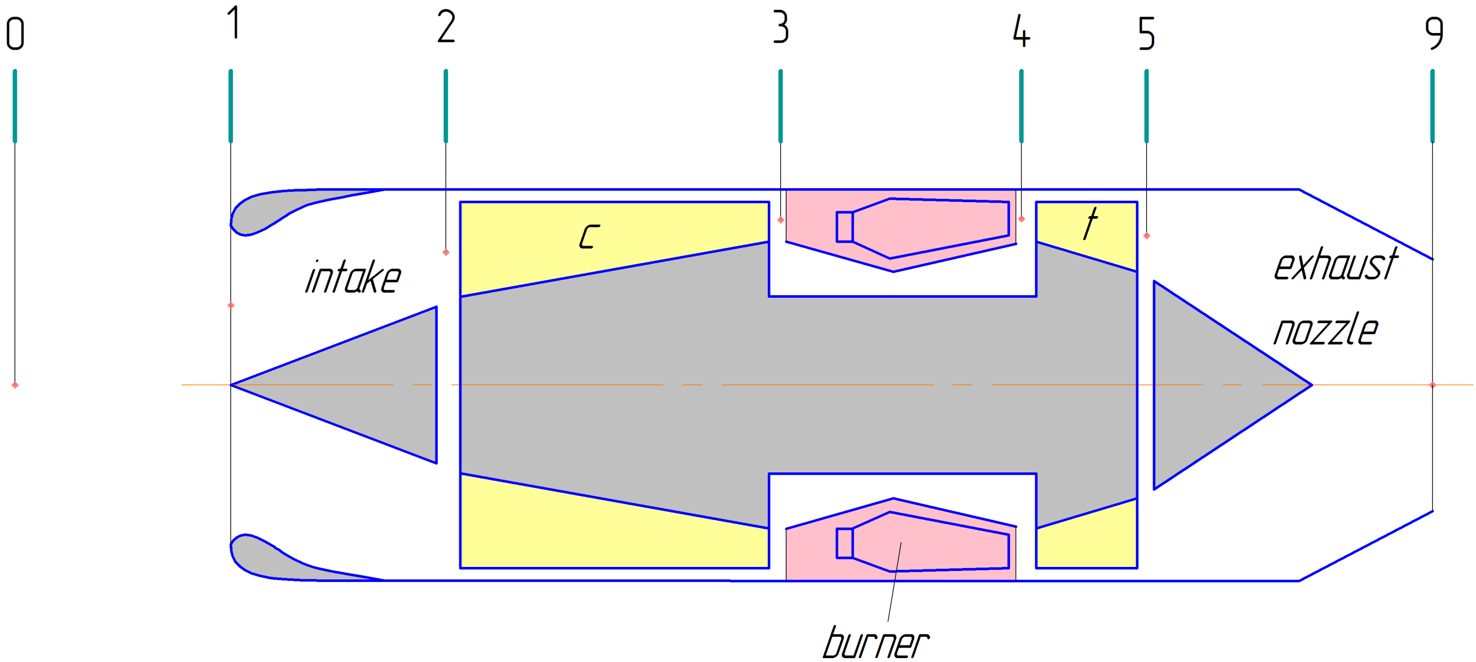
The hot, high pressure gas is then expanded through the **turbine** where work is extracted to produce shaft power; both temperature and pressure are reduced. The shaft power is required to drive the compressor and any engine and 'customer' auxiliaries, and to overcome engine mechanical losses such as disc windage and bearing friction. The turbine nozzle guide vanes and blades are often cooled to ensure acceptable metal temperatures at elevated gas temperatures. This utilizes relatively cool air from the compression system which bypasses the combustor via air system flow paths which feed highly complex internal cooling passages within the vanes and blades.

On leaving the turbine the gas is still at a pressure typically at least twice that of ambient. This results from the higher inlet temperature to the turbine.

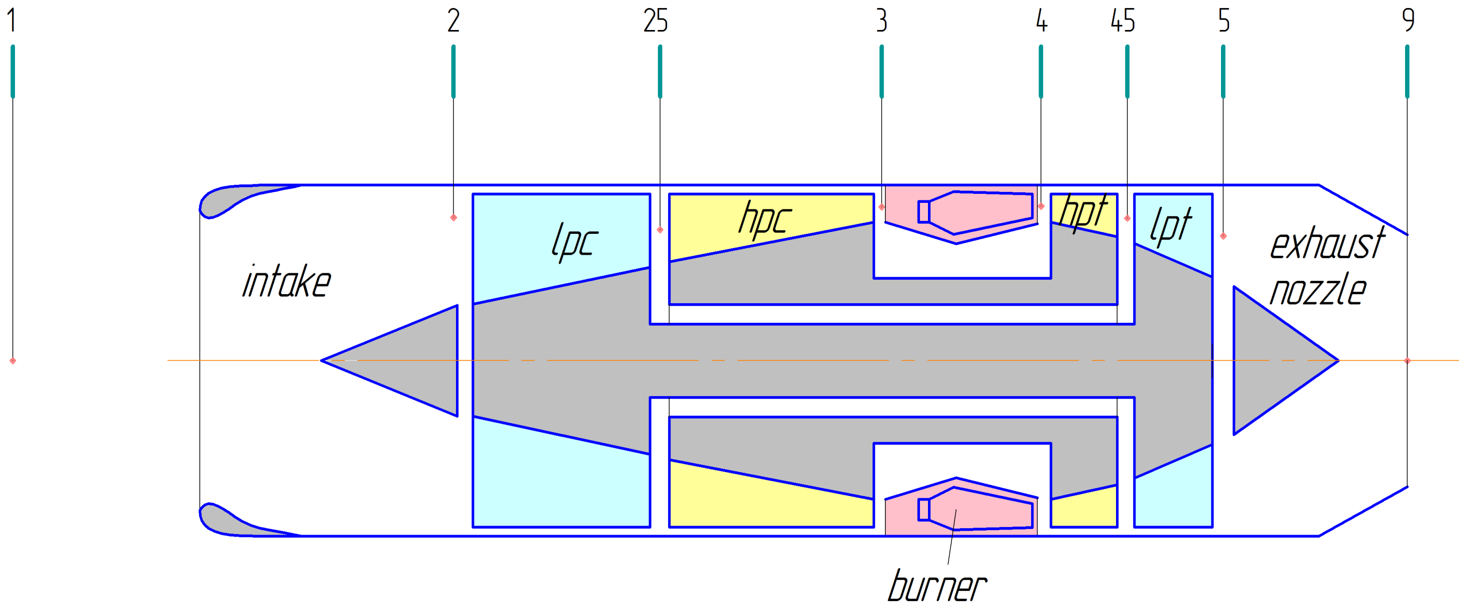
Downstream of the turbine the gas diffuses in the **jet pipe**. This is a short duct that transforms the flowpath from annular to a full circle at entry to the propelling nozzle.

The propelling nozzle is a convergent duct that accelerates the flow to provide the high velocity jet to create the thrust. If the available expansion ratio is less than the choking value, the static pressure in the exit plane of the nozzle will be ambient. If it is greater than the choking value the Mach number at the nozzle will be unity (i.e. sonic conditions), the static pressure will be greater than ambient and shock waves will occur downstream.

Conventional single spool turbojet configuration and station numbering.

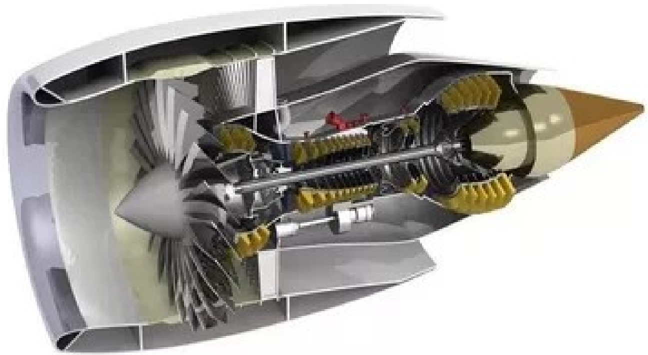


In addition to single spool turbojet, there are also twin spool turbojet. They differ in that the compressor is divided into two spools (cascades) of low (LP) and high (HP) pressure, not mechanically connected. Similarly, the turbine is also divided into two spools, each of them rotates the corresponding compressor.



Separate jets turbofan

Here the first compressor or a fan supplies flow to a bypass as well as an engine core. The core stream is like a turbojet and provides thrust. However, the low pressure turbine also provides power to compress the bypass flow.

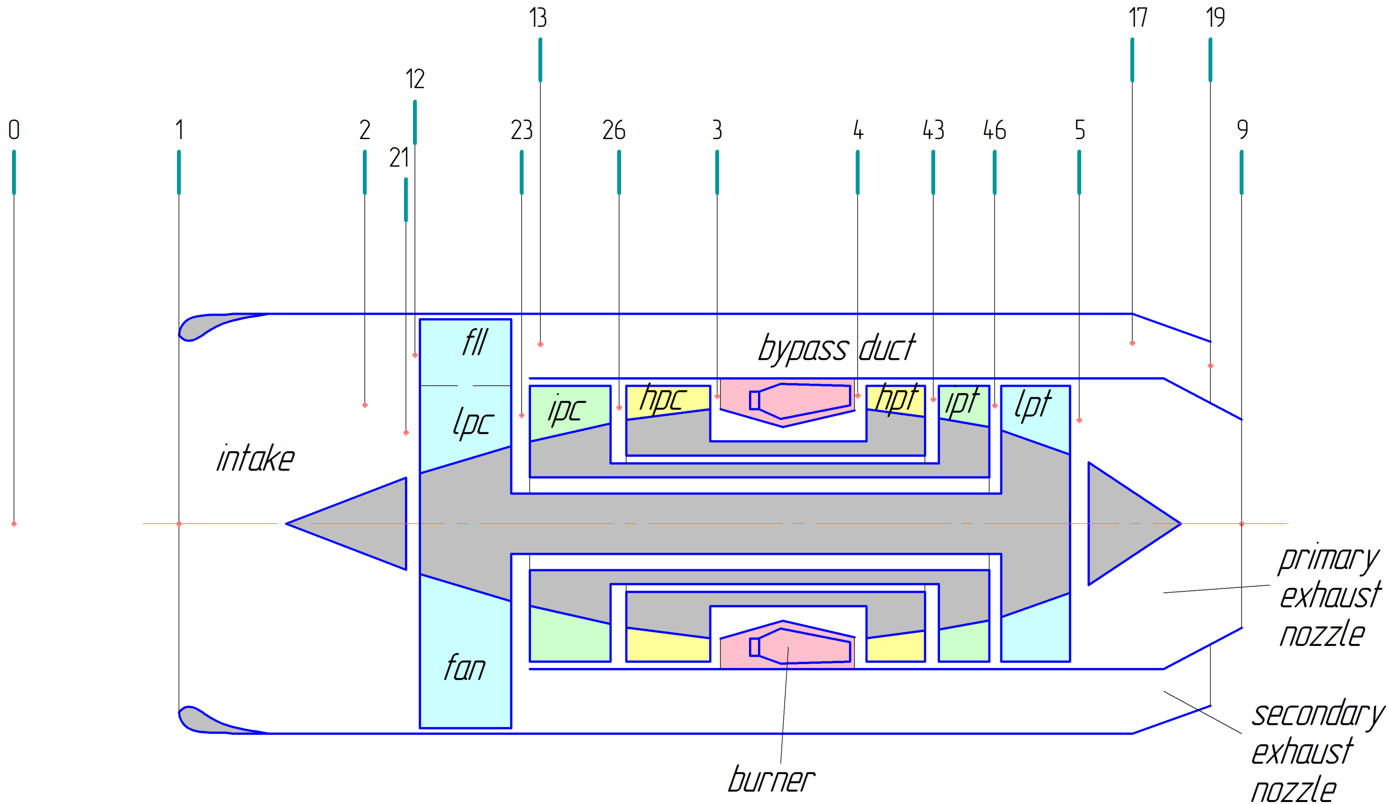


The bypass flow bypasses the core components via the bypass duct, incurring a small total pressure loss. It then enters the secondary nozzle.

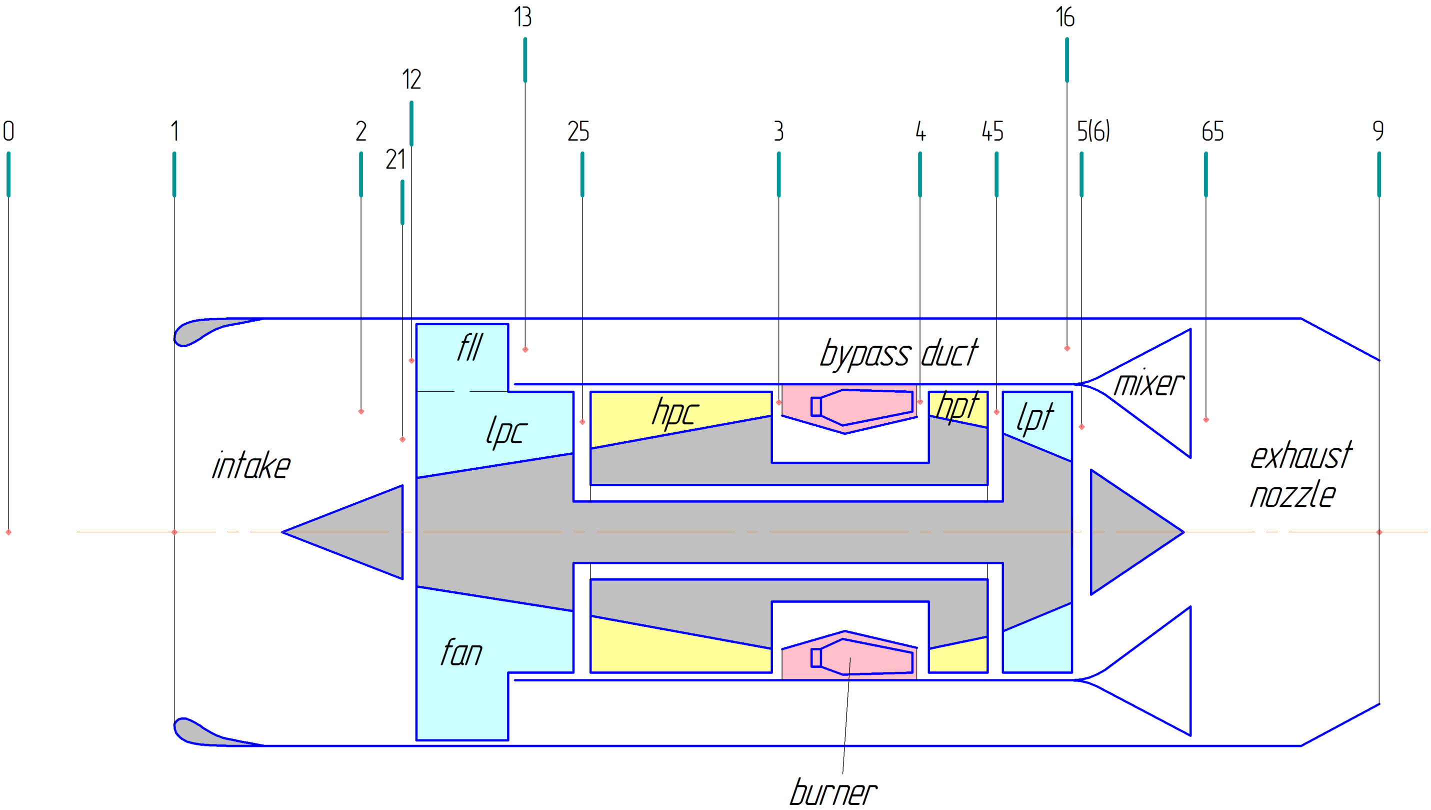
The purpose of the bypass stream is to generate additional thrust with a high mass flow rate but low jet velocity, which improves specific fuel consumption (SFC) relatively to a pure turbojet. However, this results in lower ratios of engine thrust to frontal area and weight.

Some turbofans have three spools, with an intermediate pressure (IP) spool in addition to HP and LP spools.

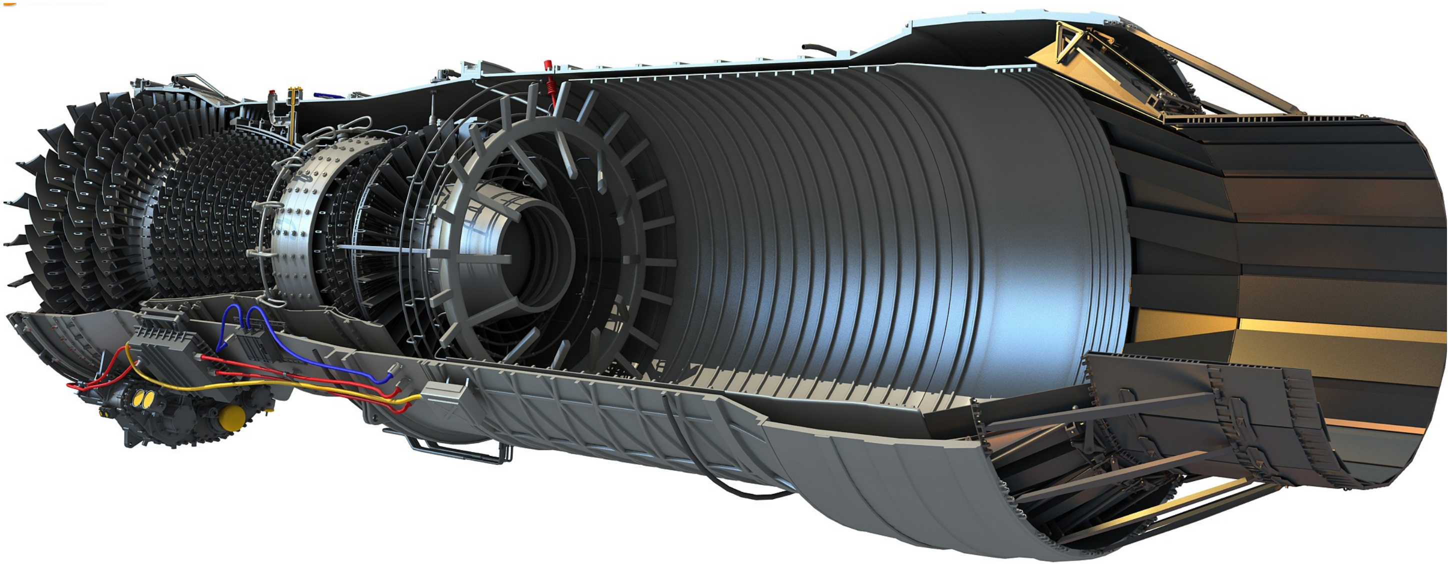
Configuration of the three spool separate jets turbofan.



Configuration of the two spool turbofan with mixer.



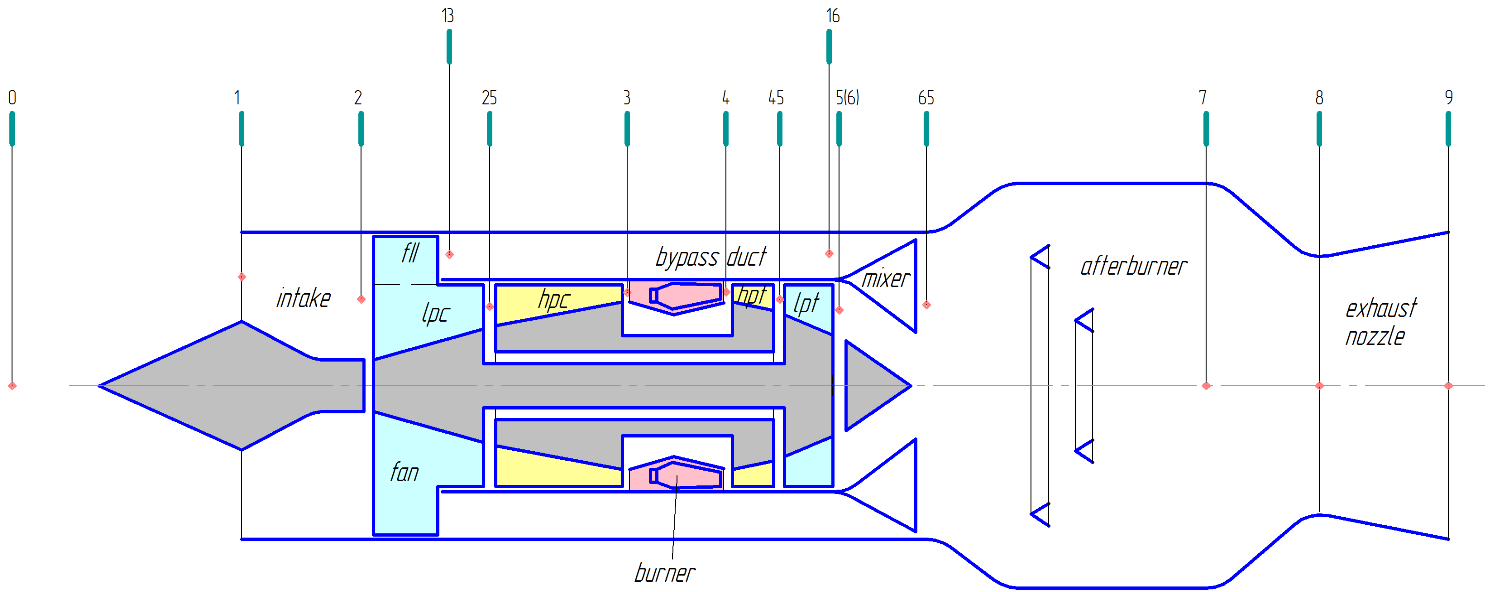
Turbojet with afterburner and convergent–divergent nozzle



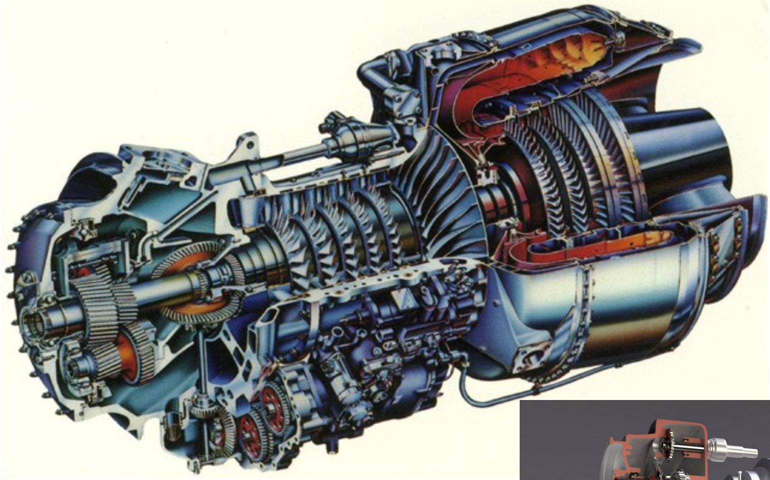
For high flight Mach number applications an afterburner is often employed, which offers higher thrust from the same turbomachinery. This is also called reheat, and involves burning fuel in an additional combustor downstream of the jet pipe. The greatly increased exhaust temperature provides a far higher jet velocity, and the ratios of engine thrust to weight and thrust to unit frontal area are greatly increased.

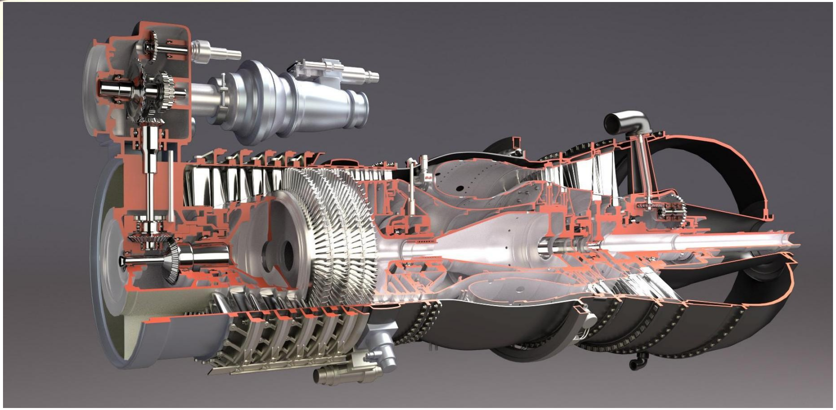
To enable the jet outflow to be supersonic, and hence achieve the full benefit of the afterburner, a convergent–divergent nozzle may be employed. Furthermore, a nozzle downstream of an afterburner must be of variable area to avoid compressor surge problems due to the increased back pressure on the engine when the afterburner is ignited. Usually for engines utilized in high flight Mach number regime a convergent–divergent intake is also employed. This enables efficient diffusion of the ram air from supersonic flight Mach numbers to subsonic flow to suit the compressor or fan. This is achieved via a series of oblique shock waves, which impose a lower total pressure loss than a normal shock wave.

Mixed turbofan with afterburner is shown in Figure. Here the two streams are combined in a mixer upstream of a common jet pipe with an afterburner and convergent–divergent nozzle to provide high jet velocities for supersonic flight. It is often also beneficial to mix the two streams for turbofans without afterburners.

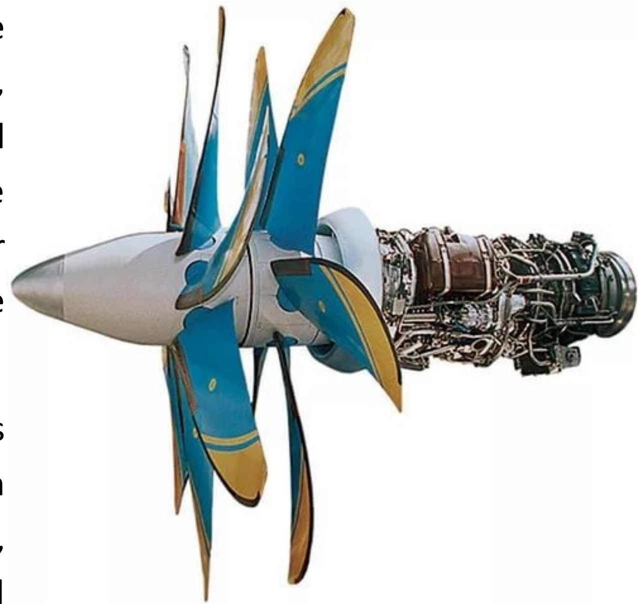


Simple cycle single spool shaft power engine



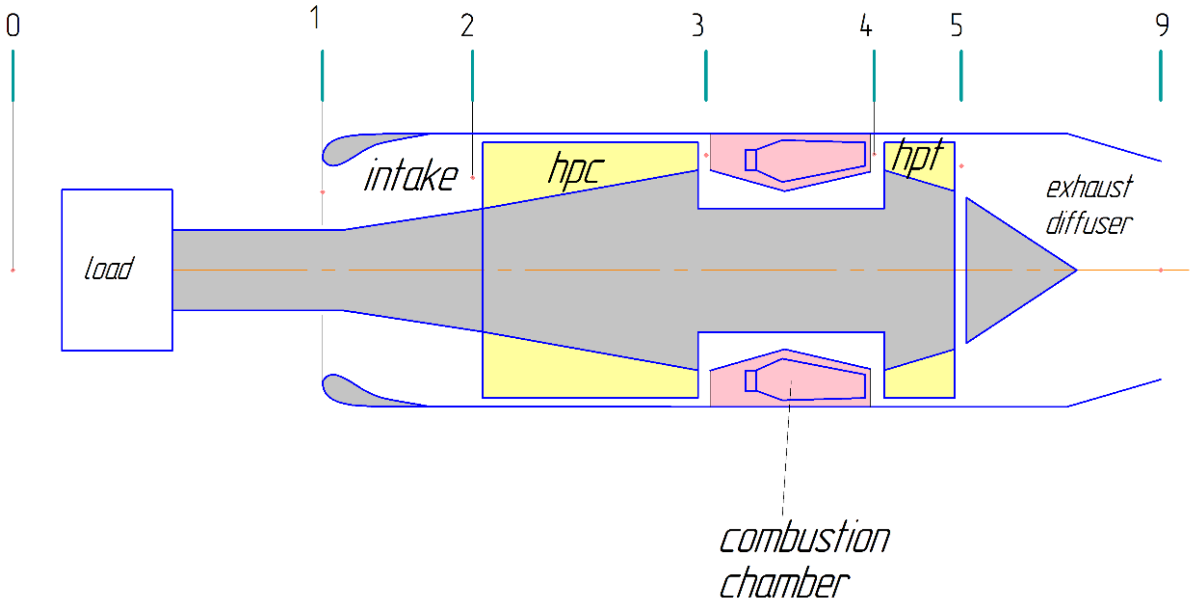


This engine configuration appears similar to a turbojet apart from the intake and the exhaust. The main difference is that all the available pressure at entry to the turbine is expanded to ambient to produce shaft power, apart from a small total pressure loss in the exhaust. After diffusion in the exhaust duct, the gas exit velocity is negligible. This results in turbine power substantially greater than that required to drive the compressor, hence excess power drives the load, such as a propeller (turboprop) or an electrical generator (turboshaft). The gas temperature at the exhaust exit plane is typically 250 °C to 350 °C hotter than ambient, which represents considerable waste heat for an industrial application.

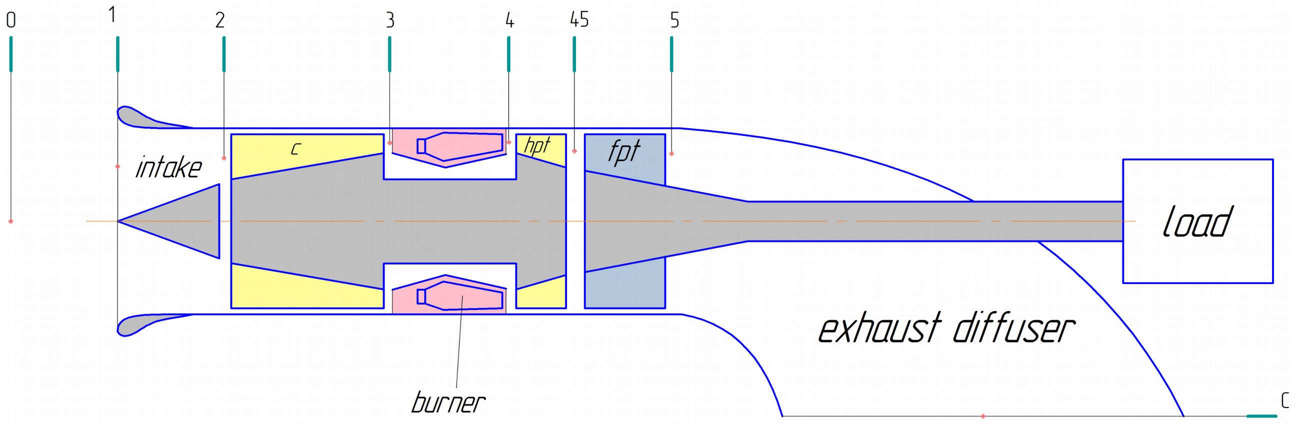


The style of the intake and exhaust varies greatly depending upon the application, though fundamentally the exhaust is normally a diverging, diffusing system as opposed to the jet pipe and nozzle employed by the turbojet for flow acceleration.

Configuration of the turboprop engine.



Configuration of the turboshaft engine



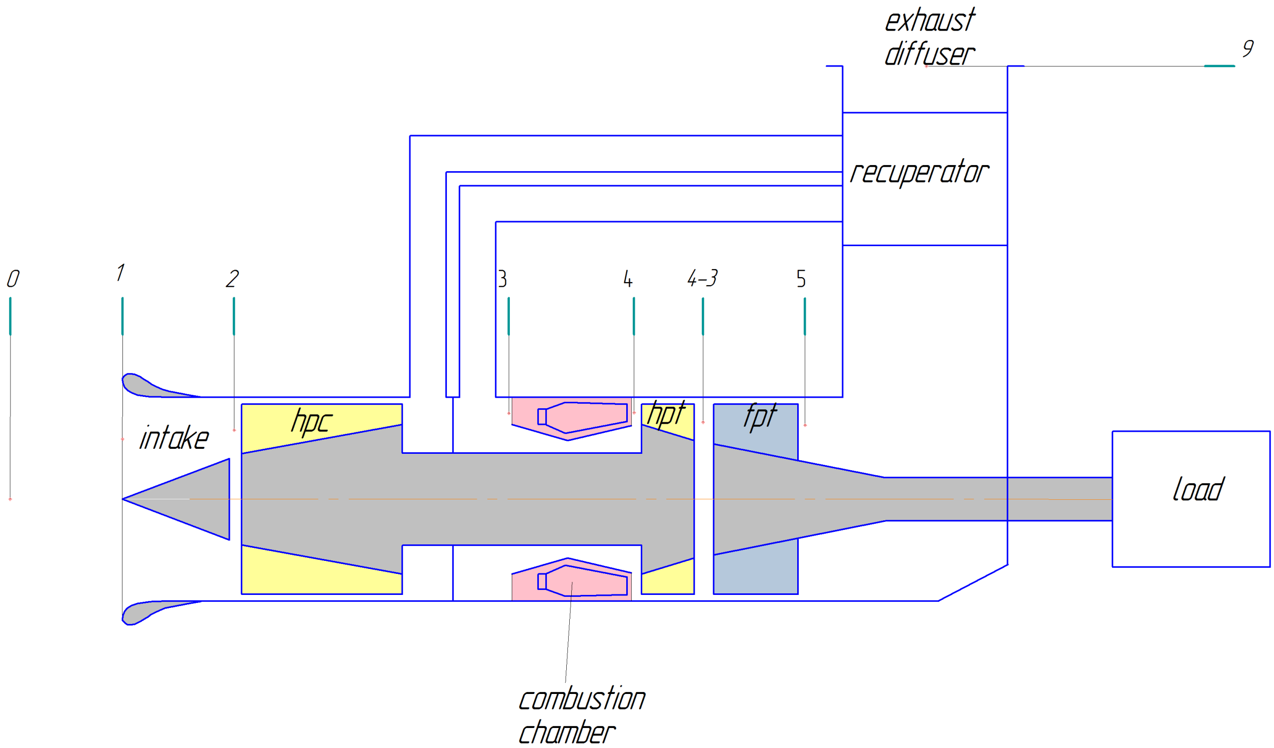
Here the load is driven by a free power turbine separate from that driving the engine compressor.

Gas generator

The term gas generator describes the compressor, combustor and turbine combination that provides the hot, high pressure gas that enters either the jet pipe and propelling nozzle for a turbojet, or the free power turbine for a turboshaft.

It is common practice to use a given gas generator design for both a turbojet (or turbofan) and an aero-derivative free power turbine engine. Here the jet pipe and propelling nozzle are replaced by a power turbine and exhaust system; for turbofans the fan and bypass duct are removed.

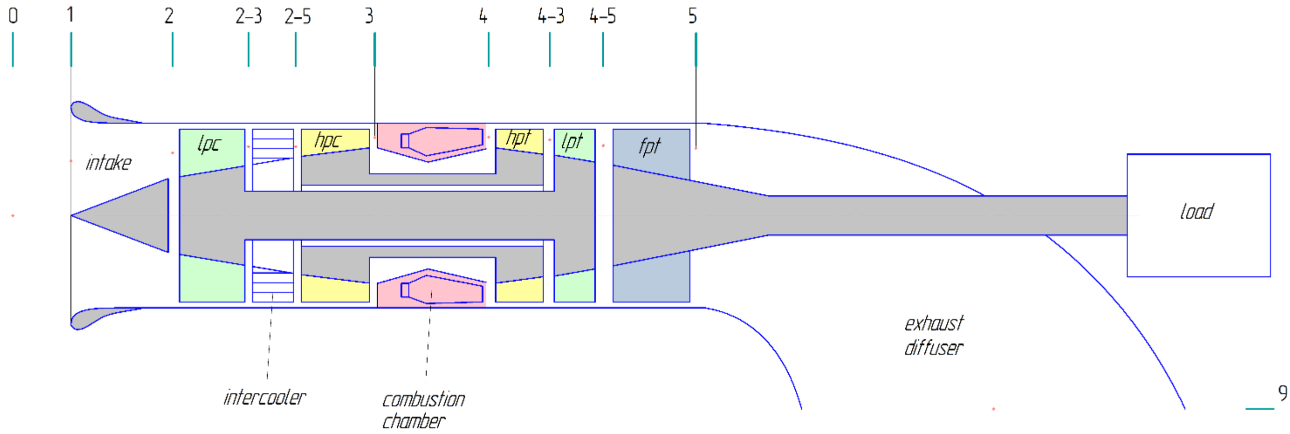
Recuperated engine



Here some of the heat that would be lost in the exhaust of a simple cycle is returned to the engine.

The compressor delivery air is ducted to the air side of the heat exchanger, where it receives heat from the exhaust gas passing through the gas side. The heated air is then ducted back to the combustor where less fuel is now required to achieve the same turbine entry temperature, which improves specific fuel consumption (SFC). Pressure losses occur in the heat exchanger air and gas sides and the transfer ducts.

Intercooled shaft power engine



Here heat is extracted by an intercooler between the first and second compressors.

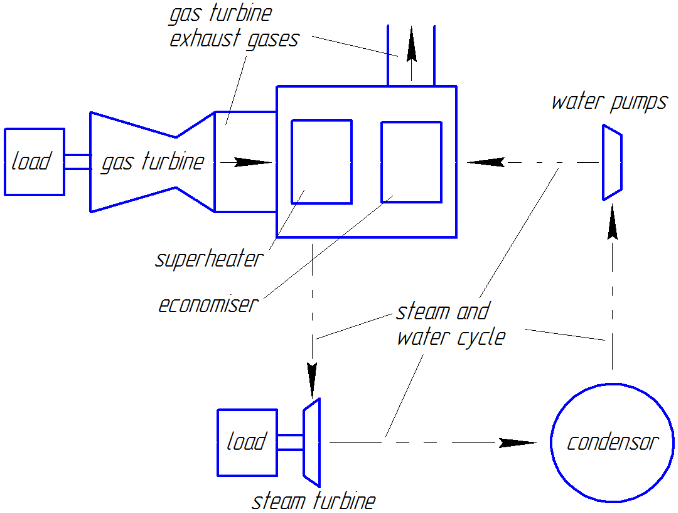
As might be expected, rejecting heat normally deteriorates SFC, since more fuel must be burnt to raise cooler compressor delivery air to any given turbine entry temperature (SOT). However, intercooling improves engine power output, and potentially even SFC at high pressure ratios via reduced power absorption in the second compressor. This is due to the lower inlet temperature reducing the work required for a given pressure ratio.

The intercooler rejects heat to an external medium such as sea water. The air side of the intercooler, and any ducting, impose total pressure losses.

In Intercooled recuperated shaft power engine both an intercooler and recuperator are employed. The increase in power from intercooling is accompanied by an SFC improvement, as the heat extraction also results in increased heat recovery in the recuperator due to the lower compressor delivery temperature.

There are another operating principles that rely on Closed and Combined cycles, but they are beyond this course.

Single pressure combined cycle



Combined heat and power (CHP) with supplementary firing