THERMODYNAMIC CYCLES OF AVIATION GAS-TURBINE ENGINES

V.B. Rutovsky
Moscow State Aviation Institute (Technical University), Russia

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Contents

Summary

Basic cycles of aviation engines are discussed in this Chapter. Losses in air-breathing jet engines and cycles of combined engines are also considered.

1. Basic Types and Concepts of Air-breathing Turbojet Engines

Among gas-turbine engines of direct response, the turbojet engine has the simplest design (Figure1).

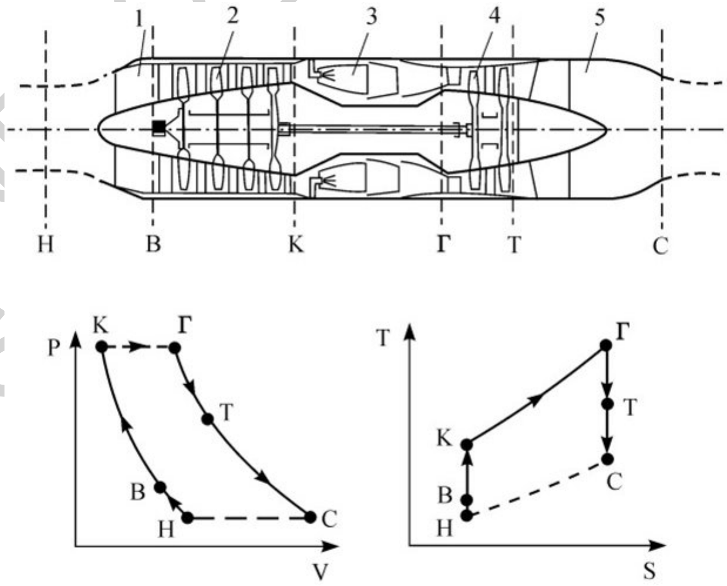

Figure1: Diagram of the turbojet and its thermodynamic cycle plotted in coordinates p-V and T-*S.* The dots show parameters in the cardinal cross section of the engine

The engine includes air intake 1, compressor 2, combustion chamber 3, turbine 4, and jet nozzles 5. The cardinal cross sections of the engine are (1) the cross section of the unperturbed flow upstream of the engine air intake (U); (2) immediately downstream of the air intake (I); (3) downstream of the compressor (C); (4) downstream of the combustion chamber (Ch); (5) downstream of the turbine (T); (6) the nozzle exit cross section (E). During a flight at a velocity V_h, the incoming flow of air is compressed in the air intake. Since the kinetic energy of the air decreases, it is dynamically compressed (point I). The air is compressed further in the compressor (point C). At supersonic velocities the dynamic compression of the air becomes so strong that it makes the largest contribution to the total pressure in the engine. For example, in the Concord jet plane the air pressure increases in the air intake by a factor of nine at a velocity of 2,200 km/h, and this pressure ratio is equal to that in the compressor. At higher velocities, the pressure ratio in the air intake can be even higher than in the compressor. From the compressor the air is fed to combustor 3, where fuel is injected (usually this is aviation kerosene), then the fuel-air mixture is ignited, and in the process of combustion the temperature increases to the limiting value determined by the heat-resistance of the engine hot section (point Ch). A fraction of the potential energy of gases is converted in turbine 4 to the mechanical work transmitted to the shaft and subsequently to compressor 2. The drop in the gas pressure acting on the turbine, which is necessary for transmitting to the shaft the amount of work required to compress the air in the compressor, compensate for friction in the bearings and drives of auxiliary machines, is always smaller than the pressure build-up in the compressor due to the increase in the specific energy of combustion products associated with their high temperature. The overpressure upstream of the jet nozzle is always higher than the pressure in the air intake upstream of the compressor, and the temperature is always higher than the impact temperature of the incoming flow. For this reason, the discharge velocity of combustion products ejected from the engine nozzle is always higher than the flight velocity, hence the reactive thrust generated by the engine. The distinct feature of the turbo-jet engine with an afterburner is shown in Figure 2.

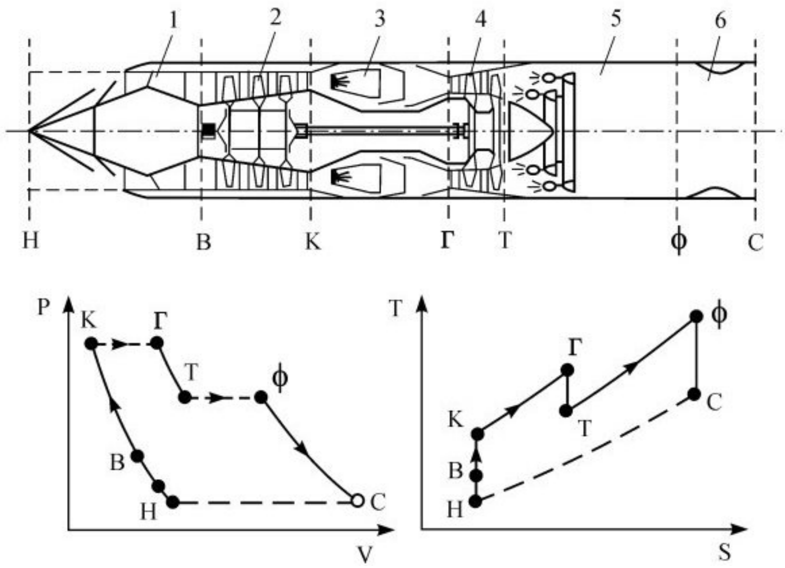

Figure 2: Diagram of the turbojet with afterburner and its thermodynamic cycle in coordinates *p*-*V*

(TJEA) is the presence of an additional combustion chamber between the turbine and nozzle where the combustion process takes place downstream of a stabilizing device designed to insure thorough mixing of additional injected fuel with the residual oxygen that has not been consumed in the main combustor. In order to increase the discharge velocity of products ejected from the nozzle at a considerable pressure difference, it is shaped as the de-Laval nozzle. As was noted above, the pressure increase at supersonic velocities due to dynamic compression can be quite considerable. Therefore air-breathing jet engines for high flight velocities can be built without compressors and turbines. Such engines are termed ramjet engines. A diagram of the ramjet engine for supersonic flight velocities [scram-jet (supersonic combustion) engine] is shown in Figure3.

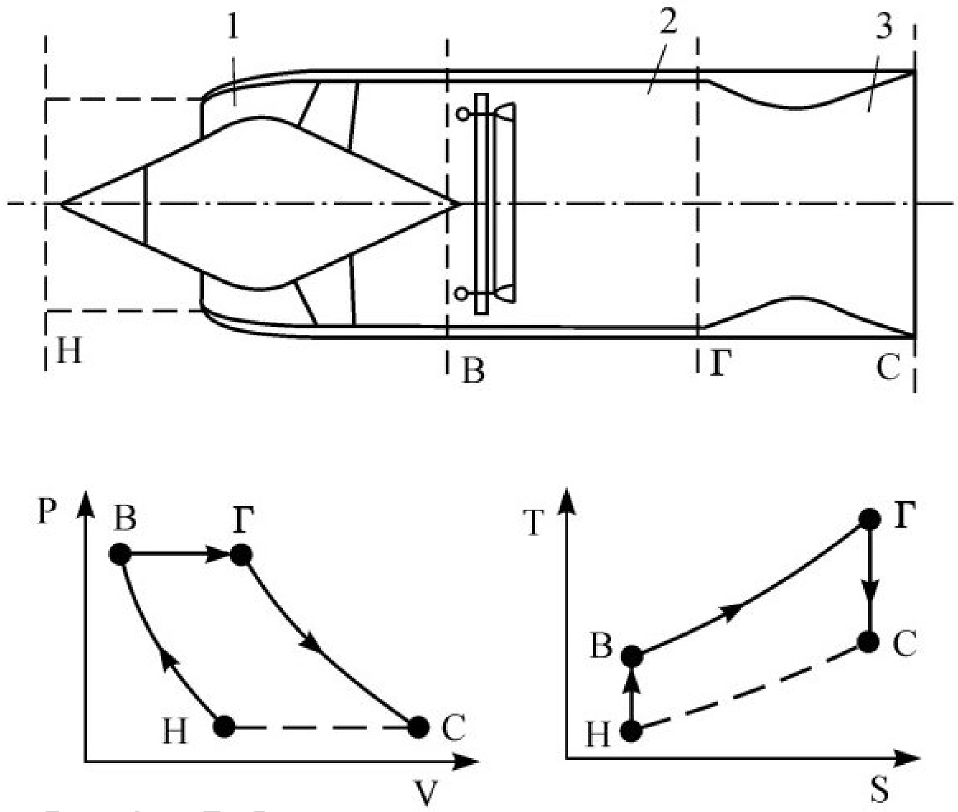

Figure 3: Diagram of the scramjet and its cycle in coordinates *p-V* and *T-S*.

Here the incoming airflow is compressed in the air intake 1, then the air flows at a subsonic velocity into combustor 2. The combustion process terminates upstream of jet nozzle 3 designed as a Laval nozzle. When the flight velocity is very high so that the Mach number M_h = 7-8, it is advisable not to compress the air in the scramjet intake so that its velocity were subsonic, but to a moderate supersonic velocity, because in this case the energy loss to the pressure change in the air intake diminishes, and the total efficiency of the engine operating is upgraded. This engine is termed a supersonic combustion ramjet (scramjet) engine. It is also advisable to diminish the pressure and temperature at the combustor input for different reasons, namely, so as to make easier operating conditions of the basic engine components. On the other hand, this scheme brings about notable difficulties in organization of the combustion process in the supersonic jet because of the short stint of the air-fuel mixture inside the combustor and other features of high-velocity gas flows. By comparing the operating processes in the air-breathing jet engines, one can conclude that most of them, in particular, turbojets, ramjets, turbofans, and direct turbojets without a fuel supply to the afterburner operate by the same thermodynamic cycle with heat addition at p=const. Various schemes of air-breathing turbojets based on the thermodynamic cycle with heat addition at v=const have been suggested.

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