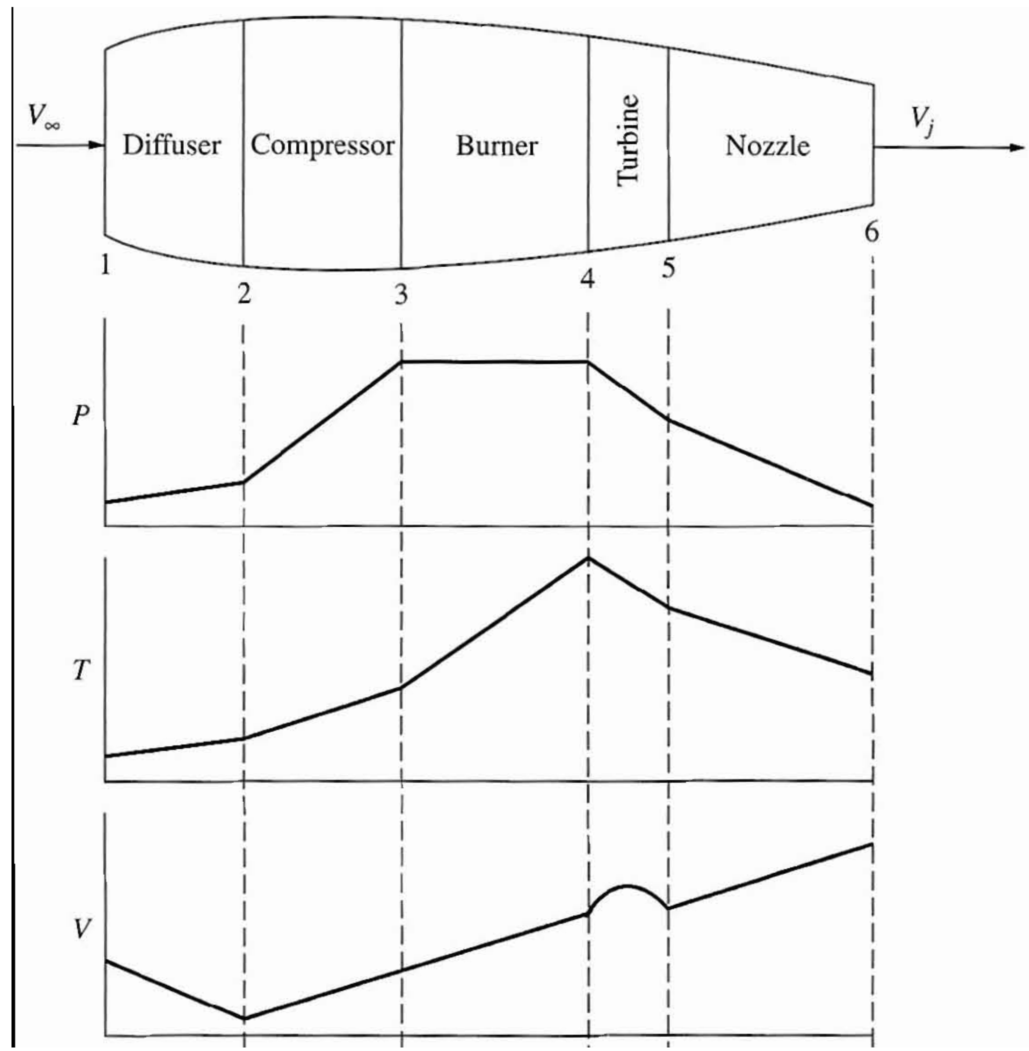
The Turbojet

Flow enters the inlet diffuser with essentially the free-stream velocity Vinf. In the diffuser (1-2), the air is slowed, with a consequent increase in P and T. It then enters the compressor (2-3), where work is done on the air by the rotating compressor blades, hence greatly increasing both P and T. After discharge from the compressor, the air enters the burner (or combustor), where it is mixed with fuel and burned at essentially constant pressure (3-4). The burned fuel-air mixture then expands through a turbine (4-5) which extracts work from the gas; the turbine is connected to the compressor by a shaft, and the work extracted from the turbine is transmitted via the shaft to operate the compressor. Finally, the gas expands through a nozzle (5-6) and is exhausted into the air with the jet velocity ***Vj.***

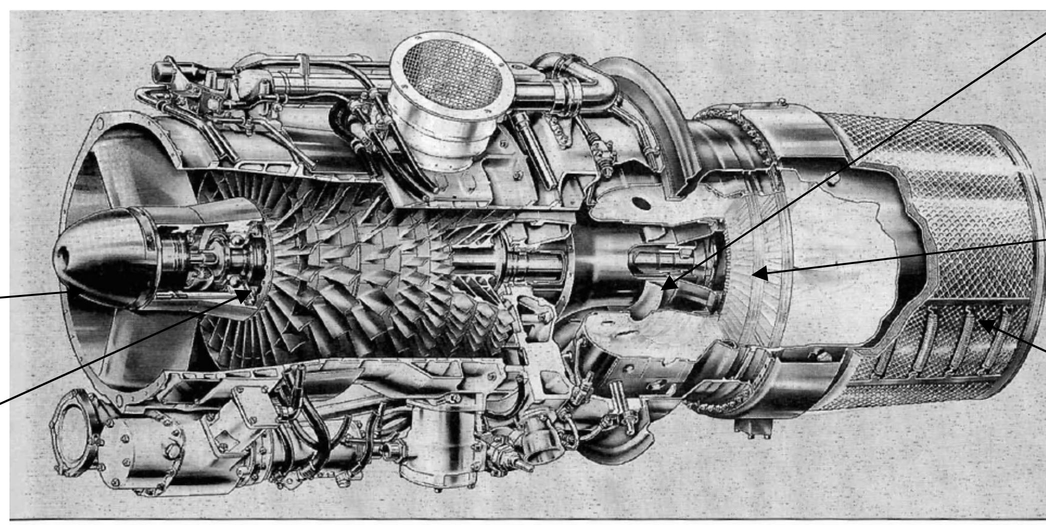


the calculation of jet engine thrust is carried out infinitely more simply by drawing a control volume around the engine, looking at the time rate of change of momentum of the gas flow through the engine, and using Newton's second law to obtain the thrust.

$$\boxed{T = (\dot{m}_{\text{air}} + \dot{m}_{\text{fuel}})\, V_j - \dot{m}_{\text{air}} V_\infty + (p_e - p_\infty)\, A_e}$$

where ***m_air,*** and ***m_fuel,*** are the mass flows of the air and fuel, respectively, p_e, is the gas pressure at the exit of the nozzle, p_inf is the ambient pressure, and **A,** is the exit area of the nozzle. The first two terms on the right side are the time rate of change of momentum of the gas as it flows through the engine. The pressure term (p_e – p_inf)A, is usually much smaller than the momentum terms. As a first approximation, it can be neglected.

A typical turbojet engine is shown in the photograph



Specific Fuel Consumption

The specific fuel consumption for a turbojet is defined differently than that for a reciprocating piston engine. The measurable primary output from a jet engine is thrust, whereas that for a piston engine is power. Therefore, for a turbojet the specific fuel consumption is based on thrust rather than power; to make this clear, it is frequently called the ***thrust*** specific fuel consumption. We denote it by **Ct,** and it is defined as

$$c_t = \text{weight of fuel burned per unit thrust per unit time}$$

$$c_t = \frac{\text{weight of fuel consumed for given time increment}}{\text{(thrust output) (time increment)}}$$

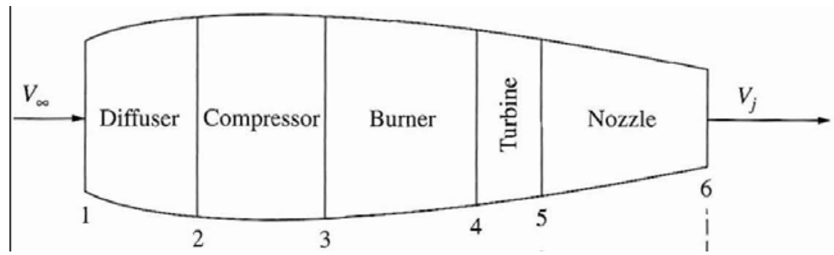
$$[c_t] = \frac{\text{lb}}{\text{lb}\cdot\text{s}} = \frac{1}{\text{s}} \qquad [c_t] = \frac{\text{N}}{\text{N}\cdot\text{s}} = \frac{1}{\text{s}}$$

However, analogous to the case of the piston engine, the thrust specific fuel consumption (TSFC) has been conventionally defined using the inconsistent time unit of hour instead of second.

$$[\text{TSFC}] = \frac{\text{lb}}{\text{lb}\cdot\text{h}} = \frac{1}{\text{h}}$$

Variations of Thrust and Specific Fuel Consumption with Velocity and Altitude

The mass flow of air entering the inlet is $\rho A V_\infty$
where **A** is the cross-sectional Area of the inlet (point 1).



As V_∞, is increased the mass flow rate increases;
the value of *Vj* is much more a function of the internal compression and combustion processes taking place inside the engine than it is of V_∞. Hence, the difference $V_j - V_\infty$, tends to decrease as V_∞ increases. These two effects tend to cancel, and therefore the thrust generated by a turbojet to be only a weak function of V_∞. Note that, especially at high altitude, T is a very weak function of Mach number.

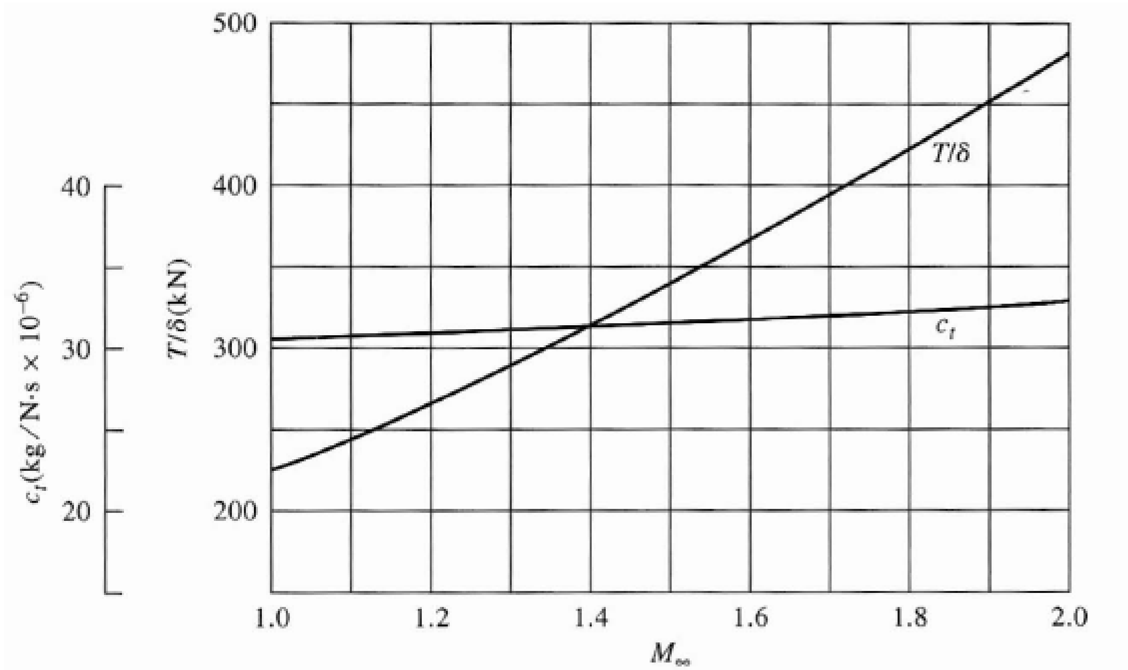
At low speed, the TSFC is about 1 lb of fuel/(1lb of thrust/h). However, at high velocities, the increase in TSFC should be taken into account. A reasonable approximation, ***for*** *Ma* < 1:

$$\boxed{\text{TSFC} = 1.0 + kM_\infty}$$

There is a strong altitude effect on thrust: $m = \rho A V_\infty$ hence *m,* is directly proportional to *p (density).* As the altitude increases, *p,* decreases. Therefore thrust also decreases with altitude. It is reasonable to express the variation of T with altitude in terms of the density ratio ρ / ρ_0
where *p* is the density at a given altitude and *p0* is sea-level density. Hence:

$$\boxed{\frac{T}{T_0} = \frac{\rho}{\rho_0}}$$

TSFC is constant with altitude



Why does T increase with ***Ma*** in the supersonic regime, whereas it is relatively constant in the subsonic regime? The answer lies in part in the large total pressures recovered in the supersonic inlet diffuser as ***Ma,*** increases. The ratio of total to static pressure is given by the isentropic relation:

$$\frac{p_{\text{total}}}{p_{\text{static}}} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\gamma/(\gamma-1)}$$

although the compression process in a supersonic inlet diffuser is not precisely isentropic. As ***Ma,*** increases, particularly for supersonic values, ***ptot*** becomes quite large. This is essentially the pressure of the flow as it enters the compressor, through which the pressure is further increased considerably. The net effect of these higher pressure levels inside the engine for supersonic flight is that ***Vj*** is greatly increased. B***oth*** $\boldsymbol{m_{air}}$, and ***Vj*** are increased substantially, hence both combine to increase T.

In regard to the thrust specific fuel consumption at supersonic speeds, there is only a small increase with ***Ma.***

$$\boxed{\frac{T}{T_{\text{Mach 1}}} = 1 + 1.18(M_\infty - 1)}$$