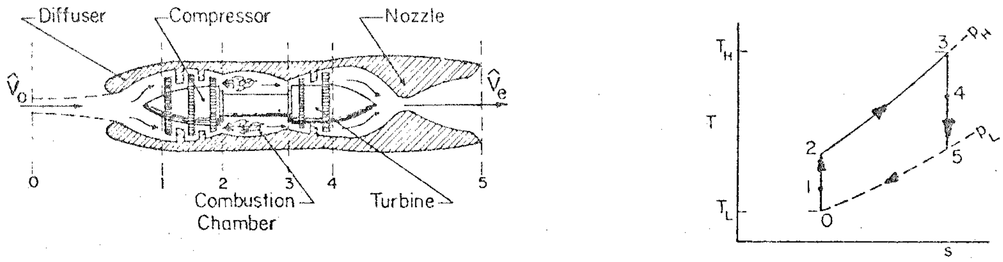

Fig. VD-1. Idealized Turbojet Engine

the TURBINE to a pressure level sufficient to generate the mechanical power required by the compressor. States 4–5; continued isentropic expansion to p_L in the fully expanded, ideal NOZZLE to accelerate the air leaving the engine to a high speed, V_e, to generate thrust. States 5–0; constant pressure heat rejection and deceleration returning the engine air to its undisturbed state (EXHAUST of the combustion products to be mixed in the atmosphere).

Example 2. A commercial aircraft cruises at a speed of 450 mph (201 m/s) at an altitude of 40,000 ft. The atmospheric conditions are p = 0.185 atm and T_o = 216 K. The engine's diffuser decelerates the air flow to 50 m/s and the pressure ratio of the compressor is 20. The limit cycle temperature, at turbine inlet, is 1700 K. The kinetic energy changes across the compressor, combustion chamber, and turbine are negligible in comparison to their work and heat interactions. Model the engine as an idealized turbojet and determine the turbine pressure ratio required to develop the compression power. What pressure ratio is then available across the nozzle and what is the exit gas velocity? Also what is the engine's thermal efficiency, efficiency ratio, propulsive efficiency and overall efficiency? How much thrust is developed per unit of exit area?

The engine operates in steady state. We will apply the energy equation to each of its components in succession. We begin with the *diffuser*

$$0 = \left(h_o^* + \frac{\hat{V}_o^2}{2}\right) - \left(h_1^* + \frac{\hat{V}_1^2}{2}\right) + \cancel{q_n} + \cancel{w_s}$$

Air is a perfect gas. Thus $h_o^* - h_1^* = c_p^*(T_o - T_1)$, $c_p^* = \gamma^* R/(\gamma^* - 1)$, and

$$T_1 = T_o + \frac{(\gamma^*-1)}{2\,\gamma^* R}\cdot(\hat{V}_o^2 - \hat{V}_1^2) = 216\text{ K} + \frac{0.33}{2\cdot 1.33}\left(\frac{28.97}{8.314}\right)(\text{g K})/\text{J}\cdot[(201)^2 - (50)^2]\,\text{m}^2/\text{s}^2\cdot 10^{-3}\,\text{J s}^2/(\text{g m}^2) = 232\text{ K}$$

The process is isentropic. Thus

$$p_1 = p_o\left(\frac{T_1}{T_o}\right)^{\gamma^*/(\gamma^*-1)} = 0.185\text{ atm}\left(\frac{232\text{ K}}{216\text{ K}}\right)^{1.33/0.33} = 0.247\text{ atm}$$

The compression process continues in the *compressor* in a similar manner; but in this stage the pressure ratio is specified, $r_{p,c} = 20$. Thus

$$p_H = p_2 = r_{p,c}\,p_1 = 20\cdot 0.247 = 4.94\text{ atm} \quad\text{and}\quad T_2 = T_1(r_p)^{(\gamma^*-1)/\gamma^*} = 232\text{ K}\,(20)^{0.33/1.33} = 488\text{ K}$$

The work required in the steady state, adiabatic compressor is

$$0 = c_p^*(T_2 - T_1) + \cancel{\Delta ke} + \cancel{q_n} + w_s \qquad |w_c| = c_p^*(T_2 - T_1) = \frac{1.33}{0.33}\left(\frac{8.314}{28.97}\right)\text{J/(g K)}\cdot(488 - 232)\text{K} = 296\text{ J/g}$$

and the heat added in the *combustor* is

$$q_H = c_p^*(T_H - T_2) = \frac{1.33}{0.33}\left(\frac{8.314}{28.97}\right)\text{J/(g K)}\cdot(1700 - 488)\text{K} = 1402\text{ J/g}$$