9-145 A turbojet aircraft that has a pressure rate of 9 is stationary on the ground. The force that must be applied on the brakes to hold the plane stationary is to be determined.

Assumptions **1** Steady operating conditions exist. **2** The air standard assumptions are applicable. **3** Air is an ideal gas with variable specific heats. **4** Kinetic and potential energies are negligible, except at the nozzle exit.

Properties The properties of air are given in Table A-17.

Analysis (*a*) Using variable specific heats for air,

Compressor:

$$T_1 = 290 \text{ K} \longrightarrow h_1 = 290.16 \text{ kJ/kg}$$
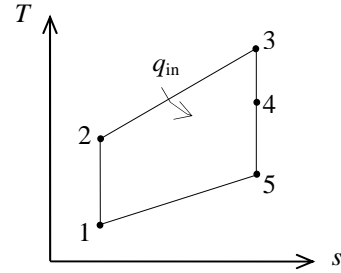$$P_{r_1} = 1.2311$$

$$P_{r_2} = \frac{P_2}{P_1} P_{r_1} = (9)(1.2311) = 11.08 \longrightarrow h_2 = 544.07 \text{ kJ/kg}$$

$$\dot{Q}_{in} = \dot{m}_{fuel} \times HV = (0.5 \text{ kg/s})(42{,}700 \text{ kJ/kg}) = 21{,}350 \text{ kJ/s}$$

$$q_{in} = \frac{\dot{Q}_{in}}{\dot{m}} = \frac{21{,}350 \text{ kJ/s}}{20 \text{ kg/s}} = 1067.5 \text{ kJ/kg}$$

$$q_{in} = h_3 - h_2 \longrightarrow h_3 = h_2 + q_{in} = 544.07 + 1067.5 = 1611.6 \text{ kJ/kg} \longrightarrow P_{r_3} = 568.5$$

Turbine:

$$w_{comp,in} = w_{turb,out} \longrightarrow h_2 - h_1 = h_3 - h_4$$

or

$$h_4 = h_3 - h_2 + h_1 = 1611.6 - 544.07 + 290.16 = 1357.7 \text{ kJ/kg}$$

Nozzle:

$$P_{r_5} = P_{r_3} \left(\frac{P_5}{P_3} \right) = (568.5) \left(\frac{1}{9} \right) = 63.17 \longrightarrow h_5 = 888.56 \text{ kJ/kg}$$

$$\dot{E}_{in} - \dot{E}_{out} = \Delta \dot{E}_{system}^{\nearrow 0 \text{ (steady)}}$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$h_4 + V_4^2 / 2 = h_5 + V_5^2 / 2$$

$$0 = h_5 - h_4 + \frac{V_5^2 - V_4^{2 \nearrow 0}}{2}$$

or

$$V_5 = \sqrt{2(h_4 - h_5)} = \sqrt{(2)(1357.7 - 888.56) \text{kJ/kg} \left(\frac{1000 \text{ m}^2/\text{s}^2}{1 \text{ kJ/kg}} \right)} = 968.6 \text{ m/s}$$

$$\text{Brake force} = \text{Thrust} = \dot{m}(V_{exit} - V_{inlet}) = (20 \text{ kg/s})(968.6 - 0) \text{m/s} \left(\frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} \right) = \mathbf{19{,}370 \text{ N}}$$