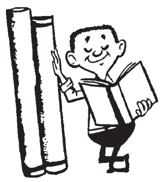
Jet Propulsion

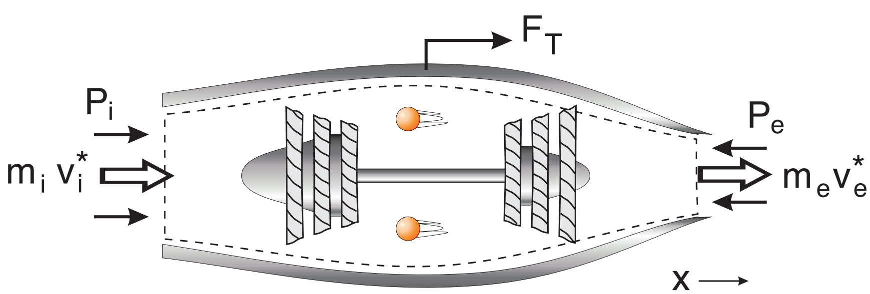


Reading	Problems
12.5	12.43, 12.44, 12.47

Gas Turbines for Aircraft Propulsion

- gas turbines are well suited to aircraft propulsion because of their favorable power-to-weight ratio
- gases are expanded in the turbine to a pressure where the turbine work is just equal to the compressor work plus some auxiliary power for pumps and generators i.e. the net work output is zero
- typically operate at higher pressure ratios, often in the range of 10 to 25

Conservation of Momentum



where v_i^* is the velocity of the aircraft

$$\frac{d(Mom)_{x,cv}}{dt} = (\dot{M}om)_{x,in} - (\dot{M}om)_{x,out} + \sum F_x$$

for steady flow $\Rightarrow \dfrac{d}{dt} = 0$ and

$$\dot{m}_i v_i^* - \dot{m}_e v_e^* + F_T + P_i A_i - P_e A_e = 0$$

Since the air-fuel mass ratio is high

$$\dot{m}_{fuel} << \dot{m}_i \qquad \Rightarrow \ \dot{m}_i \approx \dot{m}_e$$

and

$$P_e \approx P_i \approx P_{atm}$$

Therefore

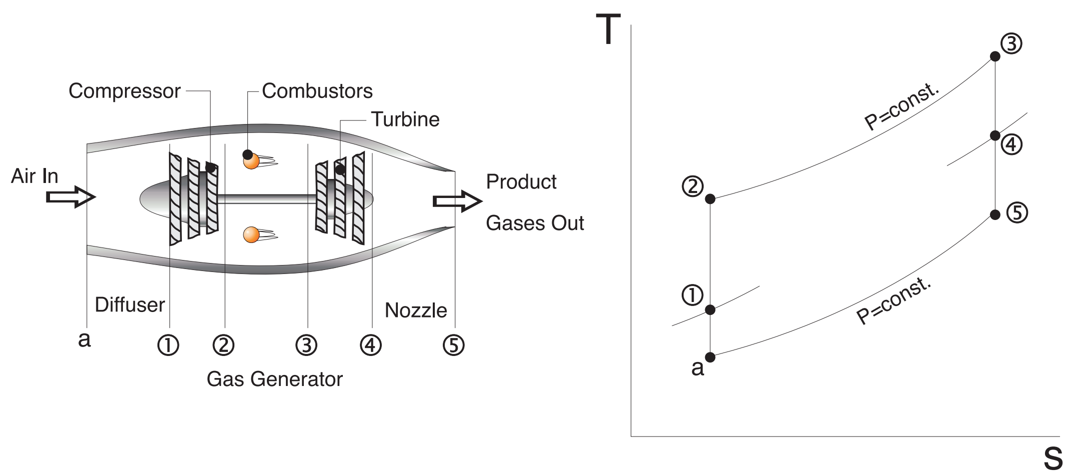
$$\begin{aligned} F_T &= \dot{m}_e v_e^* - \dot{m}_i v_i^* - \underbrace{P_{atm}(A_i - A_e)}_{negligible} \\ &= \dot{m}_i (v_e^* - v_i^*) \end{aligned}$$

Specific Impulse: $I = \dfrac{F_T}{\dot{m}_i} = v_e^* - v_i^* = \dfrac{\text{thrust}}{\text{mass}}$

Propulsive Power: $\dot{W}_T = F_T \, v_i^* \approx \dot{m}_i (v_e^* - v_i^*) v_i^*$

Propulsive Efficiency: $\eta = \dfrac{\dot{W}_T}{\dot{Q}_{in}}$

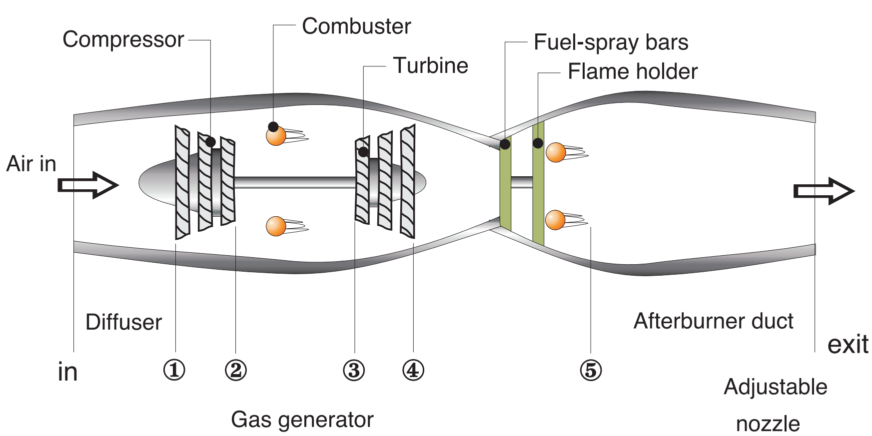
Turbojet Engine



Sections

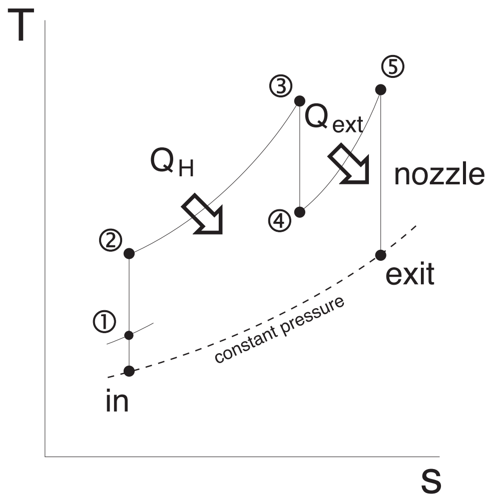
- **a-1**: **diffuser**
  - decelerates the incoming flow relative to the engine
- **1-4**: gas generator
  - compressor, combustor and turbine
  - turbine power just enough to drive the compressor
  - $P_T >> P_{atm}$
- **4-5**: nozzle
  - gases are expanded to produce a high velocity, $v_e^* >> v_i^*$ results in a thrust
  - $v_1^* << v_a^*$ $\qquad$ v_1^* is negligible
  - $v_4^* << v_5^*$ $\qquad$ v_4^* is negligible

Afterburner



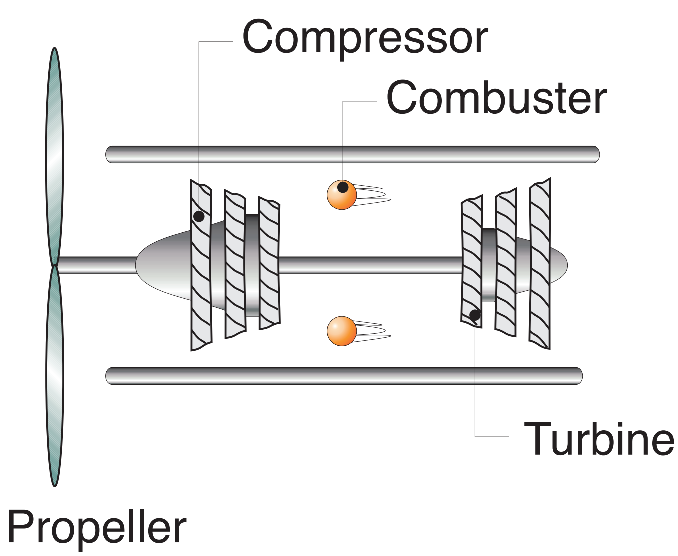
- similar to a reheat device
- produces a higher temperature at the nozzle inlet, $T_5 > T_4$

- exit velocity proportional to $v_e^* \propto \sqrt{2c_p(T_4 - T_e)}$
- afterburner is used to increase T_4 to T_5
- similar to a reheat device
- produces a higher temperature at the nozzle inlet



Other Types of Engines

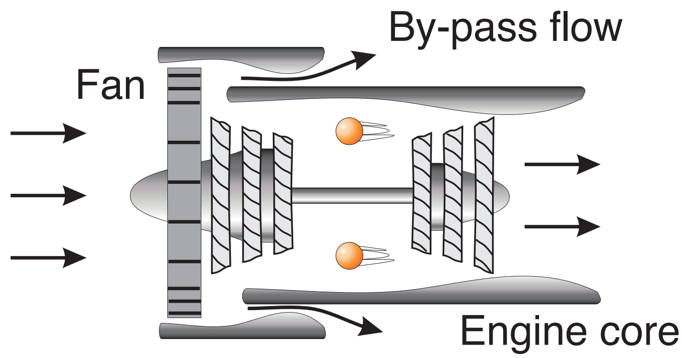
1. Turbo-Prop Engine



- gas turbine drives the compressor and the propeller
- works by accelerating large volumes of air to moderate velocities
- propellers are best suited for low speed ($<$ 300 mph) flight
- by-pass ratio of 100:1 or more
- by-pass ratio defined as:

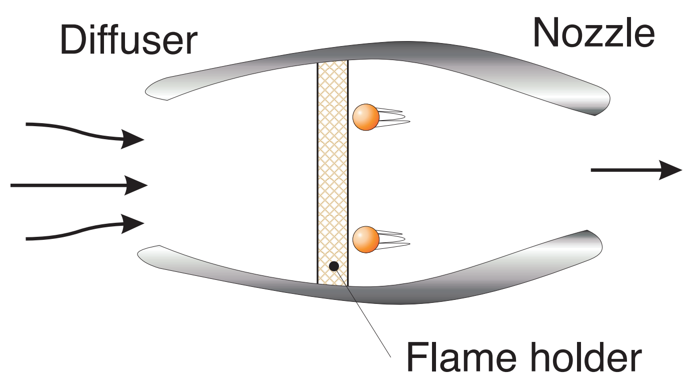
$$\text{bypass ratio} = \frac{\text{mass flow bypassing the combustion chamber}}{\text{mass flow through the combustion chamber}}$$

2. **Turbo-Fan Engine** (Ducted Turbo-Prop Engine)



- high speed exhaust gases are mixed with the lower speed air in the by-pass resulting in a considerable noise reduction
- typically used for speeds up to 600 mph
- typical by-pass ratios are 5-6

3. **Ramjet**



- compression is achieved by decelerating the high-speed incoming air in the diffuser
- aircraft must already be in flight at a high speed

4. **Pulse Jet Engine**

- similar to a ram jet but lets in a slug of air at a time and then closes a damper during the combustion stage
- used in German V1 missile
- the combustion firing rate was approximately 40 cycles/sec with a maximum flight velocity of 600 mph

PROBLEM STATEMENT:

An airplane is flying at $\mathbf{950}\ \boldsymbol{km/h}$ at an altitude where the pressure is $\mathbf{74.26}\ \boldsymbol{kPa}$ and the temperature is $\mathbf{-23.15}\ {}^\circ\boldsymbol{C}$. The airplane is powered by a jet engine having a maximum cycle pressure of $\mathbf{280}\ \boldsymbol{kPa}$ and a maximum cycle temperature of $\mathbf{1090}\ {}^\circ\boldsymbol{C}$. The air flow rate is $\mathbf{100}\ \boldsymbol{kg/s}$. Determine the maximum propulsive force that can be produced by the engine. Assume that the velocities at the entrance to the compressor and the exit of the turbine are negligible.