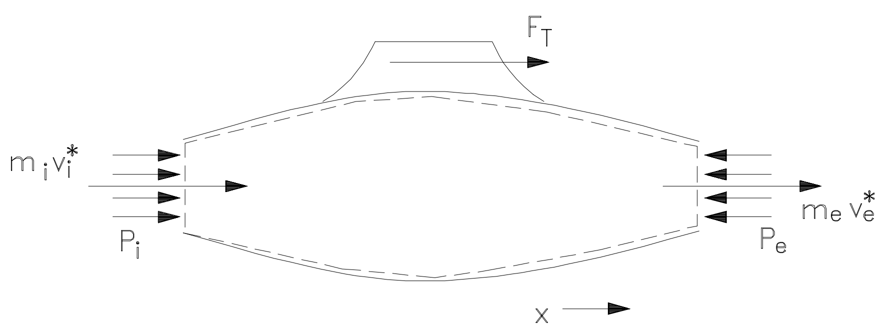
Week 9: Lecture 1

Gas Turbines for Aircraft Propulsion

- gas turbines are well suited to aircraft propulsion because of their favorable power-to-weight ratio
- the exhaust pressure of the turbine will be greater than that of the surroundings
- since the gases leave at a high velocity, the change in momentum that the gas undergoes gives a thrust to the aircraft
- 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



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

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

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

Therefore

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

Week 9: Lecture 1

$$\text{Specific Impulse:} \quad I = \frac{F_T}{\dot{m}_i} = v_e^* - v_i^*$$

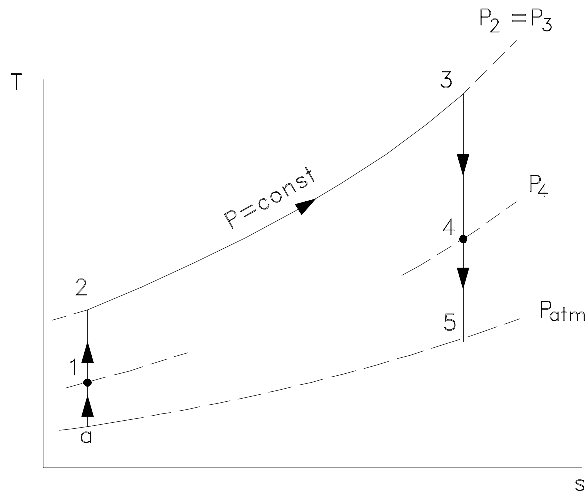
$$\text{Propulsive Power:} \quad \dot{W}_T = F_T v_i^* \approx \dot{m}_i (v_e^* - v_i^*) v_i^*$$

$$\text{Propulsive Efficiency:} \quad \eta = \frac{\dot{W}_T}{\dot{Q}_{in}}$$

Since the net work output is zero, we must define the propulsive efficiency as propulsive power over the heat flow rate in the combustion process. This then becomes a measure of how efficiently the energy released during the combustion process is converted to propulsive energy.

Week 9: Lecture 2

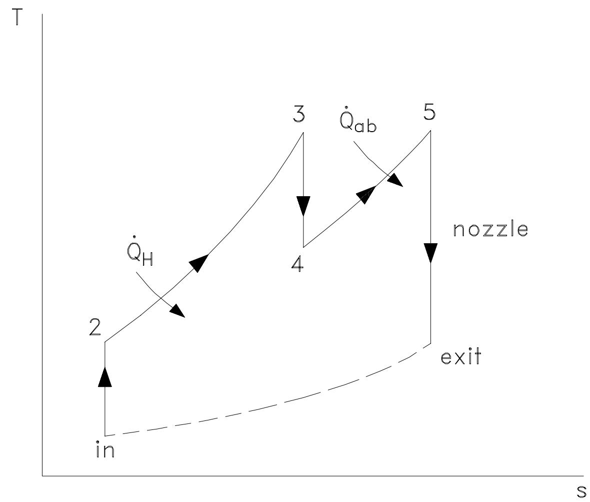
Turbojet



- **a-1**: diffuser
  - decelerates the incoming flow relative to the engine
  - a pressure rise known as a ram effect occurs
- **1-4**: gas generator
  - compressor, combustor and turbine
  - turbine power just enough to drive the compressor
  - air and fuel are mixed and burned in the combustion chamber at constant pressure
  - $P_T >> P_{atm}$
- **4-5**: nozzle
  - gases leave the turbine significantly higher in pressure than atmospheric pressure
  - gases are expanded to produce a high velocity
  - $v_e^* >> v_i^*$
  - results in a thrust

Week 9: Lecture 2

Afterburner



By performing a 1st law energy over the nozzle we can obtain an expression for the exit velocity in terms of the entrance temperature to the nozzle.

$$\frac{d\cancel{E}^{\,0}}{dt} = \cancel{\dot{Q}}^{\,0} + \cancel{\dot{W}}^{\,0} \left\{ \dot{m} \left[h_4 + \frac{(v_4^*)^2}{2} \right] \right\} - \left\{ \dot{m} \left[h_e + \frac{(v_e^*)^2}{2} \right] \right\}$$

If we assume that the air velocity leaving the turbine is relatively small, the kinetic energy term at 4 can be assumed to go to zero and we get

$$\begin{aligned} v_e^* &= \sqrt{2(h_4 - h_e} \\ &= \sqrt{2c_p(T_4 - T_e)} \end{aligned}$$

- 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

Week 9: Lecture 3

Other Types of Engines

1. Turbo-prop Engine

   - gas turbine drives the compressor and the propeller
   - propellers are best suited for low speed (< 300 mph) flight
   - by-pass ratio defined as

$$by - pass\ ratio = \frac{mass\ flow\ by - passing\ the\ combustion\ chamber}{mass\ flow\ through\ the\ combustion\ chamber}$$

   - by-pass ratio of 100:1 or more

2. Turbo-fan Engine (Ducted Turbo-prop Engine)

   - best choice for fuel economy and speed
   - high speed exhaust gases are mixed with the lower speed air in the by-pass resulting in a considerable noise reduction
   - by-pass ratio can be adjusted
   - by-pass provides thrust for takeoff
   - the core provides thrust for cruising
   - used for speeds up to 600 mph
   - increasing the by-pass ration results in increased thrust
   - typical by-pass ratios are 5-6

3. Ramjet

   - no moving parts
   - compression is achieved by decelerating the high-speed incoming air in the diffuser
   - aircraft must already be in flight at a high speed