Jet and Rocket Propulsion

AE4451

LECTURE 1

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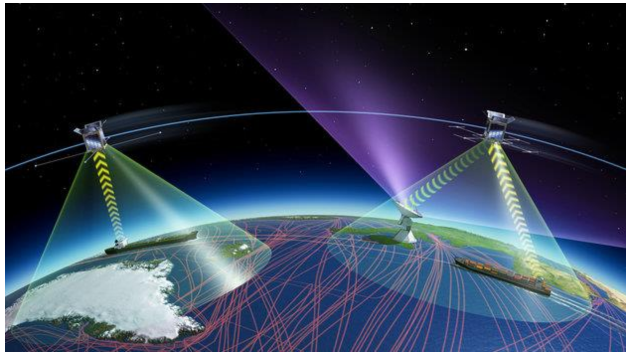
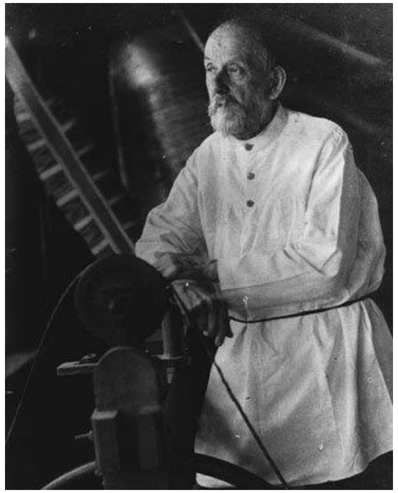
Introduction

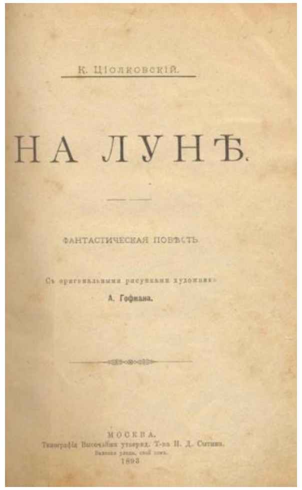
What should a propulsion system do?

- accelerate an object
- maintain velocity/positioning of object

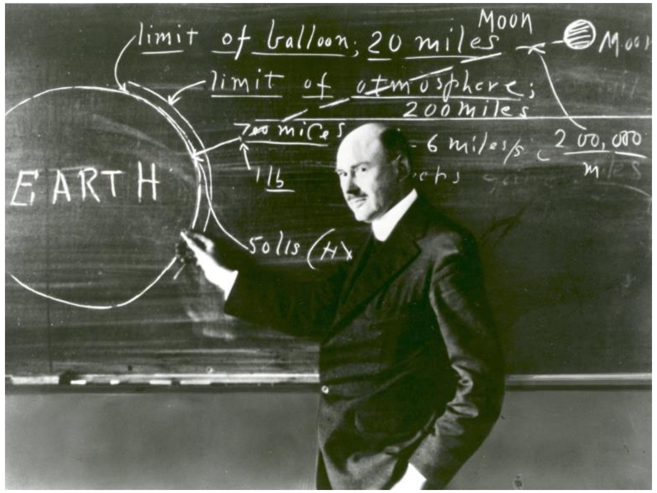


Modern notions of propulsion systems date back to Tsiolkovsky (1903)

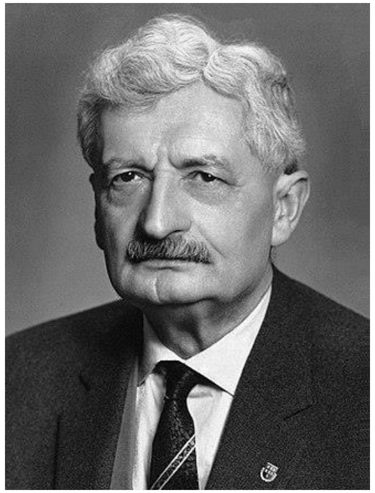




K. E. Tsiolkovsky (1857- 1935)



R. H. Goddard (1882 - 1945)



H. J. Oberth (1894 - 1989)

Introduction

Important considerations for a propulsion system

- provide adequate thrust for required maneuvers

  - aircraft: takeoff, climb, cruise, adjustment of trajectory
  - spacecraft: launch, orbit transfer, deorbiting, planetary mission

- possess high efficiency and sufficient lifetime

  - maximize thrust/input energy ratio
  - low weight
  - durable: structural and material components

Air-breathing engines and **rockets**

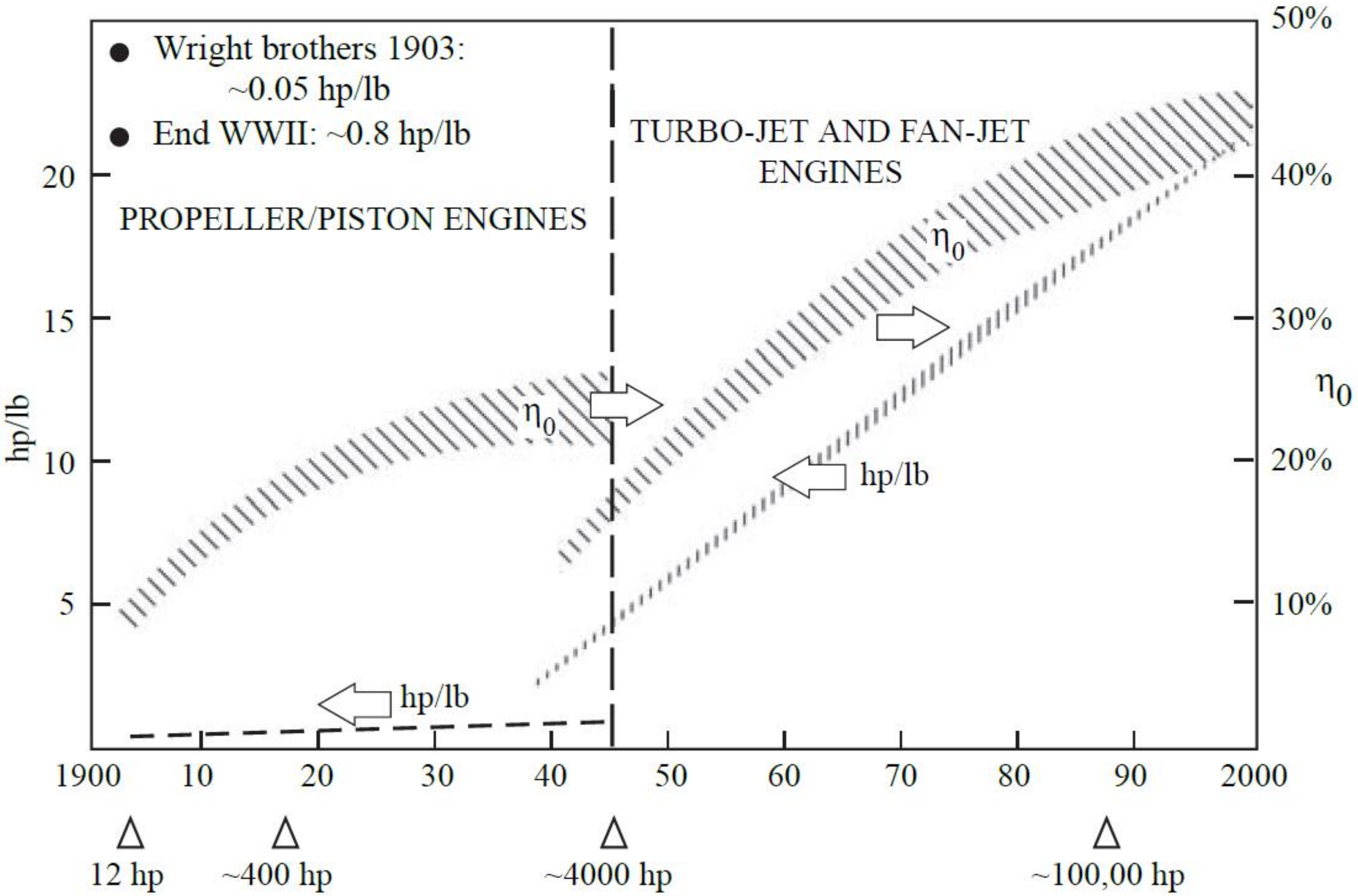
first chemical rocket (1926, Goddard)

Air-breathing engines

Introduction

Development history

significant increases in both efficiency and power-weight ratio

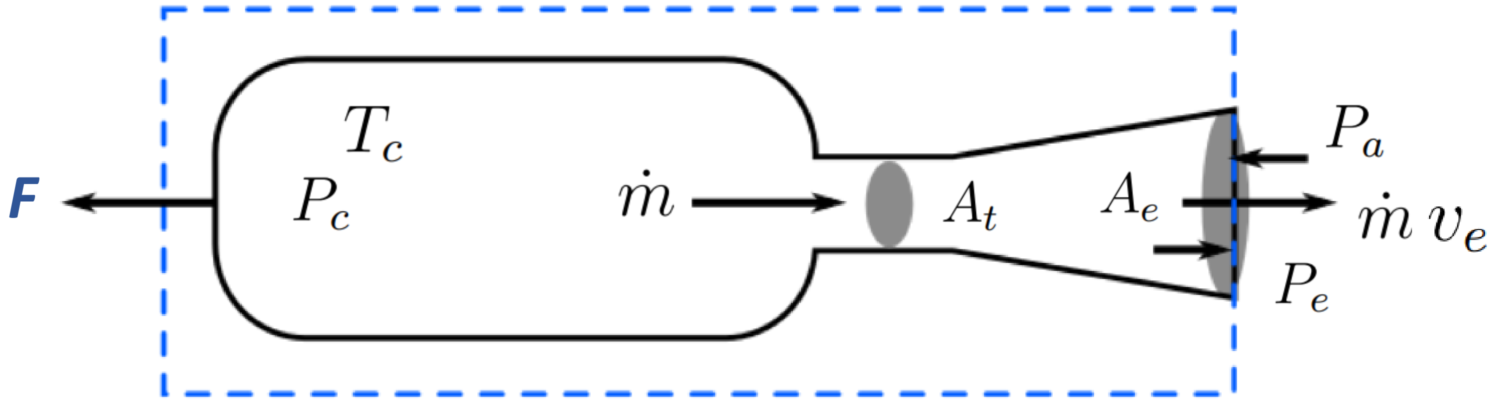


Some basic concepts

Thrust

control volume

combustion chamber → throat → nozzle



for steady flow, $\dot{m} = \rho v A$ constant

$$F = \dot{m} v_e + (P_e - P_a) A_e$$

jet thrust pressure thrust

notice independence of the thrust on the velocity of vehicle

assumed: axisymmetric flow

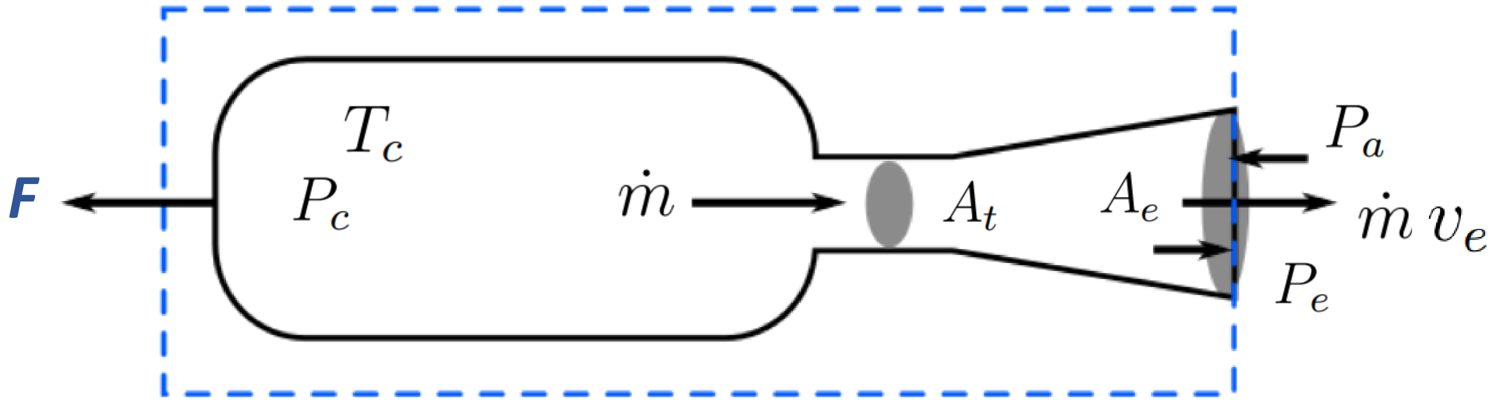
in ground testing of plasma thrusters, seek to minimize P_a

Some basic concepts

Total impulse and specific impulse

control volume

combustion chamber → throat → nozzle



total impulse $I_t = \int_0^t F\,dt$

specific impulse $I_s = \frac{\int_0^t F\,dt}{g \int \dot{m}\,dt}$ → $I_s = \frac{F}{\dot{m}g}$ alternatively, $\frac{v_e}{g}$

why is *Is* key? $$\frac{m_f + m_p}{m_f} = e^{\frac{\Delta v}{g I_s}}$$

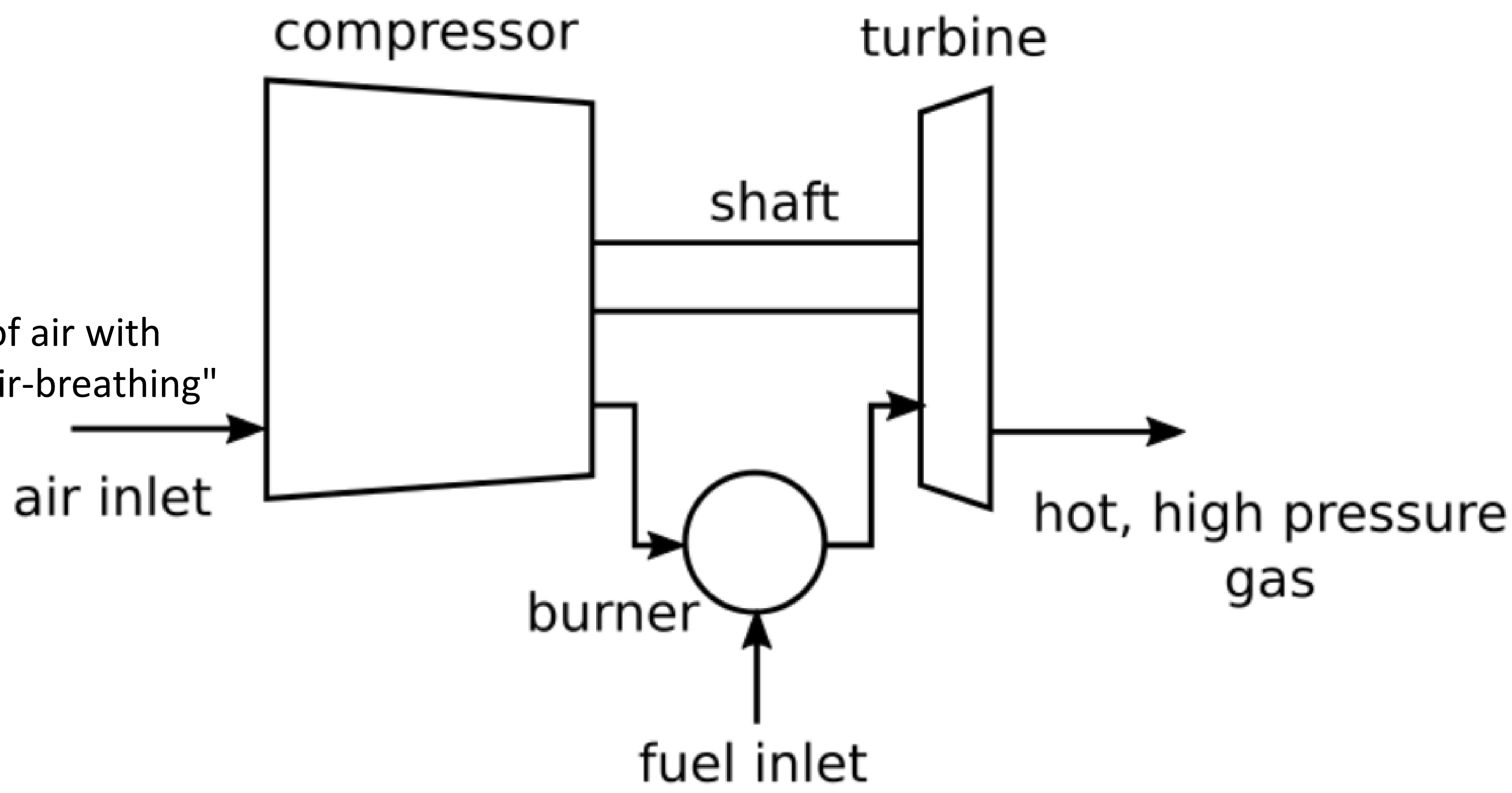
Tsiolkovsky's rocket equation (1903)

m_p = propellant mass
m_f = final mass
Δv = velocity change for maneuver

Structure and types

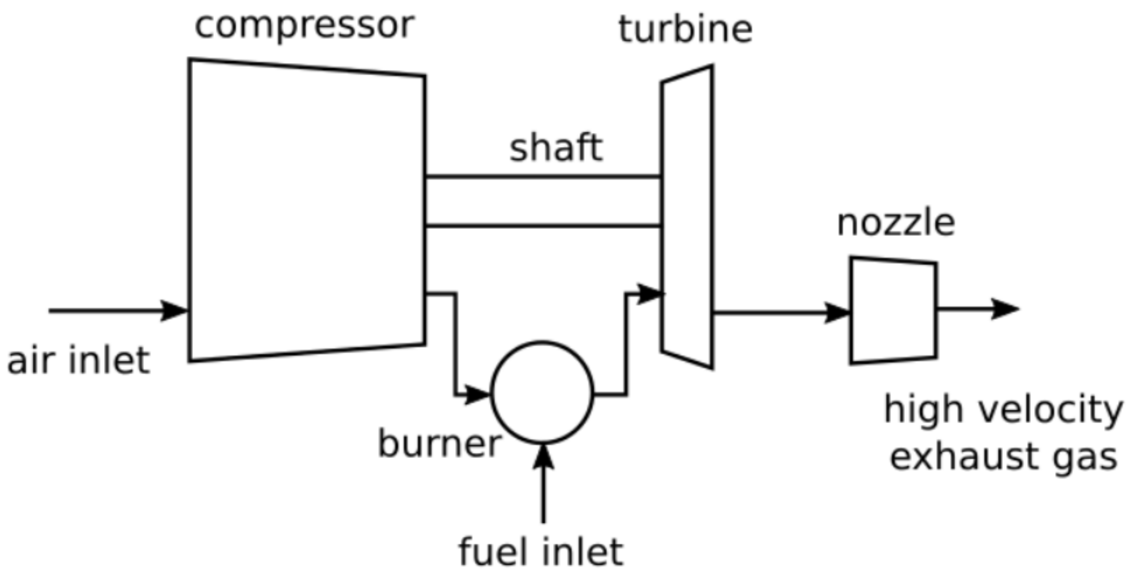
Gas generator: common to the different jet systems

combination of air with
fuel, hence "air-breathing"



Structure and types

1. Turbojet

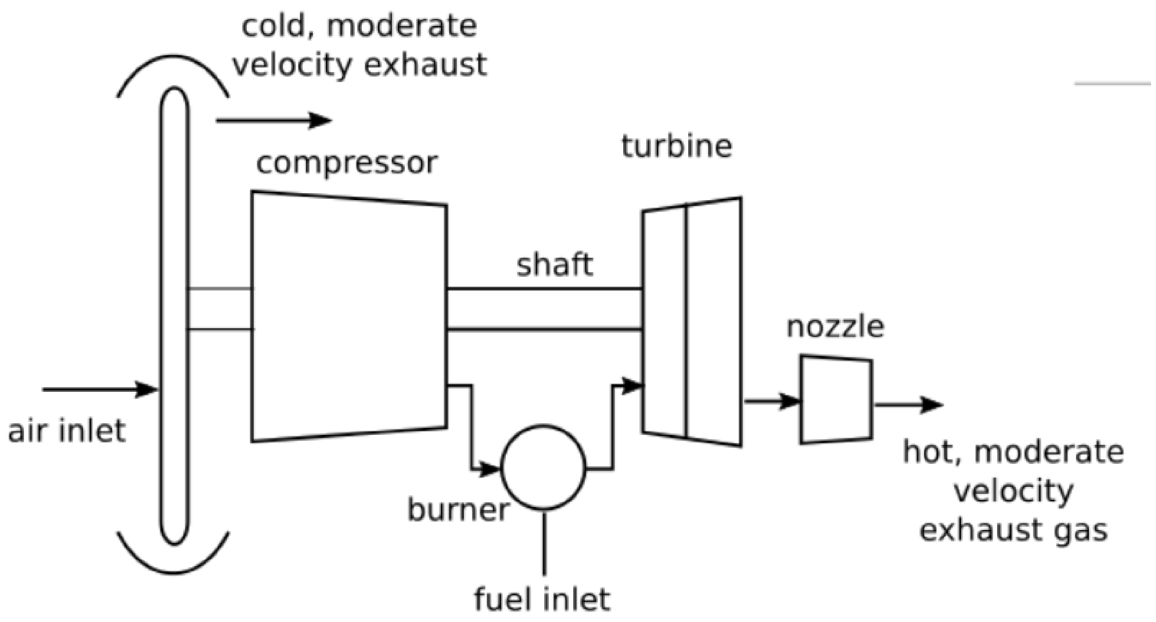


- gas generator coupled to a nozzle
- first uses: Ohain (1939) and Whittle (1941)

compress air at inlet → mix with fuel and burn → expand through turbine and nozzle

Structure and types

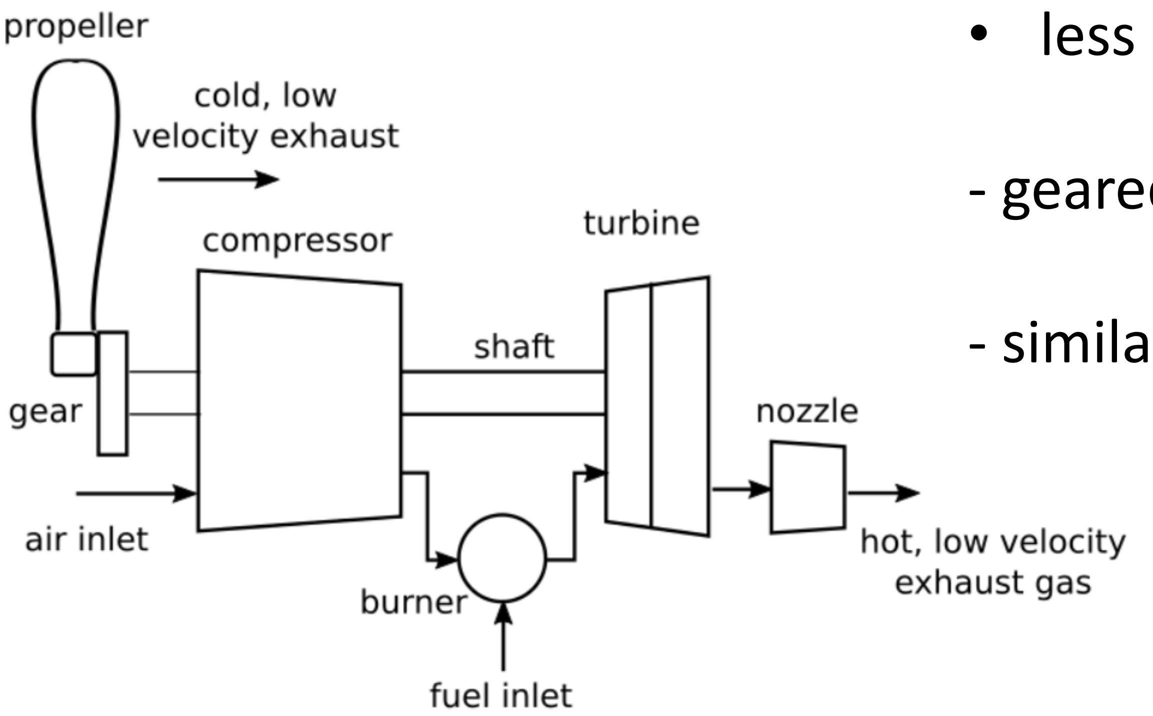
2. Turbofan



- more economical than turbojet in subsonic flight: large mass of air driven into engine

- disadvantage: larger frontal section, heavier and drag increased

3. Turboprop



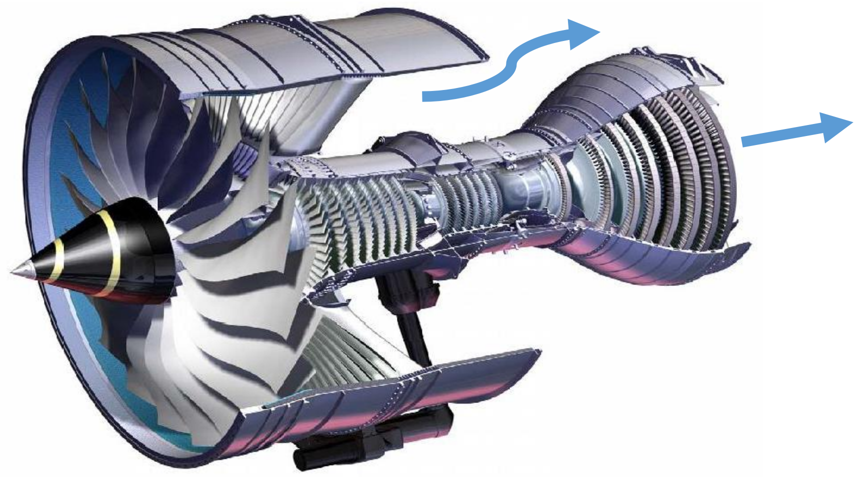
- suited for low-speed flight
- less efficient than turbofan (lacks duct)

- geared transmission between the propeller and engine shaft
- similar propeller tips speeds to turbine are required; reduction in rotational speed needed

Some basic concepts

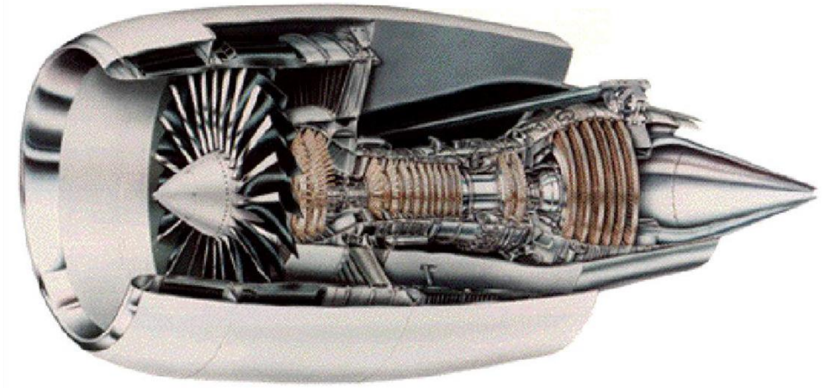
Bypass ratio

$$\text{BPR} = \frac{\text{mass flow rate of bypass stream}}{\text{mass flow rate through turbine}}$$



high-bypass ratio turbofan

what BPR for this turbojet?



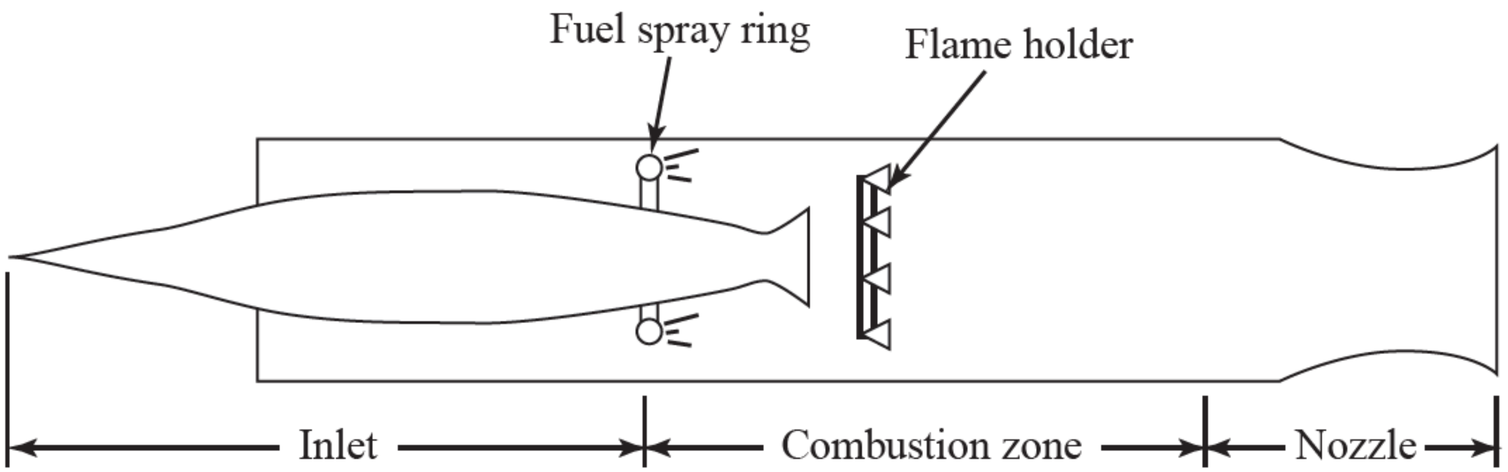
low-bypass ratio turbofan

aim of bypass:

- increase mass flow (and yield thrust) while lowering fuel consumption

Structure and types

4. Ramjet



best suited for supersonic velocity operation to ensure large pressure increase

- standard ramjet: combustion at low subsonic velocities – deceleration of air and large pressure losses + temperature increase

- scramjet: supersonic combustion ramjet

Structure and types

Performance