PS41 Propulsion – Chapter 6

Parametric cycle analysis of ideal engines

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Objectives

Introduction

- Parametric cycle analysis

Steps

- Assumptions of ideal cycle analysis
- Steps of parametric cycle analysis

Ideal Engines

- Ideal turbojet
- Ideal ramjet
- Ideal turbofan (TD)

Introduction (1)

Cycle analysis studies the thermodynamic changes of the working fluid (air and products of combustion in most cases) as it flows through the engine.

Parametric cycle analysis (design-point or on-design)

- Performance of engines @ different flight conditions
- Values of design choice (eg. Compressor pressure ratio)
- Design limit parameters (eg. Combustor exit temperature)

Engine performance analysis (off-design)

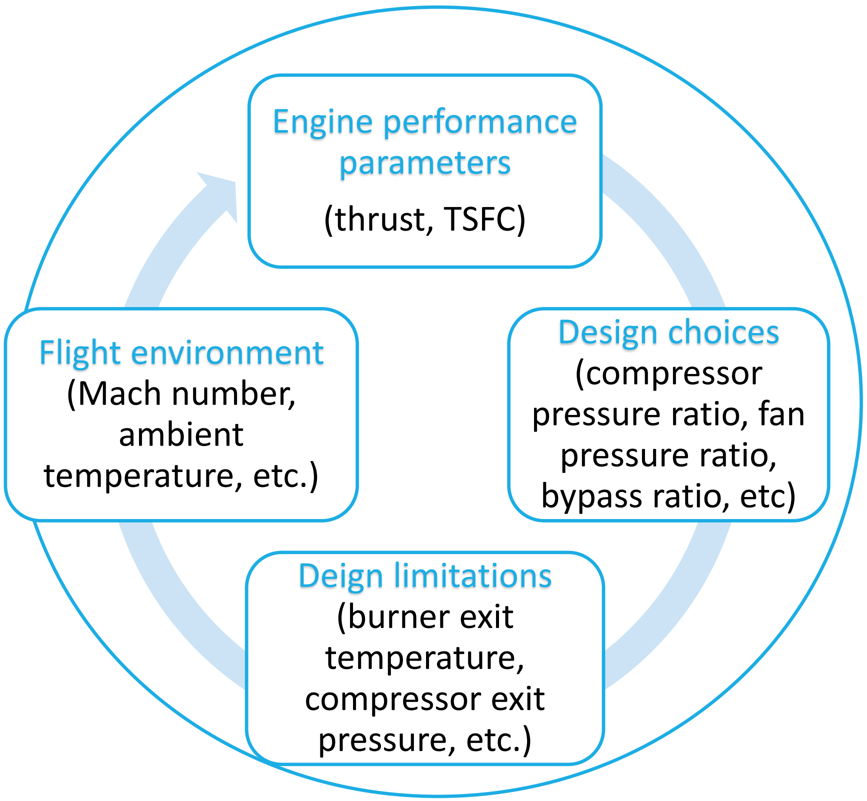
- Performance of a specific engine at all flight conditions
- Throttle settings

Change in properties

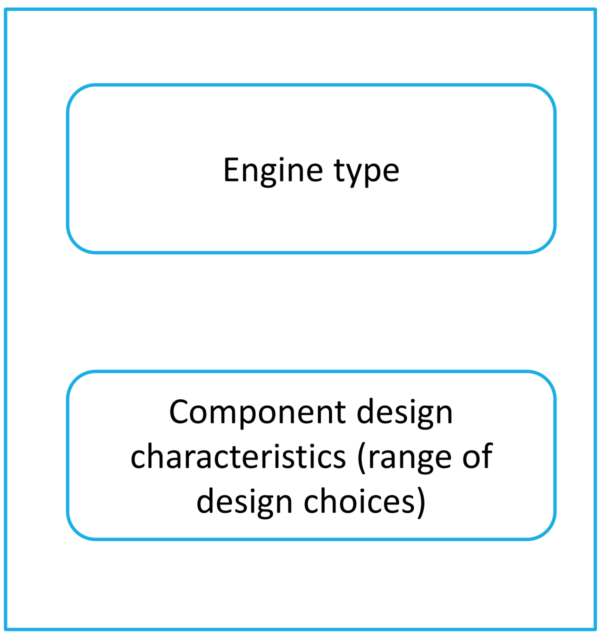
Plotted engine ✗ Geometry

Introduction (2)

Objective of
parametric cycle analysis



Satisfy a particular need



The parametric cycle analysis of ideal engines allow us to look at the characteristic of aircraft engines in the simplest possible ways so that they can be compared.

Notation (1)

The total or stagnation temperature:

$$T_t = T(1 + \frac{\gamma - 1}{2} M^2)$$

The total or stagnation pressure:

$$P_t = P\left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma - 1}}$$

A ratio of total pressure across a component : π

- With a subscript indicating the component: d for diffuser (inlet), c for compressor, b for burner, t for turbine, n for nozzle, and f for fan.

$$\pi_a = \frac{\text{total pressure leaving component } a}{\text{total pressure entering component } a}$$

Similarly, the ratio of total temperature: τ

$$\tau_a = \frac{\text{total temperature leaving component } a}{\text{total temperature entering component } a}$$

Notation (2)

Exceptions:

- The total/static temperature and pressure ratios of the freestream (τ_r and π_r):

$$\tau_r = \frac{T_{t0}}{T_0} = 1 + \frac{\gamma - 1}{2} M_0^2$$

$$\pi_r = \frac{P_{t0}}{P_0} = \left(1 + \frac{\gamma - 1}{2} M_0^2\right)^{\frac{\gamma}{\gamma-1}}$$

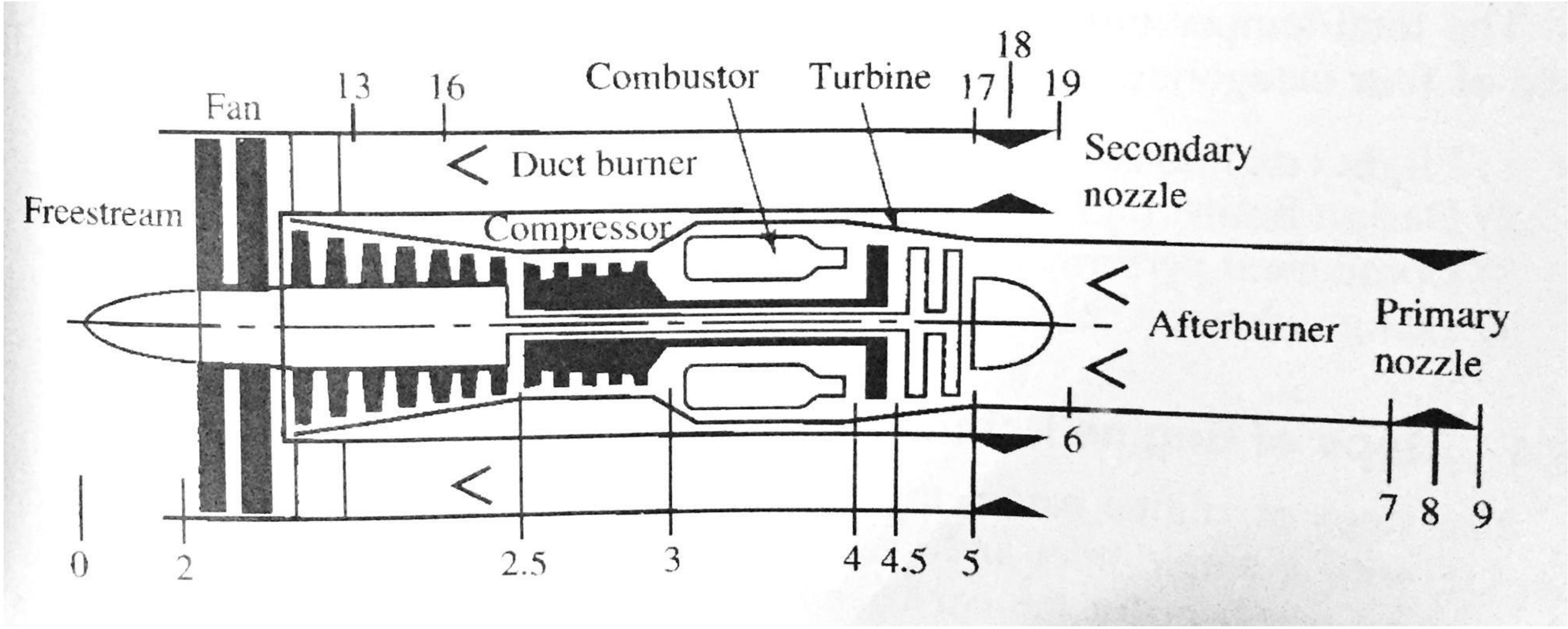
  Thus, the total temperature and pressure of the freestream can be written as

$$T_{t0} = T_0\tau_r,\ P_{t0} = P_0\pi_r$$

- The ratio of the burner exit enthalpy to ambient enthalpy:

$$\tau_\lambda = \frac{h_{t\ burner\ exit}}{h_0} = \frac{\left(c_p T_t\right)_{burner\ exit}}{\left(c_p T\right)_0}$$

Notation - Station numbering



Assumptions of ideal cycle analysis

For analysis of ideal cycles, we assume the following:

- There are isentropic (reversible and adiabatic) compression and expansion processes in the inlet (diffuser), compressor, fan, turbine, and nozzle. Thus we have the following relationships:

$$\tau_d = \tau_n = 1, \pi_d = \pi_n = 1, \tau_c = \pi_c^{\frac{\gamma-1}{\gamma}}, \tau_t = \pi_t^{\frac{\gamma-1}{\gamma}}$$

- Constant-pressure combustion ($\pi_b = 1$) is idealized as a heat interaction into the combustor. The fuel flow rate is much less than the airflow rate through the combustor such that

$$\pi_b = 1, \quad \frac{\dot{m}_f}{\dot{m}_c} \ll 1 \text{ and } \dot{m}_c + \dot{m}_f \cong \dot{m}_c$$

- The working fluid is air that behaves as a perfect gas with constant specific heats.
- The engines exhaust nozzle expand the gas to the ambient pressure ($P_9 = P_0$)

Design Inputs

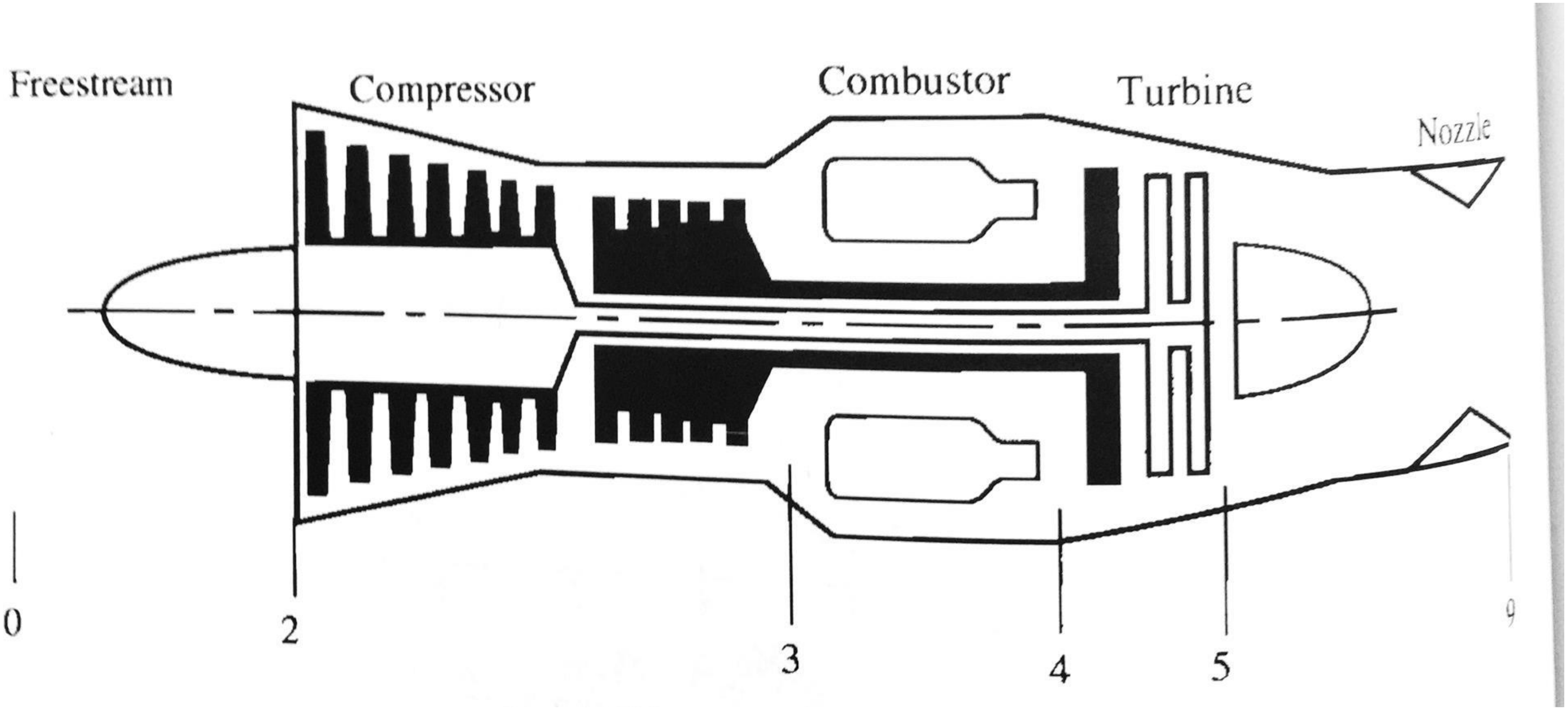
Flight conditions: $P_0, T_0, M_0, c_p, \tau_r, \pi_r$

Design inputs: $\left(c_p T_t\right)_{burner\ exit}$

Component performance: π_d, π_b, π_n, etc.

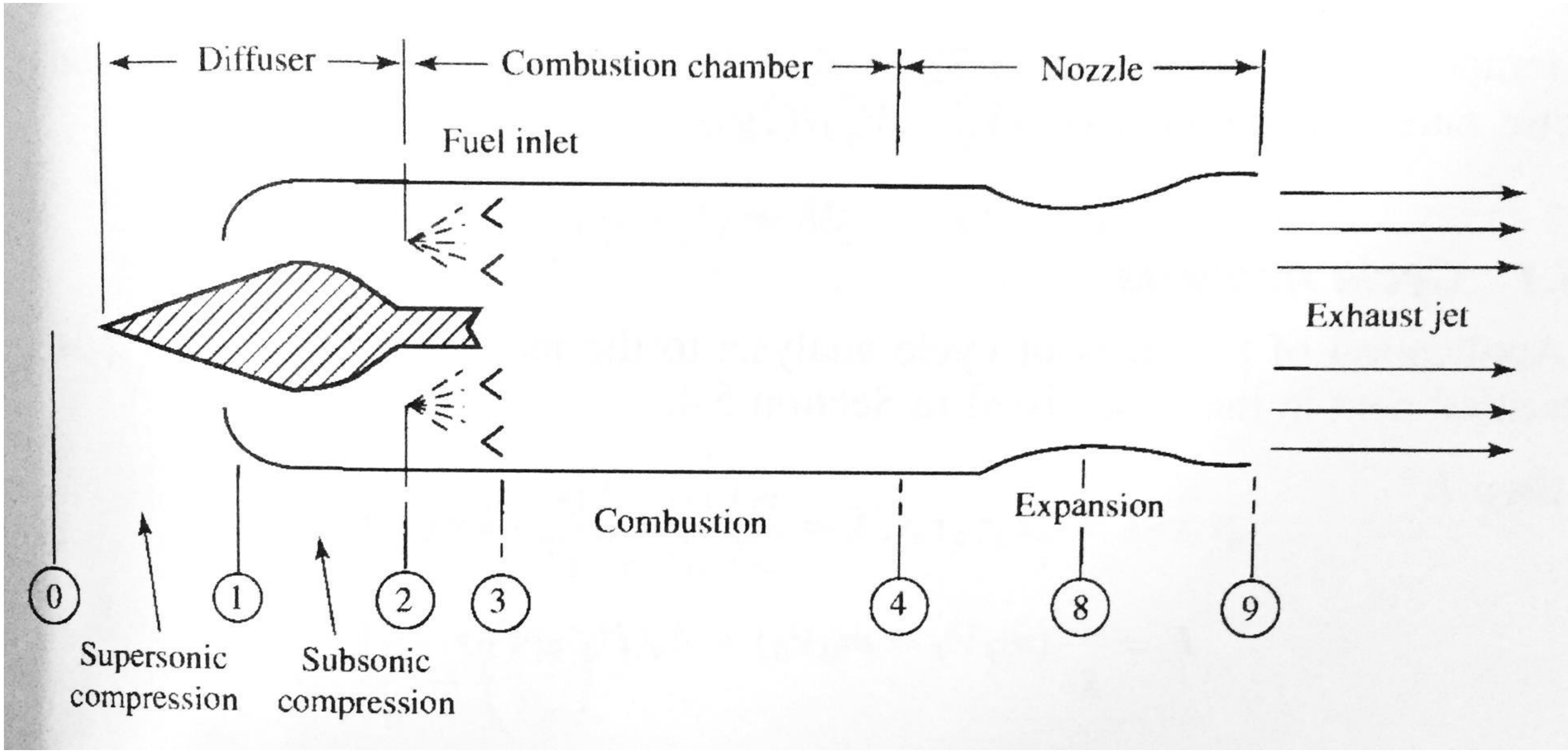
Design choices: π_c, π_f, etc.

Ideal Turbojet



Station numbering of ideal turbojet engine.

Ideal Ramjet



Ideal Turbofan