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School of Aerospace Engineering

Aircraft Propulsion: Review

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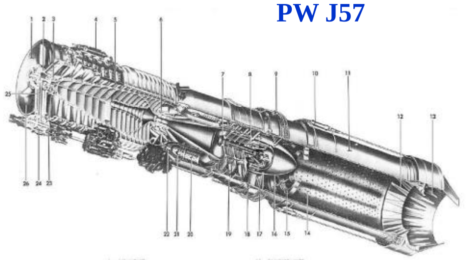
Conventional Jet Engine Architectures

PW J57



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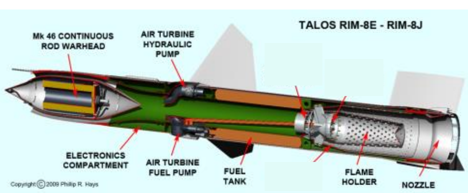

Bendix

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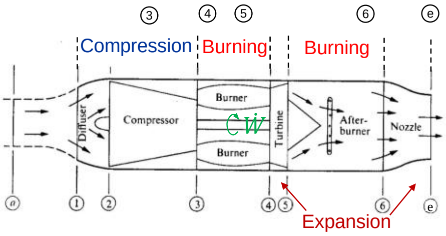
Jet (Aircraft) Engine Architectures

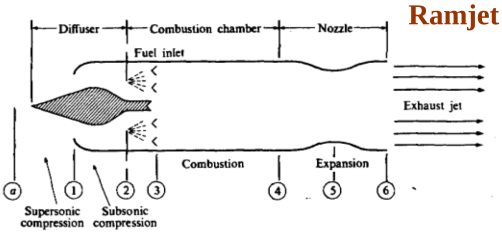
- Propulsion from exhaust of accelerated propellant

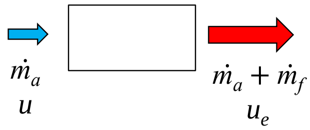


Turbo-engines

jet
fan
prop
shaft

Ramjet





Figures adapted from Hill and Petersen, *Mechanics and Thermodynamics of Propulsion*, Addison Wesley

AE4803

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Aircraft Propulsion Performance

- Performance parameters
  - relevant to making a "good" propulsion system
    - **Specific Thrust (ST)**

$$\equiv \frac{\tau}{\dot{m}_a}$$

    - **Specific Fuel Consumption (SFC)**

$$TSFC \equiv \frac{\dot{m}_f}{\tau} \qquad = \frac{u}{\eta_o \Delta h_R}$$

    - **engine efficiencies, η**

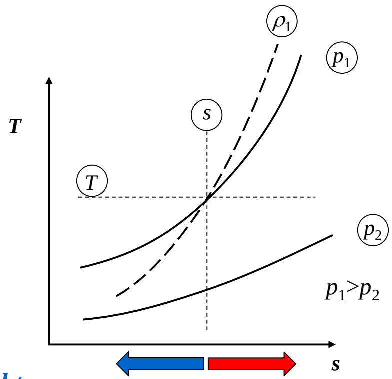
overall ***thermal (cycle)*** ***propulsive***

$$\eta_o \equiv \frac{\tau u}{\dot{m}_f \Delta h_R} \qquad \eta_{th} \equiv \frac{\Delta \dot{KE}}{\dot{m}_f \Delta h_R} \qquad \eta_p \equiv \frac{\tau u}{\Delta \dot{KE}} \qquad \eta_o = \eta_{th} \eta_p$$

AE4803

T-s (Mollier) Diagrams

- Often drawing an engine cycle on a T-s state diagram is very helpful to understanding performance
  - isothermal process?
  - isentropic process?
  - isobaric process?
  - isochoric (isodensity) process?



Note: p lines diverge to the right

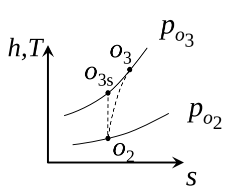
Cooling **Heating or Irrev.**

Component Adiabatic Efficiency

- η≡ ratio of enthalpy change across device and enthalpy change if device was: 1) reversible, 2) adiabatic, 3) same inlet state, 4) same exit pressure AND must be < 1
  - e.g. for compressor,

$$\boxed{\eta_c = \frac{h_{o_{3s}} - h_{o_2}}{h_{o_3} - h_{o_2}}} \quad \text{OR} \quad \cancel{\eta_c = \frac{h_{o_3} - h_{o_2}}{h_{o_{3s}} - h_{o_2}}}$$

$$= \frac{\dot{W}_{c,ideal}}{\dot{W}_{c,actual}} < 1$$



Single-point Design/On-design Analysis

- **First** - understand specific thrust and fuel burn/SFC performance for ***varying engine designs***
  – changing *design values:*
    - BPR (β) • OPR (Pr_o) • FPR (Pr_f) • T4
    - most other values constrained, e.g., fuel heating value (~43MJ/kg_{fuel} for standard jet fuels), and component (polytropic) efficiencies
  – changing flight conditions
    - altitude: T_a, p_a (or T_∞, p_∞)
    - flight Mach # M (or flight velocity u)
  – cycle design typically focused on point **where most efficient operation is desired** (usually cruise)

Improved Engine Performance

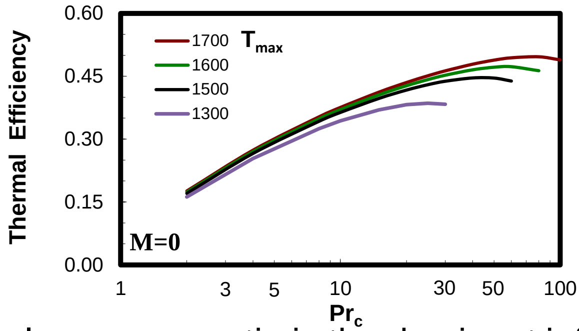
- Generally want to increase overall efficiency

$$\eta_o = \eta_{th} n_p$$

1. How to improve thermal (cycle) efficiency?

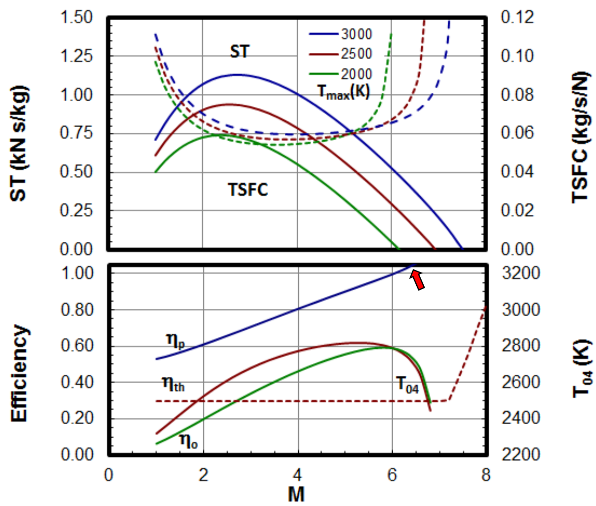
2. How to improve propulsive efficiency?

Gas Turbine Thermal (Cycle) Efficiency



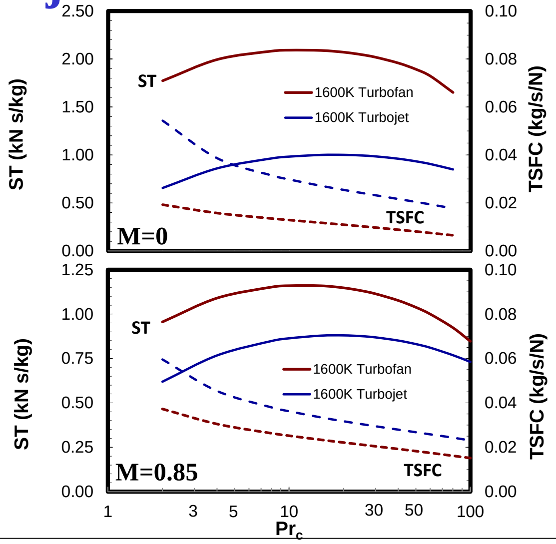
- Cycle pressure ratio is the dominant influence
  - $\eta_{th} \uparrow$ with Pr
- With irreversible (real) turbomachinery, $\eta_{th}=f(T_{max})$
  - $\eta_{th} \uparrow$ with T_{max}

Ramjet Performance



γ=1.3-1.4
T_a=220K
HV=45MJ/kg
η_D=0.92&ram recovery
η_B=0.99
p_{rb}=0.98
η_N=0.95

Turbojet and Turbofan Performance



Single-point Design/On-design Analysis

- **Second** - select *design point*(s) to **size** the engine mass flow or area to produce required thrust
  - size usually set for **most demanding point in terms of thrust**
    - typically takeoff (or dash for fighter aircraft)
  - mass flow rate dependence on flow area also impacted by flow conditions
    - e.g., for tpg/cpg

$$\dot{m} = A\frac{p_o}{\sqrt{RT_o}} f(\gamma, M)$$

Single-point Design/On-design Analysis

- So engine sizing done in terms of **corrected mass flow rates**

$$\dot{m}_c = \dot{m}\frac{\sqrt{T_o/T_{ref}}}{p_o/p_{ref}}$$

e.g., T_{ref}=288.2K(518.7R)
p_{ref}=101.3kPa (14.7psi)

  – inlet size constrained by Mach number and choking considerations
  – flow areas of fan, compressors, turbines, combustor also must handle required mass flow rate within velocity/Mach number constraints

Course Focus

- The issues raised so far
  – single-point cycle design and performance

  were the focus of AE 4451

- So what will be the focus of this course?
  1. Design of jet engine components
  2. Off-design engine performance
  3. “Unconventional” cycles for hypersonic flight, increased efficiency and reduced emissions

Design of Jet Engine Components

- Want to design efficient and “robust” engine components
  - – turbomachinery: compressors, fans, turbines
    - blade geometry (e.g., angles), rpm, flowrate,…
  - – combustors
    - geometry, fuel atomization, air staging and liner cooling …
- Also want to know how these components will operate when we go an “off-design” condition

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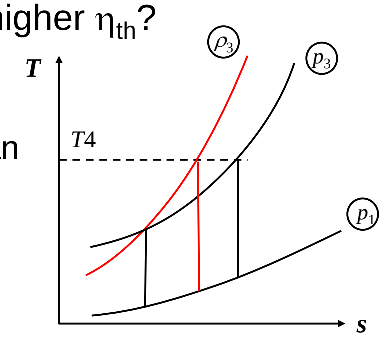
Unconventional Cycles

- Conventional jet engines based on Brayton cycle
  - – assumes constant pressure heat addition
- Can we do better, i.e., higher η_{th}?
  - – yes!, constant volume combustion will result in less entropy rise than constant pressure for the same temperature rise



Unconventional Cycles

- To achieve high supersonic (hypersonic) flight speeds with airbreathing engines need supersonic internal flow: **scramjets**
  – what are the unique design issues for scramjet engines?

- To reduce emissions and improve efficiency, **electric propulsion** can be helpful
  – what are the issues for using electrical energy to drive motors that turn propulsors (e.g., propellers or fans)?