Gas Turbine Engine

Construction and Components (Part B)

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Introduction

- Main Components of Gas Turbine Engine
- Their functions, main types and differences

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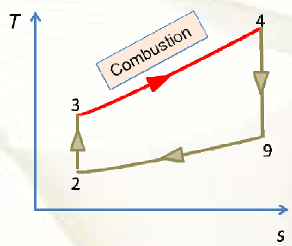
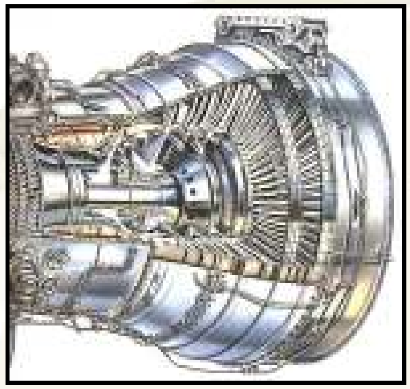
Combustor (Main Burner)

- Burns mixture of fuel and air
- Delivers to the turbine the rapidly expanding gases
  - At a uniform temperature
  - Cooled to below the allowable structural temperature of the turbine



Source: Soon Kim Tat



Source: The Jet Engine (1986) by Rolls Royce plc, page 35

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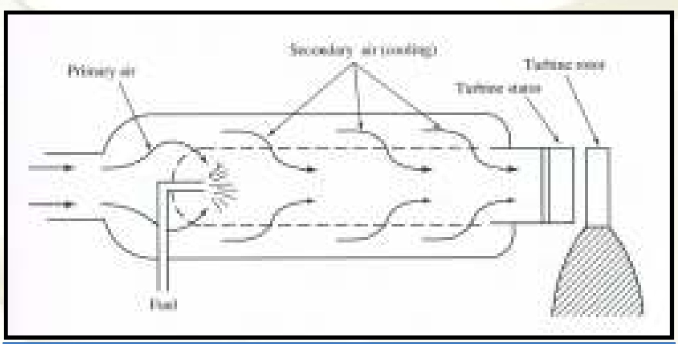
Combustion Process

- Decelerate compressor discharge air
- Create region of low axial velocity in the chamber
- Keep the flame alight throughout the range of engine operating conditions
- Maintain structural temperature limits



Schematic of Combustor

Source: "Elements of Propulsion: Gas Turbines and Rockets" by Jack D. Mattingly, page 247

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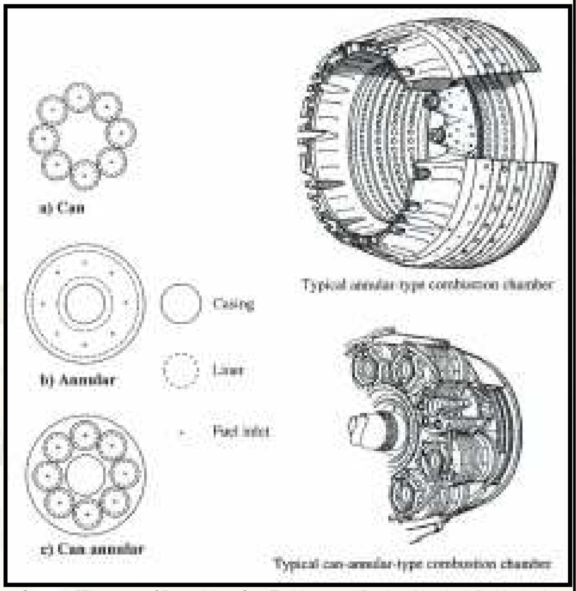
Combustor (Main Burner)

Configurations:

- ***Can*** Type
- ***Annular*** Type
- ***Can-Annular*** combustor (combination of the above)



Source: "Elements of Propulsion: Gas Turbines and Rockets" by Jack D. Mattingly, page 248

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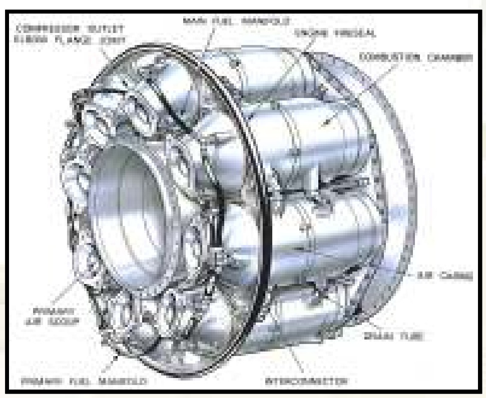
Can Combustor

- Compressor discharge air is streamed into separate cans
- Advantages (compared to annular combustor):
  - Higher rigidity
  - Ease of maintenance
- Disadvantage(s):
  - Heavier and provide less air flow per frontal area



Source: The Jet Engine (1986) by Rolls Royce plc, page 40

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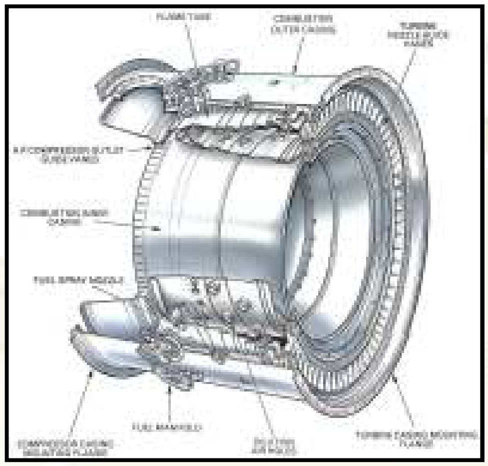
Annular Combustor

- Combustion chamber housed within two annular liners
- **Advantages:**
  - Lower pressure losses
  - Higher mass flow rate
  - Uniform combustion propagation distribution
- **Disadvantage:**
  - Less rigid



Source: The Jet Engine (1986) by Rolls Royce plc, page 42

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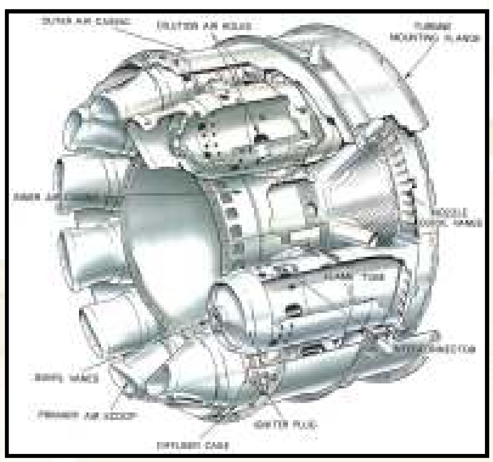
Can-Annular Combustors

- Combination of can and annular combustor
  - Cans arranged inside an annular casing
- Advantage:
  - Compact
  - Rigid
  - Ease of maintenance
- Disadvantage:
  - Inconsistent airflow pattern



Source: The Jet Engine (1986) by Rolls Royce plc, page 41

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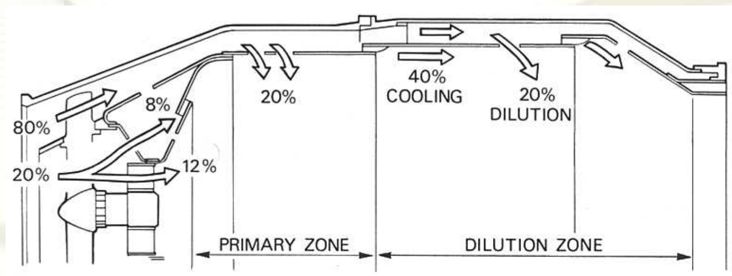
Combustor Cooling Air

- Air-fuel ratio for complete combustion –15
- Typical air-fuel ratio of gas turbines: 30 to 60
- >60% of airflow is not used for combustion



Apportioning the Airflow

Source: The Jet Engine (1986) by Rolls Royce plc, page 37

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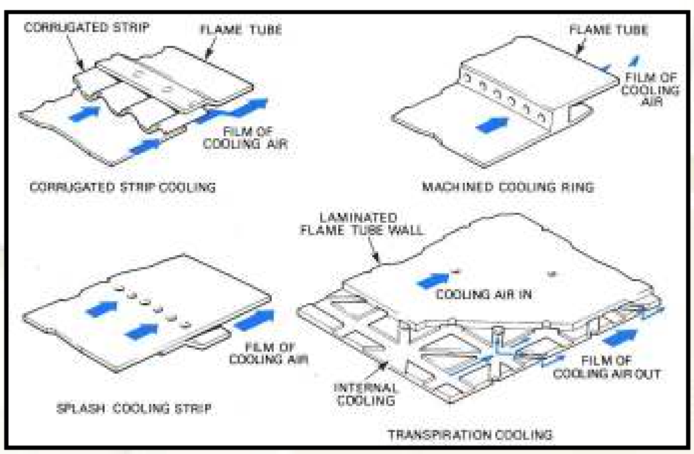
High Temperature Resistance

- Wall Cooling



Source: The Jet Engine (1986) by Rolls Royce plc, page 38

- Thermal Barrier Coating (TBC)
  - Usually Ceramic or Chromium Carbide
  - Low emissivity and thermal conductivity

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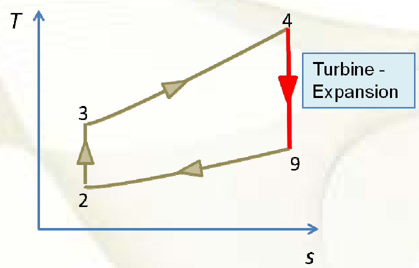
Turbine

- Extracts gas energy and convert to mechanical energy through gas expansion
- **Each axial-flow turbine stage**:
  - stationary *stator* vanes or nozzle guide vanes
  - *rotor* blades mounted on turbine wheel



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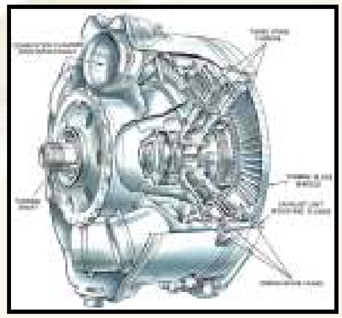

Source: The Jet Engine (1986) by Rolls Royce plc, page 46

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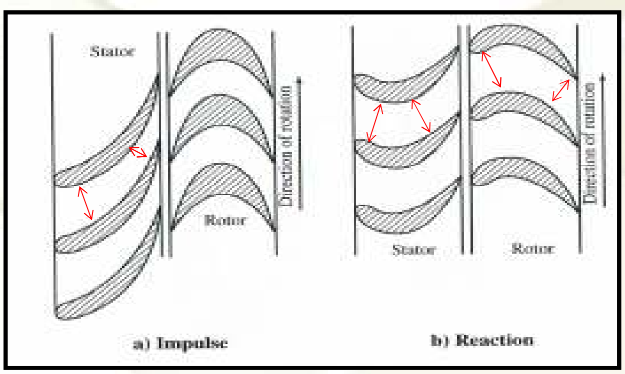
Turbine Design

- Stators and rotor blades are of basic aerofoil shape
- Three types of turbines:
  - Impulse
  - Reaction
  - A combination of the two, known as impulse-reaction



Source: "Elements of Propulsion: Gas Turbines and Rockets" by Jack D. Mattingly, page 250

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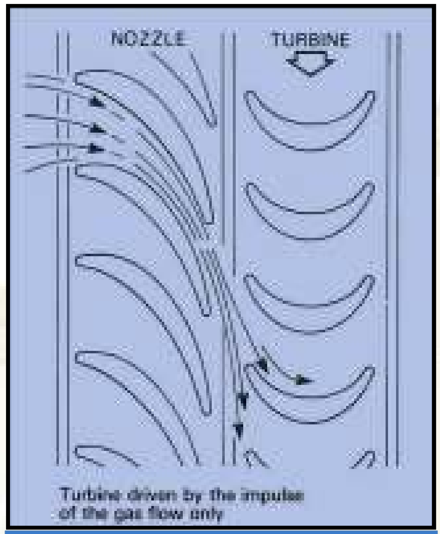
Impulse Turbine

- Stator nozzle accelerates the incoming gas
- Rotor extracts kinetic energy from the gas flow through impulse
- Pressure and relative velocity stay the same through the rotor inlet to rotor exit



Impulse Turbine

Source: The Jet Engine (1986) by Rolls Royce plc, page 50

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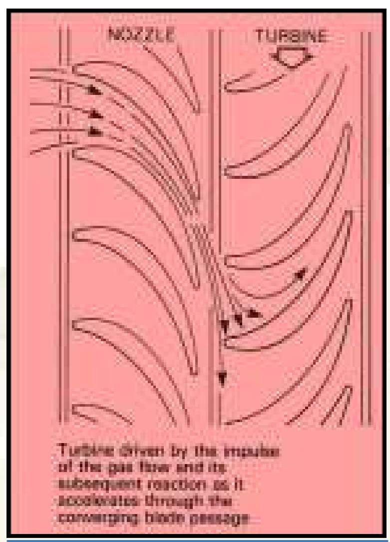
Reaction Turbine

- Pure Reaction Turbine
  - Energy is extracted through rapid expansion of the fluid in the rotor
  - Stator nozzle merely alters the direction of the flow
- Most modern jet engines make use of a combination of impulse and reaction turbines



Impulse-Reaction Turbine

Source: The Jet Engine (1986) by Rolls Royce plc, page 50

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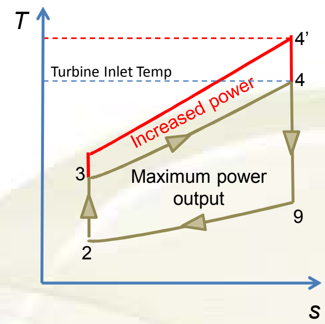
Turbine Temperature

- Maximum power output is limited by the turbine inlet temperature
- Impetus to achieve higher operating temperature limit
- Use of new material, advanced coating and more sophisticated cooling technique



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Turbine Blade Design

- Turbine blades are subject to:
  - High bending loads
  - High temperatures / thermal shock
  - High frequency vibrations induced by combustion
  - Corrosive / oxidising environment
  - High centrifugal forces
- Which can lead to damage by:
  - Fracture
  - Yield
  - Fatigue
  - **Creep** (permanent deformation under high centrifugal stress at elevated temperature)

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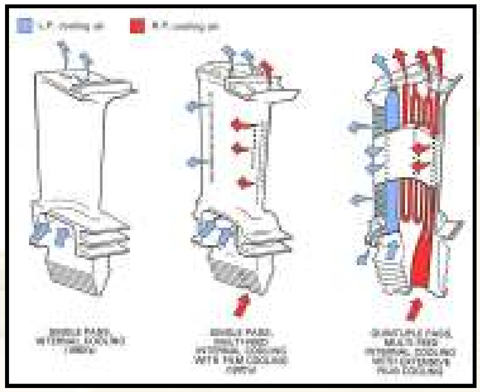
Turbine Blade Design

- Cooling:
  - Convection (passing cooling air through passages internal to the blade)
  - Impingement (by hitting the inner surface of the blade with high velocity air)
  - (thin) film cooling (pumping cool air out of the blade through small holes in the blade)
  - Transpiration cooling (air is "leaked" through a porous shell rather than injected through holes)
- Thermal barrier coating



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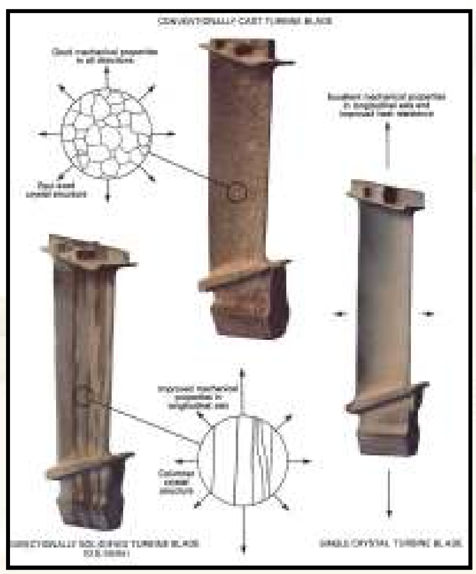
Turbine Blade Material

- Early material – steel forgings
- Cast nickel-chromium based alloys (Inconel) for better fatigue and creep resistance
- Directional solidification (aligning the crystals to form columns along blade length) improves the service life
- Advanced technique makes blades out of a single crystal, allows higher operating temperatures



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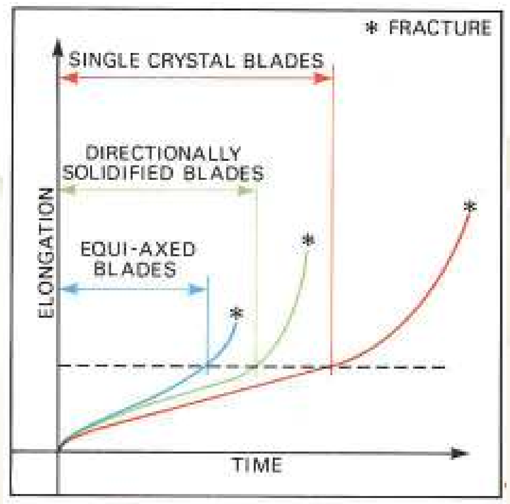
Turbine Blade Life Properties



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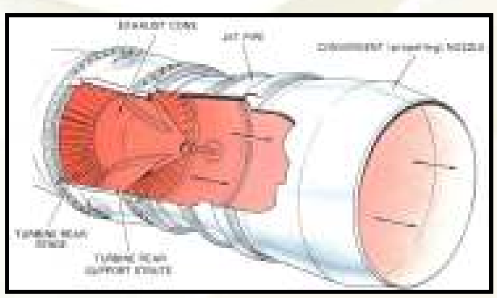
Exhaust (Propelling) Nozzle

- To accelerate exhaust gas to desired exit velocity
- Straighten the exhaust gas
- Generates thrust
  - Requires high exhaust velocity
  - Gas is expanded (pressure decrease, velocity increase)
  - Maximum thrust when the exit pressure equals ambient pressure



Source: The Jet Engine (1986) by Rolls Royce plc, page 60

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Exhaust (Propelling) Nozzle

Two common types of nozzles used in jet engines

- *Convergent Nozzle*
- *Convergent-Divergent Nozzle*

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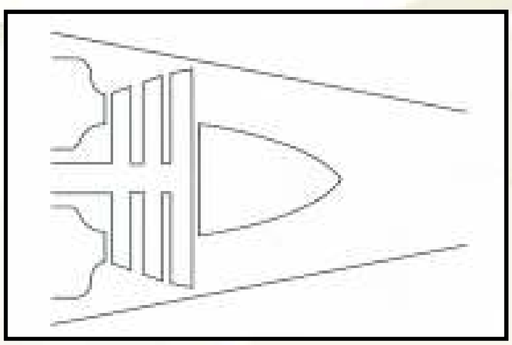
Photo credit: Soon Kim Tat

Convergent Exhaust Nozzle

- Simple convergent duct
- Popular in low-thrust subsonic aircraft engines
- Increase in upstream total pressure:
  - May lead to choked condition (sonic velocity at throat)



Source: "Elements of Propulsion: Gas Turbines and Rockets" by Jack D. Mattingly, page 251

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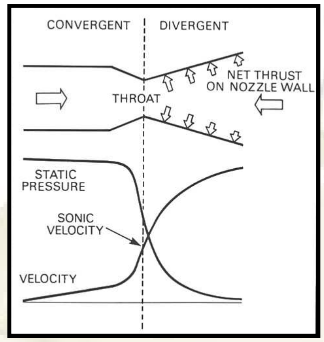
Convergent-Divergent (C-D) Nozzle

- A convergent duct followed by a divergent duct
- Used if the nozzle pressure ratio is high
- Typically incorporated with variable geometry



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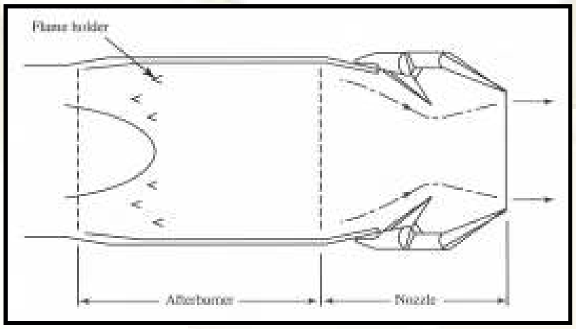

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Summary

- Functions, different construction and applications
  - Engine Inlet
  - Compressor
  - Combustor
  - Turbine
  - Exhaust Nozzle
- Challenges in design for extreme conditions

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Reflection Question

- Investigate new developments in gas turbine construction technology in modern engines like the GEnx.

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