



Jet Aircraft Propulsion

Prof. Bhaskar Roy, Prof. A M Pradeep

Department of Aerospace Engineering,
IIT Bombay

Lect-7

In this lecture...

- Jet engine cycles for aircraft propulsion
 - Turbojet engine
 - Turbojet engine with afterburning
 - Turbofan and its variants
 - Turboprop and turboshaft engines
 - Ramjet engines

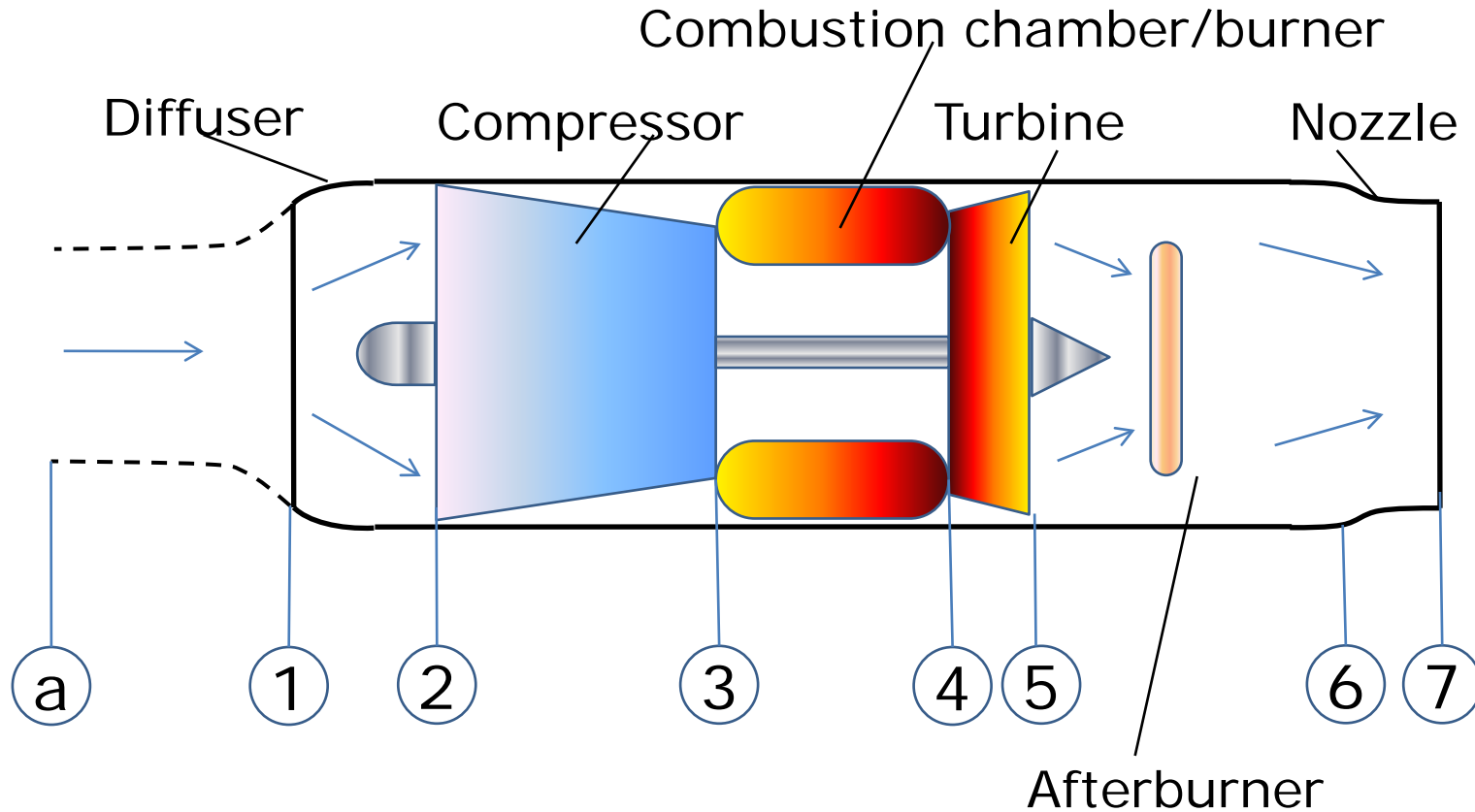
Gas Turbine Cycles

- Gas turbine engines operate on Brayton cycles.
- Ideal Brayton cycle is a closed cycle, whereas gas turbines operate in the open cycle mode.
- Ideal cycle assumes that there are no irreversibilities in the processes, air behaves like an ideal gas with constant specific heats, and that there are no frictional losses.

Ideal cycle for jet engines

- All air-breathing jet engines operate on the Brayton cycle (open cycle mode).
- The most basic form of a jet engine is a turbojet engine.
- Some of the parameters of a jet engine cycle are usually design parameters and hence often fixed *a priori*: eg. compressor pressure ratio, turbine inlet temperature etc.
- Cycle analysis involves determining the performance parameters of the cycle with the known design parameters.

Ideal cycle for jet engines



Schematic of a turbojet engine and station numbering scheme

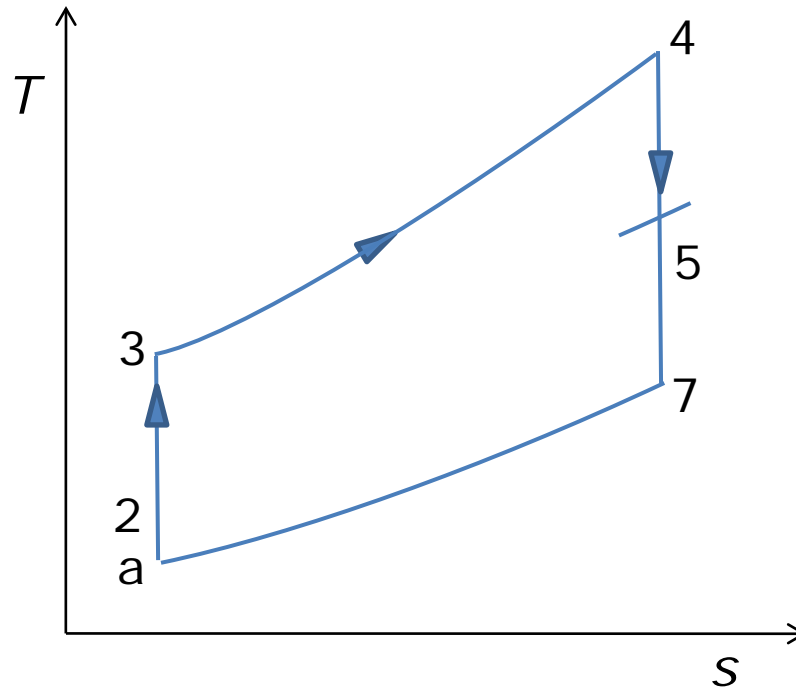
Ideal cycle for jet engines

- The different processes in a turbojet cycle are the following:
- a-1: Air from far upstream is brought to the air intake (diffuser) with some acceleration/deceleration
- 1-2: Air is decelerated as it passes through the diffuser
- 2-3: Air is compressed in a compressor (axial or centrifugal)
- 3-4 The air is heated using a combustion chamber/burner

Ideal cycle for jet engines

- 4-5: The air is expanded in a turbine to obtain power to drive the compressor
- 5-6: The air may or may not be further heated in an afterburner by adding further fuel
- 6-7: The air is accelerated and exhausted through the nozzle.

Ideal cycle for jet engines

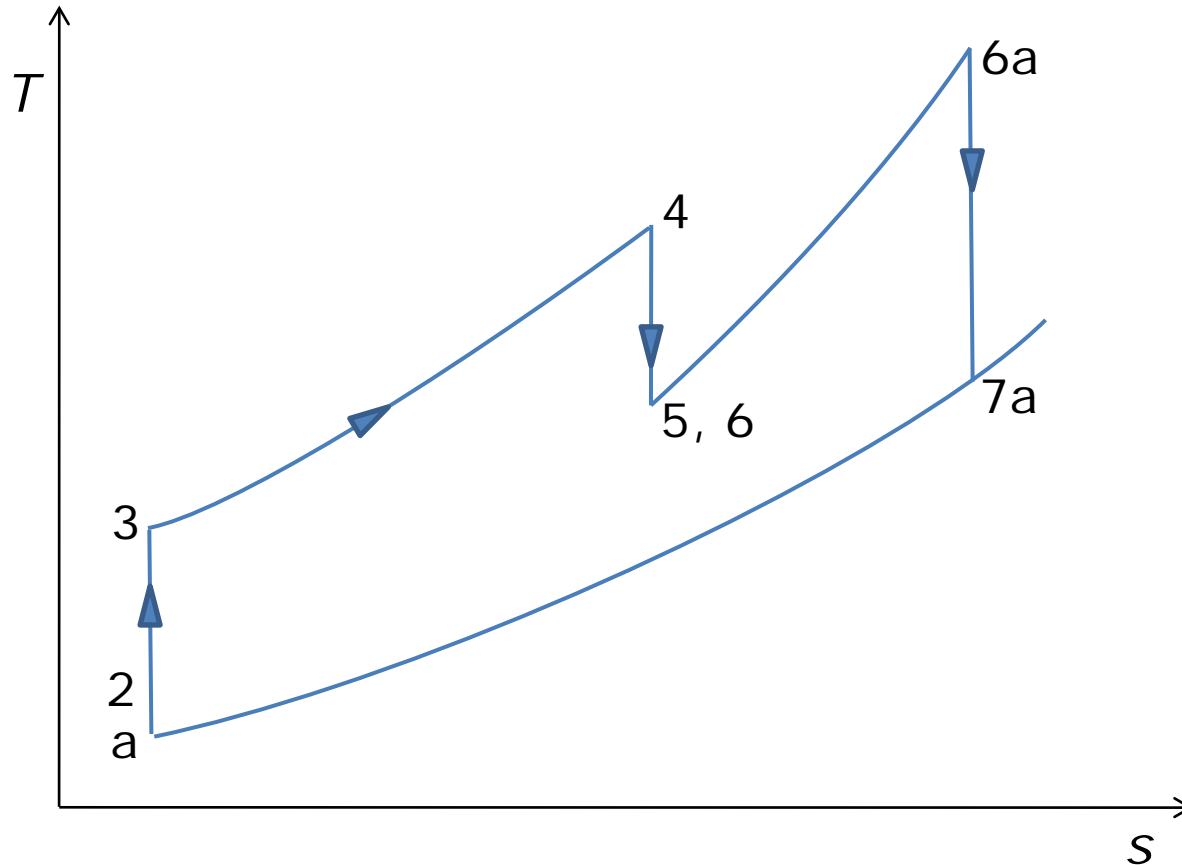


Ideal turbojet cycle (without afterburning)
on a T-s diagram

Ideal cycle for jet engines

- Afterburning: used when the aircraft needs a substantial increment in thrust. For eg. to accelerate to and cruise at supersonic speeds.
- Since the air-fuel ratio in gas turbine engines are much greater than the stoichiometric values, there is sufficient amount of air available for combustion at the turbine exit.
- There are no rotating components like a turbine in the afterburner, the temperatures can be taken to much higher values than that at turbine entry.

Ideal cycle for jet engines

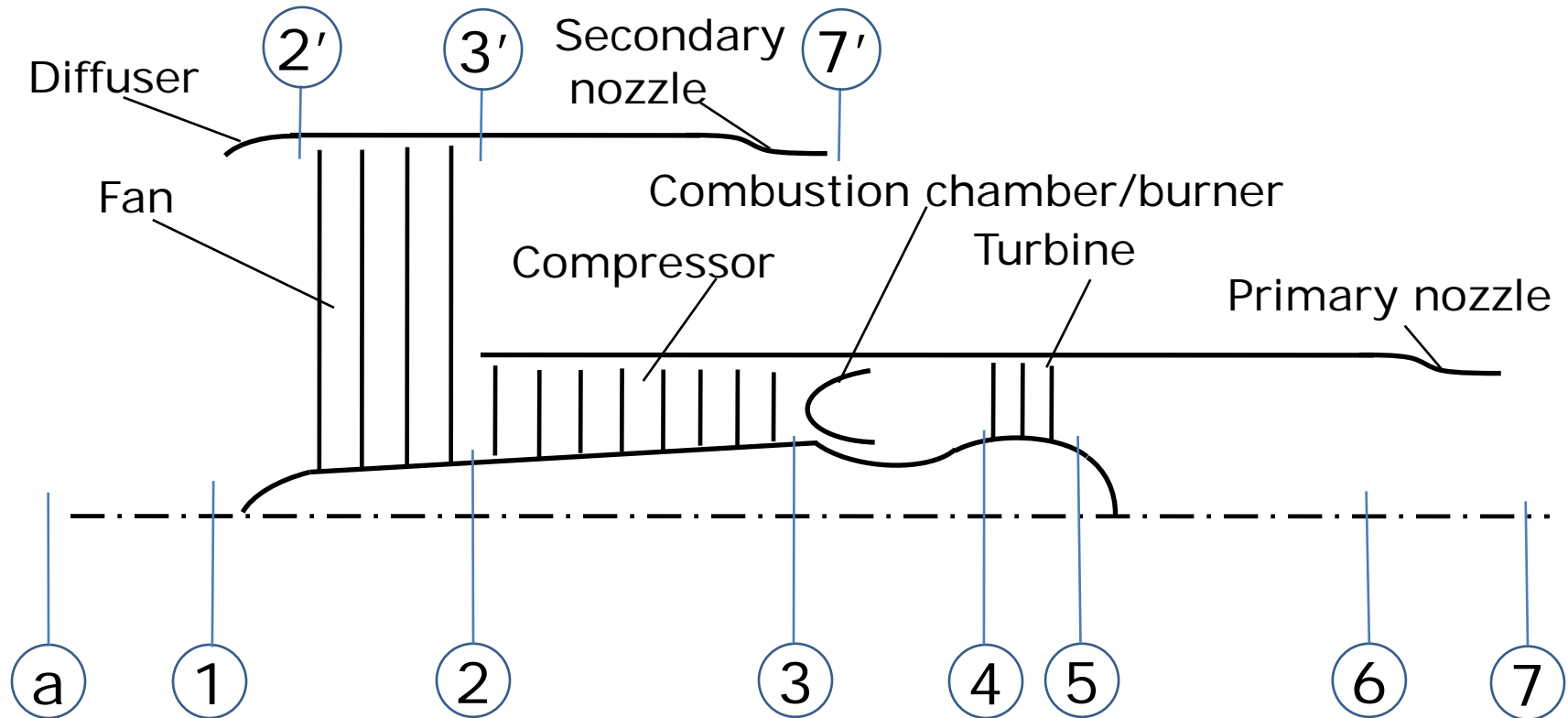


Ideal turbojet cycle with afterburning on a T - s diagram

Turbofan engine

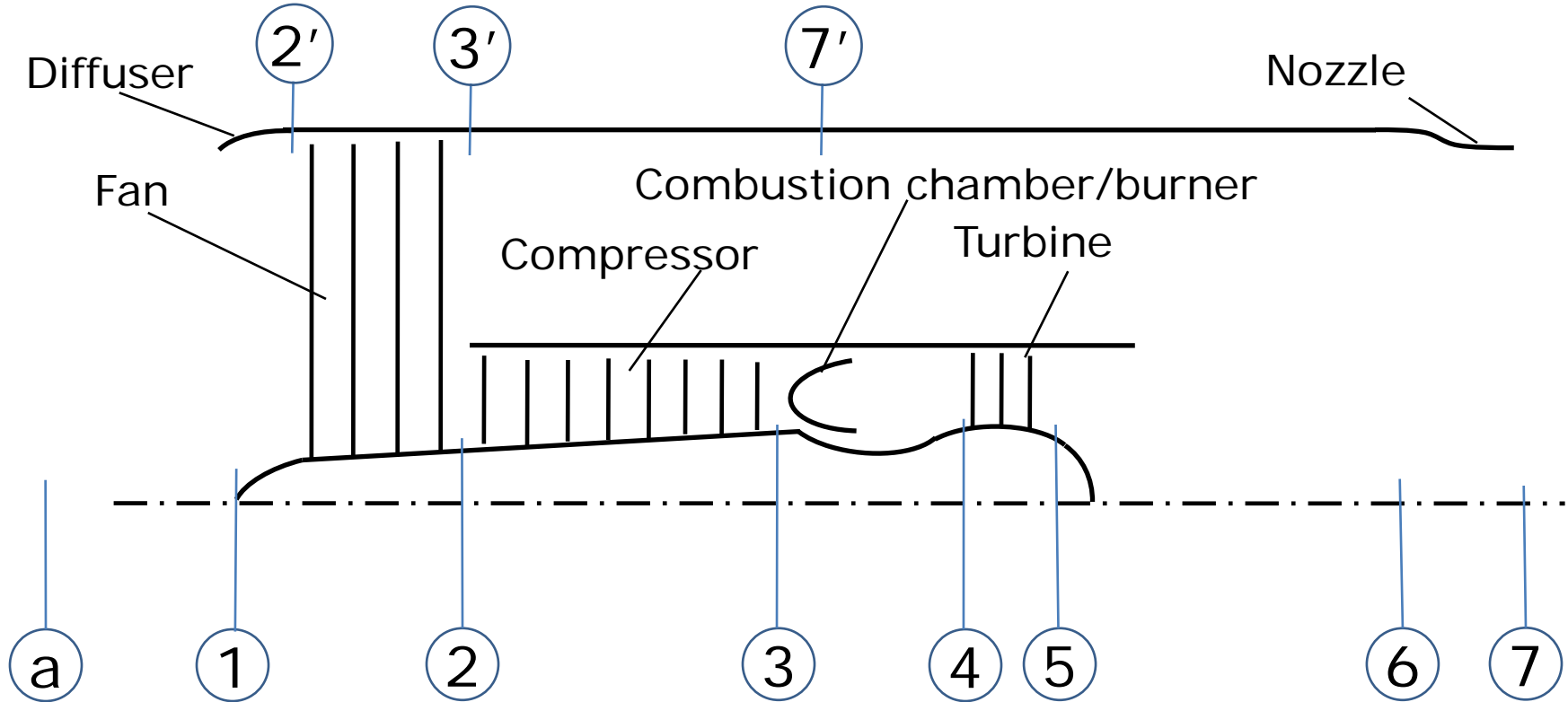
- Propulsion efficiency is a function of the exhaust velocity to flight speed ratio.
- This can be increased by reducing the effective exhaust velocity.
- In a turbofan engine, a fan of a larger diameter than the compressor is used to generate a mass flow higher than the core mass flow.
- This ratio ($\dot{m}_{cold} / \dot{m}_{hot}$) is called the bypass ratio.
- Turbofan engines have a higher propulsion efficiency as compared with turbojet engines operating in the same speed range.

Ideal turbofan engine



Schematic of an unmixed turbofan engine and station numbering scheme

Ideal turbofan engine



Schematic of a mixed turbofan engine and station numbering scheme

Ideal turbofan engine

- The different processes in an unmixed turbofan cycle are the following:
- a-1: Air from far upstream is brought to the air intake (diffuser) with some acceleration/deceleration
- 1-2': Air is decelerated as it passes through the diffuser
- 2'-3': Air is compressed in a fan
- 2-3: Air is compressed in a compressor (axial or centrifugal)

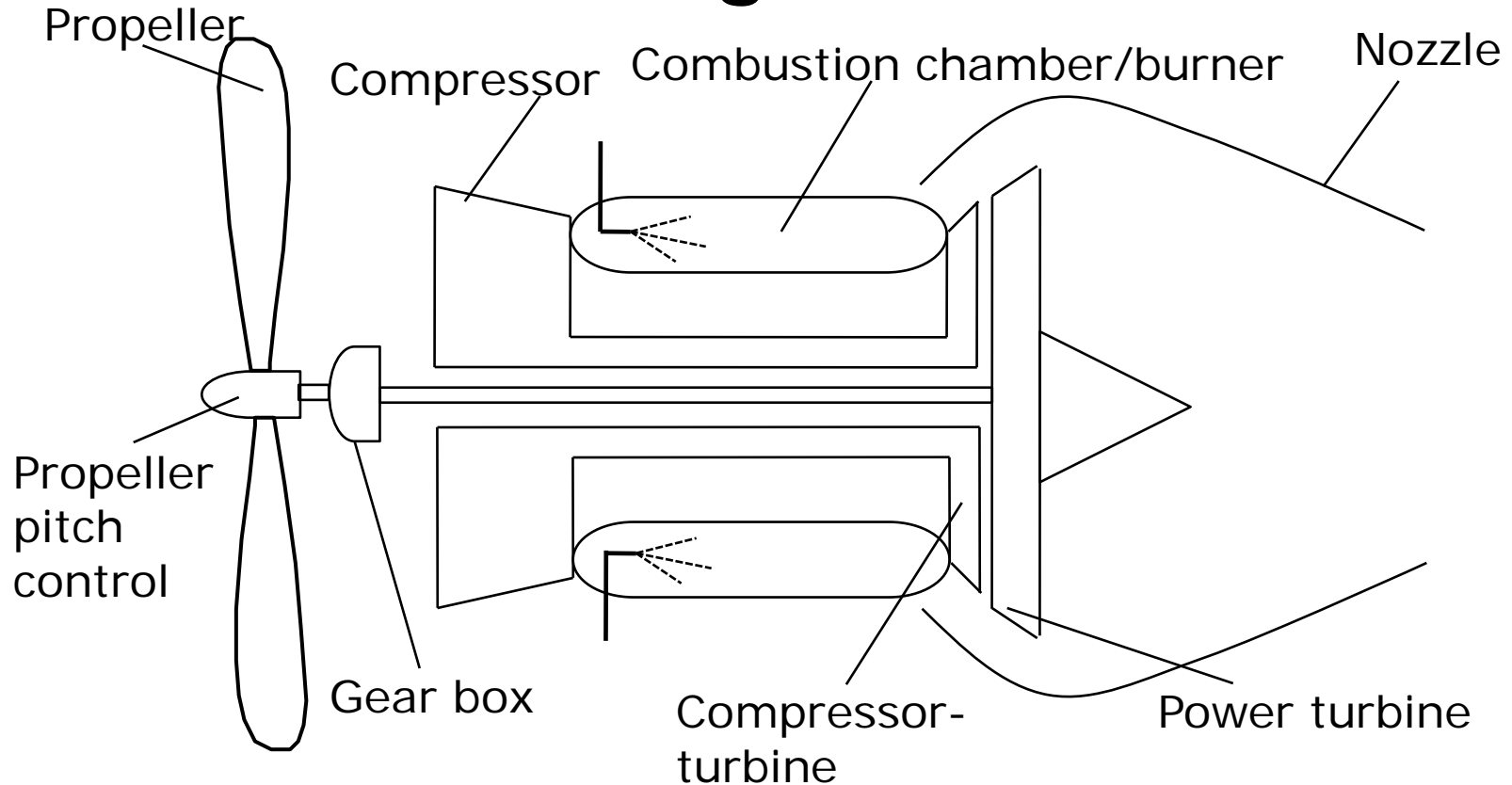
Ideal turbofan engine

- 3-4: The air is heated using a combustion chamber/burner
- 4-5: The air is expanded in a turbine to obtain power to drive the compressor
- 5-6: The air may or may not be further heated in an afterburner by adding further fuel
- 6-7: The air is accelerated and exhausted through the primary nozzle.
- 3'-7': The air in the bypass duct is accelerated and expanded through the secondary nozzle.

Ideal turboprop and turboshaft engines

- Turboprop engines generate a substantial shaft power in addition to nozzle thrust.
- Turboshaft engines, generate only shaft power. These engines are used in helicopters. The shaft power is used to drive the main rotor blade.
- In a turboprop engine, the advantages and limitations are those of the propeller.
- Both turboprops and turboshafts have applications at relatively lower speeds.

Ideal turboprop and turboshaft engines



Schematic of typical turboprop engine

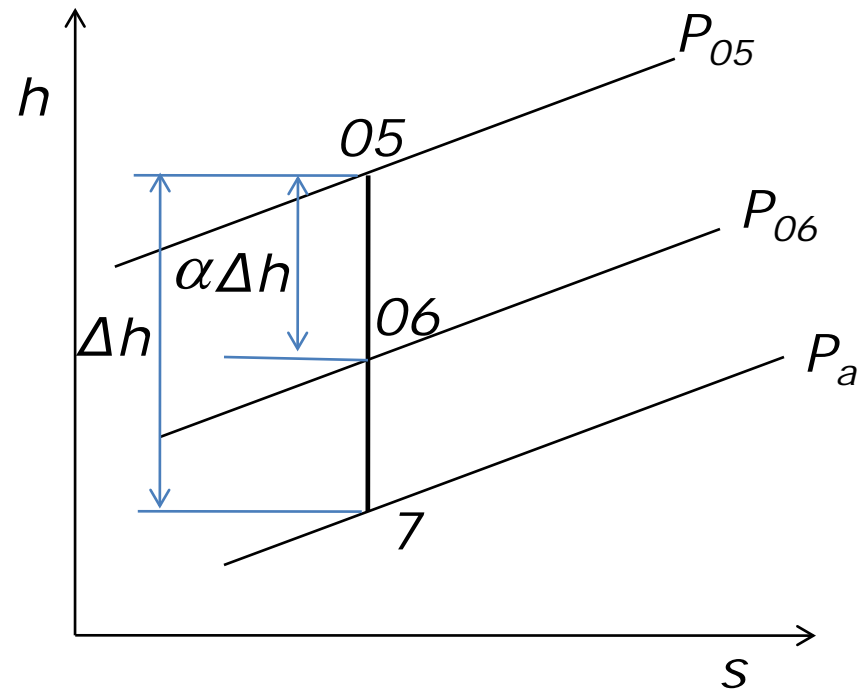
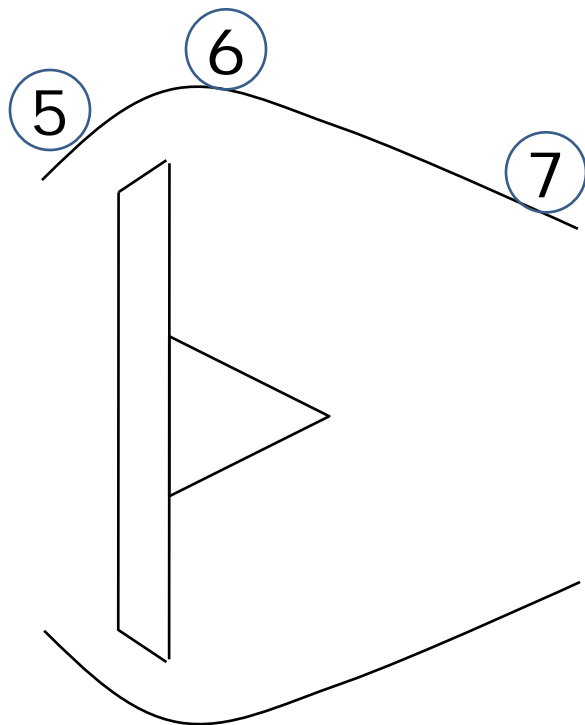
Ideal turboprop and turboshaft engines

- Turboprops and turboshafts usually have a free-turbine or power turbine to drive the propeller or the main rotor blade (turboshafts).
- Stress limitations require that the large diameter propeller rotate at a much lower rate and hence a speed reducer is required.
- Turboprops may also have a thrust component due to the jet exhaust in addition to the propeller thrust.
- In turboshafts, however, there is no thrust component due to the nozzle.

Ideal turboprop and turboshaft engines

- In turboprops, thrust consists of two components, the propeller thrust and the nozzle thrust.
- The total thrust of a propeller is equal to the sum of the nozzle thrust and the propeller thrust.

Ideal turboprop and turboshaft engines

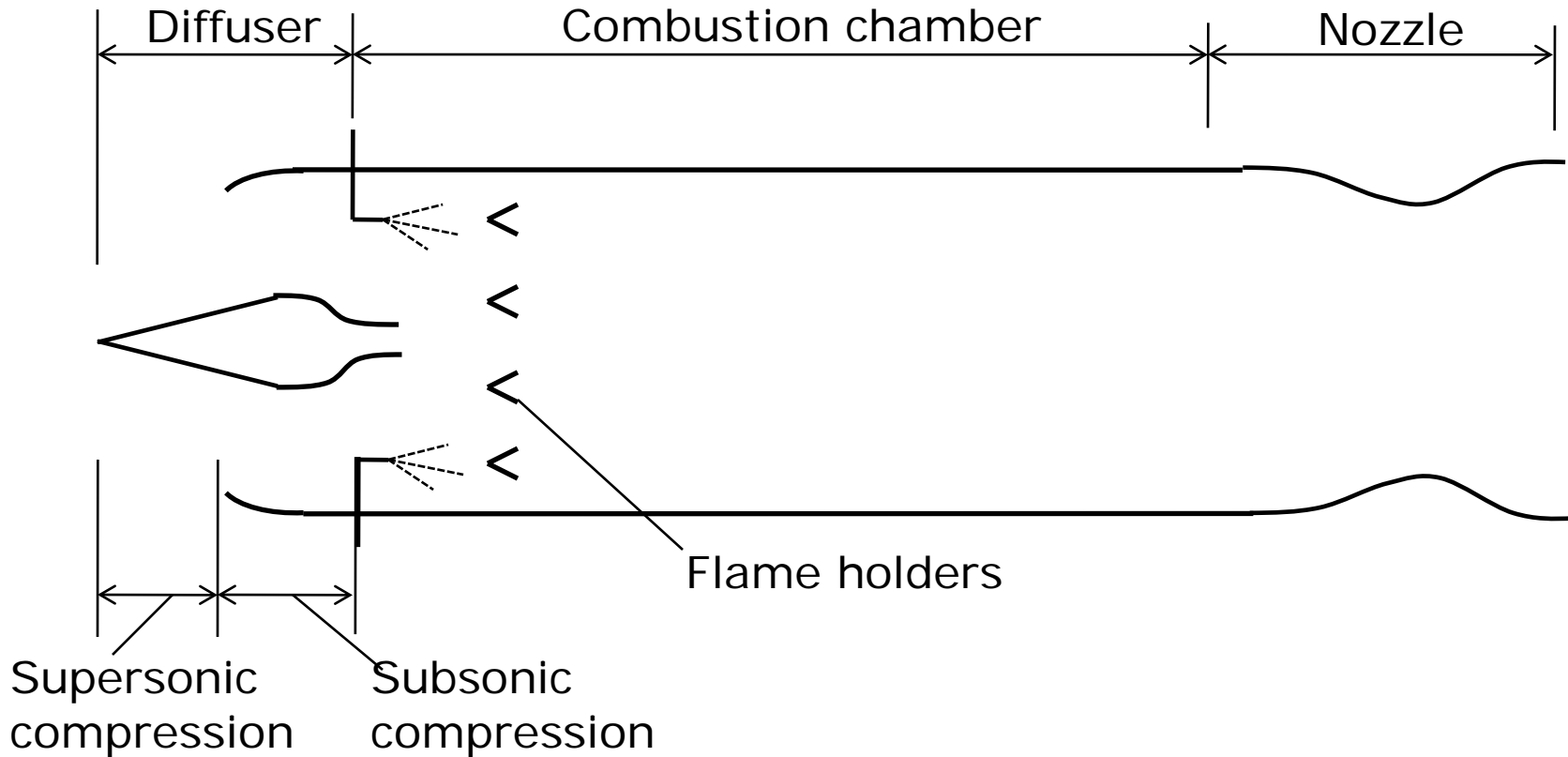


Enthalpy-entropy diagram for power turbine-exhaust nozzle analysis

Ideal ramjet engines

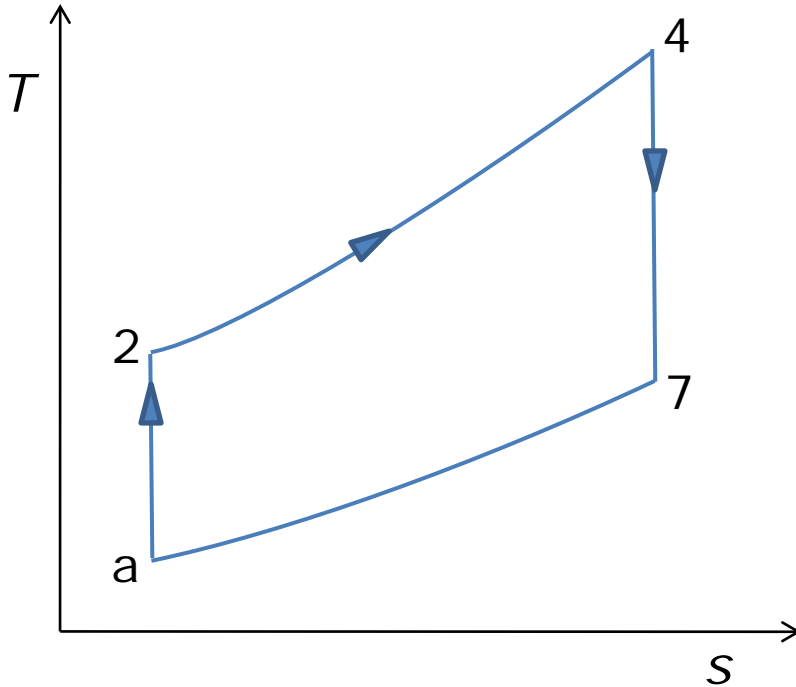
- Ramjet is the simplest of all the airbreathing engines.
- It consists of a diffuser, combustion chamber and a nozzle.
- Ramjets are most efficient when operated at supersonic speeds.
- When air is decelerated from a high Mach number to a low subsonic Mach number, it results in substantial increase in pressure and temperature.
- Hence Ramjets do not need compressors and consequently no turbines as well.

Ideal ramjet engines



Schematic of typical ramjet engine

Ideal ramjet engines



a-2: Isentropic compression in the intake
 2-4: Combustion at constant pressure
 4-7: Isentropic expansion through the nozzle

Ideal ramjet cycle on a T-s diagram

Ideal ramjet engines

- In a ramjet, there are no compressors and turbines and hence the analysis is simpler.
- Since ramjets depend upon the ram compression without the use of compressors, ramjets cannot generate static thrust.
- Therefore ramjets have to be taken to a sufficiently high speed at which ramjets can start generating thrust of its own.

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In the next lecture...

- Cycle components and component performance
 - Intake
 - Compressor/fan
 - Combustion chamber
 - Turbine
 - Nozzle