Jet Aircraft Propulsion

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Lecture 21

Axial Turbine –

- Characteristics
- Multi-staging
- Blade Cooling

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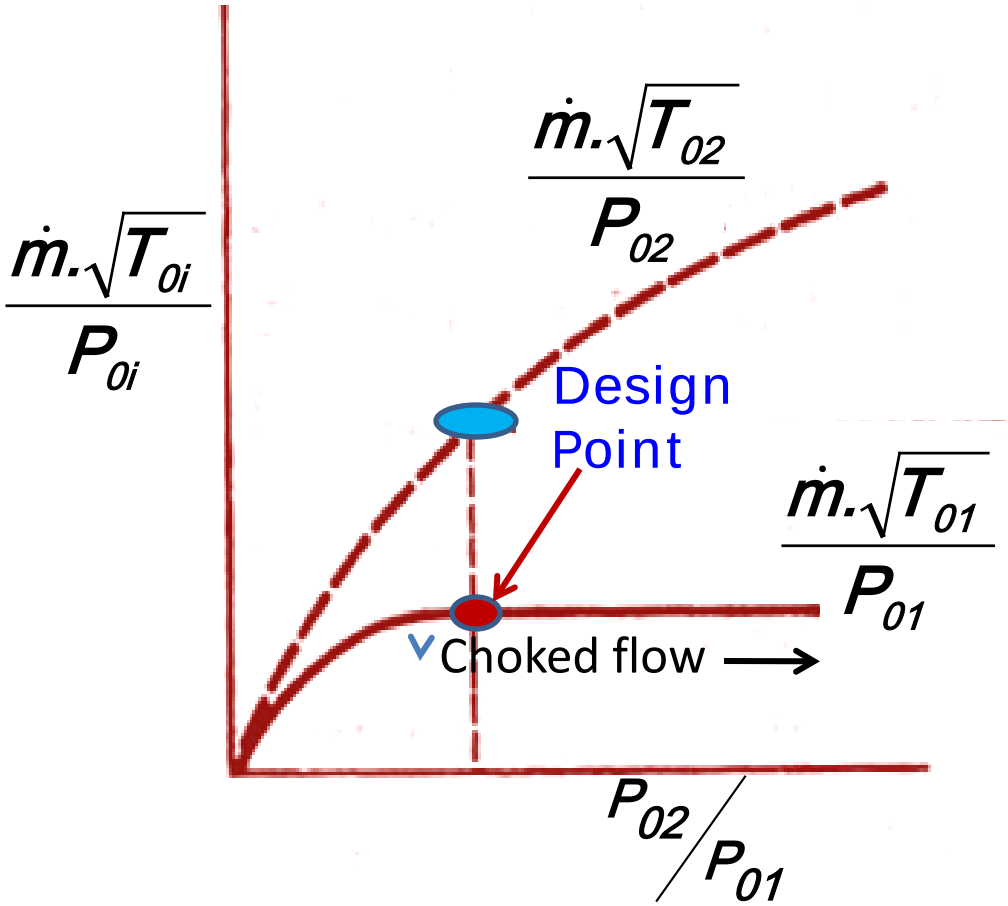
Turbine Characteristics



- A typical aircraft gas turbine operating line would show choking after a pressure ratio
- A typical design point is where the flow is just choked
- Characteristics based on exit flow conditions would show higher pressure ratio operation possibilities

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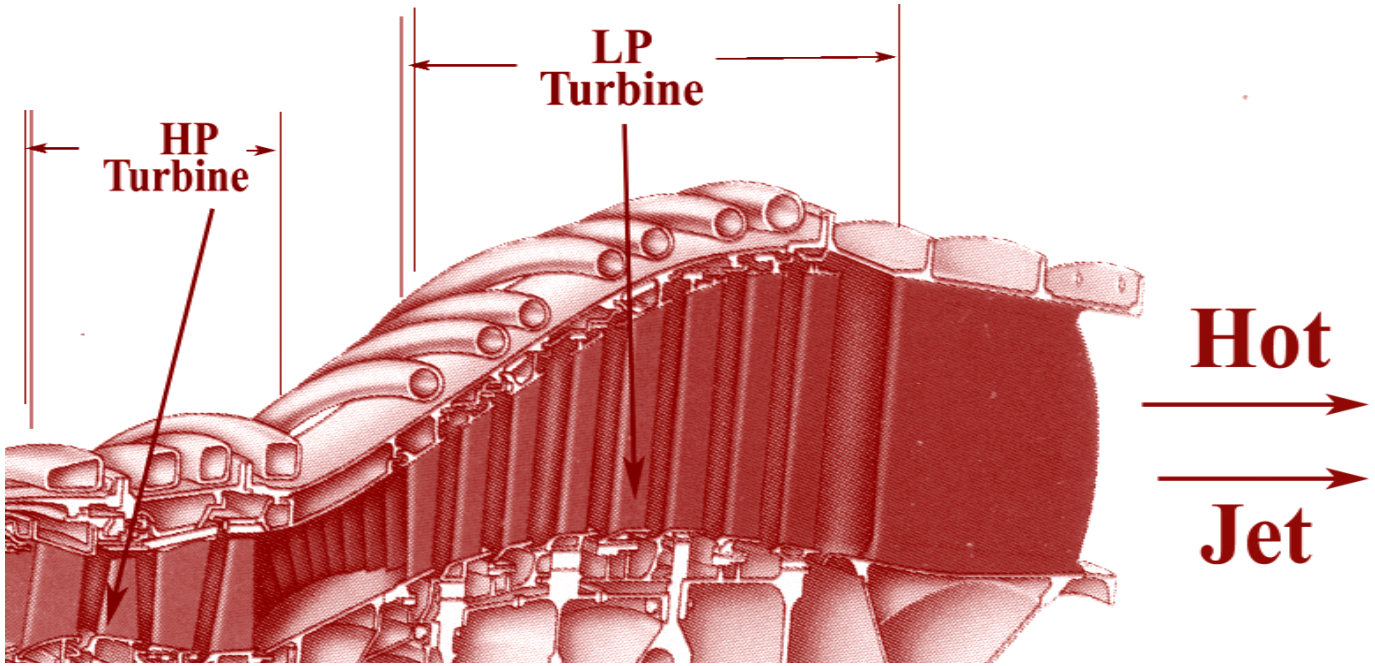
- Multi-staging of turbine is done extract more energy for mechanical power
- To restrict size and number of stages each stage does more work (aerothermodynamically loaded)
- Multi-spooling is done to make the spools rotate at different speeds



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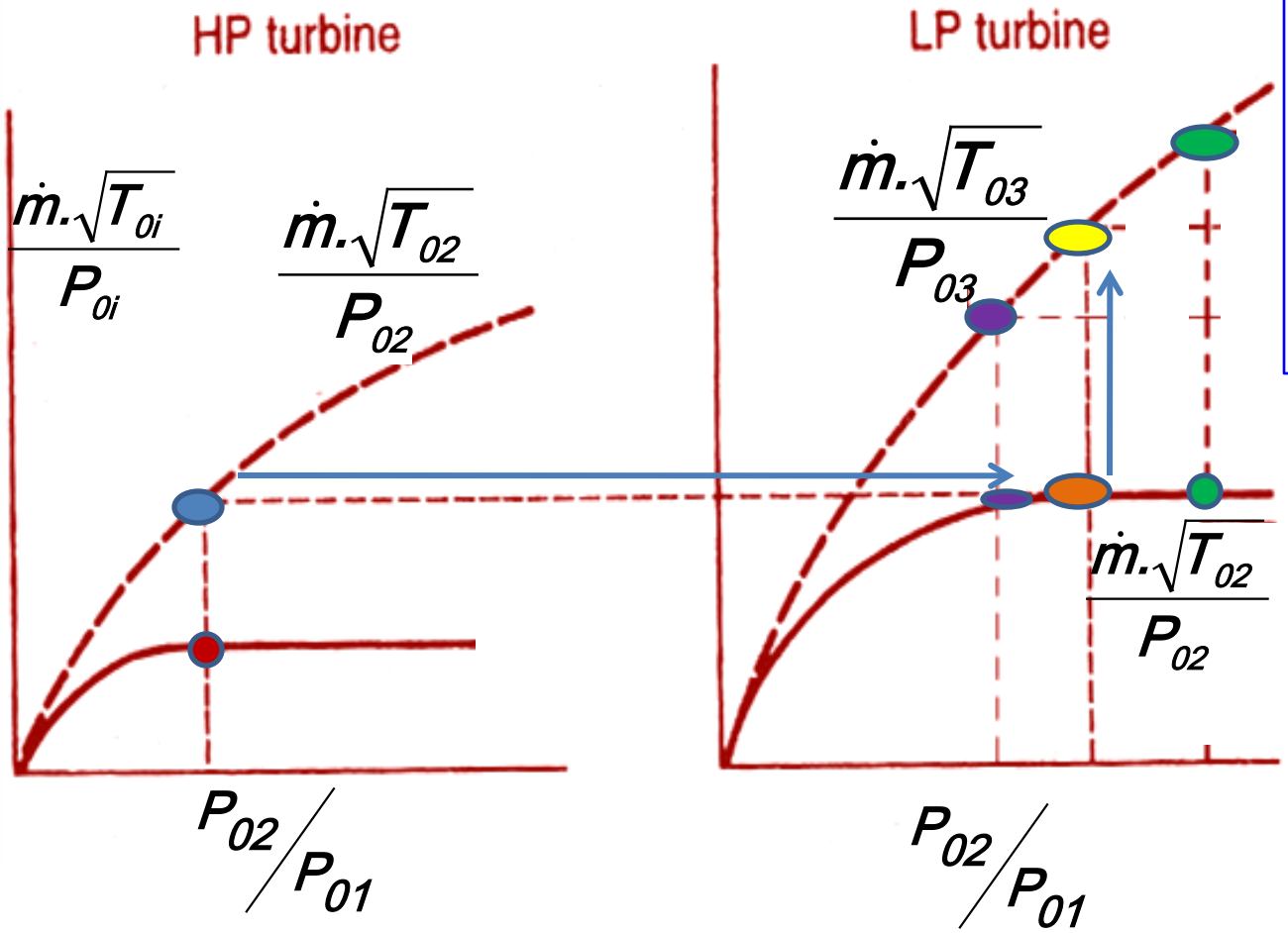
Multi-stage turbine characteristics

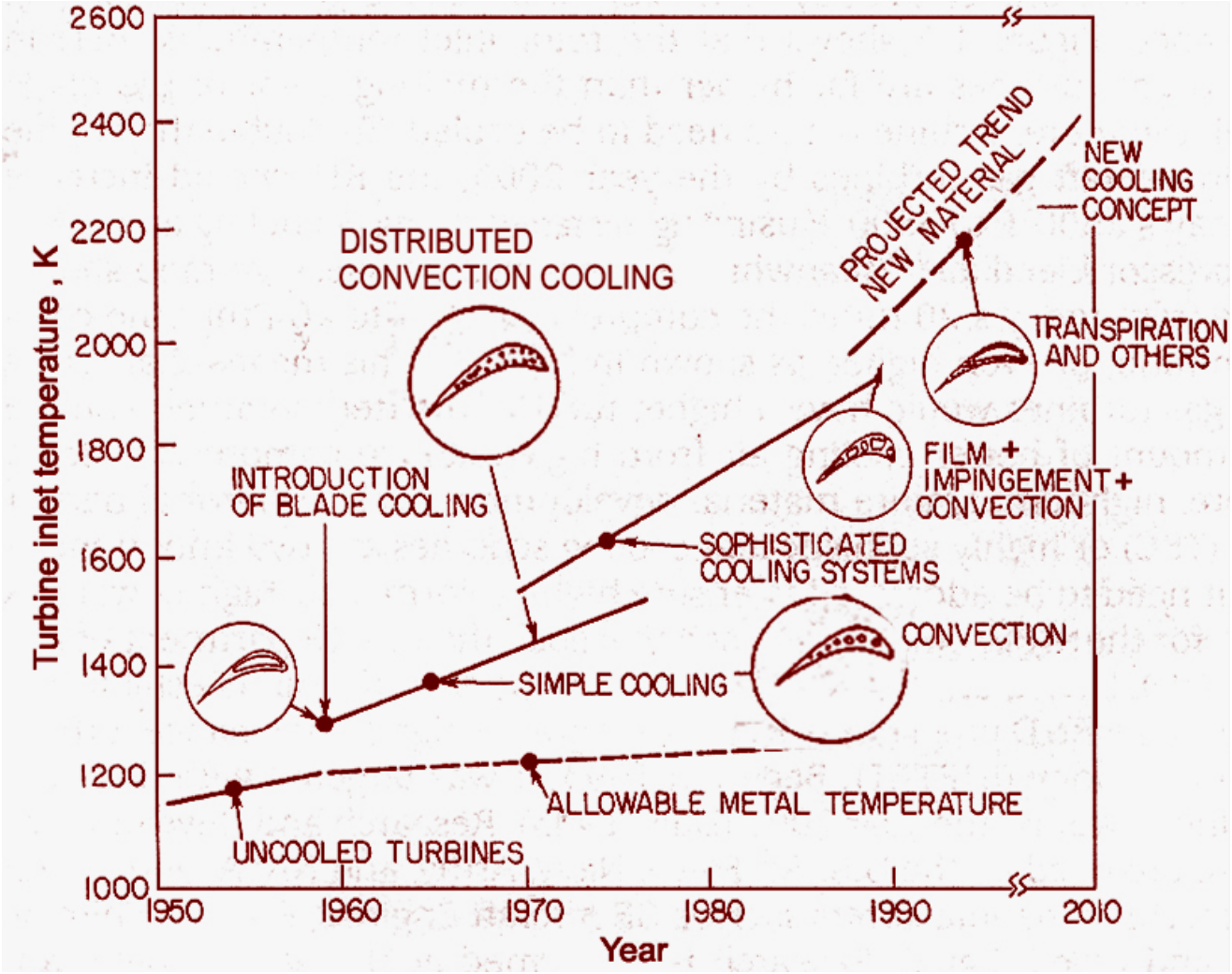


A matched LP + HP turbine operation, HP turbine may be choked all the time, as the pressure ratio across the LP turbine change.

Typical Multi-stage turbine inlet and outlet parameters

Parameters	Front stages (HP)	Last stages (LP)
α_2	75^0 - 70^0	65^0 - 60^0
R_x	0.20 – 0.25	0.35 – 0.45
M_3	0.25 – 0.35	0.5 for turbojet and turbofan engines 0.65 –0.70 for turbo-prop engine
α_3		0 - 10^0

Turbine Cooling



Turbine materials : Inconel, Monel

Additional Cooling Techniques for Life

Gas Flow over a Turbine blade profile

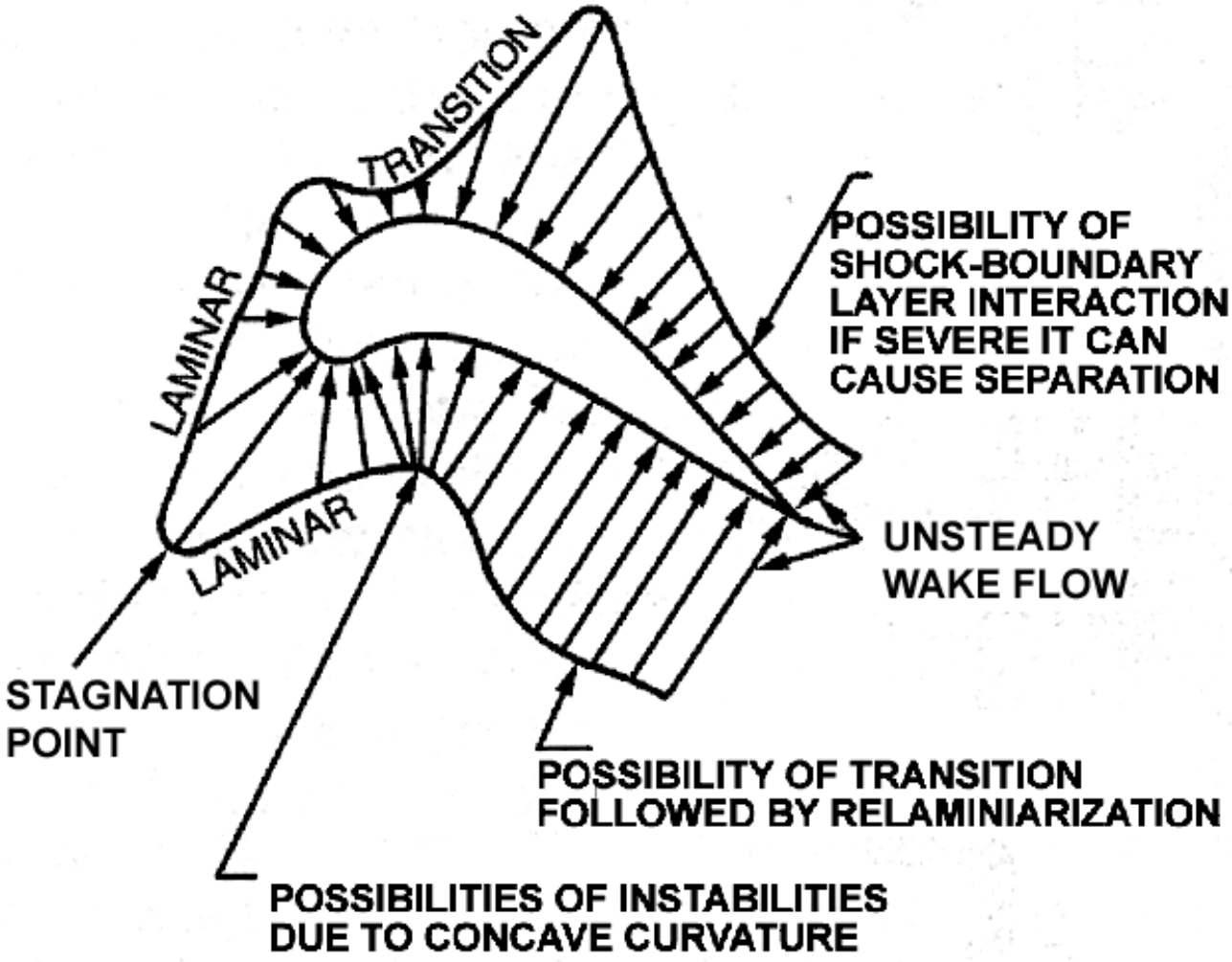
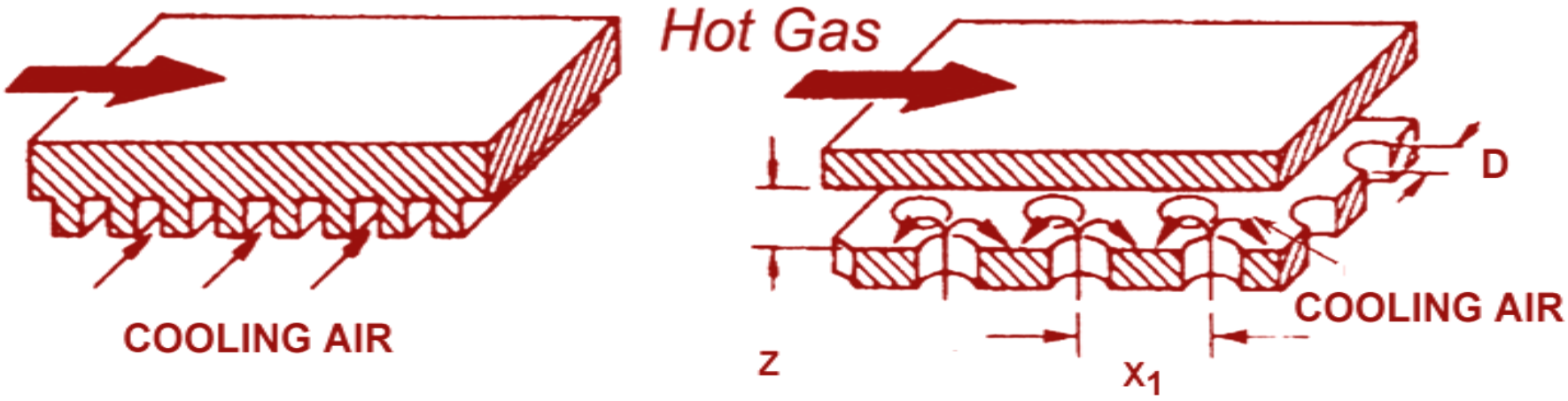


Fig. shows the typical manner in which heat transfer co-efficient may vary locally around the surface of the turbine.

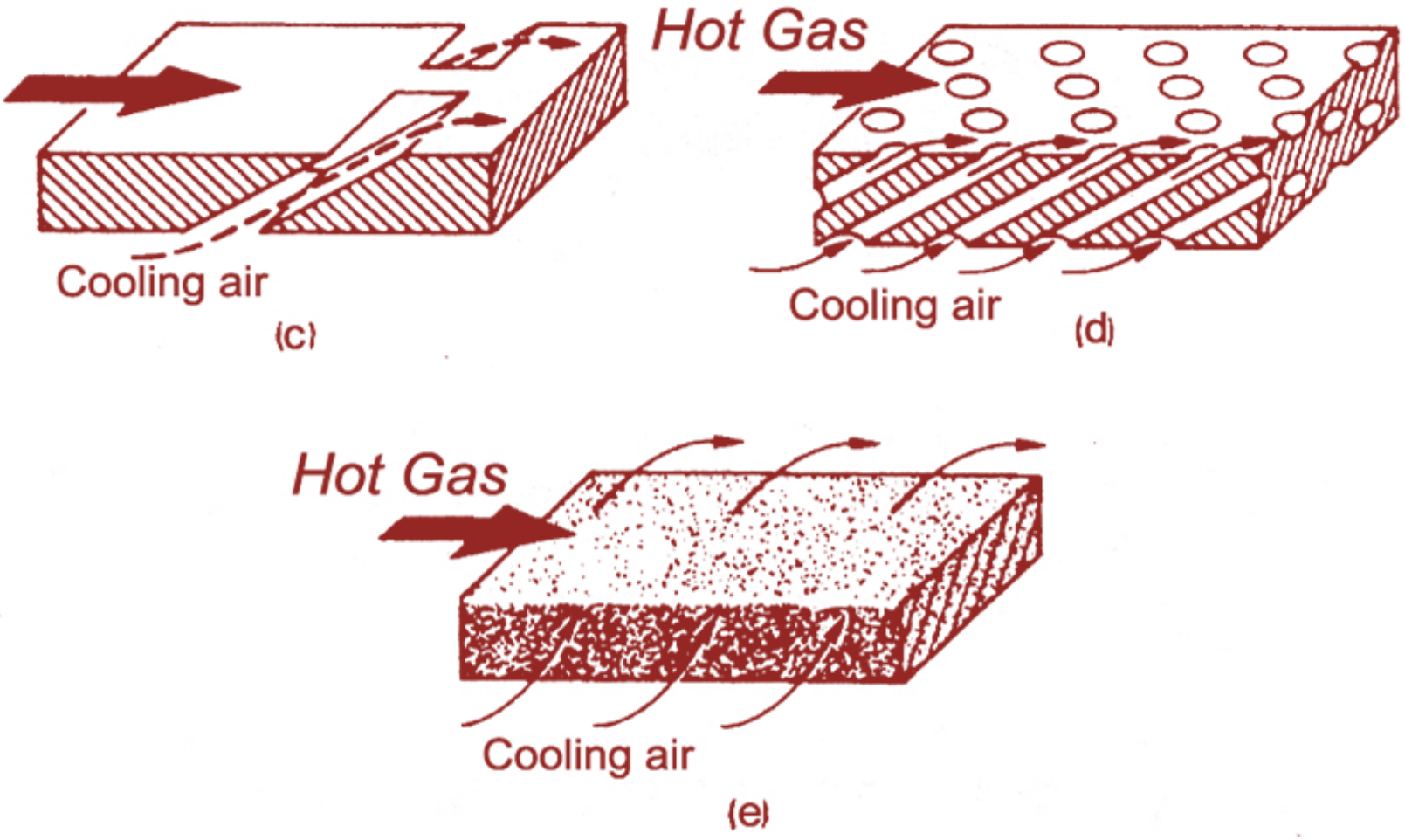
$$\text{Heat transfer coefficient} = \frac{\text{Quantity of heat transferred}}{\text{surface area} \times t \times \Delta T \text{ between hot gas \& surface}}$$

Temperature on a blade surface as felt by it

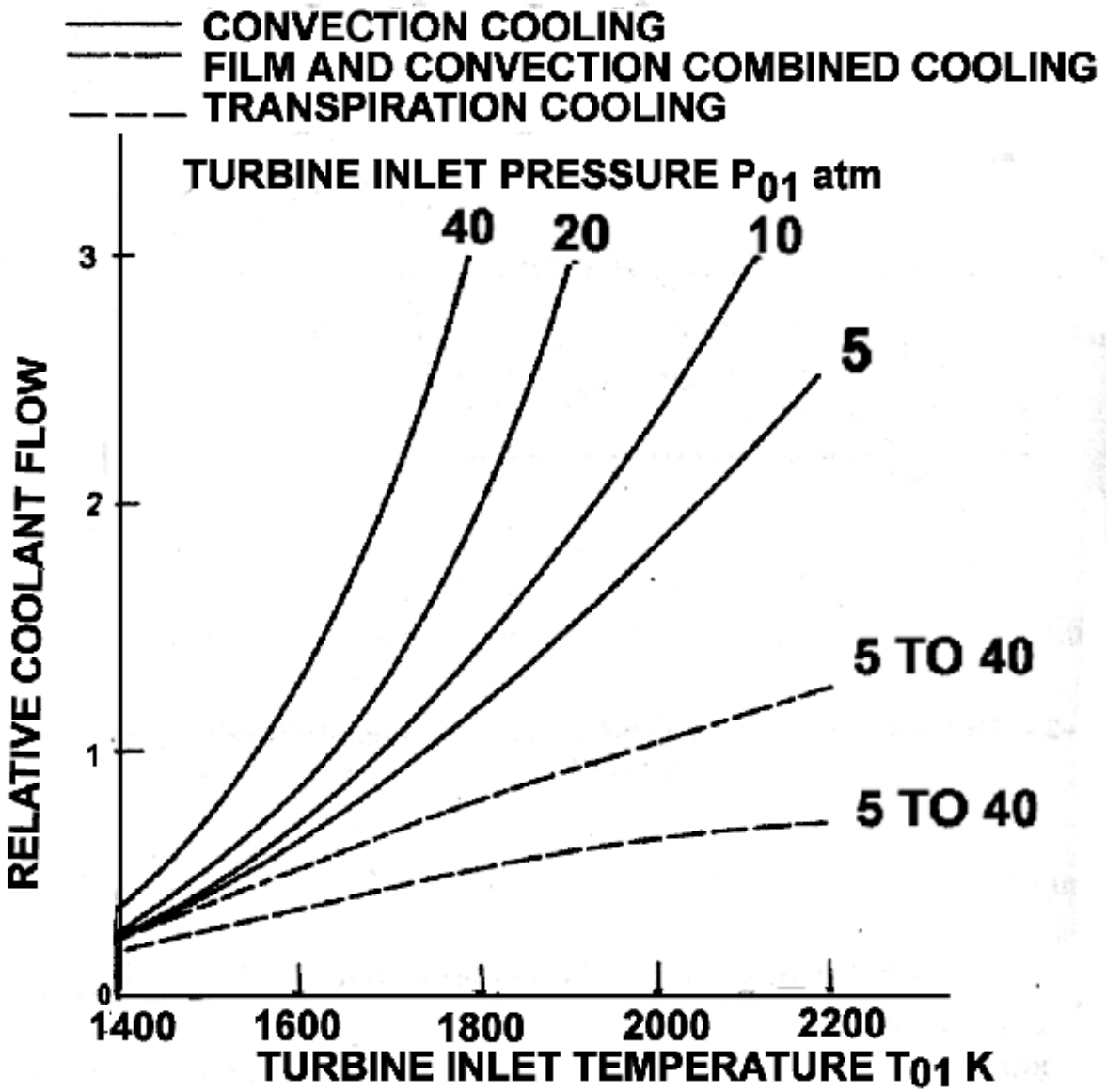
$$T_{0\text{-}bl} = \frac{T_{01} + T_{02}}{2} - \frac{U_{mean}^2}{2.c_{p\text{-}gas}}(1 - 2.DR)$$

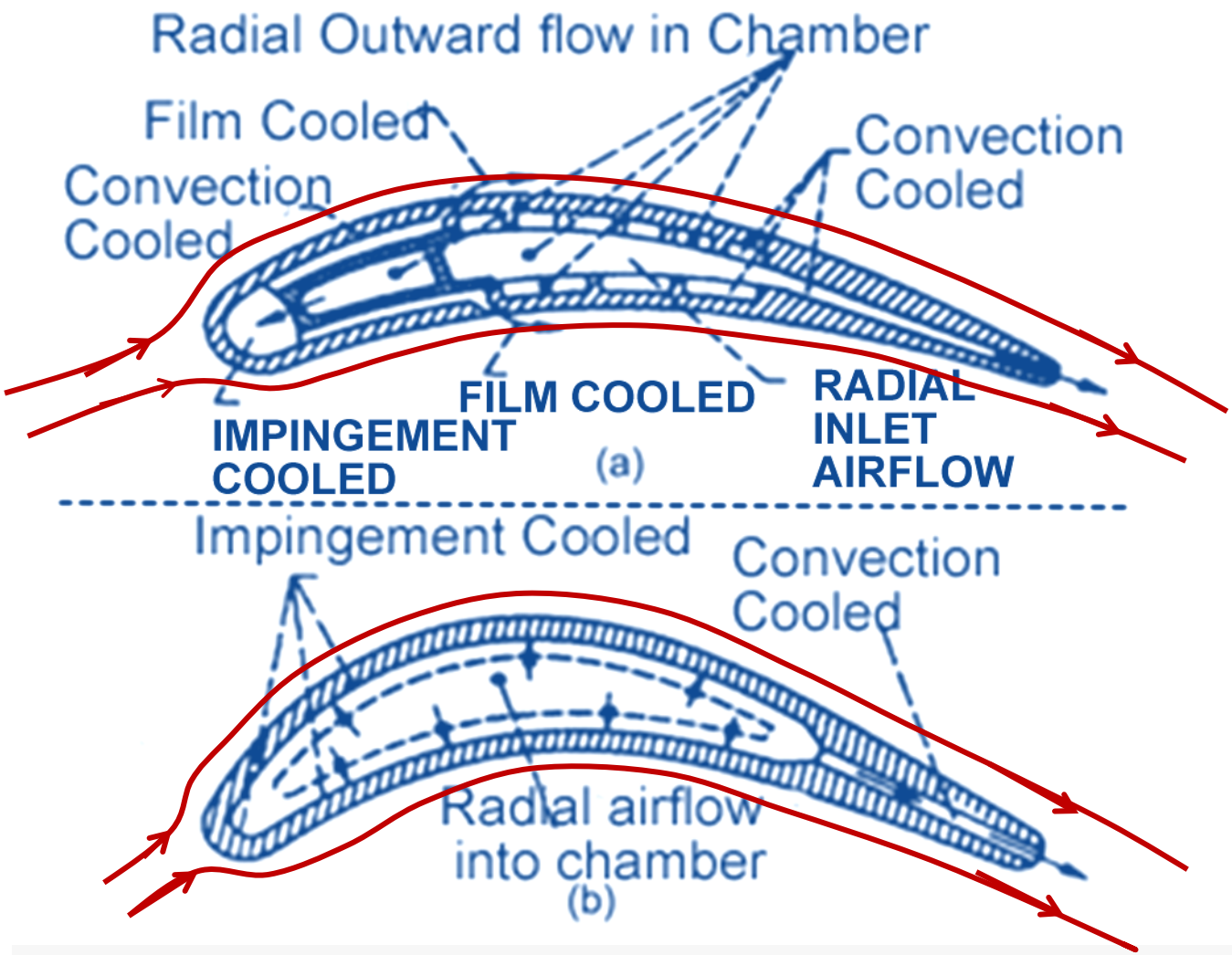


(a) Internal convection cooling (b) Internal impingement cooling

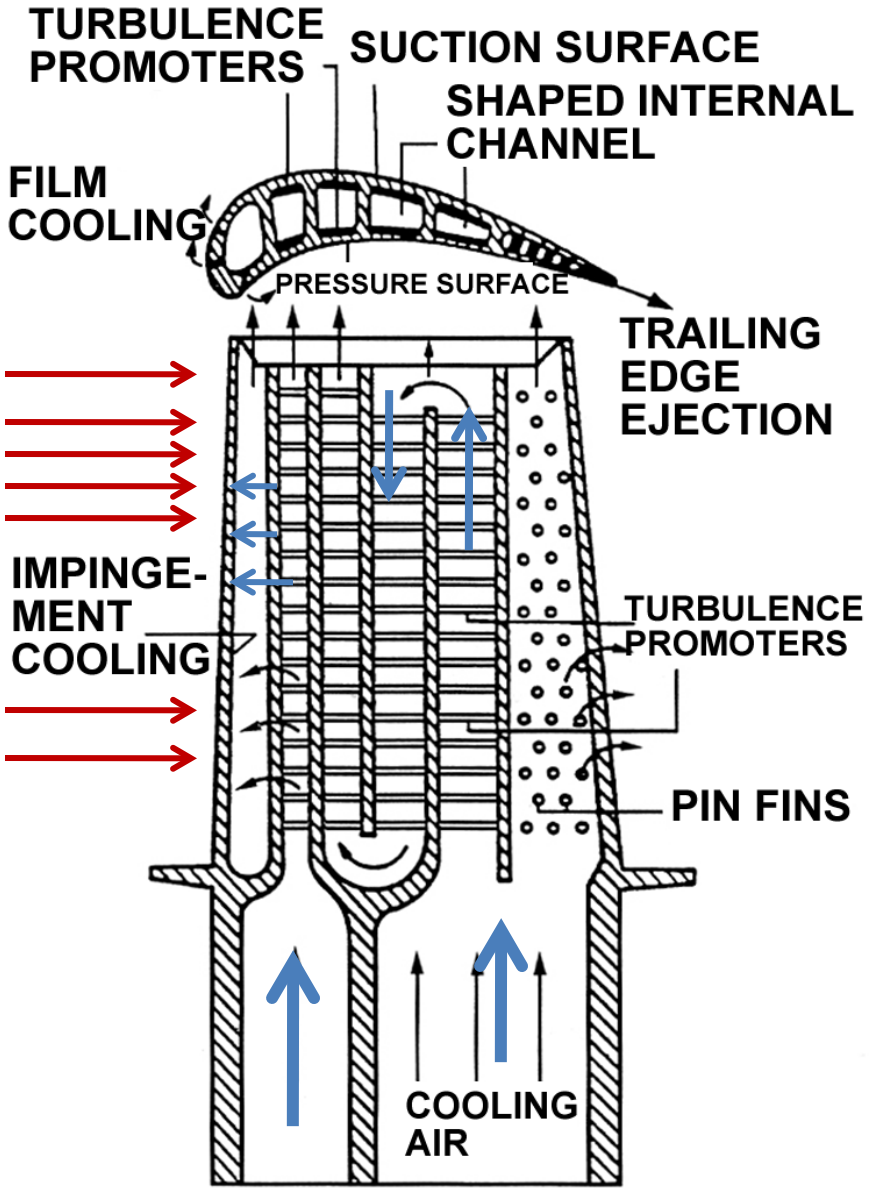


(c) Discrete film cooling (d) Full blade film cooling
(e) Full blade transpiration cooling (porous blade)


CONVECTION COOLING
FILM AND CONVECTION COMBINED COOLING
TRANSPIRATION COOLING
TURBINE INLET PRESSURE P_{01} atm
40
20
10
5
5 TO 40
5 TO 40
RELATIVE COOLANT FLOW
0
1
2
3
1400
1600
1800
2000
2200
TURBINE INLET TEMPERATURE T_{01} K



a) Combined convention, impingement & film cooled
b)Combined internal convection and impingement cooled



Coolant flow paths in a modern HP turbine stator

- Various blade cooling techniques provide various amounts of cooling
- Maximum cooling is normally applied to first HP stage stator, which faces the highest temperature
- Cooling is also applied to HP rotors. But the details of this technology is a little more complicated as the cooling has to be effected when the blades are rotating at high speeds
- Modern LP stage stators are also cooled.
- Last stage blades do not require cooling as the gas temperature is already substantially reduced.

- Over the last fifty years more effort has been given to turbine cooling rather than to turbine aerodynamics.
- As the flow in turbine is always in favourable pressure gradient, high turbine efficiency is comparatively easily achieved.
- Cooling actually reduces turbine efficiency slightly
- Cooling occurs differentially across the blade surface depending on the local temperature fields of gas and cooling available locally.
- Amount of local cooling may vary from 50^0 to nearly 500^0 centigrade in modern blades
- Coatings are also applied on blade surfaces for saving the blades from high temperature

Next class

Radial Flow Turbines

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