TURBOMACHINERY AERODYNAMICS

Lect 28

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Axial Flow Turbine

Blade Cooling Technologies

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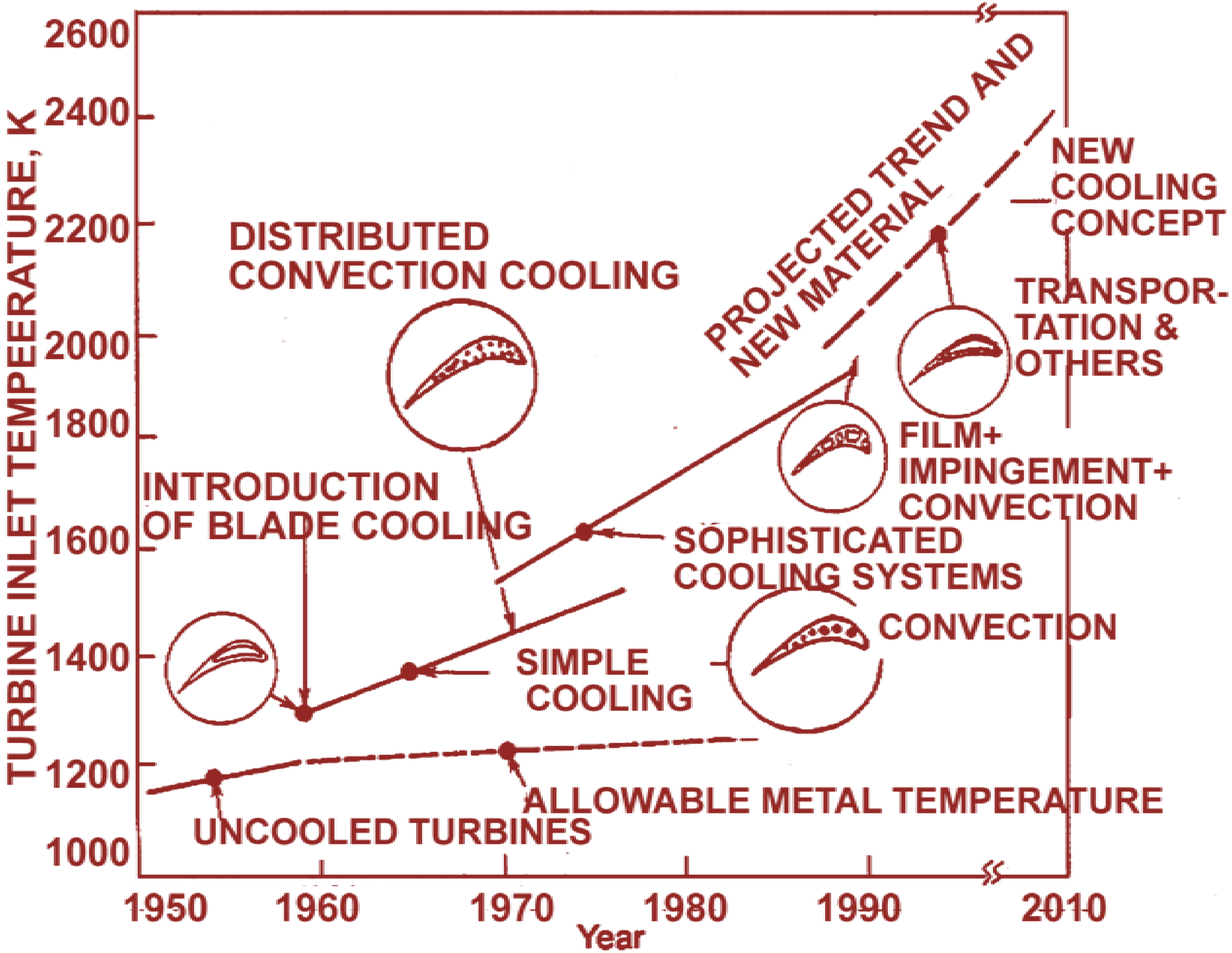

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Time history of Turbine blade cooling

1950 – Uncooled blade – Temp. – 1000 to 1100 K

1960 - Internal 1 or 2 pass cooling, 1200-1400 K

1970 – Distributed internal convection cooling – 1300 – 1500 K

1980 - Film Cooling + Internal cooling – 1600-1800 K

1990 – Film + Impingement cooling– 1600-1900 K

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Temperature on turbine blade surface (felt by it)

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

Where, DR= R_x

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

Where,
t – time ;
ΔT – Temp difference

$$Nu \propto f_1(Re).f_2(Pr),$$

$$Nu = 0.0296.Re^{0.8}.Pr^{1/3}$$

Where, Nu – Nusselt's No. ;
Pr – Prandtl no.;
Re – Reynolds no.

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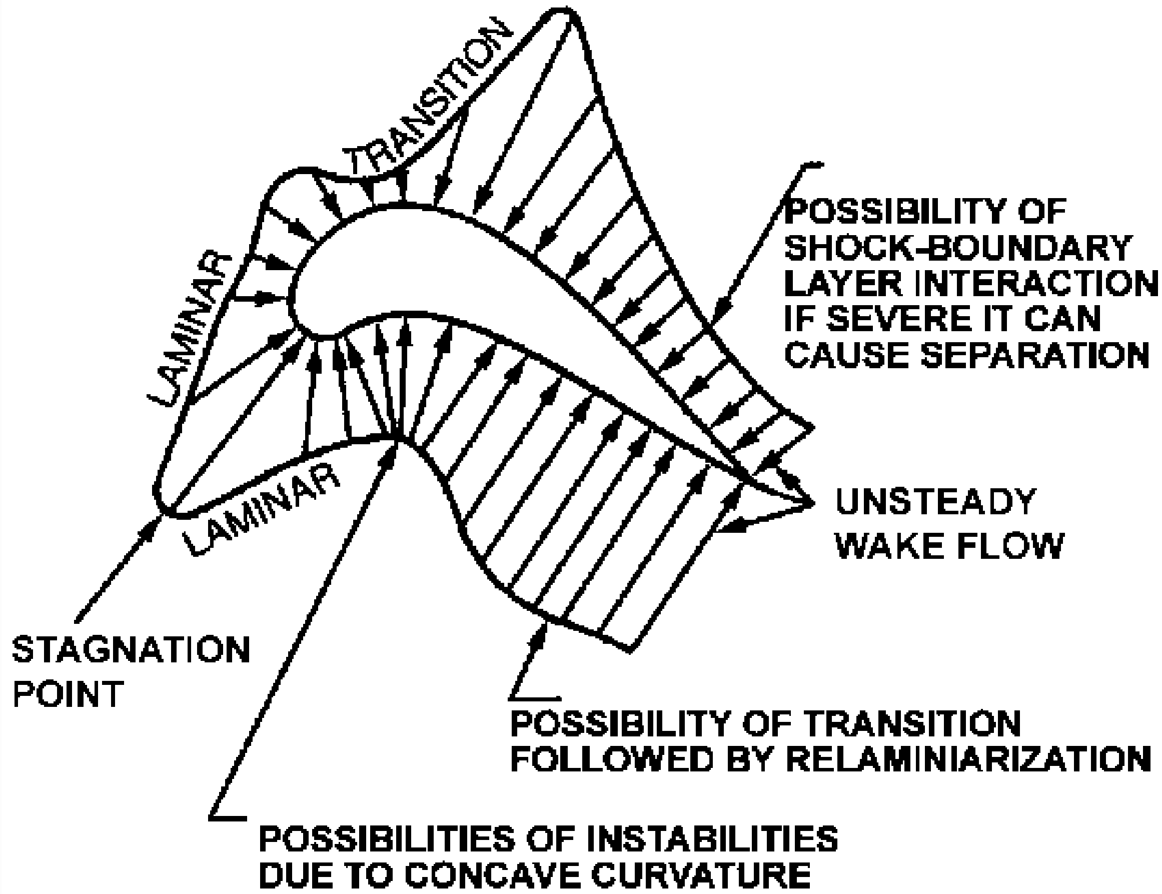
Heat Transfer

- The heat transfer is mainly by surface convection, conduction and then internally mainly by forced convection.
- *Radiation heat transfer is negligible.*



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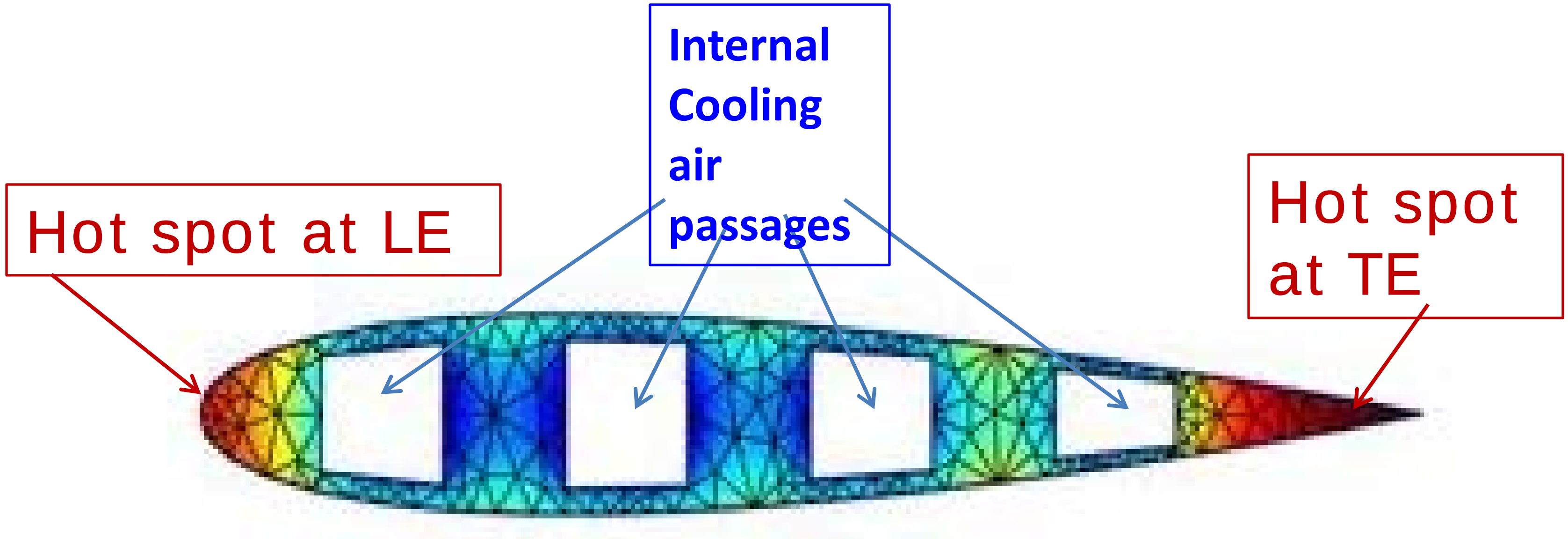
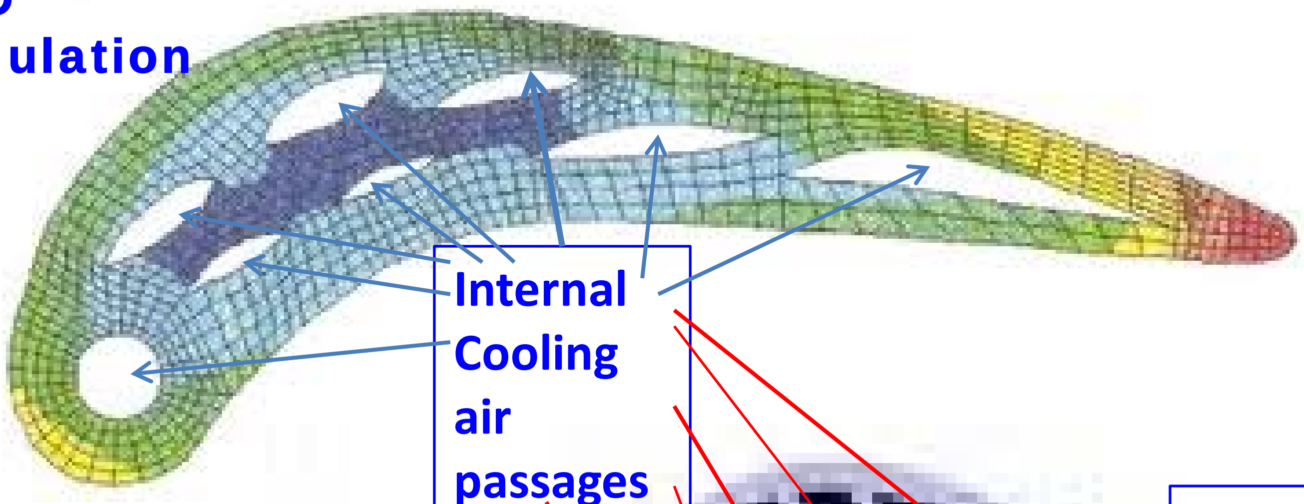
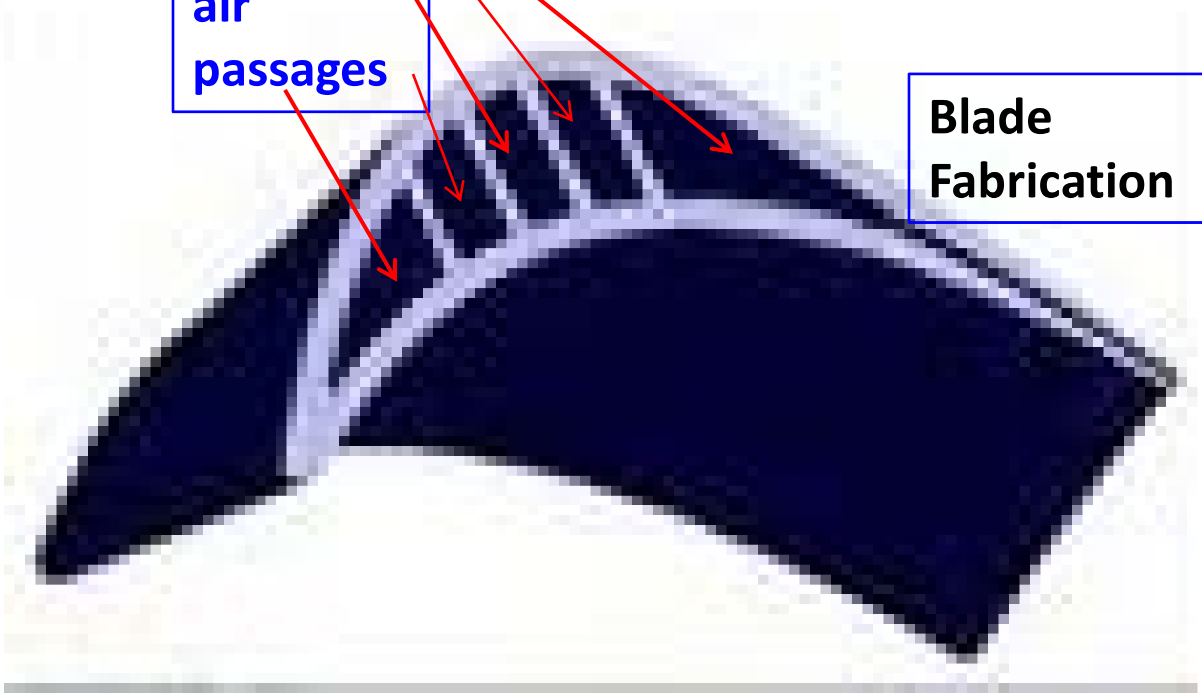


Large Temperature gradient along the chord

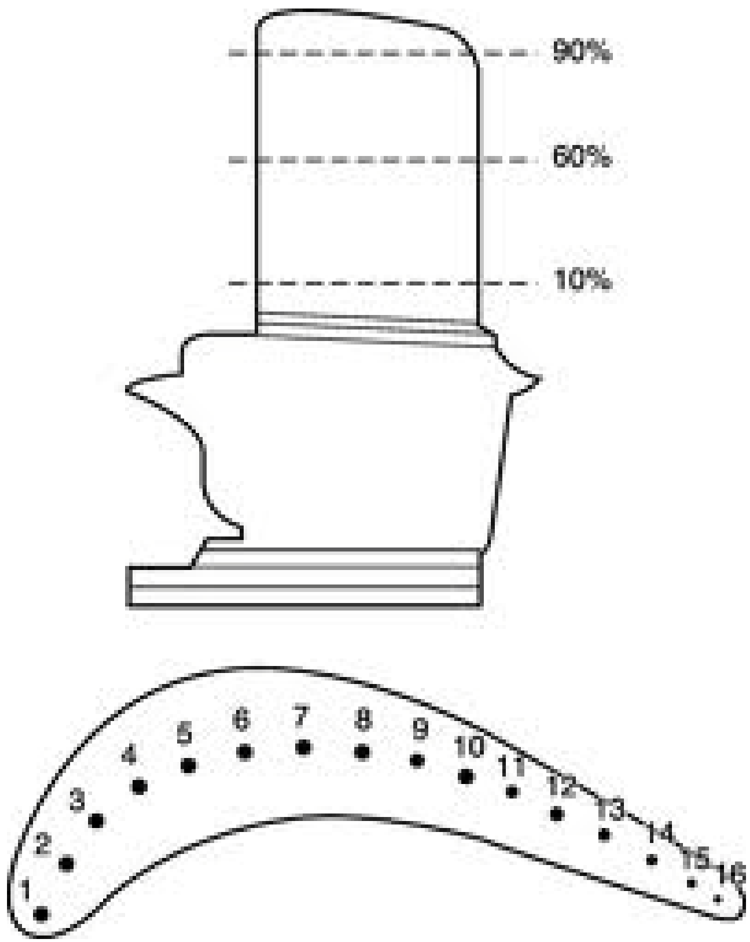
CFD simulation

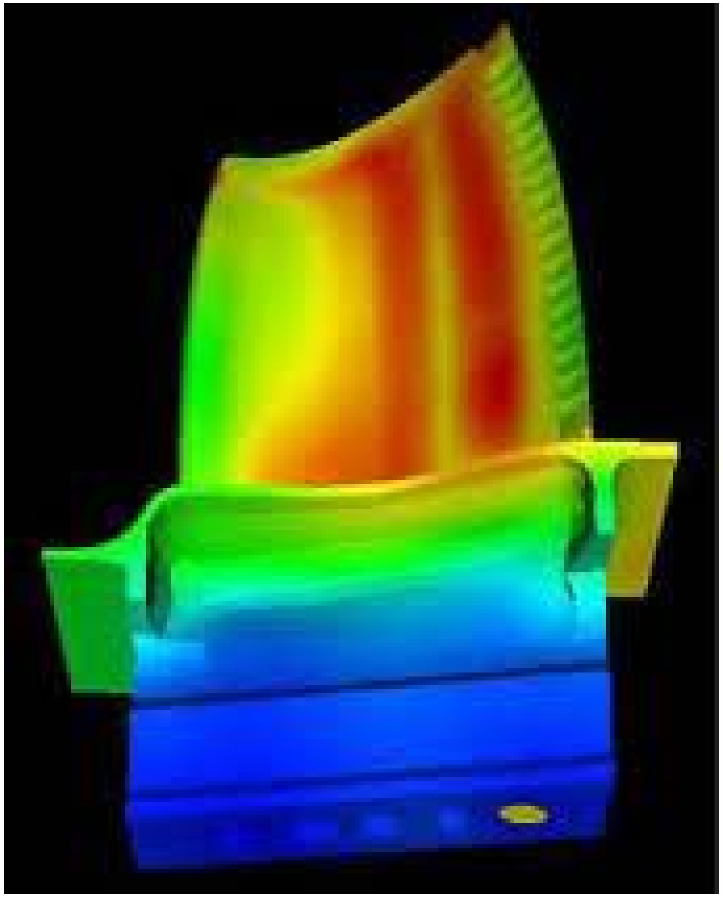


Distributed Internal Blade cooling



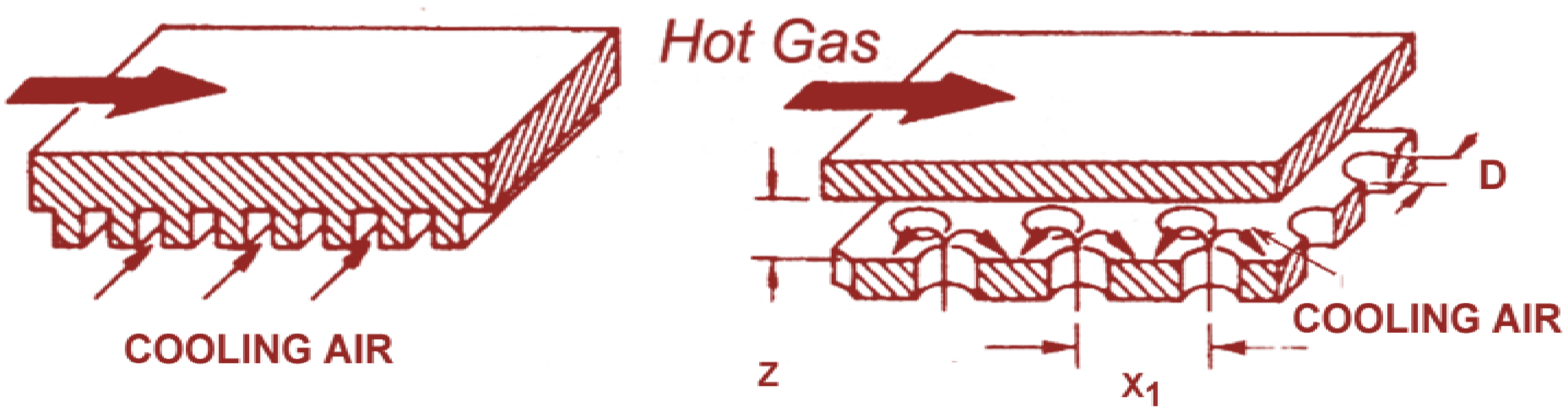
- Blade Temperature may vary along the blade surface from LE to TE by 200 to 300 K
- Blade temperature may also vary from the root to the tip of a rotor
- Maximum blade temperature is felt at the LE of the first stator – as the flow comes from C.C.
- HP turbine blades have maximum temperature and maximum temperature gradient across both the rotor and the stator
- Blades are thermally loaded in cycles of operation
- Turbine failure occurs mostly in creep (thermal fatigue)





Turbine blade internal temperatures captured : ref : ONERA, France

Turbine Cooling



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

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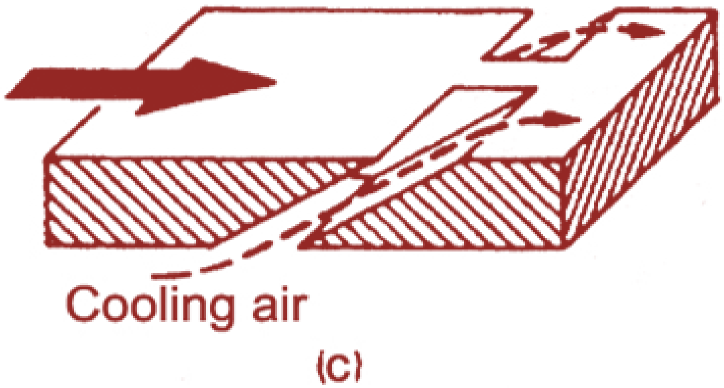

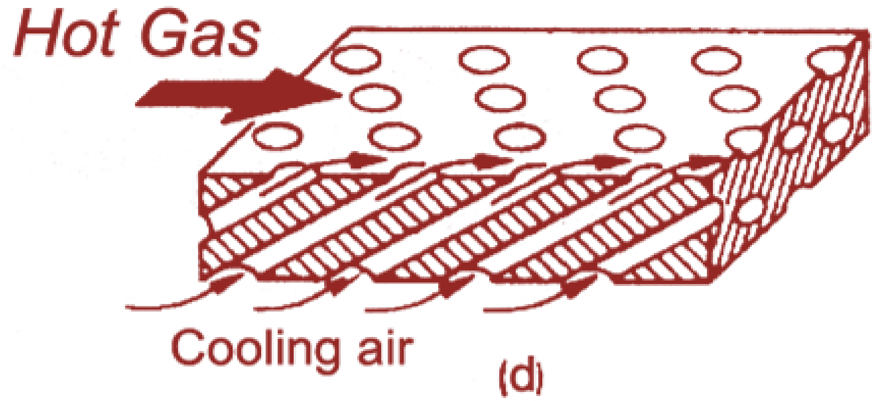

(c) Discrete film cooling

(d) Full blade film cooling

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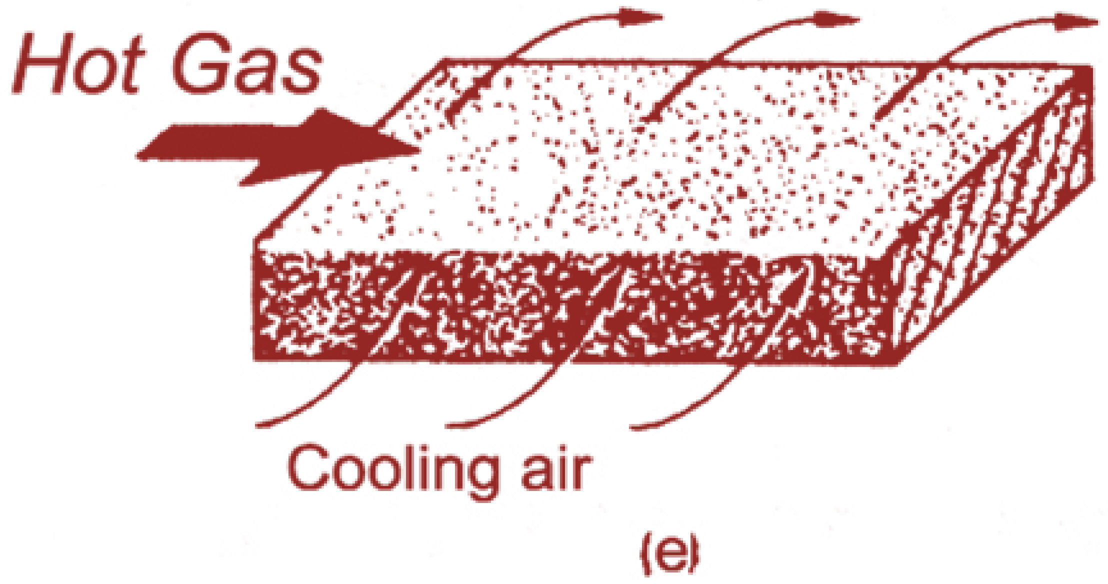
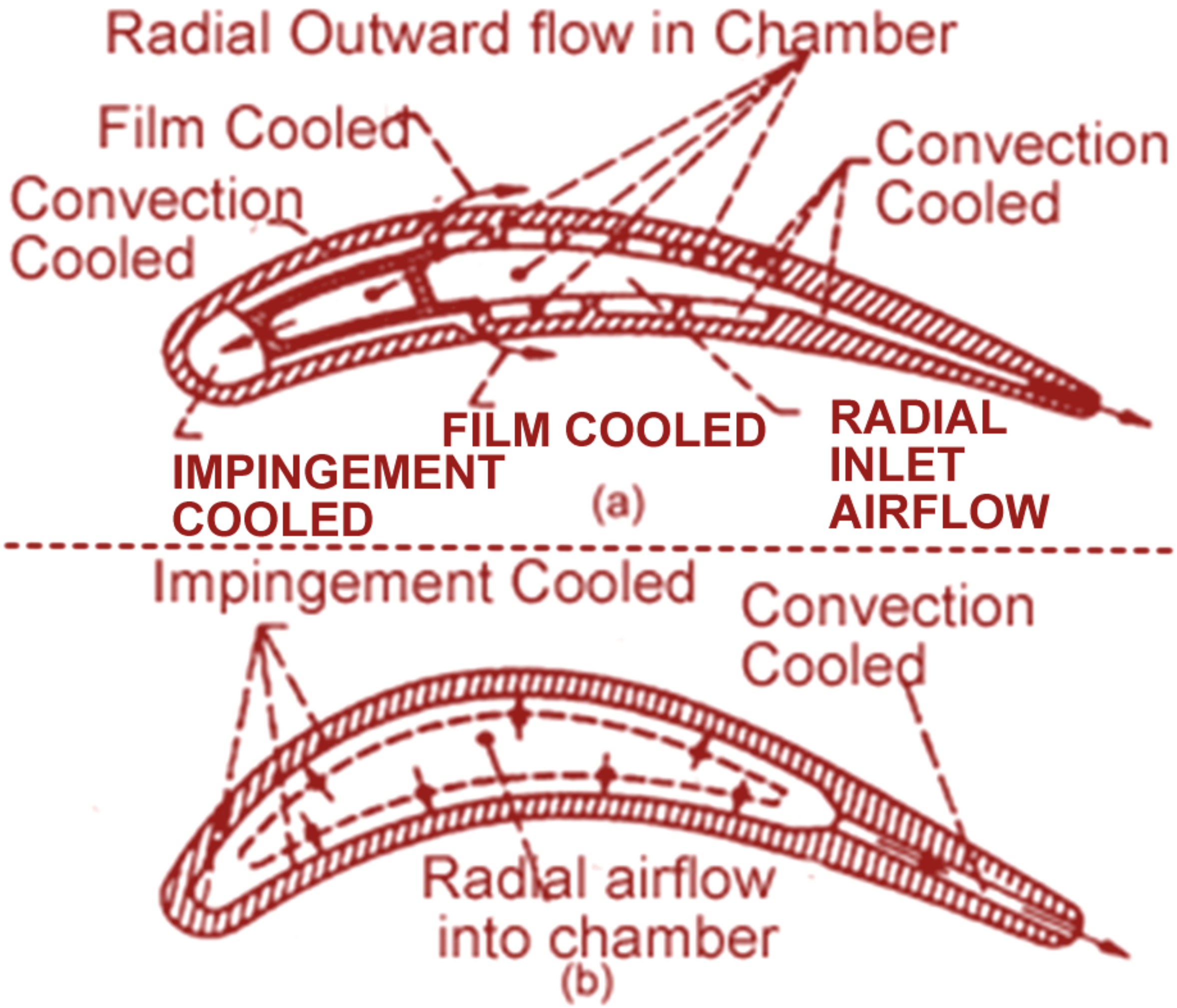
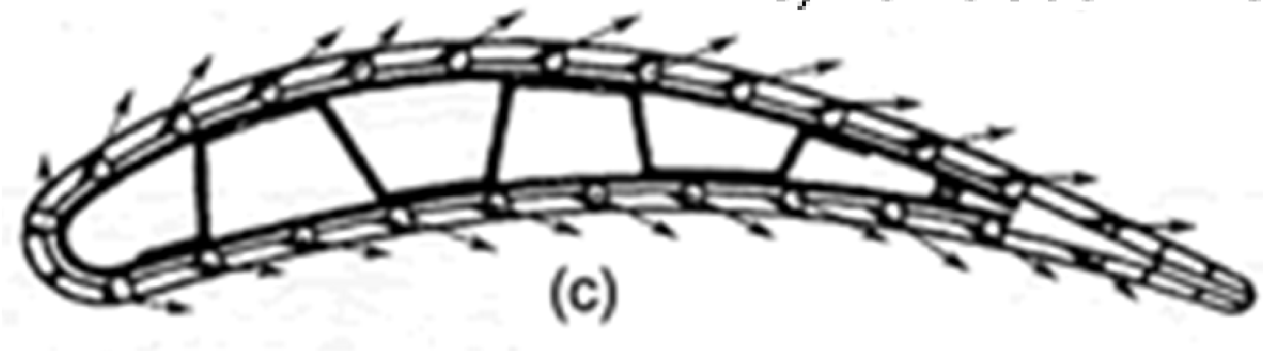
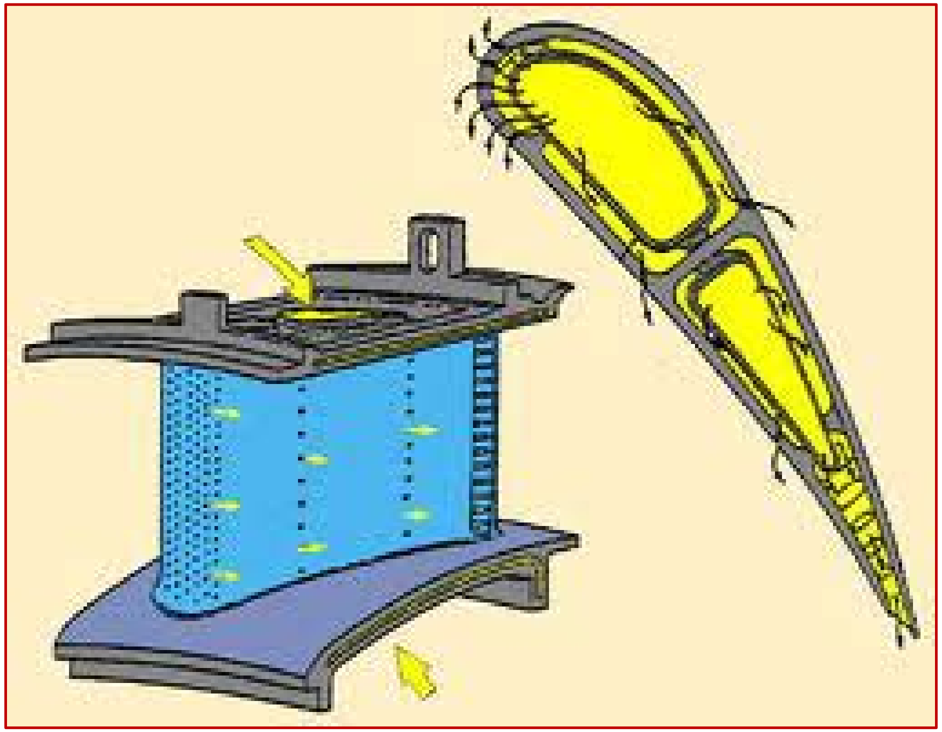


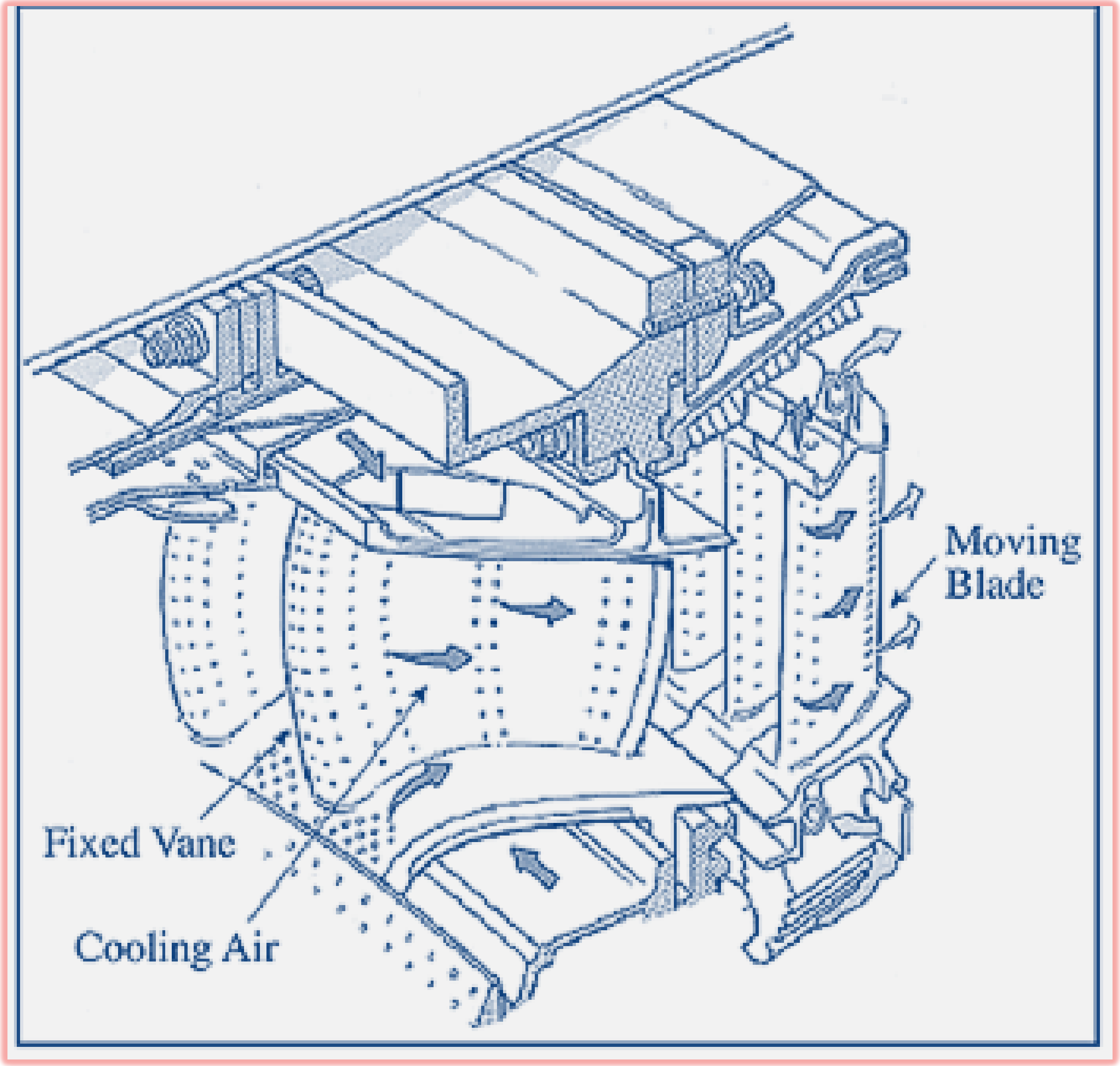
(e) Full blade transpiration cooling (porous blade)

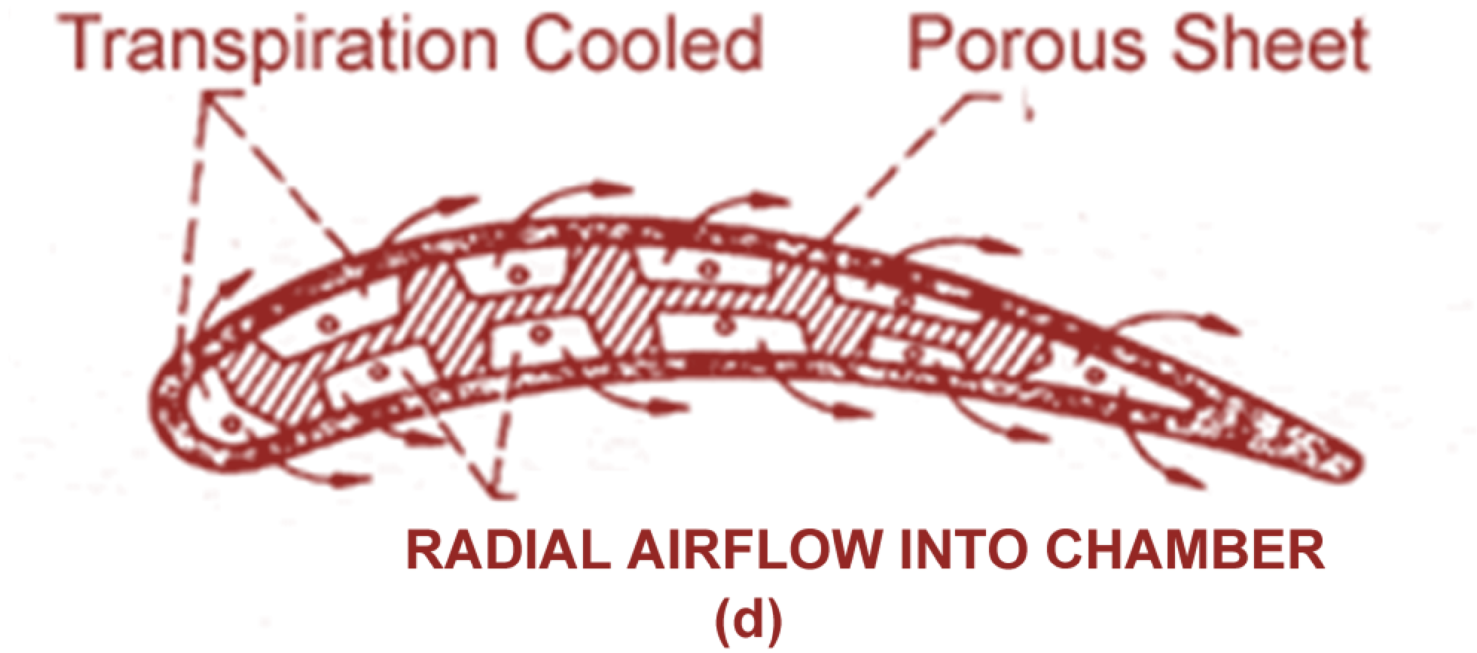

Radial Outward flow in Chamber
Film Cooled
Convection Cooled
Convection Cooled
FILM COOLED
IMPINGEMENT COOLED
RADIAL INLET AIRFLOW
(a)
Impingement Cooled
Convection Cooled
Radial airflow into chamber
(b)

c) Full blade film cooled

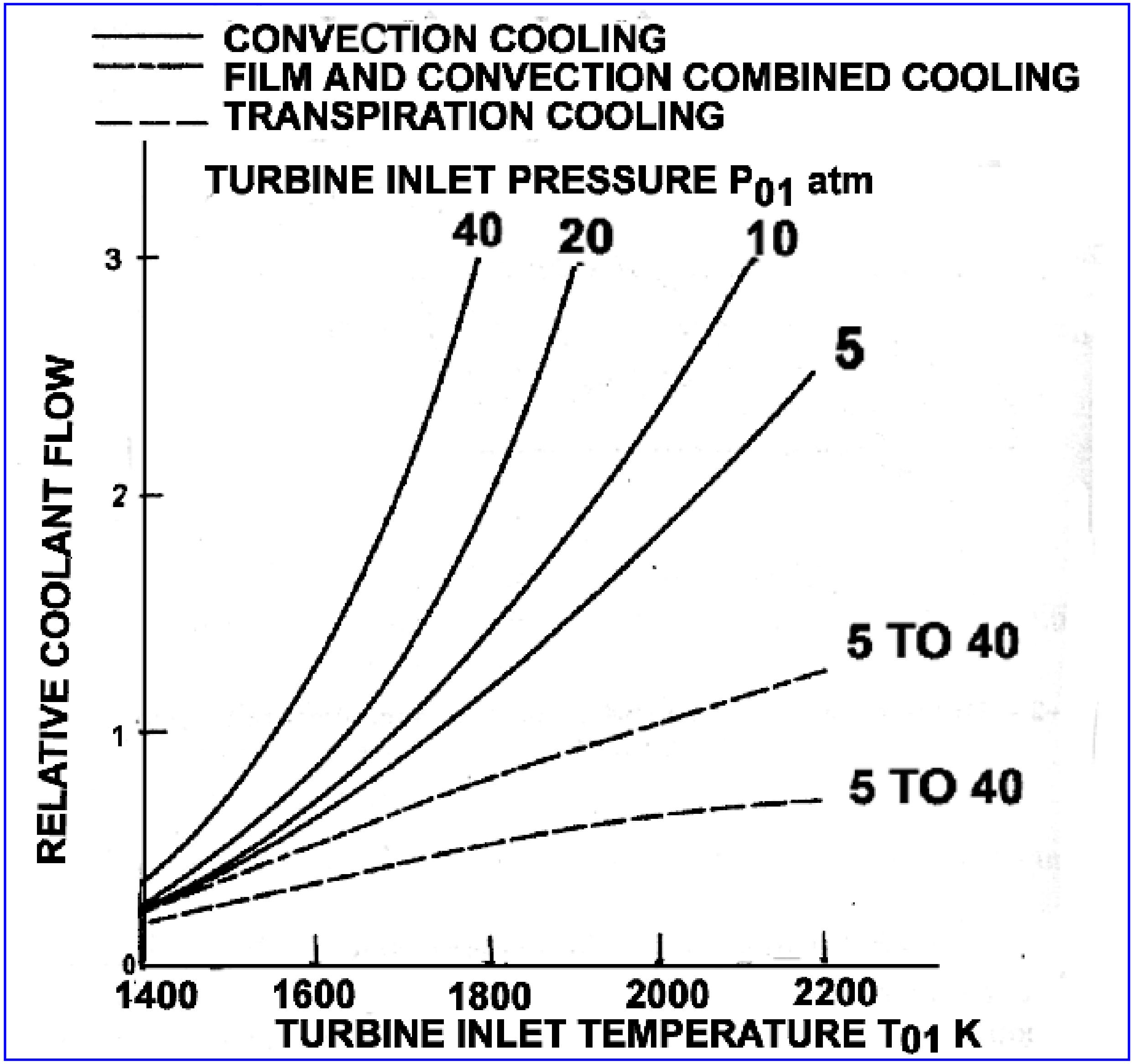




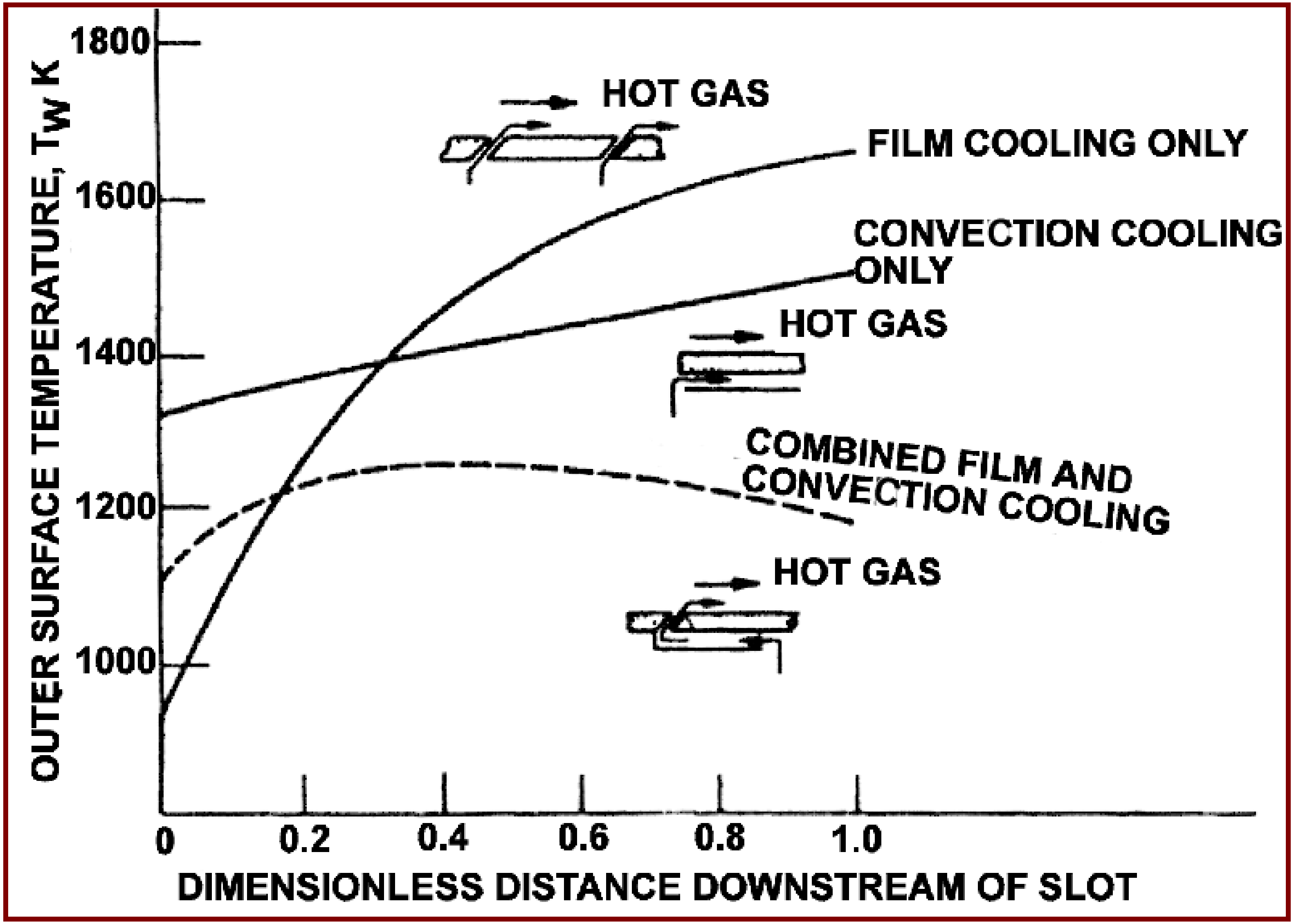

Moving
Blade
Fixed Vane
Cooling Air

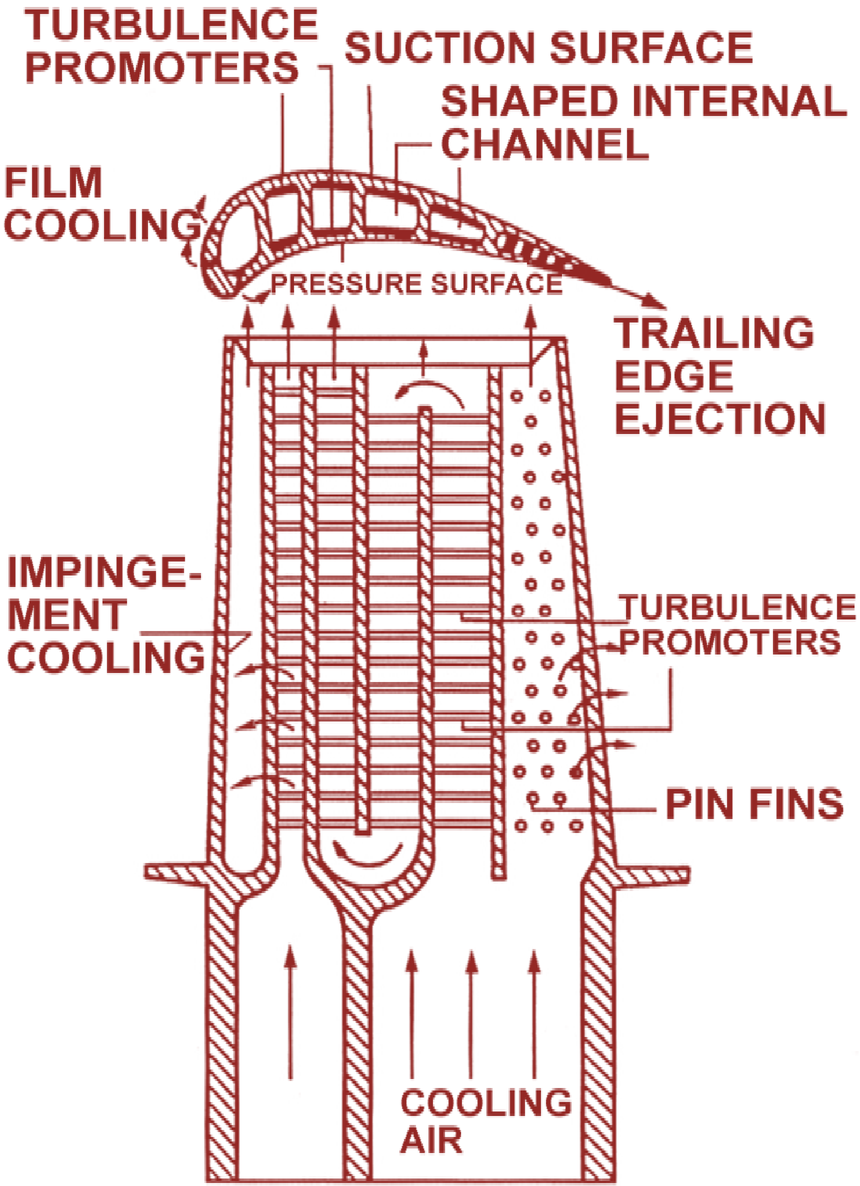


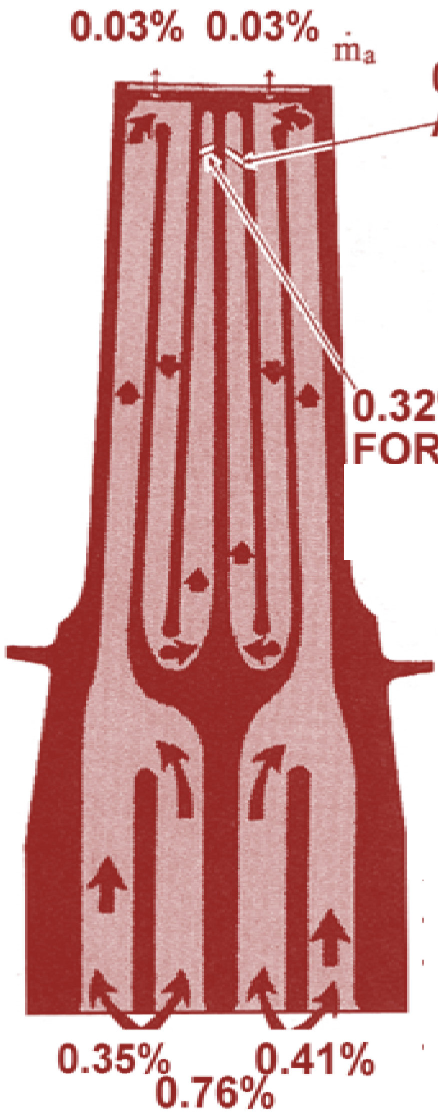
d) Transpiration cooled

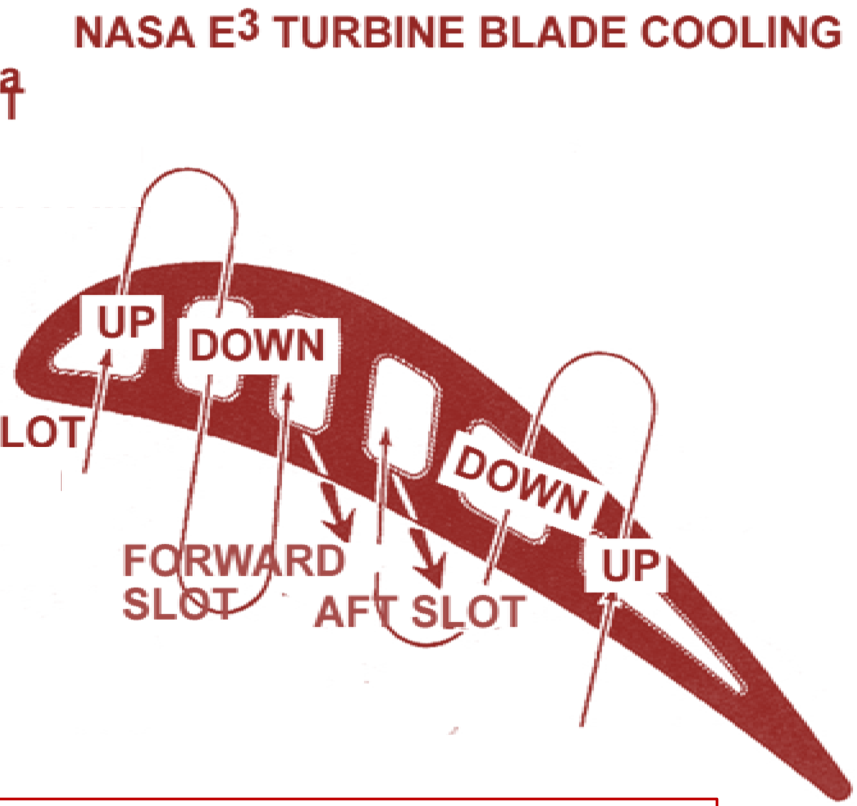


- **Need for high turbine temperature was reduced due to high compressor pressure ratio**
- **Advanced cooling has extended both TET and Compr ratio**


1800
1600
1400
1200
1000
OUTER SURFACE TEMPERATURE, T_W K
HOT GAS
FILM COOLING ONLY
CONVECTION COOLING ONLY
HOT GAS
COMBINED FILM AND CONVECTION COOLING
HOT GAS
0
0.2
0.4
0.6
0.8
1.0
DIMENSIONLESS DISTANCE DOWNSTREAM OF SLOT


TURBULENCE PROMOTERS
SUCTION SURFACE
SHAPED INTERNAL CHANNEL
FILM COOLING
PRESSURE SURFACE
TRAILING EDGE EJECTION
IMPINGE-MENT COOLING
TURBULENCE PROMOTERS
PIN FINS
COOLING AIR





Inside surfaces of the holes are often ribbed to promote turbulence and higher flow through the internal holes

Next Lecture ---

Design of Axial Turbine Blades

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