TURBOMACHINERY AERODYNAMICS

Lect - 29

Prof. Bhaskar Roy, Prof. A M Pradeep
Department of Aerospace Engineering,
IIT Bombay

Axial Flow Turbine

Blade design - Profiles

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Axial Turbine Design Considerations :

1) Selection of design point – from engine cycle
2) Selection of fundamental design parameters

   π_{0T} , $\dot{m}_{gas}$, D_{max} , T_g , P_a , T_a at design point

3) Compute : Stage Loading Coeff, $\psi = \Delta H_{0T} / \frac{1}{2}\rho U^2$

   Flow Coefficient, $\phi = C_a / U_{mean}$

   Degree of Reaction, R_x

   Blade Flow Turning, $\Delta\beta$

   Velocity Triangles, α_1, α_2 , α_3 , β_2 , β_3

   C_1, C_2, C_3, V_2, V_3

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Selection of

1) Design requirements η_T^* , $T^*_{g\text{-}max}$, α^*_{exit}, M^*_2

2) Design constraints : for both **HPT & LPT** –

i) n_1, n_2, U_{m1}, D_{m1}, U_{m2}, D_{m2}

ii) *Blade and Disk Stress levels*

iii) *Materials Technology*

iv) *Blade cooling Technology*

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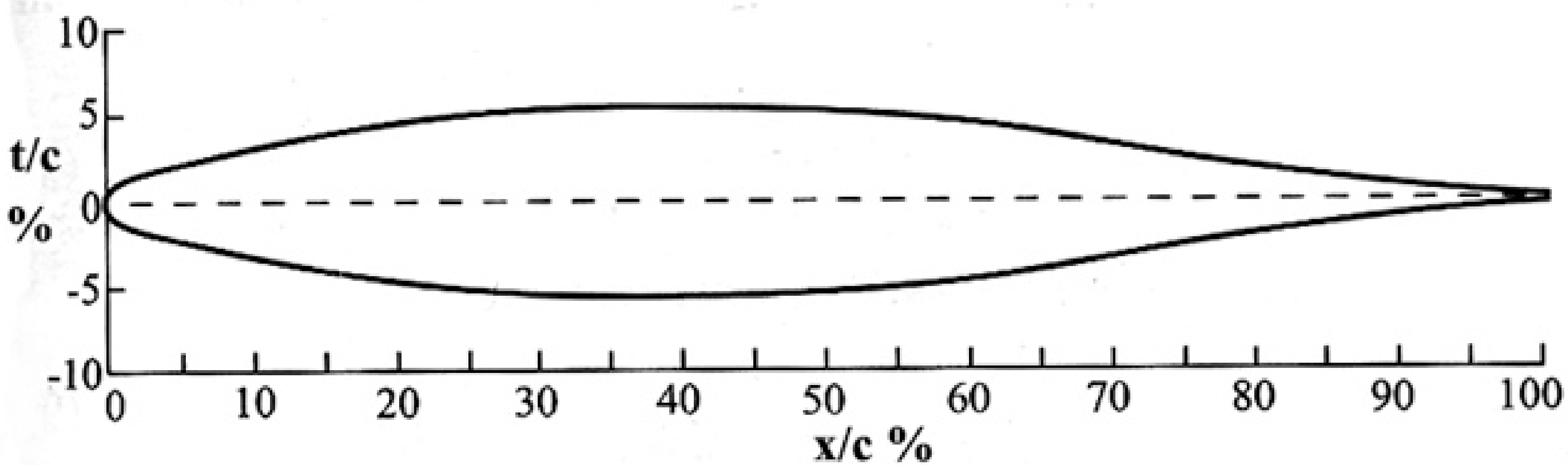
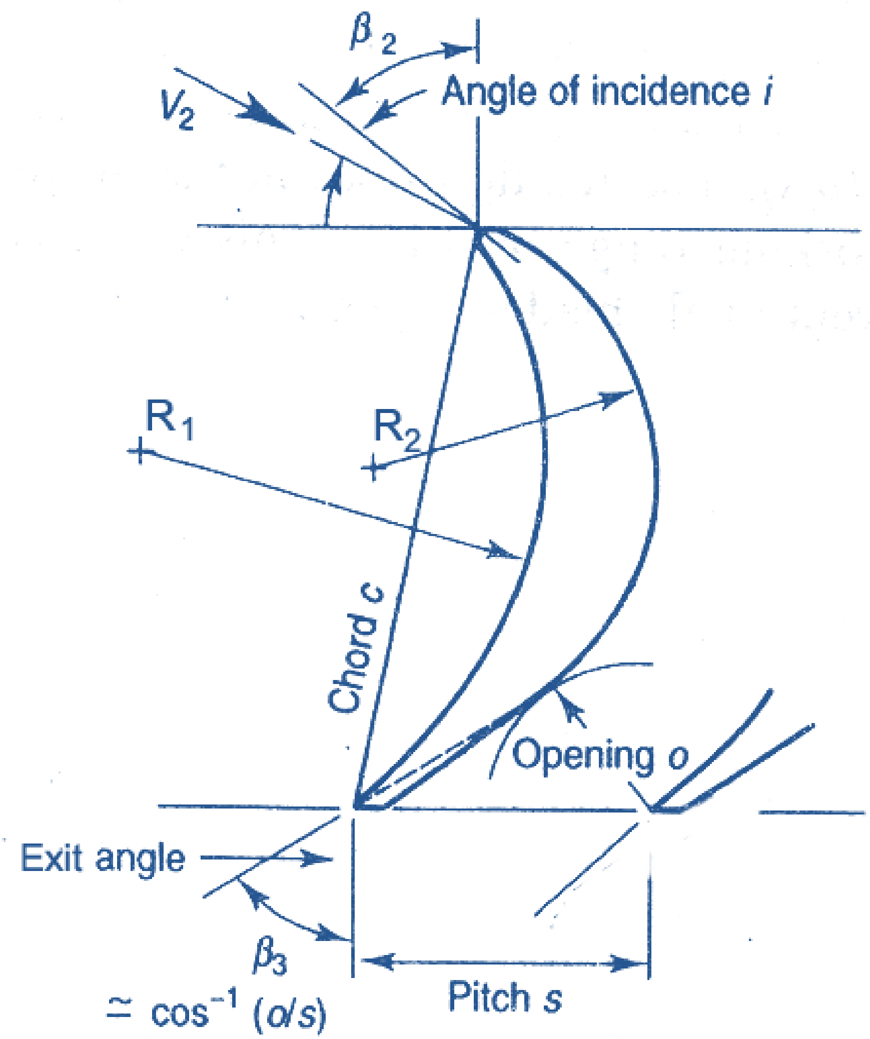
Airfoils for Gas Turbine

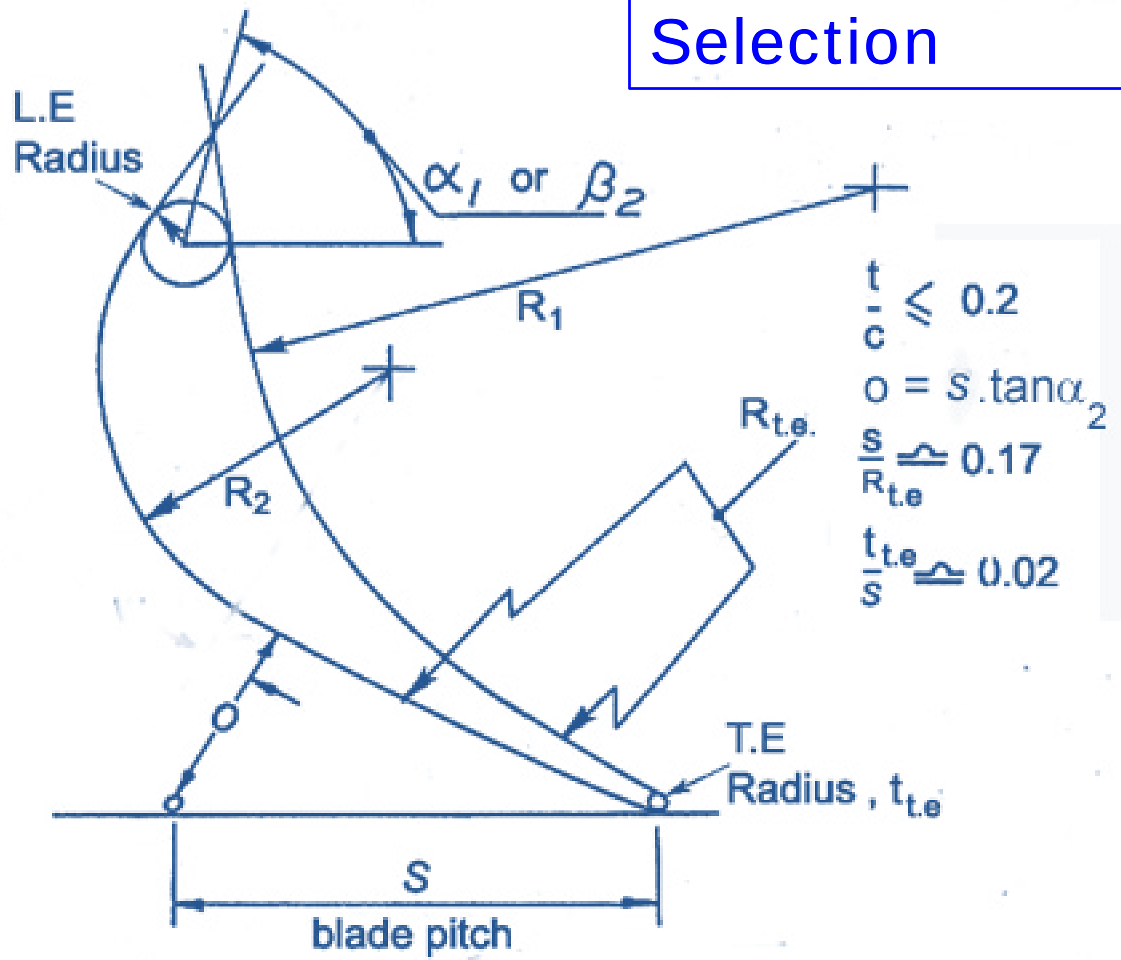


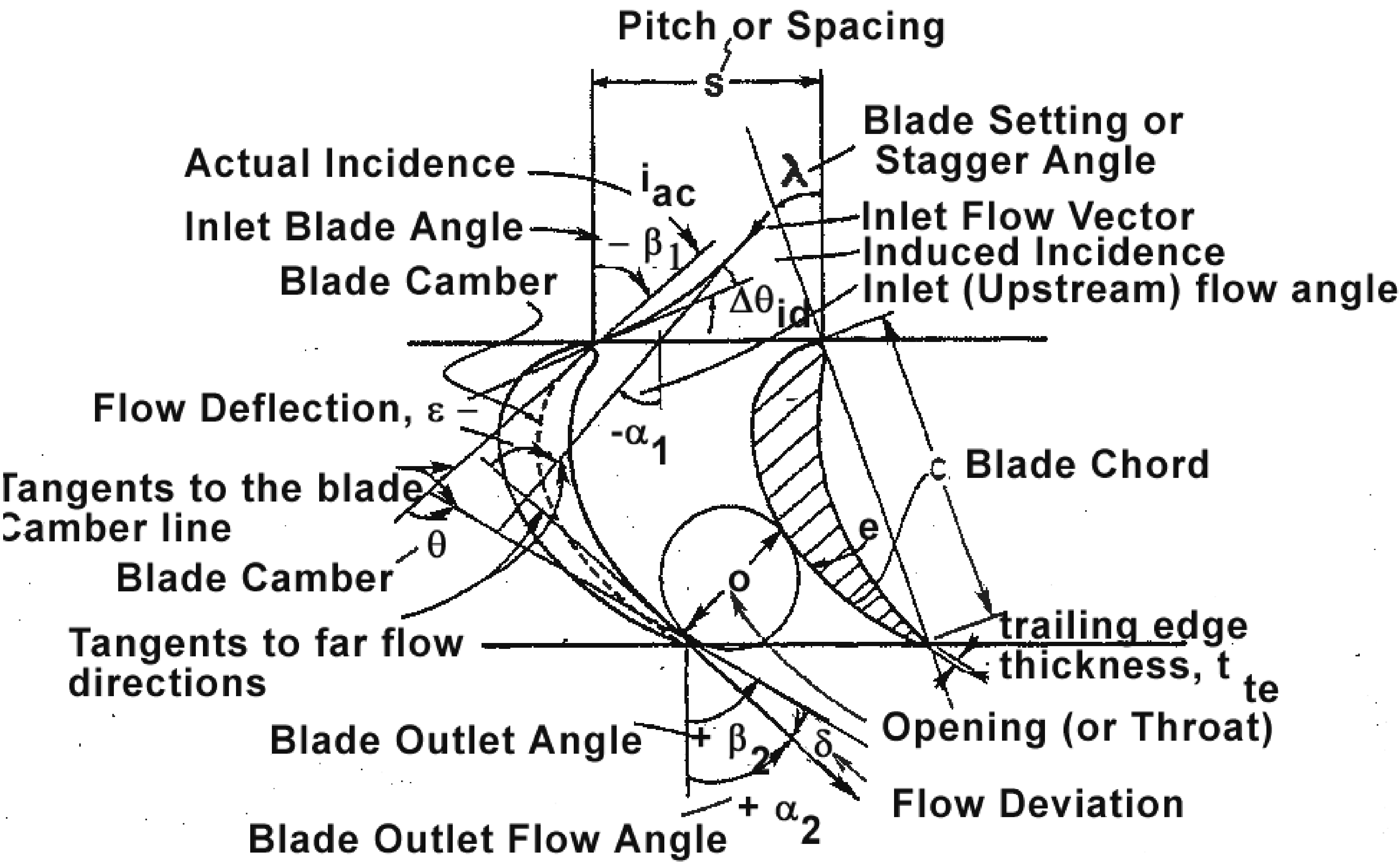
T6 10% thick turbine airfoil base profile.

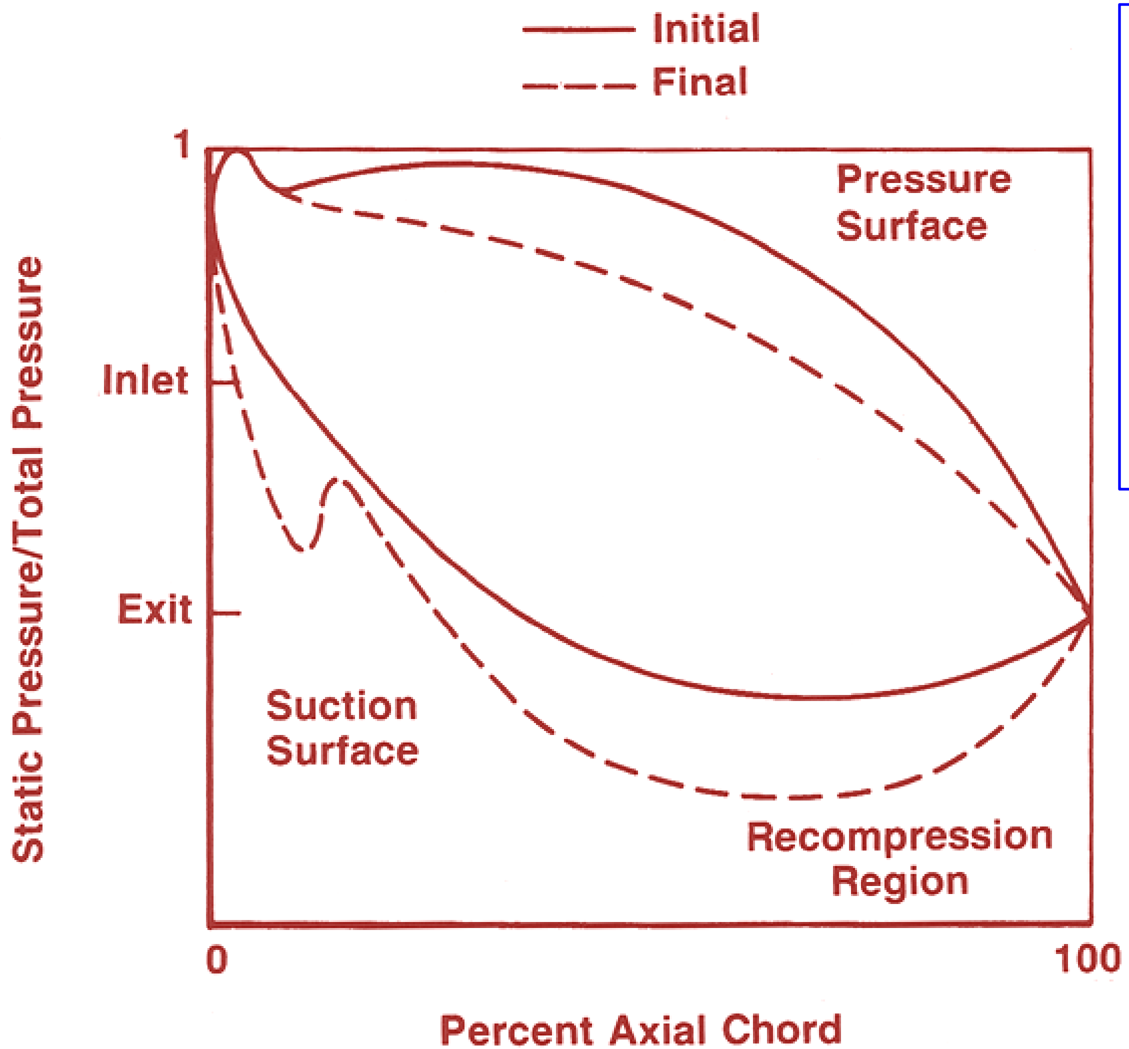


Important Aerodynamic Parameters for blade airfoil selection

Airfoil Geometry Selection




Pitch or Spacing
s
Blade Setting or Stagger Angle
λ
Actual Incidence
i_{ac}
Inlet Blade Angle
$-\beta_1$
Blade Camber
Inlet Flow Vector
Induced Incidence
$\Delta\theta_{id}$
Inlet (Upstream) flow angle
Flow Deflection, ε
$-\alpha_1$
Blade Chord
c
Tangents to the blade Camber line
θ
Blade Camber
e
o
Tangents to far flow directions
trailing edge thickness, t_{te}
Opening (or Throat)
Blade Outlet Angle
$+\beta_2$
δ
Flow Deviation
$+\alpha_2$
Blade Outlet Flow Angle



Cascade airfoil pressure distributions.

Airfoil pressure distribution applied as per requirement to deviate from a starting profile

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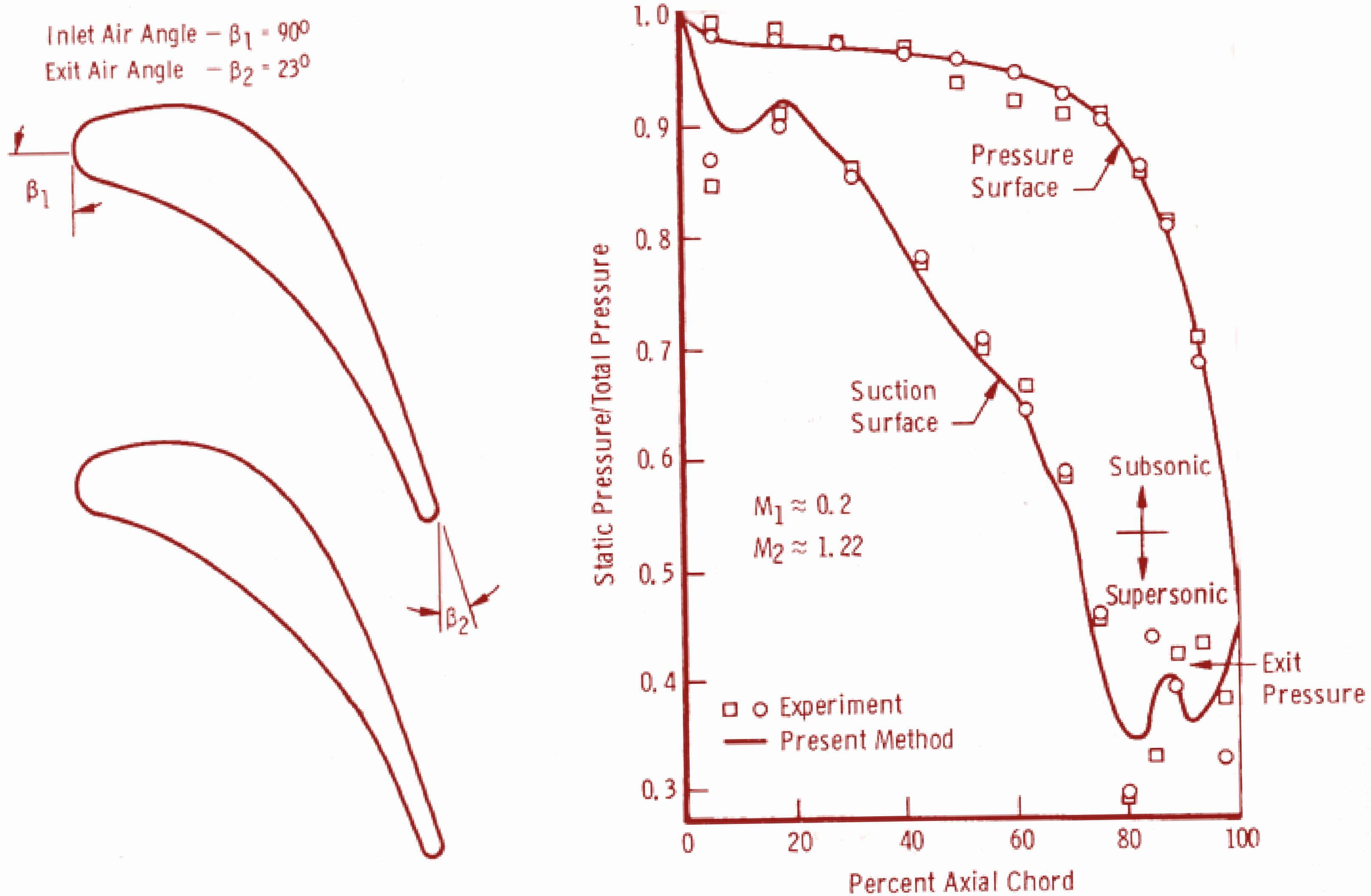
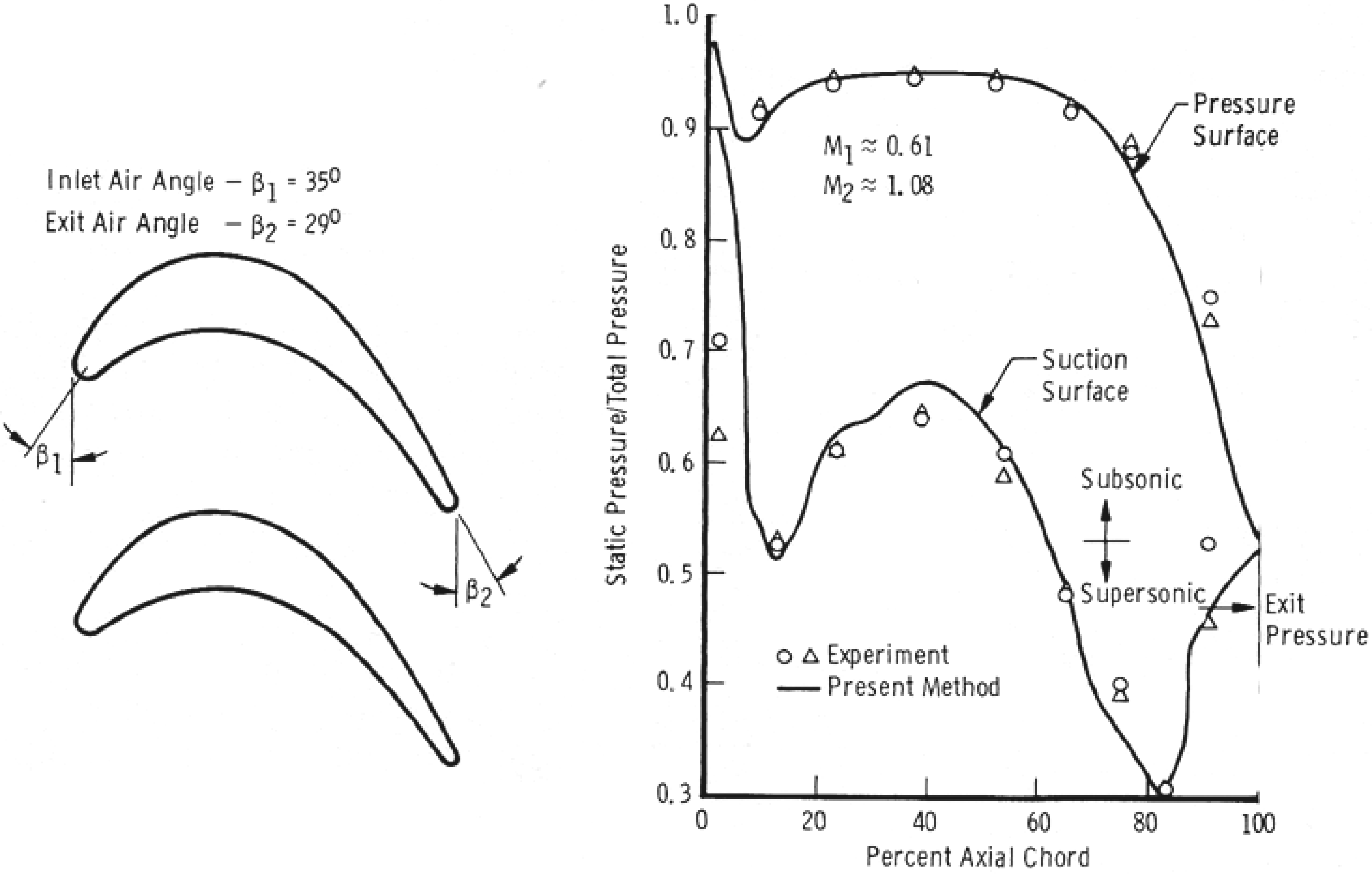
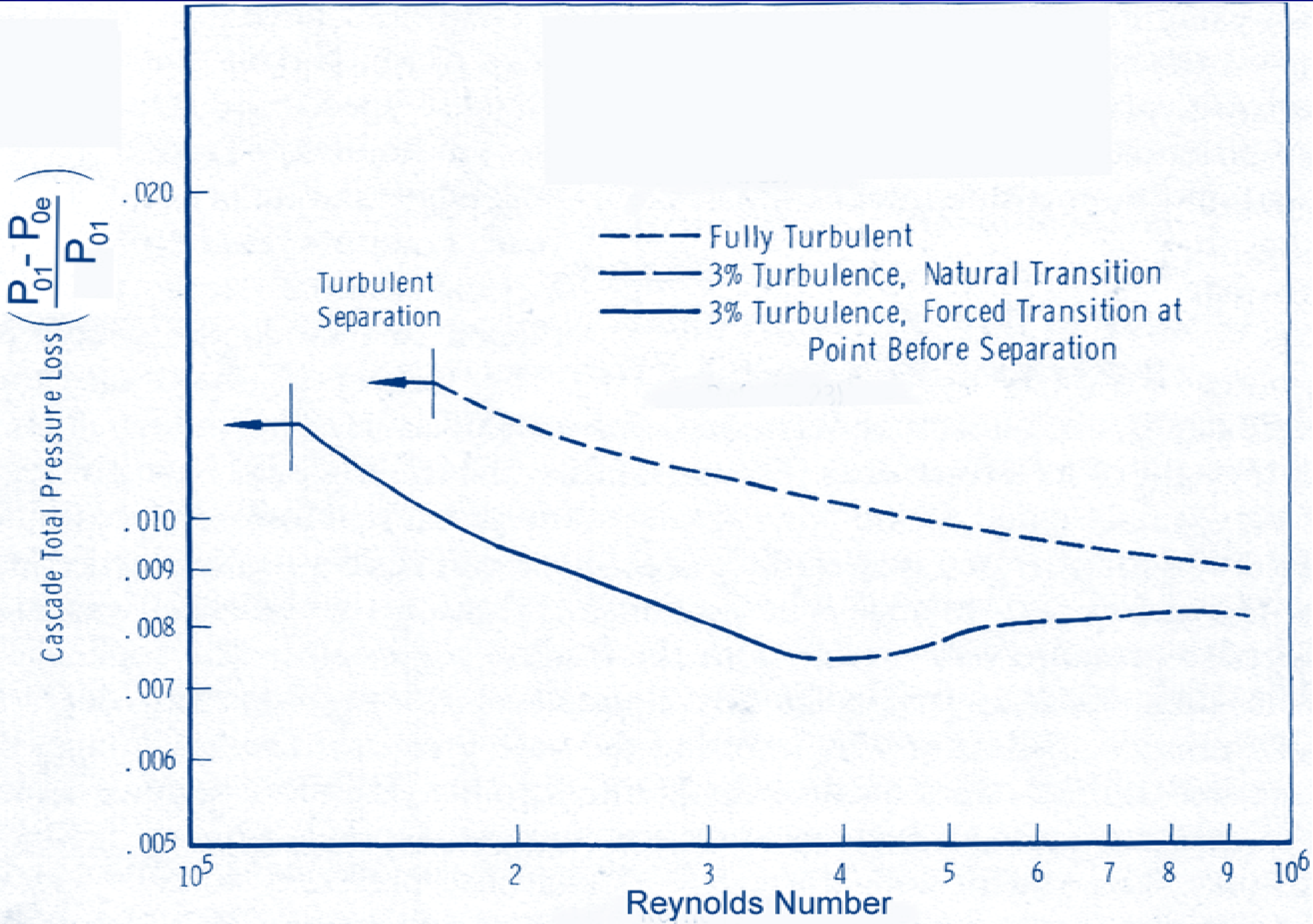


Predicted and measured stator pressure distribution.



Predicted and measured rotor pressure distribution.



Cascade profile loss vs Reynolds number.

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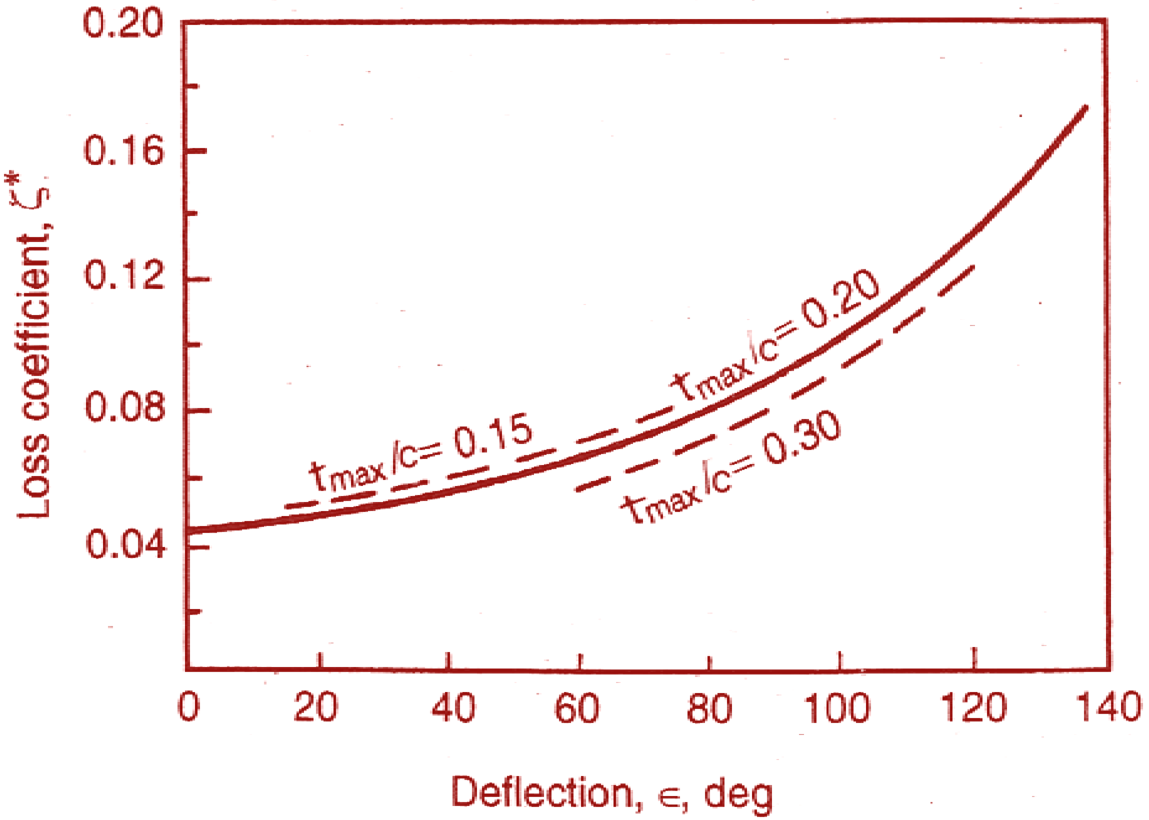

Soderberg's correlation of turbine blade loss coefficient with fluid deflection

Blade loading vs Blade Spacing

If the spacing between the blades is small, the blades provide maximum guidance of the fluid , but the surface area goes up and the surface friction loss (primary loss) goes up.

Zweifel criterion specifies: $Z_w = \Delta H_{0T} / \Delta H_{0T\text{-ideal}} \approx 0.8$

Which in terms of blade tangential loads ,

$$Z_w = 2.s/c.\cos^2\alpha_2 \, (\tan\alpha_1 + \tan\alpha_2)$$

The above criterion allows the designed to arrive at a minimum loss blade spacing.
However modern design exploration has proven that the specification is valid for $60^o < \alpha_2 < 70^0$

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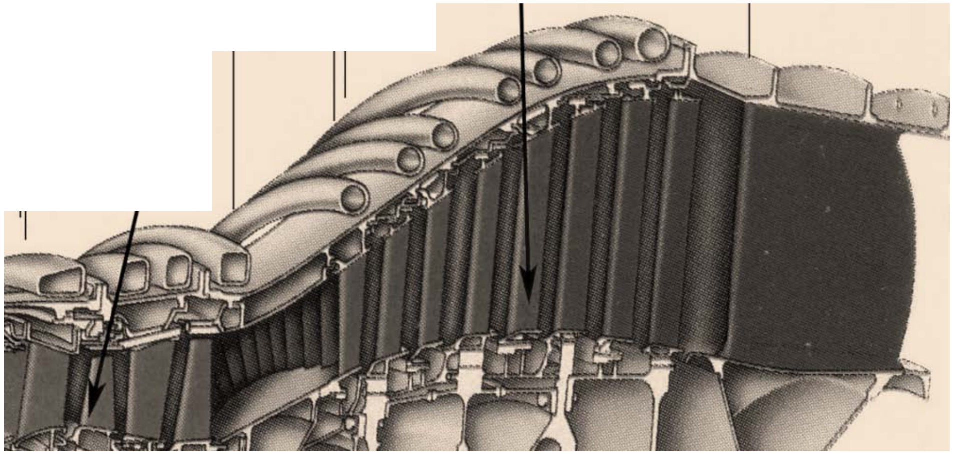
HPT turbines and LPT Turbines

- HPT blades are short and run at high rpms
- LPT blades are long and run at low rpms
- HPT blades face high temperature
- LPT blades work with high velocity flows



Because of vastly different loading patterns the airfoils used for HPT and LPT are often quite different from each other

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- Airfoils designs are generally done in cascade format
- A starting airfoil shape (T6 or T106) with appropriate starting camber matching the flow turning angle ($\Delta\alpha$) is selected
- The airfoil is suitably modified by interactive or Direct method of numerical analysis
- At the final stage when a acceptable blade loading has been reached, Indirect method may be used by specifying a Cp distribution over the blade to arrive at a final airfoil shape in cascade

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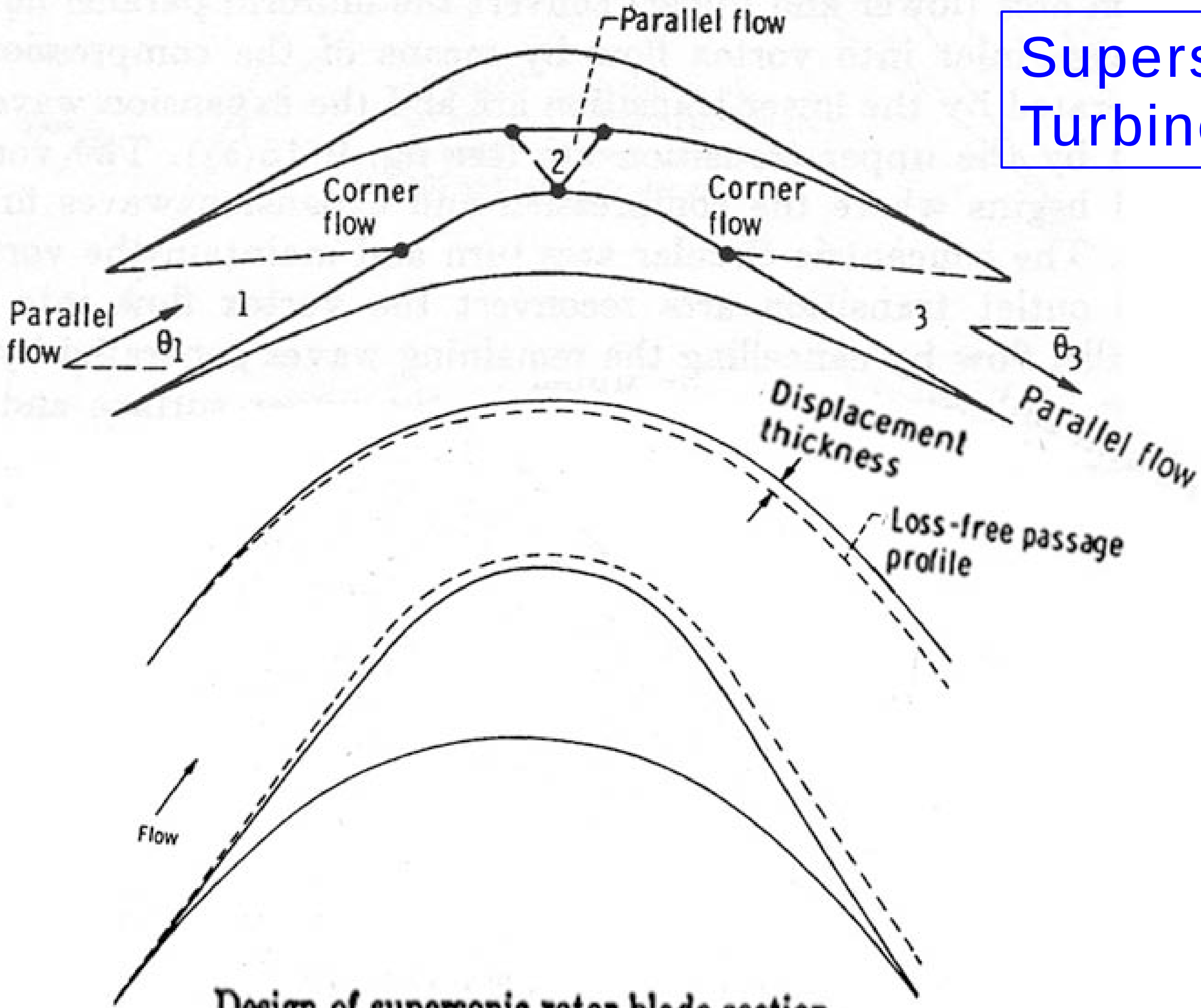
Supersonic Turbine airfoils



Design of supersonic rotor blade section.

Next Class

Design of 3-D Turbine blade shapes

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