Jet Aircraft Propulsion

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Lect-15

In this lecture...

- Cascade analysis
  - Cascade wind tunnel
  - Cascade nomenclature
  - Loss and blade performance estimation

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Cascade aerodynamics

- A cascade is a stationary array of blades.
- Cascade is constructed for measurement of performance similar to that used in axial compressors.
- Cascade usually has porous end-walls to remove boundary layer for a two-dimensional flow.
- Radial variations in the velocity field can therefore be excluded.
- Cascade analysis relates the fluid turning angles to blading geometry and measure losses in the stagnation pressure.

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Cascade aerodynamics

- The cascade is mounted on a turntable so that its angular direction relative to the inlet can be set at different incidence angles.
- Measurement usually consist of pressures, velocities and flow angles downstream of the cascade.
- Probe traverse at the trailing edge of the blades for measurement.
- Blade surface static pressure using static pressure taps: c_p distribution.

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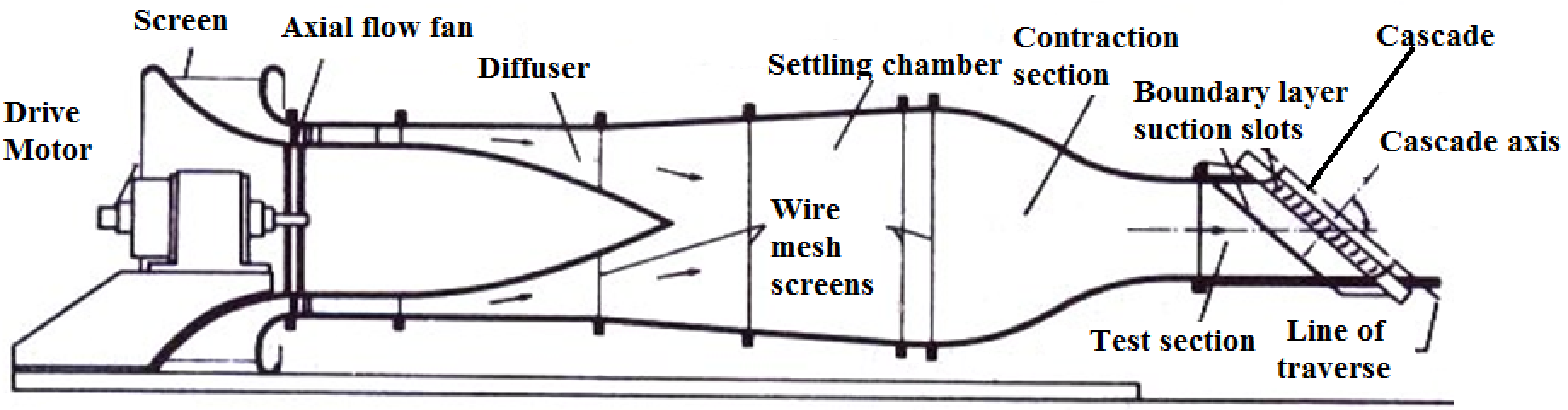
Cascade wind tunnel



Linear open circuit cascade wind tunnel

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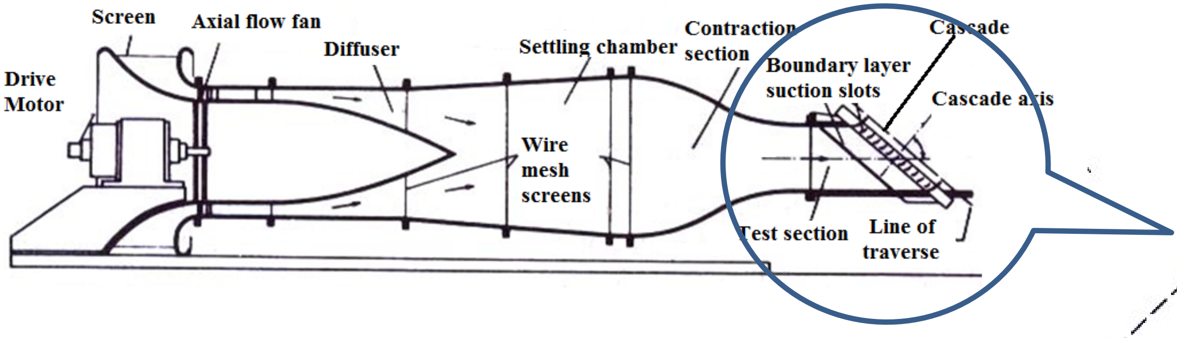
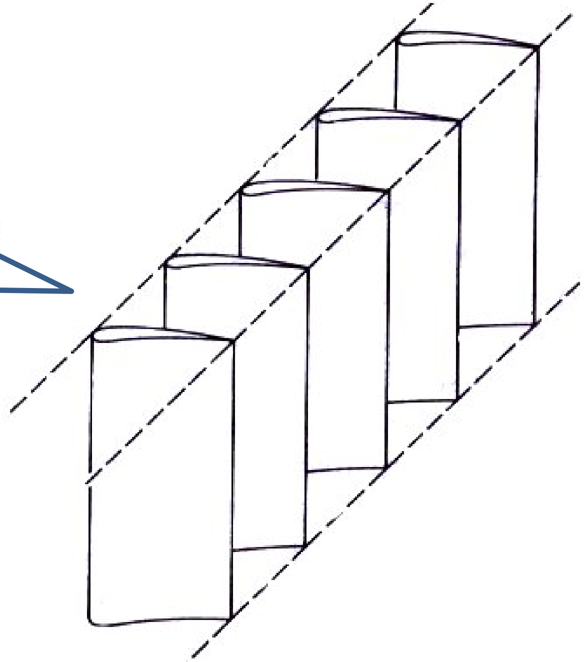
Cascade wind tunnel





Linear open circuit
cascade wind tunnel

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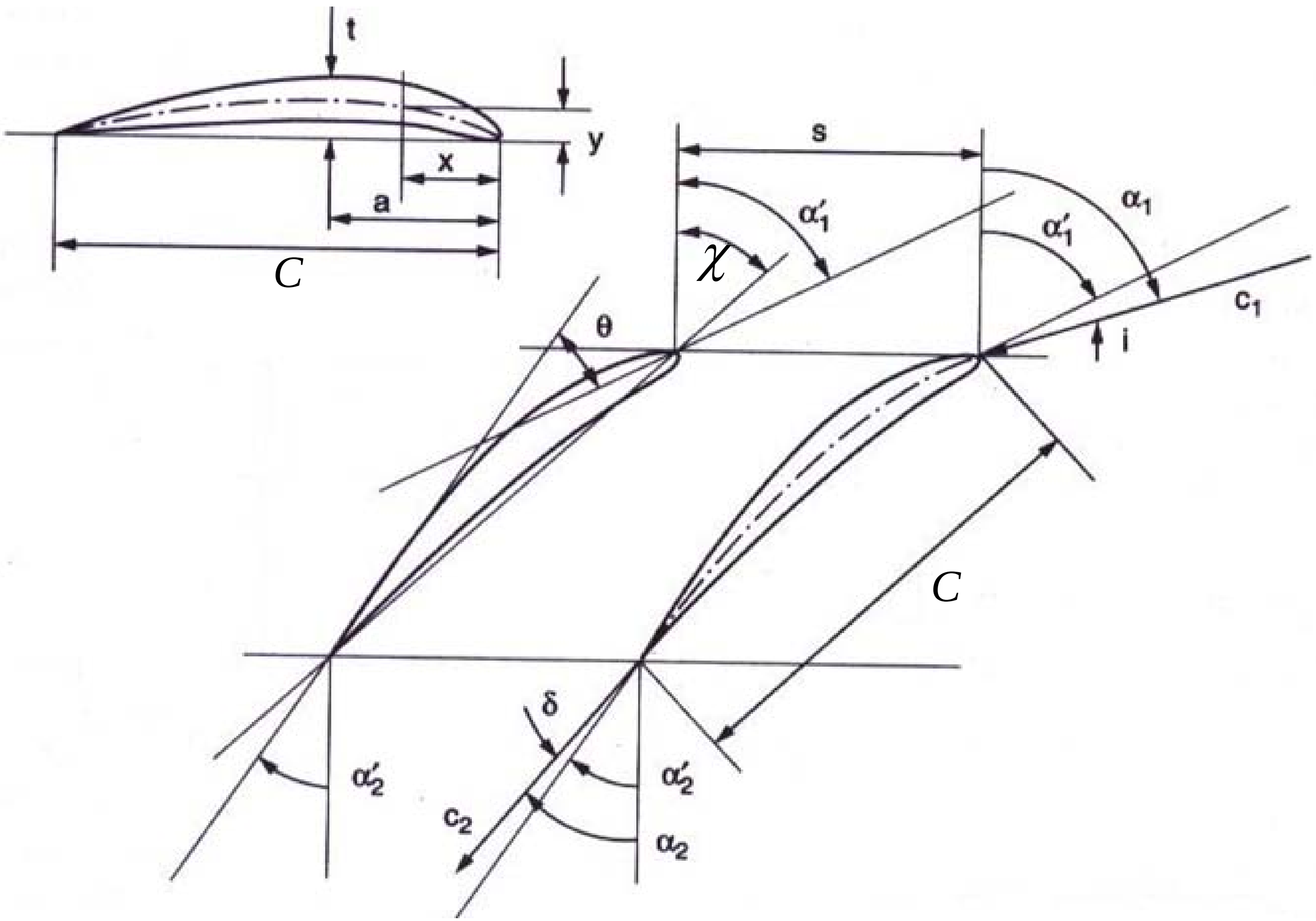
Cascade nomenclature



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Cascade aerodynamics

- The cascade is mounted on a turntable so that its angular direction relative to the inlet can be set at different incidence angles.
- Measurement usually consist of pressures, velocities and flow angles downstream of the cascade.
- Special nulling type probes (cylindrical, claw or cobra type) are used in the measurements.

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Performance parameters

- Measurements from cascade: velocities, pressures, flow angles …
- Loss in total pressure expressed as total pressure loss coefficient

$$\overline{W}_{PLC} = \frac{P_{01} - P_{02}}{\frac{1}{2}\rho V_1^2}$$

- Total pressure loss is very sensitive to changes in the incidence angle.
- At very high incidences, flow is likely to separate from the blade surfaces, eventually leading to stalling of the blade.

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Performance parameters

- Blade performance/loading can be assessed using static pressure coefficient:

$$C_P = \frac{P_{local} - P_{ref}}{\frac{1}{2}\rho V_1^2}$$

Where, P_{local} is the blade surface static pressure and P_{ref} is the reference static pressure (usually measured at the cascade inlet)

- The C_P distribution (usually plotted as C_P *vs. x/C*) gives an idea about the chordwise load distribution.

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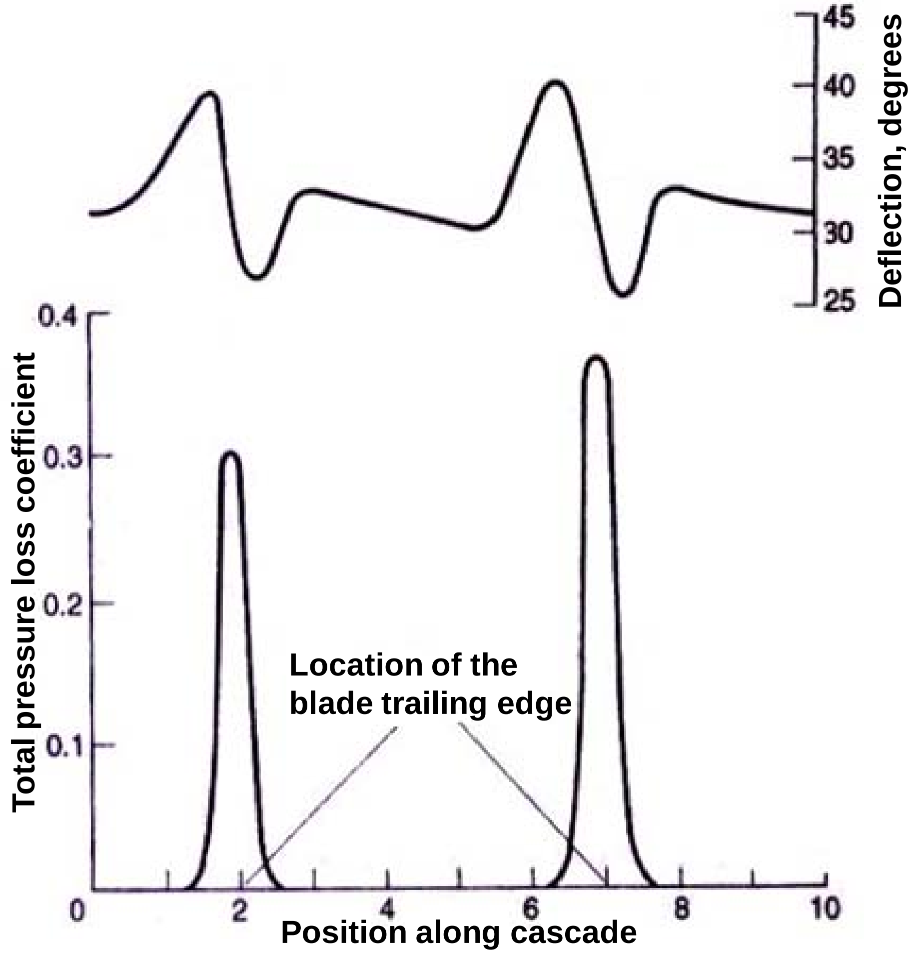
Performance parameters



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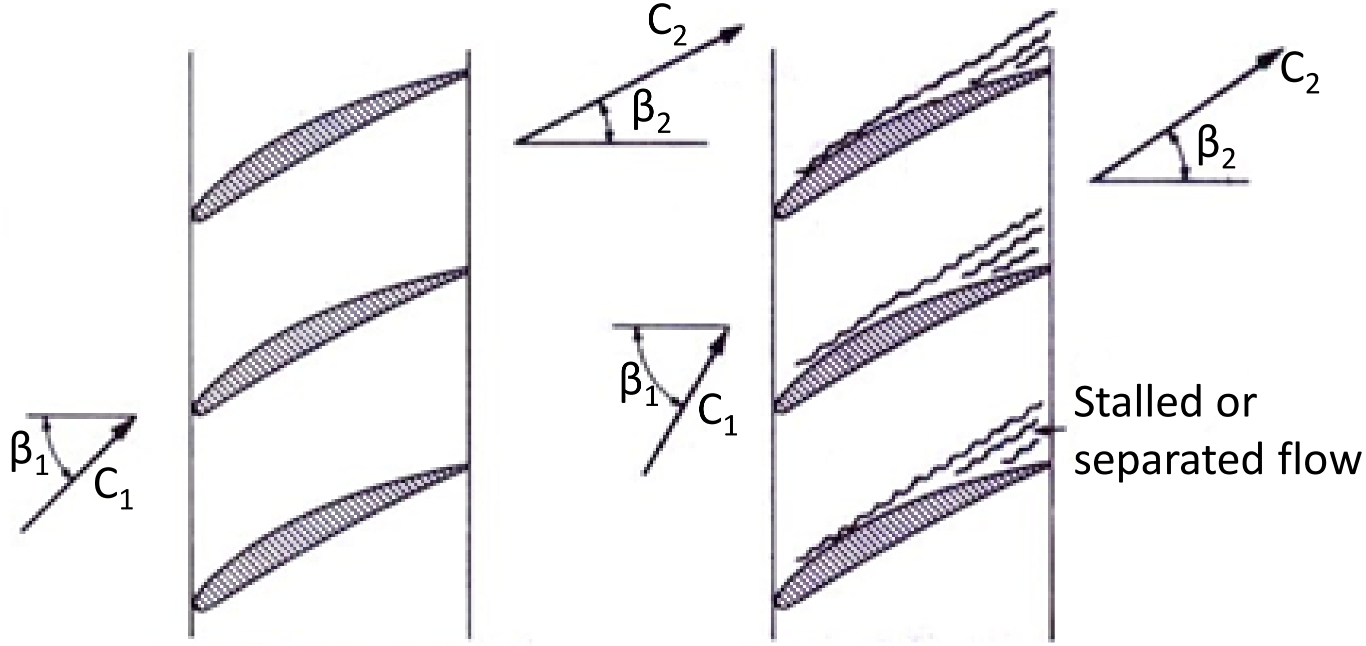
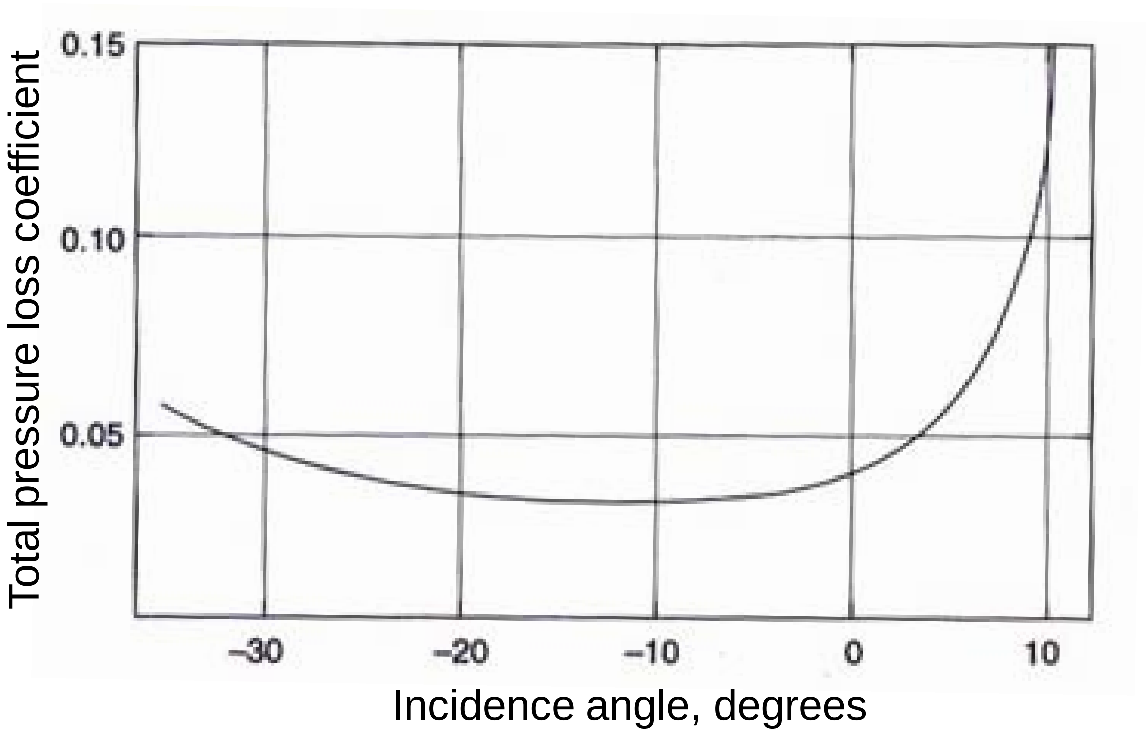
Performance parameters



(a) Normal operation (b) Stalled operation

Performance parameters



Losses in a compressor blade

- Nature of losses in an axial compressor
  - Viscous losses
  - 3-D effects like tip leakage flows, secondary flows etc.
  - Shock losses
  - Mixing losses
- Estimating the losses crucial designing loss control mechanisms.
- However isolating these losses not easy and often done through empirical correlations.
- Total losses in a compressor is the sum of the above losses.

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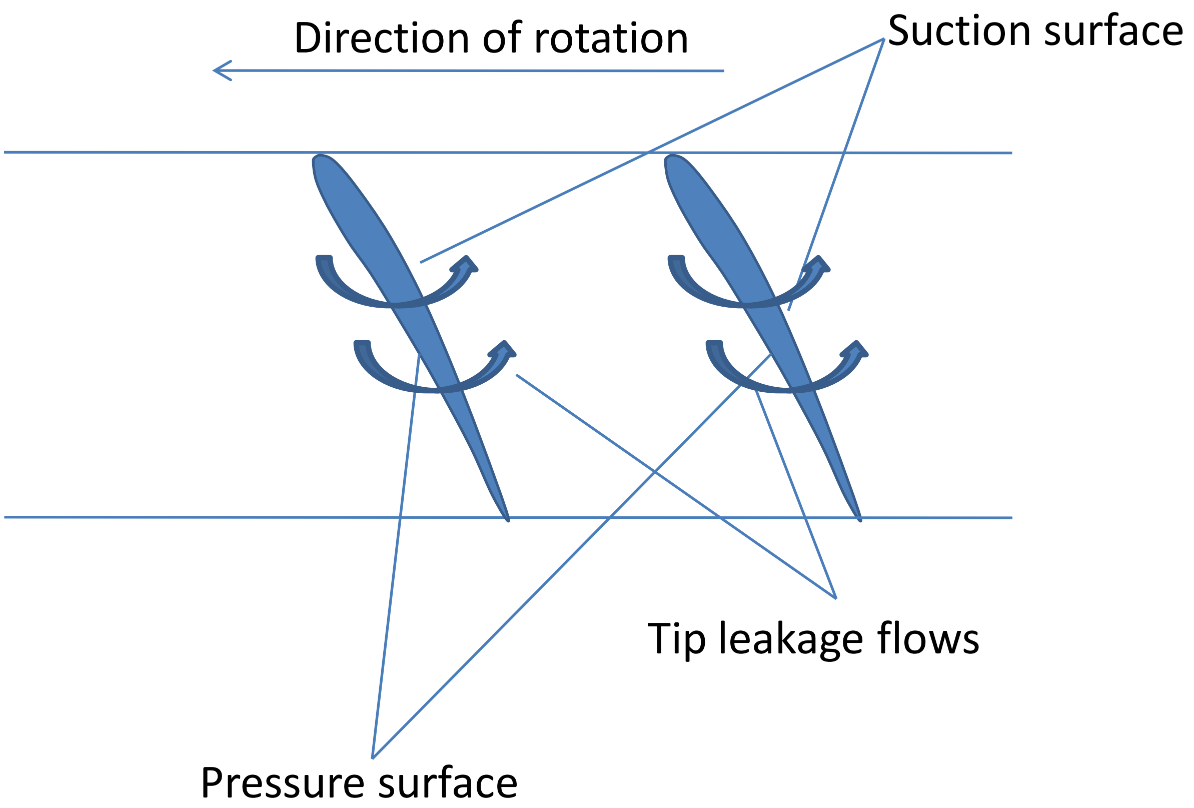
Losses in a compressor blade

- Viscous losses
  - Profile losses: on account of the profile or nature of the airfoil cross-sections
  - Annulus losses: growth of boundary layer along the axis
  - Endwall losses: boundary layer effects in the corner (junction between the blade surface and the casing/hub)
- 3-D effects:
  - Secondary flows: flow through curved blade passages
  - Tip leakage flows: flow from pressure surface to suction surface at the blade tip

Losses in a compressor blade



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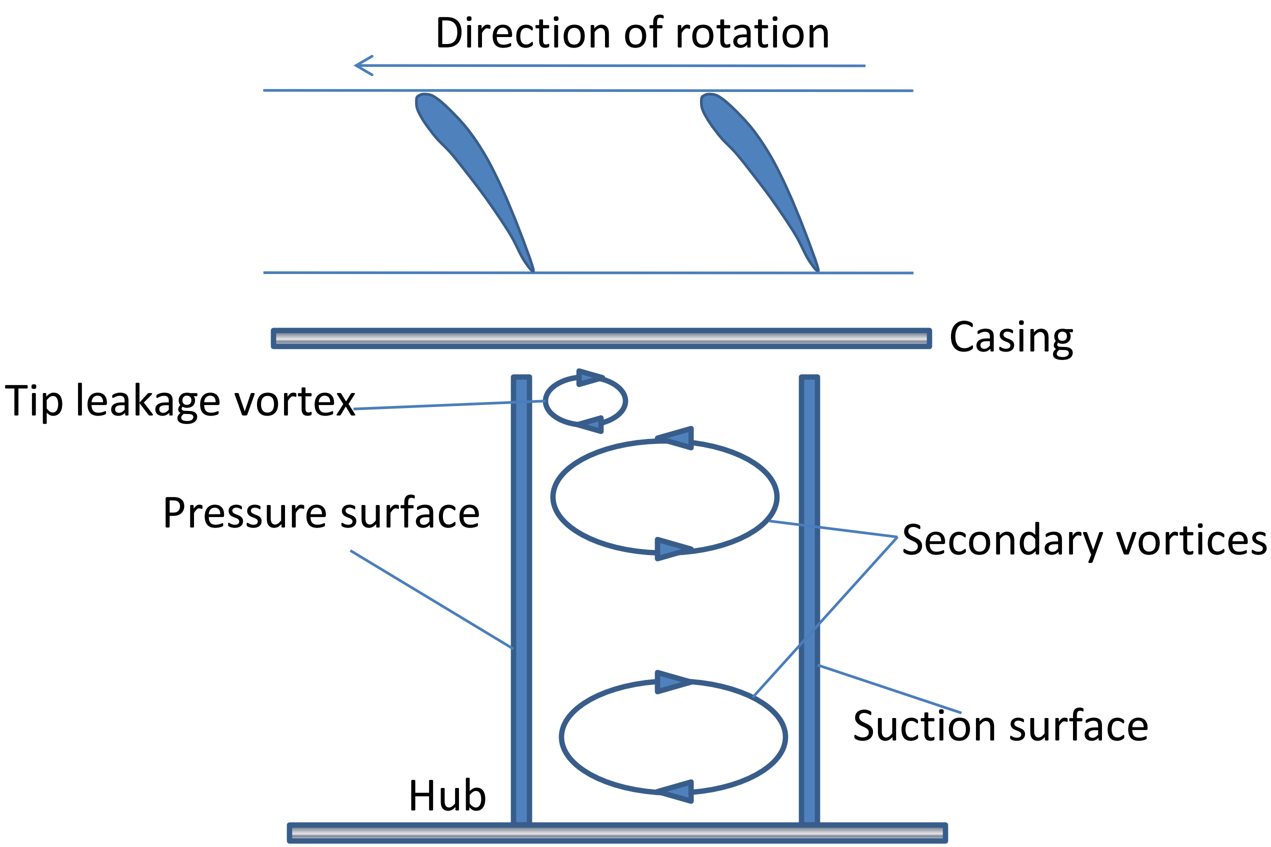
Losses in a compressor blade



Losses in a compressor blade

- Shock losses
  - Due to interaction of shocks at the blade tip with the primary flow
  - Of concern in transonic rotors
- Mixing losses:
  - Interaction of the flow from the rotor with the succeeding stator, stator wakes with the succeeding rotor etc.
  - Includes the effect of wakes interaction with the blades.

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Losses in a compressor blade

- The annulus-wall region accounts for up to 50 % of the total losses.
- The leakage vortex interacts with the blade boundary layer, casing boundary layer and the secondary flows.
- There is a large turbulence production due to mixing in this zone.
- The presence of a shock wave increases the complexity.
- In the hub region, there are corner stalls, which may increase the effective blockage.

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In the next lecture...

- Free vortex theory
- Single and multi-stage axial compressor characteristics

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