TURBOMACHINERY AERODYNAMICS

Lect-15

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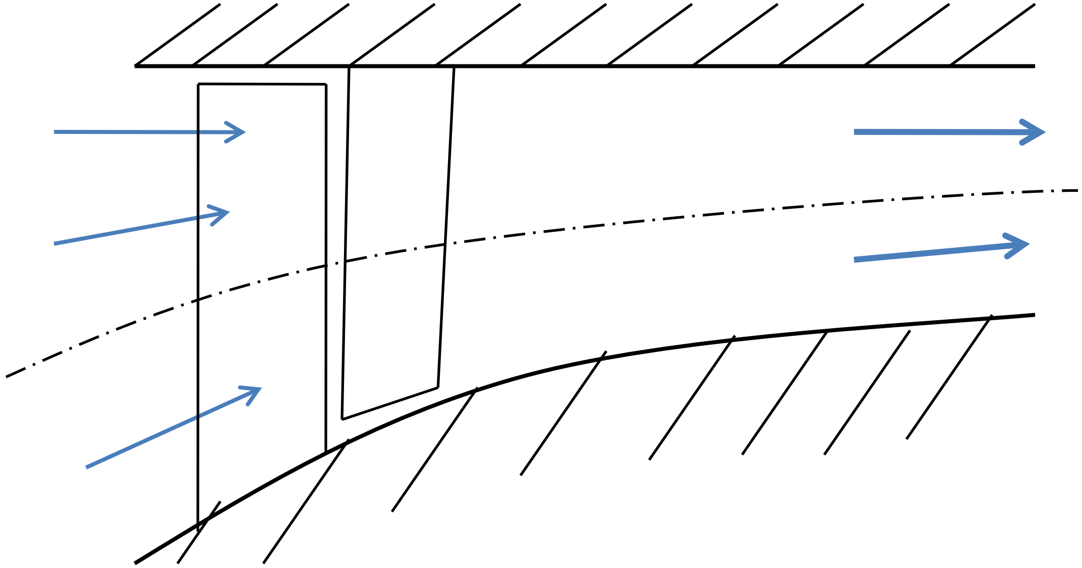
Design of Axial Compressors

Flow Track shapes in a multi-stage compressor

Constant Tip Diameter Flow Track



Typically used in high pressure ratio initial stages of a multi-stage compressor

- Maintains High U_{tip} and increasing U_{mean} through the stages
- Caters to rapidly changing density through the stages
- Uses the maximum size of the engine

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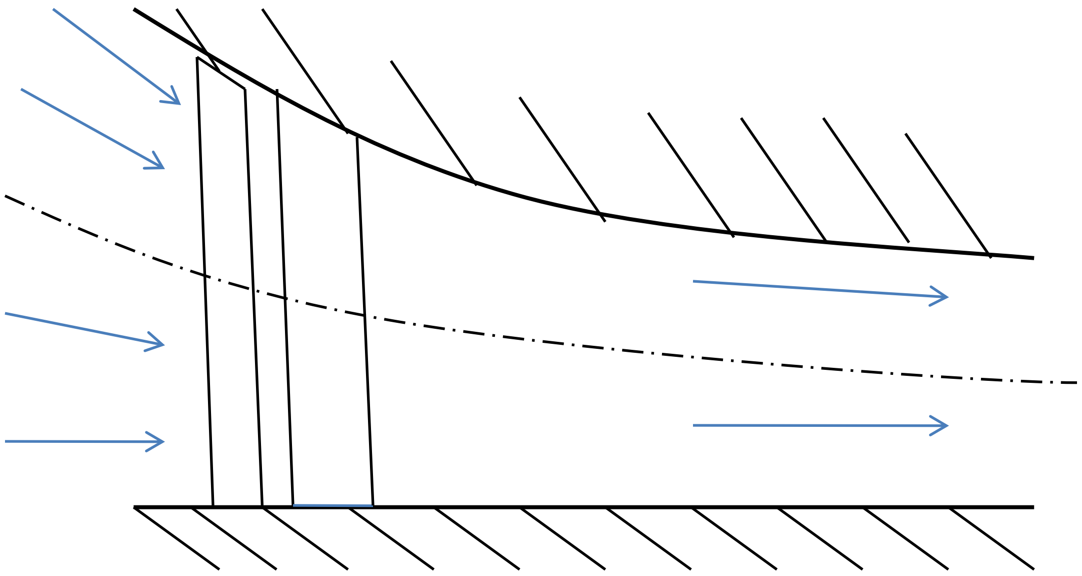
Constant Hub Diameter Flow Track

Typically used in high pressure ratio in the middle stages of a multi-stage compressor



- Decreasing U_{mean} through the stages
- Caters to rapidly changing flow density
- Reducing work done per stage
- Avoid very small blade sizes in the end stages

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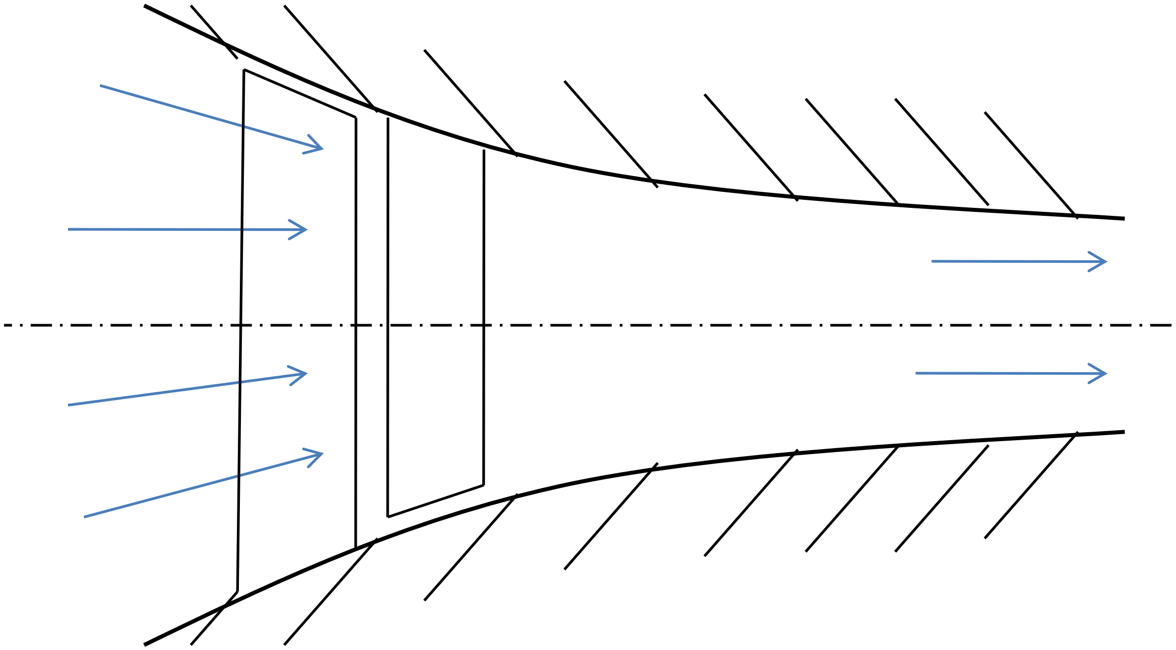
Constant Mean Diameter Flow Track



- Holds U_{mean} constant throughout the multi-stage arrangement
- Caters to medium size engines with single spool
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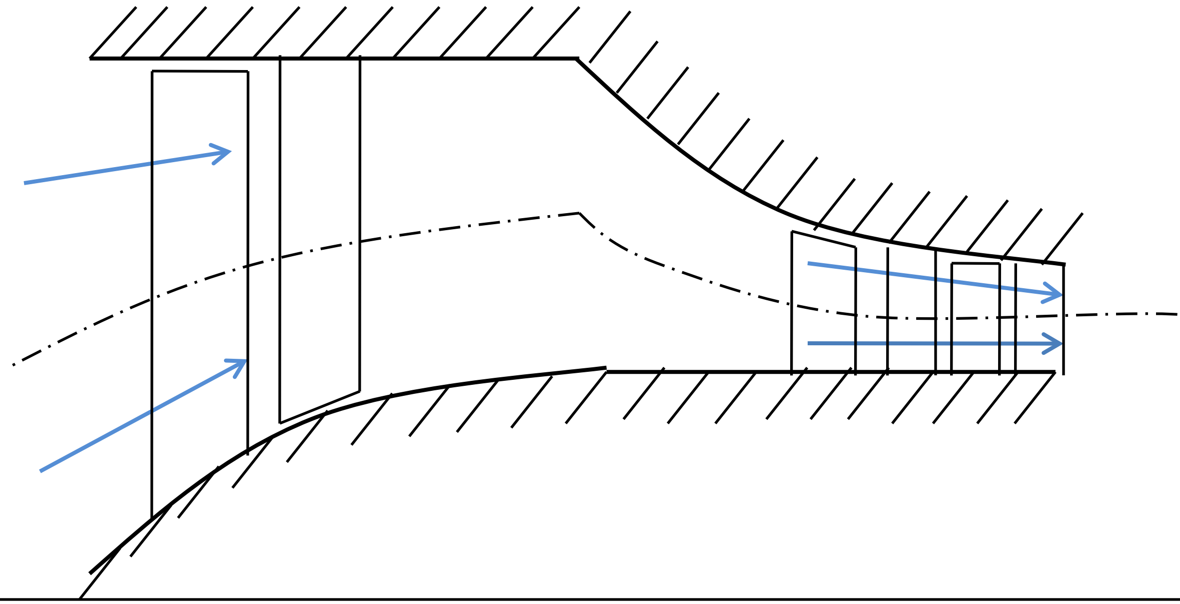
Constant Tip & Hub Diameter --Combination Flow Track



- U_{mean} changes throughout the multi-stage arrangement
- Caters to large/medium size engines of multiple spool
- Controls the work distribution and blade size through flow track design

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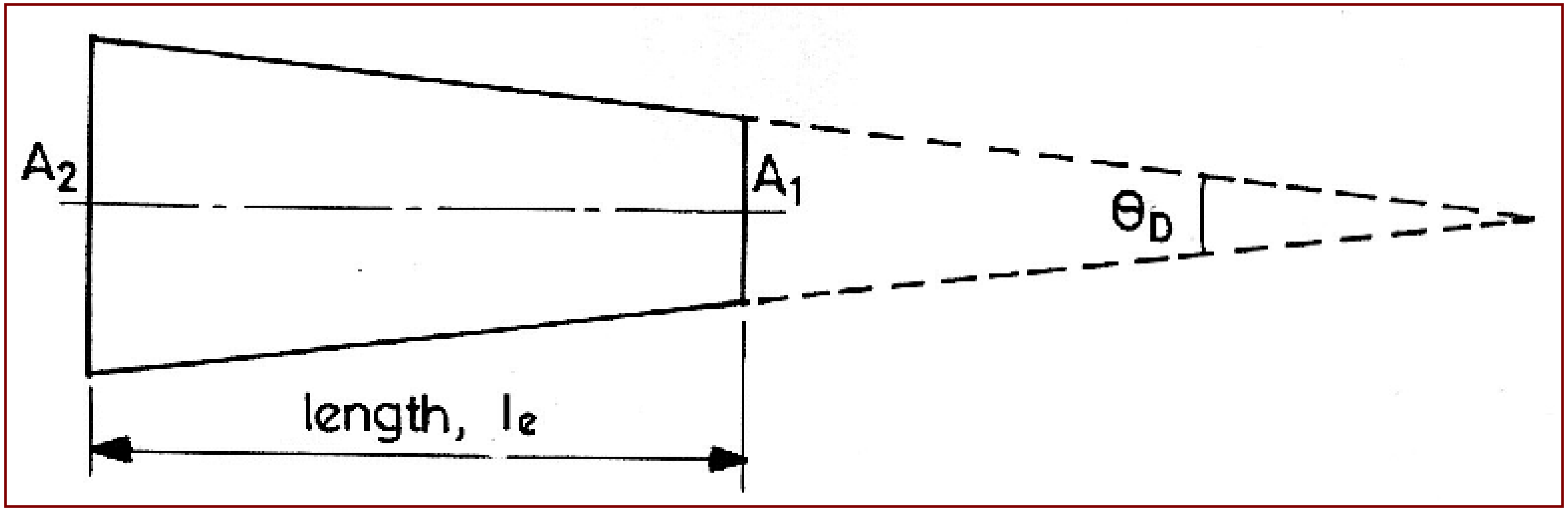
Choice of Flow Tracks:

1) Actual flow track annular area is computed from mass flow and continuity applied to the local flow through the stages
2) Flow track needs to be smooth
3) Inter-spool duct flow track is estimated from various engine design considerations
4) Substantial design and CFD analysis is required to arrive at a correct flow track



$$\frac{180}{\pi}\frac{A_2 - A_1}{l_c} = \theta_D^* = \frac{180}{\pi}\frac{s}{} \times \frac{\cos\beta_2 - \cos\beta_1}{l_c}$$

$$\theta_D = \frac{180}{\pi}\frac{c}{h_c} \times \frac{\cos\left(\beta_1 + \beta\right) - \cos\beta_1}{c/s}$$

Generally $\theta_D^* = 6 - 8^0$

check on maximum flow track angle

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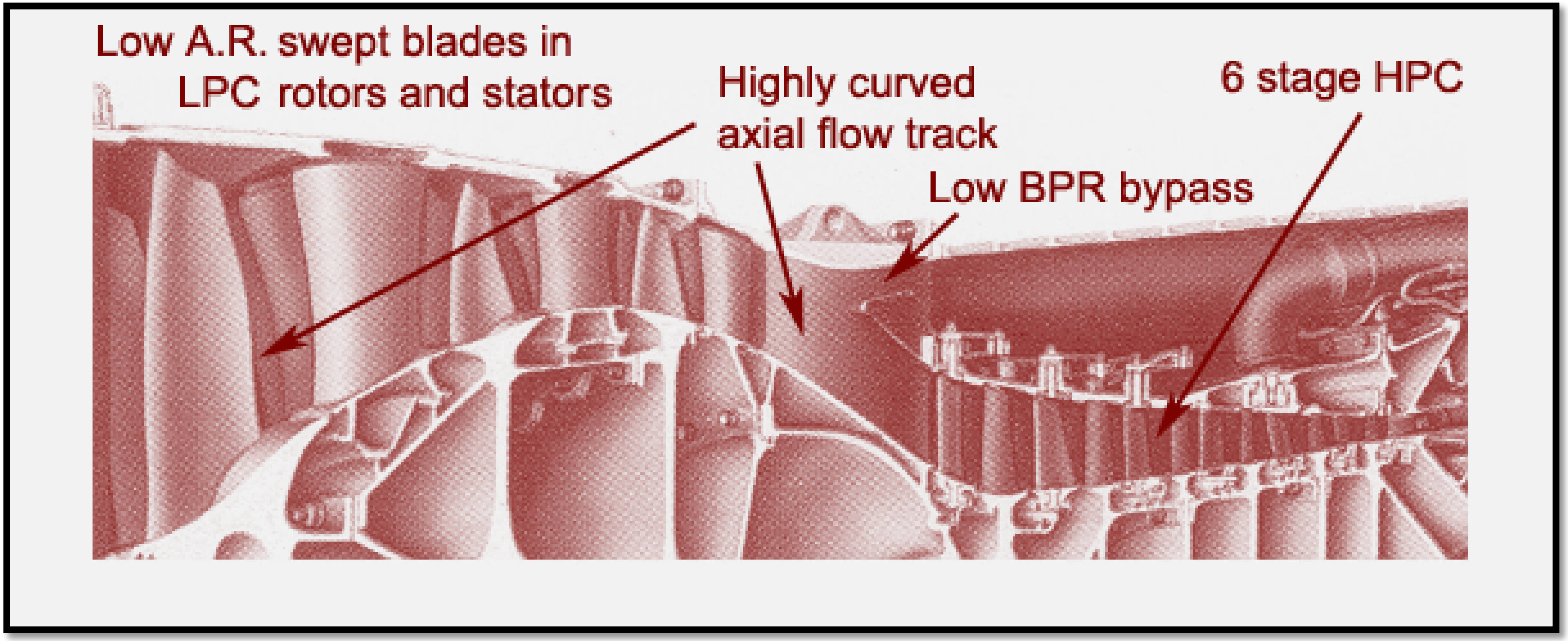

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Design Point Fixation

Functional relationship between various compressor performance parameters may be written down as :

$$\frac{P_{02}}{P_{01}}, \eta_{0C}, \frac{\Delta T_0}{T_{01}} = f\left(\frac{\dot{m}\sqrt{T_{01}}}{P_{01}}, R_e, \frac{N}{\sqrt{T_{01}}}\right)$$

Which are not actually dimensionless parameters.

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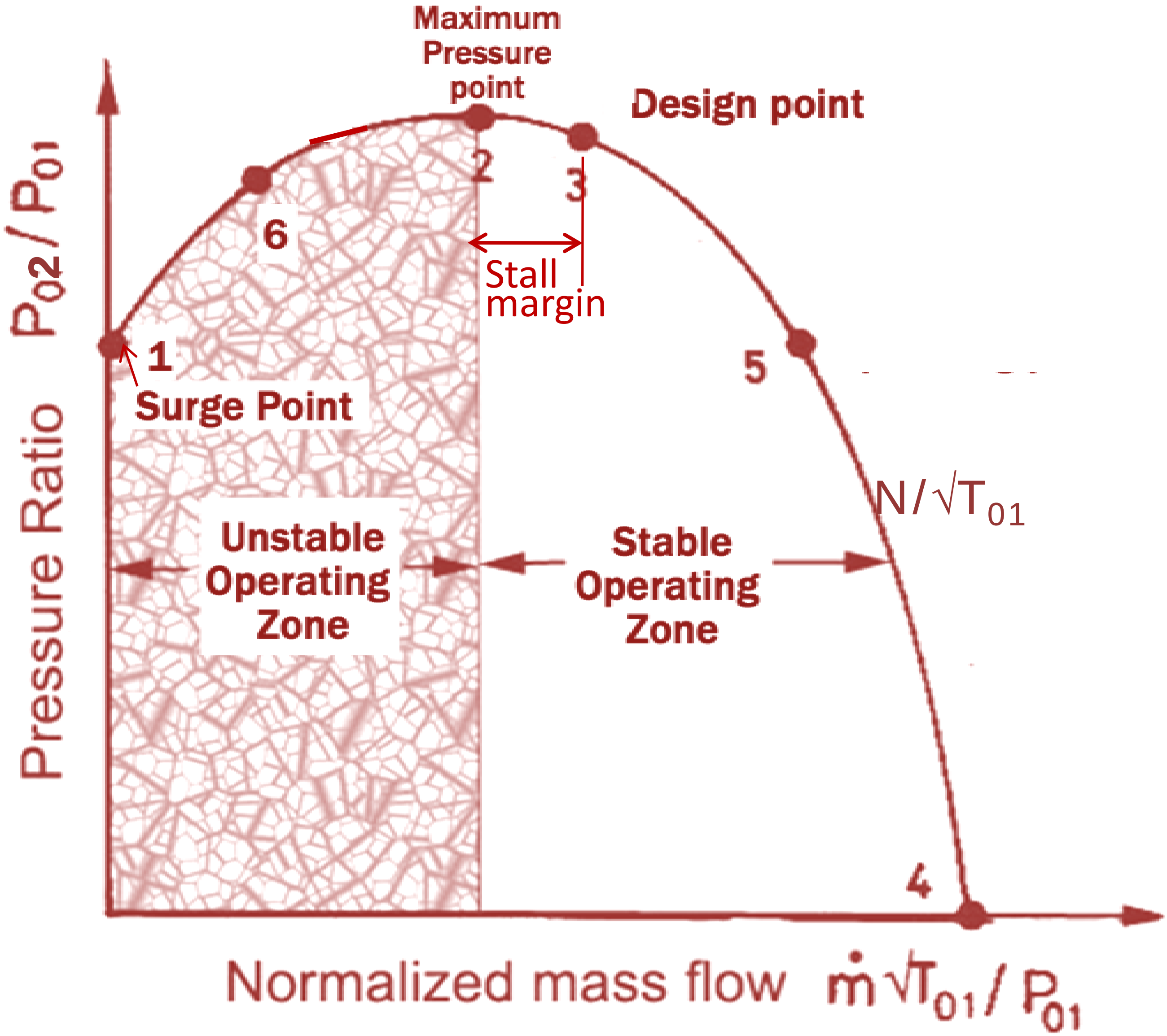
Maximum
Pressure
point
Design point
2
3
6
Stall
margin
1
Surge Point
5
$N/\sqrt{T_{01}}$
Unstable
Operating
Zone
Stable
Operating
Zone
4
Pressure Ratio P_{02}/P_{01}
Normalized mass flow $\dot{m}\sqrt{T_{01}}/P_{01}$

Fixing of Initial Design Point Parameters

Distribution of specific work (W_{th}) and efficiency (η_i) along the stages is the first step towards multi-stage. W_{th} and η_i of the multi-stage compressor and the individual compressor stages are arrived at from engine cycle analysis as per following guidelines:

	Initial Stages (Transonic)	Middle stages (Trans / Hi Subsonic)	Last stages (Hi Subsonic)
η	0.86	0.92	0.88
π	1.4-1.8	1.2-1.4	1.05 -1.2
ΔT_0 °C	40-75	30- 45	15-30

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Fixing of Initial Parameters

1) From mass flow balance between compr & turbine

From continuity, $m_C = \varpi\ m_T$, - between HPC & HPT

-- where ϖ is the factor of change of mass flow.

2) From work balance,

$$m_C = m_T . H_{0T} / H_{0C},$$ between LPC & LPT

3) Also, between Fan and HPC, $m_{Fan} = B.\ m_{T\text{-}HPC}$

Where B is the bypass ratio

4) Rotating speed, $N_C = N_T$ for both Fan + LP & HP spools

5) Power balance, $\dot{W}_C = \dot{W}_T \cdot \eta_{0T} \cdot \eta_{0C} \cdot \eta_{mech}$

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Fixing of Initial Parameters

For a rotor $$\dot{W}_{th} = \left(C_{w1} - C_{w2}\right)U$$

$$\overline{C}_{a1} = \frac{C_{a1}}{U} = \phi < 1$$

$$\overline{W}_{th-i} = \frac{\dot{W}_{th-i}}{U^2} = \psi < 0.5$$

Actual work done on the fluid

$$\dot{W}_{Ci} = \frac{\left(\dot{W}_{th1} \cdot \lambda \right)}{\left(\eta_{gap} \cdot \eta_f\right)}$$

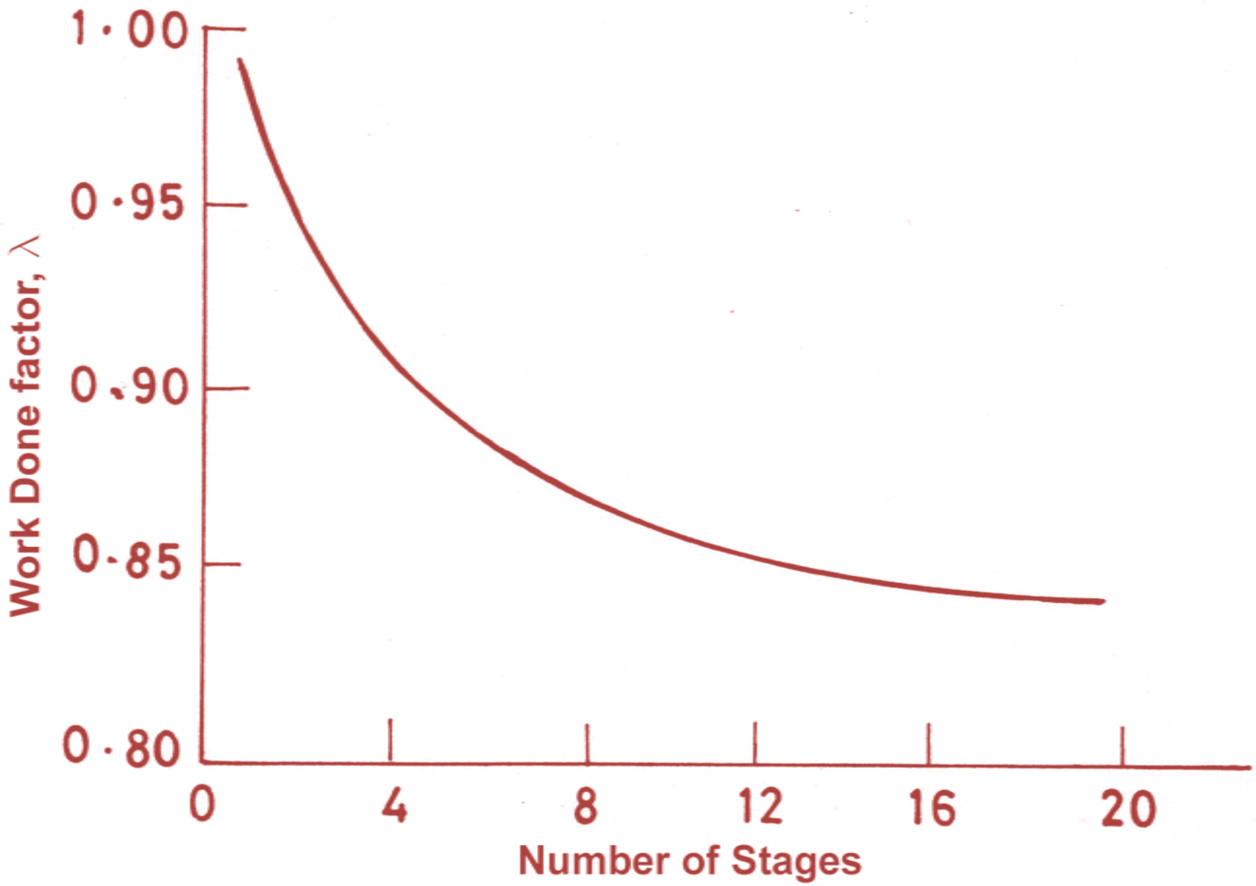
Where, λ = work done factor,

η_{gap} = radial gap loss factor,

η_{fan} = fan loss factor.

$$\dot{W}_{Ci} = \left(1.01 - 1.03\right)\dot{W}_{th-i}$$

Fixing of Initial Parameters



Work Done factor varies with the position of the stage

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Fixing of Initial Parameters

Generally for average stage work done first cut calculation

$$\dot{W}_{C,m} = \frac{\dot{W}_{C\text{-}1}}{0.7 - 0.8}$$ For subsonic stages.

$$\dot{W}_{C,m} = \frac{\dot{W}_{C,1}}{0.8 - 0.9}$$ For transonic stages

number of stages $$Z = \frac{W_C}{W_{C,m}}$$

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Fixing of Initial Parameters

1. The work done, Wc_i , and the efficiencies for the each stage is first decided upon. For correctness of distribution, calculate pressure ratio of each stage and check back that all the stages put together give the design overall total pressure ratio.

2. This leads us to density variation and annulus area variation along the flow track - assuming constant axial velocity. From aerodynamics point of view, the annulus area must be smoothly varied. Axial velocity may be then varied to arrive at smooth flow track.

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Next Lecture

Blade Design Methodology