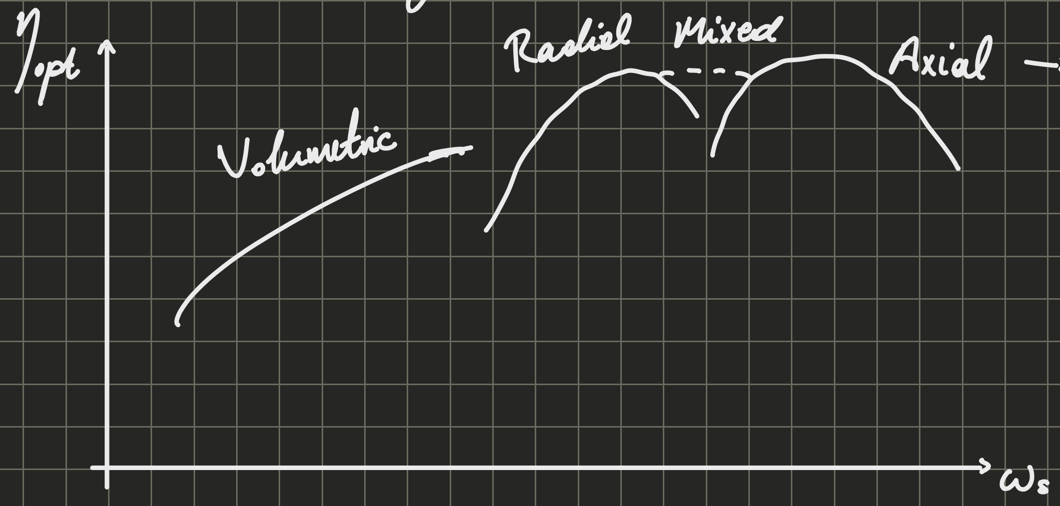
Lezione 23 - Radial Compressors

The Balje diagram were for one specific value of M_u, so for one specific β_T

Cordier Diagram for Compressors



Axial → Used in aeroengines and associated energy generation.

Balje diagram for compressors

↳ similar shape to pump diagram.

Comparison at the same M_u, since radial machines take advantage of radial potential, so axial compressors are usually not alone but in series to match it.

Higher β_T in axial compressors, comes with very low efficiency.

The standard design for a compressor is for a high efficiency compressor.

$\boxed{8:45}$

The radial machine starts with an inducer which is axial before the impeller which is to turn the flow axial to radial.

→ Because our flow is covering the impeller, we have additional parasitic losses which are caused by the friction on the disk.

Our flow after the rotor enters a veinless diffuser which increases the pressure and decreases speed. It's also possible to introduce a veined differer with wedges to increase the pressure even more, but this can decrease efficiency since α_2 in non-constructive so we may have incidence.

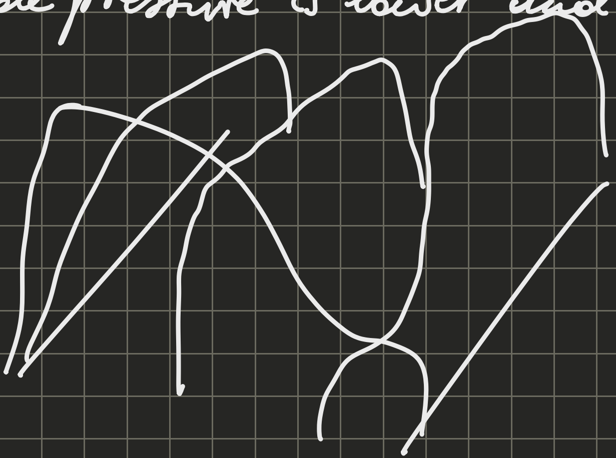
For radial compressors, the blades are not as backwards as pumps, around 40-60 rather than 70-80, in these case the χ is low so a diffuser is necessary.

We are not interested in l but β, if we increase l but decrease β, the it is useless.

between blades. ✓

In a typical radial compressor, flow separation is experienced, this phenomenon is called jet and wake.

The pressure side of the blade is the side of the blade which the pressure is higher, on the other side pressure is lower and so the flow is decellerated.



Wake → the velocity field is not uniform, the flow slows to maintain pressure.

If we leave some gap the flow will remix, returning our flow to normal so it doesn't affect our efficiency.

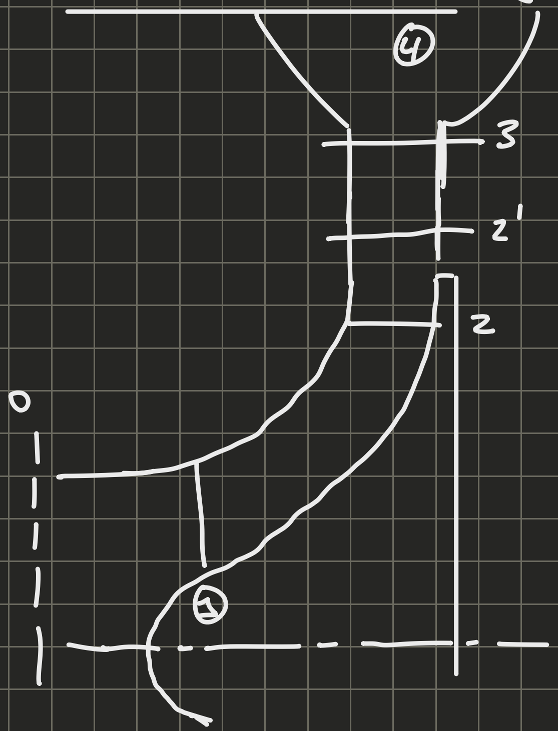
Because of the separation there are two β_2 angles, one for the wake the other for the jet, the angles are different because of Coriolis forces which push the flow more tangential, eventhough these forces don't change the energy (as see in a BERF) the still have some effect.

The angle not depends on the geometry and the "slip effect" caused by Coriolis forces.

The jet, wake effect is not hard to estimate, the slip effect on the other hand is hard to calculate because the Coriolis forces change locally.

Vaneless diffuser, then analysis of a thermo fluid in a compressor.

Vaneless Diffuser ($2 \to 2'$)



Angular Momentum Balance

$$C_{AERO,x} = \dot{m}\left(r_{OUT} V_{t,OUT} - r_{IN} V_{t,IN}\right) = 0$$

↳ neglecting friction ≈ 0

$$\Rightarrow r_{2'} V_{2't} = r_2 V_{2t}$$

$$\Rightarrow V_{2't} = V_{2t} \underbrace{\frac{r_2}{r_{2'}}}_{<1}$$ ⇒ tangential velocity is decellerating, first sign of diffuser.

We also have another diffusing effect: Mass Balance

$$\dot{m}_2 = \dot{m}_{1} \Rightarrow \rho_2 V_{2m} \pi D_2 b_2 = \rho_{2'} V_{2'm} \pi D_{2'} b_{2'}$$

$$\Rightarrow V_{2'm} = V_{2m} \frac{r_2}{r_{2'}} \frac{b_2}{b_{2'}} \underbrace{\frac{\rho_2}{\rho_{2'}}}_{<1}$$

Since both r and ρ are reducing, it will become more and more tangential.

If $b_2 = b_{2'} \Rightarrow$ $V_{2't} < V_{2t}$, $V_{2'm} << V_{2m}$ $\Rightarrow \alpha_{2'} > \alpha_2$!

in case of pumps/fans:

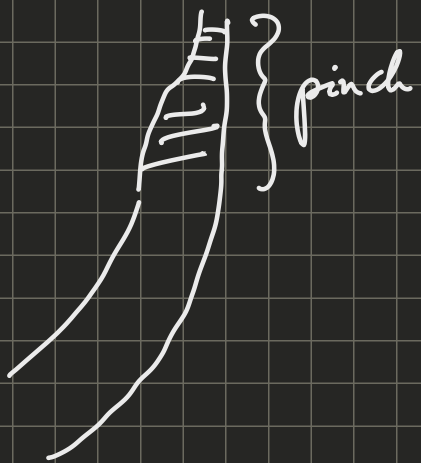
$\rho_2 = \rho_{2'}$

If $b_2 = b_{2'} \Rightarrow \begin{cases} V_{2't} = V_{2t} \frac{r_2}{r_{2'}} \\ V_{2'm} = V_{2m} \frac{r_2}{r_{2'}} \end{cases}$ ⇒ both are reducing, P increases, so we are diffusing

$\Rightarrow \alpha_{2'} = \alpha_2$ since V_t and V_m are decreasing at the same rate.

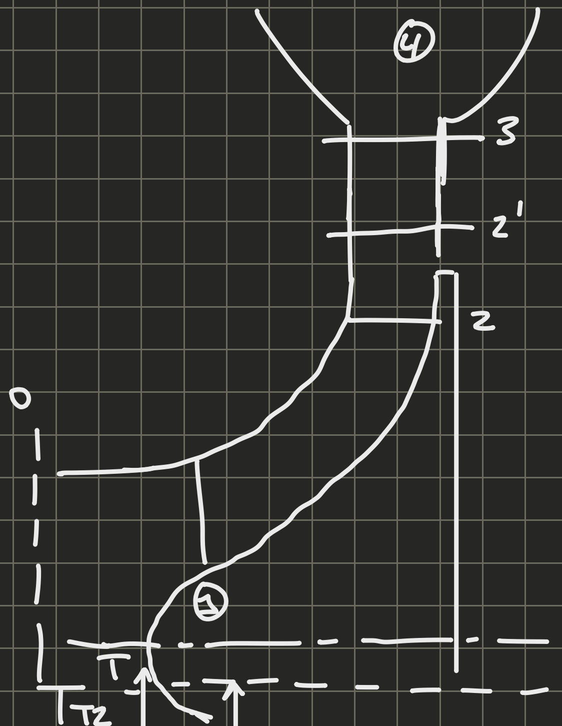
↳ Sometimes it's possible for $\alpha_{2'}$ to be too high, if it surpasses 65°, it becomes more convenient to have a veined diffuser. This is because we could have flow separation even in the diffuser causing losses.

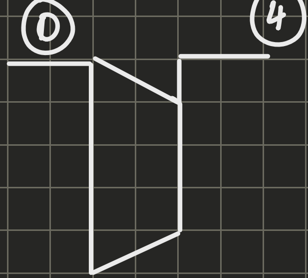
If we do not want to use a veined diffuser, we can use a pinch, reducing $b_{2'} < b_2 \rightarrow V_{2m} \uparrow \Rightarrow \alpha_{2'} \downarrow$ which helps stop separation at the veinless diffuser.



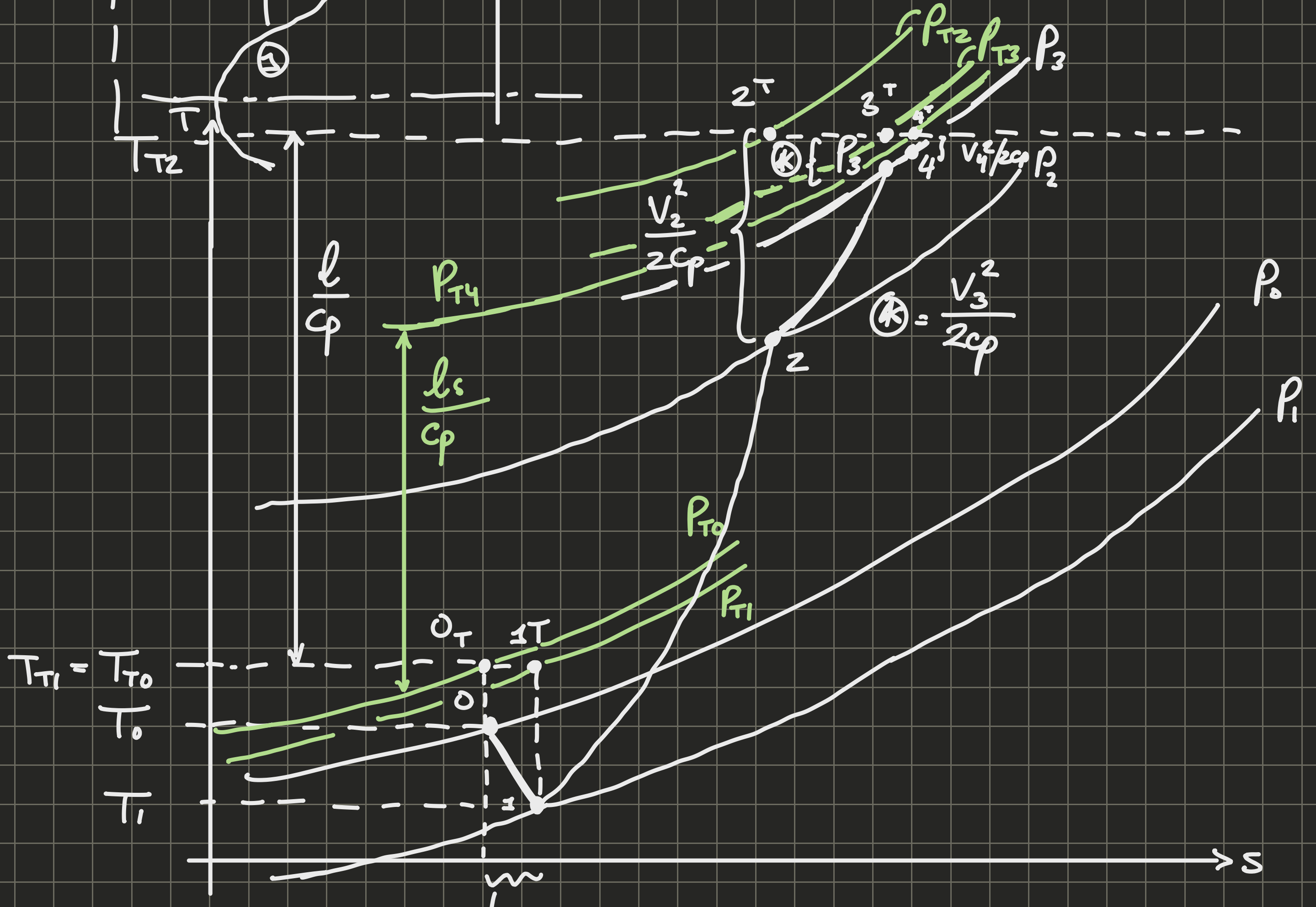
9:35 in case

Thermofluid dynamic diagrams of a compressor
(single stage radial compressor)





We said last lecture that ignoring $\frac{\Delta v^2}{2}$ is dumb, so we now have to consider that too.



Since adiabatic real process

Energy Balance $0 \to 1$:

$\cancel{l} + \cancel{q} = \Delta h_T = 0 \Rightarrow \Delta T_T = 0$ between 0 and 1

There is no l in a static element, it just cause a a acceleration and diffusion. $\Delta P \downarrow \Rightarrow \Delta v \uparrow$. In any static component, inducer in $0 \to 1$, T_T is conserved.

We can also show that while T_T is conserved in a real adiabatic transformation, the P_T is not, it changes. I did not write it since said it's long so to not write it. He purposely didn't do it while studying the transformations to do it now.

The result is:

$$\Delta s = c_p \ln \frac{T_1}{T_0} - R \ln \frac{P_1}{P_0} = c_p \ln \frac{T_{T1}}{T_{T0}} - c_p \ln \frac{P_{T1}}{P_{T0}}$$

With a Δs, the state is the same whether we consider a static or total state. We can also say this because the total state is derived from an isoentropic transformation of the static one.

$$\underbrace{T_{T1} = T_{T0}}_{\text{what occurs in a stator component}} \Rightarrow \Delta s = -R \ln \frac{P_{T1}}{P_{T0}} \Rightarrow P_{T1} = P_{T0}\, e^{-\frac{\Delta s}{R}}$$

The l/c_p goes from T_{T1} to T_{T2}

Energy Balance $2 \to 4$

$\cancel{l}^{\,0} + \cancel{q}^{\,0} = c_p (T_{T4} - T_{T2}) \Rightarrow T_{T2} = T_{T4}$

If the diffuser has done it's job $\frac{V_3^2}{2c_p} < \frac{V_2^2}{2c_p}$

Better sketch

$0 \rightarrow 4 =$ Expansion + Compression + Diffusion + Isobaric heat.

$$\chi = \frac{h_2 - h_1}{l}$$

↳ for thermo compressors

$$\eta = \frac{l_s}{l} = \frac{c_p\left(\beta_T^{\frac{\gamma-1}{\gamma}} - 1\right)}{l}$$