

lezione 19-20

Schiere supersoniche

$$M_1 < 1$$

$$M_2 < 1$$

compressore subsonico

$$M_1 > 1$$

$$M_2 < 1$$

compressore
transonico

$$\underline{M_{1a} < 1}$$

- a) Regime innescato
- b) Regime non innescato

$$\underline{M_{1a} > 1}$$

regime saturo

Schiere supersoniche

$$M_1 < 1$$

$$M_2 > 1$$

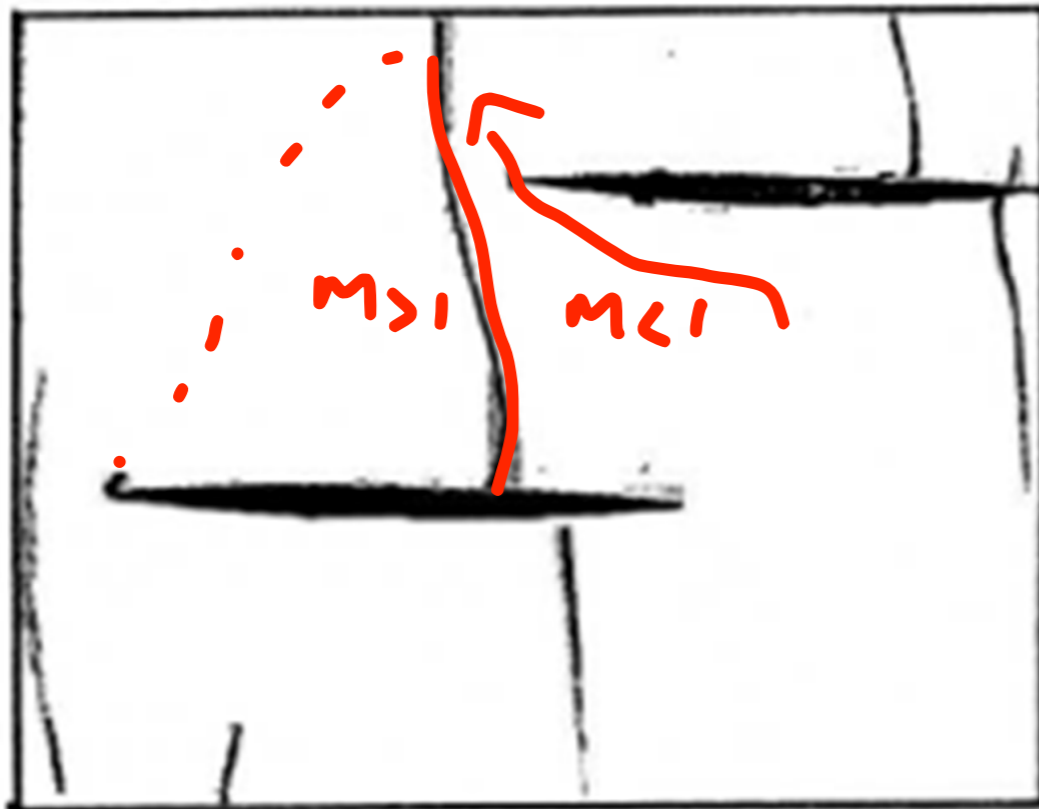
Flusso accelerato (non rilevante per i compressori)

$$M_1 > 1$$

$$M_2 > 1$$

Flusso completamente supersonico

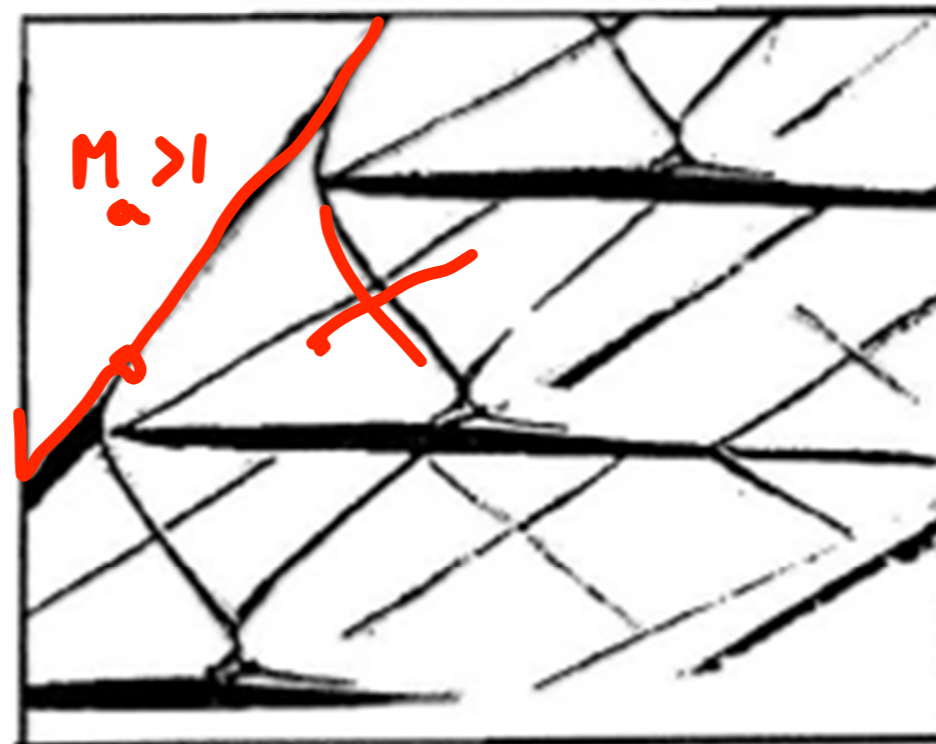
Schiere supersoniche



a) Regime non innescato

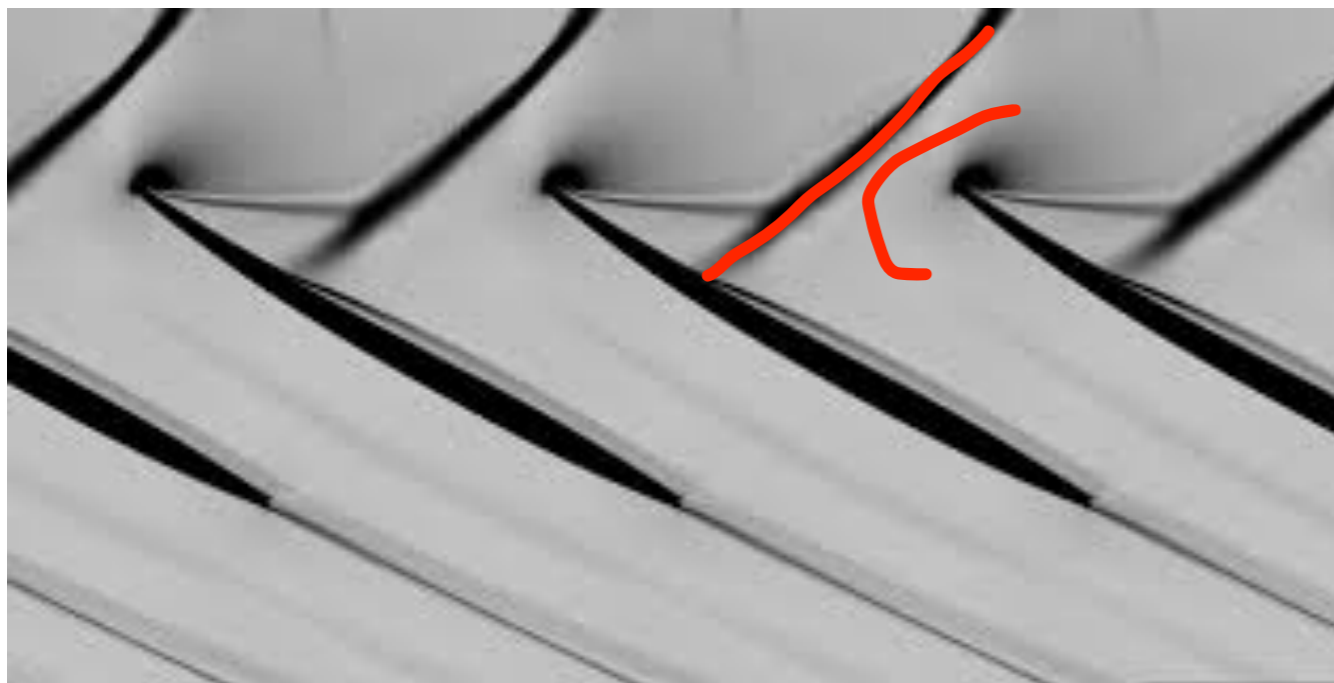


b) Regime innescato

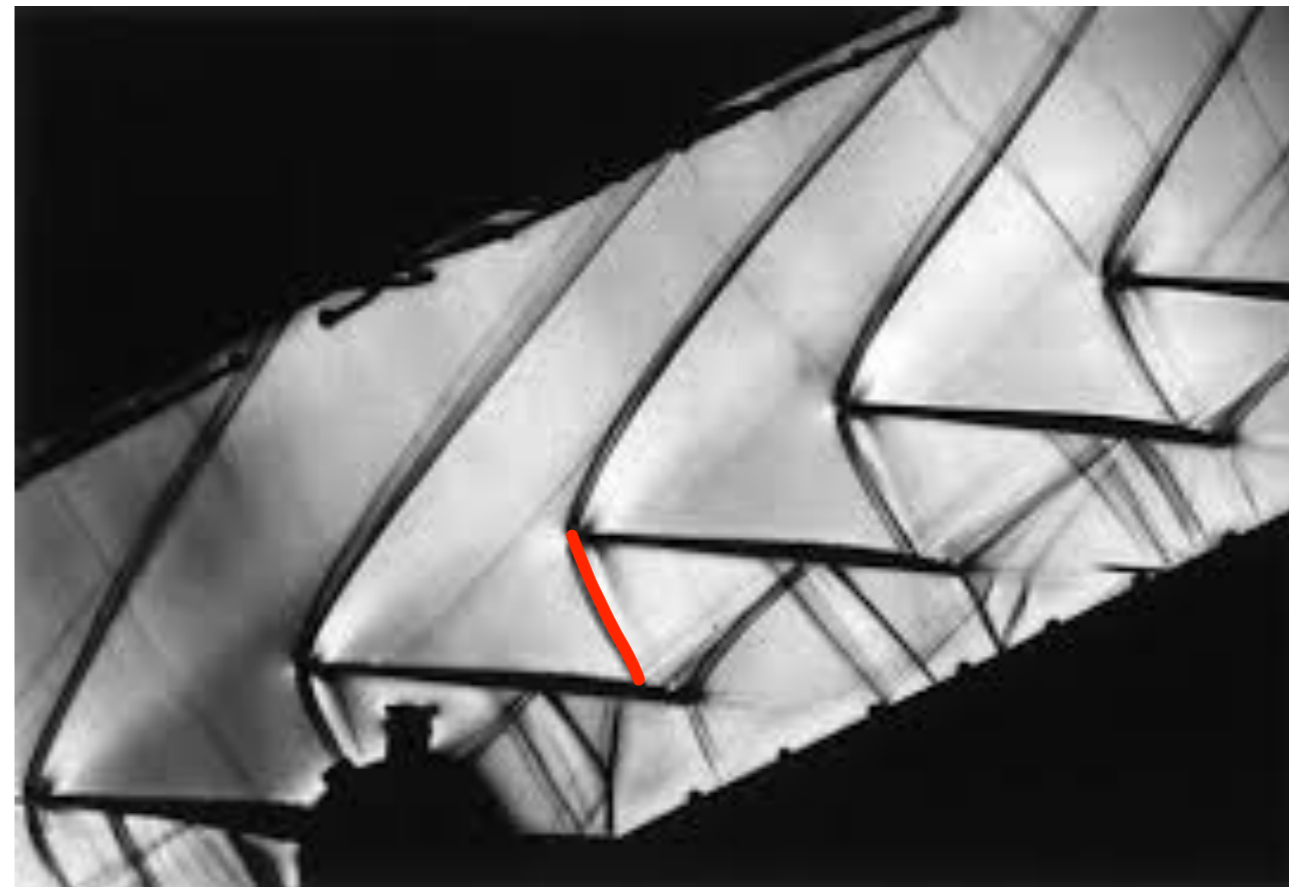


c) Regime saturato

regime non innescato

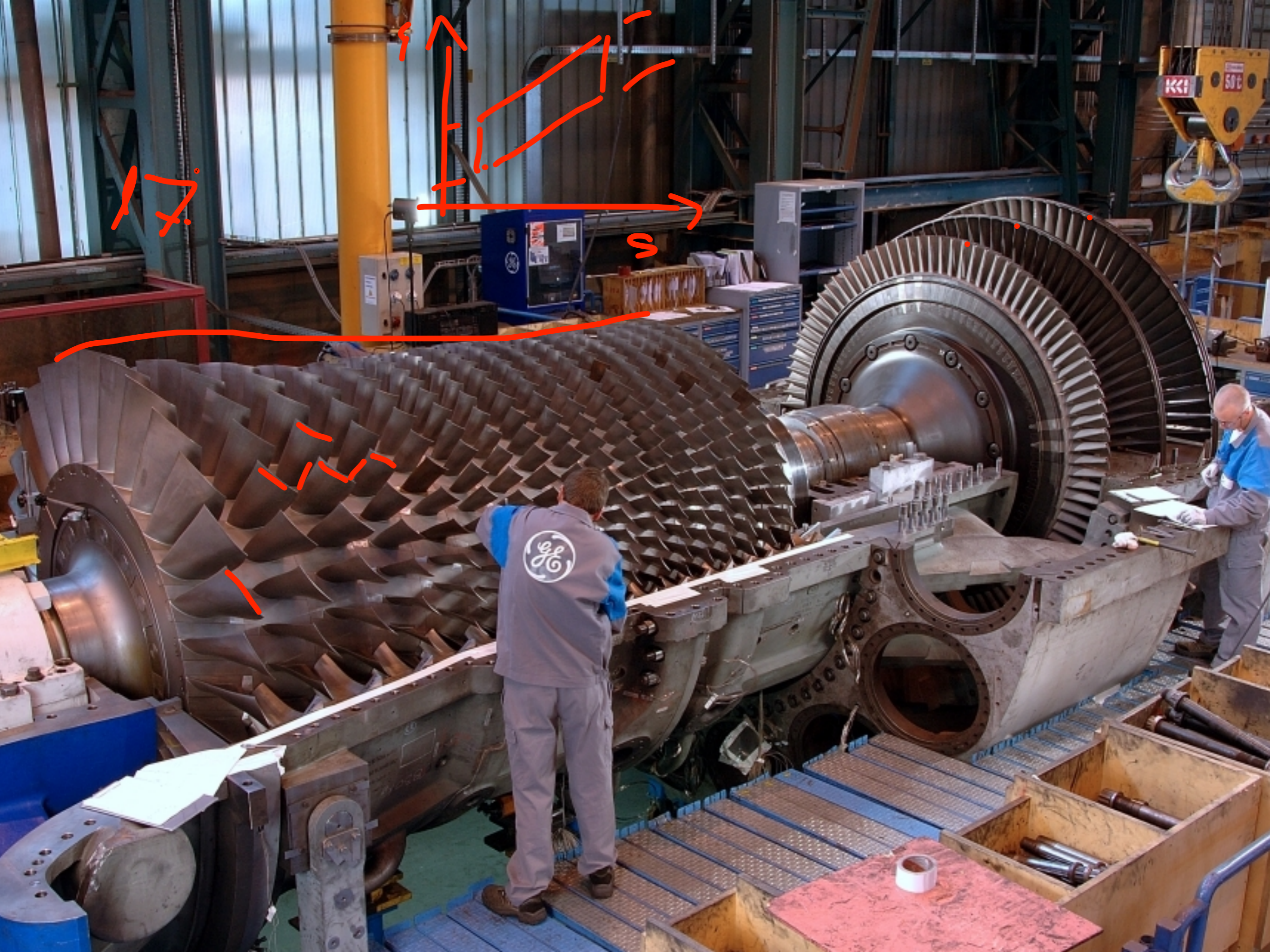


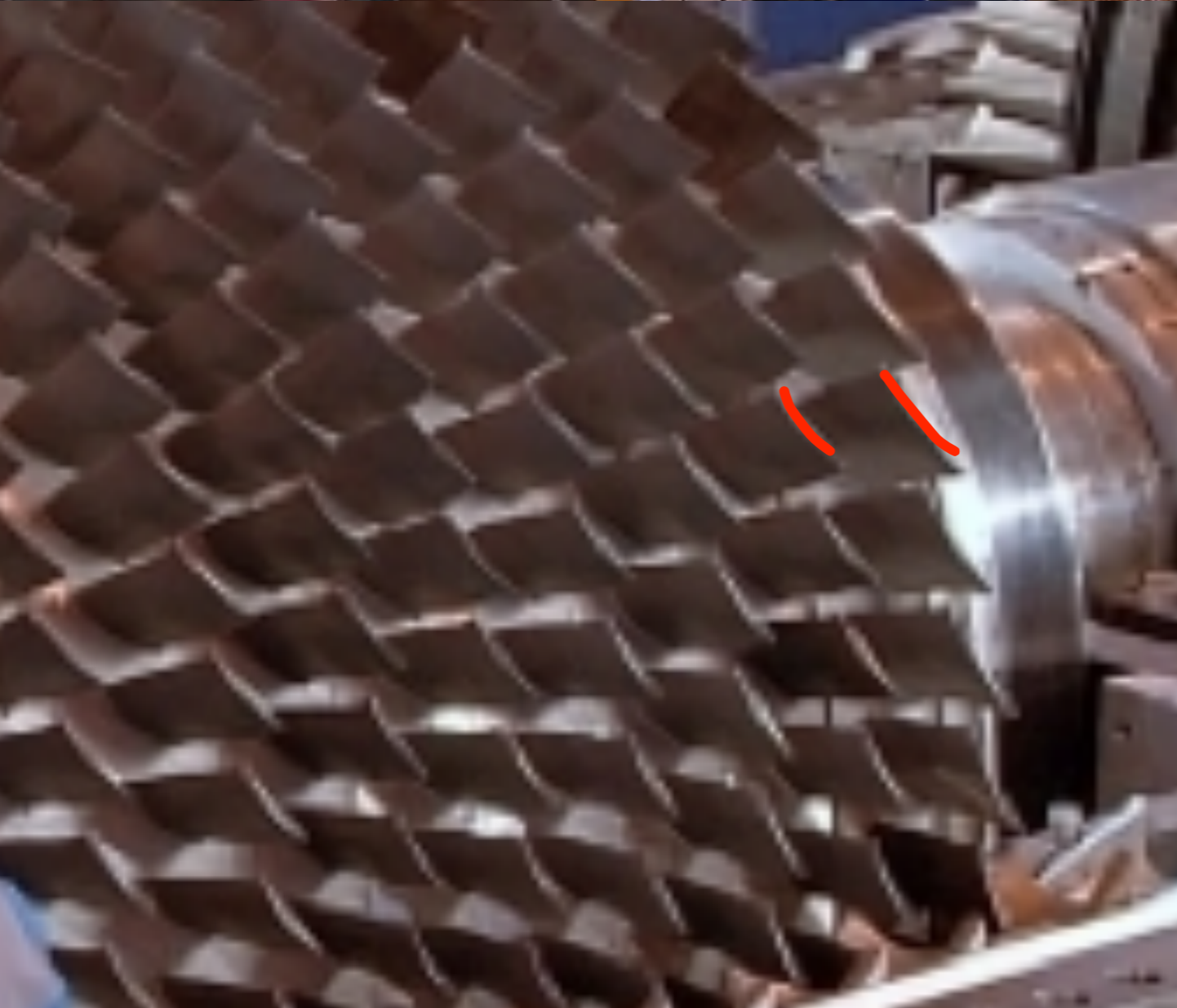
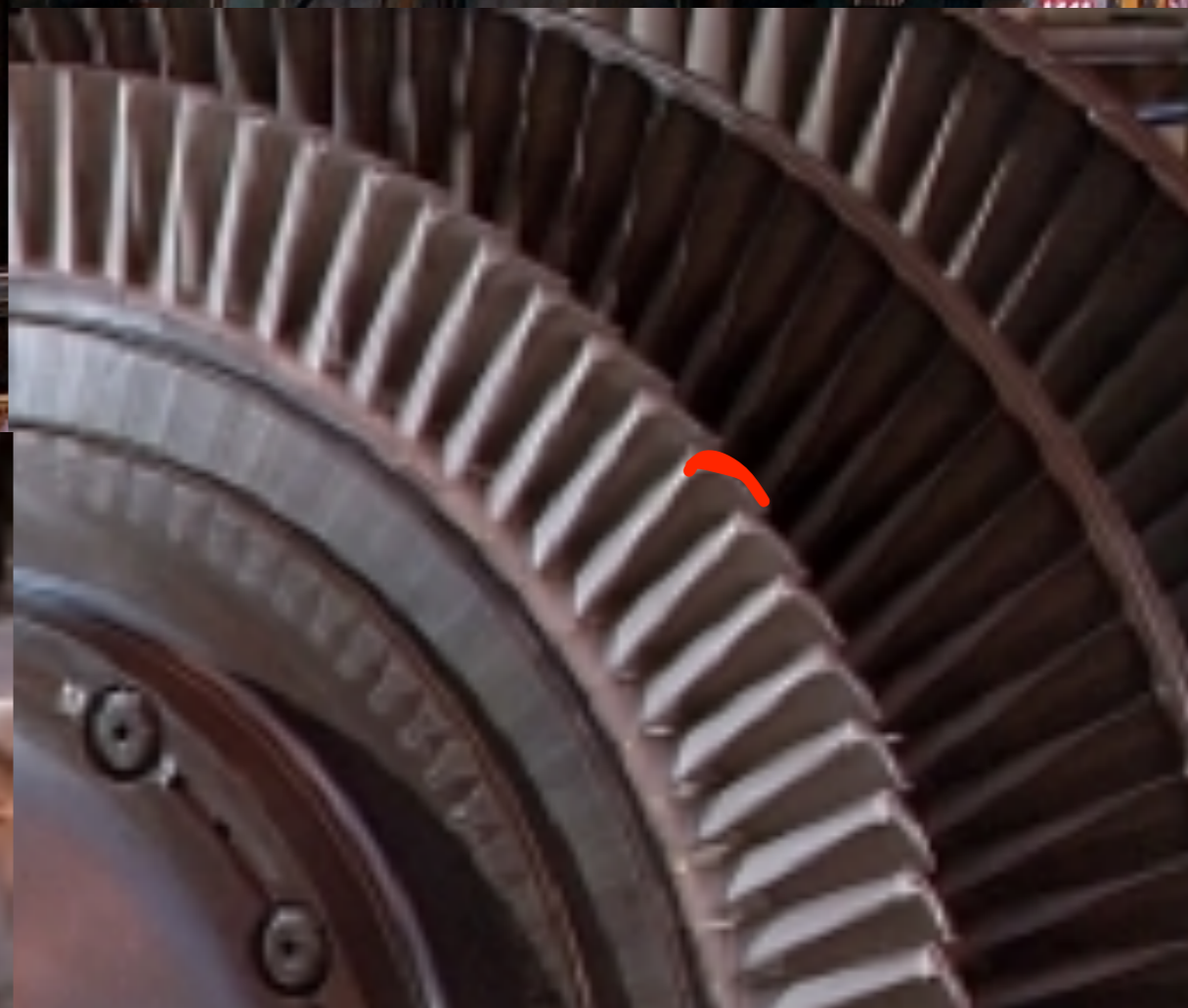
regime innescato



Turbine a flusso assiale e misto

- 1) h_0 e T_0 decrescono molto rapidamente nello stadio, $\rho \neq \text{cost}$
- 2) T elevata, $> 900^\circ\text{C}$
- 3) Deflessione maggiore rispetto ai compressori:
Turbina $50^\circ-180^\circ$, compressore $20^\circ-35^\circ$
- 4) profili diversi dai compressori, variazione di sezione importante





Turbine a flusso assiale e misto (dal corso di macchine)

- Stadi ad azione $R = 0$

{	De Laval	$z_v = 1$	(primo stadio)
	Curtis	$z_v = 2 \div 3$	
	Reteau	$z_v = 1$	(stadio intermedio)

$R = 0,5$

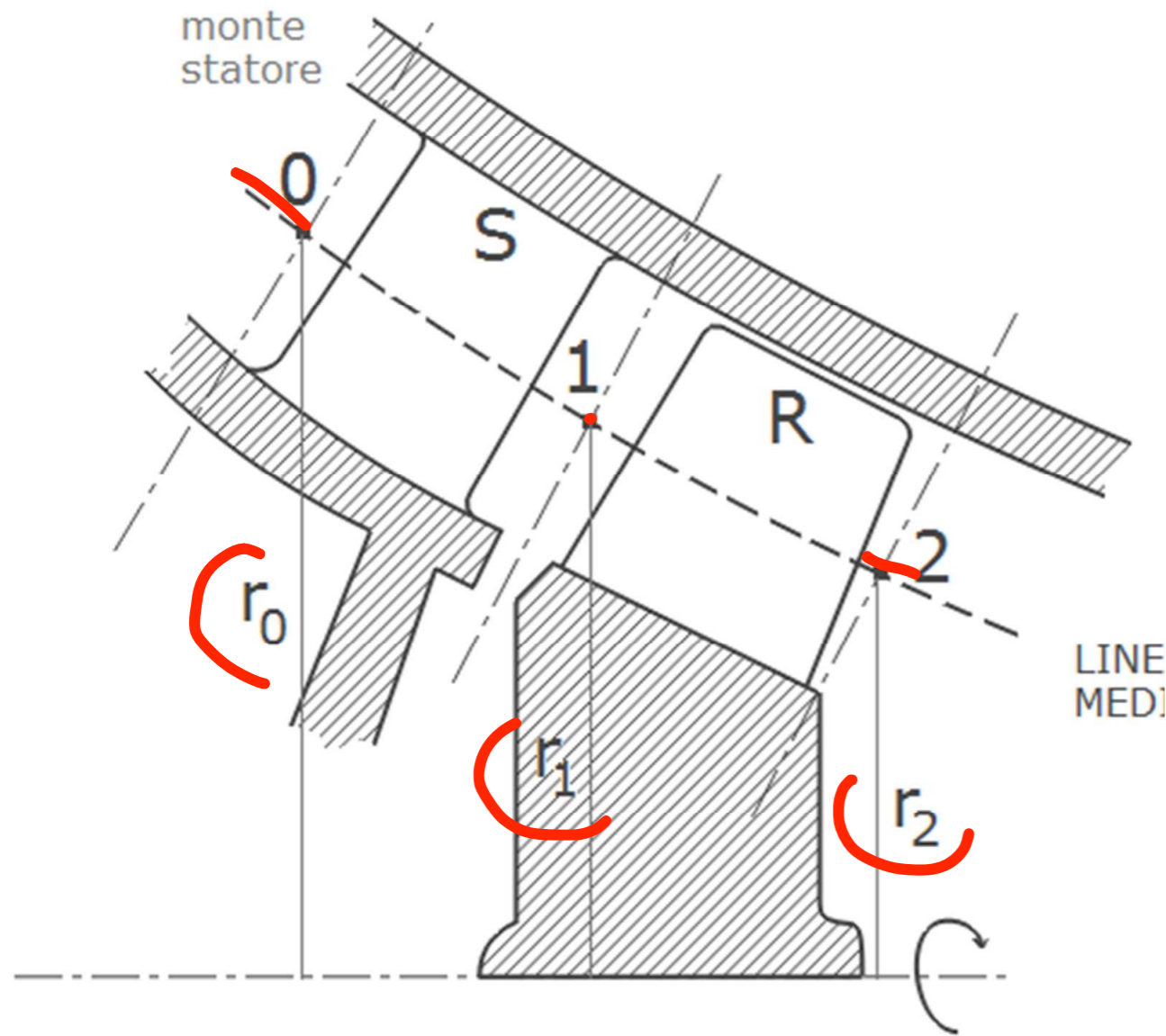
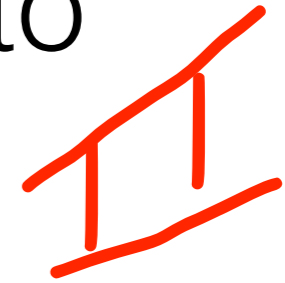
{ Parsons

$$\left(\frac{u}{c_1} \right)_{opt} = \frac{\text{sen} \alpha_1}{2z_v} \quad \text{per } \underline{R = 0}$$

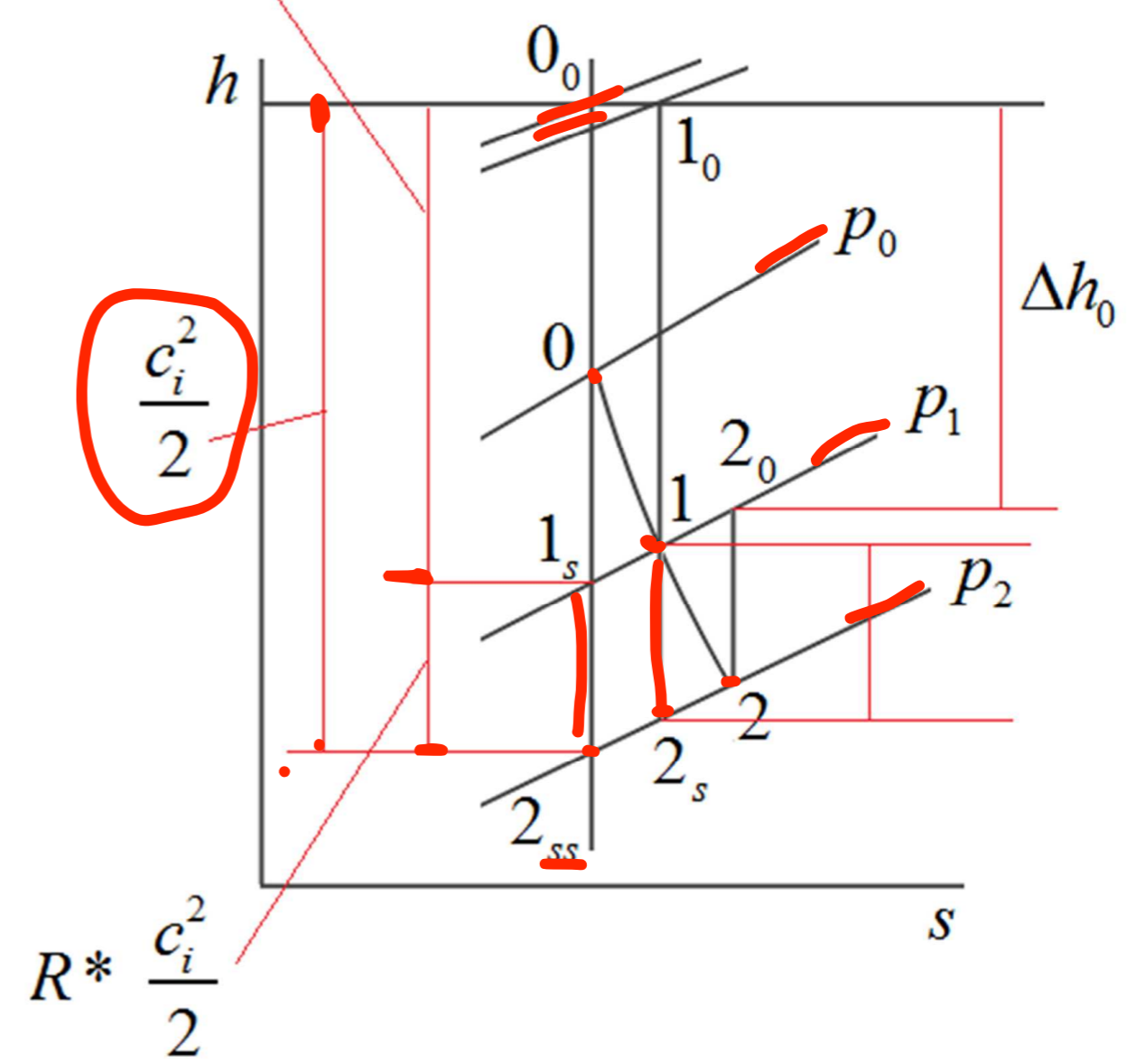
$$\left(\frac{u}{c_1} \right)_{opt} = \text{sen} \alpha_1 \quad \text{per } R = 0,5$$

α_1 piccolo \rightarrow $\text{sen} \alpha_1 = \alpha_1$

Turbine a flusso assiale e misto



$$(1 - R^*) \frac{c_i^2}{2}$$



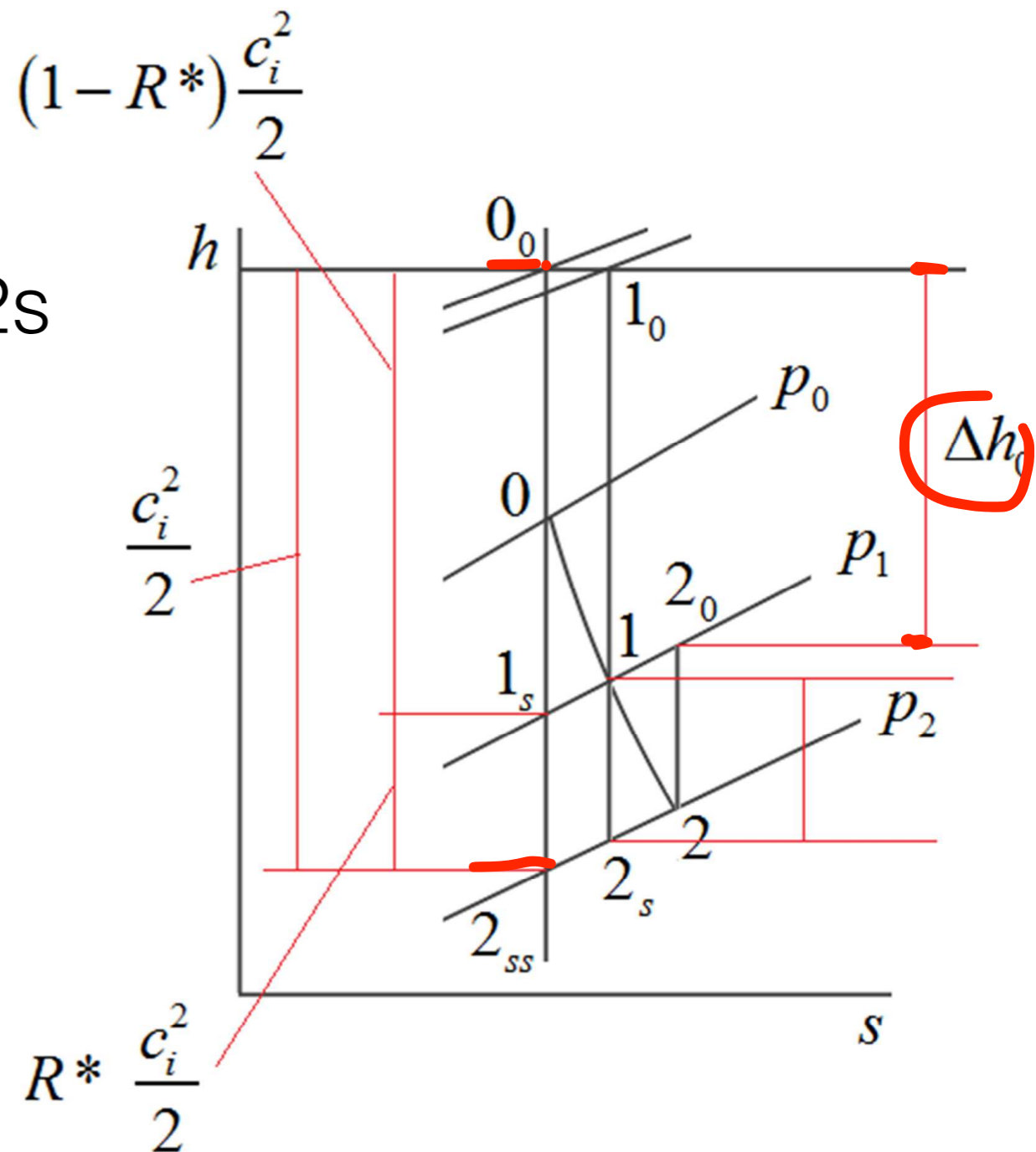
Turbine a flusso assiale e misto

$$\underline{(1 - R^*) \cdot \frac{c_i^2}{2}}$$

Salto entalpico con espansione isoentropica

$$\underline{(1 + f) R^* \cdot \frac{c_i^2}{2}} \quad \text{Salto fra 1 e 2s}$$

f fattore di recupero



Turbine a flusso assiale e misto

$$\eta = \frac{h_{0_0} - h_{0_2}}{h_{0_0} - h_{2_{ss}} - \phi_E \frac{c_2^2}{2}} = \frac{\Delta h_0}{\Delta h_{iS_{ts}} - \phi_E \frac{c_2^2}{2}}$$

$\phi_E = 1 \Rightarrow \eta = \eta_{tt}$
 $\phi_E = 0 \Rightarrow \eta = \eta_{ts}$

definizioni:

$$\psi = \frac{h_{0_0} - h_{2_{ss}}}{\frac{u_1^2}{2}} = \frac{c_i^2}{u_1^2} = \frac{\Delta h_{iS_{ts}}}{\frac{u_1^2}{2}}$$

$$\phi_1 = \frac{c_{m1}}{u_1} \quad \text{Coeff. di portata}$$

$$R^* = \frac{h_{1s} - h_{2_{ss}}}{h_{0_0} - h_{2_{ss}}} = \frac{\Delta h_{Ris}}{\Delta h_{ists}} \quad \text{Grado di reazione}$$

Turbine a flusso assiale e misto

definizioni:

$$\psi = \frac{h_{0_0} - h_{2_{ss}}}{\frac{u_1^2}{2}} = \frac{c_i^2}{u_1^2} = \frac{\Delta h_{i_{sts}}}{\frac{u_1^2}{2}} \quad \text{Coeff. di lavoro specifico ideale}$$

$$\frac{c_i^2}{2} = h_{0_0} - h_{2_{ss}} \quad \text{energia cinetica ideale}$$

$$k_{is} = \frac{u_1}{c_i} = \frac{1}{\sqrt{\psi}} \quad \text{Coeff. di velocità periferica}$$

$$\lambda = \frac{h_{0_0} - h_{2_0}}{\frac{u_1^2}{2}} = \frac{\Delta h_0}{\frac{u_1^2}{2}} \quad \text{Coeff. di lavoro specifico reale}$$

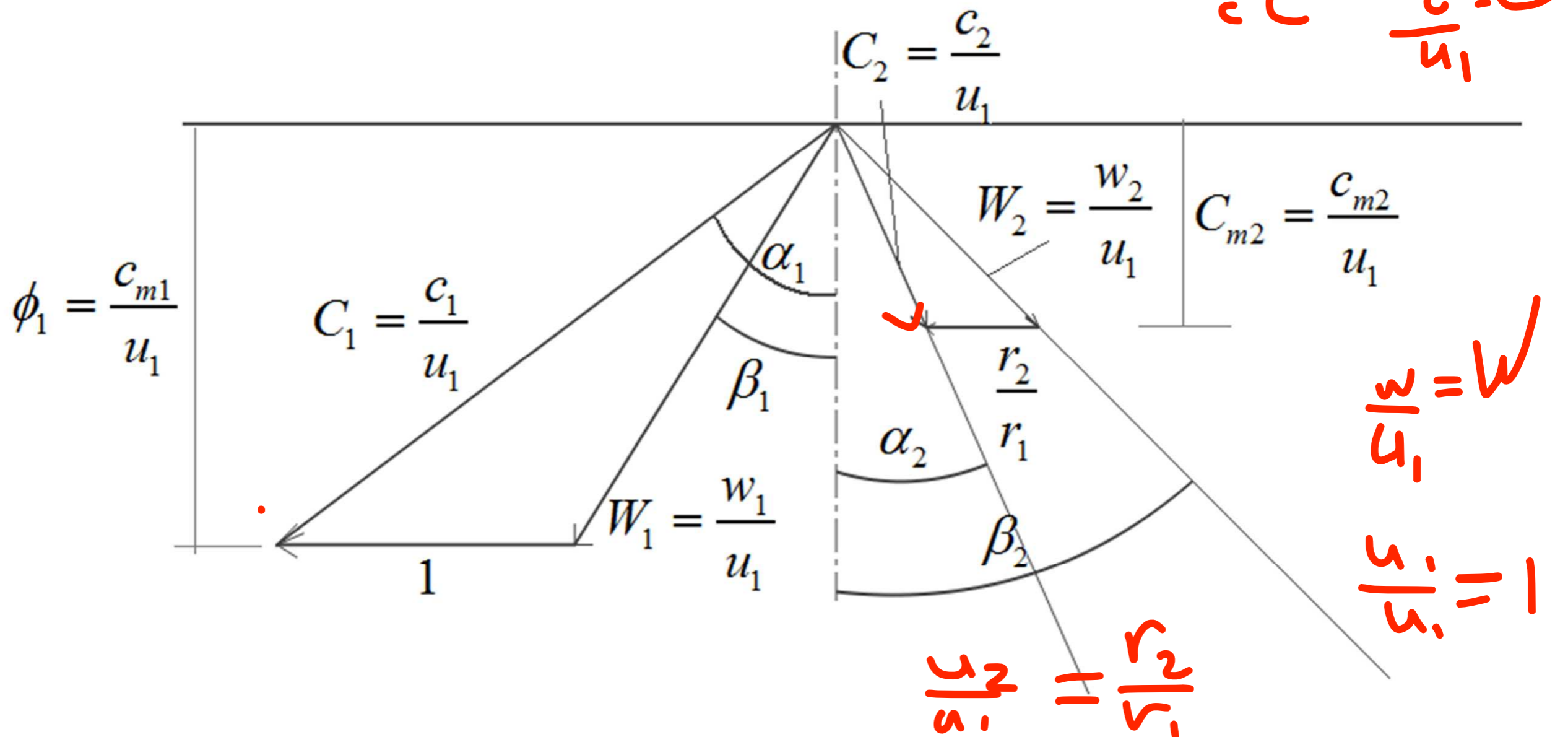
Turbine a flusso assiale e misto

$$\frac{c_{m2}}{c_{m1}}$$

$$\frac{r_2}{r_1}$$

rapp. fra le velocità meridiane

rapporto fra i raggi, =1 macchina assiale



Turbine a flusso assiale e misto

$$\eta = \frac{\Delta h_0}{\Delta h_{iS_{ts}} - \phi_E \frac{c_2^2}{2}} \cdot \frac{1}{\left(\frac{u_1^2}{2}\right)} = \frac{\lambda}{\psi - \phi_E \left(c_2^2\right)}$$

$$\lambda = \frac{\Delta h_0}{\frac{u_1^2}{2}} = \frac{2(u_1 c_{u1} - u_2 c_{u2})}{u_1^2} = 2 \left(c_{u1} - \frac{r_2}{r_1} c_{u2} \right)$$

Turbine a flusso assiale e misto

C1 Velocità assoluta adimensionalizzata

$$\frac{c_1^2}{2} = (1 - R^*) \frac{c_i^2}{2} \cdot \eta_s \quad \rightarrow \quad c_1 = \sqrt{\eta_s (1 - R^*)} \cdot c_i$$

$$C_1 = \frac{c_1}{u_1} = \sqrt{\eta_s (1 - R^*)} \cdot \frac{c_i}{u_1}$$

$$\frac{c_i}{u_1} = \frac{1}{k_{is}}$$

$$C_1 = \frac{\sqrt{\eta_s}}{k_{is}} \sqrt{1 - R^*}$$

Turbine a flusso assiale e misto

W1 Velocità relativa adimensionalizzata

$$W_1^2 = \underline{C_1^2} + 1^2 - 2 \cdot 1 \cdot \underline{C_1} \cos(90^\circ - \alpha_1)$$

$$W_1 = \sqrt{1 + \frac{\eta_s}{k_{is}^2} (1 - R^*)} - 2 \frac{\sqrt{\eta_s}}{k_{is}} \sqrt{1 - R^*} \cdot \sin \alpha_1$$

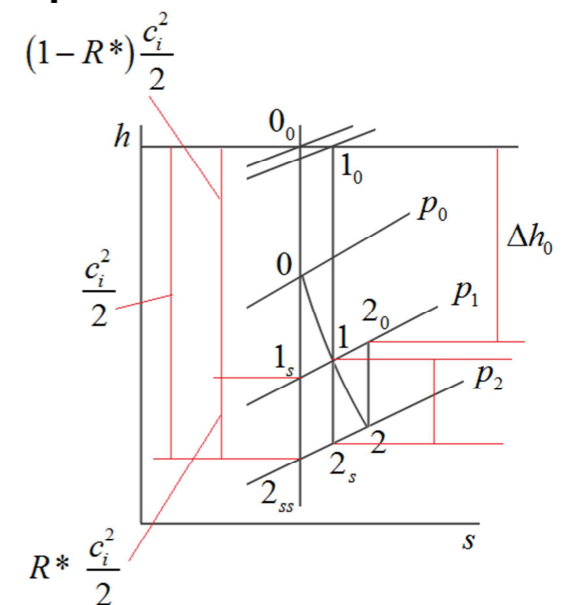
Turbine a flusso assiale e misto

W2 Velocità relativa adimensionalizzata

$$h_2 - h_1 = \frac{u_2^2 - u_1^2}{2} - \frac{w_2^2 - w_1^2}{2}$$

$$h_1 - h_2 = \frac{c_i^2}{2} \cdot \underbrace{R^*}_{\text{rotalpia}} \cdot \underbrace{(1+f)}_{\text{rotalpia}} \cdot \underbrace{\eta_R}_{\text{rotalpia}}$$

rotalpia



$$\frac{w_2^2 - w_1^2}{2} - \frac{u_2^2 - u_1^2}{2} = \frac{c_i^2}{2} \cdot R^* \cdot (1+f) \cdot \eta_R$$

$$\cdot \frac{1}{u_1^2}$$

$$W_2 = \sqrt{\frac{\eta_R (1+f) R^*}{k_{is}^2} + \frac{\eta_S (1+R^*)}{k_{is}^2} - \frac{2\sqrt{\eta_S} \sqrt{1-R^*} \sin \alpha}{k_{is}} + \left(\frac{r_2}{r_1}\right)^2}$$

Turbine a flusso assiale e misto

C_{m2} Velocità meridiana assoluta adimensionalizzata

$$C_{m2} = C_{m1} \cdot \frac{C_{m2}}{C_{m1}} = C_1 \cos \alpha_1 \cdot \frac{C_{m2}}{C_{m1}}$$

$$C_{m2} = C_1 \cos \alpha_1 \cdot \frac{C_{m2}}{C_{m1}}$$

$$C_{m2} = \frac{C_{m2}}{C_{m1}} \cdot \frac{\eta_s}{k_{is}} \cdot \sqrt{1 - R^*} \cos \alpha_1$$

Turbine a flusso assiale e misto

$$\eta = f \left(\psi, \phi_R, R^*, k_{is}, f, \frac{c_{m2}}{c_{m1}}, \frac{r_2}{r_1}, \alpha_1, \eta_S, \eta_R \right)$$

$\psi, \phi_R, R^*, k_{is}$: parametri funzionali

f : unica grandezza che dipende dalla natura del fluido

$\frac{c_{m2}}{c_{m1}}, \frac{r_2}{r_1}, \alpha_1$: parametri di progetto

η_S, η_R : parametri della schiera rotorica e statorica

Turbine a flusso assiale e misto

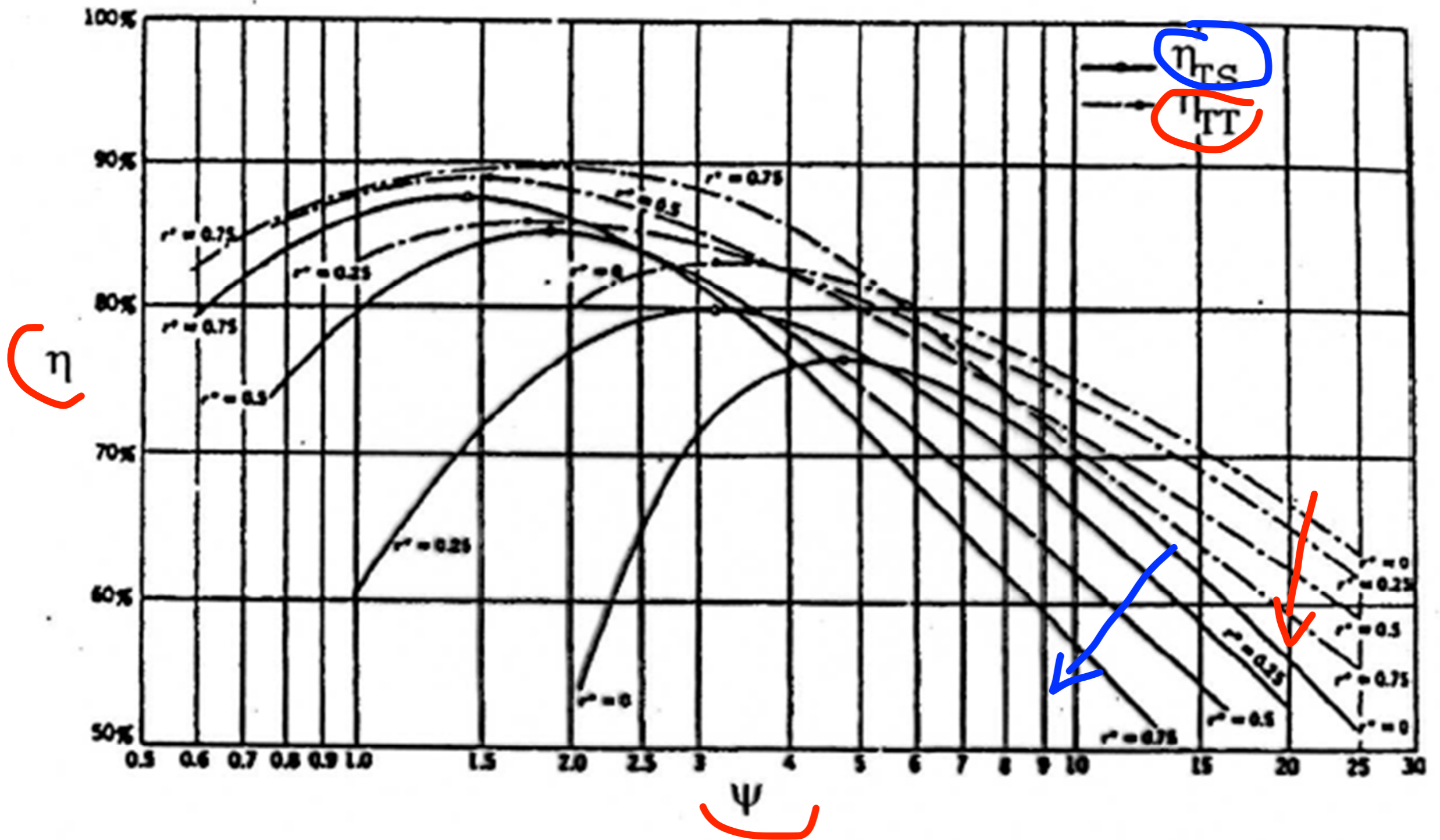
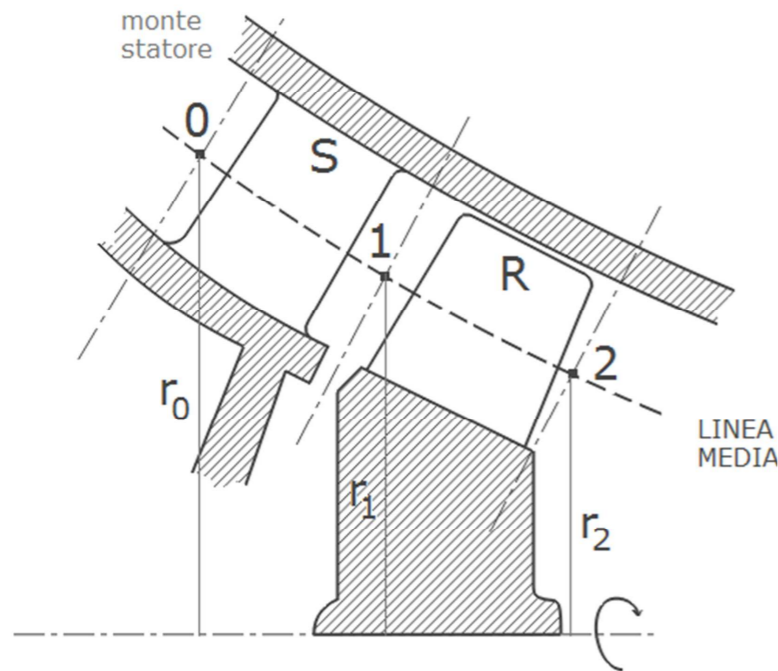


Figura 9.9: Rendimenti total/static e total/total di un generico stadio di turbina in funzione del lavoro adimensionale per diversi gradi di reazione.

Calcolo delle proprietà termodinamiche nell'attraversamento della turbina



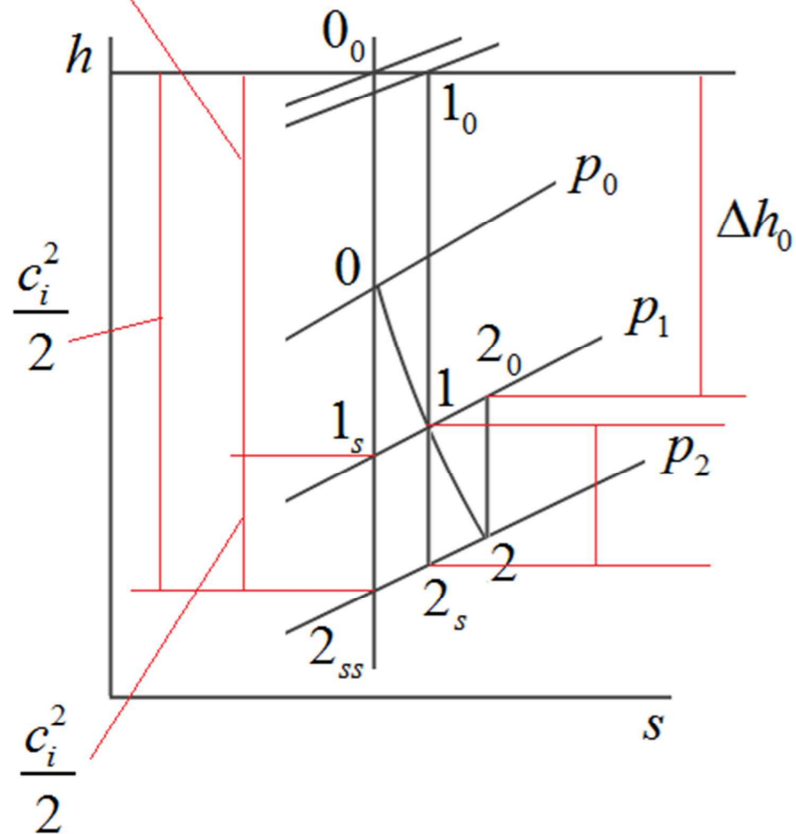
$$M_u = \frac{u_1}{a_{0_0}} \quad \text{def. Mach periferico}$$

$$a_{0_0} = \sqrt{kRT_{0_0}} = \sqrt{\frac{c_p}{c_v} (c_p - c_v) T_{0_0}} = \sqrt{h_{0_0} (k - 1)}$$

$$(1 - R^*) \frac{c_i^2}{2}$$

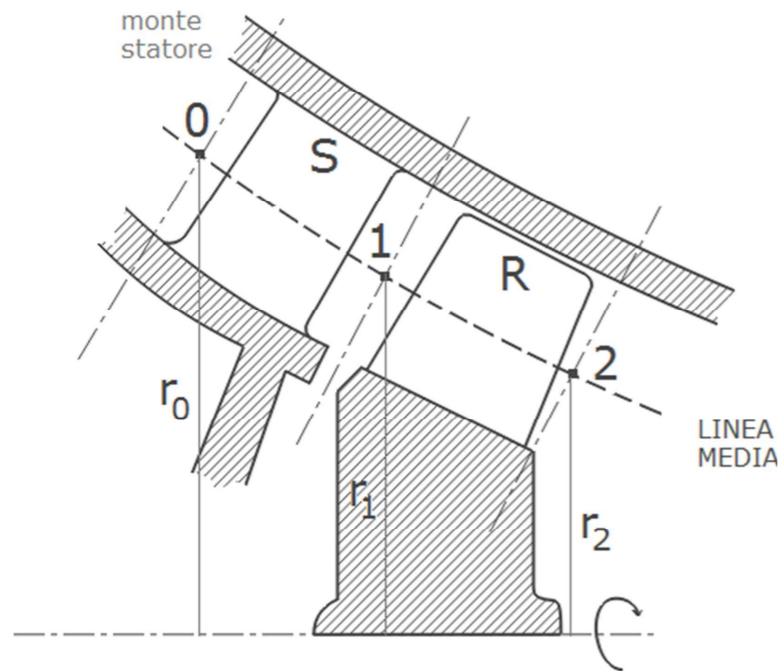
ricordiamo:

$$\psi = \frac{h_{0_0} - h_{2_{ss}}}{\frac{u_1^2}{2}} = \frac{c_i^2}{\frac{u_1^2}{2}} = \frac{\Delta h_{is_{ts}}}{\frac{u_1^2}{2}}$$



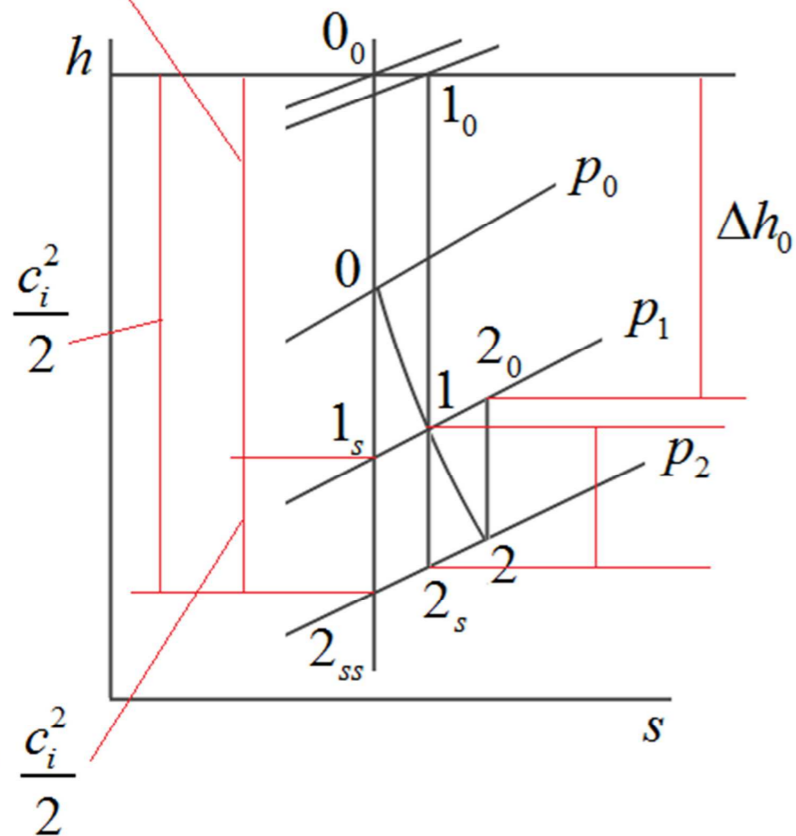
$$\frac{c_i^2}{2} = \psi \frac{u_1^2}{2} \frac{a_{0_0}^2}{a_{0_0}^2} = \frac{\psi}{2} M_u^2 (k - 1) h_{0_0}$$

Calcolo delle proprietà termodinamiche nell'attraversamento della turbina



$$h_{1s} = h_{0_0} - (1 - R^*) \frac{c_i^2}{2} = h_{0_0} \left[1 - (1 - R^*) \frac{k-1}{2} \psi M_u^2 \right]$$

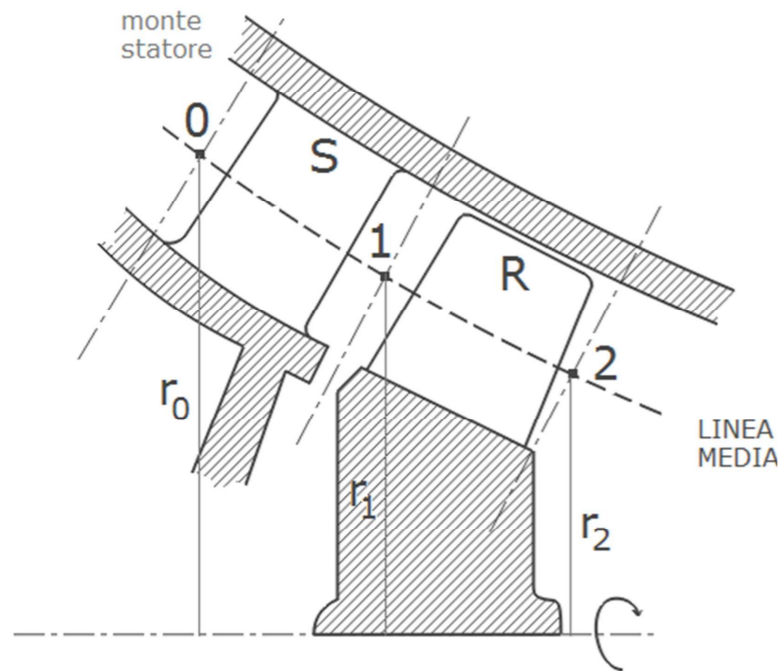
$$(1 - R^*) \frac{c_i^2}{2}$$



$$h_{2_{ss}} = h_{0_0} - \frac{c_i^2}{2} = h_{0_0} \left[1 - \frac{k-1}{2} \psi M_u^2 \right]$$

$$R^* \frac{c_i^2}{2}$$

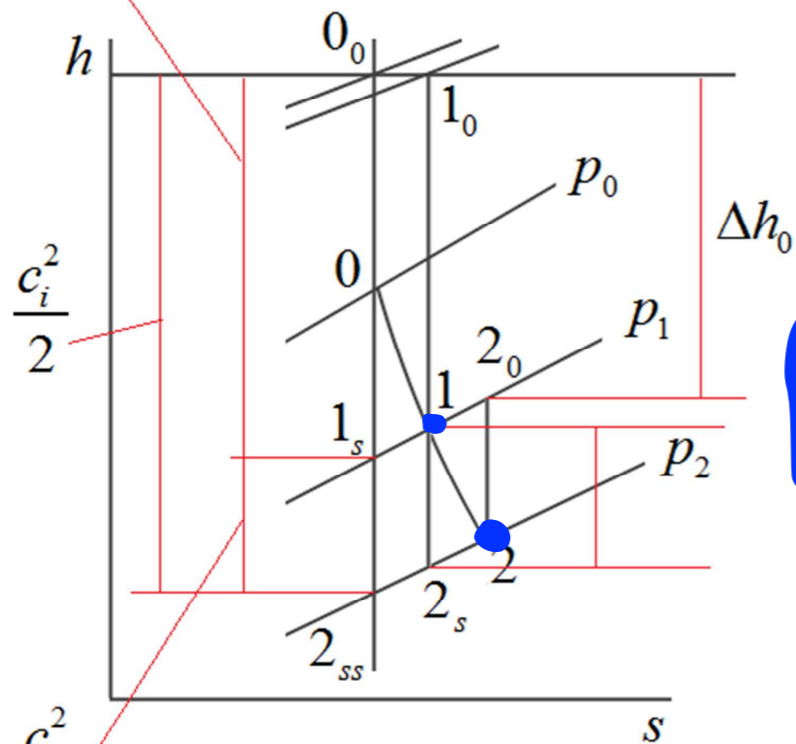
Calcolo delle proprietà termodinamiche nell'attraversamento della turbina



$$\frac{c_1^2}{2} = \eta_s \frac{c_i^2}{2} (1 - R^*)$$

$$h_1 = h_{0_0} - \frac{c_1^2}{2} = h_{0_0} \left[1 - (1 - R^*) \frac{k-1}{2} \eta_s \psi M_u^2 \right]$$

$$(1 - R^*) \frac{c_i^2}{2}$$



$$h_2 = h_{0_0} - \Delta h_0 - \frac{c_2^2}{2} = h_{0_0} \left[1 - \left(\eta_{T,S} + \frac{C_2^2}{\psi} \right) \frac{k-1}{2} \psi M_u^2 \right]$$

$$R^* \frac{c_i^2}{2}$$