

lezione 19-20

Schiere supersoniche

$$M_1 < 1$$

$$M_2 < 1$$

compressore subsonico

$$M_1 > 1$$

$$M_2 < 1$$

compressore
transonico

$$M_{1a} < 1$$

- a) Regime innescato
- b) Regime non innescato

$$M_{1a} > 1$$

regime saturo

Schiere supersoniche

$$M_1 < 1$$

$$M_2 > 1$$

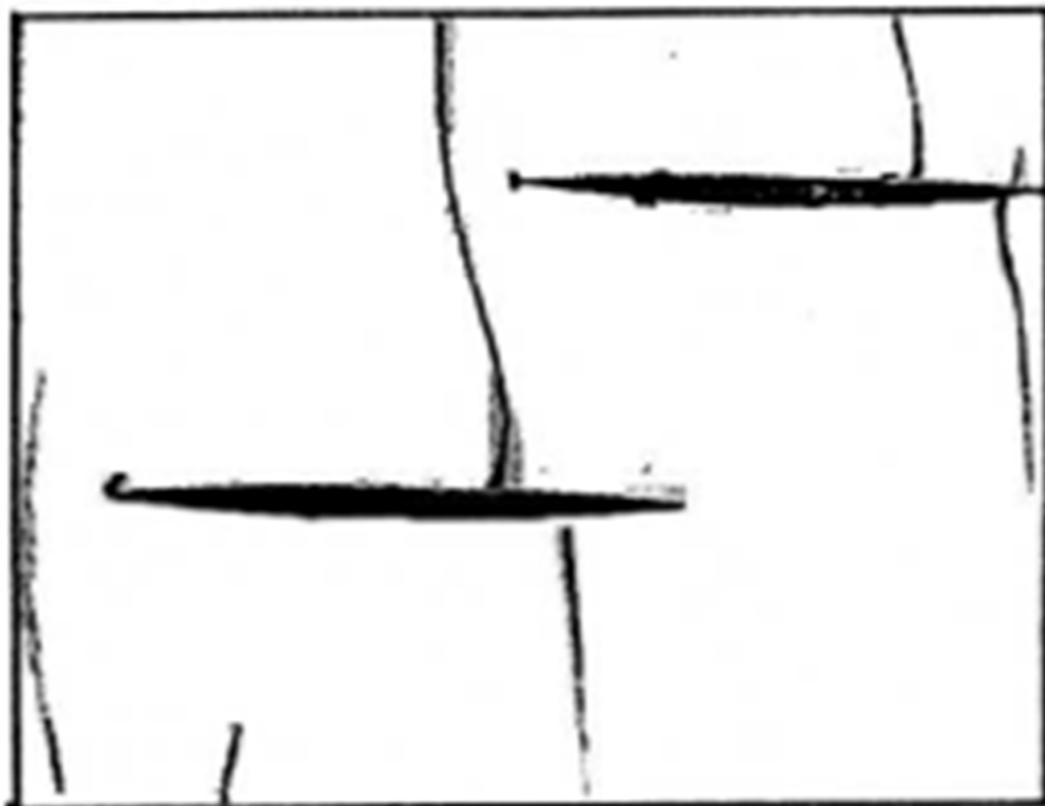
Flusso accelerato (non rilevante per i compressori)

$$M_1 > 1$$

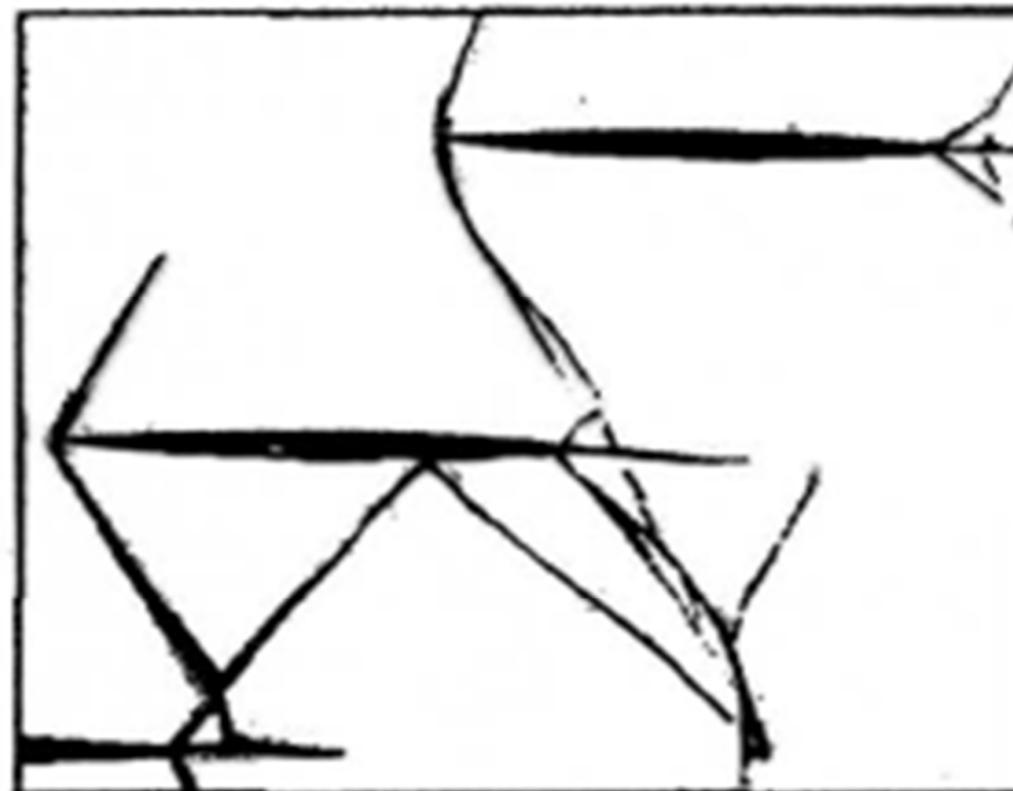
$$M_2 > 1$$

Flusso completamente supersonico

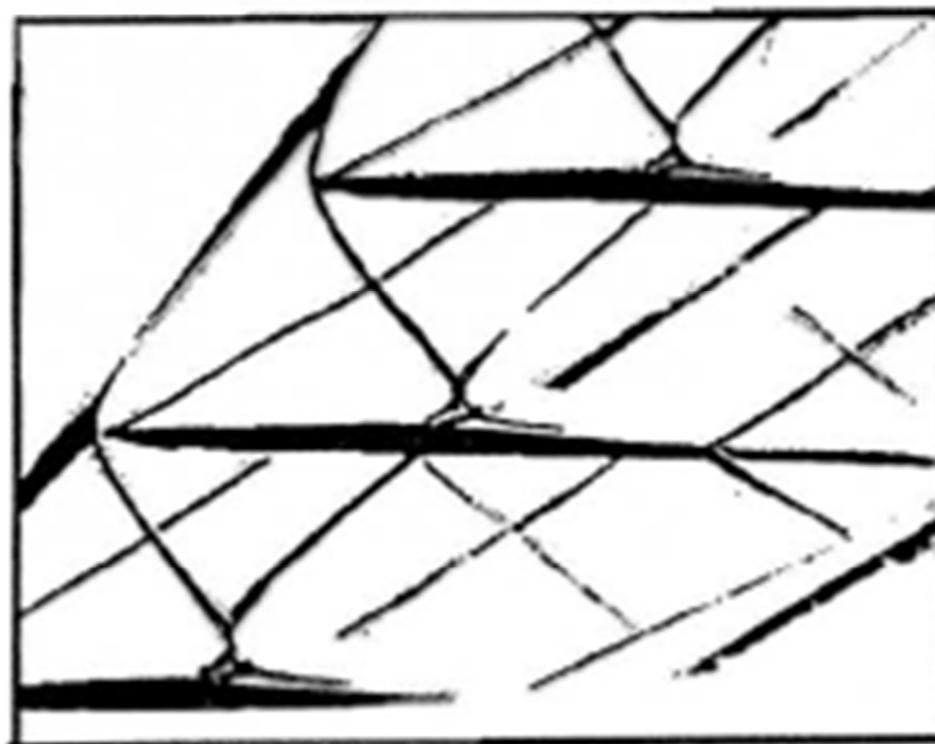
Schiere supersoniche



a) Regime non innescato

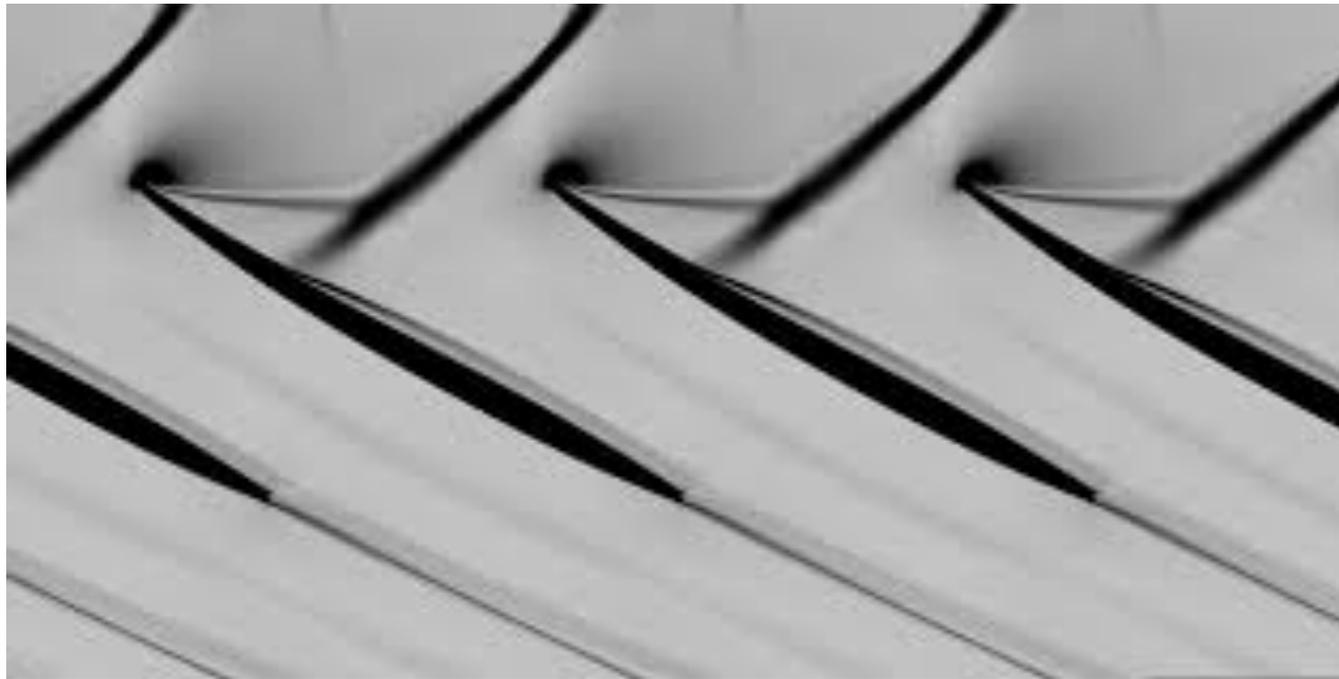


b) Regime innescato



c) Regime saturato

regime non innescato

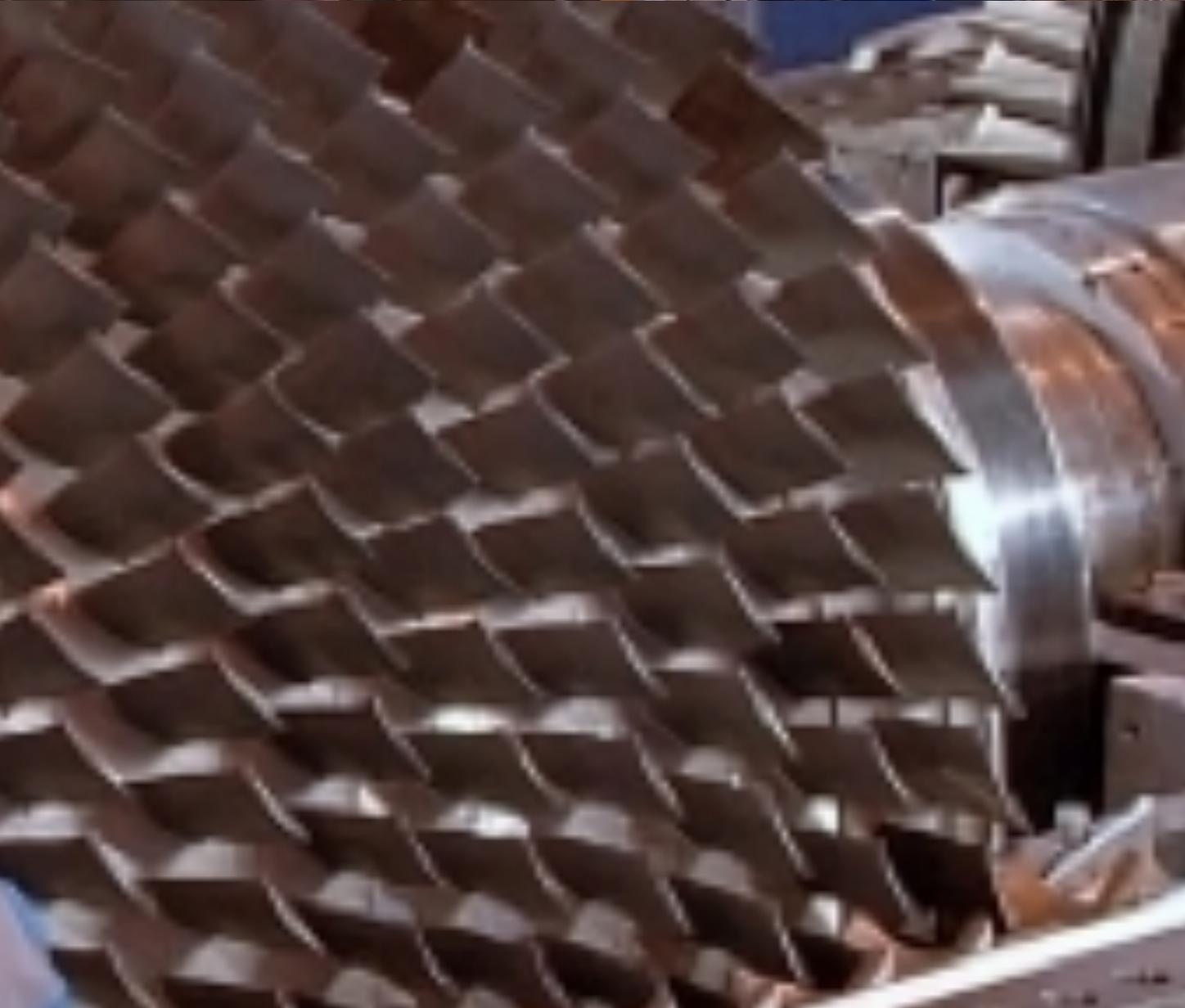
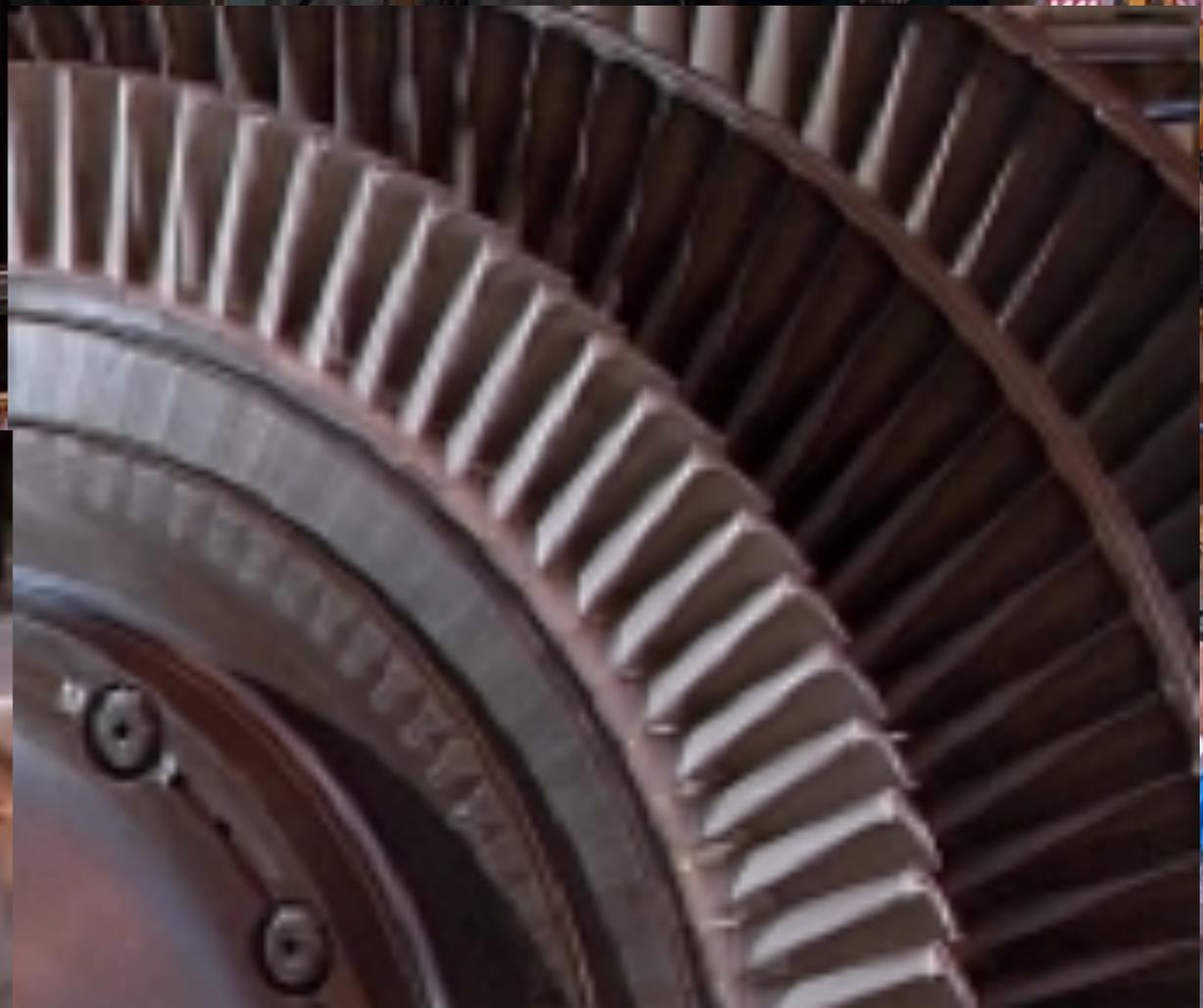


regime innescato



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° - 180° , compressore 20° - 35°
- 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

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

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

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

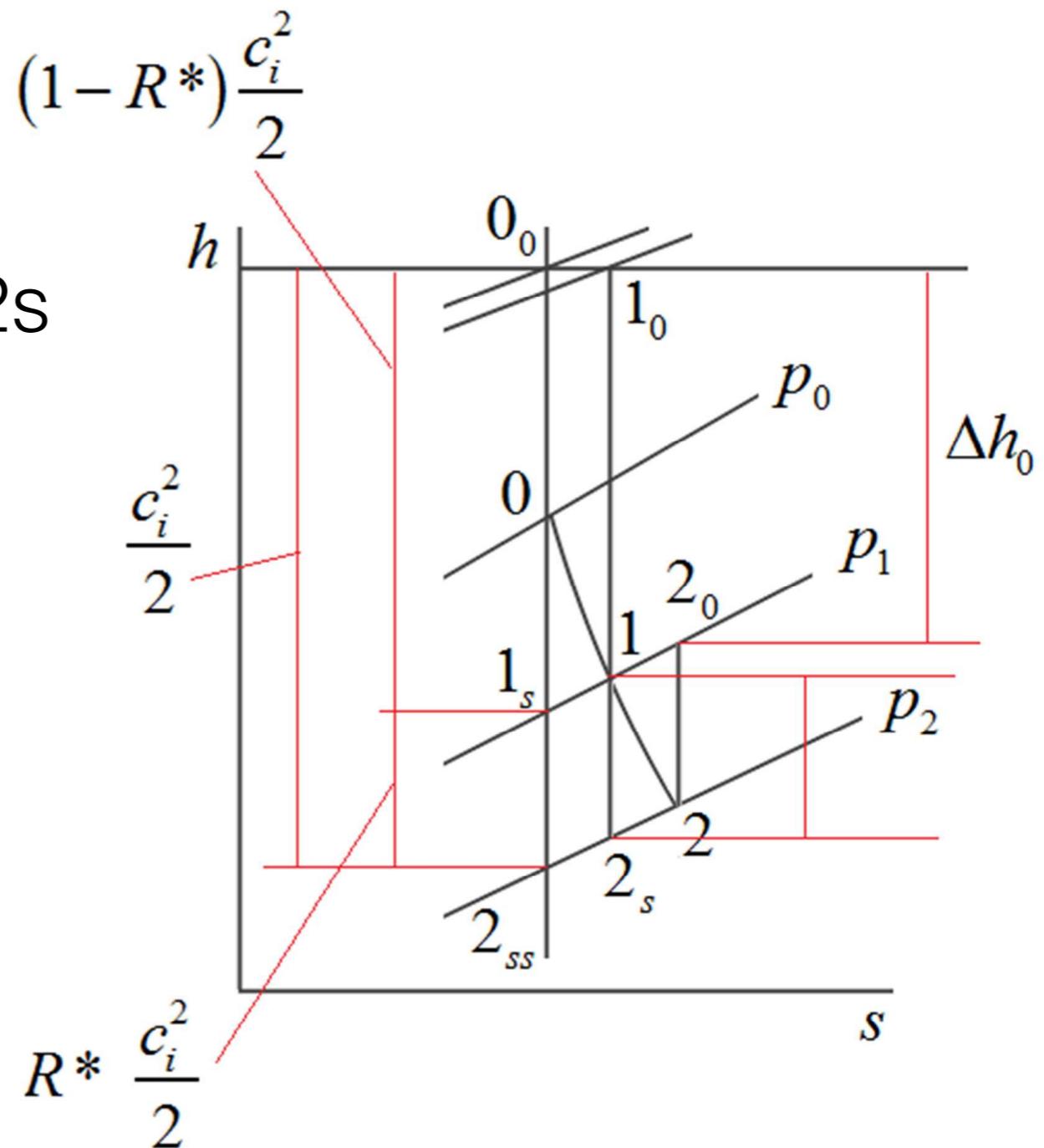
Turbine a flusso assiale e misto

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

Salto entalpico con espansione isoentropica

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

f fattore di recupero



Turbine a flusso assiale e misto

$$\eta = \frac{h_{0_0} - h_{0_2}}{h_{0_0} - h_{2_{ss}} - \phi_E \frac{c_2^2}{2}} = \frac{\Delta h_0}{\Delta h_{iS_{ts}} - \phi_E \frac{c_2^2}{2}} \quad \begin{array}{l} \phi_E = 1 \quad \Rightarrow \quad \eta = \eta_{tt} \\ \phi_E = 0 \quad \Rightarrow \quad \eta = \eta_{ts} \end{array}$$

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

$$\frac{C_{m2}}{C_{m1}}$$

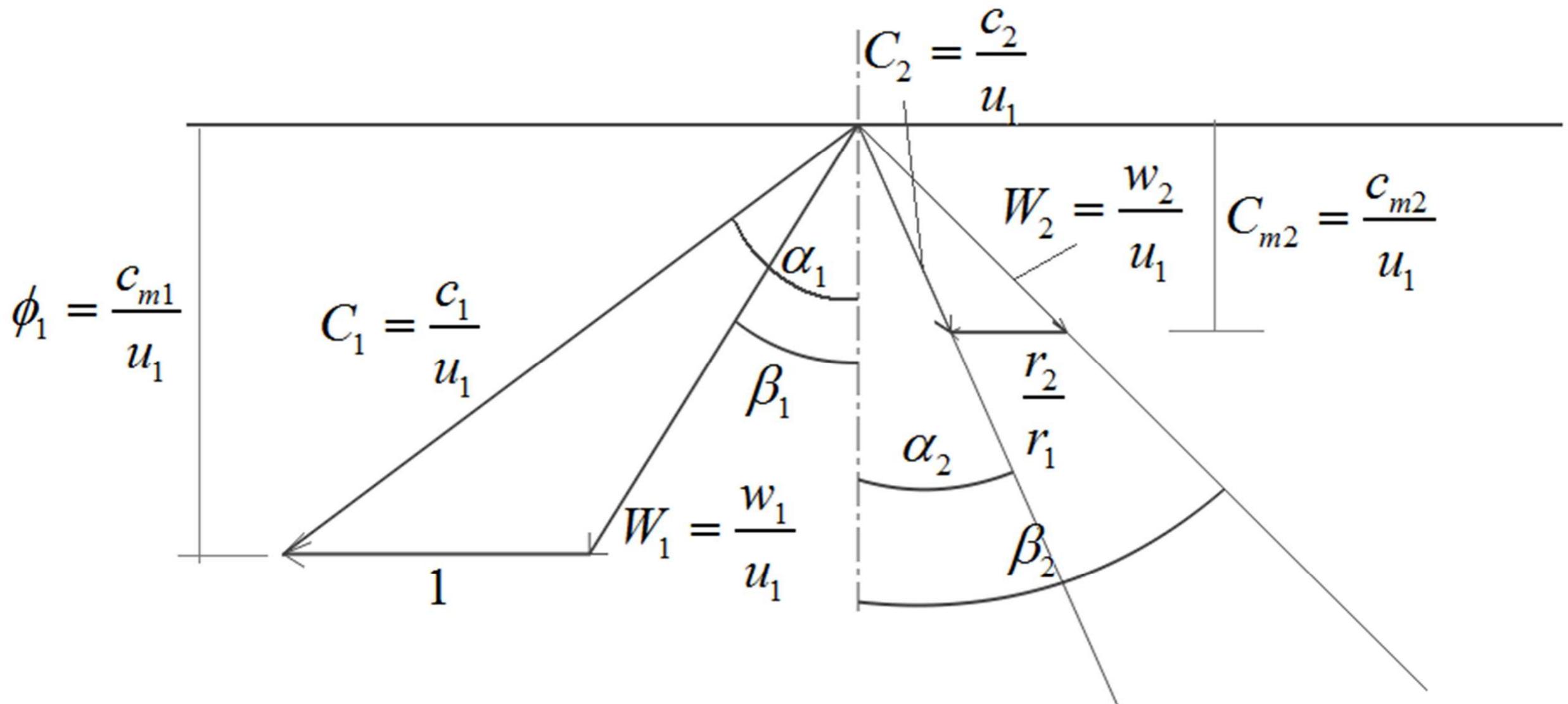
rapp. fra le velocità meridiane

$$C_{m1}$$

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

rapporto fra i raggi, = 1 macchina assiale

$$r_1$$



Turbine a flusso assiale e misto

$$\eta = \frac{\Delta h_0}{\Delta h_{iS_{ts}} - \phi_E \frac{c_2^2}{2}} \cdot \frac{1}{\left(\frac{u_1^2}{2}\right)} = \frac{\lambda}{\psi - \phi_E (C_2^2)}$$

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

Turbine a flusso assiale e misto

C1 Velocità assoluta adimensionalizzata

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

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

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

Turbine a flusso assiale e misto

W1 Velocità relativa adimensionalizzata

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

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

Turbine a flusso assiale e misto

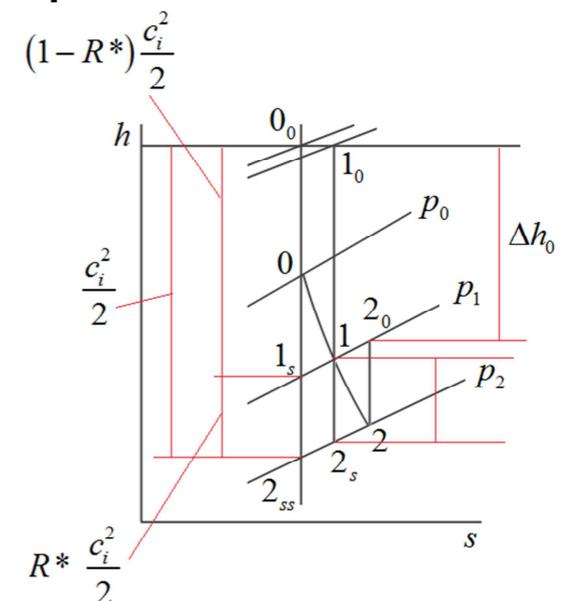
W2 Velocità relativa adimensionalizzata

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

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

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

rotalpia



$$W_2 = \sqrt{\frac{\eta_R (1 + f) R^*}{k_{is}^2} + \frac{\eta_S}{k_{is}^2} (1 + R^*) - \frac{2\sqrt{\eta_S}}{k_{is}} \sqrt{1 - R^*} \operatorname{sen} \alpha_1 + \left(\frac{r_2}{r_1} \right)^2}$$

Turbine a flusso assiale e misto

C_{m2} Velocità meridiana assoluta adimensionalizzata

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

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

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

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

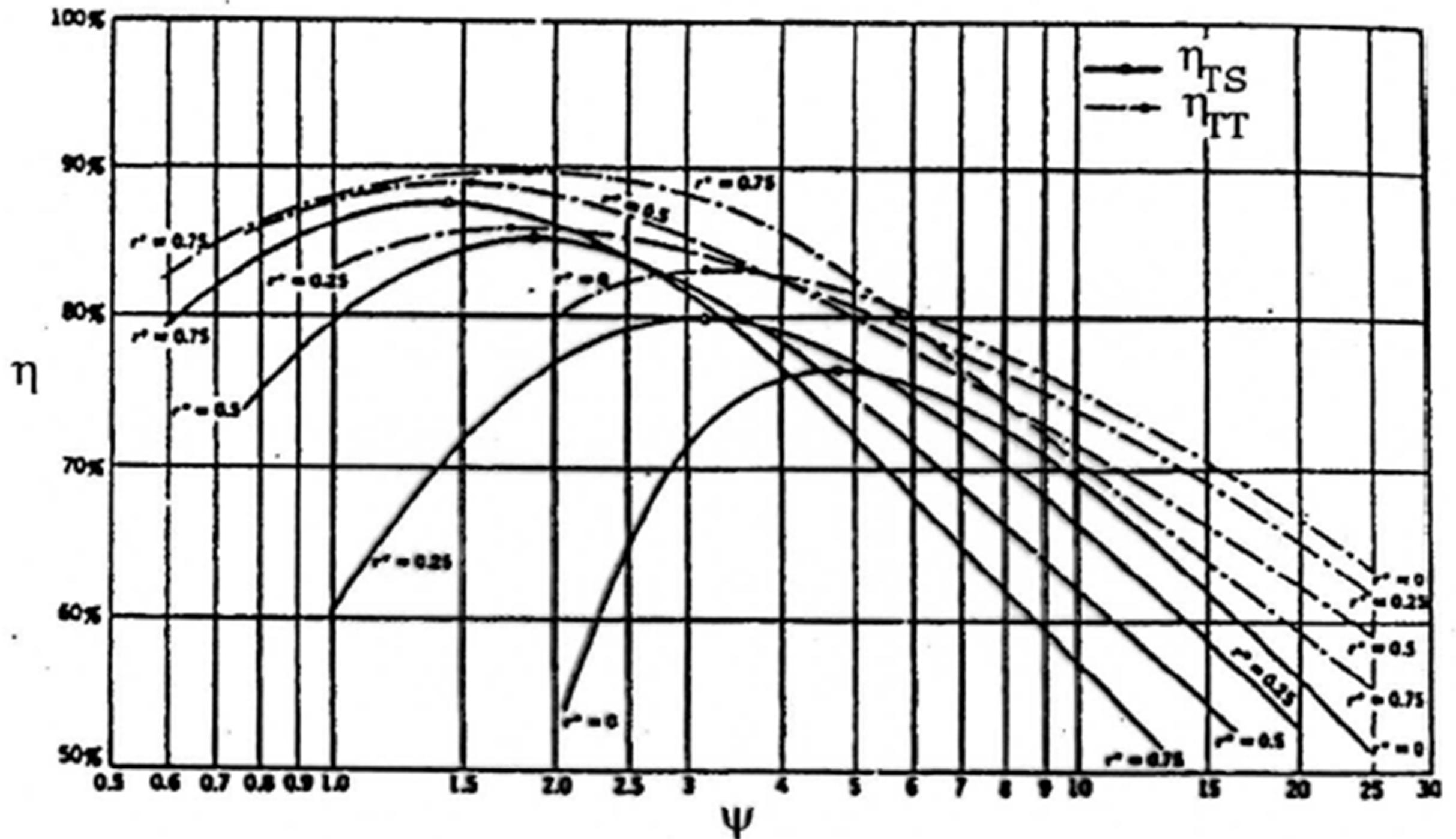
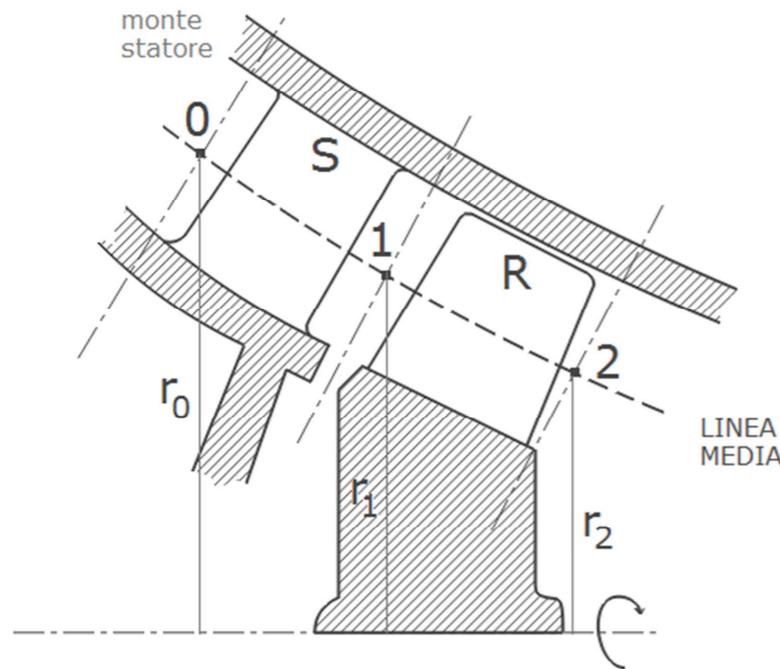


Figura 9.9: Rendimenti total/static e total/total di un generico stadio di turbina in funzione del lavoro adimensionale per diversi gradi di reazione.

Calcolo delle proprietà termodinamiche nell'attraversamento della turbina

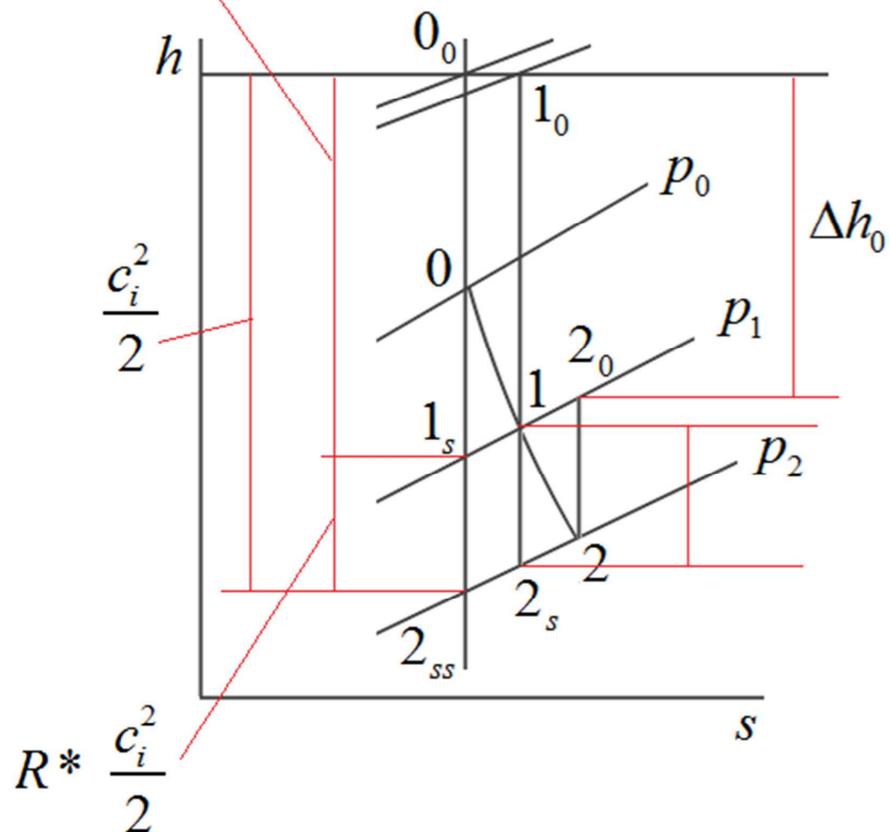


$$M_u = \frac{u_1}{a_{0_0}} \quad \text{def. Mach periferico}$$

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

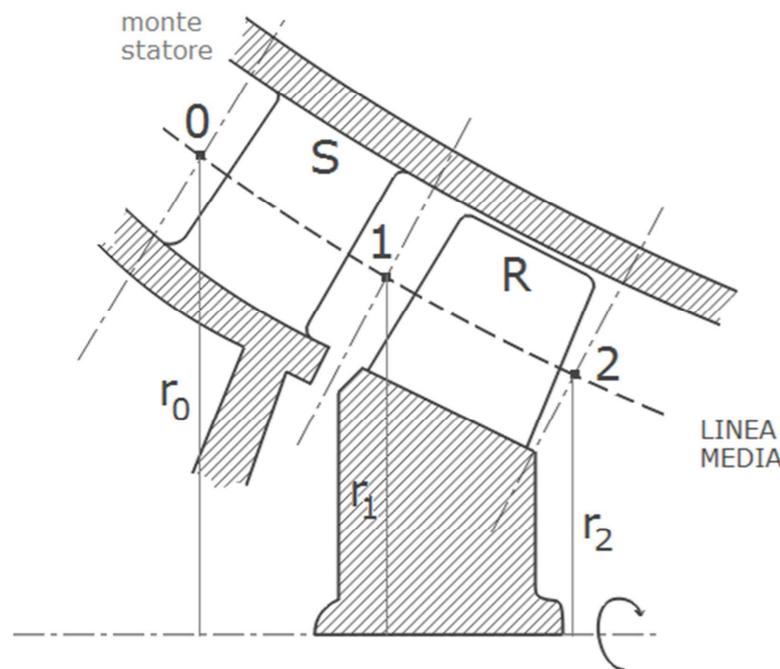
$(1 - R^*) \frac{c_i^2}{2}$ ricordiamo:

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

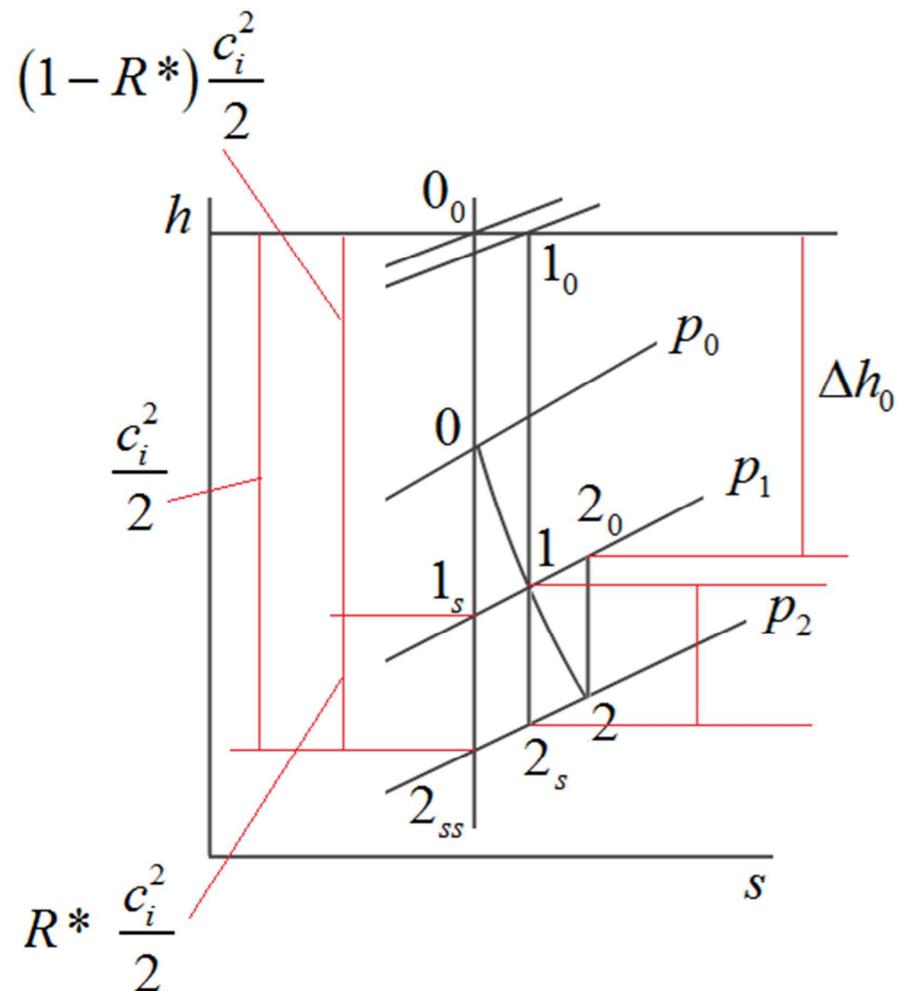


$$\frac{c_i^2}{2} = \psi \frac{u_1^2}{2} \frac{a_{0_0}^2}{a_{0_0}^2} = \frac{\psi}{2} M_u^2 (k - 1) h_{0_0}$$

Calcolo delle proprietà termodinamiche nell'attraversamento della turbina

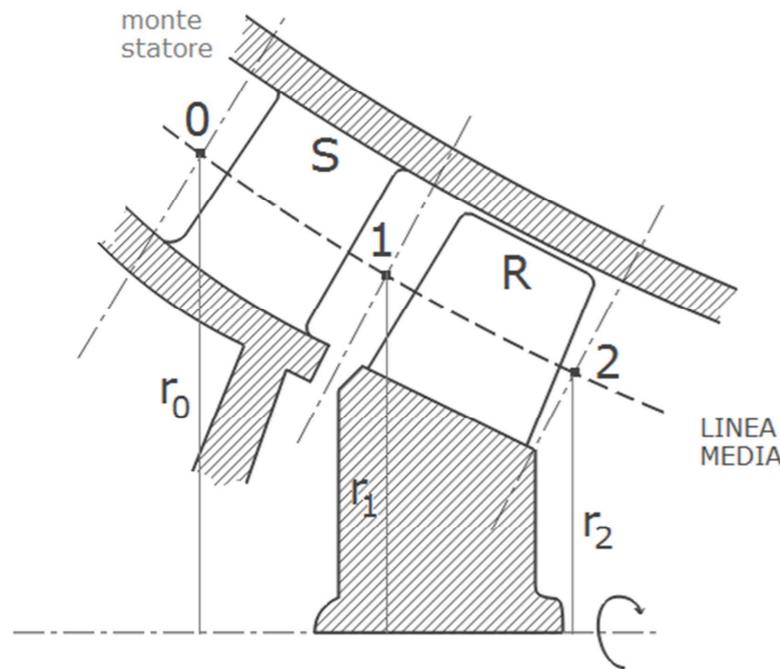


$$h_{1s} = h_{0_0} - (1 - R^*) \frac{c_i^2}{2} = h_{0_0} \left[1 - (1 - R^*) \frac{k-1}{2} \psi M_u^2 \right]$$



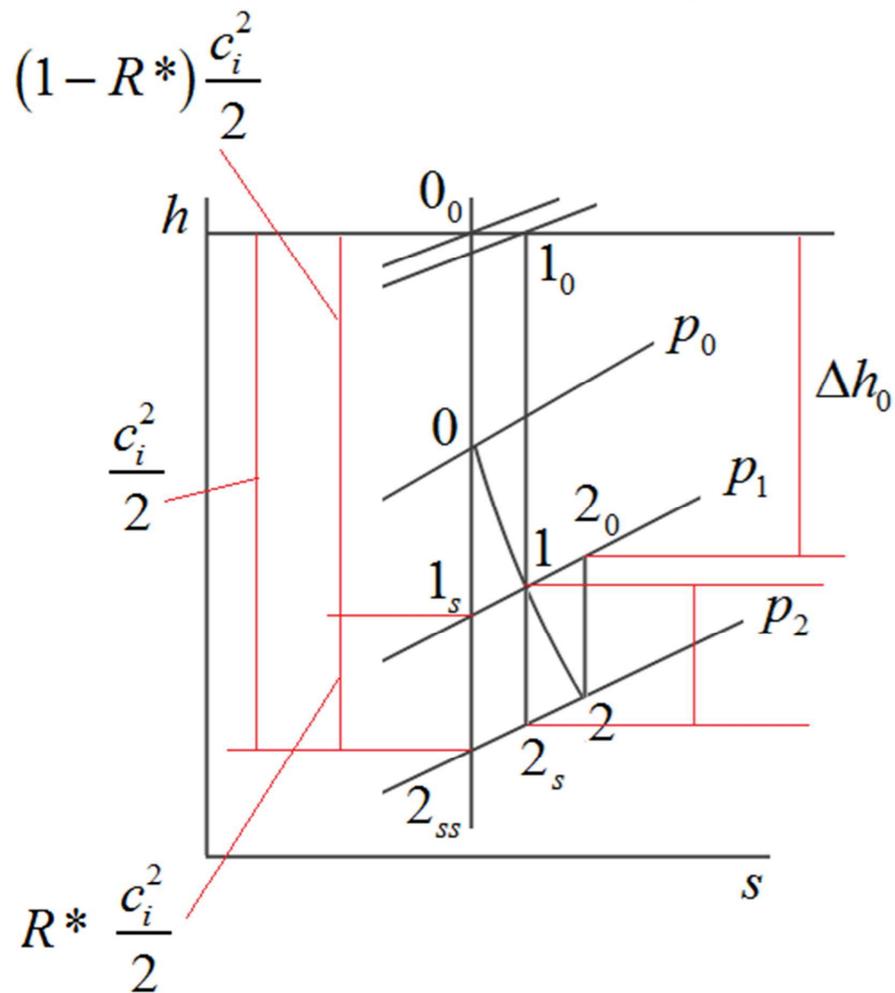
$$h_{2_{ss}} = h_{0_0} - \frac{c_i^2}{2} = h_{0_0} \left[1 - \frac{k-1}{2} \psi M_u^2 \right]$$

Calcolo delle proprietà termodinamiche nell'attraversamento della turbina



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

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



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