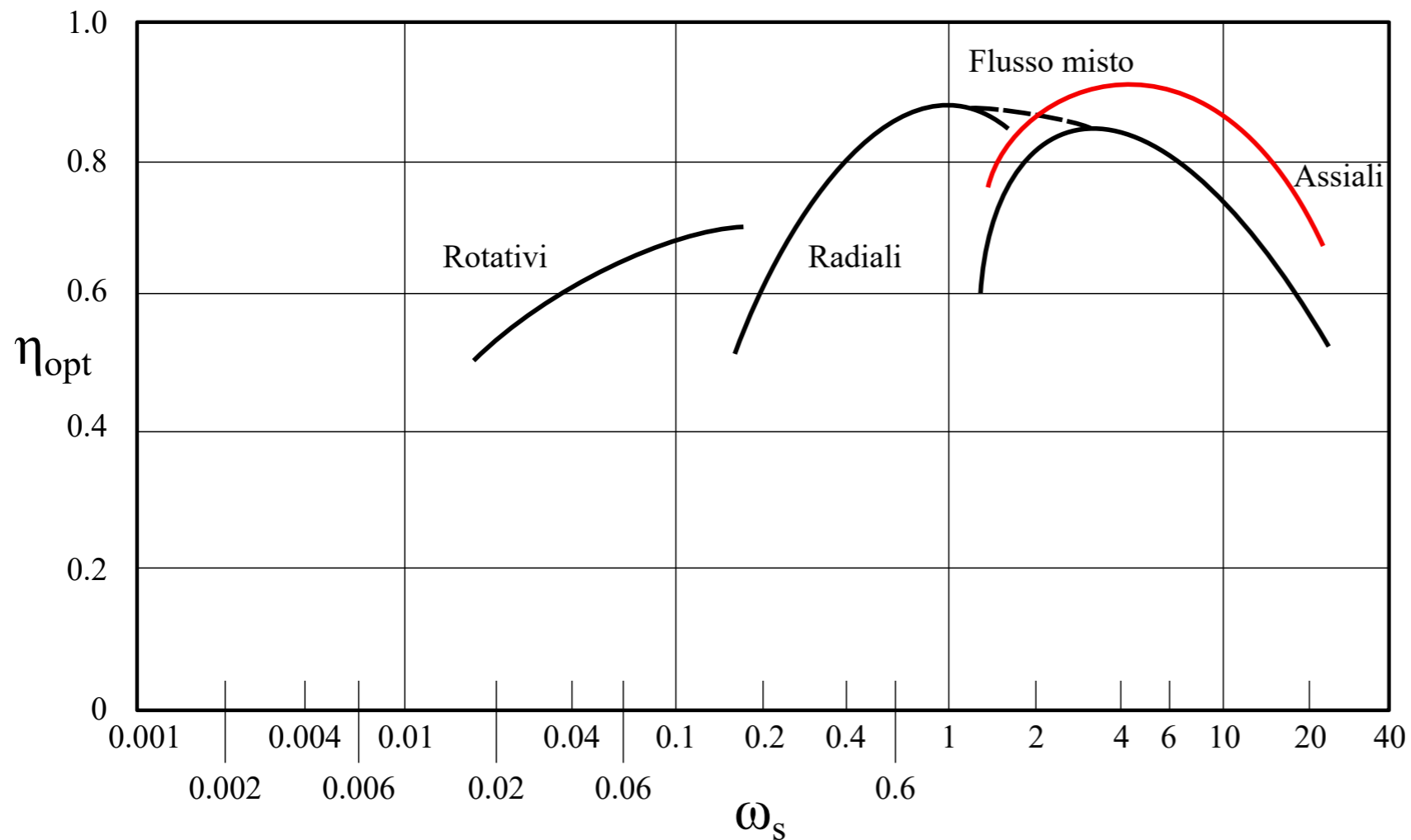


15-16

compressori



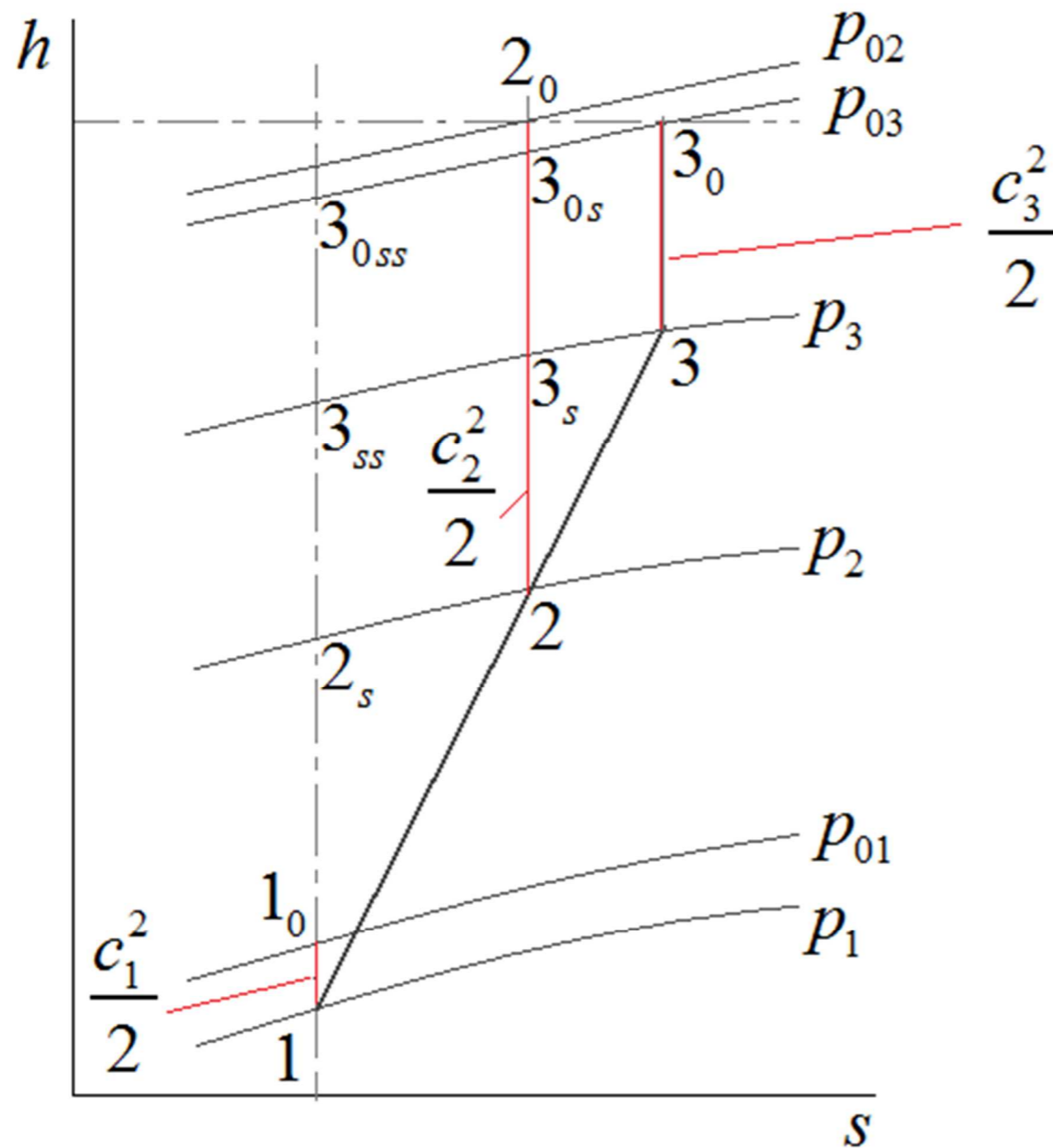
Prestazioni dei compressori assiali in funzione della velocità specifica

$$\omega_s = \frac{\sqrt{\varphi}}{\psi^{\frac{3}{4}}} \cdot \sqrt{\left(\frac{D_e}{D_i}\right)^2 - 1}$$

$$\varphi = \frac{Q}{u \cdot S}$$

$$\psi = \frac{\Delta h_{0is}}{\frac{u^2}{2}}$$

compressori



$$\omega_s = \frac{\sqrt{\varphi}}{\psi^{\frac{3}{4}}} \cdot \sqrt{\left(\frac{D_e}{D_i}\right)^2 - 1}$$

$$\varphi = \frac{Q}{u \cdot S}$$

$$\psi = \frac{\Delta h_{0is}}{\frac{u^2}{2}}$$

compressori assiali

Ipotesi:

- 1) Flusso adiabatico;
- 2) Stadio "normale" o "ripetuto" (tutti gli stadi con gli stessi profili):

$$\boxed{c_1 = c_3} \quad \rightarrow \quad \boxed{h_3 - h_1 = h_{03} - h_{01}}$$

- 3) Velocità assiale costante (coincide con la velocità mediana):

$$c_{m1} = c_{m2}$$

- 4) $\rho = \text{cost}$ (nello stadio)

compressori

nel rotore si conserva la rotalpia

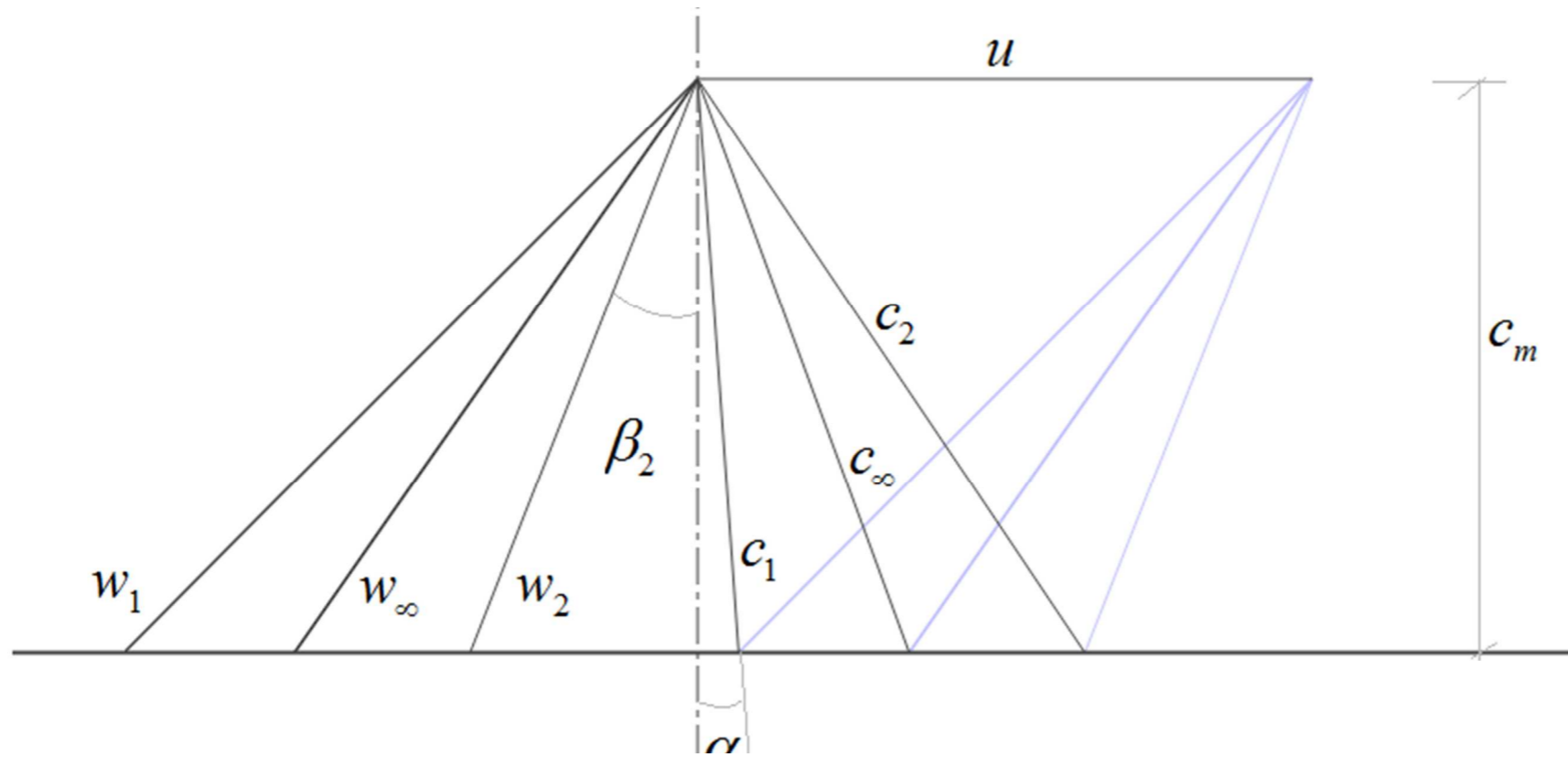
$$h_1 + \frac{1}{2} w_1^2 = h_2 + \frac{1}{2} w_2^2$$

nello statore si conserva l'entalpia

$$h_2 + \frac{1}{2} c_2^2 = h_3 + \frac{1}{2} c_3^2$$

$$\lambda = \frac{u c_{u2} - u c_{u1}}{u^2} = \frac{c_{u2} - c_{u1}}{u} \quad \text{lavoro scambiato}$$

compressori assiali



$$c_{u2} = u - w_{u2}$$

$$w_{u2} = c_m \operatorname{tg} \beta_2$$

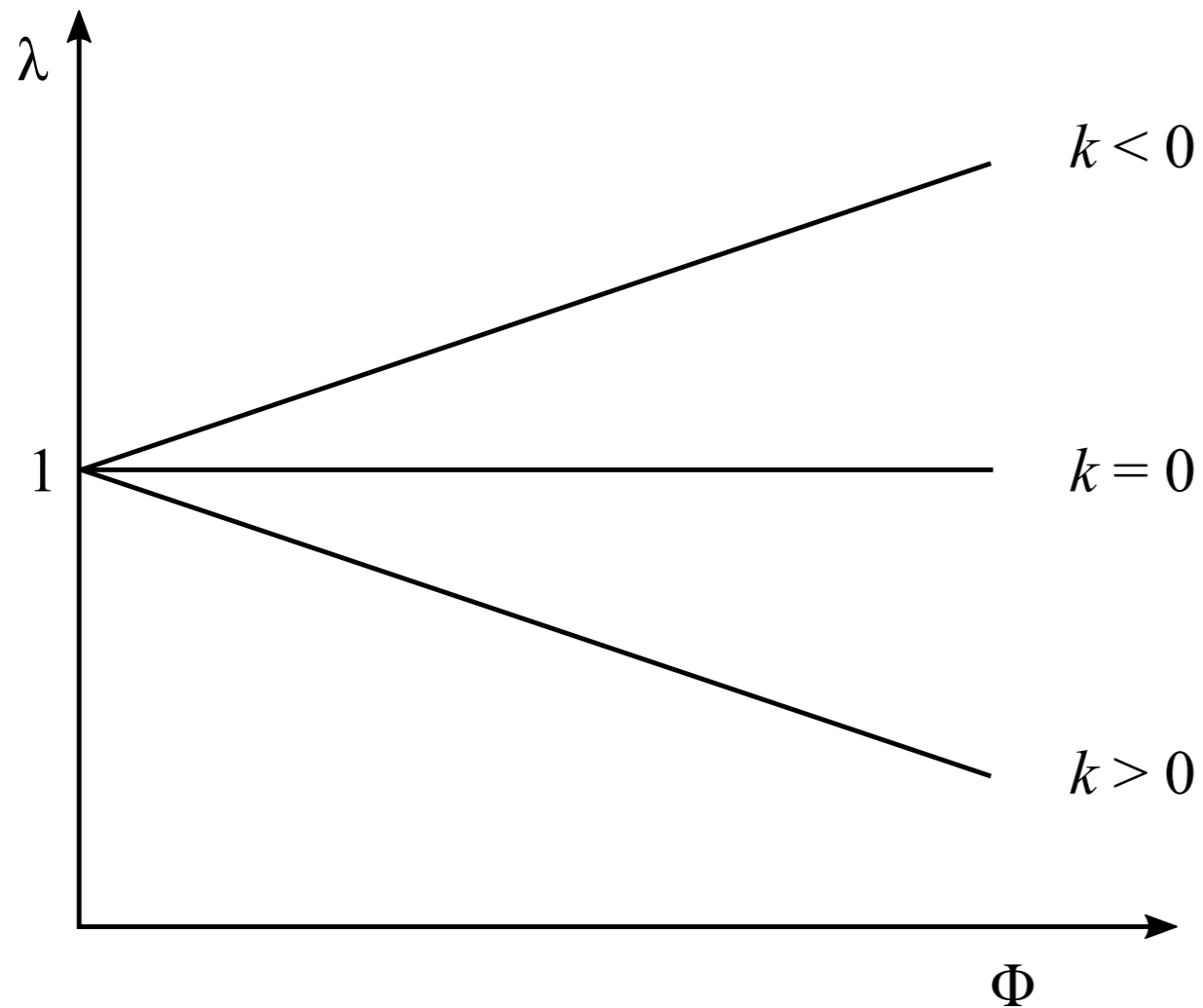
$$c_{u1} = c_m \operatorname{tg} \alpha_1$$

$$\lambda = 1 - \frac{w_{u2}}{u} - \frac{c_{u1}}{u} = 1 - \frac{c_m}{u} (\operatorname{tg} \beta_2 + \operatorname{tg} \alpha_1) \quad \text{def.} \quad \phi = \frac{c_m}{u}$$

$$\lambda = 1 - \phi (\operatorname{tg} \beta_2 + \operatorname{tg} \alpha_1) = 1 - k \cdot \phi$$

compressori assiali

def. condizioni di progetto:



$$\lambda_d = 1 - k \cdot \phi_d$$

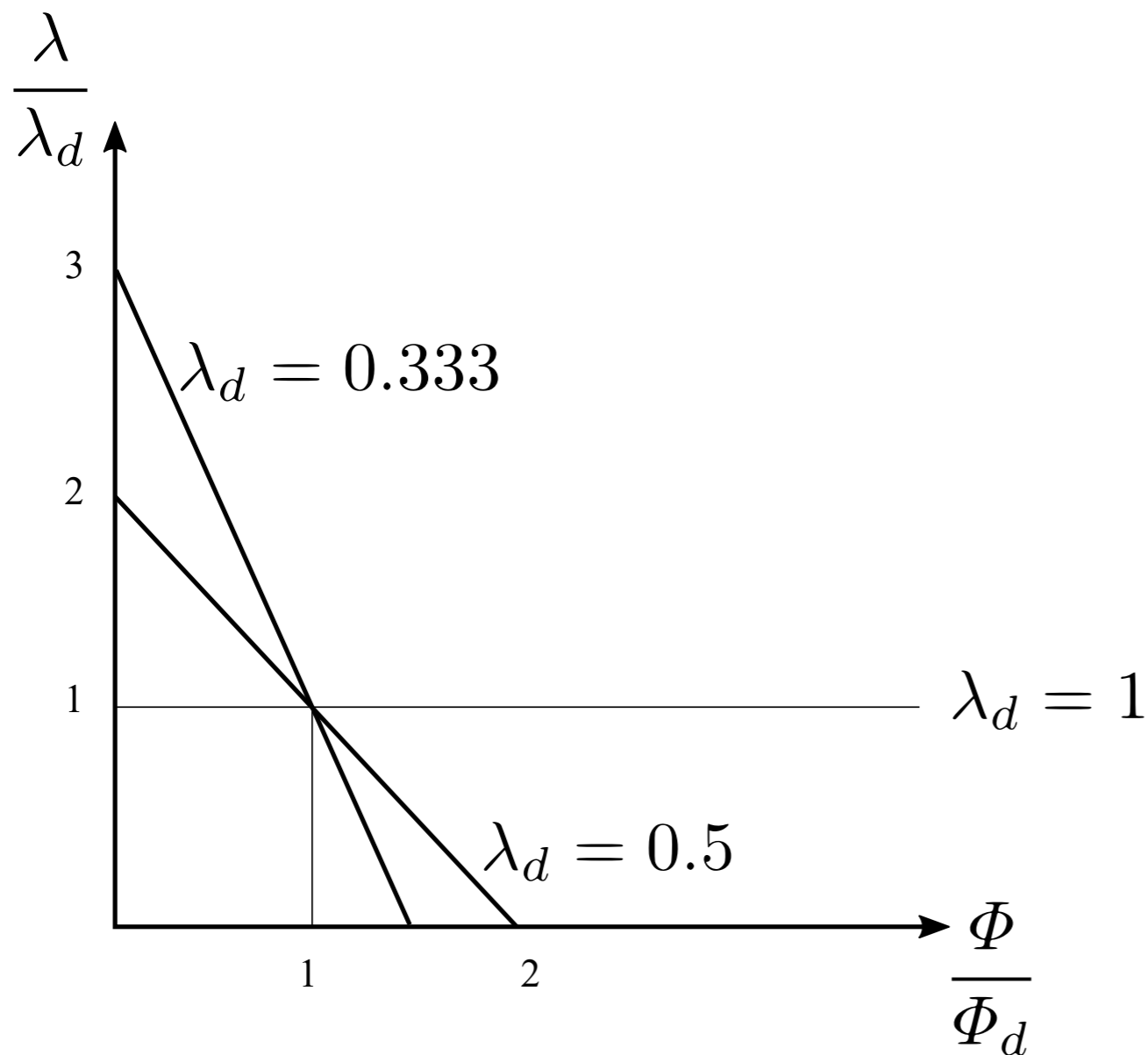
$$\rightarrow k = f(\lambda_d, \phi_d)$$

compressori assiali

def. condizioni di progetto:

$$\lambda_d = 1 - k \cdot \phi_d$$

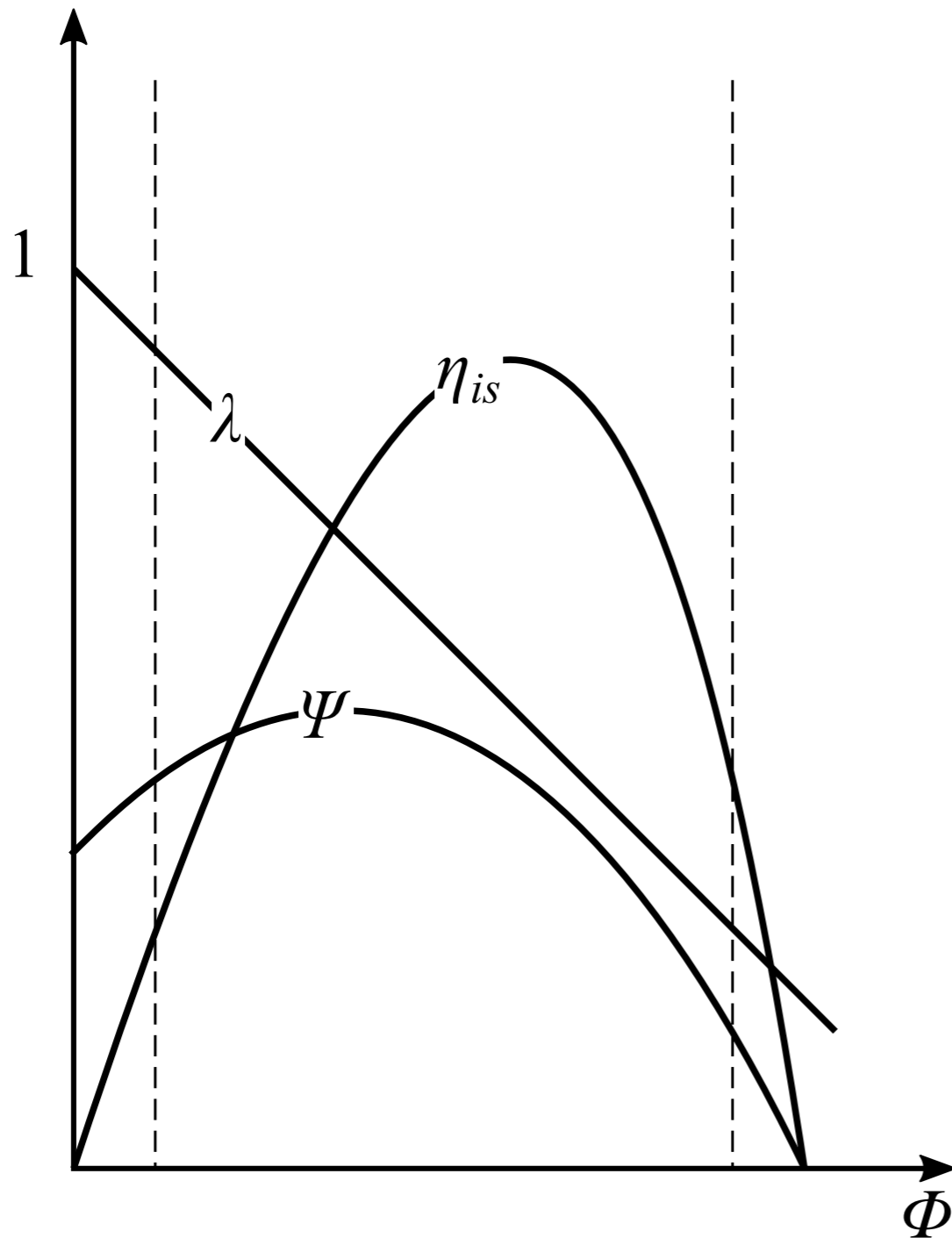
$$\rightarrow k = f(\lambda_d, \phi_d)$$



$$\frac{\lambda}{\lambda_d} = \frac{1}{\lambda_d} - \frac{\phi}{\phi_d} \left(\frac{1 - \lambda_d}{\lambda_d} \right)$$

$$0,3 < \lambda_d < 0,4$$

compressori assiali



caratteristica reale:

$$\psi = \frac{\Delta h_{0is}}{u^2} = \lambda \cdot \eta_{is}$$

$$\Delta h_{0is} = h_{3_{0ss}} - h_{1_0}$$

compressori assiali

la forma della palettatura dipende dal grado di reazione:

$$R = \frac{h_2 - h_1}{h_3 - h_1} \qquad R = \frac{w_1^2 - w_2^2}{2u(c_{u2} - c_{u1})} = \frac{(w_{u1} + w_{u2})(w_{u1} - w_{u2})}{2u(c_{u2} - c_{u1})}$$

$$\left. \begin{array}{l} c_{u2} = u - w_{u2} \\ c_{u1} = u - w_{u1} \end{array} \right\} \Rightarrow c_{u2} - c_{u1} = w_{u1} - w_{u2}$$

$$R = \frac{(w_{u1} + w_{u2}) \cancel{(w_{u1} - w_{u2})}}{2u \cancel{(c_{u2} - c_{u1})}} = \frac{(w_{u1} + w_{u2})}{2u} = \frac{c_m (\operatorname{tg} \beta_1 + \operatorname{tg} \beta_2)}{2u}$$

compressori assiali

$$\operatorname{tg} \beta_{\infty} = \frac{\operatorname{tg} \beta_1 + \operatorname{tg} \beta_2}{2}$$

$$\phi = \frac{c_m}{u}$$

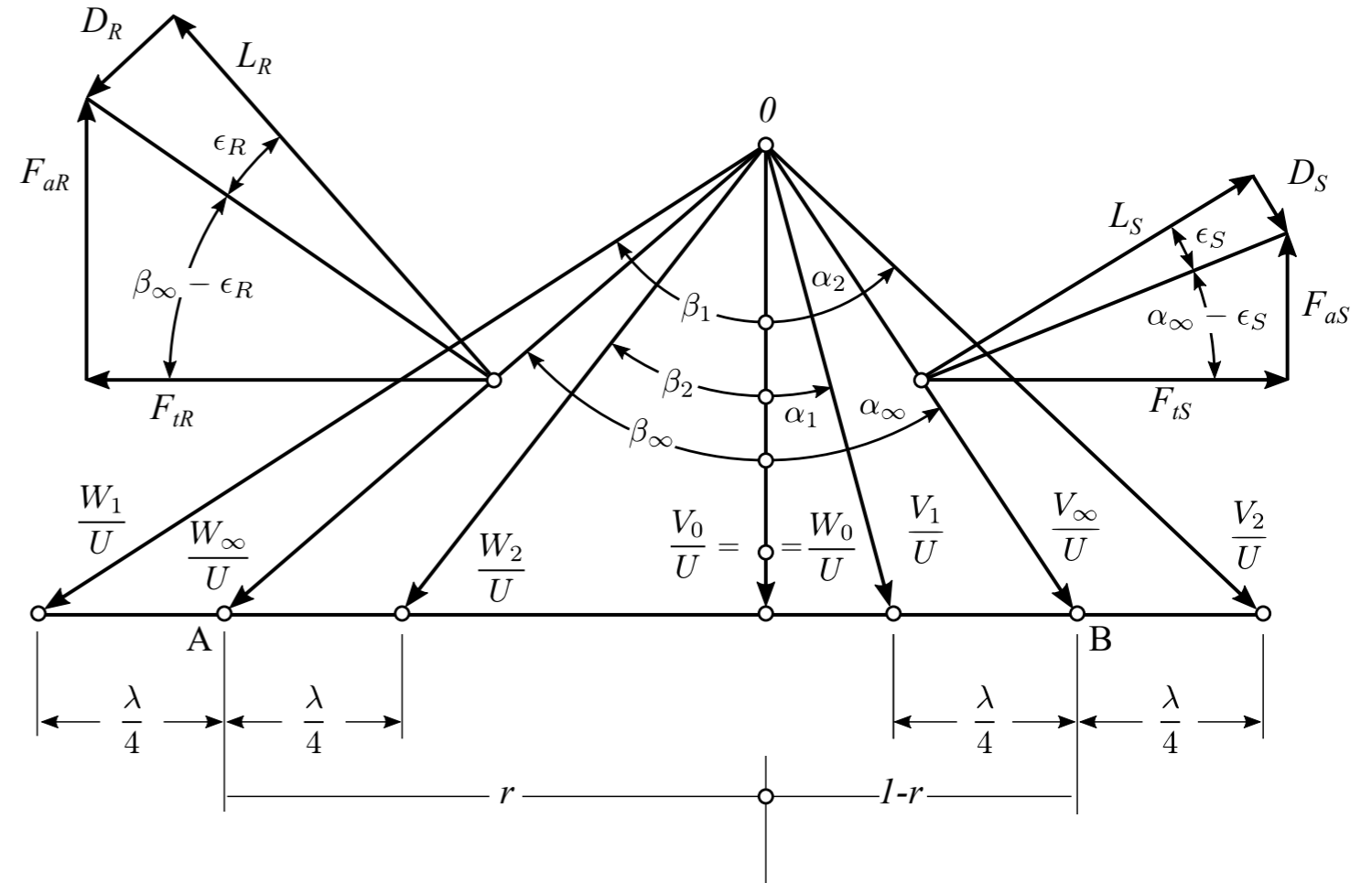
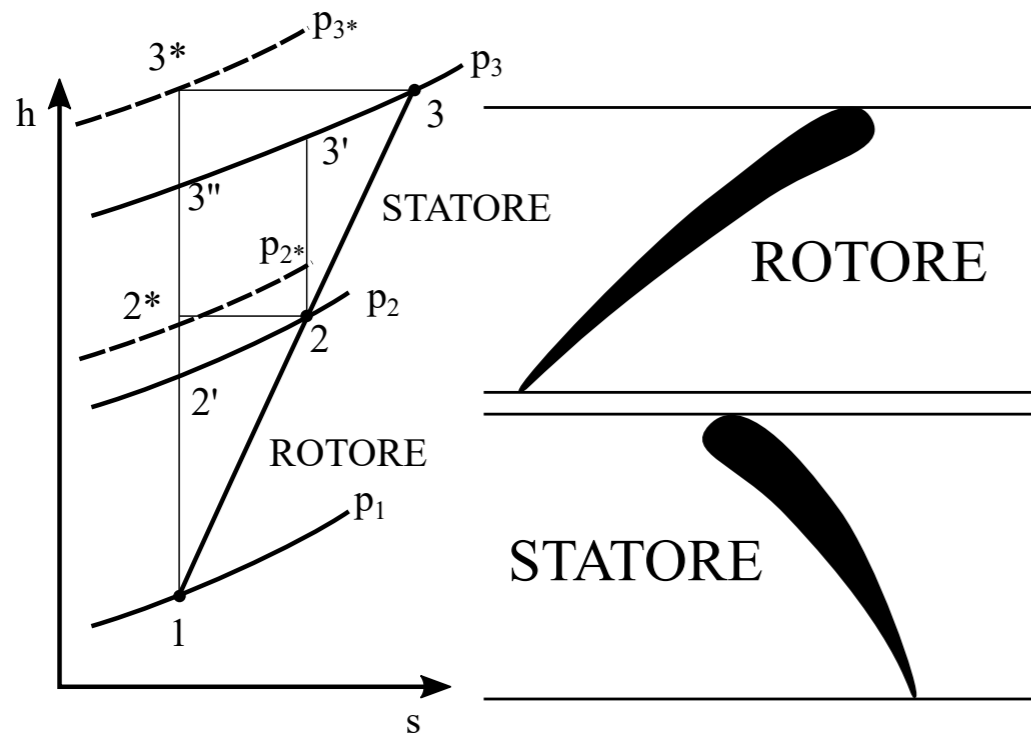
$$R = \phi \operatorname{tg} \beta_{\infty} = \frac{w_{u\infty}}{u}$$

$$w_{u1} = u - c_{u1}$$

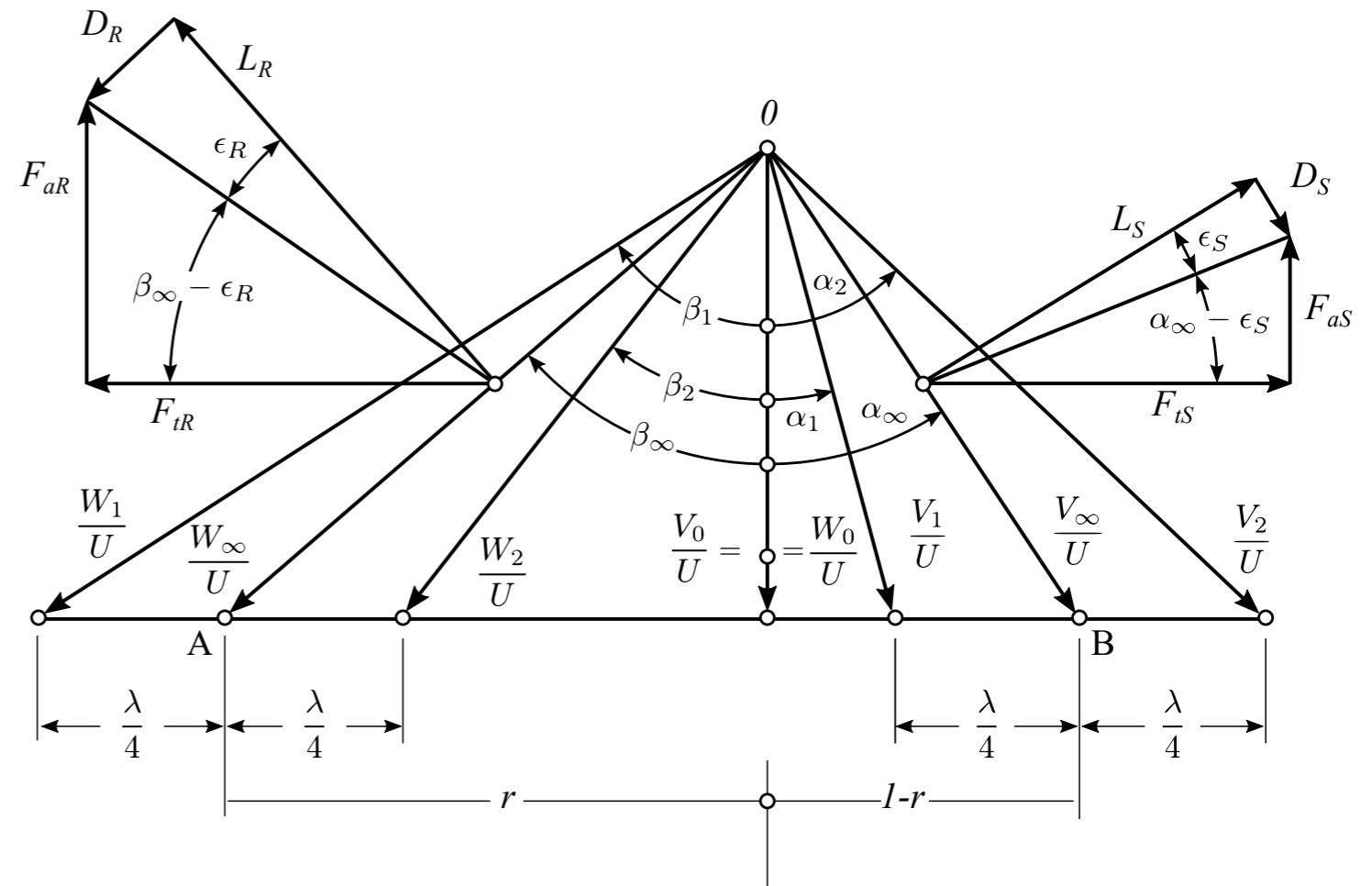
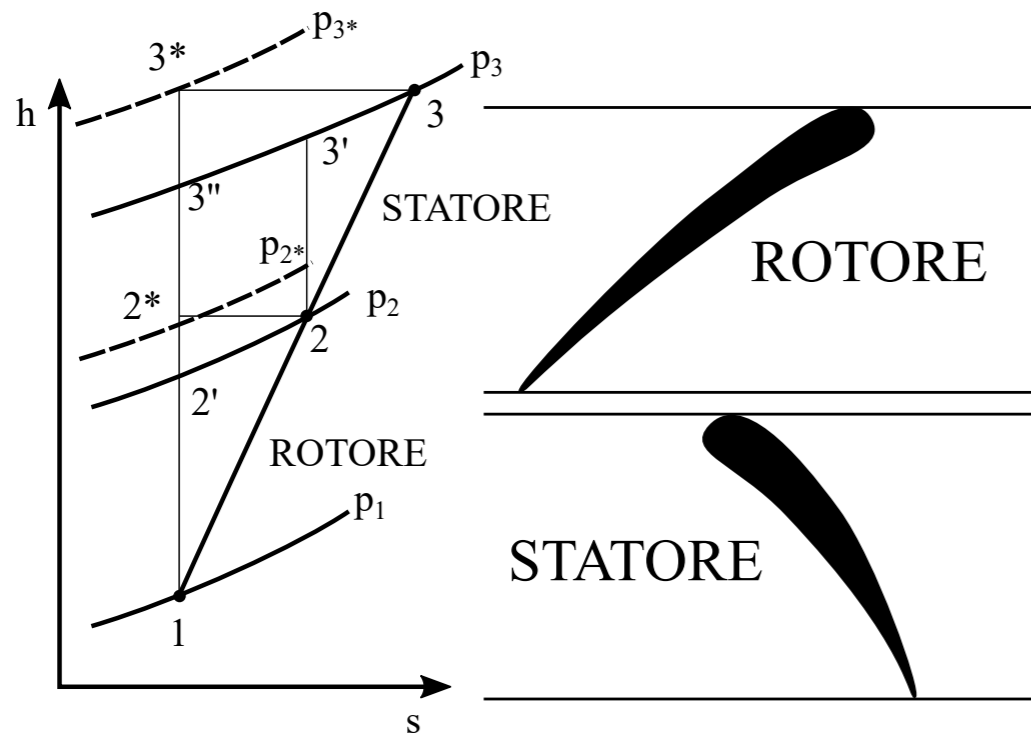
$$R = \frac{1}{2} + \frac{\operatorname{tg} \beta_2 - \operatorname{tg} \alpha_1}{2} \cdot \phi \simeq \frac{1}{2} + \operatorname{cost} \cdot \phi$$

compressori assiali, stadio

ripetuto



compressori assiali, stadio ripetuto



$$r \cdot \operatorname{tg} \beta_\infty = R$$

$$\lambda = \frac{\Delta h_0}{\frac{u^2}{2}} = \frac{u \Delta c_u}{\frac{u^2}{2}} = \frac{2 \Delta c_u}{u} = \frac{2 \Delta w_u}{u}$$

$$\frac{\Delta c_u}{u} = \frac{\Delta w_u}{u} = \frac{\lambda}{2}$$

compressori assiali, stadio ripetuto

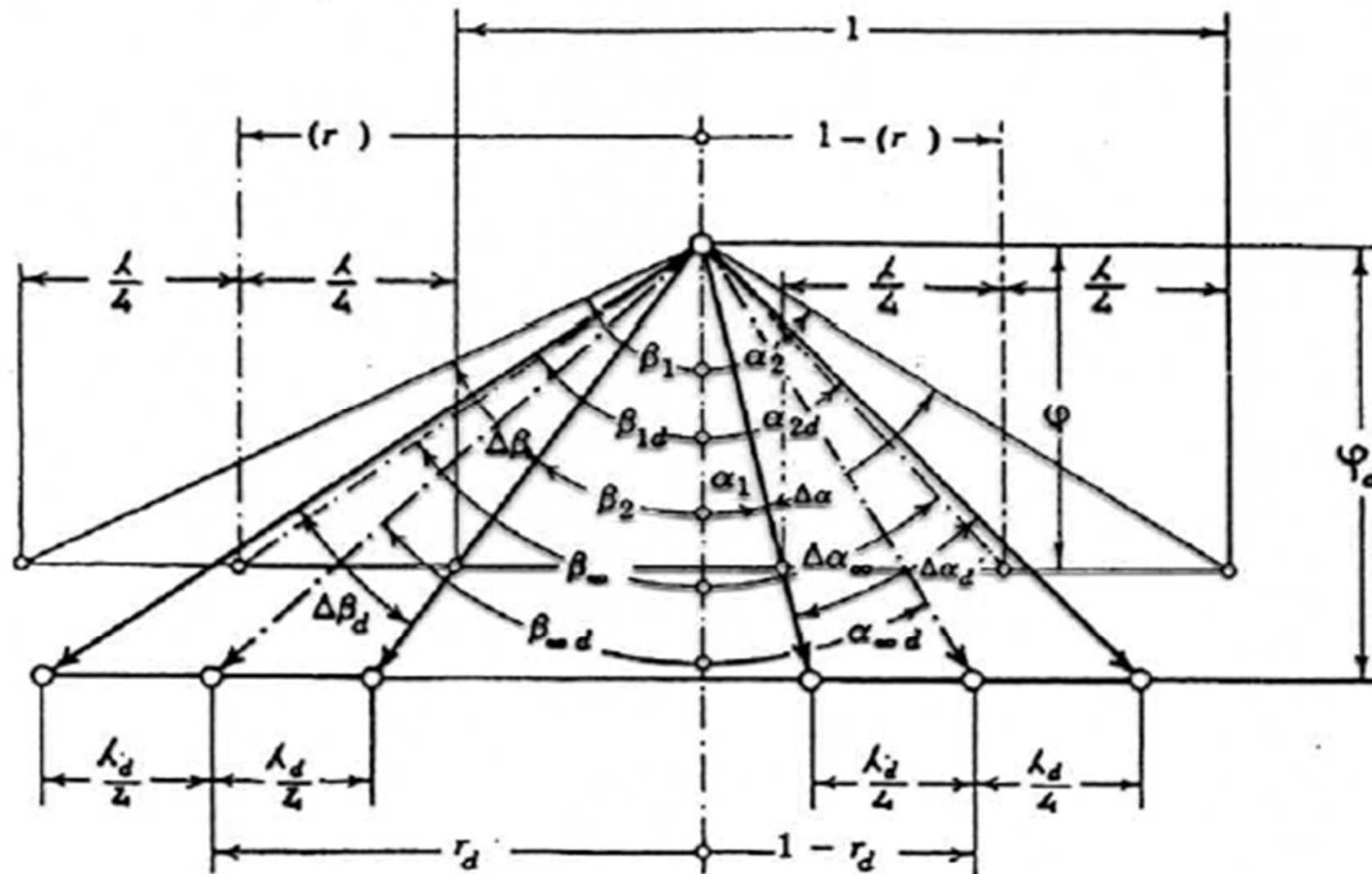
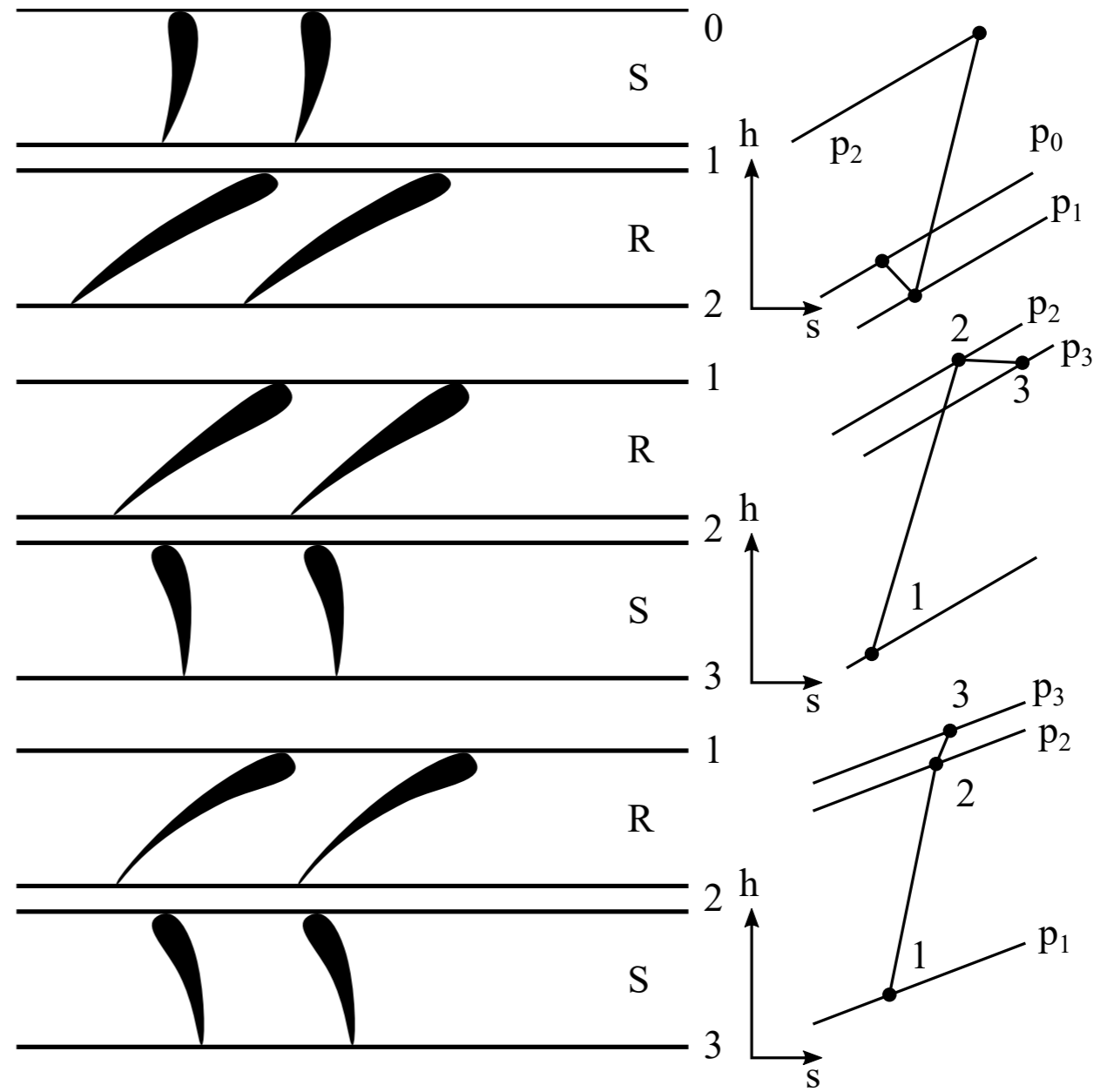
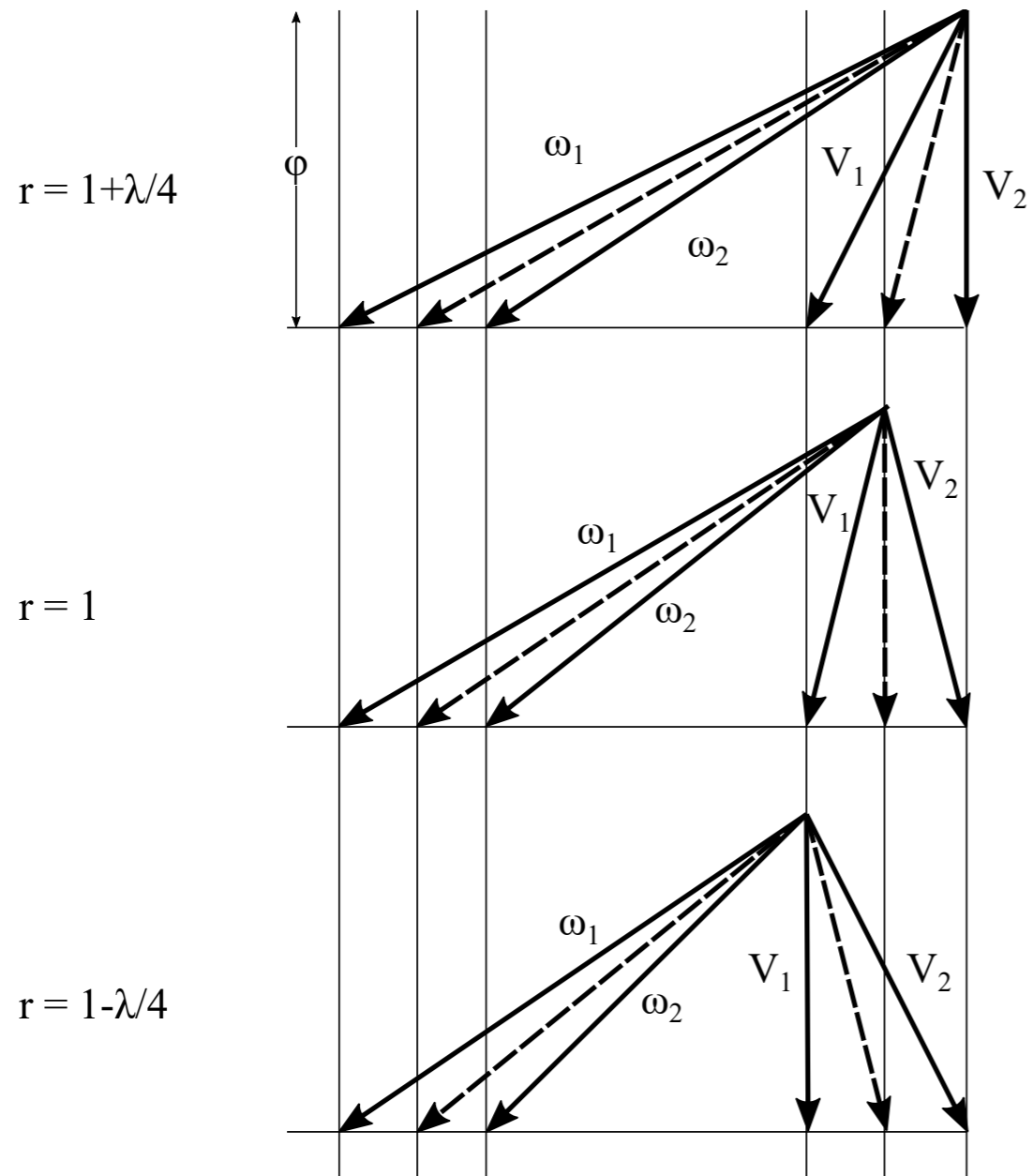
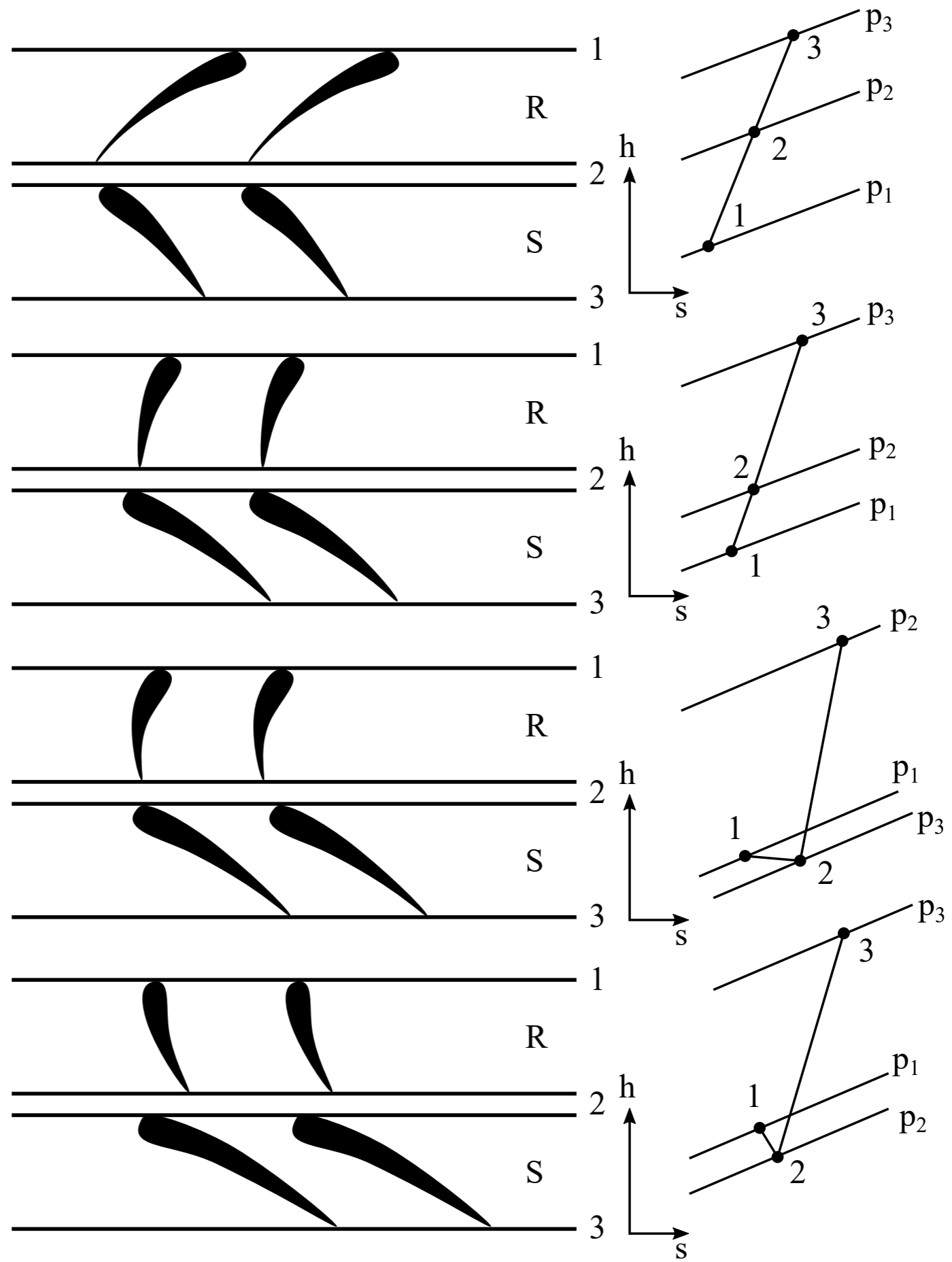
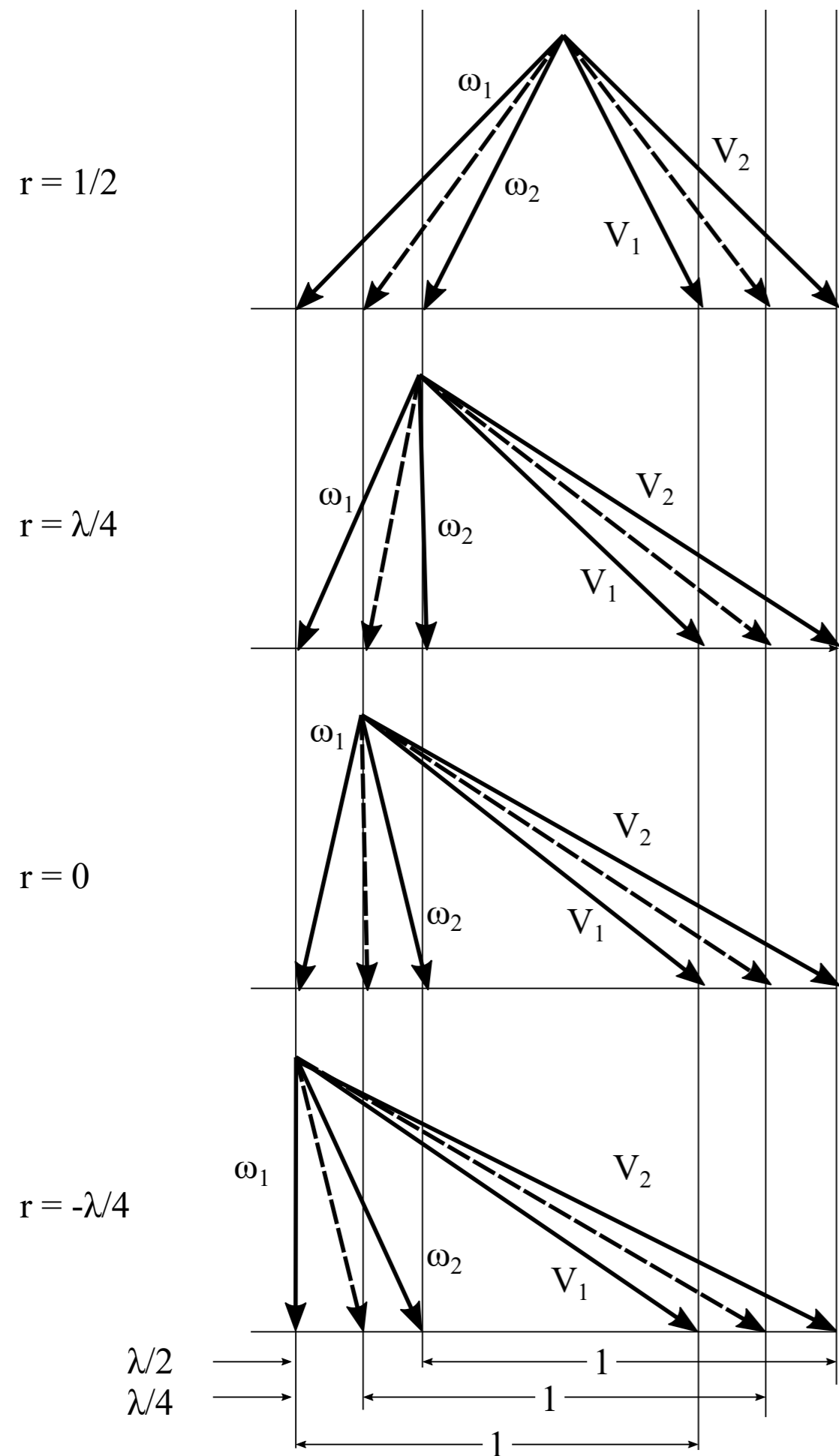


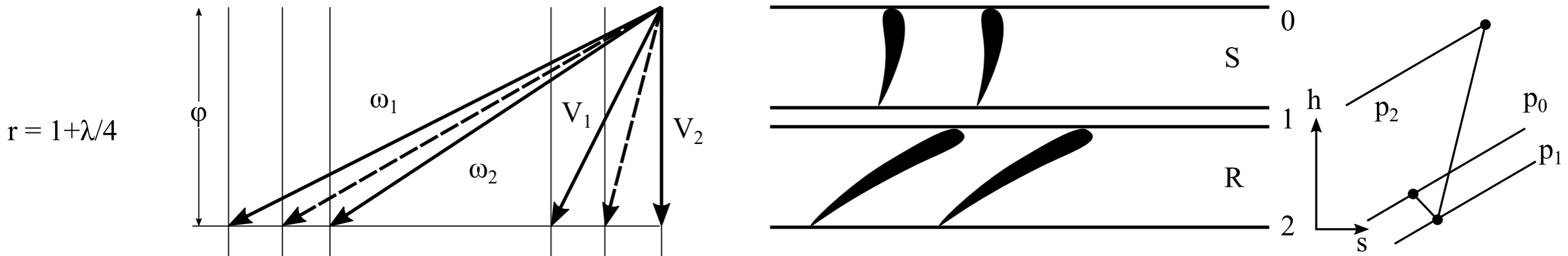
Figura 6.6: *Triangoli delle velocità per uno stadio di compressore assiale in condizioni fuori progetto, e triangoli in condizioni di progetto (indice "d").*

compressori assiali





- $r = 1 + \frac{\lambda}{4}$ compressori assiali



ingresso con $V_t = 0$

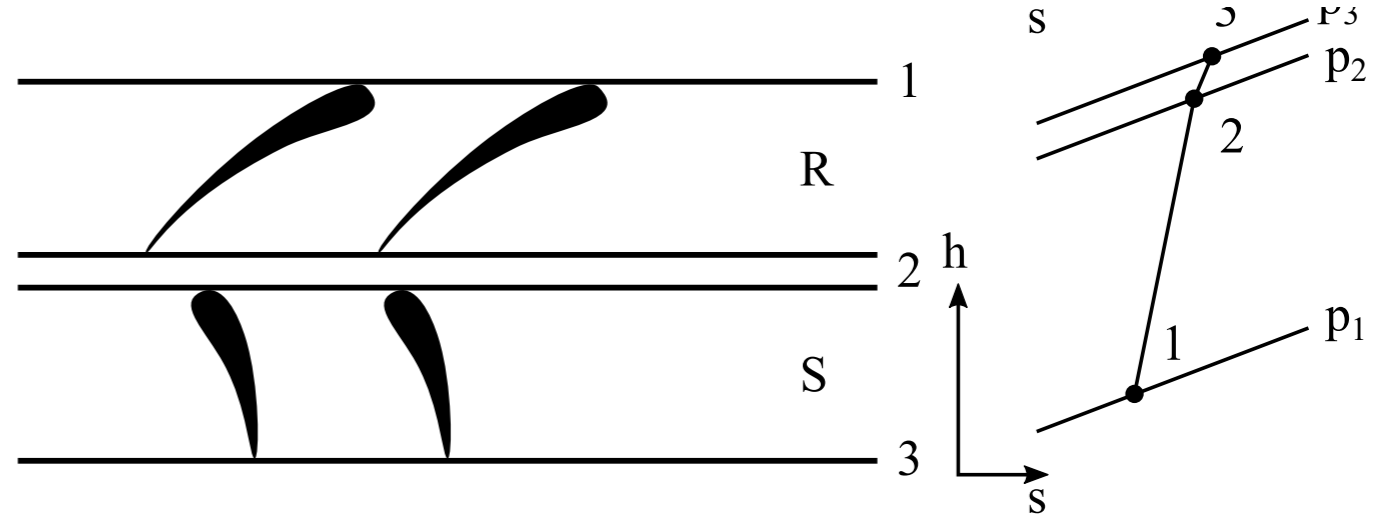
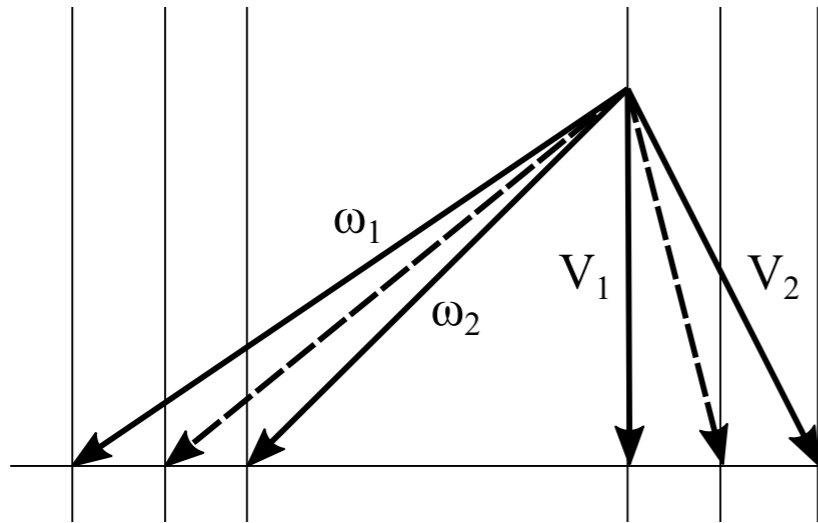
Uscita con $V_t = 0$

Non serve IGV, si inizia con lo statore

Non serve raddrizzatore allo scarico

compressori assiali

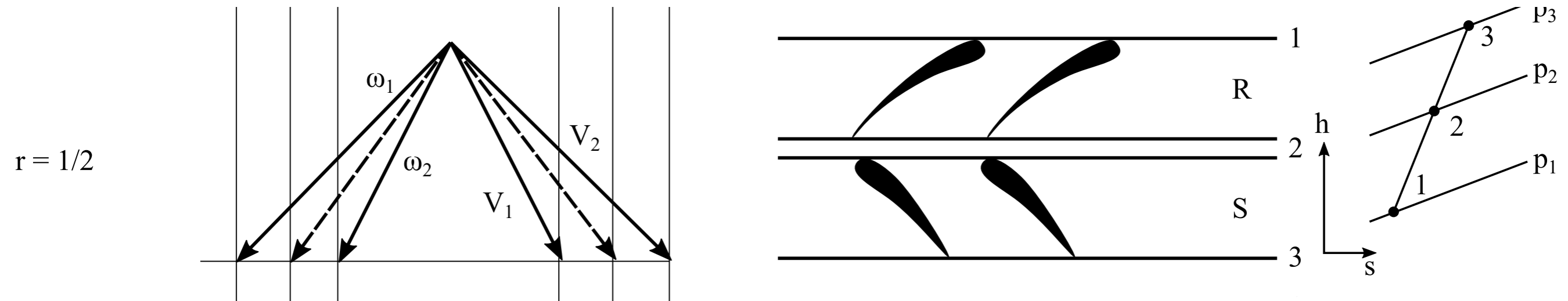
$$r = 1 - \lambda/4$$



ingresso con $V_t = 0$
Uscita con $V_t = 0$

Non serve IGV

compressori assiali



Triangoli di velocità simmetrici,
stessa palettatura rotorica e statorica

rendimento al variare della portata e
grado di reazione

$$\eta_{is} = \frac{\Delta h_{is}}{\Delta h_0}$$

$$\eta_{is} = \frac{\Delta p}{\rho \cdot \Delta h_0}$$

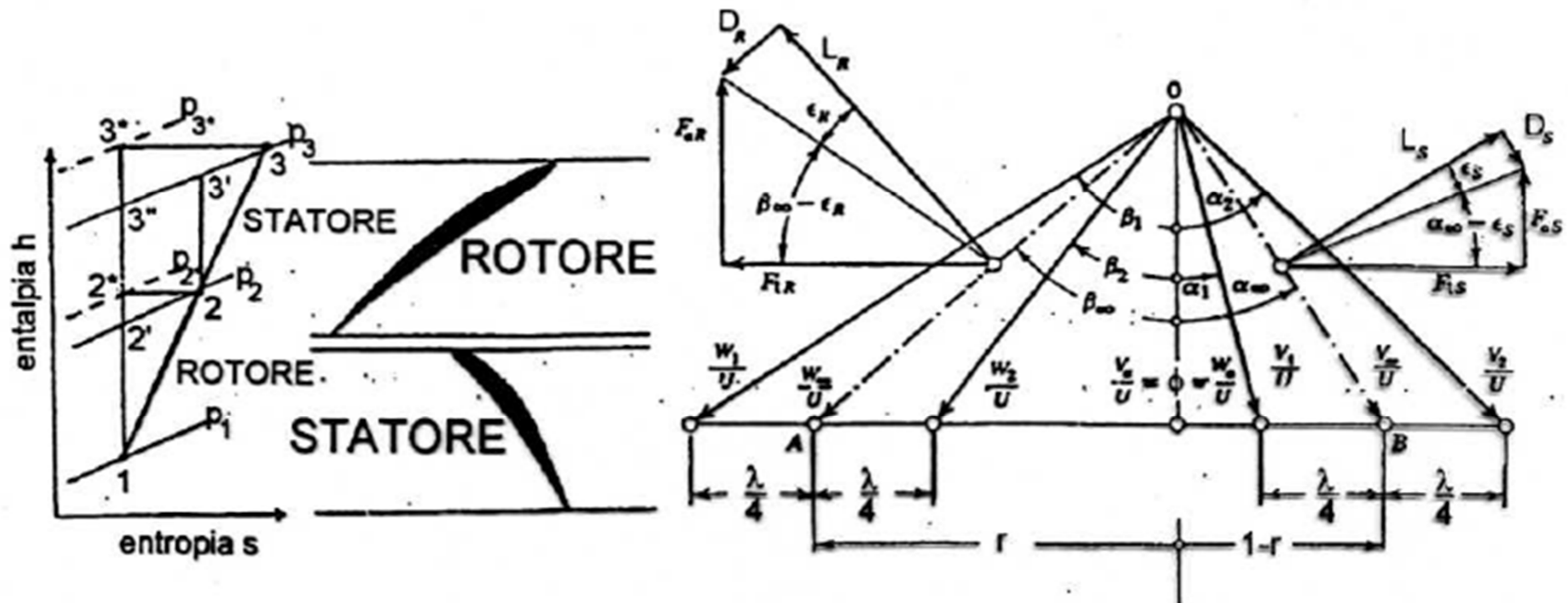
$$Tds = dh - \frac{dp}{\rho} \quad 1^\circ \text{ Principio}$$

$$ds = 0 \quad \rightarrow \quad dh = \frac{dp}{\rho}$$

$$\eta_{is} = \frac{\Delta p}{\rho \cdot \Delta h_0} = \frac{\Delta p}{\rho \cdot \frac{\lambda}{2} u^2}$$

rendimento al variare della portata e grado di reazione

$$\Delta p = \Delta p_R + \Delta p_S = \frac{F_{aR}}{S_R} + \frac{F_{aS}}{S_S} \quad \text{Incremento di pressione totale}$$



$$\Delta p = \frac{F_{aR}}{S_R} + \frac{F_{aS}}{S_S} = \frac{F_{tR} \cdot \operatorname{tg}(\beta_\infty - \epsilon_R)}{S_R} + \frac{F_{tS} \cdot \operatorname{tg}(\alpha_\infty - \epsilon_S)}{S_S}$$

rendimento al variare della portata e
grado di reazione

$$\operatorname{tg} \varepsilon_R \simeq \varepsilon_R = \frac{D_R}{L_R} \qquad \operatorname{tg} \varepsilon_S \simeq \varepsilon_S = \frac{D_S}{L_S}$$

$$F_{tR} = \dot{m} \Delta w_u = \underbrace{s_R \cdot \rho \cdot c_m}_{\dot{m}} \cdot \underbrace{\lambda \cdot u \cdot \frac{1}{2}}_{\Delta w_u} \qquad \phi = \frac{c_m}{u} \quad \rightarrow \quad c_m = \phi \cdot u$$

$$F_{tR} = s_R \cdot \rho \cdot \lambda \cdot \phi \cdot u^2 \cdot \frac{1}{2} \qquad F_{tS} = \dot{m} \cdot \Delta c_m = s_S \cdot \rho \cdot \lambda \cdot \phi \cdot u^2 \cdot \frac{1}{2}$$

rendimento al variare della portata e grado di reazione

$$\Delta p = \frac{1}{2} \rho \lambda u^2 \left[\phi \operatorname{tg}(\beta_\infty - \varepsilon_R) + \phi \operatorname{tg}(\alpha_\infty - \varepsilon_S) \right]$$

Ricordiamo

- $R = \phi \operatorname{tg} \beta_\infty$
- $1 - R = \phi \operatorname{tg} \alpha_\infty$
- $\operatorname{tg}(\beta_\infty - \varepsilon_R) = \frac{\operatorname{tg} \beta_\infty - \operatorname{tg} \varepsilon_R}{1 + \operatorname{tg} \beta_\infty \operatorname{tg} \varepsilon_R} \approx \frac{\operatorname{tg} \beta_\infty - \varepsilon_R}{1 + \operatorname{tg} \beta_\infty \cdot \varepsilon_R}$
- $\operatorname{tg}(\alpha_\infty - \varepsilon_S) \approx \frac{\operatorname{tg} \alpha_\infty - \varepsilon_S}{1 + \operatorname{tg} \alpha_\infty \cdot \varepsilon_S}$

$$\Delta p = \frac{1}{2} \rho \lambda u^2 \left[\frac{R - \varepsilon_R \phi}{\phi + \varepsilon_R R} + \frac{1 - R - \varepsilon_S \phi}{\phi + \varepsilon_S (1 - R)} \right] \cdot \phi$$

rendimento al variare della portata e
grado di reazione

$$\eta_{is} = \left[\frac{R - \varepsilon_R \phi}{\phi + \varepsilon_R R} + \frac{1 - R - \varepsilon_S \phi}{\phi + \varepsilon_S (1 - R)} \right] \cdot \phi$$

ottimizzazione dello stadio

$$\eta_{is} = \left[\frac{R - \varepsilon_R \phi}{\phi + \varepsilon_R R} + \frac{1 - R - \varepsilon_S \phi}{\phi + \varepsilon_S (1 - R)} \right] \cdot \phi$$

$$\varepsilon_S \simeq \varepsilon_R = \cos t = \varepsilon$$

$$\frac{d\eta_{is}}{dR} = 0 \quad \rightarrow \quad R_{opt} = 0,5 \quad \text{per } \forall \phi$$

$$\eta_{(R=0,5)} = 2\phi \cdot \frac{1 - 2\varepsilon\phi}{\varepsilon + 2\phi}$$

ottimizzazione dello stadio

$$\eta_{is} = \left[\frac{R - \varepsilon_R \phi}{\phi + \varepsilon_R R} + \frac{1 - R - \varepsilon_S \phi}{\phi + \varepsilon_S (1 - R)} \right] \cdot \phi \quad \eta_{(R=0,5)} = 2\phi \cdot \frac{1 - 2\varepsilon\phi}{\varepsilon + 2\phi}$$

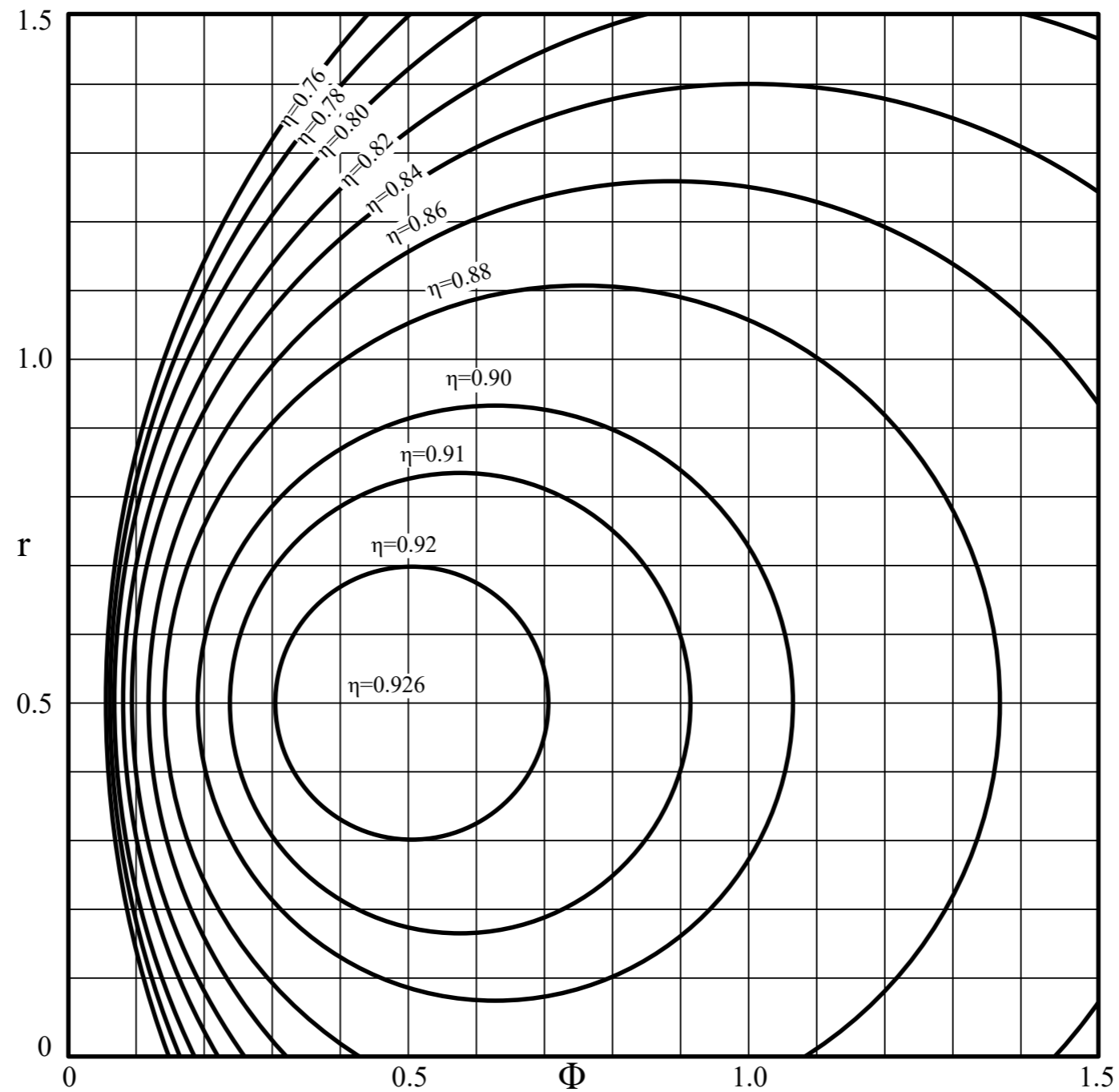
$$\varepsilon_S \simeq \varepsilon_R = \text{cost} = \varepsilon$$

$$R = R_{opt} = 0,5$$

$$\frac{d\eta_{(R=0,5)}}{d\phi} = 0 \quad \rightarrow \quad \phi_{opt} = \frac{1}{2} \left(\sqrt{1 + \varepsilon^2} - \varepsilon \right) \simeq \frac{1 - \varepsilon}{2}$$

$$\eta_{\max} = 1 + 2\varepsilon^2 - 2\varepsilon\sqrt{1 + \varepsilon^2} \simeq 1 - 2\varepsilon(1 - \varepsilon)$$

ottimizzazione dello stadio



Curve isorendimento di uno stadio assiale in funzione del grado di reazione e coeff. di portata per efficienza del profilo assegnata (0.04)