3.3. Thrust affecting rotor blades

A. Thrust generation mechanism

- Real component (due to gas flow turn)

- Reactive component (due to flow acceleration)

Consequences:

$\rho = 0$ (pure reaction stage) → No acceleration (convergence is equal to 1).

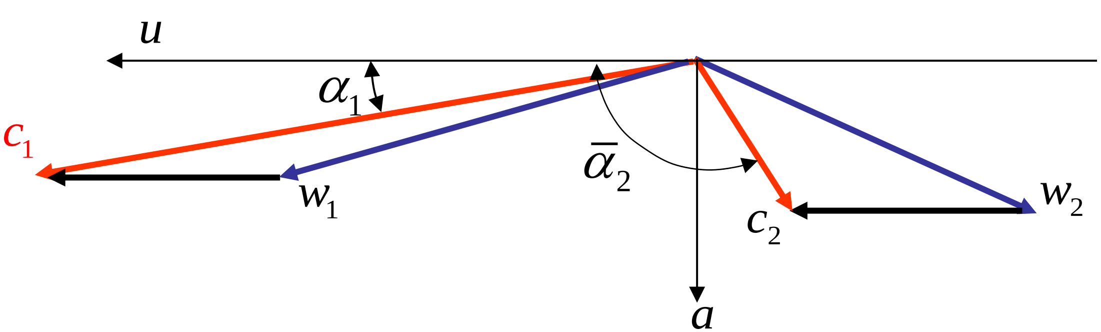
$\beta_2 = \beta_1$

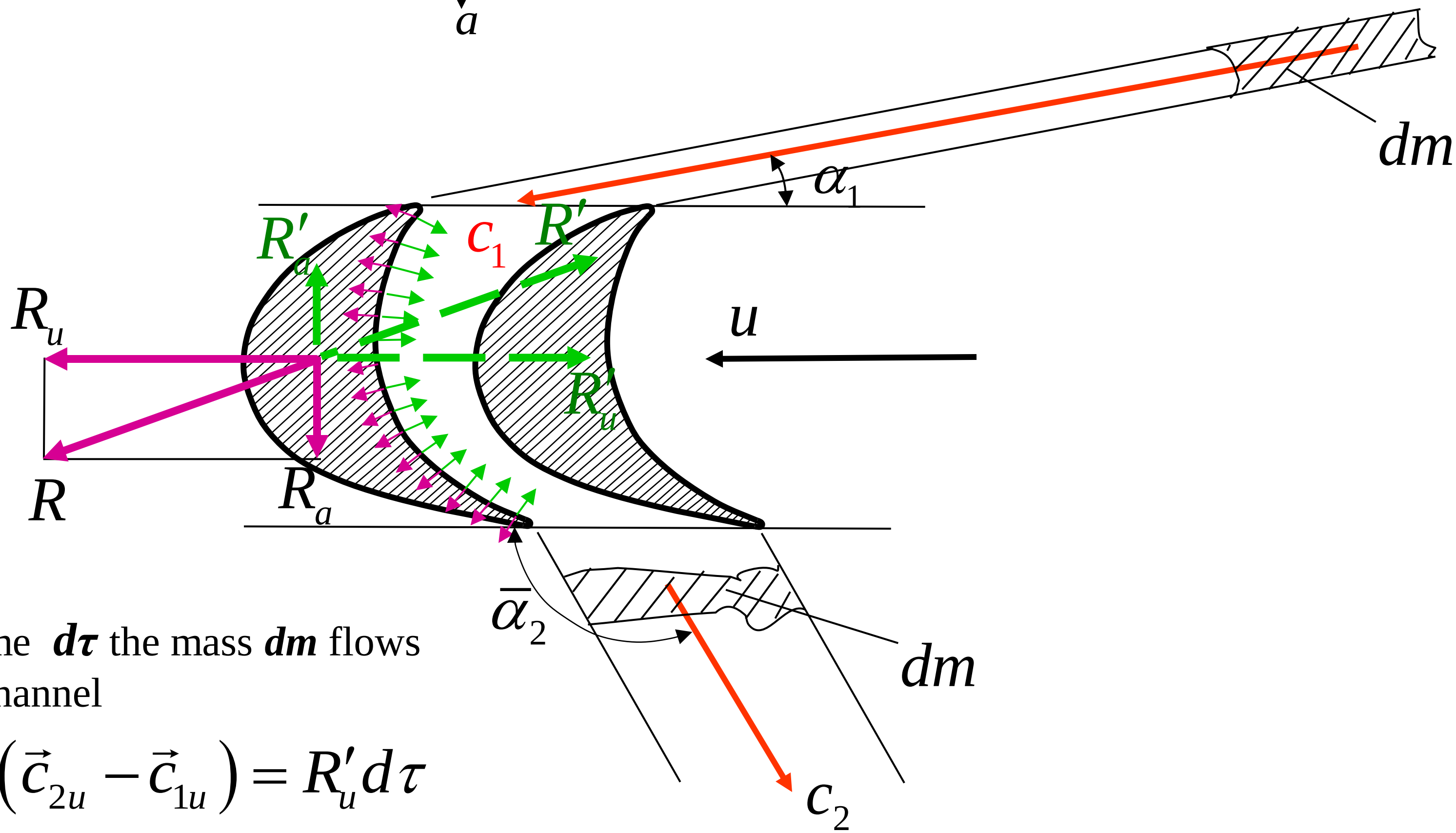
$\rho > 0$ → The flow across rotor blades is accelerated (convergence is greater than1).

$\beta_2 < \beta_1$

Conclusion: the angle chosen for the flow leaving rotor blades depends on stage reactivity

Б. Determination of thrust acting on the rotor blades by the equation of momentum





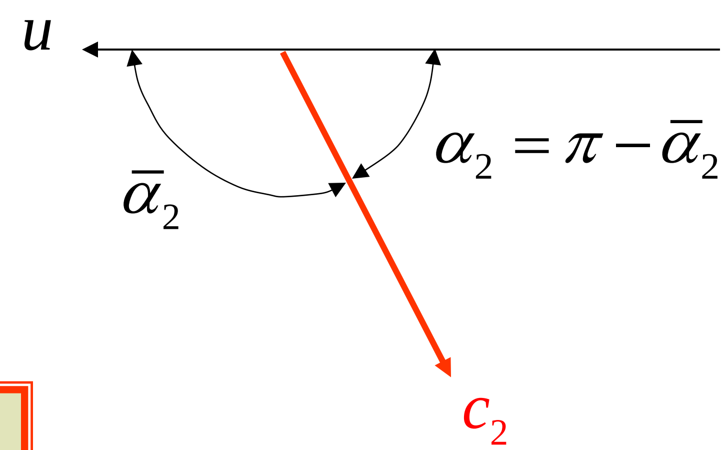
Within the time ***dτ*** the mass ***dm*** flows through the channel

$$dm\left(\vec{c}_{2u} - \vec{c}_{1u}\right) = R'_u d\tau$$

$$R'_u = \frac{dm}{d\tau}\left(c_2 \cos\bar{\alpha}_2 - c_1 \cos\alpha_1\right)$$

$$\frac{dm}{d\tau} = G\left[{}^{кг}\!/_{с}\right]$$

Circumferential thrust :

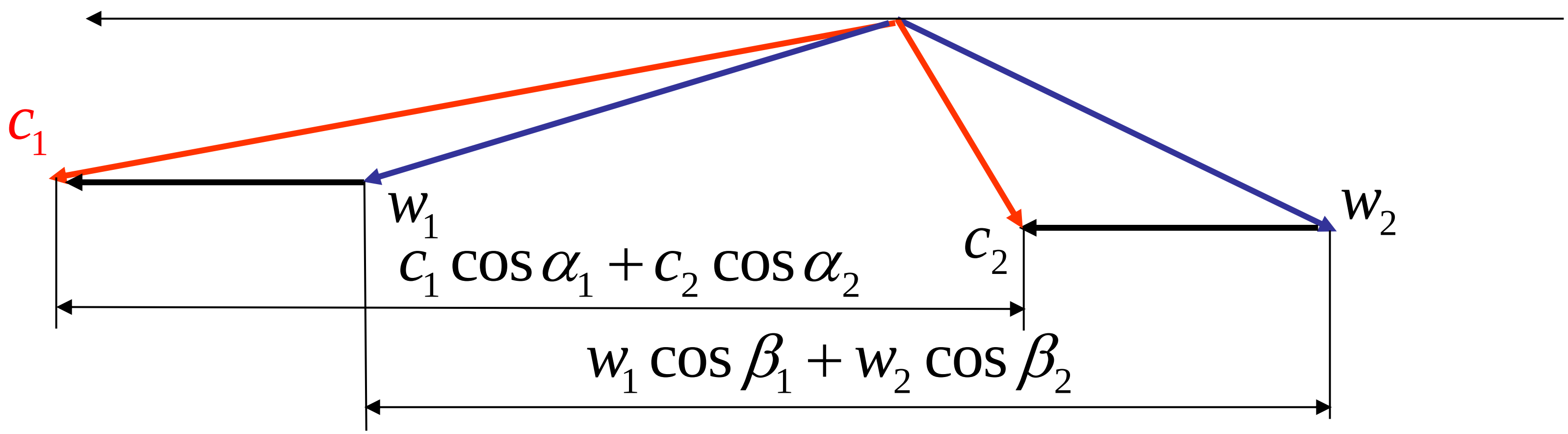


$$R_u = -R_u' = G\left(c_1 \cos\alpha_1 - c_2 \cos\bar{\alpha}_2\right)$$

$$\cos\bar{\alpha}_2 = \cos\left(\pi - \alpha_2\right) = -\cos\alpha_2$$

$$R_u = G\left(c_1 \cos\alpha_1 + c_2 \cos\alpha_2\right)$$

$$R_u = G\left(w_1 \cos\beta_1 + w_2 \cos\beta_2\right)$$



Axial thrust:

$$R_a = G\left(c_1 \sin\alpha_1 - c_2 \sin\alpha_2\right) + \Omega\left(p_1 - p_2\right) =$$
$$= G\left(w_1 \sin\beta_1 - w_2 \sin\beta_2\right) + \Omega\left(p_1 - p_2\right)$$

where $\Omega = \pi d l$ - rotor blade-swept area

Full thrust of the steam, which acts on rotor blades

$$R = \sqrt{R_u^2 + R_a^2}$$

Thrust affecting one blade:

$$r = \frac{R}{z}$$

where z **-**is the number of blades

3.4. Work (power) produced by the blades of a turbine stage (according to the equation of momentum)

Typically it is work produced per minute – **power**

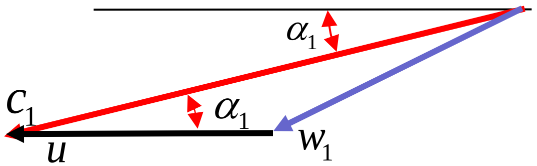
Stage power: $N_u = R_u u$

Work (power) transferred to blades by 1 kg of gas

$$L_u = N_u / G = u\left(c_1 \cos\alpha_1 + c_2 \cos\alpha_2\right) = u\left(w_1 \cos\beta_1 + w_2 \cos\beta_2\right)$$

For inlet velocity diagram

$$w_1^2 = c_1^2 + u^2 - 2uc_1 \cos\alpha_1 \quad \Rightarrow c_1 \cos\alpha_1 = \frac{c_1^2 + u^2 - w_1^2}{2u}$$

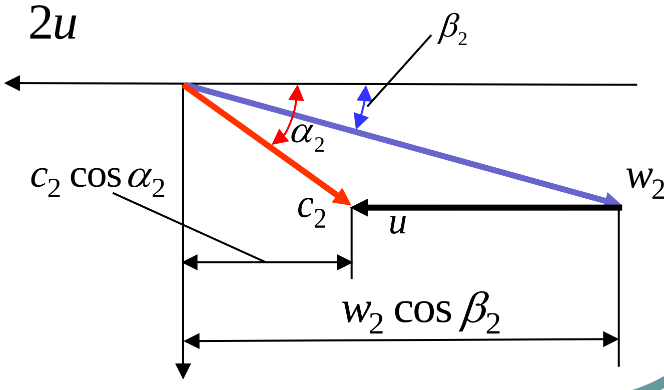


For outlet velocity diagram

$$c_2^2 = w_2^2 + u^2 - 2uw_2 \cos\beta_2 \qquad c_2 \cos\alpha_2 = \frac{w_2^2 - u^2 - c_2^2}{2u}$$

$$w_2 \cos\beta_2 = c_2 \cos\alpha_2 + u$$

$$c_2^2 = w_2^2 - u^2 - 2uc_2 \cos\alpha_2$$



$$L_u = \frac{c_1^2 - c_2^2 + w_2^2 - w_1^2}{2}$$

Trigonometric ratios for an oblique-angled triangle:

For inlet velocity diagram:

$$w_1^2 = c_1^2 + u^2 - 2uc_1 \cos\alpha_1$$

$$\beta_1 = arctg\left(\frac{\sin\alpha_1}{\cos\alpha_1 - \frac{u}{c_1}}\right)$$

For outlet velocity diagram:

$$c_2^2 = w_2^2 + u^2 - 2uw_2 \cos\beta_2$$

$$\alpha_2 = arctg\left(\frac{\sin\beta_2}{\cos\beta_2 - \frac{u}{w_2}}\right)$$

Power generated by centrifugal motion

$$L_u = {N_u}/{G} = u\left(c_1 \cos\alpha_1 + c_2 \cos\alpha_2\right) = u\left(w_1 \cos\beta_1 + w_2 \cos\beta_2\right)$$

$$N_u = uG\left(c_1 \cos\alpha_1 + c_2 \cos\alpha_2\right) = uR_u = \pi dnR_u = 2\pi rnR_u$$

$\omega = 2\pi n$ **- angular velocity of rotation**

$M_u = rR_u$ **- torque generated by the steam for rotor blades**

$$N_u = \omega M_u$$