AXIAL FLOW TURBOMACHINERY

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1.1. Classification

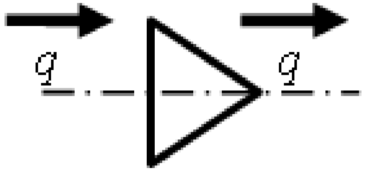
Gas
(Liquid)
(Multiphase)

Power input
(Power output)

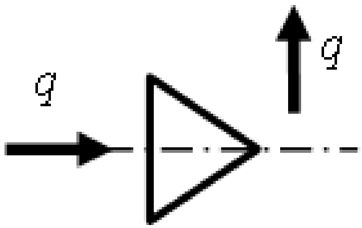
Principle:
Euler principle: TURBOMACHINERY
(Volumetric principle)

1.2. Classification of turbomachinery

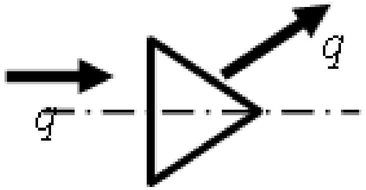
Flow direction:



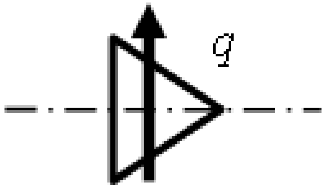
axial



(radial)



(mixed)



(cross-flow)

Pressure increase, <u>pressure ratio:</u>

p_2/p_1 pressure ratio

A/ $p2/p1 < 1.1\ (1.2)$ fans

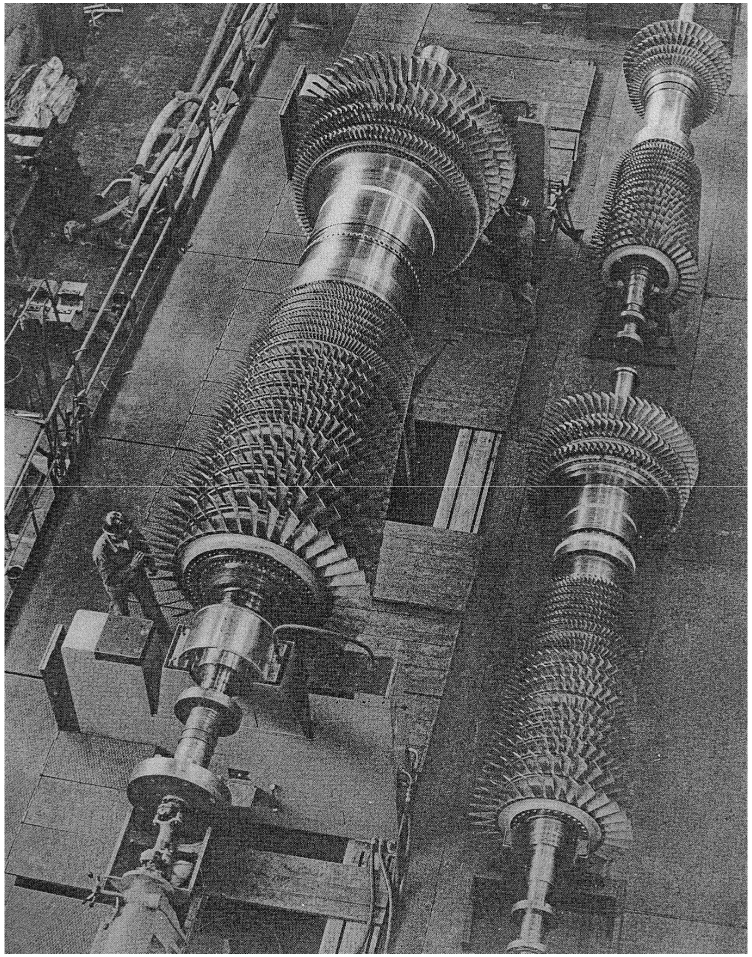
$\rho \approx$ constant, $\Delta T \approx 0$

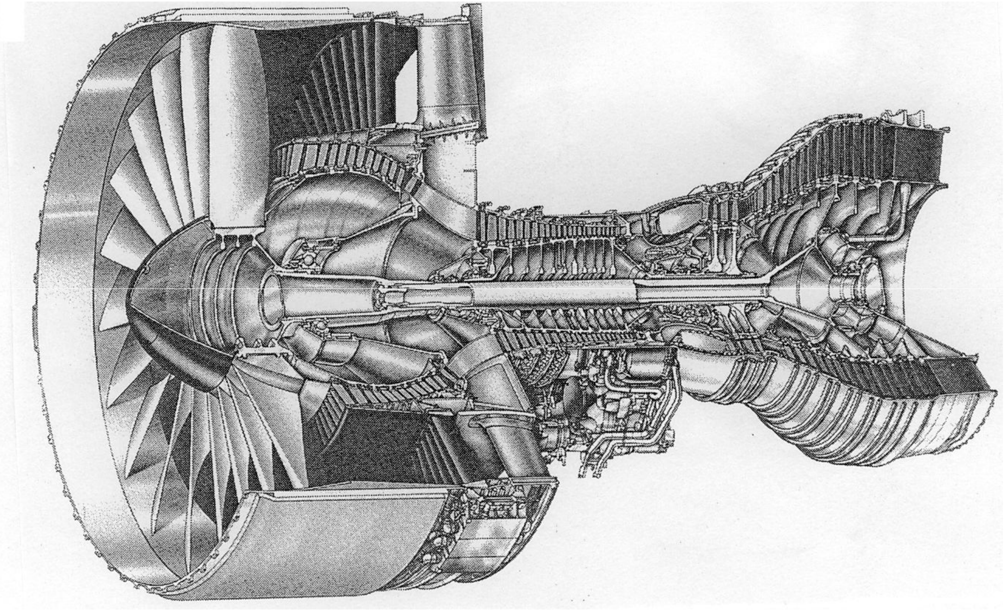
B/ $1.1 < p2/p1 < 3$ blowers

$\rho \neq$ const, $\Delta T > 0$, natural cooling

C/ $3 < p2/p1$ compressors

$\rho \neq$ const, $\Delta T >> 0$, artificial cooling.





FANS:

- Isentropic approach: $p_2/p_1 = (\rho_2/\rho_1)^{\chi}$

$$\frac{\rho_T}{\rho_S} = \left(\frac{T_T}{T_S}\right)^{\frac{1}{\kappa - 1}}$$

- If $p_2/p_1 = 1.1$, $\rho_2/\rho_1 = 1.07$
- Even more strict condition $\left|\rho_T - \rho_S\right| \leq 0.05\rho_S$
- Energy equation between S of suction side point and T of stagnation point of nose cone:

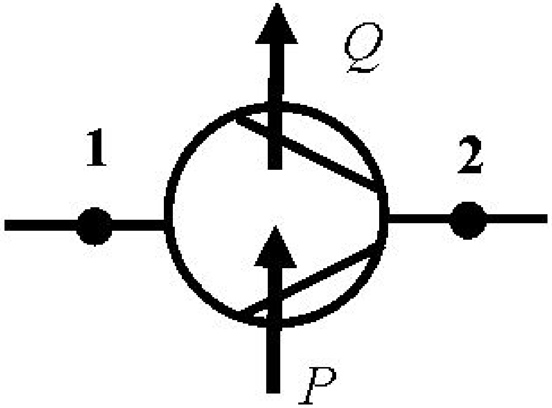
$$T_S + \frac{v_S^2}{2c_p} = T_S\left(1 + \frac{\chi R Ma_S{}^2}{2c_p}\right) = T_T$$

$Ma_S < 0.31$

Nearly atmospheric pressure on the suction side: $\Delta p < 0.1$ *bar*

Circumferential speed of blade tip < 100 *m/s*

1.3. Work process of fans



Ideal (inviscid) case:

$$\frac{P}{q_m} - \frac{Q}{q_m} = \left[\frac{v^2}{2} + gh + U + \frac{p}{\rho} \right]_1^2 = i_{t2} - i_{t1}$$

$Q = 0$, $\Delta U = 0$, *gh generally plays no role*

$$P = q_m \left[\frac{v^2}{2} + \frac{p}{\rho} \right]_1^2 = q_V \left[\rho \frac{v^2}{2} + p \right]_1^2 = q_V \Delta p_{tid}$$

Euler equation of turbomachines:

$$\Delta p_{tid} = \rho\left(\underline{v}_2 \underline{u}_2 - \underline{v}_1 \underline{u}_1\right)$$

A/ Volumetric losses

$$P = q_{VR} \Delta p_{tid} \qquad q_{VR} > q_V \qquad \eta_V = q_V / q_{VR}$$

B/ Friction losses

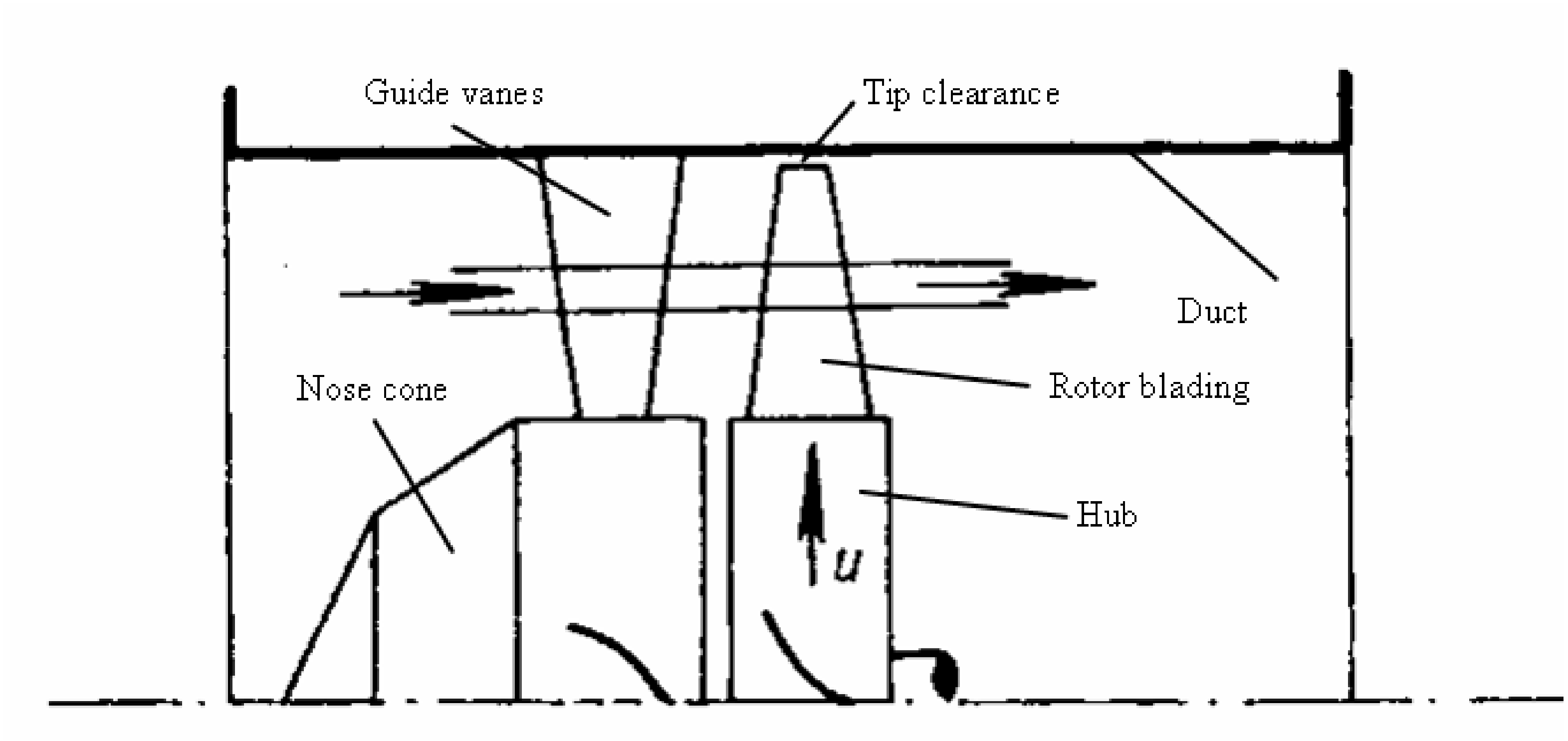
$$\eta_h = \Delta p_t / \Delta p_{tid} \qquad P = q_{VR} \Delta p_{tid} = \frac{q_V}{\eta_V} \frac{\Delta p_t}{\eta_h} = \frac{P_{useful}}{\eta_V \eta_h}$$

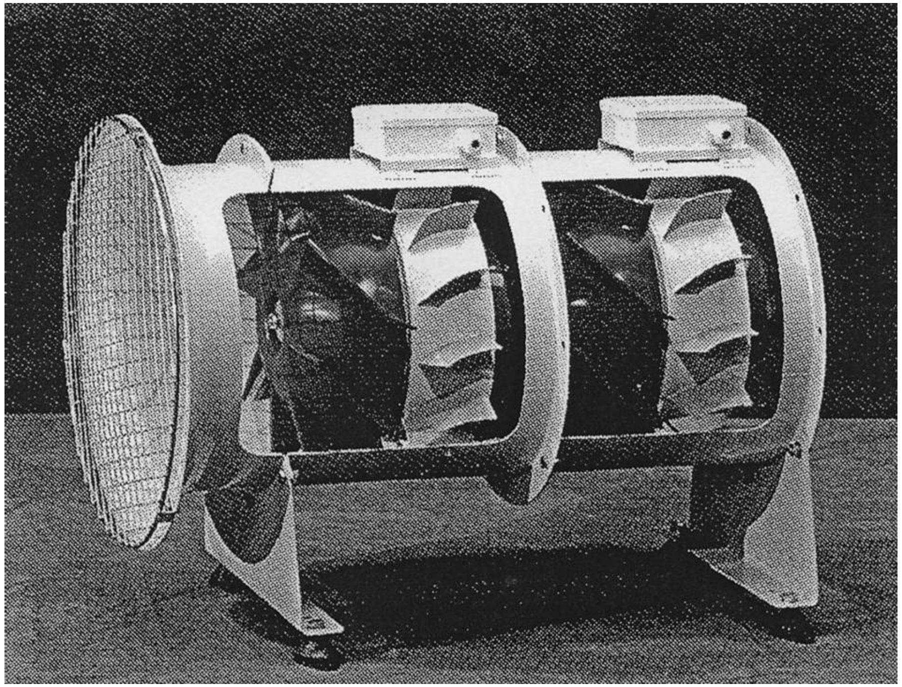
C/ Mechanical losses

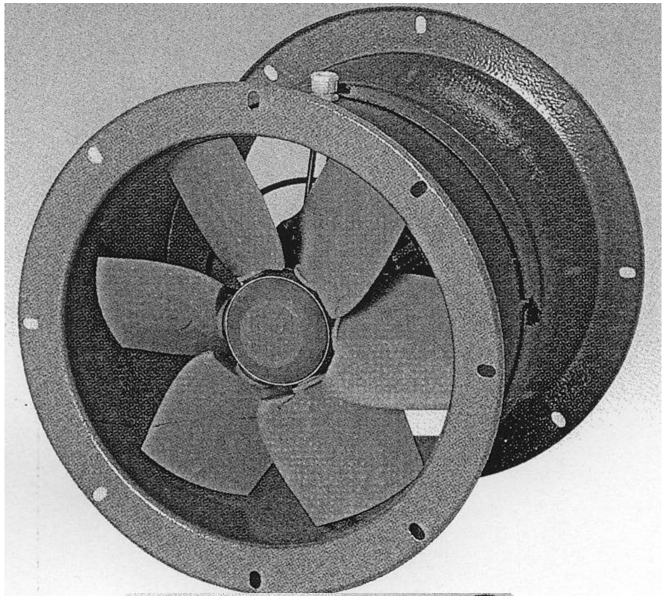
$$\eta_m = P / P_{mechanical} \quad P_{overall} = \frac{P_{useful}}{\eta_V \eta_h \eta_m} = \frac{P_{useful}}{\eta_{overall}}$$

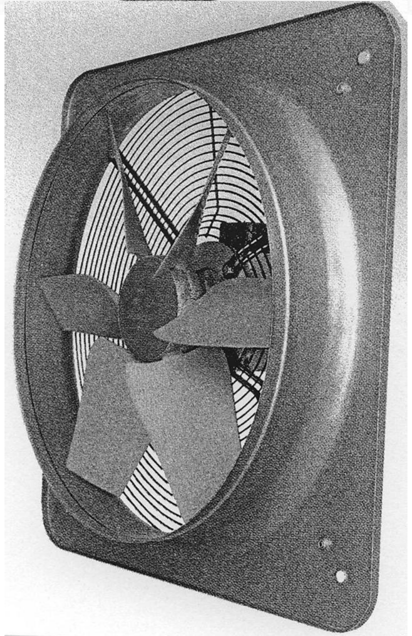
Fans: $\eta_\mathrm{m} \approx 1$, $\eta_\mathrm{V} \approx 1$, $\eta_\mathrm{overall} \approx \eta_\mathrm{h}$

1.5. Construction of axial fans







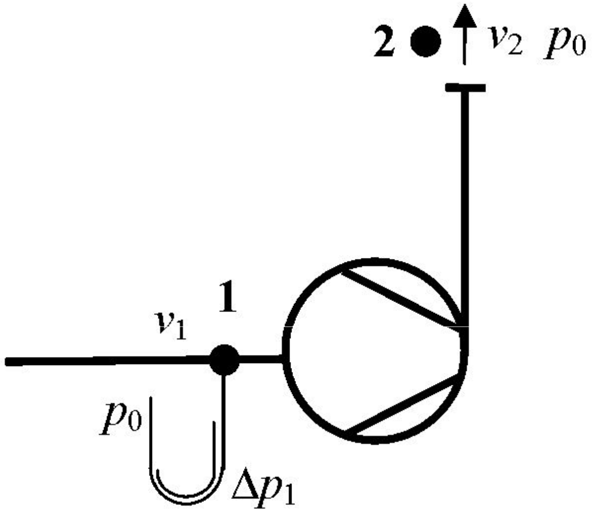


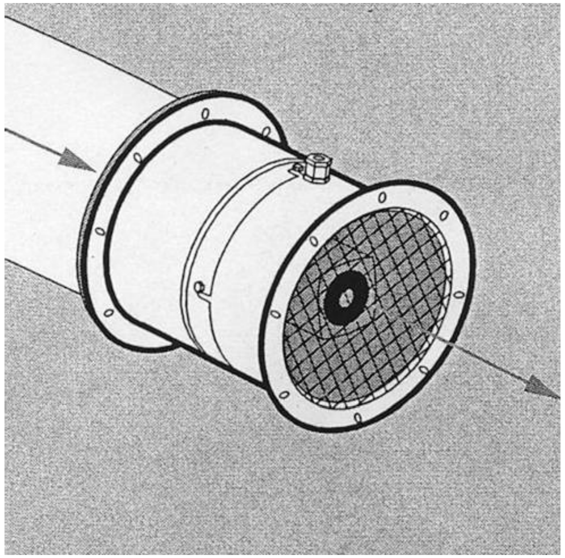
PRINCIPAL DIFFERENCES BETWEEN RADIAL AND AXIAL TURBOMACHINES:

- Axial turbomachinery: usually smaller total pressure rise
- Axial turbomachinery: usually higher volume flow rate
- Axial: moderate flow deflection: moderate fluid mechanical losses: higher stage efficiency
- Axial: moderate flow deflection in the connecting system: moderate system losses

1.6. Fan arrangements: technology- and geometry-dependent!

From the duct to the surroundings

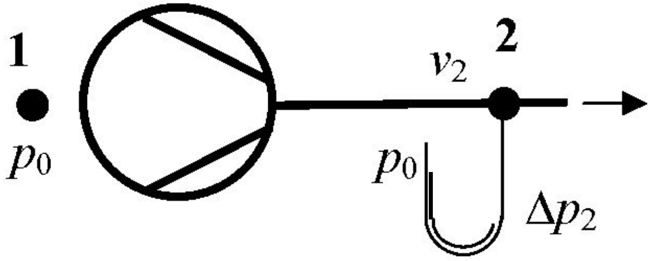


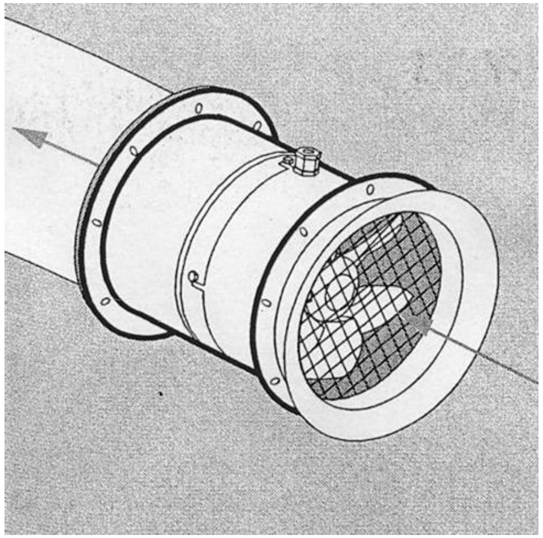


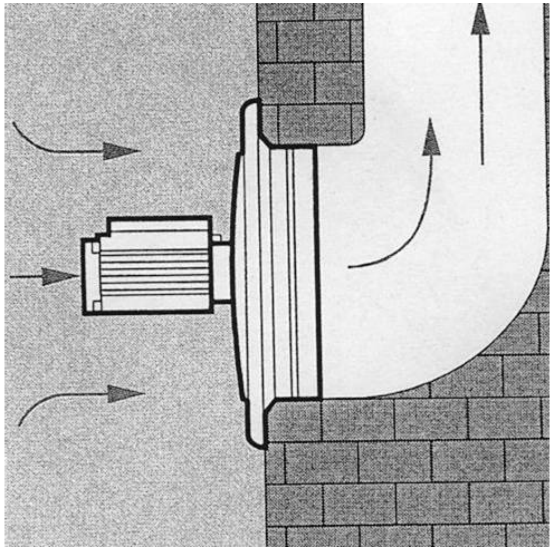
$$\Delta p_t = \left(\rho \frac{v_2^{\,2}}{2} + p_0 \right) - \left[\rho \frac{v_1^{\,2}}{2} + \left(p_0 - \Delta p_1 \right) \right] = \Delta p_1 + \rho \frac{v_2^{\,2}}{2} - \rho \frac{v_1^{\,2}}{2}$$

$$\Delta p_{st} = \Delta p_t - \rho \frac{v_2^{\,2}}{2} = \Delta p_1 - \rho \frac{v_1^{\,2}}{2}$$

From the surroundings to the duct



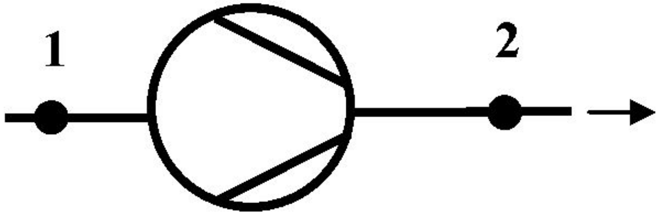


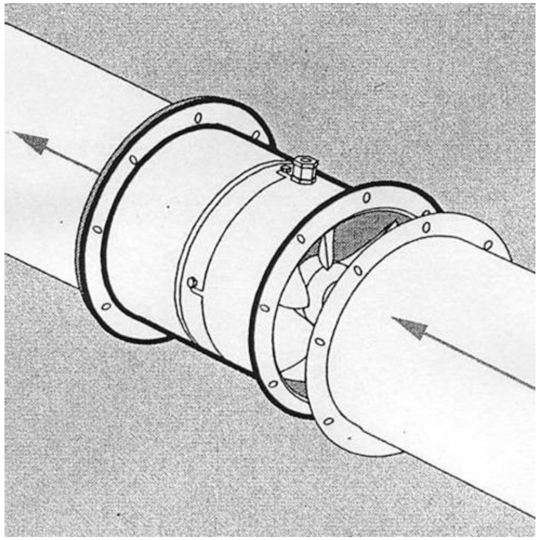


$$\Delta p_t = \left[\rho \frac{v_2^{\ 2}}{2} + \left(p_0 + \Delta p_2 \right) \right] - p_0 = \Delta p_2 + \rho \frac{v_2^{\ 2}}{2}$$

$$\Delta p_{st} = \Delta p_2$$

From duct to duct

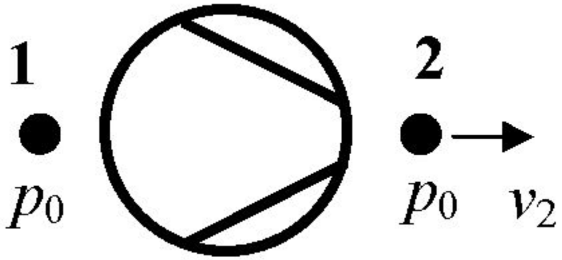




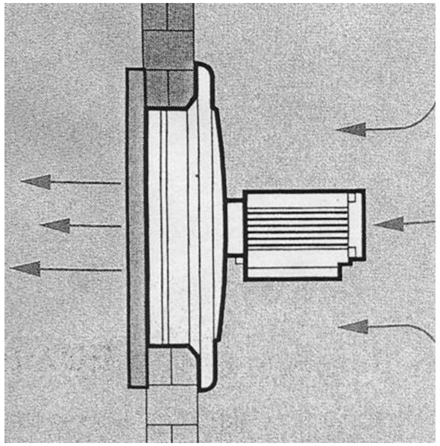
$$\Delta p_t = \left(\rho \frac{v_2^{\ 2}}{2} + p_2 \right) - \left(\rho \frac{v_1^{\ 2}}{2} + p_1 \right)$$

$$\Delta p_{st} = p_2 - \left(\rho \frac{v_1^{\ 2}}{2} + p_1 \right)$$

From the surroundings to the surroundings

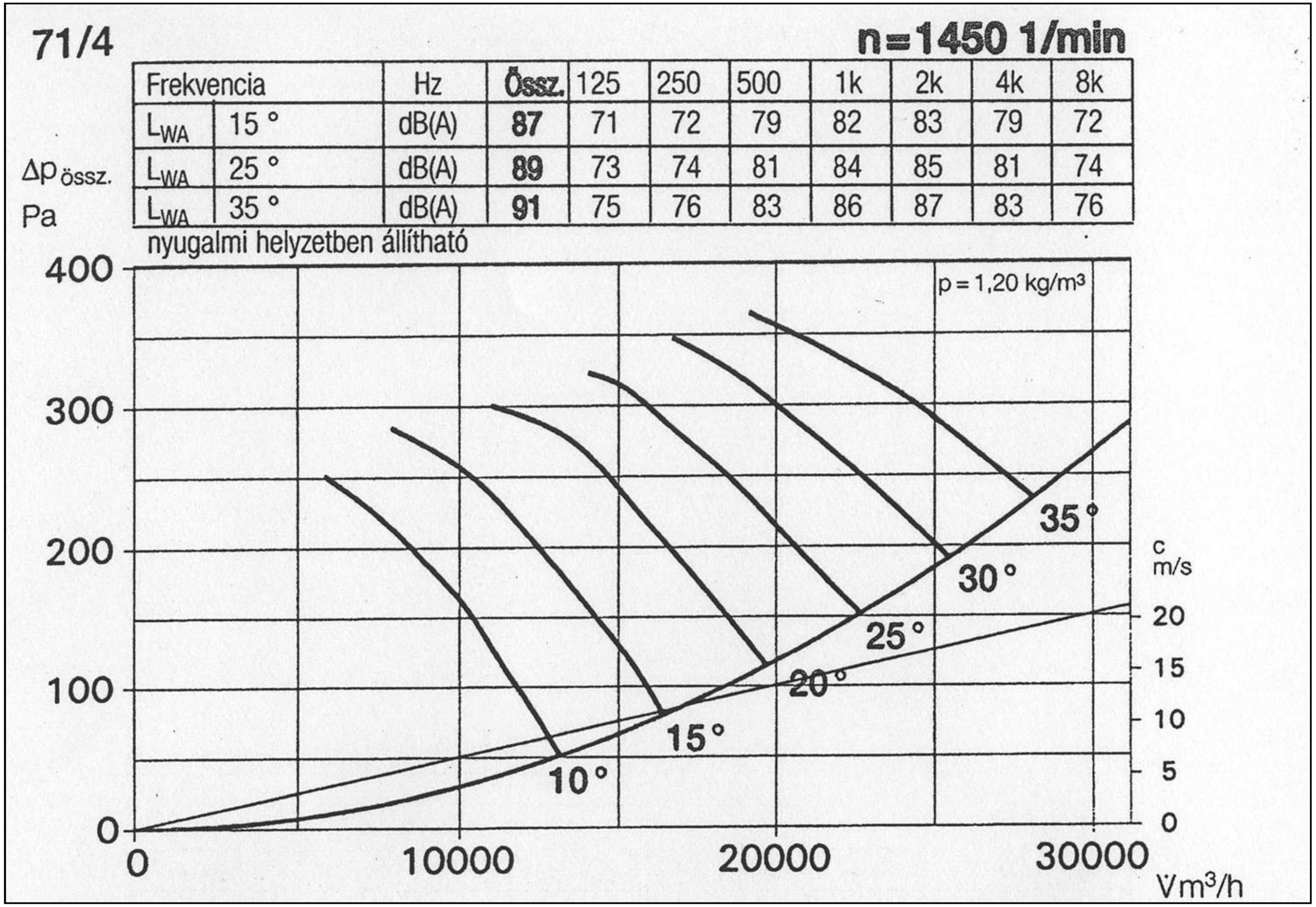


$$\Delta p_t = \left(\rho \frac{v_2^2}{2} + p_0\right) - p_0 = \rho \frac{v_2^2}{2} \qquad \Delta p_{st} = \Delta p_t - \rho \frac{v_2^2}{2} = 0$$



The static pressures are different on the two sides!

1.7. Characteristic curve: an example



71/4

n=1450 1/min

Frekvencia		Hz	Össz.	125	250	500	1k	2k	4k	8k
L_{WA}	15 °	dB(A)	**87**	71	72	79	82	83	79	72
L_{WA}	25 °	dB(A)	**89**	73	74	81	84	85	81	74
L_{WA}	35 °	dB(A)	**91**	75	76	83	86	87	83	76

1.8. Dimensionless characteristics, comparison

User demands: Δp_t , (Δp_{st}), q_V, $P_{overall}$
Machine characteristics: D (rotor outer diameter), n
Fluid characteristics: ρ , ν

For comparison of various machines: $u_t = D \pi n$

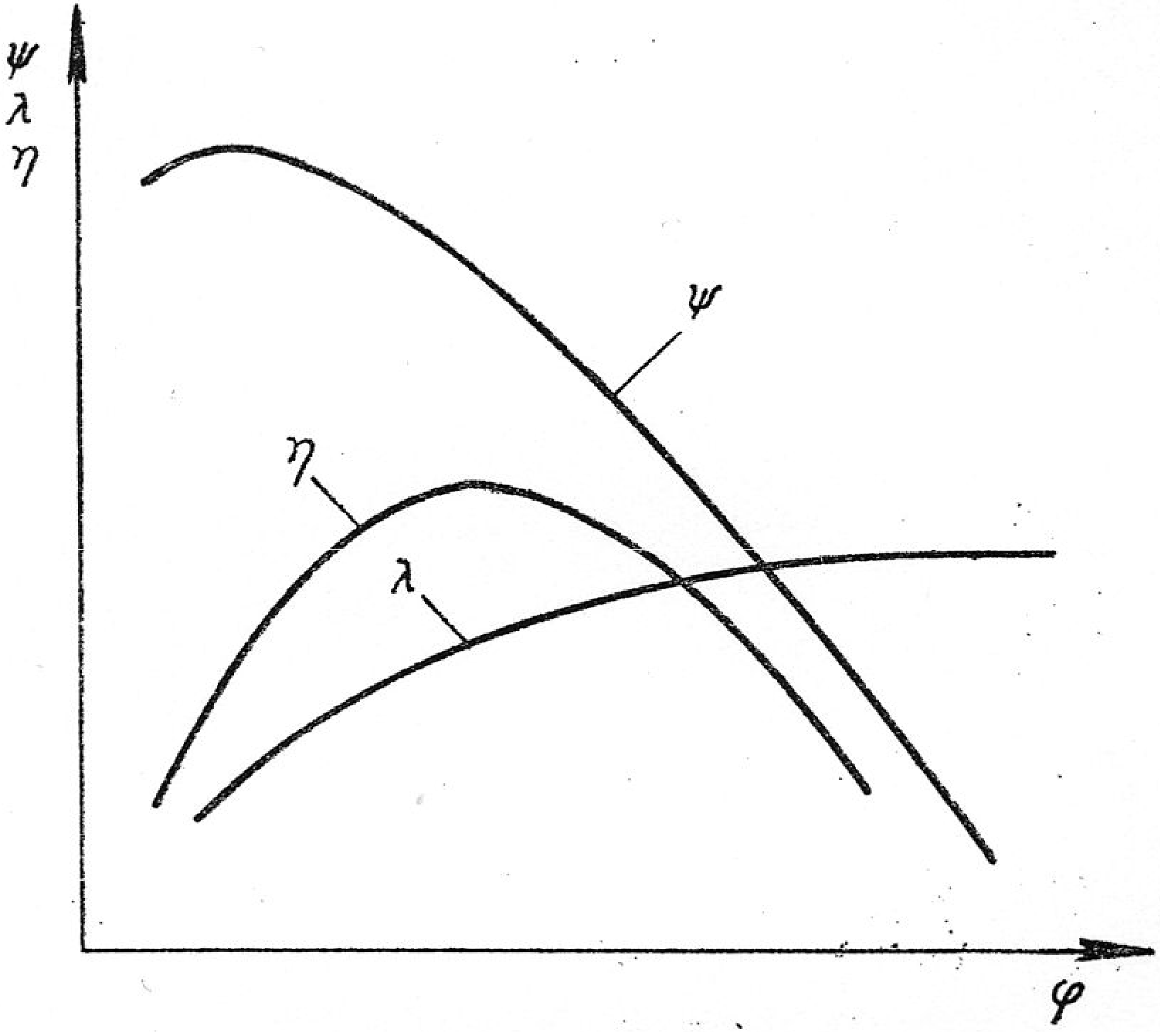
Total pressure coefficient: $$\Psi_t = \frac{\Delta p_t}{\frac{\rho}{2} u_t^2}$$

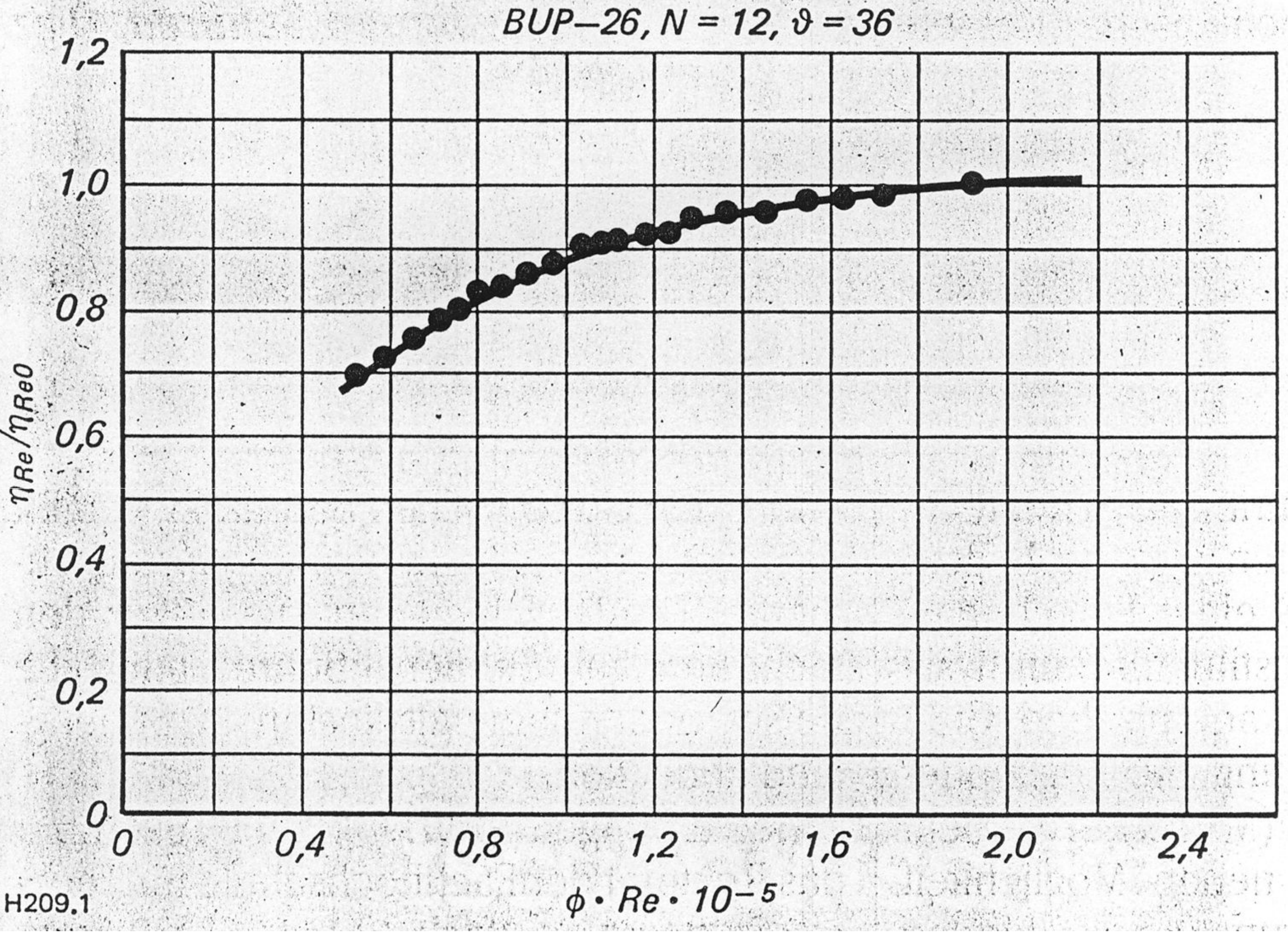
Static pressure coefficient: $$\Psi_{st} = \frac{\Delta p_{st}}{\frac{\rho}{2} u_t^2}$$

Flow coefficient: $\Phi = \frac{q_v}{A_{char} u_t}$

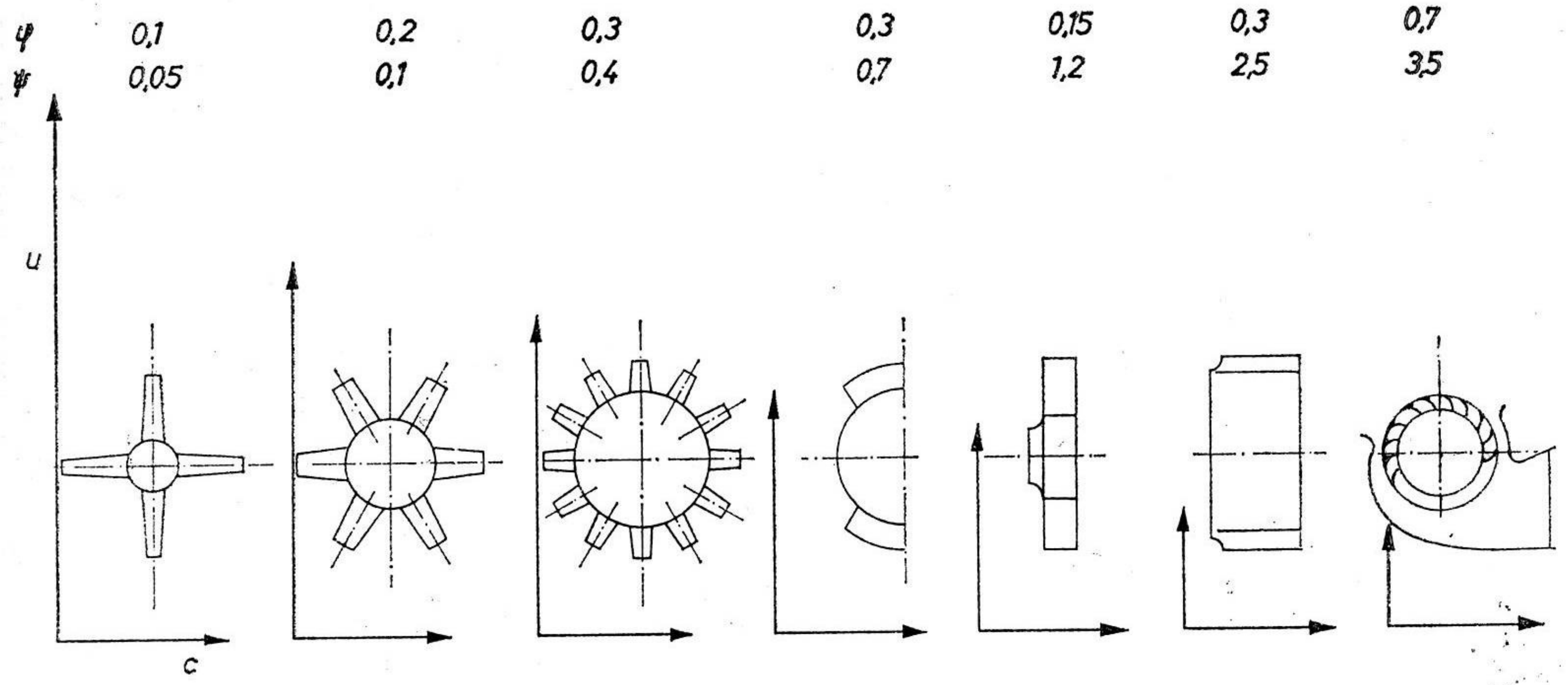
Power coefficient: $\lambda = \frac{P_{overall}}{\frac{\rho}{2} u_t^2 A_{char} u_t} = \frac{\frac{\Delta p_t q_V}{\eta_{overall}}}{\frac{\rho}{2} u_t^2 A_{char} u_t} = \frac{\Psi_t \Phi}{\eta_{overall}}$

Reynolds number: $\mathrm{Re} = \frac{u_t \ell}{\nu}$


ψ
λ
η
ψ
η
λ
φ


BUP—26, N = 12, ϑ = 36
1,2
1,0
0,8
0,6
0,4
0,2
0
η_{Re}/η_{Re0}
0
0,4
0,8
1,2
1,6
2,0
2,4
$\phi \cdot Re \cdot 10^{-5}$

H209.1


φ
ψ
0,1
0,05
0,2
0,1
0,3
0,4
0,3
0,7
0,15
1,2
0,3
2,5
0,7
3,5
u
c