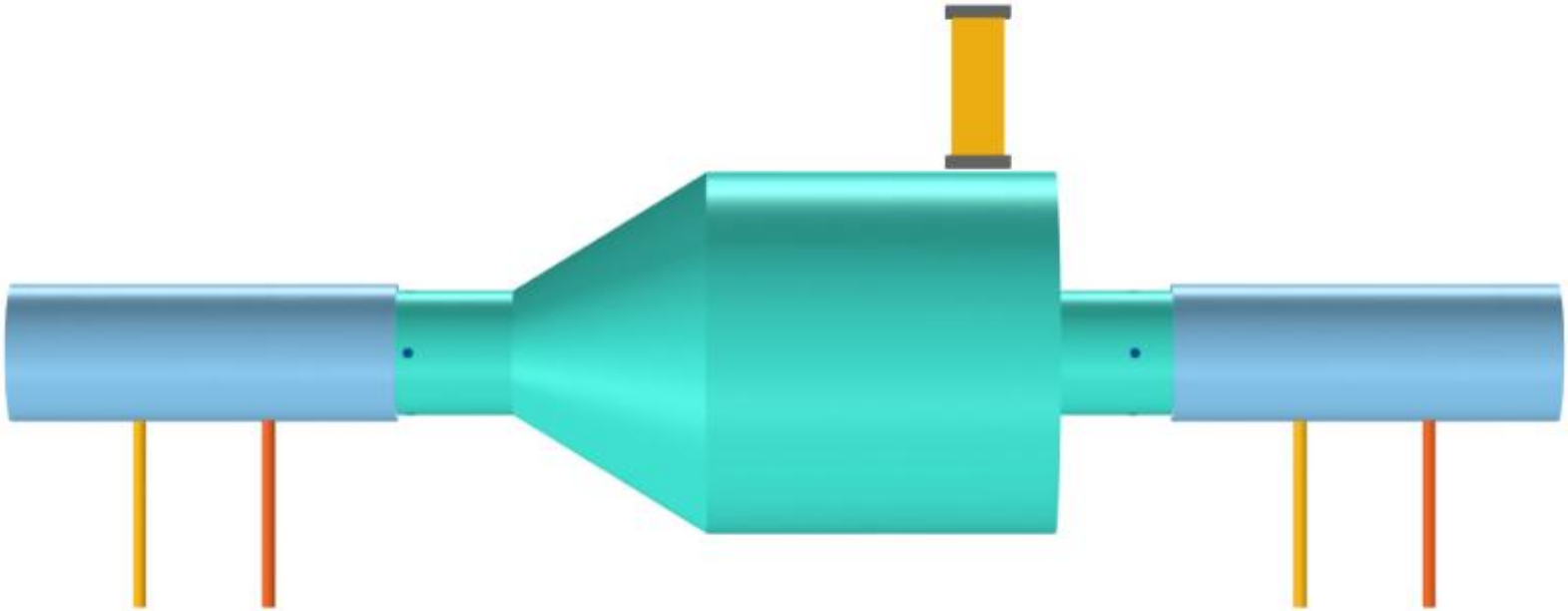
Al-Farabi Kazakh National University

Satbayev University

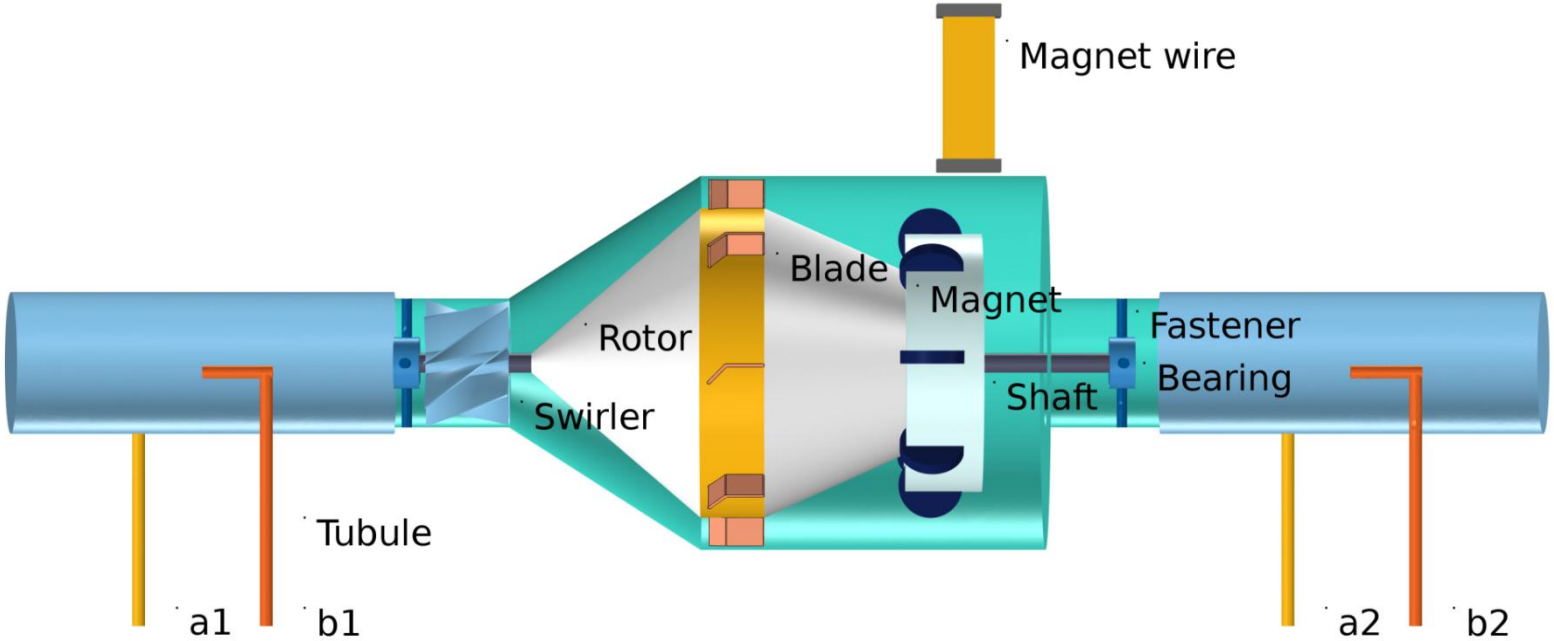
Theoretical and experimental investigations to define optimal parameters of the straight-flow turbine for non-dam hydro power station

D. E. Turalina, D. Zh. Bossinov
Kazakhstan

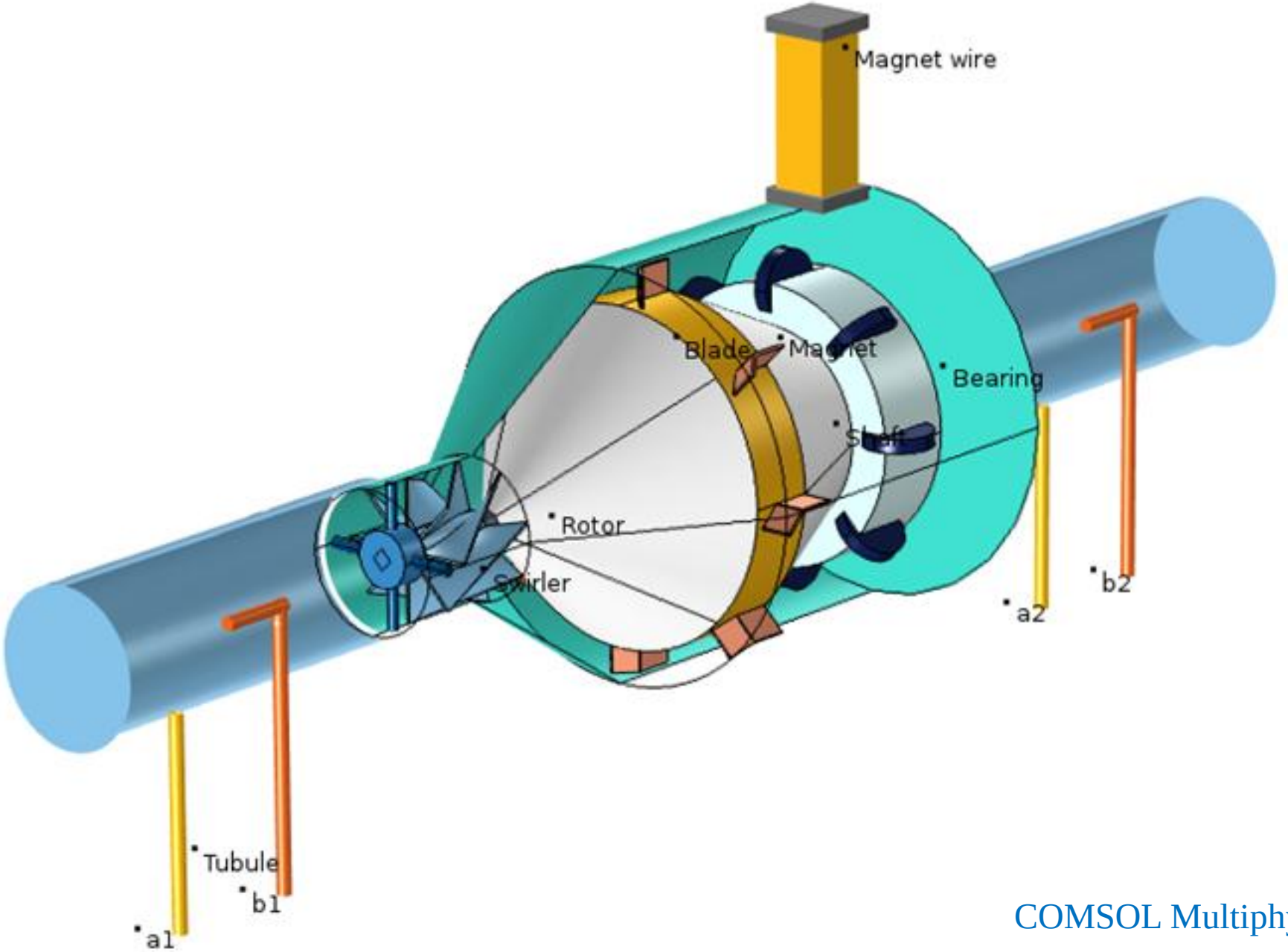
A general view of the flow turbine



A transparent view of the flow turbine

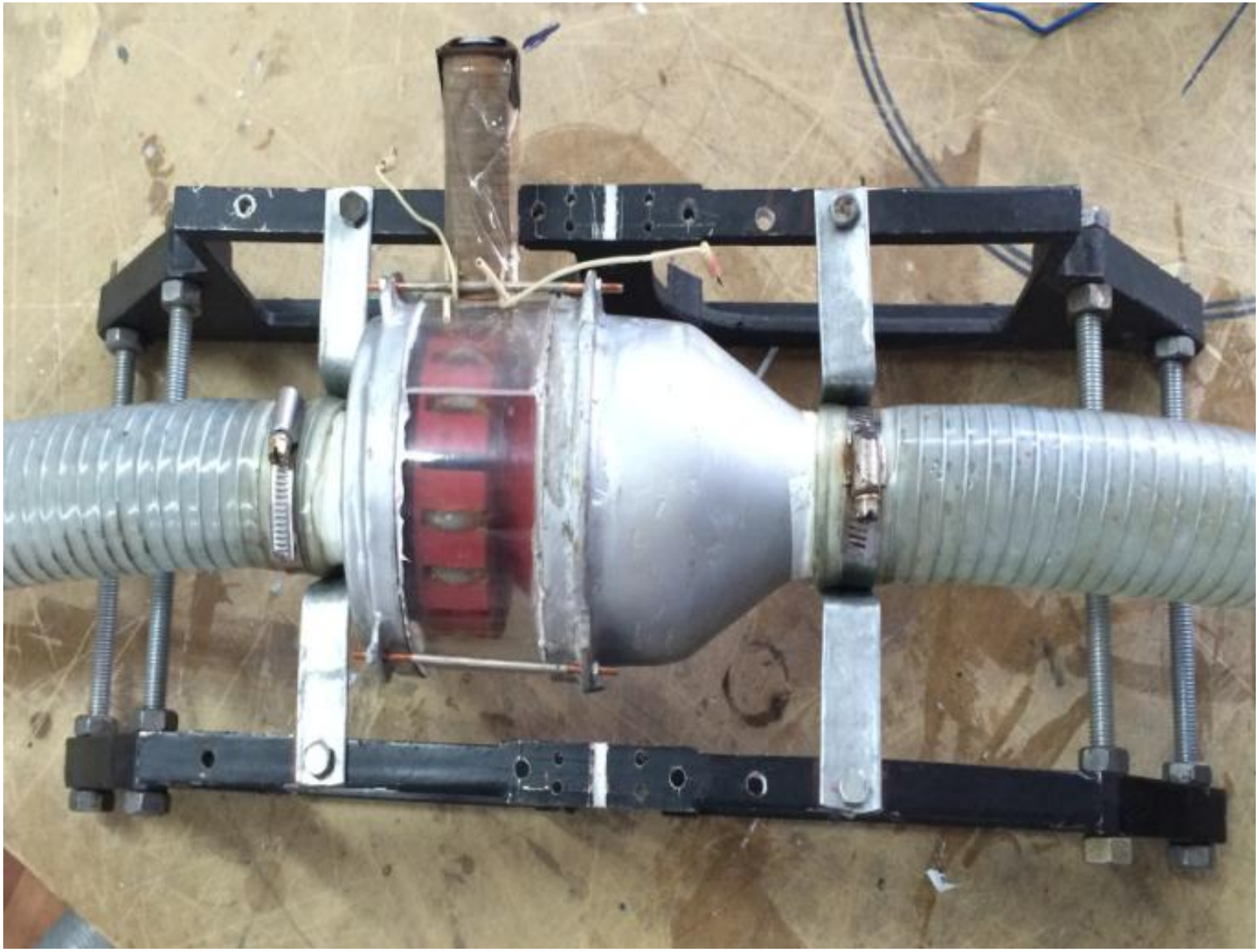


A transparent view on the flow turbine from the aside perspective



COMSOL Multiphysics

A general view of the straight-flow turbine

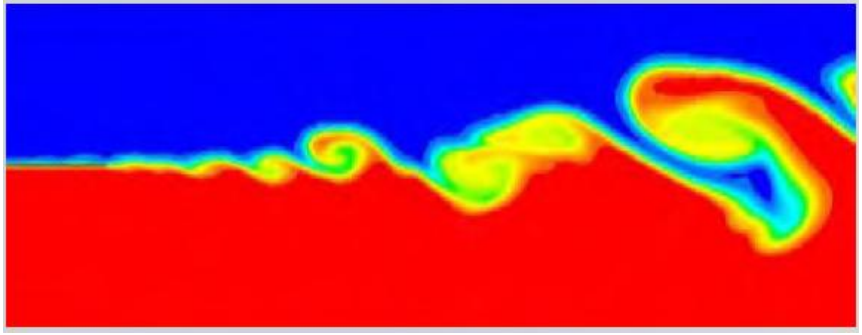


The experimental device applied during the studies

LAMINAR AND TURBULENT FLOW SIMULATION METHODS

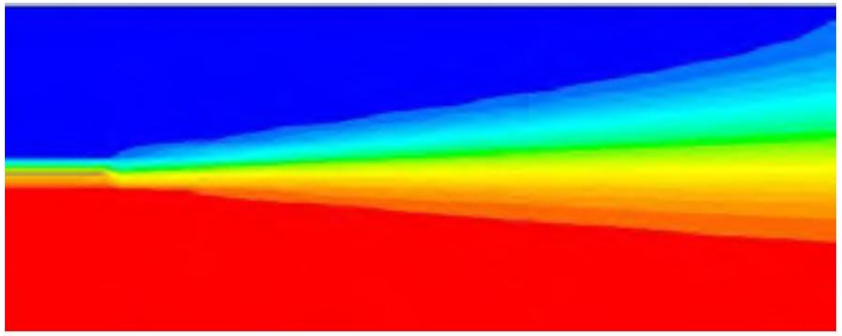
DNS

(Direct Numerical Simulation)



RANS

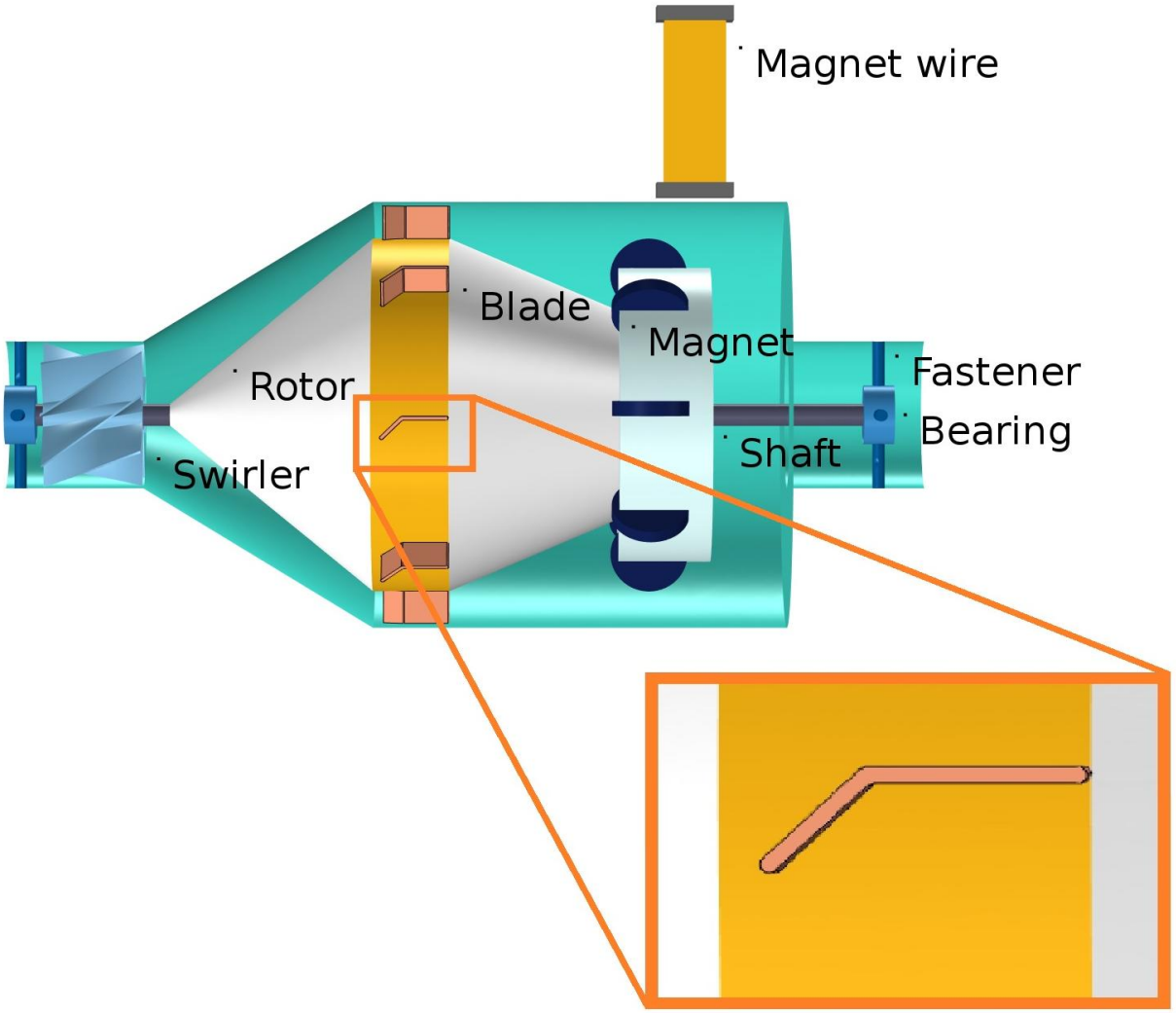
(Reynolds Averaged Navier-Stokes Simulations)



More mesh
More time
More accurate

Less accurate
Less mesh
Less time

The part of the blade is located in the hydro turbine rotor



COMSOL Multiphysics

Mathematical model of the 2D fluid domain

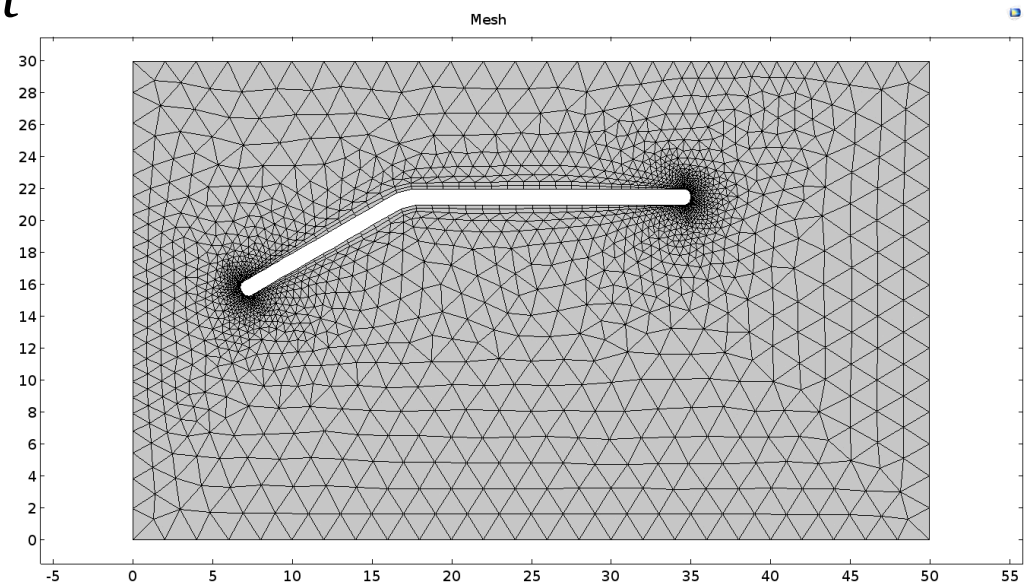
Conservation of mass (continuity)

$$\nabla \cdot u = 0$$

Conservation of momentum (Newton's second law)

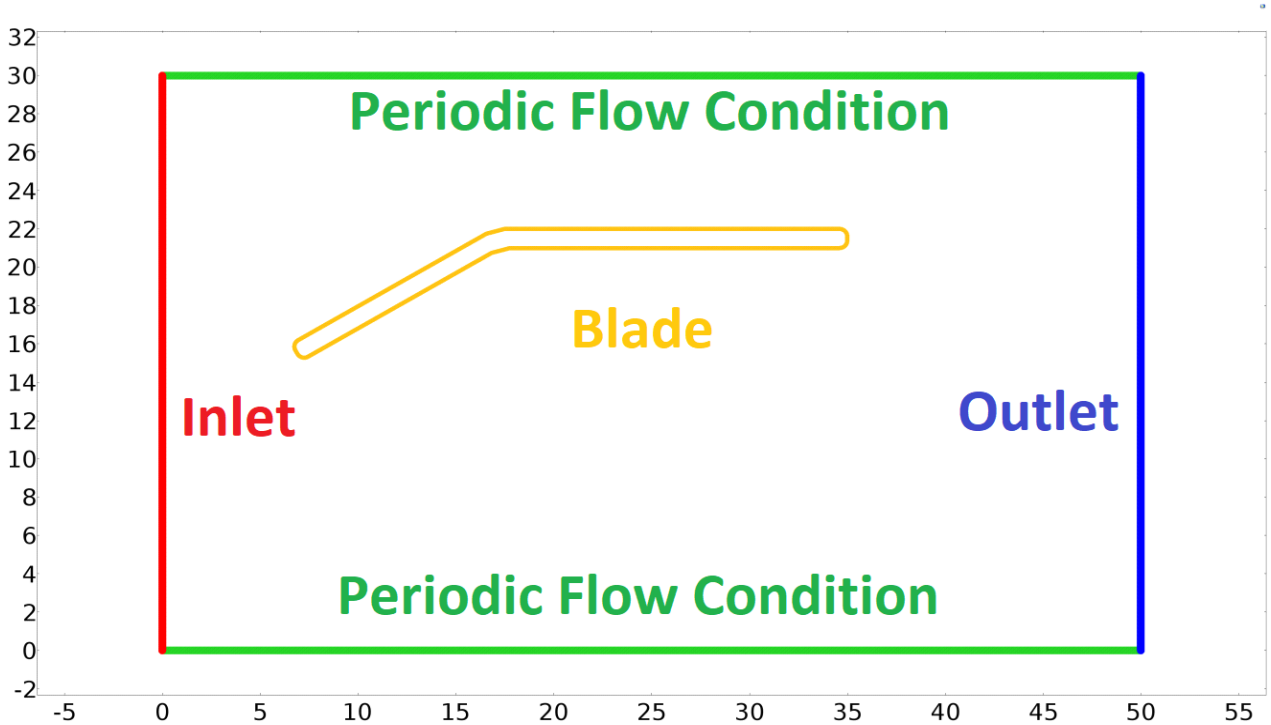
$$\rho \frac{\partial u}{\partial t} + \rho (u \cdot \nabla) u = \nabla \cdot [-pI + \mu(\nabla u + (\nabla u)^T)] + \rho g$$

Domain length *L = 30 mm*
Domain width *W = 50 mm*
Blade length *28.25 mm*
Blade width *2 mm*



Mesh allocation in two-dimensional domain

Initial and boundary conditions



Inlet:

x	$U \cdot \cos(\alpha \cdot \pi/180)$
y	$U \cdot \sin(\alpha \cdot \pi/180)$

Periodic flow condition:

$$U_{source} = U_{dest}$$
$$P_{source} = P_{dest}$$

Outlet: *Neumann boundary condition*

Wall: *No slip*

Dynamic viscosity 0.001 $(\mathrm{Pa} \cdot s)$
Kinematic viscosity $1 \cdot 10^{-6} \quad m^2/s$
Density 999 kg/m^3
Temperature 20 °C
$U = 1\, m/s$

RESULTS

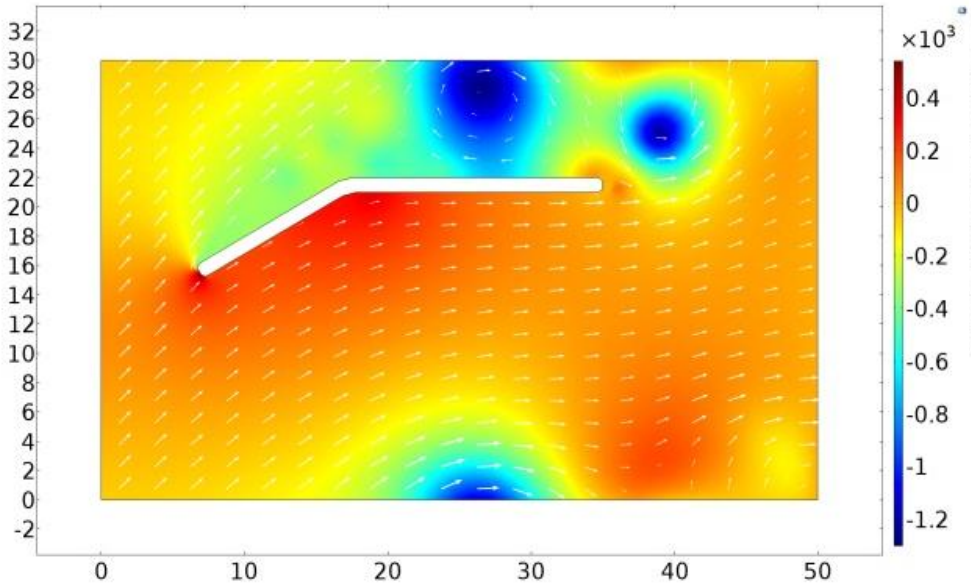


Fig.5 Velocity magnitude (m/s)

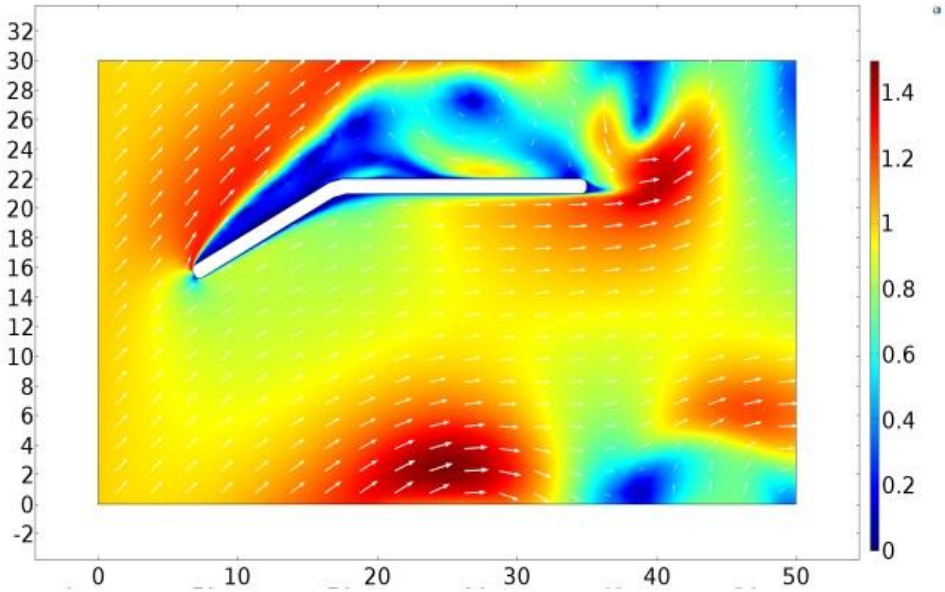
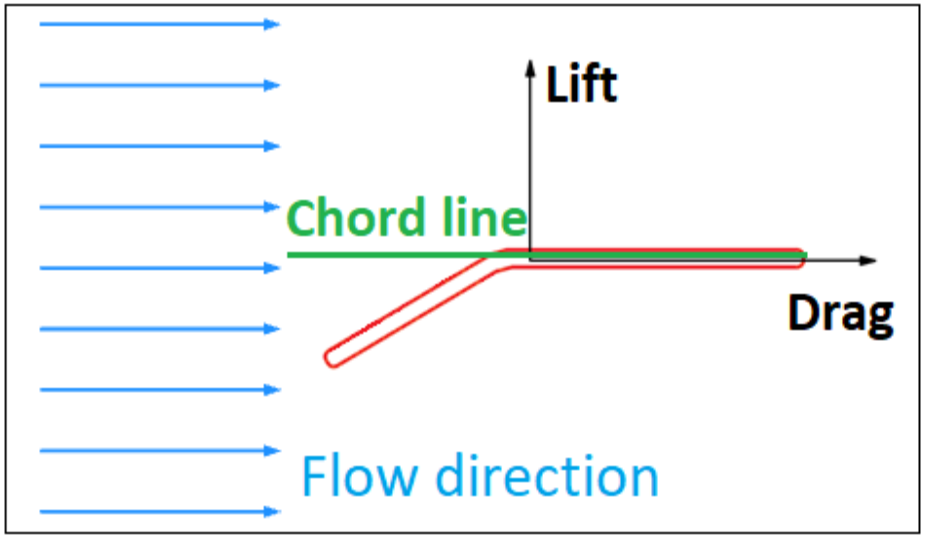
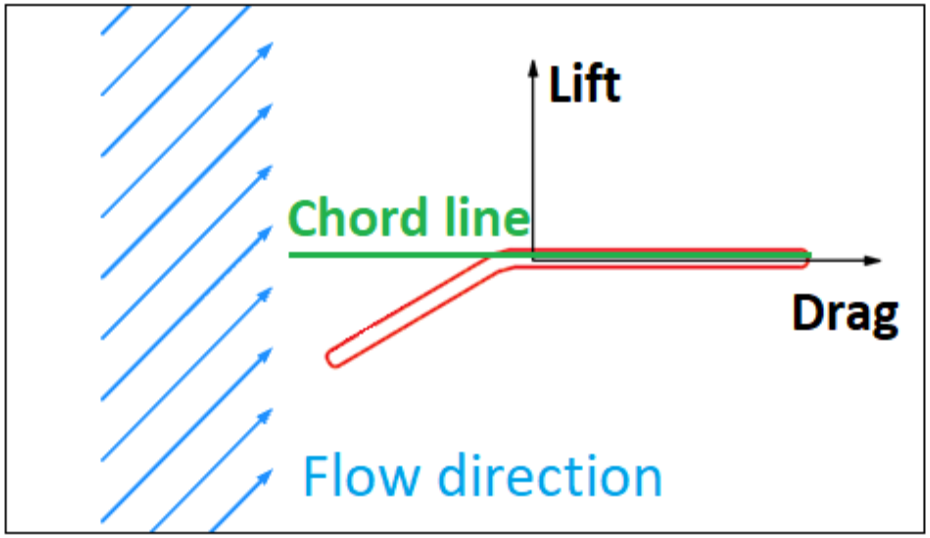


Fig.5 Pressure (Pa)

Calculation of the lift and drag forces



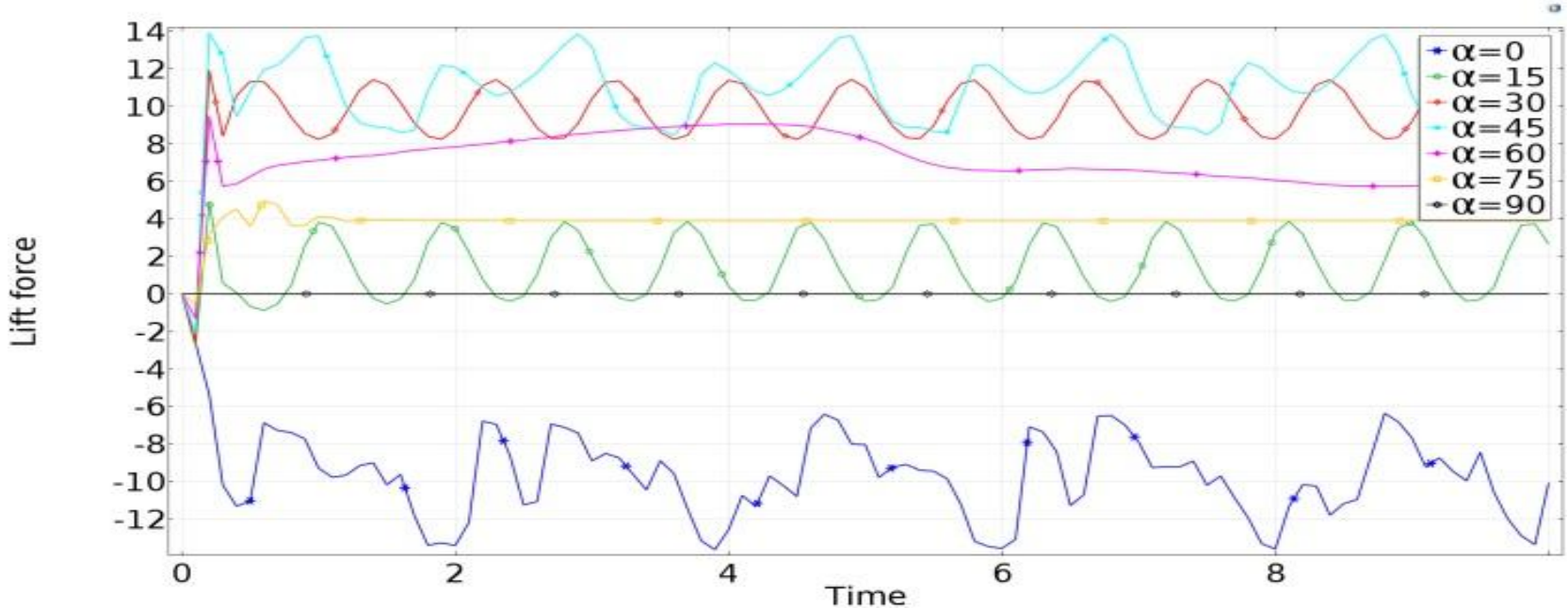
Flow at a *0*-degree angle of attack



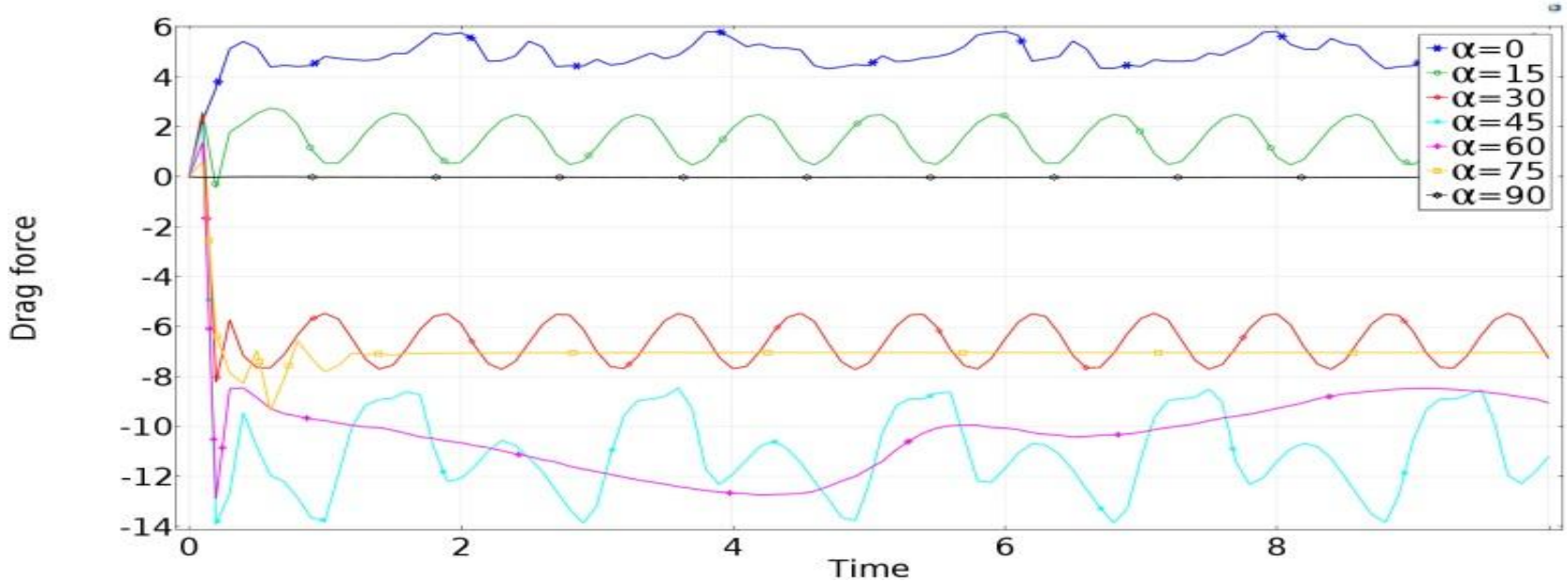
Flow at a *45*-degree angle of attack

$$F_D = \int_S (\rho_f \mu_f \frac{\partial u}{\partial n} n_y - p n_x) dS$$

$$F_L = \int_S (\rho_f \mu_f \frac{\partial u}{\partial n} n_x + p n_y) dS$$



Lift forces at various angle of flow attack



Drag forces at various angle of flow attack

Calculation of the lift and drag coefficients

$$C_D = \frac{2F_D}{\rho f u^2 d} \qquad C_L = \frac{2F_L}{\rho f u^2 d}$$

$$C_L(\alpha) = \oint_c c_p(s)/c)\,(n_y(s)cos(\alpha) - n_x(s)sin(\alpha))ds$$

$$C_D(\alpha) = -\oint_c (c_p(s)/c)\,(n_y(s)cos(\alpha) - n_x(s)sin(\alpha))ds$$

$$c_p(s) = \frac{p(s) - p}{\frac{1}{2}\rho U^2}$$

c is the blade length

p is the fluid's pressure

ρ is the fluid's density

U is the mean velocity

n_x is the unit normal vector in the x direction

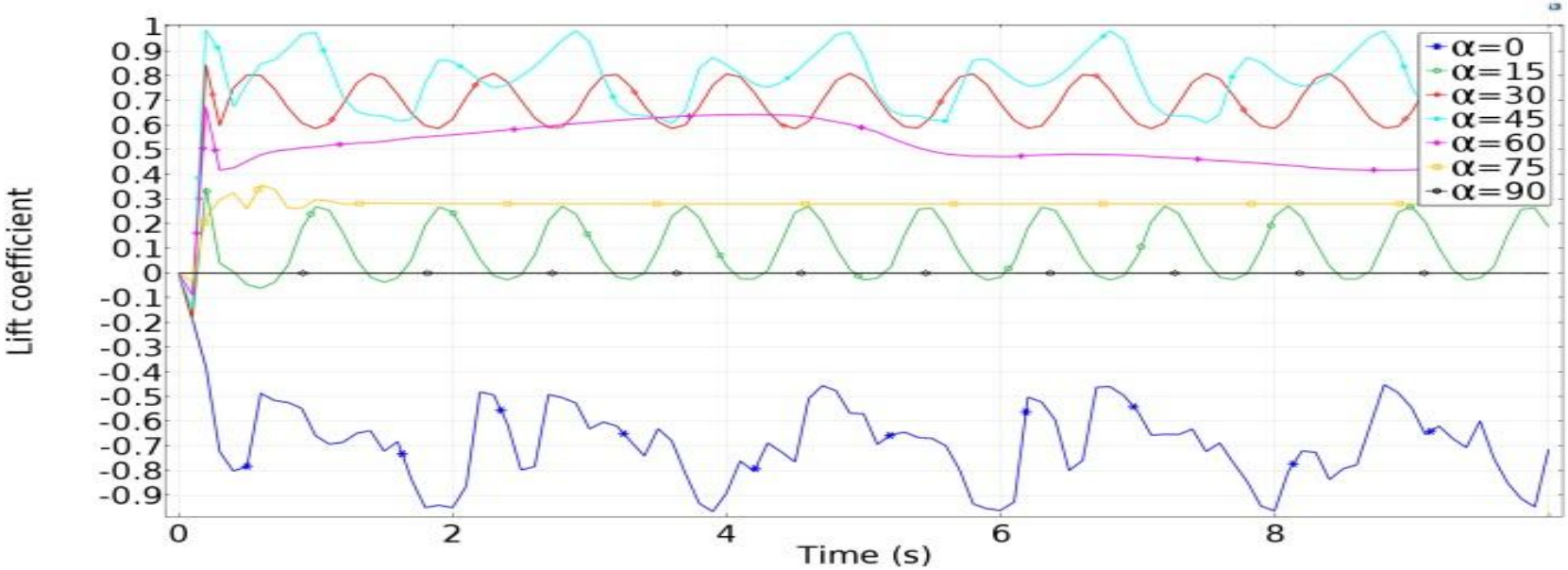
n_y is the unit normal vector in the y direction

s is the contour of the blade

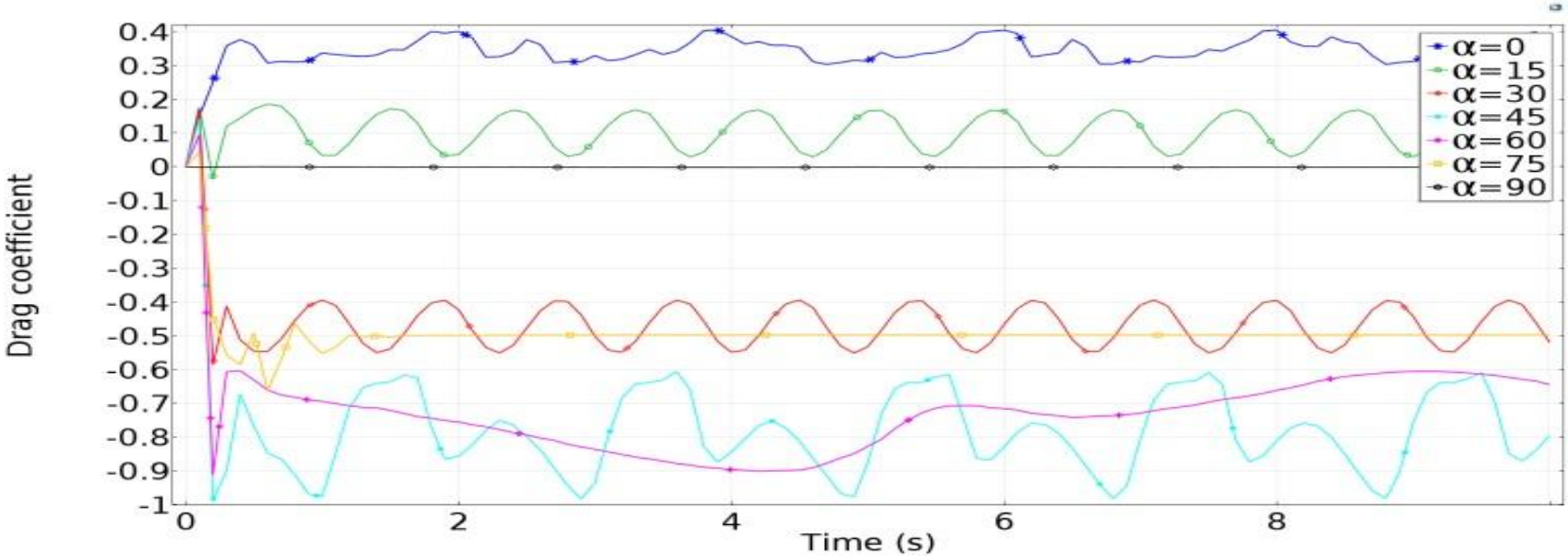
α is the angle of attack in degrees

C_L is the dimensionless lift coefficient

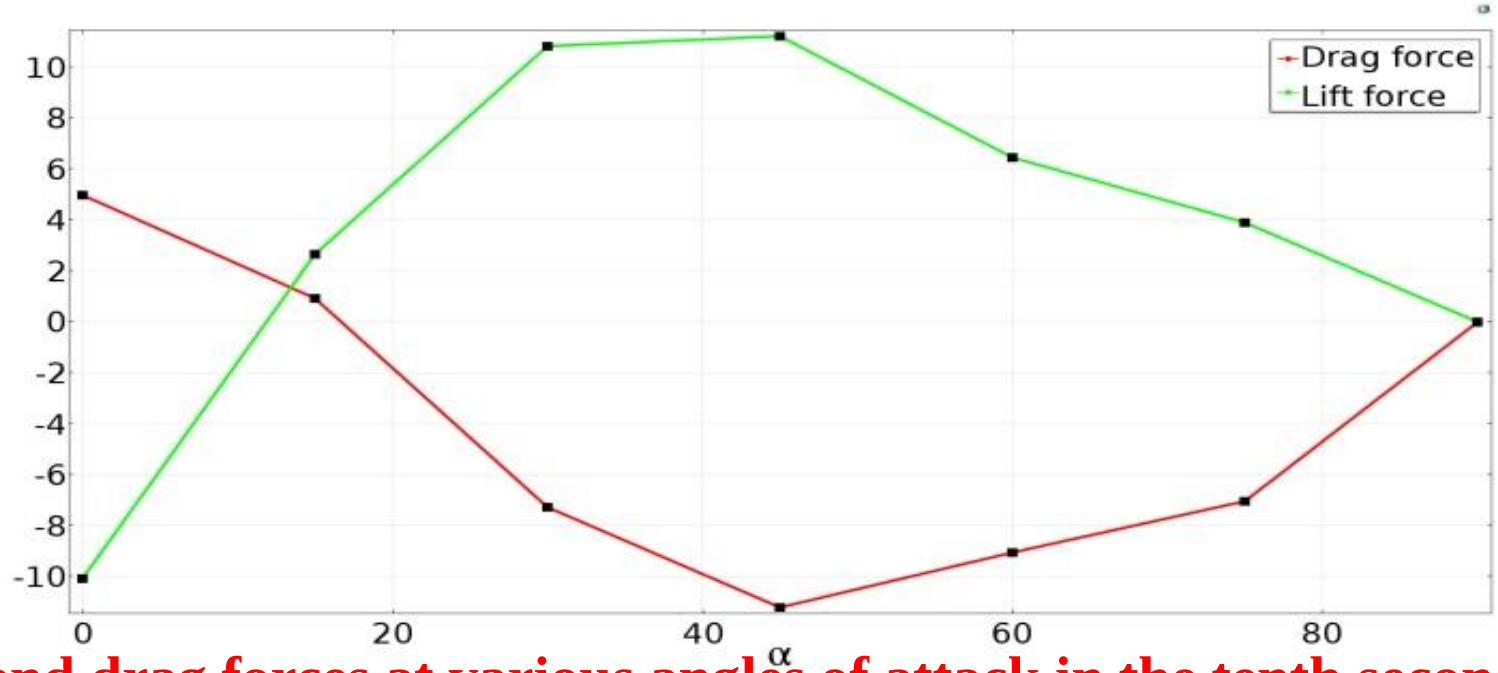
C_D is the dimensionless drag coefficient



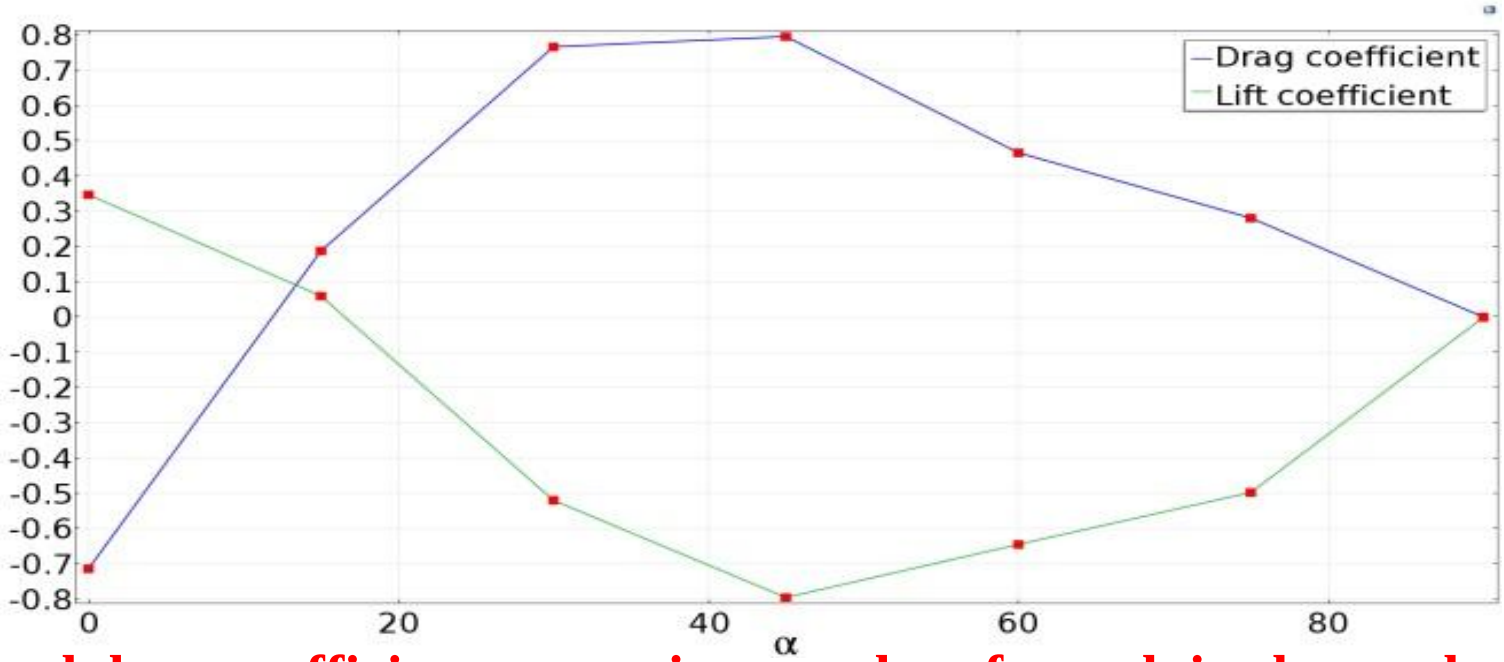
Dimensionless lift coefficients at various angles of flow attack



Dimensionless drag coefficients at various angles of flow attack



Lift and drag forces at various angles of attack in the tenth second



Lift and drag coefficients at various angles of attack in the tenth second

Determination of the thickness and number of blades

$$\delta_{\max} = (0.005 \div 0.01) D_1 \sqrt{\frac{h_{\max}}{Z}} + 0.002, m$$

Z=6:

$$\delta_{\max} = 0.005 * D_1 * \sqrt{\frac{h_{\max}}{Z}} + 0.002 = 0.005 * 0.05 * \sqrt{\frac{20}{6}} + 0.002 = 0.0028 m$$

Z=9:

$$\delta_{\max} = 0.005 * D_1 * \sqrt{\frac{h_{\max}}{Z}} + 0.002 = 0.005 * 0.05 * \sqrt{\frac{20}{9}} + 0.002 = 0.0025 m$$

Z=12:

$$\delta_{\max} = 0.005 * D_1 * \sqrt{\frac{h_{\max}}{Z}} + 0.002 = 0.005 * 0.05 * \sqrt{\frac{20}{12}} + 0.002 = 0.0024 m$$

Z= 6: rpm = 110

Z= 9: rpm = 155

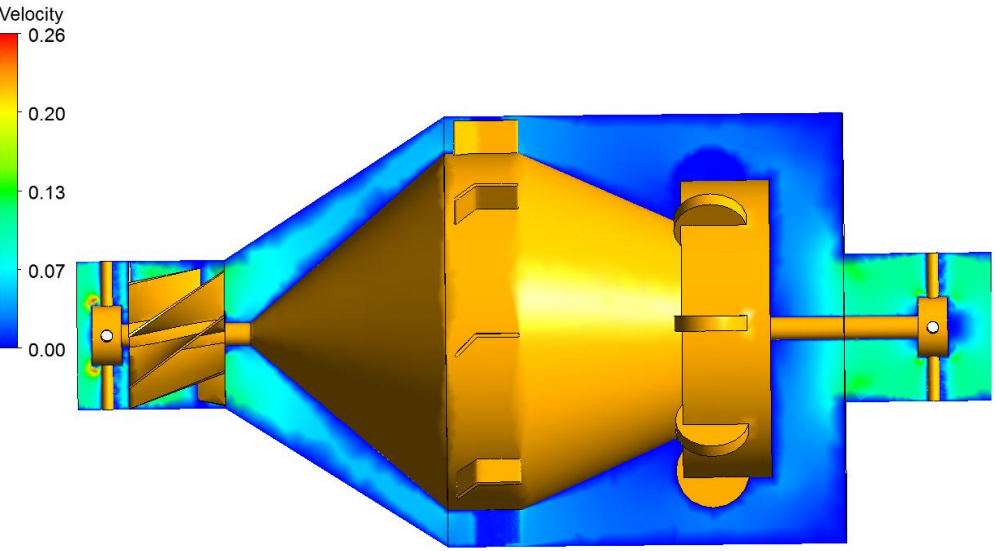
Z= 12: rpm = 120

Blades along the rotor of the hydraulic turbine

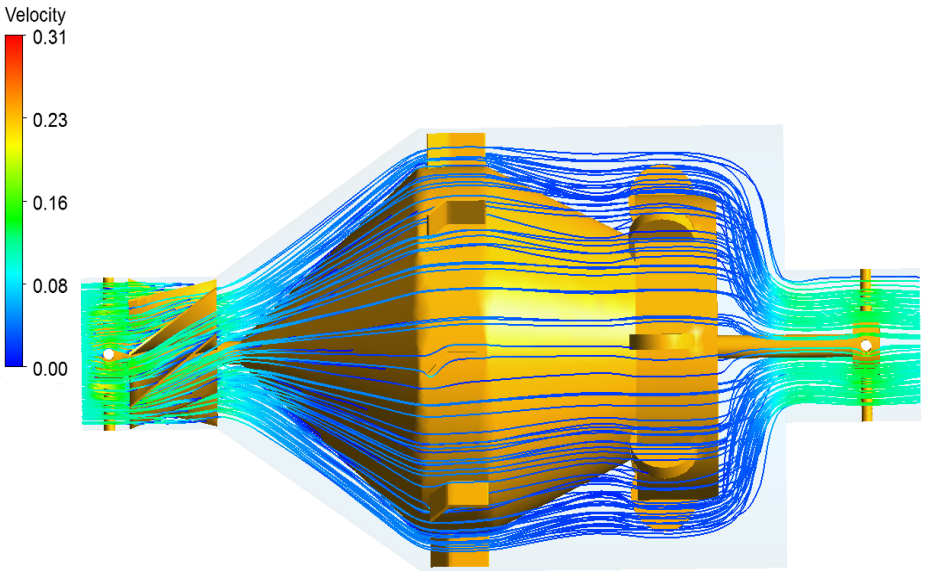
VISUALIZATION OF HYDRO TURBINE PERFORMANCE

- **The Case of Non-rotating Rotor Mode**
  - **Water velocity at Inlet 0.1 m/s**
- **The Case of Rotating Rotor Mode**
  - **Water velocity at Inlet 0.8 m/s**
  - **Rotating domain revolves 155 times per minute along the axis Z**

• The Case of Non-rotating Rotor Mode



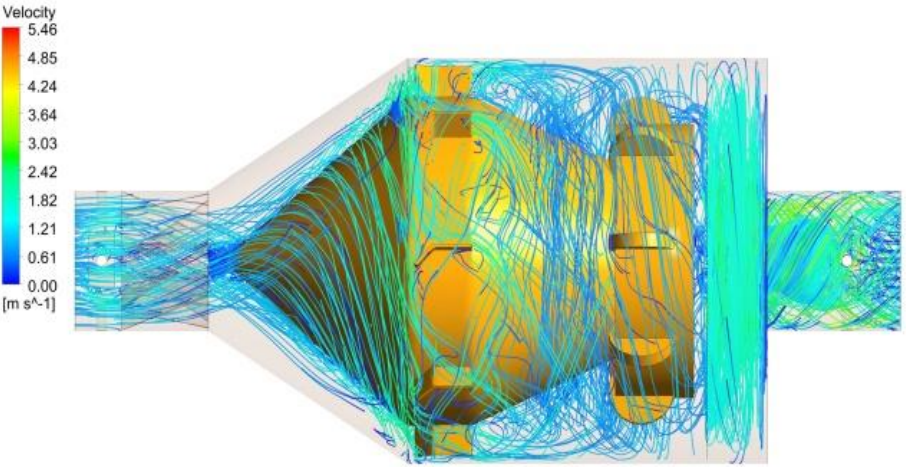
Velocity surface (m/s)



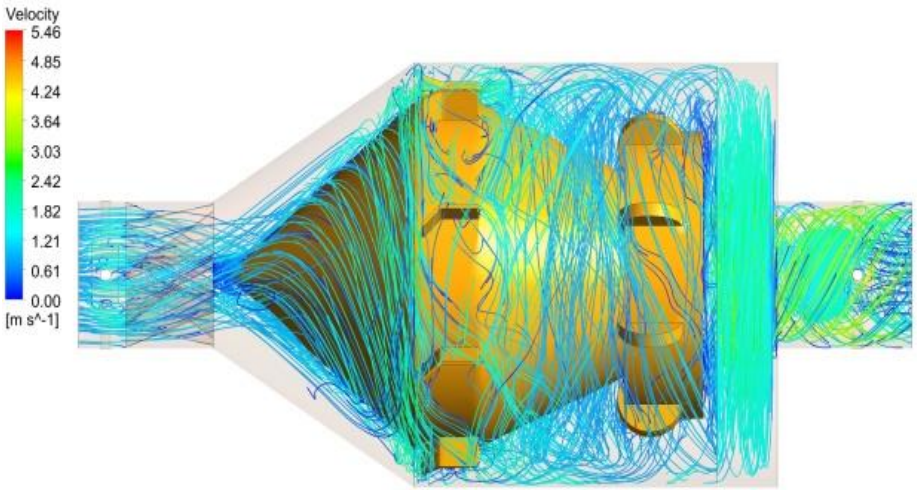
Velocity streamlines (m/s)

ANSYS Fluent

• The Case of Rotating Rotor Mode



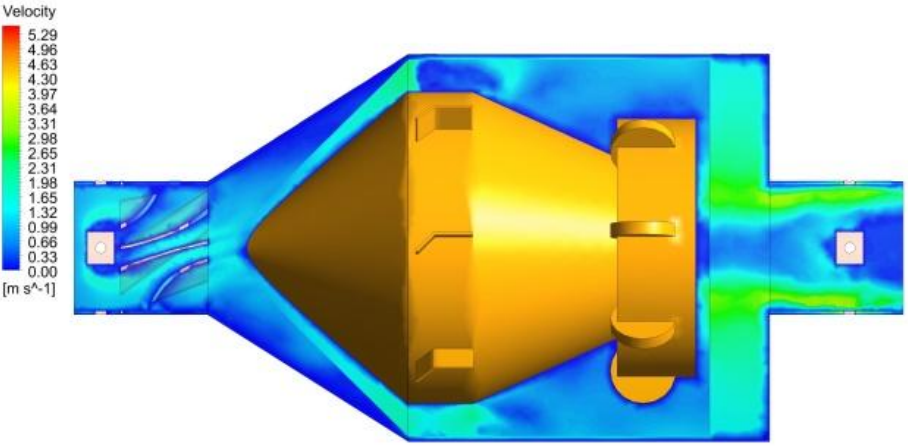
Velocity streamlines at t =0.5s



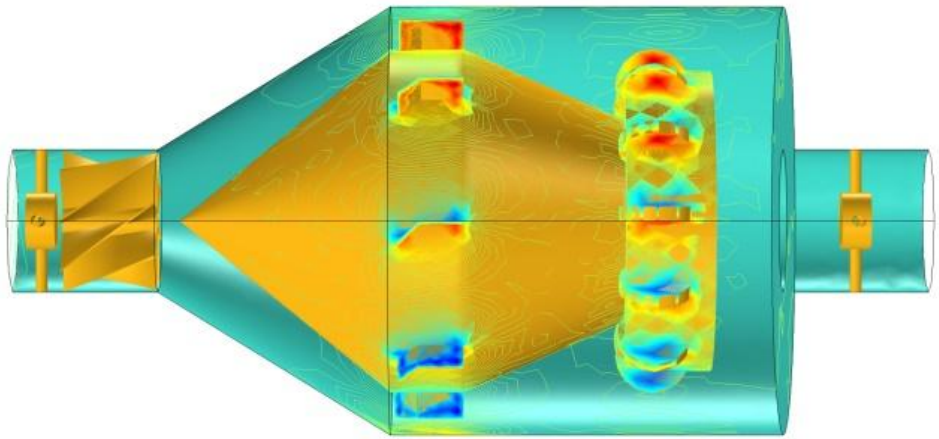
Velocity streamlines at t =2.5s

ANSYS Fluent

• The Case of Rotating Rotor Mode



Velocity surface at t =0.5s (*m/s*)



Pressure contour (Pa)

Energy conversion efficiency of hydro turbine

The stream power driven to the hydro turbine:

$$N = 9.81QH, kW.$$

Increasing power (efficient) via hydro turbine:

$$N_{Эф} = 9{,}81QH\eta, kW.$$

$$\upsilon_u = \sqrt{2gH},$$

Full efficiency of hydraulic turbine:

$$\eta_T = \frac{N_{Эф}}{N} = \frac{M\omega}{\gamma QH},$$

$$M = \rho Q[(\upsilon_u r)_1 - (\upsilon_u r)_2] = \frac{\rho Q}{2\pi}[\Gamma_1 - \Gamma_2],$$ **or**

$$\Gamma_1 = 2\pi(\upsilon_u r)_1; \Gamma_2 = 2\pi(\upsilon_u r)_2;$$

$$(\upsilon_u r)_1 = \Gamma_1 / 2\pi; (\upsilon_u r)_2 = \Gamma_2 / 2\pi;$$

$$M = \frac{\gamma Q}{g}\frac{z\Gamma_л}{2\pi}, \quad \Gamma_л = \int_1^2 \gamma(s)ds,$$

$$\omega = \frac{\upsilon_u}{r};$$

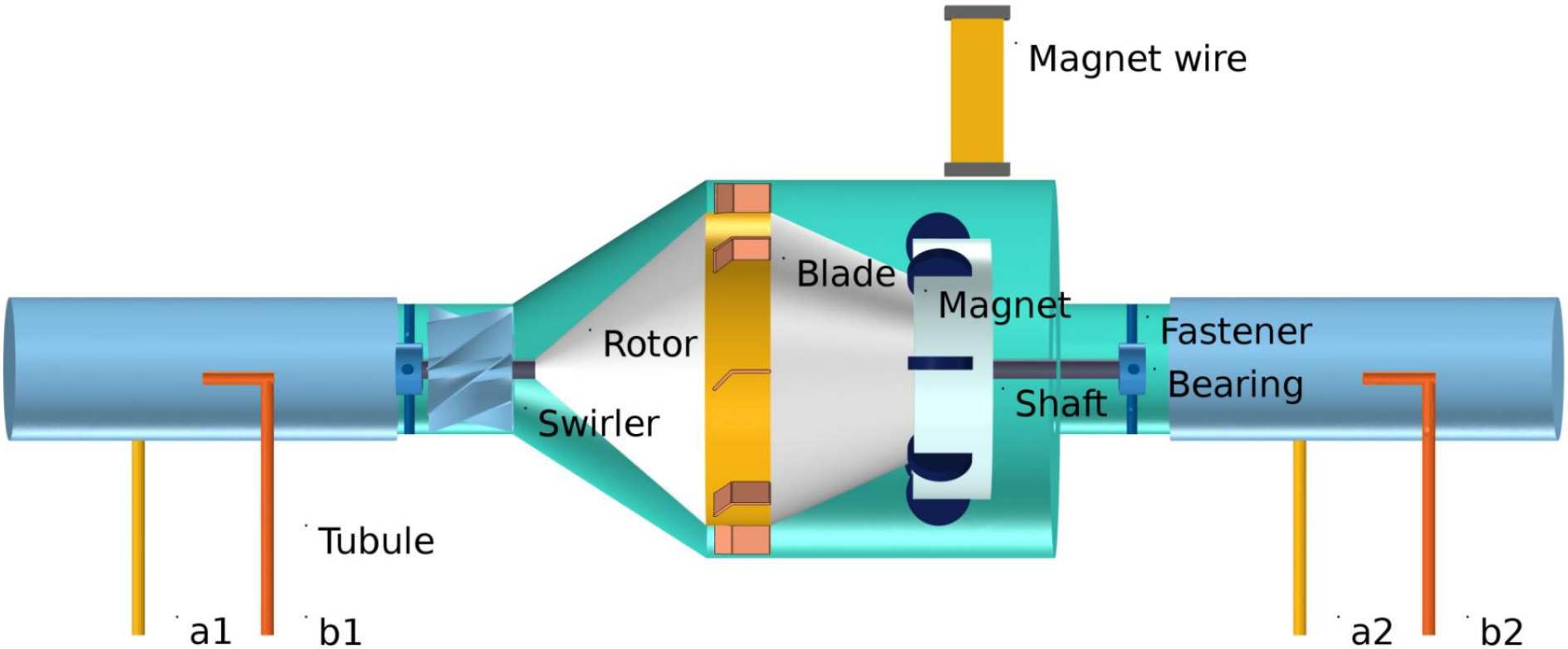
$\Gamma_л$ **- circulation around the blades;** ds **- the skeleton element of the profile;**

$\gamma(s)$ **- specific density of vortices, placed blade profiles;**

$$\gamma = \rho g;$$

$$\upsilon_u = \sqrt{2gH},$$

$\boldsymbol{a_1}, \boldsymbol{a}$ $\quad p = \rho g H,$ $\qquad$ $\boldsymbol{b_1}, \boldsymbol{b_2}$: $\quad P = \rho g H + \dfrac{p\vartheta^2}{2},$



EXPERIMENTAL RESEARCHES

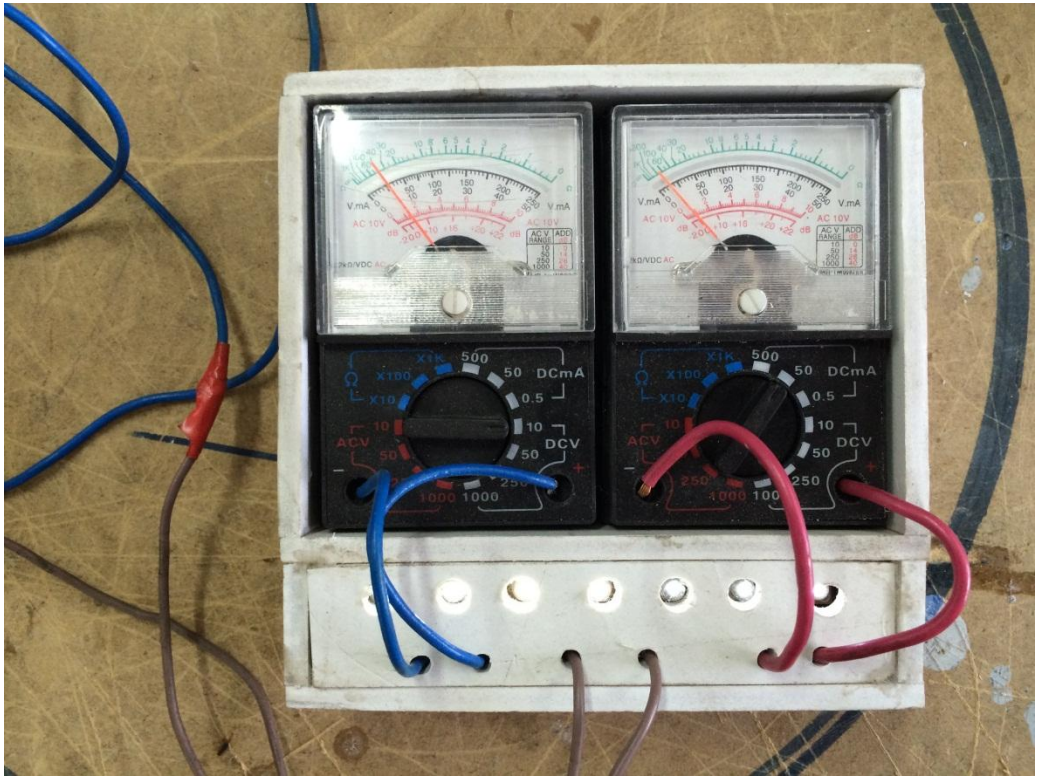
The experimental device applied during the studies

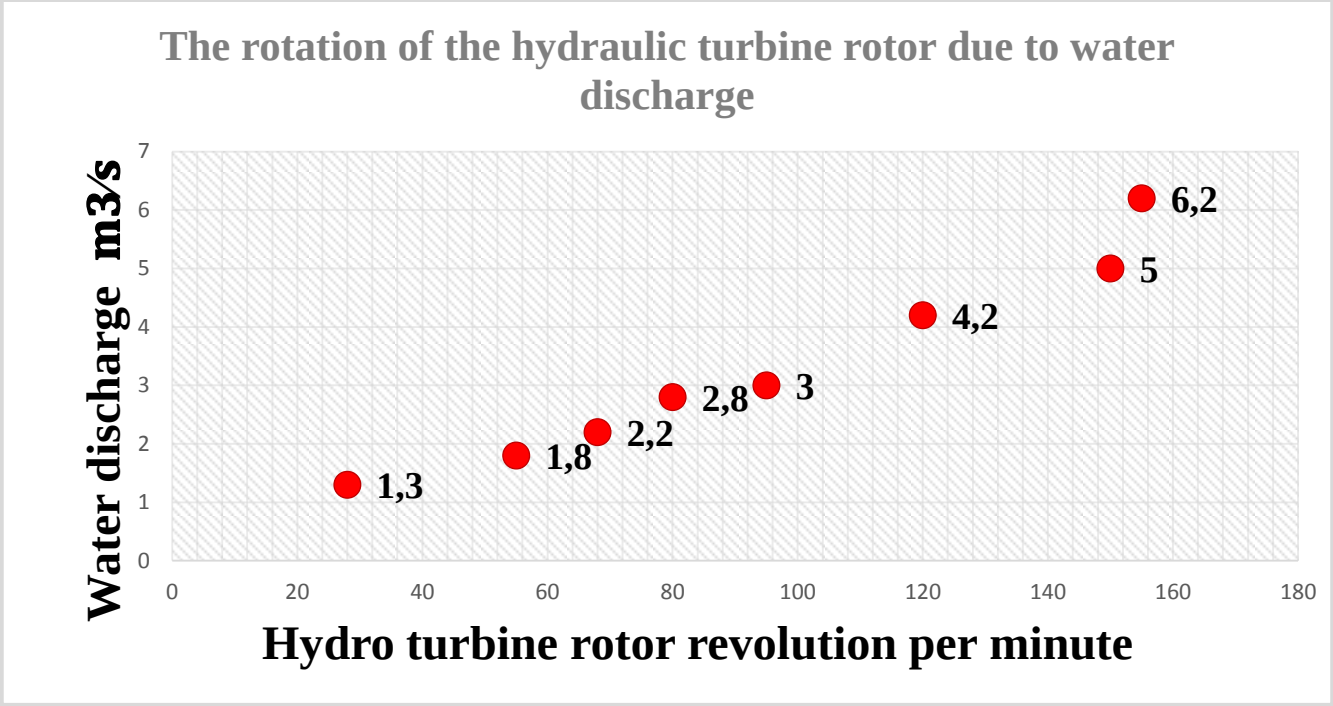
Hydro turbine values regarding water discharge

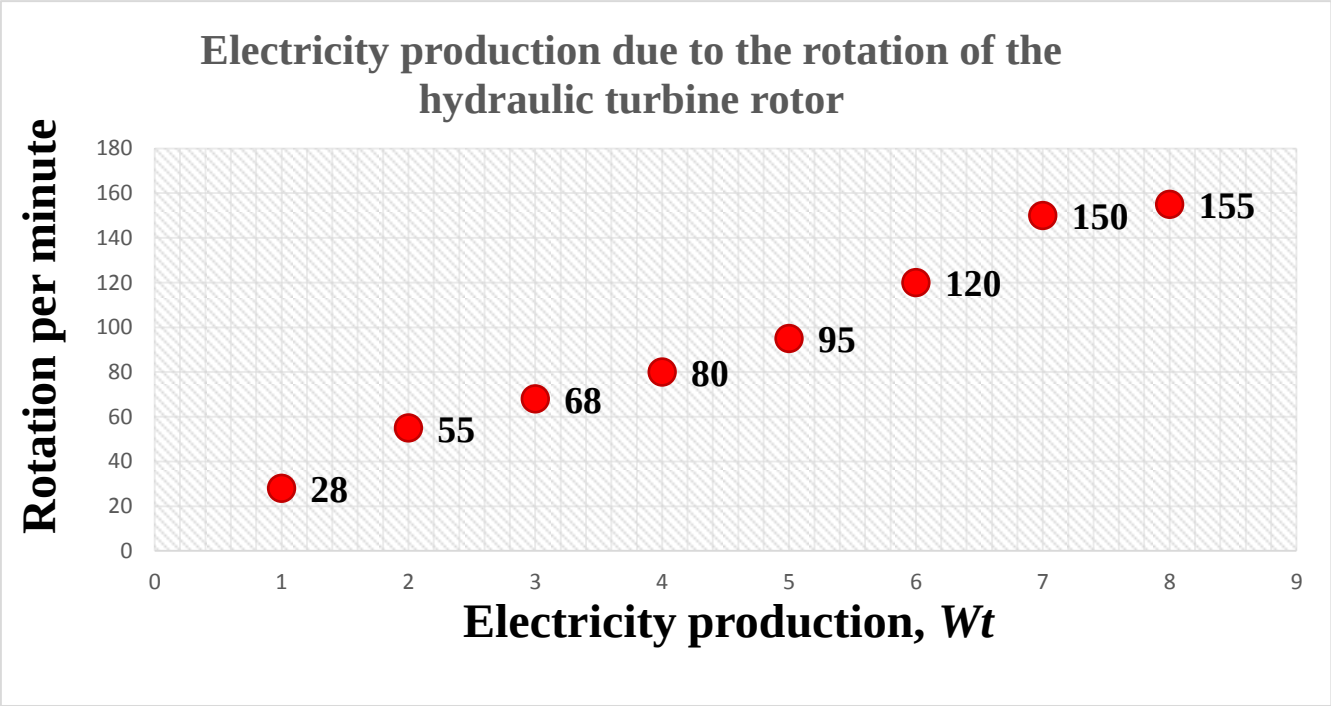
№	Water discharge m^3/s	Flow velocity *m/s*	Hydro turbine rotor revolution per minute	Electricity production *Wt*
1	0.0013	0.17	28	0.5
2	0.0018	0.23	55	0.7
3	0.0022	0.28	68	1.4
4	0.0028	0.36	80	4.5
5	0.003	0.38	95	5
6	0.0042	0.535	120	6.2
7	0.005	0.64	150	8
8	0.0062	0.8	155	8.1

Tachometer

Multimeter




The rotation of the hydraulic turbine rotor due to water discharge
Water discharge m3/s
Hydro turbine rotor revolution per minute
0
1
2
3
4
5
6
7
0
20
40
60
80
100
120
140
160
180
1,3
1,8
2,2
2,8
3
4,2
5
6,2


Electricity production due to the rotation of the hydraulic turbine rotor
Rotation per minute
Electricity production, Wt
0
20
40
60
80
100
120
140
160
180
0
1
2
3
4
5
6
7
8
9
28
55
68
80
95
120
150
155

Flow turbine №2

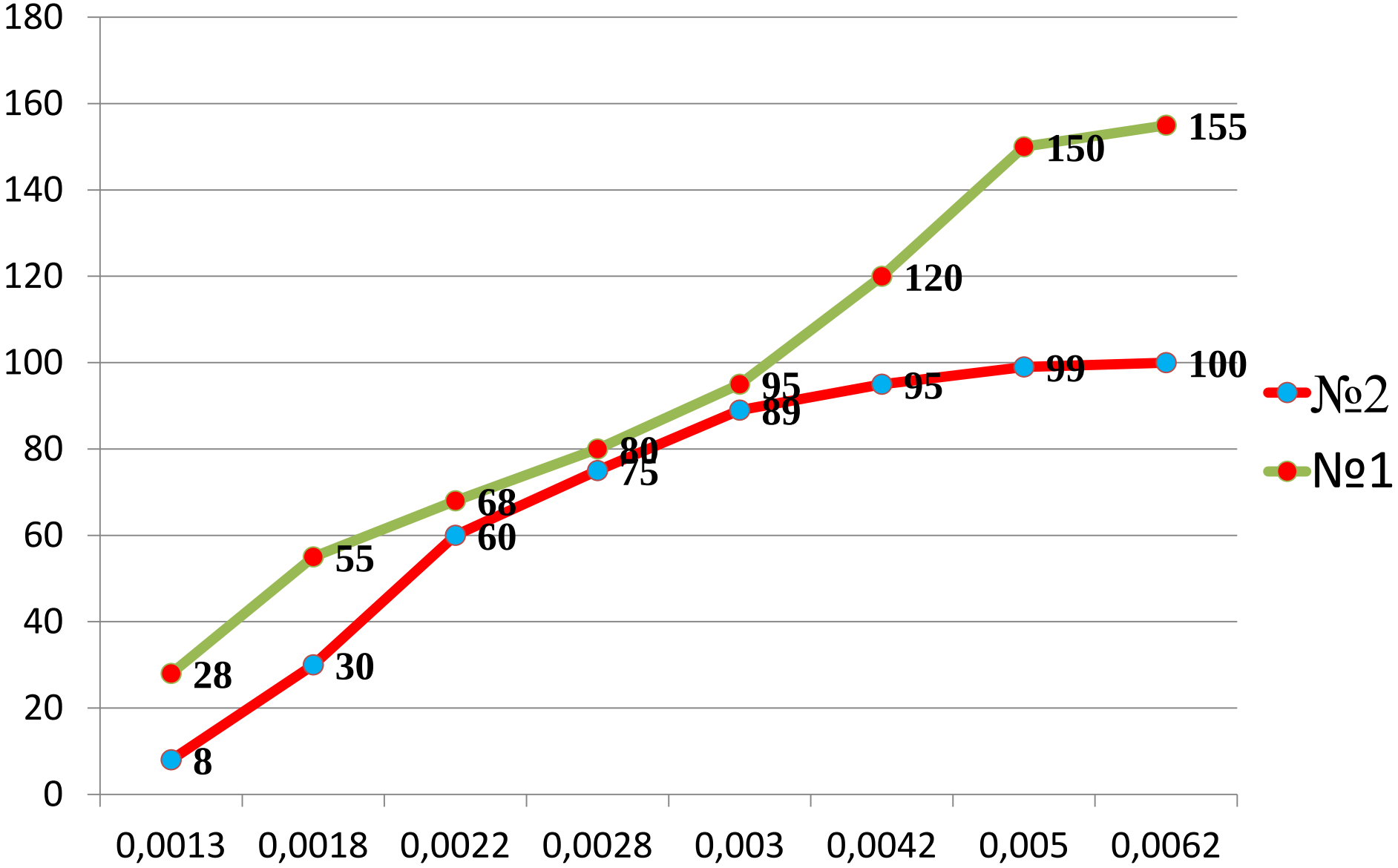
A general view of the flow turbine

Constituent parts of hydro turbine

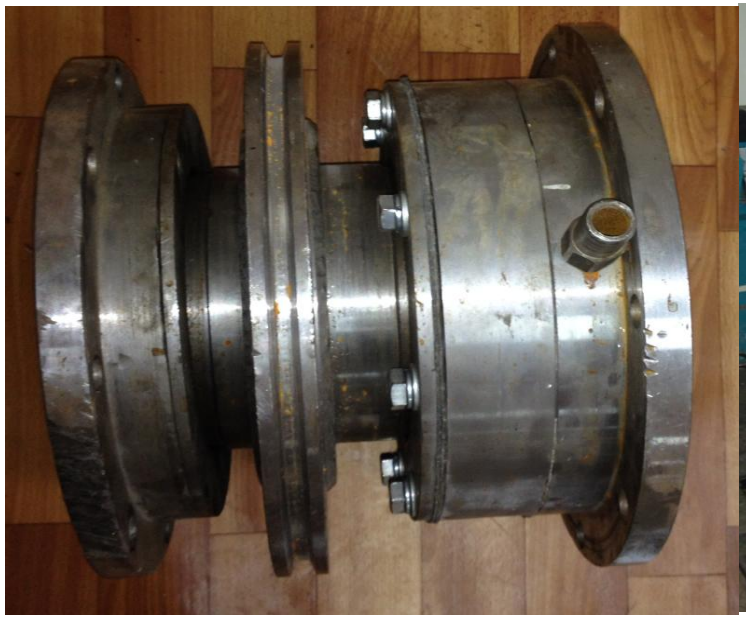
Hydro turbine values regarding water discharge

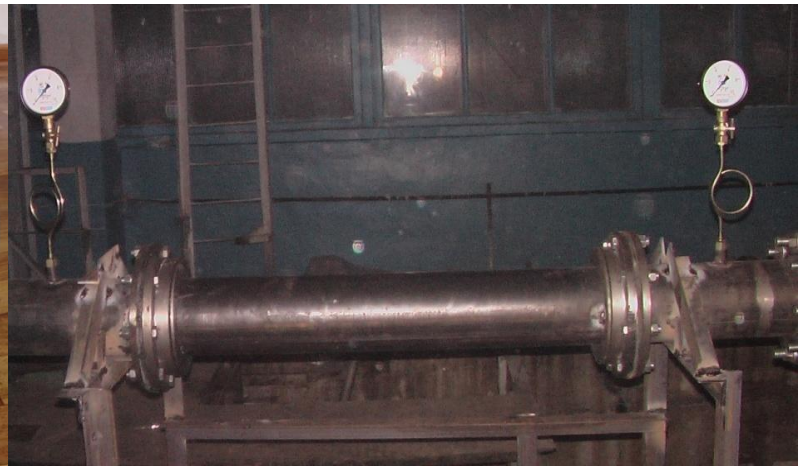
№	Water discharge m^3/s	Flow velocity *m/s*	Hydro turbine rotor revolution per minute	Electricity production *Wt*
1	0.0013	0.17	8	0
2	0.0018	0.23	30	0.5
3	0.0022	0.28	60	1.3
4	0.0028	0.36	75	4.2
5	0.003	0.38	89	4.7
6	0.0042	0.535	95	5
7	0.005	0.64	99	5.1
8	0.0062	0.8	100	5.2

Comparison of the characteristics of two models



Previous models of hydro turbines





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Thank you for attention!

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