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APPLICATION OF SIMILARITY THEORY IN MATHEMATICAL MODELING OF HYDRAULIC PROCESSES.

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Abstract: This thesis studies the theory of similarity as the main methodological tool in the mathematical modeling of complex hydraulic processes. The theory allows for the analysis of real systems using scaled models in laboratory conditions. The main goal of the research is to optimize the calculation volume by reducing hydrodynamic equations to dimensionless form using such criteria as Reynolds, Froude, Euler. The correct application of similarity theory substantiates methods for extrapolating experimental results to real conditions with high accuracy. The obtained conclusions have important practical significance in the design of hydraulic structures and increasing the efficiency of computational hydrodynamic (CFD) models.

Keywords: Reynolds, Froude, Euler, physical modeling, geometric similarity, kinematic similarity, dynamic similarity.

Introduce. There are mainly two types of modeling of hydraulic processes (events): mathematical and physical. There are various methods of modeling hydraulic processes. Of these, the one related to hydraulics is the physical modeling method. In physical modeling, mainly geometric, kinematic, and dynamic parameters are studied. Such processes include the movement of fluid flow bound to a solid wall and the movement of sediments in it, etc.

Methodology. *Geometric similarity.* For two fluid flows to be geometrically similar, there must be a constant ratio between their mutual length and dimensions.

$$\frac{l_a}{l_m} = \alpha_l = const,$$

There: α_l - the length scale shows how many times the length measurement l_m of this model is reduced compared to the original length measurement l_a .

Kinematic similarity. If in a flow in the natural state and in a flow in the model the fields of velocity and acceleration are similar and at the same points in the same flows the velocities u and accelerations a are in the same ratio at the corresponding time, then the flow of two liquids is kinematically similar.

$$\frac{u_a}{u_m} = \frac{\frac{l_a}{t_a}}{\frac{l_m}{t_m}} = \frac{l_a}{l_m} \cdot \frac{t_m}{t_a} = \frac{l_a}{l_m} \cdot \frac{1}{\alpha_t} = \frac{\alpha_l}{\alpha_t} = \alpha_u;$$

$$\frac{\alpha_a}{\alpha_m} = \frac{\alpha_l}{\alpha_t^2} = \frac{\alpha_u^2}{\alpha_l} = \alpha_a.$$

At the same time, they remain constant in terms of total volume:

$$\alpha_u = const$$

$$\alpha_a = const$$





Kinematic similarity is performed only in the presence of geometric similarity. $\left(\frac{t_a}{t_m} = \alpha_t = \text{const} - \text{time scale}.\right)$

Dynamic similarity. Newton's law of similarity. If the forces acting on the fluid particles at similar points in the model and in reality are the same and the vectors of the applied forces form geometrically similar polygons, then such forces are called dynamically similar.

$$\alpha_F = \alpha_\rho \cdot \alpha_l^2 \cdot \alpha_w^2,$$

or

$$\frac{\alpha_F}{\alpha_\rho \cdot \alpha_l^2 \cdot \alpha_w^2} = 1,0.$$

The above formula is called Newton's law of similarity, expressed through scales.

O. Reynolds's law of similarity. According to this, during the movement of a liquid, the friction force in it prevails over other forces.

$$\frac{u_a \cdot l_a}{\nu_a} = \frac{u_m \cdot l_m}{\nu_m} = Re.$$

According to:
Speed

$$\frac{u_a}{u_m} = \alpha_u = \alpha_l^{-1,0};$$

water consumption

$$\frac{Q_a}{Q_m} = \alpha_Q = \alpha_l;$$

Time

$$\frac{t_a}{t_m} = \alpha_t = \alpha_l^{-3};$$

hydraulic slope

$$\frac{J_a}{J_m} = \alpha_J = \alpha_l^{-3};$$

Results and discussions. Problem. Study of the change in velocity of a sharply expanding pipe of H caliber, all parameters of which are given in Fig. 1, based on the theory of similarity.

We solved this problem using the geometric similarity theory. That is, we have a constant Reynolds number, we took the pipe scales at scales 1:1, 1:4 and 1:10 relative to H.

Given:





Name	Expression	Value	Descriptive
H	10[cm]	0.1 m	
h1	H/4	0.025 m	
h2	H/10	0.01 m	
Re	300	300	
nyu	15e-6[m^2/s]	1.5E-5 m ² /s	
U1	Re*nyu/H	0.045 m/s	
U2	Re*nyu/h1	0.18 m/s	
U3	Re*nyu/h2	0.45 m/s	

Figure 1. Given parameters.

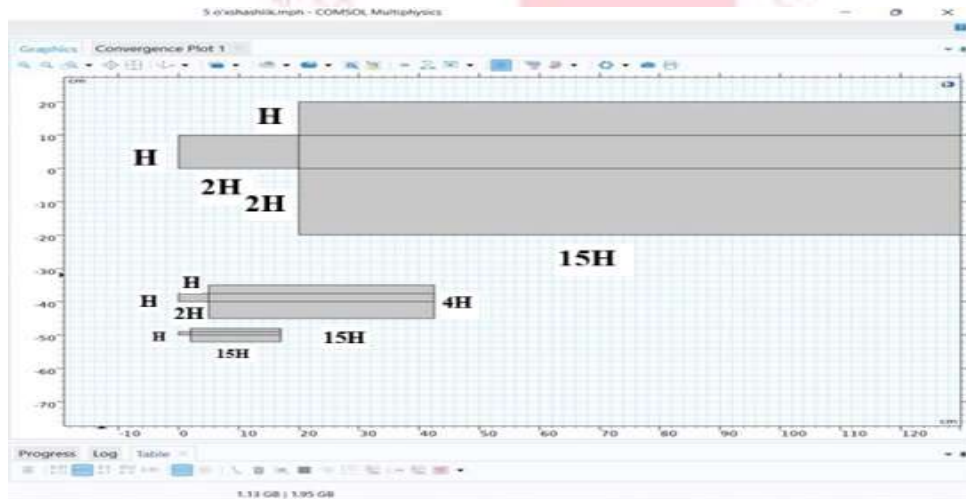


Figure 2. Geometric figure constructed based on the above parameters.

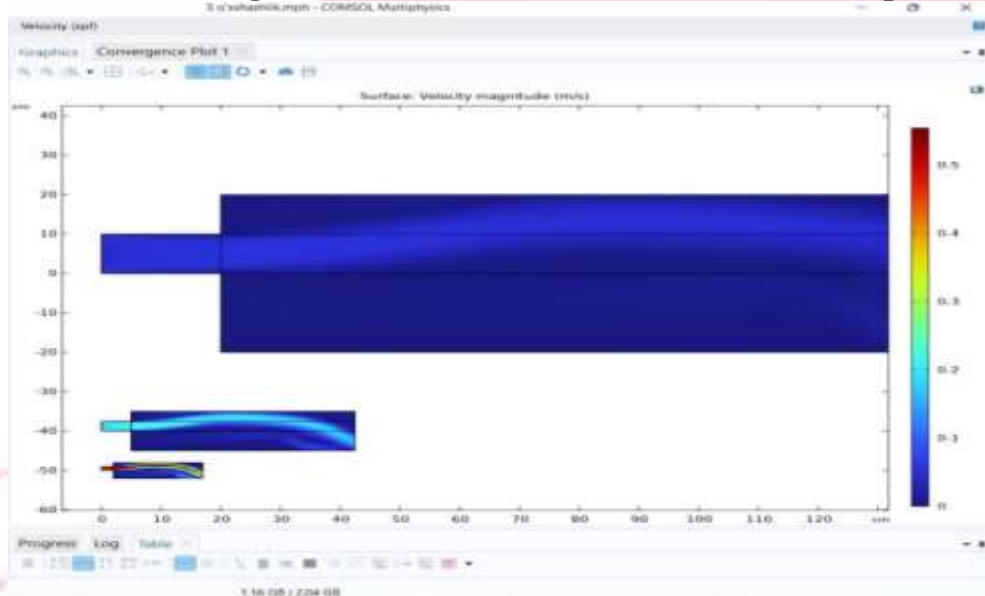


Figure 3. Speed isolines.



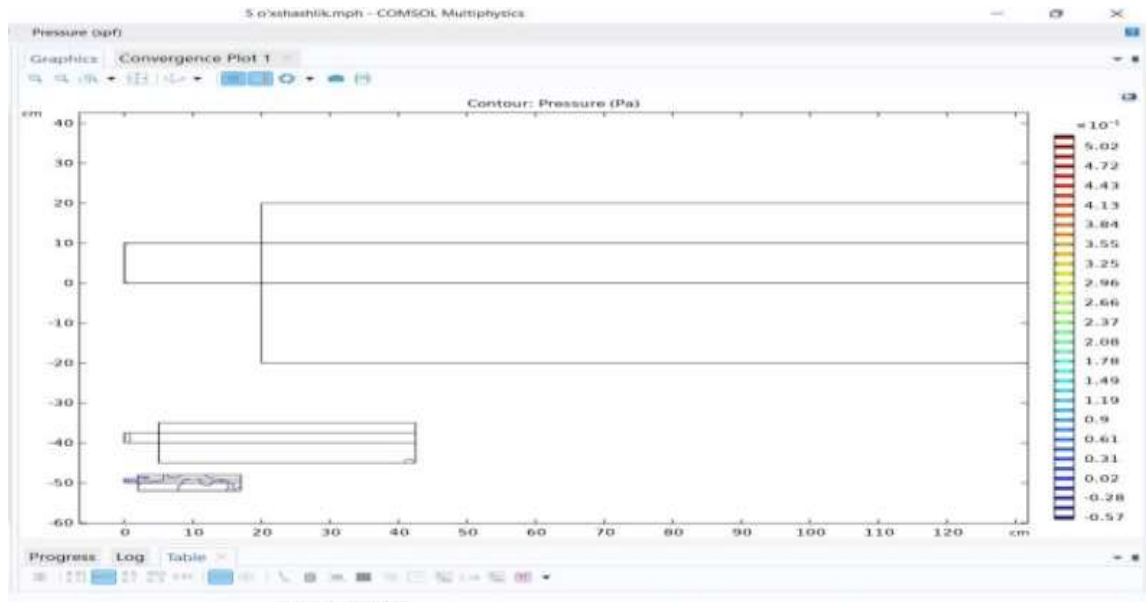


Figure 4. Graph of pressure change.

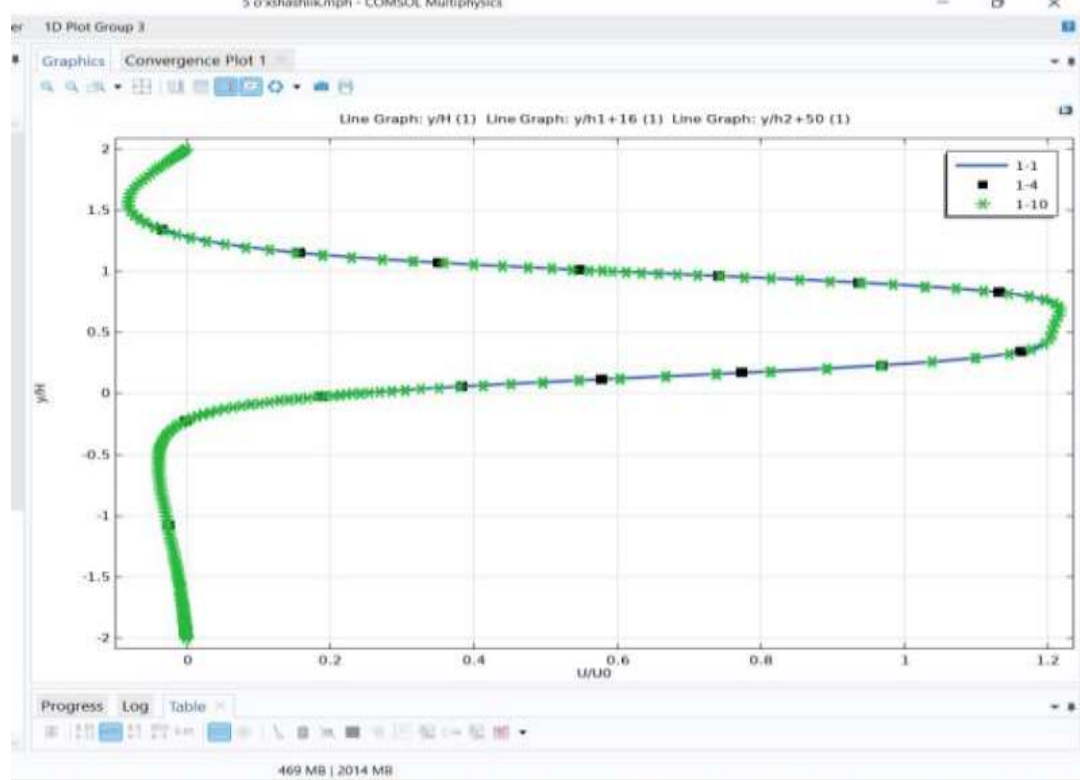


Fig. 5. Graph of velocity change in H caliber.



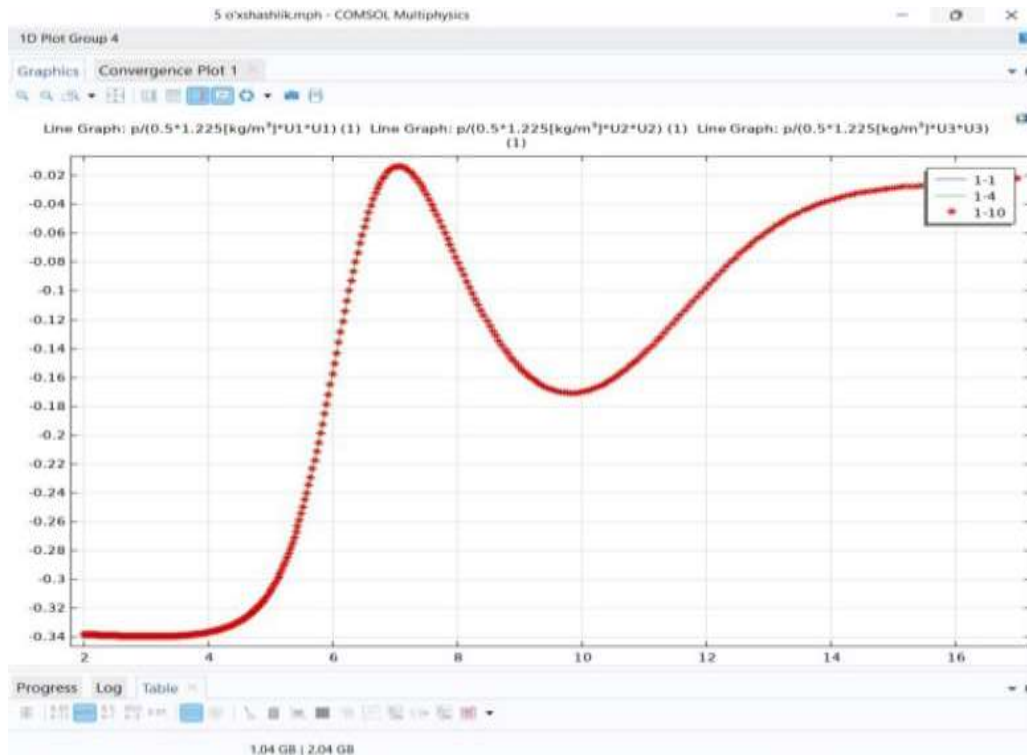


Figure 6. Graph of pressure change in H caliber.

Conclusion. The application of similarity theory in the mathematical modeling of hydraulic processes is the most reliable method for solving very complex water flow problems. This theory allows, instead of a complete study of real (large) hydraulic systems, to conduct experiments on their reduced models. The main goal is to significantly simplify calculations by determining the basic laws of water movement using criteria such as Reynolds, Froud, and Euler. This significantly reduces computational work in modeling. The final conclusion is that similarity theory is the main bridge that allows you to easily and accurately apply the data obtained in the laboratory to real structures. Therefore, this approach has great practical value for reducing costs in the design of water structures and networks and increasing the efficiency of the project.

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