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THE PROBLEM OF FLUID FLOW FROM A CHANNEL WITH A SIDE OUTLET

Babazhanov Yuldash Tilavovich
Candidate of Physical and Mathematical Sciences, Karshi State University, Republic of Uzbekistan, Karshi city

Babazhanova Iroda Yuldashevna
Military Aviation Institute, Republic of Uzbekistan, Karshi city

Zaripov Musliddin Bahodir ugli, Hazratov Alisher Rahmatillo ugli
Karshi Engineering Economics Institute, Republic of Uzbekistan, Karshi city

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Abstract: The article investigates the process of water distribution along the canal routes. The forms of these channels that ensure vortex-free flow are determined. This problem is reduced to solving the issue of the flow of an ideal incompressible fluid in a channel with a side outlet.

A jet model of planar fluid flow in a channel with a side outflow is proposed. Analytical formulas for velocity distribution before and after the outflow are obtained, which allow regulating water supply to consumers.

Keywords: channel, liquid, velocity, jet model, outflow, water, flow, incompressible.

Introduction.

The water supply for many feeder channels is carried out through a non-physical intake from rivers or main canals. River waters carry a large amount of suspended particles of sand or. When the flow velocity decreases (in stagnant areas), suspended particles settle intensively, reducing the live cross-section of the riverbed and complicating water intake. For example, from the Amu Darya River to the intake canal (the Karshi main canal), 10-12 million cubic meters of sediment enter annually, which hinders significant water intake [3,5].

To ensure a constant water supply to the channel during low water levels and in dry periods, it was necessary to implement measures for regulating the riverbed. Therefore, the shape of the drainage channel, which ensures a non-turbulent flow, plays a significant role in the operation and design of non-pressurized water intakes. The study of such processes is of great importance in preventing deformation in the area of the earth channel division [9,10].

The solution to the issues of water distribution in channel beds and determining the shape of these channels that ensures non-cavitating and non-turbulent flow boils down to solving the problem of the flow of an ideal incompressible fluid in a channel with a lateral outlet [1,2].

The process of fluid flow from a channel through an opening in a hydraulic system was studied by Mohammad and Cill [7]. In this work, propose an analytical formula for calculating the flow through an orifice. Here, the process of drainage and the geometric characteristics of the flow in the discharge channel are not considered. The work [6] investigates the problem of the flow of an ideal fluid in a channel of constant cross-section with lateral outflow using the method of stream theory. [2]

The work [3] addresses the problem of flow division in a channel with lateral discharge, determining the shape of the drainage channel that ensures smooth flow. In this work, the width of the main channel remains unchanged. In the work [3,4], an algorithm has been developed for the numerical determination of flow parameters and the jet compression coefficient during the lateral discharge of liquid from a semi-restricted flow through a nozzle of finite depth, positioned at an arbitrary angle to the direction of the main flow.

A comprehensive bibliography and review of the results of similar studies on all types of flow division problems can be found in the works. [2,6,7]

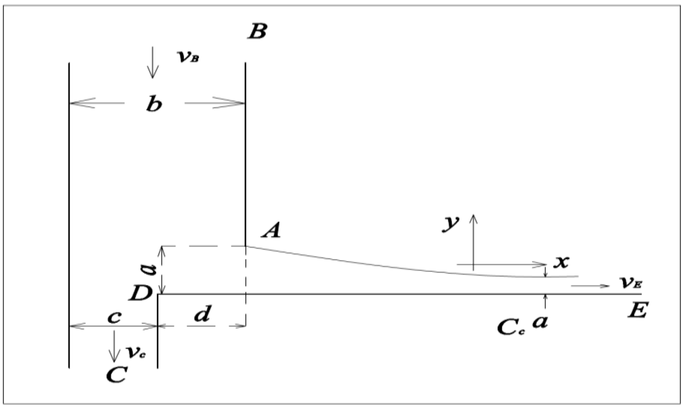
Numerous numerical calculations for problems concerning the steady motion of an ideal fluid in various channels are presented in the works [8,9,12].

In these works, the shape of the free surface that ensures non-vortex flow in the channel with outflow is not defined when determining the hydrodynamic and geometric parameters of the flow.

Materials and Methods.

Let's consider a two-dimensional problem of fluid flow from a channel with a lateral outlet on a plane.

a)



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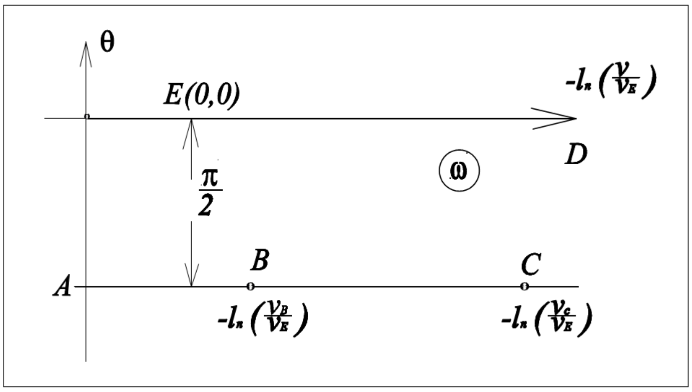

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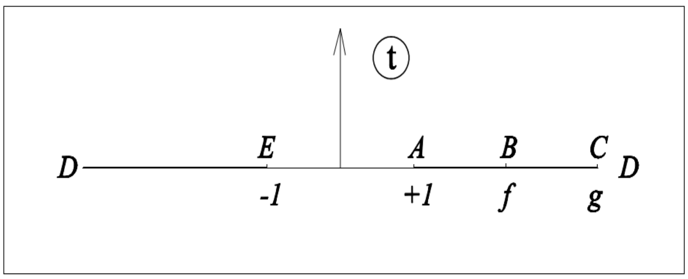

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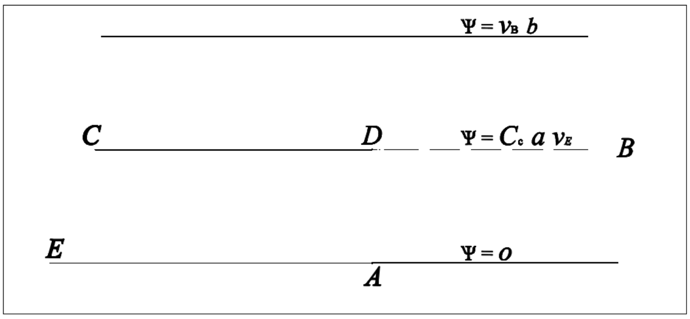

Fig.1

a) liquid flow pattern

b) area of the velocity hodograph

c) auxiliary plane

d) plane of complex potential

The speed of the incoming flow in a channel with a width of ϑ_B . A part of the flow enters the infinitely long side section through an opening of width a and reaches point $C_c a$ after the flow narrows down to a at infinity. The rest of the flow continues in a channel with a width of C and reaches a final speed of ϑ_C (Fig. 1.a).

The difference between the initial and final width of the channel is denoted by d . Clearly, determining the jet compression coefficient C_c and the relative velocity $\frac{\vartheta_C}{\vartheta_B}$ as functions of the channel geometry is the main objective of this study. The geometry of the channel boundary is expressed by the relationships a/b and d/b , as well as C_c and $\frac{\vartheta_C}{\vartheta_B}$, derived from these relationships, i.e.

$$C_c = S_1\left(a/b, d/b\right) \text{ и } \frac{\vartheta_C}{\vartheta_B} = S_2\left(a/b, d/b\right)$$

To determine these functions, we need to define the complex potential function ω as a function of Z .

Let's move on to solving the problem using the Zhukovsky method [2] for which we will consider the function

$$\omega = -\ln\left(\frac{1}{\vartheta_E}\frac{dw}{dz}\right) = -\ln\frac{v}{\vartheta_E} + i\theta \text{, (1)}$$

here ϑ - liquid speed module

θ - the angle of velocity with the *x*-axis.

Along the free boundary *AE*, we have $V = V_E$, from where $\ln\frac{V_E}{V} = 0$ is located. The area of the function ω change is shown in Fig.1b. The region of change ω forms a triangle, with vertex *D* being removed to infinity.

The representation of triangle *DEA* onto the upper half-plane *t* is carried out using the Christoffel-Schwarz formula:

$$\omega = M\int (t-t_1)^{\frac{\alpha_1}{\pi}-1}(t-t_2)^{\frac{\alpha_2}{\pi}-1}...(t-t_n)^{\frac{\alpha_n}{\pi}-1}dt + N \text{ , (2)}$$

here $\alpha_1\pi,\ \alpha_2\pi...\alpha_n\pi$ - the internal angles of a polygon in plane ω :

M and *N* are complex constants.

The angles of triangle *DEA* are equal to 0, π/2, π/2. For the correspondences of points indicated in figures 1 (b and c), formula (2) gives:

$$\omega = M\int \frac{dt}{\sqrt{(t-1)(t+1)}} + N = M\int \frac{dt}{\sqrt{t^2-1}} + N \text{ т.е,}$$

$$\omega = Marcht + N$$

The semi-infinite application – the ω -plane now becomes the upper half of the t-plane. In this plane, a point can be placed arbitrarily. Points *A* and *E* are placed on the horizontal axis at equal distances from the origin and are assigned the values +1 and -1, respectively, while point *D* is positioned at infinity as shown in fig.1c. The values of constants *M* and *N* can be determined by simultaneously substituting the values of ω and t for points *A*, *E*, and *D* in successive steps. In this way

$$\omega = \frac{1}{2}archt - i\frac{\pi}{2}.$$

The parameters $\frac{C}{B}$, $\frac{\vartheta_B}{\vartheta_E}$ are given, where b and c are the widths of the channel at points *B* and *C* respectively; $\frac{\vartheta_B}{\vartheta_E}$ represents the velocities at points *B* and *E* respectively (Fig.1a).

We need to determine $\frac{Q_C}{Q_B}$ in relation to $\frac{d}{b}$, the flow change coefficient C_C in relation to $\frac{a}{b}$, where *d* and *α* are shown in Fig.1a.

From (1) and (2) it follows that:

$$\frac{\vartheta_E dz}{dw} = -ie^{\frac{1}{2}}\text{archt} \text{ (3)}$$

From the last formula, expressions for the velocities at points *B* and *C* can be obtained:

$$\frac{\vartheta_B}{\vartheta_E} = e^{-\frac{1}{2}\text{archt}} \text{ (4)}$$

$$\frac{\vartheta_C}{\vartheta_E} = e^{-\frac{1}{2}\text{archg}} \text{ (5)}$$

The conformal mapping of the plane *w* (Fig.1d) onto the upper half-plane t is carried out by the function

$$w = \varphi + i\psi = M'\int \frac{dt}{(t-f)(t-g)(t+1)} + N' \text{ (6)}$$

We differentiate *w(t)* with respect to *t*, from (6) we obtain:

$$\frac{dw}{dt}=\frac{M'}{(t-g)(t-g)(t+1)} \quad (7)$$

The fluid flow in section *B* is defined as the increase in the imaginary part of the function *w(t)* when encircling point $t=f$:

$$Q_B=\vartheta_B\cdot b=-\int_{t=1}\left(\frac{dw}{dt}\right)dt$$, откуда

$$M'=\frac{\vartheta_B b(g-f)(f+1)}{\pi}. \quad (8)$$

Substituting the value of *M′* into (7), we get:

$$\frac{dw}{dt}=\frac{\vartheta_B b(g-f)(f+1)}{\pi(t-f)(t-g)(t+1)} \quad (9)$$

Using formulas (3) and (9), we transition to the physical plane of flow.

$$Z(t)=\frac{1}{\vartheta_E}\int e^w\frac{dw}{dt}dt$$ or

$$\frac{dz}{dt}=\frac{dw}{dt}\frac{dz}{dw}=\frac{ib\vartheta_B(g-f)(f+1)}{\pi\vartheta_E(t-f)(t-g)(t+1)}\cdot e^{\frac{1}{2}arccht} \quad (10)$$

The width of the channel in the section is defined as the increment of the imaginary part $Z(t)$ when traversing *t=f;*

$$b=\frac{\vartheta_B b}{\vartheta_E}e^{\frac{1}{2}\mathrm{ar}chf} \quad (11)$$

In the same way, you can find the width *C*:

$$C=\frac{\vartheta_B b}{\vartheta_E}\frac{(f+1)}{(g+1)}\cdot e^{\frac{1}{2}\mathrm{arcch}g} \quad (12)$$

or

$$\frac{c}{b}=\frac{(f+1)}{(g+1)}\cdot e^{\frac{1}{2}(\mathrm{arcch}g-\mathrm{arcchf})} \quad (13)$$

From (11) one can determine *f*:

$$f=ch\left[\ln\left(\frac{\vartheta_E}{\vartheta_B}\right)^2\right] \quad (14)$$

From Fig.1a, it is clear that:

$$Q_E=Q_B-Q_C=C_c a\vartheta_E, \quad (15)$$

where C_C is the compressibility coefficient of the flow. It follows from (15):

$$C_c a=\frac{\vartheta_B}{\vartheta_E}b-\frac{\vartheta_C}{\vartheta_E}c \quad (16)$$

From Fig.1a, we show that:

$$a = C_c a + Jm\int_{-1}^{+1}\frac{dz}{dt}dt = C_C a + \frac{\vartheta_B b(g-f)(f+1)}{\pi\vartheta_E}\int_{+1}^{1}F(t)\cdot e^{\frac{1}{2}\mathrm{arch}t}dt\,,\ (17)$$

here $F(t) = \dfrac{1}{(t+f)(t-g)(t+1)}$.

Consequently, the compressibility factor is determined by the following formula:

$$C_c = \frac{\frac{\vartheta_B}{\vartheta_E} - \frac{\vartheta_C}{\vartheta_E}\frac{c}{b}}{a/b}.\ (18)$$

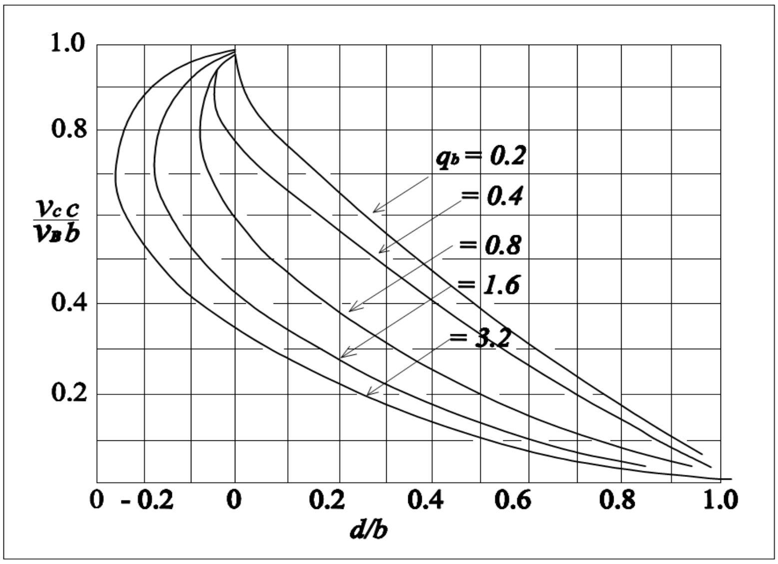

Fig. 2 *Characterization of the outflow of an infinite lateral line*

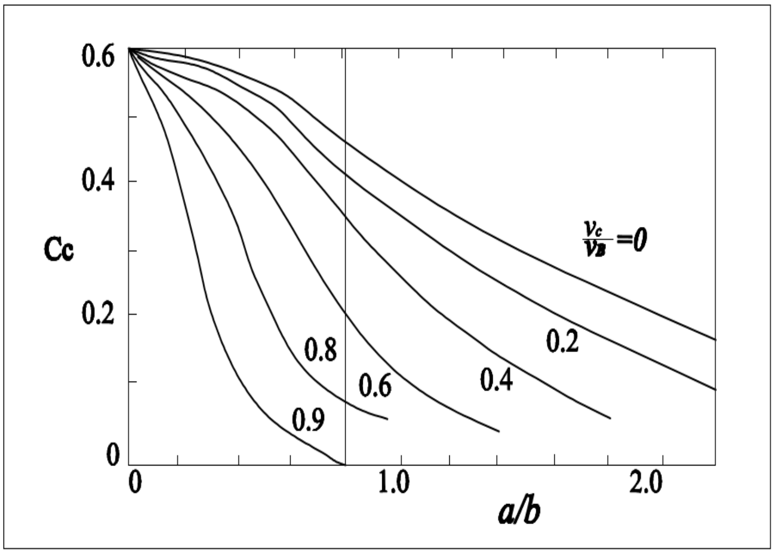

Fig. 3. *Dependence of the flow coefficient on the width of the opening.*

Results and Discussion

The values of *A* and *B* must satisfy the equations (16) — (18). The numerical calculations of equations (17-18) yield the graphs presented in Figures 2 and 3. Graphs certainly illustrate the conditions of flow more clearly than the equations, showing the possibilities based on the assumptions made.

In Figure 2, the relationship $\frac{d}{b}$ is shown as both negative and positive, as well as positive. The minus sign simply indicates that the width of the channel after the diversion is greater than b. Then $\frac{a}{b}$ approaches zero, resulting in the limit value $C_C = 0,61$, as shown in Figure 3.

Conclusion

The problems of water distribution along the channel route reduce to the problem of the motion of an incompressible ideal fluid in a channel with lateral outflow. Such problems are easily solved using the method of conformal mapping, that is, the method of stream theory. The article presents analytical formulas for velocities at all sections of the channel.

Calculations of hydrodynamic parameters of the flow are presented depending on the changes in the velocity of the incoming flow and the geometry of the channel. The graphs illustrate the relationship between the jet compression ratio and the flow rate of the drainage channel in relation to the incoming flow velocity and the channel geometry.

As the speed of the incoming flow approaches zero, the process corresponds to the outflow of liquid from a vessel, approaching 0.61.

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