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PRINCIPLE OF MAXIMUM DISCHARGE

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It was shown in [1] that discharge in a swirl sprayer with a Borda mouthpiece is based on conservation laws and does not agree with the value established by means of the PMD. This conclusion casts doubt on the overall validity of the PMD for determining flow parameters in centrifugal nozzles, spillways, and similar flow channels.

Stepanov (see [2]) asserts that the results presented in [1] were erroneous. However, this was actually not the case that was made. For example, it was stated the the flow scheme examined in [1] was erroneous. Without proving this, the author then proceeds to consider a different scheme which bears no relationship to the flow in a swirl sprayer.

Stepanov writes: "A suction force exists at sharp edges in a continuous potential flow, and this force should be incorporated into Eq. (15)." However, in [1] the object study was not a continuous potential flow, but a potential flow with a closed separation zone (region) which arose at the sharp inside edge of a cylindrical nozzle. The structure of the flow in this region is determined solely by the requirement that the velocity be finite and, thus, that there be no suction force. The flow structure in a closed separation region cannot be determined unambiguously within the model of an ideal incompressible fluid. This fact, however, does not preclude the effective use of conservation laws.

Stepanov goes on to write that "As is known from the hydraulic theory of spillways with a wide ramp...the PMD corresponds to the critical flow and follows from the Euler equation." This statement is accurate only in the sense that, under certain conditions and in certain cases, the PMD makes it possible to approximately determine flow parameters. However, it is possible to cite numerous examples where the PMD gives erroneous results for flows in spillways and similar channels.

Let us examine the flow in the spillway depicted in Fig. 1. Discharge across an infinitesimally thin horizontal ramp OC occurs from an infinitely deep reservoir with a quiescent liquid. Meanwhile at an infinitely distant point A on the free surface, the level of the quiescent liquid is no greater than the level H of the ramp OC. Within the framework of the model of an ideal incompressible fluid, it is natural to suggest that the flow is a potential flow except for a closed separation region which develops in the neighborhood of the sharp edge O. There is no suction force present (the boundary streamline of the separation zone has a horizontal tangent at point O). The structure of the flow in this region is unimportant to the subsequent discussion. Uniform flow is presumed to take place at infinity above the ramp. The discharge down such a spillway can be found by means of the laws of conservation of mass, momentum, and energy. As a result, we have

$$Q = uh = \frac{2}{3\sqrt{3}} H\sqrt{gH}, \quad u = \frac{2}{\sqrt{3}}\sqrt{gH}, \quad h = \frac{1}{3}H.$$

If we use the PMD, we find that

$$Q = \frac{2}{3}\sqrt{\frac{2}{3}} H\sqrt{gH}, \quad u = \sqrt{\frac{2}{3}}\sqrt{gH}, \quad h = \frac{2}{3}H.$$

Novosibirsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 4, pp. 105-106, July-August, 1991. Original article submitted March 23, 1990.

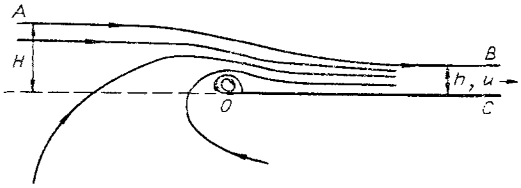

Fig. 1

It is not hard to see that use of the PMD gives an erroneous result in the given case. In fact, the flow turns out to be supercritical, and its depth proves to be half as great as that predicted by the PMD.

Thus, Stepanov's statement that the "PMD...follows from the Euler equations" is erroneous.

It should be mentioned that there is no rigorous mathematical proof of the existence of a solution in the above example. However, the same can be said regarding all of the calculations performed by means of the PMD. Previous experiments involving flows with separation regions do not provide sufficient grounds for doubting the existence of the above-examined flow (at least we are not aware of any countervailing arguments), even though a rigorous proof of its existence is a very complex problem.

However, it is possible to cite an example of a flow for which such proof is available. The example can be found in [3], which studied the discharge of a heavy liquid from under a cover. In this case, exact values of the main flow parameters can also be obtained from the conservation laws, and they differ from the PMD results. In particular, the flow at the outlet turns out to be supercritical.

The author considers the assertion by G. Yu. Stepanov that [1] was in error to be completely without foundation.

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