# FORMULATION OF THE PROBLEM OF A STRONG EXPLOSION ON THE SURFACE OF A LIQUID

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## Abstract

## Full Text

## HYDROMECHANICS

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# FORMULATION OF THE PROBLEM OF A STRONG EXPLOSION ON THE SURFACE OF A LIQUID

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This note considers the formulation of the problem of the motion of a liquid of infinite depth caused by an explosion on the free surface. The explosion is assumed to be strong, i.e., the action of the explosion is determined by a single parameter and the accelerations of the liquid particles are much greater than the acceleration of gravity.

Since the velocity of the shock wave in water exceeds the velocity of expansion of the cavity by several orders of magnitude, one may assume, in studying the motion of the liquid, that the shock wave has gone off to infinity and that the compressibility of the liquid may be neglected.

**Fig. 1.** Shape of the cavity according to the data of work (1)

The determining parameters of this phenomenon are the following: $\rho_0$—the density of the liquid; $\rho_1$—the density of the surrounding medium ($\rho_1 \ll \rho_0$); $\gamma$—the adiabatic exponent for the surrounding medium; $\Pi$—a parameter characterizing the action of the explosion on the motion of the liquid.

The choice of the parameter $\Pi$ determines the formulation of the problem. In work ([1]), when considering the problem posed, the explosion energy $E_0$ was taken as the parameter $\Pi$. In this case the motion of the liquid depends on the dimensionless coordinates:

$$\xi = \left(\frac{\rho_0}{E_0}\right)^{1/4} \frac{x}{\sqrt{t}}, \qquad \eta = \left(\frac{\rho_0}{E_0}\right)^{1/4} \frac{y}{\sqrt{t}}.$$

A simple analysis of the resulting equation and of the conditions on the free surface reveals a singularity at the free boundary for $\xi = 0$; the cavity has the form shown in Fig. 1.

Along with the formulation considered, another formulation of the problem is also possible. As the parameter $\Pi$ characterizing the action of the explosion on the motion of the liquid, one takes $J_0$—the impulse received by the liquid during the explosion. In this formulation the motion of the liquid depends on the dimensionless coordinates:

$$\xi = \left(\frac{\rho_0}{J_0}\right)^{1/3} \frac{x}{\sqrt[3]{t}}, \qquad \eta = \left(\frac{\rho_0}{J_0}\right)^{1/3} \frac{y}{\sqrt[3]{t}}.$$

The problem of the motion of the liquid reduces to finding a harmonic function $\varphi(\xi, \eta)$ in the semi-infinite domain $D$, satisfying on the unknown boundary $\Gamma$ ($\eta = \zeta(\xi)$) the conditions:

$$\varphi_\xi^2 + \varphi_\eta^2 - \frac{2}{3}\left(\varphi + \xi\varphi_\xi + \eta\varphi_\eta\right) = 0,$$

$$\frac{\zeta - \xi\zeta'}{3} + \zeta'\varphi_\xi - \varphi_\eta = 0.$$

An additional condition is imposed on the harmonic function $\varphi(\xi, \eta)$:

$$\iint_D \varphi_\eta \, d\xi \, d\eta = 1.$$

In this formulation, the free surface at $\xi = 0$ remains smooth, and $\zeta_0 = \zeta(0)$ is nonzero.

In order to determine which of the two possible self-similar formulations of the problem of a strong surface explosion corresponds to reality, experiments carried out at the Institute of Hydrodynamics of the Siberian Branch of the Academy of Sciences of the USSR were processed. In these experiments an apparatus was used that made it possible, with an SKS-3 motion-picture camera, to film the process of formation and growth of the crater during an explosion. In a tank measuring $500 \times 500 \times 40$ mm, with transparent walls, a wire 40 mm long and 0.1 mm thick was placed on the surface of the water. The wire was directed perpendicular to the large faces of the tank and was exploded by means of the discharge of a capacitor bank of capacitance $55\,\mu$F at a voltage of 2.5 kV. Filming was carried out at a rate of 1250 frames per second. The appearance of the resulting crater is shown in Fig. 2. The absence of a singularity at the free boundary at $\xi = 0$ gives grounds for believing that the scheme of self-similar motion of the liquid with the determining parameter—the energy $E_0$—does not take into account the basic features of the motion.

**Fig. 2. Shape of the crater according to experimental data**

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Figure 2: Fig. 2. Shape of the crater according to experimental data

Fig. 3. Dependence of the crater diameter $d$ on time ($N$—number of frames)

Figure 3: Fig. 3. Dependence of the crater diameter $d$ on time ($N$—number of frames)

Next, an experimental curve was constructed for the dependence of the crater diameter on time. This dependence, on a logarithmic scale, is given in Fig. 3. The experimental points lie on a straight line with slope coefficient equal to 1/3.

**Fig. 3. Dependence of the crater diameter $d$ on time ($N$—number of frames)**

This fact confirms the validity of the self-similar formulation of the problem in which the impulse imparted to the liquid during the explosion is taken as the parameter determining the effect of the explosion on the motion of the liquid.

**Remark.** The energy $E$ possessed by the entire liquid at time $t$, in the impulse formulation, is expressed by the relation

$$E = \frac{J_0^{4/3}}{\rho_0^{1/3}} \frac{c}{t^{2/3}};$$

here $c$ is a dimensionless constant different from zero. If $c$ is a finite quantity, then the energy $E$ changes with time; if $c$ is infinite, then the energy $E$ is equal to infinity at any instant of time.

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## CITED LITERATURE

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*Note: Figure translations are in progress. See original paper for figures.*