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INTERACTION OF A PLANE SHOCK WAVE IN WATER WITH A THIN LAYER OF LOWER DENSITY

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UDC 536.6.011

A numerical analysis is conducted on the interaction of a plane shock wave in water with a thin layer of lower density, which is perpendicular to the wave front. Parameters are defined for the perturbed flow structure and for large-scale precursors, which arise ahead of the shock front. Possibilities are discussed of experimentally investigating this phenomena with a cylindrical shock wave using standard explosives.

The "thermal layer" effect occurs when a large-scale wedge-shaped or conical perturbation or "precursor" grows smoothly in time ahead of a shock front, which interacts with a thin flat layer or a cylindrical channel of lower density. Intense vortical motion occurs inside this precursor. As the characteristic dimensions of the precursor increase to values much larger than the thickness of the thermal layer (or channel), the latter stops playing a significant role. Thus, a small (in the limit, infinitely small) extended perturbation of the density leads to a basic and global rearrangement of the flow.

The thermal layer effect was discovered in the 1950s during investigation of a shock wave in gases. Recently it was investigated in some detail, both theoretically and experimentally (see [1] for example, which gives references to previous efforts). It was shown [2] that the same effect can take place in cases when the shock wave propagates in condensed matter. Here a simple equation of state with a constant adiabatic index for the thermal component [3] was used to model the condensed matter. There is interest in investigating the thermal layer effect experimentally. Here we apply the results of [2] to the specific case of an easily compressed material, namely water. We use the tabular equation of state calculated by G. S. Romanov and A. S. Smetannikov using methods similar to those described in [4]. The pressure function $p(e, \rho)$ is shown in Fig. 1. For densities $(\rho/\rho_0) > 1$, a cold component

$$p_c = \frac{\rho_0 c_0^2}{4}\left[(\rho/\rho_0)^{5.122} - (\rho/\rho_0)^{1.122}\right]$$

is added to the magnitude of the pressure, where ρ_0 and $c_0 = 1.5$ km/sec (the contribution of the cold component to the internal energy is also considered simultaneously in the equation of state).

We now present several results of a numerical calculation of the plane piston problem for a Mach number $M = 6.2$ for the basic shock wave, and a relative density $\omega = 0.25$ in the lower-density channel.

Institute of Dynamics of the Geosphere, Russian Academy of Sciences, Moscow. Translated from Inzhenerno-fizicheskii Zhurnal, Vol. 62, No. 2, pp. 217-219, February, 1992. Original article submitted June 17, 1991.

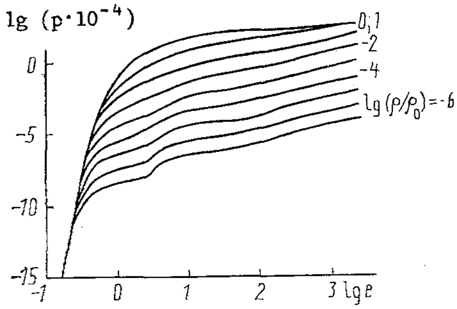

Fig. 1. Equation of state p(e, ρ) for water: p (bar); e (kJ/g).

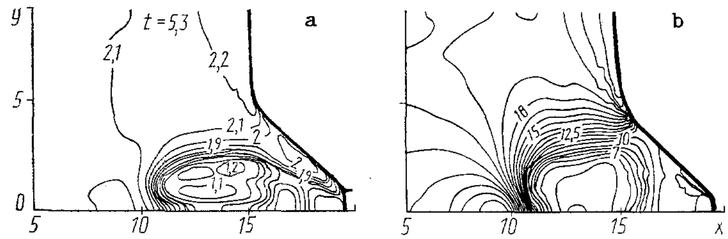

Fig. 2. Contours of a) density and b) pressure: M = 6.2 and ω = 0.25.

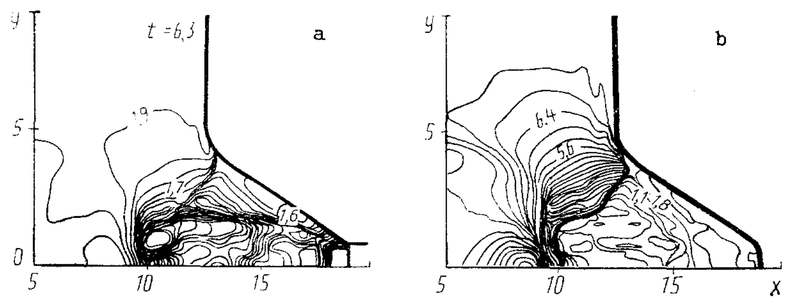

Fig. 3. Contours of a) density and b) pressure: M = 4.2 and ω = 0.1.

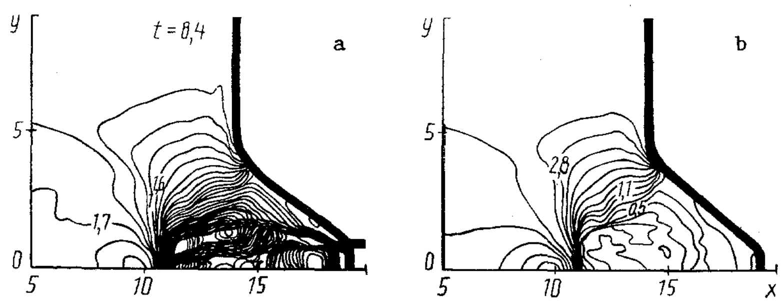

Fig. 4. Contours of a) density and b) pressure: M = 3.1 and ω = 0.1.

Figure 2 shows a typical graph of (a) the density and (b) the pressure distribution for this example. (In this and subsequent figures the numbers on the isochors are ρ_0, and on the isobars are $\rho_0 c_0{}^2$. The distances x and y are ratioed to the channel thickness Δ, and the time t to Δ/c_0.) The resultant distributions coincide qualitatively with the distributions in the calculations in [2] for an equation of state based on a close value M ≈ 6.6 and the same ω = 0.25. The relative growth velocities of the precursors in the laboratory coordinates $\xi = (D_r - D)/D \approx 0.17$ also practically coincide.

The assumed Mach number for the basic shock wave $M = 6.2$, that is a velocity $D \sim 9$ km/sec is rather high, although it has been reached in recent laboratory experiments.

Shock waves in water, which propagate with velocities of 4-6 km/sec ($M \sim 3$-4), can easily be initiated by using standard explosives. In this regard, calculations were done for the same problem for lower Mach numbers, namely $M \approx 4.2$ and 3.1. At the same time, the density in the channel was reduced to $\omega = 0.1$, in order to obtain conditions for a large-scale self-similar precursor development.

The calculated results are illustrated by contour maps of (a) the isochors and (b) the isobars in Fig. 3 ($M = 4.2$) and Fig. 4 ($M = 3.1$). The relative precursor growth velocities for these variants are $\xi = 0.42$ and $\xi = 0.45$, respectively. As in the "gas" problem [1], this parameter increases as ω decreases for constant M and as M decreases for constant ω. It is interesting that the absolute values of ξ are also close to the gas quantities (in the problem of a piston in gas [1], $\xi \approx 0.41$ for $M \approx 3.5$ and $\omega = 0.1$), in spite of the fact that the state of the material both behind the front of the oblique shock wave of the precursor and behind the front of the main shock wave in water is far from an ideal gas: The contribution of the cold component to the magnitude of the total pressure in these cases is on the order of 80-90%.

An analogous calculation for $M = 4.2$ and a relative channel density increased to $\omega = 0.3$ leads to a small-scale, almost standard precursor; that is, the thermal layer effect disappears.

Thus, these calculations show the possibility of experimentally observing the thermal layer effect in condensed matter — water (or ice) or other easily compressed materials — at relatively low shock velocities in the materials (for specific values of the material density in the channel). There is interest in conducting experimental research on this effect, which we think has a fundamental value.

We thank G. S. Romanov and A. S. Smetannikov for making available the tables of the equation of state.

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