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STABILITY OF SHAPED-CHARGE JETS GENERATED UNDER PULSED ACTION ON CONICAL TARGETS

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A problem that simulates the experiment on explosive initiation of the D–D reaction in conical targets [1] is considered. The diagram of the experiment is shown in Fig. 1. An aluminum striker 2 mm thick hits a lead target at a speed of ~5.4 km/sec. The lead target is filled with deuterium at a pressure close to atmospheric and is closed by an aluminum lid 0.3 mm thick. The hole on the surface of the target has a radius of 1 mm, and the opening angle is 53°. For the equations of gas dynamics, the problem was solved numerically in [3] with the use of wide-range equations of state [2].

Figure 2 shows the interfaces of the media for two moments of time. One can see that an annular shaped-charge jet of aluminum appears near the boundary of the cone (Fig. 2a) and then collapses at the axis of symmetry (Fig. 2b).

The present paper is devoted to a numerical investigation of the stability of the flow relative to the axially symmetric perturbations of the inside boundary of the target lid, i.e., of the aluminum–deuterium interface.

Let r denote the radial coordinate and z denote the axial coordinate reckoned from the base of the cone. The initial position of the unperturbed interface is determined by the equality $z = z_0$ for $0 \leqslant r \leqslant r_0$, where r_0 and z_0 are the coordinates of the point of intersection of the boundary and the cone. We consider the problem with a sine-shaped perturbation of the interface

$$z = z_0[1 + d\sin(m\pi r/r_0)] \qquad \text{for} \quad 0 \leqslant r \leqslant r_0, \tag{1}$$

where d is the amplitude of perturbations and m is the harmonics number which gives, in this case, the number of extrema in the initial profile of the interface.

The problem is solved in the same formulation as in [3]. The method of calculation uses a moving regular (i.e., with natural two-dimensional numbering of the nodes) curvilinear grid with explicit separation of the basic interfaces as grid lines [4].

Figure 3 shows a typical example of a fragment of such a grid at a sufficiently developed stage of perturbation growth. The left boundary line is the axis of symmetry, and the right boundary line is the conic boundary of the target in which the grid is not shown in Fig. 3. The points refer to the aluminum–deuterium interface. To calculate the internal nodes of the grid, a method which guarantees the convexity of all four-angled grid cells is employed [5]. In addition, the calculational procedure is split into a Lagrangian stage and a stage of recalculation for a grid corresponding to the next moment. Quasi-monotone schemes of second-order accuracy are used at both stages. At the Lagrangian stage, this is an almost conservative modification [6] of the scheme described in [7]. To calculate the decay of an arbitrary discontinuity at the cell sides, the equation of state in each cell is replaced by the two-constant equation from [4], which was constructed using the sound speed and the ratio of the specific heats of the initial equation of state. At the stage of recalculation, the conservative interpolation algorithm, which is a modification of the well-known algorithm from [8], is used. This algorithm is not applicable if the cells of the grid are closely spaced. In this case, the nonconservative algorithm of third-order accuracy from [9], which can be applied to any, however closely spaced, grids, is employed.

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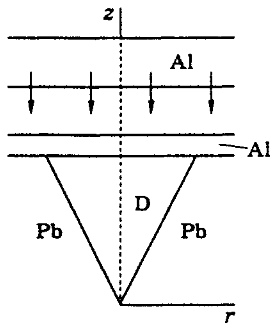

Fig. 1

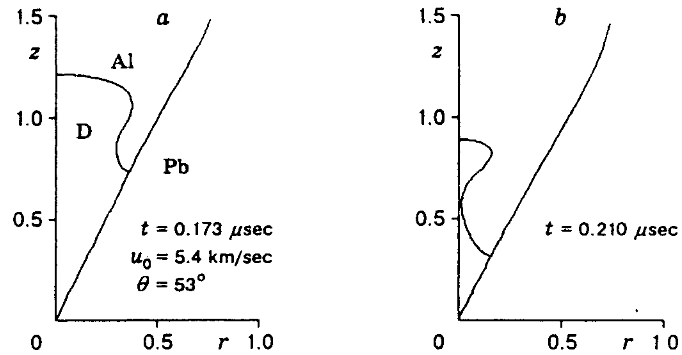

Fig. 2

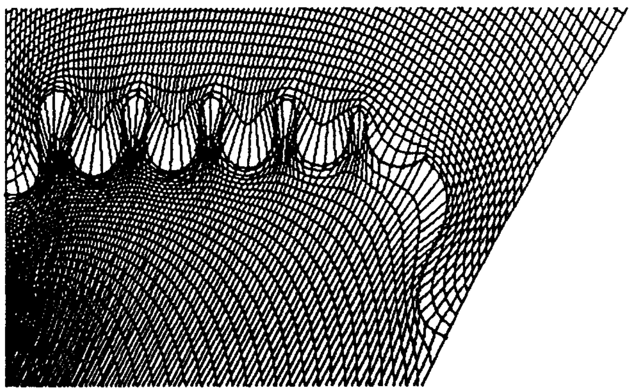

Fig. 3

An impinging striker initiates a shock wave in the target lid. When the wave reaches the internal boundary of the lid, the Richtmyer–Meshkov instability occurs [10, 11]. The performed calculations reproduce the known pattern of development of this instability during shock propagation from a heavy substance into a light one (see, for example, [12]).

Figure 4 shows the initial stage of instability for $d = 0.002$ and $m = 20$. Figure 4a shows the locations of the interface for a series of moments, and Fig. 4b shows the perturbation amplitude near the axis of symmetry versus the time of impact against the lid. It is seen that the perturbations first change sign ("humps" become "valleys" and vice versa). The amplitudes then grow linearly in time with further transition to the nonlinear stage. The curves in Fig. 4b correspond to calculations with number of grid intervals along the lid edge $N = 100$ (i.e., five intervals per half period of the initial perturbation), 200, and 400. Fairly good agreement between the curves for $N = 200$ and 400 is indicative of satisfactory accuracy of calculations. For the later moments, calculations were carried out on the grid with $N = 200$. For the same grid, the calculational accuracy increases with decreasing m.

Figure 5 shows the further development of perturbations as the positions of the interface for a series of moments, beginning with the last moment shown in Fig. 4a up to the time of collapse of the shaped-charge jet at the axis of symmetry. The shaped-charge jet is formed against the developed Richtmyer–Meshkov instability in the basic section of the interface. This instability is traced on the jet boundary as small nonmonotonic perturbations decaying with time. At the time of jet collapse, these perturbations disappear, and the jet boundary becomes smooth.

The shaped-charge jet boundary and the section of developed Richtmyer–Meshkov instability are spaced by a small section in which the amplitude of oscillations decreases rapidly as the shaped-charge jet boundary

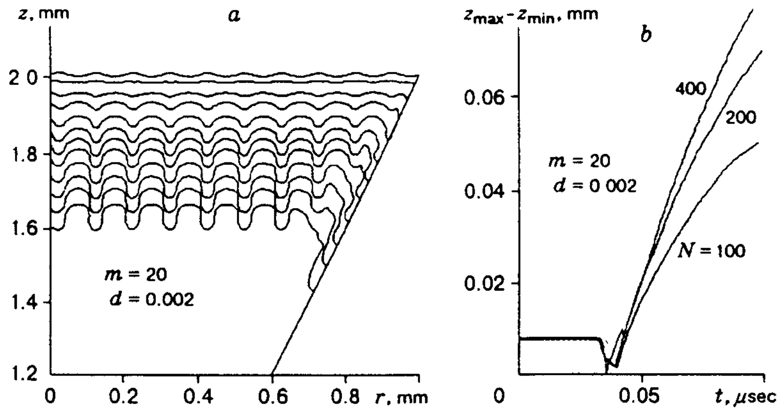

Fig. 4

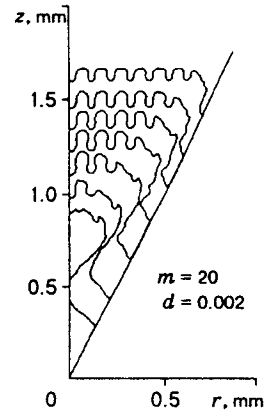

Fig. 5

is approached. The mechanism of oscillation "damping" in this section is due to an increase in pressure behind the shock-wave front which propagates in aluminum from the boundary of the cone to the axis of symmetry. Further acceleration of the heavy substance–light substance interface, which is caused by pressure elevation, leads to the change in the sign of oscillations. In the vicinity of the shaped-charge jet boundary, opposite-sign oscillations have no time to arise, because the corresponding section of the boundary is curved and becomes the jet boundary.

With time, the larger and larger part of the interface becomes the shaped-charge jet boundary. At the time of jet collapse, the shock wave in aluminum also reaches the axis of symmetry. As a result, the interface section with the initial Richtmyer–Meshkov instability disappears, and the boundary becomes sufficiently smooth even in the vicinity of the axis of symmetry, although opposite-sign oscillations can arise there later.

In calculations, the wave number $m = 20$ in (1) was maximal. For $m < 20$, the perturbations develop similarly. Clearly, a numerical study cannot give an exact answer to the question on the stability to perturbations (1) for any m. At the same time, it is not clear which parameters of the problem govern the critical value of m at which the perturbations begin to penetrate into the shaped-charge jet and to increase in amplitude. Therefore, the calculations performed make it possible to hypothesize with high probability that the shaped-charge jets that occur in the experiment of [1] are stable to axially symmetric perturbations of the aluminum–deuterium interface. The Richtmyer–Meshkov instability in the remaining part of the interface is largely damped owing to its further acceleration caused by pressure elevation in aluminum as the shock wave passes from the cone boundary to the axis of symmetry.

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