NUMERICAL SIMULATION OF HIGH-VELOCITY IMPACT IN ANTI-METEORITE PROTECTION SYSTEMS OF SPACE VEHICLES

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The research of dynamics of processes that proceed at high-velocity impact is of interest for many problems of space physics and astrophysics: study of meteoric craters, origin of planetary atmospheres, consequences of fall of large space objects on the Earth, anti-meteorite protection of space vehicles, etc.

At a collision velocity of the order 100 km/s the energy density at impact is by three orders of magnitude higher than at explosion. Therefore particles even of small mass can make significant destructions. For protection of space vehicles against high-velocity impacts of micrometeorites it is offered to use a system of several (in the simple case - two) shields located at some distance from each other. At collision with the first shield there is destruction of a meteorite and some part of the shield near a place of impact. The formed jet consisting mainly of a material of the first shield (in plasma and dispersed state) is held up by the second shield. Thus it is important that the influence of the jet is considerably less than at impact of a particle (as the jet strongly extends) and its velocity is appreciably smaller than a meteorite velocity.

For the description of flow arising at impact, the system of gas dynamics equations in the r - z coordinates (axial symmetry) is used:

$$\rho\left(\frac{\partial u}{\partial t}+v\frac{\partial u}{\partial r}+u\frac{\partial u}{\partial z}\right)=-\frac{\partial P}{\partial z}, \qquad \rho\left(\frac{\partial v}{\partial t}+v\frac{\partial v}{\partial r}+u\frac{\partial v}{\partial z}\right)=-\frac{\partial P}{\partial r},$$

$$\frac{1}{\rho}\frac{d\rho}{dt}=-\left[\frac{1}{r}\frac{\partial(rv)}{\partial r}+\frac{\partial u}{\partial z}\right], \qquad \rho\frac{d\varepsilon}{dt}=-P\left[\frac{1}{r}\frac{\partial(rv)}{\partial r}+\frac{\partial u}{\partial z}\right],$$

where t - time, ρ - density, P - pressure, ε - specific internal energy, v, u - radial and axial components of velocity vector. For numerical solution this system of the equations is approximated by a fully conservative difference scheme with the consistent approximation of fluxes in Eulerian variables [1]. The description of a technique of numerical calculation is given in [2]. For closing the system of gas dynamics equations we use wide-range semi-empirical equations of state for aluminium [3] which describe the characteristics of material of target (shields) and impactor (micrometeorite) in all phase plane of thermodynamic variables – from solid state to transition in liquid and further in vapor or plasma.

As an example we discuss results of calculation for a micrometeorite impact on two plane aluminium shields located at the distance Δ = 0.5 mm, with the velocity u_0 = 50 km/s directed normally to a plane of shields. The micrometeorite is simulated by the aluminium cylinder of length H = 0.1 mm and diameter D = 0.1 mm. The thickness of the shields is equal H_1 = 0.4 mm, H_2 = 0.1 mm. The initial density of the shields and impactor is equal to 2.7 g/cc, the density of an environment – 10^{-6} g/cc. In the initial time moment the impactor comes in contact with the first foil – their boundary is located at z = 0. At the place of impact the pressure quickly grows and reaches a maximum equal to 20 Mbar. There are two shock waves – one deeply propagates into the target, another – into the body of the impactor. The impactor goes deeply into the target, the crater is formed and the material of the impactor spreads on the crater surface. On the edge of the formed crater the jet going upwards is formed. The shock wave (SW) going in the impactor body quickly increases the specific energy of matter and evaporates it. Second SW going downwards on the first foil gradually gets the semi-spherical shape. By 20 ns this shock wave reaches the back side of the foil. At this contact boundary there is splitting of the shock wave into past and reflected . The reflected one goes back into the material of the foil and interacts with falling SW, and the past one forms a plasma jet extending in the direction of the second foil.

Fig. 1 shows the dynamics of these processes, and the vertical line designates the coordinate z (mm), and the horizontal one – r (mm). Of special interest are the data on the form and sizes of apertures in the first shield arising at impact. As the boundary of the aperture it is natural to accept the isoline of the density that is by 10 % less than the normal solid-state one. In 120 ns the aperture in the first screen practically is formed, second isoline in the field of the first shield corresponds this density. The complex shape of the aperture is well visible, the input size is a little less than the output one. On the front side of the shield the sharp edge is formed. On the back side of the shield the characteristic cavity and two sharp tooth are formed. The axial velocity of a jet after punching the first shield and achieving the second (85 ns) appears almost constant and makes approximately 6 km/s. When accumulating the jet on the second shield the maximal pressure makes 100 kbar, and the temperature – 1.5 eV. Such influence does not destruct the second shield, i.e. its thickness is sufficient for protection. In subsequent the jet is reflected from the shield and spreads in the lateral direction. Note that at impact the maximal evaporated mass makes 23 M_0 and the melted one – 142 M_0 (M_0 - mass of a micrometeorite).

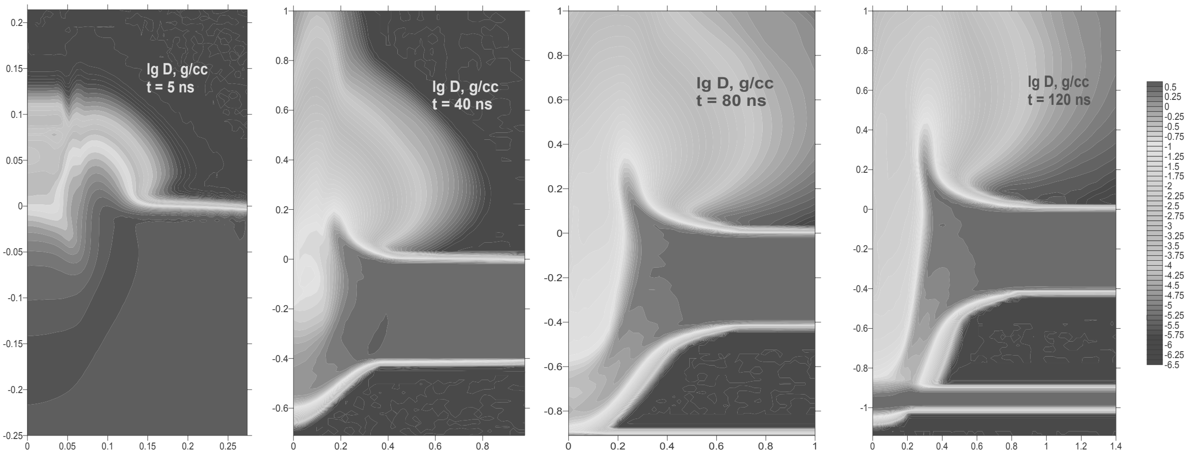

Fig. 1. Density distributions for 5, 40, 80 and 120 ns

In summary we shall note the following. The calculation of two-dimensional problems on the basis of fully conservative difference schemes with the consistent approximation of fluxes shows a satisfactory quality of the solutions obtained using this technique. The numerical simulation is practically a unique method for study of impact destruction at large velocities of collision with regard to real properties of materials. The results of calculations allow one to estimate the efficiency of anti-meteorite protection, to determine the shape and sizes of formed craters and apertures. Besides, this technique makes it possible to find phase composition of destruction products and to study dynamics of plasma jets, etc.

References

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