SIMPLE HYDRODYNAMIC MODEL OF ATMOSPHERIC BREAKUP OF HYPERVELOCITY PROJECTILES; B.A. Ivanov; O.Yu. Schmidt Institute of the Earth Physics, USSR Academy of Sciences, Moscow

The size-frequency distribution of Venusian craters shows the significant effect of the massive atmosphere (1) perhaps as a result of the atmospheric breakup of meteoroids. In this paper we present selected results of numerical calculations modeling the deformation of a fluid spherical body passing through the atmosphere.

The internal motion of the projectile material is computed through the Laplace equation

$$\Delta \phi = 0 \tag{1}$$

where ϕ is the potential of velocity field, which is $\vec{v} = \text{grad}\ \phi$. The boundary conditions include zero pressure on the trailing side of the body and pressure (P) such that $P = \rho \cdot v^2 \cdot \sin \beta$, on the leading side, where ρ is the altitude-dependent atmospheric density; v, the velocity of the boundary point in the direction of flight; and β, the angle between the local tangent plane to the boundary and the flight direction.

Equation (1) has been solved numerically. The potential at each point of boundary ϕ_i was presented as a sum of the Lagrange polynomials P_n:

$$\phi_i = \sum_{n=0}^{N_p} a_n \cdot R_i^n \cdot P_n(\cos \theta_i) \tag{2}$$

at a number of points on the boundary with spherical coordinates R_i (radius) and Θ (angle from vertical). The boundary was approximated by m = 50 points with the number N_p in Equation (2) equal to 7, 13 and 25. If $N_p < m$, the model exhibits dissipation analogous to surface tension. At each time step Δt, new boundary ϕ values were computed through equation (2)

$$\phi_i^{j+1} = \phi_i^j + \left(0.5 \cdot (v_i^j)^2 + p_i^j/\delta\right) \cdot \Delta t$$

where δ is the projectile density and where i and j indicate the number of the boundary point and time step, respectively.

Figures 1 through 3 show the changing shape of a fluid projectile with an initial diameter of 1 km at different altitudes during entry. The results of the model do not depend on the projectile initial velocity but primarily reflect the distance traveled through the atmosphere. Mass loss occurred when the sharp angles of boundary were artificially truncated. The models reveal the phenomenon of instability growth on the leading side of the projectile. For $N_p = 7$ the rate of instability growth is less than the speed of lateral motion. As N_p increases (Figure 2) instabilities grow more rapidly. When $N_p = 25$ (Figure 3), the instabilities eventually grow faster than the rate at which they move off the symmetry axis.

These hydrodynamic calculations reveal a double role for the internal strength of the projectile material: strength not only conserves projectile shape (it is hard to imagine the projectile not to be deformed at pressures as high as 20–30 GPa (see ref. 1), but in the stabilization of the internal body motion. In other words strength inhibits uncontrolled growth of instabilities. If the internal strength is insufficient to constrain such instabilities, the body may be destroyed.

The results of our simple simulation reveal that a fluid projectile with density 1 g/cm^3 and initial diameter near 2.5 km would create a crater with diameter one-half that of a crater formed on an atmosphere-free planet. The same decrease in the crater dimension in the case of pure deceleration of an undeformed solid body would occur at a diameter of approximately 0.5 km.

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(1) Ivanov, B.A., Basilevsky, A.T., Krychkov, V.P. and Chernaya, I.M. (1986) *Proc. Lunar Planet. Sci. Conf. 16th*, D413–D430. (2) Lavrentiev, M.A. and Schabat, B.V. (1977) *Problems of Hydrodynamic and their Mathematical Models,* Nauka Press, Moscow, 407 pages.

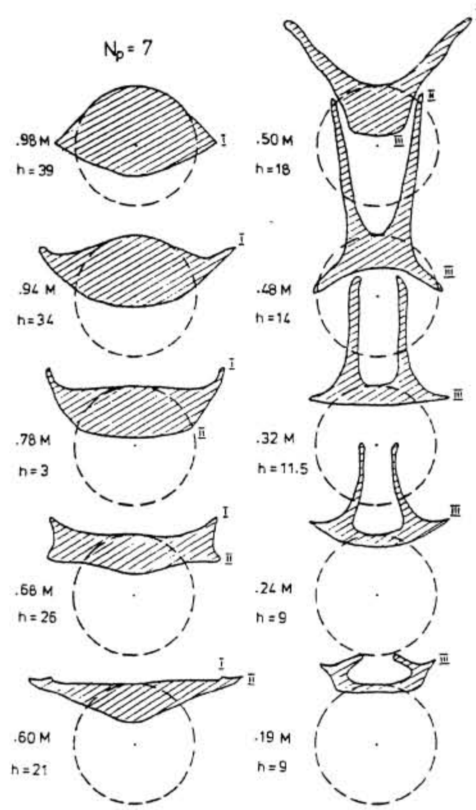

Figure 1. Evolution of projectile shape and remaining mass (M) during entry through the venusian atmosphere at different altitudes, h (in km) for a value of N_p = 7 from equation (2).

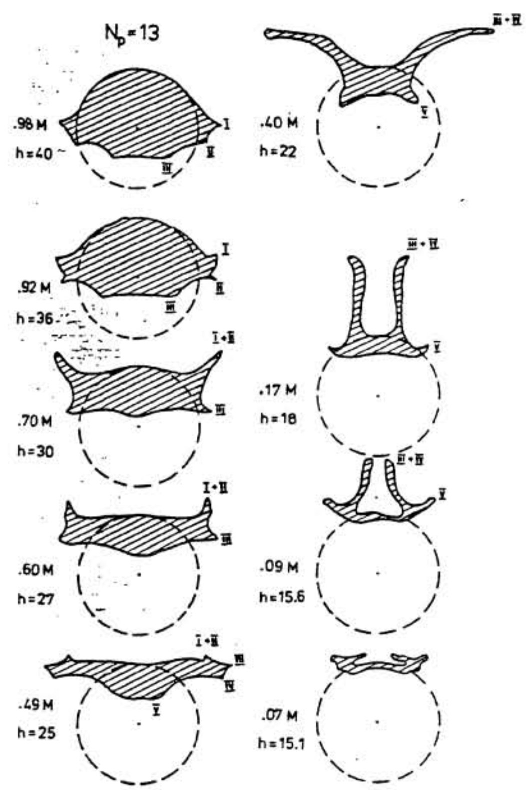

Figure 2. The same nomenclature as in Figure 1 but with N_p = 13. As the value of N_p increases, instabilities on the leading side of the projectile increase.

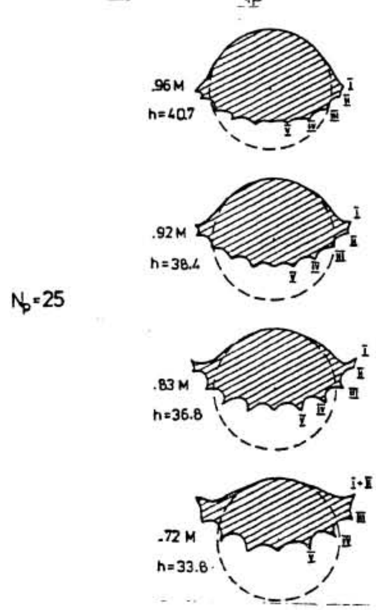

Figure 3. The same nomenclature as in Figure 1 but with N_p = 25. For large values of N_p, instabilities grow faster than the rate of lateral motion.

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