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Jelly Technique Applications in Evolution Study of Hydrodynamic Instabilities on Unstable Plane and Cylindrical Surfaces*

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VNIIEF has developed and is now using the method [1],[3],[4] for the investigation of geometrically complex hydrodynamic flows based on jelly models accelerated by compressed air or by explosion products of a gaseous explosive mixture (GEM). The jelly (gelatin water solution) turned out to be a very convenient material for visual imitation of hydrodynamic processes in metal shells and layers loaded by the pressures of solid explosive burst products. On one hand, the jelly has a sufficient strength allowing to fabricate the shells and layers of complicated form. On the other hand, it behaves as an incompressible fluid under low pressure loading. The jelly transparency permits to use photo recording methods.

The objective of the work is to study hydrodynamic instabilities on plane and cylindrical surfaces development using the jelly technology and numerical simulation.

1 Experimental scheme

1.1 Localized perturbations on unstable interface

The experiments for study the evolution of localized perturbations under the interface acceleration initially specified as cone, cylinder and hemisphere were carried out on an experimental assembly with the layout shown in Fig. 1.

The experiments used the jelly consisting of gelatin water solution with the concentrations C = 2.5% (respective strength is 0.05 atm). The layer was accelerated by compressed air with high spatial pressure uniformity.

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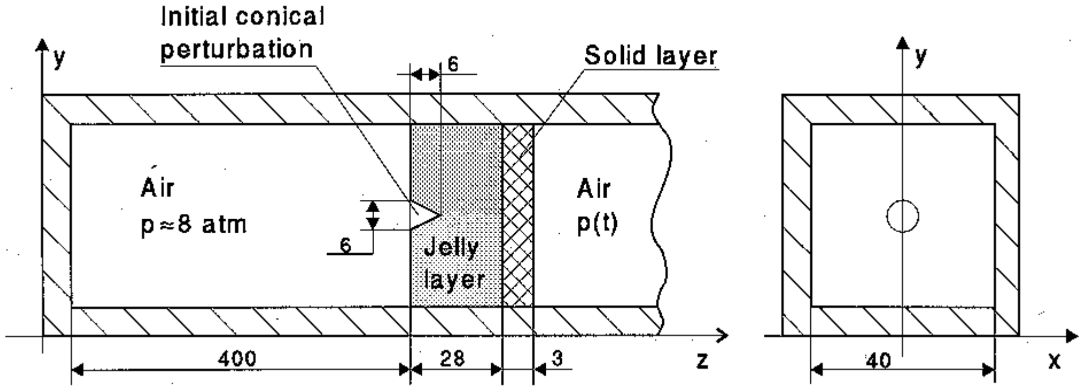

Figure 1: Schematic of experimental device for local perturbation evolution study. Initial local perturbation specified as a cone on unstable interface. Dimensions are in mm.

The assembly casing represented a transparent accelerating channel of a square shape 40×40 mm. It was divided by the jelly layer into chambers: the working and auxiliary chambers. The end of the working chamber was closed with a sealing cover and the auxiliary chamber was closed with a 0.2 mm mylar film (not shown in figure). The assembly channel was filled with air compressed to pressure P = 8 ± 0.1 atm through a gas pipe. The pressures in chambers (left and right layer) were equilibrated using a joint channel 2.5 mm in diameter.

Electrical burst of nichrome wire destroyed the membrane. Gas from the auxiliary chamber leaked to the atmosphere. Pressure difference accelerated the jelly layer.

The initial perturbation of the unstable interface were chosen in the form of hemispherical cavity (6 mm in diameter), cylindrical cavity (6 mm in diameter and 6 mm in height) and a cone-shape cavity (the base diameter - 6 mm and the cone height - 6 mm).

1.2 Experiments imitating CEA/DAM experiments

Assembly layout for CEA/DAM experiment imitation is presented in Fig. 2. The experimental device design consisted of: 1 - parallel transparent plates supporting directed motion of jelly shell; 2 - enhancing elements to avoid plates deformation; 3 - GEM initiation system composed of 36 spark dischargers on inner surface of cylindrical casing; 4 - GEM filling system; 5 - system for GEM EP pressure relief representing 24 holes 11 mm in diameter closed by membranes.

The membranes were manufactured of polyethylene film 0.05 mm thick. After GEM explosion the membranes were destroyed and explosion products leaked through the

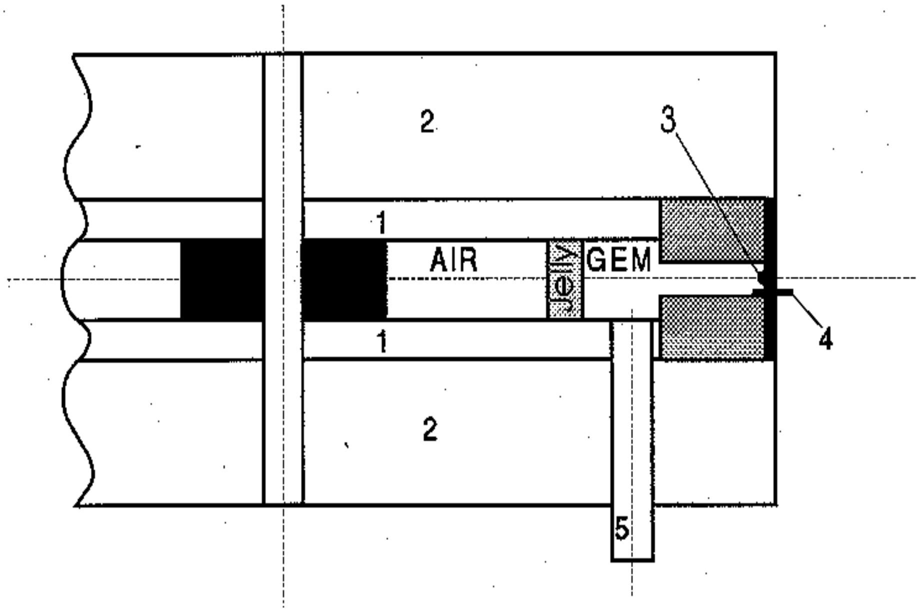

Figure 2: Schematic of the experimental device with the jelly shell for the imitation of CEA/DAM experiments.

holes. Two experiment versions were implemented for jelly shells 14.5 + 0.1 mm high and mean radius $R_0 = 72$ mm.

In the first version, perturbations were specified as harmonic perturbations represented by a single 2 mm amplitude harmonic with $N = 26$ and as the superposition of harmonics with the numbers $N = 26$, 42 and 58 and equal amplitudes of 2 mm in the second version.

To ensure the geometrical similarity of experiments the ratio of perturbation amplitudes to the initial average shell radius was the same as in experiments [2].

Cylindrical jelly shells were also made from gelatin water solution with the concentrations C = 4.4%.

2 Experimental results

2.1 Localized perturbation evolution

The experimental results for investigation of evolution of localized perturbations initially specified in the form of cone-shape cavity on unstable surface of the plane jelly layer are given in Fig. 3.

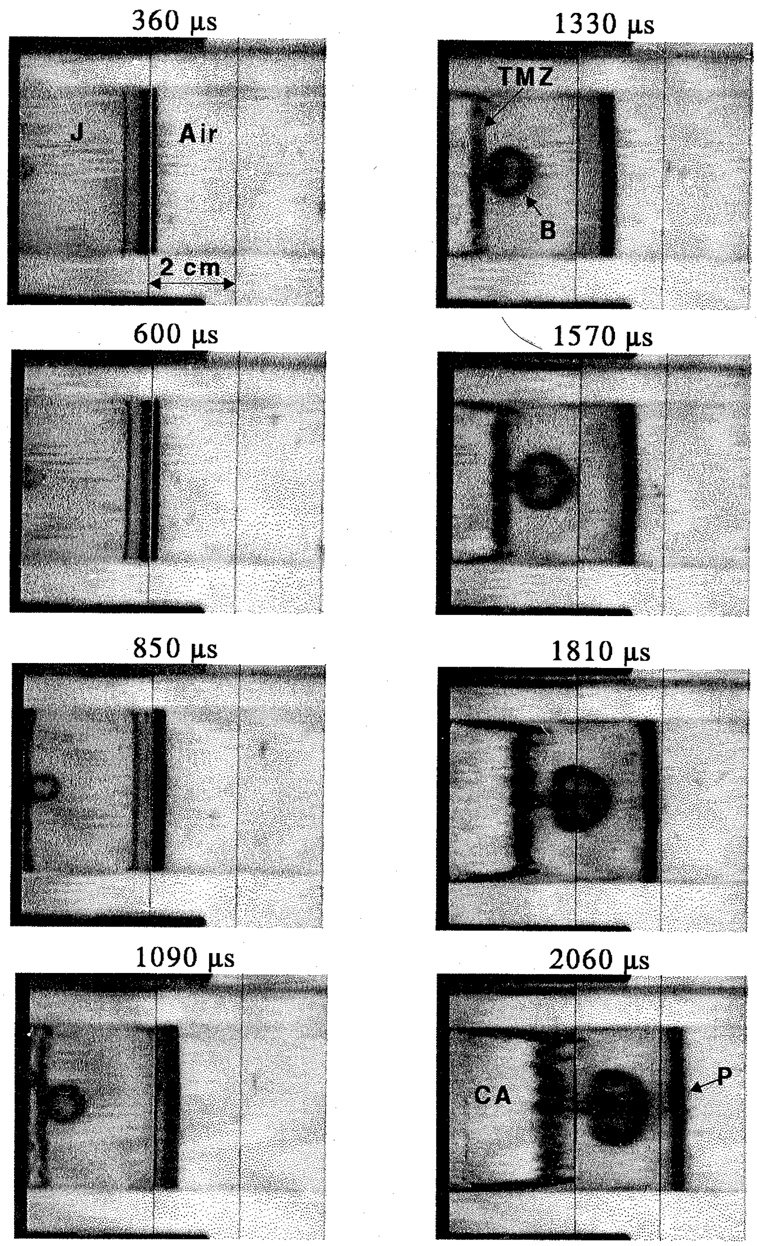

Figure 3: Photochronogram of the experiment on conical perturbation growth at unstable jelly interface. J - jelly; CA - compressed air; P - moving rigid plate; TMZ - turbulent mixing zone; B - bubble.

At initial time the jelly layer (J) is in the left part of the frame with its left boundary coinciding with the edge of vertical black strip limiting the image field. The perturbations were specified on unstable (left) surface of the jelly layer. Compressed gas domain is on the left from this boundary and is not visible on the photographs. The black strip on the right jelly layer boundary corresponds to the plane rigid plate (P) 3 mm thick that permanently contacts the jelly. On the right from this plate there is air with its pressure decreasing with time due to leakage to ambient atmosphere. Photographs show vertical reference lines on the walls of acceleration channel spaced by 2 cm.

At early times, $t < 1000\,\mu$s, perturbation size demonstrates a permanent growth by about 2 times. In all cases under investigation it takes the form approaching a hemisphere.

Later the perturbation converts to a spherical bubble that moves from the left unstable surface of the layer to its right boundary. This is followed by increase of bubble size.

Inside the bubble on the left pole the jet forms moving with velocity higher than that of both bubble poles. At time $t \approx 1300 \div 1500\mu$s this jet impacts the opposite pole and the spherical bubble converts to a toroid. This form is retained till final recording time. It should be emphasized that the velocity of this toroid is much higher than that of jelly layer interfaces. It comes to the opposite layer interface with time.

The left unstable layer interface demonstrates evolution of the turbulent mixing zone (TMZ) for jelly and air that can be seen on the photographs as a vertical strip with rough edges. The thickness of turbulent mixing zone increases with time.

Additional experiments show that evolution pattern for conical, hemispherical and cylindrical shape initial perturbation are very similar.

Evolution pattern of localized perturbation initially specified as a cone cavity on a stable surface of jelly layer qualitatively differs. Perturbation amplitude decrease with time and accelerated interface becomes plane.

2.2 Harmonic perturbations on the inner interface of converging cylindrical shell

Fig. 4 shows time dependence of the inner radius of cylindrical shell in dimensionless variables obtained from CEA/DAM data [2]. The same figure presents the $\mathrm{R}_{in}(t)$ and $\mathrm{R}_{out}(t)$ functions obtained in the experiment with initially unperturbed jelly shell. The measurement scale here is represented by initial values of radii R^* and time interval $t\%^*$ between the beginning of the shell motion and the time of maximum gas cavity compression. Comparison of these dependencies indicates an approximate similarity between the jelly shell dynamics and that of metal shell in CEA/DAM experiment [2]. These dependencies are characterized by that at early stage the shells are accelerated rapidly after which they move with an approximately the same velocity. Then they are

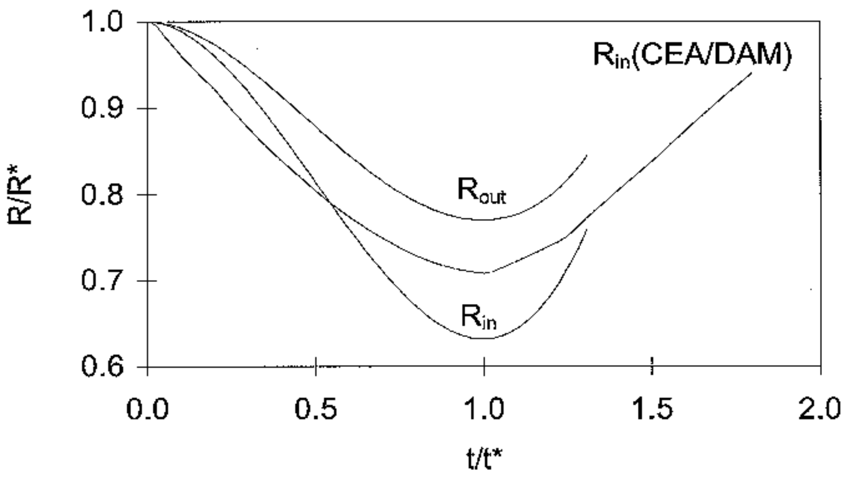

Figure 4: Time dependencies of radii in the jelly experiment and in the CEA/DAM experiment.

decelerated. When the minimum radius is reached being about 70 % of the initial value the shells move from the center.

Similarity of jelly and metal shell dynamics is not complete. For the jelly experiments, shell is accelerated more slowly in the stage of shock wave propagation as compared to the experiments involving metal shells and solid explosives which results from a greater density difference of GEM and jelly.

Fig. 5(a) presents the photochronogram of the experiment where the inner boundary was perturbed in the form of harmonics with $N = 26$ and the amplitude $a_{26} = 2$ mm. Air fills the gap between its inner boundary and the boundary of a cylinder 7 cm in diameter (black circle) located at the center. It is compressed by the shell converging to the center. At $t = 200\mu$s, the outer boundary of jelly layer has the radius somewhat smaller than that of the light circle - flow recording domain. GEM explosion products are beyond this domain.

The photographs illustrate dynamics of the perturbation on the inner boundary. The specific feature is represented by the change of perturbation phase. This occurs at $t = 400\mu$s. Positions of peaks and valleys interchange. Then the amplitude increase is observed. At $t \geq 1890\mu$s amplitude decreases.

Fig. 5(b) presents photochronogram of the experiment where the inner boundary experienced the perturbation in the form of superposition of three harmonics with $N = 26$, 42, 58 and the amplitude $a_N = 2$ mm. Perturbation growth dynamics here is more complicated than in the above case. However there are some common features. For example, at $t \approx 400\mu$s there is change of phase of perturbations with the greatest

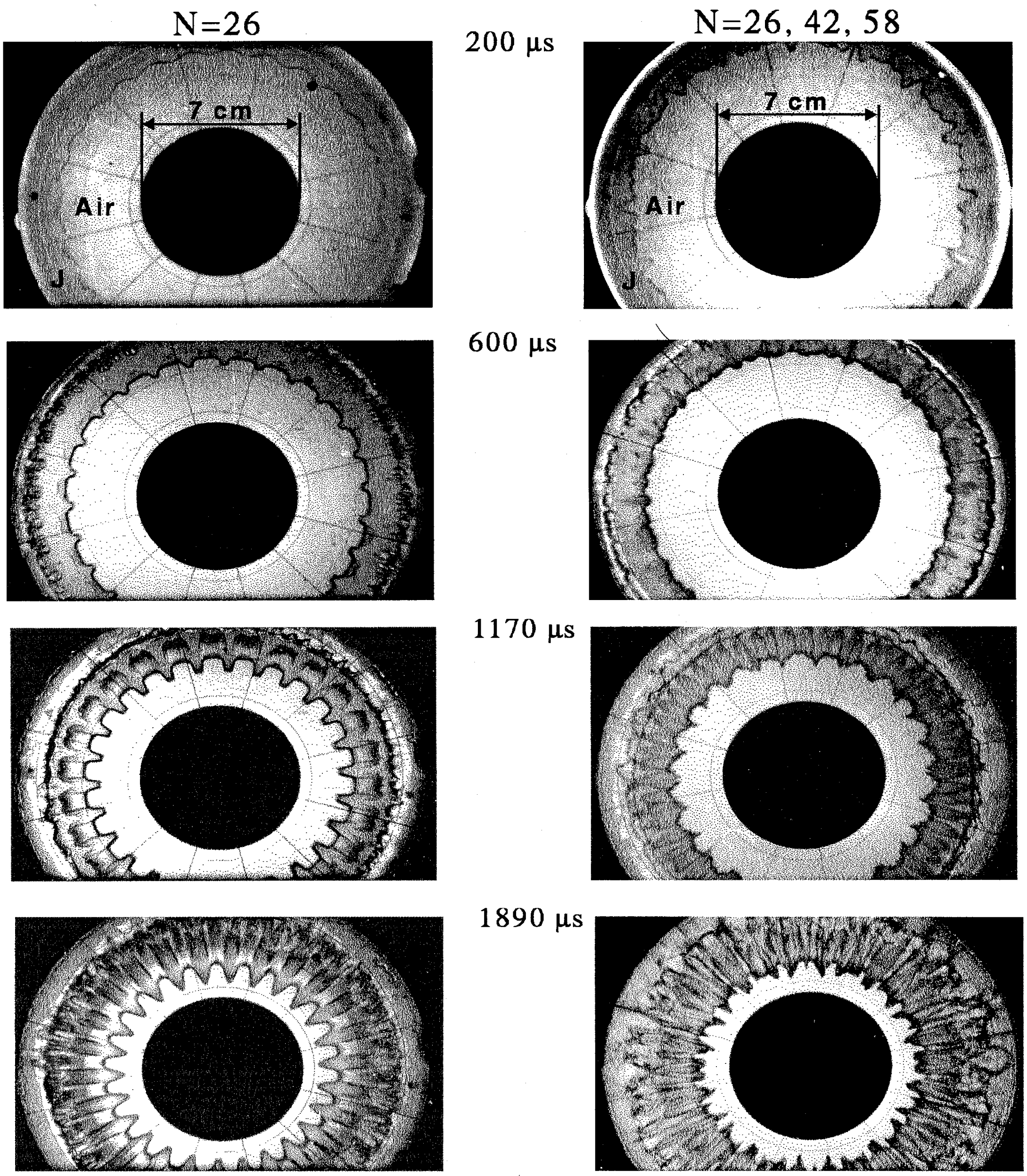

Figure 5: Photochronogram of the experiment on convergence of jelly shell accelerated by GEM explosive products. J - jelly shell.

wavelength. Thin jets form where initially the cavities were present. The perturbation amplitude grows till $t = 1890\mu$s.

3 Conclusions

The results of the experiments are:

- It was shown that the perturbation initially specified as cone, hemispherical or cylindrical cavities at the unstable layer interface converts to a compact gas toroid. It moves across the layer reaching its opposite interface. Perturbation evolution pattern turned out to be slightly dependent on the initial cavity shape.

- Detailed patterns of perturbation evolution in the experiments with converging cylindrical jelly shells are obtained. A good agreement with CEA/DAM experiments is observed.

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