VISUALIZATION OF FLOWS ON THE TRAJECTORIES OF CONTROLLED THROWING OF BODIES FROM BALLISTIC SYSTEMS

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Main subjects: body throwing, flow visualization
Fluid: high speed flows, flows with shock waves
Visualization method(s): shadowgraph, holographic interferometry, X-ray impulse filming
Other keywords: stabilizer, detachable flow, numerical analysis

Visualisation, i.e. acquiring a visual picture of the process, is widely used for analyzing gas-dynamic flows and the character of interaction of high-speed projectiles with different targets. Visualisation methods are developed mostly in optically transparent environments (shadow methods, holography, etc.). Flow visualisation of revolving bodies with and without aerodynamic attachments by a supersonic current is a topical problem of aerodynamics and impact ballistics ([1], [2]).

In our research throwing of cylindrical bodies of different lengths was carried out from powder and light-gas ballistic systems of different caliber the speed of flight of which approached the Mach number $M_\infty \leq 10$ with the help of special detachable drivers. Visualisation of functioning of the thrown bodies along the trajectory and approaching the target was carries out with the help of X-ray impulse filming and high-speed filming. For visualization of gas-dynamic flows along the bodies' trajectory shadow spark pictures and a multi-angle holographic interferometer (MHI) were used.

The optical scheme of the MHI and the method of interferograms' handling are described in the paper ([3]). Schematically the directions are pictured on fig. 1.

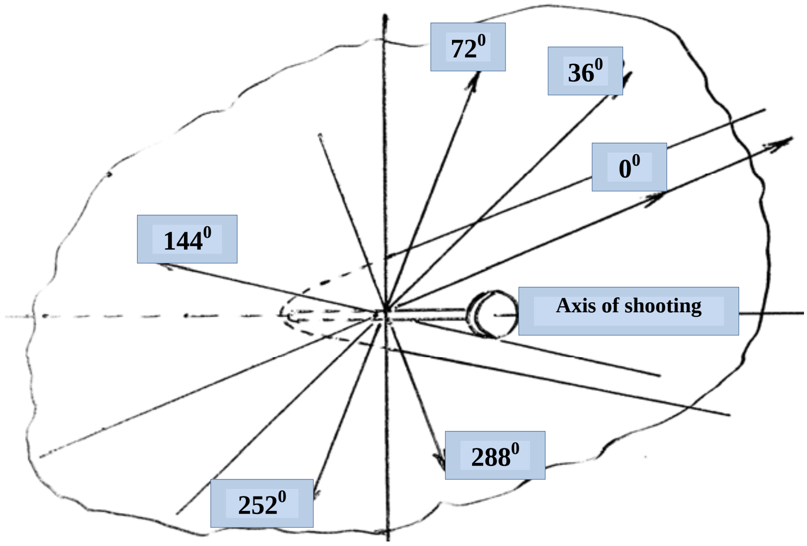

Fig. 1. The scheme of multi-angle filming by the holographic interferometer

Holograms are obtained using the double exposure method. The source of light was the impulse laser OGM-20. Fig. 2 is the example of multi-angle holographic filming and in addition to the research ([3]) it represents flow interferograms received when the interferometer was set up to record the stripes of finite width which can be used for other angles of monitoring.

Throwing cylindrical bodies with flat aerodynamic attachments the flow in the zone of detachment in front of flat stabilizers was surveyed by way of visualisation. Fig. 3 and fig. 4 show the picture of the flow obtained with the help of the MHI.

The analysis of detachment flows of long distance cylinders with different disc stabilizers was of particular importance. The idea of this research consisted in using the detachment zone in front of disc stabilizers as a special stabilizer called "the pseudo-skirt". Fig. 5 illustrates this flow.

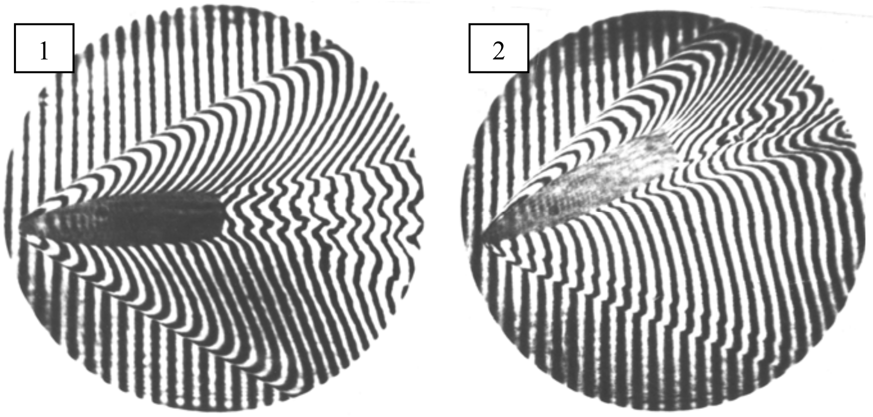

Fig. 2. Flow interferograms in the direction of monitoring: 1 - 36º, 2 - 108º

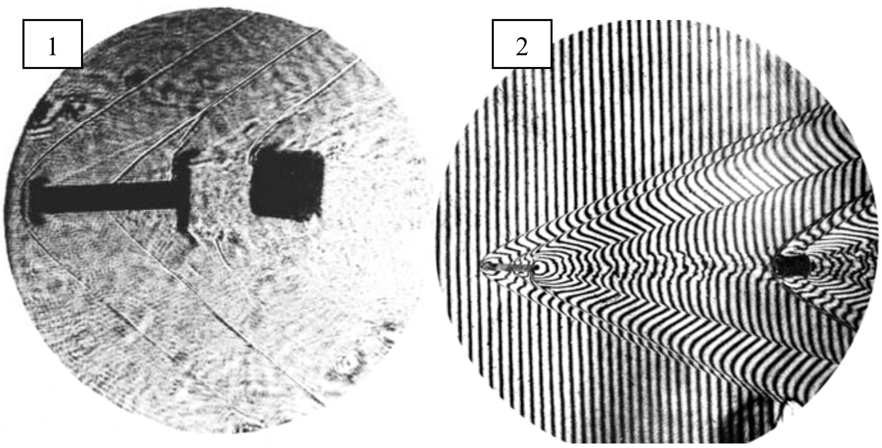

Fig. 3. Visualisation of detachment flows for a 6-diameter cylinder flow with a flat stabilizer and an impact disc: 1 – direct shadow angle picture where M_∞ = 2,0**;** 2 – the interferogram in the stripes of finite width

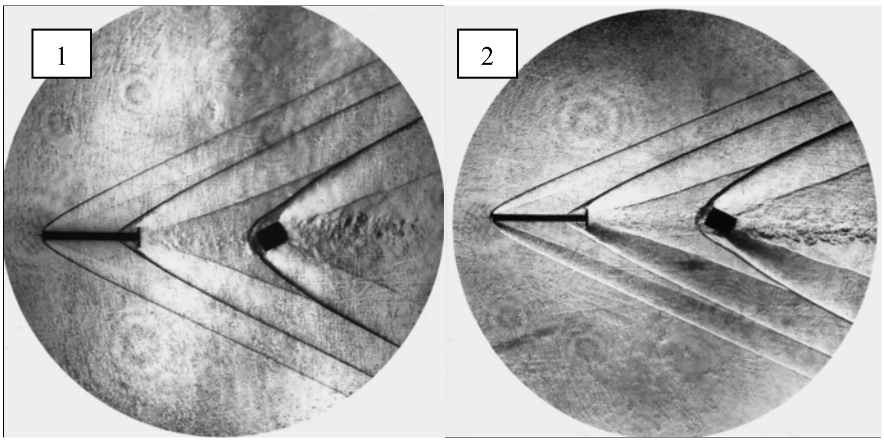

Fig. 4. Visualisation of flow discontinuity of compression for a 12-diameter cylinder flow with a flat stabilizer and an impact disc with the help of the Foucault knife: 1 – the knife vertically**;** 2 – the knife horizontally

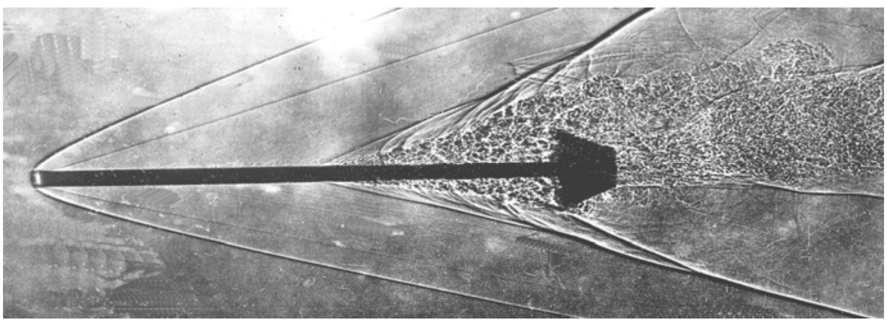

Fig. 5. Shadow picture of a 25-diameter cylinder flow with a dished stabilizer where M_∞ = 3,0

Visualisation of detachment flows with the help of shadow and holographic methods was complemented with a model visualisation applying the numerical analysis. It is practical to make the calculation of flow of complex-shaped bodies with a great number of peculiarities employing nonstationary differential schemes of open ended counting. To solve this problem the numerical method ([4]) was used which was based on the Euler-Lagrange equation when examining the system of differential equations in quotient derivatives describing the main conservation laws of mass, impulse and energy with the usage of the equation of the ideal gas condition. Flow parameters were found by means of ascertainment, i.e. multiple repetitions of the steps by time until flow parameters reached a quasi-stationary value. The calculation for cylindrical bodies was carried out with stabilizers in the form of flat and dished discs. Fig. 6 portrays lines of equal density (figures ρ/ρ_0) for a flat disc; Fig. 7 exposes the range of speed for a dished disc.

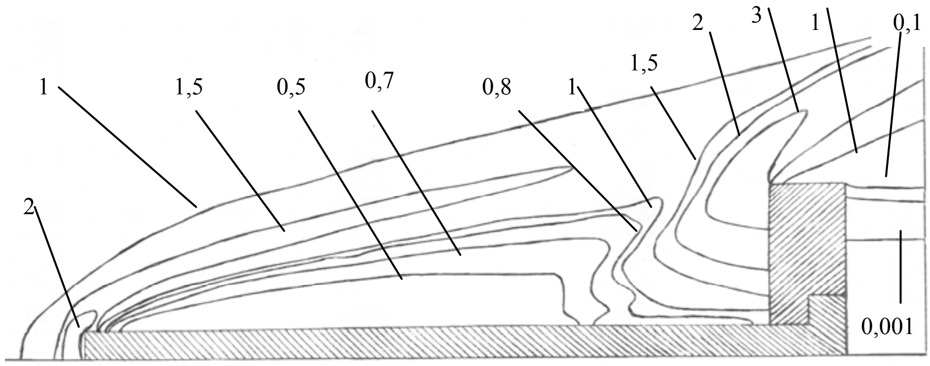

Fig. 6. Isolines ρ/ρ_0 in the density range of a flat disc flow, $M_\infty = 5,0$

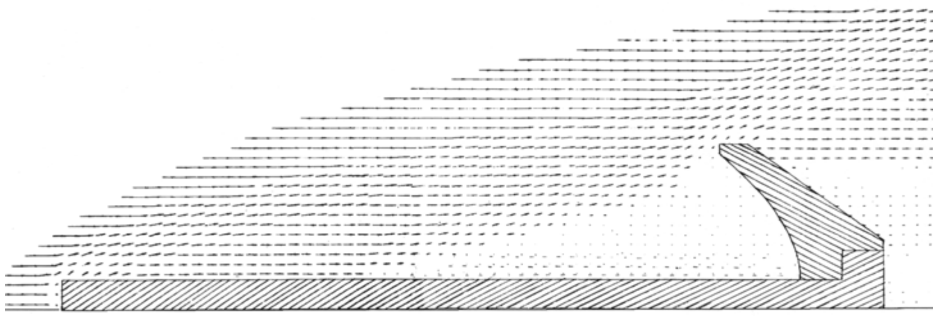

Fig. 7. The speed range of a dished disc flow, $M_\infty = 5,0$

Numerical calculations allowed getting a more detailed picture of the flow in the zone of detachment in front of circular stabilizers. The form of the detachment zone in front of discs makes a considerable difference for the given flows. In front of the dished-disc stabilizer there was deeper underpressure and a larger zone of turbulent flows than in front of the flat disc. The current line that separates a potential flow from a turbulent one and defines the geometry of a pseudo-hard body into which the disc stabilizer transforms is built on the distribution of the speed vector.

The point of detachment in the zone of the positive gradient pressure is determined according to the distribution of pressure along the cylinder surface. For the flat disc the detachment point is located at the distance of $7d_0$, where d_0 is the cylinder diameter, from the face plane of the cylinder, but for a dished disc it is located at the distance of $3,7d_0$, so the dished disc is transformed into a more powerful pseudo-skirt. The calculation of the resistance coefficient in this setting showed that for the flat disc $C_p = 0,978$, and for the dished disc $C_p = 0,865$.

The research of detachment flow visualisation in the zone of disc stabilizers which was carried out by experimental and calculation methods indicated that it was possible to design a detachment zone the geometry of which would be more beneficial aerodynamically if we changed the form of the disc. We could also ensure stabilization of cylindrical bodies of greater lengths on the trajectory and the following regular functioning of constructions near the target.

One of the practically important tasks of mechanics of deforming environments is to survey interaction of a group of bodies with a target under the conditions of a high-speed impact ([5]). This task is directly connected with the necessity to protect spacecrafts, satellites, space stations and astronauts in outer and circumterrestrial space from a flow of meteoric bodies and anthropogenic rubbish. A comprehensive experimental and theoretical analysis of this complex task included elaborating methods and devices of controlled throwing of a group of bodies in the laboratory environment (in the air and in the vacuum), experimental studying of the dynamics of the bodies' impact on the target and its consequences (the remains) and numerical modeling with working out an adequate closed method to count an impact of a group of bodies on targets that simulate protection of spacecrafts. Numerical calculations were held in the three-dimensional setting applying the method of finite elements.

Flow visualisation when a group of bodies was thrown allowed to perfect methods of a controlled throwing of different bodies and to ensure their necessary distribution in space (fig. 8).

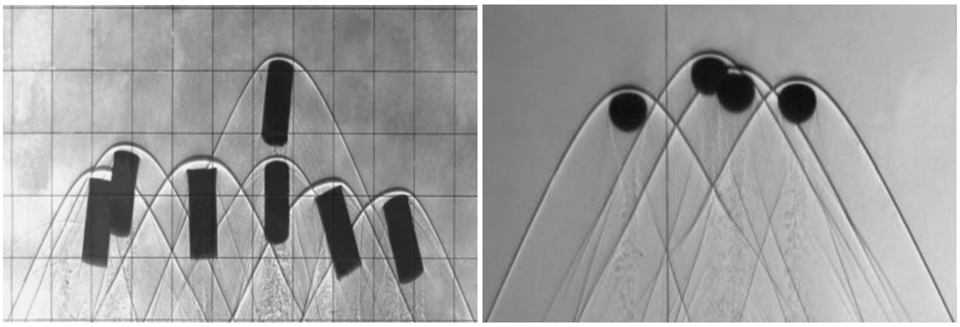

Fig. 8. Shadow photographs of movement of groups of seven and four bodies along the trajectory where $M_\infty = 3{,}3$

Fig. 9 illustrates the result of a comprehensive experimental and theoretical analysis of group interaction of high-speed bodies with a target imitating the spacecraft defense.

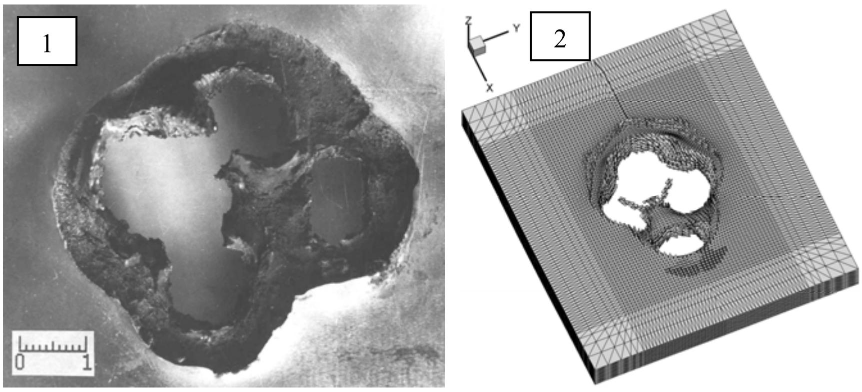

Fig. 9. The view of the back surface after an impact of a group of four bodies at a speed of 2873 m/s: 1 – physical experiment; 2 – numerical experiment

There are wide-ranging tasks connected with high-speed biphase flow diagnostics. Depending on the aggregative state of flow particles different visualisation methods are applied. We have carried out visualisation research of the flow of particles behind the target generated when a target is pierced by a high-speed projectile. Fig. 10 demonstrates the interferogram received with the help of the MHI. Its left side is the back surface of the target.

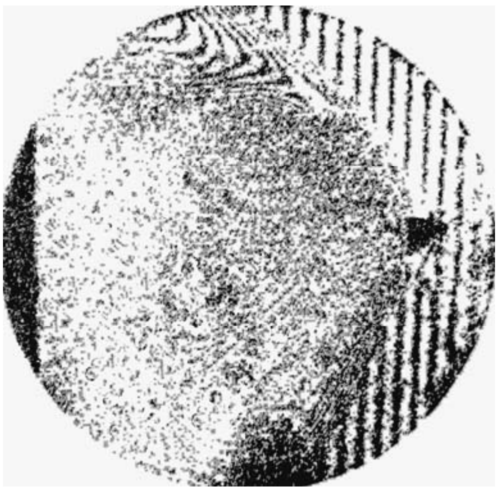

Fig. 10. The interferogram of the high-speed flow behind the target

Visualisation shows that the flow makes up a cloud of particles edges and geometry of which are explicitly recorded at the interferogram. Separate particles are not identified with such recording, only the flow front and its leading fragment (the head of the pointed projectile) are visible. For defining certain flow particles X-ray impulse filming can be used along with multi-angle holographic filming.

Visualisation of phenomena in optically nontransparent environments has a circumstantial character and is based on quadratic effects (deformation of the pattern surface, for example) or employs secondary effects (thermal, etc.).

X-ray filming is one of the most wide-spread methods of visualisation in optically nontransparent environments. Natural limitations are only the size and the density of the material of the examined pattern or construction.

In real constructions high-strength fragile materials (alloys, glass, ceramics, etc.) are used as an anti-impact defense. To construct adequate models of such phenomena real physical data about the character of material destruction are required. Fig. 11 represents X-ray photographs of interaction of high-speed projectiles at different stages of the process with the plexiglass block.

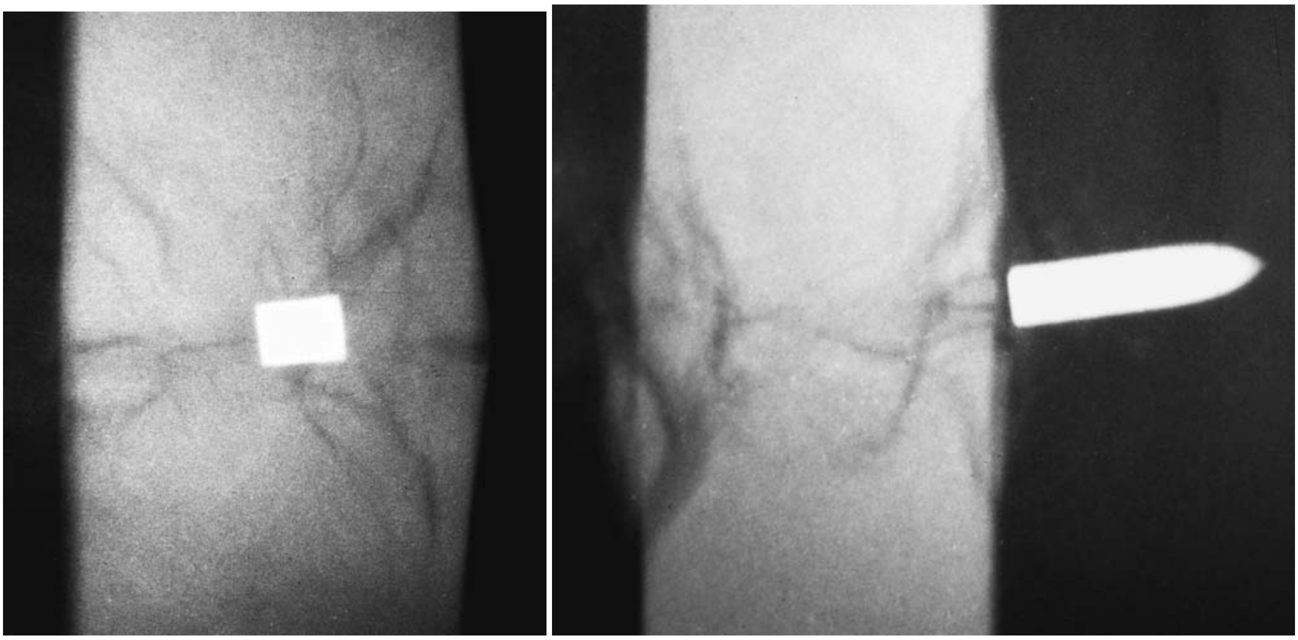

Fig. 11. X-ray photographs of destruction of a 40-millimeter plexiglass target: left – a compact steel projectile piercing the target, right – a hard pointed projectile piercing the target

X-ray photographs give a clear view about the character of the front and the back destruction of a target and the distribution of the destruction front inside it.

The aforementioned methods of visualisation together with calculation help to solve a wide range of topical problems of aerodynamics and impact ballistics.

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