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Visualization of 3D non-stationary transonic flow in shock tube using nanosecond volume discharge.

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Gas discharge visualization method is used in gas dynamics investigations of 3D supersonic/hypersonic stationary gas flows [1, 2]. Shock wave and boundary layer positions, some density inhomogeneities, vortexes are successfully visualized due to dependence of gas local conductivity on the value of E/ρ (E is discharge electric field). Stationary discharge current thermal heating of gas influences flow configuration and parameters thus.

Non-stable flow, high - speed gas dynamics processes and microsecond-lasting interactions can be visualized with pulse (nanosecond-lasting) volume discharge [3, 4]. Special type of discharge was involved for original method for visualizing of supersonic flows: pulse volume discharge with ultraviolet preionization by radiation from the sliding surface discharges (plasma electrodes).

The experimental setup consists of the special discharge chamber mounted with a shock tube. The tube and test chamber have rectangular profile 48×24 mm. Incident shock waves Mach numbers M = 2-6. Two opposite side walls of the test chamber are the quarts windows, another tow walls - plasma electrodes (Fig.1). The ionization time τ =200 ns is much less than characteristic times T of non-stationary gas dynamics interactions in a shock tube flow: $\tau << T$. In time interval τ changes in configuration of flow discontinuities and non-homogeneities do not occur. The initiation of the pulse discharge in a supersonic flow in the rectangular shock tube channel allows ionizing gas flow in short time interval. The time of discharge glow is 200 ns – it is possible to use the total discharge glow as exposure time for recording of non-stationary flow visualizing method. During short exposure time discharge does not influence the flow structure. Ionization of non-homogeneous flow results in spatial redistribution of discharge plasma. Electron concentration depends on local gas density. Shock waves, vortexes, weak disturbances in gas flow are visualized as far as local plasma glow intensity depends on local gas flow density.

Various configurations of 2D, axy-simmetrical non-stationary flows were visualized in shock tube test chamber using pulse volume discharge with ultraviolet pre-ionization [3, 4]. Instant discharge images of different supersonic flows after shock wave diffraction on obstacles were obtained. Numerically computed gas density fields had been compared to images obtained with pulse discharge visualization method [5].

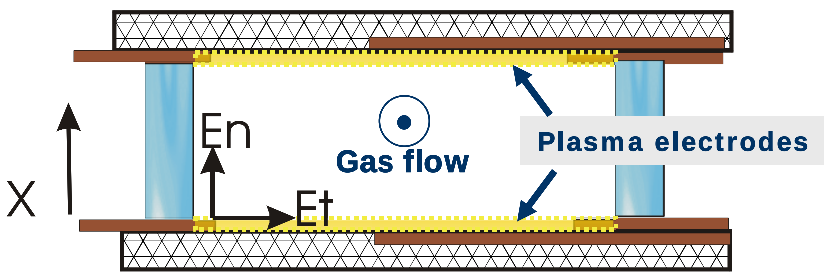
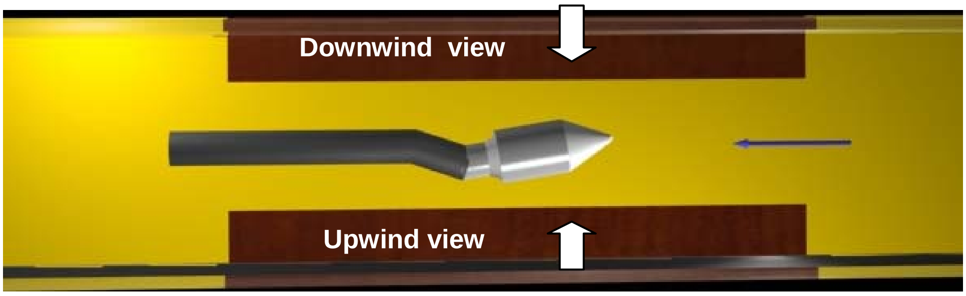


Fig.1. Shock tube test chamber scheme.

Experimental investigations of 3D transonic flow over complex model of payload shrouds were conducted in wind tunnel [6] and in shock tube. Surface pressure pulsations were mated with transition from developed separation of a boundary layer to local one. Shadow technique can not be used successfully to study 3D non-stable flow over model: optical path in the central flow area is not transparent for sounding light beam – the model blocks it.

Pulse electrical discharge method allowed visualization of local low-density areas from two different views – upwind and downwind the model. Instant images of 3D transonic flow around complex cone model were obtained.



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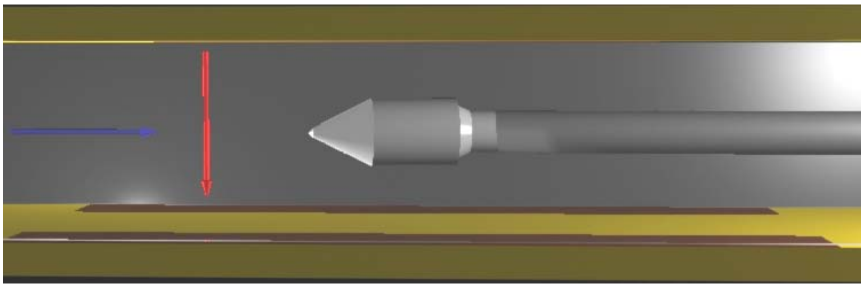

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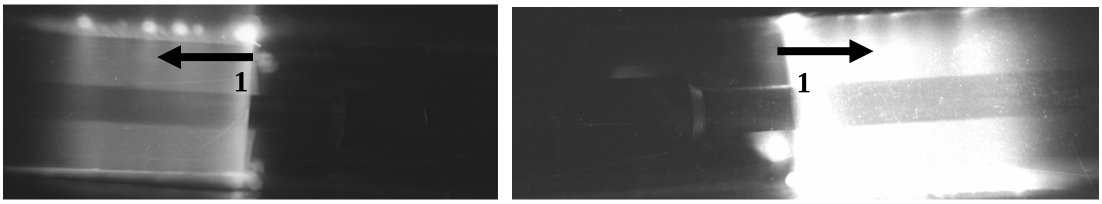
Figure.2. Pulse discharge visualization: scheme of experiment with model of cone shroud.

Complex model (2 cylinders, 2 cones) was mounted in discharge gap in shock tube channel at angle of attack 9°(figure 2a). The upwind and downwind sides were oriented on windows of a shock tube test chamber (figure 2b). Distance between opposite shock tube windows was 48 mm. Transonic non-stable flow behind the incident shock wave was tested. Low pressure values – 10-30 Torr. Model diameter 9 mm, Re = $10^4 \div 10^5$. Incident shock Mach number M=1,9-2,3, flow Mach number 0,8 ÷ 1,1. Flow duration was 300-350μs. Discharge pulse was synchronized with pressure sensors signal: discharge was initiated in different stages of gas dynamics process. The simultaneous instant images from two windows were taken on 2 cameras, scanned and analyzed. Images were compared to color shadow images [6].

Images of different stages of shock wave diffraction on complex model were obtained. On fig.3 2 pairs of instant (200ns-exposure) images of 2 different stages of shock diffraction are presented. On Fig.3a incident plane shock wave (marked 1) had passed over complex model. Discharge glow is only in front of plane shock wave front - in low density (pressure) area. On Fig.3b the gas dynamics process stage is presented when the incident shock had passed away from discharge gap. Redistribution of discharge plasma glow in complex 3D transonic non-stationary gas flow over the model occurred. Shock waves, separation zones, vortexes positions and configurations are visualized. Instant image of pulsating 3D separation zone in cone rear side is of special interest: Spatial configurations of 2 vortexes are recorded (marked 3 on fig.3b) with nanosecond volume discharge visualization.



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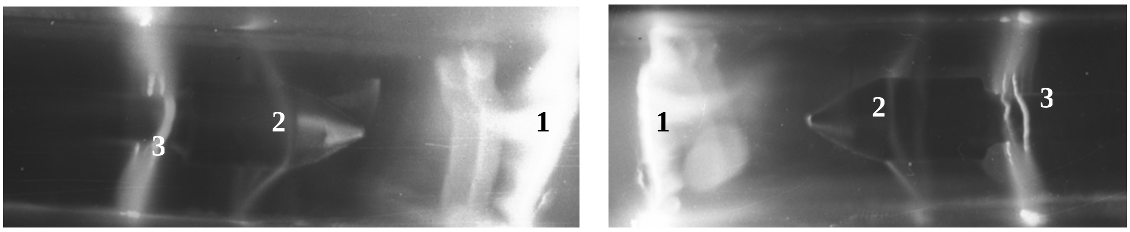

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Figure.3. Pulse discharge visualization: flow images (200 ns exposure).

Elements of visualized flow structure are: shock wave (1), line of separation (2), vortexes in rear separation zone (3); closing discontinuity. Glow reflections in windows glass spoil images.

On the image of a downwind side of model the shock wave configurations in forward lift-off zone is visualized. It is limited with two lines: line of shock intersection with a boundary layer on glass surface of chamber window - and spatial line of separation on model (2). Thus, the spatial shock wave configuration is visualized.

Instant (nanosecond-lasting) images of the same flow from opposite sides of test chamber allow reconstructing spatial flow structure. Boundary layer instabilities on glass windows surface are also visualized with nanosecond discharge plasma.

Acknowledgement

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