Shock Tube Boundary Layer Measurements with 4 Visualization Digital Methods

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Abstract High-speed gas flow in shock tube with special discharge test section has been studied with four visualization methods: Particle Image Velocimetry (PIV); high speed shadowgraphy recording with digital CCD cameras, particle tracing and; pulse discharge visualization method. The flow evolution was recorded for 12 ms after shock wave with Mach number range from M = 1,3 to M = 4,0 had passed by windows. Boundary layer transition on the walls was investigated with optical methods. It was shown that with the Mach number of the incident shock wave 3, a boundary layer is visualized 100 μs after the passage of the shock wave; a subsonic flow with a speed of 200m lasts up to 10 ms.
Keywords: boundary layer, shadowgraph, PIV, image processing, laminar flows, turbulent flows, shock tube, discharge, visualization methods.

1 Introduction

Shock tube is primary tool to study kinetic processes in gases at high temperatures, and non-stationary processes of shock waves interactions [1]. In addition, it is possible to investigate quasistationary processes in high speed flow behind the shock wave, The shock wave is followed by a uniform flow of a compressed gas whose region in the low-pressure channel is separated from a flow of a cold light pushing gas by the contact surface. Piezoelectric sensors are used to measure shock wave speed. To visualize high speed flows, schlieren methods, interferometry are used. The gas parameters just behind the shock wave are determined by the Mach number M and initial parameters in low pressure camera through Rankine-Hugonio ratio. But increasing boundary layer, rarefaction fan and contact surface change the flow. The flow speed decreases, turbulent pulsations increase. Modern digital technologies allow to study flow evolution far away from initial shock and thus to use the evaluating flow with known parameters for various processes study.

2 Setup and visualization methods

Shock wave is initiated on breaking of the diaphragm in the shock tube separating the high pressure chamber (helium) and the low pressure chamber (200 cm length, air). The tube and the test cross section is 24x48 mm^2. Quartz windows are mounted instead of the two opposite sidewalls of the chamber for flow visualization. The flow evolution was recorded for 5 – 10 ms after shock wave with Mach number range from M = 2,3 to M = 4,0 had passed by windows with several panoramic methods.
Shadow videos were recorded with high speed digital camera, at recording rate 300000 – 500000 frames per second. 2 different obstacles (small size 0,9 and long – 48 mm) were mounted on the lower wall to study oblique shocks evolution with high speed shadowgraphy (conical and flat).
Flow velocity fields; formation and evolution of boundary layers near the walls of the shock tube test section were obtained with PIV method. BOS method has been tested but proved to be non-effective inside shock tube. Also the velocities of single tracer particles in the flow were measured by the shadowgraphy high-speed recording [2].
Pulsed volume discharge with preionization by ultraviolet radiation (combined discharge) was switched in different time moments in the flow behind a shock wave. The plasma sheets on the top and bottom walls preionized the gas promoting the formation of a homogeneous volume discharge between them. The combined discharge current lasted for 150 – 200 ns. Instant glow images redistribution in flow was analyzed (pulse discharge visualization method [3])

3 Results and discussion.

Figures 1 – 3 present PIV, shadow and discharge visualization results for initial shock Mach number 3,0±0,1. A uniform flow with a negligible boundary layer thickness increasing with time is recorded with the PIV method behind shock wave up to 80 – 100 μs. Then, near the walls, a decrease in the flow velocity is evident. At the same time, on the glass, the striped parallel structures, - horizontal non-intersecting ensembles, are recorded by the shadow method. Gradually, by 300 – 500 microseconds, they begin to break up and intersect. The angle of inclination of the conical oblique shock indicates the flow velocity at the center of the channel. It decreases with a decrease in the flow speed. After 1000 mks the oblique wave is weak and the angle does

not change – the flow becomes subsonic. The oblique shock arising from a long rectangular obstacle is visualized by pulse discharge method. It disappears after approximately 1200 µs. The afterglow of the plasma arising during the discharge breakdown along the channel vertical wall (glass) also visualizes extended striped structures in the boundary layer on the glass - in the time range of 600 – 1100 mks. The glow color indicates the presence of helium in the flow.
Thus, with the Mach number of the incident shock wave 3,0, a visible boundary layer and striped structures on it appear 100 µs after the passage of the shock wave; developed turbulence in a subsonic flow with a speed of 200 m/s, lasts for a long time – up to 10 ms. This flow can also be used for researches, taking into account its features and parameters. For smaller Mach numbers the transition starts later and vice versa.

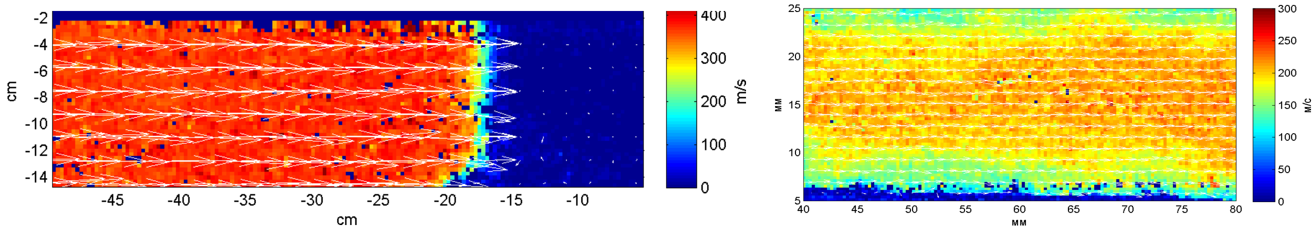

Fig. 1 PIV velocity field: shock wave and flow behind it 3600 µs after it.

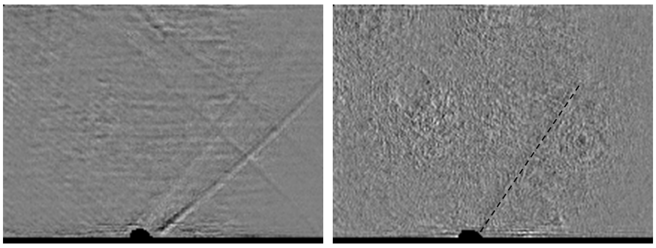

Fig. 2 Oblique shock wave and sound wave at different time moments 100 µs and 1590 µs, respectively.

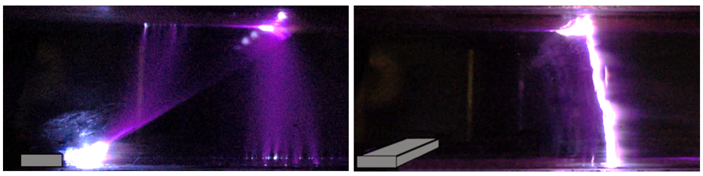

Fig.3 Visualizations oblique shock wave (t = 190 mks) and boundary layer on window (630 mk), respectively

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