EXPERIMENTAL STUDY ON VORTEX / BOW SHOCK INTERACTION AT MACH NUMBER OF 6

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Summary A review of a complex experimental study of various regimes during the interaction of the wing-tip vortex with the bow shock generated by the cylinder obstacle at Mach number of 6 is presented. Complex of visualization techniques included: high-speed shadow technique with adaptive visualization transparencies [1], high-speed shlieren visualization and laser sheet visualization. Pitot pressure and recovery temperature distributions were measured in free wing wake. The fast-response pressure transducers were used to measure pressure pulsation on the face of the cylinder. Time-averaged pressure distribution on the cylinder butt was measured as well. It was obtained that the wing-tip vortex is the initiator of self-oscillatory process with salient fundamental.

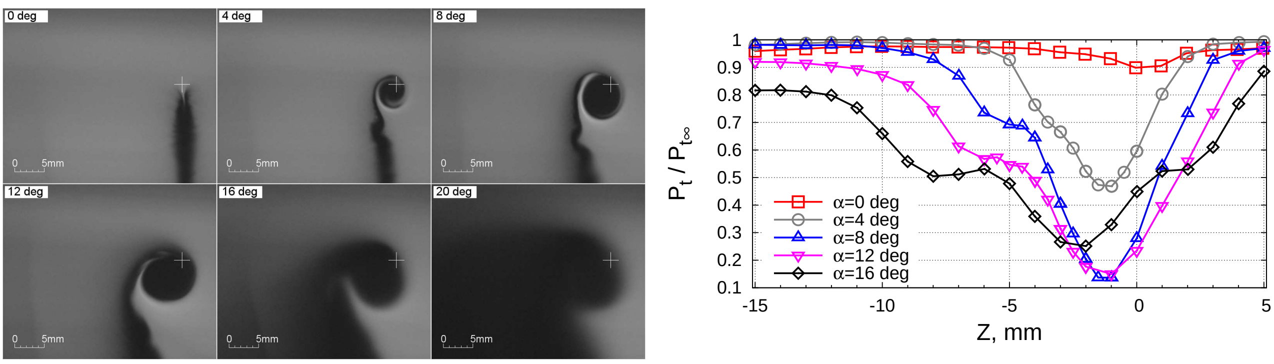
INTRODUCTION

Shock/Vortex Interaction is one of the fundamental problems of aerogasdynamics, which has been adequately studied neither theoretically nor experimentally. Interference of te vortex with shock waves in the inlet or other elements of the flying vehicle located downstream often leads to vortex breakdown, which, in turn, can deteriorate the lifting capacity of aerodynamic surfaces, lead to inadequate regimes of engine operation and to a drastic increase in heat transfer. Despite the adverse features of this phenomenon, it can be used as one method for improving mixing in the combustor. This phenomenon was first observed in [2], where interaction of a vortex core with a system of shock wave at the inlet of a supersonic flying vehicle was examined. In subsequent years, researchers of Russia, Germany, France, and USA studied this problem. One specific feature of interaction of a vortex wake with a shock wave is the unsteadiness of this process. It is manifested in experimentally observed fluctuations of gas-dynamic parameters of the flow and the changes in the flow structure and interaction region size with time. Numerical and experimental results on interaction of a supersonic vortex with oblique and normal shocks were reviewed in [3, 4]. The absence of experimental data at Mach numbers of 6 and higher should be especially noted. Present study was aimed to detailed investigation of vortex / bow shock interation at Mach number of 6. Experimental technique and some of the results were previously presented at PSFVIP-8 [5] and ISSW-28 [6].

RESULTS

The experiments were conducted in the supersonic wind tunnel T-326 of ITAM SB RAS at Mach number of 6. Experimental data were obtained for angles of attack up to 20deg., a radius of a cylinder of 42mm, chord b of a wing of 20mm and 40mm, and the distance x from the wing axis to the cylinder face of 25-155 mm.

Free wing wake



(a) Typical laser sheet images ($b = 40$mm, $x = 155$mm)

(b) Pitot pressure distribution across the vortex core ($b = 40$mm, $x = 155$mm)

Figure 1. Free wing wake

Laser sheet visualization results shows the vortex core destruction at big angles of attack. Figure 1(a) shows typical laser sheet images in a cross-section located 155 mm downstream from the trailing edge of the wing. Figure 1(b) shows typical pitot pressure distribution across the vortex core in the same cross-section. In the free vortex wake experiments both sufficiently high Pitot pressure loss and total temperature loss was detected. Location of Pitot pressure and total temperature minimums were found to be in good agreement with visualization results. The minimum values of the recovery temperature and Pitot pressure in the vortex core decrease as the angle of attack increases up to 16 degrees, and

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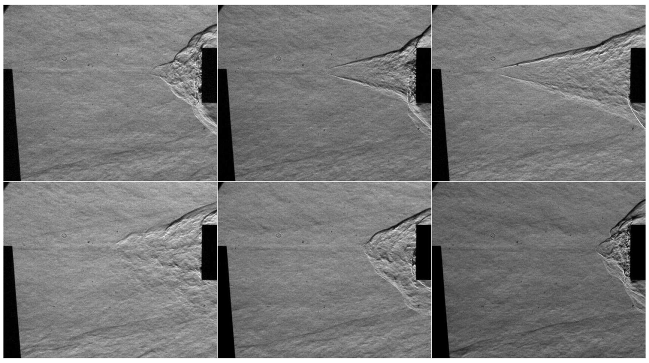
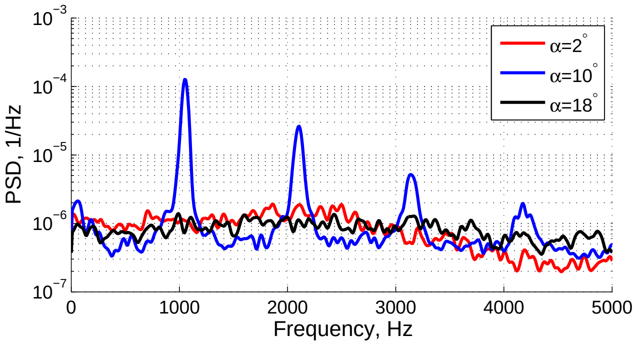
the increase in recovery temperature and Pitot pressure with a further increase in the angle of attack also confirms the laser sheet visualization results about possible vortex core destruction.

Vortex / bow shock interaction

Two different regimes depending on angle of attack were found during the interaction at Mach number of 6. Pulsing bow shock was observed at angles of attack from 0 to 2 and from 18 to 20 degrees. The self-oscillating process showed on Figure 2(a) was observed at angles of attack from 6 to 14 degrees. Pressure fluctuation measurements confirm the results of visualization.



(a) Typical schlieren images of self-oscillating process at $\alpha = 10°$ (b = 20mm, $x = 155$mm)



(b) Power spectra density distribution (b = 20mm, $x = 155$mm)

Figure 2. Vortex / bow shock interaction

Figure 2(b) shows power spectral density distribution for three different angles of attack. It clearly indicates a fundamental with a sufficiently high power and a frequency of about f =1000 Hz during the interaction at $\alpha = 10°$. Similar data were obtained for angles of attack $\alpha = 6 \div 14°$. At the same time, the spectral analysis has not revealed significant peaks in the normalized power spectral density distribution for angles of attack of $\alpha = 0 \div 2°$ and $\alpha = 18 \div 20°$. Disappearing of self-oscillations at big angles of attack can be connected with previous described vortex core destruction.

CONCLUSIONS

A hypersonic interaction of a wing-tip vortex with a bow shock generated by the cylinder obstacle has been examined at Mach number of 6. The experiments revealed a highly unsteady processes during the interactions. Global reorganization of flowfield structure with a high level of pressure fluctuations was observed. At low angles of attack the experiments has detected an interaction process with a pulsing bow shock wave. The self-oscillatory process was observed at moderate angles of attack. This process is characterized by a fundamental with a sufficiently high power. Further increase in angle of attack reveals to pulsing regime similar to the one observed at low angles of attack. Disappearing of self-oscillations at big angles of attack can be connected with vortex core destruction.

ACKNOWLEDGEMENTS

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