REVIEW OF ITAM EXPERIMENTS ON SHOCK WAVE / VORTEX INTERACTION

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Summary The interaction of concentrated streamwise wing-tip vortices and shock waves is investigated at Mach numbers of 3, 4 and 6. Research programm included observations of the flowfield in the core of supersonic wing tip vortices, a study of bow shock / vortex interaction and a hypersonic interaction of the streamwise vortex with a Pitot-type inlet.

INTRODUCTION

Shock/Vortex Interaction (SVI) is one of the fundamental problems of aerogasdynamics, which has been adequately studied neither theoretically nor experimentally (e.g. [1-3]). At the same time, this type of interaction is frequently encountered in numerous applications. The absence of numerical and experimental data for hypersonic velocities should be specially noted. Obtaining results for this range of velocities is extremely important for the development of promising flying vehicles. The objective of present work is an experimental study of the interaction of streamwise vortices with shock waves generated by different types of a shock generator. A fundamental differences between previous experimental studies (e.g. [1,2]) is a wide Mach number range of 3–6. One of the factors affecting SVI is the flow characteristics in the core of the streamwise vortex, and the presented study included a surveys of the tip vortices.

INVESTIGATIONS OF WING TIP VORTICES

The experiments were conducted in the supersonic wind tunnel T-313 of ITAM SB RAS with a 60×60 cm^2 test section. A wing-tip vortex is generated by a rectangular half-wing with a span of 300 mm. A hexahedral airfoil has a chord length of 80 mm, a half-angle of 8 deg. Three 5-hole conical pressure probes were used to measure local Mach number, total pressure and flow angularity. Flow field visualization with a schlieren technique and a laser light sheet imaging technique was carried out. The experiments were performed at Mach numbers of 3 and 4. Vortex generator was mounted at angles of attack $\alpha = 5,\ 10,\ 15$ deg.

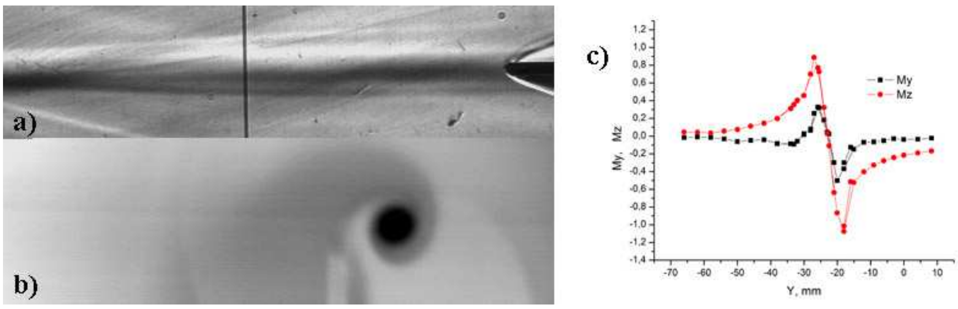

Figure 1. Wing-tip vortex surveys at $M = 3$, $\alpha = 10$ deg: (a) 5-hole probe in the vortex core; (b) Laser light sheet image; (c) Distributions of vertical and horizontal Mach numbers

The experiments revealed many vortex core characteristics commonly found in previous studies [1,2], including an asymmetric swirl distribution and significant total pressure and total Mach number deficits. The spatial scale, Mach number deficit and total pressure loss of the vortices were observed to increase with wing angle of attack.

BOW SHOCK / VORTEX INTERACTION

The experiments were conducted in the supersonic wind tunnel T-313 of ITAM SB RAS. The bow shock generator is cylinder obstacle mounted 260 mm downstream of the trailing edge of the vortex generator described above. The experiments were performed for angles of attack of the vortex generator up to 20 deg and Mach numbers of 3, 4, and 6. The shadowgraph visualization of the flow was carried out using a spark light source with microsecond exposure times. Shadowgraph images were recorded at a rate of 33 frames per second. Piezoelectric fast-response pressure transducer was used to measure of pressure pulsation on the face of the cylinder. The amplified output from the transducer was digitized using an AD converter at a rate of 300 kHz. Time-averaged pressure on the cylinder butt was measured by the multi-channel pressure transducer MID-100.

Shadow images during a bow shock/vortex interaction shows a conical interaction zone. At $\alpha = 10$ deg and 15 deg the flow field is similar that one observed in previous study of the normal shock/vortex interaction [2]. The conical interaction region consists of two zones: a central conical zone containing the distorted vortex and an outer supersonic zone bounded by the conical shock. At $\alpha = 5$ deg these two zones are almost merged. At $\alpha = 20$ deg an interaction region is extended

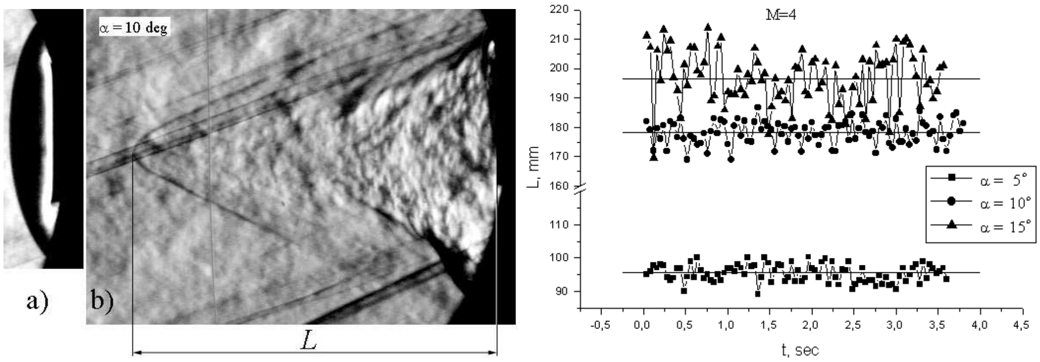

Figure 2. Bow shock / vortex interaction at $M = 4$: (a) Flowfield without vortex; (b) Shadowgraph for $\alpha = 10$ deg; (c) Time history of the measured length of the interaction region

upstream from the shock generator right up to the vortex generator. An examination of multiple spark shadowgraphs has revealed an unsteady character of the interaction. Flow topology is changed during one test run. However the spectral analysis has not revealed discrete harmonic of pressure pulsations signals. The length of the interaction zone is varied up to 20 percent of its average value at the same angle of attack of the vortex generator while one is increased with wing angle of attack.

INTERACTION OF A WING-TIP VORTEX WITH A PITOT-TYPE INLET

The experiments were conducted in the hypersonic wind tunnel T-326 of ITAM at Mach number of 6. A wing-tip vortex is generated by a rectangular half-wing with a chord length of 40 mm and diamond-shaped cross-sections. The Pitot-type inlet is the tube with sharp leading edge and the diameter of 30 mm. A normal shock wave is created in front of the inlet by an adjustable obstruction in the form of truncated cone. The Pitot-type inlet was mounted 100 mm downstream of the trailing edge of vortex generator. The experiments were performed for wing angles of attack up to 15 deg with the step of 2.5 deg. Described above shadow visualization and pressure pulsation measurements on the butt of the cone obstruction were used. Time-averaged static pressure was measured along of the inlet as well.

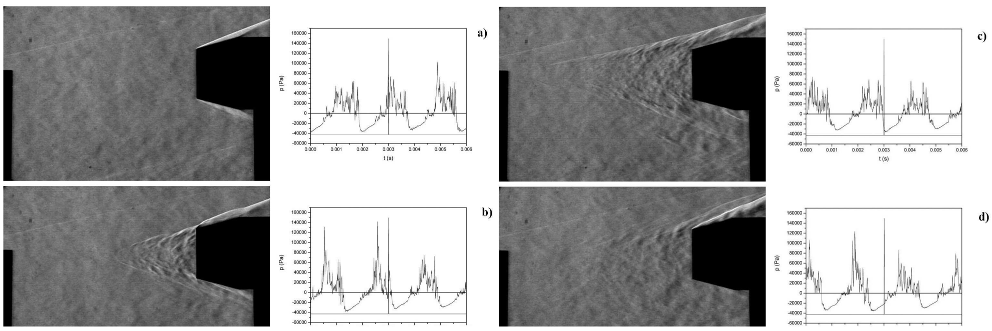

Figure 3. Interaction of a streamwise vortex with Pitot type inlet at $M = 6$, $\alpha = 10$ deg.: (a) I phase; (b) II phase; (c) III phase; (d) IV phase.

Contrary to experiments by Kalkhoran et al. [2] (which detected a bimodal feature of the flowfield at M=2.49) there are four phases of the interaction process were detected (see Fig. 3). It was obtained that the longitudinal vortex is the initiator of self-oscillatory process with salient fundamental. Fundamental amplitude and fundamental frequency as well as static pressure distribution along the inlet slightly depend on the vortex strength.

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References

[1] Delery J., Horowitz E., Leuchter O., Solignac J.: Fundamental Studies on Vortex Flows. *La Recherche Aerospatiale, (English ed.)*, **2**: 1–24, 1984.
[2] Kalkhoran I.M., Smart M.K.: Aspects of shock wave-induced vortex brakdown. *Prog. in Aerospace Sciences*, **36**: 63–95, 2000.
[3] Thomer O., Schroeder W., Krause E.: Normal and oblique shock-vortex interactions. *Proc. at Int. Conf. RDAMM-2001, Special Issue,* **6** (2): 737–749, Novosibirsk, 2001.