Experimental study of hypersonic boundary layer stability and laminar-turbulent transition on sharp cone with passive porous coatings at zero and small angles of attack

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Abstract The present work is devoted to an experimental study of small angles of attack on the efficiency of stabilization of high-frequency disturbances in hypersonic boundary layer with a passive porous coating. The experiments are carried out on a sharp cone with apex half-angle 7^0 installed under angles of attack $\alpha = 0\text{-}1^0$ in a flow at the free-stream Mach number $M_\infty = 5.8$. High-frequency pressure pulsations on the sides of the cone with the continuous and passive porous surfaces are measured. It is shown that at small angles of attack the passive porous coating permits an efficient suppression of disturbances in hypersonic boundary layer both on the windward and leeward sides of the cone.
Keywords: hypersonic boundary layer, passive porous coating, boundary-layer stability, laminar-turbulent transition

1 Introduction

Currently investigations of hypersonic boundary layer stability are performed for the porous coating of regular (perforations [1], layers of wire mesh [2]) and random (felt metal [0], carbon-carbon ceramic [0]) microstructure. It was shown that all of these coatings serve well for stabilization of the second mode disturbances and the laminar to turbulent transition delay at certain conditions. However, hypersonic boundary layer stability is strongly depends on small angle of attack of the cone, therefore the aim of this study is experimental investigation of the influence of the small angle of attack on the effectiveness of the stabilization of a hypersonic boundary layer on a cone using passive porous coating.

2 Effect of the angle of attack

The model is a cone with an apex half-angle 7° and generatrix length 353 mm (Fig. 1). The temperature of the cone surface, Tw, is 295 ± 3 K. On one half of the cone, along the generatrix, a passive porous coating of 286-mm total length is installed. The passive porous coating presents a three-layer mesh with the porosity of 44%. For measuring pressure pulsations, two PCB132A31 pressure sensors are installed at the distance x = 343 mm from the cone nose tip; one sensor is installed on the side with the solid surface, and the other, on the side with the porous surface. The pressure sensors allowed measurements of pressure pulsations in the frequency range from 11 to 1000 kHz. The experiments is carried out at free-stream Mach number $M_\infty = 5.8$, the unit Reynolds number $Re_{1\infty} = 6.8 \cdot 10^6$ m^{-1} and stagnation temperature $T_0 = 387 \pm 3$ K.

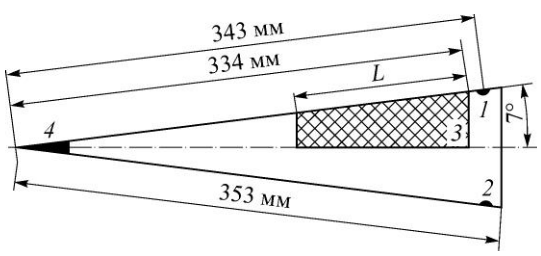

Fig. 1 Cone model. 1, 2 — high-frequency pressure sensors, 3 — passive porous coating, 4 — interchangeable nose.

Fig. 2 shows the spectra of pressure pulsations on the windward and leeward sides of the cone at angles of attack up to 1°. Here, the second-mode disturbances on the solid surface of the cone at zero angle of attack with a peak at frequency $f \approx 200$ kHz is seen distinctly against the background of other disturbances in the examined frequency range. And the amplitude of second-mode disturbances on the windward side of the cone decreases, and the frequency of the disturbances, increases with increasing the angle of attack, this observation being in compliance with previous studies. In the examined range of frequencies, the amplitude of other disturbances remains roughly unchanged. On the passive porous coating, the amplitude of the second disturbance mode is smaller than that on the solid surface at all the examined angles of attack. At zero angle of attack and on the windward side of the cone at $\alpha = 0.5°$ and 1° the amplitude of the disturbances with frequencies $f \approx$ 100–150, 110–145, and 120–180 kHz on the porous coating is higher than that on the solid surface.
On the solid surface of the cone, on the leeward side the amplitude of the second-mode disturbances increases in value on increasing the angle of attack to $\alpha = 0.5°$; simultaneously, the disturbances in the whole frequency range start growing, this fact pointing to a transient regime of the boundary layer at the measurement point. Further increase of the angle of attack to 1° leads to an almost complete suppression of the second-mode disturbances and to a persistent growth of disturbances in the frequency range $f = 25$–125 kHz, this observation being indicative of the onset of turbulent flow regime. On the leeward side, the amplitude of disturbances in the whole examined frequency range on the porous coating is lower that at the same angles of attack on the solid surface.
Experimental results show that, with the considered angles of attack, the passive porous coating effectively suppresses the most unstable second-mode disturbances in the hypersonic boundary layer of the cone.

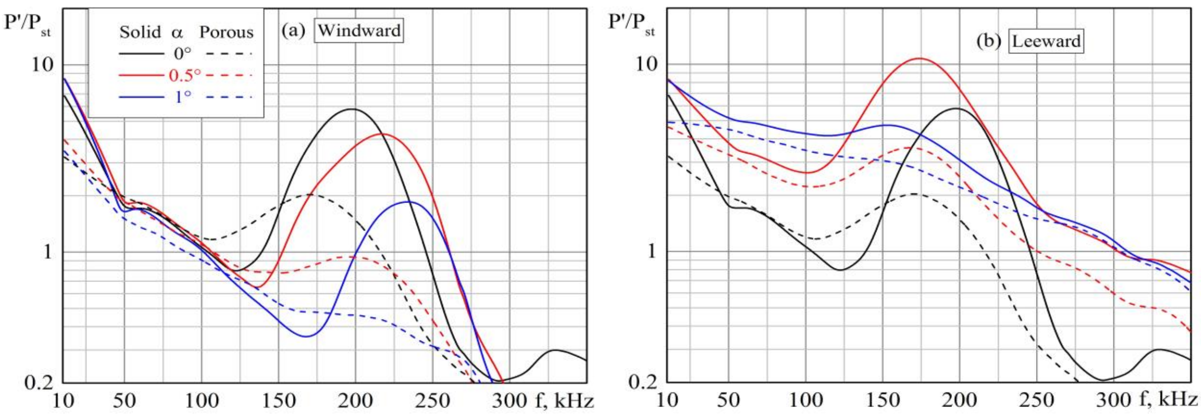

Fig. 2. Spectra of pressure fluctuations on the windward (a) and leeward (b) sides

[1] Rasheed A, Hornung H G, Fedorov A V, Malmuth N D (2002) Experiments on passive hypervelocity boundary-layer control using an ultrasonically absorptive surface. AIAA J. 40 (3), 481-489. doi: 10.2514/2.1671

[2] Lukashevich S V, Morozov S O, Shiplyuk A N (2016) Experimental study of the effect of a passive porous coating on disturbances in a hypersonic boundary layer 2. Effect of the porous coating location. J. App. Mech. and Tech. Phys. 57 (5), 873-878. doi: 10.1134/S002189441605014X

[3] Fedorov A, Shiplyuk A, Maslov A, Burov E, Malmuth N (2003) Stabilization of a hypersonic boundary layer using an ultrasonically absorptive coating. J. Fluid Mech. 479, 99-124. doi: 10.1017/S0022112002003440

[4] Wagner A, Kuhn M, Martinez Schramm J, Hannemann K (2013) Experiments on passive hypersonic boundary layer control using ultrasonically absorptive carbon-carbon material with random microstructure. Experiments in Fluids, 54 (10), 1606. doi: 0.1007/s00348-013-1606-3