EXPERIMENTAL INVESTIGATION OF EFFECT OF ULTRASONICALLY ABSORPTIVE COATING LOCATIONS ON SECOND MODE DISTURBANCES IN HYPERSONIC BOUNDARY LAYER

Sergey Lukashevich[1], Sergey Morozov [1] & Aleksandr Shiplyuk [1]
[1]*Khristianovich Institute of Theoretical and Applied Mechanics, Novosibirsk, Russia*

Abstract Experimental investigation about second mode disturbances in hypersonic boundary layer on a cone with different location of ultrasonically absorptive coating (UAC) is carried out at $M_\infty = 5.8$. It is shown that UAC location has strong influence on second mode amplitude. Locations of UAC with maximum efficiency on second mode stabilization is found.

INTRODUCTION

Laminar-turbulent transition causes significant increase in heat transfer and viscous drag that leads to severe restrictions on performance of high-speed vehicles. This motivates developments of hypersonic laminar flow control (LFC) concepts to delay the transition onset. Under hard environmental conditions of hypersonic flight (high temperatures and large heat fluxes to aerodynamic surfaces), passive LFC methods are of primary interest. For the wedge-like configuration of hypersonic vehicles with aerodynamically smooth surface, dominant instabilities are the second mode disturbances. Fedorov et al. [1] showed theoretically that an ultrasonically absorptive coating (UAC), which is a thin porous layer with fine microstructure, can strongly stabilize the second mode and, presumably, increase the laminar run. These predictions were made using the linear stability theory (LST). Further experimental studies of second mode disturbance development on UAC [2-3] confirmed this LFC concept. It has been shown that porous coatings of random and regular microstructures can massively suppress the second mode and significantly (more than twice) increase the laminar run in high-speed boundary-layer flows on sharp cones at zero angle of attack. It was experimentally found that, in accord with the theoretical predictions, there is an optimal UAC thickness (h) at which the second-mode stabilization is maximal [4]. This optimum corresponds to the UAC thickness ratio $h/b \approx 3$ that is consistent with the theory. These findings allow to assume that an optimal UAC thickness ratio can be established for sufficiently wide ranges of basic parameters. The objective of present work is experimental study of second mode disturbances in hypersonic boundary layer on a cone with different locations of ultrasonically absorptive coating (UAC) with optimal thickness.

EXPERIMENTAL SETUP

Experiments are carried out in the ITAM hypersonic wind tunnel tunnel “TRANZIT-M” at the free-stream Mach number $M_\infty = 5.8$ and the unit Reynolds number $Re_{1\infty} = (2.6 - 13.2)\cdot 10^6$ m^{-1}. The run time is about 110- 200 ms. Although the “TRANZIT-M” wind tunnel is a conventional noisy facility, the free-stream noise is relatively small in the high-frequency band related to the second mode instability and its higher harmonics. This allows us to identify the second-mode waves in the boundary layer on the cone model and measure their stability characteristics. The model is a half-angle sharp cone (Figure 1). Here L – UAC length, x_0 – distance to the end of UAC, x_g – distance to PCB pressure gages; 1, 2 – PCB pressure gages. The UAC strip is flash mounted on the solid backup between the streamwise stations x=67 – 286 mm. The coatings comprise several layers of the wire mesh with the open screen area 44%. The thickness of UAC layer is 0.18 mm, it corresponds to the optimal UAC thickness found in [4]. Wall temperature $T_w = 295 \pm 1$ K. Angle of attack $\alpha = 0 \pm 2'$. To evaluate stability characteristics of the boundary-layer flow, the wall pressure disturbances are measured by the high-frequency piezoelectric pressure gauges PCB which are able to capture disturbances in the frequency band 11 – 1000 kHz.

RESULTS

It is found that the UAC location has strong influence of second mode amplitude. Example of pressure pulsations spectra on solid wall and the wall with UAC of different locations are shown in Figure 2 for $Re_{1\infty} = 4.6\cdot 10^6$ m^{-1}. The length of UAC is fixed. It is well seen that amplitude of second mode maximum at UAC with location at x = 106 – 183 mm is higher than the amplitude maximum on solid surface. The further moving of UAC location downstream leads to decrease of second mode amplitude. Finally at x = 297 mm the second mode amplitude on UAC is minimal. Therefore it is found that UAC could both decrease (if UAC is located well downstream) and increase (if UAC is located well upstream) second mode amplitude.

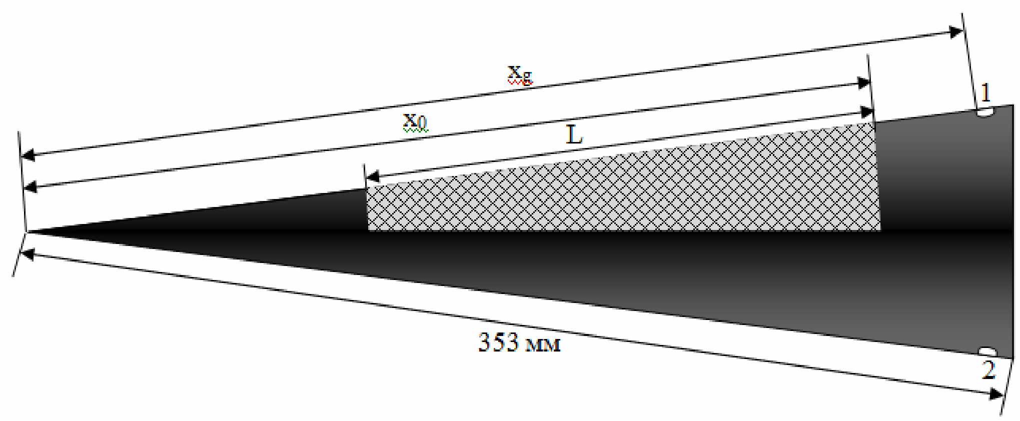

Figure 1. Sketch of the model.

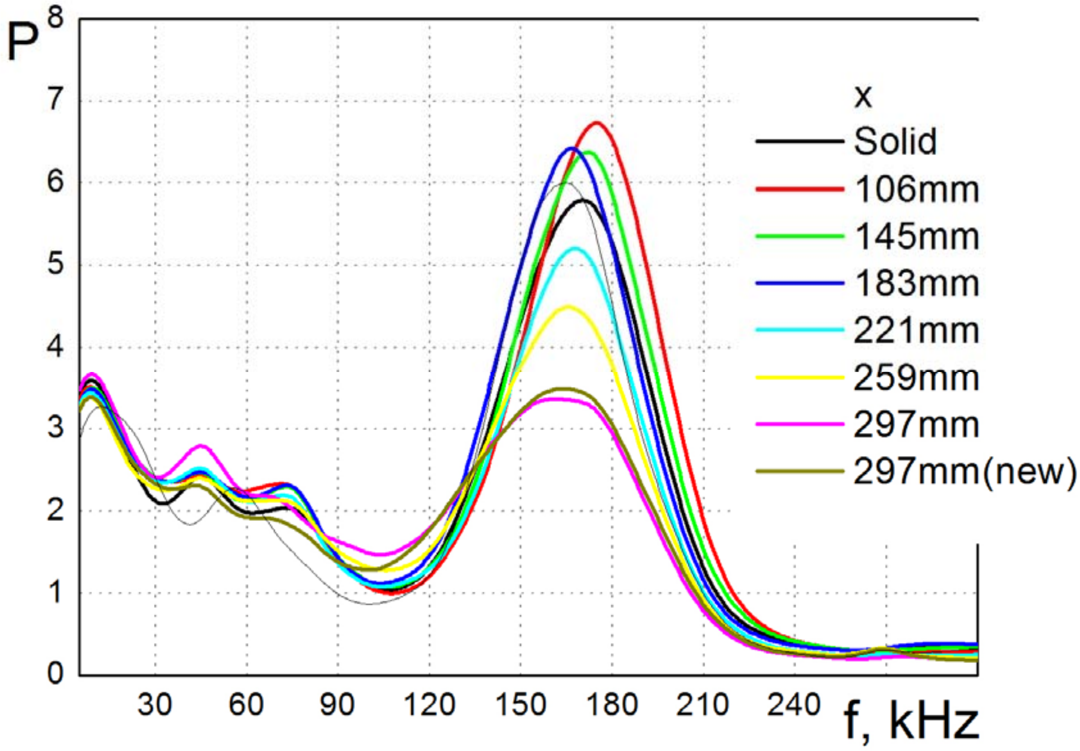

Figure 2. Pressure pulsations spectra on cone with different UAC locations for $Re_{1\infty} = 4.6 \cdot 10^6$ m^{-1}.

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