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Buffet delay on transonic airfoil by tangential jet blowing

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Abstract
The results of the experimental investigations of the tangential jet blowing from the slot located on the upper surface of the supercritical airfoil to eliminate the shock-induced separation and aerodynamic buffet on transonic Mach numbers are presented. The experimental study with the tangential jet blowing was carried out in the transonic wind tunnel T-112 TsAGI with the square test-section of 0.6x0.6 m^2. Investigations have shown that the tangential jet blowing shifts the shock wave downstream and increases the lift. It also suppresses the shock-induced separation and delays the buffet onset.

1. Introduction

The flight envelope of a civil transonic aircraft is limited by the buffet phenomenon associated with the separation under shock foot on the upper surface of the wing. The buffet results in lift and drag variations that affect the aircraft aerodynamics greatly. This phenomenon can further lead to structural vibrations (buffeting). Wing design standards impose margins between the buffeting onset and the cruise condition. As a consequence, a delay in buffeting onset could lead to improved aerodynamic performance characteristics resulting in reduced wing area and then reduced friction drag and weight. One of the ways to delay buffet is the concept of flow control.
This problem is very close to the problem of the shock-boundary layer interaction (SBLI). In literature, there is a big variety of methods to control SBLI (cavity under the shock foot, bump, mechanical and fluidic vortex generators, suction, plasma actuators).
Some of these devices were investigated as the buffet control means. Mechanical VGs were studied in [1]. Special mechanical trailing edge device (TED) which can change rear loading of the airfoil was also considered in [2]. Fluidic VGs (air-jet VGs) as well as fluidic TED (jet near the trailing edge normal to airfoil pressure side) were studied in [3]. It was shown that mechanical and fluidic VGs were able to delay buffet onset in the angle-of-attack domain by suppressing separation downstream of the shock. The effect of the fluidic TED was different: the separation was not suppressed. In this case, the buffet onset was not delayed in the angle-of-attack domain, but only in the lift domain.
Tangential jet blowing with the position at 15% to control SBLI was also investigated in [4]. Further in [5-7], this method was modified and tangential jet was blown near the shock with a relatively small intensity. This method is effective for lift increase.
In the present study, buffet control method by tangential jet blowing is investigated. The jet of compressed air is blown continuously from small slot nozzle tangentially to the wing upper surface in the region of shock location to reduce the shock-induced separation. Experimental studies of the flow over transonic supercritical airfoil with active flow control are carried out. The experimental research with the tangential jet blowing was carried out in the transonic wind tunnel T-112 TsAGI with the square test-section of 0.6x0.6 m^2 and the length of 2.59 m. The model of the straight wing was manufactured with the chord of 200 mm and was installed between the side walls of the wind tunnel. The jet of compressed air was blown from the small slot of 0.15 mm in height tangentially to the upper surface of the wing at 60% of the chord from the leading edge. During the experiment the pressure distribution and pressure pulsations on the model surface and on the wind tunnel walls were measured, and also the total pressure profile in the wake downstream of the model with the use of rake was obtained. Moreover, the flow visualization over the upper surface of the airfoil was obtained using shadow-type pictures method on every regime.

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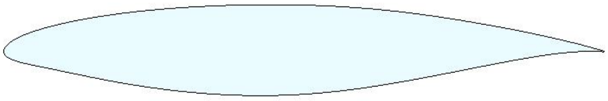
2. Experimental Setup

The experiments were carried out in the transonic wind tunnel (WT) T-112 TsAGI. This wind tunnel is a half closed layout test facility with a suction ejector and a closed test section, horizontal walls of which can be perforated. Movable valves are located downstream of the test section. Their purpose is to adjust velocity in transonic range (M=0.5-1.5) reducing the cross section. WT T-112 (Fig. 1) has the following characteristics: square test section – 0.6x0.6 m^2; length of test section – 2.59 m; side walls are solid; top and bottom walls were with the perforation of 23%; stagnation temperature – environmental temperature T_0=287 K; stagnation pressure – 1 atmosphere; Reynolds number based on free-stream parameters and chord length (200 mm) – ~2.6×10^6; standard run duration – 300 s.
A model of the airfoil is performed in the form of rectangular wing with the same cross section (Fig. 1) and located between the side walls of the test section. The side walls in the region of the model installation have optical windows, which enable optical measurements of the flow around the model by means of Schlieren-type images with the diameter of monitoring area equal to 230 mm.

Figure 1: T-112 TsAGI transonic wind tunnel with the model, view from leading edge

The model contains the equipment for tangential jet blowing and various measurements performed during WT tests. The following measurements were carried out: shadow-type visualization of flow over the upper surface; pressure taps on the upper (20 points) and bottom surfaces (15 points); unsteady pressure pulsations measurements on the upper surface (10 points); wake investigations using the rake to measure stagnation pressure profile; pressure (16 points) and pressure fluctuations (3 points) measurements on wind tunnel walls.
P-184-15SR (Fig. 2) supercritical airfoil was chosen as the baseline configuration. The wing model had the following parameters: thickness – 15%; chord length – 200 mm; span – 600 mm. For these WT tests, the model was equipped with a slot for tangential jet blowing. The slot was located at 60% of chord and had height of 0.15 mm. Range of total pressure of the blown jet is P_{0jet}=1.5; 2; 2.5; 3 atm.
Boundary layer transition was triggered at 15% of the chord by cylinders with 0.1 mm height on the upper and bottom airfoil surfaces.



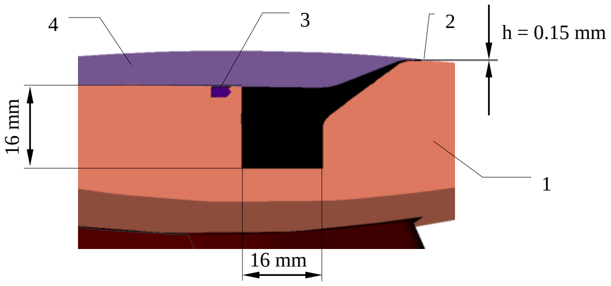


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Figure 2: Airfoil P-184-15SR and slot nozzle cross-section; 1 – wing, 2 – slot nozzle, 3 – seal, 4 – cover of the air chamber

3. Experimental Results

The following typical dependencies are shown in figure 3: pressure coefficient Cp on the model surface corresponding to the different jet intensities; root-mean-square (RMS) values of Cp; total pressure distribution in the wake downstream of the model in the central cross section in vertical direction. One can see that the increase of a jet stagnation pressure moves the shock wave downstream and leads to a better trailing edge Cp recovery.

It should be noted that there are no pressure pulsation sensors at 0.5<x/c<0.65. The maximal value of RMS Cp can be in this region and thus it is impossible to estimate the maximal values of RMS Cp and the region of high pulsations. The increase of RMS Cp appears due to the shock wave generation. Peak of pulsations follows the shock wave. In the case with jet blowing, P_{0jet}=2.5-3 atm, Cp at trailing edge shows that there are no separations. In these cases peaks of RMS values can relate to the unsteadiness in the region of the slot location due to the jet blowing.

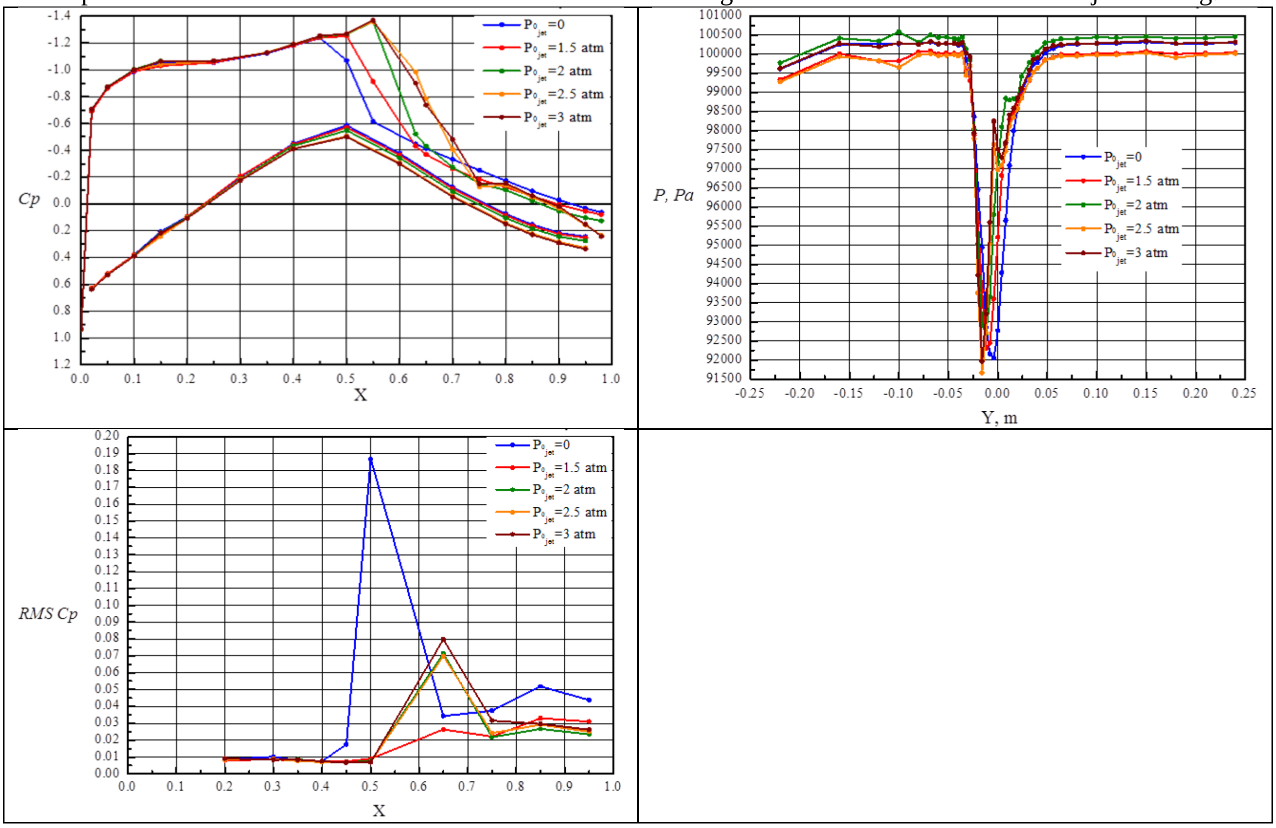
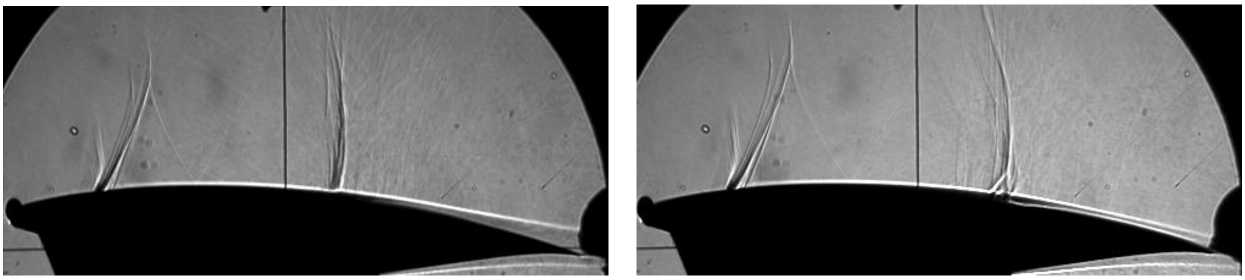


Figure 3: Pressure coefficient Cp, RMS Cp and total pressure in the wake downstream of the model for M=0.75, α=6°



M=0.74

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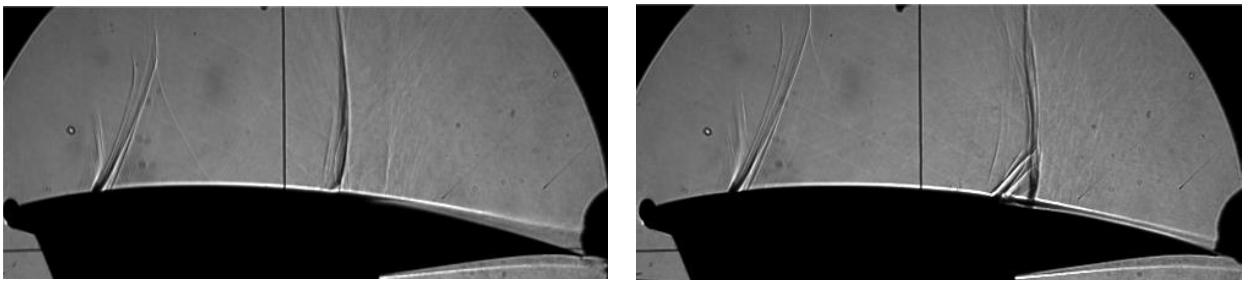
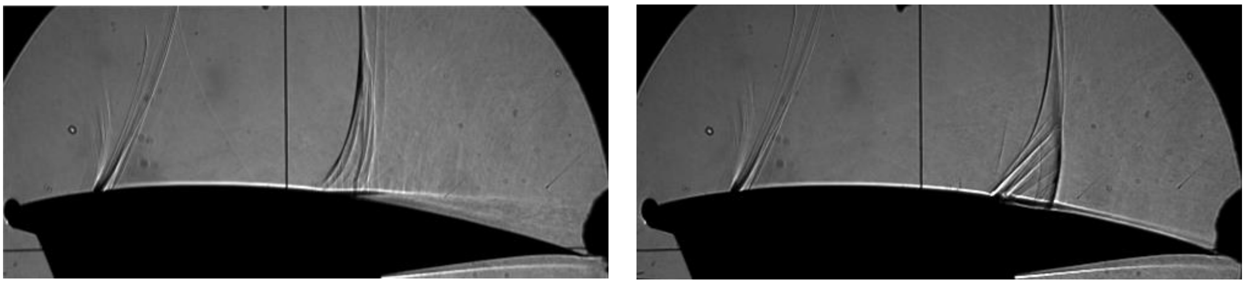
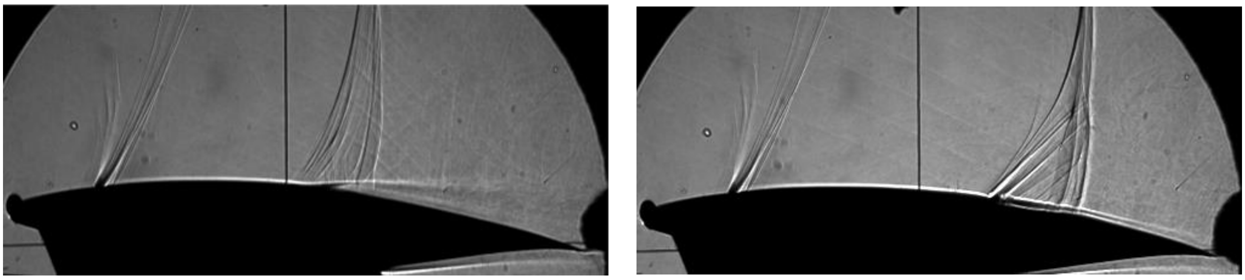


M=0.75



M=0.78



M=0.80

Figure 4: Shadow images for baseline configuration (left) and configuration with tangential jet blowing (right) at P_{0jet}=3 atm; α=5°

In figure 4, one can see the difference between the shock wave locations for the case without blowing (left column) and for the case with jet blowing (right column). Moreover, it is clearly seen from the right column that even for the highest Mach number there is no separation under the shock and at the trailing edge for the cases with the jet blowing P_{0jet}=3 atm.

One of the main parameters to be obtained in this experiment was buffet frequency. The pressure difference on time was obtained using pressure pulsation sensors for each regime. Then the spectra were calculated (figure 5). Figure 5 shows spectra for the case of α=6° at different sections x/c and for different Mach numbers. It is clearly seen that there is a discrete peak at ~140 Hz. This peak is relatively close to the value predicted by preliminary CFD studies. Two dimensional CFD gives the buffet frequency ~110-120 Hz. In all chordwise sections, there is a second peak at ~800 Hz. It should be noted that there is no peak on the wall (figure 6). Probably it can arise on the model due to the three dimensionality of the flow and/or wall interference.

One can see that in the cases with jet blowing, the discrete peak ~140 Hz typical to the baseline configuration disappears while the level of pulsations in this region increases. The peak with ~800 Hz is approximately the same as in the case without jet blowing.

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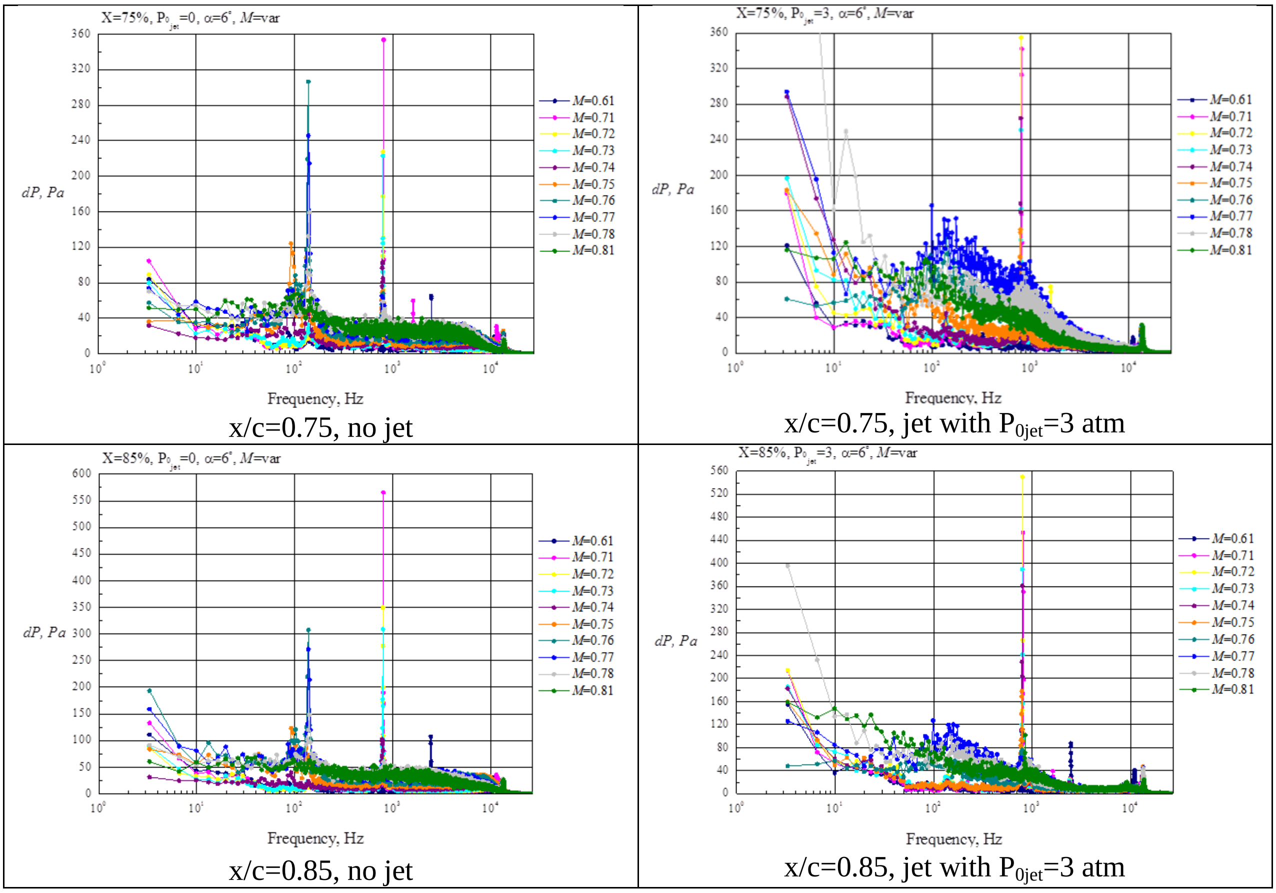

Figure 5: Spectra of pressure pulsations for α=6° for baseline (left) configuration and tangential jet blowing (right) with P_{0jet}=3 atm

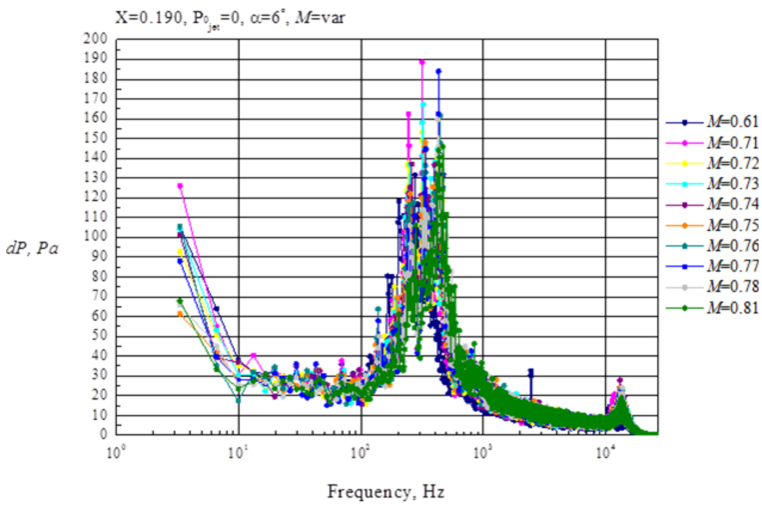

Figure 6: Spectra of pressure pulsations on the wall at x/c=0.190 without jet blowing

4. Conclusions

The wind tunnel tests of the configuration with tangential jet blowing have been carried out in the TsAGI transonic wind tunnel T-112. The pressure distributions on the airfoil, wind tunnel walls and in the wake have been obtained. The tangential jet blowing moves the shock location downstream at all regimes. The increase of a jet intensity leads to a more downstream location of the shock and a better recovery of the trailing edge pressure. The jet suppresses the shock-induced separation and separation at the trailing edge.

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The buffet frequency was measured. It is clearly seen that there is a discrete peak at ~140 Hz. This peak is relatively close to the value predicted by preliminary CFD studies. Two dimensional CFD gives the buffet frequency ~110-120 Hz. In all chordwise sections, there is a second peak at ~800 Hz. It can probably arise due to three dimensionality of the flow and/or wall interference.

In the cases with jet blowing, there is no discrete peak associated with buffet at ~140 Hz, which is typical for the baseline configuration, while the level of pulsations in this region increases. The peak with ~800 Hz is approximately the same as in the case without jet blowing.

One can conclude that tangential jet blowing is an effective method to delay transonic buffet onset.

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