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INVESTIGATION OF UNSTEADY TRANSONIC FLOW FIELD ABOVE LAMINAR AIRFOIL BY PIV METHOD

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Abstract

Experimental investigation of flow field above a laminar airfoil in a transonic wind tunnel was conducted. The aim of the research was to provide a quantitative information about the shock position for various angles of incidence at Mach number = 0.7. The flow field in a test section of high speed blow down wind tunnel was investigated by means of Particle Image Velocimetry (PIV). The resulting instantaneous vector velocity field was processed in order to determine the variation of shock position above the airfoil. As expected, the shock moved closer to the leading edge while the angle of incidence was increased. More interestingly, the experimental data revealed an increase in shock oscillation amplitude for angle of incidence between 3° and 5°. Experiments allowed to quantitatively describe the transonic flow field above the airfoil by non-intrusive method.

1 General Introduction

One of the most investigated fields of aviation research [19] is optimization of the aerodynamic performance of new aircrafts at low [2][8][21] and transonic speeds. Especially for airline transport the balance between the time of traveling and economy of flight require cruising speeds in proximity of critical Mach number of used airfoils. In such conditions the flow is often affected by the presences of nonlinearities and instabilities. The flow field oscillations are caused by interaction of the shock with the boundary layer. This interaction influences the development of the shock-induced separation bubble or rear separation [7]. The unsteady flow field with shock wave oscillations might cause unsteady buffet loads acting on airplane structure. Therefore, applied research on the transonic flow are important for control, economics and safety reasons.

The experimental investigations of unsteady transonic flow over an airfoils was carried out since 1950s. Complex phenomena such as creation of shock, oscillations, buffet onset and shock wave boundary layer interaction was examined with pressure [9] and stress measurements [20], the flow filed was visualized Schlieren method [10]. A comprehensive review of recent progress in shock wave/boundary layer interactions research can be found in [6].

The Particle Images Velocimetry (PIV) is instantaneous whole field velocity measurements technique [12] applied in fluid dynamic research, aerodynamics [15][16] and related fields [18]. The PIV method was used for instantaneous whole field velocity measurements of flow at transonic speeds [5][11][13]. The SWBLI was investigated with PIV method by Giepman [3]. Hartmann [4] performed time resolved stereo PIV measurements of unsteady shock-boundary layer interaction on a supercritical airfoil.

This paper presents application of PIV method for investigations of shock oscillations above the surface of an airfoil. The experiments was performed in high speed wind tunnel N-3 in Institute of Aviation, Warsaw, Poland. In a course of presented study a 2D vector velocity field of the flow over an airfoil for Mach number of 0.7 has been determined. The PIV measurements results were used for determination of the shock wave position in relation to the chord of the airfoil. The various angles on incidence for fixed freestream Mach number were examined. Experiments allowed to quantitatively describe the transonic flow field above the airfoil and to determine the buffet onset conditions.

2 Materials and methods

The experimental investigation has been conducted in the Trisonic Wind Tunnel N-3 of the Institute of Aviation in Warsaw. The N-3 wind tunnel is a closed circuit blow down type wind tunnel with partial recirculation of the flow. The cross-section of the test chamber is a square of side H = 0.6 m. The flow field above V2C airfoil was investigated for Mach number 0.7 with accuracy ±0.01. The airfoil has been under investigation in the TFAST project (TFAST - Transition Location Effect on Shock Wave Boundary Layer Interaction program, Seventh Framework Programme European Union). The airfoil chord was c = 0.2 m.

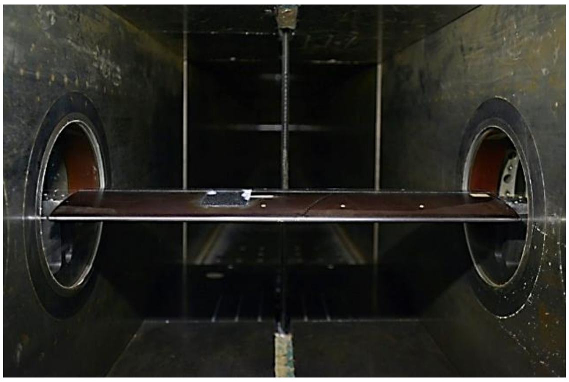

Fig. 1. The investigated airfoil in the test section of the IoA N-3 trisonic wind tunnel

Measurements of the flow field were performed by PIV method at airfoil's incidence angle 0, 1°, 2°, …, 7° for 2 seconds. The PIV system consisted of dual-cavity solid-state (Nd:YAG) nanosecond pulse laser and digital 4 MP camera. The frequency of measurements was 7 Hz. The flow was seeded with a droplets of Di-Ethyl-Hexyl-Sebacat (DEHS, CAS-No. 122-62-3) with mean diameter of 2 µm according to the seeding generator specification. The Stokes number for the parameters of the flow and the particles was Stk = 0.02. In order to provide uniform seeding distribution in the test section, the seeding was introduced to the flow approximately 6 m upstream. The particles images were recorded with Dantec Dynamic HiSense camera with 2048x2048 pixel sized sensor. The Field of View (see Figure 2) of the PIV camera covered the area rear to tailing edge and above the airfoil.

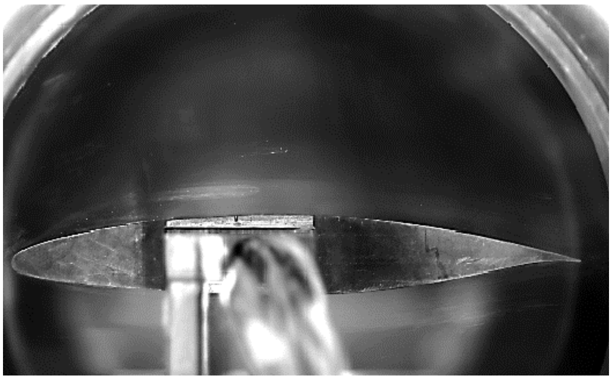

Fig. 2. Field of view of PIV camera

The light sheet forming optics was mounted downstream the test section and periscope system was used to redirect the laser beam. This configuration allowed to provide good illumination conditions at trailing edge and over upper and bottom surface of the investigated airfoil. Unfortunately, it did not allow to investigate the flow field in front of leading edge [14]. The experimental setup is shown in Figure 3.

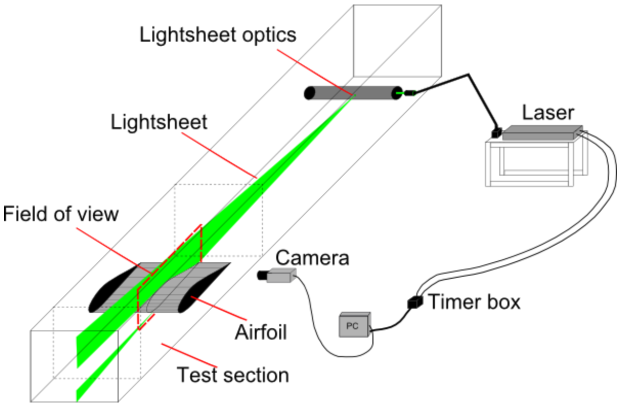

Fig. 3. Experiment setup

3 Results and discussion

The images were analysed using Dantec DynamicStudio software. The adaptive correlation scheme was used with 3 steps of the interrogation area refinement. The final interrogation area size was 32 x 32 pixels with overlap factor of 50 %. The measurements results were processed in order to determine the range of shock oscillations. For every angle of attack approximately 300 instantaneous vector velocity fields were analyzed. For post-processing the universal outliner procedure was applied using normalized median test using surrounding vectors. Small size of the neighbourhood (5 x 5 pixels) was used in order to avoid smoothing of the velocity gradient on the shock. Figure 4 presents an exemplary instantaneous vector velocity field. An abrupt decrease of the flow velocity at the shock terminating the supersonic flow region above the airfoil surface can be observed. The flow separation starts close to shock wave at approximate position x/c ≈ 0.7. The spatial resolution of the PIV measurements and the laser light reflections form the airfoil's surface do not allowed to determine the separation bubble is presence.

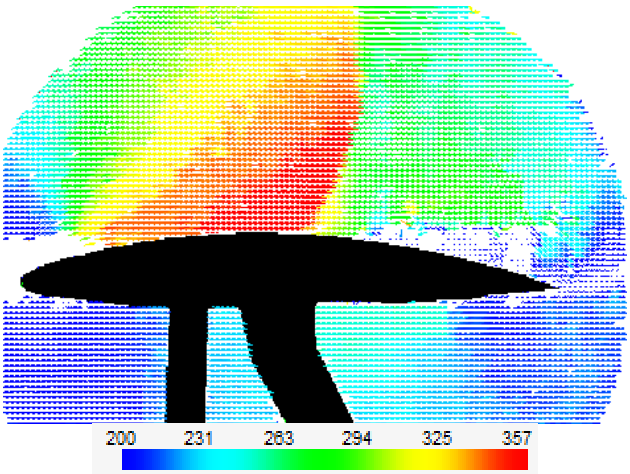

Fig. 4. Exemplary 2D vector velocity field above an airfoil for angle of incidence 4° and Mach number 0.7. Colors of the velocity map indicated the flow velocity in [m/s].

In order to determine the shock wave position the velocity gradient in the freestream direction was calculated. The position of the shock was assigned to the x-coordinate of the maximum value of the velocity gradient. The average location was determined form 300 instantaneous velocity field measurements. The variation of the shock position versus the angle of attack is shown in Figure 5. The data are presented in dimensionless units referred to the airfoil's chord length *c*. The location of the shock at x/c ≈ 60 % is typical for investigated airfoil. One can notice, that while the angle of attack was increased the average position of the shock moved closer to the leading edge.

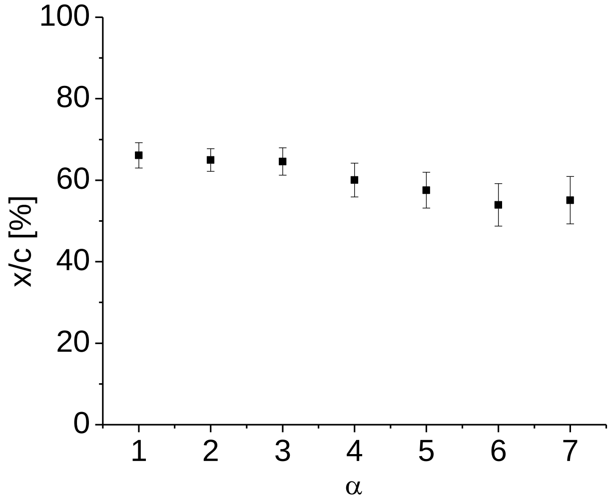

Fig. 5. Position of the shock above the airfoil for various angle of incidence

The data were used for determination of relation between the angle of attack and the shock motion amplitude. For every angle of attack the difference Δ*x* between maximum (x_{max}) and minimum (x_{min}) distance of shock form the leading edge was determined by equation (1). Figure 6 presents the variation of Δ*x* versus the angle of incidence.

$$\Delta x = x_{max} - x_{min} \qquad (1)$$

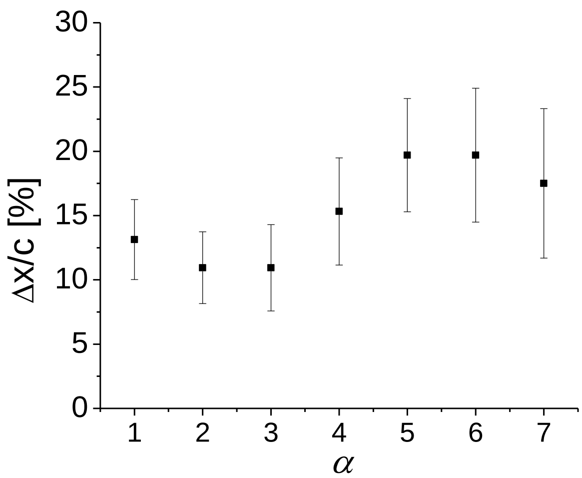

Fig. 6. The range of shock oscillations versus the angle of incidence for Mach number 0.75

As can be seen form the Figure 6. the range of the shock position variation *Δ*x changed form 13% to 20%. The transition in the level of shock wave oscillation amplitude occurred for angle of incidence between 3° and 5°. A small

decrease of the period shock motion amplitude can be also observed for angle of incidence above 6°. The results corresponds well with results of pressure measurements and Schliren visualization performed in IoA in a course of shock boundary layer investigations on V2C profile in the TFAST project. An increase of shock wave oscillation amplitude over supercritical airfoils for constant Mach number and varying angle of attack is widely reported literature [6][9][10] and related to buffet onset.
The previous section have shown that PIV data analysis can be used for buffet onset investigations. Although sampling frequency of the PIV system did not allowed to measure the frequency of the oscillations it was possible to detect an increase of amplitude of periodic shock motions.

4 Conclusion

In the presented work the PIV method was used to measure the position of the shock wave above the airfoil. The experiments revealed sharp increase of the shock position oscillations with increasing of the angle of attack. In spite of the limitations of the measurement frequency the results are comparable to pressure measurements and CFD calculations [17]. The data presents excursion into the buffet regime. For more detailed investigations time resolved PIV should be used. It is worth to notice that most measurement methods applied in wind tunnels for transonic flow investigation provide quantitative information only about the flow characteristic on the surface of the airfoil. The proposed methodology provide information of the position of the shock above the airfoil and can be used in investigations of unsteady flow field over airfoils at transonic speeds.

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