30th Congress of the International Council
of the Aeronautical Sciences
DCC, Daejeon, Korea ; September 25-30, 2016

NEW METHOD OF TRANSONIC BUFFET DECREASING ON SUPERCRITICAL AIRFOIL

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Keywords: *experimental investigation, optical method, buffet phenomenon*

Abstract

Standard and optical experimental studies of a buffet onset phenomenon on a model of a supercritical airfoil at transonic speeds are presented. It is shown that application of the proposed passive method of flow control by making use of special jet vortex generator leads to delaying of buffet onset and decreasing of buffet phenomenon.

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. Buffet results in lift and drag variations that greatly affect the aircraft aerodynamics. 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 that can lead to 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. One of the well-known passive methods is a cavity under shock foot covered with a perforated plate [1]. Other passive devices are grooves and stream-wise slots [2]. The main objective of these methods is to weaken the shock and reduce wave drag. Other passive control method is a bump. 2D bump leads to significant wave drag reduction, but also results in to high penalty under off-design conditions [3]. More recent studies were performed with 3D bumps to enhance the off-design performance [4].

There are also different passive and active methods to energize the boundary layer under shock foot to prevent flow separation. Vortex generators (VGs) are the most popular method for this purpose. Well-known mechanical VGs show their effectiveness. The main disadvantage of this method is drag increase under cruise condition. Other active methods for SBLI control are suction and application of plasma actuators. These devices for active flow control can be turned off during cruise regime and can be used in a closed-loop strategy to optimize flow control. Their disadvantages are additional equipment, complexity and weight.

Some of these devices were investigated as the buffet control means. Mechanical VGs were studied in [5]. Special mechanical trailing edge device (TED) which can change rear loading of an airfoil was also considered in [5]. Fluidic VGs (air-jet VGs) as well as fluidic TED (jet near the trailing edge normal to airfoil pressure side) were studied in [6]. It was shown that mechanical and fluidic VGs are 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.

In the present study, buffet control passive method by making use of special jet vortex generator is investigated.

2 Experimental arrangement and test conditions

Experimental investigations of the new method of transonic buffet control were carried out in the transonic wind tunnel T-112 of the TsAGI. The test section is rectangular with a height of 0.6m, a width of 0.6m and a length of 2.6m. The Mach number domain extends from 0.6 to 1.25. The running stagnation temperature is maintained to approximately T=310K. The top and bottom walls of the test section are perforated. The side not perforated walls are equipped with special Schlieren quality windows for optical researches. The experimental study was carried out on a modified model of aerodynamic profile P-184-15 with chord length $c = 0.2m$. Fig. 1 shows the TsAGI designed airfoil named P 184-15. It is a supercritical airfoil with a relative thickness of 15 % in chord units.

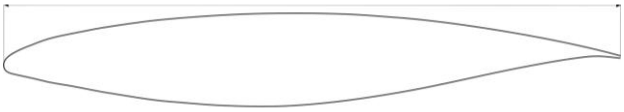

Fig. 1. Geometry of the non-modified airfoil P 184-15

Angles of attack α differs from 0° to 6°. The most complete results were obtained for α=4°. Investigations were carried out at Mach numbers M_∞=0.6 – 0.8. Reynolds number values are changed in the range $(2.4 – 3.0) \cdot 10^6$. Model was fixed between the optical windows in a test section of the wind tunnel on a special mechanism allowing continuous change of the angle of attack α. Simultaneously with optical investigations aerodynamic loads acting on a model were obtained and aerodynamic coefficients of lift and drag were determined by means of standard technique.

3 Description of the device for passive buffet control at transonic speeds

The basic reason of buffet onset at transonic speeds is the oscillations of λ- shock wave during the effect of shock-boundary layer interaction. For weakening the negative influence of such interaction in NIO-2 of TsAGI has been developed and examined a new method based on creation of jet vortex generators, disposed before a shock wave and working by means of a by-pass of air from a zone behind a shock wave (Fig. 2).

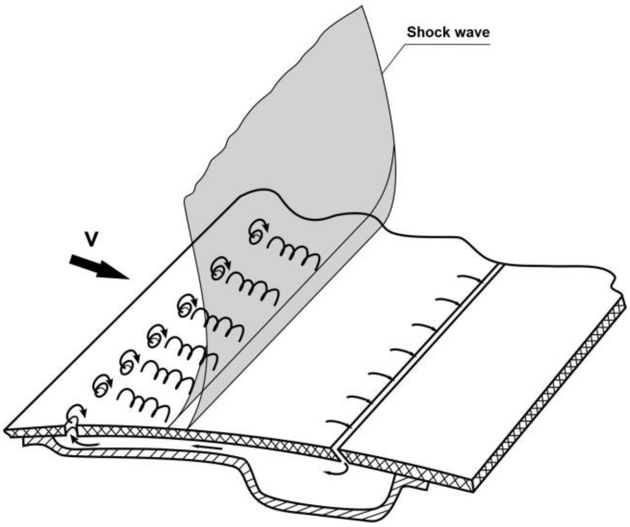

Fig. 2. The principal scheme of the device for creation passive fluidic VGs (air-jet VGs)

Efficiency examination of the new method was conducted on modified model of TsAGI’s airfoil P-184-15 and carried out in the transonic wind tunnel T-112 of the TsAGI. Modification of a model consisted in that the cavity for air by-pass through a slot disposed on 75 % of a chord in area behind a shock wave has been made in model in order to create VGs executed in the form of number of holes disposed on 52 % of a chord before a shock wave. VGs holes have been disposed spanwise with the step of 3 % of a chord.

For the best vortex generation holes have been executed at angle 45° to a model surface in the vertical section, disposed at an angle γ =45° to a streamline. Investigations of model with air by-pass were conducted at an angle of attack α =4° with simultaneous registration of an optical flow pattern, fast-track video registration and load measurements of aerodynamic characteristics. Investigation results for the model with air by-pass were compared with corresponding results for the initial non-modified airfoil P-184-15 model without air by-pass.

4 Experimental results and discussion

On optical pictures obtained at $M_\infty = 0.75$; 0.76 the influence of VGs are appeared in formation of an oblique shock wave near the blowing streams position. Existence of the oblique shock wave leads to deceleration of flow before the main shock and consequently to weakening of its intensity. Longitudinal vortices' generated by streams lead to boundary layer mixing before and after the main shock and delay the onset of separation of a flow connected with shock wave- boundary layer interaction.

In whole VGs effect delays the process of vortex generation on upper surface of a boundary layer behind a shock wave.

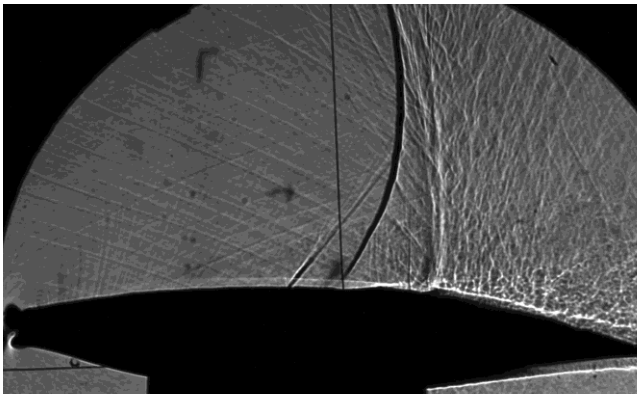

Fig. 3. Schlieren picture of flow around airfoil model without air by-pass

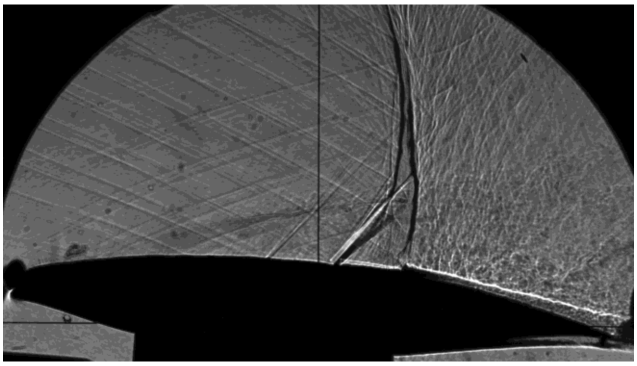

Fig. 4. Schlieren picture of flow around airfoil model with air by-pass and VGs generation

At free stream Mach numbers $M_\infty > 0.8$ on the model without air by-pass instead of the main normal shock wave the λ - shock wave is organized. This leads to significant expansion of rotational vortex flow region behind a shock wave (Fig. 3). We can see that presence of VGs essentially diminish vortex generation development (Fig. 4). Load measurements have shown that this phenomenon leads to reduction of drag and appropriate lift-to-drag ratio growth (Fig. 5).

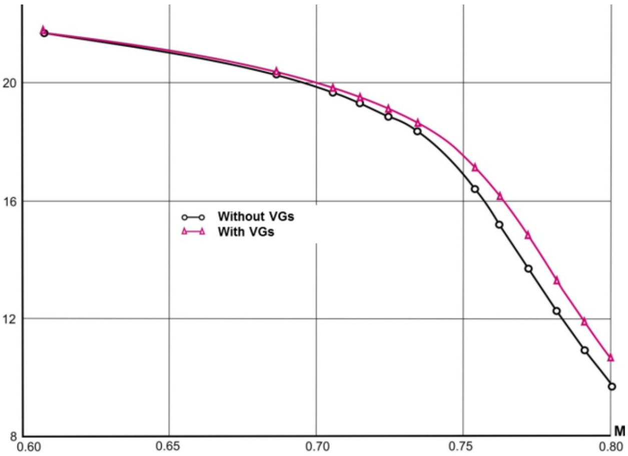

Fig. 5. Lift –to-drag ratio as a function of the free stream Mach number with (red line) and without (black line) vortex generators (VGs)

Formation of λ - shock is due to a boundary layer thickening before the main shock wave. The thickening occurs because of a positive pressure gradient at the vicinity of a shock wave and because of a kinetic energy deficiency of boundary layer's lower streams.

Vortex generators mesh the lower streams of a boundary layer which have small energy with the upper power streams of a boundary layer. This process allows the meshed boundary layer to overcome positive pressure gradient near the shock wave without thickening and formation λ - shock wave.

From the received optical flow patterns, it is possible to draw a conclusion that using passive VGs allows enough effectively to detain formation λ - shock and weaken development of a rotational vortex region behind a shock wave.

Investigations made by means of a high-speed video camera have shown that VGs delay formation of λ - shock, stabilize flow and hence detain buffet development.

4. Conclusions

It is found that experimental configuration of the shock depends on the Mach number and the angle of attack of the airfoil. Appearance of jet vortex generator because of air crossover reduces degree of unsteadiness of a flow, stabilizes lambda-shock position and finally leads to decreasing of a buffet phenomenon. Investigations made by means of a high-speed video camera also show that proposed passive jet vortex generator stabilizes a flow and detains development of a buffet.

On the basis of the provided experimental studies it is possible to make a real conclusion that proposed new method of flow control at transonic speeds allows to decrease the buffet onset phenomenon.

Acknowledgments

We gratefully acknowledge the chief of TsAGI's wind tunnel T-112 Alexander Ivanov for his support of our efforts.

This work has been carried out with the financial support of Russian Scientific Foundation (project No 16-19-10407).

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