Journal of KONES Powertrain and Transport, Vol. 21, No. 2 2014

ISSN: 1231-4005
e-ISSN: 2354-0133
ICID: 1133889
DOI: 10.5604/12314005.1133889

WIND TUNNEL INVESTIGATION OF THE WING LOAD CONTROL USING SELF-SUPPLYING FLUIDIC DEVICES

Andrzej Krzysiak

Institute of Aviation (IoA)
Krakowska Av. 110/114, 02-256 Warsaw, Poland
tel.: +48 22 846 00 11 ext. 363, fax +48 22 868 51 07
e-mail: andkrzys@ilot.edu.pl

Abstract

The wing-load-control systems are developed as a mean to modify a distribution of aerodynamic load on the wing. Such systems are usually used in extraordinary, off-design flow conditions. Particularly, it concerns the reduction of bending loads during accelerated flight manoeuvres or sudden gusts. In such situations, rising bending loads may lead to fatigue damage of the wing.

A new concept of active flow control system based on self-supplying blowing devices for the control of the aerodynamic load on aircraft wing was designed in Institute of Aviation and tested in IoA low speed wind tunnel. The study was carried out in the framework of the European project STARLET. The project scope comprises two systems of fluidic control devices: the nozzles blowing air in direction normal and inclined with respect to the upper wing surface, located at 40-70% of wing chord, as classical spoilers, and an alternative system composed of specially designed nozzles located on a modified trailing edge surface. The fluidic control devices were supplied with air from the high-pressure area situated at lower wing surface close to its leading edge.

The experimental tests were performed in low speed wind tunnel T-3 (5-meter diameter test section) in the Institute of Aviation. For these tests the model of semi-span wing (2.4 m span) situated vertically on the endplate in wind tunnel test section was used. The model was situated on the two aerodynamic wall balances. To measure the load distribution along the semi-span wing model the 8 strain-gauge bridges were glued to the model front spar, the strain-gauge bridges were arranged in 14.6% wing chord. Wind tunnel test were performed at Mach number M = 0.1.

Keywords: *applied aerodynamics*

1. Introduction

In recent years, in aerodynamics, a new idea of "smart structures" appeared. This idea consists in controlling aerodynamic characteristics of the flying objects through the use of various flow control methods. Flow control can be realized through the use of passive or active devices. Active flow control is generally understood as flow control introducing a small amounts of energy into the flow in order to obtain some desired effects, such as delaying flow separation, extending the area of laminar flow, noise reduction, reduce the level of vibration, etc. There are a lot of active flow control methods, which were fully described in the literature [1-8]. Some of them were tested experimentally in Institute of Aviation wind tunnels [9, 10].

One of the popular active flow control method is realized by blowing additional air jets on the surface of the flying objects. This causes an increase of the flow energy and prevents or limits the boundary layer separation. The active flow control method realized by blowing additional air jets allows controlling aerodynamic loads in non-classical but more advanced way. The effectiveness of the new concepts with a use of active flow control methods appears to be much higher in comparison with traditional solutions. Traditional wing-load-control systems utilise passive techniques like deflections of spoilers, ailerons, flaps etc. A good example of such approach is the active load system of Lockheed C-5A Galaxy aircraft, where symmetrical deflection of ailerons and elevators were applied [11].

Active load control system based on additional air blowing makes it possible to adjust wing loads to the current flow conditions, most often being a result of the gusts or rapid maneuvers. By that means, it is possible to avoid excessive stresses on critical structural elements. As an effect of the development of load control technology, it is possible to design structures having longer fatigue life or such that are lighter and economic throughout their life. It is also possible to lower drag during the airplane mission by adjusting the wing load distribution to current flight conditions.

Described in the article active load control devices, use the self-supplying air system, which supplies these devices with the air, ensuring an additional air blowing. In this case, no other source of compressed air was needed.

Experimental studies of the active load control system were preceded by a numerical analysis, which allowed determining the shape and construction of the blowing devices. The wind tunnel tests of the semi-span wing model equipped with these devices were carried out in 5 m diameter low speed wind tunnel T-3 (Institute of Aviation - IoA).

Work was performed under the European Project “STARLET” - CLEAN SKY (Basic Wind Tunnel Investigations to Explore the Use of Active Flow Control Technology for Aerodynamic Load Control).

2. General concept of the load control system

General idea of the load control devices, designed in the STARLET project, was the reduction of local lift in wing outer segments, and in consequence reduction of wing root bending moments. In this case, the load control devices fulfil the role of “fluidic spoilers” and “fluidic ailerons.” Based on the numerical investigations two concepts of the fluidic control devices were proposed. The first of these systems used the set of the nozzles blowing air in direction normal or inclined (blowing against the flow) with respect to the upper wing surface. This active load control device was located at 45-65% of wing chord in the outer part of the wing, Fig. 1. Therefore, the system worked like a classical spoiler.

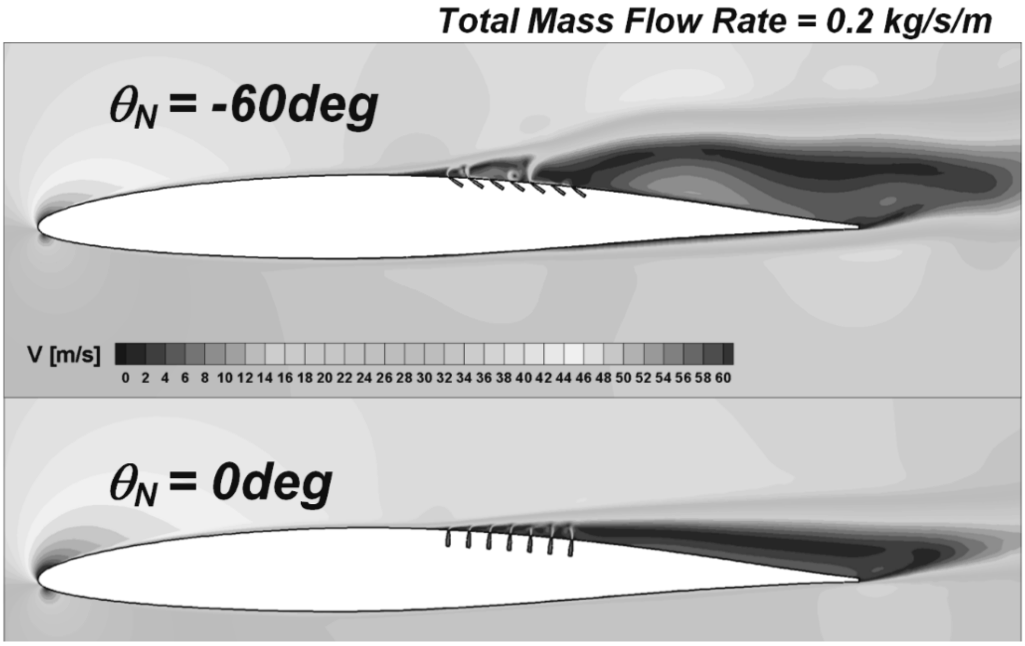

Fig. 1. The concept of the “fluidic spoiler”

The second proposed concept of the fluidic control device was based on specially designed nozzles located on a modified trailing edge surface (Fig. 2), so this system worked like a “fluidic aileron“. This concept assumed application of nozzles diverting flow upwards, taking advantage of Coanda effect.

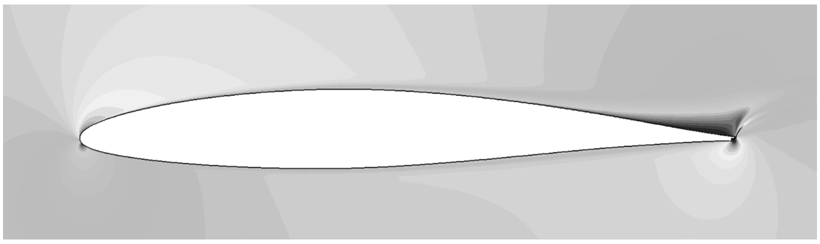

Fig. 2. The concept of the "fluidic aileron"

3. Wind tunnel T-3

The wind tunnel tests of the semi-span wing model equipped with active flow control devices were carried out in 5 m diameter low speed wind tunnel T-3 (IoA).

The T3 Institute of Aviation Low Speed Wind Tunnel is an atmospheric, closed-circuit tunnel with an open test section of 5-meter diameter, and 6.5 m length, which can reach velocity of 57 m/s with a dynamic pressure of 2000 N/m^2. Scheme of the wind tunnel T-3 is presented in Fig. 3. The Reynolds number per meter ranges from 0 to 3.8×10^6. The flow in the test section is relatively uniform with a longitudinal turbulence level of about 0.5 percent. Test section airflow is produced by 7-m diameter 8-bladed fan powered by a 2040 hp direct current motor.

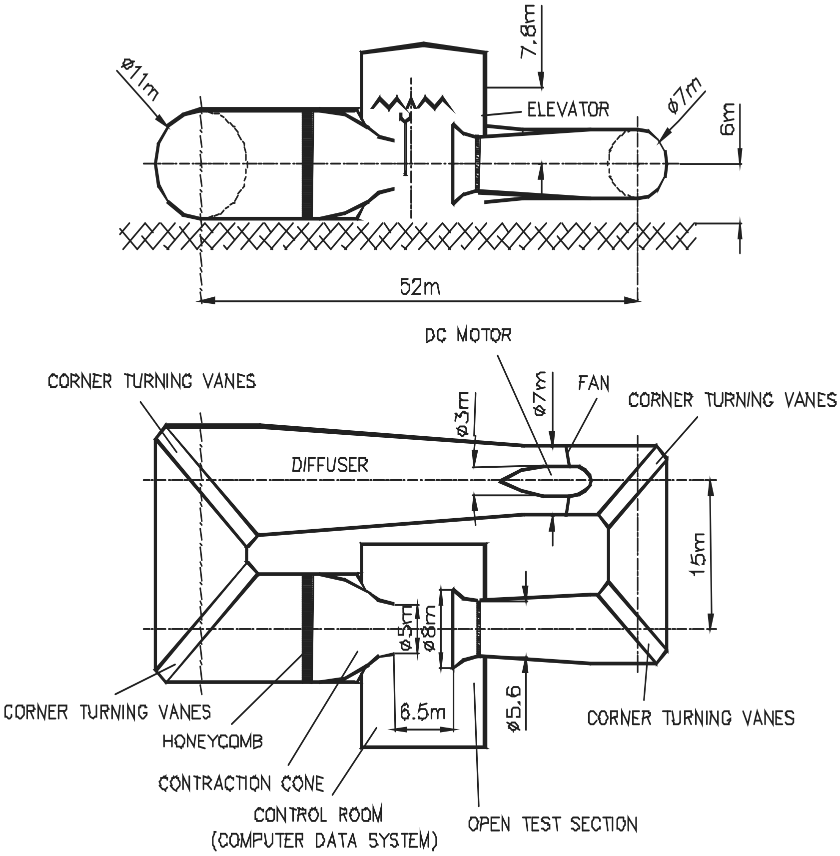

Fig. 3. Scheme of the wind tunnel T-3

4. Semi-span wing model

Experimental tests of the active load control systems based on additional air blowing were carried out using the semi-span wing model (2.4 m span) equipped with the proposed active flow control devices. The model was situated in wind tunnel test section in vertical position on the endplate (Fig. 4) and fixed at its base to the two wall balances, i.e. 5 component (front balance) and 3 component (rear balance). These wall balances measured both bending moment and lift force (normal to model chord at its root).

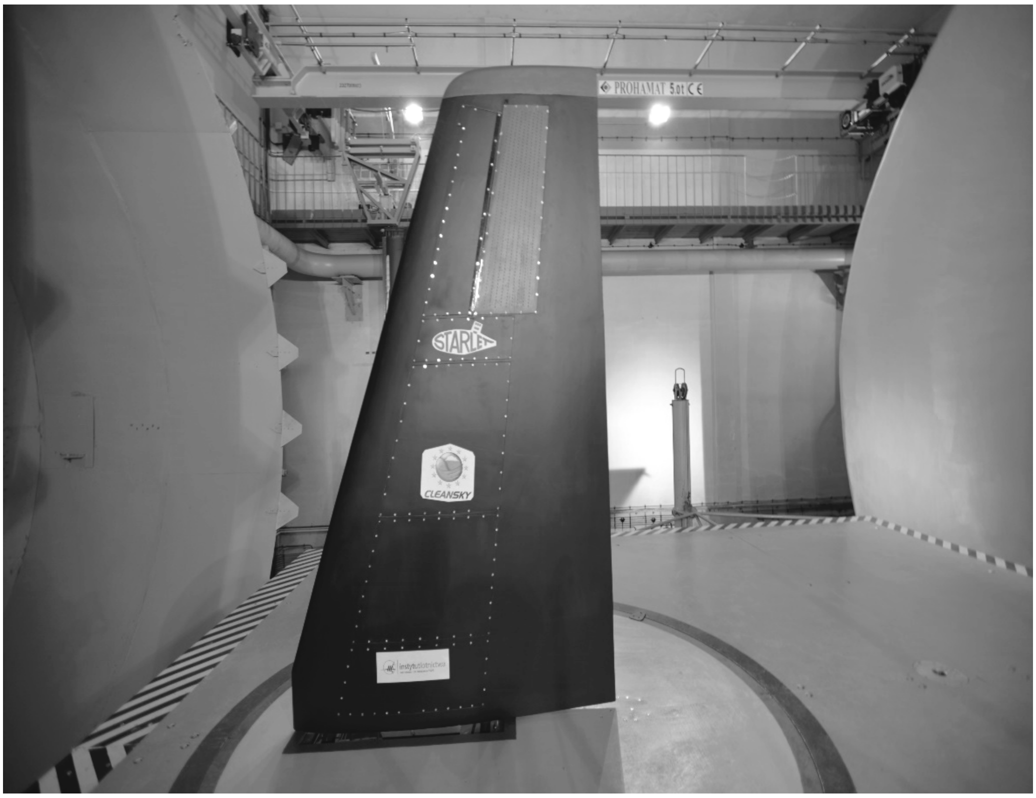

Fig. 4. The semi-span wing in the wind tunnel T-3

The semi-half wing model was equipped with the two independent air source systems (external and internal), which supplied active flow control devices with the compressed air. The external air supplying system consisted of the compressor, two tanks (high and low pressure), control valve and flow meter. Described in the article wind tunnel tests refer to the case when active flow control devices were supplied with air from the internal self-supplying air system. In order to obtain compressed air, said internal self-supplying air system, uses airfoil overpressure regions, as a source of the air. Those regions appear in the nose part of the lower wing surface at the high angle of attack. To most effectively use, the natural effect of air compression that occurs on the wing ten air inlets were situated as close as possible to the flow stagnation points. Their axes were positioned parallel to the air stream direction in those points. Due to wing twist, (root wing section was set on the higher angle of incidence than tip wing section) the air inlets were situated at the root wing part, Fig. 5. Through a pipe system arranged inside the semi-span wing model, the compress air was supplied from the inlets to the active flow control devices.

To measure the load distribution along the semi-span wing model, the 8 strain-gauge bridges were glued to its front spar. The strain-gauge bridges were arranged in 14.6% wing chord, Fig. 6.

The load control system mentioned above, which worked like a classical spoiler, consisted of 540 nozzles arranged in nine rows located at the 59-92% of the wingspan and 45-65% of the wing chords (every 2.5%). Two sets of the nozzles were used, i.e. nozzles having axes perpendicular to the outer wing surface and having axes directed at an angle of about 45 degrees to that surface. In each of these variants there was a possibility to use all rows of the nozzles or only selected. The outlets of nozzles had rectangular shape (5.6 mm x 1 mm) with rounded corners.

Load control system, which worked like a “fluidic aileron“ consisted of 26 nozzles arranged in one row located at the wing trailing edge. Their sophisticated shape and its activity is a subject of pending patent.

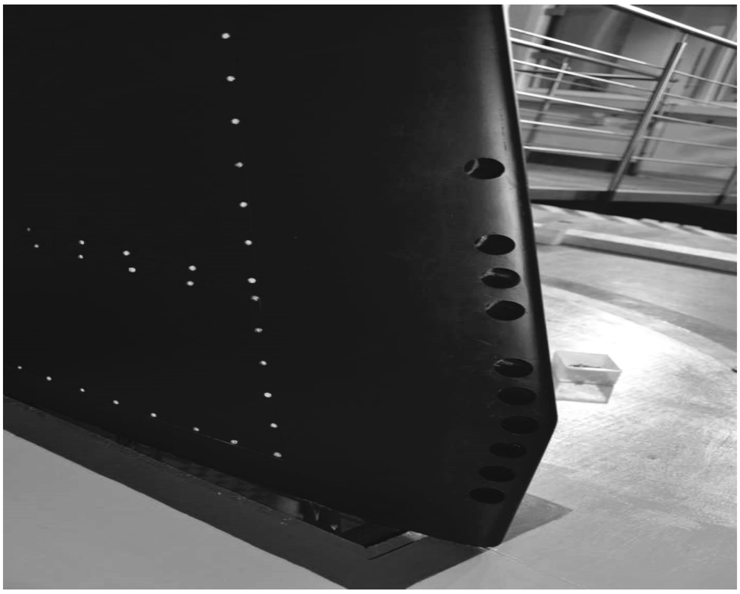

Fig. 5. The inlets of the air at semi-span wing model

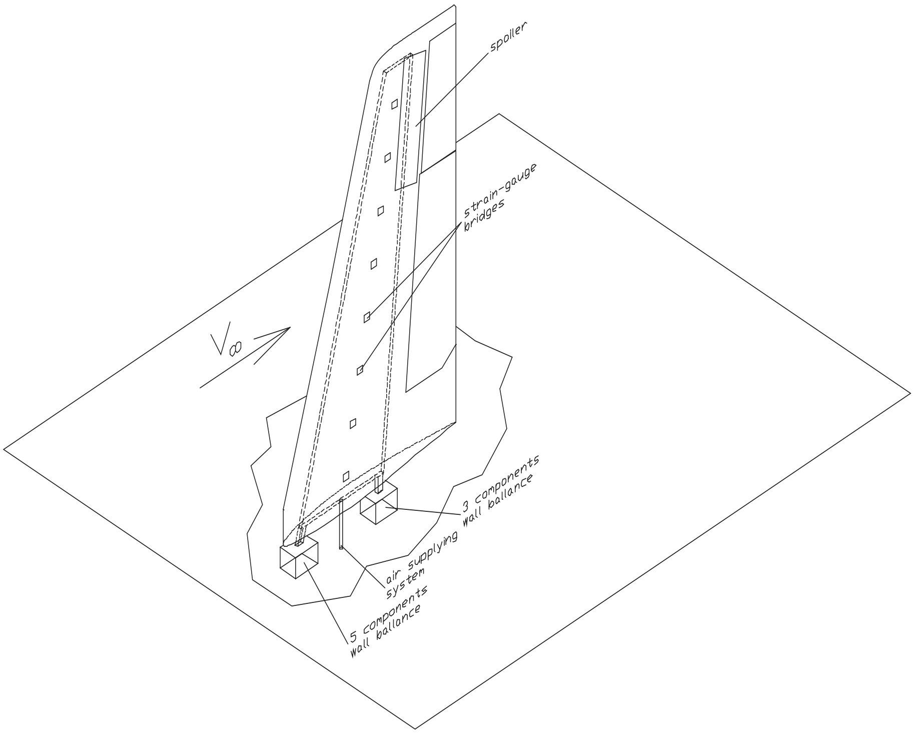

Fig. 5. The semi-span wing in the wind tunnel T-3

5. Wind tunnel tests results

Wind tunnel tests of the active load control devices based on air self-supplying system, installed on the semi-span wing model, were performed in IoA low-speed wind tunnel T-3 at the Mach number M = 0.1 (Re = 2.4 10^6) for the angles of attack (with respect to root chord) α = 0°, 2°, 4°, 6° ,8° 10° and 12°. The following model configurations were tested.

- Smooth wing model,
- Wing model with Fluidic Spoiler – 90°,
- Wing model with Fluidic Spoiler – 45°,
- Wing model with Fluidic Aileron.

In Fig. 6, the impact of the active load control devices on the root wing bending moment, measured by wall balances, is presented.

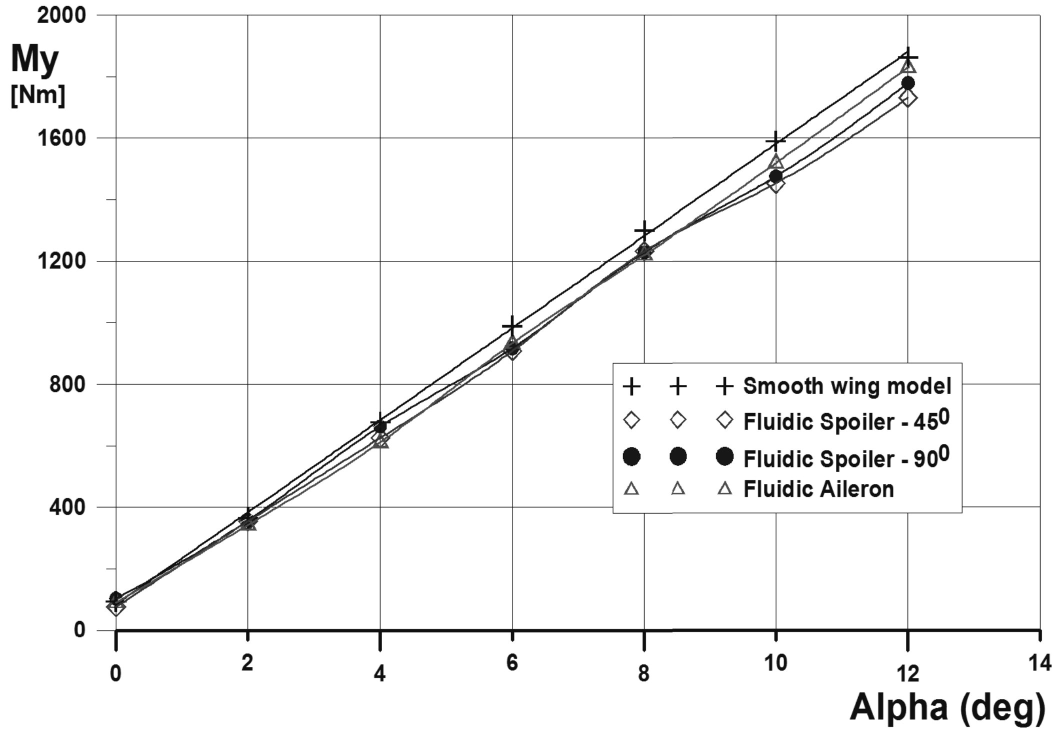

Fig. 6. Impact of the active load control devices on the root wing bending moment

The observed decrease in the wing bending moment, caused by the active load control devices action, was the result of flow separation, which appeared on the upper wing surface, Fig. 7.

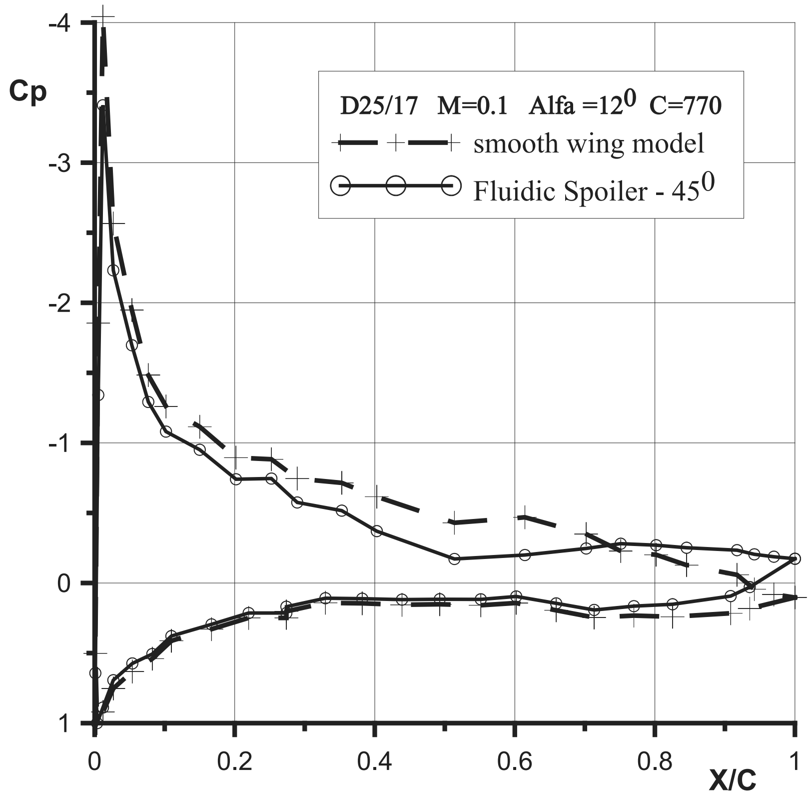

Fig. 7. Impact of the active load control device (FS-45°) on the pressure distribution along the wing chord

6. Conclusions

In the paper two active load control devices (i.e. Fluidic Spoiler and Fluidic Aileron) based on air self-supplying system were presented. The main task of these devices was to reduce the excessive stresses of the wing being a result of the gusts or rapid maneuvers. Proposed active load control devices were supplied with air from the airfoil overpressure area, which appear in the nose part of the lower wing surface at the high angles of attack. Therefore, they do not require installation on an airplane any additional source of compressed air.

Experimental tests of the semi-half wing equipped with mentioned above active load control devices showed, that using proposed devices it is possible to evidently reduce the root wing bending moment (up to 10% in the tested range of the wing angles of attack). The decrease in the wing bending moment was the result of flow separation, which appeared on the upper wing surface.

For the angle of attack $\alpha = 0°$ the load control devices based on air self-supplying system remained inactive. This resulted from the fact that the pressure difference between upper and lower wing service was small. In the case of a gust from the bottom of the aircraft or rapid aircraft, maneuver its angle of attack rises rapidly. In effect, efficiency of tested devices also increased. This increase of the efficiency was associated with the formation of the overpressure area in the nose part of the lower wing surface.

Among the tested active load control devices the most effective was Fluidic Spoiler with nozzles inclined at 45° to the upper wing surface and blowing against the flow (the root wing bending moment was reduced of about 10% at $\alpha = 12°$). On the other hand the least effective was Fluidic Aileron (the root wing bending moment was reduced only about 3% at $\alpha = 12°$). This resulted from the fact, that using air self-supplying system was not possible to produce a sufficiently strong air streams to change the direction of flow at the wing trailing edge area.

References

[1] Gad-el-Hak, M., *Flow Control – Passive, Active, and Reactive Flow Management*, Cambridge University Press, 2000.

[2] Gad-el-Hak, M., *Flow control - The future*, Journal of Aircraft, No. 38, pp. 402-418, 2001.

[3] Braslow, A. J., *A History of Suction-Type Lamina-Flow Control with Emphasis on Flight Research,* Aerospace History, No. 13, Washington DC 1999.

[4] Kerho, M., Hutcherson, S., Blackwelder, R. F., Liebeck, R. H., *Vortex Generators Used to Control Laminar Separation Bubbles,* Journal of Aircraft, Vol. 30, No. 3, 1993.

[5] Kachanov, Y. S., Koslov, V. V., Levchenko, Y. V., *Experimental Study of the Influence of Cooling on the Stability of Laminar Boundary layers*" Izvestia Sibirskogo Otdielenia Ak. Nauk SSR, Seria Technicheskich Nauk, Vol. 8-2, pp. 75-79, Novosibirsk 1974.

[6] Goksel, B., Greenblatt, D., Rechenberg, I., Singh, Y., Nayeri, C. N., Paschereit, C. O., *Pulsed plasma Actuators for Separation Flow Control*, Proceedings of Conference on Turbulence and Interaction, Porquerolless 2006.

[7] Jabbal, M., Zhong, S., *The near wall effect of synthetic jet in a boundary layer*, Heat and Fluid Flow, Vol. 29, pp. 119-130, 2008.

[8] Lee, S. J., Jang, Y. G., *Control of flow around a NACA 0012 airfoil with a micro-riblet film*, Journal of Fluids and Structures, No. 20, pp. 659-672, 2005.

[9] Krzysiak, A., Narkiewicz, J., *Aerodynamic Loads on Airfoil with Trailing-Edge Flap Pitching with Different Frequencies,* Journal of Aircraft, Vol. 43, No. 2, pp. 407-418, 2006.

[10] Krzysiak, A., *Control of Flow Using Self-Supplying Air Jet Vortex Generators*, AIAA Journal, Vol. 46, No. 9, pp. 2229-2234, 2008.

[11] Hargrove, W. J., *The C-5A active lift distribution control system*, Lockheed-Georgia Company, http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19760024060_1976024060.pdf.