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PRESSURE DISTRIBUTION ON THE SURFACES OF THE NACA 0012 AIRFOIL UNDER CONDITIONS OF CHANGING THE ANGLE OF ATTACK

***Abstract**: The results of computer calculation of changing pressure of air flows on the surfaces of the NACA 0012 airfoil under conditions of subsonic flight speed of the aircraft are presented in the article. The formation of zones of positive and negative pressure near the upper and lower surfaces of the wing (lift), which provide takeoff or landing of the aircraft, occurs when changing the angle of attack of the airfoil in the range from 15 to -15 degrees. The maximum pressure values were determined at the leading and trailing edges of the airfoil. The calculated pressure values will be valid when air flows around the symmetrical airfoil.*

***Key words**: the airfoil, the angle of attack, pressure, subsonic flight speed.*
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Introduction

The aircraft is an engineering construction designed for flying over various distances in the atmosphere. The geometric shape of the wing should provide the necessary lift, which allows you to support the aircraft in air [1-2]. Ellipsoidal airfoils have the best aerodynamic qualities. The aerodynamic qualities of the wing are determined by the results of experimental studies and computer calculations [3].

The airfoil in the cross section is characterized by the chord, relative thickness and relative curvature [4-5]. The NACA 0012 (the US National Advisory Committee for Aeronautics) symmetrical airfoil has no relative curvature. The maximum thickness corresponds to 12% of the chord length of the wing. This airfoil is used in conditions of subsonic flight speed of the aircraft [6-7].

Studies of the aerodynamic characteristics of the airfoils were carried out in the number of works [8-10]. In particular, a new method for reducing interference on the walls of the NACA 0012 airfoil was proposed, which is the combination of perforated plates and the controlled boundary layer. The results of the experiments were confirmed by the results of numerical modeling. The solution to the problem of low-speed flow around the airfoils with strongly separated stream was proposed by Zumwalt, G. W. The author has developed a special program that animates the process. Based on the k-ω turbulence model, two modified models are presented, designed to obtain the results similar to the results of the Wilcox's original k-ω model, but without its strong dependence on the arbitrary values of free flow and taking into account the transfer of main shear stress in the boundary layers with an unfavorable pressure gradient.

In this article, for the NACA 0012 standard airfoil at the different angles of attack, the calculation of changing air flow pressure on the various surfaces of the aircraft wing was performed. This will allow you to determine the value of frontal drag and lift of the wing during takeoff and landing of the aircraft.

Materials and methods

The stationary process of flow around the airfoil of the aircraft wing with air streams at constant speed was implemented in the two-dimensional formulation in the Comsol Multiphysics program. The NACA 0012 symmetrical airfoil was adopted for the study. The cross section of the NACA 0012 airfoil and its geometric characteristics along the coordinate axes are presented in the Fig. 1 and in the table 1.

Figure 1 – The cross section of the NACA 0012 airfoil.

Table 1. The geometric characteristics of the NACA 0012 airfoil.

***X*, mm**	0.00000	0.05839	0.23342	0.52468	0.93149	1.45291	2.08771	2.83441	3.69127	4.65628
Y_u, mm	0.00000	0.42603	0.84289	1.25011	1.64706	2.03300	2.40706	2.76827	3.11559	3.44792
Y_l, mm	0.00000	-0.42603	-0.84289	-1.25011	-1.64706	-2.03300	-2.40706	-2.76827	-3.11559	-3.44792
***X*, mm**	5.72720	6.90152	8.17649	9.54915	11.01628	12.57446	14.22005	15.94921	17.75789	19.64187
Y_u, mm	3.76414	4.06310	4.34371	4.60489	4.84567	5.06513	5.26251	5.43715	5.58856	5.71640
Y_l, mm	-3.76414	-4.06310	-4.34371	-4.60489	-4.84567	-5.06513	-5.26251	-5.43715	-5.58856	-5.71640
***X*, mm**	21.59676	23.61799	25.70083	27.84042	30.03177	32.26976	34.54915	36.86463	39.21079	41.58215
Y_u, mm	5.82048	5.90081	5.95755	5.99102	6.00172	5.99028	5.95747	5.90419	5.83145	5.74033
Y_l, mm	-5.82048	-5.90081	-5.95755	-5.99102	-6.00172	-5.99028	-5.95747	-5.90419	-5.83145	-5.74033
***X*, mm**	43.97317	46.37826	48.79181	51.20819	53.62174	56.02683	58.41786	60.78921	63.13537	65.45085
Y_u, mm	5.63200	5.50769	5.36866	5.21620	5.05161	4.87619	4.69124	4.49802	4.29778	4.09174
Y_l, mm	-5.63200	-5.50769	-5.36866	-5.21620	-5.05161	-4.87619	-4.69124	-4.49802	-4.29778	-4.09174
***X*, mm**	67.73025	69.96823	72.15958	74.29917	76.38202	78.40324	80.35813	82.24211	84.05079	85.77995
Y_u, mm	3.88109	3.66700	3.45058	3.23294	3.01515	2.79828	2.58337	2.37142	2.16347	1.96051
Y_l, mm	-3.88109	-3.66700	-3.45058	-3.23294	-3.01515	-2.79828	-2.58337	-2.37142	-2.16347	-1.96051
***X*, mm**	87.42554	88.98372	90.45085	91.82351	93.09849	94.27280	95.34372	96.30873	97.16559	97.91229
Y_u, mm	1.76353	1.57351	1.39143	1.21823	1.05485	0.90217	0.76108	0.63238	0.51685	0.41519
Y_l, mm	-1.76353	-1.57351	-1.39143	-1.21823	-1.05485	-0.90217	-0.76108	-0.63238	-0.51685	-0.41519
***X*, mm**	98.54709	99.06850	99.47532	99.76658	99.94161	100.00000				
Y_u, mm	0.32804	0.25595	0.19938	0.15870	0.13419	0.12600				
Y_l, mm	-0.32804	-0.25595	-0.19938	-0.15870	-0.13419	-0.12600				

The airfoil was built according to the coordinates of the points in two directions. The origin of the coordinate system was located at the front point of the chord of the airfoil. The values corresponding to the chord length of the airfoil were plotted along the X coordinate axis. The shapes of the upper and lower contours of the airfoil were set along the *Y* coordinate axis relative to the chord according to the values of the Y_u and Y_l parameters.

The airfoil model was placed into the airspace model. The airfoil position was changed to the angle of attack in the range from 15 to -15 degrees. The step of changing the angle of attack was taken 3 degrees in each direction. The calculation was carried out in conditions of subsonic flight speed of the aircraft. The Reynolds number was $1{\times}10^5$. The smaller division of the airspace into finite elements near the surfaces of the airfoil model allowed us to obtain the most reliable results of computer modeling.

Results and discussion

The results of computer modeling were presented in the form of color pressure contours applied to the airspace areas. The calculated air pressure contours on the surfaces of the airfoil under conditions of changing the angle of attack are presented in the Figs. 2-12.

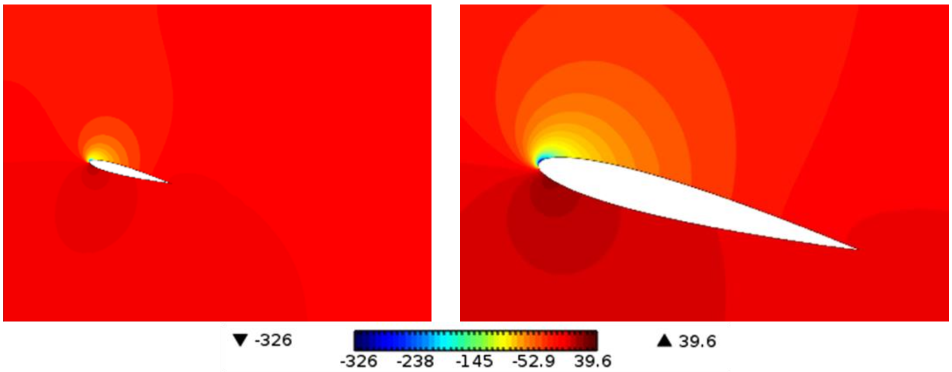

Figure 2 – The air pressure contours on the airfoil surfaces at the angle of attack of 15 degrees. The unit of measurement on the scale is kPa.

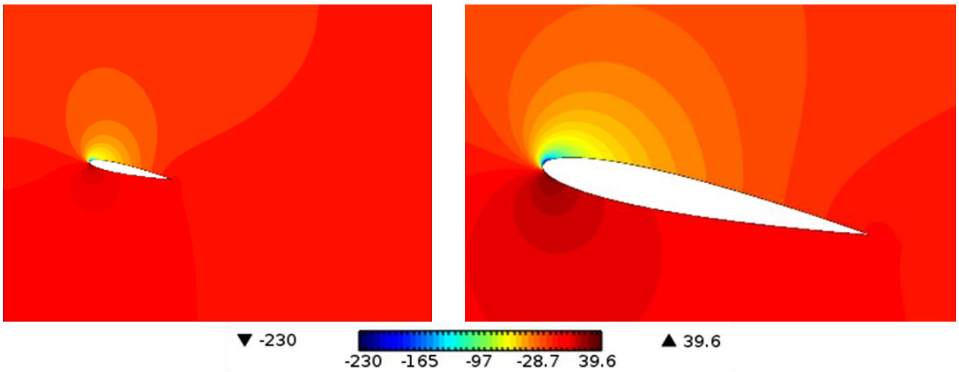

Figure 3 – The air pressure contours on the airfoil surfaces at the angle of attack of 12 degrees. The unit of measurement on the scale is kPa.

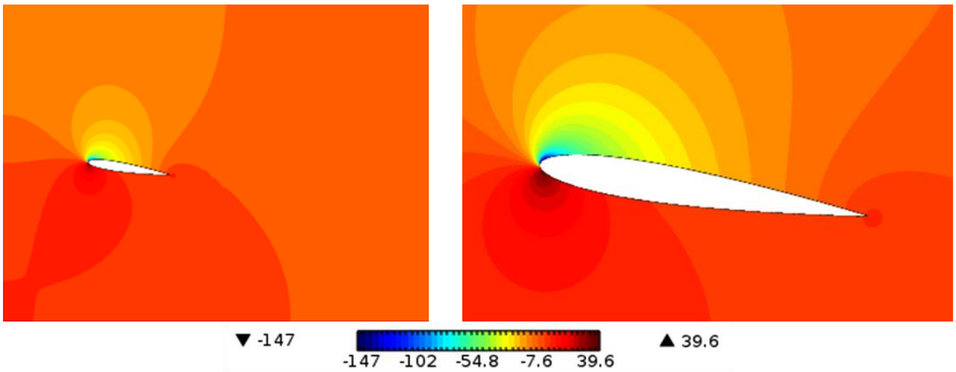

Figure 4 – The air pressure contours on the airfoil surfaces at the angle of attack of 9 degrees. The unit of measurement on the scale is kPa.

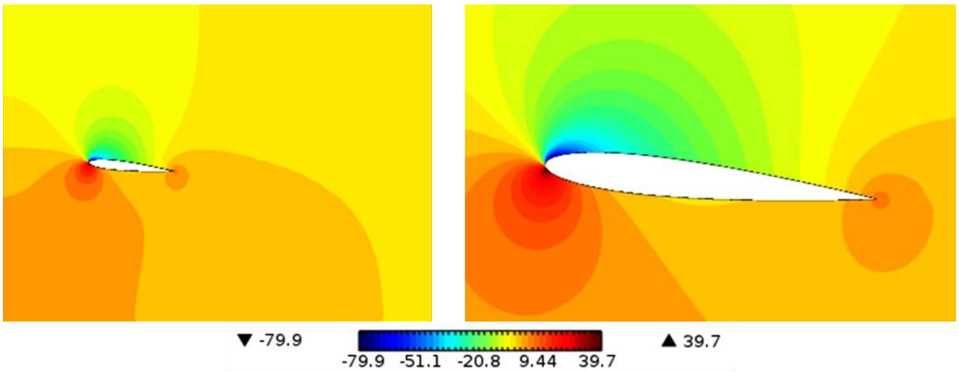

Figure 5 – The air pressure contours on the airfoil surfaces at the angle of attack of 6 degrees. The unit of measurement on the scale is kPa.

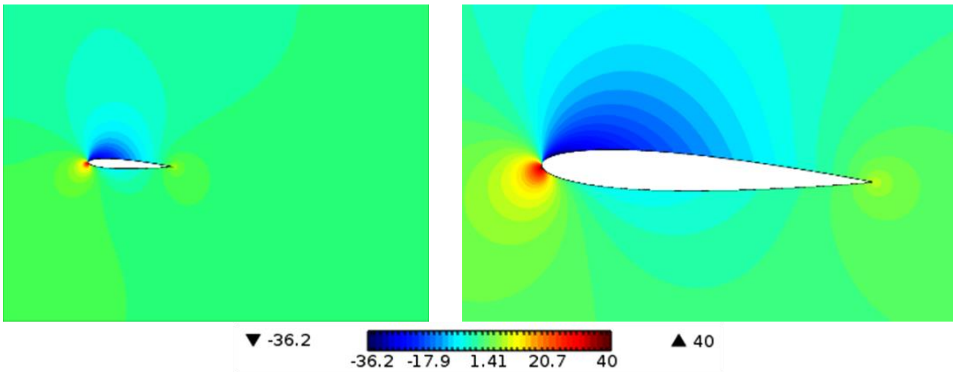

Figure 6 – The air pressure contours on the airfoil surfaces at the angle of attack of 3 degrees. The unit of measurement on the scale is kPa.

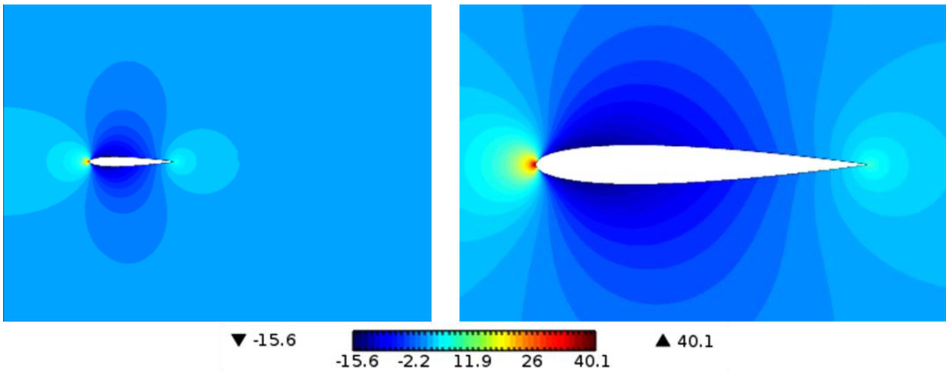

Figure 7 – The air pressure contours on the airfoil surfaces at the angle of attack of 0 degrees. The unit of measurement on the scale is kPa.

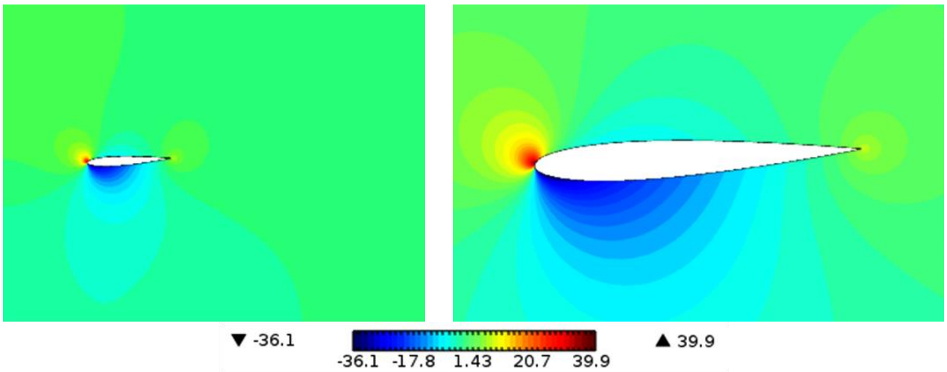

Figure 8 – The air pressure contours on the airfoil surfaces at the angle of attack of -3 degrees. The unit of measurement on the scale is kPa.

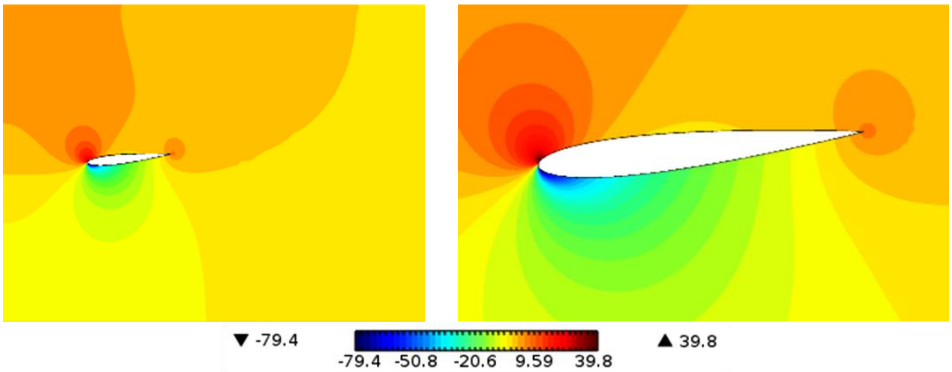

Figure 9 – The air pressure contours on the airfoil surfaces at the angle of attack of -6 degrees. The unit of measurement on the scale is kPa.

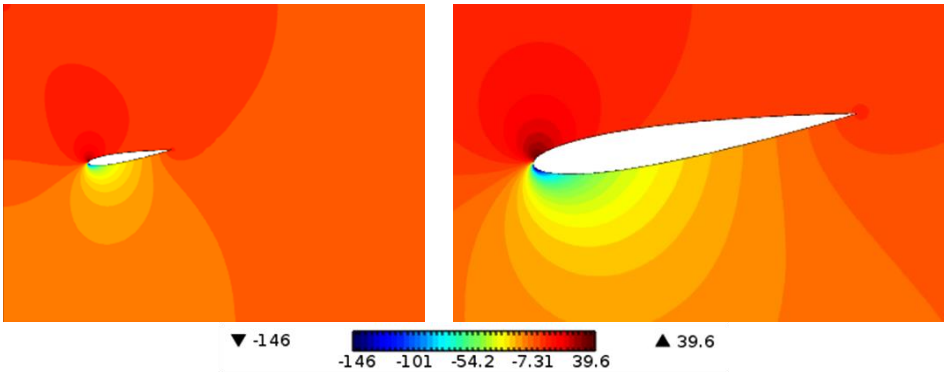

Figure 10 – The air pressure contours on the airfoil surfaces at the angle of attack of -9 degrees. The unit of measurement on the scale is kPa.

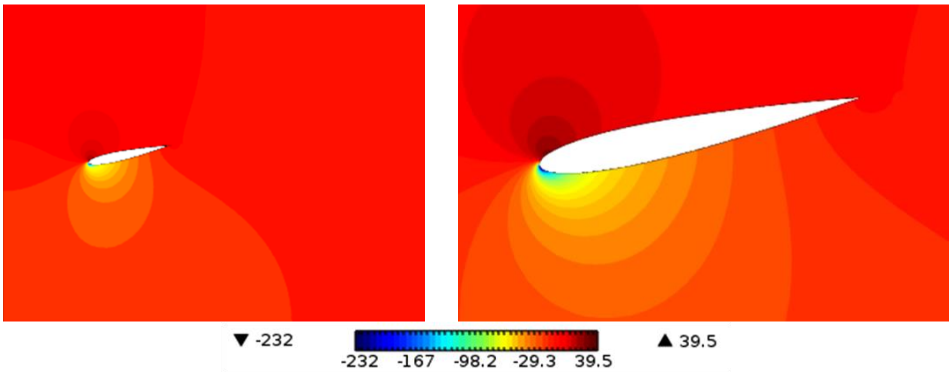

Figure 11 – The air pressure contours on the airfoil surfaces at the angle of attack of -12 degrees. The unit of measurement on the scale is kPa.

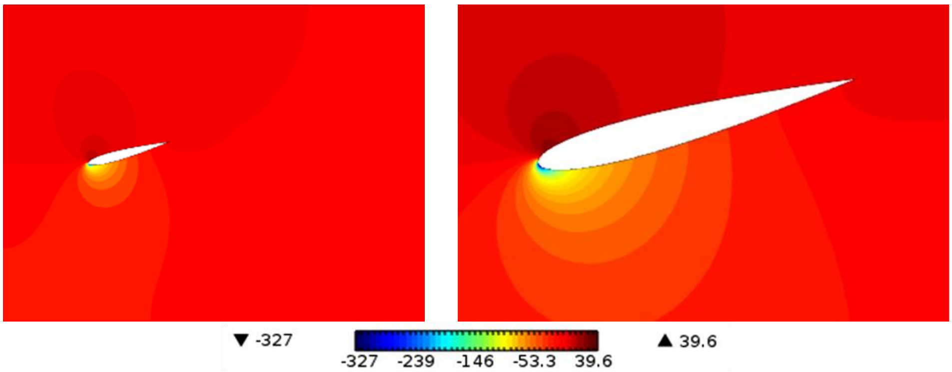

Figure 12 – The air pressure contours on the airfoil surfaces at the angle of attack of -15 degrees. The unit of measurement on the scale is kPa.

The zone of negative air flow pressure occurs with an increase in the value of the positive angle of attack on the upper surface of the airfoil of the aircraft wing. The zone of positive air flow pressure is observed on the lower surface of the airfoil. The maximum values of negative and positive pressures were calculated at the leading edge of the airfoil. The pressure values decrease at the distance from the leading to the trailing edges. Near the trailing edge, regardless of the angle of attack of the airfoil, only positive air flow pressure acts. The negative pressure drop on the upper surface of the airfoil is: at the angle of attack from 3 to 6 degrees – 54.7%, at the angle of attack from 6 to 9 degrees – 45.7%, at the angle of attack from 9 to 12 degrees – 36.1%, at the angle of attack from 12 to 15 degrees – 29.5%. The pressure drop averaged 13.83% when changing the angle of attack of the airfoil by one degree. Thus, condition of the lift component is fulfilled, i.e. the pressure difference corresponding to the rarefaction on one side of the wing and compression on the other causes the appearance of a force directed towards the positive angle of attack. Since the considered airfoil of the aircraft wing is symmetrical, at the negative values of the angle of attack, the formation of the negative pressure zone occurs near the lower surface, and the positive pressure zone occurs near the upper surface. The change in pressure of air flow at the negative values of the angle of attack of the airfoil is almost similar to the change in pressure at the positive values of the angle of attack. The uniform distribution of positive pressure on the leading and trailing edges of the airfoil is determined at the zero angle of attack. Negative pressure acts on the upper and lower surfaces of the airfoil. Positive pressure is greater in magnitude than negative pressure.

Conclusion

Flow around the airfoil of the aircraft wing with air stream is characterized by the appearance of the gradients of positive and negative pressures on the leading and trailing edges and the upper and lower surfaces. When the angle of attack increases from 0 to 15 (-15) degrees, the value of negative pressure decreases in the range from 56.91 to 29.5%, respectively. The positive pressure zone on the surface of the airfoil is distributed in the form of circles of different diameters. The negative pressure zone on the surface of the airfoil is distributed in the form of ellipses. Maximum positive pressure (approximately 40 kPa) that occurs near the leading edge of the airfoil does not change at the different angles of attack.

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