MATHEMATICAL MODEL OF A STATIONARY VORTEX IN RECIRCULATION AREA BEHIND THE SPOILER ON THE AIRFOIL

Ksenia V. Redkina
Samara State Aerospace University (national research university)
Russia, Samara, Moskovskoe shosse, 34
redkina.kv@gmail.com

Vladimir A. Frolov
Samara State Aerospace University (national research university)
Russia, Samara, Moskovskoe shosse, 34
folov_va_ssau@mail.ru

Abstract. A mathematical model of a stationary vortex for the circulational potential flow around airfoil-spoiler combination has been proposed. The solution is obtained for model of the incompressible ideal fluid. The Complex Variable Function Theory is applied in which record the complex potential with Zhukovsky mapping determines the solution of the problem. Numerical-analytical method is applied a spoiler and trailing edge of airfoil simulation is performed using a set of point vortexes uniformly distributed over their surface. For the simulation of the recirculation area a stationary vortex is used the location of which is found by minimizing a velocity function. In this paper the field of kinematic and geometric characteristics of the airfoil-spoiler combination are defined for which there is a stationary vortex. Dependence of the lift on the angle of attack, relative length of the spoiler and its angle of deflection is obtained for the detected modes. The results show reduction of an airfoil lift for a deflected spoiler. The study results may be useful for assessment limit to reduction of the lift of thin airfoils with spoilers.

Keywords. **spoiler, airfoil, potential flow, stationary vortex**

1 Introduction

Spoilers are currently used to provide high lateral control of modern aircraft and also to reduce the lift and increase the drag force on the landing regime and landing run the plane on runway. Spoiler extension on the wing can cause changes its aerodynamic characteristics due to formation separation zone on the wing. The essential need to determine the aerodynamic characteristics of the aircraft arises in problems of aeroelasticity and the development of active control of wing lift. In this regard, in designing the spoilers necessary properly understand the aerodynamics of spoilers.

The purpose of this work is to develop a mathematical model of the flow around the airfoil with a spoiler. The theoretical importance of the work is to provide fundamental new knowledge about the parameters of the circulational potential flow around the airfoil with a spoiler.

In the number of papers [1-3] the mathematical model of the flow around aerodynamic profiles with spoilers has been proposed. In [1, 2] stationary recirculation zone behind the spoiler modeled by conformal mappings. In [3] a mathematical model based on the time-dependent approach and on the discrete vortices method. In this paper a mathematical model based on the assumption of stationary point vortex located behind the spoilers has been proposed. The accuracy of the calculation of the lift coefficient of airfoil with spoiler is estimated by comparison the results obtained by the ANSYS CFX.

2 Mathematical model

The problem of flow around the symmetric airfoil with elliptical nose section $\bar{t} = t/c = 0{,}15$; $\bar{x}_t = x_t/c = 0{,}3$ in the presence of a stationary vortex behind the spoiler simulation a separation zone has been considered (Fig. 1).

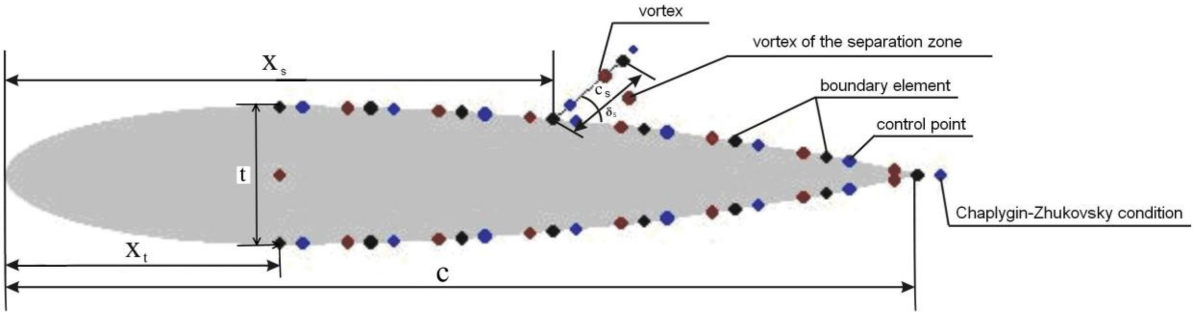

Figure 1: Geometrical scheme of the problem

According to the numerical-analytical method (NAM) spoiler and rear trailing edge of the airfoil simulation is performed using a set of point vortexes uniformly distributed over their surface. The trailing edge of airfoil and spoiler divided by boundary elements within each placed a point vortex and the control point using the numerical scheme of the discrete vortices method «¼ - ¾» (see Fig. 2 contour D).

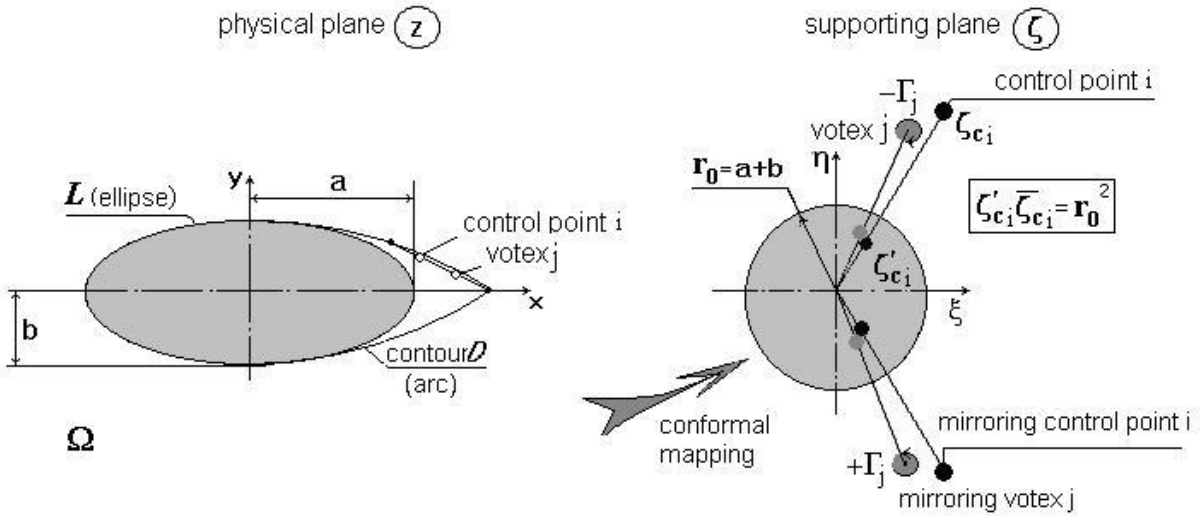

Figure 2: Physical and conformal mapping complex plane

The flow in the conformal mapping complex plane based on the Milne-Thomson theorem [5] describe the complex potential

$$W(\zeta) = \frac{1}{2}\left(\bar{V}_\infty \zeta + \frac{V_\infty r_0^2}{\zeta}\right) + \frac{1}{2\pi i}\left[\sum_{j=1}^{N+1} \Gamma_j \ln \frac{(\zeta - \zeta_{vj})\zeta}{\zeta - \dfrac{r_0^2}{\bar{\zeta}_{vj}}} + \Gamma_{N+2} \ln \zeta\right], \qquad (1)$$

where w_1 – complex potential flow around an elliptical cylinder; w_2 – complex potential flow of the sum of point vortices and their inversions; $z = x + iy$ – complex variable; $V_\infty, \bar{V}_\infty$ – complex and conjugate free-stream velocity, respectively; r_0 – radius of the circle in the auxiliary plane, which is a conformal mapping of the ellipse by Zhukovsky function; ζ – complex variable in the conformal mapping complex plane; $\zeta_j, \bar{\zeta}_j$ – complex and the conjugate variable of the discrete vortex in the conformal mapping complex plane; Γ_j – intensity of the discrete vortex; N – total number of discrete vortices, located on the arcs of the circle D; $N+1$ – number of the stationary vortex; $N+2$ – number of the vortex for Chaplygin-Zhukovsky condition.

For the numerical part of the method the geometric feature of the scheme is the correct location of the control points on trailing edge of airfoil near the ellipse and the beginning of the spoiler. This is ensures consistency of the boundary conditions and a well-conditioned system of linear algebraic equations. The problem is reduced to solving linear algebraic equation the physical meaning of which is the satisfaction of impermeability conditions at the control points. To ensure the circulation flow around an airfoil point vortex is placed at the center of the circle in the auxiliary plane. On the basis of the complex potential (1) linear algebraic equation is form

$$\mathbf{A} \cdot \mathbf{\Gamma} = \mathbf{R}, \tag{2}$$

in which the aerodynamic influence matrix $\mathbf{A}$ is filled based on the coefficients at Γ_j of the complex potential (1); $\mathbf{\Gamma}$ – the column vector of the unknown intensity; $\mathbf{R}$ – the right paths column vector formed by the coefficients obtained from the first three terms of the complex potential (1).

To create the model the hypothesis of a stationary vortex located after spoilers was used. Its intensity is found from the finite speed at the trailing edge of the spoiler and the coordinates are calculated by minimizing the target speed function $\min f(\mathbf{X})$ for two design parameters $\mathbf{X} = \begin{Bmatrix} x_{\text{vortex point}} \\ y_{\text{vortex point}} \end{Bmatrix}$, which are taken as the coordinates of the stationary vortex.

As the target function in the optimizing method full-speed flow module is used in the real plane except for the velocity components induced by the stationary vortex is excluded inductance.

$$f = V_{\text{vortex point}} = \left|\bar{V}\right| - \left|\bar{V}_{\text{vortex}}\right|$$

Vortex taken stationary if the full velocity module in the real plane except for the velocity components induced by the vortex is less than 1% of the basic external flow velocity.

3 Results

On the basis of the NAM in the developed Fortran computer program written subroutine that implements the construction of the streamlines in the presence of basic flow velocity around the airfoil, spoiler and stationary vortex (Fig. 3).

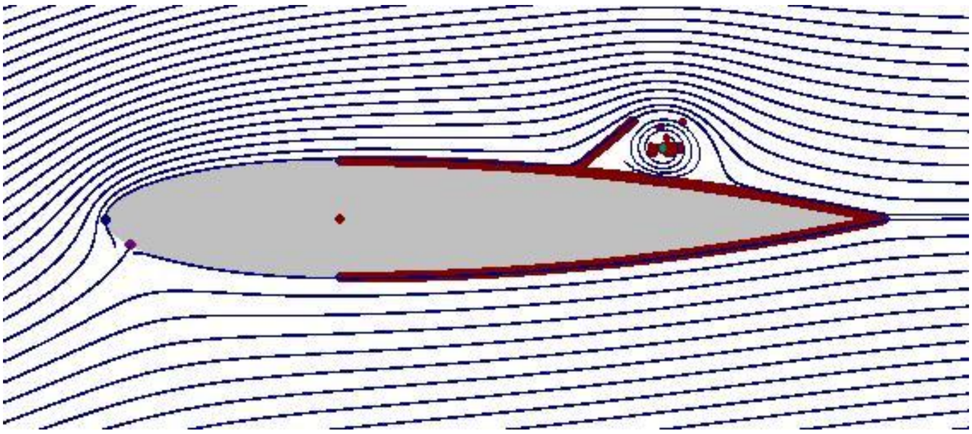

Figure 3: The streamlines around combination airfoil–spoiler (NAM)

As well modeling was performed by the control volume method in the computational aerodynamics package ANSYS CFX. 156,000 hexagonal shape elements grid been used. The streamlines around combination airfoil-spoiler which was obtained by ANSYS CFX is shown on Fig. 4.

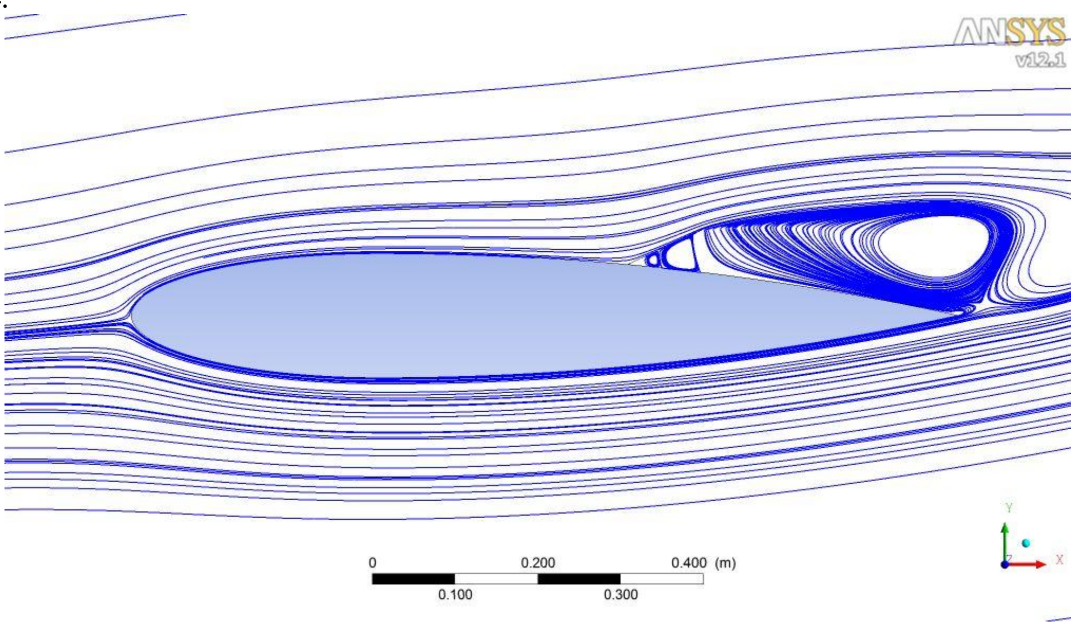

Figure 4: The streamlines around airfoil with spoiler. $\alpha = 5^{\circ}; \overline{x}_s = 0,6; \overline{c}_s = 0,1; \overline{t} = 15\%; \overline{x}_t = 0,3$

Calculations showed that the lift coefficient C_L decreases with increasing relative length spoiler $\overline{c}_s = c_s/c$ (Fig. 5) and the spoiler deflection angle δ_s (Fig. 6).

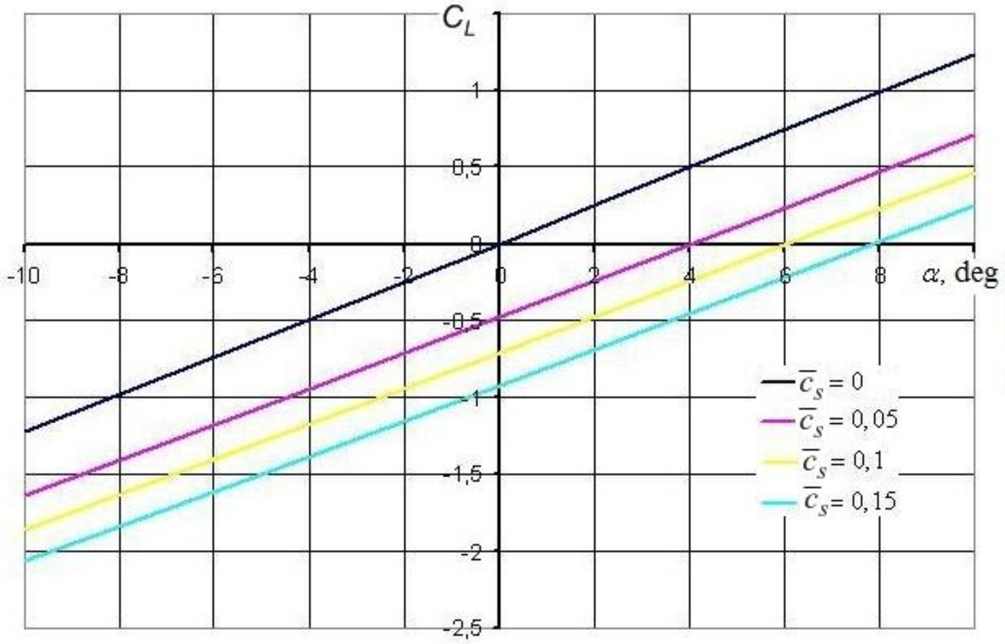

Figure 5: The dependence of the lift coefficient on the angle of attack at different relative length of spoiler

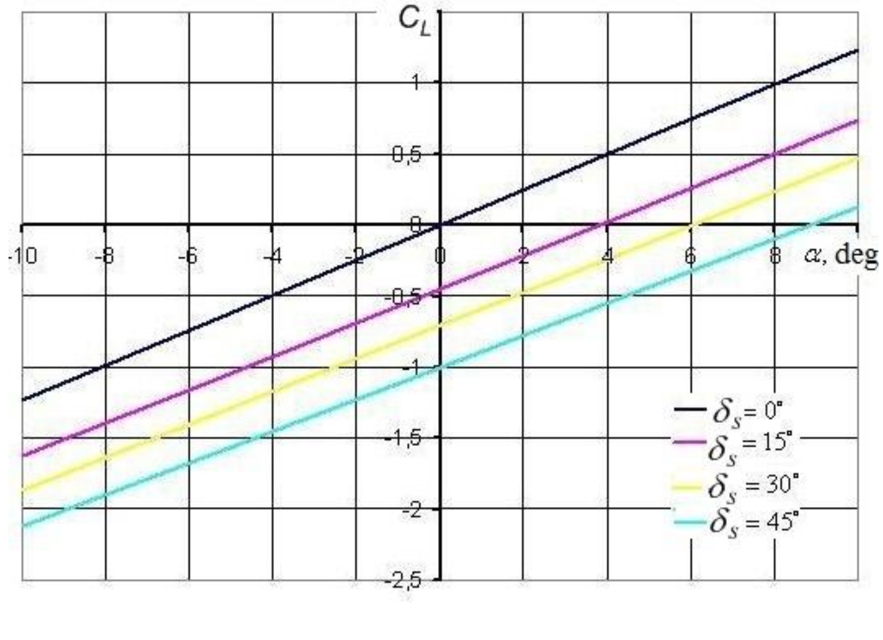

Figure 6: The dependence of the lift coefficient on the angle of attack at different angle of spoiler deflection

On Fig. 7 (NAM, $|V|$ – modul velocity) and on Fig. 8 (ANSYS CFX) shows the velocity field.

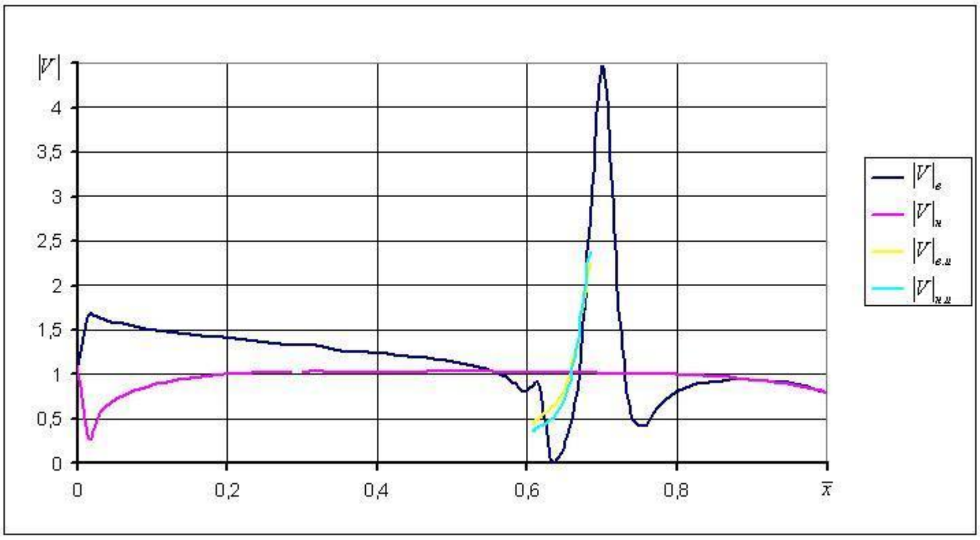

Figure 7: The velocity distribution (NAM)

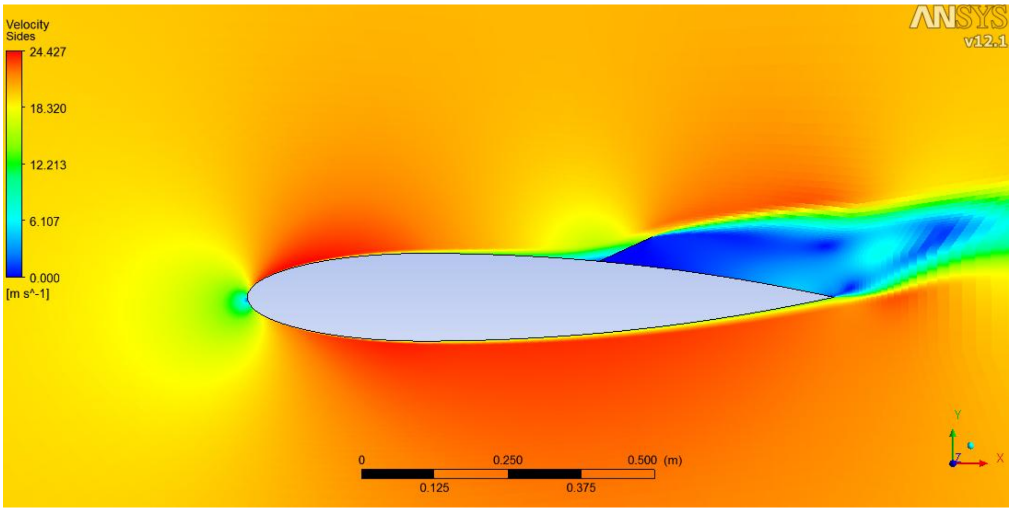

Figure 8: The velocity field (ANSYS CFX)

On Fig. 9 (NAM, c_p – pressure coefficient) and on Fig. 10 (ANSYS CFX) shows the pressure field

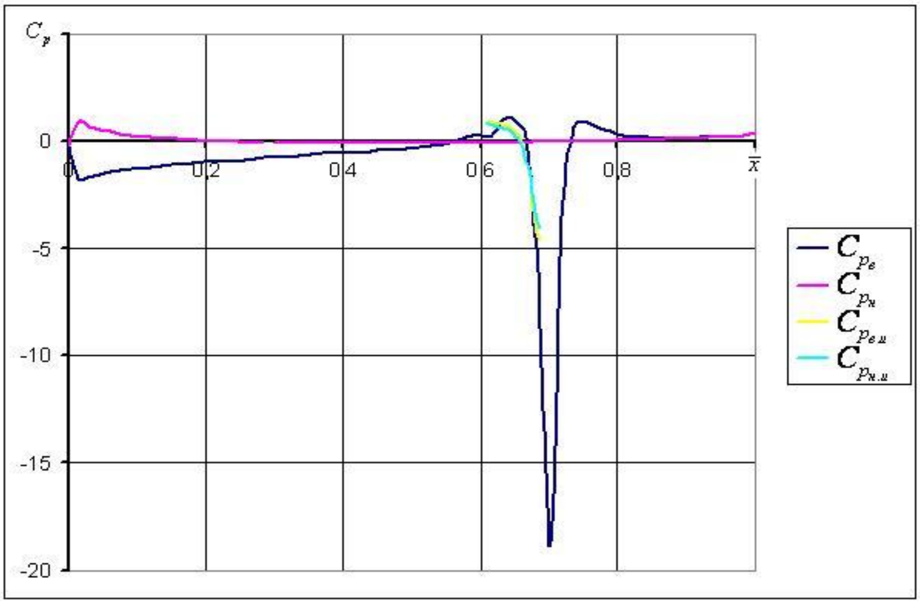

Figure 9: The pressure distribution (NAM)

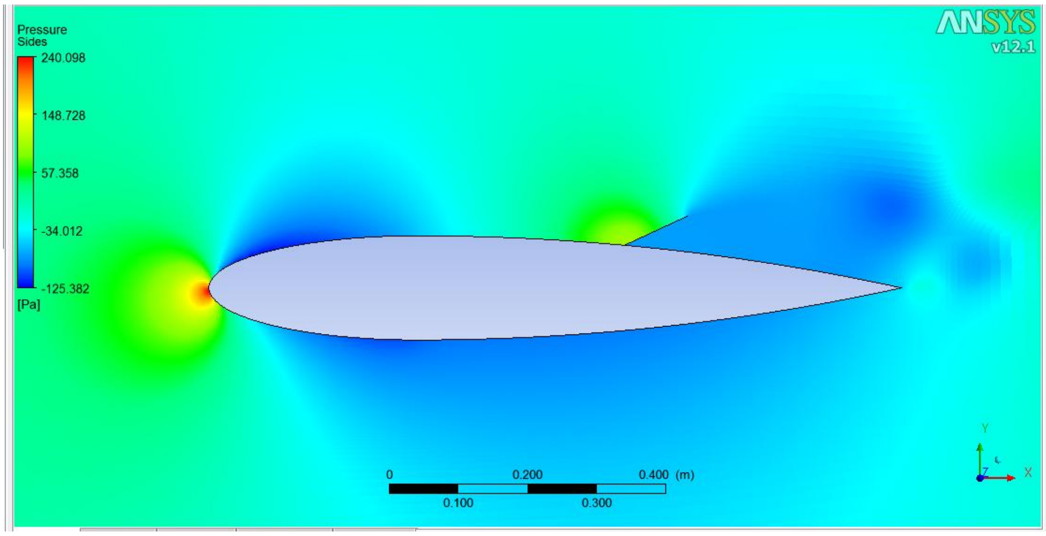

Figure 10: The pressure field (ANSYS CFX)

Comparison (Fig. 11) with the results of computer simulation (ANSYS CFX) has given

$$\alpha \in \left[0^\circ;5^\circ\right] \quad \delta = \frac{\left|C_{L\,ANSYS} - C_{L\,NAM}\right|}{\left|C_{L\,ANSYS}\right|} < 10\%$$

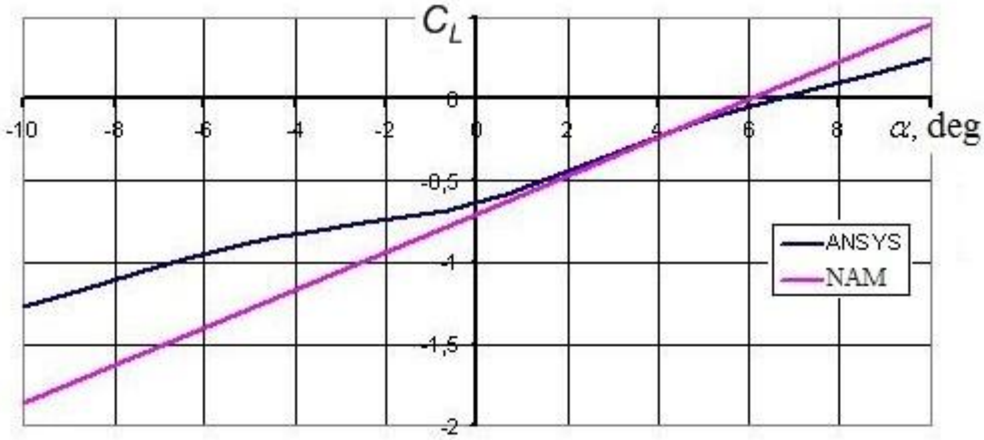

Figure 11: Comparison of the calculated lift coefficient obtained by NAM and ANSYS CFX

4 Conclusion

On the basis of the numerical-analytical method developed a mathematical model of the circulation flow around the airfoil with the spoilers in the presence of a stationary vortex in the recirculation zone.

The dependence of the lift coefficient on the angle of attack at different relative length of spoiler and its angle of deflection show reduce in lift with increasing these parameters.

In this report the limiting angles of spoiler deflection is defined.

Comparison of the results obtained by numerical-analytical method and ANSYS CFX gave accuracy of less than 10 percent at angles of attack from zero to five degrees.

The results can be used to limit assessments to reduce the lift of airfoils with spoilers.

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