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THE EFFECT OF USING THE KLINE-FOGLEMAN MODIFICATION UPON THE COEFFICIENT CHARACTERISTICS OF AERODYNAMIC FORCES IN THE AIRFOIL

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Abstract

The wing is the main aircraft construction element, whose main task is to produce the lift, balancing the aircraft weight as well as ensuring the execution of all flight states for which the aircraft was designed. The selection of appropriate airfoils or the development of new ones is one of the most important constructions goals. As a rule, constructors aim at ensuring a sufficiently large lift with little aerodynamic drag in order to increase the scope of utility angles of attack and such shaping of these characteristics so that the aircraft performance, close to the critical angles of attack, guarantees an adequate level of safety. One of the methods of improving the aerodynamic properties of airfoils is the Kline-Fogleman modification. It involves an application of a step into the airfoil contour at a place. It enforces the creation of a swirling air stream, preventing the separation and maintaining airflow over the profile and thus the reduction of drags, as well as delaying separation. The use of this type of a solution is justified when designing unmanned aerial vehicles, of small sizes, which move with slow speeds and sometimes-large angles of attack, including those close to critical angels of attack. The Kline-Fogleman modification decreases the likelihood of aircraft stalling.

The aim of this work is to present an analysis of airflow over NACA0012 airfoil with Kline-Fogleman modification. The calculations were made by solving the problem of numerical fluid mechanics. For calculations, the Comsol Maribor programme was used. The investigation focused on several different airfoil modifications (KFm-1, KFm-2, KFm-3). This enabled a selection of a solution, providing the most desirable aerodynamic characteristics.

Keywords: *airfoil, CFD, aerodynamics characteristics, Kline-Fogleman modification, NACA0012 airfoil*

1. Introduction

Unmanned aerial vehicles play an increasing role in both civilian and military operations, especially in missions exposed to high risk of losing an aircraft, e.g. during reconnaissance, search and rescue operations for military and civilian purposes. Therefore due to dynamically growing electronics (possibilities of creating small components and electronic control systems), there emerged a new problem linked with the aerodynamics of such small air constructions. At low speeds, it has become necessary to manoeuvre at high angles of attack, which may lead to aircraft stalling [16]. The problem can be eliminated by the use of ornithopters [8, 15], however due to high complexity of the design, it proves extremely difficult. Therefore, based on the classical design of an air construction, it is possible to improve the aerodynamics of an aircraft using various types of modifications. One such modification was made by Kline Fogleman.

Richard Kline and Floyd Fogleman are the constructors, who in 1960 designed various types of stepped airfoils, intended only for paper planes. Various types of airfoils [5] were related to the shape of a step on the geometry of the upper and lower surface of the airfoil.

Richard Kline's original goal was to create a paper airplane that will be able to fly long distances and overcome wind resistance and turbulence, automatically increasing altitude. This objective was achieved by the so-called stepped airfoils. Owing to such a design, when the stream flows over the airfoil, it moves towards the space behind the step. The swirling air behaves in such a manner that it can be considered as part of the airfoil. As the air flows over the surface, behind the step the air stream becomes separated from the airfoil. This phenomenon is referred to as the laminar swirling flow. Having carried out preliminary investigations and after making the models, the designers submitted their patents to the patent office [9, 10]. The first one concerned the wedgelike airfoil, hollow at the bottom, while the other one was an airfoil "backward-facing step on the pressure side". On the basis of these patents a whole family of modifications with steps emerged, both at the bottom and at the top of the airfoil, see Tab. 1.

In the successive years, following the publication of Kline and Fogelman's patents, further modifications were made: Fertis [5] patented a backward-facing step on the upper surface of the airfoil. In the successive years [4], he published the experimental results of this project. Experimental studies concerning the introduction of such modifications into airfoils [6, 18] were also conducted. After the development of numerical methods, the results of computational analyses were also published [6, 13]. The results of these tests denied that the KFm airfoil introduced some practical innovations; however, the obtained findings, in some cases, brought about good results (not for all angles of attack and at various speeds of flying).

2. Numerical verification

The present work shows the investigation results of a numerical analysis regarding the impact of the application of Kline Fogleman modification upon the drag characteristics of the airfoil. The conducted investigations are intended to verify the phenomena occurring on the airfoil NACA0012 with KFm modification as well as determining the quantitative change in the airfoil force coefficients.

In the available literature, there appear research findings [19] for both two-and three-dimensional models with CFD, using Navier-Stokes solver for deep dynamic experiments on stalling with the NACA 23012 airfoil.

2.1. Numerical computations in Comsol Multiphysics software

The calculation model as well as the research methodology [2, 17] was implemented for the numerical Comsol Multiphysics software, where a flow analysis around the NACA 0012 airfoil with modifications was made, with the following initial parameters (Tab. 1). The computing space was divided into finite elements with computational nodes (sample calculation model), as shown in Fig. 1. The computational grid was condensed in computational areas where there are large changes in the computed parameters.

For the sake of the simulation, the models of SST turbulence were used, simulating the singlephase flow of compressible fluid at low Mach numbers, using the Wall Distance Initialization option, solving the equation of momentum conservation and continuity equation for conservation of mass.

Tab. 1. Computational condition

Density	1.2043 kg/m^3
Wind speed	16 m/s
Angle of attack (Deg)	-13 – +13
Chord lengths	1.0 m
Temperature	293 K
Reference pressure	1 atm

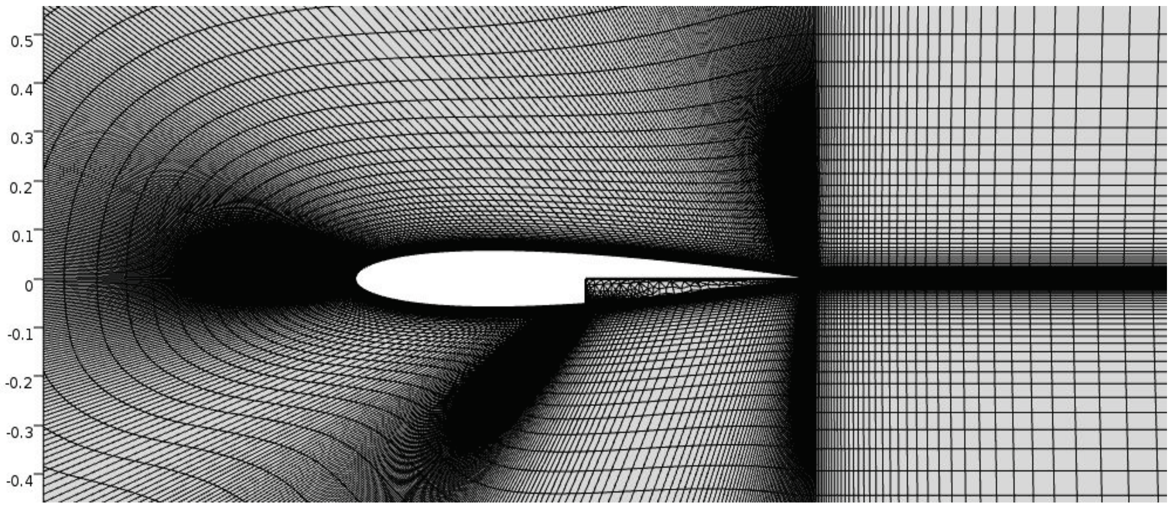


Fig. 1. Sample calculation model

2.2. Results and analysis of numerical investigations of Kfm NACA0012 airfoil

The simulation of the airflow was conducted on the assumption that air constitutes the fluid medium. As the initial condition, the velocity of airflow was assumed equal to 16 m/s. The results of the numerical investigations have been presented in Fig. 2. The distributions of the field of velocity around the examined airfoil models and the values of the pressure coefficient for these models were depicted. Five airfoil models NACA0012 (one without modification and four with Kline Fogleman modifications). All the photos around the model were presented for the angle of attack equal to 0 degrees (Fig. 2).

In Fig. 3, in order to better illustrate the impact of modifications upon the distribution of pressure and velocity around the airfoil model as well as the pressure coefficient, depending on changing the angle of attack, the author respectively placed the field pressure and velocity around the model for five selected angles of attack (-12, -7, 0, 7, 12) of the NACA0012 model with KFm-3 modification and a collective distribution of the pressure coefficient for these computational models of the airfoil NACA0012 with KFm-3 (Fig. 3f)).

The results of numerical calculations obtained using the Comsol Multiphysics form the basis for the analysis of aerodynamics of the aircraft wing. Therefore, the lift coefficient and the drag coefficient were determined for the airfoil NACA0012 with its modifications. The obtained values of the coefficients with modifications for the analysed airfoil with modifications, for various analysed modifications, have been illustrated in Fig. 4 compared to the available literature values of the airfoil NACA0012 without modifications.

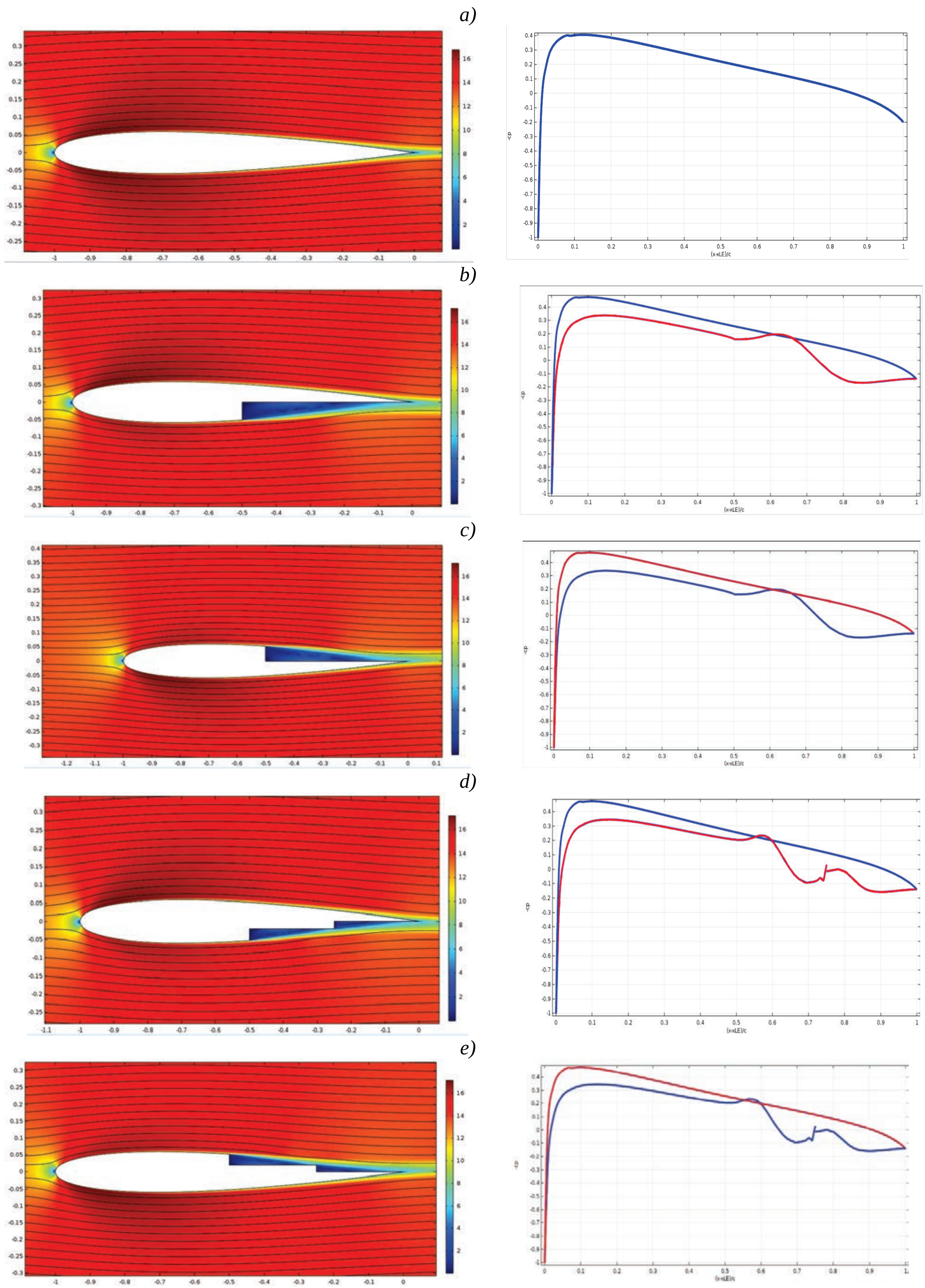


Fig. 2. The velocity field around the airfoil NACA0012 and pressure coefficient
a) without modified, b) KFm – 2, c) KFm– 1, d) KFm – 3 upside-down, e) KFm – 3

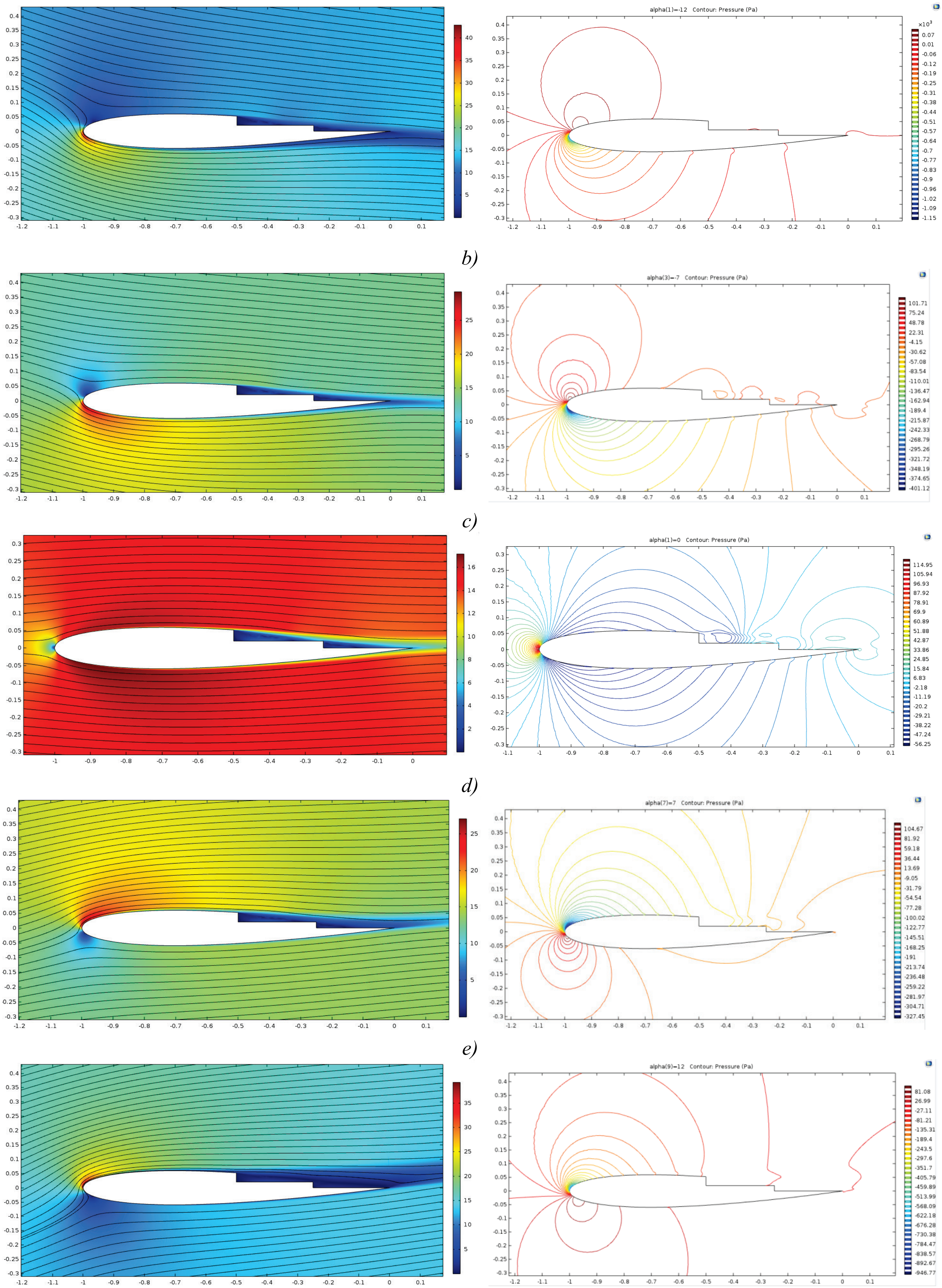
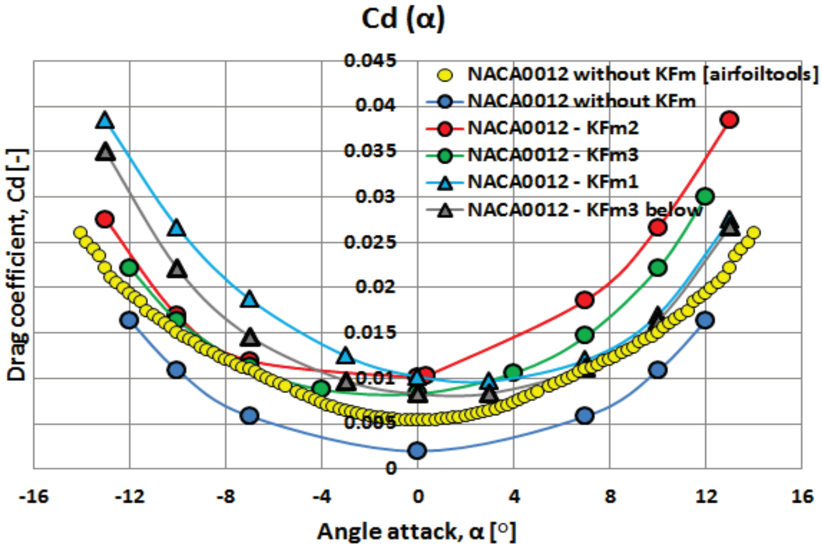


Fig. 3. The velocity and pressure field around the airfoil NACA0012 with KFm-3
a) angle attack -12°, b) angle attack -7, c) angle attack 0°, d) angle attack +7°
e) angle attack +12°, f) pressure coefficient

a)



b)

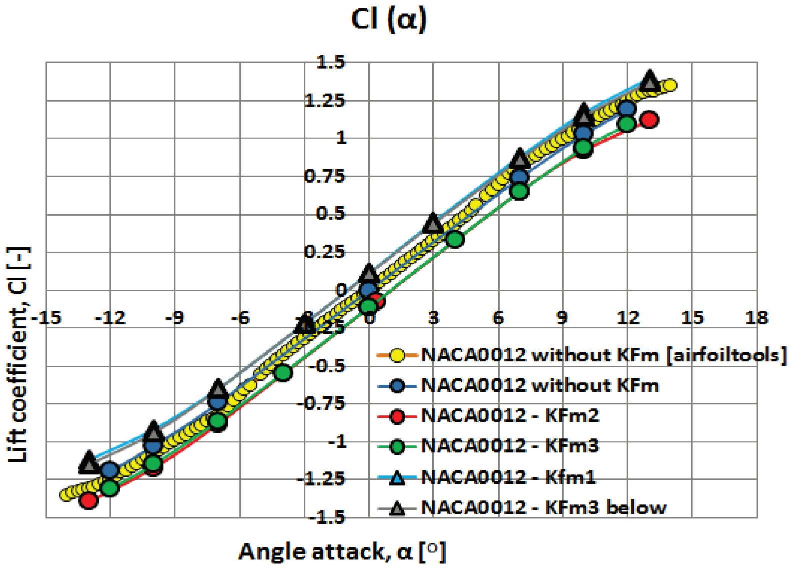


Fig. 4. Aerodynamic characteristics of NACA0012 airfoil with KFm a) drag coefficient b) lift coefficient

3. Conclusion

The airflow control is one of the most promising and the most sought after areas of research in the field of fluid mechanics and aerodynamics. Aircraft are constantly being developed to optimize aerodynamic flows around the aircraft. KFm airfoils, apart from their economic values, can also increase the level of flight safety, preventing accidents caused by exceeding the critical angles of attack (by increasing the value of the critical angle of attack).

Airfoils with modification behave like classical turbulent airfoils, where the steps take on the function of classical high drag turbulators. They are resistant to stalling, although not necessarily characterised by more lift, as confirmed in simulation tests, which resulted in a significant improvement in aerodynamic characteristics obtained around critical angles (reduction of drag coefficient and an increase in the value of the critical angle through an introduction of modifications).

In accordance with the adopted method of the analysis, both direct modelling results of the two-dimensional field flow, as well as the aerodynamic characteristics are compared. Special attention was paid to specify a 2D pressure distribution and velocity around the numerical model with the set initial parameters. When carrying out a detailed analysis, it is possible to formulate the following conclusions:

– the obtained results of the simulation investigation from all computational programmes confirmed the correct nature of the Cza course in the function of the angle of attack,
– the simulation results of the lift coefficient obtained in the Comsol programme, in the whole range of the simulated angles of attack, are almost identical with the values obtained in the wind tunnel. The difference is approximately 1-2% in relation to the experimental investigation of the airfoil without modification,
– on the basis of the conducted numerical simulations qualitatively, it is possible to observe the places of the formation of vortices and the detachment of a stream of passing air on the upper surface at large angles of attack and during the occurrence of the "modification step in the airfoil",
– the obtained results of the simulation investigation are burdened with numerical errors and the constraints of the applicability of computational models and mesh generation. After the whole calculation process with regard to the aerodynamic characteristics, it appears that the possibility of the application of numerical methods and initial calculations in order to roughly examine the airfoils of interest is very beneficial due to time. However, it is necessary to perform experimental validation of the obtained findings of the numerical investigation of creating aerodynamic characteristics in wind or water tunnels.

The presented results of the investigation constitute an analysis of the capabilities of applying numerical methods in the development of the issue of the calculation of flows, both for the introduction of more complex two-dimensional models (introducing airfoil modifications, the use of flaps, slots, analysis of icing) and in order to further develop 3D models of the aircraft wing.

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