Simulation of transient aerodynamic characteristics of oscillating airfoil.

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Abstract. This paper deals with the problem of incident airflow streaming around oscillating airfoil under the effect of the harmonic law. Two types of helicopter airfoil oscillations were considered: airfoil oscillations parallel to incident airflow and oscillating rotational motion relative to the aerodynamic focus. To solve the problem, CFD method technique was used on which numerical simulation of transient airflow around airfoil was based. For the case of airfoil oscillation around aerodynamic focus, the authors present the results of simulation of transient airflow around airfoil and its aerodynamic characteristics. They also compare the obtained results with well-known results of experiments carried out for a series of Strouhal numbers. For the case of airfoil oscillations parallel to incident airflow, the paper contains results of simulation of transient airflow around airfoil and aerodynamics data for a number of airfoil setting angles. Also, the structure of airflow around airfoils and time dependencies of resultant and distributed aerodynamic characteristics are given.

Introduction. The flow around a helicopter rotor blade section is characterized by unsteady behavior of incident airflow in the case of angle of attack and velocity value variations. The unsteady factors become more sizable and they have to be considered for rotor aerodynamic characteristics as helicopter velocity increases. To take into account the behavior of incident airflow in the case of angle of attack α(t) variations, the semi-empirical methods are designed [1], but there are not methods to take into account the behavior of incident airflow in the case of velocity value V(t) variations. In this work, the attempt is made on the base of CFD methods to evaluate the influence of the incident airflow unsteady behavior on airfoil aerodynamic for regimes that are similar real helicopter rotor blade regimes.

Problem formulation and results. The aerodynamic characteristic calculations of the airfoil Vertol23010 are performed in ANSYS CFX 10.0 [2]. The full Reynolds-averaged Navier-Stokes equations are solved. *SST* k-ω turbulence model is used for closure. Ideal gas equation is used for the air. The velocity value around airfoil vary according to the law: $U = U_\infty + 0.5U_\infty \sin(\Psi)$, here $U_\infty = 200\,\text{m/s}$ – incident airflow velocity. Airfoil setting angle α = 3.5°. In this work, the moving mesh is used to model airfoil motion. To resolve boundary layer and separation zones perfectly, airfoil position relative to calculation domain is fixed during mesh motion process and so mesh element distribution is fixed too. Thus, domains mesh with frozen airfoil moves like rigid body. For each mesh node the motion equations may be written as:

$$\begin{cases} X_n = X_{n-1} + U(t_n) \cdot dt \\ Y_n = Y_{n-1} + V(t_n) \cdot dt \\ Z_n = Z_{n-1} + W(t_n) \cdot dt \end{cases},$$

here $dt = t_n - t_{n-1}$, (X_n, Y_n, Z_n) – mesh node coordinates defined in "earth" coordinate system for time t_n. (U, V, W) – mesh node velocity vector components. Such discretization has first order of the time approximation and very small time step is required to perform high precision calculation. The results of the steady state airfoil calculation are used as initial conditions for unsteady problem. The steady state calculations have second order of the approximation but unsteady state calculations for moving mesh have only first order of the approximation. The solution results for moving mesh show the numerical dissipation of the solution.

Figures 1-2 show aerodynamic coefficient comparison for steady and unsteady flow regime depending on degree of rotation Ψ (for steady state regime the degree of rotation is defined via equivalent velocity). The starting point of the unsteady regime is the case of steady state regime for $U_\infty = 200$ m/s.

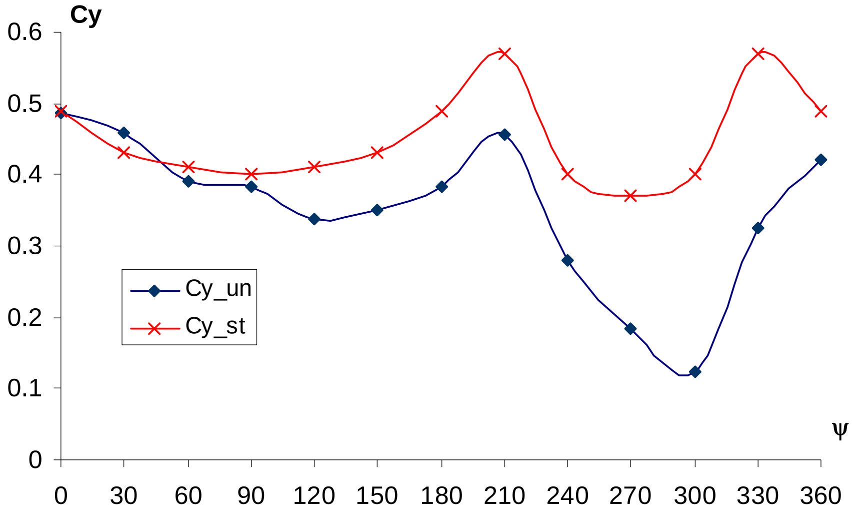

Fig 1. Lift coefficient.

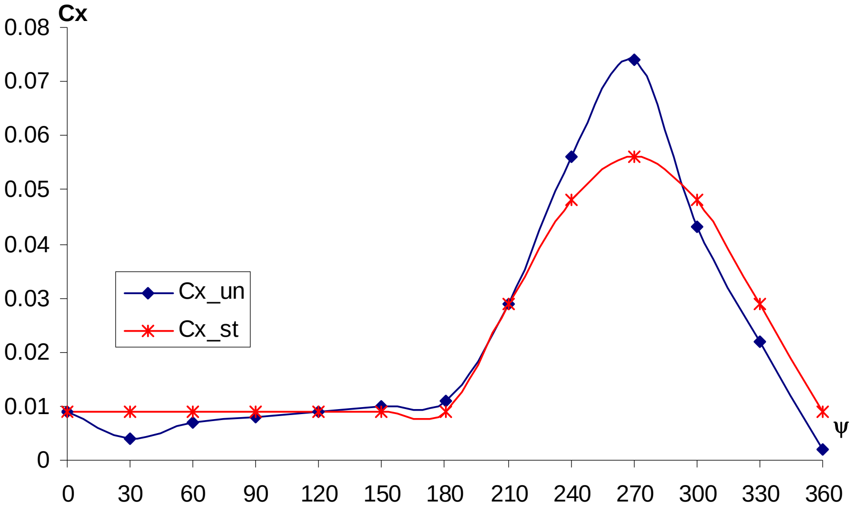

Fig. 2. Drag coefficient.

Figures 3-6 show instant velocity field around airfoil for setting angle $\alpha = 3.5^\circ$. Color legend corresponds to values in airfoil coordinate system. Figures 3-4 refer to deceleration regime and figures 5-6 refer to acceleration regime.

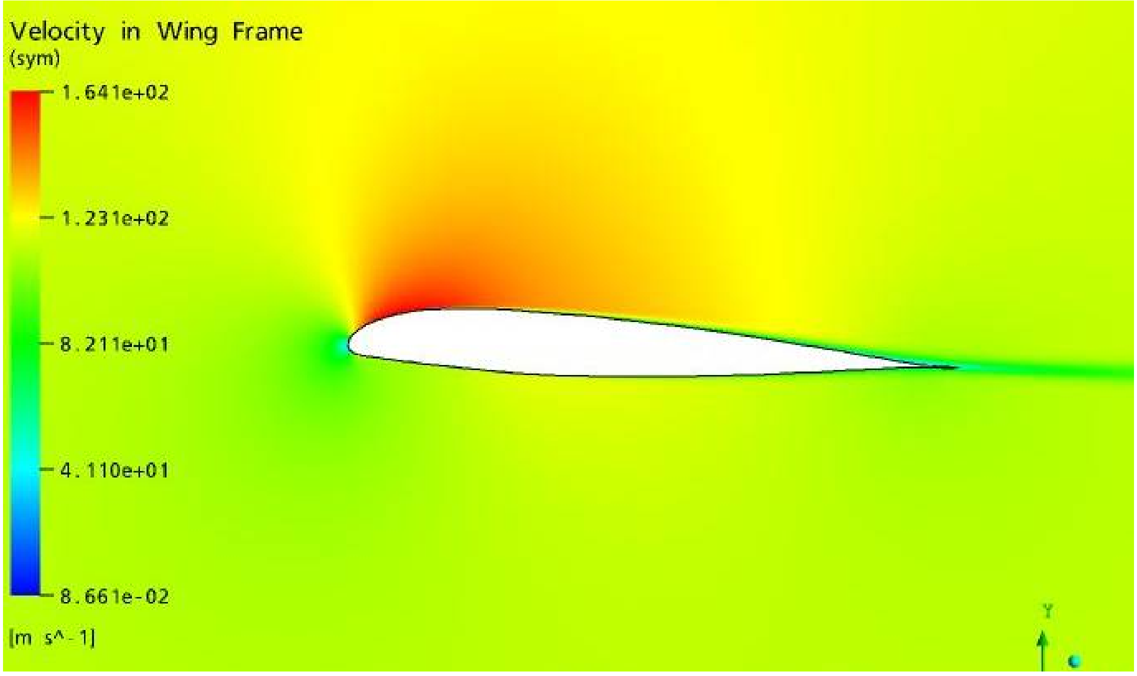

Fig. 3. Velocity field for ψ=60°

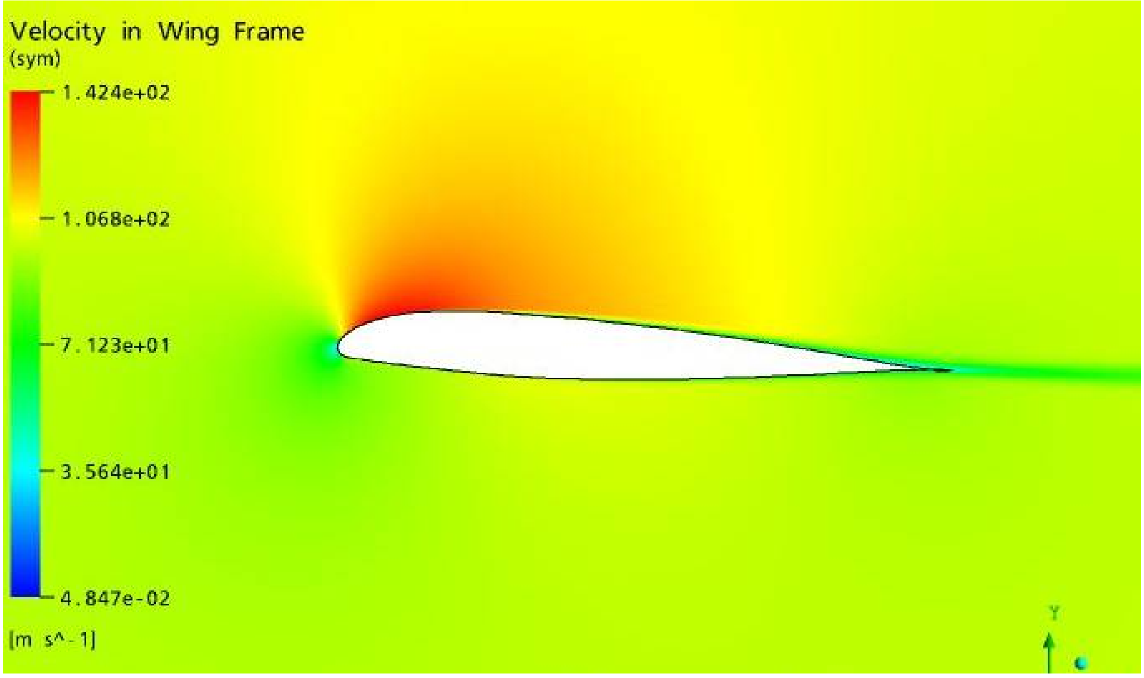

Fig. 4. Velocity field for ψ=90°

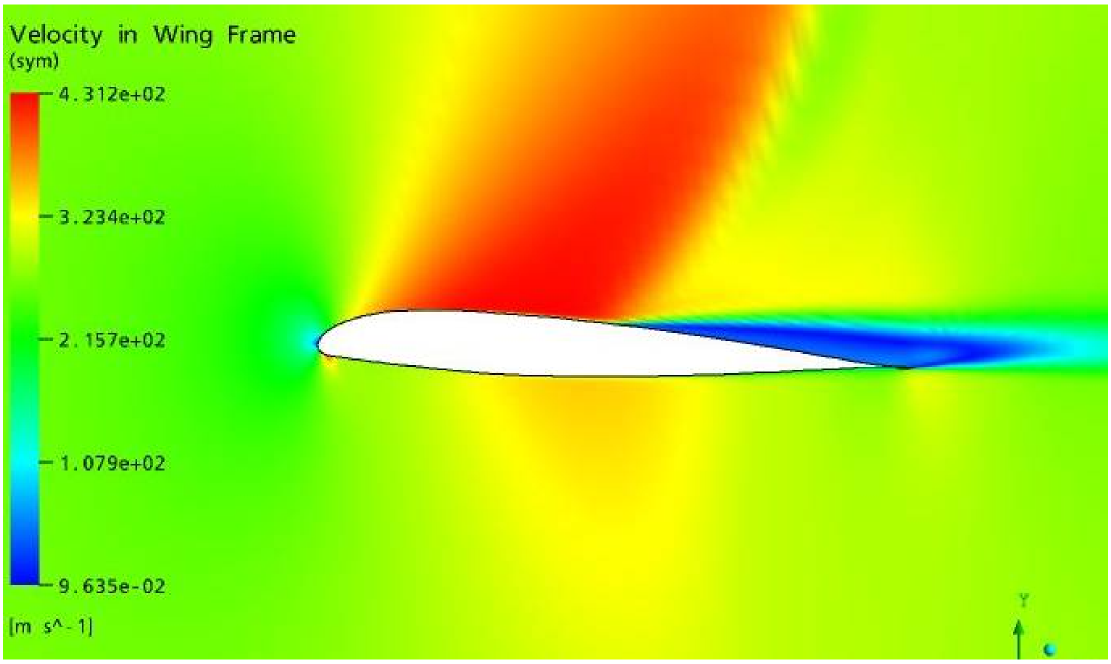

Fig. 5. Velocity field for ψ=240°

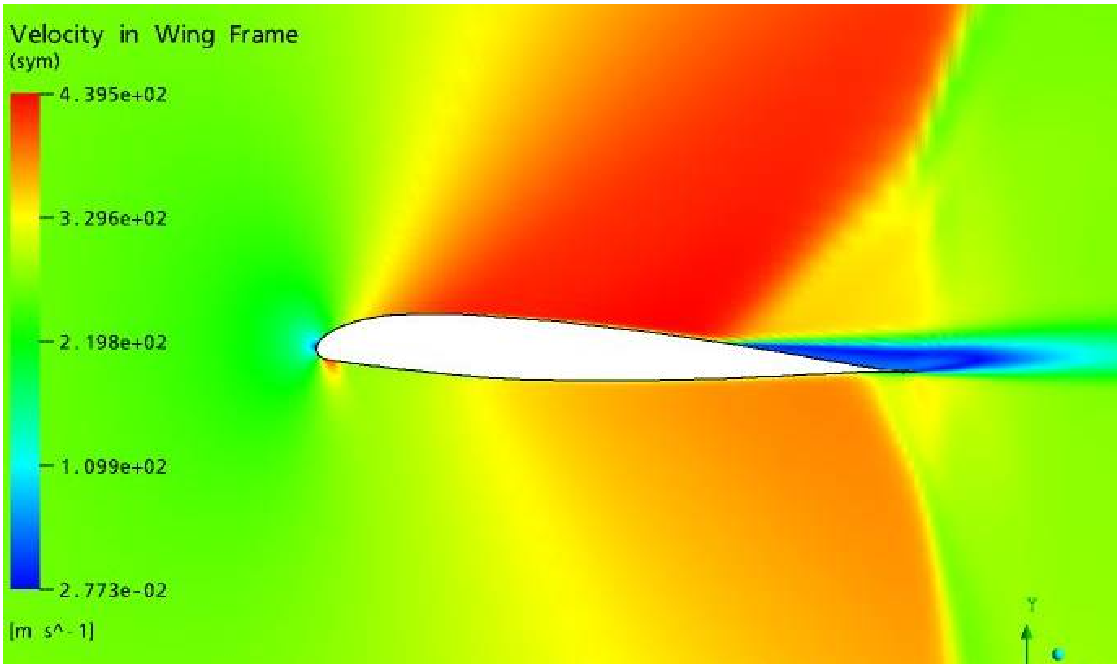

Fig. 6. Velocity field for ψ=270°

The same approach is applied to solve the problem of the airfoil oscillation around aerodynamic focus. The regime are: P=172370 Pa, T=294° K, M=0,4, Re=2,5·10^6, V=137,5 m/s, b= 0,162 m, here P, T, M, Re, V – pressure, temperature, Much and

Reynolds numbers, incident airflow velocity respectively, *b* – airfoil chord. The harmonic low of the airfoil oscillation may be written as:

$$\alpha = \alpha_0 - \alpha_m (\cos(Sh \cdot V / b \cdot t) - 1)$$

here α - angle of attack, α_0 – initial angle of attack, α_m - amplitude of the airfoil oscillation, Sh - Stroubal number, *t* - time.

The standard turbulence model SST is modified by coefficient σ_k diminishing three times. Figures 7-8 show a comparison of a calculated airfoil normal force coefficients with the [3] experiment data for different Stroubal numbers.

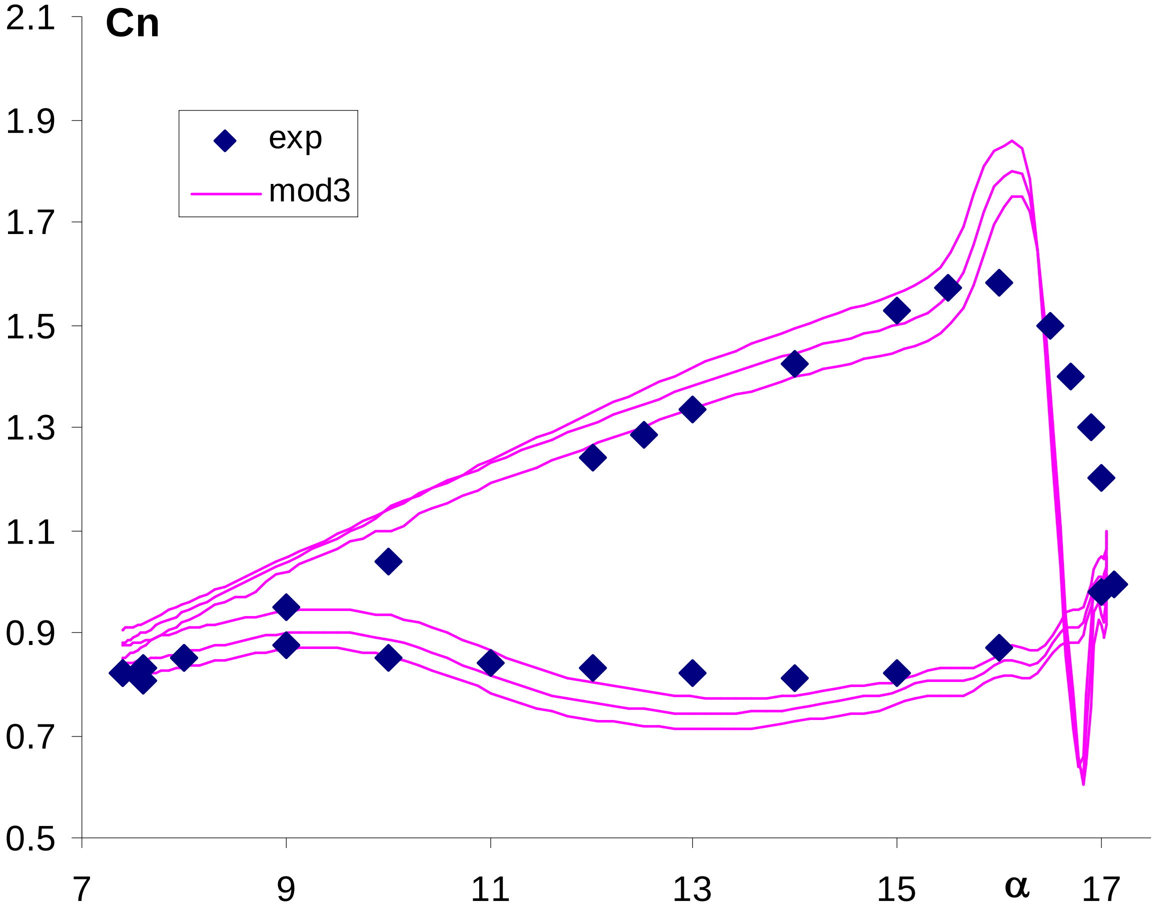

Fig. 7. The comparison of the numerical and experimental data's for Sh = 0.124.

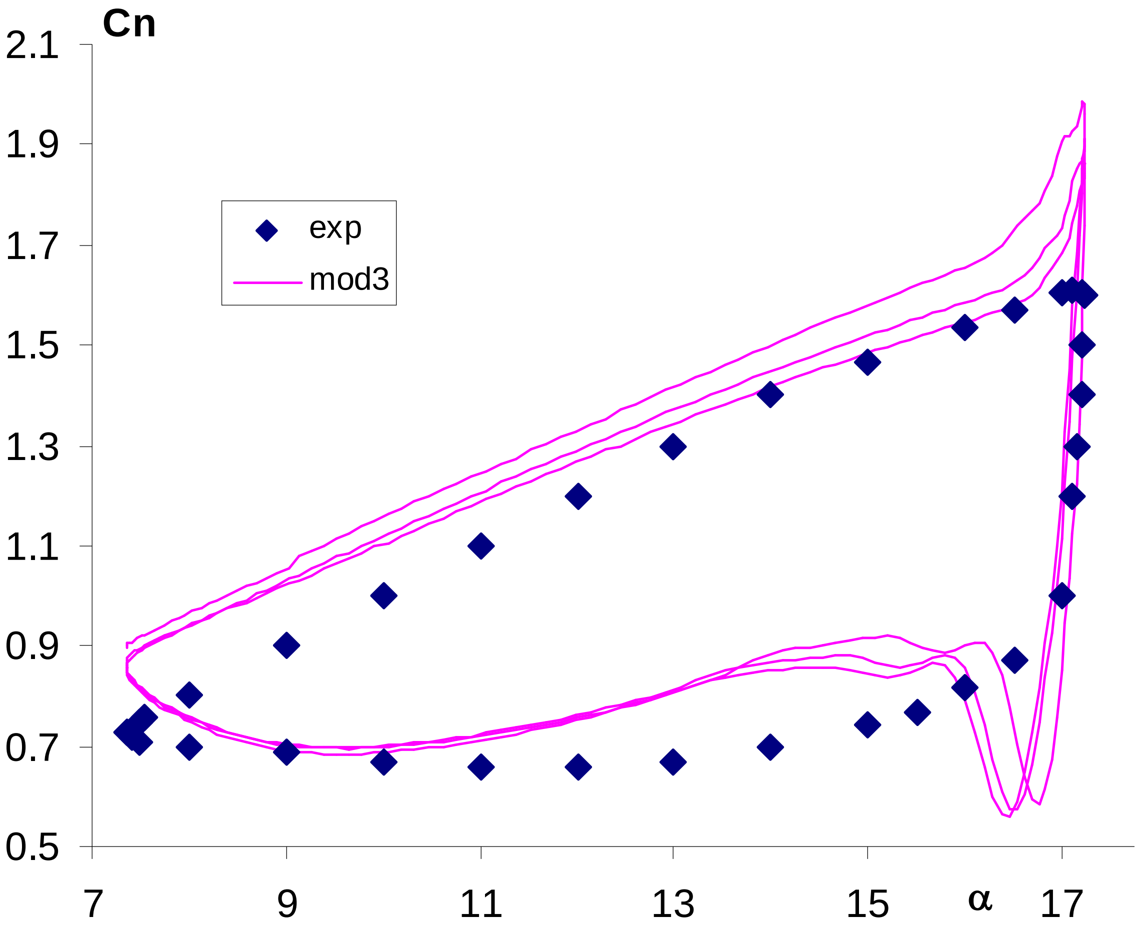

Fig. 8. The comparison of the numerical and experimental data's for Sh = 0.248.

Conclusion. The performed results show that airfoil aerodynamic characteristics are depend on the incident airflow unsteady behavior appreciably and an account must be taken of this fact to model a rotor aerodynamic.

Literature.

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3. L.M. Carr, «*Progress in Analysis and Prediction of Dynamic Stall*», J. of Aircraft, No.1, 1988.