EXPERIMENTAL AND NUMERICAL INVESTIGATION OF THE INFLUENCE OF AIRFOIL DISTURBANCE ON ROTOR PERFORMANCE

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Abstract

The influence of blade shape disturbances on performance of helicopter rotor was investigated The research covered measurements of aerodynamic loads on airfoil and rotor model in wind tunnels and numerical calculations using CFD codes for airfoil and the FLIGHTLAB code for the rotor.

The static airfoil aerodynamic coefficients were measured in wind tunnel for undisturbed and undisturbed shape of the blade airfoil in full scale and the numerical calculations done for the same cases. The model of helicopter rotor was tested in wind-tunnel in hover conditions with nominal and disturbed shapes of airfoils of the blades and the results were compared with numerical calculations.

As the general result of the research the possibility of capturing by numerical calculations the influence of the blade shape deterioration on rotor loads was proved.

Introduction

Helicopter rotor performance, vibrations and external noise depend on the shape and dynamic properties of the blades. The rotor blade shape is complex, the blades have build-in twist, variable cross sections and specially formed tip.

New types (families) of airfoils for helicopter rotor blades were developed to improve rotor performance [1] and were applied in modern helicopters providing better performance comparing to “classical” cross sections.

The real blade cross sections may differ from these carefully designed airfoils, due to manufacturing errors, wearing in time of operation, influence of temperature, icing conditions etc. These changes may influence rotor performance.

The blade shape may also be changed purposely. The concept of “smart structures” makes feasible active control of the airfoil shape. The blade shape may be controlled in “a large scale” by changing the blade camber, adding the trailing edge flap or leading edge slot [2], and also in “a small scale” by varying the shape of the airfoil [3]. A concept of an active control of blade shape is also consider in wind-turbines design. [4].

These two reasons formed the background of this research. In the long term the research should give the answer about feasibility of controlling airfoil shape for improvement of helicopter rotors performance.

In the first part of the research, described in [5], information from manufacturer, operators and literature about the “typical” blade deformations arising during helicopter rotor life was collected. According to the results of this survey, the airfoil changes during operation were not substantial.

The objective of the next part of the research reported in this paper was to investigate to what extend rotor performance may be influenced by small changes of rotor blade cross-sections. Three various topics were covered:

1) experimental tests and numerical calculations of static airfoil characteristics,

2) experimental tests of the rotor model in wind tunnel,

3) numerical calculations of rotor loads and comparison with the experimental data.

The airfoil named ILHX4A-12M1,5 developed in the Institute of Aviation was explored in the static tests. The Mach scaled, aeroelasticaly similar model of the IS-2 helicopter rotor was tested in the Institute of Aviation large low-speed wind-tunnel. The FLIGHTLAB software was used to calculate loads on model and full scale rotor to get insight on the influence of blade scaling on rotor loads and on the possibility of prediction by numerical calculations rotor load variations due to disturbances of airfoil shape.

Rotor model

The main rotor of the IS-2 helicopter designed in the Institute of Aviation was investigated in this study. The three blade rotor is fully articulated with flap/lag/pitch sequence of hinges. The planform, airfoil and linear twist distributions of the rotor model are given in Fig. 1. The rotor was Mach scaled 1:3,23 for experimental tests in wind tunnel. The main data of the rotor model are given in Table 1.

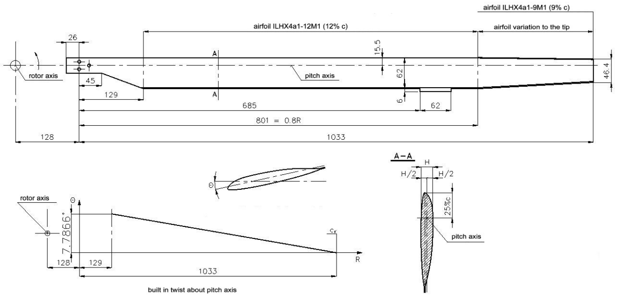


Fig. 1. The blade geometry of the IS-2 helicopter rotor model.

Table 1. Data of the rotor model.

Numer of blades	3
Rotor radius	1.161 [m]
Hinge offsets	
Flap	0.023 [m]
Lag	0.0495 [m]
Pitch	0.0836 [m]
Rotor angular velocity	163.6531[rad/s]
Pitch-flap coupling	0.4019
Lag damping	17.2686 [Nms/rad]
Lag hinge offset	0.0022 [m]

Family of helicopter airfoils

For the main part of the blade span the ILHX4A-12M 1,5 airfoil is used. This is one of the family of airfoils for helicopter blades, denoted as “ILHX–“, which was developed in the Institute of Aviation by numerical methods and tested in wind-tunnel [6]. The ILHX4A-12M airfoil shape is shown in Fig. 2.

In this paper undisturbed shape of airfoil is denoted as Case A. During the study the shape of the airfoil was changed in two ways shown in Fig. 3 and referred as Case B and C.

Static tests of undisturbed airfoil.

The base airfoil (no shape disturbances, Case A) was tested in two wind tunnels of the Institute of Aviation: the low speed wind tunnel with the open circular cross section of diameter 1,5 m and high speed (trisonic) wind tunnel with the square 0.6 m x 0.6 m closed test section. The Mach and Reynolds numbers for tests are given in Table I.

Table 2. Data for static airfoil tests

	Low speed tunnel	High speed tunnel
Ma	0,1	0,3
Re	595 000 750 000	1300 000

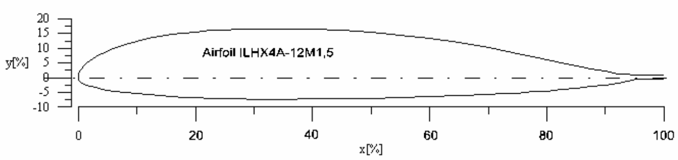
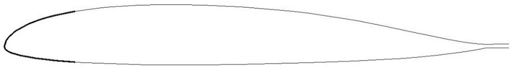


Fig.2. The shape of ILHX4A-12M airfoil.

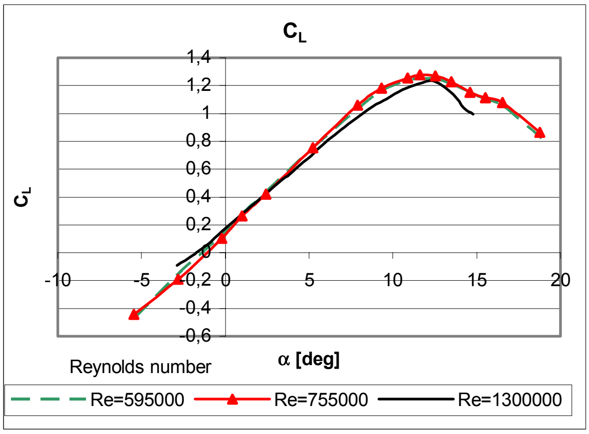


Case B

Case C

Fig.3. Disturbed shapes of the ILHX4A-12M airfoil.

In Fig 4 the lift, drag and moment coefficients obtained from the static airfoil tests in two wind tunnels are compared.



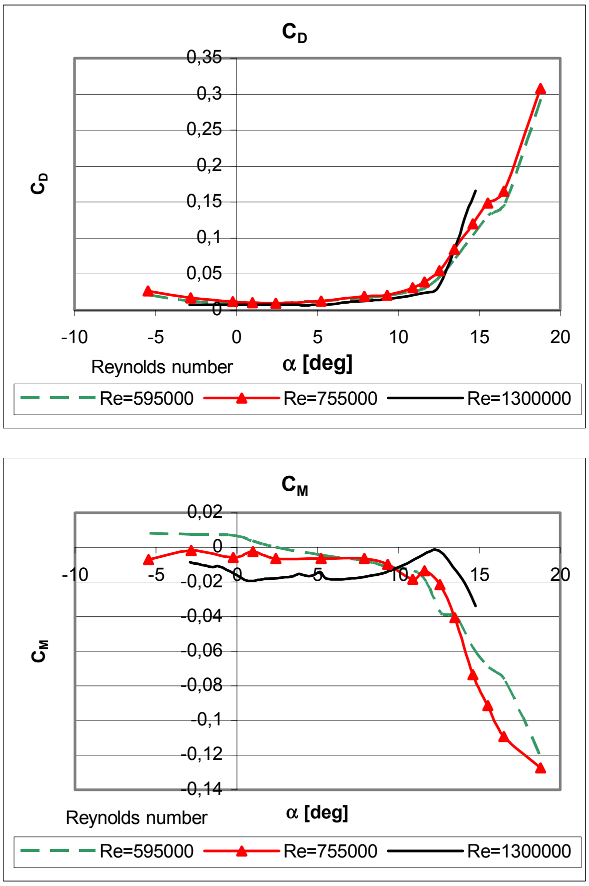


Fig. 4. Comparison of the aerodynamic coefficients of the ILHX4A-12M airfoil obtained in two wind tunnels.

The major differences occur in values of moment coefficients. The differences between two wind-tunnel results may be attributed to the differences in Mach and Reynolds numbers, different in these two tests.

To validate the methodology of the wind-tunnel measurements, the static airfoil coefficients were calculated using the software available in the Institute of Aviation. Two computer programs were used named here as: Epper and MSES.

Epper method is published in [7]. The panel method for potential flow is used including laminar and turbulent boundary layers with calculation of the placement of separation point. The drag is calculated using Squire-Young formulae with empirical corrections on separation. Lift and moment are calculated based on potential flow. It was effective for Re in the range $2*10^6$ - $1*10^8$.

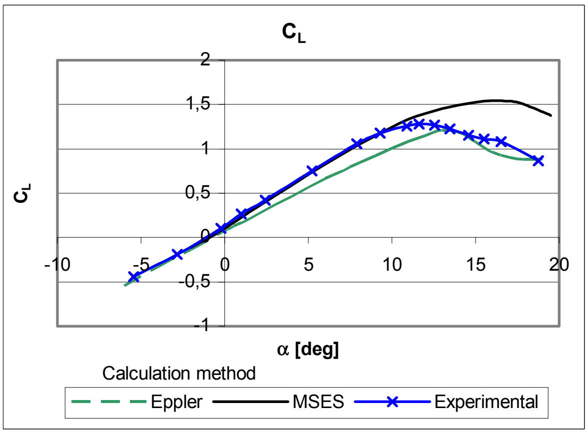
MSES is a commercial software, solving Euler flow equations with accounting of boundary layer. It may be used for calculating aerodynamic coefficient beyond the stall angle.

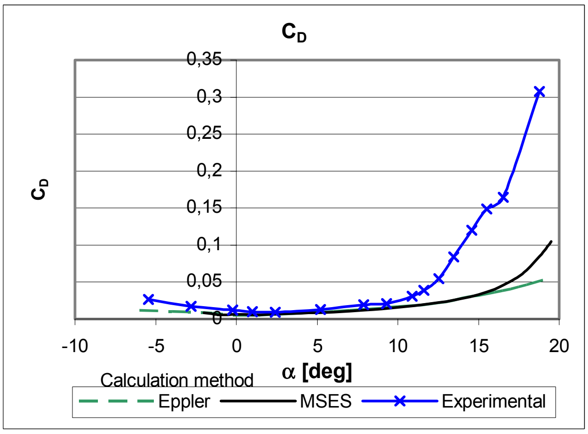
The results of comparison of calculated and measured aerodynamic coefficients are shown in Fig.5.

Only the range of small angles of attack has good correlation, which makes this software rather unreliable for capturing properly the small changes in airfoil shapes.

Blade segment in the wind-tunnel

To investigate this problem further the part of full scale blade of the IS-2 helicopter was tested in the same low speed wind tunnel (Fig.6). The length of the blade part was 598 mm, the chord 200 mm. Along the span of this specimen, the cross sections were twisted by φ = 1,6°. Using the methodology of correcting the test results for 2D effects, the results of direct measures were corrected to obtain the 2D flow coefficients in the mid-span of the section.





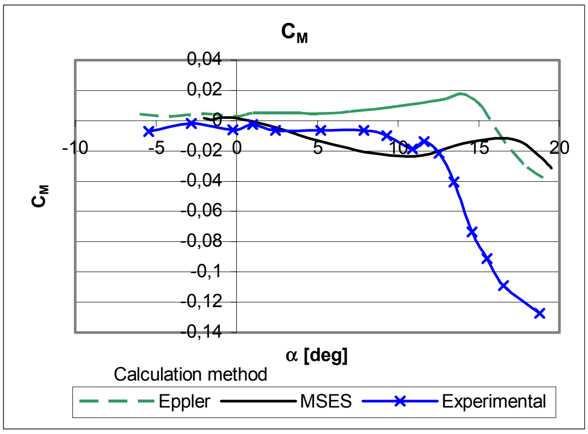


Fig.5. Comparison of the results of calculations with those obtained in wind tunnel tets

The results of this tests, shown in Fig. 7 are given as the functions of the angle of attack in the mid-span of the model for Re= 750 000 and Ma=0,1. The results are compared with the non-twisted airfoil model.

Fig.6. The blade segment in wind-tunnel.

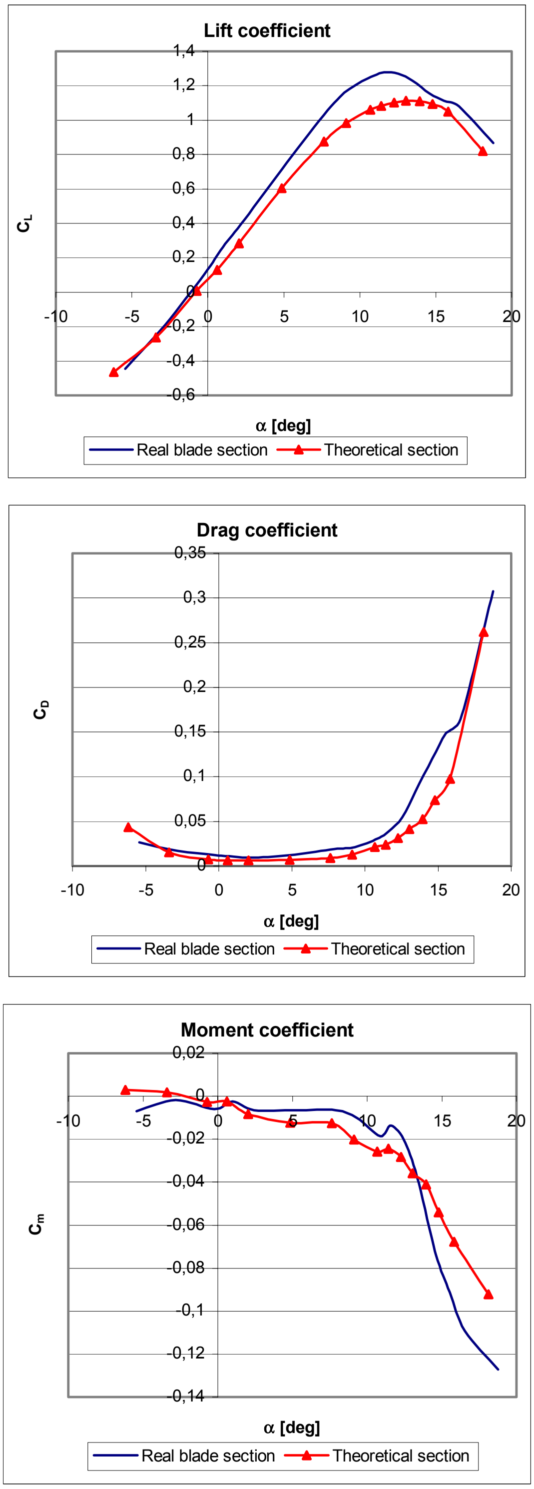


Fig.7. Comparison of the aerodynamic loads on the blade segment and the airfoil.

FLIGHTLAB software option

For calculating the loads on rotor model the FLIGHTLAB software were used, with the options of: isolated rotor model, wind-tunnel trim, articulated rotor with lead-lag linear damper, rigid blade, quasisteady aerodynamics, table look procedures for airfoil coefficients, uniform Glauert induced velocity model.

The base model data are given in Table. 1.

To investigate the influence of scalling on rotor loads, the rotor loads for the data of full blade and model blade were calculated. The results are shown in Fig. 8.

The main difference in the loads for this option of rotor computation occurs in the range of small collective pitch angles, both for thrust and moment.

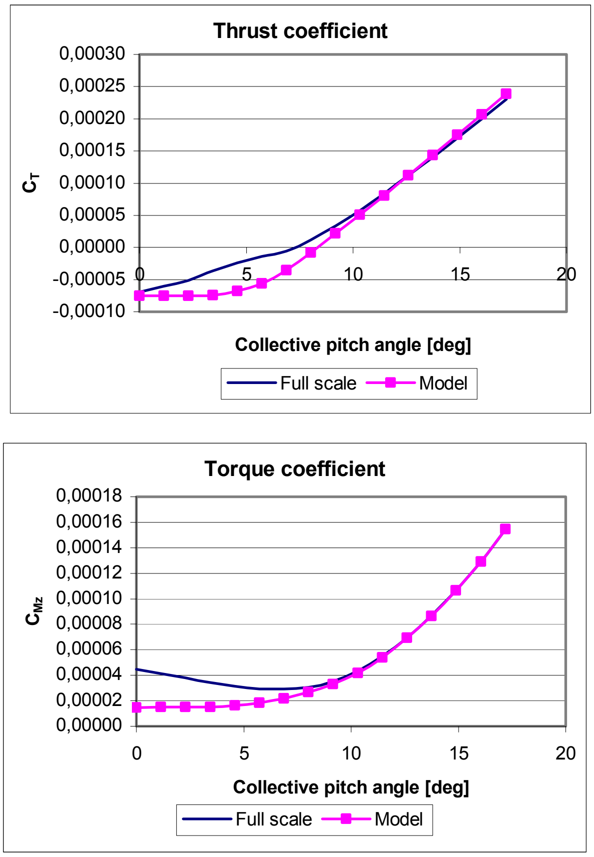


Fig. 8. Comparison of rotor calculated rotor loads in hover for blade data of full scale blade and model scale.

Rotor model tests in wind tunnel

The rotor model was investigated in hover (no horizontal velocity component). Thrust and moment were measured for:

1. the blades with undisturbed airfoils for various rotating velocities,
2. two cases of airfoil disturbances shown in Fig.3, applied to the full length of the blade.

The results of the wind-tunnel tests with FLIGHTLAB calculations are shown in Fig. 9. The correlation is the best for tip speed of the rotor blade close to nominal, i.e 190 m/2

The results of the next group of wind tunnel tests are shown in Fig.10. The loads on rotor model with nominal and disturbed blades are compared.

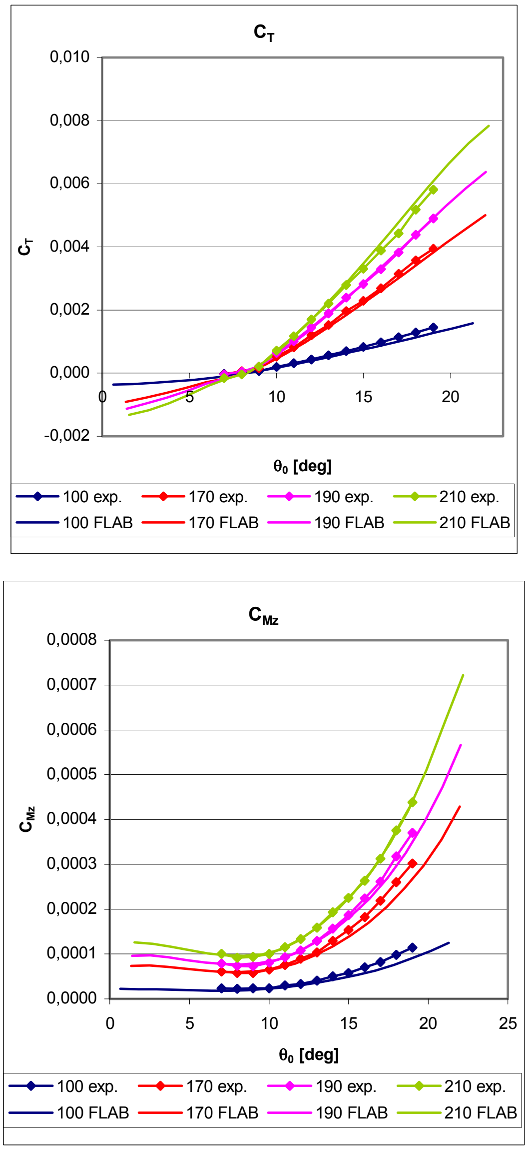


Fig. 9. Rotor loads in hover. Comparison of wind tunnel-tests with numerical calculations for various model tip speed (in m/s).

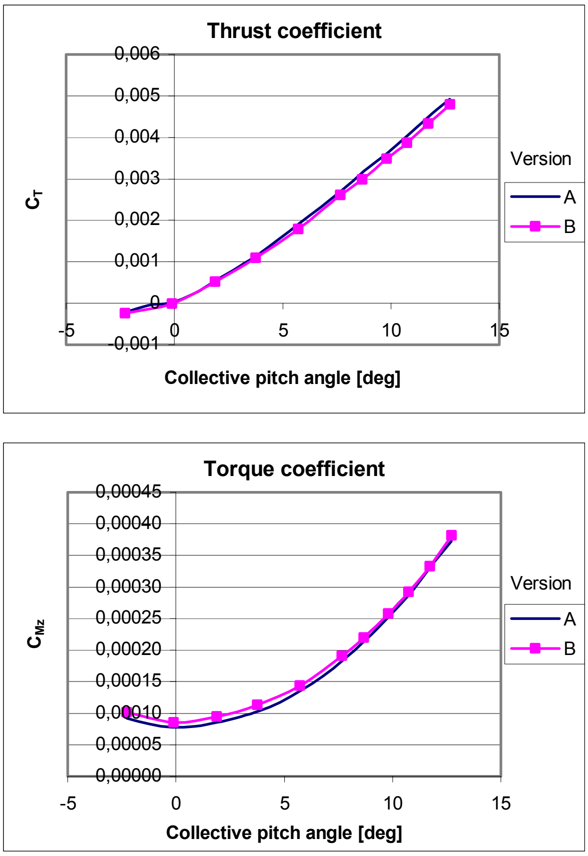


Fig.10. Comparison of loads on rotor model for nominal and disturbed (Case B) airfoil.

The influence of this type of airfoil disturbance is not very much.

Calculation of rotor loads for blades with disturbed airfoil coefficients.

In FLIGHTLAB model used in this study the airfoil shape disturbances enter into computations as variation of airfoil aerodynamic coefficients.

In Fig.11 the disturbances of aerodynamic coefficients used in this study are shown.

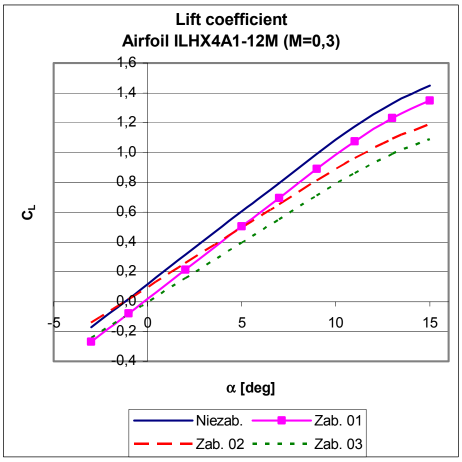


Fig.11. The blade characteristic disturbances for numerical calculations.

These disturbances are summarized as the translation or rotation of the lift v/s angle of attack curve. The results of calculations shown in Fig. 12 may be used for analysis of sensitivity of rotor loads to aerodynamic modeling

Conclusions

Experimental and numerical data were gathered for evaluation of the possibility of influencing rotor behaviour by variation of airfoil shape. The computer model reacts in the same way as experimental results for airfoil shape variation. The accuracy of airfoil static loads prediction is unadequate for shape variation investigation. The future plans cover tests in forward flight and more realistic blade shape deformation.

Acknowledgements

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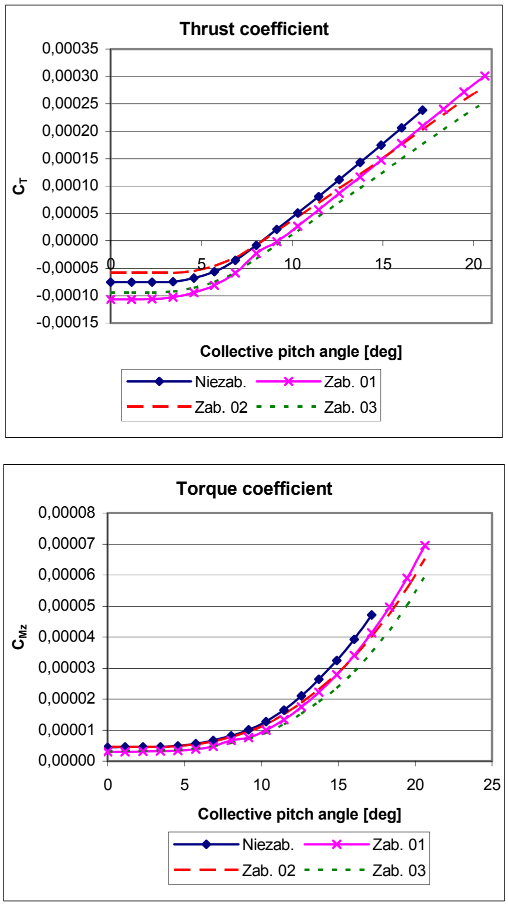

Fig.12. Calculated influence of airfoil characteristic disturbance (Fig.11) on rotor loads

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