CFD investigation of deflection effect of trim tab and tail of a rotor blade profile on aerodynamic characteristics

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Abstract: One of the most important characteristics of main rotor profile is a pitching moment. Marginal changes in profile geometry can significantly influence aerodynamic characteristics of the rotor blade. One of the concepts of the rotor blade profile development is to create profiles with the trailing edge plate (trim tab). In the present work, an investigation of the deflection effect of trim tab and rotor blade profile tail on the pitching moment and aerodynamic characteristics is carried out by means of computational fluid dynamics (CFD) methods. Numerical solutions for the flows over two profiles (in the framework of Reynolds averaged Navier-Stokes equations) are presented. The first rotor blade profile is mounted in the middle part of the rotor blade and has the relative thickness of 11.3%. The second profile is mounted in the end part of the rotor blade and has the relative thickness of 9.6%. Comparisons of the numerical solution and experimental data are also given. Presented results illustrate the influence of the deflection angle of the trim tab and the rotor blade tail section on the pitching moment and aerodynamic characteristics of the profiles.

INTRODUCTION

Aerodynamic characteristics of the main and tail rotors are permanently improved. The main factor, which specifies the quality of rotors, is the series of rotor blade profiles. The improvement of their performance is carried out by different ways. One of the methods of developing of the profile with high aerodynamic quality is to design of supercritical profiles, which have high lift force. However, such profiles have significant values of the negative pitching moment, which lead to the increase of the pitch link load and, hence, to the general increase of loading in the control system of the helicopter main rotor.

For compensation of the pitching moment, designers applied trailing edge plate (trim tab), which is the profile chord extension. The length and the deflection angle of the trim tab essentially influence on aerodynamic characteristics of the profile, particularly on the pitching moment. The example of this method is the profile of main rotor blade of "Apache" helicopter created in USA in 70^{th} years.

Another example is the series of profiles for main and tail rotor blades of Mi-28 helicopter (Mil Moscow Helicopter Plant, Russia). These profiles were developed in Central Aerohydrodynamic Institute (TsAGI, Russia). Two profiles were designed for main rotor. One of them (SB profile) is mounted in the middle part of the rotor blade and has relative thickness 11.3%, while another (KS profile) is mounted in the end part of the rotor blade and has relative thickness of 9.6%. The third profile (MB profile) with relative thickness of 11.5% is mounted in the tail rotor.

Preliminary parameters of the trim tab were chosen at the stage of design and experiments in the aerodynamic wind tunnel T-106 TsAGI. SB and KS profiles with trim tab of 6% length with several deflection angles δ were investigated. These parameters were realized on the blade prototype, but significant loading in the main rotor control system was obtained in the experimental investigation at full-scale test bench of Mil Moscow Helicopter Plant. This motivated further research to correct trim tab length as well as deflection angle.

However, experimental investigations are rather expensive, especially in the case of full-scale tests. Therefore the available experimental data is very limited. On the other hand, improvement in the design and technology of the blade production leads to the change of the aerodynamic characteristics and pitch link load. Empirical dependences to define parameters of trim tabs, required to obtain necessary pitch link load, were presented in [1]. These dependences allow one to evaluate the influence of the trim tab parameters on aerodynamic characteristics of the rotor blades.

Modern computational methods for the Reynolds Averaged Navier-Stokes equations make it possible to carry out accurate investigations of the aerodynamic characteristics of profiles with trim tab. In the present paper, calculations of SB and KS profiles with different free-stream Mach number and angles of attack were performed. One of the aims is to evaluate changes of aerodynamic efficiency and pitching moment of these profiles with the presence of trailing edge plate with different parameters. Comparison with available experimental results is also presented.

SB and KS profiles are mounted from two segments (front and tail). The front segment has the length of 230 mm, tail segment has the length of 350 mm, and trim tab has the length of 40 mm. In the second part of the present paper, deflection of the tail section of the profile is investigated. In this case, trailing edge plate is located along the tail section.

1. PROFILES GEOMETRY

In the first part of the paper the influence of the trim tab deflection on aerodynamic characteristics of KS profiles is investigated. Figure 1 shows the sketch of the trim tab location.

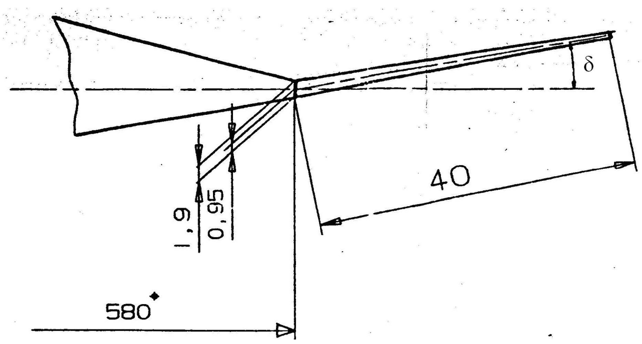

Figure 1. Sketch of the trim tab location

The following trim tab locations are studied for the KS profile: no trim tab, trim tab is deflected on δ=0, 4.5°, 8° up relative to chord direction. Geometry of these configurations is presented in figure 2.

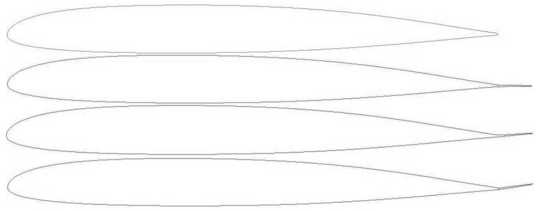

Figure 2. Geometry of KS profile without trim tab and with trim tab deflected on δ=0, 4.5°, 8°

The second part of the paper is devoted to the study of the influence of the tail section deflection on aerodynamic characteristics of KS profiles. In this case, trailing edge plate is located along the tail section. The tail section is rotated on the angles δ_0=0, 2°, 3°, 5° relative to upper point of the profile at the location *x*=230 mm. These modified profiles are shown in figure 3. In this figure, the first case δ_0=0 is the similar to the second case in the figure 2.

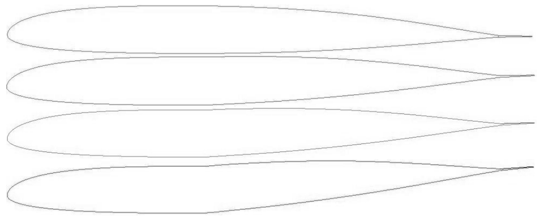

Figure 3. Geometry of KS profile with tail section deflected on δ=0, 2°, 3°, 5°

Similarly, SB profile was investigated. This profile with different locations of the trim tab (deflection angles are δ=0, 6°, 8°) is shown in figure 4. Geometry of SB profile with deflected tail section (δ_0=0, 2°, 3°, 5°) presented in figure 5.

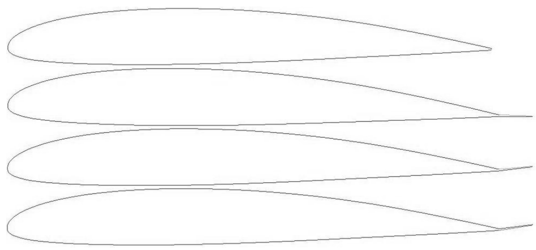

Figure 4. Geometry of SB profile without trim tab and with trim tab deflected on δ=0, 6°, 8°

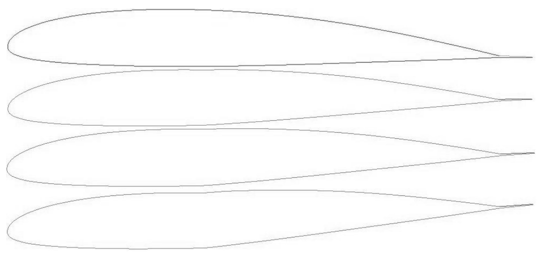

Figure 5. Geometry of SB profile with tail section deflected on δ=0, 2°, 3°, 5°

2. COMPUTATIONAL GRID

Multiblock structured computational grid was developed for the given geometry. Grid for the whole computational domain is presented in figure 6 (left figure). Grid contains approximately 65 thousands cells. Y+ of the first cell normal to the wall boundary is less than unity. Grid near the profile is shown in figure 6 (right figure). Approximately 340 grid nodes are located along the profile surface.

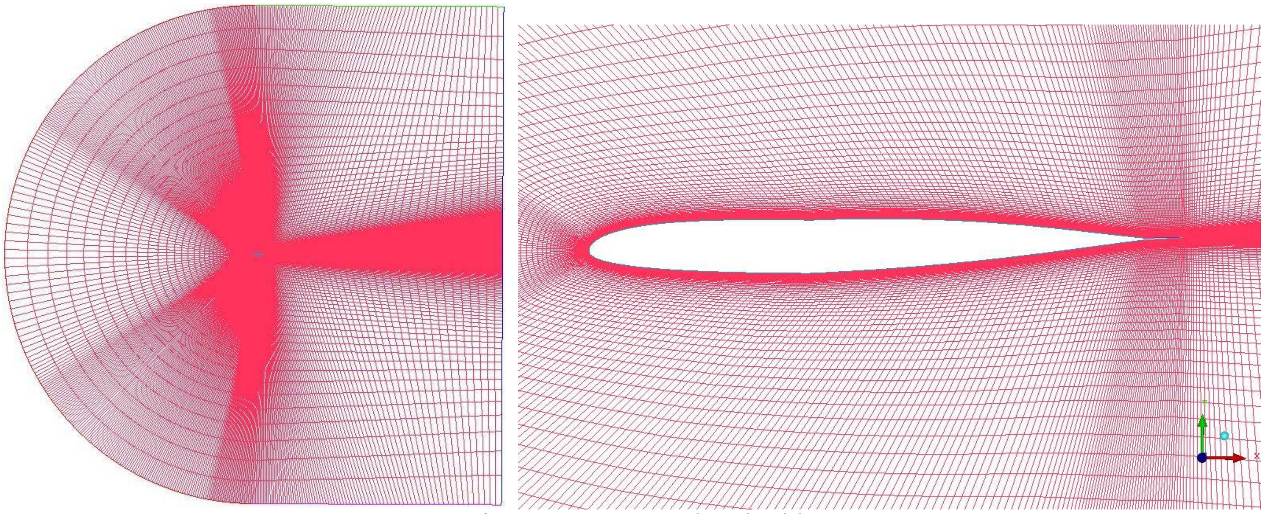

Figure 6. Computational grid

3. PROBLEM FORMULATION

Reynolds Averaged Navier-Stokes (RANS) equations for compressible gas are solved numerically using a conservative implicit finite-volume method. The flux vector is evaluated by an upwind, flux-difference splitting of Roe [2]. MUSCL algorithm is applied with third order TVD space discretization [3]. An Euler implicit discretization in time of the governing equations is combined with a Newton-type linearization of the fluxes to produce the linearized system [4]. The resulting system of algebraic equations is solved using a point Gauss-Seidel scheme. In the steady case, it is assumed that time marching proceeds until a steady-state solution is reached.

Spalart-Allmaras one-equation turbulence model is used for closing of the system. The following regimes are investigated: 1) Mach number M=0.3 (Reynolds number $Re=4.3\cdot10^6$); 2) M=0.6 ($Re=8.7\cdot10^6$); 3) M=0.8 ($Re=11.6\cdot10^6$). For all cases turbulent-laminar viscosity coefficient ratio is $\mu_t/\mu=10$. The profile surface is assumed to be adiabatic. On the external computational boundary nonreflecting boundary conditions are stated along with stretching of the grid cells. External boundaries are moved away from profile on 50 chord lengths. Laminar-turbulent transition do not fixed in our computations. Aerodynamic characteristics are referenced to the profile chord with trim tab (620 mm) and are presented in the coordinate system associated with velocity vector. Pitching moment coefficient is calculated relative to the profile nose. Angle of attack is computed from geometric chord of initial (without deflected elements) profile.

4. COMPARISON WITH EXPERIMENTAL DATA

The comparison of the calculated results with experimental data was performed. Experiments were carried out in aerodynamic wind tunnel T-106 TsAGI previously in the late seventies. A wing with KS profile was investigated. Trim tab (6% of chord length) with $\delta=4.5°$ was stated near the trailing edge. In our computations, a slightly longer trim tab is investigated (6.9% of chord length). This trim tab was studied because of it is used in practice. Moreover, experiments and calculations were performed for slightly different Reynolds numbers. Therefore, an exact agreement of results is not expected.

One of the comparisons is presented in figure 7 where aerodynamic characteristics $C_L(\alpha)$, $C_L(C_D)$ and $C_L(m_z)$ are shown for the case of M=0.8. Here C_L is lift coefficient, C_D is drag coefficient, m_z is pitching moment coefficient and α is angle of attack.

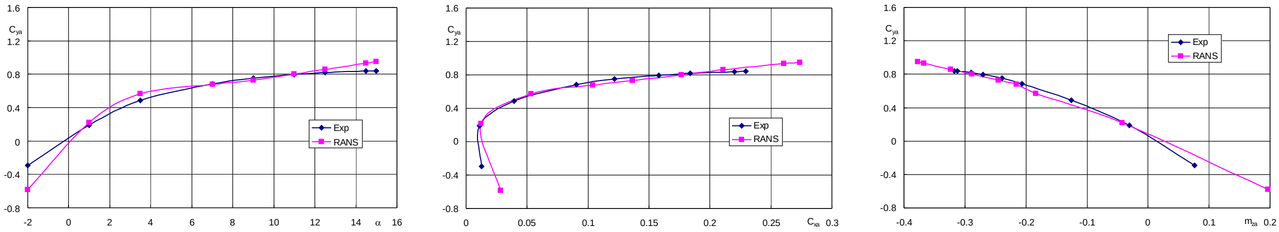

Figure 7. Comparison of calculated (magenta) and experimental (blue) data: $C_L(\alpha)$, $C_L(C_D)$ and $C_L(m_z)$

5. INFLUENCE OF TRIM TAB DEFLECTION

In this section, computational results for the KS and SB profiles with trim tab deflected with different angles upward. $C_L(\alpha)$, $C_L(C_D)$, and $C_L(m_z)$ for KS profile are shown for the case of M=0.3, M=0.6 and M=0.8 in figures 8-10. Pitching moment coefficient for zero lift m_{z0} is presented in figure 11.

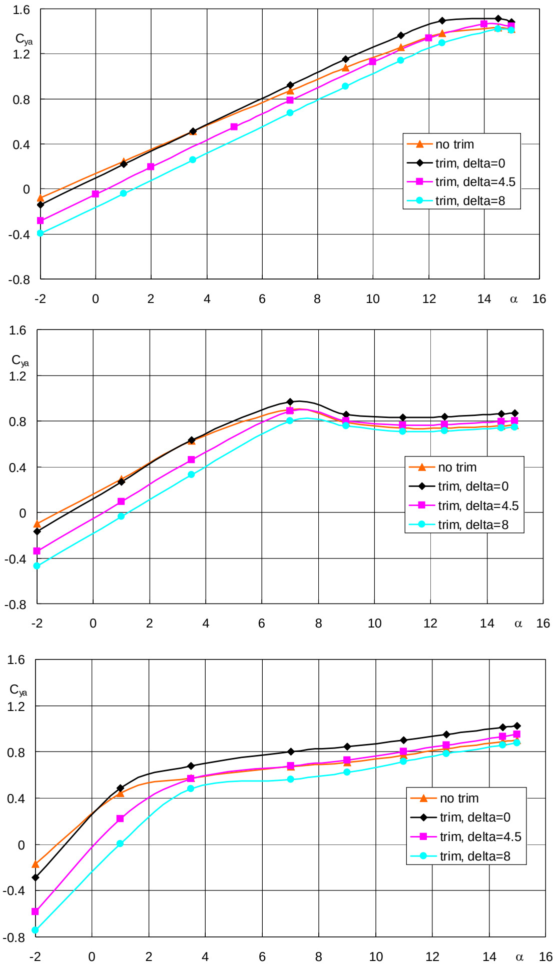

Figure 8. $C_L(\alpha)$;M=0.3 – first line, M=0.6 – second line and M=0.8 – third line

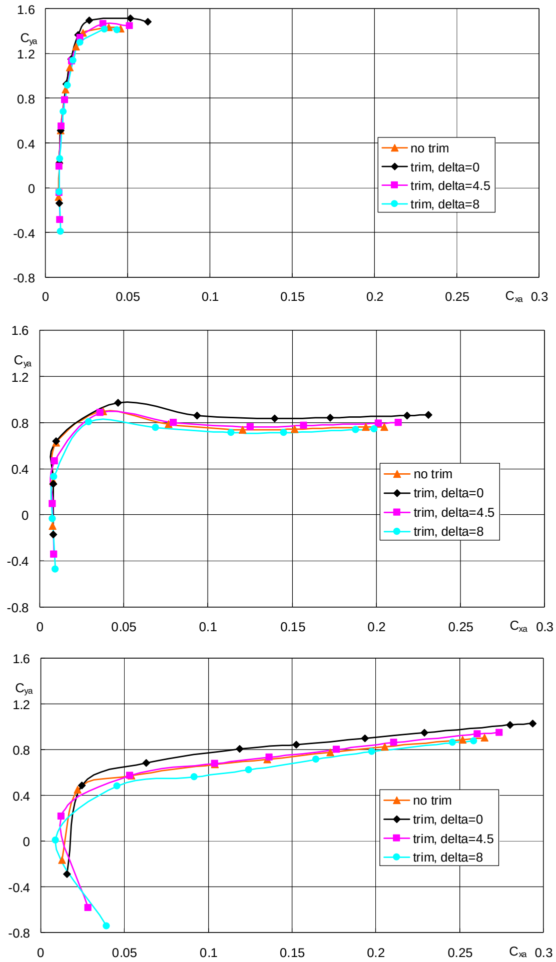

Figure 9. $C_L(C_D)$;M=0.3 – first line, M=0.6 – second line and M=0.8 – third line

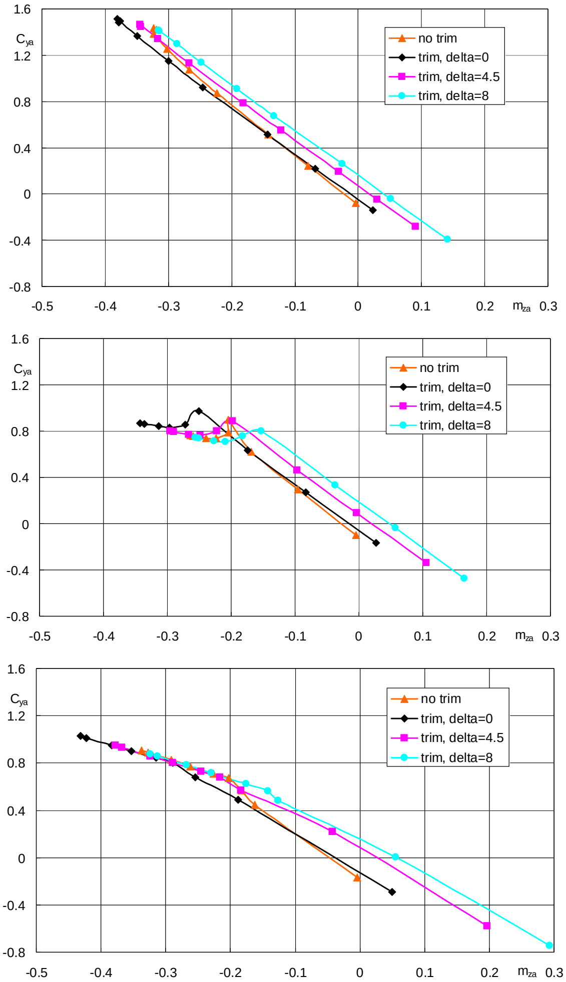

Figure 10. $C_L(m_z)$;M=0.3 – first line, M=0.6 – second line and M=0.8 – third line

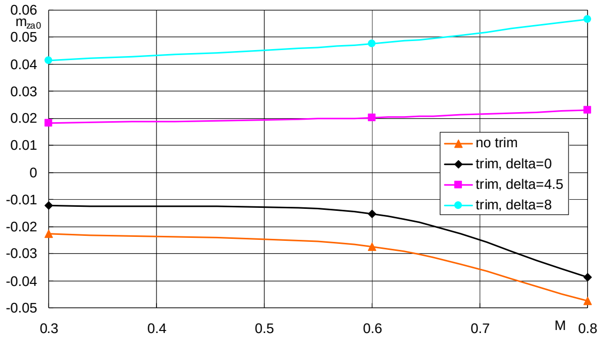

Figure 11. m_{z0} for different Mach number, KS profile

C_L is reduced for the same angle of attack as deflection angle of trim tab is increased. Dependence of $C_L(\alpha)$ has a different slope for the case when the trim tab is not used. For the case of M=0.3, maximal lift coefficient C_{Lmax} is achieved at α=14°, for the case of M=0.6 – at α=7°, for the case of M=0.8 – the behavior of the $C_L(\alpha)$ curve changes to monotone with two region of different slopes. Drag polar deteriorates with increasing deflection angle δ. Values of m_{z0} are negative for the case of profile without trim tab and for the case of δ=0°, while m_{z0} are positive for the cases of δ=4.5° and 8°.

Dependences of $C_L(\alpha)$, $C_L(C_D)$, and $C_L(m_z)$ for SB profile were calculated for the deflection angles δ=0°, 6° and 8°. The results are similar to those for the case of KS profile and are not shown here. Pitching moment coefficient for zero lift m_{z0} is presented in figure 12. Values of m_{z0} are negative for the case of profile without trim tab and for the case of δ=0°, while values of m_{z0} are positive for the cases of δ=6° and 8° and decrease with Mach number increasing.

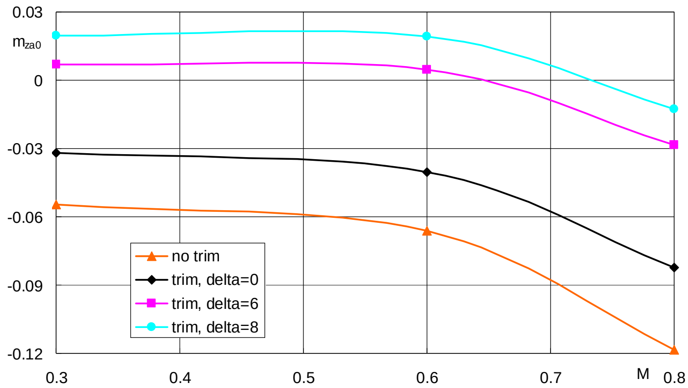

Figure 12. m_{z0} for different Mach number, SB profile

6. INFLUENCE OF TAIL SECTION DEFLECTION

In this section, computational results for the KS and SB profiles with the tail section deflected with different angles upward. $C_L(\alpha)$, $C_L(C_D)$, and $C_L(m_z)$ for KS profile are shown for the case of M=0.3, M=0.6 and M=0.8 in figures 13-15. Pitching moment coefficient for zero lift m_{z0} is presented in figure 16. For comparison, results for the case of trim tab deflected on δ=8° are plotted.

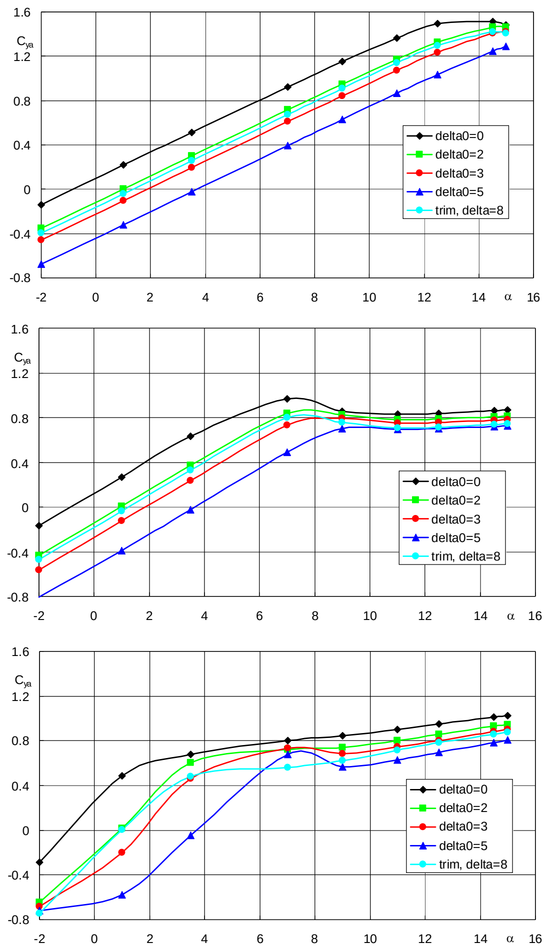

Figure 13. $C_L(\alpha)$;M=0.3 – first line, M=0.6 – second line and M=0.8 – third line

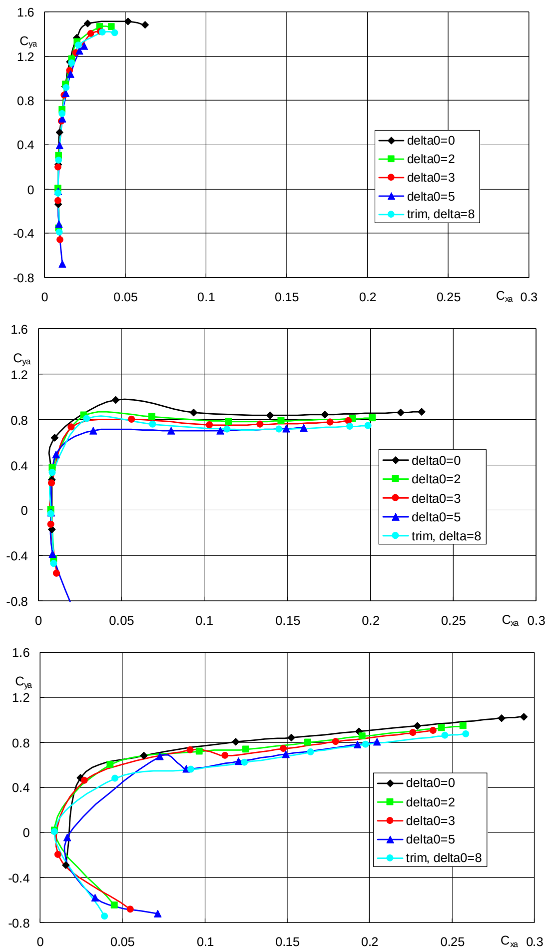

Figure 14. $C_L(C_D)$;M=0.3 – first line, M=0.6 – second line and M=0.8 – third line

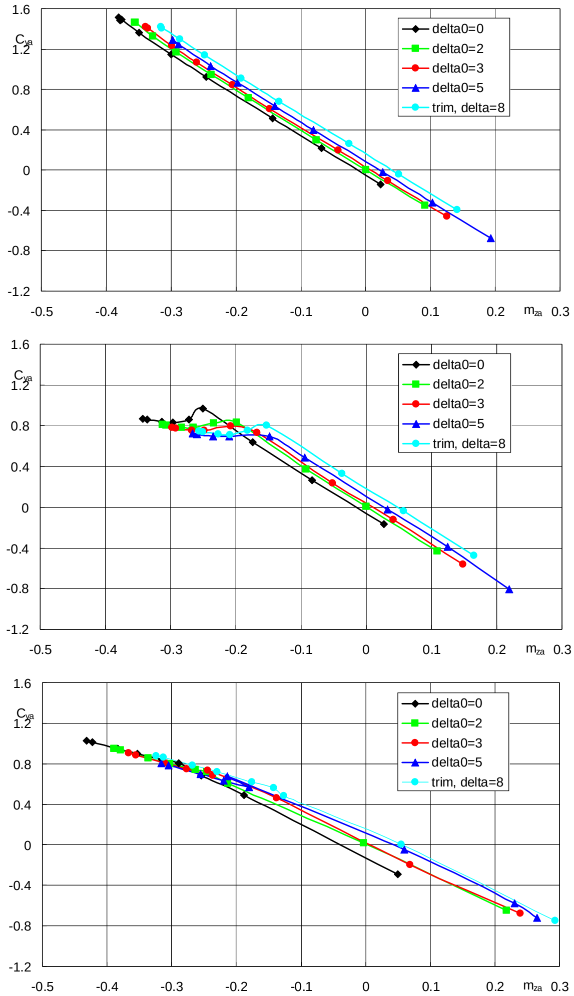

Figure 15. $C_L(m_z)$;M=0.3 – first line, M=0.6 – second line and M=0.8 – third line

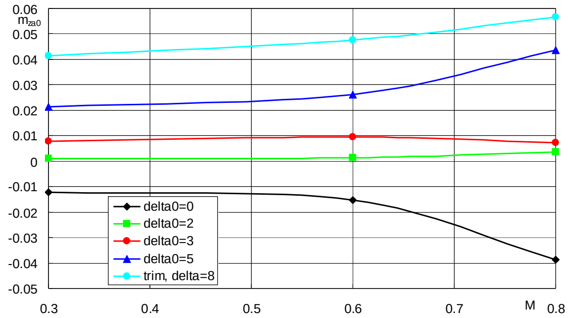

Figure 16. m_{z0} for different Mach number, KS profile

For the same angle of attack C_L reduces as deflection angle of tail section increases. Drag polar with increasing the deflection angle δ_0 is deteriorated. Values of m_{z0} are positive for the cases of δ_0=2°,3° and 5°. Deflection of tail section on δ_0=5° gives smaller moments than deflection of the trim tab on δ=8°.

Dependences $C_L(\alpha)$, $C_L(C_D)$, and $C_L(m_z)$ for SB profile were calculated for the deflection angles δ_0=0°, 2°, 3° and 5°. The results are similar to those for the case of KS profile and are thus omitted. Pitching moment coefficient for zero lift m_{z0} is presented in figure 17. Value of m_{z0} is negative for the case of tail section deflection on δ_0=0°, 2°,3° and is about zero for the case of δ_0=5°.

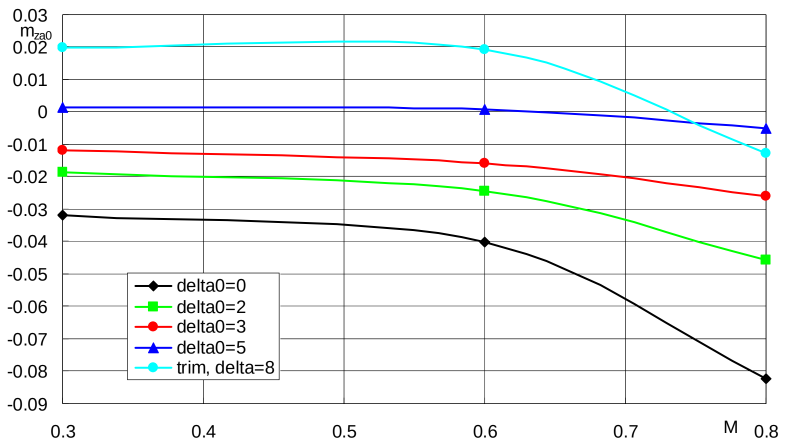

Figure 17. m_{z0} for different Mach number, SB profile

7. CONCLUSIONS

One of the concepts of the rotor blade profile development is to create profiles with the trailing edge plate (trim tab). In the present work, an investigation of the deflection effect of trim tab and rotor blade profile tail on the pitching moment and aerodynamic characteristics is carried out by means of computational fluid dynamics (CFD) methods. Numerical solutions for the flows over two profiles (in the framework of Reynolds averaged Navier-Stokes equations) are presented. The first rotor blade profile is mounted in the middle part of the rotor blade. The second profile is mounted in the end part of the rotor blade. Comparisons of the numerical solution and experimental data are also given.

For both profiles KS and SB C_L and C_{Lmax} decrease as the deflection angle of trim tab or tail section increases. Drag polar with increasing the deflection angle δ or δ_0 is deteriorated. Values of m_{z0} are positive for the cases of δ_0=2°,3° and 5°. Even deflection of tail section on δ_0=5° gives smaller pitching moments than deflection of the trim tab on δ=8° for both profiles.

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