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SIMULATION OF FLOW AROUND FUSELAGE OF HELICOPTER USING ACTUATOR DISC THEORY

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Abstract

This article examines the effect of a simplified model of the main rotor in the form of an actuator disc on the aerodynamic characteristics of the helicopter fuselage. The actuator disc is an infinitely thin disc creating a pressure jump to mimic the effect of the rotor. Calculations using the present actuator disc model account for the averaged effect of the rotor on the fuselage. This approach has a speed advantage in comparison to a detailed simulation with fully-resoled rotor blades. The obtained results show that at low flight speed the main rotor has a significant effect on the drag of the helicopter fuselage. For advance ratio over 0.2 the influence of rotor can be negligible.

1 Introduction

The study of the aerodynamic characteristics of the helicopter is a complex task highly relevant to the aerospace industry. Due to the complexity of modeling the complete helicopter configuration, studies are usually conducted in stages. For example, previous studies looked at the numerical simulation of the flow around an isolated fuselage approximating the "ANSAT" helicopter [1,2] along with added components [3] like landing gear, tail plane and engine exhausts. These CFD results were in good agreement with experimental data obtained in the T1-K wind tunnel of the Kazan National Research Technical University n.a. A.N. Tupolev.

The numerical simulation of aerodynamic characteristics of the fuselage with a 4-bladed main rotor is a much more difficult task for several reasons. To begin with, the flow is unsteady flow due to the complex movement of the rotors blades. Therefore, CFD computations require large grids and high performance computers.

1.1 Actuator disc model

In this paper a simplified approach is consider based on actuator-disc models instead representing the main rotor. The actuator-disc is an infinitely thin disc, which supports a pressure difference between the upper and lower surfaces. The pressure difference corresponds to the rotor thrust. The actuator disc model can simulate the effects like downwash and tip vortices on the helicopter fuselage (Fig. 1).

The pressure distribution on the disc can be determined by various methods. The simplest pressure distribution is uniform. In this case the pressure jump is determined by the momentum theory (1). The additional pressure ΔP corresponds to the rotor thrust T distributed over the rotor disc area A.

$$\Delta P = \frac{T}{A} \qquad (1)$$

Another approach is to mimic a typical load on each blade using experimental data. Such a distribution is shown in figure 2.

This typical distribution is often used in engineering techniques like the vortex models of Shaydakov [4]. In his paper the pressure jump distribution on the actuator disc is given by equation (2).

$$\Delta P = \rho\gamma[\frac{\gamma sign(\delta)}{2} + V_\infty \cos(\alpha - \alpha_a + \delta)] \quad (2)$$

As we can see from this equation, the pressure jump depends on the radius and on the azimuthal position of the blade. The resulting pressure distribution is shown in figure 3.

2 Computational method

2.1 HMB solver

The actuator disc models discussed in the previous paragraphs, are implemented in the computational fluid dynamics (CFD) tool HMB. HMB (Helicopter Multi-block) is in-house tool developed at the University of Liverpool. The actuator disc models are combined with the Reynolds-averaged Navier-Stokes equations with the k-ω turbulence model. Computations are performed in steady-state mode.

2.2 Computational grid

Multi-block structured hexa-grids are used in this work. The rids were generated using the ICEM-hexa CFD tool. Multi-block grids are chosen because they allow for good control of the mesh quality. Near the fuselage, an O-type topology is used that allows for a high quality boundary layer grid. To provide the condition y+<1 the size of first cells near fuselage surface was chosen about $1 \cdot 10^{-5}$ relatively the reference (fuselage) length. On top of the fuselage, an additional layer of blocks was used to host the actuator disc and blocks were associated with accessory geometry. It is necessary for accurate determination of disc actuator position and provide the condition “absolute thin disc”. The multi-block topology is presented in figure 4. Total number of blocks is equal to 964 and total number of cells is 13.7 million.

2.3 Results and discussing

The calculations were performed using a parallel computer cluster of the Beowulf type. On 48 CPU cores, a typical calculation takes 48 hours of clock time. Calculations were performed with both uniform and non-uniform actuator discs, at various flight speeds. The most interesting effect is on the fuselage drag. This effect depends strongly on the flight speed as shown in figure 5.

As can be seen from the figure 5, the downwash of the main rotor on the characteristics of the fuselage has a significant effect at low speeds. One of the reasons for the significant increase in fuselage drag at low speeds is the appearance of a larger area of flow separation on the rear fuselage. This region can be visualized using streamlines near the surface of the fuselage (Fig.6). From figure 5 it follows that drag coefficient for fuselage with non-uniform disc load distribution is less than the drag coefficient for uniform load distribution. One of possible reason of this effect is presence of low pressure area on the surface of left forward part of the fuselage (“blue spot” on figure 7).

Thus, the estimates of the effect of the main rotor on the fuselage drag depend on the flight speed. However, the present approach to modeling of main rotor is simplified, and this approach does not reproduce effect of variable unsteady flow due rotation of rotor. To comparison with real condition of modeling the fuselage with a 4-bladed main rotor was also calculated. Figure 8 shows the surface pressure distribution on the helicopter. The figure shows that the distribution is asymmetric. The dependence of the aerodynamic characteristics of the time is quite substantial. The oscillation amplitude of the main rotor thrust is about 2.25%, and the amplitude of oscillation of the fuselage drag is about 13%. However, the averaged value of the drag is close to the result obtained by the simplified model. The difference between these approaches is about 3.6% which is significant in engineering terms for real helicopter cases.

3 Conclusions and future work

For quick approximate analysis of the fuselage drag, the employed actuator disc model provided insightful results in the effect of my and CT. When compared with a fully resolved rotor, the employed model showed relatively large differences in the overall drag (about 3.6%) which is significant. In the future, further unsteady versions of the actuator disc will be employed and evaluated using the present setup as a starting point.

Acknowledgements

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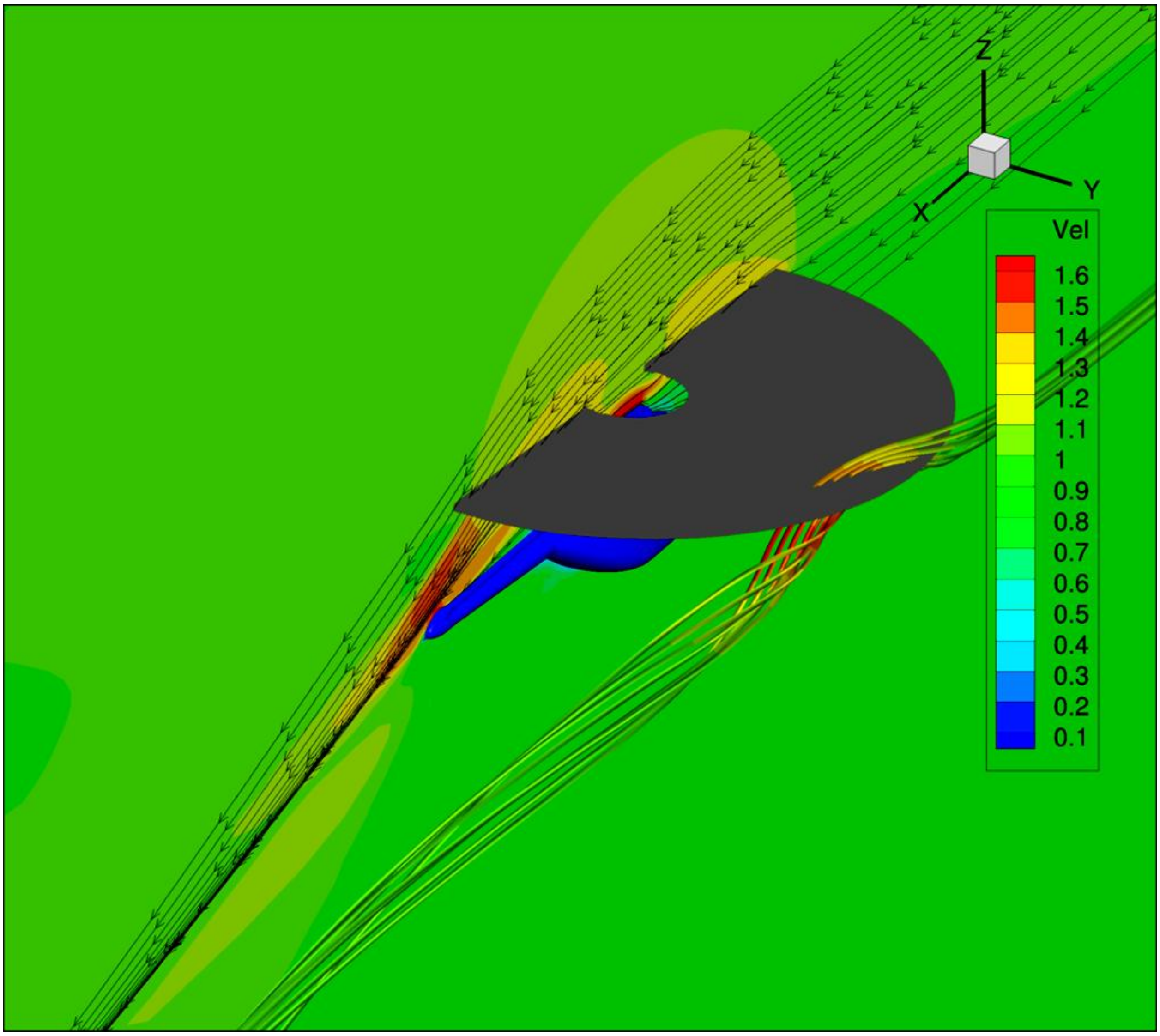

Fig. 1. Reproducible phenomenon: downwash and tip vortices

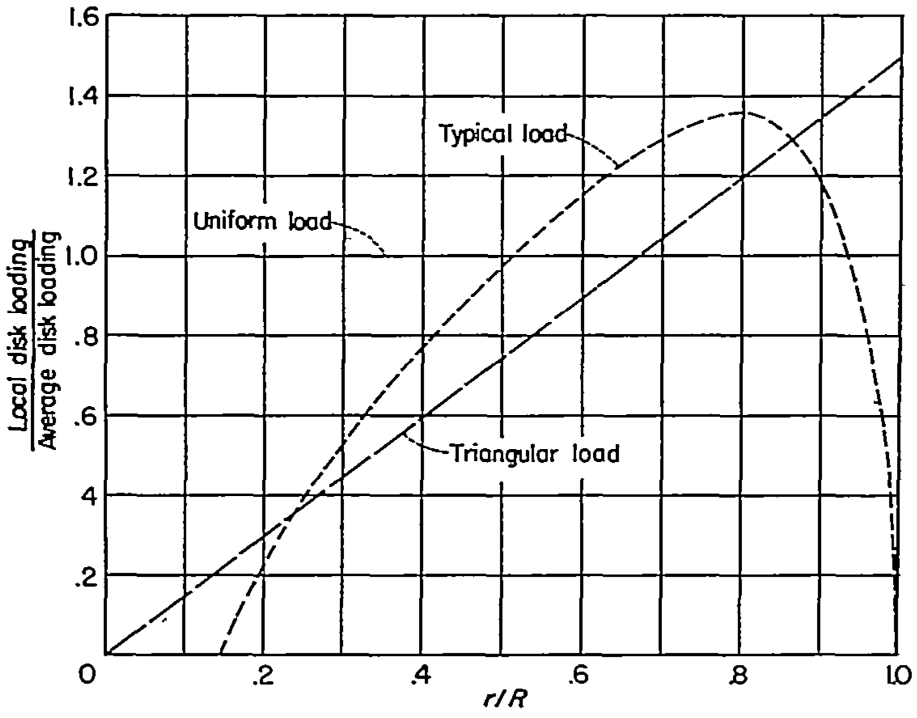

Fig. 2. Typical load distribution on the blade (NACA TR 1319)

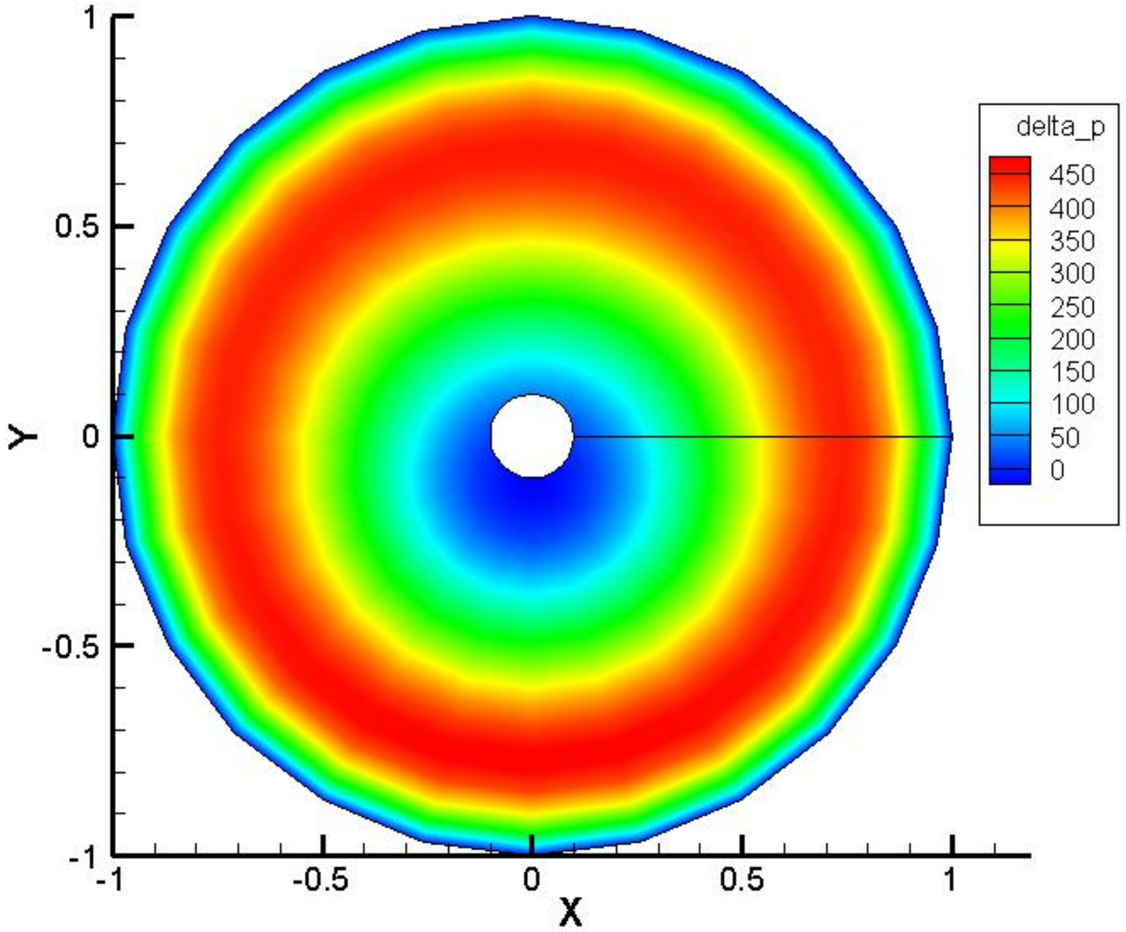

Fig. 3. Nonuniform distribution of the additional pressure (Pa) on the actuator disc

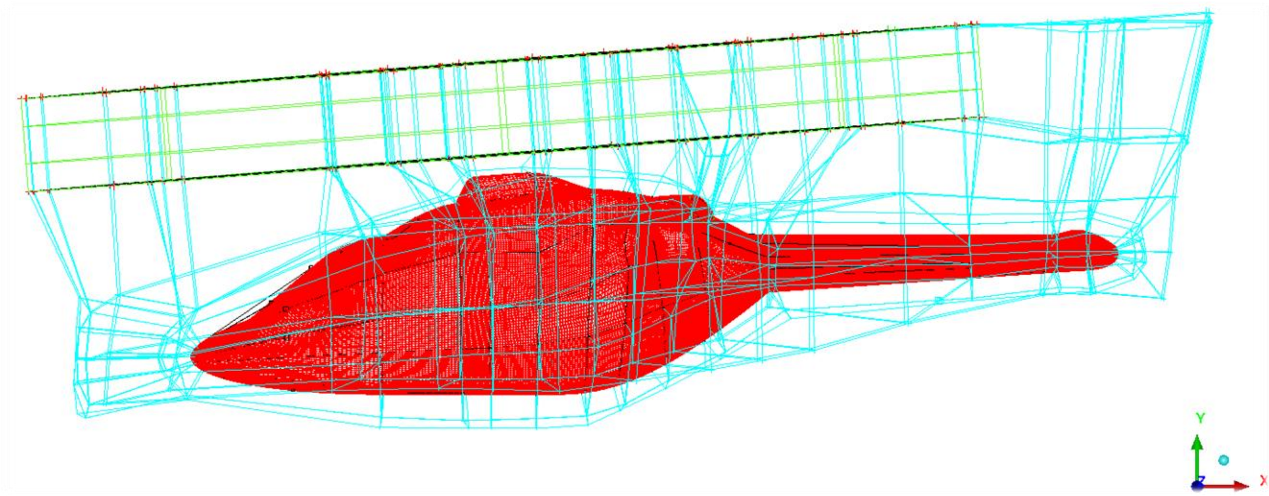

Fig.4. Bloking near the fuselage

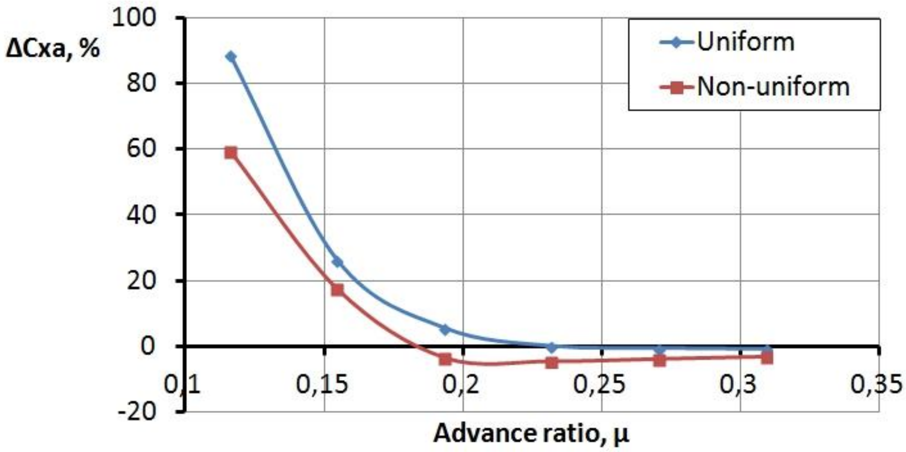

Fig. 5. The drag change depending on the flight speed

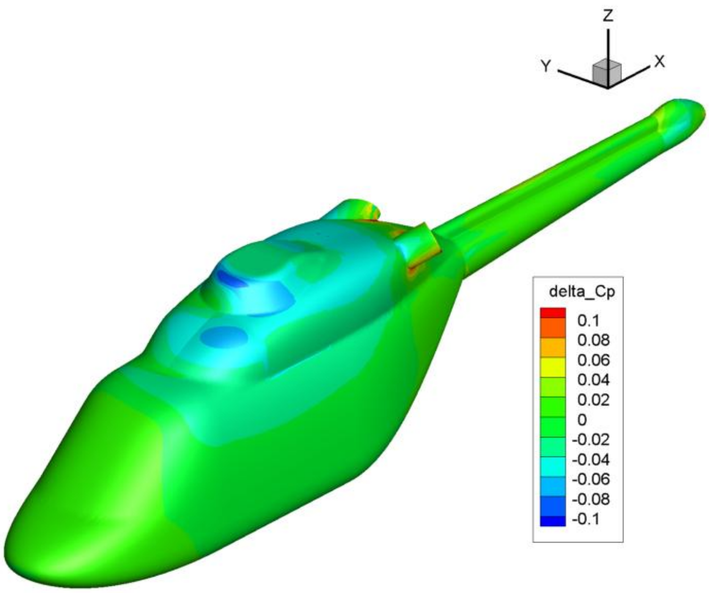

Fig. 6. Difference of pressure coefficient for uniform and non-uniform disc actuator load distribution

a) b) c)

Fig.7. Streamlines near surface fuselage:
a) without disc actuator; b) with disc actuator; c) with 4-bladed rotor (averaged per revolution)

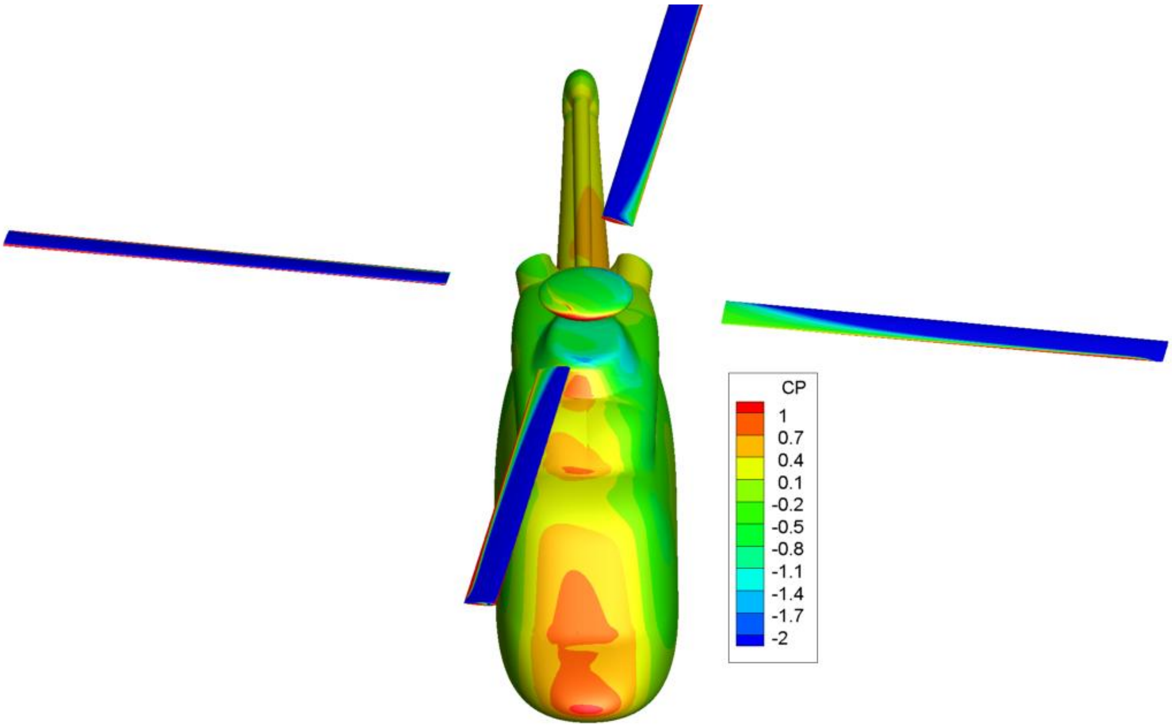

Fig.8. Pressure distribution on the helicopter: collective pitch θ=8˚; cycle pitch θ_C=2˚, θ_S=-2˚; advance ratio μ=0.15; freestream Mach number M=0.1