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Research Article

ANALYSIS OF THE INFLUENCE OF HELICOPTER DESCENT VELOCITY CHANGES ON THE PHENOMENON OF VORTEX RING STATE

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ABSTRACT
The paper presents the results of a numerical aerodynamic analysis whose purpose was to determine the influence of the rate of descent on the vortex ring state (VRS). This phenomenon occurs for an appropriate combination of induced velocity and the velocity of the incoming airstream from the bottom. The rates of change of velocities delimit dangerous areas of flight. The simulations were performed using FLUENT software and the geometry of helicopter W-3 „Sokół".

Keywords: helicopter, Vortex Ring State (VRS), vertical descent, numerical analysis, CFD.

INTRODUCTION

In order to increase aircrafts exploitation safety, certain limitations are introduced in both the instruction manuals for flight and in the legal provisions for air traffic, which define safe area of operations. According to the flight manual, the aircrafts must be used in accordance with the operational limitations it stipulates. For helicopters, one of the limitations concerns the manoeuvre of vertical descend. The information is given, among others, in a form of limits of vortex ring state (VRS). Theoretical range of this phenomenon is related to the value of component velocities. The aim of the present paper is to evaluated if the development of cortex ring state phenomenon is influenced by not only speed but also the speed of its changes. The analysis was conducted with the use of numerical calculations with a method of computer fluid dynamics (CFD). The results obtained during the attempt to evaluate the influence of velocity of vertical descend are presented below.

LIMITATION OF HELICOPTER DURING DESCENT

In case of helicopters, doing the manoeuvre of descent, both vertical and with advancing velocity forward or sideways, is related with the necessity to control helicopter velocity. During this manoeuvre there is a threat of vortex ring state (VRS), settling with power [4].

As the name implies, vortex ring state is characterised by the development of toroidal eddies in the area of helicopter rotor. They are the result of balancing the streams of air induced by the rotor and the upward stream of air (as it is during descent). As a result of the interaction between these two streams the induced flow that is responsible generating thrust decelerates. This causes abrupt decrease of thrust, what accelerates the velocity of helicopter decent [1, 2].

The area of hazardous flight conditions, which may generate circulatory movement of air around helicopter rotor is the areas defined by velocity components: vertical velocity w, horizontal velocity v, and side velocity u. Figure 1 presents a three-dimensional graph of theoretical presence of VRS (gray field), which can be described by the following relations:

$$w = (0{,}5 \div 1{,}5)v_{io},\ v = (-1 \div 1)v_{io},\ u = (-1 \div 1)v_{io},$$

where: v_{io} – velocity induced in hover.

The helicopter in this hazardous range of velocity acquires "unpleasant" pilotage properties (worsened steerability and helicopter balance),

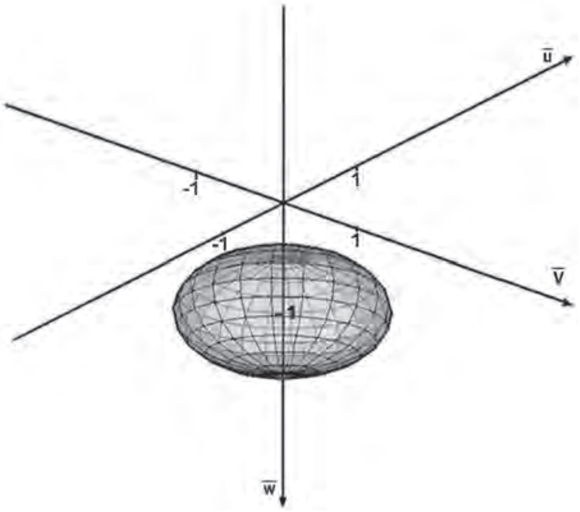


Fig. 1. Three-dimensional theoretical area of VRS

increased level of vibrations and increased consumption of power are observed.

The information about safe and dangerous decent conditions are discussed in helicopter flight manual in the chapter entitled Vortex Ring. Below there is an fragment example of helicopter flight manual (Fig. 2). It contains the guidelines for descent velocity and translational velocity, whose exceeding may result in VRS. The text also provides information necessary to avoid the situation.

THE ASSUMPTIONS OF CALCULATION MODEL

The evaluation of the influence of descent velocity on the phenomenon of vortex ring state was conducted by making a simulation of helicopter descent at different rates of velocity changes. Numerical calculations were made with commercial software FLUENT [3]. Numerical analysis of generating and development of rotor eddies was conducted with the geometry and parameters of helicopter W-3 Sokół (presented in Fig. 3) (helicopter mass m = 6400 kg, rotor radius R = 7.85 m, induced velocity at hover $v_{io} \approx$ 14.56 m/s).

For the purpose of calculations, non-structural calculation grid was prepared in ICEM CFD software which is part of ANSYS bundle. Figure 4 presents the structure of calculation grid around the helicopter.

The calculation domain has a form of a cube sized 50×50×50 m. The following boundary conditions were assumed:

- pressure outlet – external surfaces of calculation grid,
- wall – helicopter body (together with undercarriage and stabilisers).
- fan – helicopter rotor (the rotor was modelled as a constant, even pressure raise at the whole disc equal to Δp ≈ 300 Pa).

The phenomenon is most likely to occur when all the conditions listed below are present:

1. in powered flight;
2. high rate of descent, in excess of 500 feet per minute; and
3. low airspeed, less than 20 MPH indicated.

Almost every transition from forward flight to a hover utilizes a powered approach, a rate of descent and a reduced airspeed. To prevent the occurrence of vortex ring, control your rate of descent less than 300 feet per minute.

Fig. 2. The part of helicopter flight training manual about VRS [6]

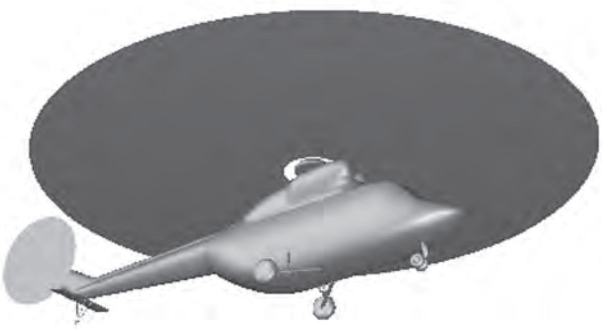


Fig. 3. A computational geometry model

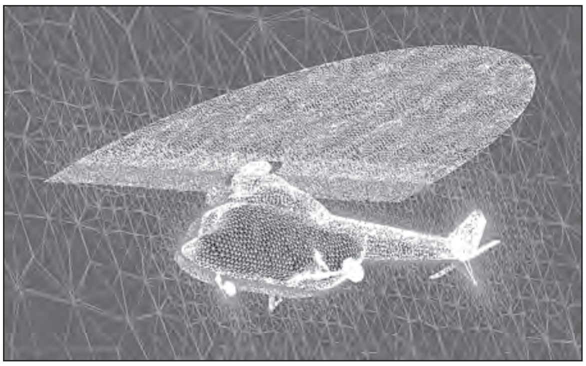


Fig. 4. Structure of the computational grid around a helicopter

Three-dimensional non-stationary helicopter manoeuvre simulations were made with the use of Spalarta-Allmarasa model for the turbulent viscosity, under the assumption of pressing flow. Helicopter kinematics was realised with a user's module written in C language, i.e. User Defined Function (UDF) tool.

The aim of the present paper was to make the simulation of the manoeuvre when helicopter exceeds theoretical conditions of vortex ring state. Three calculation cases were considered. All of them covered vertical flight of a helicopter at the speed of descending under 20 m/s. Different rates of velocity changes were used in the simulations.

The first and the second of the represented examples was a manoeuvre starting at hover position, then the speed of descending was increased up to 20 m/s, then it was limited down to 0 m/s.

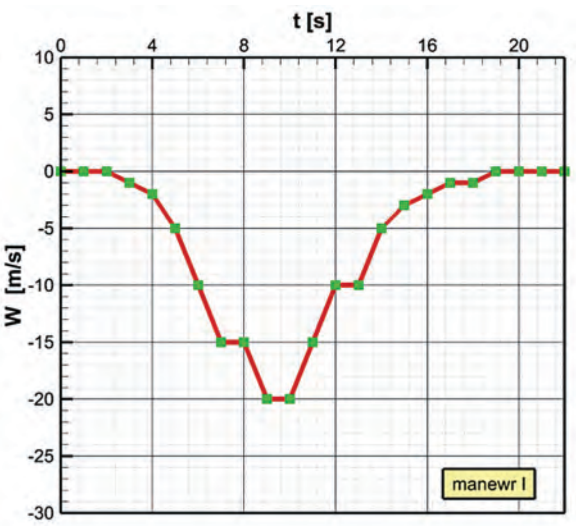


Fig. 5. A velocity versus time graph for maneuver I

The characteristics of velocities in the function of time were presented below (Fig. 5, Fig. 6). The former lasted 22 s, the latter was 25 s.

The third case started with descending speed of 15 m/h, i.e. close to the speed induced in hover. Thus, the manoeuvre started when the vortex ring was developed. Another stage of this manoeuvre was a gradual limitation of velocity, down to 0 m/s. Flight characteristics in this case was presented in the graph (Figure 7) as a lighter field (starting from 9th second, in the presented graph).

RESULTS OF CALCULATIONS

The results of aerodynamic analysis of the vortex ring state are going to be presented in a form of visualisation of the flow field around the helicopter with a velocity streamline. The model used in the present calculations to model a rotor (FAN model) is a simplified tool and does not provides detailed data on the work of fan. It is based on stream theory [5], which assumed homogenous distribution of thrust in the whole rotor disc. In this particular case, the model provides significant information about on the influence of two opposite streams. One advantage of this method of modelling is lack of necessity to build a detailed geometry of rotor, what reduces the time of discretisation and calculations (in comparison to other available methods).

The time of the first simulated manoeuvre was 22 s starting from hover, when relatively smooth flow around the helicopter was observed. Figure 8 presents a helicopter flow in this state, which a starting point for two analysed manoeuvres. The

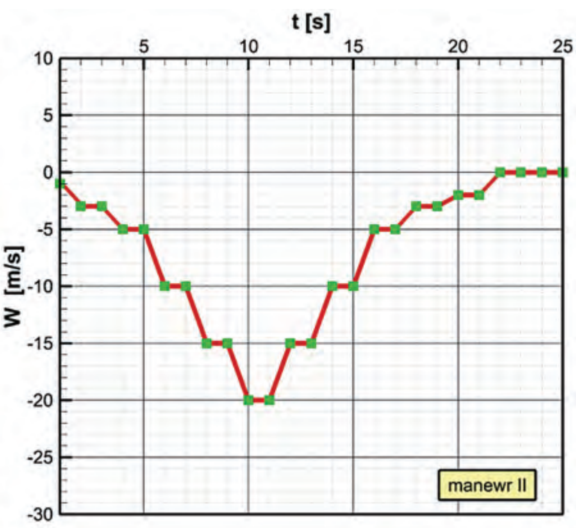


Fig. 6. A velocity versus time graph for maneuver II

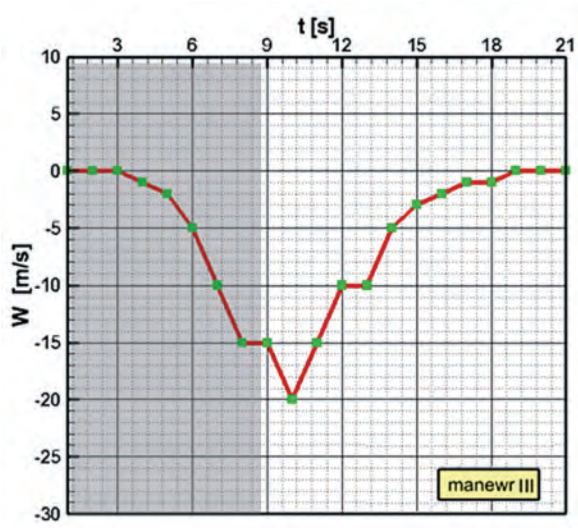


Fig. 7. A velocity versus time graph for maneuver III

Table 1. A visualization of the 1st maneuver

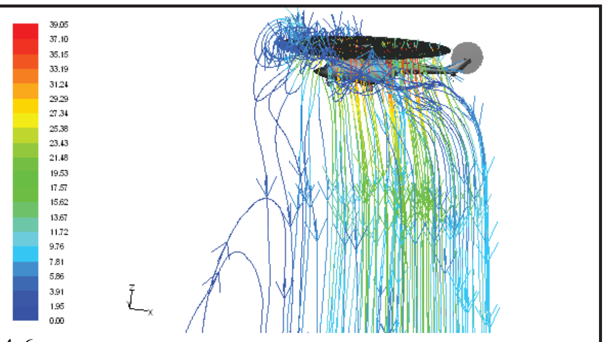
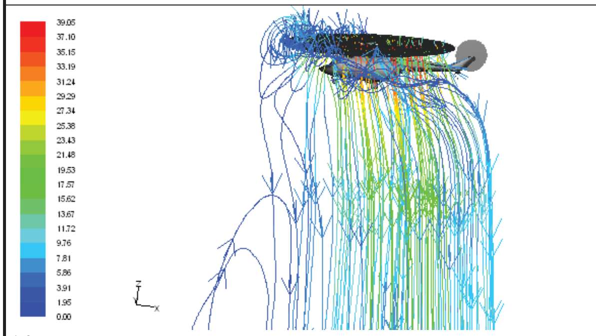
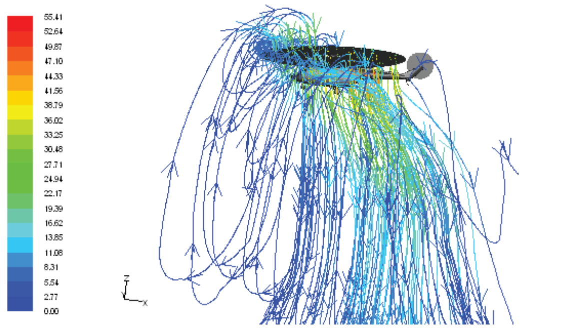
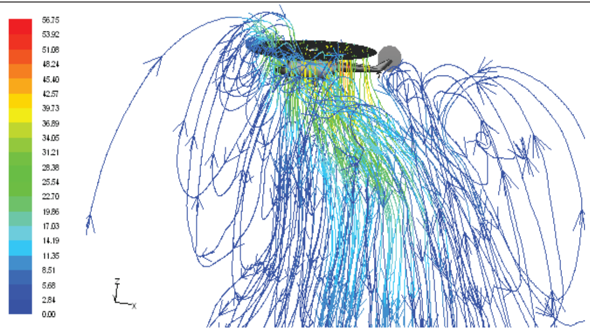
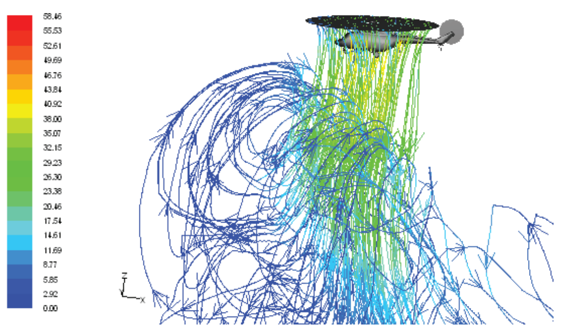
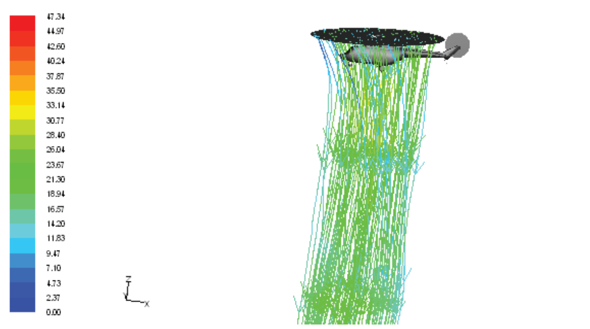
 2s	 4.6s
 10s	 12s
 13s	 14s
 15s	 16s
 18s	 22s

Table 2. A visualization of the 2nd maneuver

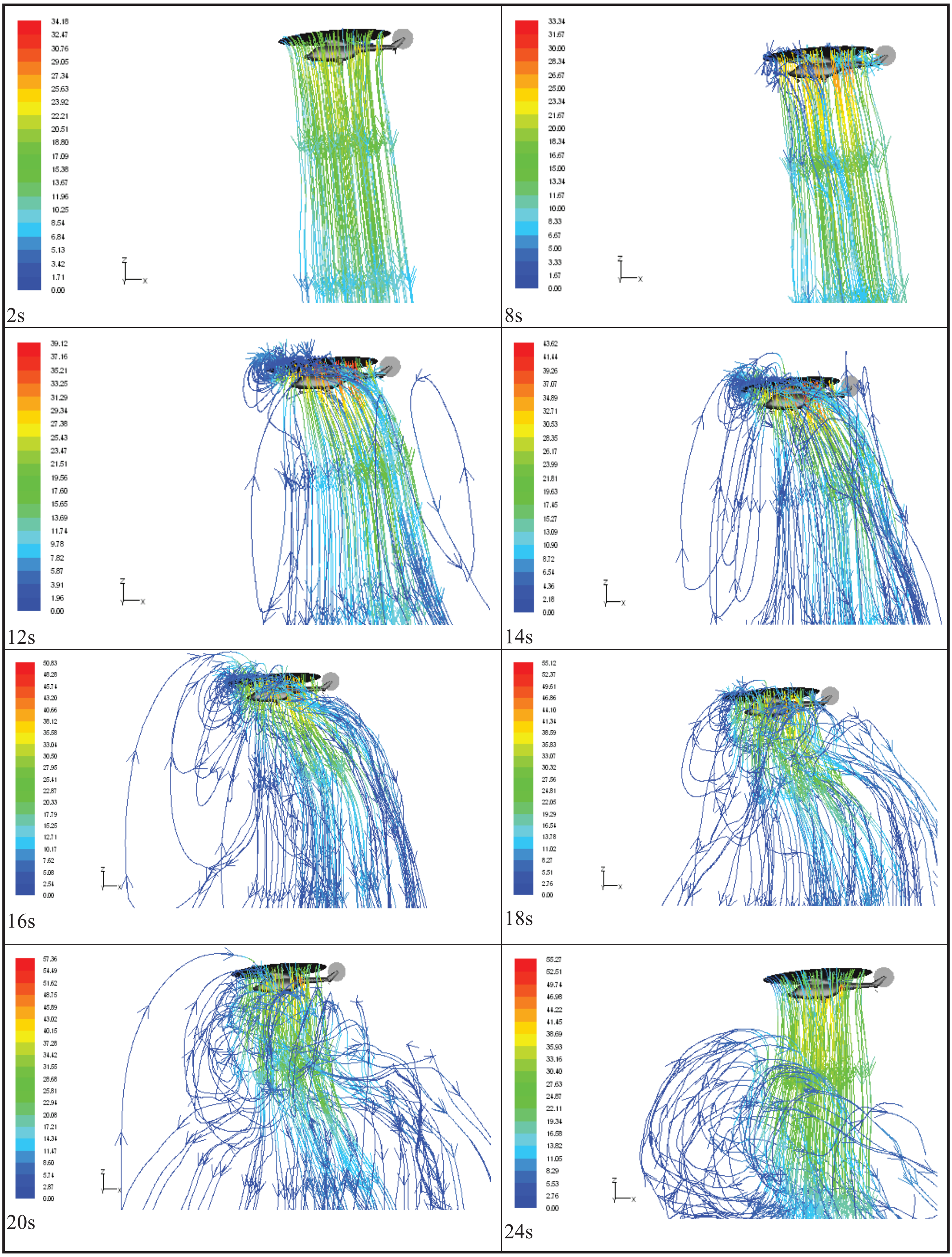
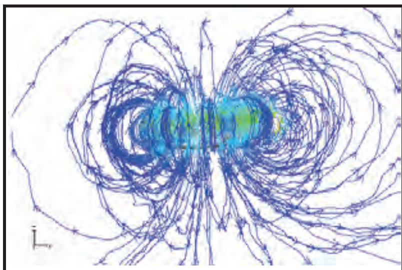
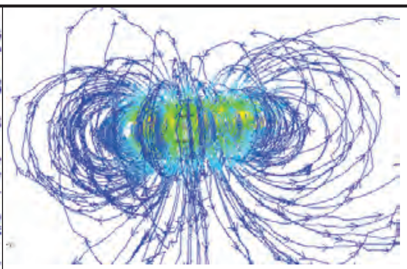
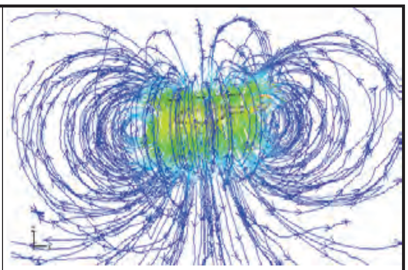
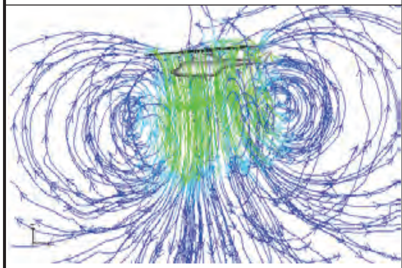
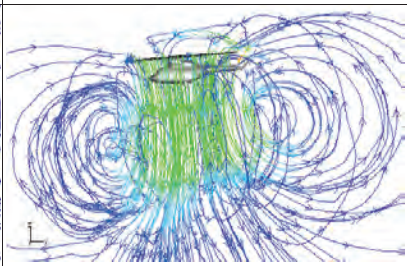
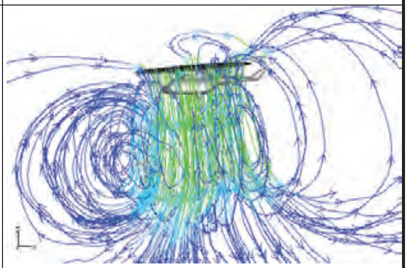
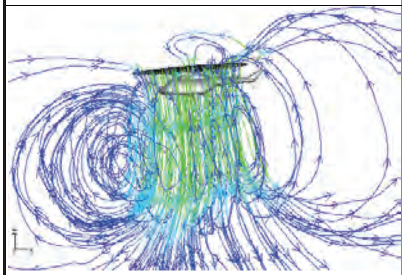
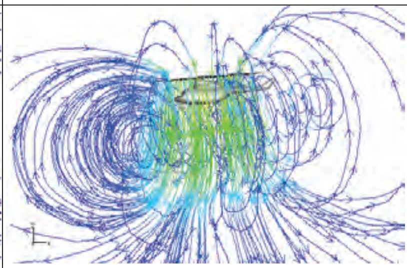
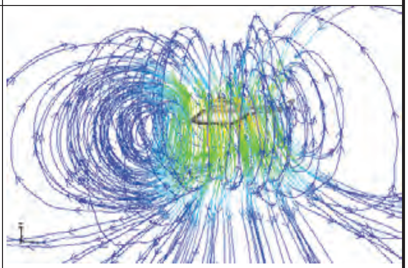
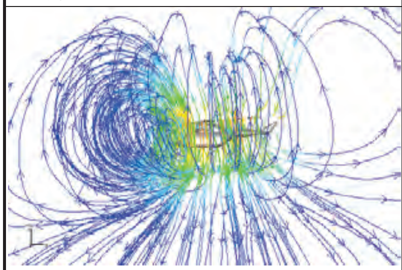
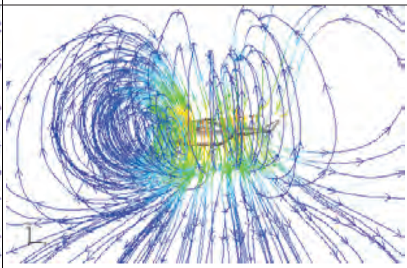
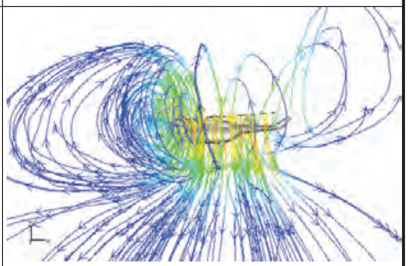
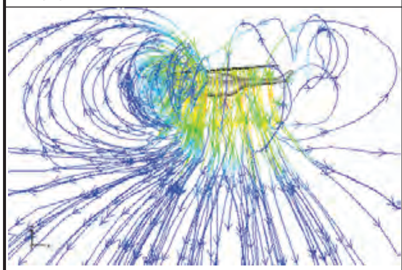
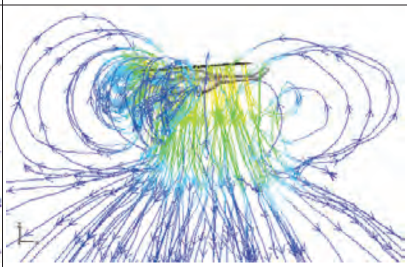
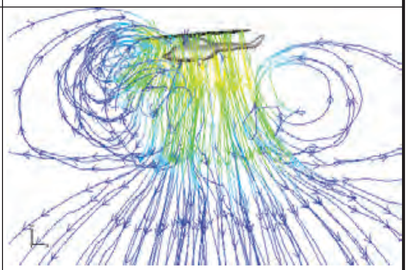
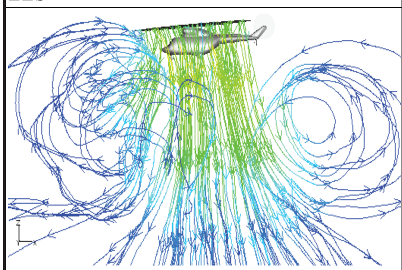
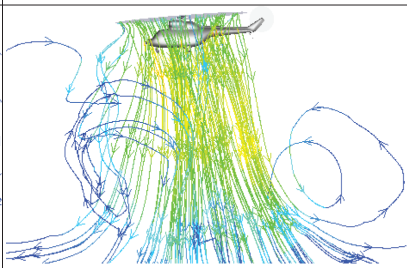


Table 3. A visualization of the 3[rd] maneuver

 10s	 11s	 12s
 13s	 14s	 15s
 16s	 17s	 18s
 19s	 20s	 21s
 22s	 23s	 24s
 25s	 26s	

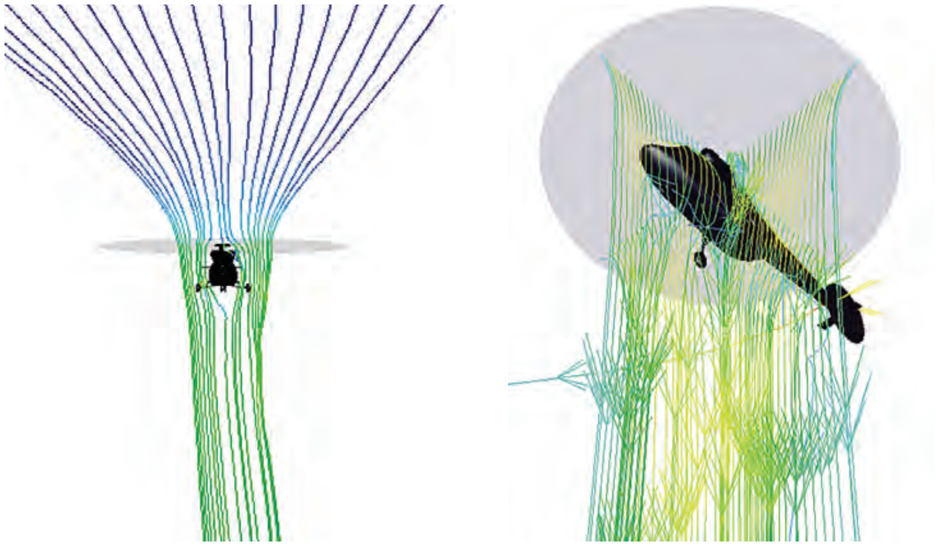


Fig. 8. A visualization of flow field around a helicopter in hover

former was the case of fast descent, when a fully developed vortex ring state took place, what is proved in the visualisations of flows around the helicopter presented in Table 1. The images of flow around helicopter for manoeuvre 2 and 3 were presented in Table 2 and Table 3 respectively.

The images of flow obtained as a result of calculations provide valuable information on vortex ring state. The results of the first and second manoeuvre are quite similar. The identification of the phenomenon was not observed in these tests. The third manoeuvre started with fully developed form of the state, when the velocity of flow onto the rotor balances the induced velocity, what generates and develops eddies around the rotor. Despite decreasing the descent velocity (analogically to manoeuvre 1) the eddy structures remain in the vicinity of rotor for much longer than in other cases. This brings to the conclusion that the development of vortex ring state depends on time. The use of this knowledge in practice can improve helicopter flight quality.

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