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PERFORMANCE REQUIREMENTS AND SIMULATION OF ROTOR OPERATION FOR HIGH-MOUNTAIN RESCUE HELICOPTER

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Abstract

Simulation results concerning performance of helicopter suitable for high-mountain rescue operations are presented. Including operations in regions of the highest Himalaya Mountains, the possibility of hover ceiling out of ground effect (OGE) at 10,000 m above sea level is assumed. Demand of high ratio of developed lift to power required for hover leads to choice the coaxial rotor configuration as the best for rescue helicopter, which can operate in extremely high mountain environment, and gives good stability features in wind gust conditions in comparison with single main rotor helicopter. For performance calculations the simple model of helicopter is applied, which consists of fuselage point mass and rotor disk. The cases of partial and total power loss are considered to define range of H-V zones and possibilities of flight continuation due to height of landing surface over level of sea. The rotor blades and rotor loads are calculated applying detail model of elastic blade, which includes effects of its deflections due to out-of-plane bending, in plane bending, and torsion. The Runge-Kutta method is applied to solve equations of motion of rotor blades with taken into account effects of blade pitch control and variable deflections of blades. According to Galerkin method, the blade parameters of motion are treated as a combination of torsion and bending eigen modes of the rotor blades. Elastic blade model allows defining behaviour rotor blades in selected states of flight: hover, level flight, wind gust conditions, and pull-up manoeuvre. The results of simulation for upper and lower rotor for blade deflections and loads are shown in form of time-run plots and rotor disk distributions. The simulation investigation may be applied to define features of helicopter configuration suitable for operation in extremely high mountain conditions.

Keywords: *rescue helicopter, high-mountain operations, rotor blade deformation*

1. Introduction

The main feature of helicopters is an ability of hover as well vertical landing and take-off at small area. From early stage of rotorcraft, development in mid 1940s helicopters began to demonstrate possibilities of performing rescue operations. On January 3, 1944, the Sikorsky R-4 flew the first helicopter mercy mission transporting in snowstorm conditions the blood plasma to the survivors of an explosion aboard American destroyer USS Turner in New York harbour [12]. The first combat rescue took place in Burma in April 1944, when Lieutenant Carter Hartman controlling the Sikorsky R-4 helicopter managed to evacuate, from deep jungle in Japanese territory, three wounded British soldiers, and pilot of plane, which had been shot down by enemy fire [7]. Helicopters (S-51, S-55, Bell-47) found usage that is more common for rescue and medevac missions in the Korean conflict. The Swiss Air-Rescue (REGA) was among the first civil organizations, which started to carry out rescue missions using a helicopter Hiller 360 in 1952 [5]. In Poland, the first rescue in Tatra Mountains with a SM-1 helicopter took place in April 1963, where at height of 1,600 m pilot Tadeusz Augustyniak evacuated the skier with broken leg from Dolina Pięciu Stawów Polskich [2].

The first generation of helicopters was powered by piston engines, which influenced on limitation of flight ceiling. Introduction the turbine engines gave helicopters large amount of power with lower weight penalty in comparison to piston engines. In 1972 French test pilot Jean Boulet, on lighter version of SA-315 Lama helicopter with mass reduced from 1,000 kg to 790 kg, set record of flight altitude climbing to 12,442 m [3]. It should be noticed that during tests in Karakorum the Lama helicopter performed take-off and landings at 6,850 m. In May, 2005 other French pilot Didier Delsalle broke the unofficial record for highest helicopter landing and take-off touching undercarriage skids on the Everest summit (8,850 m) for nearly 4 minutes with kept whirling rotor of his AS350B3 helicopter with extremely reduced weight [6].

During the last decade, growing amount of trekking tourists and mountain climbers were observed in Nepal and Himalaya region, which was accompanied by quick development of local air transport and air rescue organizations (Fishtail Air, Simrik Air, Shree Airlines) [1]. The helicopter rescue activity in Nepal was personally supported by Simone Moro known Italian mountaineer, pilot, and owner of AS350 helicopter [8]. Nowadays the Airbus Helicopters H-125 (earlier name AS350B3) is consider as the best helicopter suitable for high-altitude mountain rescue missions. However, even for this rotorcraft, manufacturer limits its operational altitude to level of 7,000 m, which is too low for performing rescue actions in the highest parts of the Himalaya range. The highest-ever helicopter rescue took place in May 2013, when Maurizio Folini solo piloting AS350B, in good weather conditions, succeeded to lift an injured Nepali climber on a long-line from 7,800 m at route to Everest [4]. Flying helicopters in Himalaya region, pilots should consider the most challenging environments as thin air, freezing temperatures and hostile weather conditions. Early in the day, katabatic sinking winds appear which can pull helicopter downwards and late in afternoon anabatic upwinds can be met.

Analysing features of different helicopter configurations, it seems that the coaxial rotor system is the most suitable for high-altitude rescue missions. For two counter-rotating rotors, the torque effects are cancelled. The lack of a tail rotor saves as much as 20% engine power, which can be used to drive coaxial rotors. Another benefit of coaxial helicopter, compared to configuration with single main rotor and tail rotor, is better stability in hover due to contrary side reactions of rotors in case of wind gusts. Additionally, helicopter with coaxial rotors is more compact than other rotor systems generating the same lift, which is useful for operations in confined area. Assuming simultaneous transport of rescuers, medevac equipment, and more than one injured person a medium class of helicopter seems to be a proper choice. Presented in the article results refer to hypothetical helicopter of assumed coaxial rotors configurations with mass of about 6,000 kg. In Fig. 1 is shown a comparison of altitude reachable in helicopter flights and height of hover without ground effect for proposed coaxial rescue helicopter.

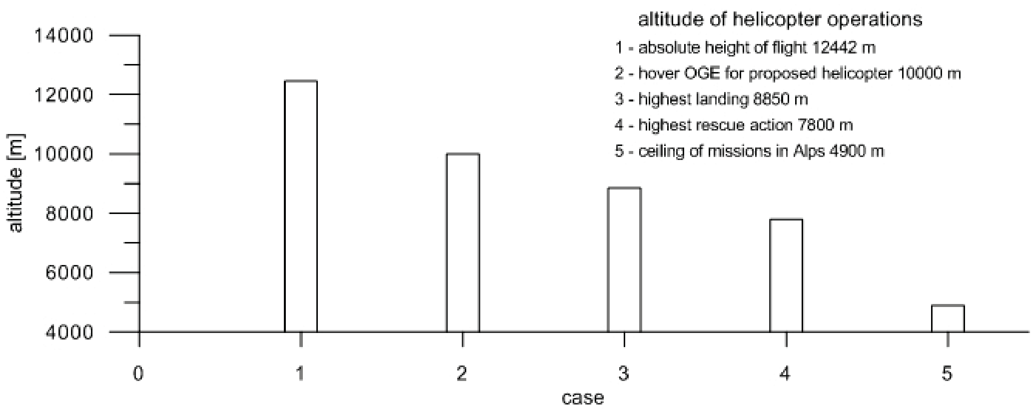

Fig. 1. Comparison of altitude of highest helicopter operations

2. Performance of helicopter

Basing on the size of the PZL Sokół helicopter used for rescue operations in Tatra Mountains, the cockpit volume of high-mountain rescue helicopter is proposed to be similar. To fulfil demand for helicopter hover in off-ground effect (OGE) conditions at altitude of Himalaya Mountains peaks the coaxial rotors configuration is selected. For calculations of power required for flight a simplified model of helicopter is applied, which includes rotors treated as a disk area with an average value of induced velocity and aerodynamic coefficients. The results of power required due to flight altitude for helicopter with coaxial six-bladed rotors of radius equal 7.75 m and blade tip speed of 180 m/s are shown in Fig. 2a. Taking into account influence of induced velocity of upper rotor on flow conditions of lower rotor blades the power required to drive coaxial rotor system in hover is calculated as the sum of power of two separated rotors multiplied by influence coefficient equals as k_{inf}=1.33. The value of influence coefficient k_{inf} is defined by comparison the sum of power required to drive system including upper rotor treated as isolated and lower rotor with flow influenced by induced velocity of upper rotor (with condition of the same power for lower and upper rotor) to the value of power required to drive two isolated rotors generating the same thrust (Tab. 1). Unit of two engines with shown in Fig. 2b characteristics of available power due to altitude would be suitable to drive coaxial rotors in hover at height of 10,000 m.

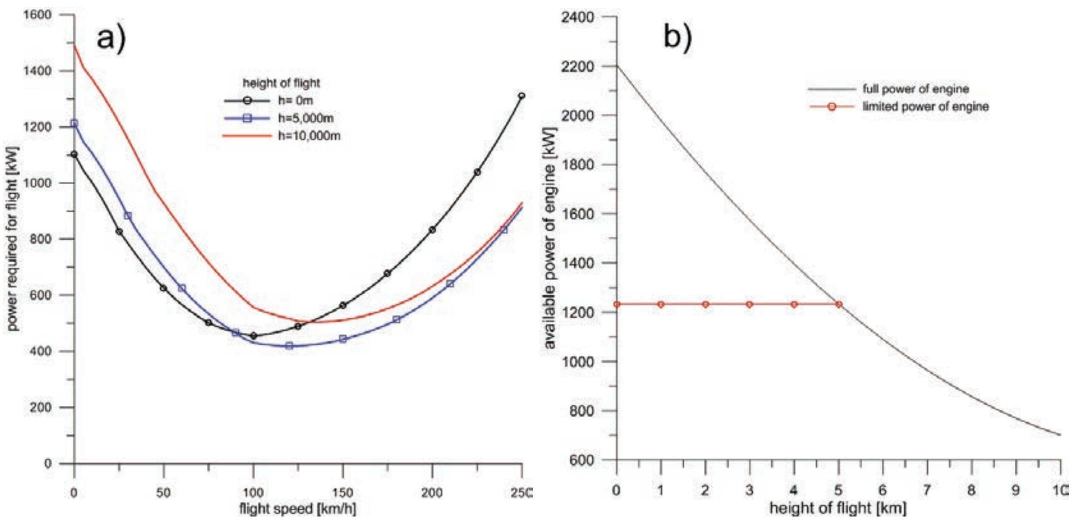

Fig. 2. Comparison of power due to height of flight
a) required for flight for coaxial helicopter, b) available power of one engine

Tab. 1. Thrust and power of two rotors system

	collective pitch [deg]	Rotor thrust [daN]	Rotor power [kW]
upper rotor	15.66	3629.4	624.77
lower rotor	17.95	2252.3	620.2
Sum for upper and lower rotors	-	T_{sum} = 5881.7	P_{sum} = 1244.97
two isolated rotors	13.3	T_{2_iso} = 5888.4	P_{2_iso} = 935.88
power influence coefficient $k_{inf}=P_{sum}/P_{2\_iso}$			k_{inf}= 1.33

The calculations of power required in hover indicate that lower blade tip speed allows generating the demanded rotor thrust at lower level of required power (Fig. 3ab). Some results concerning helicopter performance at high altitude in the case of one engine inoperative (OEI) are shown in Fig. 4. Results of applied method of simulation [11] point out that available power of the second engine enables continuation of level flight at altitude of 9,000 m in speed range 80÷180 km/h (Fig. 4a). If loss of power occurs in hover or in flight at low speed, the emergency manoeuvre for flight continuation will demand the height loss reaching about 70 m at altitude of 9,000 m (Fig. 4b). In the case of total power loss the safety range of H-V zone are define (Fig. 5a) for landing area located at altitude of 2.5 km and 5 km, where UHV, LHV, VHV are upper, lower and velocity branches of Height-Velocity zone diagram. The time-runs of parameters of the simulated emergency manoeuvre in the case of total power loss and landing area localization at altitude of 5 km are presented in Fig. 5b.

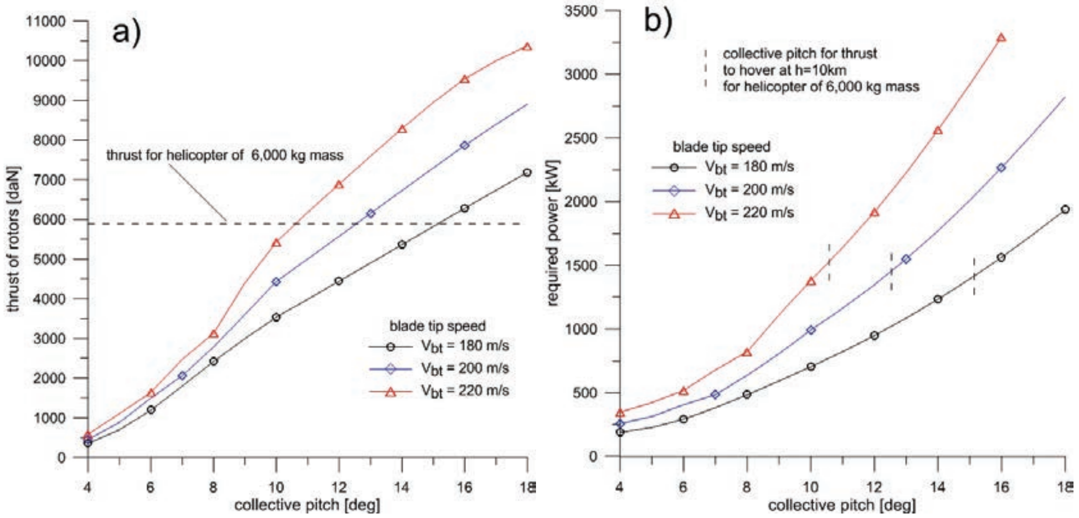

Fig. 3. Thrust of coaxial rotors (a) and power required to drive rotor (b) in hover at altitude of 10 km due to blade tip speed and collective pitch

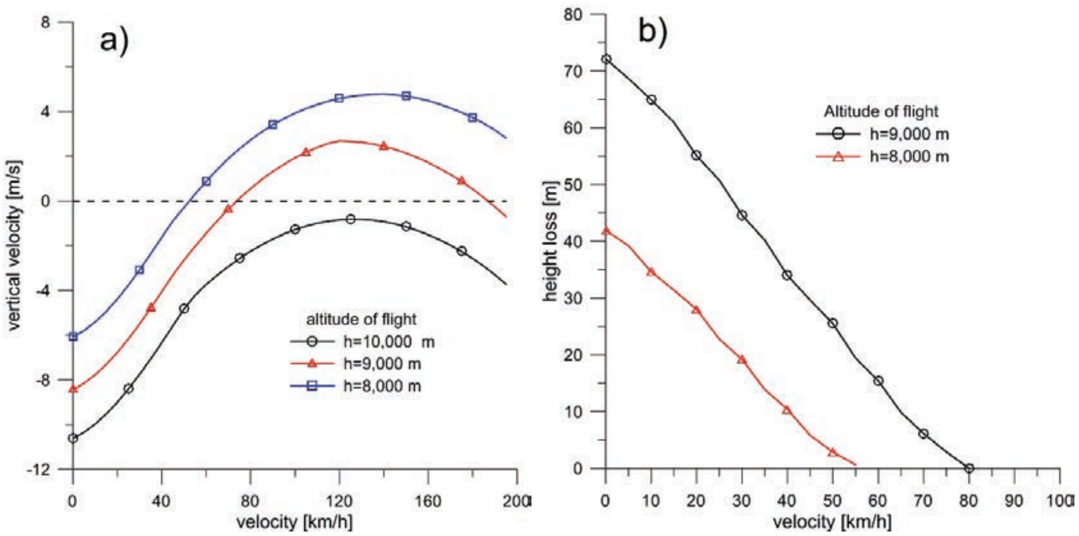

Fig. 4. Vertical velocity possible to achieve (a) and height loss in emergency manoeuvre for flight continuation (b) in the case of one engine failure (OEI) for coaxial rotor helicopter with mass of 6,000 kg

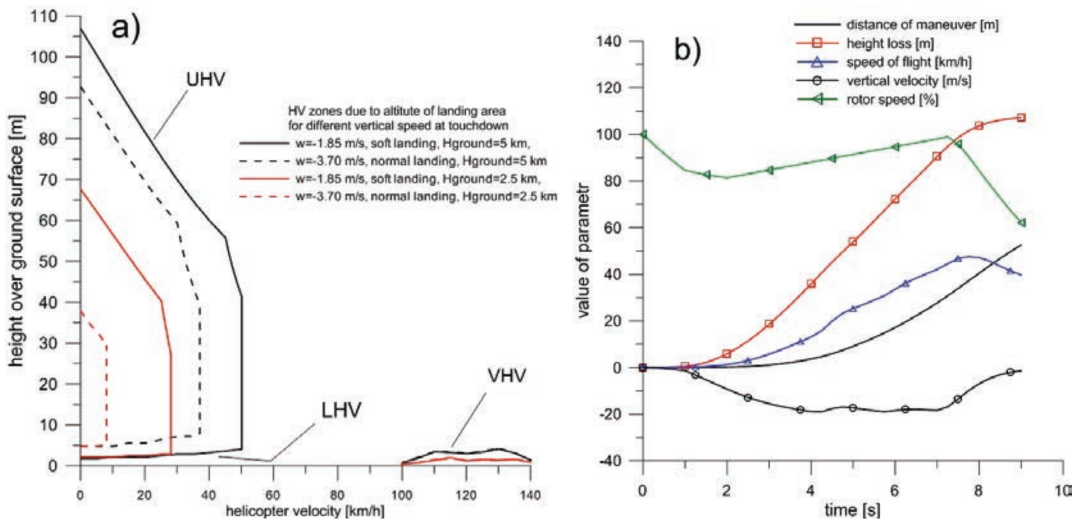

Fig. 5. a) HV zones for coaxial rotors helicopter with mass of 6,000 kg in the case of total power loss b) simulation of emergency manoeuvre after total power loss in hover over ground at altitude of 5 km

3. Rotor loads and blades deflections

The results of calculations of rotor loads and blades deflections are obtained using more detailed model of rotor blades, which includes data of their mass, stiffness, and aerodynamic characteristics. The Runge-Kutta method is applied to solve equations of motion of rotor blades, which include effects of blade's deflections treated, according to Galerkin method, as a combination of torsion and bending eigen modes of rotor blades. Further information concerning method of computing rotor loads with applied model of elastic blade can be found in [10]. To achieve high-lift feature of rotor blades, it is assumed application of the ILH family airfoils [9] designed in the Institute of Aviation. The proposed coaxial configuration consisted of two six-bladed rotors gives total thrust with significantly low level of variable components (Fig. 6ab) which cause vibration of helicopter construction.

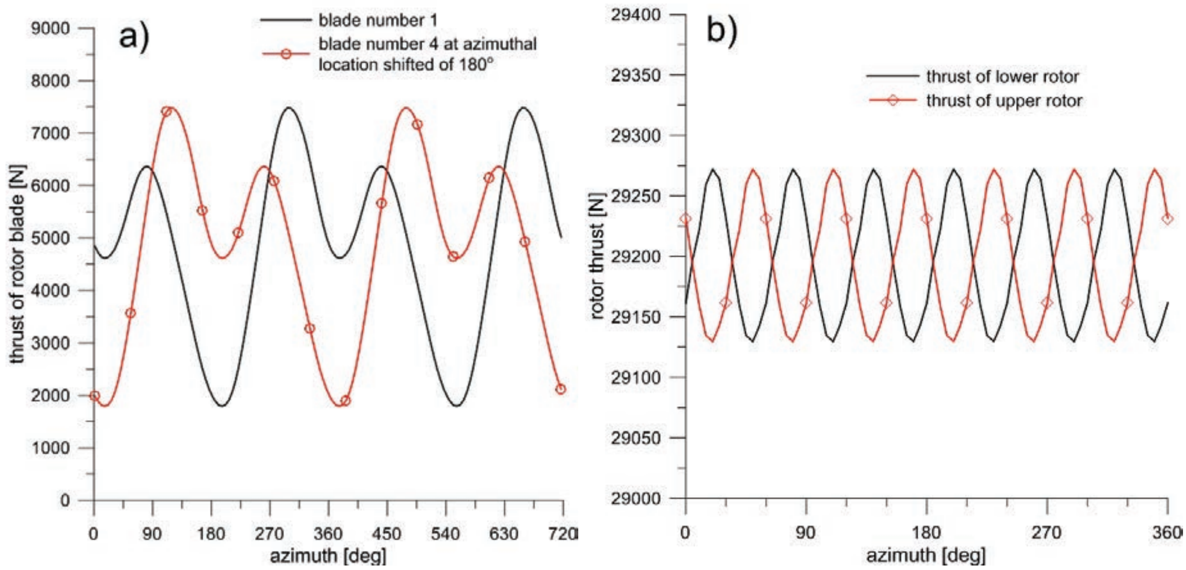

Fig. 6. a) Thrust of individual two blades at opposite location on rotor disk as function of time azimuth position b) thrust of lower and upper coaxial six-bladed rotors, level flight at speed of 200 km/h at altitude of 10,000 m

One of the important feature of the coaxial configuration is a vertical separation of upper and lower rotors, which should prevent collision of blades of counter-rotating rotors. In Fig. 7-10 are presented distributions of blade out-of-plane deflections at upper and lower rotor disks for different states of flight: in hover with side wind gust (Fig. 7), in level flight at speed of 200 km/h (Fig. 8), in flight of 200 km/h with swashplate deflected to right turn (Fig. 9), in pull-up manoeuvre for maximum thrust at speed of 100 km (Fig. 10). The blade azimuthal position of 90^o refers to advancing blade when speed of helicopter flight is added to speed of rotating blade and azimuthal position of 270^o refers to retreating blade when speed of flight and rotation are subtracted. For selected states of flight, differences of vertical locations of blade tips for upper and lower rotors comprise in the range of 1 m. For shown in Fig. 7 the case of hover the upper rotor was treated as isolated one but for lower rotor inflow was increased by induced velocity coming from upper rotor. In hover with fulfilled condition of directional balance with equal power of both rotors, the upper rotor generated greater thrust than lower rotor. In the case of left-side wind gust, the cones of blades for both rotors are tilted backward relative to direction of wind but in opposite direction for sideward tilt which helps pilot to react to gusts. In the cases of level, flight and pull up manoeuvre due to large inflow through rotor disks coming from component of flight speed calculation of blade deflections were performed for rotors treated as isolated. The largest out-of-plane deflection of blade can be noticed for pull up manoeuvre (Fig. 10). The lowest out-of-plane blade tip position occurs for flight in turn with deflected swashplate (Fig. 9).

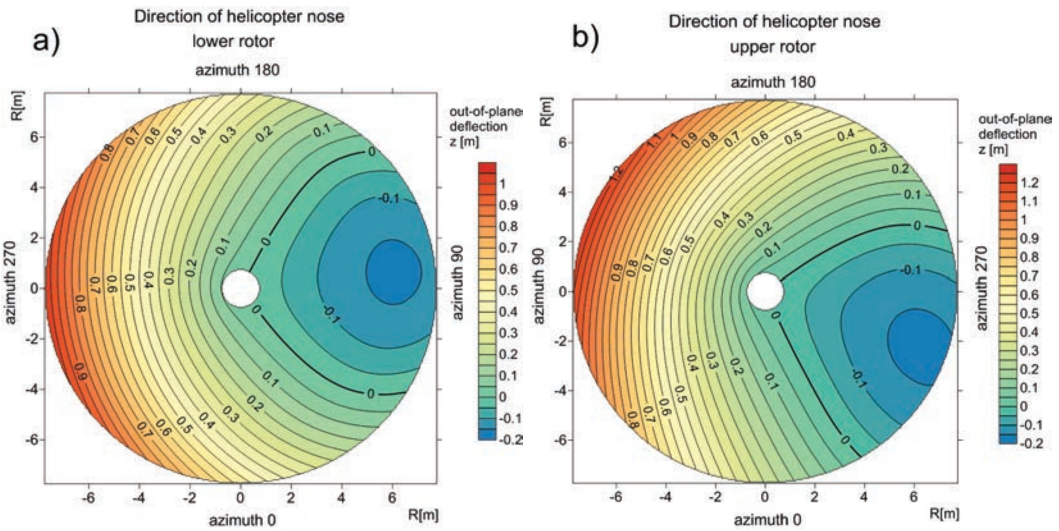

Fig. 7. Distribution of out-of-plane blade deflection at rotor disks in hover with wind gust of V_{gust}=20 m/s from the left side: a) for lower rotor at azimuth 270°, b) for upper rotor at azimuth 90°

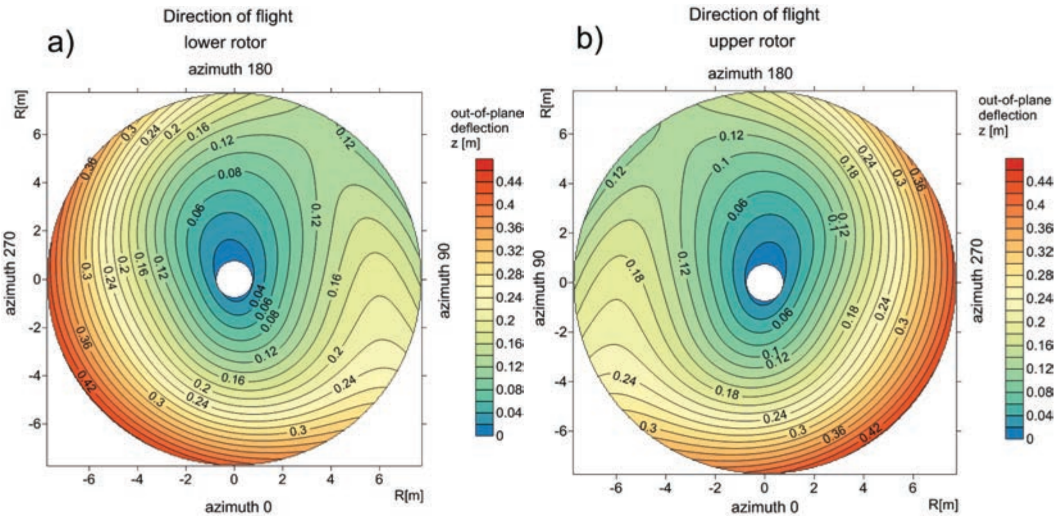

Fig. 8. Distribution of out-of-plane blade deflection at rotor disks in level flight at speed of V=200 km/h a) for lower rotor, b) for upper rotor

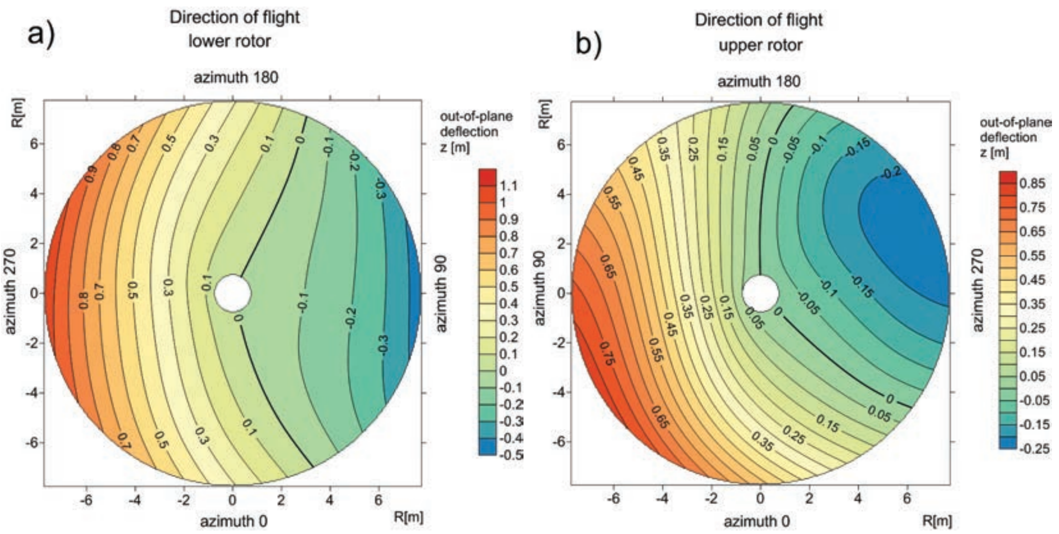

Fig. 9. Distribution of out-of-plane blade deflection at rotor disks with swashplate deflected for turn to the right in flight at speed of V=200 km/h: a) towards azimuth 90° for lower rotor, b) towards azimuth 270° for upper rotor

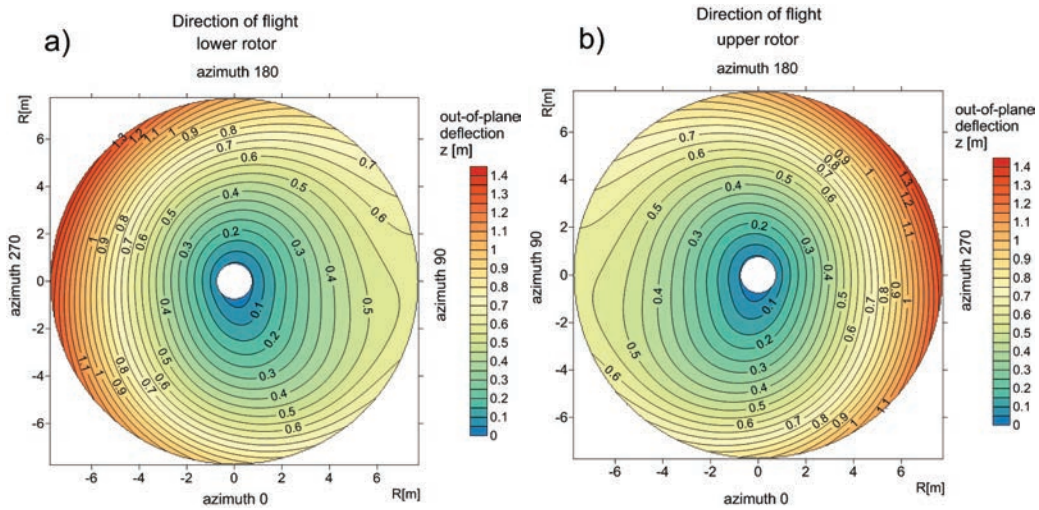

Fig. 10. Distribution of out-of-plane blade deflection at rotor disks in pull up manoeuvre at speed of V=100 km/h a) for lower rotor, b) for upper rotor

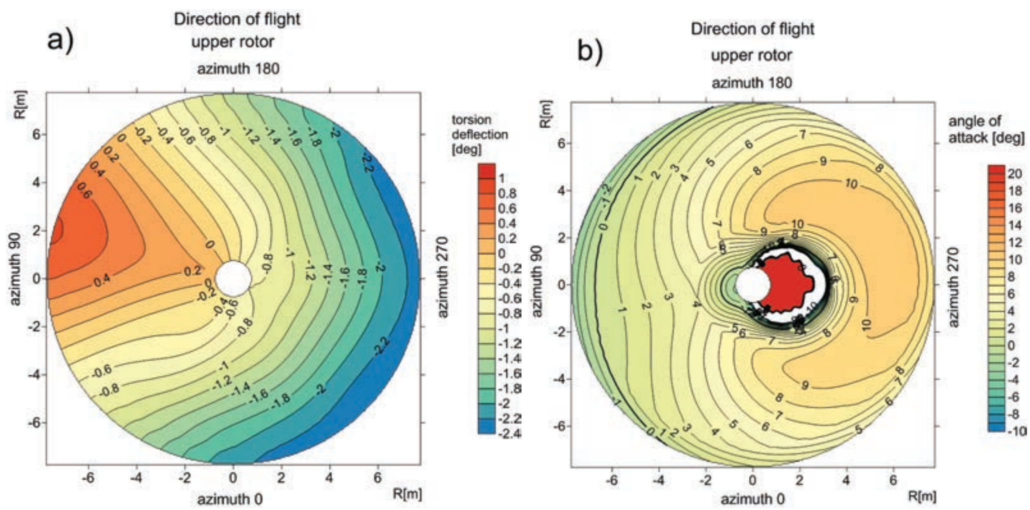

Fig. 11. Distribution of blade parameters for disk of upper rotor in level flight at speed of V=200 km/h a) torsion deflection, b) local angle of attack

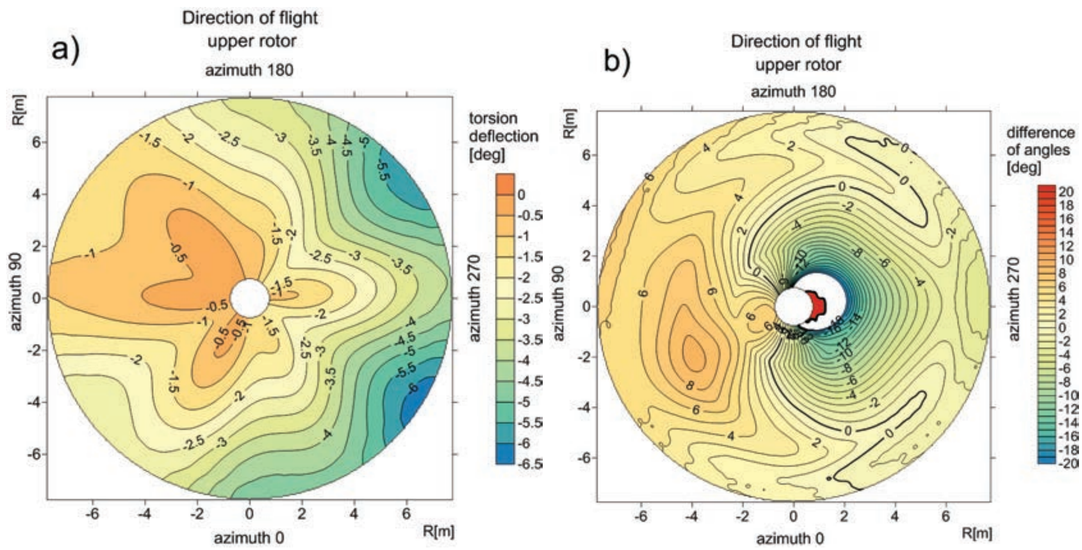

Fig. 12. Distribution of blade parameters for disk of upper rotor in pull up manoeuvre at speed of V=100 km/h a) torsion deflection, b) difference of local attack and critical angles

In Fig. 11 are shown distributions of blade torsion deflection and angle of attack at cross-sections of blade of the upper rotor in level flight at speed of 200 km/h. It can noticed that the angles of blade torsion deflection comprise in the range between -2.4^o and 0.8^o (Fig. 11a). Distribution of angle of attack shows in vicinity of retreating blade position (azimuth 270^o) zone of greater values of attack angles (Fig. 11b), for tip of advancing blade position at azimuth of 90^{o,} attack angles reach negative values. Distributions of blade torsion deflection and differences of local attack and critical angles for final phase of pull up manoeuvre are presented in Fig. 12. At tilted up position of rotor, perpendicular to plane of rotation components of flight velocity may increase local attack angles of blade cross-sections even to appearance of separation flow zone (Fig. 12b). Blade passing through the separation flow zone causes increased its torsion vibration and deflections (Fig. 12a). Simulations of rotor behaviour in manoeuvres may be useful to define limits of helicopter flight envelope.

4. Conclusions

Results of simulation calculations show that helicopter of 6,000 kg mass built in coaxial configuration with two six-bladed rotors will be able to perform rescue operations at altitude of the Himalaya peaks if unit of two engines provides total available power about 1,400 kW. The demand of hover in OGE condition at height of 10,000 m will ensure to prevent enough margin of power enabling manoeuvres during missions at lower height of Himalaya range even in difficult weather conditions. The helicopter with ability of hover at high-altitude could find wider usage, not only for mountain rescue. In regions of high mountains, without good road networks, such helicopters with considerable lift will be useful in passenger or load transport.

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