VORTEX RING SAFETY OF ROTORCRAFT

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Abstrakt: *Vírový prstenec je nebezbečný režim letu akéhokoľvek lietadla s rotorom. Numerická simulácia potvrdzuje, že režim je záležitosťou iba celkového obrazu prúdenia, a pád vztlaku na profile je iba sekundárnym javom. Simulácia je v dobrej zhode s teoretickou predpoveďou, preto nástup režimu vírového prstenca na rotore môže byť ľahko predpovedaný jednoduchým analytickým vzťahom. Je simulovaný aj prechod medzi vírovým prstencom a normálnym letovým režimom. Článok predstavuje obrazy prúdenia vypočítané pri CFD (Computational Fluid Dynamics) simulácii rotorového disku.*

Abstract: *The vortex ring is dangerous regime of the flight of any rotorcraft. Presented numerical simulation evidences it is matter of overall flow pattern, and airfoil stall is only secondary phenomenon. Simulation is in good agreement with theoretical assumptions therefore the onnset of vortex ring regime on rotors of rotorcraft can be easily predicted by simple analytic equation. Transition between vortex ring and normal flight regime is simulated as well. Article presents flow patterns resulted from CFD (Computational Fluid Dynamics) simulation of rotor disc.*

Key Words: *rotorcraft, vortex ring, CFD*

1 INTRODUCTION

The vortex ring regime – one of the main causes of rotorcraft accidents is still not well understood and often misinterpreted. The aim of this article is to give simple explanation of this regime and to prove simple method for prediction of its onset. This is done by means of Computational Fluid Dynamics (CFD) simulation of flow pattern around simple rotor device in vertical movement. This work was motivated by the need for reliable prediction of vortex ring onset for prepared small Unmanned Aerial Vehicle (UAV).

2 PRESENT STATE OF EXPLANATION

In almost all explanation of vortex ring regime for helicopter pilots is said that too rapid descending of any rotorcraft leads to generation of vortex ring around the rotor, which moment rotor loses thrust after, and majority of the power on the rotor shaft is consumpted by turbulent motion of vortex ring. Then follows that rotor is most vulnerable to this phenomenon when descending directly vertical relatively to surrounding air. However it is often unrecognised that the tail rotor shows similar behaviour.

3 CFD SIMULATION

First misinterpretation of this explanation is caused by ignoring the fact, that hovering rotorcraft allways generates vortex ring. The main cause of thrust loss must be else. Therefore it was conducted CFD simulation of flow around simple rotor restricted in vertical movement. Simulated rotor represents small UAV, therefore its radius is 0.128 m and thrust is fixed at 5.2 N. Simulated vertical movement ranges from ascending at 8m/s through hovering at 0m/s to descending at –13 m/s, which allowed to obtain all typical flow patterns around the rotor. Rotor was simulated as a unfinitely thin plane with fixed pressure step, which allowed to analyze the problem of vortex ring regardless of local flow around rotor blades.

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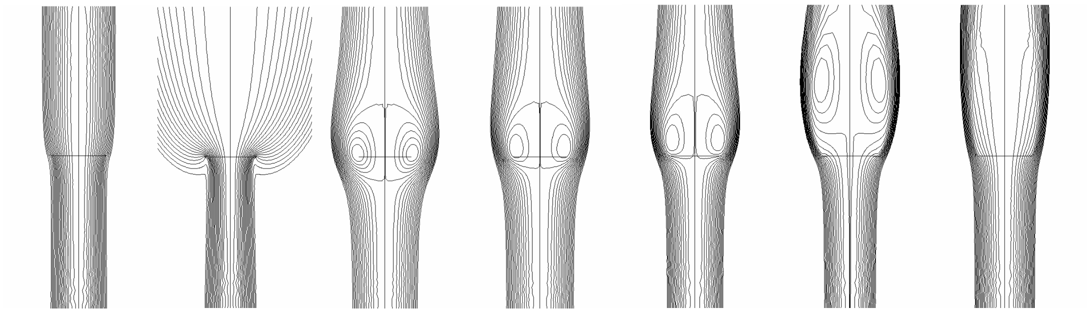

Figure 1 Flow patterns around the rotor at ascending (from the left): +8, 0, -8, -10, -11, -12, -13 m/s.

Flow patterns above 0 m/s and below –12 m/s shows similar no-circular motion (although mathematicaly speaking, the circulation is always present). In these regimes the rotor works similarly to propeller on aircraft.

Vortex ring for howering at 0 m/s is not shown, because it lies far to the bottom sides. At the descent of 11 m/s occurs big change in flow pattern, where the flow is no more coming from upper side of rotor. This axial motion relative to rotor disc is evident from table 1 (velocity v_r). The power consumpted by the rotor is linear function of this movement:

$$P = v_r T \quad (1)$$

Table 1 Relative velocity v_r and input power P as a function of vertical movement of the rotor v.

v (m/s)	v_r (m/s)	P (W)
8	11.99	62.3
4	9.4	48.8
0	8.28	43.0
-4	6.25	32.5
-8	4.49	23.3
-10	2.92	15.1
-11	-0.72	-3.7
-12	-3.02	-15.7
-13	-6.63	-34.4

4 DISCUSION

It is evidently feasible to keep the needed thrust in whole range of vertical movement of rotor and the input power for decreases with decreasing of vertical movement. For rapid descending of rotor – after onset of so called vortex ring (below -11 m/s) the input power is even negative. So the real cause of negative behaviour of the rotor on the real rotorcraft is inability to quickly adapt blade configuration to abrupt change of flow pattern below some value of descending. Onset of vortex ring regime is characterised by quick change of axial flow which causes big angle of attack on rotor blades which are consequently fully stalled and produce very low thrust and consume big torque. This abrupt change in axial flow through the rotor is evident from the figure 2.

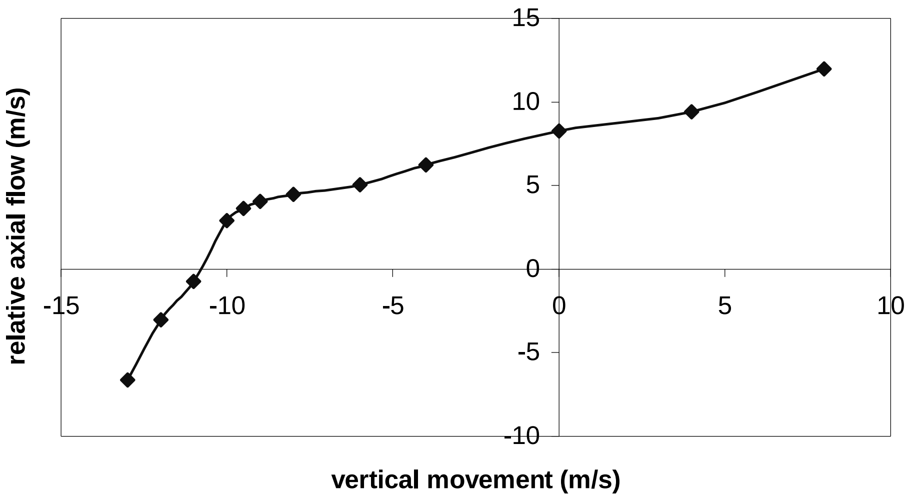

Figure 2 Relative axial flow through the rotor as a function of vertical movement of the rotor.

Abrupt change of flow pattern can be explained such way that pressure under rotor cannot drive the circular movement of vortex ring against stagnating pressure of the air flowing from below. Equilibrum is reached at the point where:

$$\Delta p / 2 = 1/2\ \rho\ v^2 \qquad (2)$$

where Δp is pressure jump on rotor disc and ρ is density of the air. After expressing v, we get simple formula for predicting onset of flow pattern change:

$$v = \sqrt{\Delta p / \rho} \qquad (3)$$

where Δp may be expressed as "thrust"/"disc area".

For simulated case we get velocity 9.73 m/s which is on the safe side close to the result of simulation ie. between 10 and 11 m/s.

5 CONCLUSION

Even simple simulation of the rotor reveals that the so called vortex ring regime is not inherently dangerous and it is only matter of rotor blade aerodynamics and inability to quickly change blade position which has adverse consequences on the flight of rotorcraft.