Testing of Experimental and Numerical Methods for Investigation of the Unsteady Flow Induced by Rotor Influence on Heliport

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The paper presents results of experimental and numerical investigations of the rotor wake in ground effect. Vibrations caused by unsteady pressure fluctuation in the rotor wake are believed to be dangerous for construction of the heliports and services performed in the buildings, eg. in hospital operating room. The purpose of the research was to develop methodology for investigation of rotor influence on helipads and buildings. In the proposed approach the full scale and model test were combined. The numerical simulations and full scale tests were performed on two blade full scale rotor. The unsteady flow filed in the rotor wake was investigated in model scale with use of Particle Image Velocimetry and pressure measurements. The results of both full and model scale investigations were consistent. The unsteady flow structures, hypothesized to be responsible for the vibrations propagations, were visualized in the model scale. The pressure fluctuations were measured both in model and full scale. The performed research proved the feasibility of proposed approach and has paved the way for detailed investigations leading to development of a general model of the phenomenon.

Keywords: rotor wake in ground, heliport, moving mesh, unsteady pressure measurements, wake flow visualisation

1 INTRODUCTION

Currently, increasing number of small helicopter airports (heliports) are being built on buildings. This allows to reduce the space needed and in some cases it is the only way to provide landing zone. Helipads can be nowadays especially visible in case of hospitals in urban environment. Nevertheless, the interaction of helicopter rotor wake on heliport might influence the patient's health. This issue was addressed by Alexa in article "*Are your heliports killing your patients?*" [1] and recently by Wąchalski [2]. Furthermore, this is especially important in operating theatres where state-of-art surgery techniques are applied and high precision lasers as well as optical sensors are used. Despite growing awareness of the problem, the influence of the rotor induced flow on the heliport and buildings structure is not well examined. There is lack of literature describing the phenomena and methodology allowing for investigations of the rotor-caused vibrations propagation in the helipad structure. As a result, nowadays the design procedure of helipads shock-absorbers do not include all vibrations sources. In this paper we perform a feasibility study of application of various experimental and numerical techniques for investigation of the rotor unsteady flow potentially causing vibrations propagations in the helipad and building structure.
Advance of non-intrusive whole field measurement techniques and development of Computational Fluid Dynamics methods in past 30 years allowed to perform detailed investigation of flow field inducted by rotor in various flight conditions. Among wind tunnel experimental measurement methods, the Particle Image Velocimetry (PIV) [3][4] is considered as the most useful and informative technique for rotor inducted flow investigations. The Vortex Ring State (VRS) was investigated by Surmacz, Ruchała and Stryczniewicz in scaled model experiments [5][6]. Nathan performed detailed wind tunnel investigation of the rotor wake in ground effect [7]. Measurements to

understand the flow mechanisms contributing to tandem-rotor outwash was performed by Ramasamy, Potsdam and Yamauchi [8]. A detailed review of the contribution of PIV to helicopter aerodynamics was recently given by Raffel [9]. Rapid development of CFD allowed to simulate rotor induced flow in the proximity of the ground and its influence on structures with great accuracy eg. the rooftop helipad operations safety was investigated by CFD simulations performed by Dziubiński [10]. Żółtak, Stalewski and Zalewski analyses the influence of the main rotor on helicopter fuselage aerodynamics characteristics [11].
Although, the performance of the helicopters rotors is widely investigated in wind tunnel, full scale and numerical tests, the aerodynamic and vibroacustic influence of unsteady flow field inducted by the helicopter on a heliport and building structure is not well examined. The purpose of the presented work is to present and discuss feasibility of application of various measurement techniques for investigation of the influence of the unsteady flow induced by rotor on landing surface. In the proposed methodology, combined numerical and experimental methods were applied for model and full scale investigations. A scaled model of a helicopter was used for flow visualisation and pressure fluctuations measurements of the rotor inducted flow. Full scale tests were performed with the use of a test stand dedicated for testing the main rotor of rotorcrafts testing. The numerical part of the unsteady flow field was simulated in Ansys Fluent. The results of the experiments proved the feasibility of proposed methodology for investigation of rotor wake influence on the landing zone.

2 MATERIALS AND METHODS

In order to test the feasibility of proposed methodology full scale and model test were performed. The scaled tests included pressure measurements in the rotor wake and PIV flow visualisation in the plane perpendicular to the rotor. The full scale test was performed on rotor-testing stand and included pressure and acoustic measurements. The full scale test conditions was simulated with use of CFD solver Ansys Fluent.

2.1 Scaled tests

The tests was performed with a T-Rex radio controlled helicopter. The diameter of the main rotor was 71 cm. The pitch angle of the blades can be changed during the test in range 0 to 10°. The maximum speed of the rotor is 2400 rpm and the maximum induced velocity of the main rotor is approximately 7 m/s. The rotation speed of the rotor and pitch angle of the blades were changed during the tests in order to simulate various conditions of helicopter flight.

Figure 1: View of helicopter model and pressure rake

The unsteady pressure field in distance approximately 192 mm underneath the rotor was measured using an aerodynamic rake. The rake was positioned 355 mm from the rotor axis. The pressures were acquired with use of ESP scanner of the DTC Initium system. The measurement range of the scanner was up to 250 Pa (10″ H_2O). The measurement frequency of the system was 500 Hz.
The unsteady pressure field in the rotor wake was investigated with use of Particle Image Velocimetry Method (PIV) and pressure sensors. The PIV system consisted of dual-cavity solid-state (Nd:YAG) pulse laser and two digital cameras. The lightsheet was formed by set of cylindrical lenses. The Canon EF 35 mm f 1:1.4 and EF 85 mm f 1:1.2 lenses were used. The seeding was produced by seeding generator form DEHC oil. The temporal resolution of the measurements was set to the maximum value of 7 Hz. In order to measure velocities in a range 1 m/s to 10 m/s the time delay between illumination pulses was set to 80 µs.

2.2 Full-scale tests

A two blade powered rotor was used in full scale tests [12]. The rotor diameter was 7.9 m and the distance to the ground was 3.95 m. The ILHX-4 airfoil developed in the Institute of Aviation was used. The measurements was performed rotational speed 300 rpm and pitch angle 14,5°. The test stand is presented on Figure 1 left.
The pressure fluctuations were measured with use of 5 ESP scanners positioned underneath the rotor at the distance 0.58 m above the ground. (see Fig 1 right for the scheme of the ESP scanners positions). The frequency of the measurements was 100 Hz. The range of the scanners was 10 mm H2O.

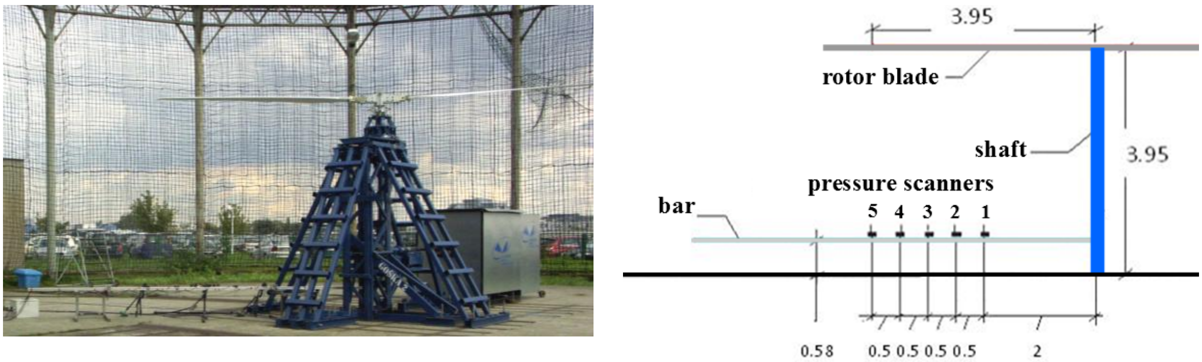

Figure 2: View the rotor test stand (left) and a scheme of ESP scanners arrangement

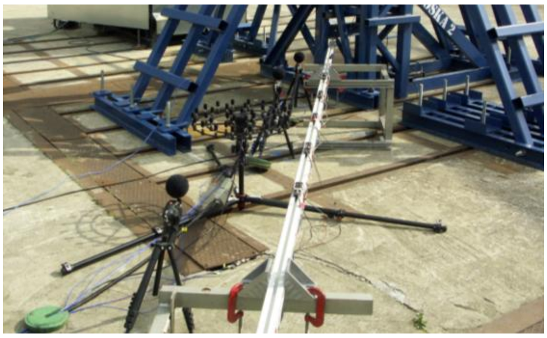

Figure 3: View the bar equipped with ESP scanners arrangement and the microphones position. The microphones are positioned in a line in azimuth 6.3° from the bar

The CFD calculations were performed using Ansys Fluent software with use of Moving Mesh method. A two bladed rotor was simulated with ILHX type rotor blades. The calculations were performed with URANS solver and SST turbulence model. Full-scale model was analyzed.

3 RESULTS

3.1 Model scale – pressure and velocity measurements

The time dependence of the pressure under the model scale rotor are presented on Figure 4. The rotational speed was 1500 rpm. One can observe fluctuation of the pressure in range of 2.5 mmH2O (24.5 Pa).

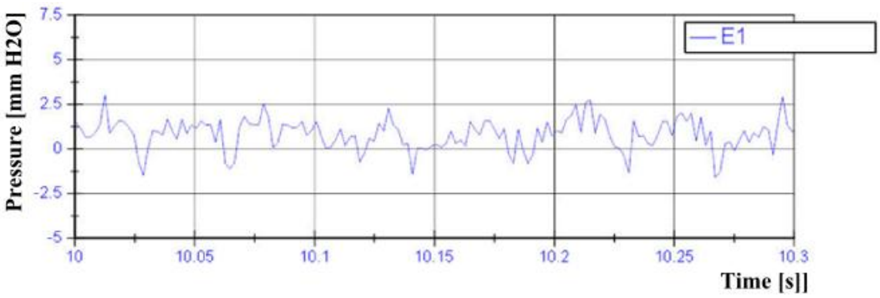

Figure 4: Time variation of the pressure under the helicopter model

The results of PIV flow visualisation in form 2D vector velocity field of are presented on Figure 5. The time averaged velocity profile in the PIV measurement plane 100 mm below the rotor is presented on Figure 6. The velocity fluctuations can be seen in the proximity of the rotor tips. The change in the velocity reach 25% of the mean rotor induced velocity.

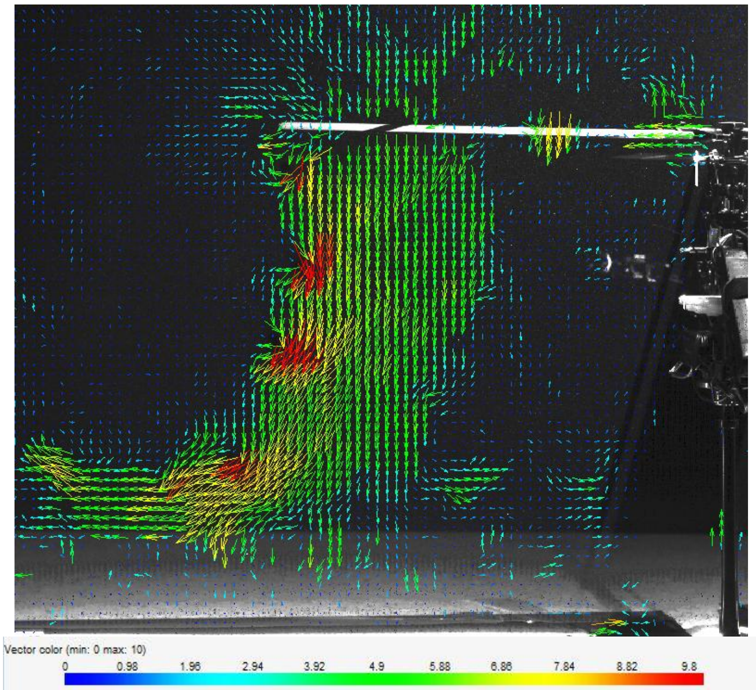

Figure 5: 2D vector velocity field of flow inducted by model at 0.6 blade length above the surface. Velocity scale in [m/s].

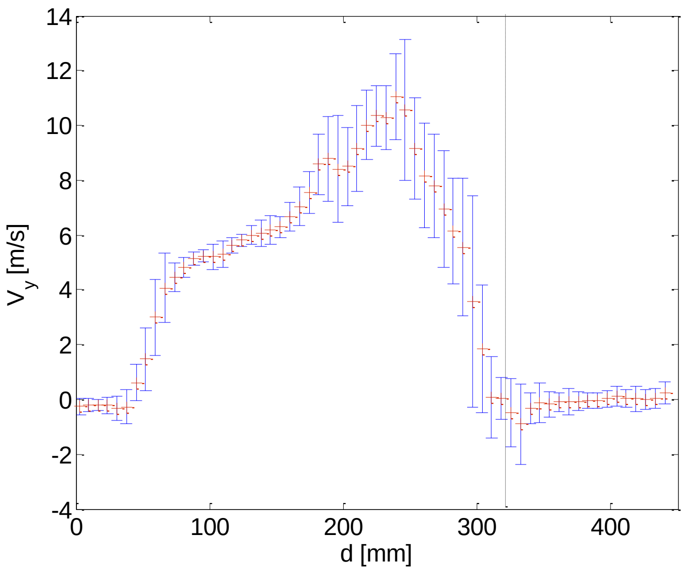

Figure 6: Vertical component of the velocity 100 mm below the rotor. The average of 10 measurements is taken (red crosses) and the standard deviation is shown as error bars. The rotor axis corresponds to d=0 and the position of the rotor tip is marked with dotted line.

The 2D vector velocity field was used for calculations of the vorticity field and streamlines. Exemplary result can be seen on Figure 7. The vortex tip path can be observed both on the vorticity map and streamlines patterns. Interestingly, an interaction between consecutive vortices was observed. One can hypothesize that the vortex tubes interact and roll over each other causing the edge of the wake to roll over the landing surface.

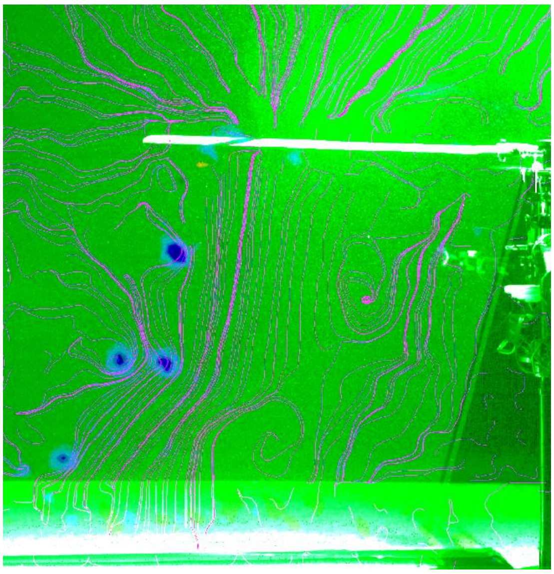

Figure 7: Scalar vorticity field with imposed streamlines. The vortices can be seen as dark blue spots indicating substantial change in the vorticity values from close to zero (green colour) to high values (blue).

3.2 Full-scale rotor and CFD tests

The full scale experiment test conditions was simulated. For rotational speed of 430 rpm the calculated lift force was 7000 N. The CFD simulations results are presented on Figure 8 and Figure 9. On the figure 9 one can observe a shift of the maximum pressure in correspondence to the rotor blades positions. The maximum pressure below the rotor at the ground surface is close to 160 Pa.

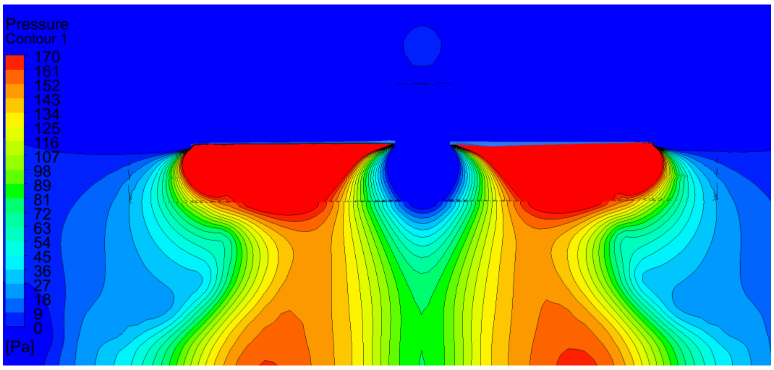

Figure 8: Pressure map of the simulated full scale rotor wake

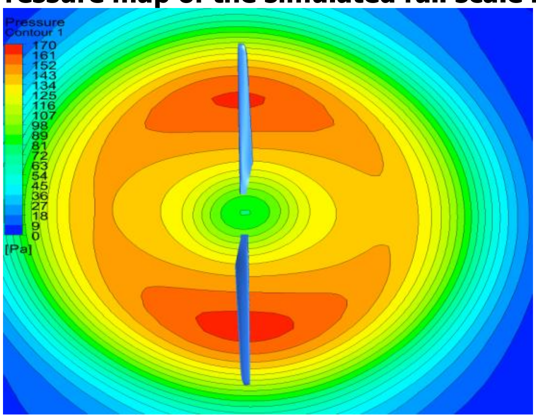

Figure 9: Map of the pressure distribution on the ground

Table 1 Average pressures form ESP scanners for 4 second measurements

Position 1	Position 2	Position 3	Position 4	Position 5
Pressure [Pa]				
64.63998	142.8094	143.1688	115.4229	8.46528

The time variation of the pressure measured with ESP scanners below the rotor are presented on Figure 10. The unsteady periodic pressure fluctuations can be seen on each scanner. The average values form 4 seconds measurement are presented in Table 1.

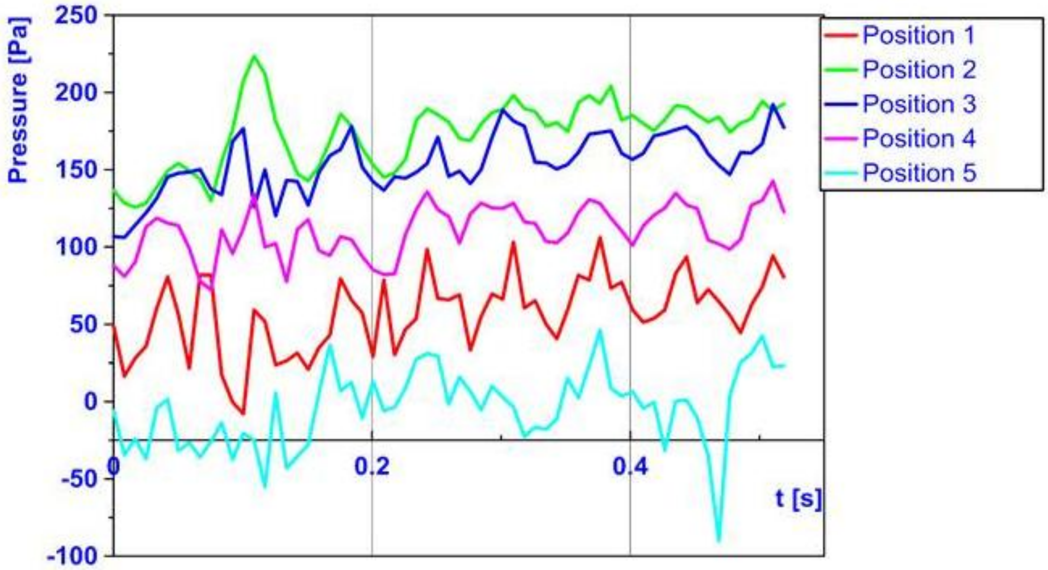

Figure 10: Time variation of the pressure under the full scale rotor

In conclusion the average pressures for full scale test and CFD calculations showed similar values. Nevertheless, the unsteady fluctuations of the pressure measured with ESP scanners was not clearly observed in the CFD simulation result. The timewise pressure fluctuations observed on experimental data can be potentially indentified as a cause of the helipad structure vibrations. Future experiments will be performed with use data acquisition system allowing for acquisition with 500 Hz frequency.
In the model scale both pressure and quantitative flow visualisation measurements revealed unsteady fluctuations in the wake and interaction between blade tip vortices. The last phenomenon will be investigated in more details, since it might result in not-trivial behaviour of the flow field surrounding the landing helicopter.

4 SUMMARY

In the paper an combined experimental-numerical methodology for rotor induced flow was presented. The purpose of the study was to validate the feasibility selected experimental and numerical methods for determination of unsteady loads acting on helipad caused by pulsating velocity field in the rotor wake. Presented results proved that proposed methods can be used for detailed study dedicated to determination of the influence of rotor-caused vibration propagation in buildings. The future research will include investigations of the unsteady rotor inducted flow in the presence of cross-flow in the wind tunnel as well as full scale experiments on helipads located on hospitals and CFD simulations. The investigations should lead to development of general scalable model of the phenomena and provide general instructions for helipad designers and users.

REFERENCES

1. R. Alexa; 2014; "Are your heliports killing your patients?"; www.airmedandrescue.com/features /are-your-helicopters-killing-your-patients;

2. K. Wąchalski; 2017; "Wyniesione lądowiska dla helikopterów na budynkach szpitalnych. Wymagania budowlane dla lądowisk szpitalnych w świetle krajowych i międzynarodowych przepisów" [Eng: "Helipads on hospitals. Building requirements for hospital landing sites - national and international regulations"]; *XII National Rotorcraft Forum*; **12**; Warsaw; June, 23
3. R.J. Adrian; 2005; "Twenty Years Of Particle Image Velocimetry"; *Experiments in Fluids*; **39**; pp. 159-169
4. W. Stryczniewicz; 2012; "Development of Particle Image Velocimetry Algorithm", *Problems of Mechatronics*; **9**; pp. 41-54
5. K. Surmacz, P. Ruchała, W. Stryczniewicz; 2016; "Wind tunnel tests of the development and demise of Vortex Ring State of the rotor"; Editors M. Kleiber, T. Burczyński, K. Wilde, J. Gorski, K. Winkelmann, Ł. Smakosz; *Advances in Mechanics: Theoretical, Computational and Interdisciplinary Issues*; **1**; CRC Press; London; pp. 551-554
6. W. Stryczniewicz, K. Surmacz; 2014; "Investigations of the Vortex Ring State of the Main Rotor of a Helicopter"; *Transactions of the Institute of Aviation*; **235**; pp. 17-27.
7. N.D. Nathan; 2010; "The Rotor Wake in Ground Effect and its Investigation in a Wind Tunnel"; *PhD Thesis*; University of Glasgow; Glasgow
8. M. Ramasamy, M. Potsdam, G.K. Yamauchi; 2015; "Measurements to Understand the Flow Mechanisms Contributing to Tandem-Rotor Outwash"; *AHS 71st Annual Forum*; Virginia Beach; May, 21-23
9. M.A. Raffel, A. Bauknecht, M. Ramasamy, G.K. Yamauchi, J.T. Heineck, L.N. Jenkins; 2017; "Contributions of Particle Image Velocimetry to Helicopter Aerodynamics"; *AIAA Journal*; **0**; pp. 0-0 article in advance
10. A. Dziubiński; 2016; "CFD Analysis of Rotor Wake Influence on Rooftop Helipad Operations Safety"; *Transactions of the Institute of Aviation*; **242**, pp. 7-22
11. J. Żółtak, W. Stalewski, W. Zalewski; 2011; "Numerical Study of Helicopter Fuselage Aerodynamic Characteristics with Influence of Main Rotor"; *Transactions of the Institute of Aviation*; **215**; pp. 50-59
12. A. Sobieszek, M. Wojtas; "Composite rotor blades tests essential before mounting on gyroplane"; *Journal of KONES*; **23**; pp. 487-494