THE ELEVATED HELIPADS – STUDY OF WIND AND ROTOR WASH INFLUENCE FOR MOST COMMON CONFIGURATION TYPES

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ABSTRACT

Problem of lack of possible places to build new buildings is well known in modern cities. When it concerns helipads, which need large area to be placed and also it have to be carefully checked, how surroundings is influencing on this new construction, the case is even more complicated, because those sites have to fulfil demanding regulations. For hospital helipads it is necessary to have possible quickest way from helicopter to surgery. When area is limited, it is usually necessary to place such construction on a building and such helipad is then called elevated. However no document can provide a strict information, how to place new helipad in its surrounding – only general data is available. Too many factors have to be considered. This is why always a detailed analysis is needed in order to be sure, that flight operations can be done safely. This paper presents the work flow concerning this topic, from regulations to fulfil to results of analysis. Some aspects of different locations and its influence on elevated helipads are discussed. Also details about performing the analysis are presented.

1. INTRODUCTION

The modern cities are growing dynamically, which implies the lack of free space for the new infrastructures. Especially it can be problematic for the large and formalised objects, such as the helipads outside airports. The design features and the surroundings of such helipads are described in details with the appropriate regulations and no derogation is allowed in order to ensure the sufficient level of safety. For buildings, that were build earlier, when its surrounding is tightly covered, almost always the only solution for adding a helipad, is to build one above the ground, mostly on the building itself or on a new construction and that way all the necessary conditions will be fulfilled. As the helipad is always surrounded by the other buildings that may interfere with each other and cause the zones of flight hazard, sometimes it is necessary to perform a detailed research to obtain optimal placement, especially when the helipad surface is below the tops of the other buildings. Some limitations about allowable helipad locations could be found in regulations concerning elevated helipads (described in next paragraph), but due to highly specific conditions in every case they should be confirmed by a CFD simulation. The paper is aimed to explain the differences and specific issues of three different types of helipad and present the ILOT capabilities and results in this area of research.

2. REGULATIONS CONCERNING ELEVATED HELIPADS

An Aerodrome Manual (AM) is the most important document for a pilot, when he is going to a new location. This document includes all the necessary information about the operating procedures, which are in use to allow for a safe operation on the airport/heliport and in its surroundings. Such manual has a strict layout and it is obligate to create such document in order to get a permission from the Aviation Authorities to use such helipad. AM for every airfield is required due to responsibility the pilot in command (PIC) for choosing place to land and safe landing. Information, how to do this properly and safely, is gathered by pilot from AM Guidelines for preparation AM are included in ICAO annex 14 volume 2 [1] – section 1.4.

The topics, that are mandatory to include in AM, are following:

- aerodrome name
- location including name of city, district, province, state and the like
- responsible person in charge with address data and phone number
- geographical coordinates of the landing site reference point according to World Geodetic System 1984, WGS84
- elevation above mean sea level
- distance from nearest city

- main activity of the airfield – types of aircraft, main activities
- access roads and types of their surface
- airfield surface description and its parameters
- navigation equipment and its location
- procedures of flight operations and their limitations
- necessary conditions of safe use of the airfield
- list of aviation obstacles with description of their day and night markings
- acrobatic flight zone description, if it occurs
- map of airfield with scale no more than 1:5000 with main infrastructure, equipment, airfield zone boundaries
- accident rescue plan (separate document):
  - all technical airfield data
  - information about most commonly aircraft types operated from airfield
  - alarm instruction with sequence of actions in case of emergency
  - secure procedures during normal actions
  - description of emergency landing sites at distance of 3 kilometres with map scale 1:25000
- map in scale 1:25000, or bigger, with all aviation obstacles at 3 kilometres distance radius from site reference point
- longitudinal and transversal profiles of ascending and descending in scale 1:1000 for vertical and 1:500 for horizontal

This list is a mandatory requirement for preparing accepted AM. Every position have to be included in final document. So basically this above list is showing, what limitations have to be considered when placing a new airfield/helipad. Ascending and descending profiles cannot be penetrated in any case by obstacles. When obstacle is hardly-visible (masts, energy lines, etc.) it is obligatory to secure 10 [m] safety gap between the obstacle and required flight profile. The access roads have to be proper for rescue teams and number of emergency landing zones should be as high, as possible. For elevated helipads also one additional problem, that has to be considered. Fig. 1 shows the problem. When helipad is placed on top of the building, above it appears a turbulence, that in worst case can be so strong, that helipad can be excluded from use. The fix for this issue is to place the helipad above the building, so there is free space, so called "air gap", role of which is to organize air flow around helipad. The minimum height of elevation was estimated for min. 3 [m] and it should prevent the occurrence of strong turbulence above the helipad.

It is not a problem to place elevated helipad on top of the highest building to meet aviation requirements. But when it is hospital helipad, some additional requirements have to be considered. The main is the patient transport time, in most cases, the one in life-threatening conditions, from helicopter to the building. This is the reason, that all transport paths also have to be carefully designed. This is real challenge in the case, when the hospital buildings are old and the helipad is designed as new construction added to old surrounding. Then it has to fulfill different requirements, in most cases excluding each other. When planning, the costs also have to be considered, as one of the important limitations.

Every case of the elevated helipad placed in the old surrounding is different and therefore has to be considered carefully. Mandatory requirements are listed above. But when helipad will be placed under the top of highest buildings/obstacles or in the dense urban area, additional limitations have to be considered. For example the influence of main rotor wake on surrounding buildings, when the approach path is placed over it, or the turbulences caused by winds blowing from different directions. Those circumstances cannot be described by any requirements and therefore have to be inspected in the other way, that will give a proof, that all flight operations will be performed with an acceptable safety level. The next chapters show some answers to this problem.

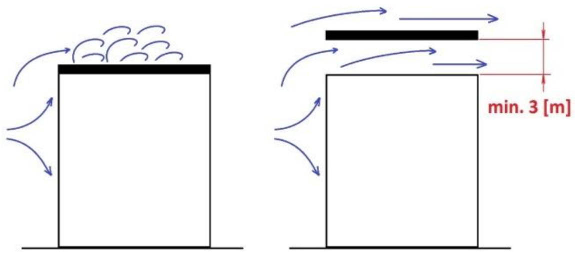


Figure 1. Differences between elevated helipad without (left) and with air gap (right)

3. CALCULATION OF AIRFLOW AROUND ELEVATED HELIPADS

The two factors are important to know, when designing the elevated helipad: how much of turbulence will be caused by the wind around the helipad and where are the dangerous zones for hover due to aerodynamic interaction with ground objects. The first of factors, the wind influence, could help to define proper approach procedures in correlation with wind direction. The other one, an interaction with ground objects, could cause a threat even in a calm, not windy conditions, due to the phenomena of a partial or full vortex ring caused by obstacles, into which the helicopter can fall. Then a mechanism similar to a Vortex Ring State [2] could cause the

a) b) c)

Figure 2. Different cases of helipad configuration: composed with surrounding architecture (a) [4], elevated above surrounding buildings (b) [5] and placed near the higher building (c)

helicopter to crash [3]. It is already known, what structures of architecture could cause such a treat, but only using the modelling methods it is safe to test if such phenomena will appear near the tested helipad or not. In this article for both areas of research an advanced flow simulation (CFD) using finite volumes method for solving the Navier-Stokes set of equations has been applied to test three different cases of helipad (fig.2). The simulation cases are a real locations of the helipads, that are to be built near hospitals in Poland. The cases are chosen methodically, being the examples of different helipad positions, that can be found in real life. Thus the three different configurations: composed, elevated and placed near obstacle (higher building) have been defined.

4. CFD MODELS AND BOUNDARY CONDITIONS PREPARATION

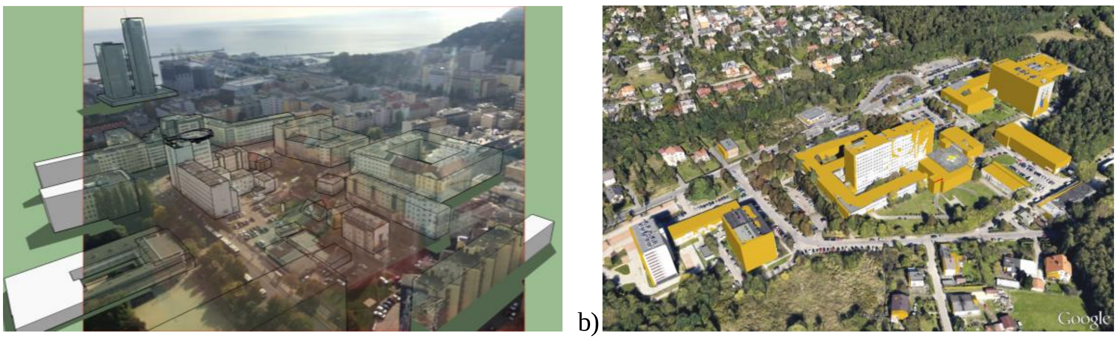
The methodology is as follows - the geometry of helipad is based on three sources: commonly available satellite maps of the terrain (Google Earth database, also – LIDAR maps if available), maps of surrounding buildings available from developer company, and the architectural plans of the building that will be equipped with helipad and plans of the helipad itself obtained from the designers. All these sources are enhanced by, or rather tested against the aerial photography of helipad locations and usage of photogrammetric tools and techniques (fig. 3). It was done using Google SketchUp software. The highest level of detail of the geometry was reproduced in the closest surrounding of helipad and decreased as moving away from landing pad due to the lower potential effect of aerodynamic interference expected. The geometry of buildings situated far from landing field was greatly simplified to make the computational grid less complicated and with less number of cells.

Around the prepared geometry a finite volume grid was created using the ICEM CFD mesh generator. Grid density was selected to properly reproduce the flow around the geometry sharp edges, so on all types of roofs and walls, lines have a slightly higher mesh density than walls (Fig. 4). The program automatically generates and smoothes the mesh, at the same time leaving the user the possibility to intervene in this process and repair the grid manually in regions, where the automatic mesher generates an error.

The simulations were carried out using the Reynolds Averaged Navier Stokes (RANS) equations. In the following work one of the most widely recognized, as an industrial standard, RANS solvers - ANSYS Fluent - was used.These equations were closed by the turbulence equations corresponding to the k-ω SST model, commonly used in the simulations of external flows.

The following simplifying assumptions were used in the simulations:

- the flow is stationary,
- although the air is viscous, the precise boundary layer modelling was neglected due to large amount of sharp edges which naturally cause a flow separation,



a) b)

Figure 3. Example comparison of created geometry with aerial photography (a) [5] and LIDAR maps (b)

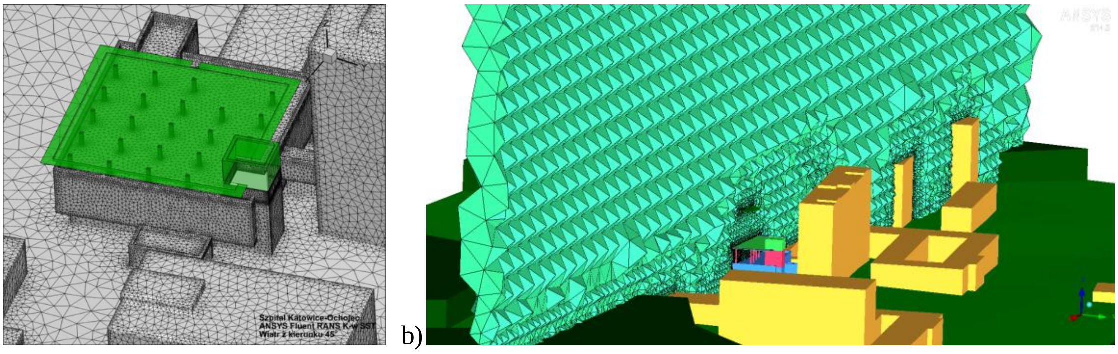


Figure 4. Mesh details around one of the helipads analyzed (a) and in the cross-section of the domain (b)

- the direct aerodynamic interference was taken into account only for neighbouring objects, but the impact of the entire surrounding district is realized by the vertical profile of wind speed and turbulence. Thanks to this approach the 3D model of the entire district was not necessary. The vertical profile of wind speed corresponded to the type and density of buildings around the area studied and so-called "ground layer". This way the average impact of further objects was taken into account.

All simulations were conducted for standard atmosphere conditions (ISA). Velocity and turbulence parameters, as a function of height, were given by vertical profiles of appropriate flow parameters, generated using the external User Defined Function (UDF). The figure 5 shows an example of the direction and the schematic distribution of velocity in the far-field.

The reconstruction of wind characteristics in a given place took into account the following requirements:

- the maximum wind speeds corresponding to allowable limits specified in the helicopter flight manual,
- the most frequent wind directions in specified location,
- the type of building in the form of an appropriate vertical distribution of wind speed.

In order to meet all the specified requirements the construction standard EN 1991-1-4 (2005) was used to prepare the wind velocity distribution in the vertical direction and then scale it to the appropriate permissible speed from the helicopter flight manual. In addition to normative data for the whole of Europe, the country-specific data included in the National Annex was also used. It allows to better reflect the vertical speed distribution based on measurements made directly in Poland. The National Annex takes into account e.g. the specificity of a typical building of a given country. In EN 1991-1-4(2005) the vertical distribution of speed is given by the formula:

$$V_m(z) = c_r(z) \cdot c_0(z) \cdot V_b \quad (1)$$

where:

V_b - base wind speed,

$c_r(z)$ - coefficient of roughness (roughness factor),

$c_0(z)$ - orthography factor, usually 1.0 is assumed.

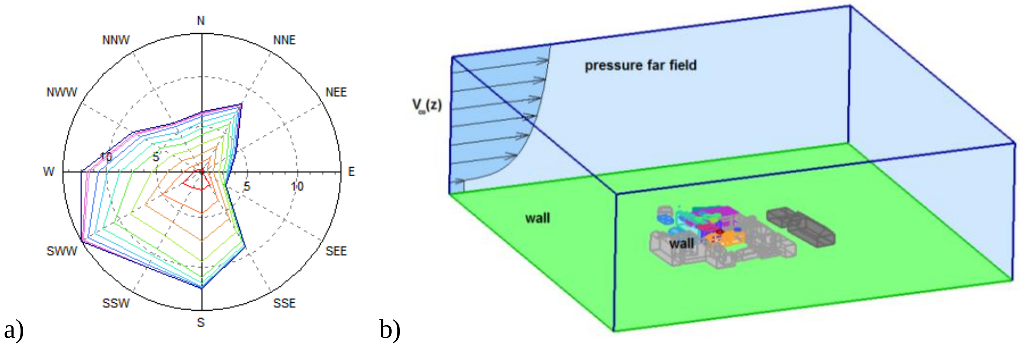


Figure 5. The example of most frequent wind directions at a given location (a) [5] and schematic distribution of wind velocity in the far-field (b)

In order to accurately represent the conditions of air flow around the tested building, it is necessary to reconstruct not only the vertical distribution of the average wind speed, but also turbulence parameters. For the purposes of calculations, they were determined in accordance with EN 1991-1-4 (2005), where the vertical distributions of turbulence intensity and the turbulence scale were defined, depending on the category of the considered area. In EN 1991-1-4 (2005), the standard deviation of wind speed data is given by:

$$\sigma_V = k_r \cdot V_b \cdot k_l \qquad (2)$$

where:

- k_r - terrain coefficient,
- V_b - base wind speed,
- k_l - turbulence coefficient, usually takes the value 1.0.

Known standard deviation allows to determine the turbulence intensity at given height:

$$I_V(z) = \frac{\sigma_V}{v_m(z)} \qquad (3)$$

The turbulence scale, on the other hand, represents the size of average wind disturbances. For a height below 200 ml AGL, according to EN 1991-1-4 (2005), it can be calculated using the following formulas:

$$L(z) = L_t \cdot \left(\frac{z}{z_t}\right)^{\alpha} \qquad (4)$$

where:

- z_t - reference height,
- L_t - reference value of the turbulence scale,
- $\alpha = 0.67 + 0.05\ln(z_0)$ - where z_0 is a roughness length .

In order to apply the determined turbulence profiles in the CFD analysis, it is necessary to calculate the corresponding turbulent values required by the selected turbulence model. In the case of the k-ω SST model, it is the turbulence kinetic energy k and the specific dissipation rate ω, defined as follows:

$$k = \frac{3}{2}(v_m I_v)^2 \qquad (5)$$

$$\omega = \frac{k^{0.5}}{0.09^{0.25} L} \qquad (6)$$

The influence of different turbulence profiles on reversed flow regions behind buildings was shown in fig. 6.

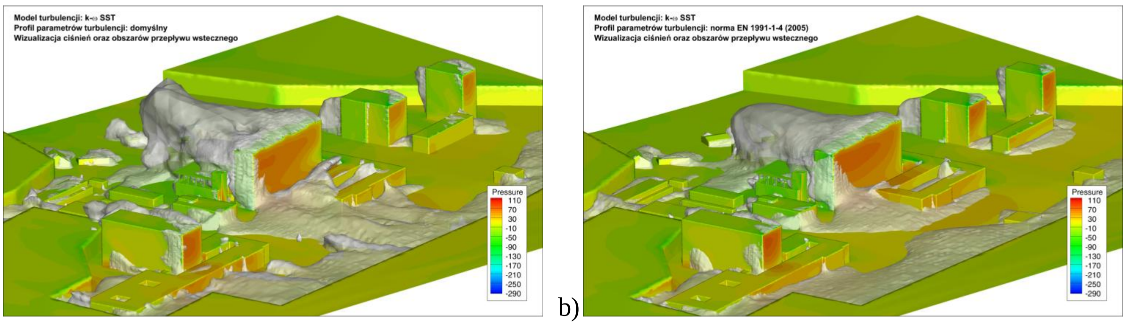
In the presented simulations one more boundary condition, concerning helicopter main rotor, had to be defined. The rotors were modelled using the simplified actuator disk approach and the constant pressure jump method (boundary condition - fan). The pressure jump values for the analysed helicopter rotor were determined using the following relationship:

$$dP = \frac{MTOW \cdot g}{\pi R^2} \qquad (7)$$

where:

- *MTOW* - maximum take-off weight of the helicopter,
- *g* - gravitational acceleration,
- *R* - radius of the helicopter rotor.

It is worth mentioning, that this type of rotor modelling - based on the boundary condition of the fan type and the maximum take-off weight of the helicopter - gives an extremely unfavourable case (the strongest stream under the rotor).



a) b)

Figure 6. The influence of turbulence profile used in simulation on areas of high turbulence behind buildings - k-ω SST default profile (a) vs profile obtained from EN 1991-1-4 (2005) (b)

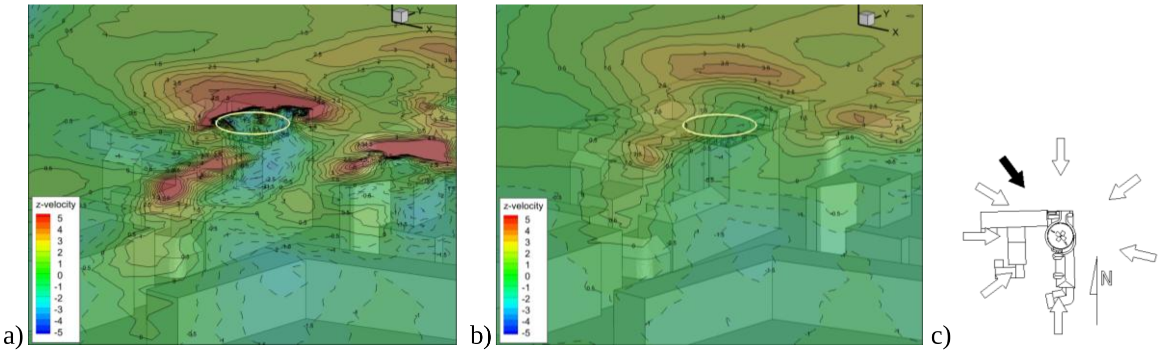


Figure 7. Example results of flow simulations: pilots view of vertical velocity restricted to range between -5 m/s and 5 m/s, in plane 5 m above helipad (a) and 15 m above helipad (b) when approaching against the wind, the wind direction is shown in (c)

5. CFD RESULTS DISCUSSION

Two types of analysis usually conducted for the elevated heliport are the aerodynamic influence of surrounding buildings and influence of rotor wake on surrounding buildings and the helicopter itself. In the first kind of simulations the wind directions are defined by usual wind conditions for the terrain, directions of approach and departure paths (operational manual of the helicopter defines maximum horizontal components of velocity). In the fig. 7 the results of such simulations are shown. Usage of the visualization methods, making available for CFD solutions to be cut and shown for all the simulated parameters, the flow is shown from rather unusual, pilot point of view. This way, the pilot, approaching from selected direction, has an information, where he can meet the vertical velocity jump above 5 m/s, which is known to be dangerous for an injured person transported on board. The example pictures show the velocities on two elevations above helipad, making the approach and planning of escape route (e.g. in case of an engine loss) to be easier. Of course the standard methods of flow visualization are still in use, for example in fig. 8, where a wake captured in photo is also shown with CFD results.

When an influence of rotor wake is analysed, the most dangerous interaction is a creation of partial or full vortex ring around the main or tail rotor. This phenomenon could be caused also by the surrounding object, although it is best known as it causes the Vortex Ring State, a.k.a. “struggle with power”. In both cases the helicopter loses its power to propel the vortex ring, instead pulling down the air in order to push the helicopter up. The velocity of the air in the vortex increases and therefore the need for power goes above the available levels. The vortex itself is a very stable form of flow, self-centring around the rotor even when it moves, so getting out of the VRS is hard to do, even having some margin of the altitude. When such phenomenon appears near the ground, it usually is fatal in results. Such partial vortex ring state caused by the near-helipad obstacles can be observed in fig. 9 (a), and in its full form in fig. 9 (b). In the left illustration there is a pathline flow visualization of rotor wake when helicopter hovers over a potentially dangerous area. Based

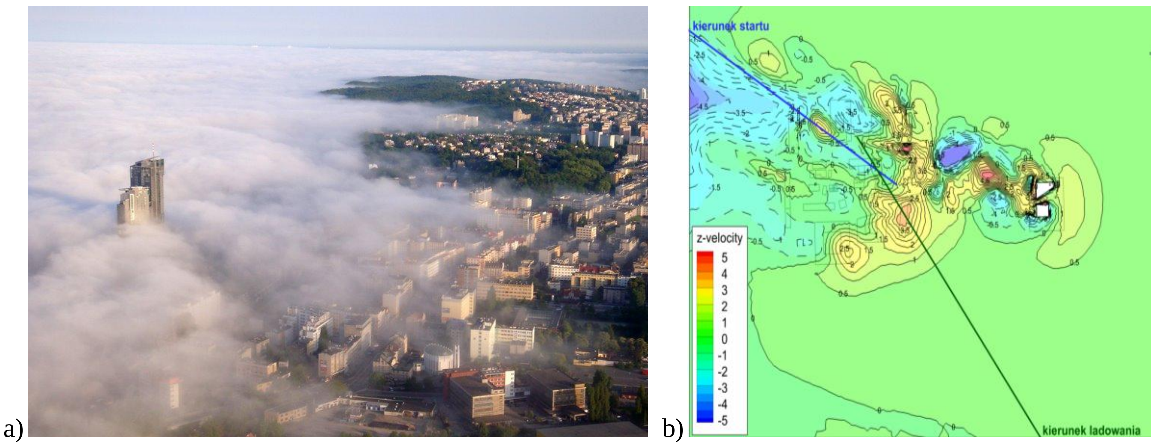


Figure 8. Wake past the skyscrapers of Gdynia’s “Sea Tower” and its CFD simulation [5]

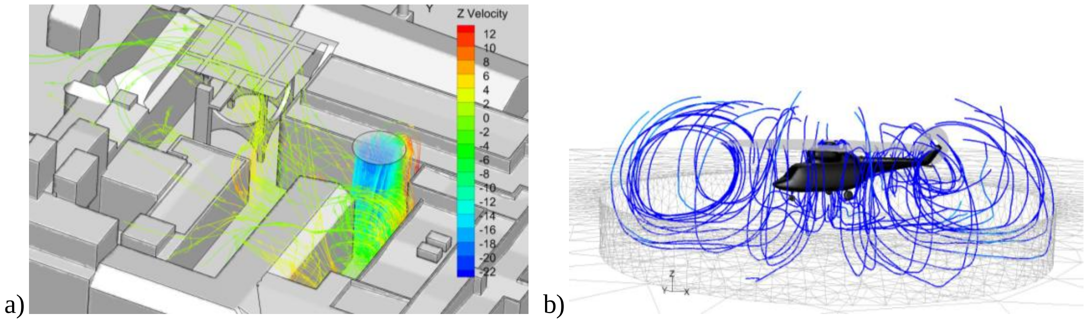


Figure 9. Example results of flow simulations: rotor wake in hover in potentially dangerous position (a), model of trapped vortex ring pulling down a helicopter (b) [6]

on such results there was an operational instruction created on how to cross such areas in emergency situations.

The CFD analysis shows the main difference between three of the described above kinds of helipads. The compound one is rather good in terms of using it in the operations, the flow above the air deck is rather stable, no areas of significant stagnation where the helicopter can lose its lift and do a heavy landing (fig. 10 (b)). This is the possibility when nearby is a high obstacle like on fig.10. (a). In fig.10. (c) the existing wall below the helideck causes up-flow, and there only an air gap present below the deck is able to diminish the area of separation above the upwind part of the helipad. How the air gap works, is shown in fig.11., where the aim was to explain the designer that he should either get rid of the obstacle below the deck or make the gap wider. Depending on the wind direction, the air gap blockage was interacting with flow above the helipad, and it was obvious that even a little gap decreases the flow separation over the deck.

Both, rotor wake and wind interactions with the buildings surrounding the helipad, have to be deeply investigated to identify possible threats and prepare the aerodrome manual with flight safety recommendations. However, for these three kinds of helipads, different problems appear in designing the operation procedures, not only from the aerodynamic point of view, but also the wake, noise and fire safety factors have to be taken into account.

6. CONCLUSIONS

Intensification of the helicopter operations and continual cities growth raises the need of placing helipads in the surroundings on high buildings. This can introduce the areas of severe turbulence or cause the rotor wake interactions with buildings. Both phenomena can have significant influence on the safety of helicopter operations and can be difficult to predict for a pilot. The Computational Fluid Dynamics (CFD) methods allow to simulate them and give necessary information to prepare operational procedures. These procedures has to be specific for selected helipad location. However, three different configurations of helipads can be distinguished: composed, elevated and placed near obstacle (higher building). The safety of helicopter operations on such helipads depends mostly on the helipad surface height in relation to the surrounding obstacles. In the case of lowering the helipad surface below the tops of the other buildings and decreasing the distance between them, the risk of a potentially dangerous phenomenon increases.

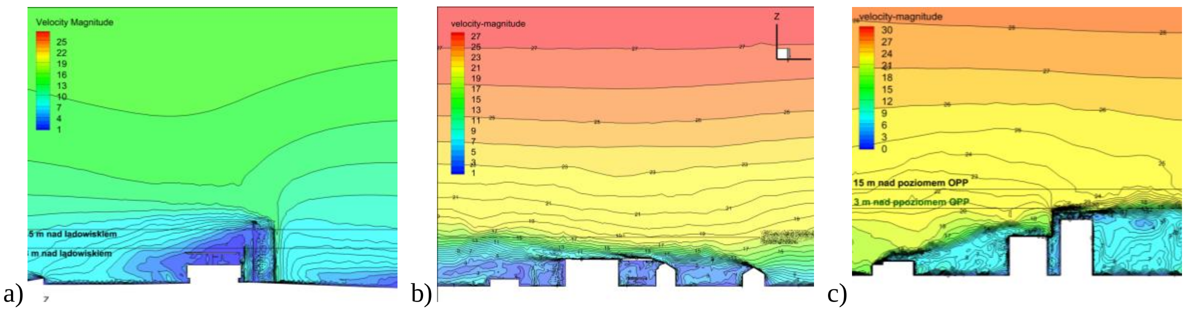


Figure 10. Three elevated helipads situated below the higher building (a), compound with the surrounding architecture (b) and elevated above surrounding buildings (c)

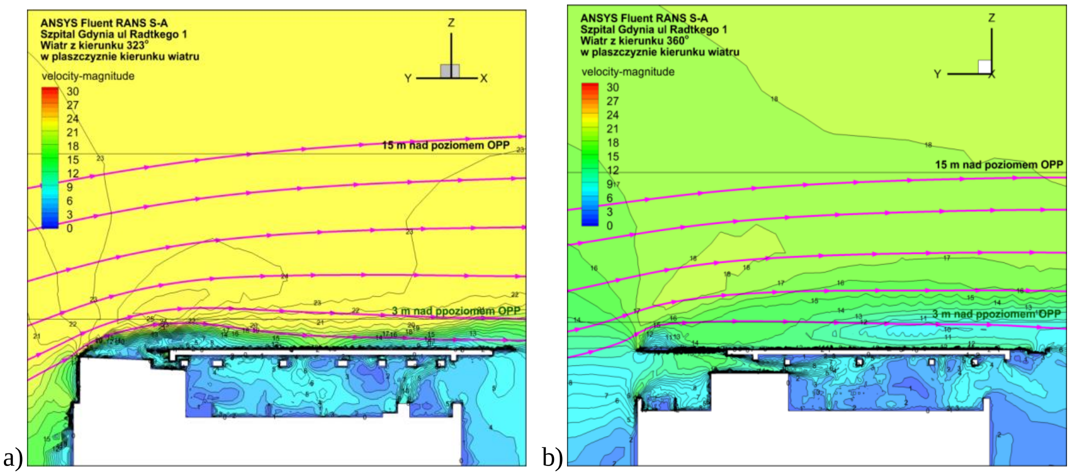


Figure 11. The influence of the air gap on flow uniformity over the helipad - without gap (a) and with the gap (b)

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