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CFD ANALYSIS OF WIND DIRECTION INFLUENCE ON ROOFTOP HELIPAD OPERATIONS SAFETY

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Abstract

The work contains the CFD results of flow calculation of two types of helipad in order to obtain flow parameters on approach areas are given. One of the helipads is situated above surrounding buildings, other is composed into the existing building shape. Both solutions have their pros and cons, which are also described in this work. The wind influence is based on values of maximum operational wind conditions of example helicopter. The flow is solved using commercial code for finite volume method solving RANS equations with Spalart-Allmaras turbulence model. This method can give reasonable results of blunt bodies aerodynamic interference. Using it, the areas of high vertical velocity can be found, and if they collide with approach path, the changes in approach procedures can be made. Also the interference of remotely situated buildings, such as skyscrapers, can be obtained that way.
Keywords: CFD, helicopters, helipad, wind influence.

1. INTRODUCTION

One of the unknown and most dangerous factors, which determine helicopter operation safety while they use helipads, is an aerodynamic interference between helicopter, buildings, surrounding the helipad, and the wind. On approach and departure areas, near the helipad, the structures of flow could appear, which are invisible for pilot, but dangerous for a helicopter. When the helicopter is also carrying an injured person to a hospital, every turbulence they meet could affect health and life of a person being saved. The existing helipads can be divided into two groups: situated above surrounding architecture, or composed into the existing building shape. Two helipads, each of different type, have been designed lately and have been tested using CFD methods. Therefore, a material to derive some conclusions is based on existing areas and buildings (Fig. 1). During investigation of possible phenomena that could cause problems on approach, a picture was found showing that a remotely situated building can cause a flow distortion, which can propagate on very long distance (Fig. 2), and it was worth checking if such phenomena could cause significant influence during approach.

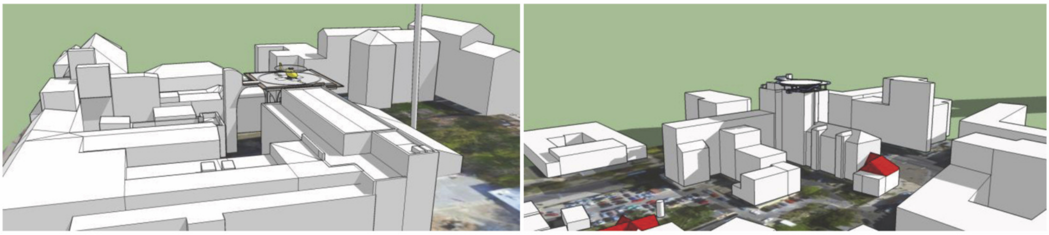

Fig. 1. Two types of helipads: composed with surrounding buildings (left) and exposed above them (right) [Dziubiński, 2015]

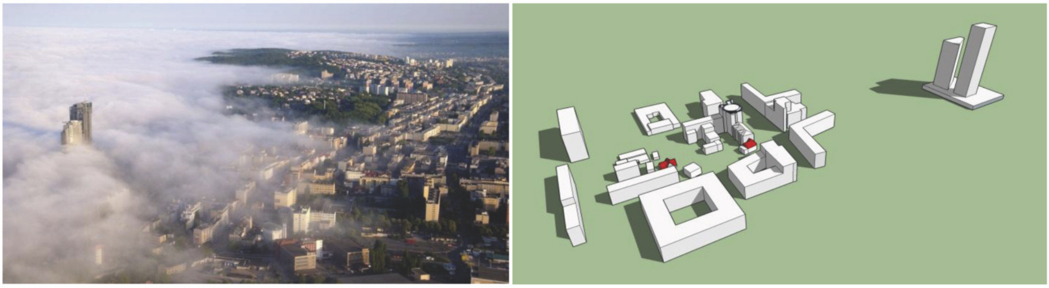

Fig. 2. Aerodynamic interference of distant buildings, as found by the cloud visualization (left) [11] and simplified geometry of this area (right) [Dziubiński, 2015]

During a reconstruction of surrounding buildings, with a great help of Helitech company and State Medical Aviation, an aerial photography of the terrain has been shot and used to create a 3d model using photogrammetric technique. In Fig. 3 results of such process, generated with Google SketchUp software, have been shown. That method is sufficient for CFD influence analysis, when the building of interest is given, in form of architectural blueprints and surrounding objects. When they are blunt (having non-aerodynamic shape), they are reconstructed with less accuracy. The shape and size errors are of minimal influence on final solution, so the surrounding architecture can be reconstructed in that way with sufficient accuracy. Usually, the owner does not have 3d model of their property, so that approach is necessary to achieve the goals of simulation.

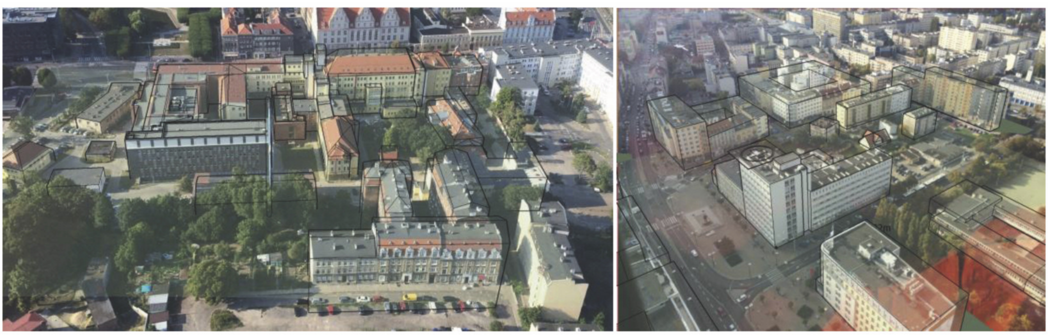

Fig. 3. Usage of photogrammetric technique to obtain geometry of surrounding buildings from aerial photography [based on Helitech, 2014]

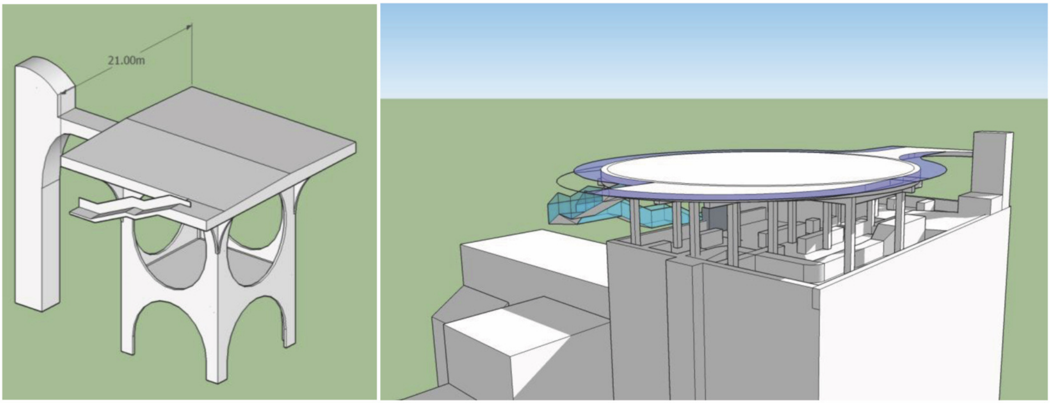

Fig. 4. Geometry of two helipads: a composed one on the self – standing tower and an exposed one, mounted on the roof of building [Dziubiński, 2015]

In the discussed case, one of the helipads (the composed one) has its own tower. The aerodynamic influence of tower is not a question of the following research, since the tower is surrounded and covered against wind. The importance of such shape is rather a question of rotor wake influence. On the other hand, the analysis of the flow under the exposed helipad gives the designers a crucial information about safety and comfort of using this area. This research is a continuation of the helicopter flight and safety analyses provided by the Institute of Aviation, in a way that translate the pure academic research results into design of real objects [16].

2. RESEARCH METHOD

The flow simulations have been computed using Reynolds Averaged Navier Stokes (RANS) equation solver based on finite volumes method. Commercial code ANSYS Fluent has been chosen for this purposes, and also because the boundary conditions could be set using the user's defined functions. The main set of equations has been closed with Spalart Allmaras turbulence model equation known as standard in external flow simulations but assuming a turbulent flow [1]. Since the PRESSURE FARFIELD condition was used on fluid boundary of the domain, the ideal gas model of density, as demanded by this condition, has been also assumed. The Spalart Allmaras model was of strain/vorticity based type with default model coefficients. The inviscid gas model would be also sufficient for this kind of simulation [12], yet these settings are not leading to error, since some variables are really becoming constants, but the calculation cases are not so prone to divergence.

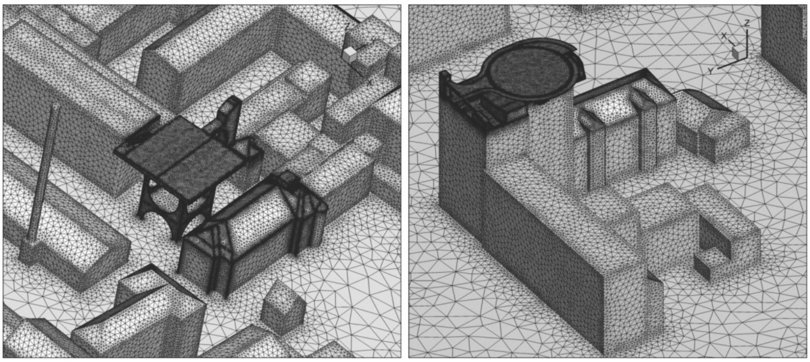

Fig. 5. Mesh density on surface of the model on composed (left) and exposed (right) helipad [Dziubiński, 2015]

The meshes for both cases were about 4 000 000 cells of size. The mesh density was defined by cell size set on the chosen surfaces and lines of a model geometry, a size smoothing has been done by the ICEM CFD software. Depending on the distance from helipad, the size of mesh elements was increasing from 0.15 m on helipad edges up to 30 m – maximum mesh element size. A computational domain size was a 600 x 600 x 200 [m] rectangular prism for the composed and 1000 x 1000 x 350 [m] for the exposed helipad.

2.1. Wind direction definition

The main factor in this research is a wind influence. Wind influence is defined with direction and vertical profile of velocity. Direction of the wind is constrained with approach and departure path direction and flight manual of given helicopter type. For EC-135, which is a monotype in Poland as a civil medical transport, approaches are permitted above 305 kt. (55.6 km/h) of headwind, 17 kt. (31.4 km/h) of crosswind and 0 kt of backwind. Those conditions are written in operational rules of State Medical Aviation (LPR) in Poland, and with information about approach – departure directions (which could be different), are fully constrained information about conditions of helipad usage.

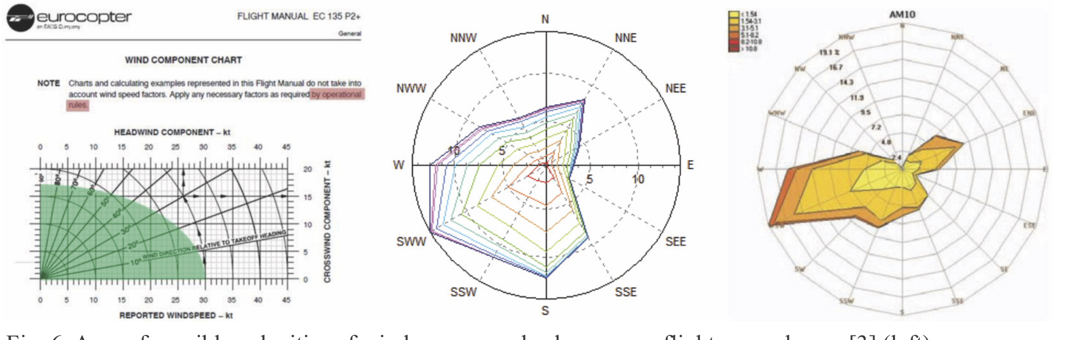

Fig. 6. Area of possible velocities of wind on approach, shown over flight manual page [3] (left); wind rose charts of winds above composed helipad [Helitech, 2014] (center) and exposed [Szymańska K. et al., 2008] (right)

Another source of information about wind conditions, in a given region, is meteorological information in form of wind rose chart, which defines most common wind directions on a given area. These directions will appear, at most, during helipad exploitation, so they have to be put into consideration. Assuming that the restricted area of wind velocities on approach is constrained with an elliptical area, as shown in Fig. 6, the wind direction appearing on the wind rose must be combined with appropriate wind velocity as defined by the ellipse and approach – departure directions. For the same reason as in work [13] the CFD calculations were performed for a selected number of wind directions since ”the calculations are very computationally intensive. (...) It is not practical to model all possible wind conditions (for example all possible magnitude and direction of the ambient wind)”.

Fortunately, for the composed helipad (Fig. 7 left), the most common wind direction defined by the wind rose chart is almost perpendicular to approach – department line, which fortunately has the same direction for both. So only four wind directions need to be calculated for this helipad: 75° (headwind, 30 kt.), 165° (crosswind, 17 kt.), 255° (headwind on approach from opposing side, 30 kt.), 345° (crosswind, 17 kt.). For the exposed helipad (Fig. 7 center) the situation is a little bit more complicated, since the approach and departure direction is bend over the helipad because of civil aviation restrictions (noise, closed zones etc.). The assumed wind directions are explained in Fig. 7 (right), where two ellipses, constraining wind velocity, are overlapping. So the wind directions are chosen from those used in boundary conditions for approach, those defined by wind statistics and the third one, architectural constraint.

The third condition is composed of the following factors: predicted influence of base building shape and unknown (checked) influence of distant buildings. For simplicity, the author assumed that approach will be along direction 323° and department along direction 301°. Including these factors, the wind direction on the exposed helipads appear as follows: 53° (crosswind), 103° (defined by distant building), 180° (perpendicular to back wall of base building), 233° (crosswind), 270° (wind rose), 301° (departure), 323° (approach), 360° (perpendicular to front wall of base building). When flow is perpendicular to base building wall, the stagnation area on this wall generates the upwind flow at the back of the helipad, which will be dangerous during takeoff.

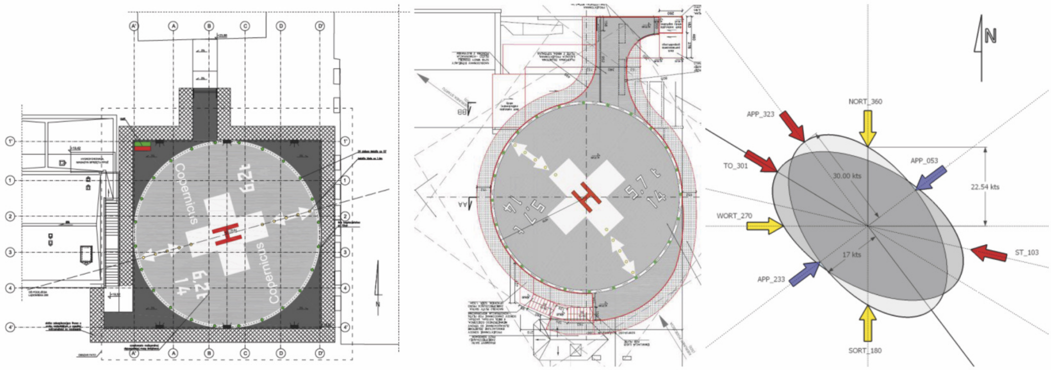

Fig. 7. Composed (left) and exposed (center) landing deck of helipad in geographic coordinate system with direction of takeoff – landing marked by double arrow [Helitech, 2014], and (right) chosen wind directions explanation for the second case [Dziubiński, 2015]

2.2. Vertical profile of wind velocity

In order to fully represent the wind influence, a vertical velocity wind profile has been assumed. This way, a difficult modeling of 3d geometry of whole city block has been avoided, only the neighbor buildings are necessary. The vertical profile corresponds to terrain roughness , which in the Eurocode EN 1991-1-4 (2005) [4] has been divided into five categories depending on obstacles (terrain, buildings, vegetation) height and terrain cover density. The approach assumed in the following work is, to take an objective velocity and use it as basic wind velocity in generating a vertical profile, given by The Eurocode [4].

According to EN 1991-1-4 (2005), the vertical velocity profile is given by the expression:

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

where v_b – base wind velocity, $c_r(z)$ – roughness factor and $c_o(z)$ – orthography factor, in this case $C_o(z) = 1$.

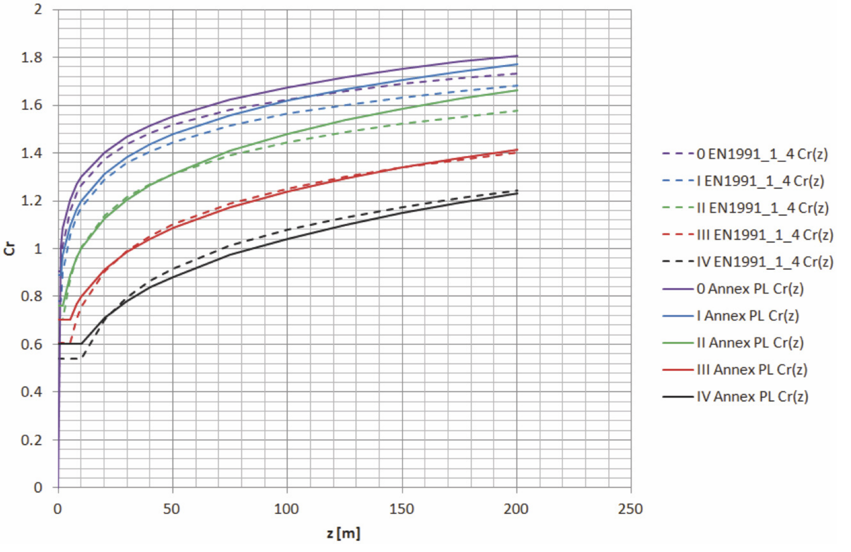

Fig. 8. Comparison of roughness factor Cr(Z) distribution, calculated according to source [4] and [5] for different classes of terrain [Dziubiński, 2014]

The roughness factor is calculated in a different way in Eurocode [4], and in National Annex to EN 1991-1-4 [5], which is allowed to use by the code and takes into consideration a country specific factors. The values for Poland from National Annex have been assumed in whole simulation. A simple, interpreted user-defined function (UDF) has been used to describe boundary condition, including vertical velocity distribution (Fig. 9). It is assumed, that around the computational domain a PRESSURE FARFIELD boundary condition is set, and it demands an ideal gas model and mach number distribution as a velocity definition. The definition of z dimension in code below is caused by the fact, that a coordinate system is placed on the helideck surface instead of on the ground.

```
#include "udf.h"

DEFINE_PROFILE(farfield_mach_number, thread, nv)
{
  float x[3]; /* Position vector*/
  float z, temp, myv;
  float Vb=15.43; /* m/s (30 kts) */
  face_t f;

  begin_f_loop(f, thread)
    {
    F_CENTROID(x,f,thread);
    z = x[2];
    myv = 0;
      if( z <= -10.0 ) {
      myv = 0.6*Vb;
      }
      else {
      temp = 0.6*((z+20)/10);
      myv = pow(temp,0.24)*Vb;
      }
    F_PROFILE(f, thread, nv) = myv/341;
    }
  end_f_loop(f, thread)
}
```

Fig. 9. The simple user-defined function code for wind velocity distribution

Since almost all the geometry consists of blunt bodies, where the flow detachments are clearly marked and all sources of turbulence are represented in geometry as objects, the default values of turbulence level in software have been set. In the work [14] the authors are stating, that for the ship airwake/helicopter flowfield, the mean advection velocity of the air is possibly several times larger than the velocity of the helicopter fuselage, precluding the use of a stationary turbulent field. Since the boundary conditions here are slightly different (ships are moving, the class of terrain is closer to I), and there are no significant objects above the helipad surface as they exist on the ship's deck, the assumed above kind of turbulence modeling is reasonable.

3. RESULTS

From the safety point of view, two kinds of information were necessary to recognize the dangerous areas, for approach and takeoff , for specified above wind velocities and directions. That was the wind velocity, shown here as a map of velocity magnitude, and vertical velocity component, also shown as a map of magnitude. The demand for vertical velocity has been defined by the State Medical Transport Aviation (LPR) representative, Mr Sawicki as it has to be below the 5 m/s of magnitude to successfully transport an injured person to hospital. For the velocity magnitude a demand defined in flight manual had to be fulfilled, and also high velocity jumps on the approach/department path had to be avoided. The vertical distribution of the velocity had also been constrained by the helicopter dimensions and distance between the rotor and the helipad deck.

3.1. Composed Helipad

In Figure 9 a headwind conditions for planning approach or takeoff have been shown, and influence of the surrounding buildings on downwind side appears to be worse in 75° wind case than in 255°, because in this case steeper changes of velocity in the wake are observed downwind the facility. When the facility appears downwind the corridor between higher buildings, the increase of the velocity causes higher flow velocity above it, and the air flows that way, where it has lower blockage, leaving stronger aerodynamic shadow of the facility.

Figure 10 shows crosswind conditions, where the high buildings on approach on the east side cause steep changes in velocity which could cause strong gusts when approaching from this side. In both those conditions an approach to helipad could be made rather from hover on the higher altitude than using standard, aircraft-like landing approach.

In Fig. 11 the vertical wind velocity profile is visible. Also the wake influence is different when the nearest building has a flat or a pitched roof. It appears that the building with flat rooftop generates more attached flow than the one with pitched roof. The separated flow area could cause sudden sinking of the helicopter when the rotor appears in the wake region, and that leads to hard landing, and it has its consequences even for an uninjured person.

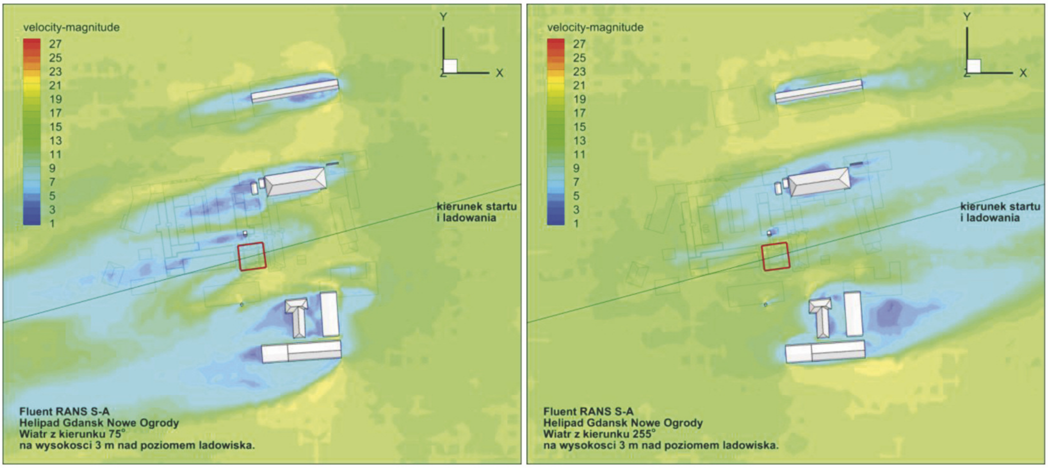

Fig. 10. Wind velocity magnitude on the level of 3 meters above helipad deck for headwind conditions: 75° (left) and 225° (right). An approach-departure direction and the helipad surface are marked [Dziubiński, 2015]

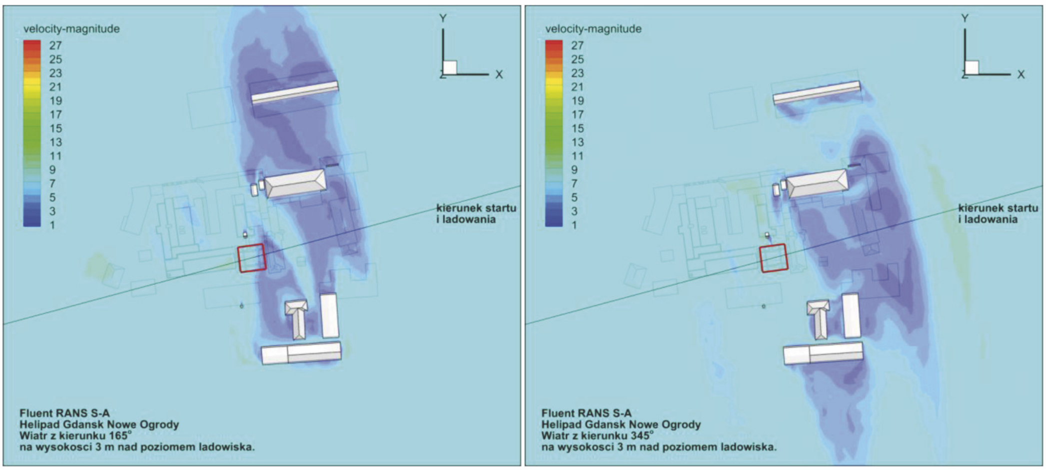

Fig. 11. Wind velocity magnitude on the level of 3 meters above helipad deck for crosswind conditions: 165° (left) and 345° (right). An approach-departure direction and the helipad surface are marked [Dziubiński, 2015]

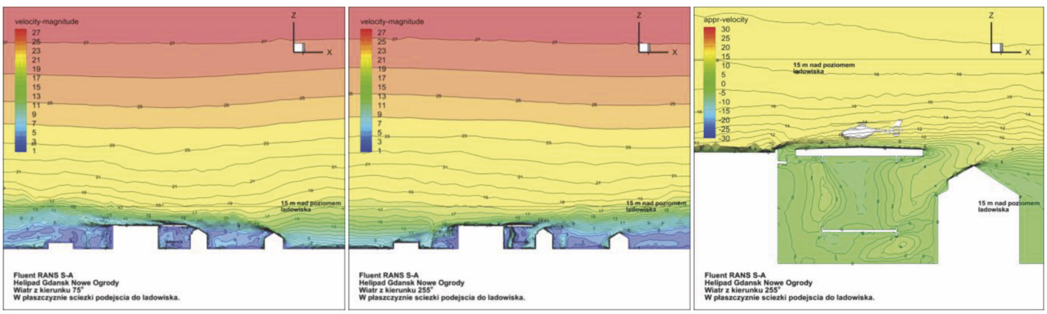

Fig. 12. Vertical cross section through the flow along approach line for both for headwind conditions: 75° (left) and 225° (center) showing the wind velocity magnitude. Zoom of the second (right) case with helicopter shape and rotor position in wake [Dziubiński, 2015]

Figures 12 and 13 show an example of vertical velocity maps from pilots' point of view. These maps, made as seen from a point placed on the flight path, are a good teaching aid for flying crews. They show the areas to avoid, when approaching such helipad, as well as they are a good tool to qualify the helipad design during certification. Areas of positive vertical velocity appearing on the headwind side of building, and on the backwind (Fig. 12), a rotor flow could cause areas of negative and positive vertical velocity, which could create spaces of high velocity jump, size of 5 m/s, which is also not recommended during medical transport.

3.2. Exposed Helipad

Similar maps of wind velocity as for the composed helipad, were made-for the exposed one (Fig. 14-16). Here, the flight directions for approach and takeoff are inclined, because of safety and air traffic control regulations. As it was suspected, the distant buildings of Sky Tower have an influence on flowfield around the helipad (Fig. 14 left). An interesting thing is, that for the wind direction of 301° (Fig. 16 left), the flow appears to be badly constrained, but it is influence of surrounding buildings. The building placed in the far left position appears to be a vortex generator, which bends all the flow over the helipad, which leads to such difference between the wind direction and a direction of the wake.

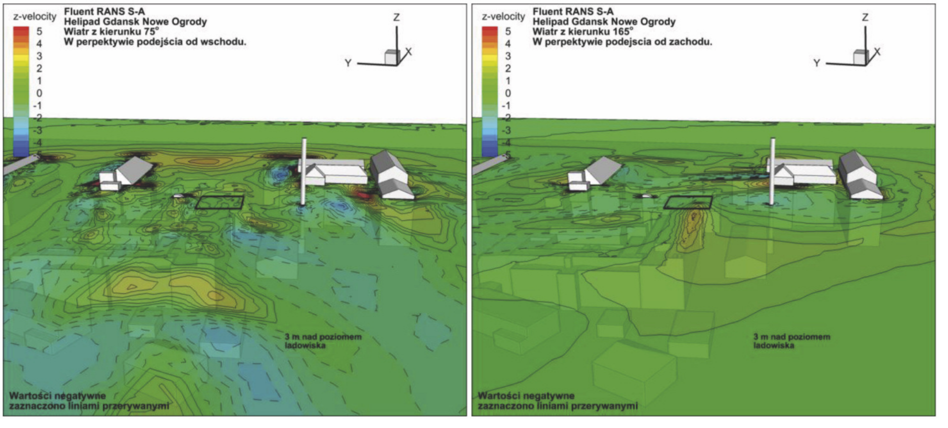

Fig. 13. Vertical velocity map from pilots' point of view, with nose wind and backwind respectively. Negative values are marked with dashed lines [Dziubiński, 2015]

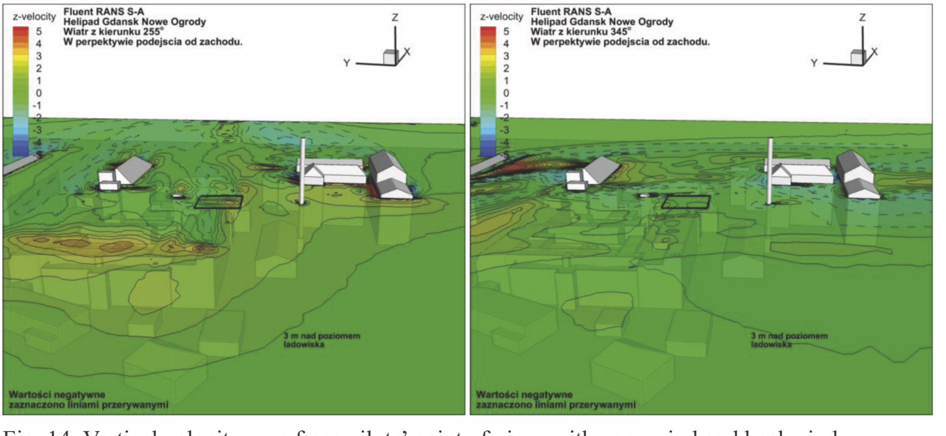

Fig. 14. Vertical velocity map from pilots' point of view, with nose wind and backwind respectively. Negative values are marked with dashed lines [Dziubiński, 2015]

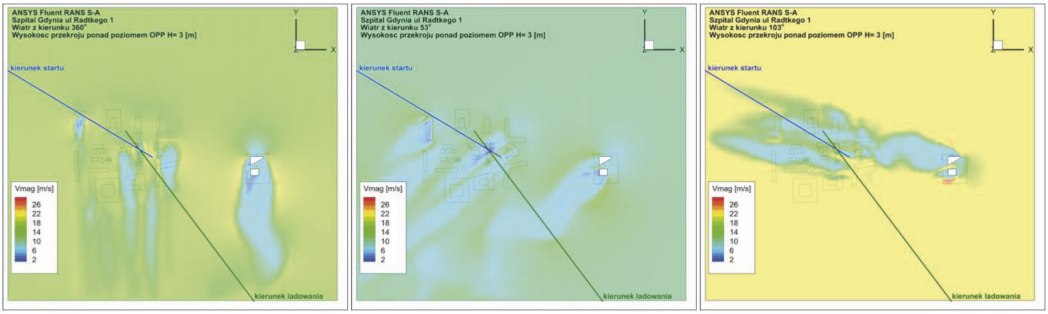

Fig. 15. Wind velocity magnitude 3 m above the helipad surface, wind directions 360° (right), 53° (center) and 103° (left). An approach and departure direction is marked with green and blue line respectively [Dziubiński, 2015]

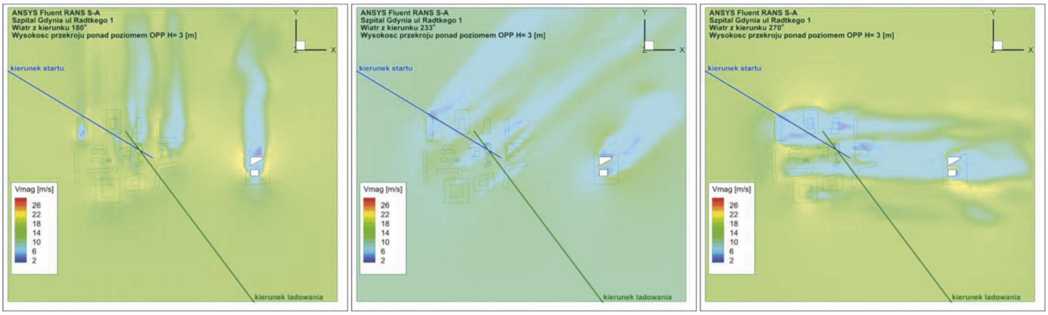

Fig. 16. Wind velocity magnitude 3 m above the helipad surface, wind directions 180° (right), 233° (center) and 270° (left). An approach and departure direction is marked with green and blue line respectively [Dziubiński, 2015]

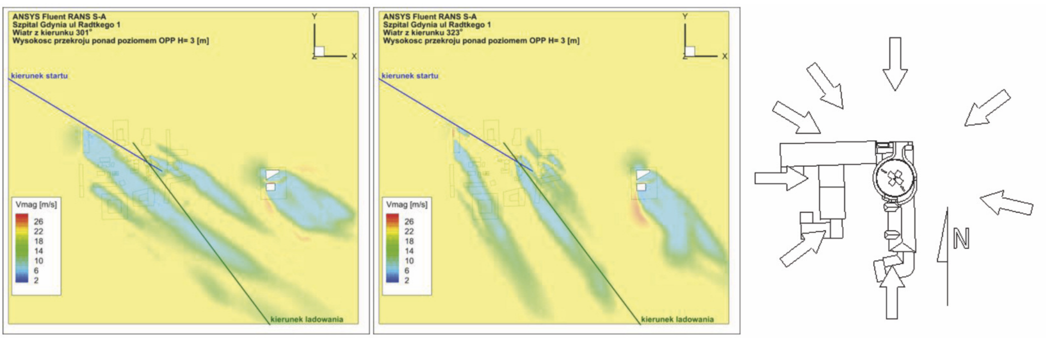

Fig. 17. Wind velocity magnitude 3 m above the helipad surface, wind directions 301° (right) and 323° (center) respectively, and description of wind directions considered (left). An approach and departure direction is marked with green and blue line respectively [Dziubiński, 2015]

While analyzing the vertical velocity maps, a characteristic phenomena for the exposed helipads has-been found. On the head wind wall the overpressure causes a high vertical velocity area. This is the place where the helicopter appears just after the takeoff. Since it was impossible to get rid of the corridors below the helipad and extend the helipad height to generate gap, and this wind direction almost never appears here (as meteorological data says), the suggested way to avoid this would be start (and landing) to a point of hover, 15 m above helipad, and then ascend (or descend) vertically to the helipad surface.

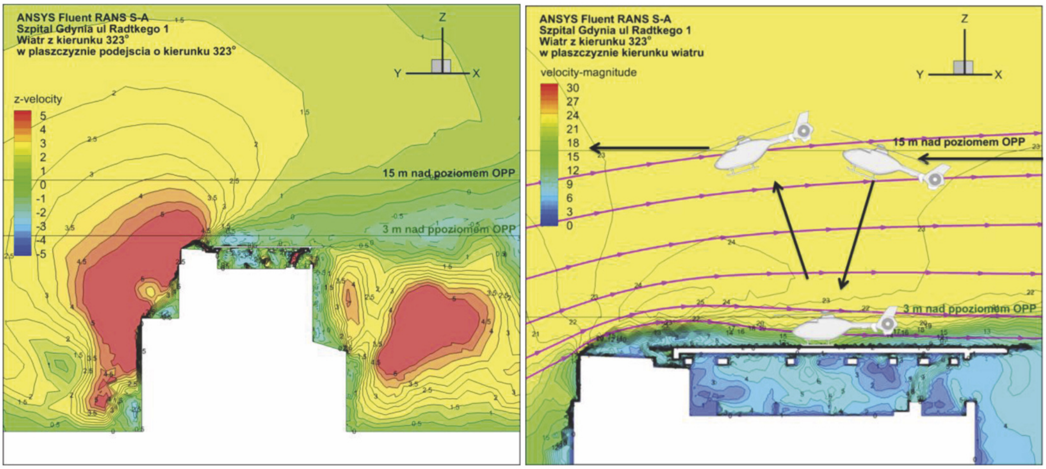

Fig. 18. Area of high vertical velocity for wind direction 323°, takeoff nose wind (left) and a suggested way to avoid this area during operations. Levels 3 m and 15 m above helideck are marked with lines [Dziubiński, 2015]

4. CONCLUSION

The CFD analysis has been described for two types of the helipad. For both, a process of geometry reconstruction and definition of the boundary conditions have been shown. The influence of the surrounding, urbanized area, have been introduced using vertical velocity profile, obtained from statistic data published in normative documents [4, 5]. CFD simulation have been done using commercial RANS solver, on unstructural mesh with Spalart-Allmaras turbulence model. Since the buildings have a blunt shape, the place of separation is usually marked by corner, so proper solution of laminar flow and its turbulization is not necessary.

The results are obtained as a spatial field of flow parameters, so the results are shown only in cross sections, at selected levels above ground and chosen vertical cut planes. The RANS method is able to deal with flow separations, and detached flows simulation, so the properties of flow around discussed helipads are reliable [2, 3, 8, 9]. Results of this work were implemented during design of both helipads, providing data for flight safety, architectural safety and ground crew safety, but also were used in ventilation issues prediction. The wind influence on the helipad safety is significant, and those simulations are necessary to provide information for safe flight path planning. The method proved that a helicopter should be safely used in detached flow condition, a rotor is above stagnation area. What is worth testing further, is an influence of rotor wake in windy conditions approach.

During operation from ”composed” helipads a helicopter is exposed to sudden gusts caused by building interference, but there are no large separations of flow above roof that would cause sudden sinking of this rotorcraft. And in this case windy conditions are not such a problem like in exposed helipads. On the other hand, the exposed helipad is more of a problem when a gap under the helideck is too small. A vertical stream of flow on upwind side then appears, causing the pilot to use specific approach/takeoff technique explained above. Also, the exposed helipad is better in terms of safety as there is a weaker aerodynamic interaction with surrounding buildings, and a smaller probability of crash into the obstacle in case of missed approach. The presented above results also can be used to analyze the helicopter approach in terms of structure response and will help in design of approach and miss-approach procedures after one engine failure, similar to the one described in [15].

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ANALIZA NUMERYCZNA WPŁYWU KIERUNKU WIATRU NA BEZPIECZEŃSTWO UŻYTKOWANIA LĄDOWISK WYNIESIONYCH

Streszczenie

W pracy zamieszczono rezultaty symulacji numerycznych opływu wokół dwu typów lądowisk wyniesionych. Wykonano je w celu określenia warunków na podejściu. Pierwsze z lądowisk jest wyeksponowane ponad okoliczną zabudowę, drugie jest w nią wkomponowane. Oba te rozwiązania mają swe wady i zalety, które również opisano w pracy. Wpływ wiatru określono za pomocą maksymalnych dopuszczalnych wartości prędkości wiatru opisanych w instrukcji użytkowania w locie przykładowego śmigłowca. Pole przepływu zamodelowano przy użyciu komercyjnego pakietu do analiz dynamiki płynów, rozwiązującego równania Naviera-Stokesa przy użyciu metody objętości skończonych, z modelem turbulencji Spalart-Allmaras. Ta metoda daje wiarygodne wyniki dla przepływów wokół nieopływowych kształtów z uwzględnieniem interferencji aerodynamicznej. Dzięki niej możliwa jest identyfikacja obszarów o podwyższonej prędkości pionowej, które mogą kolidować ze ścieżką podejścia. W przypadku wystąpienia kolizji można dokonać zmian w procedurach wykonywania operacji lotniczych z danego lądowiska. Tą metodą można również określić wpływ aerodynamiczny odległych budynków np. wieżowców.
Słowa kluczowe: Aerodynamika Numeryczna, śmigłowce, lądowisko wyniesione, wpływ wiatru.

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