Assessing the Interaction of Helicopter Rotor Downwash and Turbulent Airwakes near Hospital Landing Sites

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Abstract

This paper presents an exploratory investigation into the safety implications of helicopter operations at hospital landing sites by analysing the interaction between rotor downwash and the turbulent wakes shed from nearby buildings. The exploratory study has used a steady RANS CFD method to compute the mean air flow in the vicinity of a hospital helipad with a generic helicopter in a 10-foot hover. The main rotor was modelled using a Virtual Blade Model, thereby enabling a coupled solution between the air flow over the buildings and the helicopter. The study examines the resulting airflow patterns and velocity magnitudes around the site for two different incoming flow directions, with a specific focus on areas where pedestrians are likely to be present. The findings show that, in certain areas, calculated air velocities approach levels considered hazardous, highlighting the need for careful consideration of helicopter landing sites when being integrated with urban environments.

1. INTRODUCTION

Hospital Landing Sites (HLS) are progressively becoming commonplace around the world. Such sites provide patients, in need of critical care, a means to reach lifesaving services found within hospitals via helicopters such as in the Hospital Emergency Medical Service (HEMS). The use of helicopters to fill this role is relatively new compared with the establishment of hospitals globally, with the first helicopter operating in an air ambulance role in the UK occurring in 1987 (Ref. 1). Consequently, many hospitals are having to retrofit HLS to provide this important service. Due to the limited space in the already built-up areas around hospitals, retrofitted HLS can commonly be found in confined spaces or on top of existing structures. HLS are often installed on top of hospital buildings or elevated over car parks. Figure 1 shows an example of an air ambulance operating to a HLS raised directly above a car park.

Figure 1: Air ambulance hovering above HLS.

The placement of landing sites is integral to the safety of not only the onboard patient and crew but also hospital staff and general members of the public, as the positioning of HLS can result in adverse aerodynamic effects on the local environment. One of these effects is helicopter downwash and outwash. Downwash around hospitals has been highlighted as a prominent issue affecting the operations to HLS by bodies such as the Australian Transport Safety Bureau (ATSB). A report published by the ATSB states that half of all reported downwash incidents within the span of five years occurred at hospital sites, with six resulting in injury to pedestrians (Ref. 2). The Air Accidents Investigation Branch (AIBB) investigated another incident that occurred at Derriford Hospital, Plymouth, UK in 2022 where downwash from the main rotor of a Sikorsky S-92A landing at Derriford was swept over the hospital's car park due to a light north-westerly wind, resulting in two members of the public being blown over by the aircraft's downwash, with one suffering fatal head injuries (Ref. 3).

The placement of HLS in dense urban areas makes them further susceptible to the effects of turbulent airwakes, generated by surrounding structures. Such airwakes not only impact the helicopter but can pose an additional threat to the environment through interactions with downwash produced by the aircraft. The interaction between turbulent airwakes and helicopter downwash has the potential to spread high-velocity winds through the environment where members of the public can be affected. More significant effects can be caused by the structural layout and geometry around HLS which may cause channelling effects that can pose serious concerns (Ref. 4).

Although not specific to the effect of helicopter downwash and outwash on pedestrians, more general studies have been conducted regarding the effect of wind on people. Findings in these studies, with some variation, show a general consensus that windspeeds greater than 15 ms^{-1} are considered dangerous for members of the public (Ref. 4-7). These windspeeds can be applied to outwash velocities produced by helicopters, indicating that the air environment around rotorcraft where such speeds may be present will likely pose a threat. In some cases where HLS are retrofitted near public car parks or walkways, the above does become a reality, resulting in cause for concern.

Although new infrastructure can be built away from hospitals, to improve safety for all parties, there are also disadvantages associated with this solution. As well as finding the available land, the drawbacks include the requirement of additional transportation and infrastructure to bring patients from off-site helipads to areas of treatment within hospitals. Crucially, off-site HLS can significantly increase the amount of time before patients can receive potentially life-saving treatment (Ref. 8).

It is worth noting that, in the UK, guidance for hospital sites is presented in CAP 1264 referred to as "Standards for Helicopter Landing Areas at Hospitals" (Ref. 9). Guidance within this document is mostly applicable to new-build facilities. As a result, due to limited resources for already established HLS in addition to the lack of understanding and knowledge of such guidance by helipad operators, issues affecting such sites can be left unknown or in some cases exacerbated.

Modelling of the environment around hospitals has been conducted, however these studies focus more prominently on helicopter operations rather than the potential effects of helicopter downwash on people (Ref. 10-11). The effects of helicopter downwash have been evaluated with such work as that carried out by the GARTEUR Action Group in the AG-22 project which focussed on the evaluation of forces acting on obstacles when immersed in rotor wakes (Ref. 12). This work aimed to improve the quality of experimental databases for rotor downwash studies; however, it did not focus on the interaction of rotor downwash with turbulent air wakes. Other studies, such as the work carried out by Polsky and Wilkinson, detail more closely the coupled air environment due to rotor downwash and turbulent air wake generated by nearby structures, in that case a helicopter hovering near a frigate hangar (Ref. 13). The modelling of helicopters within Computational Fluid Dynamics (CFD) has been previously achieved using an actuator disk to represent the main rotor. Crozon et al. utilised this method to model a helicopter hovering in the turbulent airflow over a ship deck, with results showing good agreement with simulations which computed the flow over individual rotor blades (Ref. 14).

In this paper a steady CFD method, Reynolds Averaged Navier Stokes (RANS), was used to model the air environment around a generic hospital site with a generic helicopter for two wind headings; the helicopter main rotor was modelled using an actuator disk approach known as the Virtual Blade Model (VBM) (Ref. 15). The paper describes the development of the simulation environment and presents some of the results obtained through steady CFD, with a specific focus on the effect on people within the environment.

2. THE HOSPITAL SITE

A three-dimensional model of a generic hospital site featuring a cluster of buildings and a helipad was created. The geometry for the site is shown in Figure 2 and includes a helipad of dimensions 30 m by 30 m, raised 3.5 m above ground level; it also has a ramp which is typical for such landing sites. The adjacent buildings were created to have features which enabled different interactions to be observed, depending on the chosen direction of the incoming flow. Such features include a mixture of flat and pitched roofs, and rectangular and curved walls. In between buildings, there is also the potential for channelling effects, once again dependent on wind direction. The CAD model further contains the geometry of a generic helicopter situated 10 ft above the helipad. The overall geometry is approximately 145 m wide and 115 m long, with the characteristic length L being defined as the largest length of the geometry with a length of approximately 85 m long.

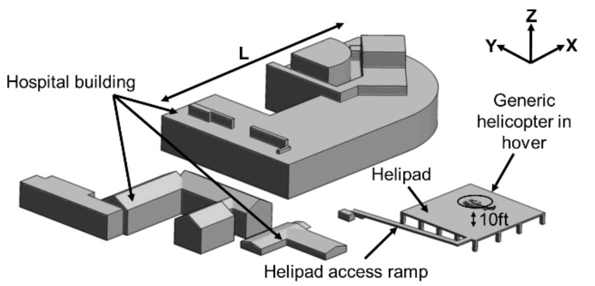

Figure 2: Isometric view of CAD model of the generic hospital site.

The nature of this study requires that flow be interacting in an environment which replicates that of reality in terms of highlighting areas where people might be affected. To achieve this, areas of the CAD model include features such as a car park and public roads that one might expect to find at retrofitted hospital sites; these can be seen in Figure 3. From the geometry it is further evident that, depending on the flow direction, turbulence due to flow separation from buildings can occur. To assess the effect of the turbulent airflow and the interaction with rotor downwash on the environment for this particular site, two opposing wind directions in the same plane were chosen. The wind direction plane, shown in Figure 3 is at an angle of 240° in the cartesian frame of reference, clockwise from the X-axis. For simplicity, these wind directions have been designated as a northerly and southerly wind, with the convention also being displayed in Figure 3. In both cases the helicopter is aligned with the Y-axis, hence the northerly wind will approach the helicopter from 30° off the port side, while the southerly wind will approach from 150° off the starboard side.

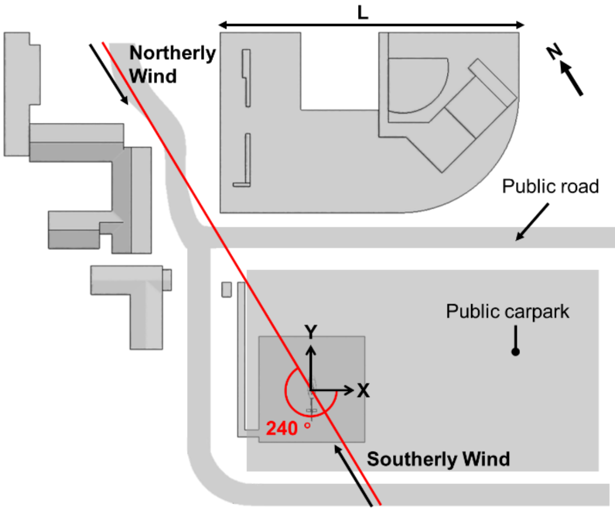

Figure 3: Plan view of generic hospital CAD model with wind directions identified.

3. CFD METHOD

To gain an initial understanding of the air flow around a generic HLS, a steady CFD method was applied. This method was selected due to being able to provide an initial study whilst having relatively low computational cost compared with other turbulence models. The RANS analysis was carried out using Ansys Fluent with a Shear Stress Transport k-ω based turbulence model and second-order discretization (Ref. 16).

The hospital geometry was placed in a rectangular domain a total of 18 L long, 12 L wide and 1.2 L high. This resulted in a domain with a blockage ratio of less than 2 %. The cell size at the surface of the helicopter, helipad, and hospital buildings was set at 0.1 m, 0.25 m, and 0.5 m respectively. Thirteen prism layers were applied on non-slip surfaces with the exclusion of the helicopter and helipad where fifteen prism layers were applied both with a growth ratio of 1.2 to achieve a desired y^+ of 30 for all non-slip regions ensuring these regions fell within the fully turbulent zone. A refinement region, with cell sizing of 0.4 m was placed around the aircraft and the helipad to better capture flow features around the area of interest. This region is shown in Figure 4. The resultant unstructured mesh was composed of approximately 35 million cells.

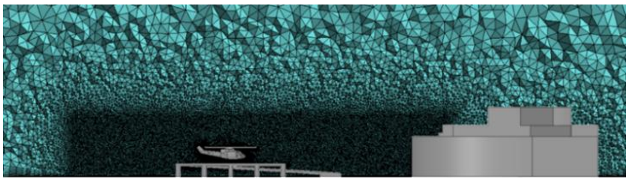

Figure 4: Section plane of the unstructured mesh in the symmetry plane, showing refinement region.

At the inlet, a velocity profile was applied to represent an atmospheric boundary layer (ABL) typical of those found in urban areas. The profile was modelled using Equation 1, where U_{ref} is the reference windspeed measured at a known height above ground level, z_{ref}, d is the hight above the ground at which zero mean wind speed is achieved and z_0 is the ground roughness level for an urban environment which can be taken as 0.3 m according to Counihan (Ref. 17).

$$U = U_{ref}\left(\frac{\ln\left(\frac{z-d}{z_0}\right)}{\ln\left(\frac{z_{ref}-d}{z_0}\right)}\right) \qquad (1) \qquad \text{(Ref. 18)}$$

The sides of the rectangular domain were set as symmetry walls and the outlet was set as a pressure outlet. The top bounding surface was set to a constant velocity in the streamwise direction, with velocity magnitude determined using Equation 1; this was achieved using a velocity inlet condition with zero normal flow. This, in combination with the bottom of the domain being set as a non-slip wall, allowed for the ABL and turbulence to be sustained throughout the domain. Figure 5 shows the rectangular domain with corresponding boundary conditions.

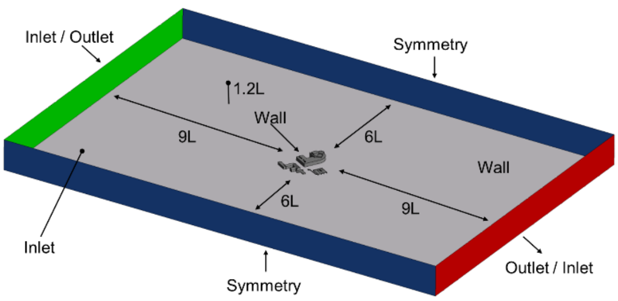

Figure 5: CFD domain.

The reference windspeed, U_{ref}, was set to a value of 10 ms^{-1}, to represent a windy day, at the reference height, z_{ref}, of 6.55 m above ground level. This height corresponds to the approximate position for the pilot's eyeline which further defines where a hover height of 10 ft for the helicopter above the helipad (approximately 3 m) was measured from. Figure 6 shows the ABL velocity profile applied to the inlet of the domain with the wind from a northerly direction, z_{ref} is shown as a horizontal red line; also shown are contours of computed velocity magnitude. The solution for both wind direction cases was initially computed for 5000 iterations to allow for a steady solution to be reached, followed by a further 1000 iterations where the data was sampled. It was decided to sample data after an initial solution had been reached due to the inclusion of trimming in the VBM model during the simulation. Each solution was computed on 120 parallel nodes taking approximately 10 hours.

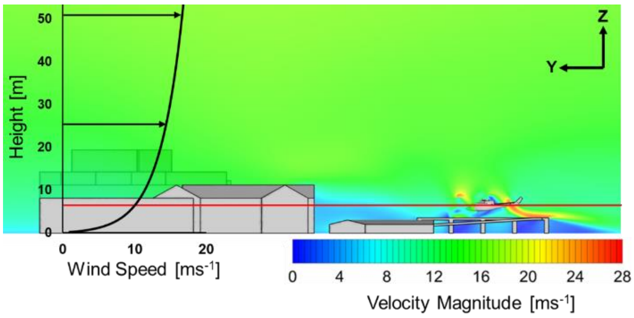

Figure 6: Velocity magnitude for northerly wind case showing applied ABL profile.

4. VBM MODEL

For this study, the main rotor of the generic helicopter was modelled using the VBM available within Ansys Fluent. The VBM, initially created for modelling vertical axis wind turbines (Ref. 19), had its functionality extended to the analysis of rotorcraft (Ref. 20), and is now integrated into Ansys Fluent as a rotor model.

The VBM replaces the three-dimensional rotor with an actuator disk which has momentum source terms distributed across the rotor disk area, so the flow over individual rotor blades are not computed directly. The method computes rotor forces using blade element theory, utilising lookup tables for lift and drag coefficients for aerofoil sections that represent the blades of the rotor (Ref. 15). The model requires the radius of the rotor to be specified, along with the number of blades and the rotor speed. Rotor blades are represented as aerofoil sections which are customised in terms of aerofoil type, twist and chord.

The model has the further built-in functionality to allow trimming of the rotor through representative collective and cyclic inputs. Trimming is achieved through a Newton-Raphson iterative method, which allows for the model to operate at a desired thrust, pitching and rolling moment (Ref. 21). The VBM has been shown to agree well with experimental wind tunnel data (Ref. 20). Crozon et al. (Ref. 14) also applied a similar actuator disk model in a CFD study and showed the results were in good agreement to those obtained by computing the flow over individual rotor blades. The VBM was therefore considered to be an effective method of including the helicopter in a coupled airwake/rotor CFD simulation.

The rotor used in this study had a radius of 7.01 m with 4 blades and a rotational speed of 33.93 rad s^{-1}. The aerofoil section used for the blades was the NACA0012, with blades featuring a twist angle of 0° and varying chord lengths along their span. Trimming for the model was enabled with the model set to trim to a desired thrust coefficient, pitch-moment coefficient and rolling-moment coefficient of 0.005, 0 and 0 respectively (It is worth noting that the VBM model within Ansys Fluent utilises the American convention for thrust coefficient (Ref. 15)).

5. RESULTS

CFD modelling was conducted for two different wind directions, northerly and southerly, as shown earlier in Figure 3. The northerly wind passes over the hospital buildings and through the channel formed between the large hospital building and the adjacent smaller buildings. It can, therefore, be expected that the northerly wind will create a more turbulent air flow to interact with the helicopter downwash than winds from the south. As described earlier, the helicopter is aligned with the Y-axis, so the northerly wind will approach the helicopter from 30° off the port side and the southerly wind will approach from 150° off the starboard side.

Considering the northerly wind case, Figure 7 shows contours of velocity magnitude in the vertical plane aligned with the wind direction. The image shows the flow being affected by the presence of the buildings upstream, as indicated by the flow streamlines. Furthermore, two regions of recirculation can be observed: one below the rotor at the front of the helicopter and another underneath the helipad. Streamlines further highlight that the flow is being redirected downwards by the helicopter rotor. Redirected flow can be seen to impact upon the helipad before moving towards the ground further downstream. Looking at the velocity magnitude, the flow increases to a velocity of about 25 ms^{-1} at the surface of the helipad due to the interaction with the rotor. The flow can be seen to move from the surface of the helipad towards ground level, while reducing in velocity to about 10 ms^{-1}. As defined previously in Figure 3, the helipad for this hospital site is positioned in a car park, meaning that this flow is being directed towards an area where people could be affected.

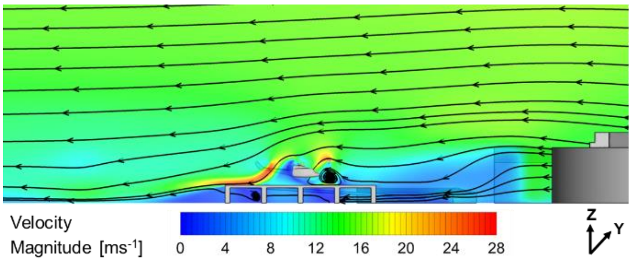

Figure 7: Contour of velocity magnitude in the flow direction passing through the rotor centre for northerly wind case.

Figure 8 shows velocity magnitude in the vertical plane aligned with the X-axis where the plane passes through the centre of the rotor. A large recirculation region is present at the building upstream of the helipad, with the recirculation zone in front of the helicopter again being visible. Flow is once again observed to be redirected by the helicopter rotor, reaching a velocity of approximately 23 ms^{-1} at the helipad surface. The flow also can be seen to move off the helipad to ground level where it has a velocity of about 6 ms^{-1}.

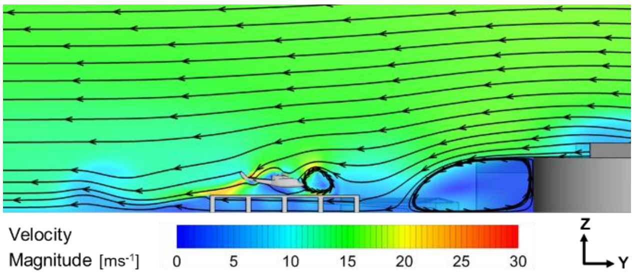

Figure 8: Contour of velocity magnitude in the X-axis passing through the rotor centre for northerly wind case.

Similar flow features can once again be seen in Figure 9 which shows the velocity magnitude in the vertical plane aligned with the Y-axis where the plane passes through the rotor centre. A recirculation zone is present where the flow encounters the body of the aircraft, with flow direction being influenced by the rotor. Redirected flow in the Y-axis, however, seems to remain largely at helipad level especially compared with flow seen in the other planes. The flow reaches a maximum speed of about 23 ms^{-1} at the surface of the helipad and reduces to about 5 ms^{-1} at ground level.

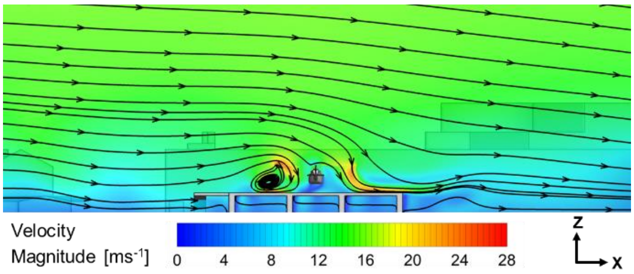

Figure 9: Contour of velocity magnitude in the Y-axis passing through the rotor centre for northerly wind case.

The impact of such velocities on people can be assessed by looking at the effects of different windspeeds on people. Although such studies have not been conducted to focus on the effects of downwash/outwash, they are able to provide insight into potential effects. Table 1 provides a breakdown of different windspeeds and their associated effect on a person from different sources. The table indicates that caution should be taken in areas where the wind speed is approximately 15 ms^{-1}, as control of walking may be difficult. As the wind speed increases above 15 ms^{-1}, the severity of the effect of the flow on individuals also increases to potentially dangerous levels. At wind speeds of around 20 ms^{-1} or higher individuals may be blown over. It is important to note that such values would be lower for those belonging to the older demographic with Hunt et al. suggesting that a gusty wind of 8.5 ms^{-1} would have a quantifiable effect on stability for people older than 50 years in age (Ref. 6).

Table 1: Effect of different windspeeds collected from different sources (Ref. 4-7).

Source	Windspeed, u [ms^{-1}]	Effect Description
Murakami	< 5	No effect
	5 – 10	Some Effect - Footsteps sometimes irregular
	10 – 15	Serious Effect - Walking irregular, walking difficult to control, upper body bends windward
	> 15	Very Serious Effect - Walking impossible to control, dangerous for elderly person, body blown sideways
Hunt	< 6	Little effect
	< 9	Most performance unaffected
	< 15	Control of walking bought into question
	< 20	Safety of walking bought into question
Anon	10	Limit for comfort when standing or sitting for lengthy periods in open spaces
	15	Limit of acceptability for comfort whilst walking
	18	Threshold of dangerous level
	23	Completely unsuitable for walking
Bottema	8 – 10.7	Wind force felt on body; possible stumbling when entering a windy zone
	10.8 – 13.8	Difficult to walk steadily
	13.9 – 17.1	Inconvenience felt when walking
	17.2 – 20.7	Great difficulty with balance in gusts
	20.9 – 24.4	People blown over

While air velocity magnitudes of up to 25 ms^{-1} are predicted over the helipad, it is more useful to consider the velocities where members of hospital staff or the public might be present. To achieve a more accurate representation of the effect on people, the velocity magnitude in a horizontal plane at a height of 1.75 m above ground level is shown in Figure 10. This height corresponds with the average height for a male in England (Ref. 22).

The figure shows the flow field around the hospital buildings, car park and helipad. Areas with wind speeds of about 13 ms^{-1} can be seen upwind of the helipad, due to the channelling effect between the buildings, and downstream of the helipad in the area which is designated as a car park and public roads. According to Table 1, people within these areas are likely to have trouble walking, with potentially more serious effects on those of an older demographic.

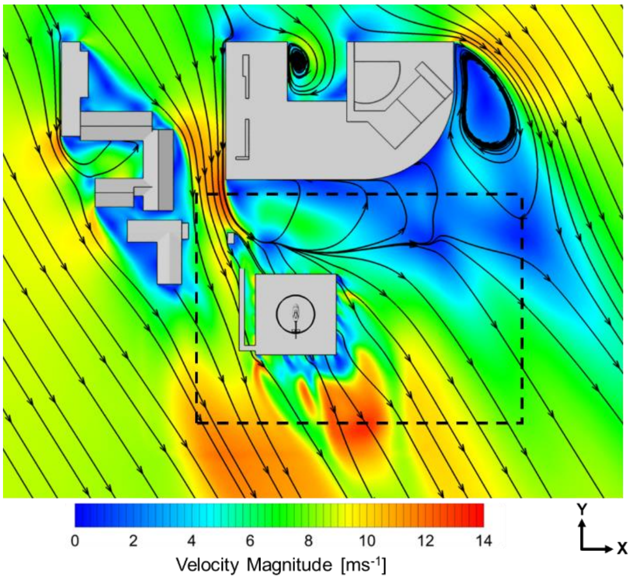

Figure 10: Contour of velocity magnitude in the horizontal plane at a height of 1.75 m from ground level for northerly wind case.

Although the use of a time-averaged solution allows for an initial understanding of the wind speeds around the site to be achieved and areas of high mean velocity magnitudes to be observed, it is important to note that in a real-world environment the site would be susceptible to velocity fluctuations. These fluctuations are not captured by a time averaged solution such as the RANS model used. The CFD simulation does, however, calculate the turbulent kinetic energy, k, which allows for velocity fluctuations to be approximated. Within RANS models the turbulence is assumed to be fully developed and isotropic, resulting in the assumption that velocity fluctuations for X, Y and Z components are equal (Ref. 23). Therefore, an approximation for the velocity fluctuation can be obtained from the standard deviation, sd, of a velocity component which can be expressed in terms of turbulent kinetic energy, as described in Equation 2.

(2) $$sd = \sqrt{\frac{2}{3}k}$$

Figure 11 presents standard deviation of velocity magnitude, assumed to be the fluctuations one would experience in x or y velocities, in the horizontal plane also at a position of 1.75 m from the ground. In some areas around the car park a standard deviation of over 3 ms^{-1} can be observed, particularly in regions just downstream of the helipad, with background atmospheric turbulence at this height having a standard deviation of about 2 ms^{-1}. Superimposing the calculated fluctuations values on the velocity magnitude obtained, indicates that there is potential for the flow in some areas of the site to reach speeds greater than 15 ms^{-1}. This causes the velocity to move into regions of Table 1 which are highlighted as being an area of potential danger for pedestrians being able to move through such a site, especially that of the older demographic.

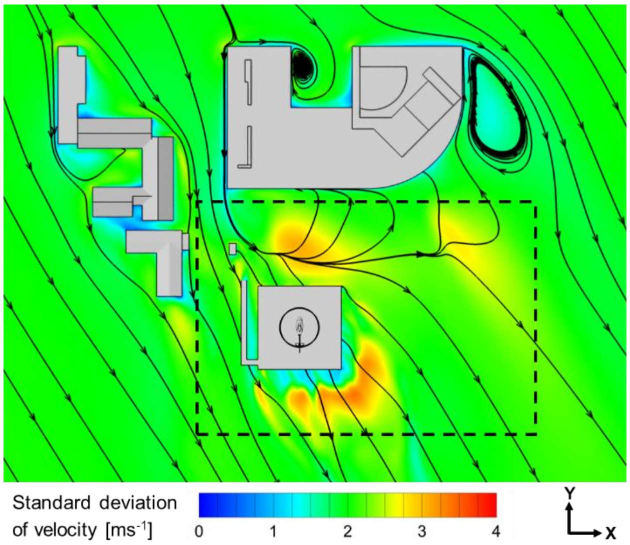

Figure 11: Contour of standard deviation of velocity in the horizontal plane at a height of 1.75 m from ground level for northerly wind case.

When the wind direction is changed to southerly, the buildings no longer affect the air flow approaching the helipad and the helicopter. Figure 12 shows velocity magnitude in the wind direction plane with a southerly wind direction. The rotor again influences the flow direction, resulting in some flow being deflected towards ground level. Interaction with the rotor results in the flow reaching speeds of about 27 ms^{-1} at the surface of the helipad.

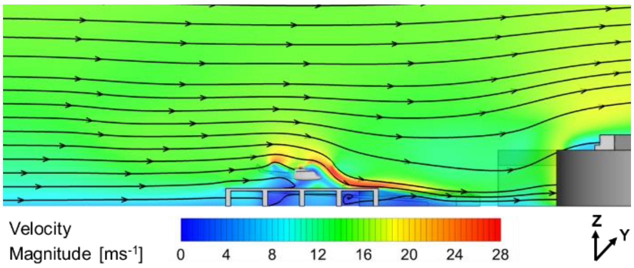

Figure 12: Contour of velocity magnitude in the flow direction passing through the rotor centre for southerly wind case.

Analysing the effect of a southerly wind in the vertical plane aligned with the X-axis, shown in Figure 13, air speeds up to about 26 ms^{-1} are seen directly below the rotor at the front of the helicopter. As the air flows off the helipad, it is then deflected upwards by the presence of the hospital buildings.

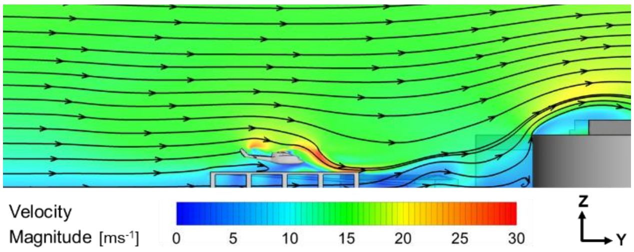

Figure 13: Contour of velocity magnitude in the X-axis passing through the rotor centre for southerly wind case.

Looking at the flow in the vertical plane aligned with the Y-axis, as seen in Figure 14, the interaction of the southerly wind with the helipad and the helicopter causes the incoming air flow to be deflected upwards in this instance. The flow can be seen to reach a velocity of approximately 26 ms^{-1} at the surface of the helipad as the air is drawn down by the rotor downwind of the helicopter.

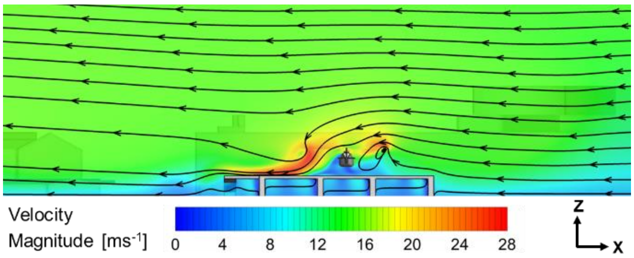

Figure 14: Contour of velocity magnitude in the Y-axis passing through the rotor centre for southerly wind case.

Examining the velocity magnitude in the horizontal plane at a height of 1.75 m above the ground, Figure 15, shows that velocities of approximately 13 ms^{-1} are present in regions designated as the car park. The figure also indicates numerous regions of recirculation downstream of the site due to the flow interaction with the hospital buildings. It is important to note that the channelling effect in the southerly case is worse with velocity magnitudes of above 17 ms^{-1} being observed. This is not directly seen in the figure due to values being clipped to allow for easier comparison between the northerly and southerly case in the immediate vicinity of the helipad. Pedestrians passing through areas affected by channelling effects would experience windspeeds which are already approaching safe limits.

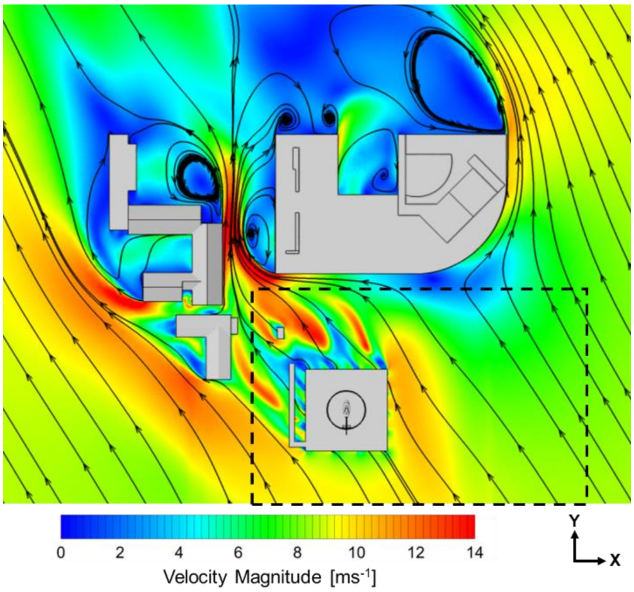

Figure 15: Contour of velocity magnitude in the horizontal plane at a height of 1.75 m from ground level for southerly wind case.

As observed in the northerly wind case, risk to pedestrians in the immediate area around the HLS is increased due to the presence of velocity fluctuations that would be expected in a real-world scenario. These fluctuations were calculated with the same procedure as described above with the use of Equation 2 and are presented in Figure 16. Fluctuations in the southerly case are slightly higher reaching velocities of about 4 ms^{-1} in regions surrounding the helipad which is designated as a carpark and public walkways. Such fluctuations can also be seen between buildings where the channelling affect is present. Superimposing calculated fluctuations on velocity magnitude obtained from simulations results in some areas of the site reaching speeds of above 18 ms^{-1}, considered dangerous and bringing into question balance concerns for individuals in the vicinity. Once again, this poses an even greater threat to individuals who are more unsteady on their feet.

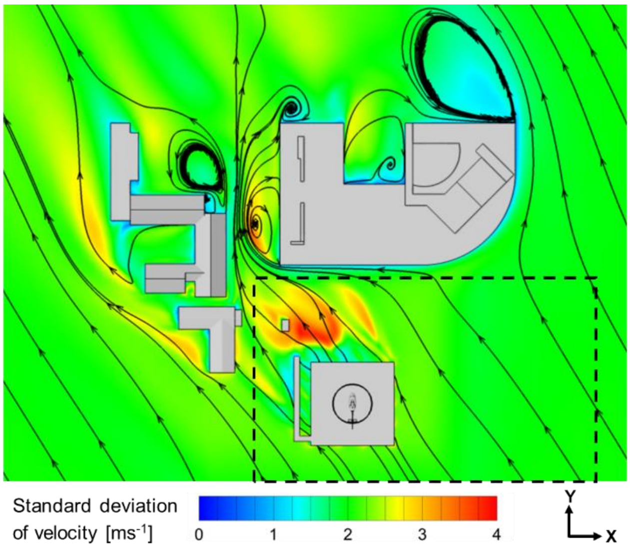

Figure 16: Contour of standard deviation of velocity in the horizontal plane at a height of 1.75 m from ground level for southerly wind case.

Comparing the two wind directions, it is evident that windspeeds in the area around the HLS are generally higher in the southerly scenario, likely due to the oncoming flow being unobstructed before interacting with the rotor. In contrast, the presence of nearby buildings did alter the airflow in the northerly case, affecting the rotor interaction and the downwash velocities. This suggests that the interaction between the rotor downwash and building-induced airwakes can influence the flow dynamics, potentially altering the velocity profiles experienced around the landing site. While the presence of buildings can lead to lower velocities around the landing site, the effects of a turbulent airwake shedding on the rotor could further amplify these interactions. Such a turbulent interaction is not fully captured by this study due to the use of a RANS method; this limitation highlights the need for future work to explore these effects in more detail utilising unsteady CFD methods. Furthermore, the interaction was also evaluated in a limited study in terms of only utilising two wind directions and one aircraft position. To provide a more comprehensive study, the effects of different aircraft positions could be evaluated to provide an insight into what conditions would be expected as the aircraft manoeuvred to and from such a landing site.

6. CONCLUDING REMARKS

This study has shown how a helipad constructed close to hospital buildings can create air speeds at ground level that are dangerous for people, particularly for those who might be unsteady on their feet. Analysis of two opposing wind directions highlights that calculated velocities in the area around the HLS were higher for a wind from a southerly direction where flow was unobstructed before interacting with the helicopter. Winds from the northerly direction were obstructed by the hospital buildings. It is noted that the unsteady wake that would be created from shedding from the upstream structures may lead to more complex rotor interactions. In both cases, velocities do indicate potentially hazardous windspeeds for people in the environment, generated by helicopter downwash. Observed velocities were deemed more serious when fluctuations in the mean air speed, estimated from the turbulent kinetic energy, were considered.

For a prevailing wind speed of 10 ms^{-1}, for both wind directions, mean wind speeds in the order of 13 ms^{-1} have been predicted for the areas adjacent to the helipad where pedestrians can be expected to transit. Air speeds in excess of the 20 ms^{-1} were observed on the surface of the helipad. Although such high-speed flow remained largely at helipad level, this does further pose the question if similar speeds may be generated at ground level, in areas of public access, when the aircraft is manoeuvring to and from the helipad. This, and the effect of unsteady air flows are left as an area of future work.

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