CFD Modelling of Helicopter Downwash and Assessment of its impact on Pedestrian Comfort

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ABSTRACT. This study used computational fluid dynamics (CFD) study to investigate the impact of helicopter downwash on pedestrian comfort. The initial stage of the study involves the development of a helicopter downwash model that was compared to experimental values which showed some degree of coherence with areas situated downstream of the helicopter rotor. The initial stage was used to find suitable modelling parameters and an adequate resolution of computational mesh to produce a reliable helicopter downwash model. The final stage of the study is to integrate a helicopter in a built environment and assess the impact of downwash on pedestrian comfort. The concluding stage of the study showed that helicopter downwash effects can impose discomforting conditions in the immediate vicinity of the helicopter along with some minute propagating effects further downstream. Although its magnitude is smaller compared to effects of prevailing wind a local mitigation must be separately planned to deal with the effects of helicopter downwash.

KEY WORDS: Computational Fluid Dynamics (CFD); Navier-Stokes; thermal comfort; pedestrian comfort, helicopter downwash.

1 INTRODUCTION

Helicopter activities within the built environment have become more commonplace. Helicopters are utilised for purposes such as life safety, transport and broadcasting. Due to its relatively small infrastructure demands compared to airplanes, helipad facilities are commonly found on many buildings including hotels, stadiums and hospitals.

As the helicopter generates thrust to propel it from the ground, it induces a downwash effect. Due to the relative proximity of a helipad relative to the ground, it can adversely affect the pedestrian's underneath. Therefore, when making assessments of the wind microclimate in urban environments, it is important to account for the interaction between the helicopter and the built environment.

Urban authorities and councils are beginning to recognize the importance of pedestrian wind comfort and wind safety. The Dutch Wind Nuisance Standard [1], to the best knowledge of the authors, is the first standard in the world to account for pedestrian wind comfort in the built environment.

As with any computer simulation, the quality of the results is dependent on the quality of the inputs, the assumptions, modelling characteristics employed and the equations used to represent the phenomena. There will inevitably be approximations, and a robust model validation process is essential. Expertise and a strong knowledge of fluid mechanics is required to properly set up a CFD model in order to reflect the real world situation. In order to capture the phenomena within the required resolution, large finite volume models require significant processing power. These large models generate a vast amount of data, which in turn needs to be stored and analysed. The advantages of CFD however, far out-weigh the disadvantages. For this study the phenomenon of interest is known as the downwash effect produced by helicopters.

2 RESEARCH SCOPE

The initial stage of the study involves the development of a helicopter downwash model that behaves similarly to experimental values. This is done by emulating the study performed by the G.W. Leese [2] in a CFD model the effectiveness of the Virtual Blade Model can be characterised . Another scope of this section find suitable modelling parameters and an adequate resolution of computational mesh to produce a reliable helicopter downwash model in relation to experimental values. The next stage of the study is to integrate a helicopter in a built environment and assess the impact of downwash on pedestrian comfort. This study will use the Lawson Comfort Criteria which is a scale used to evaluate pedestrian comfort under different activities. The final stage will introduce a helicopter with the built environment and analyse changes to the pedestrian comfort.

3 LAWSON COMFORT CRITERIA

The Lawson Comfort Criteria is a specified range that quantifies an individual's experience with a local wind micro-climate [2,3]. This. A person's discomfort is dictated by the strength of the wind experienced in conjunction with numerous factors such as clothing, general environment, expectation, temperature, humidity and sunshine. In general, the acceptability criteria rely on both comfort and distress. The Comfort levels show how tolerable is the wind condition in a specific area and how functional is it for its intended use.

For instance a public park will have a lower threshold windspeed compared to a walkway towards a bus stop where the pedestrians can tolerate a higher wind speed due to the difference in clothing, posture and expectation. The onset of discomfort criteria depends on the mean hourly wind speed which is satisfied if the threshold wind speed is not exceeded for more than 5 % of the time. Each activity has different range of exceedance which is outlined in the table below Fig 1 where green is considered acceptable, yellow means the space will be tolerable and orange will deem it unacceptable. An “Acceptable “condition means that wind is not felt by pedestrian , “Tolerable” means that the force of the wind can be felt on the skin but a pedestrian can adjust to it correspondingly while unacceptable means that space is not suitable for occupants to use it for its designed function.

Distress levels indicates the safety criteria of a space and deals with wind speeds significantly greater than that of comfort. There are two types of criterion which applies different levels of infirmity. For the “General Public” the distress criteria is not satisfied when a mean hourly speed of 15 m/s and a gust speed of 28 m/s are exceeded more than once a year. For the “Able- Bodied” the distress criteria is not satisfied when a mean hourly speed of 20 m/s and a gust speed of 37 m/s are exceeded more than once a year. Where the distress criteria is not satisfied pedestrian access should be discouraged as it will be tremendously difficult to navigate this space and considerably unsafe for pedestrians. Fig 1 highlights the distress levels which shows the pink for “General public” and the red for “Able - Bodied ” pedestrians.

Wind effect	Threshold	Stationary	Strolling	Transit
Calm				
Felt on face				
Leaves move	4.0m/s			
Dust raised	6.0m/s			
Felt on body	8.0m/s			
Hard to walk	10m/s			
Trees moving				
Storm	15m/s			
Dangerous	20m/s			

Fig 1: Lawson Comfort Criteria

Before the Lawson Comfort Criteria , wind engineering used the Beaufort scale was the first empirical measure that related wind speed to observed conditions, it has been presented and incorporated in wind comfort studies [5,6]. Other authors [7] also proposed the standardising of threshold wind velocities for pedestrian wind comfort

More detailed comfort criteria reflecting individual opinions on acceptable frequencies of occurrence of various wind speeds have been proposed in [8,9 and 10]. Later, grades of comfort are introduced related to the probability that a threshold wind speed may be exceeded [9].

4 ADVERESE WIND EFFECTS

Wind effects is heavily considered on building design and as such all buildings are built to withstand wind loading. Under extreme circumstances the fluid structure between prevailing wind and a structure can lead to catastrophically failures. Although the adverse effect of building and wind interaction does not stop there, as wind hits a bluff body it navigates around it and takes the path of least resistance. Translating this effect to a series of development a particular arrangement of buildings can impose a local wind microclimate on an area. As a result different flow phenomenon can be experienced at different location in a development given a particular building arrangement. Adverse wind effects are often what causes discomforting or distressing conditions in a particular space.

One of the common wind effects found in a series of buildings is the sheltering effect. When buildings of similar height are in close proximity to each other it provides a sheltered space in between the gaps of the buildings as each upstream building allows the wind to pass over it. However, given a sufficient large gap wind can be invited into this gap due to a presence of a low-pressure space. This effect is at its strongest when the spacing formed in between buildings is at 2.5 heights where the gap is getting filled and emptied cyclically. Another concerning wind phenomenon occurs when buildings in close proximity of each other forms a narrow gap it forces a large volume of wind through it and causes it to accelerate which brings about discomforting conditions in this space. Downdraft is another adverse effect that is unique to tall buildings, if a building is significantly taller to buildings surrounding it fast high wind speed at higher elevation can hit the building which directs it to the base of the building. Areas close to a corner of buildings tend to be windy as this is where separation occurs when wind hits a bluff body and navigates its way around it.

5 HELICOPTER DYNAMICS

Downwash is produced due to the production of thrust by the rotor blades. Most helicopter will contain two sets of rotors which are the main rotor and tail rotor. The main rotor generates the thrust required to generate lift. Thrust is produced under two controls, firstly is the collective control which increases the pitch angle of the rotor blades that will subsequently increase drag but also produce more lift as a result of a higher angle of attack. To sustain all these forces under a stable RPM the throttle controls are opened in order to produce a corresponding power output. The tail rotor counteracts the reaction forces experienced by the helicopter due to the generated thrust by the main rotor this is controlled by the anti-torque pedals. The cyclic controls are implemented to maneuver the roll and pitch angles of the helicopter which will allow it to move forwards, backwards and side to side. These components work hand in hand to stabiles and maneuver the helicopter towards a desired path.

6 HELICOPTER MODELLING

In the past there has been a number of attempts in modelling helicopter rotor blades. One of the pioneer models is the mathematical model of an actuator disk which was used by

Rankine et al. [11]. This method modelled the physical propeller blades as an actuator disk that is infinitely thin and is considered a one-dimensional analysis. The actuator disk supported a pressured difference on either side of the actuator disk which caused fluid to move across it that varied along the radius and azimuthally. The model does not incorporate complex viscous effects such as drag and momentum diffusion.

The Actuator Disk Theory was considered a coarse analysis as it completely disregards blade characteristics and interaction between the blade and surrounding fluid. Alternatively, the Blade Element Theory (BET) is another form of the rotor disk model that breaks up the rotor disk into discrete momentum sources which models a disk volume that is swept by spinning rotor disk about a rotor shaft plane [12]. This method calculates the blade forces on each point in the rotor disk region are calculated by accounting for the local flow field, the blade geometric angles and through the usage of a lookup table for the 2D lifting and drag line for a given aerofoil shape. Calculating the aerodynamic forces acting upon the blade gives rise to the resultant momentum sources imparted by the blade to the surrounding fluid for each discrete blade element. The total forces on the blade is calculated by integrating over the wing span from root to tip. The blade tip effect is included in the model to account for the presence of a relatively strong secondary flow in the form of blade tip vortices located close to the blade tip [13]. This is accounted for by specifying a correction factor to indicate the location on the rotor disk where this is in effect. The part of the rotor disk under the blade tip effects experience no lift forces but drag remains accounted for.

The calculated forces induced are instantaneous therefore it is necessary to account for the blades traversing across the fluid. Under a time-averaged simulation forces experienced by each element in the rotor disk model as the blades rotate about the rotor shaft plane is a fraction of the instantaneous forces experienced. To consider this the calculated instantaneous forces is subjected to a scaling factor to convert it to time-averaged forces. Under the assumption of constant rotational speed, the time averaging of a rotor over one period is a similar process as obtaining the ratio between the azimuthal angle of an element over one cycle.

7 MODEL SET UP

This study will model a UH-1H helicopter in the OpenFOAM environment and characterize its downwash effects using Virtual Blade Model.

7.1 Comparison of Experimental and CFD Model

The domain is comprised of a 154 x 154 m domain at 64 m high. The domain incorporates an inlet at the top to initialise flow into the setup by having a very low inlet velocity of 1 m/s , the sides are split into two groups where the top half is a symmetry wall and the bottom half are pressure outlets. The ground and the helicopter body have a no-slip condition. The helicopter operation was matched to those of a UH-1H helicopter and its blade geometry and blade profile were based from D. Lednicer 's material [14] and Airfoil tools [15].
Similar to the experiment the helicopter will be set up to hover at heights of 10, 30 and 70 ft. Same 14 number of probes will be placed at same locations as the transducers used in the experiment which are positioned at 360 °, 330°, 300°, 270° in relation to the helicopter nose. The transducers are spaced 4 feet apart and the first six transducers also collect velocity data at an elevation of 2, 4 and 6 feet above ground.

7.2 Effects of Helicopter Downwash on Pedestrian Comfort

For this section of the research the UH-1H helicopter was placed in a common built environment with a helipad in the middle where the helicopter is placed to hover at 18 m above ground level. Each section of the built environment is designed to invite an adverse wind phenomenon mentioned in section 4. Where a tall building is situated north of the site to promote downdraft, east of the site there is a development that has a pedestrian tunnel through it to promote downdraft and south and west of the site includes alleyways of different sizes to promote wind around corners and sheltering effects. Two simulations were ran for this section of the research where the first one involved no helicopter and ran a south-westerly wind of 9 m/s which is a common wind based on a Dublin windrose [16]. The second simulation ran a no wind case but incorporated a helicopter to assess if helicopter downwash compromised the pedestrian comfort in this built environment and also its magnitude compared to a prevailing wind. A total of Probes were placed in the vicinity of the expected adverse phenomenon and close to the helipad where the wind conditions are expected to be worst at a typical pedestrian height of 1.6 m.

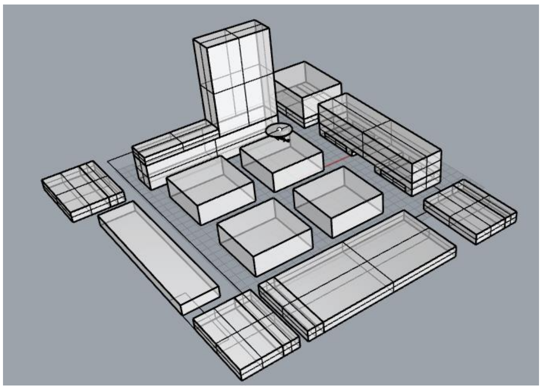

Fig 2 : Built Environment used to quantify effects of helicopter downwash

8 RESULTS AND DISCUSSION

8.1 Mesh Refinement

The mesh was initially optimized for the verification of the model versus experimental to assess the sufficient mesh resolution to fully account for the effects of helicopter downwash. The initial run had a cell count of 3 million cells and had a single refinement region encapsulating half of the rotor diameter which is extruded down directly beneath the helicopter body. The results show that the helicopter downwash was being under predicted throughout except for few probe locations that showed very low velocity measurements for both cases. This offset in velocities was highly apparent further downstream of the helicopter where some probes were predicting half of the velocity of what was recorded in the experiments. To remedy this further refinement regions were added that followed the general flow direction of the helicopter downwash which extended up 40 m from the helicopter rotor. Further refinement was added by adding an inflation layer from the ground to obtain a cell size of 0.4 m at ground level which aids in forming a better solution of the downwash effect the final cell count for the final iteration of the mesh is at 8 million cells.

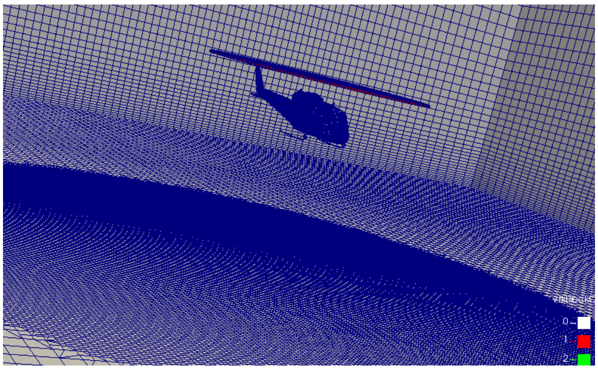

Fig 3: Computational Mesh usd in the study

8.2 Comparison of Experimental and CFD Model

A comparison of the recorded velocity of helicopter downwash was made between model and experimental values. Although this proved quite difficult due the data missing at certain locations from the experimental case. Overall from the CFD model shows a general trend that helicopter downwash was vertically dominant underneath the helicopter and became more apparent horizontal velocity away from the helicopter which holds true for all hover heights. By examining the graph at Fig 4 it is evident that from velocity pick up points 1-11 the velocity values do not deviate much from each other at these locations which are situated away from the helicopter. However when it comes to the velocity pick up number 12 onwards which is situated approximately underneath the helicopter the values predicted by the model tend to be more vertically dominant whereas the experiment records mainly horizontal flow at these locations. Another thing that was evident in the model is that the magnitude of helicopter downwash diminished with higher hovering heights which is true both for resultant horizontal and vertical velocities as seen in Fig 5 where the flat line at probes 1 -17 shows vertical velocities measured at ground level and the experimental data also follows this trend.

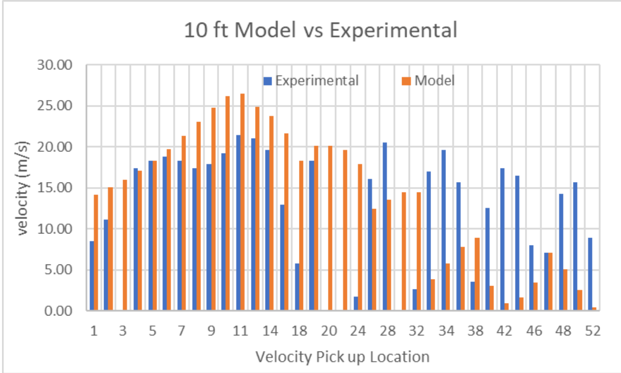

Fig 4: Horizontal velocity Measurements at a helicopter hovering 10 Ft.

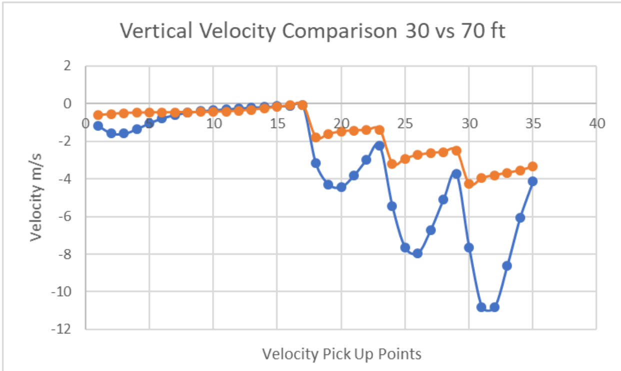

Fig 5: Vertical Velocity comparison between model helicopters hovering at 30 and 70 Ft.

There are numerous reasons why there are some discrepancies between the experimental velocity values versus the model values. From the experiment side of things which was performed in 1972 making it a fairly dated research. Firstly, no weather data was provided and given that the experiment was performed in an open environment the wind may have some influence on the data obtained. Also, the transducers used are quite old and most likely not calibrated given the incomplete data set that was published in the research. Filtering error could have occurred during data acquisition as horizontal and vertical velocity measurements were measured simultaneously and presented separately. A more recent research could benefit this study with improvements to data acquisition technology

From a modelling standpoint the Blade Element Model has some weaknesses. First is by not accounting for wing tip vortices a large part of the downwash characteristic is unaccounted. These vortices originate from blade tips which has a contribution to the overall downwash effect hence the discrepancies between the model and real world operating helicopter. The model indicates that this occurs on the last 4% of the blade span and the model resolves this by introducing no momentum in this part of the blades when transformed into the rotor disk region it's some area that does not provide a momentum source. The simulation used Reynold Averaged Navier Stokes (RANS) which timed averaged the effects of turbulence and helicopter downwash tends to be an unsteady phenomenon. Although the Blade Element |Theory does a good job of the blade interaction with the surrounding fluid transient modelling techniques such as Large Eddy Simulation (LES) or Detached Eddy Simulation which is a RANS and LES hybrid that could benefit this study dues to the unsteadiness of helicopter downwash by modelling small turbulent eddies that contribute to the downwash effect. Although one can consider that the Virtual Blade Model appropriate for quantifying the effects of helicopter rotor downwash further mesh study is required to form a fully integral solution due to the rapid changes in the velocity profile of a downwash effect.

Other sources of error from the model could be the difference in the blade profile used since two profile points were only given on the reference where a real rotor blade of a UH-1H could have a more intricate profile. Further mesh refinements could improve data obtained from the model along with stricter tolerance for the solvers implemented.

8.3 *Built Environment*

Results were collected from the two built environment simulation that was ran for this section of the study. First simulation included the built environment with no helicopter present that incorporated a south-westerly wind as seen in Fig 6. The results show that the built environment will experience calm condition for the most part particularly south of the developments. This shows that majority of the development are adequately sheltered due to the building blocks being situated relatively close to each other. There however are few exceptions to this firstly by examining south-east of the site high wind speed around the corner of buildings are detected. Wind speed recorded in this space exceed 10 m/s and would certainly cause an issue of discomfort to pedestrians regardless of the activity being undertaken. Funneling is highly apparent north west of the site as the streets get narrower due as the space gets tapered by the presence of two buildings and there is also a light funneling issue east of the site due to the tunnel although its presence is no that prominent due to the orientation of the tunnel in relation the wind passing it. The worst conditions occur north of the site. This is due to downdraft caused by the tall building where it hits by the fast free stream wind at a high elevation and it forces it to descend down to the base of the building. This induces a prolonged effect north east of the site where the high wind speed gets funneled furthered into the space in between the building. Highest recorded wind speed is recorded at 16 m/s which occurred in the aforementioned area. This is certainly an area susceptible to pedestrian distress.

Fig 6 : Velocity Contour at 1.6 m AGL for a built environment with a non operating helicopter

Results were also obtained for the built environment simulation with the helicopter rotor acting as the sole momentum source. The site is calmer overall under this condition. Many of the adverse wind condition detected in the previous simulation were diminished or reduced to none which included high wind speed around corners and funneling issue throughout the site. Since the orientation of the helicopter downwash is different from the prevailing wind this produced a distinct micro climate profile. In general the areas in the immediate vicinity of the helipad will experience elevated wind speed as seen in Fig 9. This is highly evident to the immediate west of the helipad facility due to a sufficient gap in between the helipad facility and the adjacent building the downwash from the helicopter gets funneled in between the space as seen in Fig 7. The T- junctions in the vicinity of the helipad experiences some vortices being diverted at ground level this is apparent north of the helipad which can be further examined at Fig 9 and south east of the helipad. It is notable that the northern vortices formed north of the helipad are far stronger than those at the south-east. This could be due to a number of reasons firstly the building at the north is far taller than the building to the east of the helipad which allows more wind to be diverted to the ground. Another reason would be the space north of the helipad is more confined compared to the t- junction formed in the east. Another observation from the microclimate obtained from this simulation is that helicopter downwash has some propagating effect further away from the helicopter as the wind traverses away from the helicopter.

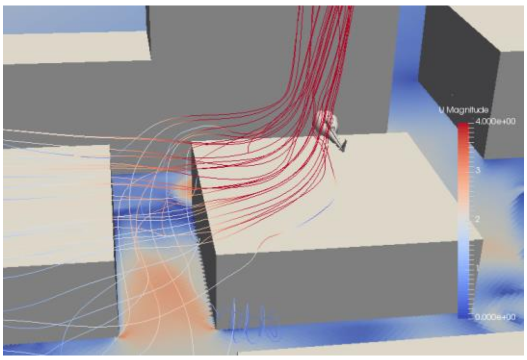

Figure 7: Sheltering effect west of the helipad facility

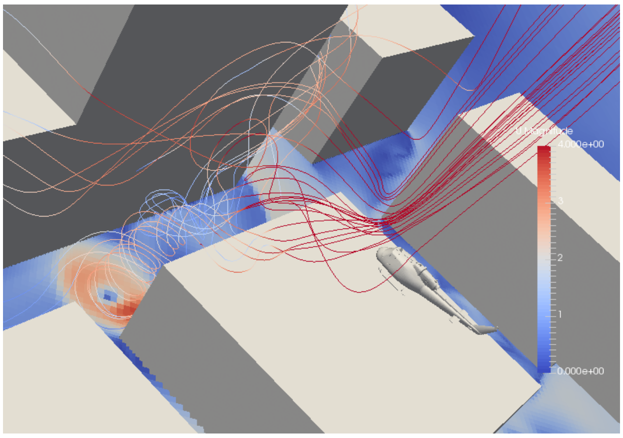

Fig 8: Downdraft due to helicopter downwash

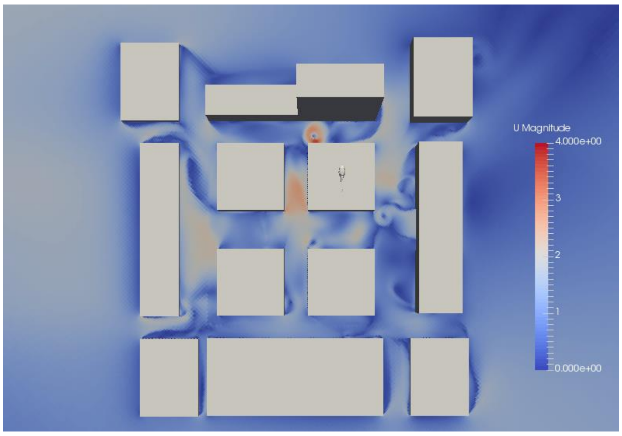

Fig 9: Velocity Contour at 1.6 m AGL for a built environment with an operating helicopter

9 CONCLUSION

This paper achieved to model helicopter downwash through CFD using the Virtual Blade Model which proved highly versatile. Despite its shortcomings and weaknesses such as the lack of accounting for wing tip vortices, requirement a high-resolution mesh to properly quantify for the effects of helicopter downwash and insufficient solution to account for the unsteady phenomenon of helicopter downwash it has proven effective for gauging the magnitude and extent of helicopter downwash. It was also tested versus a dated research which despite the incomplete data set was in accordance with most of the results particularly with downwash effects further downstream of the helicopter. It also agrees with the experiment that helicopter downwash effect induces a more dominant horizontal flow rather than a vertical flow for spaces not directly underneath the helicopter. Future work should evaluate other CFD methods to reduce the shortcomings of the Blade Element model.

Finally this study pioneered the assessment of the effects of helicopter downwash on pedestrian comfort. Through a built environment the effects of a prevailing wind were independently gauged against helicopter downwash. The results showed that the adverse effects of the prevailing wind is greater in magnitude and extent compared to the effects of helicopter downwash . Although that's not to say the effects of helicopter downwash is negligible because the immediate vicinity of the helipad facility will still experience some degree of discomfort and further contribute to the magnitude of experienced adverse wind effects. The study also showed that helicopter downwash will induce different microclimate profile than that of a prevailing wind which under the subject of Wind Engineering shows that mitigations geared towards prevailing winds may not be completely applicable for alleviating the effects of downwash on pedestrians. Future work should investigate the combined effects of prevailing wind and helicopter downwash as amalgamating effects of both will most likely pose distress and safety issues to pedestrians . The extent of the adverse effects of helicopter downwash should be quantified in further studies as this can aid in amending regulations in relation to planning for helipad facilities.

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