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Hong Kong International Airport

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Low level wind effects of the hangars at the Hong Kong International Airport

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ABSTRACT: In strong north to northwesterly winds associated with tropical cyclones, significant differences of the wind speeds ($\sim 5 - 8$ m/s) have been observed between the measurements of the north runway and south runway anemometers at the western part of the Hong Kong International Airport (HKIA). From the simulation results of a computational fluid dynamics (CFD) model, it is shown that the hangars between the two runways of HKIA could be a factor leading to the difference in the wind speeds,. Moreover, as found from the simulated wind field of this CFD model, the hangars could bring about significant variations of the winds at the western end of the south runway of HKIA that may affect the operation of the landing aircraft. Simulation results for a tropical cyclone case in 2008 would be discussed in this paper. They are found to be generally consistent with the wind data recorded onboard a landing aircraft and the pilot report of the winds experienced by this aircraft

1 INTRODUCTION

Windshear and turbulence associated with airflow disruptions by obstacles could bring difficulties to the control of the aircraft. The obstacles may be natural terrain. For instance, at the Hong Kong International Airport (HKIA), the complicated terrain of the mountainous Lantau Island south of the airport may lead to low-level windshear and turbulence in cross-mountain airflow. The geographical setup of HKIA could be found in Figure 1. There have also been suggestions of the low-level wind effect by artificial structures on the airport, such as buildings.

One case of suspected low-level wind effects by buildings on HKIA occurred on 23 August 2008. On that day, Typhoon Nuri brought gale force north-northwesterly winds to the airport. The anemometer at the western end of the north runway of HKIA recorded a wind speed of about 19 m/s, whereas that one at the western end of the south runway recorded a wind speed of about 12 m/s. The crosswind at the north runway was rather high so that aircraft landings took place at the south runway. However, two aircraft at about 10:30 and 10:50 a.m. respectively reported to have hard landing at the south runway. According to the pilot report from one of the aircraft, the plane appeared to “drop out of the sky” before landing, and experienced flipping to the right shortly after landing and passing out of the hangars to the left. Chan and Cheung (2009) studied that uphill effect of Lantau Island (an island to the south of the airport) may contribute towards the wind variation over HKIA. There is also a suggestion that the hangars might have caused turbulent airflow over the touchdown zone at the western end of the south runway.

The present paper aims at studying the potential effects of the hangars at the western side of HKIA on the north-northwesterly flow in the morning of 23 August 2008 using a computational fluid dynamics (CFD) model. The simulation results would be compared with the anemometer readings and the wind recorded on the aircraft.

2 CFD MODEL, MODEL SETUP AND GRIDDING

The model used for the study is FLUENT. The fluid is assumed to be incompressible and turbulent, as commonly adopted in environmental fluid mechanics studies under isothermal conditions. Hence, the mathematical model is in the form of Reynolds-averaged Navier-Stokes (RANS) equations that consist of the continuity and the pseudo steady-state momentum conservation. The finite volume method with the first-order accurate upwind scheme is used to discretize the transport equations for momentum, turbulent kinetic energy (TKE), and TKE dissipation rate, while the SIMPLE algorithm was used to solve the implicit pressure-velocity coupling in incompressible flow. Mathematical details of the model and another application of this model for a hypothetical building at the airport could be found in Liu et al. (2010).

The major buildings relating to the airflow disturbances at the western end of the south runway have been included in the CFD simulation, including the hangar 1, hangar 2, hangar 3A, CASL hangar and the engineering test-run facility, as shown in Figure 2. The mesh consists of about 4 million grids. The inlet and outlet directions are generally in line with the prevailing wind direction in the morning of 23 August 2008. A closer look of the meshing pattern could be found in Figure 3. It could be seen that the mesh is denser in the first 75 metres or so above ground and over the buildings and the runways.

As in Liu et al. (2010), in order to have a more realistic representation of the surface characteristics around the airport, different surface features with specific roughness lengths have been implemented in the simulation domain. The distribution of the surface features and the selected values of roughness lengths are shown in Figure 4. The latter is mostly based on the values available in http://www.most.gov.mm/techuni/media/CE_04016_chap5.pdf.

The background wind profile is based on the measurements from the radar wind profiler at Sha Lo Wan (location in Figure 1) at about 10 a.m. of 23 August 2008. The wind data are given in Table 1. The wind profiler measures the vertical profile of the horizontal winds by emitting electromagnetic waves with a frequency of about 1299 MHz into the atmosphere and receiving the reflected waves from the refractive inhomogeneity features in the air as advected by the horizontal winds. Due to the limited vertical extent of the simulation domain, only the wind data from the first two range gates are considered, namely, 116 and 174 m. Using the measurements at these two heights of the wind profiler, the following power law of the background wind speed profile is obtained:

$$u = 6.436z^{0.2255}$$

where u is the wind speed and z is the height above sea surface. The background wind direction is assumed to be uniform and taken to be that near the surface anemometer, namely, 346 degrees from the North. These background wind speed profile and wind direction are then used at the inlet for the model simulation.

3 SIMULATION WITHOUT THE BUILDINGS/STRUCTURES

Firstly, simulation is carried out with the absence of all the buildings/structures in Figure 2. Two aspects of the simulation results would be studied, namely, (a) comparison of the simulated winds at the anemometers at the western ends of the north and the south runway, and (b) cross-wind along the glide path of aircraft landing at the south runway from the west.

The simulated wind profiles at the two anemometer locations are shown in Figure 5. It could be seen that the two profiles look basically identical. As such, due to the roughness of the

surface only, the winds do not change much after passing over the airport surface, even for a height of about 10 m above ground which is the standard height of the measurement of the runway anemometers.

The simulated crosswind along the glide path is shown in Figure 6. The crosswind change from a distance of about 1000 m fore of the runway threshold to a distance of about 400 m aft of it is very gradual, and has a magnitude of about 2 m/s only. The change is related to the power law wind profile with height.

4 SIMULATION WITH THE BUILDINGS/STRUCTURES

With the presence of the buildings/structures, the simulated vertical wind profiles at the two anemometer locations are shown in Figure 7. It could be seen that there is significant difference of the wind speeds at a height of 10 m above ground, reaching about 6 m/s. The wind traces of 1-minute mean wind speeds at the two anemometers between 10 and 11 a.m., 23 August 2008 are shown in Figure 8. The wind difference is about 6.4 m/s over this hour, which is similar to the simulation result. However, the simulated wind speeds tend to be lower: it is just 7.2 m/s over the south runway, vs. 12.1 m/s of the actual anemometer measurement, and just 13.2 m/s over the north runway, vs. 18.5 m/s of the actual data. Such differences may be due to lower wind speeds as measured at Sha Lo Wan wind profiler as a result of uphill effect due to Lantau Island to the south (Chan and Cheung, 2009). In order to reach the wind speeds as measured by the two anemometers, the background wind profiler has been scaled up according to the following equation:

$$u = 10.75z^{0.167}$$

and this background profile as a function of height is given in Table 2.

The simulated wind speeds at the two anemometer locations using the scaled-up profile are shown in Figure 9. The wind speeds at a height of 10 m, namely, 12.5 m/s over the south runway and 18.4 m/s over the north runway, are more consistent with the actual observations. The simulated wind speed difference at 10 m at the two anemometers is 5.9 m/s, which is again similar to the actual observations. Thus, the buildings are believed to contribute towards the wind speed difference between the north and the south runways, at least at the western ends of the runways, for the present case of gale-force north-northwesterly wind.

In the following, only the results with the scaled-up wind profile would be presented. The simulated wind speed contours at a height of 10 m are shown in Figure 10. It could be seen that the buildings together result in a wake over the touchdown zone at the western part of the south runway. The resulting crosswind profile along the glide path for aircraft landing at the south runway from the west is shown in Figure 11. In general, there is a crosswind decrease of about 11 m/s from about 500 m fore of the touchdown point to the location just before touchdown. This feature is also shown in the actual wind data measured onboard an aircraft landing at that time (Figure 12), though the aircraft data do not show the fluctuations of the crosswind (at locations of about -500 m and -100 m in Figure 11). This crosswind change is much greater than the 7-knot criterion adopted for Schiphol airport (Nieuwpoort et al, 2006) and as such it may cause difficulties in the control of the landing aircraft.

Unfortunately, the aircraft wind data are not available after landing. The simulated result shows that there is a rather rapid increase of crosswind beyond the landing point, namely, from about 8 m/s rising up to 19 m/s or so after passing out of the wake of the buildings/structures.

This is consistent with the pilot report that there was much stronger crosswind beyond the buildings, causing the aircraft to flip to the right.

5 DIFFERENT WIND DIRECTIONS

As the wind direction was not steady with time in reality, the building wake over the south runway has been simulated with different background wind directions, namely, from 320 degrees to 360 degrees from the North, with an interval of 10 degrees. For simplicity, only the results of 320 and 360 degrees are presented in this paper.

Figures 13(a) and (b) show the wind speed contour at 10 m and wind profile along the glide path for a background wind direction of 320 degrees. As expected, the building wake mainly affects the runway itself. The crosswind change over the airborne region (i.e. before the touchdown) is rather gradual, with a change of about 4 m/s over a distance of 1000 m.

Figures 14(a) and (b) show the corresponding results for a background wind direction of 360 degrees. It appears that the building wake affects the western end of the south runway. From the glide path plot, the wake area (lower crosswind) mostly appears between the touchdown point and 400 m fore of it. The crosswind drop (about 6 m/s) occurs before about 400 m from the touchdown point.

As such, the above two wind directions represent the situations in which the major part of the building wake occurs either after the touchdown (320 degrees) or before the touchdown (360 degrees). The wind direction in the morning of 23 August 2008, namely, 346 degrees, corresponds to a situation somewhere in between. Under this circumstance, the aircraft may experience crosswind drop when moving into the building wake before touchdown, and crosswind rise in moving away from the building wake after touchdown.

6 CONCLUSIONS

The low-level wind effects of some buildings/structures at the western part of HKIA for gale-force north-northwesterly wind in the morning of 23 August 2008 are studied in the present paper using a CFD model. With the presence of the buildings/structures, the wind speed difference between the north and south runway anemometers is reproduced, and the crosswind drop along the glide path before the touchdown (for landing at the south runway from the west) is consistent with the aircraft data. The crosswind rise after passing out of the buildings/structures is also generally in line with the pilot report. The building wakes in different background wind directions are simulated and the wind direction in the morning of 23 August 2008 appears to correspond to the situation in which crosswind drop may be experienced before touchdown and crosswind rise after the touchdown.

Further study for the case in the morning of 23 August 2008 would be carried out in two aspects. First, simulation would be carried out with another CFD model that has been calibrated against wind tunnel data and employed previously for similar study of low-level wind effects of buildings at another airport. Second, simulation would be repeated with both the buildings/structures and the mountains to the south of the western part of HKIA in order to have a more realistic representation of the setup of the obstacles. The present paper focuses on the buildings/structures themselves while a previous paper (Chan and Cheung, 2009) considers the natural terrain only in which the uphill effect of Lantau Island is shown to cause wind variations over the airport as well. It would be important to see the resulting wind effect when both obstacles are present. The wind fluctuations over the western part of the south runway may be

related to the effects of the hangars, the natural terrain, or both of them. The study result could only be more complete by considering both the hangars and the natural terrain.

7 ACKNOWLEDGEMENT

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8 REFERENCES

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Height (m)	velocity magnitude (m/s)	Direction (degree)
116	18.8	346
174	20.6	344
231	20.2	347
289	21.4	344
347	20.5	357

Power law: $u = 6.436z^{0.2255}$
 Under 116m, Wind direction: 346 deg

Table 1 The background wind profile for the model simulation, based on the wind measurements of Sha Lo Wan wind profiler.



Figure 1 The geographical setup around HKIA. Height contours are in 100 m. The red dots are the locations of the surface anemometers, whereas the green dots are the wind profilers.

Height (m)	velocity magnitude (m/s)	Direction (degree)
0	0	346
10	15.8	346
116	23.8	344

Scale Up Power law: $u = 10.75z^{0.167}$

Table 2 The background wind profile for the model simulation, after scaling up to match the 10 m wind data from the runway anemometers at the airport.



Figure 2 Locations of the airport facilities that have been included in the simulation study of the present paper. Also shown in the figure are the locations of the two runways of HKIA.

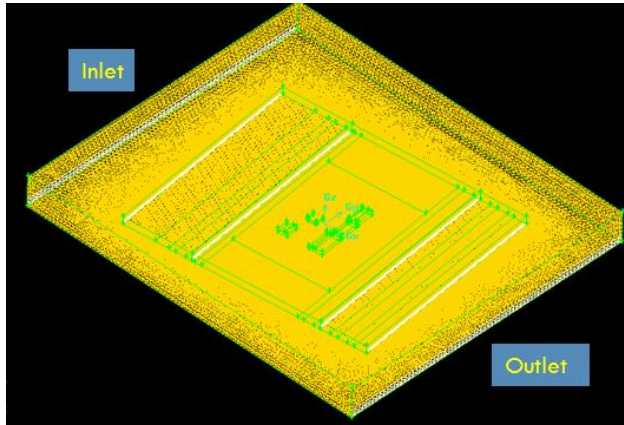
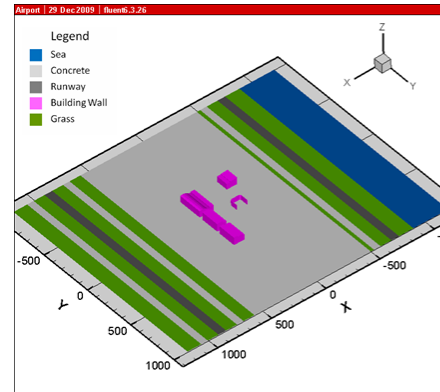


Figure 3 Model setup for the simulation, showing the mesh as well as the buildings and runways included in the simulation.



	Roughness height k(ft)
sea	0.05
Concrete	0.005
Runway	0.0005
Building wall	0.005
Grass	0.05

Source:
www.most.gov.mm/techuni/medial/CE_04016_chap5.pdf

Figure 4 The buildings and runways included in the model simulation. The roughness lengths for different surfaces are given in the table on the right hand side.

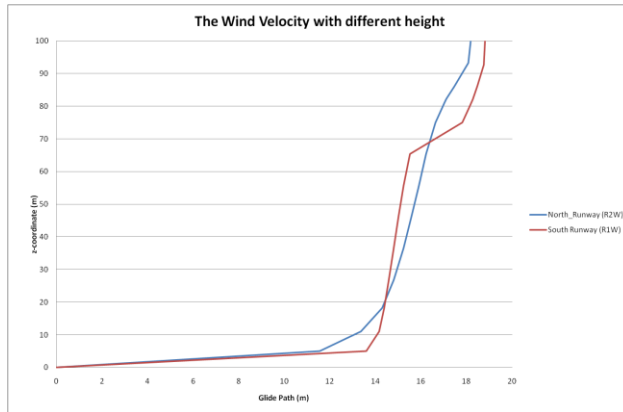


Figure 5 Vertical wind profiles at the anemometer locations at the north and the south runways of HKIA for the simulation without the buildings.

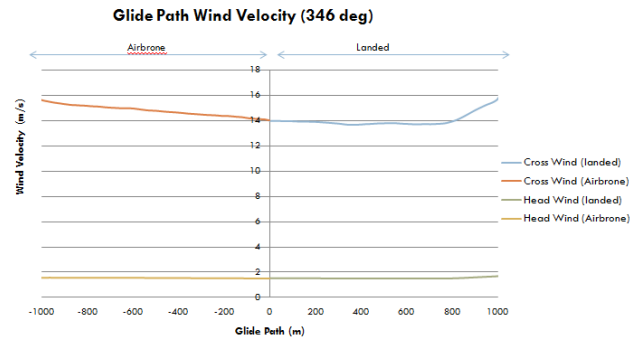


Figure 6 Crosswind (upper) and headwind (lower) profiles over the glide path for the aircraft landing at the south runway of HKIA from the west for the simulation without the buildings. Landed means 10 m above runway.

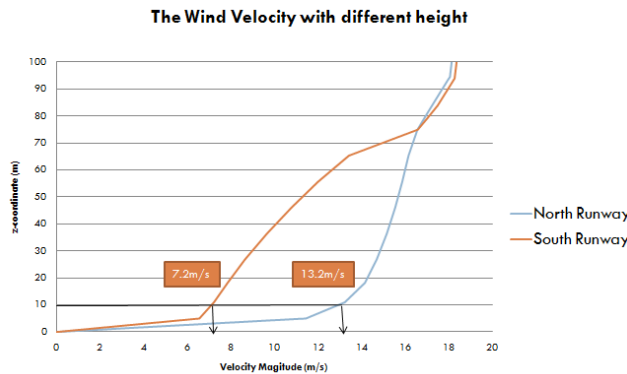


Figure 7 Same as Figure 5 but for the simulation with the presence of the buildings using the background wind profile in Table 1.

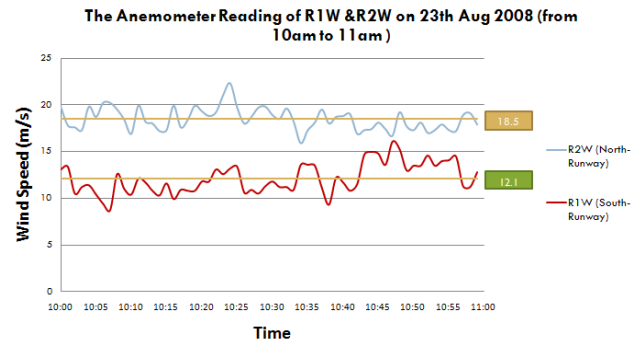


Figure 8 Actual wind speed readings from the two anemometers at the western ends of the two runways of HKIA during the tropical cyclone case of 23 August 2008.

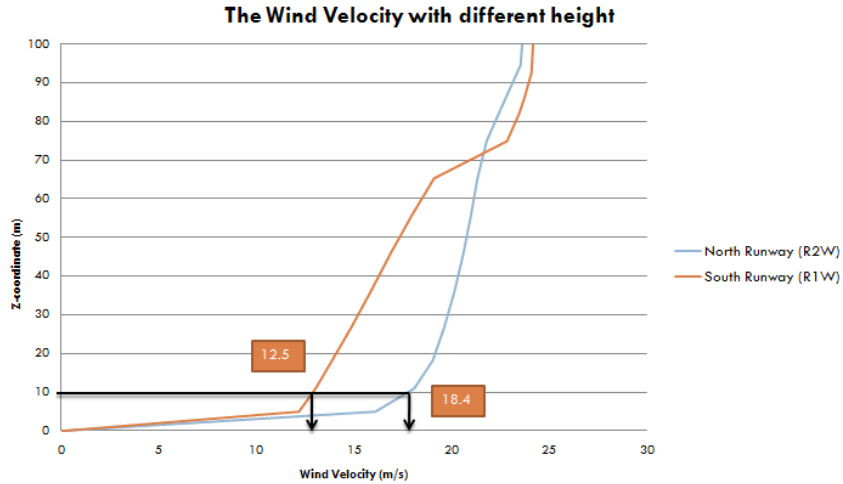


Figure 9 Same as Figure 5 but for the simulation with the presence of the buildings using the background wind profile in Table 2.

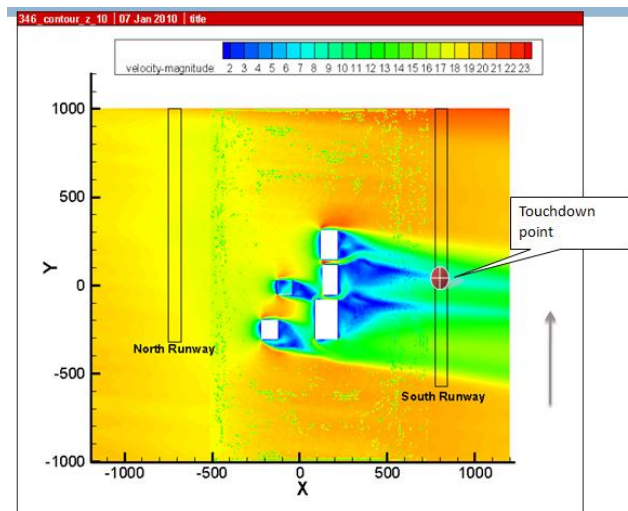


Figure 10 Wind speed distribution in the model simulation domain at a height of 10 m for the simulation with the buildings using the background wind profiler in Table 2.

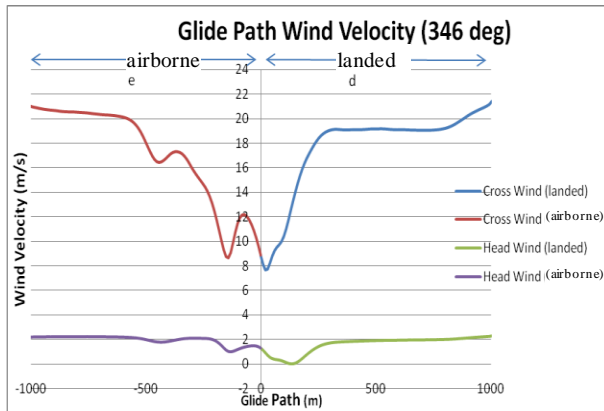


Figure 11 Same as Figure 6 but for the simulation with the buildings using the background wind profiler in Table 2.

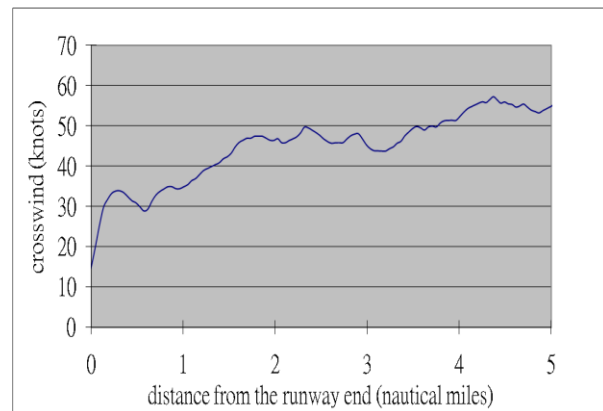
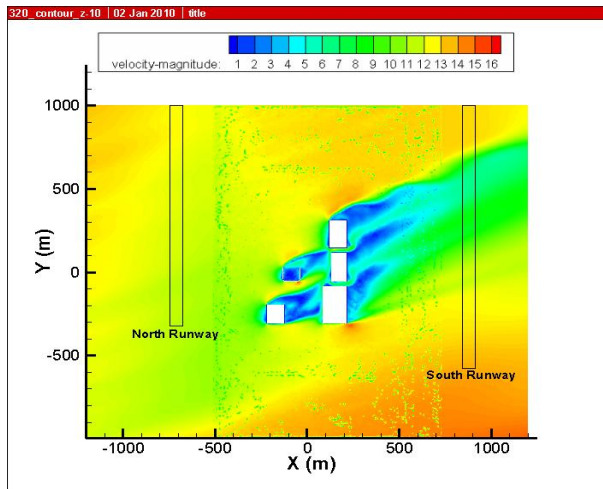
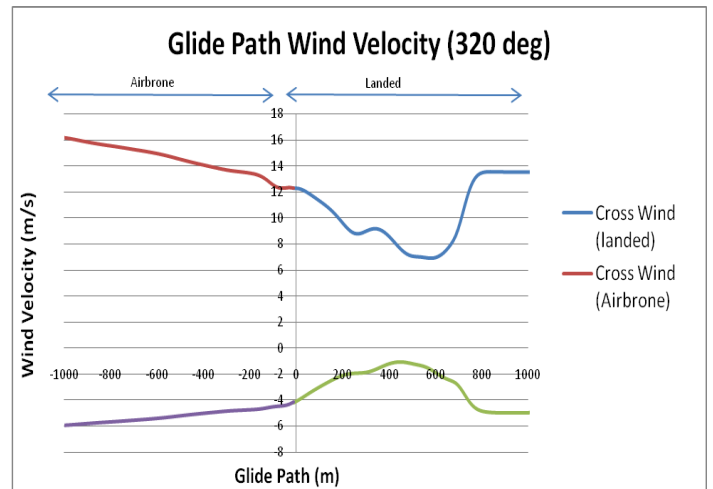


Figure 12 Crosswind profile measured on board an aircraft landing at the south runway from the west in the morning of 23 August 2008.

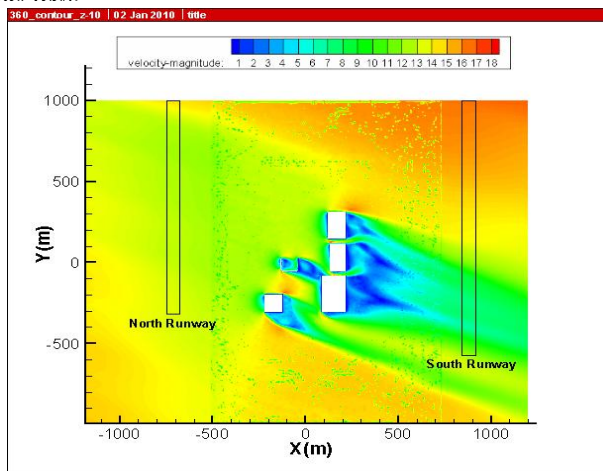


(a)

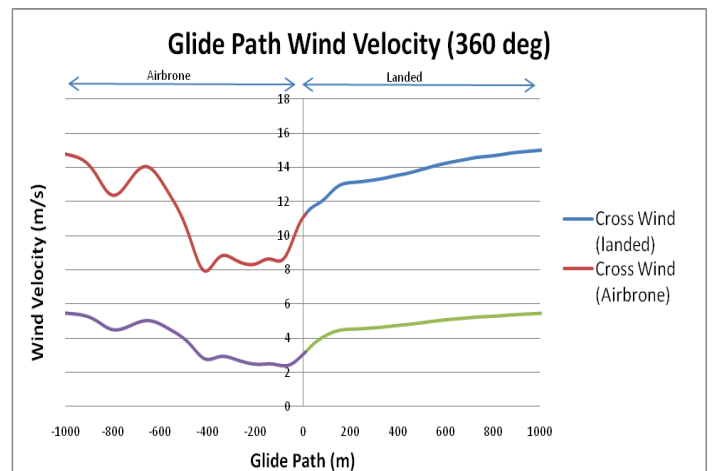


(b)

Figure 13 Wind speed distribution in the model simulation domain at a height of 10 m (a), and the simulated crosswind and headwind profiles along the glide path for aircraft landing at the south runway from the west (b) for wind direction 320 degrees.



(a)



(b)

Figure 14 Same as Figure 13 but for wind direction 360 degrees.