NOVA
FLUID MECHANICS

Atlas Business Park
Manchester, UK

Runway Wind Impact Study

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Runway Wind Impact Study

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Executive Summary

A boundary layer wind tunnel study has been carried out by NOVA Fluid Mechanics Ltd to assess the potential impact of the proposed Atlas Business Park development on the wind conditions along the flight path from Runway 05L/23R of Manchester Airport, UK.

The building induced turbulent effects (the “wake”) of the proposed development are expected to expand and dissipate up to a maximum distance, both horizontally downstream and vertically upwards, beyond which it’s effects are expected to become insignificant. Where the wake intersects with the flight path, it will have an impact on wind conditions.

Based upon wind tunnel measurements of the wind properties in terms of the turbulence at key locations along the flight path, acquired for a full range of wind directions as requested by the Aerodrome Safeguarding Team, the impact of the proposed development is quantified in terms of the change in annual probability of exceedance of threshold turbulence levels.

In our professional opinion, the results indicate that the proposed development will have no practical impact on operations along the flight path for Runway 05L/23R of Manchester Airport.

Atlas Business Park, Manchester

1. Introduction

This report summarises the results of a boundary layer wind tunnel study conducted by NOVA Fluid Mechanics Ltd (NOVA), commissioned by Aviva Life & Pensions UK Limited, to assess the potential impact of the proposed Atlas Business Park development on the wind conditions along the flight path from Runway 05L/23R of Manchester Airport, UK.

The building induced turbulent effects (the “wake”) of the proposed development are expected to expand and dissipate up to a maximum distance, both horizontally downstream and vertically upwards, beyond which it’s effects are expected to become insignificant. Where the wake intersects with the flight path, it will have an impact on wind conditions.

Based upon an assessment of the wind properties in terms of the turbulence at key locations along the flight path, the impact of the proposed development is quantified in terms of the change in annual probability of exceedance of threshold turbulence levels.

2. Study Area

2.1. Site Location & Surrounding Area

The proposed development is situated approximately 1200 m north-east of the eastern threshold of Runway 05L/23R of Manchester Airport, UK. At the closest point, the nearest building is 140 m from the extended runway centreline and it is understood that the flight path runs parallel to the runway at this position.

The standard convention for naming of a runway is taken from the heading to which it is aligned. Thus, Runway 05L and Runway 23R correspond to the same stretch of tarmac, for movements from the west (when the wind is blowing from the east) and from the east (when the wind is blowing from the west), respectively.

At present the area immediately surrounding the proposed development principally comprises open countryside with the suburban terrain of Greater Manchester located to the north.

The site location is presented within the context of the wider surrounding area in Figure 2.1.

2.2. Proposed Development

The proposed development comprises six industrial units ranging from approximately 11-18 m in height, each nominally rectangular in plan with a vaulted roof surrounded by a short parapet.

Figure 2.2 presents a plan view of the proposed development.

Whilst the site is surrounded by a number of wooded areas, these were not included in the model, in line with industry practice, in order to obtain conservative results.

3. Assessment Methodology

3.1. Boundary Layer Wind Tunnel Studies

Details of the annual wind climate analysis and wind field simulation relevant to the site are presented in Appendix A.

Based on standard operational procedure, take-off and landing are typically flown into oncoming (head) winds. As such, given the orientation of Runway 05L/23R, it is expected that aircraft will be landing on to Runway 23R for winds from 157.5° to 315.0° and taking off from Runway 05L for winds from 337.5° to 135°. Whilst it is noted that the development will be downstream of the flight path for winds between 67.5° and 225.0°, meaning that the wake will be propagated away from the flight path and thus the development should not have any impact on the corresponding operations, measurements were taken for a full range of wind directions in 22.5° increments as requested by the Aerodrome Safeguarding Team.

Whilst it is also noted that under certain conditions operations may switch to an alternate runway, this has not been explicitly accounted for in the assessment.

The 0° wind direction has been chosen to coincide with north (90° east, 180° south, 270° west). The wind direction denotes the direction, which the wind is blowing from.

Figure 3.1 presents the adopted nomenclature for the assessment.

3.2. Wind Tunnel and Model Details

Details of the model scale and construction, along with photos of the model and wind tunnel setup are presented in Appendix B.

The wind tunnel model was built at a scale of 1:500, which is large enough to allow a good representation of the details that are likely to affect the local and overall wind flows at full scale. In addition, this scale enables a good simulation of the turbulence properties of the wind to be achieved.

3.3. Measurement Technique

Flow velocity measurements were made using a multi-hole pressure (Cobra) probe able to resolve 3-components of velocity and local static pressure in real time.

The analogue signal from the Cobra probe was sampled at 2000 Hz for 60 seconds. The recorded data were processed to give the required mean and standard deviation of the flow speeds.

It is noted that for all circuits, aircraft altitude is expected to be above the maximum height of the wake of the proposed development (typically between 2 to 4 times the height of the building, being a maximum of 70 m (~230 ft)) with the exception of initial climb and final approach. Consequently, the wind field has been assessed at 25 locations per wind direction, on the flight path along the extended runway centreline, covering a range of elevations up to 128 m (418 ft) as shown in Figure 3.2.

3.4. Analysis Procedure

The prediction of the response of aircraft and pilot to disturbed wind is not amenable to an exact solution. Thus, specific guidance is generally not provided by aviation authorities on the subject of the influence of airport buildings on flying conditions. In practice, much depends on operational experience to recognise and overcome any shortcomings inherent in the design of the airport. As is evident from the broadly trouble-free operations of airports, this has proved to be a satisfactory approach and problems are likely to exist only in marginal situations.

During previous studies carried out by BMT, information supplied by BAA relating to aircraft handling on runway 27R at London Heathrow Airport in strong south-westerly winds were used to identify specific days on which landings were switched to 27L for an improved approach path. For these particular days and times, wind data supplied by the U.K. Met. Office indicated that unfavourable conditions could be associated with winds from 190° to 230° and mean wind speeds at 10 m height of around 15 knots.

Based on this finding, a mean wind speed of 7.5 m/s (15 knots) was selected as the threshold above which landing conditions might be expected to deteriorate. The wind tunnel studies carried out at the time established that this corresponded to a turbulence standard deviation (σ) value of 1.44 m/s for the horizontal components and 0.94 m/s for the vertical component.

More recently, work conducted at the National Aerospace Laboratory in the Netherlands (Report NLR-TP-2010-312[1]) has demonstrated a root-mean-square (RMS) threshold of 2.06 m/s (4 knots) for the horizontal components, which is understood to relate to the combined magnitude of both components, and has been included in the assessment for comparison to the aforementioned thresholds.

Consequently, in order to provide guidance on the overall impact of the proposed development, conditions at the airport have been assessed against the aforementioned thresholds using the following procedure:

1. Measure the turbulence intensity at each location along the flight path, for each wind direction;
2. Determine the mean wind speed that, for the measured turbulence levels at each location, is required to generate standard deviations of turbulence that exceed the thresholds;
3. Determine the annual exceedance of the resulting wind speeds and turbulence criteria for each location, using appropriate wind statistics for the airport.

By comparing the annual exceedance for the existing site with that for the proposed development, the impact of the proposed development on the flight path wind conditions can be quantified.

The wind tunnel measurements also allow a direct comparison of turbulence intensity at the runway with and without the proposed development. This parameter is key to understanding if the proposed development has an unacceptable impact on the runway wind conditions, and the comparison provides an indication of the impact of the proposed development on the flight path wind conditions.

4. Results

4.1. Results Summary

The wind tunnel measurements of the turbulence intensity along the flight path are summarised as follows:

- The longitudinal (along-wind) turbulence intensity (being the ratio of the standard deviation of the turbulence parallel to the runway divided by the magnitude of the mean wind speed) at each measurement location is presented graphically in Figures 4.1 and 4.16.
- The lateral (cross-wind) turbulence intensity (being the ratio of the standard deviation of the turbulence perpendicular to the runway divided by the magnitude of the mean wind speed) at each measurement location is presented graphically in Figures 4.17 and 4.32.
- The vertical turbulence intensity (being the ratio of the standard deviation of the turbulence perpendicular to the ground divided by the magnitude of the mean wind speed) at each measurement location is presented graphically in Figures 4.33 and 4.48.

For Figures 4.1 to 4.48, the horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

The resulting impact on wind conditions along the flight path, derived from the above turbulence measurements, is summarised as follows:

- The change in the annual probability of exceedance of longitudinal, lateral, vertical and combined horizontal root-mean-square (RMS) speed thresholds are presented in Tables 4.1 to 4.4.

4.2. Discussion

The change in the measured turbulence intensity (see Figures 4.1 to 4.48) is generally less than ±1%, with a maximum increase of 2% for the cross-wind component at the points closest to the ground where the aircraft is less likely to be, for less prevalent northerly wind directions, namely 0° and 315° (see Figures 4.17 and 4.31, respectively). For context, based on the background turbulence levels at the airport, for a “strong breeze” of 13 m/s (25 knots), a 2% increase in the turbulence intensity equates to an increase in variability of the wind speed from ± 2.2 m/s (4.3 knots) to ± 2.5 m/s (4.8 knots), i.e. wind speeds typically varying between 10.8 m/s to 15.2 m/s change to between 10.5 m/s to 15.5 m/s.

Consequently, for the vast majority of wind angles, the change in the annual probability of exceedance of the root-mean-square (RMS) speed thresholds (see Tables 4.1 to 4.4) is ±0.1% or less. The greatest change in terms of the annual probability of exceedance of the RMS speed thresholds occurs for the cross-wind component from 180°, being 0.2% (see Table 4.2). This results from a 0.4% increase in the associated turbulence intensity at the critical location for that wind angle, which is being amplified by the fact that the most common winds blow from the south.

Notably, when reviewing the raw tunnel data it is evident that the difference between the measurements for the existing site and proposed development at the critical location for 180° winds is within the tolerance of the instrumentation, i.e. the measurements are effectively the same. Furthermore, it is noted that the proposed development is located downstream of the flight path for this wind direction, meaning that the building wakes will be propagated away from the flight path and thus should not change the wind conditions.

5. Conclusions

The boundary layer wind tunnel study has assessed the potential impact of the proposed development on the wind conditions along the flight path. On the basis of the wind tunnel modelling, the following conclusions have been drawn:

- With the introduction of the proposed development, the peak absolute change in the measured turbulence intensity along the flight path is 2%, associated with cross-winds from 0° and 315°, although the vast majority of the measurement locations change by 1% or less.
- Consequently, for the vast majority of wind angles the change in existing levels of the annual probability of exceedance of the threshold turbulence levels is nominally zero, with an increase of 0.1% for winds from 202.5°, 292.5° and 315°. There is also a peak increase of 0.2% for the cross-wind component from 180°. However, 180° and 202.5° correspond to winds from the south, for which the proposed development will be downstream of the flight path, meaning that the wake will be propagated away from the flight path, and thus the development should not have an impact on wind conditions.

In our professional opinion, the results indicate that the proposed development will have no practical impact on operations along the flight path for Runway 05L/23R of Manchester Airport.

6. References

[1] A.M.H. Nieuwpoort, J.H.M. Gooden and J.L. de Prins. NLR-TP-2010-312, Wind criteria due to obstacles at and around airports. National Aerospace Laboratory NLR, July 2010.

[2] ESDU (Engineering Science Data Unit) Item 01008. Computer Program for Wind Speeds and Turbulence Properties: Flat or Hilly Sites in Terrain with Roughness. 2001.

Table 4.1: Maximum annual probability of exceedance across all locations, longitudinal component

Wind Direction	Exceedance of longitudinal turbulence threshold (σ_U = 1.44 m/s)		Absolute Difference
	Existing Site	Proposed	
0.0°	0.1%	0.1%	0.0%
22.5°	0.3%	0.3%	0.0%
45.0°	0.8%	0.8%	0.0%
67.5°	0.9%	0.9%	0.0%
90.0°	0.8%	0.8%	0.0%
112.5°	0.4%	0.4%	0.0%
135.0°	0.1%	0.1%	0.0%
157.5°	0.4%	0.4%	0.0%
180.0°	1.4%	1.3%	-0.1%
202.5°	2.1%	2.0%	-0.1%
225.0°	0.8%	0.9%	0.0%
247.5°	0.5%	0.5%	0.0%
270.0°	0.5%	0.5%	0.0%
292.5°	0.5%	0.6%	0.1%
315.0°	0.1%	0.1%	0.0%
337.5°	0.1%	0.1%	0.0%

Table 4.2: Maximum annual probability of exceedance across all locations, lateral component

Wind Direction	Exceedance of longitudinal turbulence threshold (σ_V = 1.44 m/s)		Absolute Difference
	Existing Site	Proposed	
0.0°	0.1%	0.1%	0.0%
22.5°	0.2%	0.1%	0.0%
45.0°	0.3%	0.3%	0.0%
67.5°	0.5%	0.6%	0.0%
90.0°	0.8%	0.8%	0.0%
112.5°	0.6%	0.6%	0.0%
135.0°	0.4%	0.4%	0.0%
157.5°	1.2%	1.2%	-0.1%
180.0°	1.7%	1.8%	0.2%
202.5°	1.4%	1.5%	0.1%
225.0°	0.3%	0.3%	0.0%
247.5°	0.1%	0.1%	0.0%
270.0°	0.3%	0.3%	0.0%
292.5°	0.9%	0.9%	0.1%
315.0°	0.4%	0.6%	0.1%
337.5°	0.1%	0.2%	0.0%

Table 4.3: Maximum annual probability of exceedance across all locations, vertical component

Wind Direction	Exceedance of longitudinal turbulence threshold (σ_w = 0.94 m/s)		Absolute Difference
	Existing Site	Proposed	
0.0°	0.2%	0.2%	0.0%
22.5°	0.4%	0.4%	0.0%
45.0°	0.8%	0.8%	0.0%
67.5°	1.0%	0.9%	0.0%
90.0°	1.0%	1.0%	0.0%
112.5°	0.7%	0.7%	0.0%
135.0°	0.5%	0.4%	0.0%
157.5°	1.4%	1.3%	-0.1%
180.0°	2.2%	2.2%	0.0%
202.5°	2.7%	2.7%	0.0%
225.0°	1.1%	1.1%	0.0%
247.5°	0.6%	0.6%	0.0%
270.0°	0.7%	0.7%	0.0%
292.5°	1.0%	1.1%	0.1%
315.0°	0.4%	0.4%	0.0%
337.5°	0.1%	0.2%	0.0%

Table 4.4: Maximum annual probability of exceedance across all locations, horizontal components[1]

Wind Direction	Exceedance of longitudinal turbulence threshold (σ_{UV} = 2.06 m/s)		Absolute Difference
	Existing Site	Proposed	
0.0°	0.0%	0.0%	0.0%
22.5°	0.0%	0.0%	0.0%
45.0°	0.1%	0.1%	0.0%
67.5°	0.2%	0.2%	0.0%
90.0°	0.2%	0.3%	0.0%
112.5°	0.2%	0.2%	0.0%
135.0°	0.1%	0.1%	0.0%
157.5°	0.2%	0.2%	0.0%
180.0°	0.3%	0.3%	0.0%
202.5°	0.5%	0.4%	-0.1%
225.0°	0.1%	0.1%	0.0%
247.5°	0.0%	0.0%	0.0%
270.0°	0.0%	0.0%	0.0%
292.5°	0.1%	0.2%	0.0%
315.0°	0.0%	0.1%	0.0%
337.5°	0.0%	0.0%	0.0%

Figure 2.1: Aerial view of the proposed development site



Figure 2.2: Plan view of the proposed development



Figure 3.1: Nomenclature

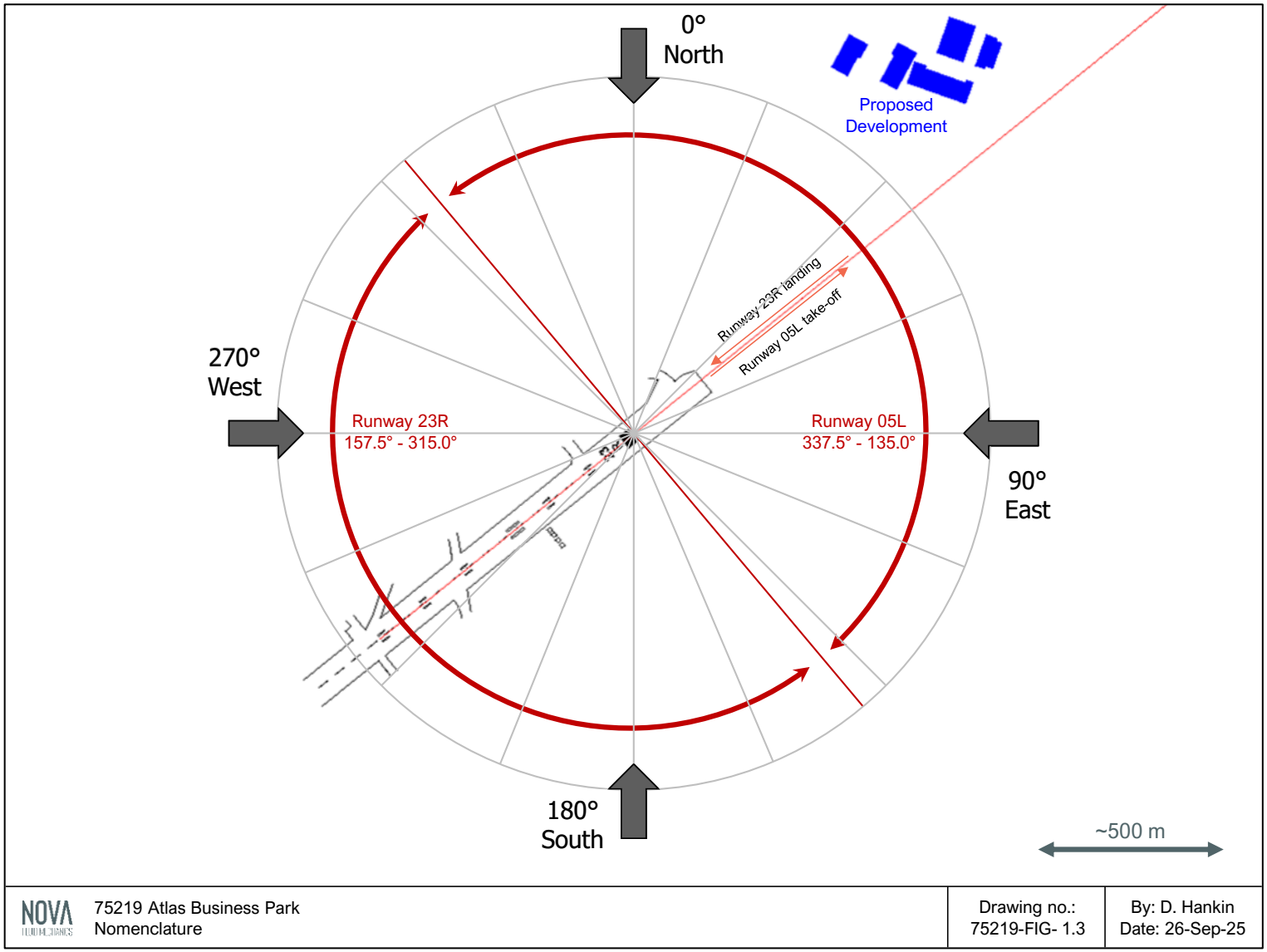


Figure 3.2: Measurement location scheme

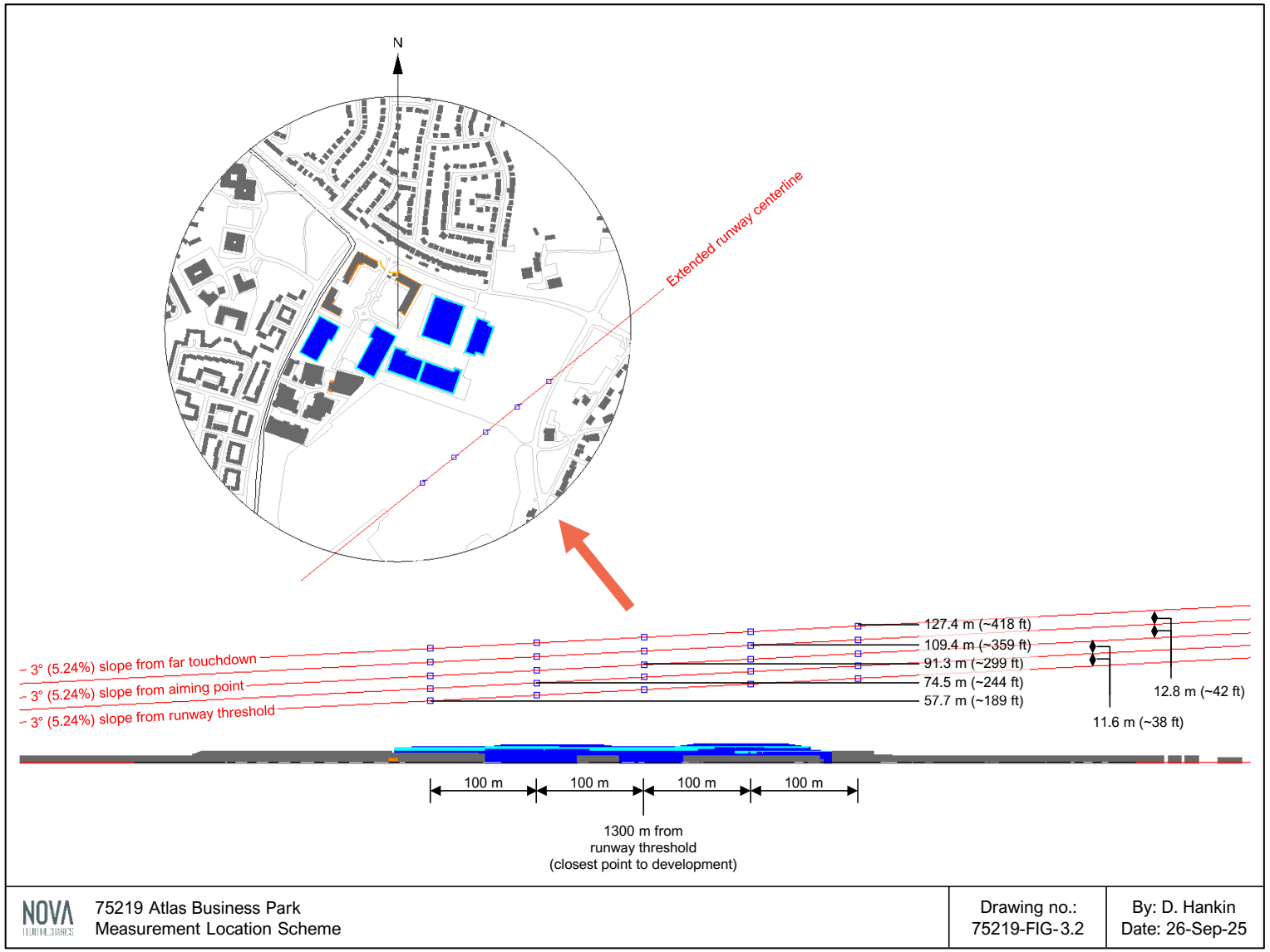


Figure 4.1: Longitudinal turbulence intensity for wind direction 0°*

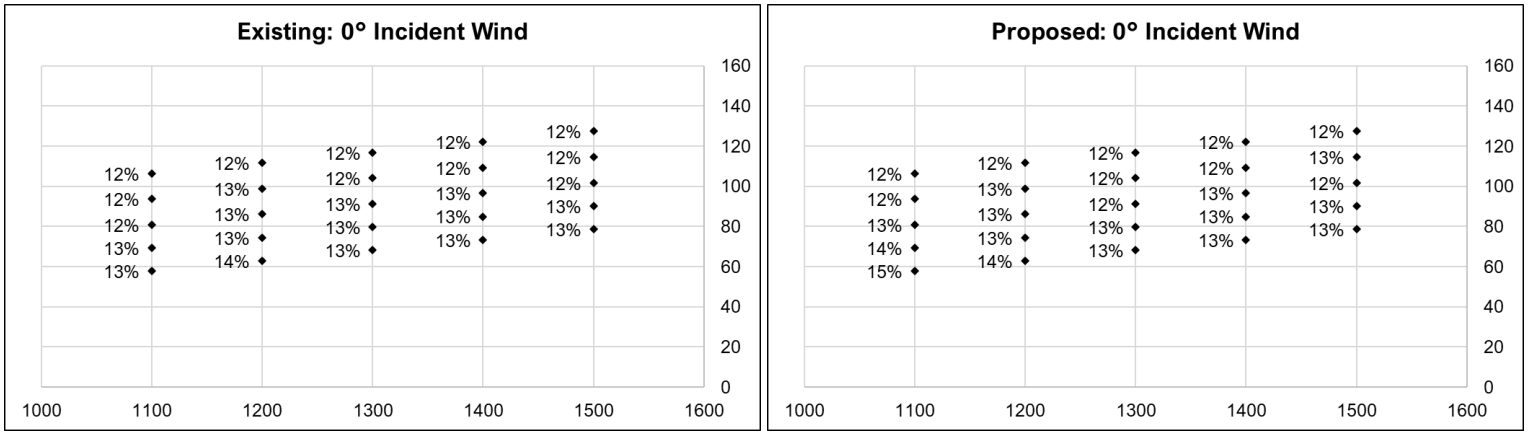
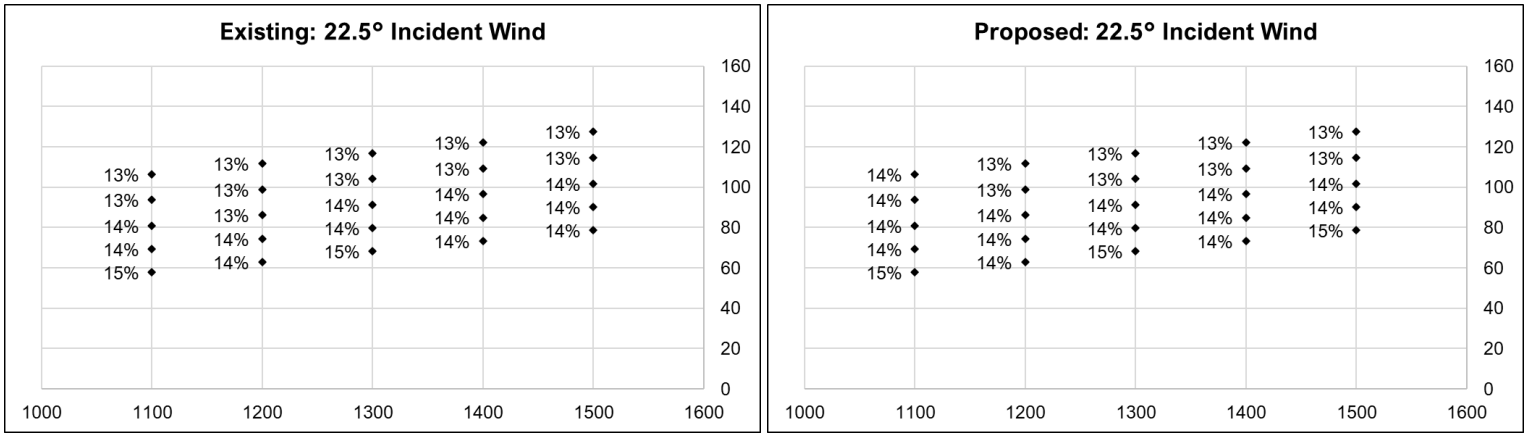


Figure 4.2: Longitudinal turbulence intensity for wind direction 22.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.3: Longitudinal turbulence intensity for wind direction 45.0°*

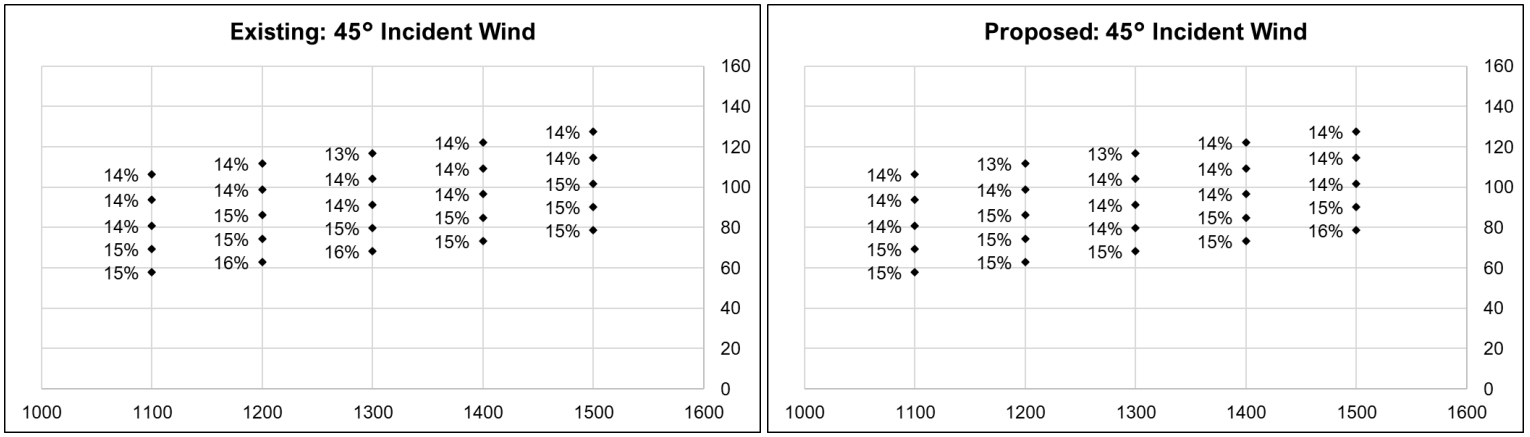
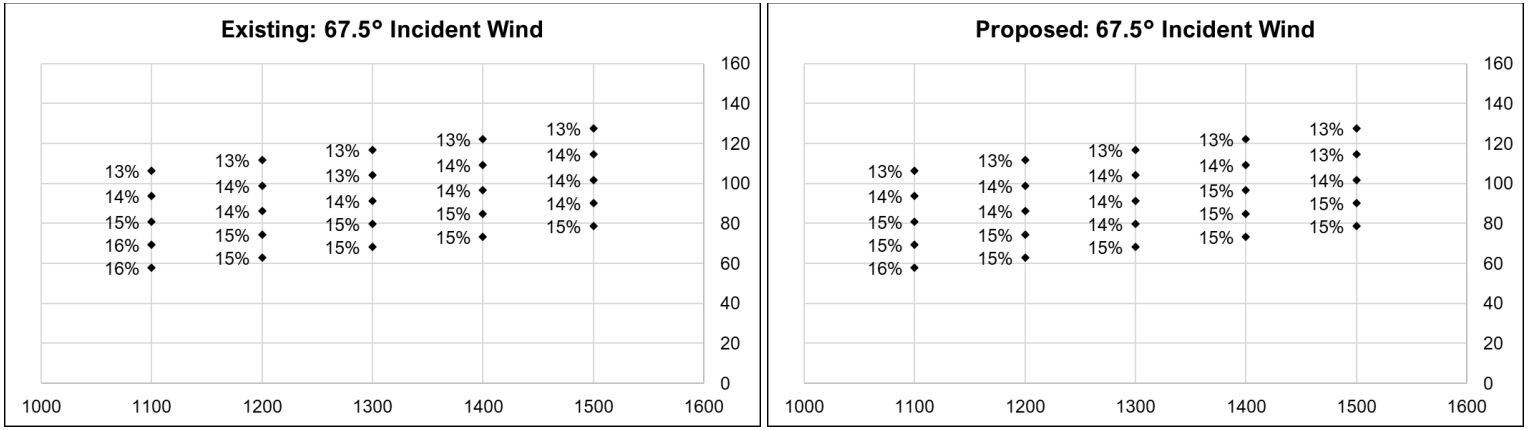


Figure 4.4: Longitudinal turbulence intensity for wind direction 67.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.5: Longitudinal turbulence intensity for wind direction 90.0°*

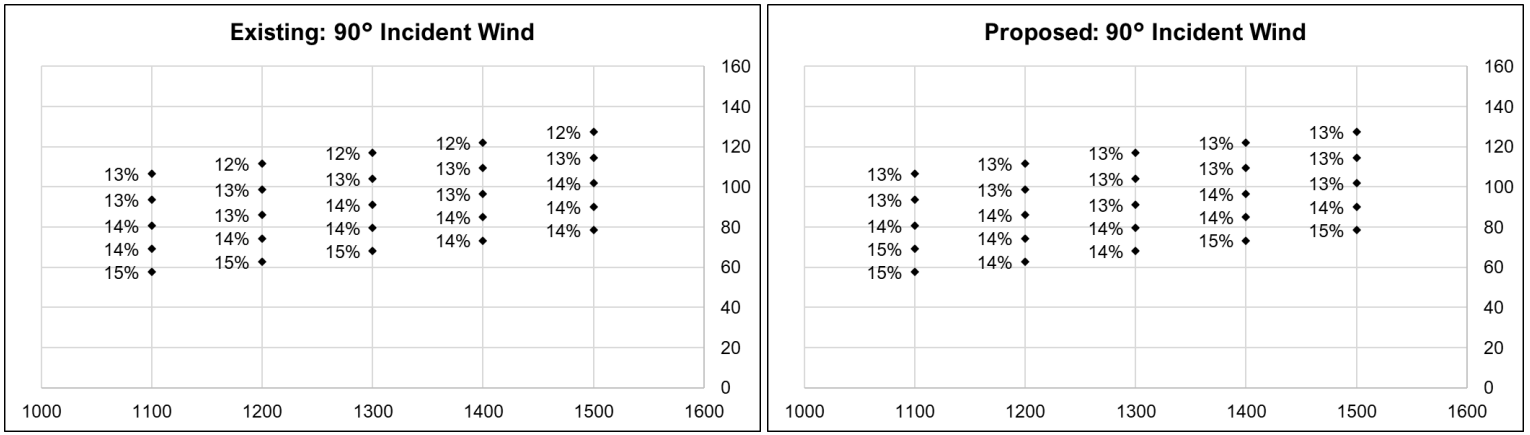
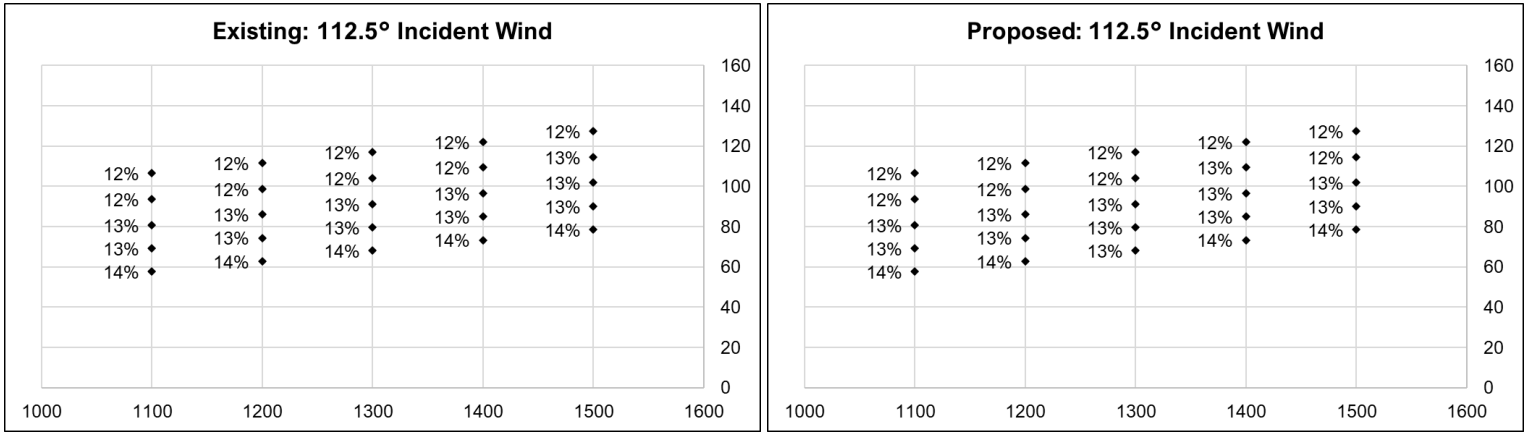


Figure 4.6: Longitudinal turbulence intensity for wind direction 112.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.7: Longitudinal turbulence intensity for wind direction 135.0°*

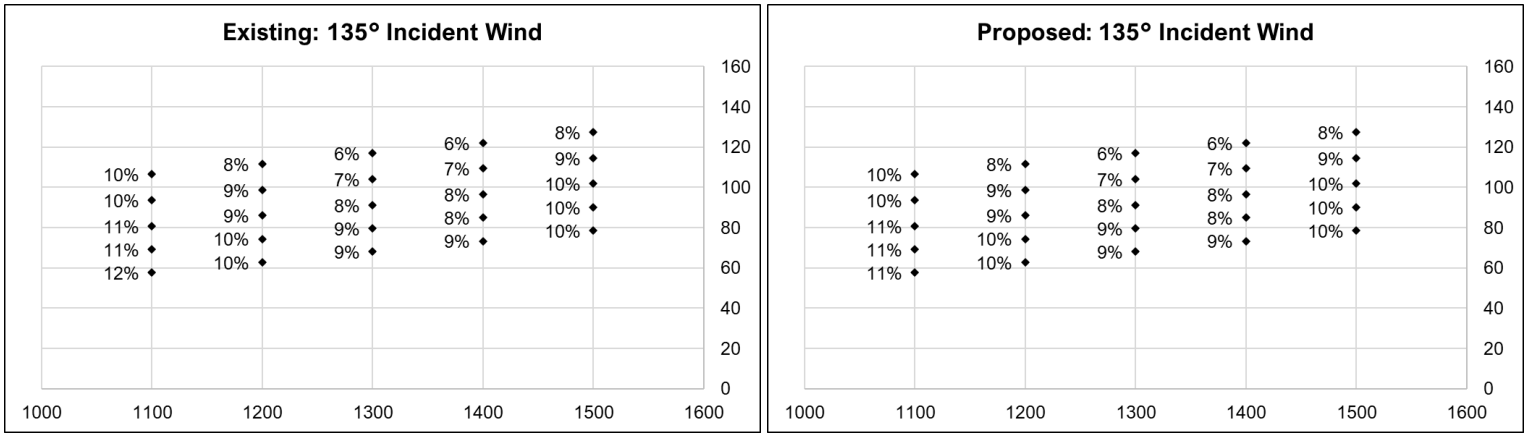
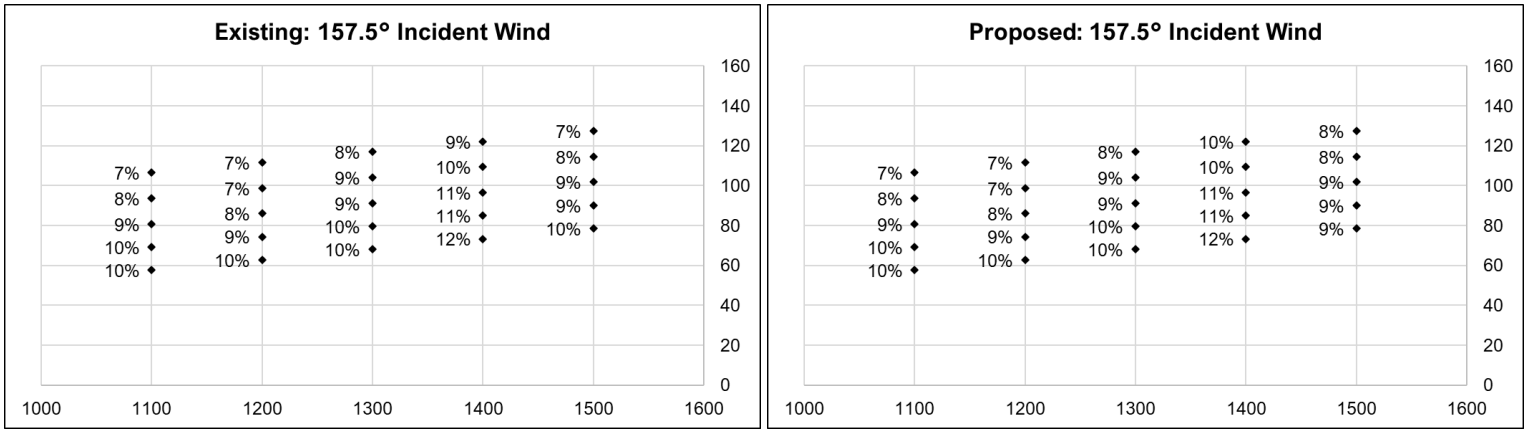


Figure 4.8: Longitudinal turbulence intensity for wind direction 157.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.9: Longitudinal turbulence intensity for wind direction 180.0°*

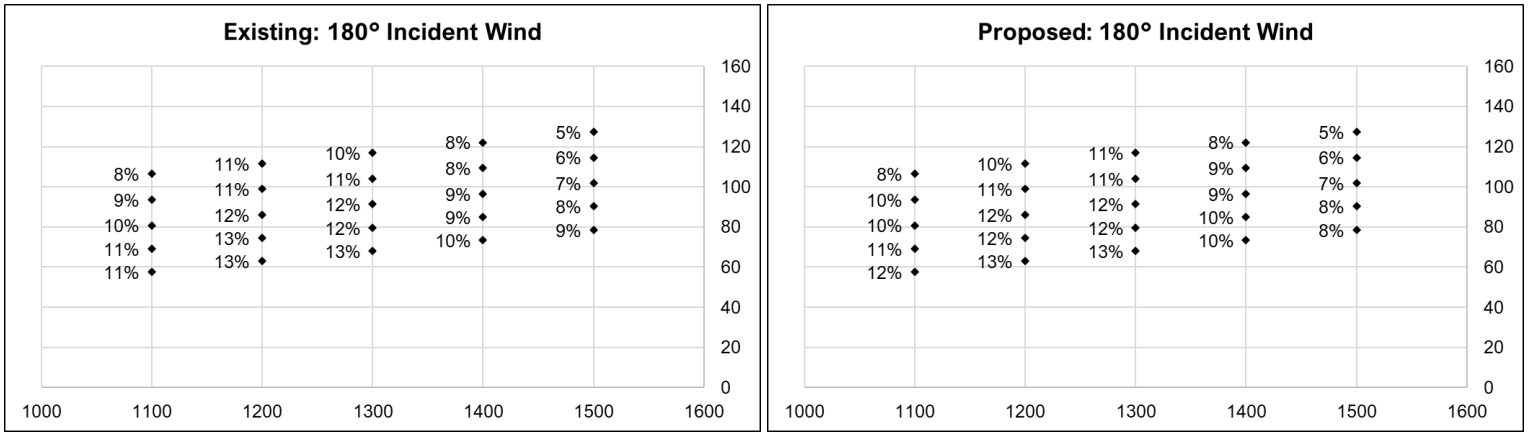
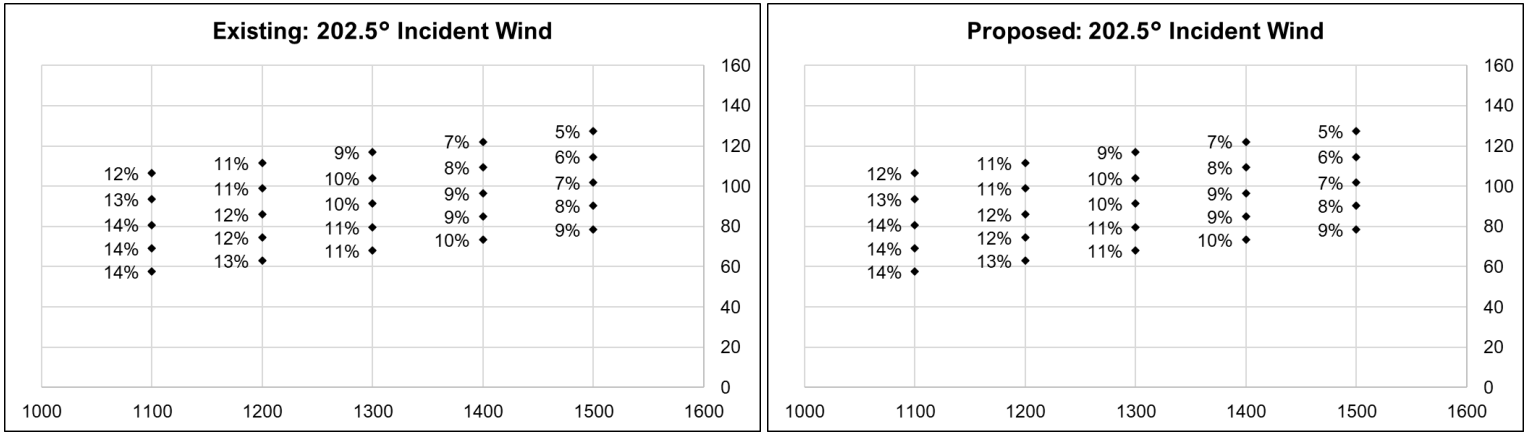


Figure 4.10: Longitudinal turbulence intensity for wind direction 202.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.11: Longitudinal turbulence intensity for wind direction 225.0°*

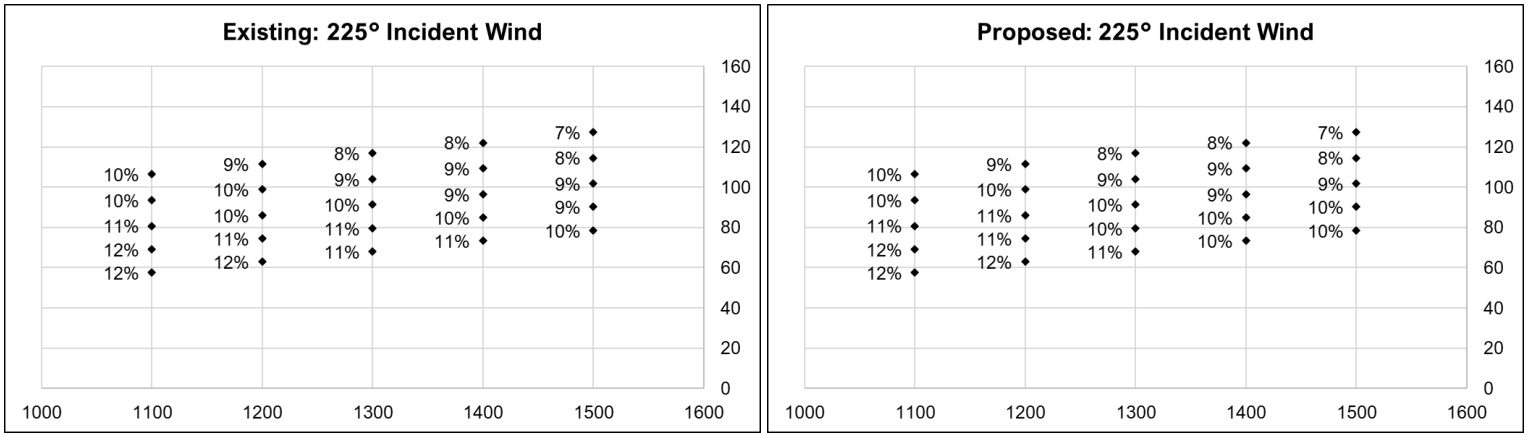
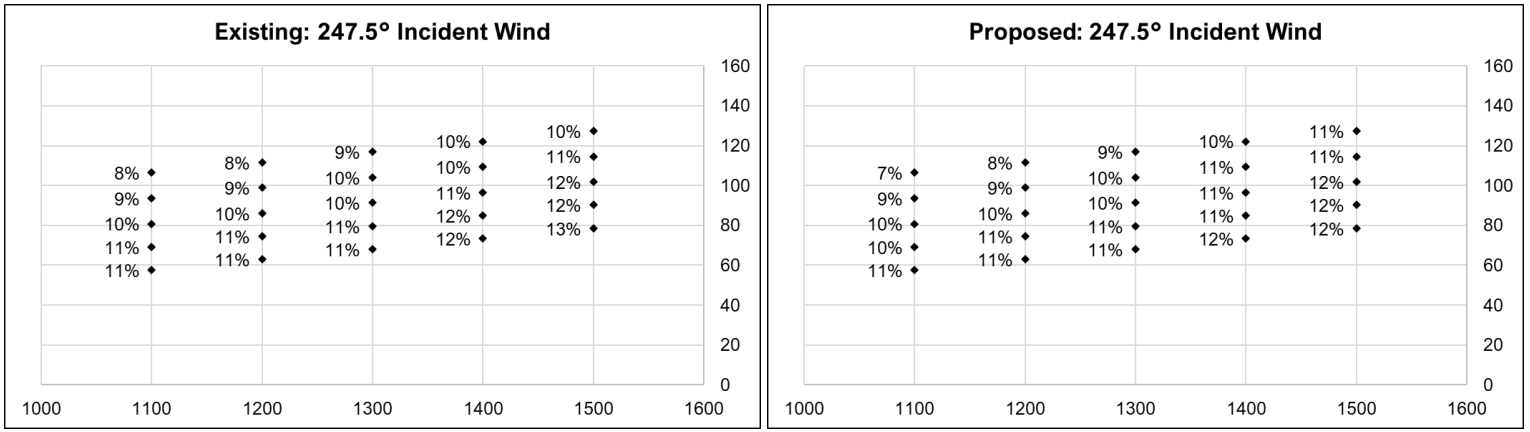


Figure 4.12: Longitudinal turbulence intensity for wind direction 247.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.13: Longitudinal turbulence intensity for wind direction 270.0°*

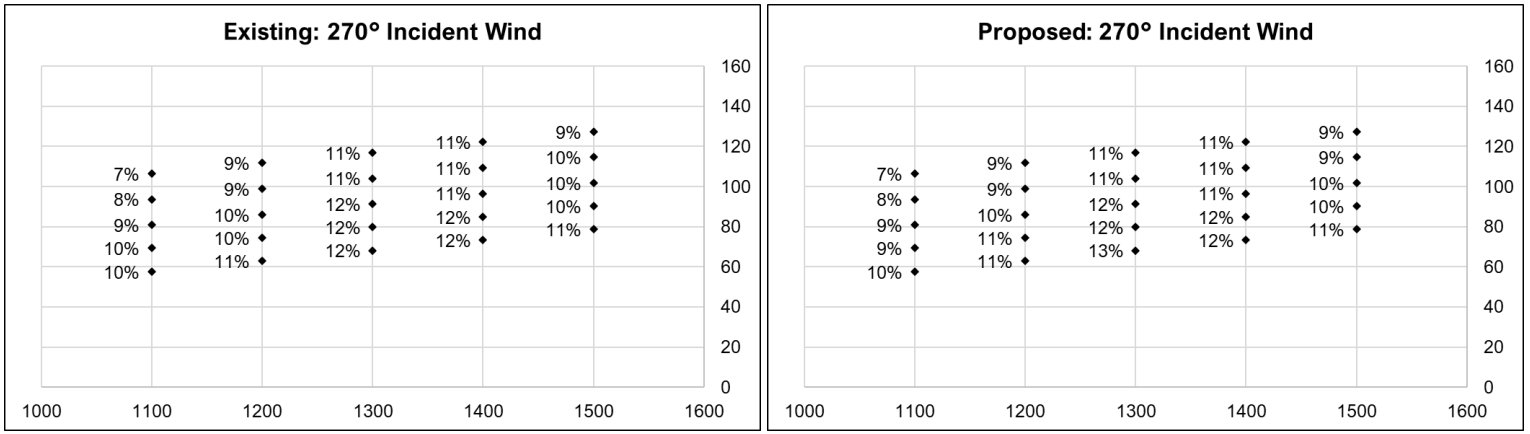
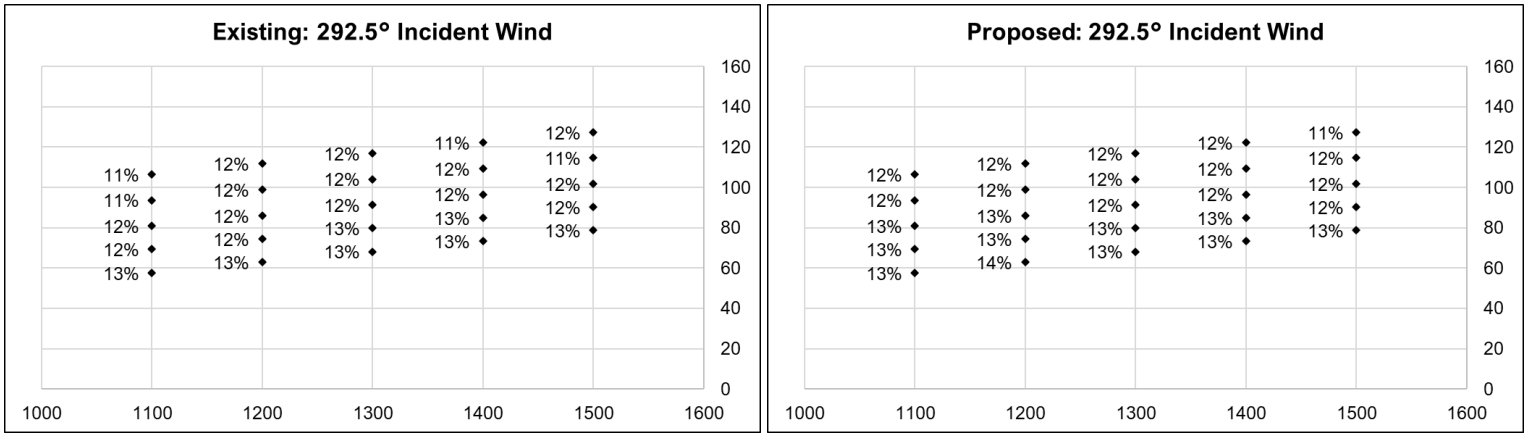


Figure 4.14: Longitudinal turbulence intensity for wind direction 292.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.15: Longitudinal turbulence intensity for wind direction 315.0°*

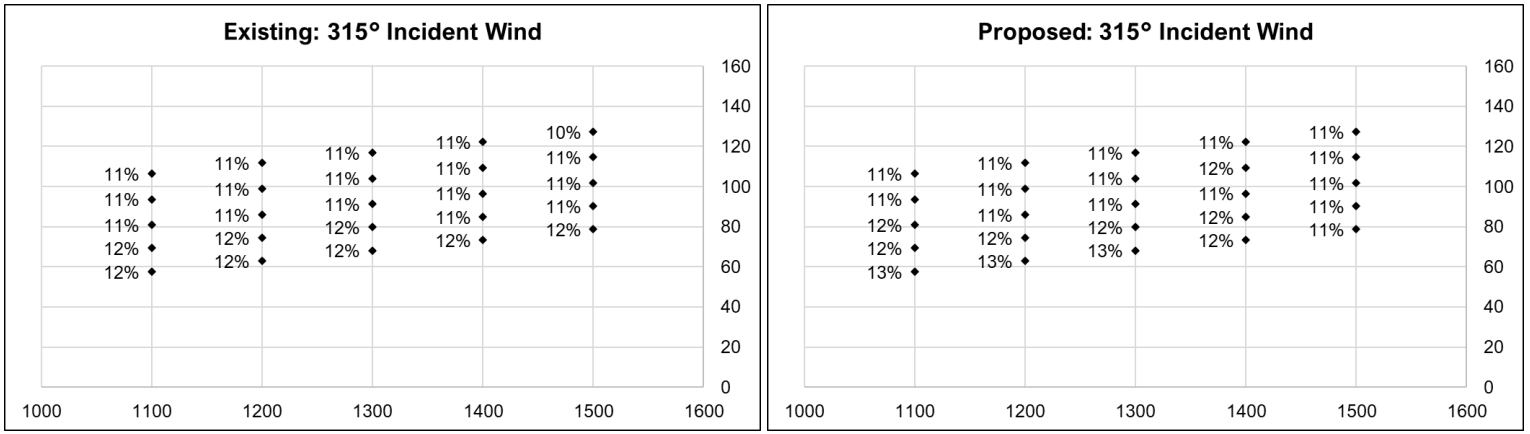
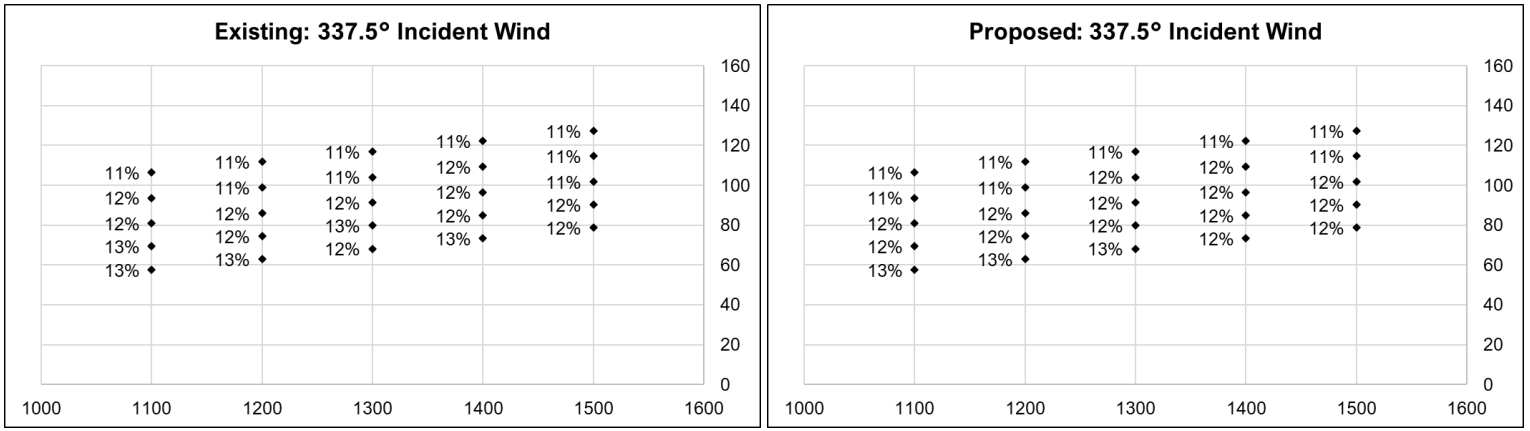


Figure 4.16: Longitudinal turbulence intensity for wind direction 337.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.17: Lateral turbulence intensity for wind direction 0°*

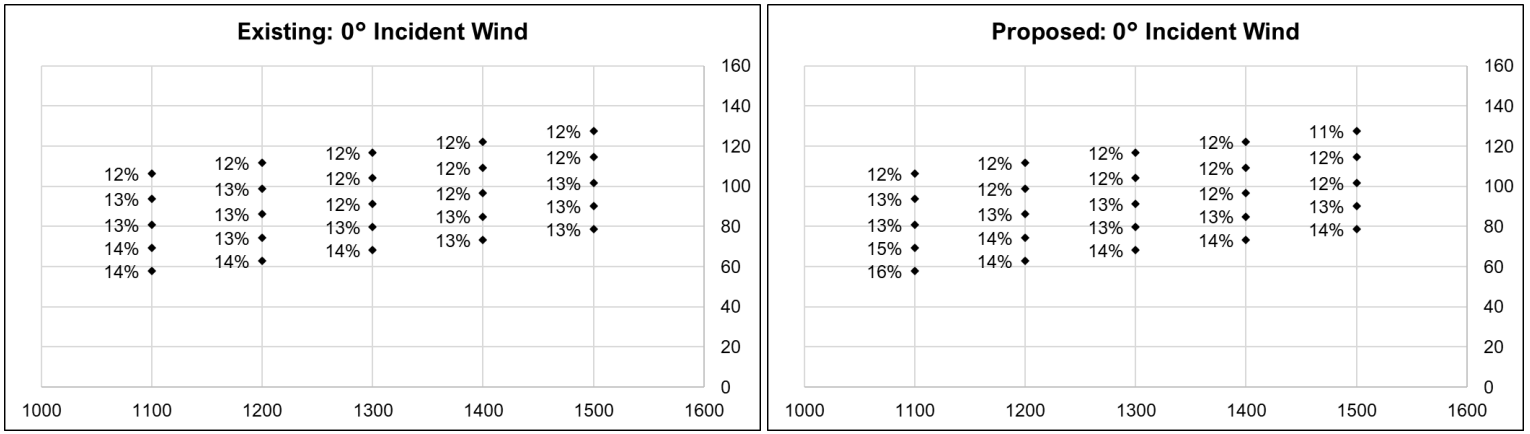
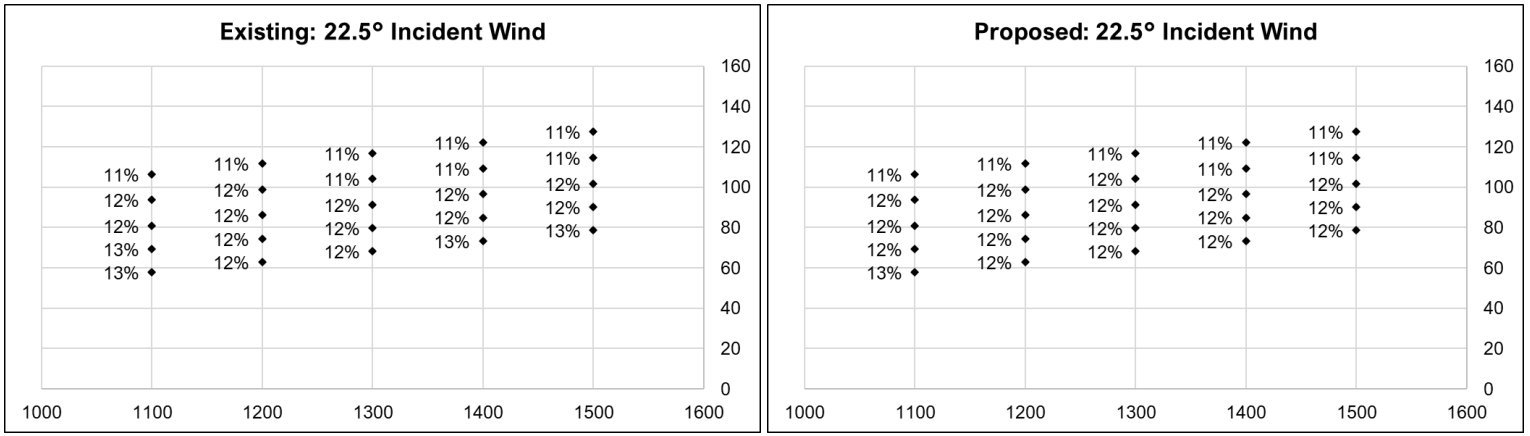


Figure 4.18: Lateral turbulence intensity for wind direction 22.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.19: Lateral turbulence intensity for wind direction 45.0°*

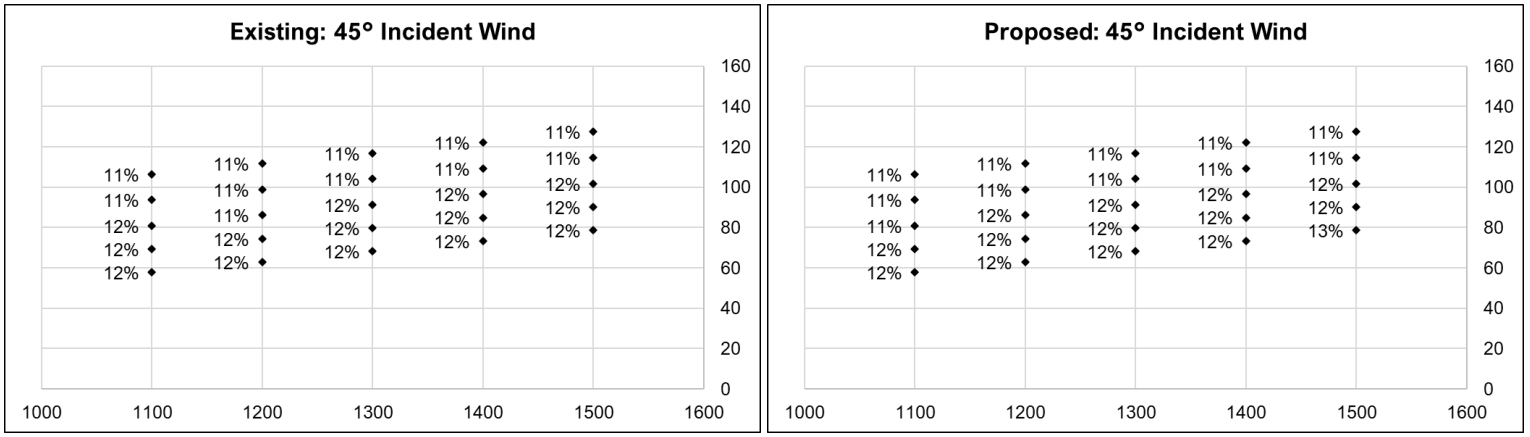
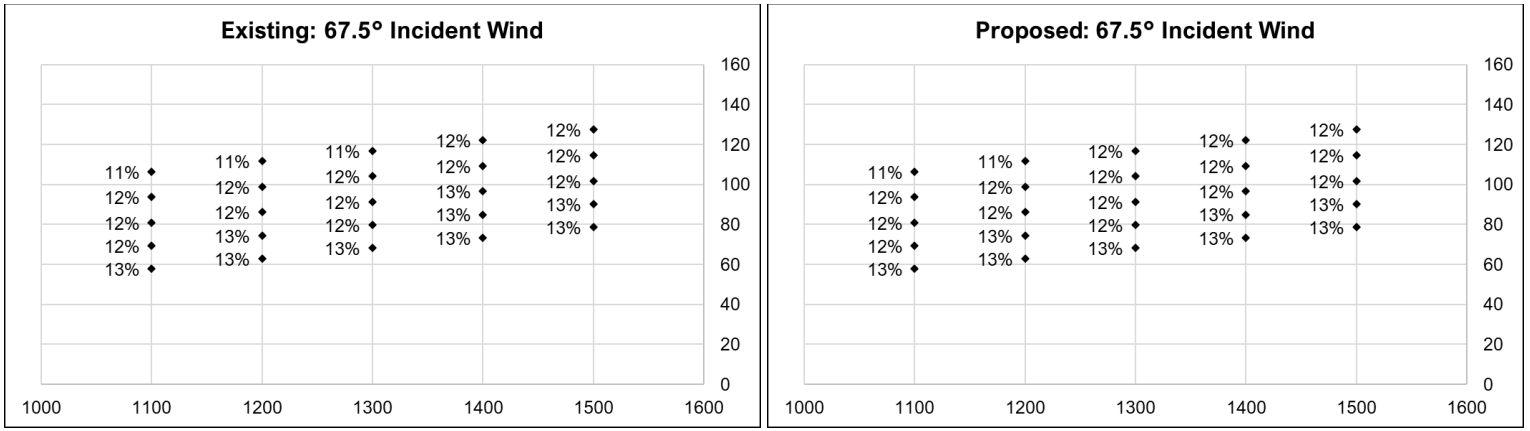


Figure 4.20: Lateral turbulence intensity for wind direction 67.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.21: Lateral turbulence intensity for wind direction 90.0°*

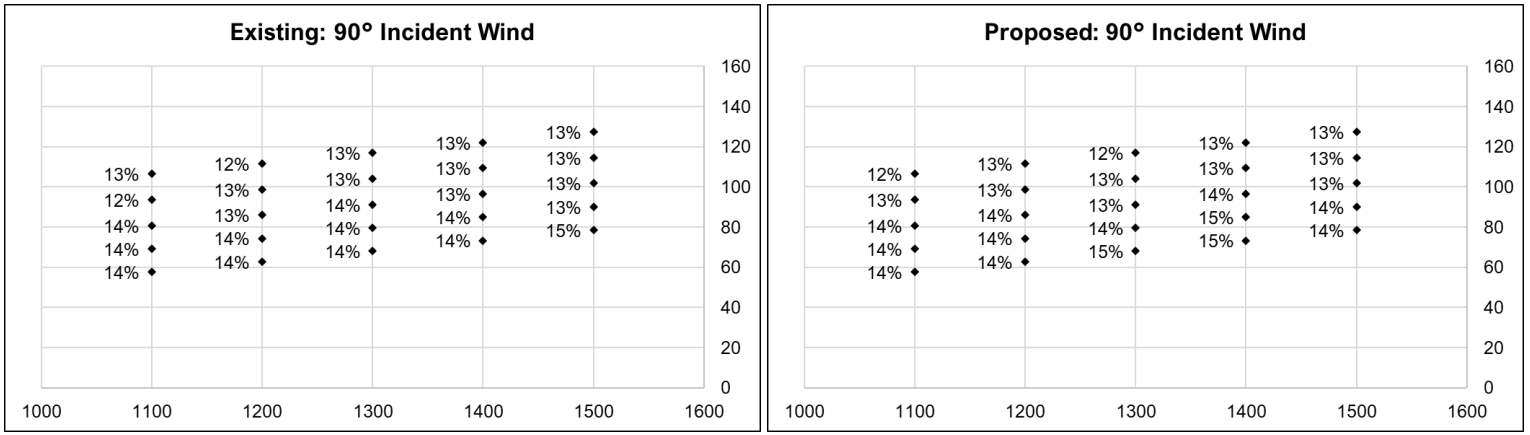
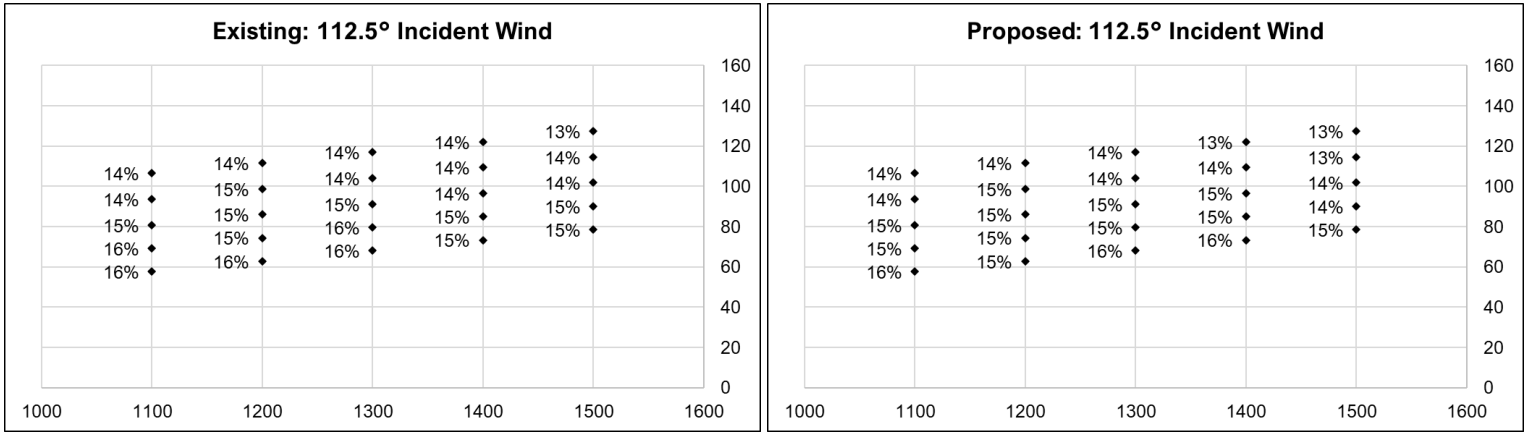


Figure 4.22: Lateral turbulence intensity for wind direction 112.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.23: Lateral turbulence intensity for wind direction 135.0°*

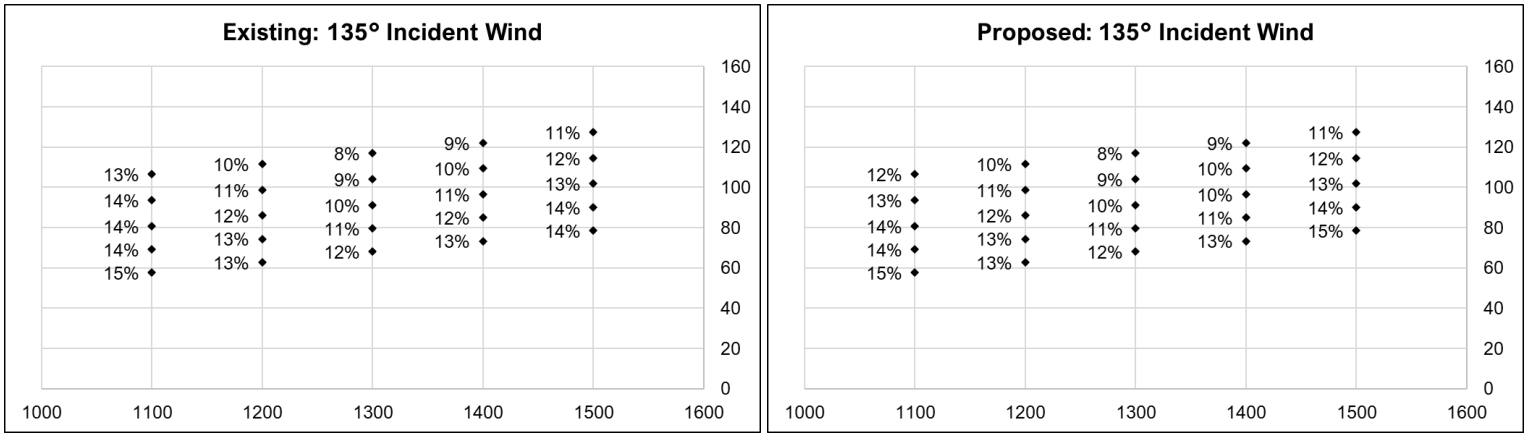
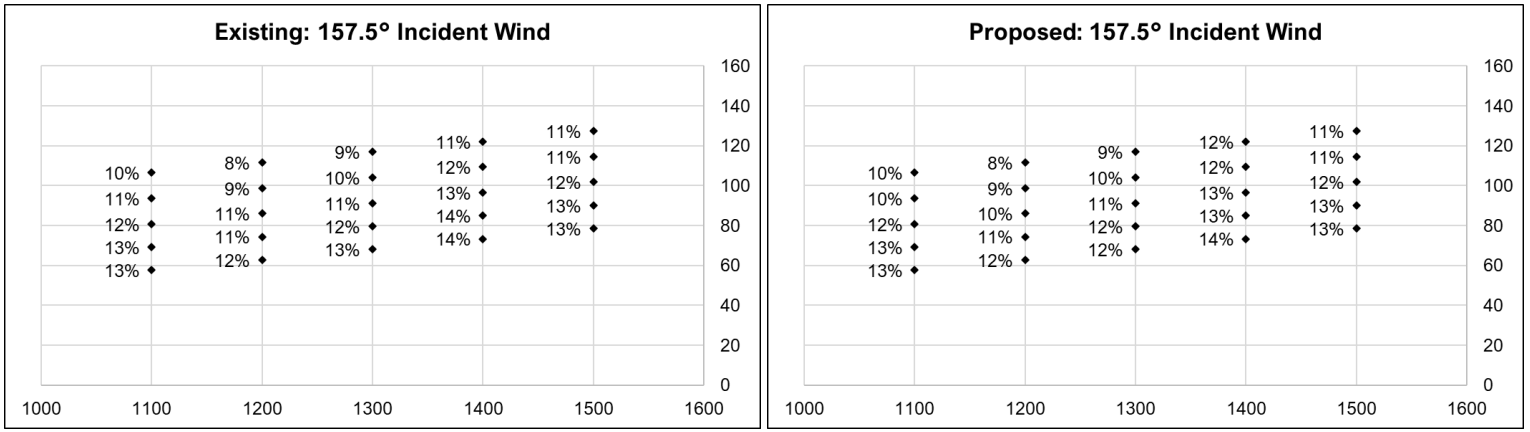


Figure 4.24: Lateral turbulence intensity for wind direction 157.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.25: Lateral turbulence intensity for wind direction 180.0°*

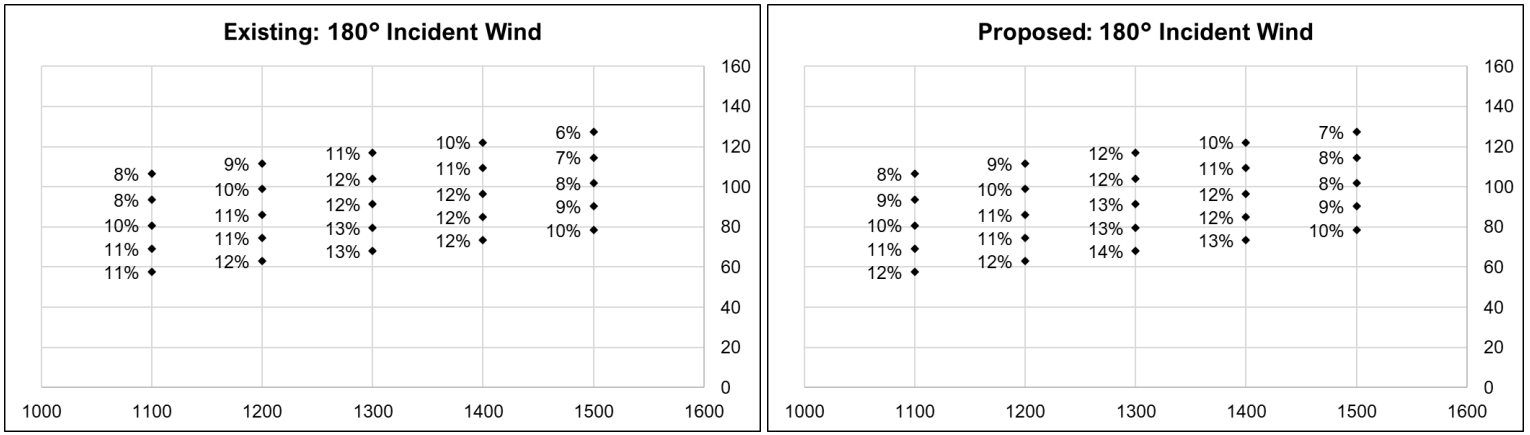
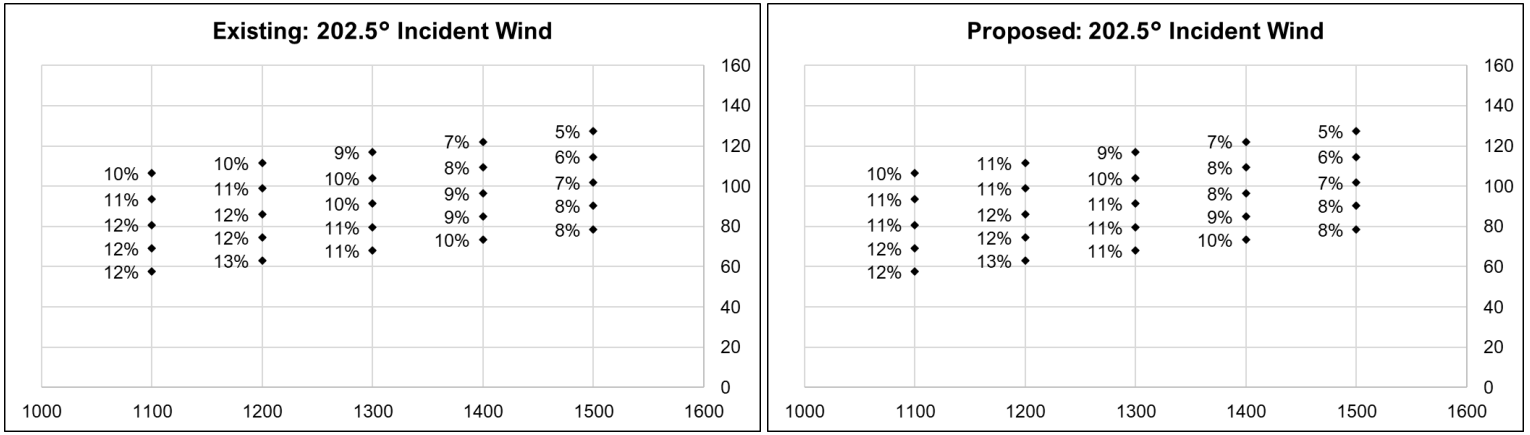


Figure 4.26: Lateral turbulence intensity for wind direction 202.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.27: Lateral turbulence intensity for wind direction 225.0°*

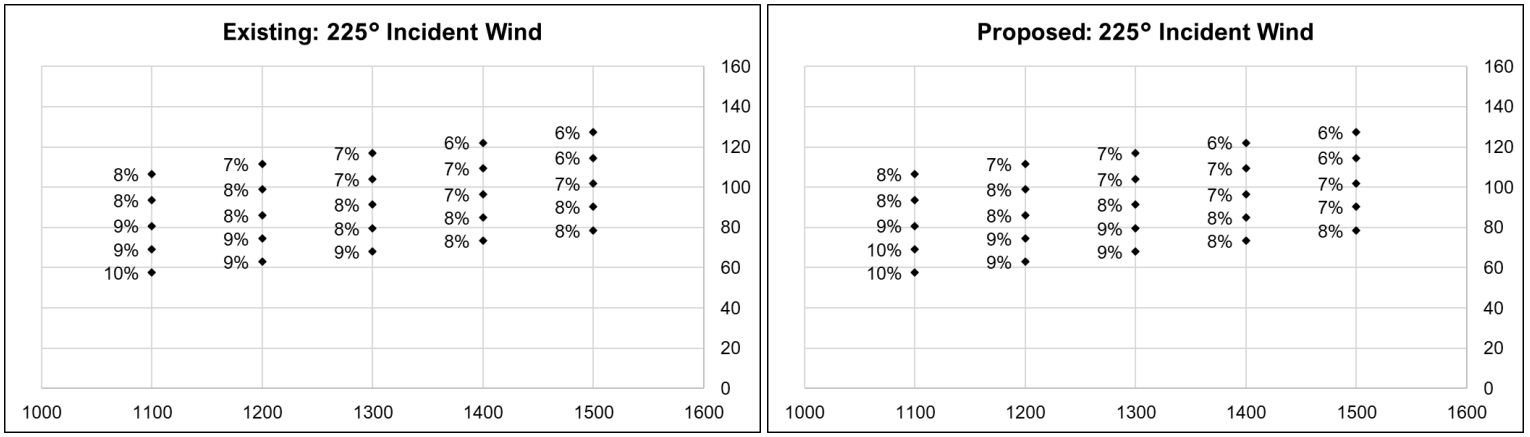
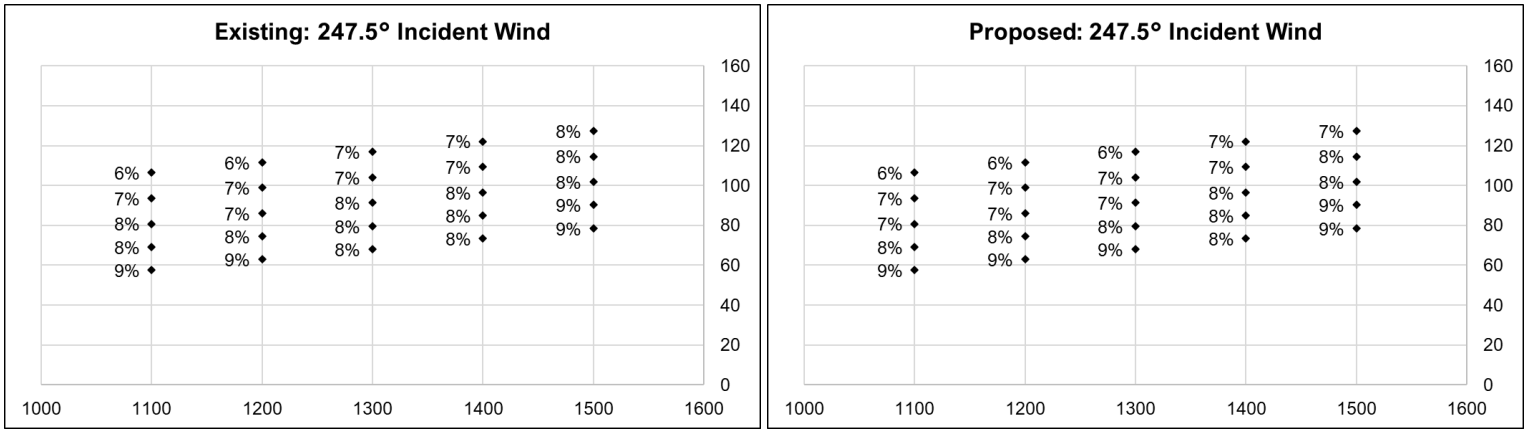


Figure 4.28: Lateral turbulence intensity for wind direction 247.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.29: Lateral turbulence intensity for wind direction 270.0°*

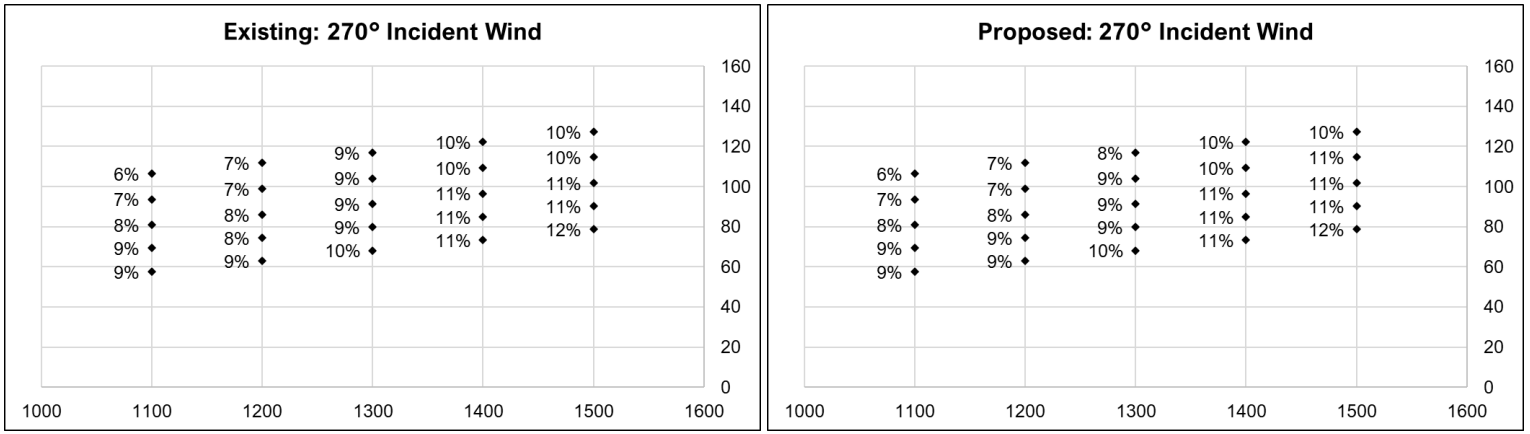
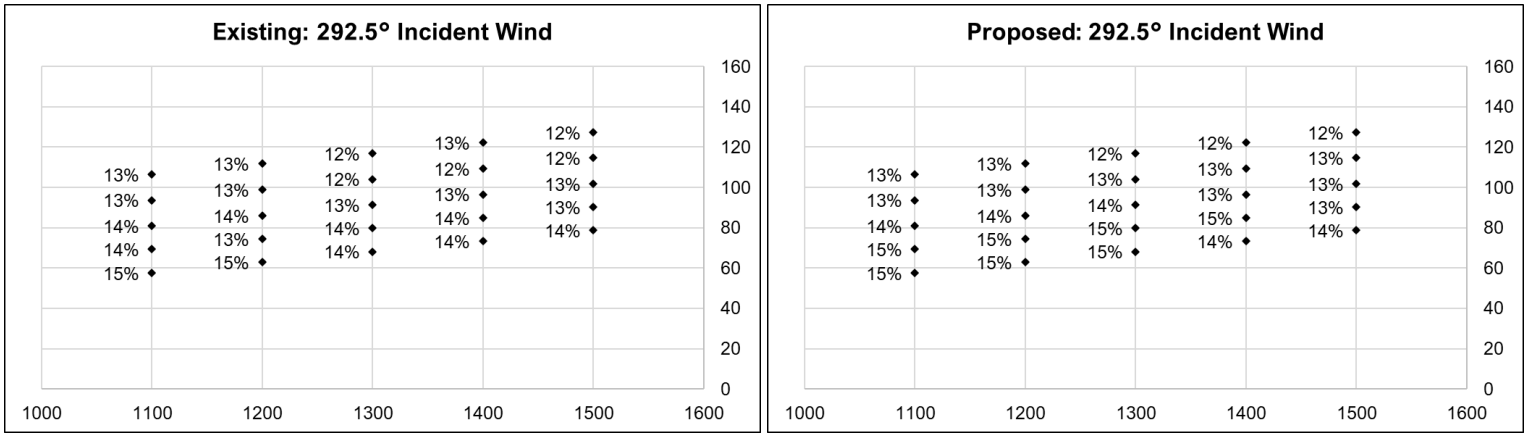


Figure 4.30: Lateral turbulence intensity for wind direction 292.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.31: Lateral turbulence intensity for wind direction 315.0°*

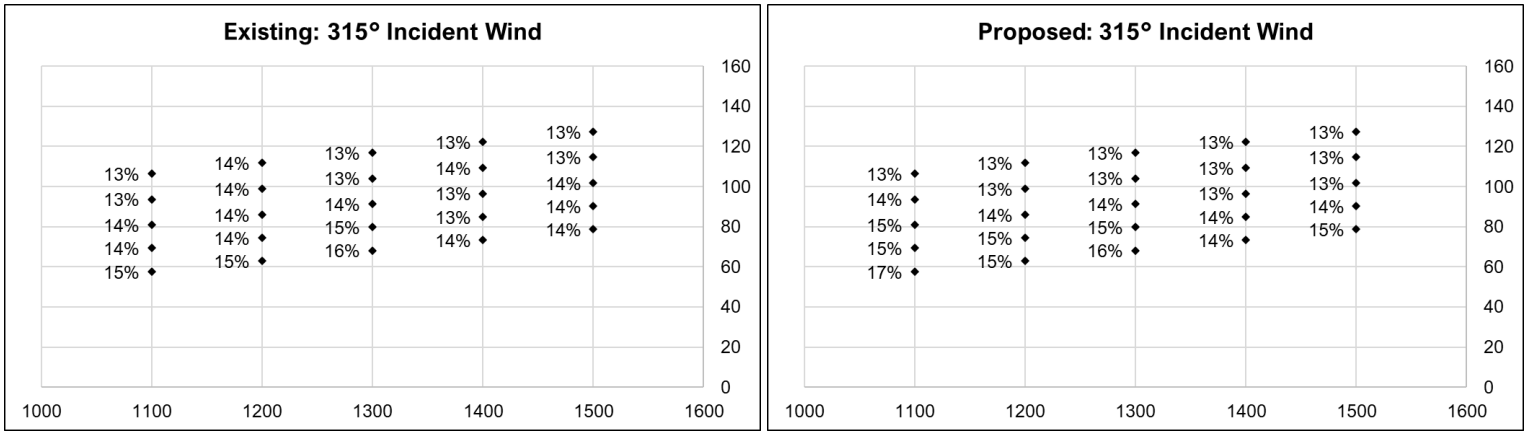
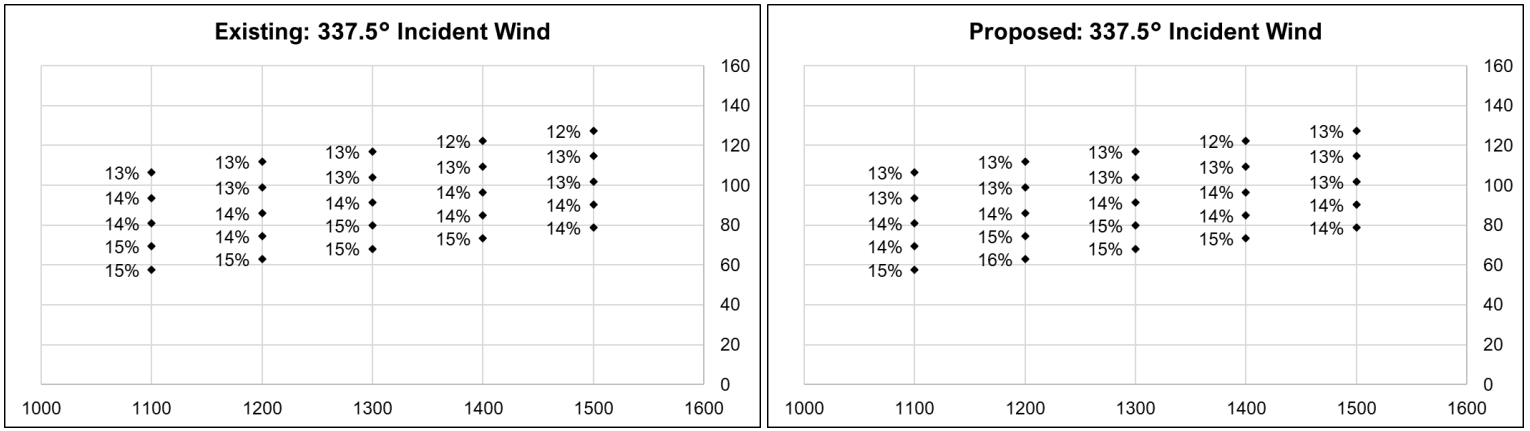


Figure 4.32: Lateral turbulence intensity for wind direction 337.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.33: Vertical turbulence intensity for wind direction 0°*

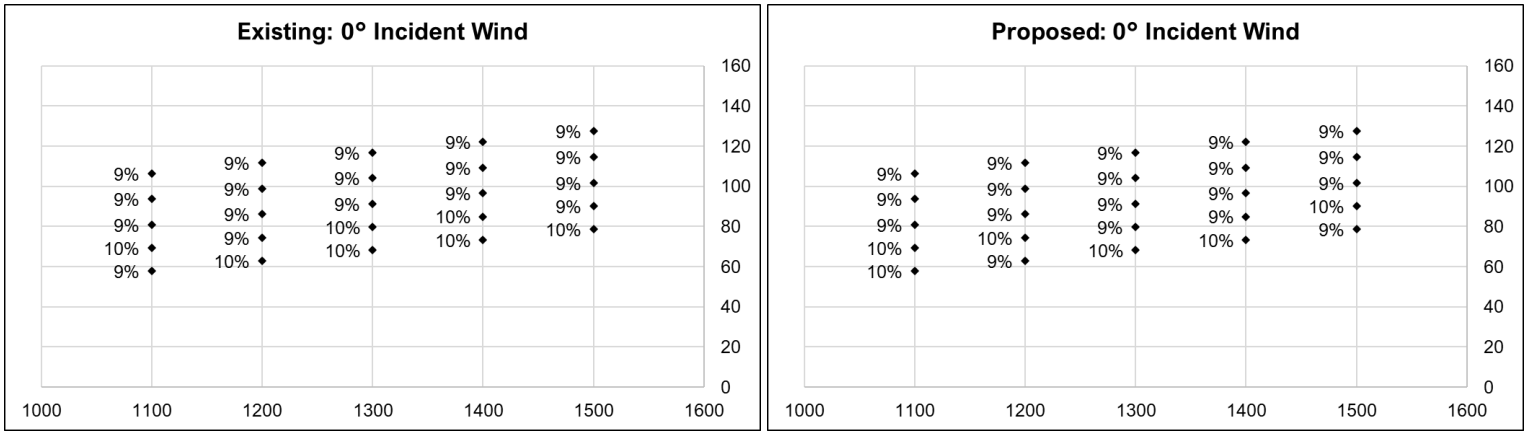
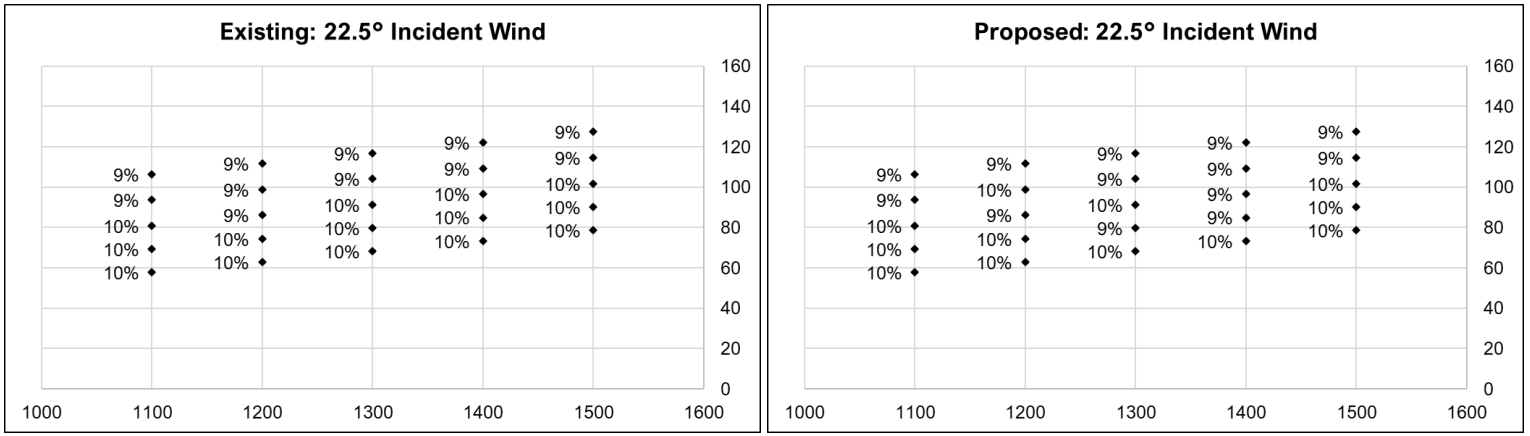


Figure 4.34: Vertical turbulence intensity for wind direction 22.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.35: Vertical turbulence intensity for wind direction 45.0°*

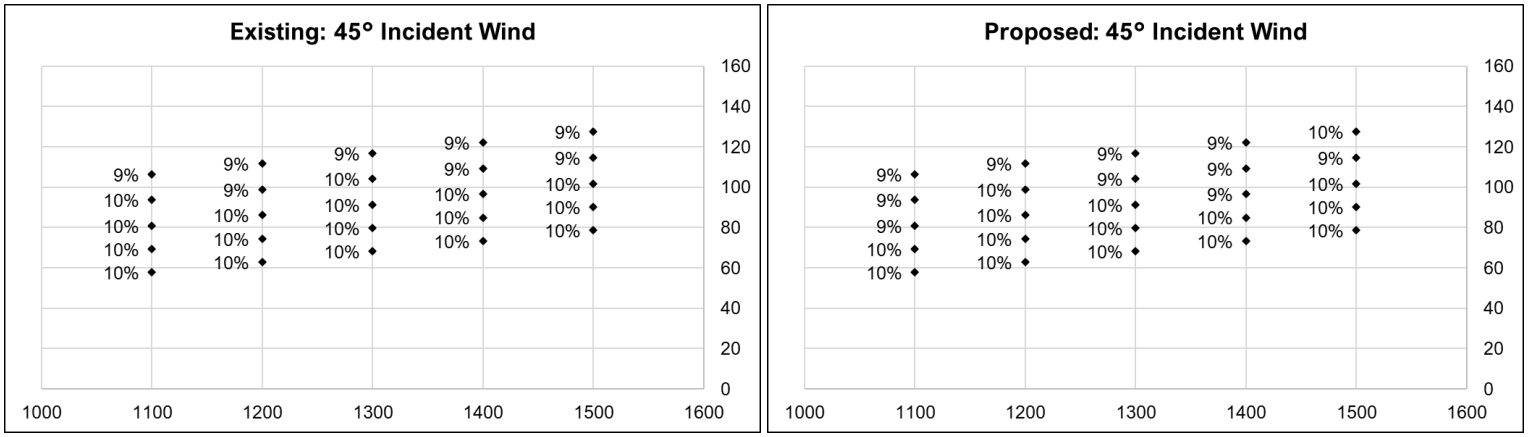
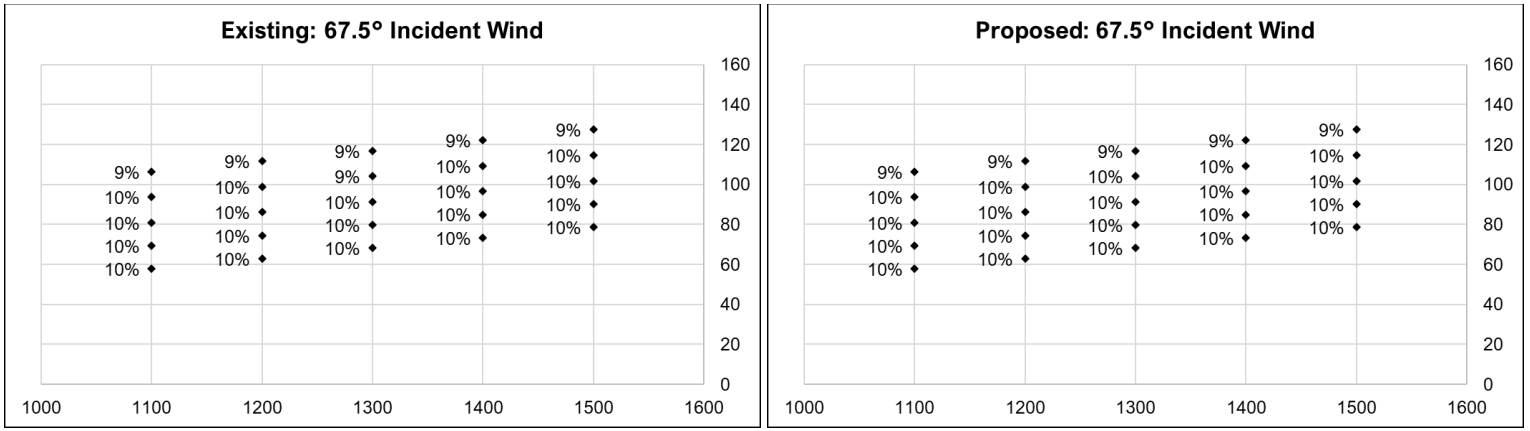


Figure 4.36: Vertical turbulence intensity for wind direction 67.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.37: Vertical turbulence intensity for wind direction 90.0°*

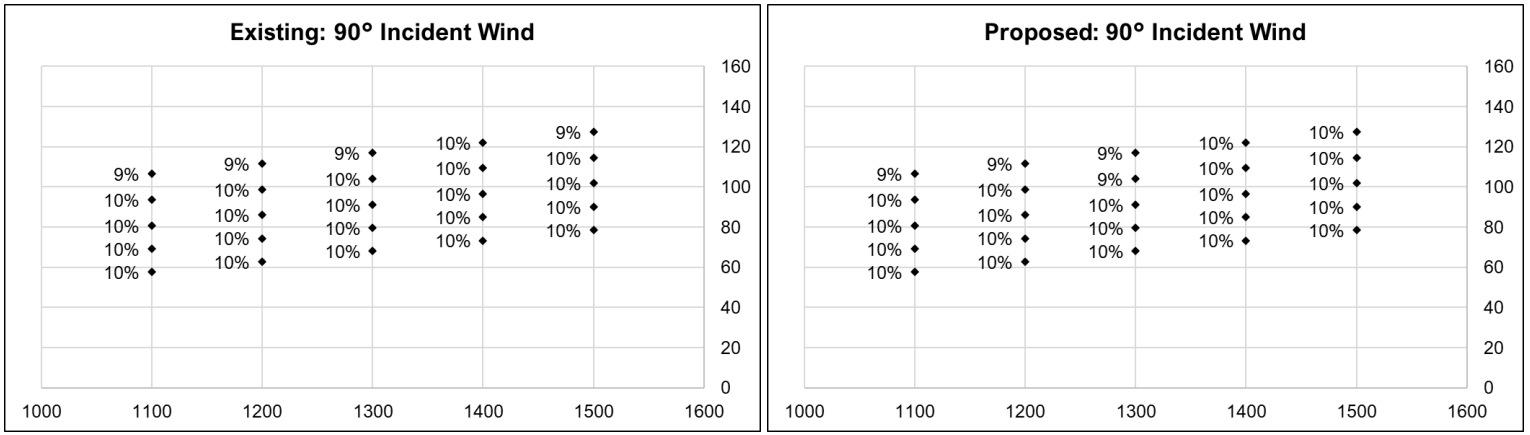
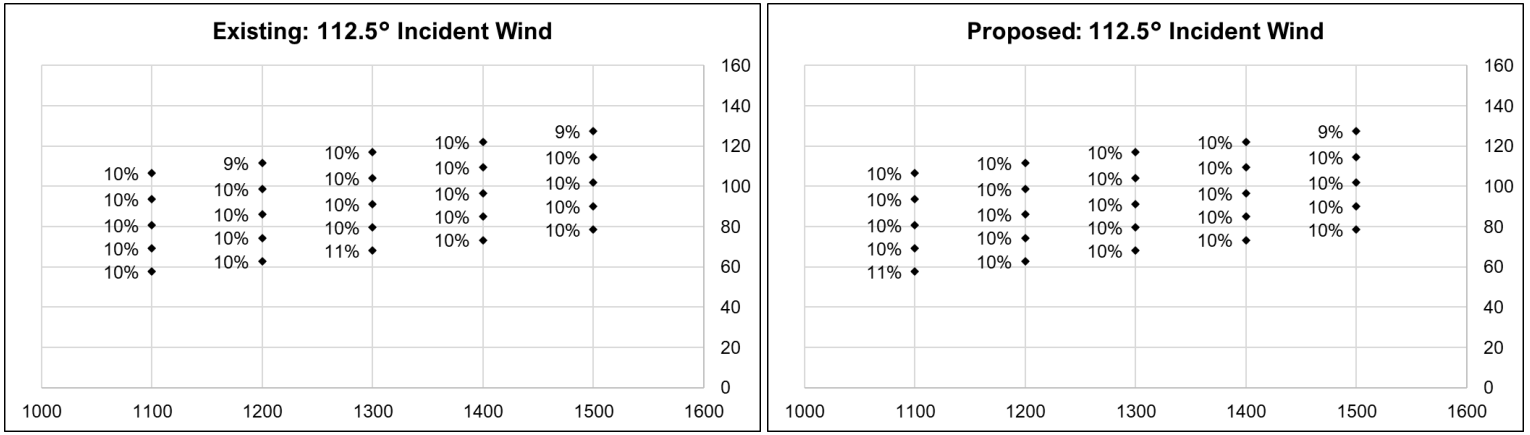


Figure 4.38: Vertical turbulence intensity for wind direction 112.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.39: Vertical turbulence intensity for wind direction 135.0°*

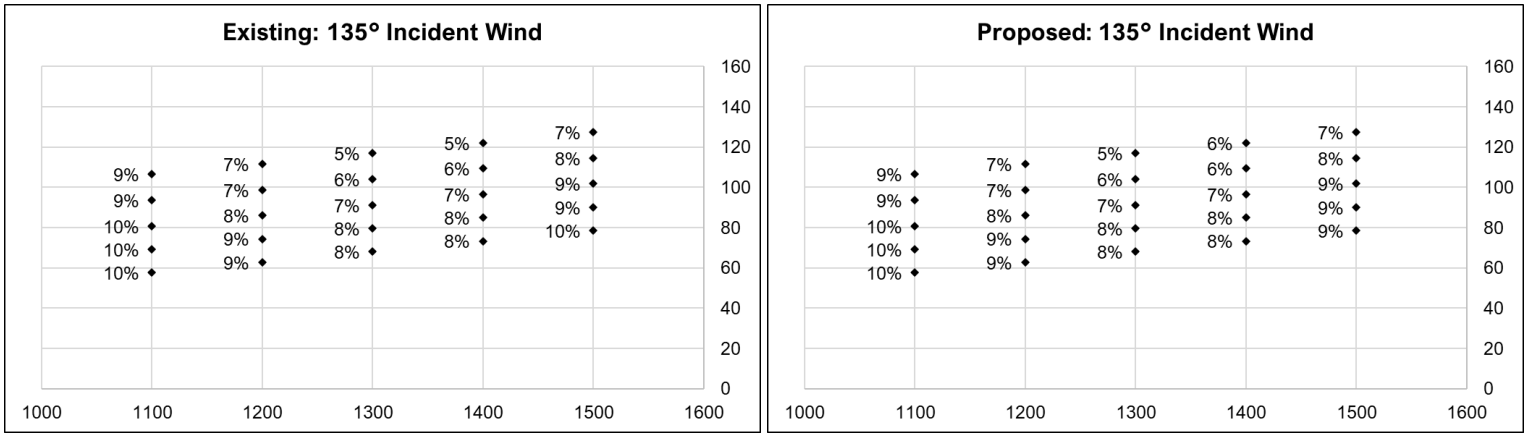
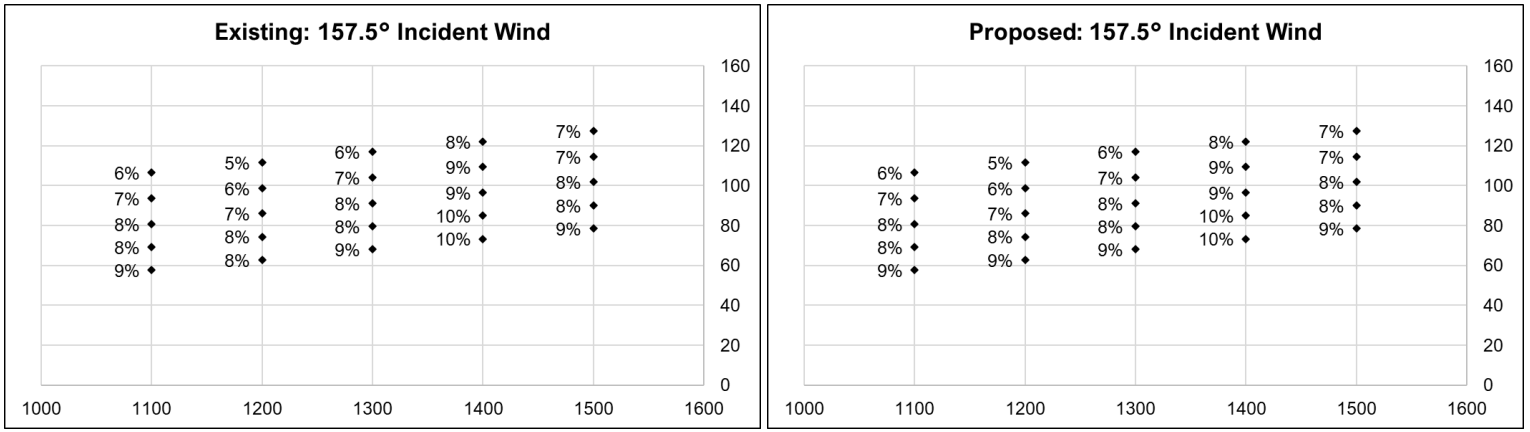


Figure 4.40: Vertical turbulence intensity for wind direction 157.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.41: Vertical turbulence intensity for wind direction 180.0°*

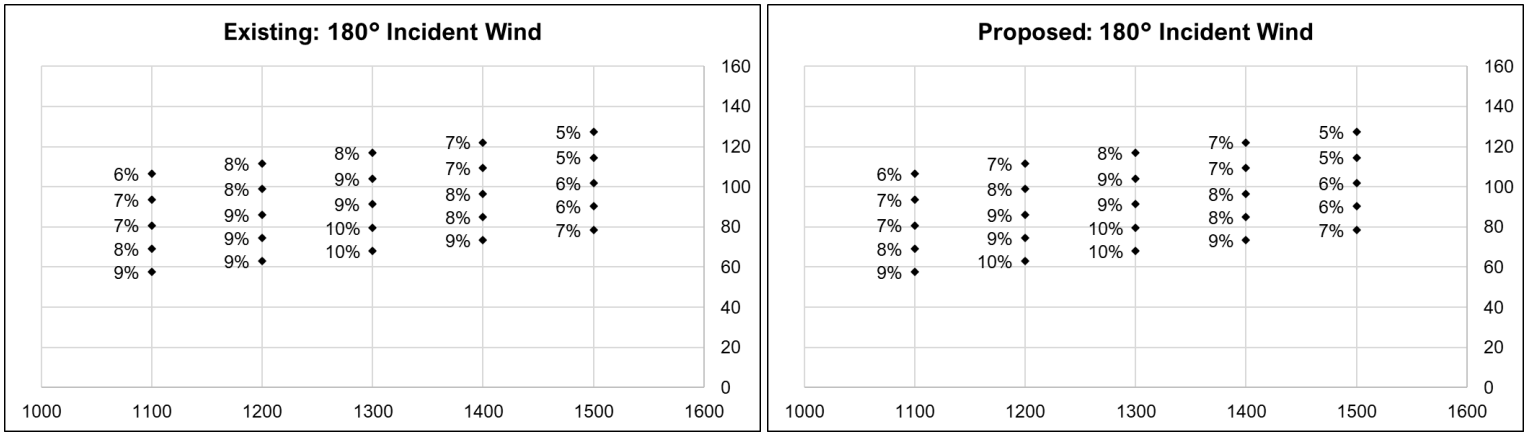
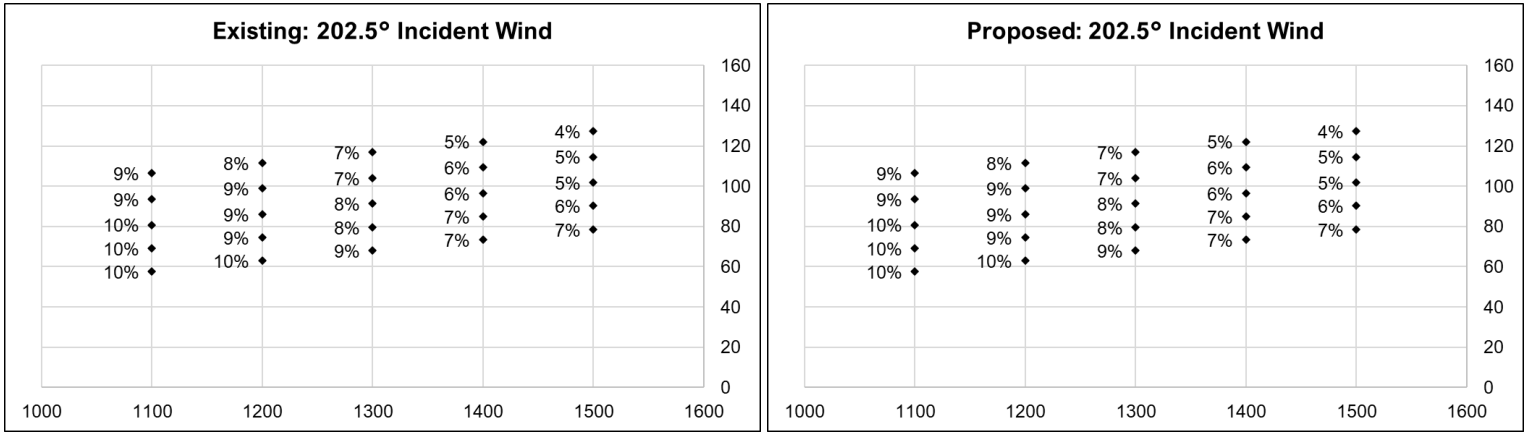


Figure 4.42: Vertical turbulence intensity for wind direction 202.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.43: Vertical turbulence intensity for wind direction 225.0°*

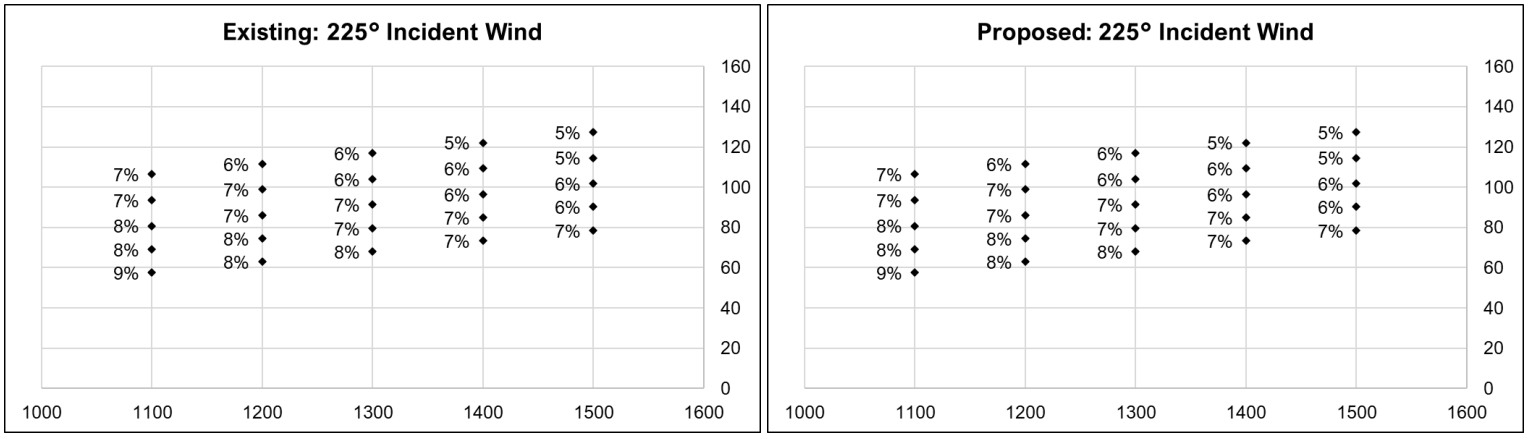
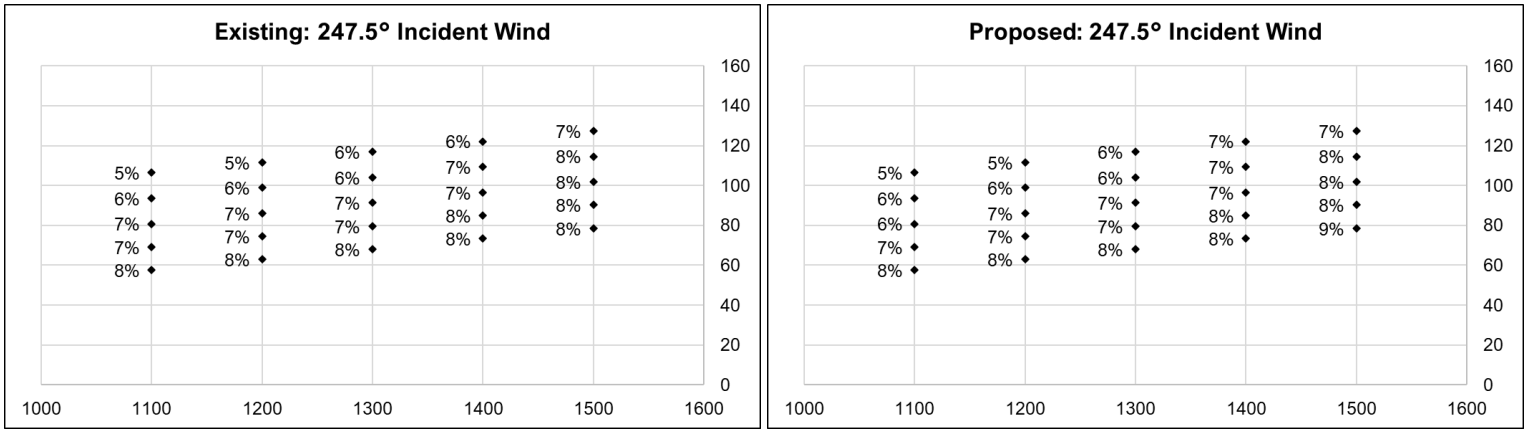


Figure 4.44: Vertical turbulence intensity for wind direction 247.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.45: Vertical turbulence intensity for wind direction 270.0°*

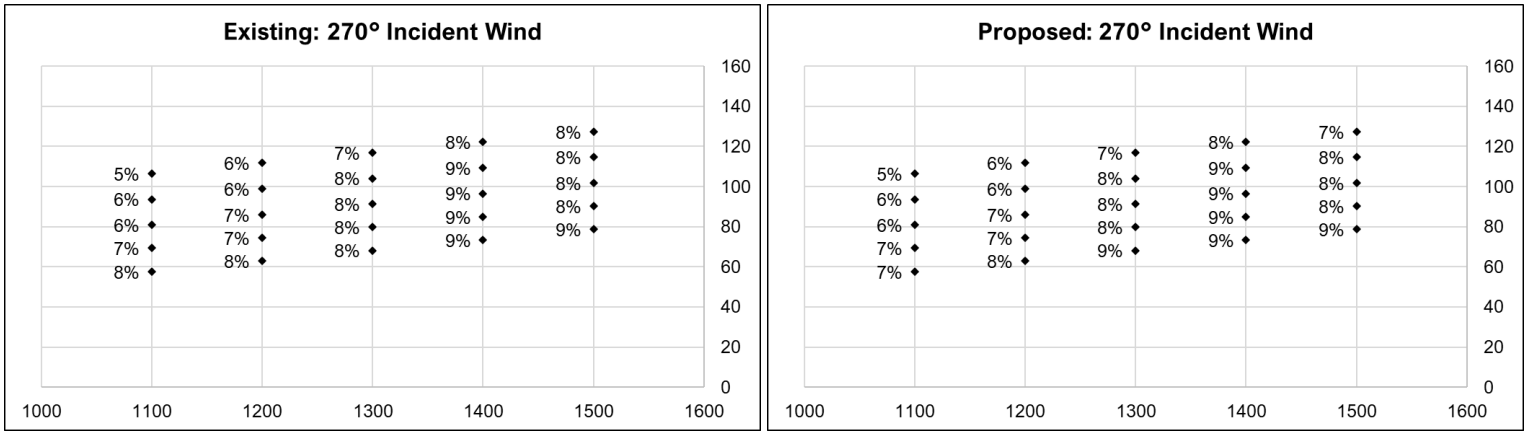
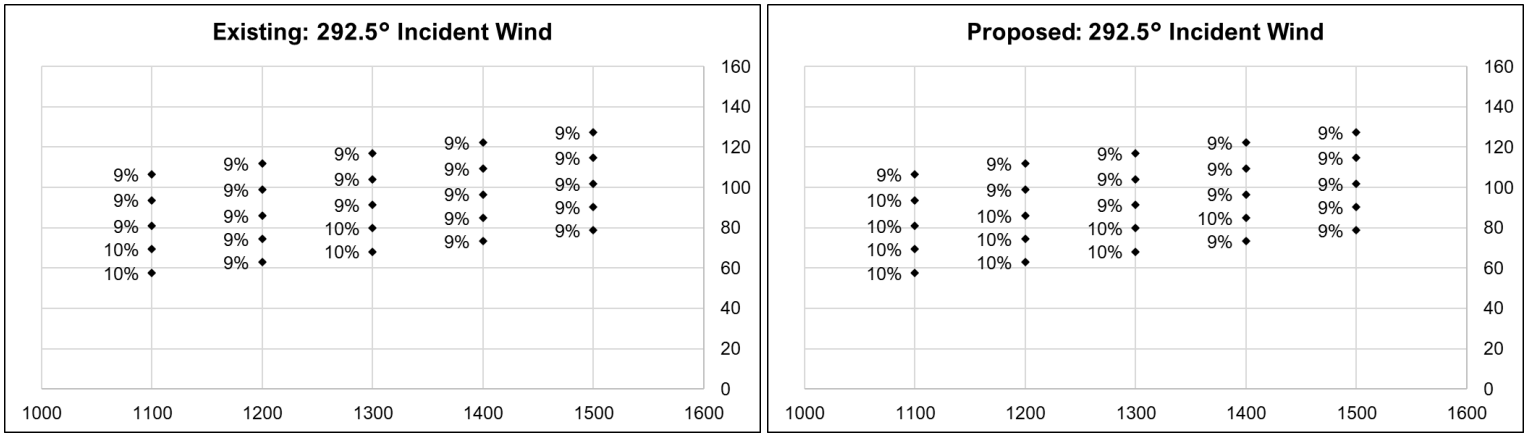


Figure 4.46: Vertical turbulence intensity for wind direction 292.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

Figure 4.47: Vertical turbulence intensity for wind direction 315.0°*

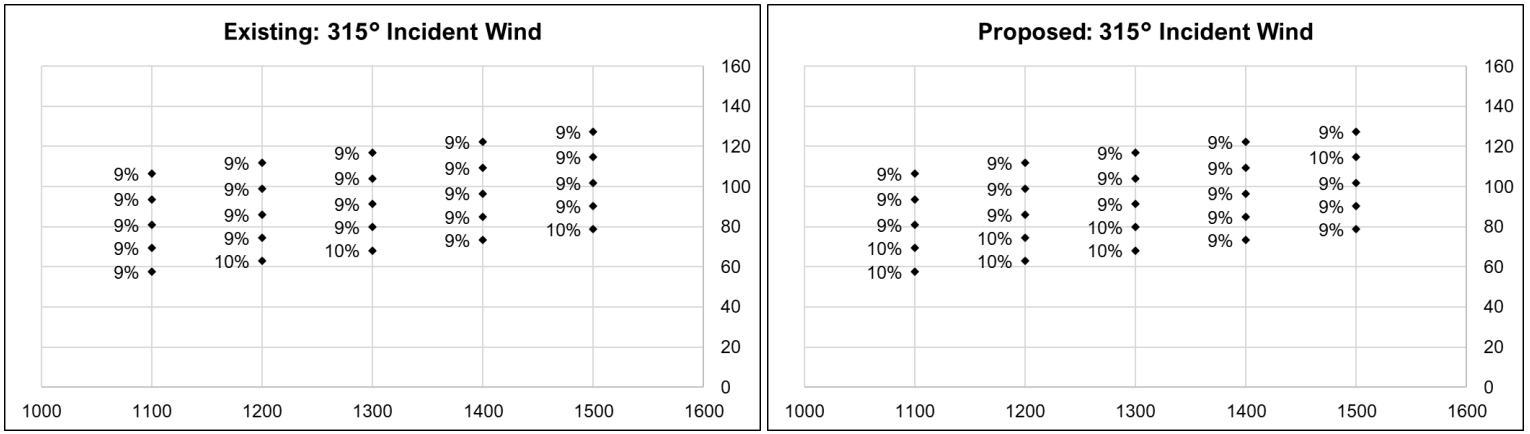
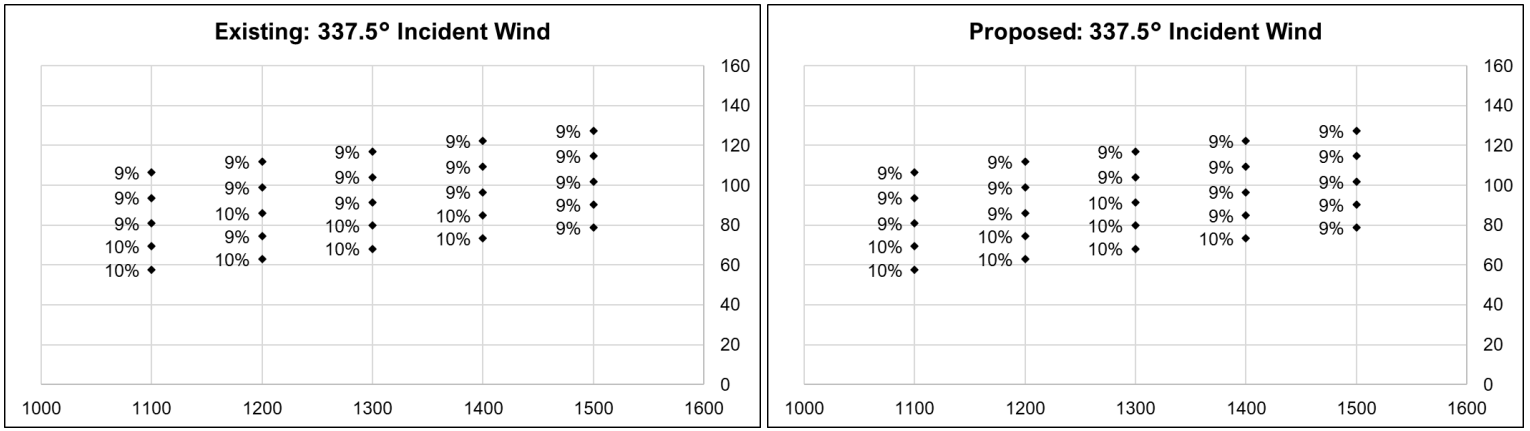


Figure 4.48: Vertical turbulence intensity for wind direction 337.5°*



* Horizontal axis denotes distance in metres relative to the runway touchdown point and the vertical axis denotes height above local ground.

APPENDIX A. WIND CLIMATE ANALYSIS

A.1. ESDU Wind Analysis

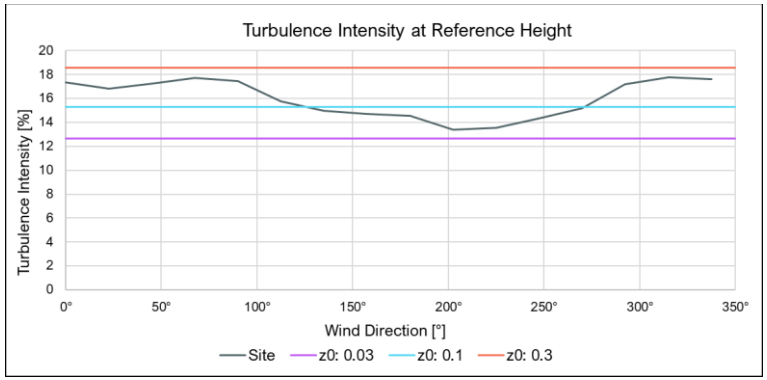
A detailed analysis was carried out to determine the wind properties at the site. The wind analysis is based on the widely accepted Deaves and Harris model of the atmospheric boundary layer (ABL), as defined in ESDU Item 01008[2], and has provided wind profiles describing the variation of wind speed and turbulence intensity with height and wind direction. From this analysis representative profiles were defined as targets for the ABL simulation in the wind tunnel.

The wind analysis takes detailed account of the variation of the upwind terrain on each wind sector. The roughness changes used in the analysis for the current study are given in Figure A.1.

A.2. Wind Properties at the Site

Figure A.2 shows the variation of longitudinal turbulence intensity with wind direction at a reference height of 90 m.

Figure A.2: Variation of turbulence intensity with wind direction at 90 m height, including reference turbulence levels



Due to the variation of wind properties with wind direction, two target profiles have been selected for the boundary layer simulation, namely 90° (for winds from 0.0°-112.5° and 292.5°-337.5°) and 240° (for winds from 135.0°-270.0°).

Figures A.3 and A.4 show the variation of mean wind-speed (normalised by the mean wind speed at the reference height of 90 m) and turbulence intensity with height for winds approaching the site from the four primary quarters.

Figures A.5 and A.6 present the variation of mean wind speed, longitudinal turbulence intensity and gust wind speed used in the tests. The wind speed profiles are normalised by the mean wind speed at the reference height of 90 m.

It can be seen that, over the range of heights of interest, the boundary layer simulations used in the tests were a good representation of the profiles expected for the site at full scale.

Figure A.1: Terrain roughness changes from the site

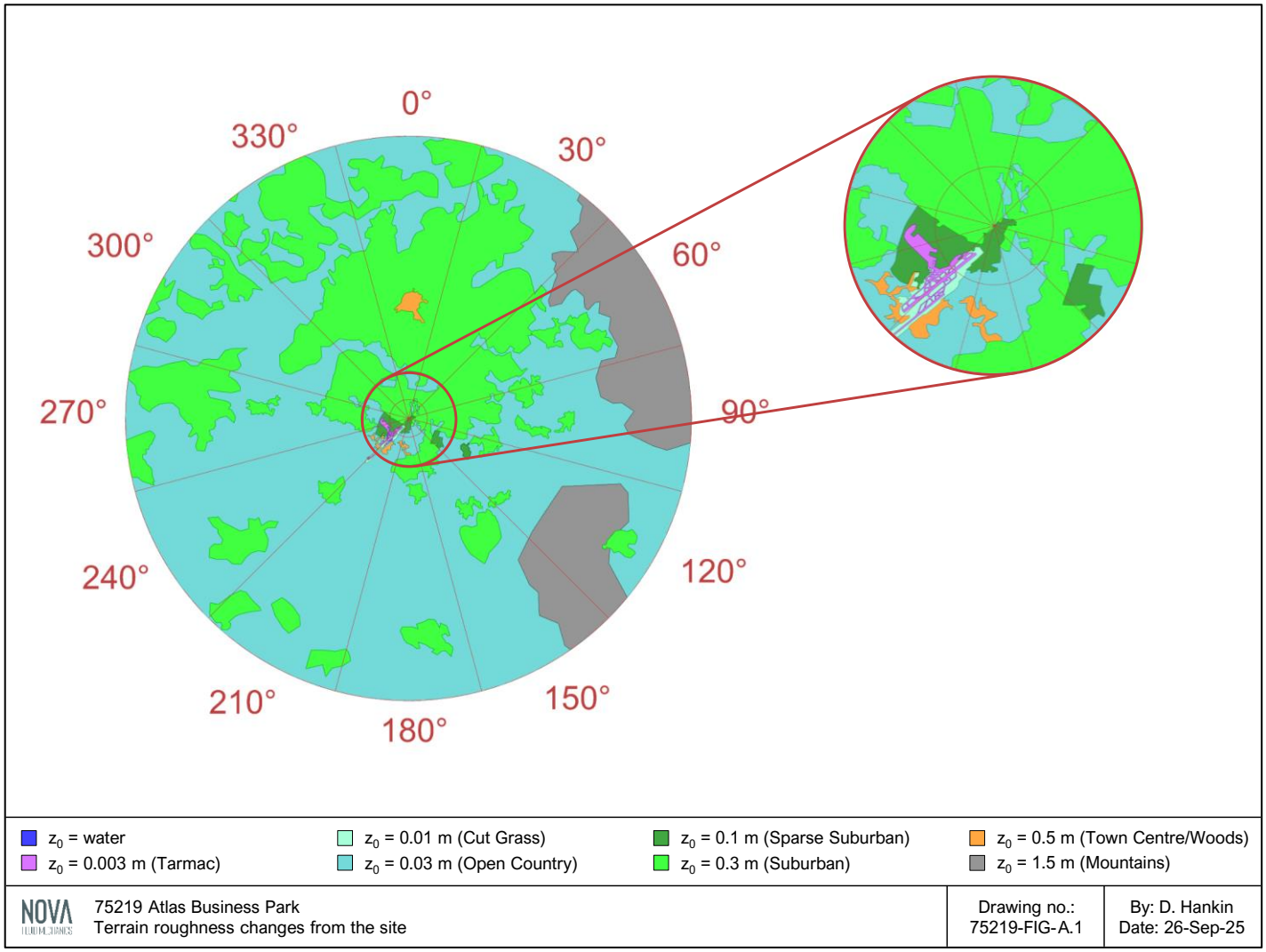


Figure A.3: Variation of mean wind speed normalised by wind speed at the reference height of 90 m.

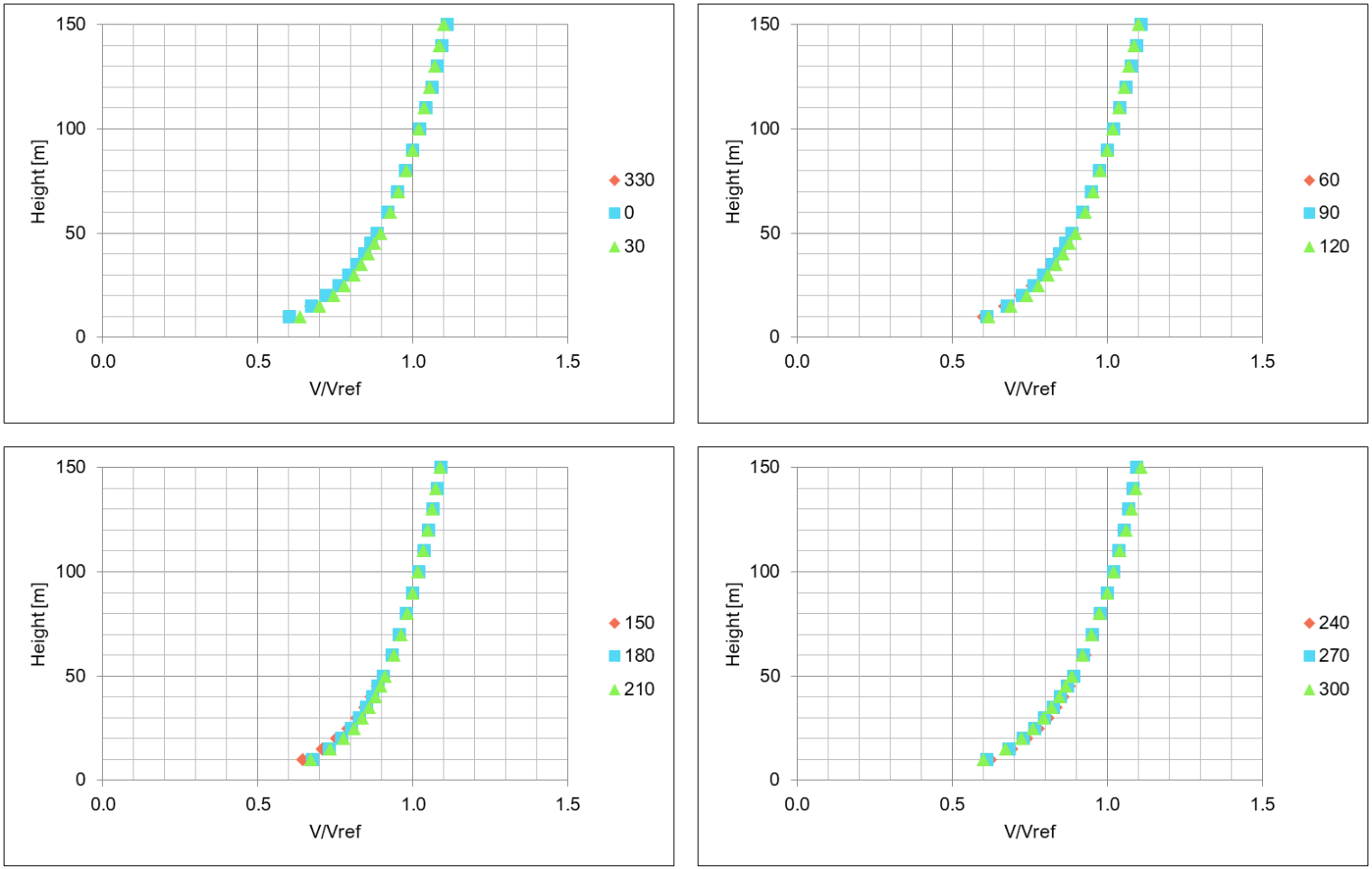


Figure A.4: Variation of longitudinal turbulence intensity with wind direction the reference height of 90 m.

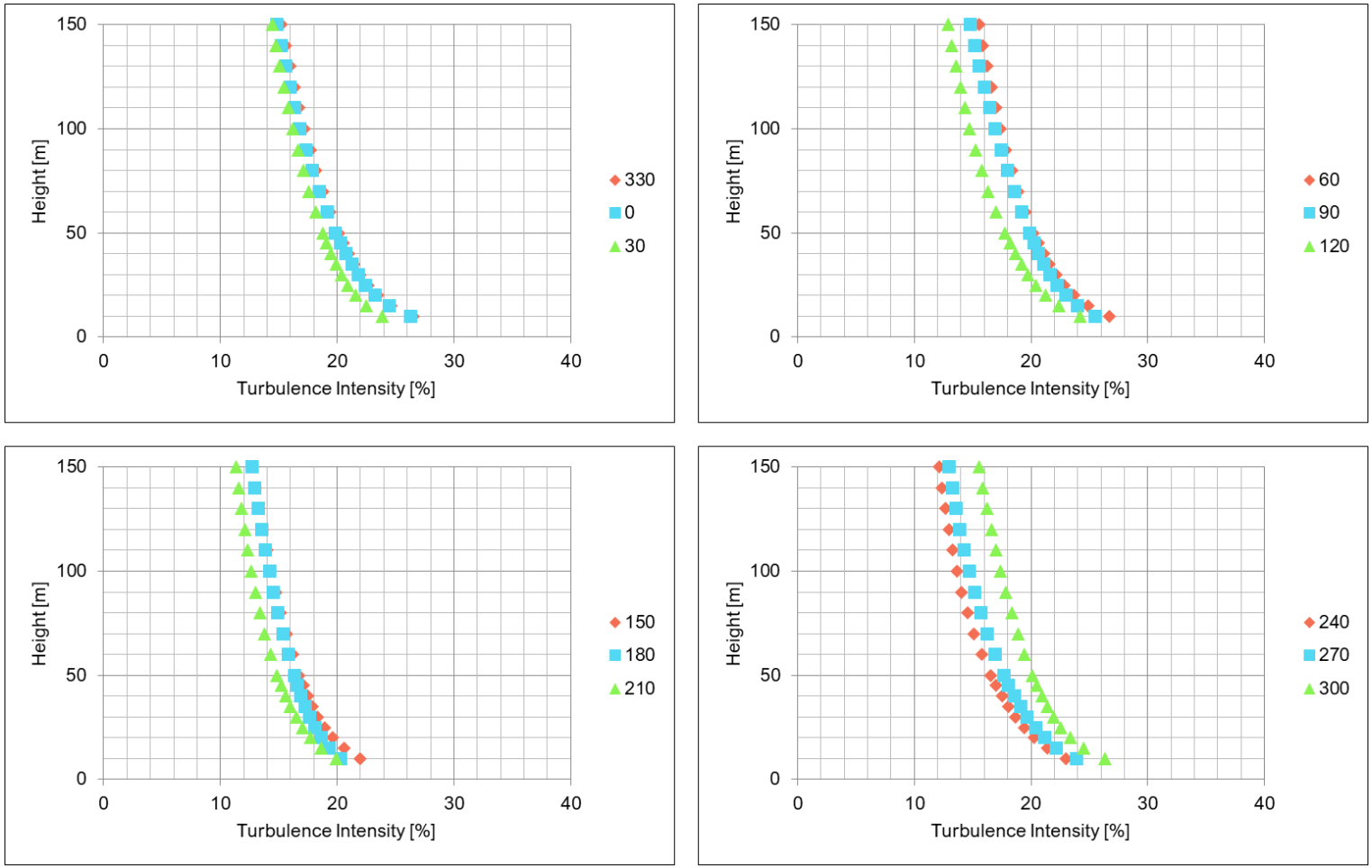


Figure A.5: Mean wind speed (U_{mean}/U_{ref})), longitudinal turbulence intensity profiles (I_u) and gust wind speed (U_{gust}/U_{ref}) modelled in the study, 90°

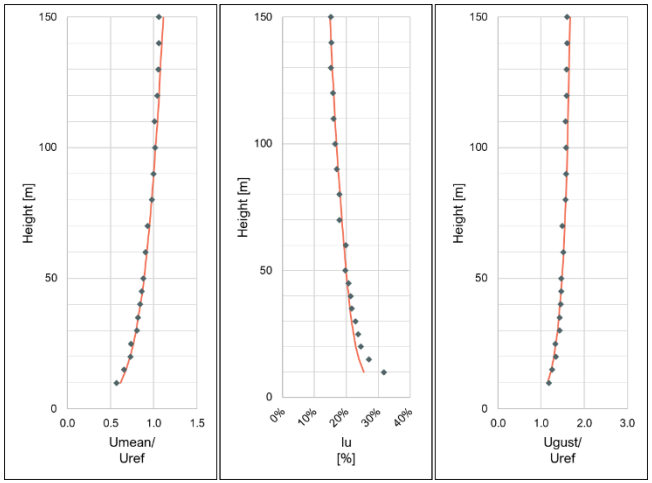
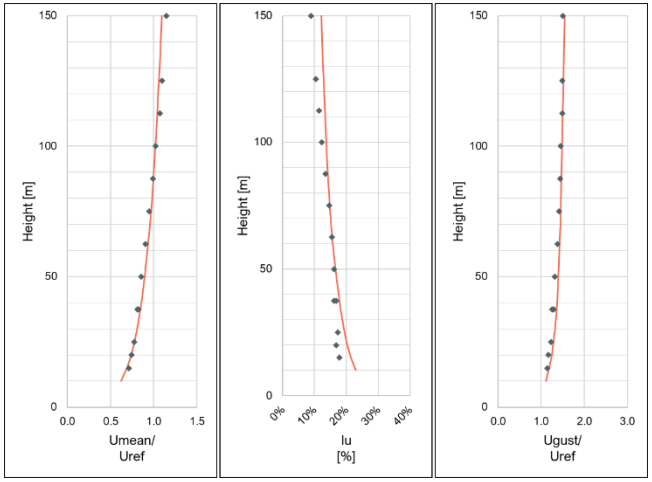


Figure A.6: Mean wind speed (U_{mean}/U_{ref})), longitudinal turbulence intensity profiles (I_u) and gust wind speed (U_{gust}/U_{ref}) modelled in the study, 240°



A.3. Wind Frequency Data

The wind speed history, provided by weather centres such as the UK Met Office or the National Oceanic & Atmospheric Administration, is reformatted into the number of observations of mean hourly wind speeds within each of several wind speed ranges, for each wind direction and for each month of the year.

To facilitate the transposition of the wind data a Weibull distribution is fitted to the wind speed distribution for each wind direction, on an annual basis. From the Weibull cumulative distribution, the probability that, for a given wind direction, a wind speed, V, will be exceeded is given by:

$$P(>V) = e^{-(\frac{V}{c})^k}$$

where c is the dispersion parameter and k is the shape parameter.

To these parameters is further added the probability, p, of each wind direction occurring. Thus, the probability that a specified wind speed is exceeded for a specified wind direction may be calculated.

The resulting weather centre wind data is transposed to a standard reference terrain category, ‘open country terrain’, at sea-level, accounting for upwind terrain, topography and altitude for the weather centre. Values of p, c and k for the Manchester Airport weather centre, being the closest station to the site with a suitable database of records, transposed to open-country terrain at 10 m height above sea-level altitude are given in Table A.1.

The open country wind data is transposed to the reference height at the site of the proposed development, accounting for upwind terrain, topography and altitude of the target site, in order to be used in the assessment.

Table A.1: Wind frequency statistics: corrected Manchester Airport weather centre data transposed to z_0=0.03 m

Annual	0.0°	22.5°	45.0°	67.5°	90.0°	112.5°	135.0°	157.5°	180.0°	202.5°	225.0°	247.5°	270.0°	292.5°	315.0°	337.5°
p	1.93	2.83	4.31	4.74	4.88	3.92	4.34	8.61	13.92	11.69	7.39	7.20	8.41	7.86	5.26	2.72
c	4.53	5.36	5.58	5.51	5.51	5.00	5.22	5.87	6.04	6.60	5.81	5.25	5.26	5.26	4.63	3.93
k	1.75	2.16	2.02	1.69	1.69	1.66	1.71	1.76	1.88	1.93	1.85	1.81	1.82	2.03	1.94	1.62

APPENDIX B. WIND TUNNEL & MODEL DETAILS

B.1. Wind Tunnel Specifications

All the tests were conducted in the Boundary Layer Wind Tunnel at STU which has a working section 2.6 m wide, 1.6 m high and 26.3m long with a 2.4 m diameter turntable and a remotely controlled 3-dimensional traversing system. The operating wind speed range is 0 – 32 m/s.

A turbulent boundary layer, representative of the conditions at the site, is set up using an arrangement of roughness elements distributed over the floor of the wind tunnel and a 2-dimensional barrier with square posts or spires at the entrance to the test section

B.2. Model

B.2.1. Information for Model Construction

The model of the proposed development was constructed based on the drawings supplied by Christopher Smith Associates LLP, received 31st July 2025.

The model of the existing site and the proximity model of the surrounding area were based on a site survey conducted by NOVA using publicly available information.

The models were reviewed and approved by the design team, prior to testing.

B.2.2. Scale

A model scale of 1:500 has been adopted. At this scale the model is large enough to allow a good representation of the details that are likely to affect the local and overall wind flows at full scale. In addition, this scale enables a good simulation of the turbulence properties of the wind to be achieved.

B.2.3. Construction

The model was constructed from a combination of materials such as hard foam and wood. The surrounding buildings were represented to a sufficient level of detail to reproduce the wind flows at the airport runway. The surrounding area was modelled to a radius of nominally 575 m from the centre of the site.

B.2.4. Model Photos

Images of the wind tunnel model are presented as follows:

- Figures B.1-B.2: Proximity model of existing site
- Figures B.3-B.4: Close-ups of existing site
- Figures B.5-B.8: Proximity model of proposed development
- Figures B.9-B.12: Close-ups of proposed development

Figure B.1: Proximity model, existing site, viewed from east



Figure B.2: Proximity model, existing site, viewed from north-west



Figure B.3: Close-up of existing site, viewed from south

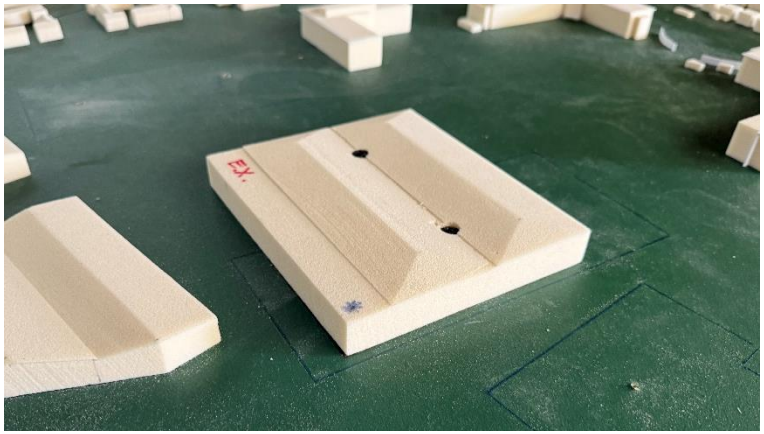


Figure B.4: Close-up of existing site, viewed from above



Figure B.5: Proximity model, proposed development, viewed from north



Figure B.6: Proximity model, proposed development, viewed from east



Figure B.7: Proximity model, proposed development, viewed from south



Figure B.8: Proximity model, proposed development, viewed from west



Figure B.9: Close-up of the proposed development, viewed from north



Figure B.10: Close-up of the proposed development, viewed from south



Figure B.11: Close-up of the proposed development, viewed from east



Figure B.12: Close-up of the proposed development, viewed from above

