

WIND SHEAR AND TURBULENCE ANALYSIS

MIX Manchester (Detailed Element)

Manchester Airport

Prepared by: B-Fluid Ltd.| Buildings Fluid Dynamics Consultants

For: CBRE Limited on behalf of MIX Manchester

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1. EXECUTIVE SUMMARY

B-Fluid Limited has been commissioned by 'CBRE Limited on behalf of MIX Manchester' to carry out a Wind Shear and Turbulence Assessment for the detailed element of the MIX Manchester proposals at Manchester Airport. The aim of this study is to assess whether there is a risk of increased wind shear and turbulence in the vicinity of Manchester Airport runways 23R/05L and 23L/05R arising from the proposed development.

Wind shear is the variation in wind speed and/or direction over a relatively short distance. When wind flow encounters a structure, the normal horizontal flow is disturbed and transformed into complicated pattern of eddies and other irregular air movements. Wind shear manifest as mechanical turbulence downwind of a building. This disturbance can modify significantly (both in magnitude and directions), the speeds along and across airport runways and glide/landing paths, as shown in the example of Figure 1.1.

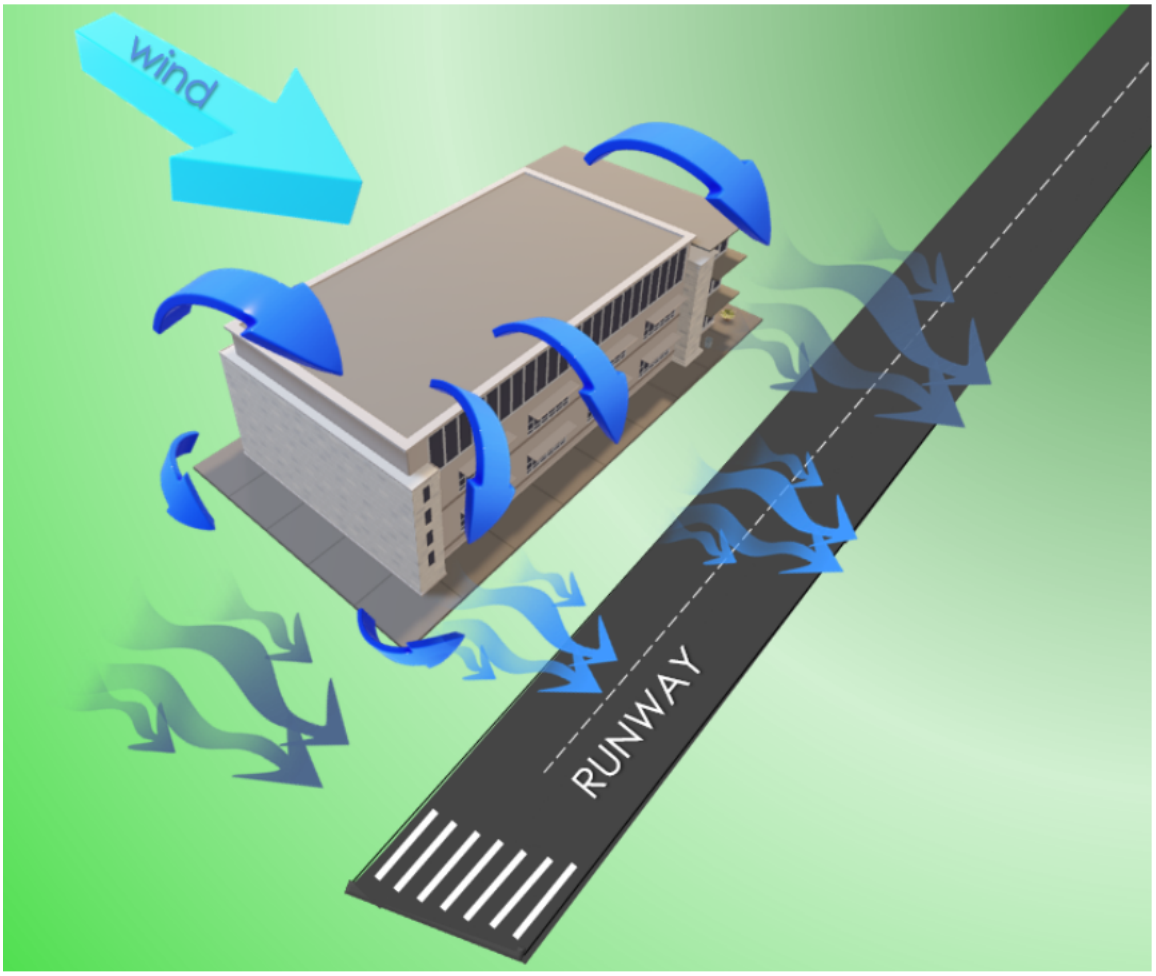


Figure 1.1: Illustration of Buildings Induced Wind Shear and Turbulence on a Runway.

The assessment of the wind shear/turbulence impacts has been conducted using Computational Fluid Dynamics (CFD). CFD is a numerical modeling technique which uses high fidelity algorithms together with High Performance Computer power (HPC) to resolve fluid flows fields and it is a well established method to simulate wind flows and to assess related aerodynamics effects.

The flow analysis objective has been to identify:

- If, and where, there is any increased turbulence and wind shear as a results of the proposed development;
- Whether the increased values could exceed the acceptable levels on the Runway 23R/05L, where the sensitivity of aircraft stability during landings is assessed using runways wind shear and turbulence exceedance criteria (referenced as **Runway - Wind Shear and Turbulence Exceedance Assessment**);
- What wind speeds and directions would cause any criteria/safety risk to be exceeded and how often, in a typical year, this can be expected to happen.

For the wind analysis, two models have been implemented, a "Pre-Development Scenario" model representing the actual built environment and, a "Post-Development Scenario" including the proposed development as shown in the Figures 1.2-1.3. Considering the proposed development location, it can pose a risk of building-induced wind shear/turbulence for the runway for all the wind directions in the range from 0° to 30° and 285° to 345° because of speed disturbances downwind of the proposed buildings blocks. Figure 1.4 shows all the wind directions mentioned above and which have been used for this assessment.

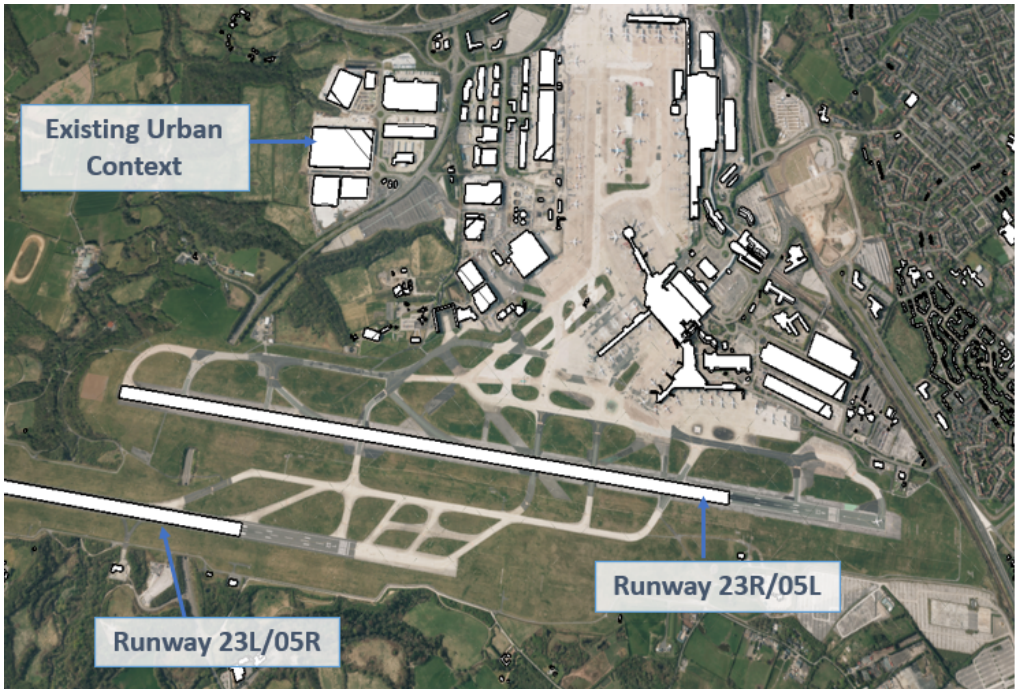


Figure 1.2: Pre-Development Scenario.

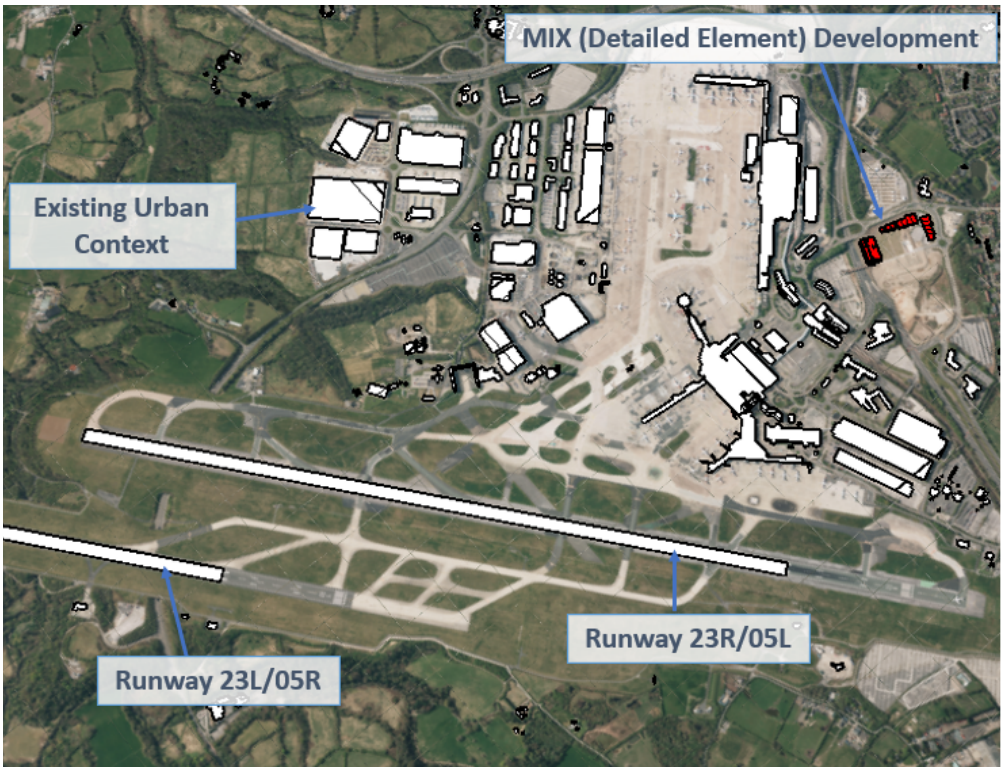


Figure 1.3: Post-Development Scenario.

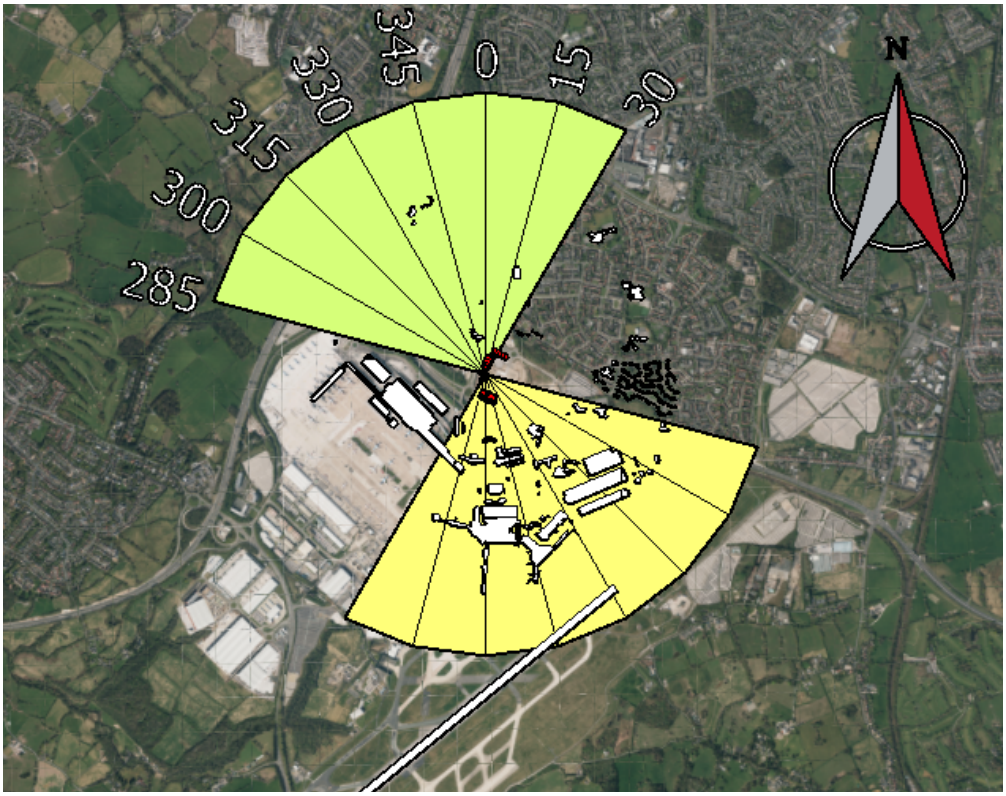


Figure 1.4: Wind Directions Used in the Analysis.

Runway - Wind Shear and Turbulence Exceedance Assessment

Acceptance criteria are well established by international aviation standards to assess the tolerable level of increased wind shear and turbulence that an aircraft can suffer near the ground.

For this assessment, three sets of guidance documents were used:

- The guidance document, Licensing of Aerodomes (CAP 168) by Civil Aviation Authority (CAA), which emphasizes the importance of a comprehensive risk assessment of any building or structure that could potentially cause wind shear problems;
- The National Airports Safeguarding Framework (NASF) guideline, which provides world-class guidance on airport design and is recognized by International Civil Aviation Organization (ICAO) and CAA;
- The National Aerospace Laboratory of The Netherlands (NLR) report, which is a report that provides further explanations on the NASF guideline and is also considered by experts on the subject as world's best practice.

In accordance with the NASF Guideline and the NLR report:

Any proposed development located at a distance of at least 35 times its own height form the centreline of a runway will not pose a risk of wind shear and turbulence on the runway;

Any proposed building which is located at a distance below 35 times its own height, needs to be assessed for potential wind shear and turbulence effects on that runway - i.e. "the building height exceeds the 1:35 rule".

When the building height exceeds the "1:35 rule", the following acceptance criteria must be applied as stated in the NLR report (NLR-CR-2006-261) to evaluate if the buildings induced flow disturbances on a runway are acceptable or not:

- The 7-knot (3.6 m/s) along wind criterion: the variation in mean wind speed due to wind disturbing structures must remain below 7 Kts along the aircraft trajectory at heights below 200 ft and, it must take place over a distance of at least 328 ft.
- The 6-knot (3.09 m/s) cross-wind criterion: the variation in mean wind speed due to wind disturbing structures must remain below 6 Kts across the aircraft trajectory at heights below 200 ft and, it must take place over a distance of at least 328 ft.
- The 4-knot (2.06 m/s) turbulence criterion: the fluctuations of wind speed around its mean value (standard deviation of wind speed) must remain below 4 Kts at heights below 200 ft.

Additionally, it is also stated in NLR report that obstacles with a width less than 30m and producing a maximum speed deficit less than 8Kts are allowed to protrude the 1:35 wind disturbance plane.

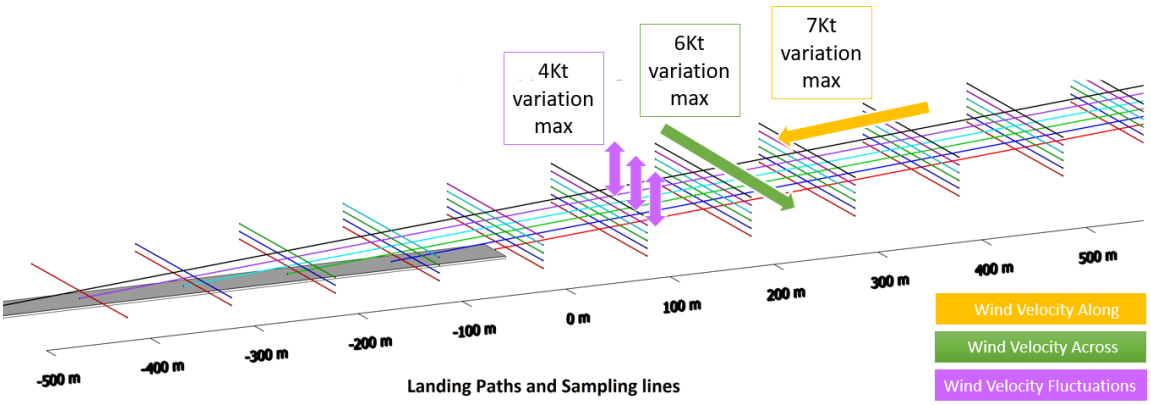


Figure 1.5: Wind Shear and Turbulence Criteria Evaluation on a Runway Landing Paths.

In this study, for each wind directions, wind velocity and turbulence are collected at the aircraft trajectory, considering 3° landing/takeoff degrees. Six possible landing paths are considered. Each path starts at approximately 1400 feet far from the runway touch down zone and continues to ground level. Data are collected along each path and every 328 feet across them and variations of velocities have been calculated (see Figure 1.6).

The reason for all the wind speed/turbulence variations, to be assessed over a distance of 328 ft, is to account for the response time of a landing aircraft to a sudden changing of wind conditions. Although an aircraft, can fly through winds speeds and turbulence higher than those mentioned in the criteria, a rapid change of the wind conditions causes detrimental instability when approaching the ground where the possibility of movements are reduced.

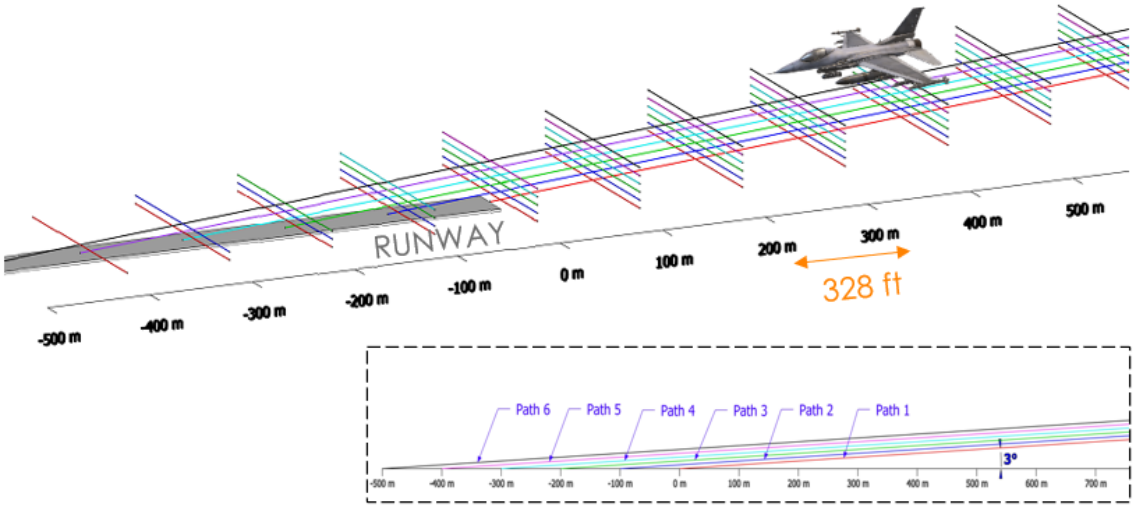


Figure 1.6: Landing Scenarios and Sampling Lines at 3° Approaching Angle.

As shown in the report, the wind shear and turbulence impact of the proposed development on the runways is as follows:

Impact on Runway 23R/05L:

- The proposed development Building A1 is not located within the trigger area of Runway 23R/05L according to the NASF guideline, while it is located within the trigger area suggested by the NLR report. The Building A1 does not penetrate the 1:35 height rule on Runway 23R/05L, but its width exceeds 30m. Consequently, the effects of the development are further analyzed in relation to Runway 23R/05L using quantitative Computational Fluid Dynamics (CFD) analysis.
- The proposed development Building A2 is not located within the trigger area of Runway 23R/05L according to the NASF guideline, while it is located within the trigger area suggested by the NLR report. The Building A2 does not penetrate the 1:35 height rule on Runway 23R/05L, but its width exceeds 30m. Consequently, the effects of the development are further analyzed in relation to Runway 23R/05L using quantitative Computational Fluid Dynamics (CFD) analysis.
- The proposed development Building A5 is not located within the trigger area of Runway 23R/05L according to the NASF guideline, while it is located within the trigger area suggested by the NLR report. The Building A5 does not penetrate the 1:35 height rule on Runway 23R/05L, but its width exceeds 30m. Consequently, the effects of the development are further analyzed in relation to Runway 23R/05L using quantitative Computational Fluid Dynamics (CFD) analysis.
- The proposed development Building E1 is located within the trigger area of Runway 23R/05L according to both the NLR report or the NASF guideline. The Building E1 does not penetrate the 1:35 height rule on Runway 23R/05L, but its width exceeds 30m. Consequently, the effects of the development are further analyzed in relation to Runway 23R/05L using quantitative Computational Fluid Dynamics (CFD) analysis.

Impact on Runway 23L/05R:

- None of the proposed buildings are located within the trigger area of Runway 23L/05R according to the NASF guideline, nor they are located within the trigger area suggested by the NLR report. None of the proposed buildings penetrates the "1:35 height rule" on Runway 23L/05R. Hence, no further analysis is required in relation to Runway 23L/05R as the proposed development, in accordance with the above guidelines, does not pose a wind shear and turbulence risk for this runway.

Tables from 1.1 - 1.4 summarize if the MIX (Detailed Element) buildings are located within any trigger area for each of the runways and specifies the distances of each unit from the runways in relation to the "1:35 rule".

Table 1.1: Trigger Areas and the 1:35 Rule for the Runways - Building A1

Runways in Dublin Airport	Building A1					
	Trigger Area		1:35 Rule			
	NASF	NLR	Building height	1:35 Distance	Distance to centreline	Is 1:35 rule penetrated?
Runway 23R/05L	Outside	Within	13 m	455 m	1303 m	No
Runway 23L/05R	Outside	Outside	13 m	455 m	1692 m	No

Table 1.2: Trigger Areas and the 1:35 Rule for the Runways - Building A2

Runways in Dublin Airport	Building A2					
	Trigger Area		1:35 Rule			
	NASF	NLR	Building height	1:35 Distance	Distance to centreline	Is 1:35 rule penetrated?
Runway 23R/05L	Outside	Within	13 m	455 m	1328 m	No
Runway 23L/05R	Outside	Outside	13 m	455 m	1717 m	No

Table 1.3: Trigger Areas and the 1:35 Rule for the Runways - Building A5

Runways in Dublin Airport	Building A5					
	Trigger Area		1:35 Rule			
	NASF	NLR	Building height	1:35 Distance	Distance to centreline	Is 1:35 rule penetrated?
Runway 23R/05L	Outside	Within	13 m	455 m	1295 m	No
Runway 23L/05R	Outside	Outside	13 m	455 m	1684 m	No

Table 1.4: Trigger Areas and the 1:35 Rule for the Runways - Building E1

Runways in Dublin Airport	Building E1					
	Trigger Area		1:35 Rule			
	NASF	NLR	Building height	1:35 Distance	Distance to centreline	Is 1:35 rule penetrated?
Runway 23R/05L	Within	Within	30 m	1050 m	1165 m	No
Runway 23L/05R	Outside	Outside	30 m	1050 m	1554 m	No

Results Summary - Runway 23R/05L

The results of the analysis on Runway 23R/05L can be summarized as follows:

7 Knot Along-Wind Criterion:

- For approaching wind speeds of 19.4 Kts (10 m/s) to 38.9 Kts (20 m/s), the NLR "7 Knot criterion" was not exceeded for a wind direction of 0°, 15°, 30°, 285°, 300°, 315°, 330°, and 345° in the Post-Development Scenario.
- For approaching wind speeds of 19.4 Kts (10 m/s) to 38.9 Kts (20 m/s), the NLR "7 Knot criterion" was not exceeded for a wind direction of 315°, 330°, and 345° in the Pre-Development Scenario.

6 Knot Across-Wind Criterion:

- For approaching wind speed 19.4 Kts (10 m/s) - 38.9 Kts (20 m/s), the NLR "6 Knot criterion" was never exceeded for the Post-Development Scenarios for approaching wind from 0°, 15°, 30°, 285°, and 300°.
- For a wind direction of 315° at 38.9 Kts (20 m/s) and above, exceedance of the criterion was observed in the Pre- and Post-Development Scenario, while all lower wind speeds satisfied the criterion.
- For a wind direction of 330° at 34 Kts (17.5 m/s) and above, exceedance of the criterion was observed in the Pre- and Post-Development Scenario, while all lower wind speeds satisfied the criterion.
- Further, for a wind direction of 345° at 29.2 Kts (15 m/s) and above, exceedance of the criterion was observed in the Pre- and Post-Development Scenario, while all lower wind speeds satisfied the criterion.

4 Knot Turbulence Criterion:

- For approaching wind speed 19.4 Kts (10 m/s) to 38.9 Kts (20 m/s), the NLR "4 Knot criterion" was not exceeded for a wind direction of 0°, 15°, 30°, 285°, 300°, 315°, 330°, and 345° in the Post-Development Scenario.
- For approaching wind speed 19.4 Kts (10 m/s) to 38.9 Kts (20 m/s), the NLR "4 Knot criterion" was not exceeded for a wind direction of 315°, 330°, and 345° in the Pre-Development Scenario.

Therefore, it can be concluded that:

- **The impact of windshear and turbulence on runway 23R/05L is expected to exceed the critical level recommended by the NLR "6 Knot across-wind windshear criterion" with an occurrence of approximately 3.147% per year for both Pre- and Post-Development.**
- **The analysis has shown that the wind shear and turbulence on runway 23R/05L will be comparable to those currently existing even after the construction of the proposed MIX (Detailed Element) development.**
- **Wind shear and turbulence exceedances are already occurring on the runway 23R/05L in the Pre-Development Scenario, and they will remain within the same ranges after the construction of the development. Furthermore, wind shear and turbulence exceedances occur under wind directions that have a reduced frequency during a typical year.**
- **Therefore, it can be concluded that the proposed development will not pose any increased risk of wind shear and turbulence compared to the existing situation.**

A summary of the analysis conducted is shown in Table 1.5.

Table 1.5: Summary of Analysis Conducted - Acceptance Criteria Evaluation

Approaching Wind Speed	Wind Direction	Is the 7-Knot Criterion Exceeded?		Is the 6-Knot Criterion Exceeded?		Is the 4-Knot Criterion Exceeded?	
		Pre-Development	Post-Development	Pre-Development	Post-Development	Pre-Development	Post-Development
19.4 Knots (10 m/s)	0^0	No	No	No	No	No	No
	15^0	No	No	No	No	No	No
	30^0	No	No	No	No	No	No
	285^0	No	No	No	No	No	No
	300^0	No	No	No	No	No	No
	315^0	No	No	No	No	No	No
	330^0	No	No	No	No	No	No
	345^0	No	No	No	No	No	No
24.3 Knots (12.5 m/s)	0^0	No	No	No	No	No	No
	15^0	No	No	No	No	No	No
	30^0	No	No	No	No	No	No
	285^0	No	No	No	No	No	No
	300^0	No	No	No	No	No	No
	315^0	No	No	No	No	No	No
	330^0	No	No	No	No	No	No
	345^0	No	No	No	No	No	No
29.2 Knots (15 m/s)	0^0	No	No	No	No	No	No
	15^0	No	No	No	No	No	No
	30^0	No	No	No	No	No	No
	285^0	No	No	No	No	No	No
	300^0	No	No	No	No	No	No
	315^0	No	No	No	No	No	No
	330^0	No	No	No	No	No	No
	345^0	No	No	**Yes (0.699% annual)**	**Yes (0.699% annual)**	No	No
34 Knots (17.5 m/s)	0^0	No	No	No	No	No	No
	15^0	No	No	No	No	No	No
	30^0	No	No	No	No	No	No
	285^0	No	No	No	No	No	No
	300^0	No	No	No	No	No	No
	315^0	No	No	**No**	No	No	No
	330^0	No	No	**Yes (0.895% annual)**	**Yes (0.895% annual)**	No	No
	345^0	No	No	**Yes* (0.699% annual)**	**Yes* (0.699% annual)**	No	No
38.9 Knots (20 m/s)	0^0	No	No	No	No	No	No
	15^0	No	No	No	No	No	No
	30^0	No	No	No	No	No	No
	285^0	No	No	No	No	No	No
	300^0	No	No	No	No	No	No
	315^0	No	No	**Yes (1.553% annual)**	**Yes (1.553% annual)**	No	No
	330^0	No	No	**Yes** (0.895% annual)**	**Yes** (0.895% annual)**	No	No
	345^0	No	No	**Yes* (0.699% annual)**	**Yes* (0.699% annual)**	No	No

Note: (*) The probability at that wind direction is already included in the range of velocity starting from 29.2 Kts and above;

Note: (**) The probability at that wind direction is already included in the range of velocity starting from 34 Kts and above.

2. PROJECT DESCRIPTION

2.1 INTRODUCTION

B-Fluid Limited has been commissioned by 'CBRE Limited on behalf of MIX Manchester' to carry out a Wind Shear and Turbulence Assessment for the proposed MIX Manchester (Detailed Element) at Olympic House, Manchester Airport, M90 1QX. The aim of this study is to assess if there is a risk of increased wind shear and turbulence on the vicinity of the Manchester airport runways due to the proposed development.

Wind shear is the variation in wind speed and/or direction over a relatively short distance. When wind flow encounters a structure, the normal horizontal flow is disturbed and transformed into complicated pattern of eddies and other irregular air movements. Wind shear manifest as mechanical turbulence downwind of a building. This disturbance can modify significantly (both in magnitude and directions), the speeds along and across airport runways and glide/landing paths, as shown in the example of Figure 2.1.

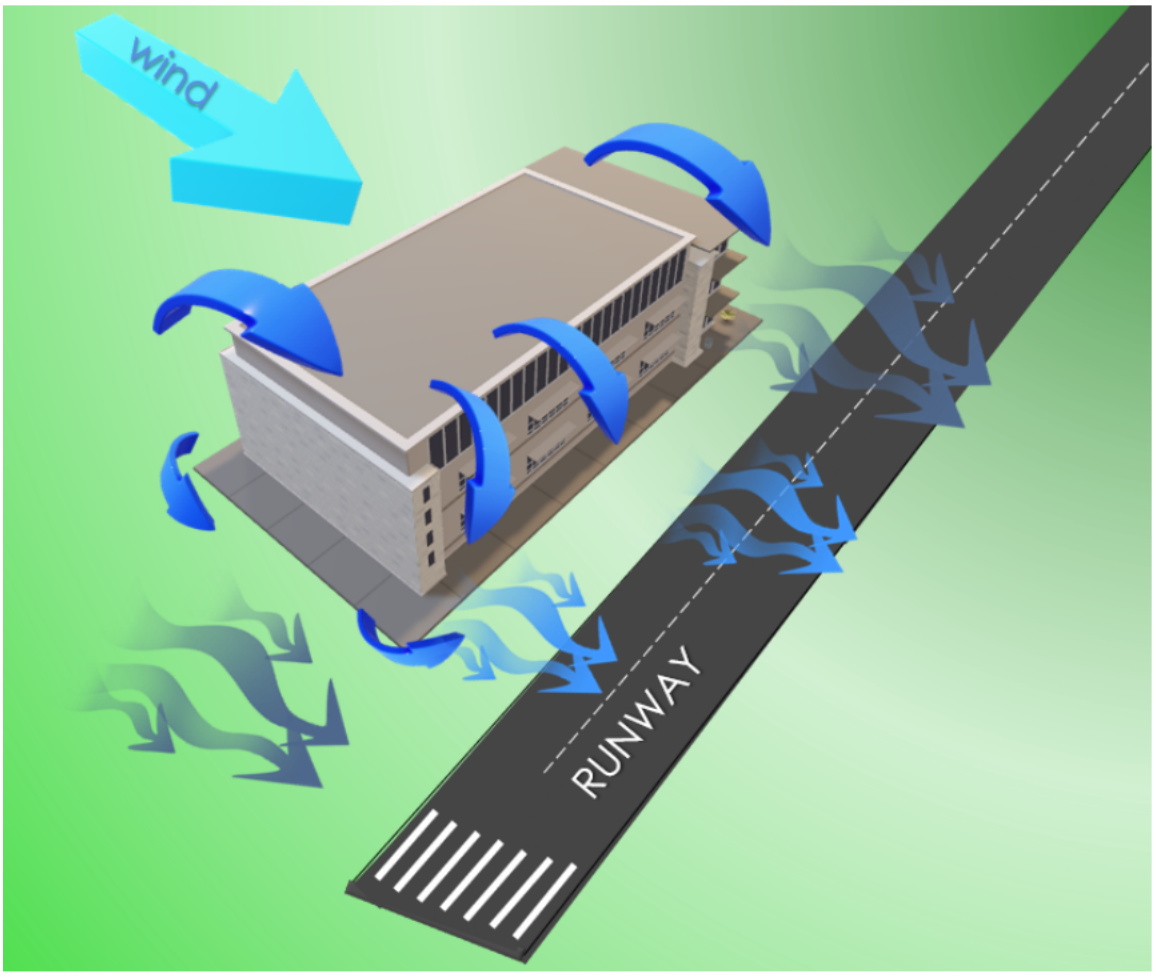


Figure 2.1: Illustration of Buildings Induced Wind Shear and Turbulence on a Runway.

The assessment of the wind shear/turbulence impacts has been conducted using Computational Fluid Dynamics (CFD). CFD is a numerical modeling technique which uses high fidelity algorithms together with High Performance Computer power (HPC) to resolve fluid flows fields and it is a well established method to simulate wind flows and to assess related aerodynamics effects.

For this assessment, three sets of guidance documents were used:

- The guidance document, Licensing of Aerodomes (CAP 168) by Civil Aviation Authority (CAA), which emphasizes the importance of a comprehensive risk assessment of any building or structure that could potentially cause wind shear problems;
- The National Airports Safeguarding Framework (NASF) guideline, which provides world-class guidance on airport design and is recognized by International Civil Aviation Organization (ICAO) and CAA;
- The National Aerospace Laboratory of The Netherlands (NLR) report, which is a report that provides further explanations on the NASF guideline and is also considered by experts on the subject as world's best practice.

In accordance with NASF Guideline and the NLR report, a proposed structure can potentially create a wind shear and turbulence impact risk if located within the trigger area of a nearby runway.

In NASF guideline, the trigger area is defined as:

- 1200m or closer perpendicular from the runway centreline (or extended runway centreline);
- 900m or closer in front of runway threshold (towards the landside of the airport); and
- 500m or closer from the runway threshold along the runway.

In NLR report, the trigger area is defined as:

- 2000m or closer perpendicular from the runway centreline (or extended runway centreline);
- 2000m or closer in front of runway threshold (towards the landside of the airport); and
- 1500m or closer from the runway threshold along the runway.

Figure 2.2 shows the trigger areas defined in NASF guideline and NLR report.

In accordance with the definitions described above, Figures 2.3 - 2.4 show the location of the development in relation to the trigger areas of Runways 23R/05L and 23L/05R defined by NASF guideline and the NLR report. More details on the trigger areas can be found in Section 4.2.

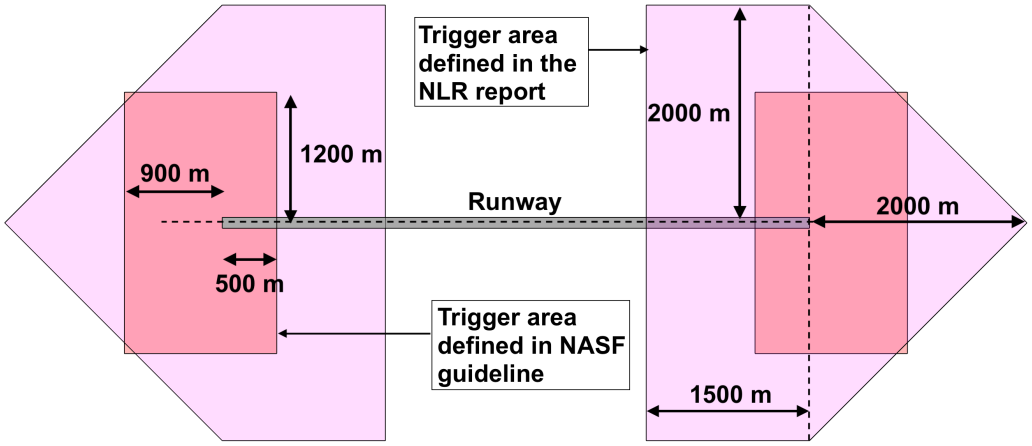


Figure 2.2: Trigger Areas Defined in NASF Guideline and NLR Report.

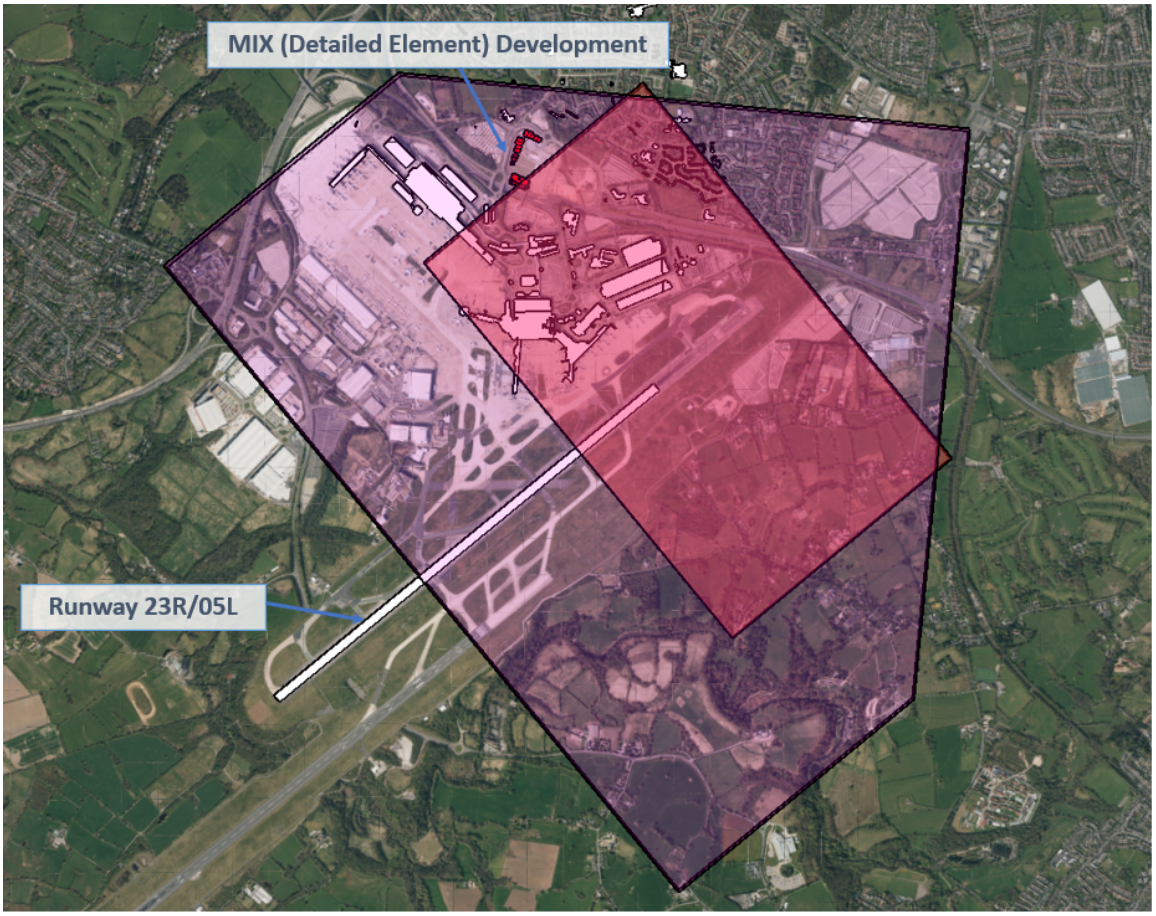


Figure 2.3: NASF Trigger Area (Colored in Red) and NLR Trigger Area (Colored in Violet) of Runway 23R/05L.

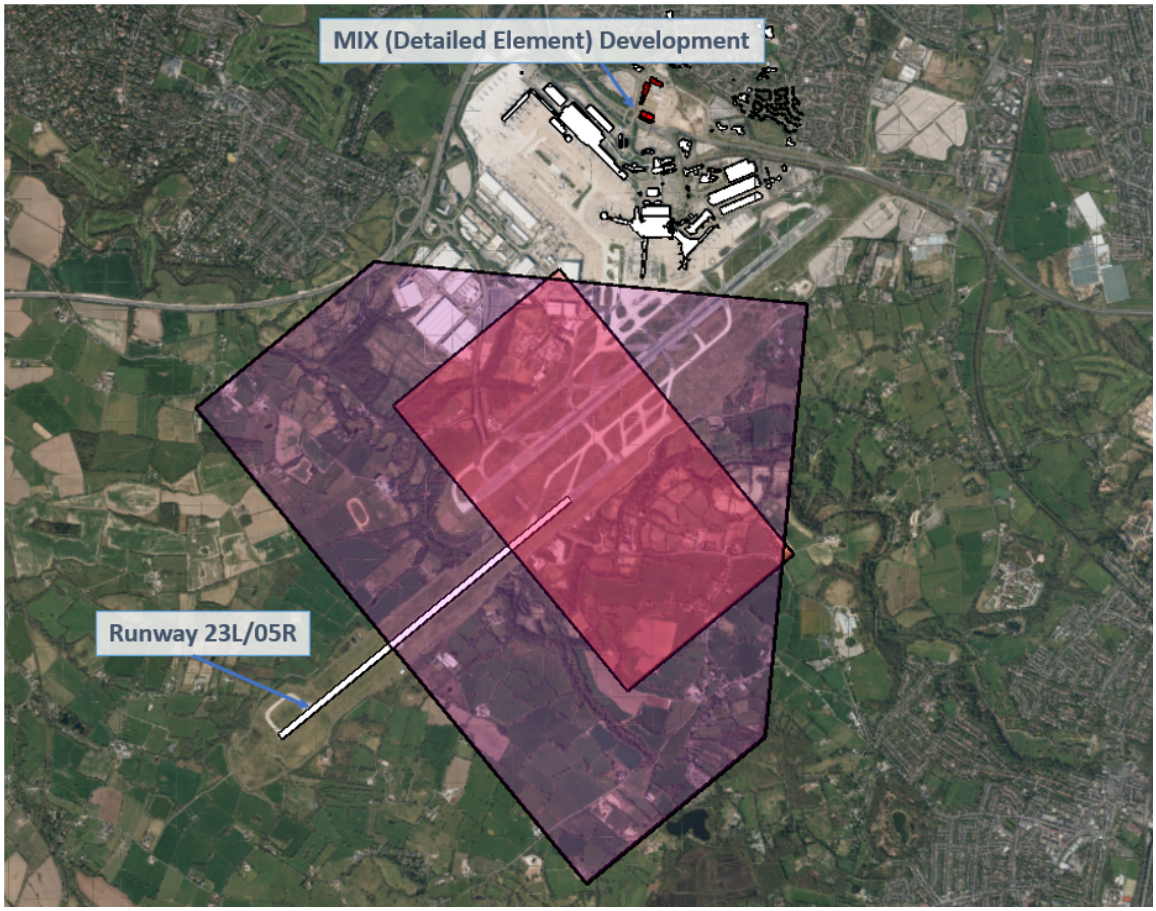


Figure 2.4: NASF Trigger Area (Colored in Red) and NLR Trigger Area (Colored in Violet) of Runway 23L/05R.

According to Figures 2.3-2.4 the development is located:

- within the trigger area of Runway 23R/05L according to both the NASF guideline and the NLR report;
- not located within the trigger area of Runway 23L/05R according to both the NASF guideline and the NLR report.

In accordance with the NASF guideline and the NLR report, if a proposed structure is located within the trigger area, then its acceptability is dictated by the 1:35 rule as follows:

- if the building is located at a distance from the centreline of a nearby runway which is more than 35 times the proposed structure height, then the building can be considered acceptable.
- if the building is located at a distance from the centreline of a nearby runway which is less than 35 times the proposed structure height, then an in-depth wind shear and turbulence analysis is required through wind tunnel or Computational Fluid Dynamics (CFD) analysis to accurately calculate the wind shear and turbulence effect to assess the building-induced wind shear and turbulence effects against the NLR-CR-2006-261 acceptance criteria (known as the "7-knot along wind criterion", the "6-knot cross-wind criterion and the "4-knot turbulence criterion").

Additionally, it is also stated in NLR report that obstacles with a width less than 30m and producing a maximum speed deficit less than 8Kts are allowed to protrude the 1:35 wind disturbance plane. The width of MIX (Detailed Element) development is shown in Figure 2.5.

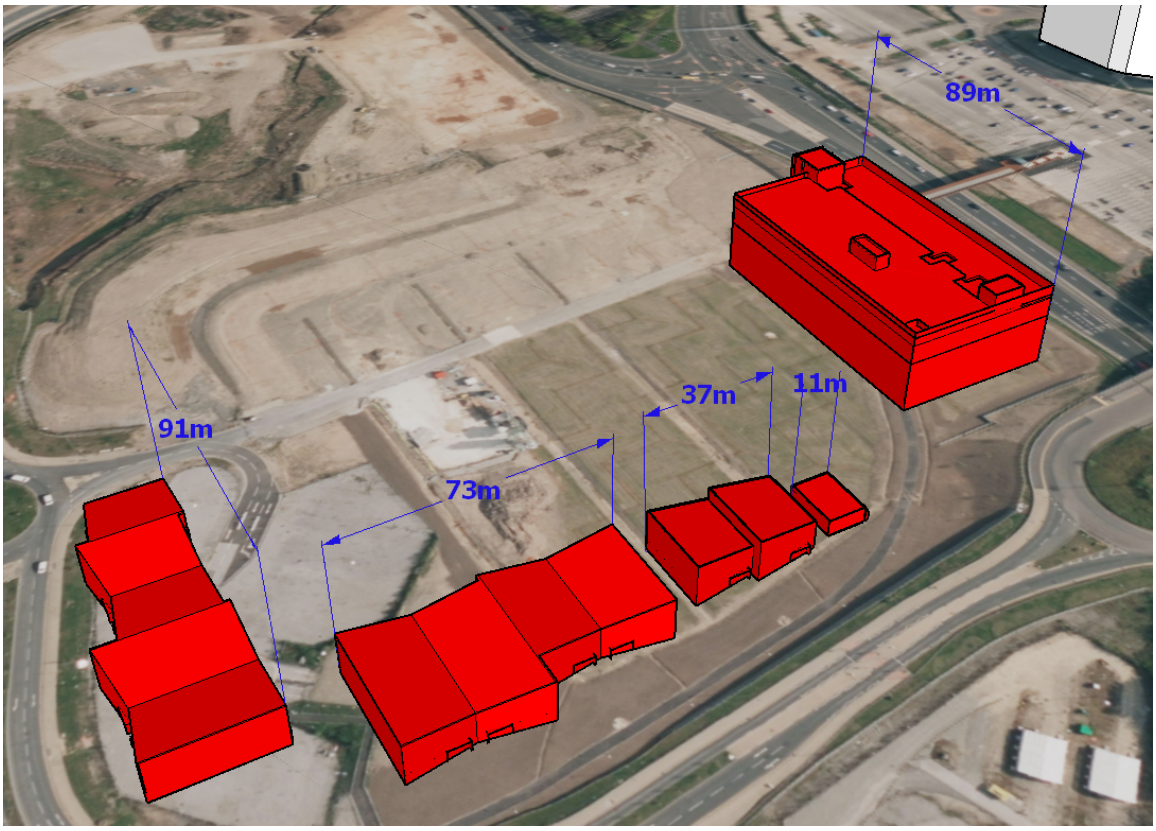


Figure 2.5: Width of MIX (Detailed Element) Development.

Table 2.1-2.4 summarize if the proposed development are located within any trigger area for each of the runways and specifies the distances of each unit from the runways in relation to the "1:35 rule".

Table 2.1: Trigger Areas and the 1:35 Rule for the Runways - Building A1

Runways in Dublin Airport	Building A1					
	Trigger Area		1:35 Rule			
	NASF	NLR	Building height	1:35 Distance	Distance to centreline	Is 1:35 rule penetrated?
Runway 23R/05L	Outside	Within	13 m	455 m	1303 m	No
Runway 23L/05R	Outside	Outside	13 m	455 m	1692 m	No

Table 2.2: Trigger Areas and the 1:35 Rule for the Runways - Building A2

Runways in Dublin Airport	Building A2					
	Trigger Area		1:35 Rule			
	NASF	NLR	Building height	1:35 Distance	Distance to centreline	Is 1:35 rule penetrated?
Runway 23R/05L	Outside	Within	13 m	455 m	1328 m	No
Runway 23L/05R	Outside	Outside	13 m	455 m	1717 m	No

Table 2.3: Trigger Areas and the 1:35 Rule for the Runways - Building A5

Runways in Dublin Airport	Building A5					
	Trigger Area		1:35 Rule			
	NASF	NLR	Building height	1:35 Distance	Distance to centreline	Is 1:35 rule penetrated?
Runway 23R/05L	Outside	Within	13 m	455 m	1295 m	No
Runway 23L/05R	Outside	Outside	13 m	455 m	1684 m	No

Table 2.4: Trigger Areas and the 1:35 Rule for the Runways - Building E1

Runways in Dublin Airport	Building E1					
	Trigger Area		1:35 Rule			
	NASF	NLR	Building height	1:35 Distance	Distance to centreline	Is 1:35 rule penetrated?
Runway 23R/05L	Within	Within	30 m	1050 m	1165 m	No
Runway 23L/05R	Outside	Outside	30 m	1050 m	1554 m	No

Accordingly, this report assesses the impact of the proposed MIX Manchester (Detailed Element) on Runways 23R/05L where the development is located within the relevant trigger areas defined by the NLR report and/or the NASF guideline. Developments A1, A2, and A5 are outside the trigger area under NASF guidelines but within the trigger area per the NLR report, whereas E1 lies within the trigger area under both NASF and NLR. None of the developments penetrate the 1:35 height rule; however, all exceed 30m in width. Consequently, a Computational Fluid Dynamics (CFD) analysis is undertaken for Runway 23R/05L to assess potential wind shear and turbulence effects in accordance with NLR-CR 2006-261.

Further, none of the proposed buildings are located within the trigger area of Runway 23L/05R according to the NASF guideline, nor they are located within the trigger area suggested by the

NLR report. None of the proposed buildings penetrates the "1:35 height rule" on Runway 23L/05R. Hence, no further analysis is required in relation to Runway 23L/05R as the proposed development, in accordance with the above guidelines, does not pose a wind shear and turbulence risk for this runway.

Figure 2.6 shows a view of the proposed development (colored in red) in the existing urban context.

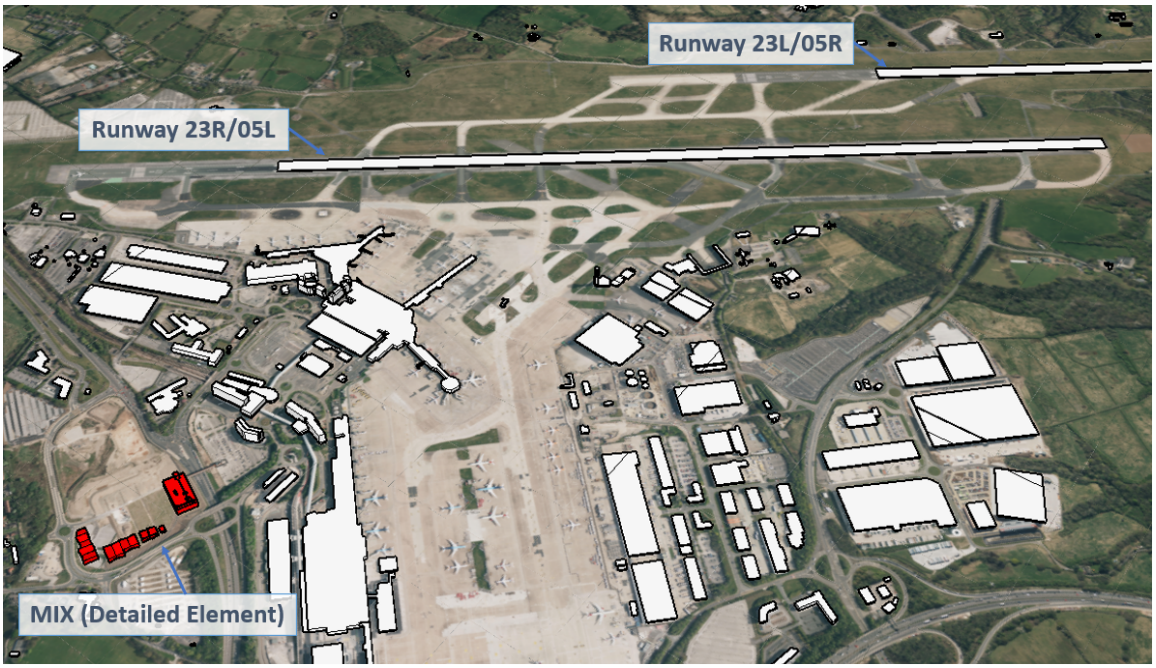


Figure 2.6: Proposed MIX Manchester (Detailed Element) Development (colored in red).

This report is completed by Dr. Cristina Paduano, Dr. Arman Safdari and Dr. Sadia Siddiqa.

Dr. Cristina Paduano is a Chartered Engineer (CEng) and member of Engineers Ireland. She has specialised in computational fluid dynamics applications for urban environment and the construction industry, with over 18 years of experience. She holds a PhD in Mechanical Engineering from Trinity College Dublin, with M.Eng and B.Eng in Aerospace Engineering from the Polytechnic University of Milan, Italy.

Lucrezia Vigo is a CFD modelling specialist and member of Engineers Ireland (MIEI). She holds a Masters degree in Aeronautical Engineering from Politecnico di Milano, with a specialization in Fluid Dynamics. She has applied CFD to various fluid dynamics problems, from aeronautics to bioreactors and wind engineering.

Dr. Sadia Siddiqa is a member of Engineers Ireland and CFD Modelling Engineer specialising in computational fluid dynamics applications. With expertise in modeling fluid flows, airflow patterns, and heat/mass transfer, she is skilled at applying her knowledge to solve real-world challenges in fluid dynamics. She holds a PhD in Computational Mathematics from COMSATS University, where her research focused on CFD applications.

2.2 OBJECTIVE OF THE ANALYSIS

The objective of this study is to investigate the wind shear and turbulence effects that will be induced, on the runway by the new proposed development.

The flow analysis objective is to identify:

- If, and where, there is any increased turbulence and wind shear as a results of the proposed development;
- Whether the increased values could exceed the acceptable levels on the Runway 23R/05L, where the sensitivity of aircraft stability during landings is assessed using runways wind shear and turbulence exceedance criteria (referenced as **Runway - Wind Shear and Turbulence Exceedance Assessment**);
- What wind speeds and directions would cause any criteria/safety risk to be exceeded and how often, in a typical year, this can be expected to happen.

2.3 WINDSHEAR and TURBULENCE IMPACT on AIRCRAFTS

Windshear refers to the situation where the wind changes direction or speed suddenly, over a short distance. It can be vertical or horizontal, affecting an aircraft either as it takes off or descends, or its horizontal flight path.

It is well known in aviation that windshear is often experienced near weather front in the form of microburst/downburst, this is often felt as turbulence and often occurring at high altitude (see Figure 2.7).

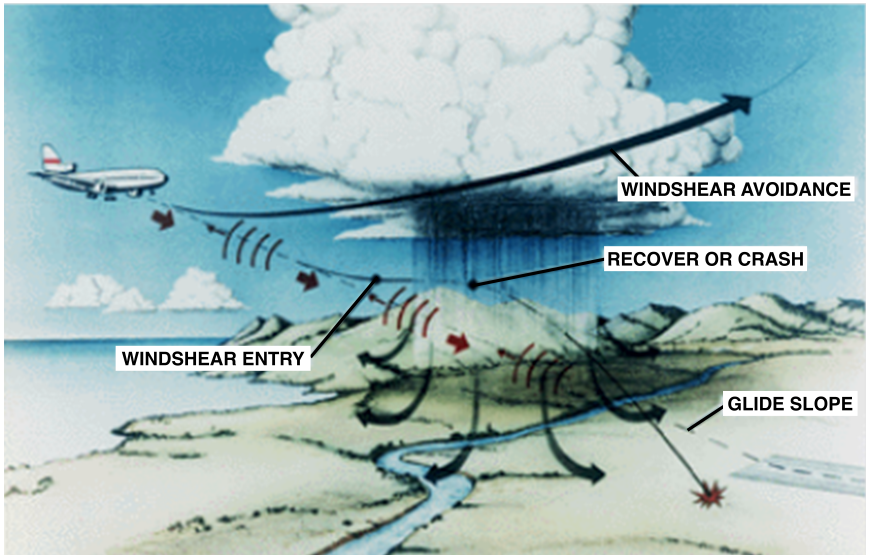


Figure 2.7: Wind Shear and Turbulence Due to Obstacles on the Ground.

Windshear, however, can be also experienced at low altitude and near the ground. Near airports, where the air flows over obstructions, such as bluffs, hills, trees, or buildings, the normal horizontal wind flow is indeed disturbed and transformed into a complicated pattern of eddies and other irregular air movements (see Figure 2.8).

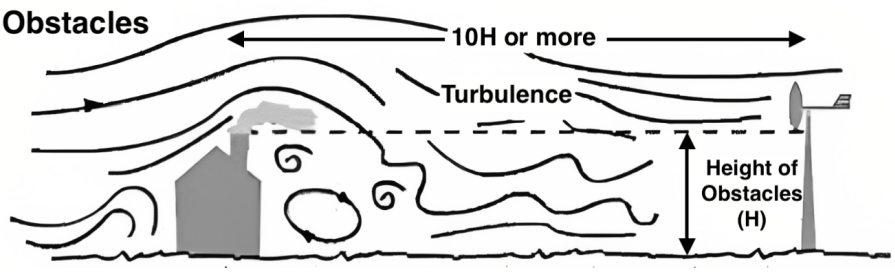


Figure 2.8: Wind Shear and Turbulence Due to Obstacles on the Ground.

The risk of wind shear, in both cases above, consists in the sudden change in the wind and its resulting effect on the aircrafts lift. If the wind speeds change, the lift of the airplane changes as well, and the pilots need to re-adjust the aircraft to the desirable lift by increasing/reducing engine power appropriately and in relation to the altitude. While this operation is quite standard at high levels, it can be more difficult close to the ground, during takeoff and landing, as the airplane have little time or room to maneuver. A a consequence, aircrafts can be particularly vulnerable to windshear when landing/taking off.

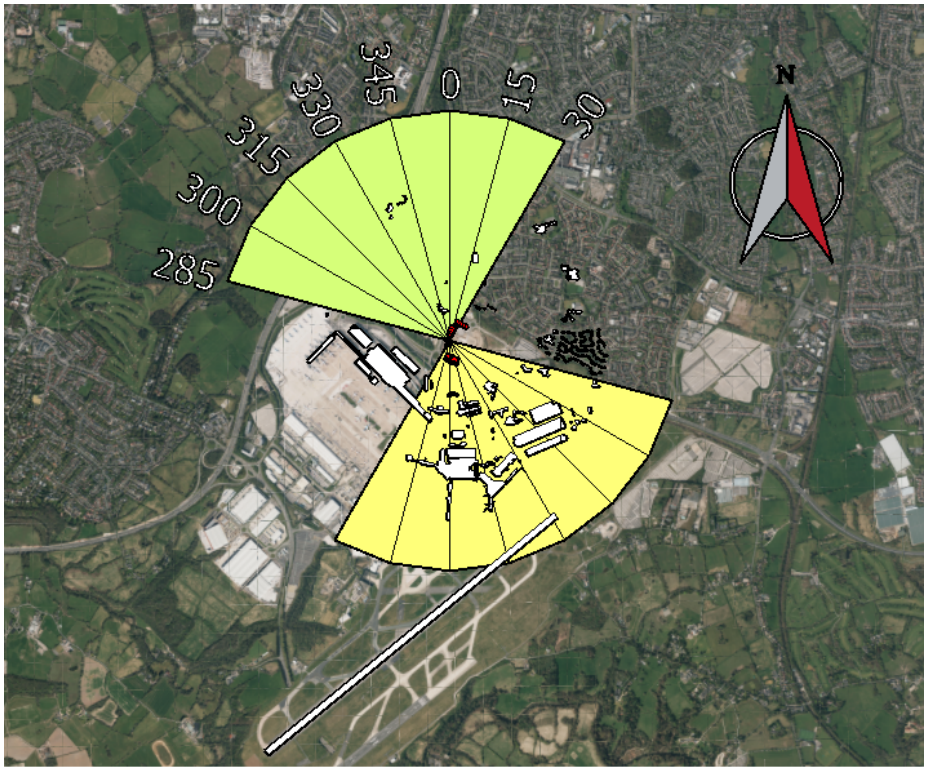


Figure 2.9: Wind Directions Used in the Analysis.

Considering the proposed development location, it can pose a risk of buildings induced wind shear/turbulence for the runway 23R/05L for all the wind directions in the range from 0° to 30° and 285° to 345° because of speed disturbances downwind of the proposed buildings blocks. Figure 2.9 shows all the wind directions mentioned above and which have been used for this assessment. The following

sections detail the impact of wind shear and turbulence on aircraft.

2.4 ACCEPTANCE CRITERIA

Attempts to establish hazardous levels of windshear can be found in several studies of weather phenomena containing windshear and their impact on aviation (especially during takeoffs and landings) (such as Fujita et al., 1997 and McCarthy, 1997).

The Amsterdam Schiphol Airport

The influence of buildings on airport windshear conditions became the focus of a number of studies conducted by scientists and researchers in The Netherlands (NLR) due to a number of pilots reports when one of the runways at Schiphol airport was used under strong southwest wind conditions. Subsequent studies determined that the primary cause was the wake behind this facility and the corresponding variation in crosswind experienced by aircraft using this runway during their last stage of approach.

A series studies were implemented by NLR considering the following conditions:

- The wind direction is perpendicular towards a stand alone obstacle. Thus effects due to a non-perpendicular wind flow are no part of this investigation.
- The work is tailored to two jet aircraft equipped with conventional controls. Propeller driven aircraft and Fly-By-Wire aircraft as well as Very Large Aircraft have not been evaluated.
- Only dry runway conditions are considered.
- High speed roll out, take-off and go-around were no part of the investigation.
- Maximum cross wind in the investigation is limited to 20 knots.

Studies between 2003-2006

A simple criterion so-called 7 knots criterion was introduced by National Aerospace Laboratory of The Netherlands based on wind tunnel tests and flight simulator tests for advising of the potential for adverse building-induced windshear (Krus et al, 2003) in the early study.

7knots criterion was given further status via a follow-up study by Nieuwpoort at al (2006) based on flight simulations. The building-induced windshear rule developed through these studies was related to the maximum allowable lateral wind speed deficit occurring behind an obstacle:

The difference in wind velocity perpendicular to the aircraft over a short distance may not exceed 7 knots

Study in 2008

An enhance study was done by Nieupoort et al. in 2008. This research is the most in-depth study of the influence of airport buildings and other bluff structures on aviation-related windshear. The report focused on developing wind disturbance criteria relevant to wake effects induced by obstacles (such as buildings and structures) close to runways, particularly during the final stages of approaches when aircraft are most vulnerable to such effects.

The report distinguished associated risk levels with three altitude bands:

- 0 ft to 200 ft;

- 200 ft to 1,000 ft;
- and >1,000 ft.

Only the lowest (first altitude) band was deemed to pose a potential critical risk to aircraft safety. Offline mathematical flight performance simulations was employed to develop the wind shear criteria with two aircraft types a B747 and a Fokker 100 were chosen.

The findings of the study were (NLR study in 2008):

- Altitude Range: 1,000 ft AGL to 200 ft AGL:
  - **"Stand alone" obstacle**:

    No distinct effect of stand alone obstacles on the aircraft handling and performance could be established in this height range. The effect is submerged in the overall surface characteristics of the build up area affecting the runway. The offline and piloted simulations showed that the obstacle clearance planes defined by ICAO Annex 14 give sufficient protection to wind disturbances as result of stand alone obstacles. No specific wind disturbance planes are required for this segment.

  - **Surface roughness:**

    In this altitude range the wind disturbance effect on the aircraft is defined by the turbulence intensity applicable for build up area affecting the runway. It is a function of the surface roughness and a reference wind speed. The offline and piloted simulations showed that RMS values of the turbulence intensity of the horizontal components in excess of 5kts (heavy turbulence) sometimes lead to large glide path deviations as result of gust and wind shear phenomena. In this height range the horizontal scale lengths used in the gust/turbulence simulation varied from 200m to 300m.

- Altitude Range: Below 200 ft AGL: wind disturbance planes are required for this segment.
  - **"Stand alone" obstacle**:

    It was established that for this segment wind disturbance criteria are necessary that are more stringent than the Annex 14 planes. It appeared that stand alone obstacles in this area not protruding an imaginary plane with a slope of 1:35 with the extended runway centerline as base did not affect the response and landing performance of the aircraft significantly. The segment where the wind disturbance plane is restrictive is bounded by a disk shaped segment with origin in the center of the runway threshold and radii of approximately 1200m (perpendicular to runway centerline) and 900m in front of the runway threshold.

    * *Along the aircraft trajectory:*

      The structure should not induce a change in mean wind speed greater than 7 knots, with the speed change taking place over a distance of at least 100m.

    * *Across the aircraft trajectory:*

      The structure should not induce a change in mean wind speed greater than 6 knots, with the speed change taking place over a distance of at least 100m.

  - **Surface roughness:**

    In this altitude range the wind disturbance effect on the aircraft is defined by the turbulence

intensity applicable for build up area affecting the runway. It is a function of the surface roughness and a reference wind speed. The offline and piloted simulations showed that RMS values of the turbulence intensity of the horizontal components in excess of 5kts (heavy turbulence) sometimes lead to too large glide path deviations as result of gust and wind shear phenomena. In this height range the horizontal scale lengths used in the gust/turbulence simulation varied from 200m to 300m.

- In addition to the mean wind speed deficit criteria described above, the study developed an additional turbulence (gust) criteria: The horizontal gust/turbulence levels caused by a stand-alone obstacle in combination with the meso-scale surface roughness must remain below an RMS (standard deviation) value of 4 knots.

As mentioned in the previous section, wind shear and turbulence caused by buildings in the vicinity of airports can cause aircraft instability during landing or take-off.

The instability which building-induced wake effects can cause to an aircraft is significantly reduced once the aircraft has touched down (upon landing) or is at reasonable height (200 ft off the ground prior to landing). After touch-down, the aircraft has increased stability/support from contact with the runway pavement and above 200 feet, both the consequences of a drop in altitude or a change in wind bank are considerably less and the pilot has increased latitude and so time to correct an induced effect on the aircraft prior to touch-down.

In accordance with NASF Guideline and the NLR report, a proposed structure can potentially create a wind shear and turbulence impact risk if located within the trigger area of a nearby runway.

If a proposed structure falls inside the trigger area, then its acceptability is dictated by the "1:35 height rule", which can be explained as follows:

- **Any proposed development located at a distance of at least 35 times its own height form the centreline of a runway will not pose a risk of wind shear and turbulence on the runway**

- **Whilst, any proposed building which is located at a distance below 35 times its own height, need to be further assessed for potential wind shear and turbulence effects on that runway - i.e. "the building height exceeds the 1:35 rule"**

When the building height exceeds the "1:35 rule", the following acceptance criteria must be applied as stated in the NLR report (NLR-CR-2006-261) to decide if the building in question can be accepted or not:

- *The 7-knot (3.6 m/s) along wind criterion*: the variation in mean wind speed due to wind disturbing structures must remain below 7 Kts (3.6 m/s) along the aircraft trajectory at heights below 200 ft. The speed deficit change of 7 Kts must take place over a distance of at least 100m.

- *The 6-knot (3.09 m/s) cross-wind criterion*: the variation in mean wind speed due to wind disturbing structures must remain below 6 Kts across the aircraft trajectory at heights below 200 ft. The speed deficit change of 6 knots must take place over a distance of at least 100m.

- *The 4-knot (2.06 m/s) turbulence criterion*: the standard deviation of wind speed must remain below 4 Kts at heights below 200 ft.

Additionally, it is also stated in NLR report that obstacles with a width less than 30m and producing a maximum speed deficit less than 8Kts are allowed to protrude the 1:35 wind disturbance plane.

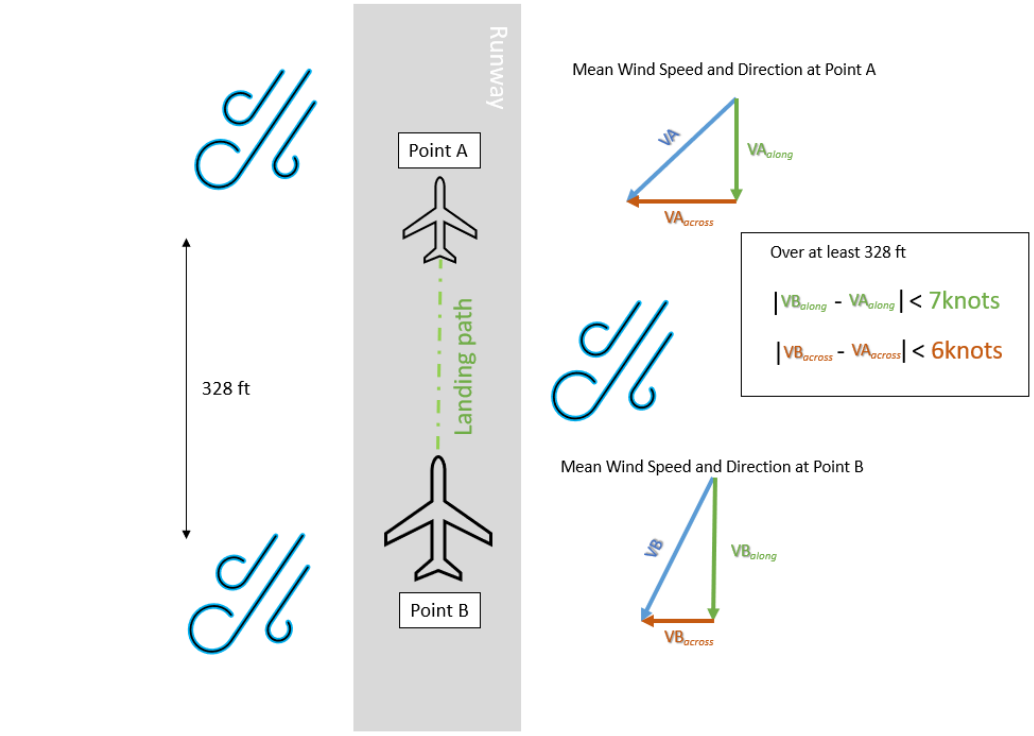


Figure 2.10: Wind Shear and Turbulence Criteria.

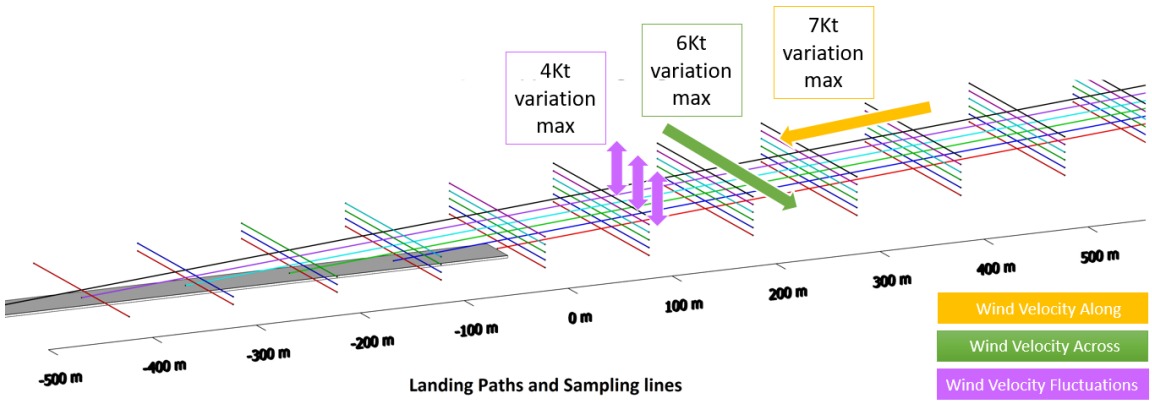


Figure 2.11: Wind Shear and Turbulence Criteria Evaluation on a Runway Landing Paths.

The reason for all the wind speed/turbulence variations, to be assessed over a distance of 328 ft, is to account for the response time of a landing aircraft to a sudden changing of wind conditions. Although an aircraft, can fly through winds speeds and turbulence higher than those mentioned in the criteria, a rapid change of the wind conditions causes detrimental instability when approaching the ground where the possibility of movements are reduced.

3. STUDY METHODOLOGY

3.1 ASSESSMENT METHODOLOGY

The assessment has been carried out through the following steps:

- Step 1 - Local Wind Data Analysis;
- Step 2 - 3D CFD Model of the Complex Environment;
- Step 3 - Wind Shear and Turbulence Predictions.

3.1.1 STEP 1 - LOCAL WIND DATA ANALYSIS

A statistical analysis of historical wind data has been carried out to calculate wind shear and natural turbulence exceedance probabilities data at Manchester Airport. Statistical assessment of the weather data is an important part of wind shear and turbulence analysis. Indeed, if any of the acceptance level of wind shear and turbulence are exceeded, for a particular wind direction and wind speed, then it is possible to predict, knowing the frequency of that wind conditions during a typical year, how often the runway would be impacted by the proposed development.

3.1.2 STEP 2 - 3D CFD MODEL of the COMPLEX ENVIRONMENT

A model has been produced for both the pre and post-construction scenarios including topography, nearby existing buildings and relevant features at the areas of interest (see Figures 3.1 - 3.2).

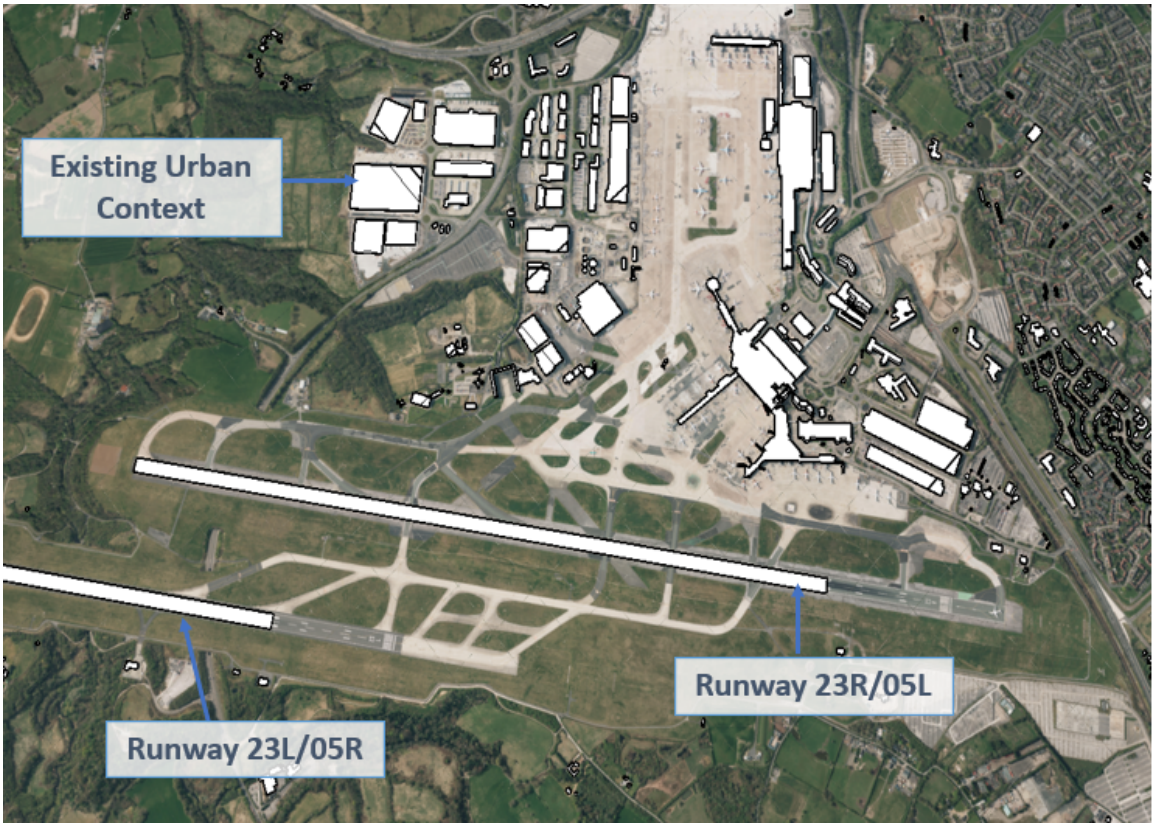


Figure 3.1: 3D Model of the Pre-Development Scenario.

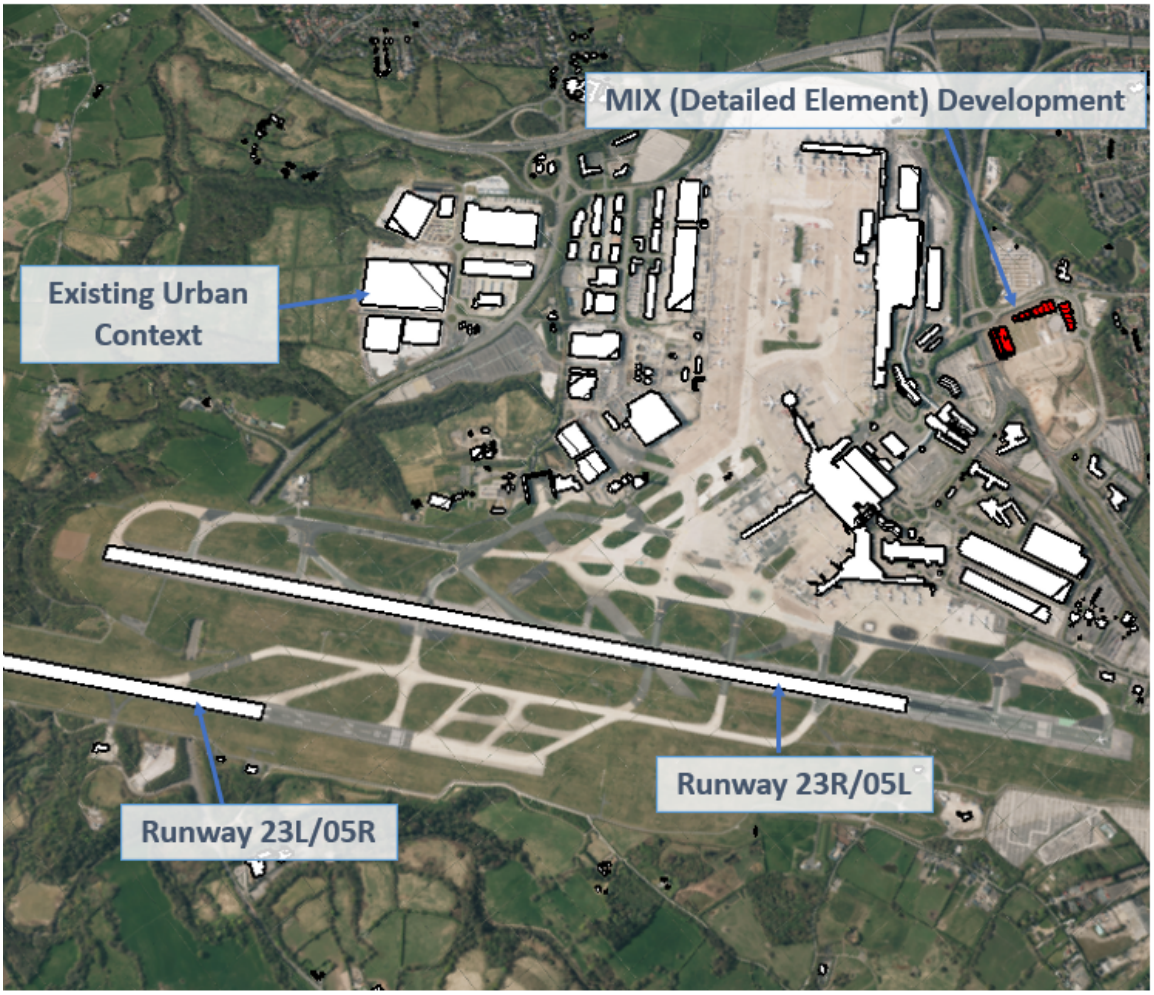


Figure 3.2: 3D Model of the Post-Development Scenario.

Considering the runway 23R/05L, a wind shear/turbulence effect can be generated by the proposed development under the following conditions:

- For all the wind directions in the range from 0° to 30° and 285° to 345°, where the speed disturbances are induced downwind by the proposed buildings. Figure 3.3 shows the wind directions used in this analysis.

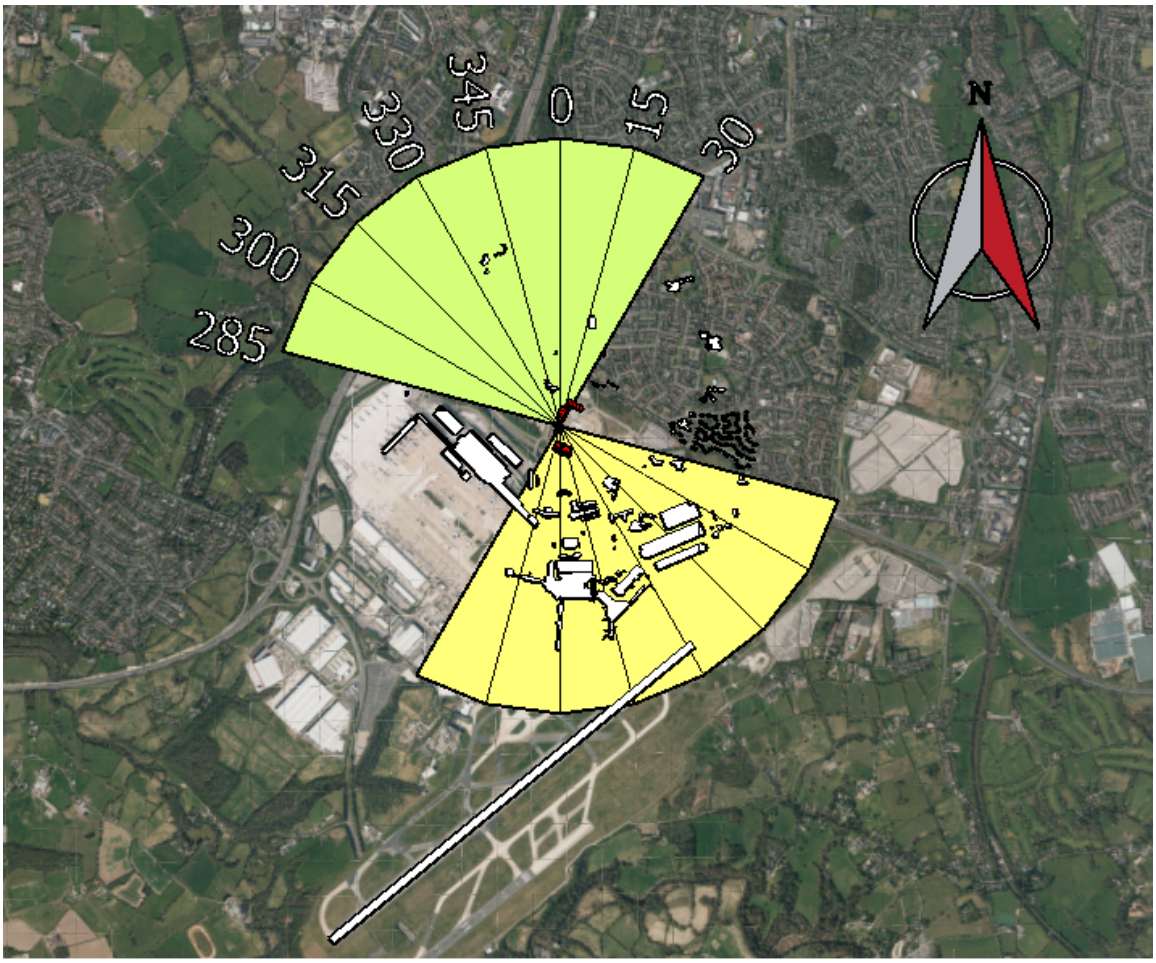


Figure 3.3: Wind Directions Used in the Analysis.

During this step, simulations at different wind directions have been implemented, each using a different wind speeds (i.e., 10m/s and 20 m/s). For all the areas of interest, velocity and turbulence kinetic energy have been collected across the runway area, including both along and across the runway.

Flow results have been collected on the horizontal plane, to understand the flow patterns and turbulence levels generated downwind the proposed building and to compare the flow patterns on the runway at pre and post-development scenarios.

Flow results have been collected also on the vertical plane across the area of interest to understand up to a height of 200m above ground, where the conditions of the flow resume to those of an undisturbed flow on the runway in pre- and post-development scenarios.

The horizontal and vertical slices at which the results are collected in both pre- and post-development scenarios, can be seen in Figure 3.4.

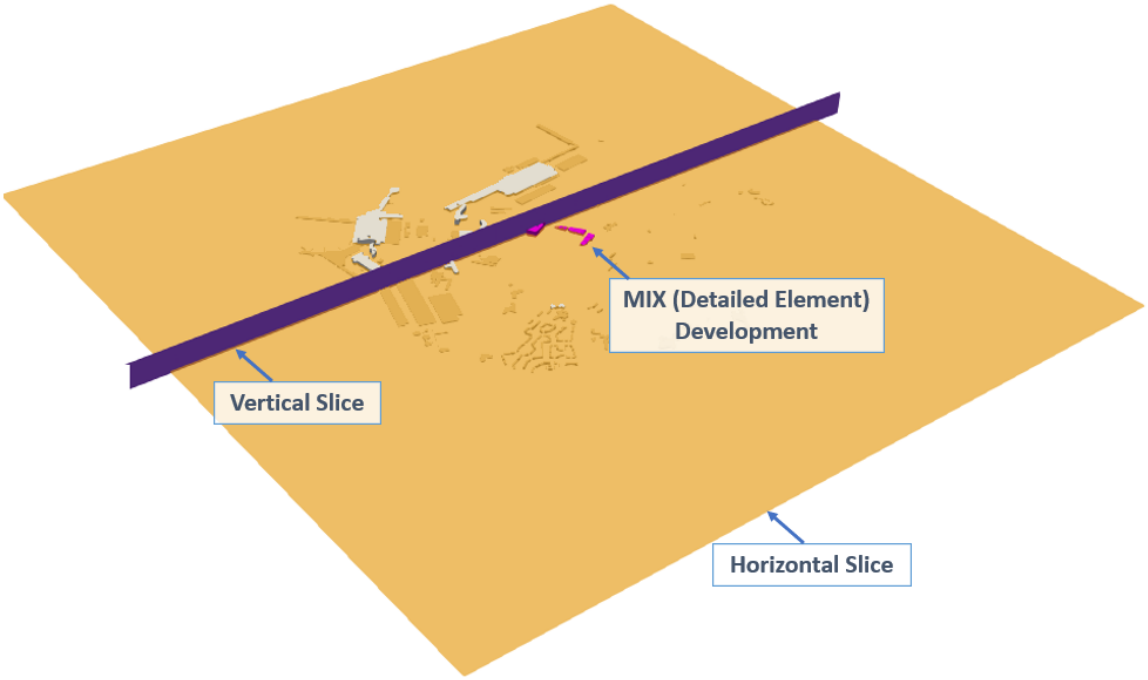


Figure 3.4: Wind Directions Used in the Analysis.

3.1.3 STEP 3 - WIND SHEAR and TURBULENCE PREDICTIONS

In this case simulations at different wind speeds and magnitudes have been implemented to assess if the wind shear and turbulence caused by the new development in the vicinity of the south, and/or north runways can cause aircraft instability during landing/ take off.

Velocity and turbulence results obtained from the flow simulations (at Step 2) are then used to calculate:

- Mean Velocity Deficit for the 6 and 7 Knot Criteria Assessment;
- Turbulence Deviation for the 4 Knot Criteria Assessment.

According to the NLR report, it is recommended that the maximum area of assessment should be above the 3° glide path to the run way threshold to a height of 60m shown in Figure 3.5. It is appreciated that aircraft could fly elsewhere in the assessable glide paths, particularly during take-off and go-arounds, however, during these events the aircraft would be under different power levels and may be more able to cope with wind shear and turbulence.

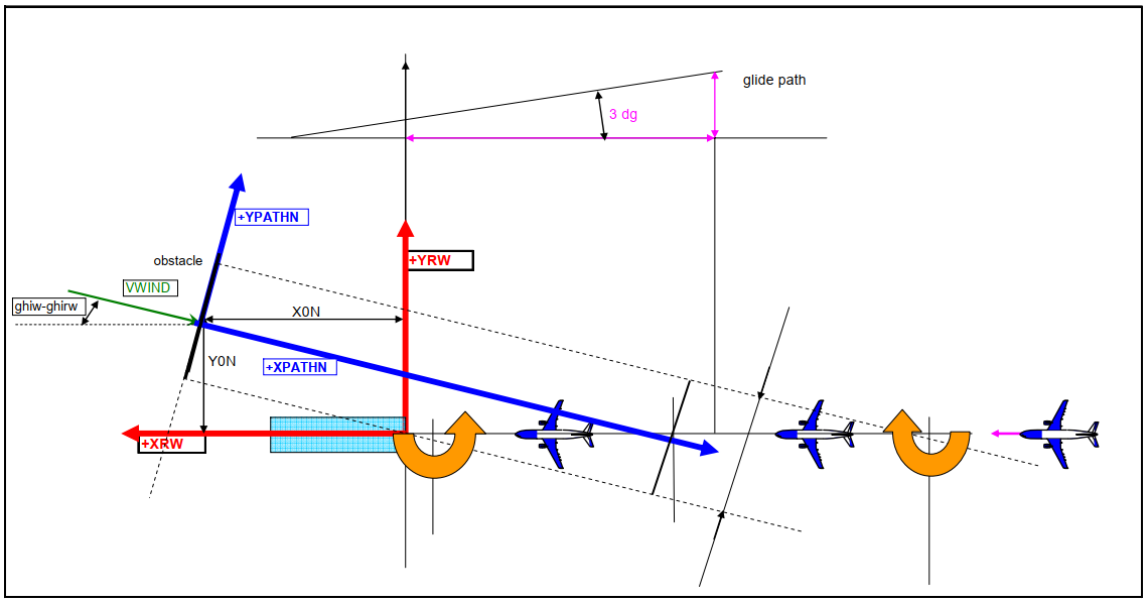


Figure 3.5: Assessable Aircraft Trajectory Defined by the NLR Report.

For this step, different wind directions have been analyzed, which correspond to the critical wind directions impacting both the development and relevant airport runways.

In this study, for each wind directions, wind speed and turbulence are collected at the aircraft trajectory, considering 3° landing/takeoff degrees and assuming that the aircraft glides down with constant speed and its track angel is 3°. Six possible paths per each landing degrees are considered. Each path starts at 900m far from touch down zone and continues to ground level. Airflow velocity and turbulence values are collected along each path. In addition, every 100m across each possible aircraft trajectory, data sampling (for wind velocity and turbulence) were performed per each landing path.

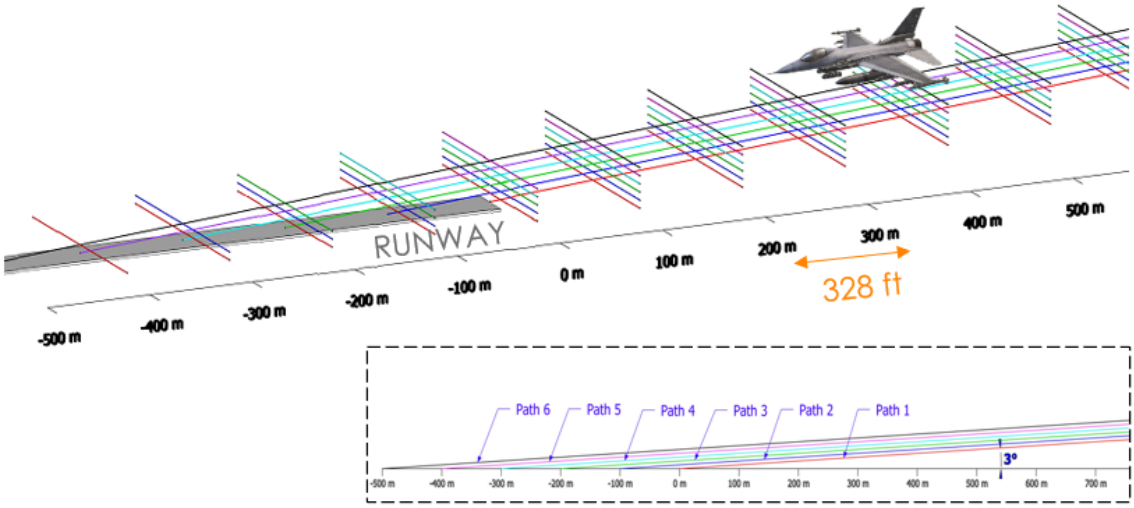


Figure 3.6: Landing Scenarios and Sampling Lines at 3° Approaching Angle.

The analysis described is carried out considering the scenario with the proposed MIX Manchester (Detailed Element) ('Post-development case' with results detailed in Appendix A) and the scenario without the proposed MIX Manchester (Detailed Element) ('Pre-development case' with results detailed in Appendix B).

The velocity and turbulence results are then used to obtain the *'Mean Velocity Deficit'* and the *'Turbulence Deviation'* for each of the wind directions and wind speeds, for the assessment of the same against the acceptance criteria.

If any of the acceptance criteria is exceeded, for a particular wind direction and wind speed, then the occurrence of that wind conditions is extracted from the Statistical Weather Data Analysis previously carried out (at Step 1) to predict at which frequency, during a typical year, the wind shear and turbulence level are expected to exceed the critical levels.

4. POTENTIAL IMPACT OF THE PROPOSED DEVELOPMENT

4.1 DEVELOPMENT DESCRIPTION

This proposed development comprises a hybrid planning application for Mix Manchester, as shown in Figure 4.1. The application involves the redevelopment of 24 hectares of brownfield land located immediately north of Manchester Airport. The development will deliver an advanced manufacturing campus, including mid-tech units (Class E (i, ii, iii)), ancillary commercial units (Class E), and a multi-storey car park (Sui Generis). Figure 4.2 illustrates the location of the site in relation to the surrounding built environment.

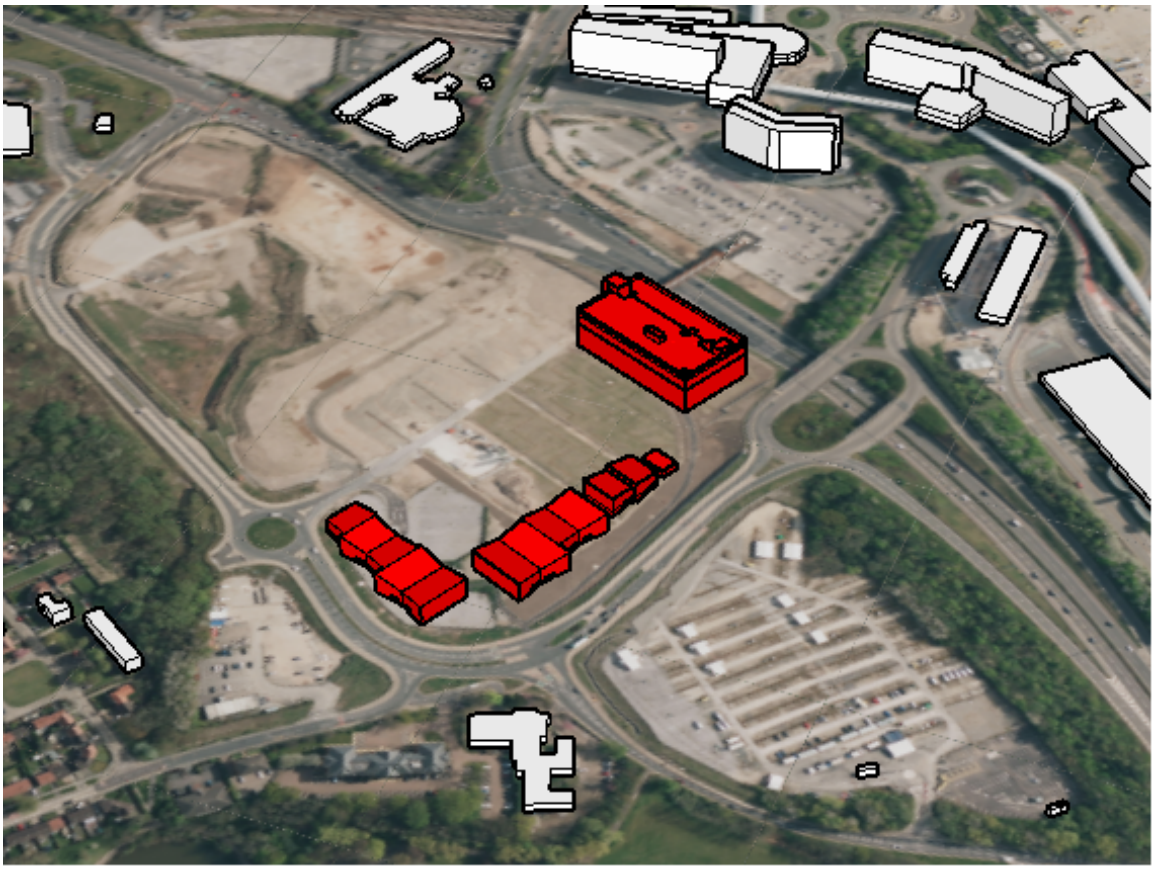


Figure 4.1: MIX (Detailed Element) Development (colored in red) - 3D View.

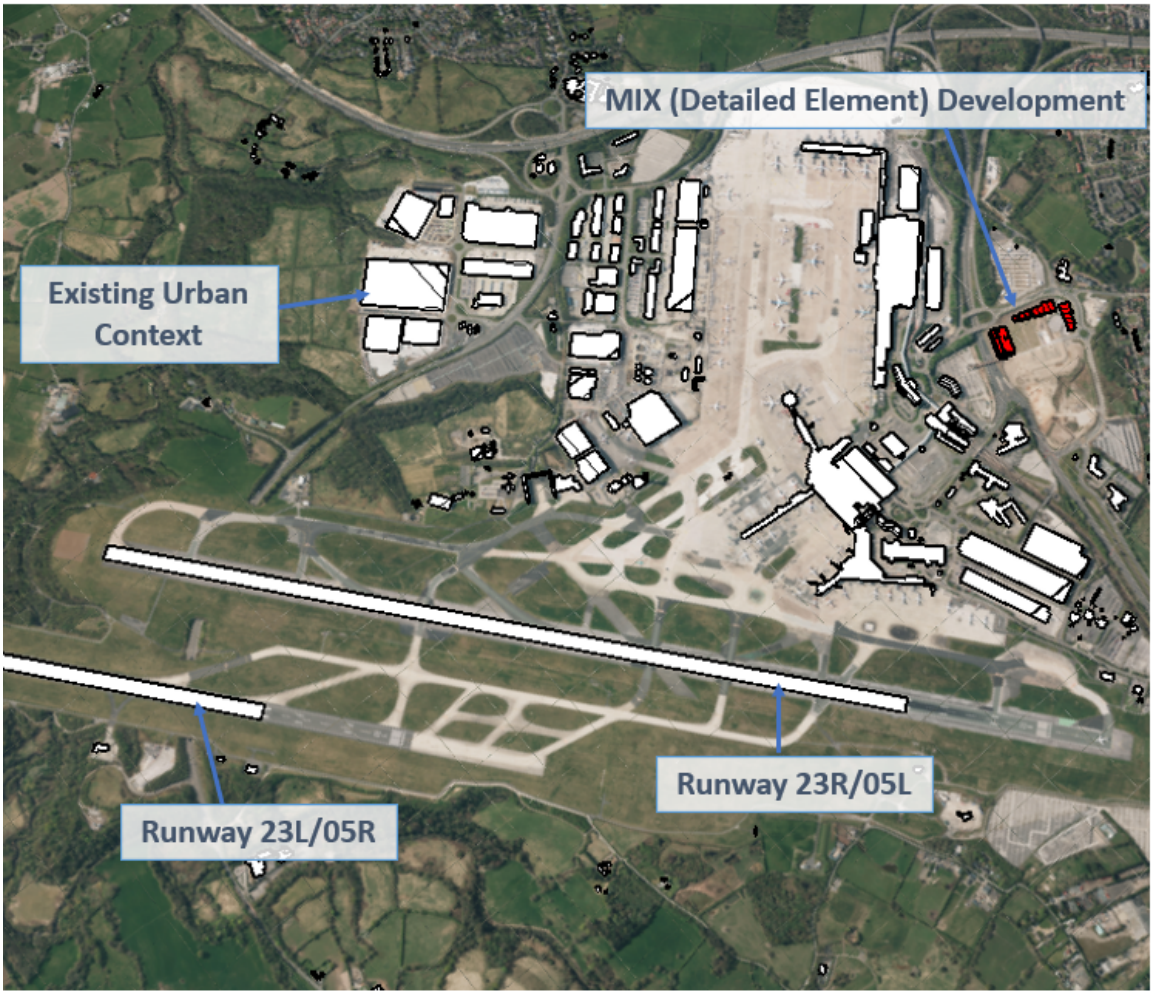


Figure 4.2: Site Location Relative to the Surrounding Built Environment.

Key features of the locality are:

- North: To the north of the site lies Enterprise Way. Beyond this, the surrounding area is associated with commercial and business park developments.
- East: To the east of the site are further commercial and airport-related developments, including logistics and light industrial units, with the wider Manchester Airport operational area located beyond.
- South: To the south of the site lies Manchester Airport, including Runway 23R/05L and associated taxiways and airside infrastructure.
- West: To the west of the site are areas of open land and commercial developments.

4.2 IMPACT ON RUNWAYS

The NASF guideline and the NLR report set the size of the zone of potential influence of a building on a runaway based on its distance from the runaway centreline as shown in Figure 4.3 below.

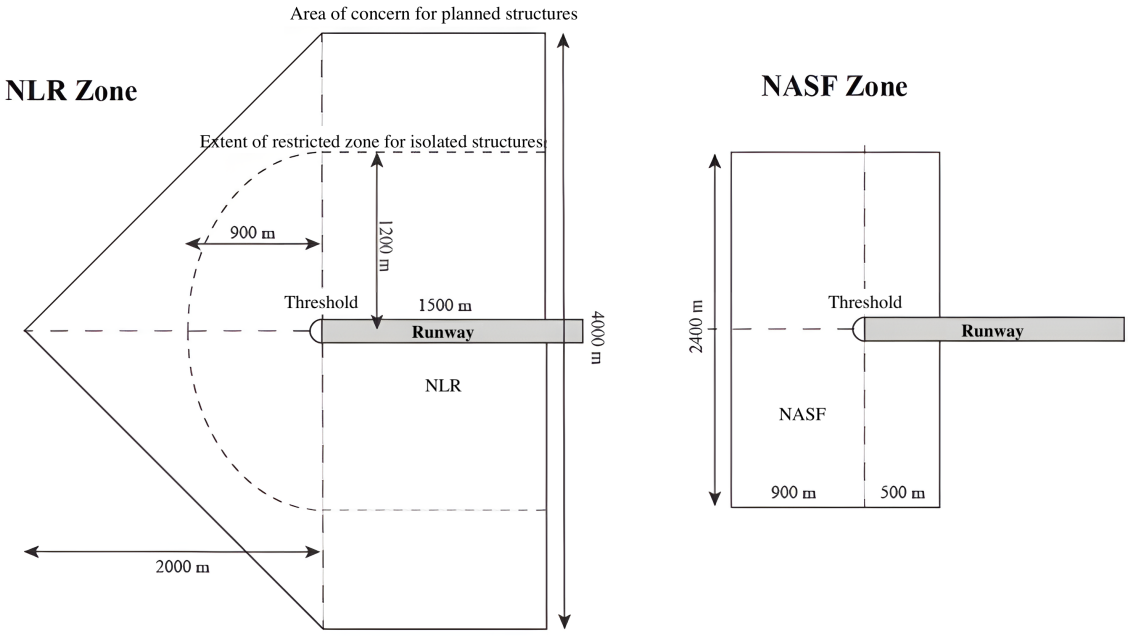


Figure 4.3: Potential Trigger Area Sizes According to the NASF Guideline and NLR Report.

The proposed development has a potential impact on aircraft landing on runways.

Figures 4.4 to 4.7 show the potential trigger areas of Runway 23R/05L, and Runway 23L/05R. In these figures, the red zones and purple zones are potential trigger areas according to the NASF guideline and the NLR report, respectively.

Findings based on these figures are listed as follow:

- The proposed development Building A1 is not located within the trigger area of Runway 23R/05L according to the NASF guideline, while it is located within the trigger area suggested by the NLR report. The Building A1 does not penetrate the 1:35 height rule on Runway 23R/05L, but its width exceeds 30m. Consequently, the effects of the development are further analyzed in relation to Runway 23R/05L using quantitative Computational Fluid Dynamics (CFD) analysis.
- The proposed development Building A2 is not located within the trigger area of Runway 23R/05L according to the NASF guideline, while it is located within the trigger area suggested by the NLR report. The Building A2 does not penetrate the 1:35 height rule on Runway 23R/05L, but its width exceeds 30m. Consequently, the effects of the development are further analyzed in relation to Runway 23R/05L using quantitative Computational Fluid Dynamics (CFD) analysis.
- The proposed development Building A5 is not located within the trigger area of Runway 23R/05L according to the NASF guideline, while it is located within the trigger area suggested by the NLR report. The Building A5 does not penetrate the 1:35 height rule on Runway 23R/05L, but its width exceeds 30m. Consequently, the effects of the development are further analyzed in relation to Runway 23R/05L using quantitative Computational Fluid Dynamics (CFD) analysis.
- The proposed development Building E1 is located within the trigger area of Runway 23R/05L according to both the NLR report or the NASF guideline. The Building E1 does not penetrate the 1:35 height rule on Runway 23R/05L, but its width exceeds 30m. Consequently, the effects of the development are further analyzed in relation to Runway 23R/05L using quantitative Computational Fluid Dynamics (CFD) analysis.
- None of the proposed buildings are located within the trigger area of Runway 23L/05R according to the NASF guideline, nor they are located within the trigger area suggested by the NLR report. None of the proposed buildings penetrates the "1:35 height rule" on Runway 23L/05R. Hence, no further analysis is required in relation to Runway 23L/05R as the proposed development, in accordance with the above guidelines, does not pose a wind shear and turbulence risk for this runway.

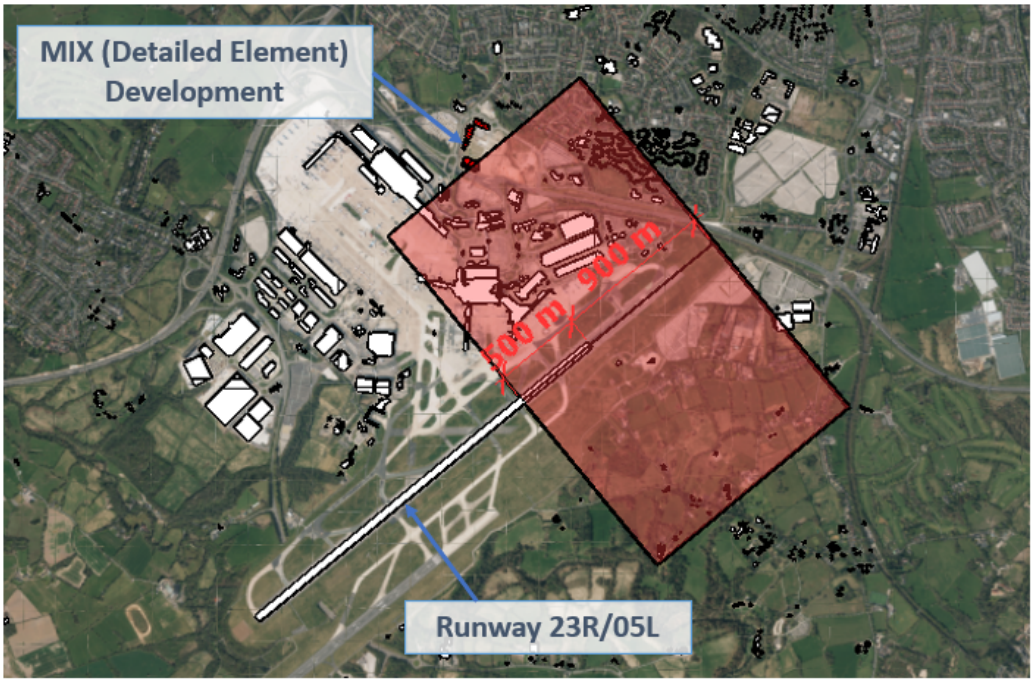


Figure 4.4: Potential Trigger Areas of Runway 23R/05L According to the NASF Guidelines.

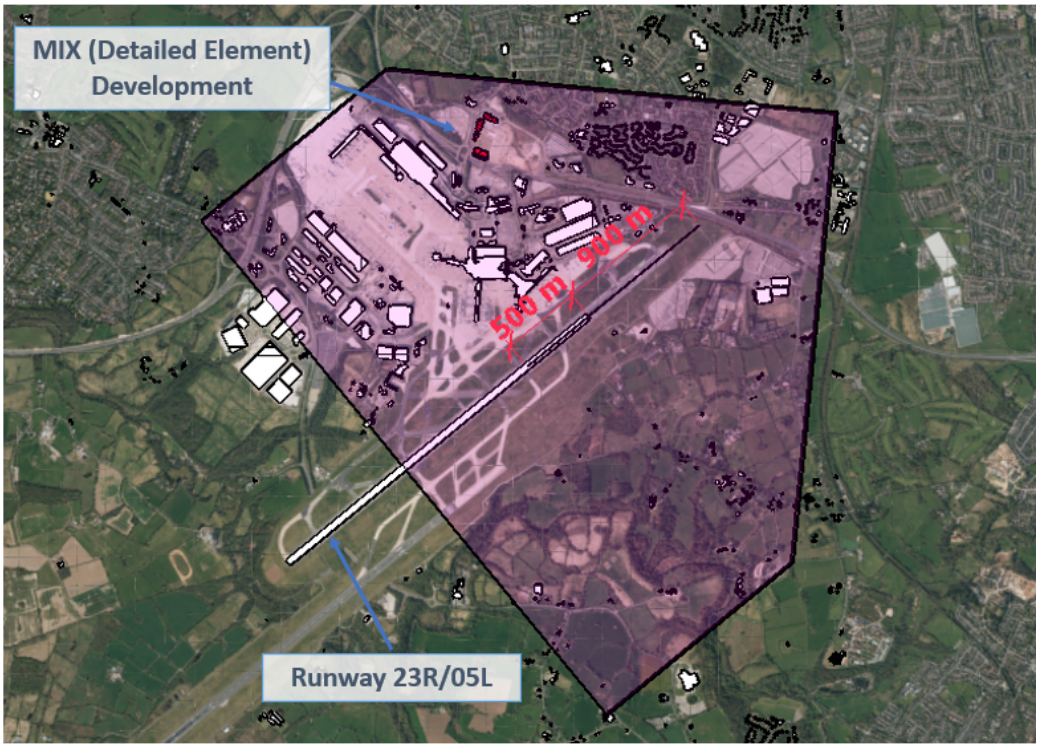


Figure 4.5: Potential Trigger Areas of Runway 23R/05L According to the NLR Report.

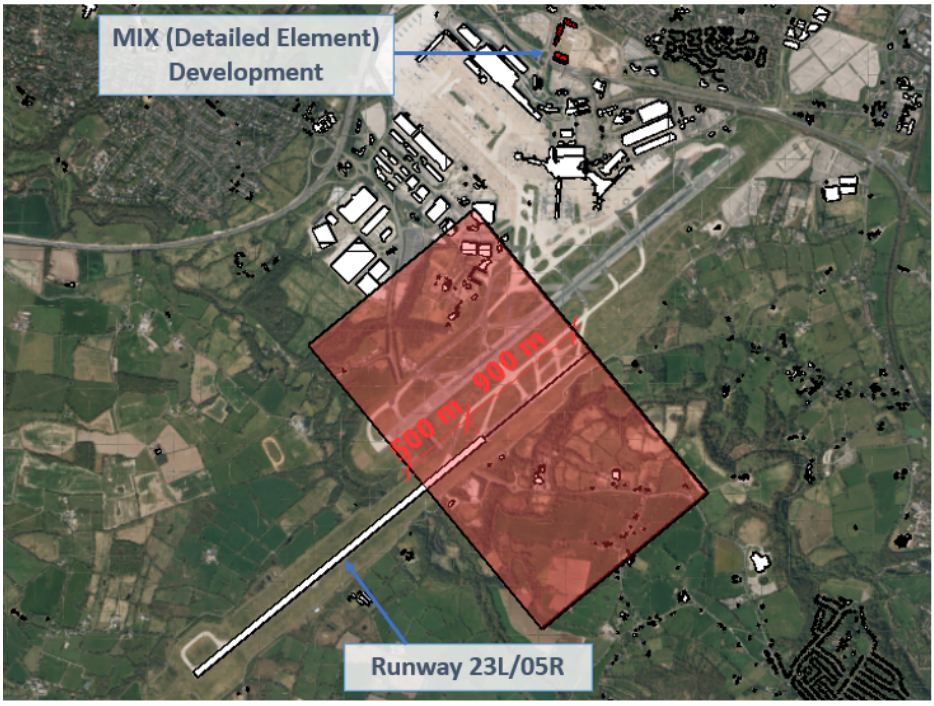


Figure 4.6: Potential Trigger Areas of Runway 23L/05R According to the NASF Guidelines.

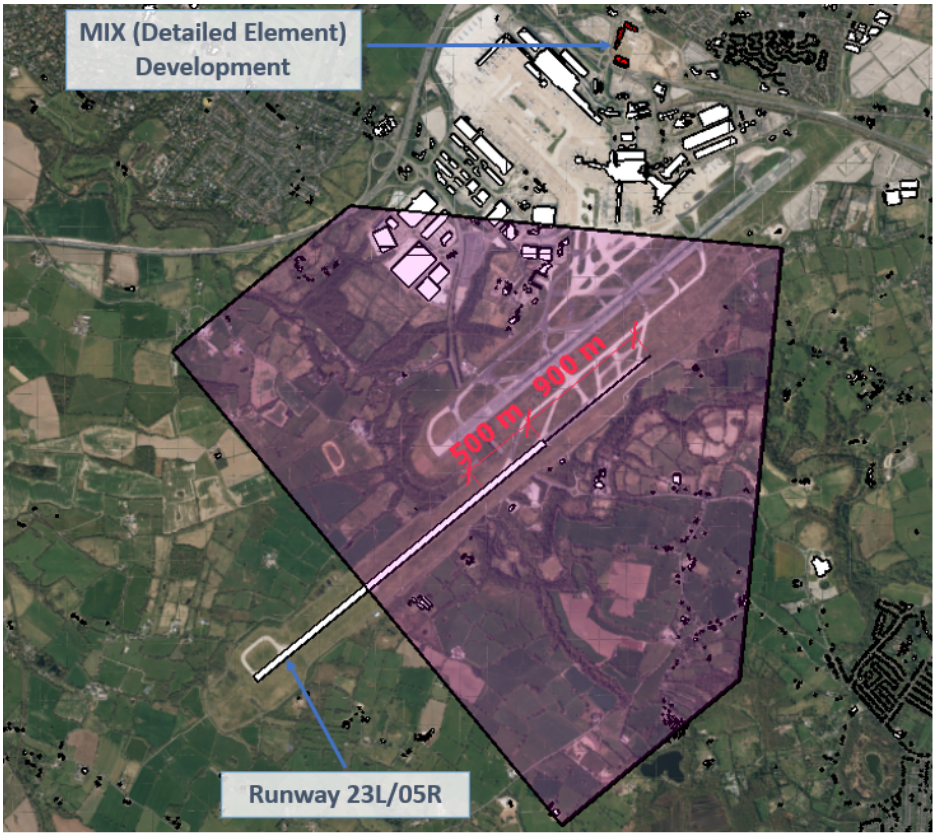


Figure 4.7: Potential Trigger Areas of Runway 23L/05R According to the NLR Report.

4.3 ASSESSMENT WIND DIRECTIONS

According to the NASF guideline, the wind shear and turbulence assessment should be undertaken along the runway centreline within the chainage range of -900 m to +500 m. Based on this requirement, the assessment areas for the Runway 23R/05L configuration are defined, as illustrated in Figure 4.8, and the corresponding wind direction sectors are identified.

For Runway 23R/05L, the assessment considers a wider wind sector, encompassing directions from 285° to 345° and from 0° to 30°. This range captures both west-northwesterly to northerly winds and northerly to north-easterly winds that may affect aircraft during approach and landing phases.

Based on these defined sectors, eight wind directions are selected for Runway 23R/05L. These directions are incorporated into the wind shear and turbulence analysis to ensure that the most operationally critical wind conditions are adequately assessed.

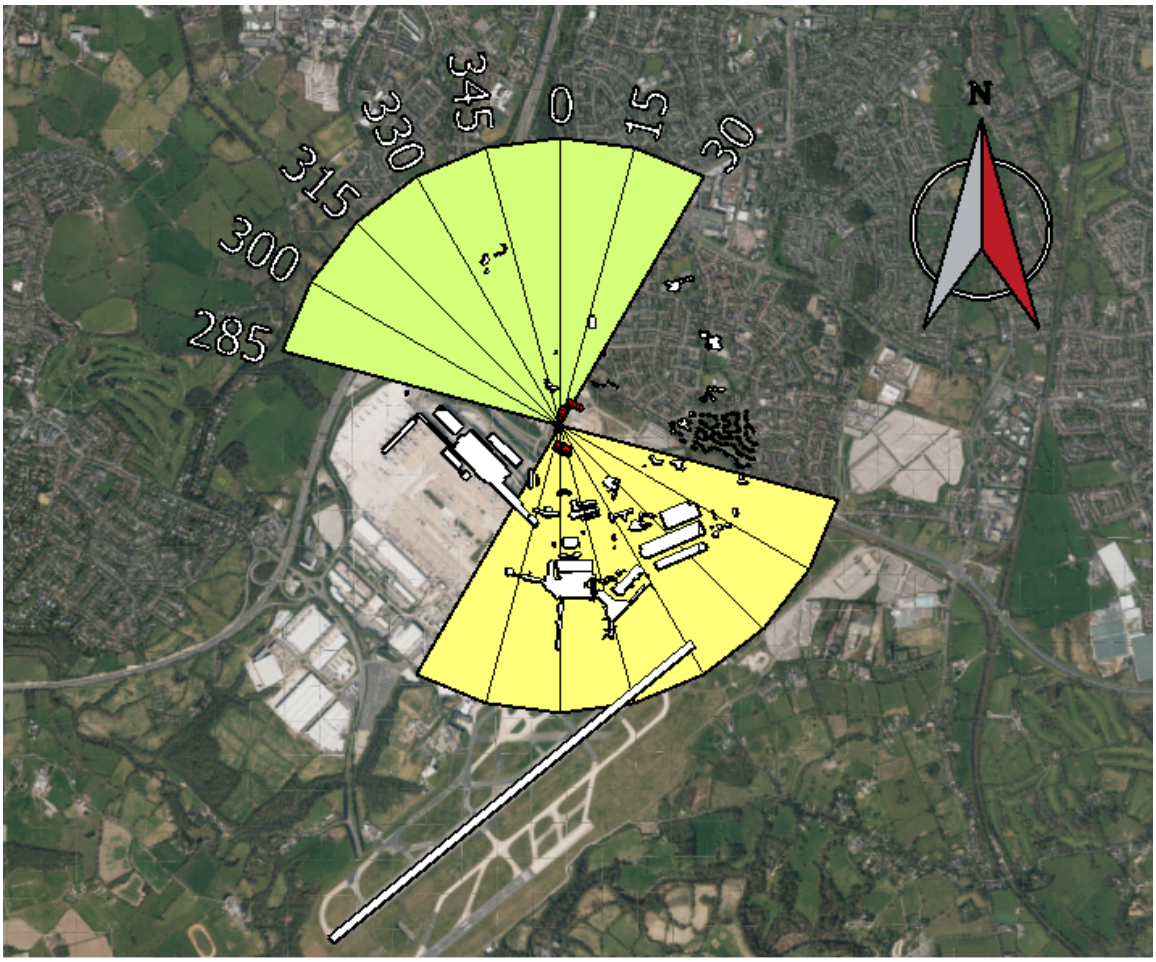


Figure 4.8: The Assessment Area and Corresponding Wind Directions for Runway 23R/05L.

5. LOCAL WEATHER DATA

5.1 STATISTICAL ANALYSIS OF WIND CONDITIONS

A statistical analysis of the historical wind data in the area has been provided to characterize the wind conditions at Manchester Airport.

Statistical assessment of the wind data is an important part of wind shear and turbulence analysis. Indeed, if the proposed development will cause any increased risk to landing to the operation of the center, for a particular wind direction and wind speed, then the occurrence of that wind conditions during a typical year or season, allows to predict at which frequency (how often), this can be expected to happen.

The wind profile is built using the annual average of meteorology data collected at Manchester Airport Weather Station and provided by Meteoblue. Data from Meteoblue are obtained based on ERA5T (ECMWF Reanalysis version 5T), a global atmospheric reanalysis dataset created by the European Centre for Medium-Range Weather Forecasts (ECMWF);

5.1.1 WIND DATA

Figure 5.1 presents the wind gust speeds recorded over a 5-year period between 2000 and 2025. The data is acquired from Meteoblue, which provides data located 10m above ground level.

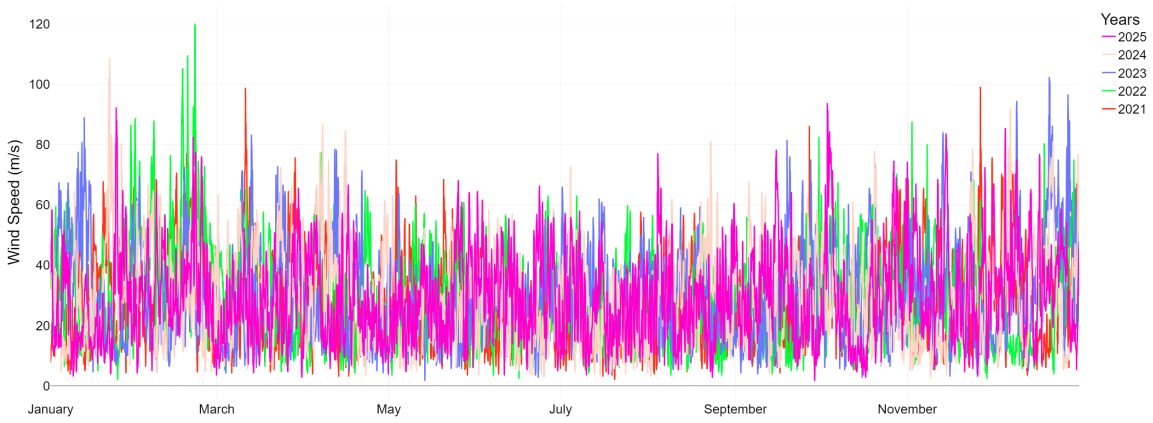


Figure 5.1: Local Wind Conditions - Wind Gust Speed.

Figures 5.2 and 5.3 present the wind gust speed diagram for Manchester, which indicates the number of days per month, during which the wind reaches a certain speed.

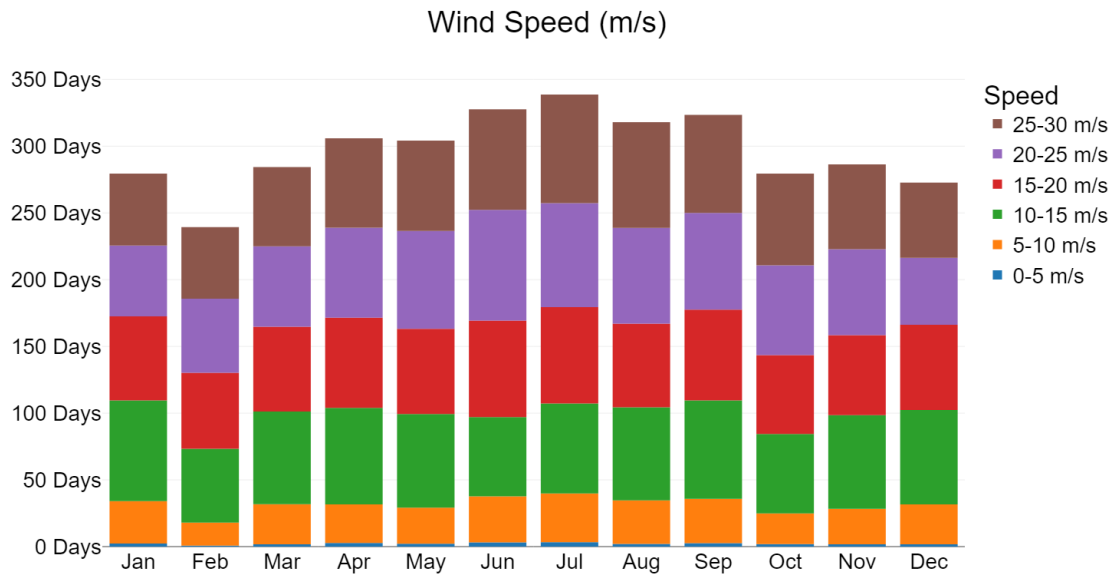
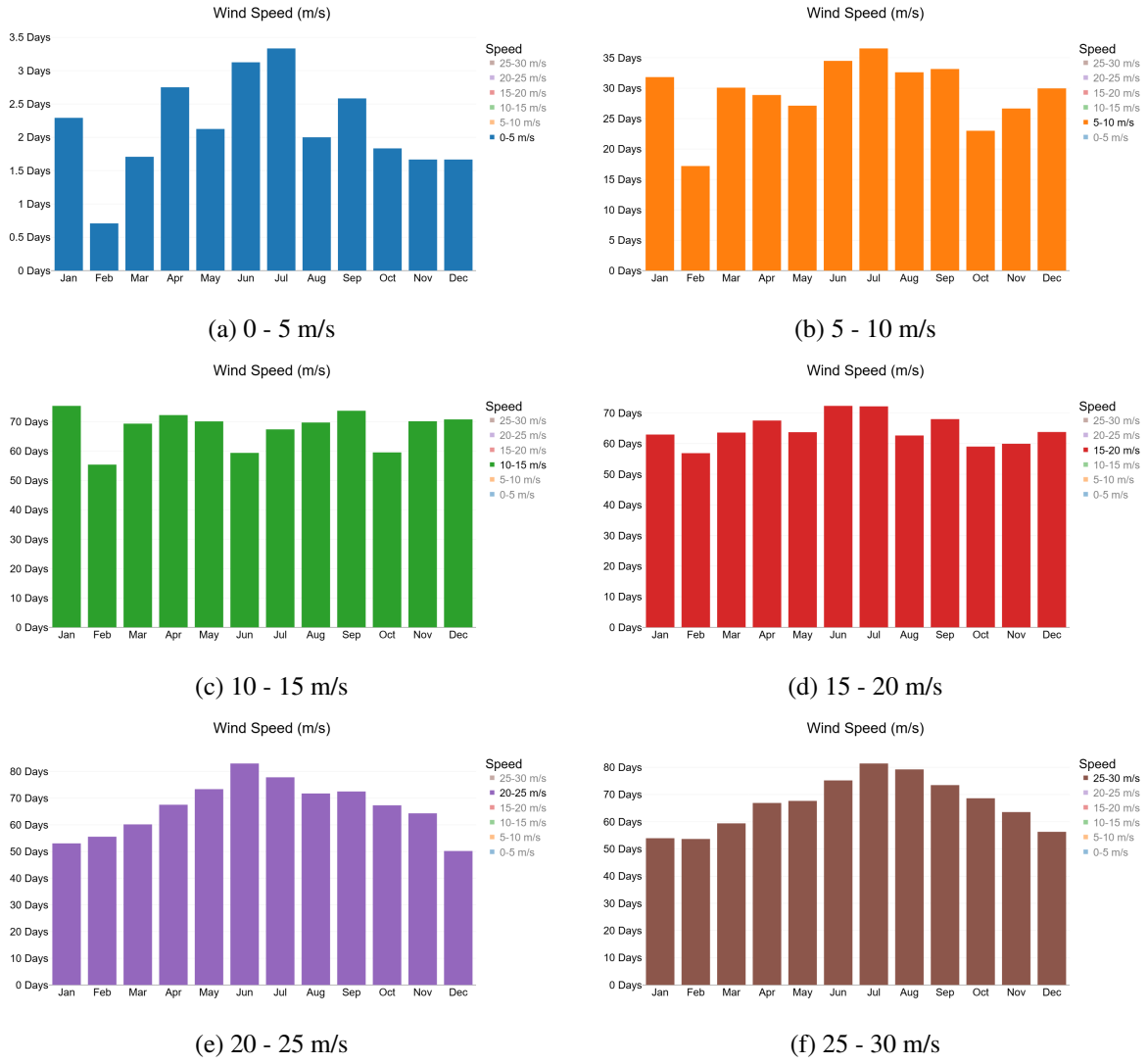


Figure 5.2: Manchester Airport Wind Gust Speed Diagram (from 2000 to 2025) - General View.



(a) 0 - 5 m/s

(b) 5 - 10 m/s

(c) 10 - 15 m/s

(d) 15 - 20 m/s

(e) 20 - 25 m/s

(f) 25 - 30 m/s

Figure 5.3: Manchester Airport Wind Speed (Gust) Diagram (from 2000 to 2025).

Figures 5.4 and 5.5 show the frequencies of wind gust speeds at different wind directions based on the weather data collected at the weather station over a period of 26 years between 2000 and 2025.

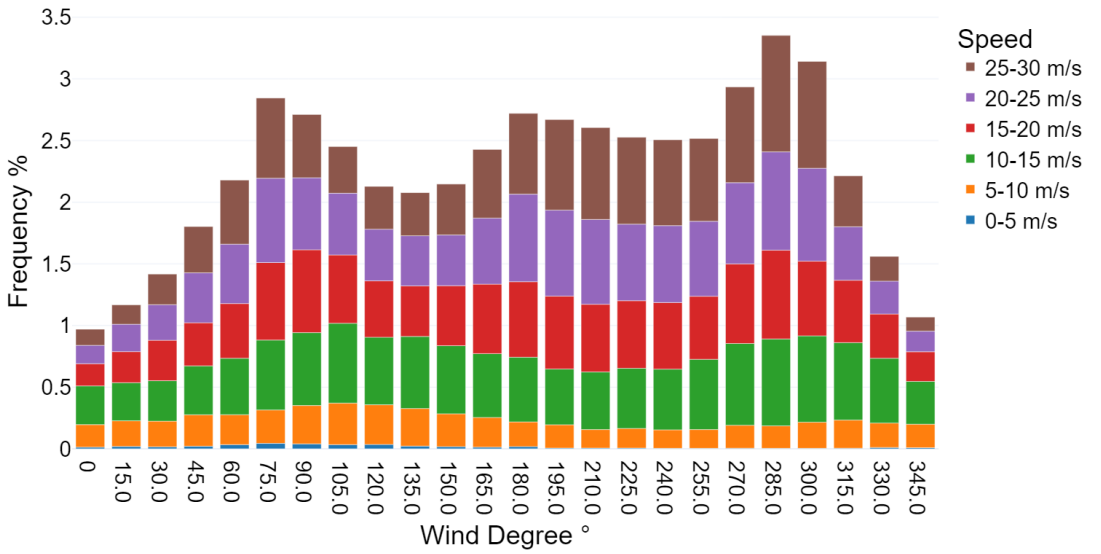
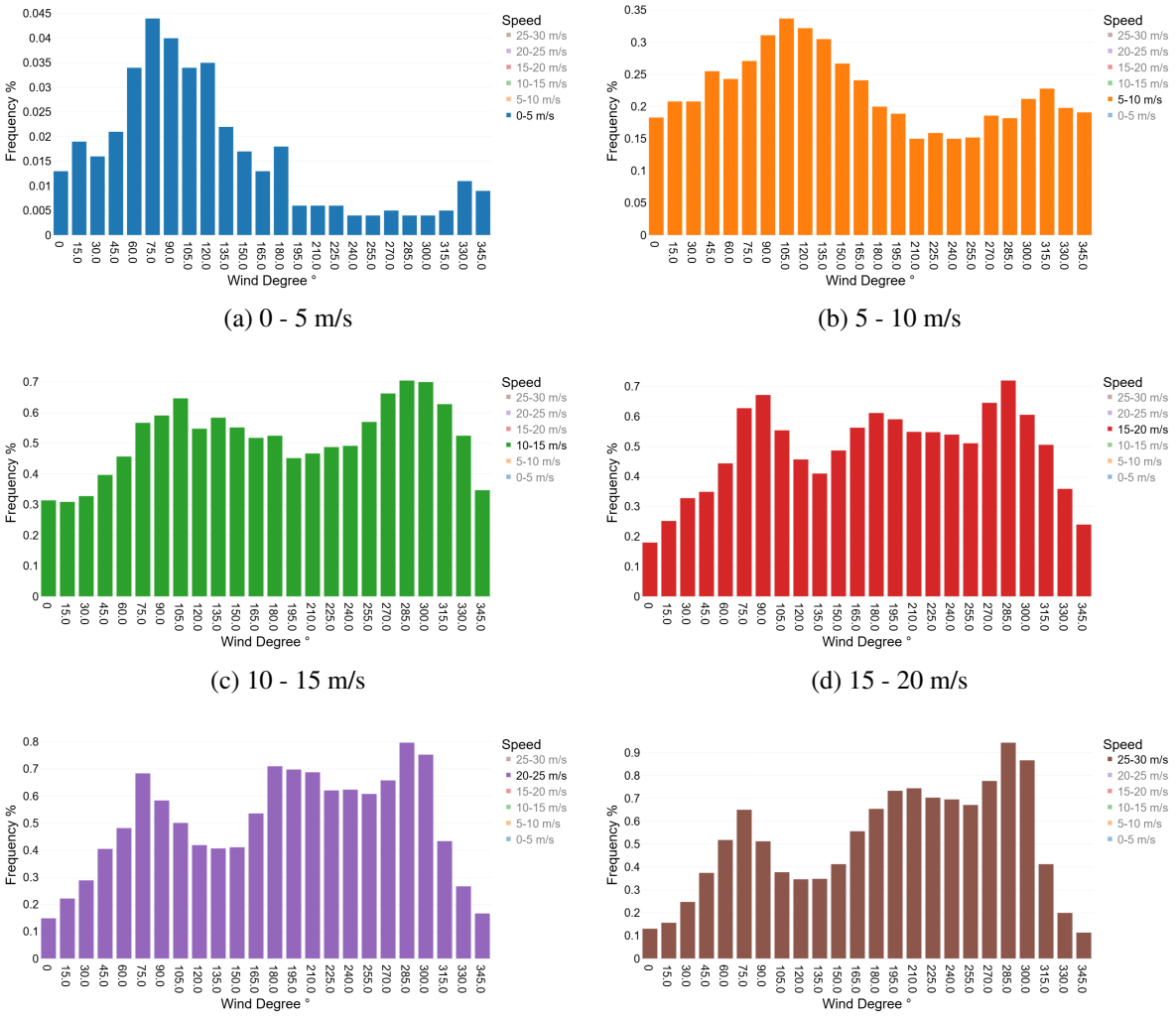


Figure 5.4: Frequency of Wind Gust Speeds at Different Wind Directions (from 2000 to 2025).



(a) 0 - 5 m/s

(b) 5 - 10 m/s

(c) 10 - 15 m/s

(d) 15 - 20 m/s

(e) 20 - 25 m/s

(f) 25 - 30 m/s

Figure 5.5: Frequency of Wind Gust Speeds at Different Wind Directions (from 2000 to 2025).

In Figure 5.6, the annual wind rose for Manchester Airport shows the annual frequency at which the wind blows from the indicated direction and with the indicated speed.

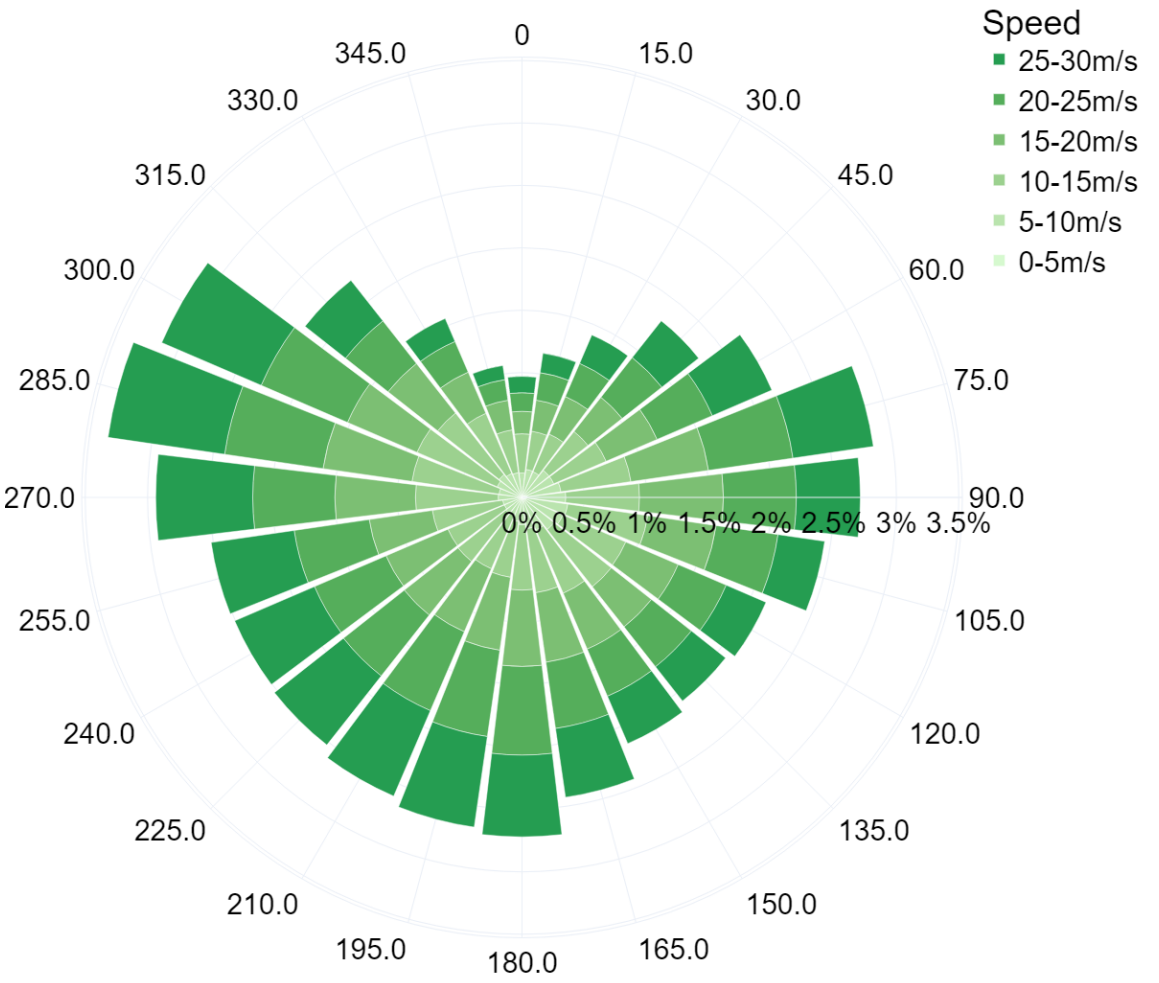


Figure 5.6: Manchester Airport Wind Rose (Gust).

6. CFD MODELING METHOD

6.1 CFD MODELING METHOD

In general, wind tunnel testing or Computational Fluid Dynamics (CFD) is required to assess the wind shear and turbulence when a proposed development does not pass the 1:35 rules.

Computational Fluid Dynamics (CFD) is a numerical technique to simulate fluid flow, heat and mass transfer, chemical reaction and combustion, multiphase flow, and other phenomena related to fluid flows. The Navier-Stokes equations, used within CFD analysis, are based entirely on the application of fundamental laws of physics and therefore produce accurate results providing that the scenario modelled is a good representation of reality.

Turbulent (gust) wind flow environment in an urban environment can be modelled with wind tunnel. However, small building features are better modelled in CFD versus wind tunnel testing, where model buildings are typically built to a scale of around 1:400 or similar. This is important when modelling small structures in the vicinity of airports or assessing the benefit of small canopies, porous screens and blades provided to mitigate adverse wind conditions. Moreover, wind tunnel measurements are performed at a few selected points within the tested model while CFD can provide comprehensive output of the entire flow field.

A high number of CFD studies have been published in the International Conferences and Journal of Wind Engineering and Industrial Aerodynamics in the past decades. CFD predictions of wind flow around bluff bodies have been compared and validated against wind tunnel and full scale measurements in the open literature. In general, good correlation is obtained when best practice guidelines are used for the modelling.

6.2 OpenFOAM SOFTWARE DETAILS

This report employs OpenFOAM Code, based on the concept of Reynolds Avarage navier Stokes (RANS) and the post-processing visualisation tool Paraview version 5.5. OpenFOAM is a CFD software released and developed primarily by OpenCFD Ltd, since 2004. It has a large user base across most areas of engineering and science, from both commercial and academic organisations. OpenFOAM has an extensive range of features to solve anything from complex fluid flows involving chemical reactions, turbulence and heat transfer, to acoustics, solid mechanics and electromagnetics. Quality assurance is based on rigorous testing. The process of code evaluation, verification and validation includes several hundred daily unit tests, a medium-sized test battery run on a weekly basis, and large industry-based test battery run prior to new version releases. Tests are designed to assess regression behaviour, memory usage, code performance and scalability.

In this study unsteady RANS (URANS) simulations with the k-ω SST turbulence model are used to assess the risks of buildings near the threshold of runways and predict wind shear and turbulence for critical flight paths. The k-ω SST turbulence model is proposed due to ability to combine the benefits of the standard k-ϵ model and the k-ω model while minimising their disadvantages.

In OpenFOAM, the simpleFoam solver is used to perform steady-state RANS simulations. The URANS simulations in this report are performed using the pimpleFoam solver, initialised by the converged results of steady-state simulations.

6.3 MODELLED GEOMETRIES

The project site is located near the runways of Manchester Airport. The airport operates 24 hours a day, with restrictions on night-time operations, including circuit training, and is equipped with two parallel runways.

A 3D model of one of the proposed design schemes and surrounding built environment is shown in Figure 6.1. The proposed development includes a hybrid planning application for Mix Manchester. The runway 23R/05L does not penetrate the 1:35 height rule but located within the trigger area suggested by the NLR and/or NASF report. In addition, the width of the buildings also exceeds 30m, therefore, the effects of this development is further analyzed in relation to all runways using a quantitative Computational Fluid Dynamics (CFD) analysis.

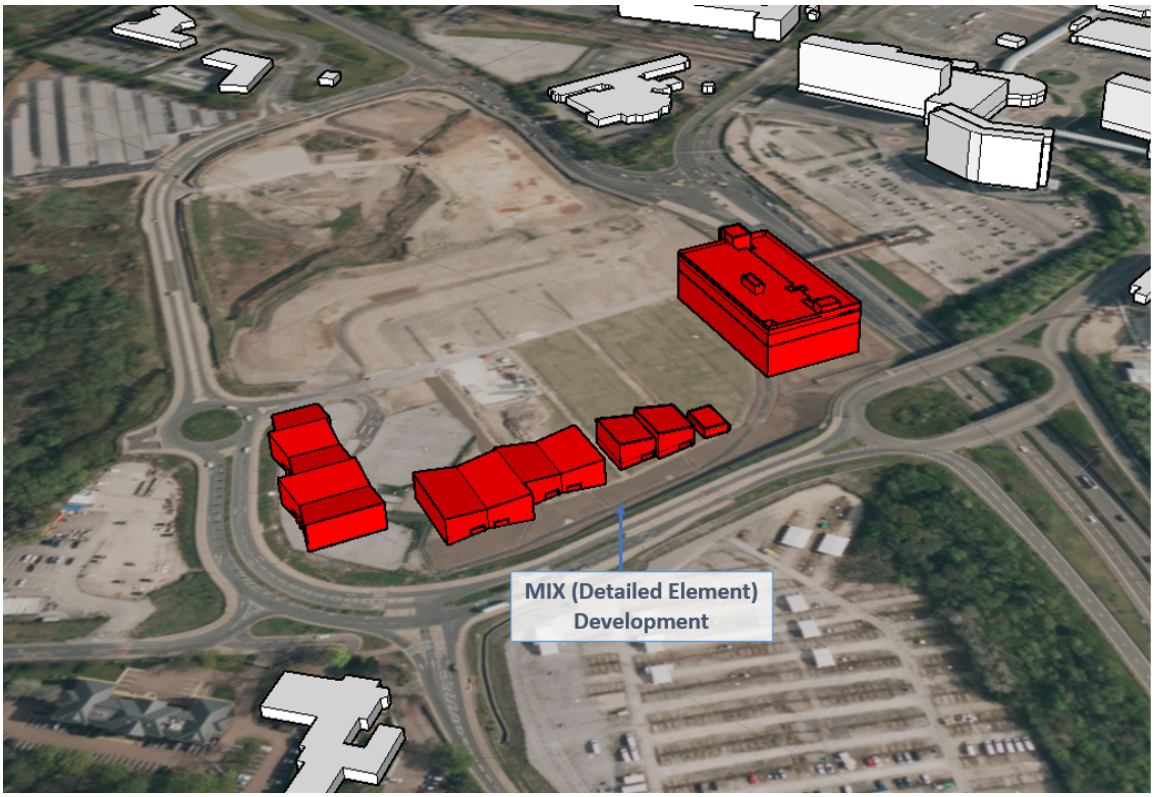


Figure 6.1: Development Site and Geometry for CFD Modelling (red color).

The modelled layout and dimensions of the surrounding environment are outlined in the table below (Table 6.1).

The size of the computational domain should be selected according to the best practice guideline. A building with height H may have a minimal influence if its distance from the area of interest is greater than 6-10H.

In order to represent reality and consider the actual wind impacting on the site, the modelled area for the wind modelling study comprises an area of 1000m radius around the aircraft hangar, as shown in Figure 6.2.

	MODELLED CFD ENVIRONMENT DIMENSIONS		
	Width	Length	Height
CFD Mesh Domain	2500m approx	2400m approx	200m approx

Table 6.1: Modelled Environment Dimensions.

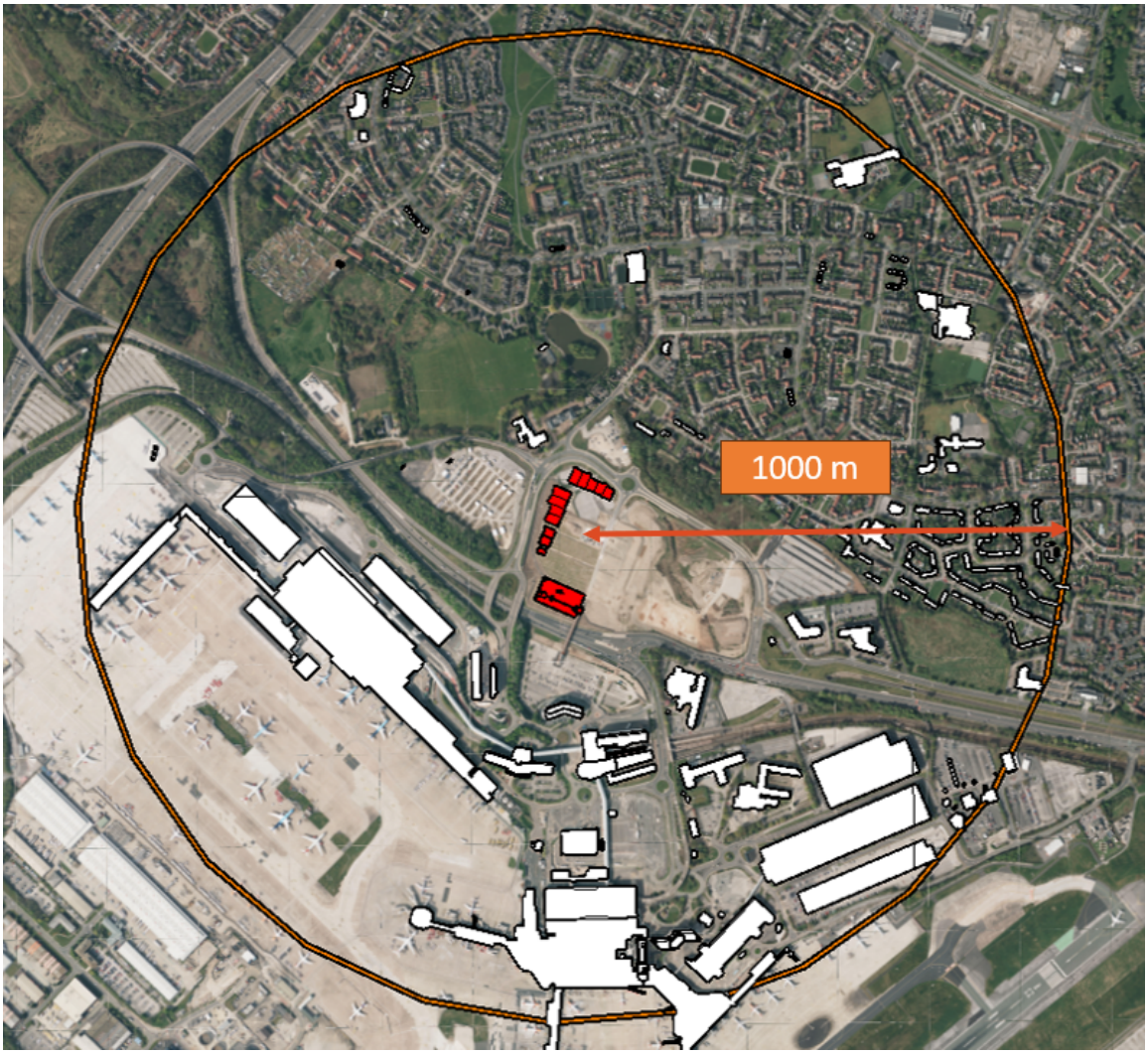


Figure 6.2: Development Site and Geometry for CFD Modelling.

6.4 COMPUTATIONAL MESH

The size of the computational domain should be selected according to the best practice guideline. A building with height H may have a minimal influence if its distance from the region of interest is greater than 6-10H. All buildings within 1000m diameter were included in the developed CFD model.

The level of accuracy of the CFD results are determined by the level of refinement of the computational mesh. Details of parameters used to calculate the computational mesh are presented in Table 6.2. Figure 6.3 show the mesh generated for this project.

The grid follows the principles of the Finite Volume Method, which implies that the solution of the model equations is calculated at discrete points (nodes) on a three-dimensional grid, which includes all the flow volume of interest. The mathematical solution for the flow is calculated at the center of each of these cells and then an interpolation function is used by the software to provide the results in the entire domain. Approximately 40 million cells were used to cover the computational domain.

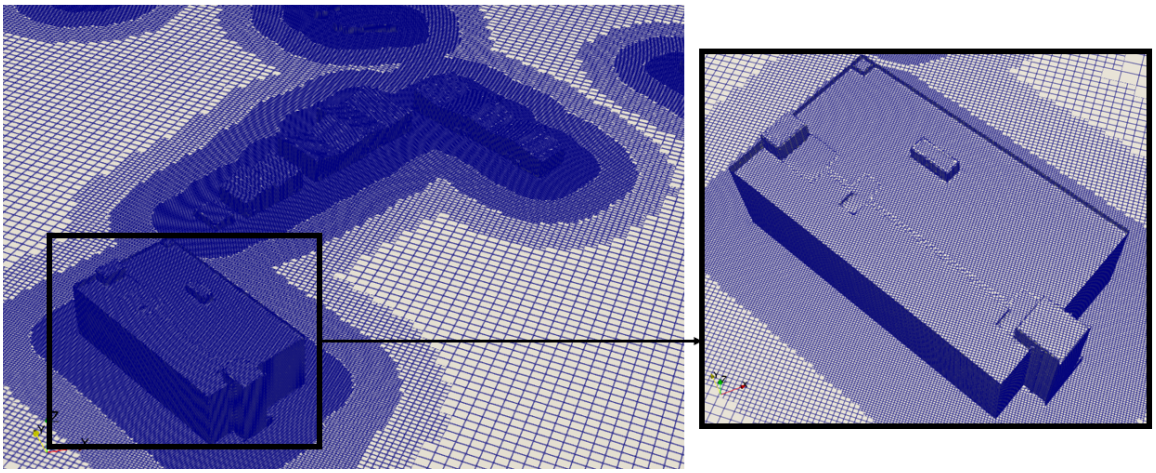


Figure 6.3: Development and Domain Mesh Example.

6.5 BOUNDARY CONDITIONS

The wind directions were altered without changing the computational mesh. For each direction, an initial wind velocity was set according to the weather data collected, in order to consider the worst case scenario. Surfaces within the model were specified as having no slip condition. This boundary condition, ensures that flow moving parallel to a surface is brought to rest at the point where it meets the surface. All the other domain boundaries are set as "Open Boundaries".

As unsteady RANS simulations require significant computational resources to obtain a valid numerical solution which includes the use of very small time steps (0.01 to 0.05s) to meet the recommendations in best practice guidelines. The simulations were run in the following way to optimize the computational time:

- Start with a steady-state RANS solution and then switch to URANS model;
- Initially use variable time steps if possible to speed up the simulation;
- Reduce time step as per the best practice guidelines; and then
- Reduce number of iterations per time step if possible.

PARAMETERS TO CALCULATE COMPUTATIONAL MESH	
Air Density ρ	$1.2kg/m^3$
Ambient Temperature (T)	$288K(approx.15C°)$
Gravity Acceleration (g)	$9.8m/s^2$
dx	0.5 m at the building 1m in the surroundings 2m to 5m elsewhere
Background Mesh cells ratio	1:1
Total mesh size	Approx. cells number = 40 million

Table 6.2: Parameters to Calculate Computational Mesh.

6.6 LOGARITHMIC WIND PROFILE

The wind velocity data provided by the historical data collection and by the local data measuring are used in the formula below for the logarithmic wind profile to specify the wind velocity profile (wind velocity at different heights) to be applied within the CFD model:

$$u_{(z)} = \frac{u^\star}{K} \cdot ln\left(\frac{z + z_0}{z_0}\right) \tag{6.1}$$

where:

- $u_{(z)}$ = wind speed measured at the reference height z;
- z = reference height to measure $u_{(z)}$;
- $z_0 = 0.05$ $[m]$ roughness length selected;
- $u^\star$ = friction velocity;
- K = Karman constant.

The wind profile used in the model has been calculated using the formula above and is represented in Figure 6.4.

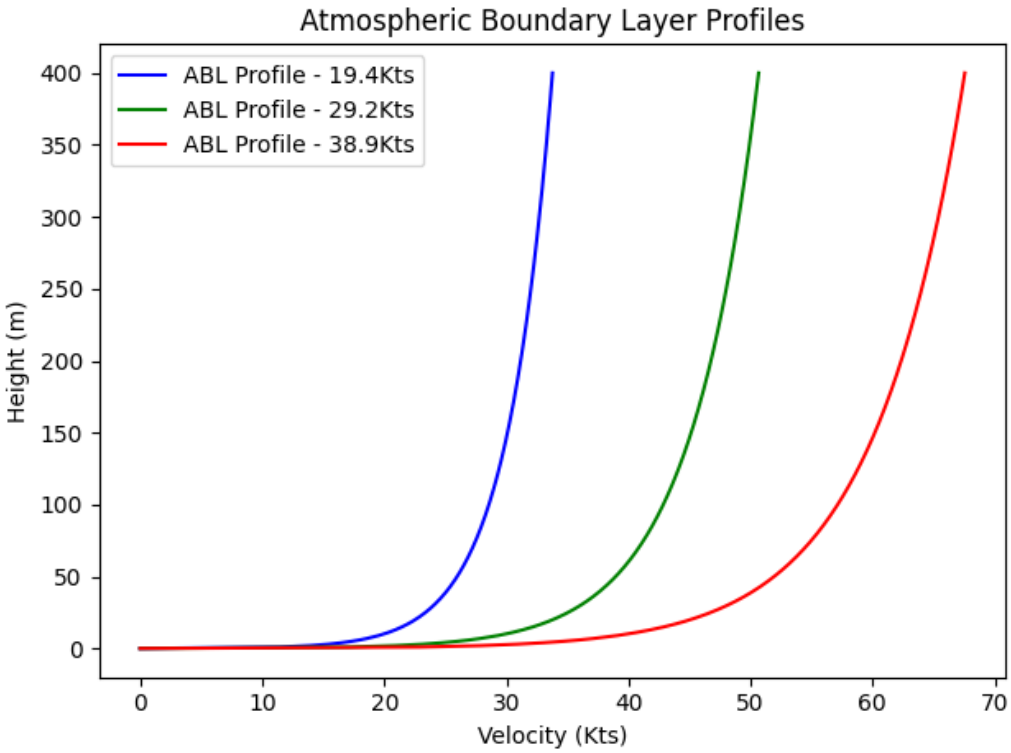


Figure 6.4: Wind Profiles Used in the Model.

7. CONCLUSION of ANALYSIS

This chapter reports the summary of the analysis carried out, showing the wind shear and the turbulence impact of the Pre- and Post-Development on the runway 23R/05L. Details of the CFD simulations and calculations that were used to elaborate the summaries can be found in Appendix A 'Post-Development Results' and Appendix B 'Pre-Development Results'. Verification and Validation of the CFD Methodology is presented in Appendix C.

7.1 IMPACT ON RUNWAY 23L/05R

As shown in Section 4.2, the proposed MIX Manchester (Detailed Element) is not located within the assessment area of runway 23L/05R suggested by the NLR report or the NASF guideline. Therefore, it is excluded from the the wind shear and turbulence assessment in this report.

7.2 IMPACT ON RUNWAY 23R/05L

As shown in Section 4.2, the proposed MIX Manchester (Detailed Element) is located within the assessment trigger area of Runway 23R/05L according to both the NLR report and the NASF guidelines. The distances from the Runway 23R/05L extended centerline to the closest point of MIX (Detailed Element) development is 1165m, which is greater than 35 times the height of MIX (Detailed Element) development (Figure 7.1). Although it does not penetrate the 1:35 height rule on Runway 23R/05L, but its width exceeds 30m as shown in Figure 7.2. Therefore, the basis of regulatory control study, which are the adoption of along-wind and across-wind windshear criteria, and the adoption of a turbulence criterion, were implemented on Runway 23R/05L by using CFD technique.

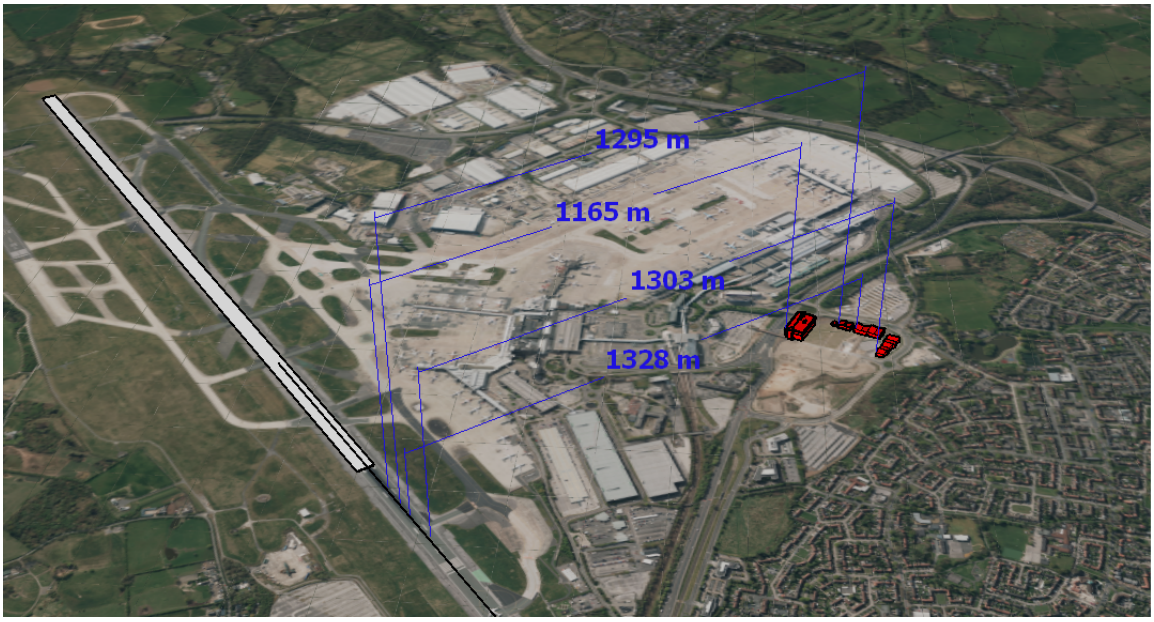


Figure 7.1: Development Relative to Runway 28R/10L.

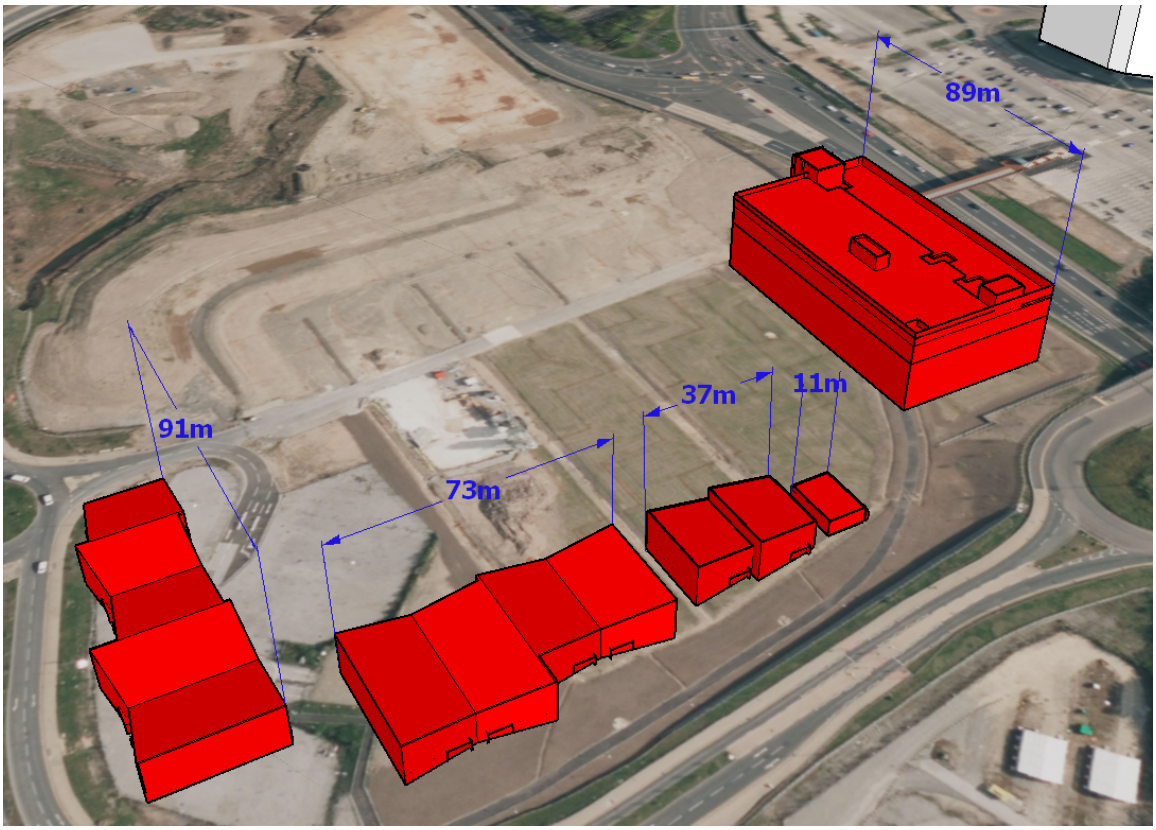


Figure 7.2: Widths of MIX (Detailed Element) Development.

7.3 Wind Shear Assessment - Runway 23R/05L

The CFD analysis assesses wind shear and turbulence impacts for the Post-Development Scenario in accordance with the acceptance criteria of NLR-CR 2006-261. Based on the results of the NLR 7-knot, 6-knot, and 4-knot criteria, a Pre-Development Scenario is considered only for those wind directions that exceed any of these thresholds. If the mean velocity deficit exceeds any one of the NLR criteria for a given wind direction, the results for the other two criteria are also checked to facilitate a consistent comparative evaluation. This is done to determine whether the observed effects are attributable to the proposed development or are part of existing conditions.

7.3.1 6 Knot Across-Wind Windshear Criterion

Figure 7.3 relate the mean velocity deficit obtained for each different aircraft trajectory paths for the Post-Development Scenario (the variables collected for the calculation of the mean velocity deficit are detailed in Appendix A - Post-Development Results) with the approaching wind speed.

Figure 7.3 show that for approaching wind speed 19.4 Kts (10 m/s) - 38.9 Kts (20 m/s), the NLR "6 Knot criterion" was never exceeded for the Post-Development Scenario for approaching wind from 0°, 15°, 30°, 285°, and 300°. For a wind direction of 315° at 38.9 Kts (20 m/s) and above, exceedance of the criterion was observed in the Post-Development Scenario, while all lower wind speeds satisfied the criterion. For a wind direction of 330° at 34 Kts (17.5 m/s) and above, exceedance of the criterion was observed in the Post-Development Scenario, while all lower wind speeds satisfied the criterion. Further, for a wind direction of 345° at 29.2 Kts (15 m/s) and above, exceedance of the criterion was observed in the Post-Development Scenario, while all lower wind speeds satisfied the criterion.

A Pre-Development Scenario is considered only for cases where potential impacts are identified, in order to determine whether these effects are attributable to the proposed development. Figure 7.4 shows the mean velocity deficit obtained for each different aircraft trajectory paths for the Pre-Development Scenario (the variables collected for the calculation of the mean velocity deficit are detailed respectively in Appendix B - Pre-Development Results).

Figure 7.4 shows that for a wind direction of 315° at 38.9 Kts (20 m/s) and above, exceedance of the criterion was observed in the Pre-Development Scenario, while all lower wind speeds satisfied the criterion. For a wind direction of 330° at 34 Kts (17.5 m/s) and above, exceedance of the criterion was observed in the Pre-Development Scenario, while all lower wind speeds satisfied the criterion. Further, for a wind direction of 345° at 29.2 Kts (15 m/s) and above, exceedance of the criterion was observed in the Pre-Development Scenario, while all lower wind speeds satisfied the criterion.

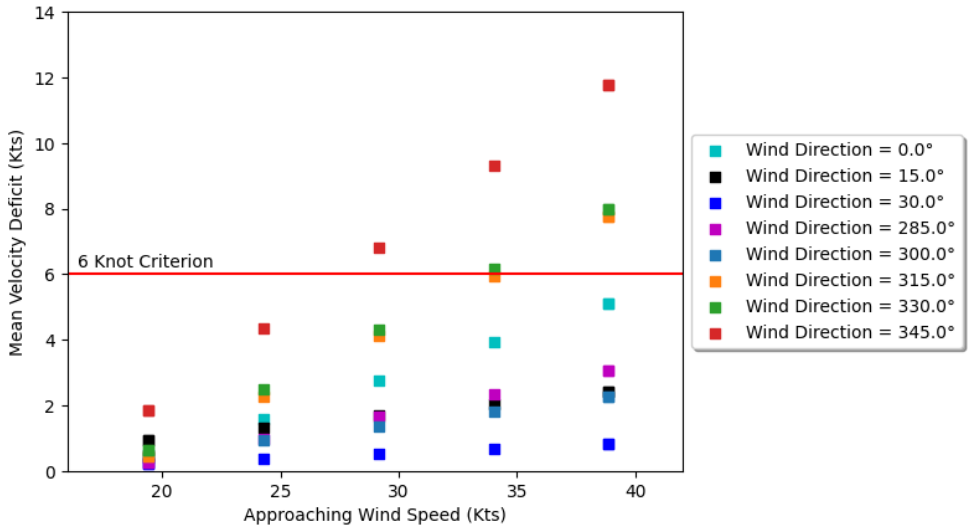


Figure 7.3: Mean Velocity Deficit Exceedance Occurrence for **Post-Development** (square mark) - 6 Knot Across-Wind Criterion.

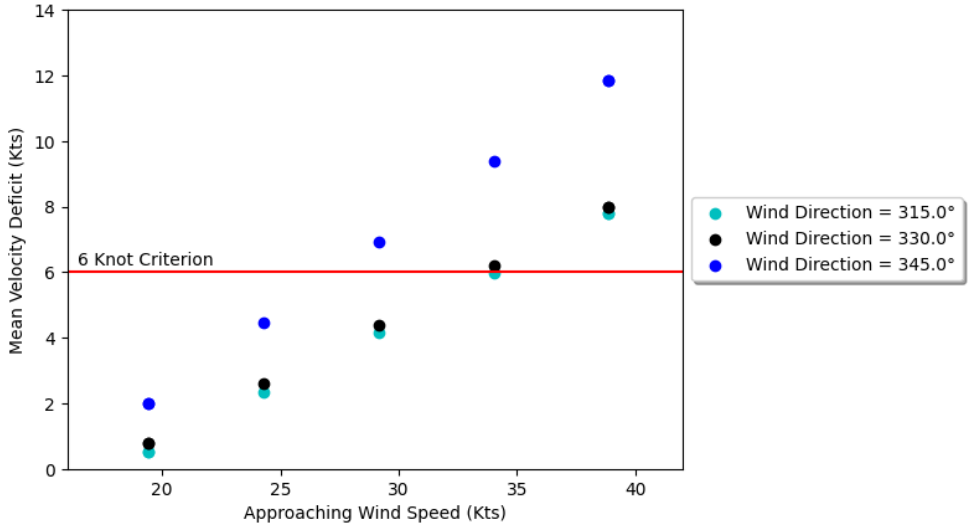


Figure 7.4: Mean Velocity Deficit Exceedance Occurrence for **Pre-Development** (round mark) - 6 Knot Across-Wind Criterion.

These findings suggest that the exceedances are predominantly governed by the baseline (Pre-Development) conditions, and that the proposed development does not introduce any significant additional wind shear impact.

In accordance to the local weather data analysis carried out in Section 5.1, it is demonstrated that:

- a wind speed of above 38.9 Kts (20 m/s) is occurring at a frequency of less than 1.553% in a typical year for a wind direction of 315° for both Pre- and Post-Development;
- a wind speed of above 34 Kts (17.5 m/s) is occurring at a frequency of less than 0.895% in a typical year for a wind direction of 330° for both Pre- and Post-Development;
- a wind speed of above 29.2 Kts (15 m/s) is occurring at a frequency of less than 0.699% in a typical year for a wind direction of 345° for both Pre- and Post-Development.

Therefore, the impact of windshear and turbulence on runway 23R/05L is expected to exceed the critical level recommended by the NLR "6 Knot across-wind windshear criterion" with an occurrence of approximately 3.147% per year for both Pre- and Post-Development. This indicates that the windshear impacts were already present in the existing environment, and the proposed development does not increase their frequency.

7.3.2 7 Knot Along-Wind Windshear Criterion

Figure 7.5 relate the mean velocity deficit obtained for each different aircraft trajectory paths for the Post-Development Scenario (the variables collected for the calculation of the mean velocity deficit are detailed respectively in Appendix A - Post Development Results) with the approaching wind speed.

As shown in Figure 7.5, for approaching wind speeds of 19.4 Kts (10 m/s) to 38.9 Kts (20 m/s), the NLR "7 Knot criterion" was not exceeded for the Post-Development Scenario.

Figure 7.6 shows the mean velocity deficit obtained for each different aircraft trajectory paths for the Pre-Development Scenario (the variables collected for the calculation of the mean velocity deficit are detailed respectively in Appendix B - Pre-Development Results).

As shown in Figure 7.6, for approaching wind speeds of 19.4 Kts (10 m/s) to 38.9 Kts (20 m/s), the NLR "7 Knot criterion" was not exceeded for the Pre-Development Scenario.

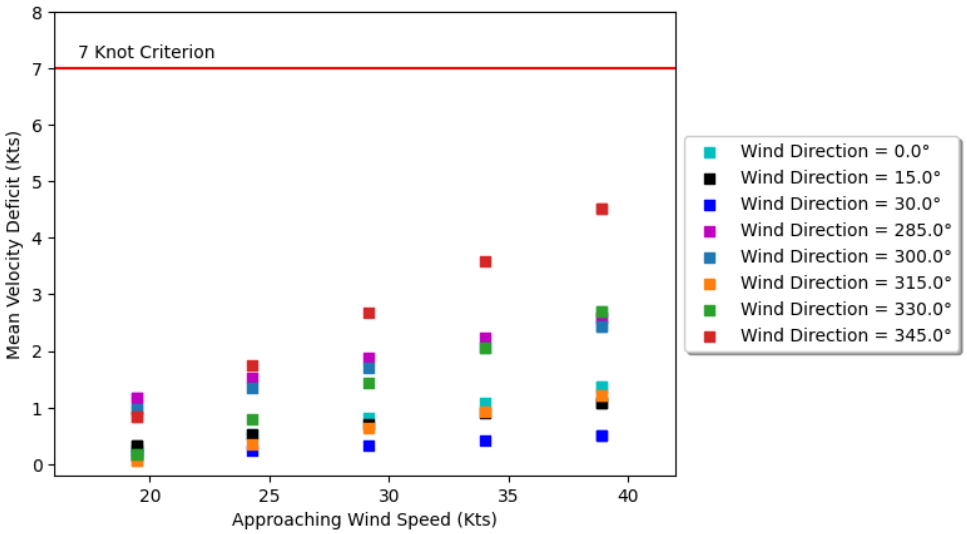


Figure 7.5: Mean Velocity Deficit Exceedance Occurrence for **Post-Development** (square mark) - 7 Knot Along-Wind Criterion.

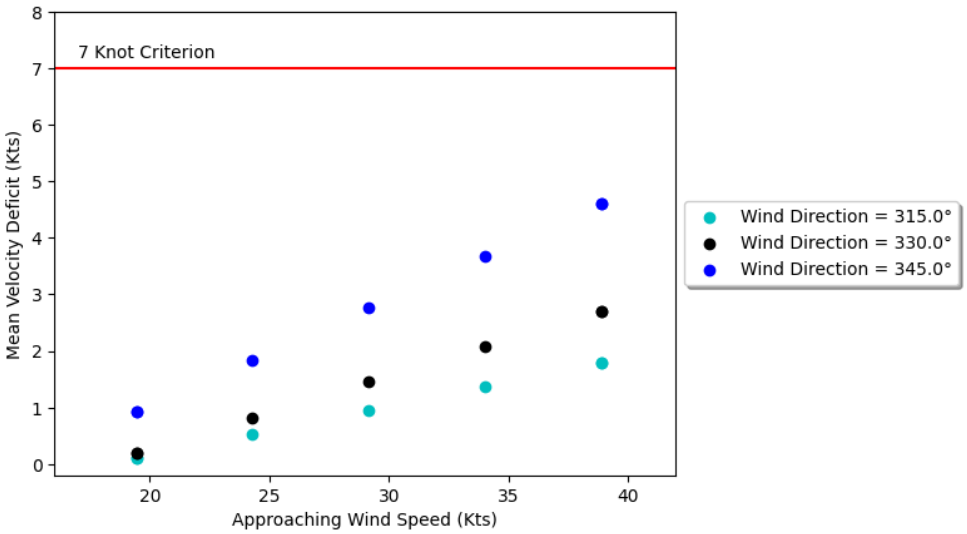


Figure 7.6: Mean Velocity Deficit Exceedance Occurrence for **Pre-Development** (round mark) - 7 Knot Along-Wind Criterion.

These findings demonstrate that the Post-Development conditions remain consistent with the baseline (Pre-Development) Scenario, indicating no significant impact from the proposed development.

7.3.3 4 Knot Turbulence Criterion

Figure 7.7 relate the turbulence deviation obtained for each different aircraft trajectory paths (the variables collected for the calculation of the mean velocity deficit are detailed in Appendix A - Post-Development Results) with the approaching wind speed.

It can be seen from Figure 7.8, for approaching wind speed 19.4 Kts (10 m/s) to 38.9 Kts (20 m/s), the NLR "4 Knot criterion" was never exceeded for the Post-Development Scenario.

Figure 7.8 shows the turbulence deviation obtained for each different aircraft trajectory paths for the Pre-Development scenario (the variables collected for the calculation of the mean velocity deficit are detailed respectively in Appendix B - Pre-Development Results).

It can be observed from Figure 7.8, for approaching wind speed 19.4 Kts (10 m/s) to 38.9 Kts (20 m/s), the NLR "4 Knot criterion" was never exceeded for the Pre-Development Scenario.

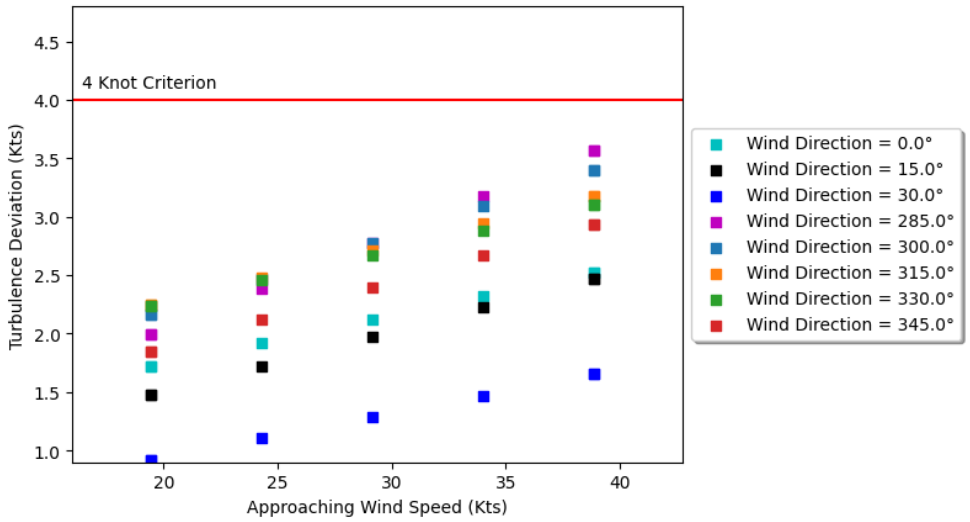


Figure 7.7: Max Turbulence Deviation (RMS) in Knot Exceedance Occurrence for **Post-Development** (square mark) - 4 Knot Turbulence Criterion.

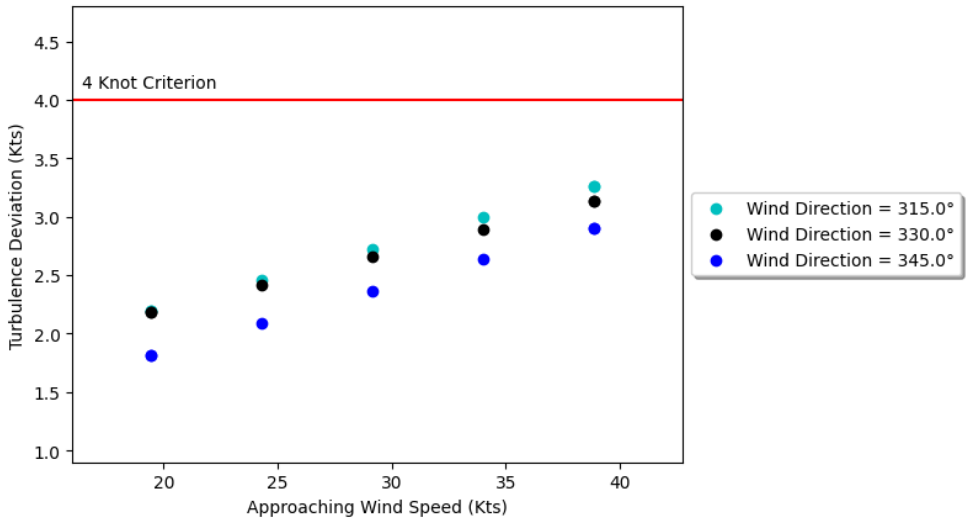


Figure 7.8: Max Turbulence Deviation (RMS) in Knot Exceedance Occurrence for **Pre-Development** (round mark) - 4 Knot Turbulence Criterion.

These findings demonstrate that the Post-Development conditions remain consistent with the baseline (Pre-Development) Scenario, indicating no significant impact from the proposed development.

7.3.4 Risk of Wind Shear and Turbulence Impact on Runway 23R/05L

The CFD analysis has assessed the wind shear and turbulence impact considering both the Pre-Development scenario (such as the existing buildings and structures) and the Post-Development scenario (where the proposed terminal expansion is included in the existing urban context) in relation to the acceptance criteria of NLR-CR 2006-261. For the Pre-Development scenario, only those wind directions for which exceedances are observed in the Post-Development scenario have been considered, in order to determine whether these effects are attributable to the existing environment or introduced by the proposed development.

The analysis has shown that the wind shear and turbulence on runway 23R/05L will be comparable to those currently existing even after the construction of the proposed MIX (Detailed Element) development.

Wind shear and turbulence exceedances are already occurring on the runway 23R/05L in the Pre-Development scenario, and they will remain within the same ranges after the construction of the development. Furthermore, wind shear and turbulence exceedances occur under wind directions that have a reduced frequency during a typical year.

Therefore, it can be concluded that the proposed development will not pose any increased risk of wind shear and turbulence compared to the existing situation.

A summary of the analysis conducted is shown in Table 7.1.

Table 7.1: Summary of Analysis Conducted - Acceptance Criteria Evaluation.

Approaching Wind Speed	Wind Direction	Is the 7-Knot Criterion Exceeded?		Is the 6-Knot Criterion Exceeded?		Is the 4-Knot Criterion Exceeded?	
		Pre-Development	Post-Development	Pre-Development	Post-Development	Pre-Development	Post-Development
19.4 Knots (10 m/s)	0^0	No	No	No	No	No	No
	15^0	No	No	No	No	No	No
	30^0	No	No	No	No	No	No
	285^0	No	No	No	No	No	No
	300^0	No	No	No	No	No	No
	315^0	No	No	No	No	No	No
	330^0	No	No	No	No	No	No
	345^0	No	No	No	No	No	No
24.3 Knots (12.5 m/s)	0^0	No	No	No	No	No	No
	15^0	No	No	No	No	No	No
	30^0	No	No	No	No	No	No
	285^0	No	No	No	No	No	No
	300^0	No	No	No	No	No	No
	315^0	No	No	No	No	No	No
	330^0	No	No	No	No	No	No
	345^0	No	No	No	No	No	No
29.2 Knots (15 m/s)	0^0	No	No	No	No	No	No
	15^0	No	No	No	No	No	No
	30^0	No	No	No	No	No	No
	285^0	No	No	No	No	No	No
	300^0	No	No	No	No	No	No
	315^0	No	No	No	No	No	No
	330^0	No	No	No	No	No	No
	345^0	No	No	**Yes (0.699% annual)**	**Yes (0.699% annual)**	No	No
34 Knots (17.5 m/s)	0^0	No	No	No	No	No	No
	15^0	No	No	No	No	No	No
	30^0	No	No	No	No	No	No
	285^0	No	No	No	No	No	No
	300^0	No	No	No	No	No	No
	315^0	No	No	**No**	No	No	No
	330^0	No	No	**Yes (0.895% annual)**	**Yes (0.895% annual)**	No	No
	345^0	No	No	**Yes* (0.699% annual)**	**Yes* (0.699% annual)**	No	No
38.9 Knots (20 m/s)	0^0	No	No	No	No	No	No
	15^0	No	No	No	No	No	No
	30^0	No	No	No	No	No	No
	285^0	No	No	No	No	No	No
	300^0	No	No	No	No	No	No
	315^0	No	No	**Yes (1.553% annual)**	**Yes (1.553% annual)**	No	No
	330^0	No	No	**Yes** (0.895% annual)**	**Yes** (0.895% annual)**	No	No
	345^0	No	No	**Yes* (0.699% annual)**	**Yes* (0.699% annual)**	No	No

Note: (*) The probability at that wind direction is already included in the range of velocity starting from 29.2 Kts and above;

Note: (**) The probability at that wind direction is already included in the range of velocity starting from 34 Kts and above.

8. REFERENCES

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9. APPENDIX A Post-Development Results

This Appendix shows the CFD results of the wind assessment considering the Post-Development scenario. Sample results of CFD models along runway 23R/05L and 10m above ground level are presented based on the following wind conditions:

- approach wind speed is 20m/s (38.9 Kts).
- approach wind directions for the runway 23R/05L is 0°, 15°, 30°, 285°, 300°, 315°, 330°, and 345°.

Figure 1 summaries the CFD model for the Pre-Development scenario. Further, Figure 2 shows the sampling locations of the simulation results where results are sampled at:

- A horizontal slice at 10m above the ground;
- A cross-section of 200m height across the proposed development.

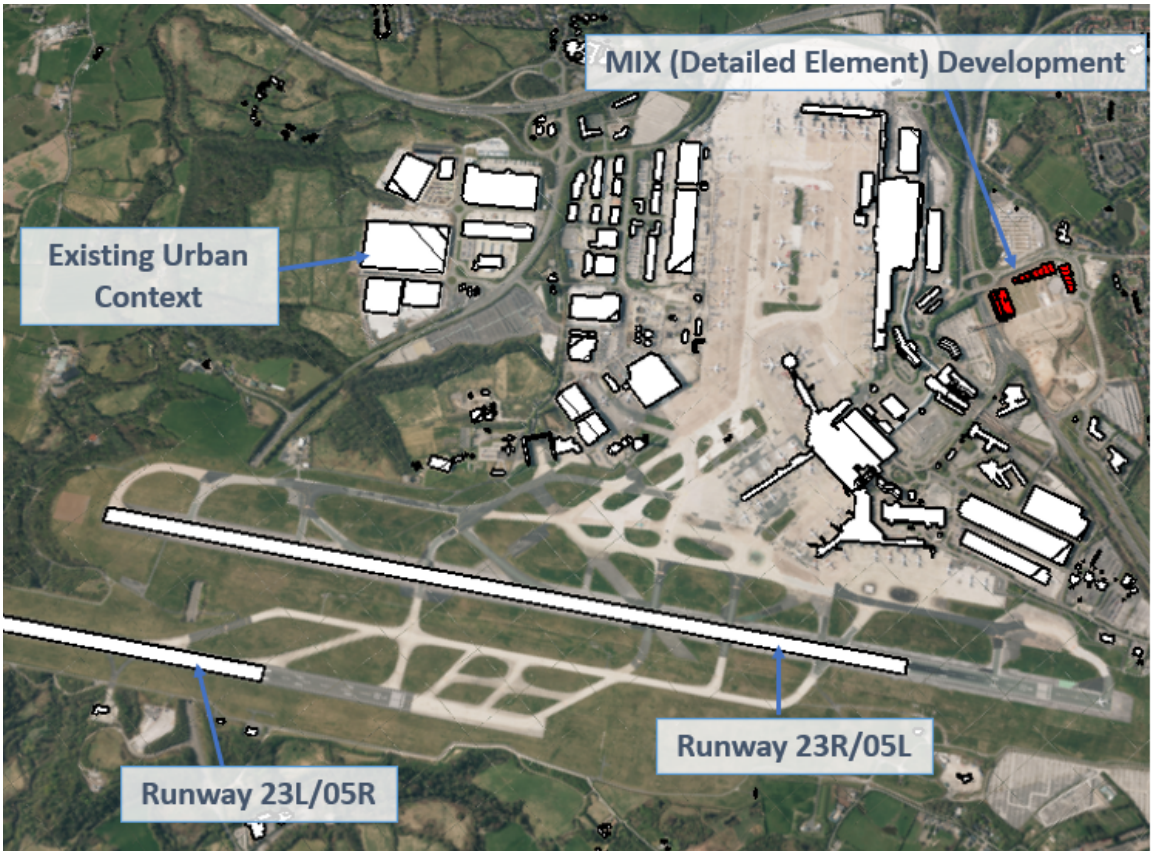


Figure 1: Summary of the CFD Model for the Post-Development Scenario.

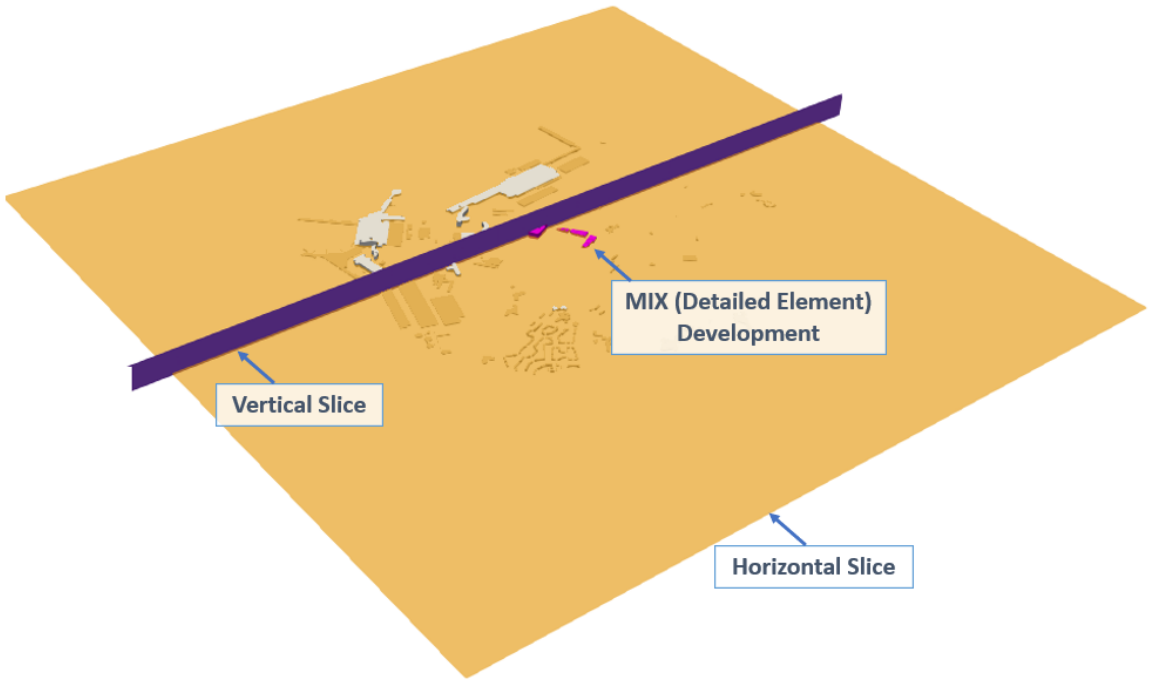


Figure 2: 3D View of the Sampling Locations.

FLOW VELOCITY and TURBULENCE RESULTS FOR RUNWAY 23R/05L (POST-DEVELOPMENT):

Results of velocity and turbulence kinetic energy of the highest wind speed scenario (38.9 Kts) along runway 23R/05L and 10m above the ground are presented in Figures 3 to 18.

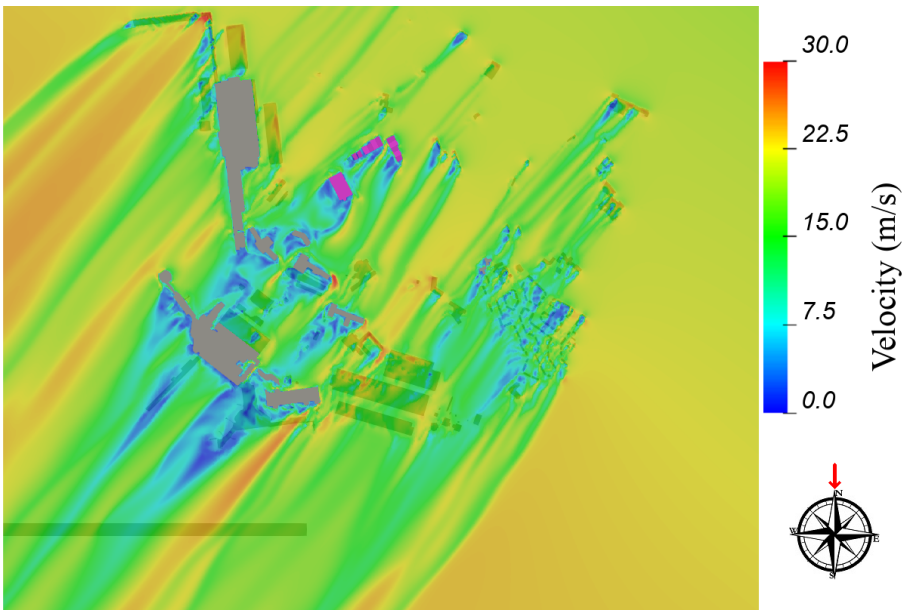


Figure 3: Flow Velocity Results at $Z = 10m$ Above the Ground and Along Runway 23R/05L - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 000.00°.

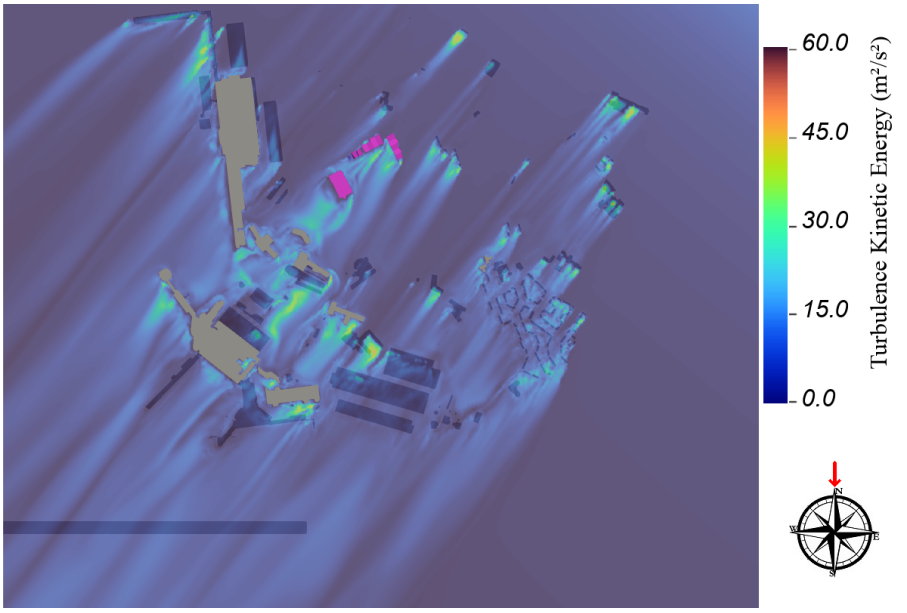


Figure 4: Turbulence Kinetic Energy Results at $Z = 10m$ Above the Ground - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 000.00°.

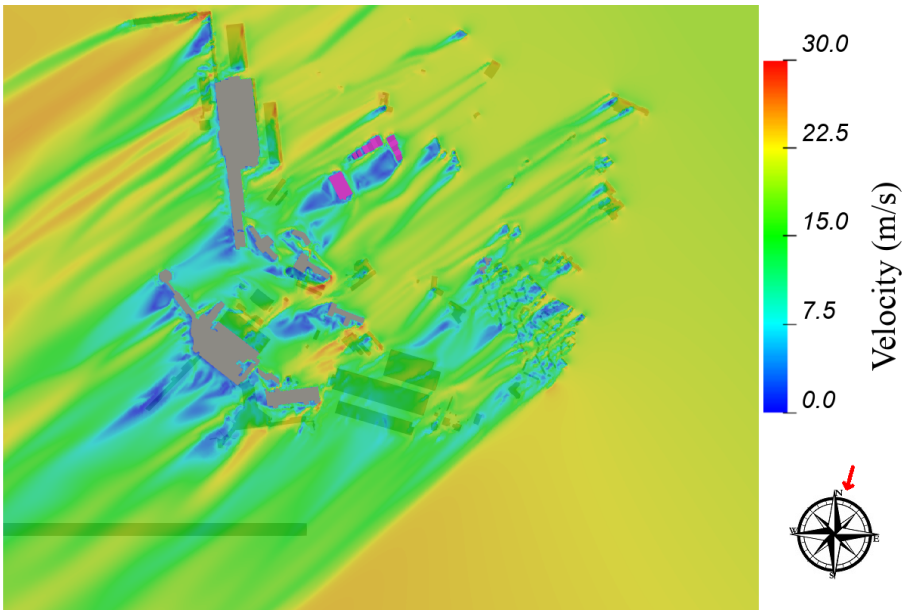


Figure 5: Flow Velocity Results at $Z = 10m$ Above the Ground and Along Runway 23R/05L - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 015.00°.

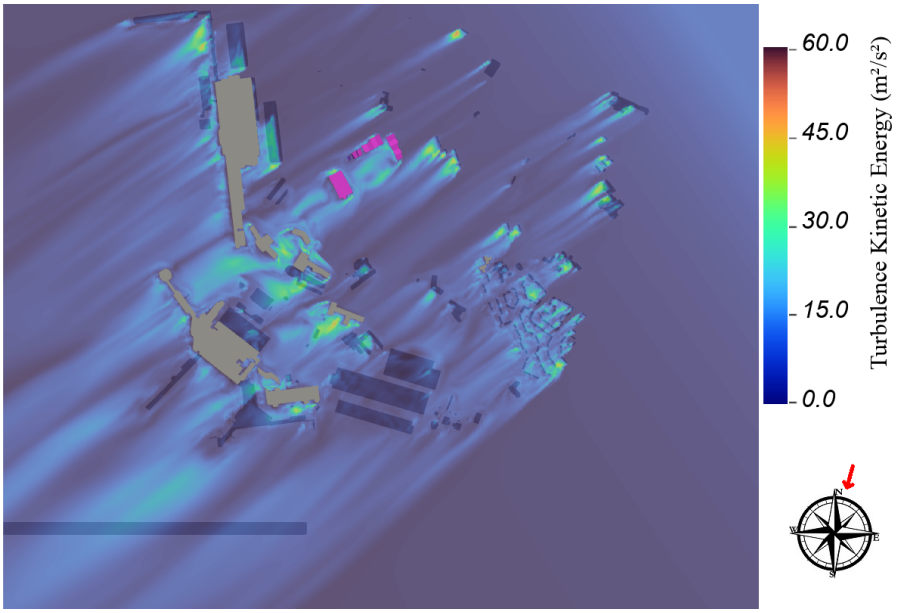


Figure 6: Turbulence Kinetic Energy Results at $Z = 10m$ Above the Ground - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 015.00°.

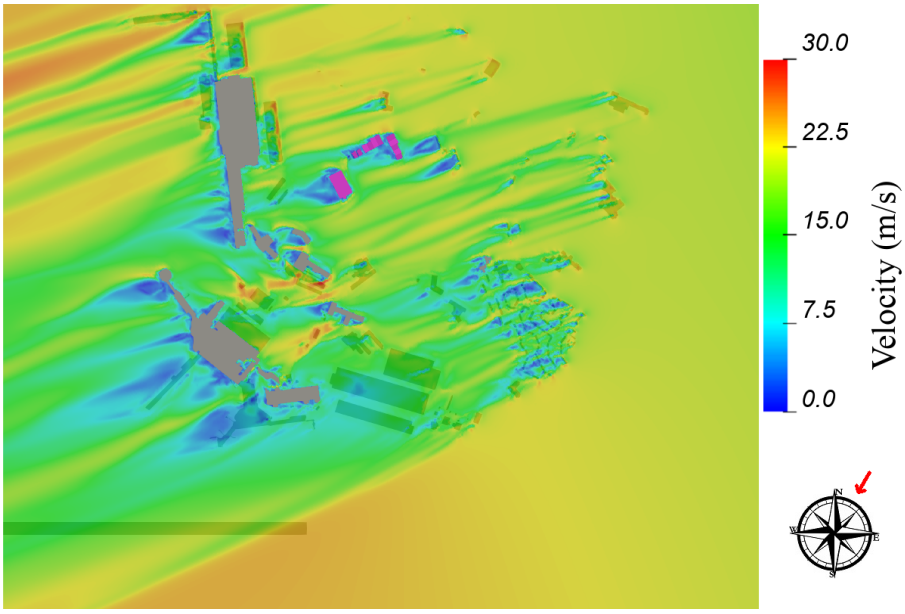


Figure 7: Flow Velocity Results at $Z = 10m$ Above the Ground and Along Runway 23R/05L - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 030.00°.

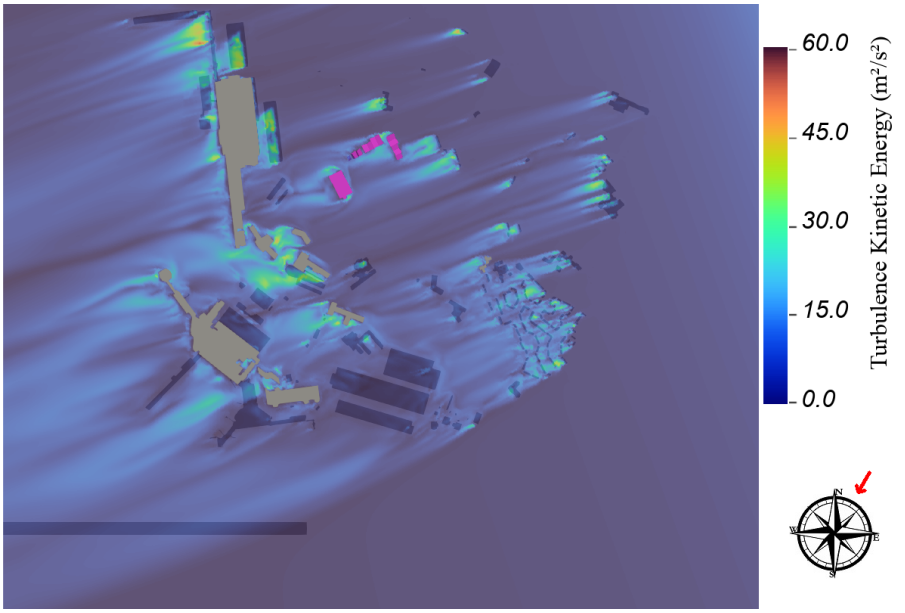


Figure 8: Turbulence Kinetic Energy Results at $Z = 10m$ Above the Ground - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 030.00°.

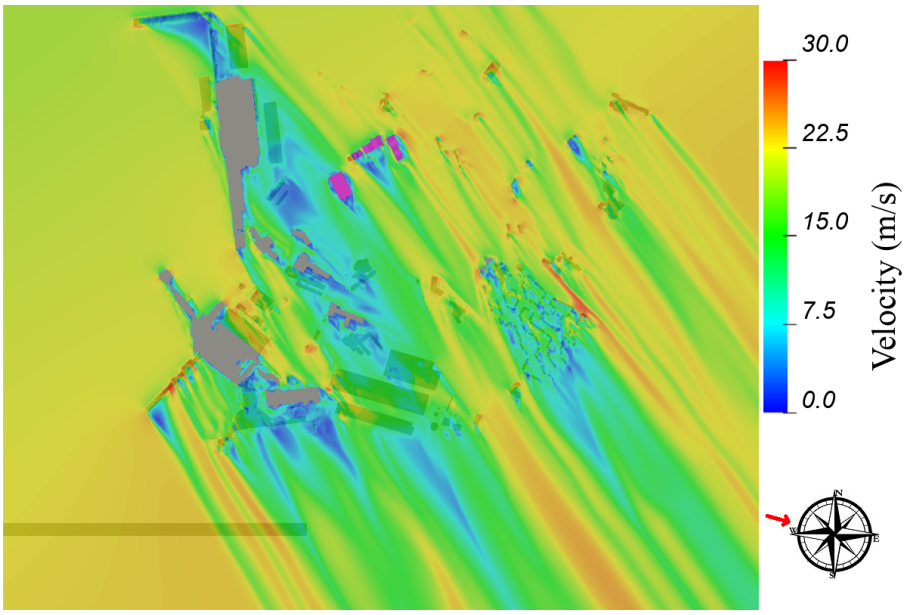


Figure 9: Flow Velocity Results at $Z = 10m$ Above the Ground and Along Runway 23R/05L - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 285.00°.

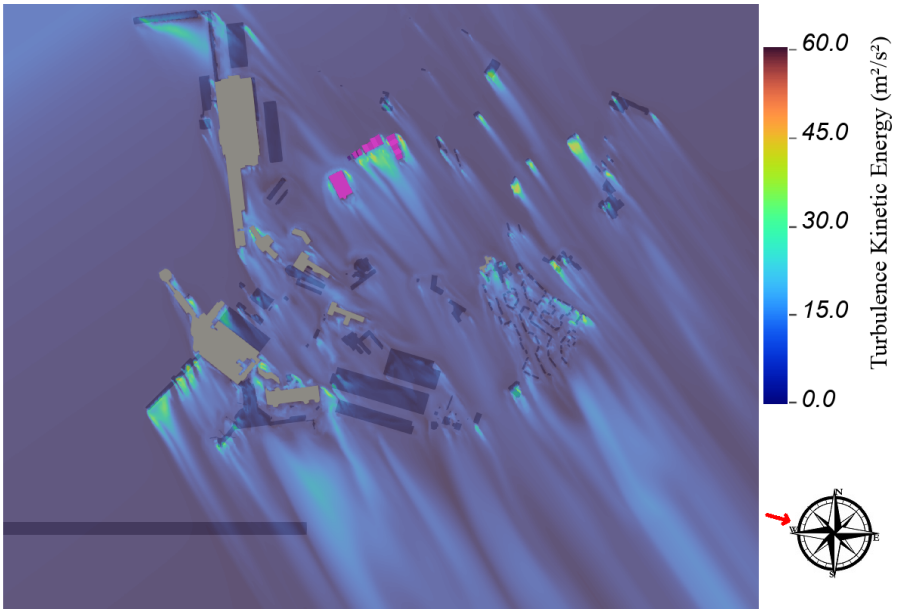


Figure 10: Turbulence Kinetic Energy Results at $Z = 10m$ Above the Ground - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 285.00°.

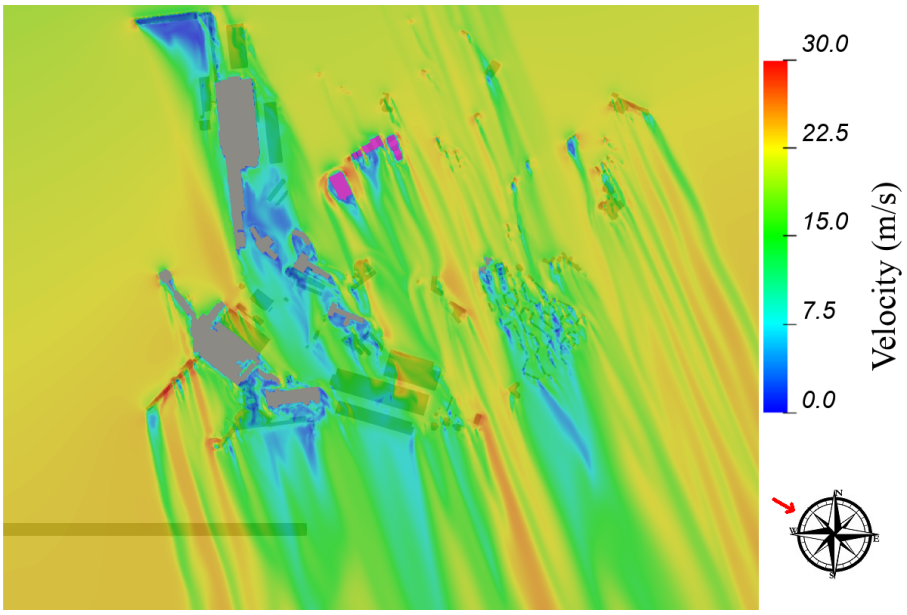


Figure 11: Flow Velocity Results at $Z = 10m$ Above the Ground and Along Runway 23R/05L - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 300.00°.

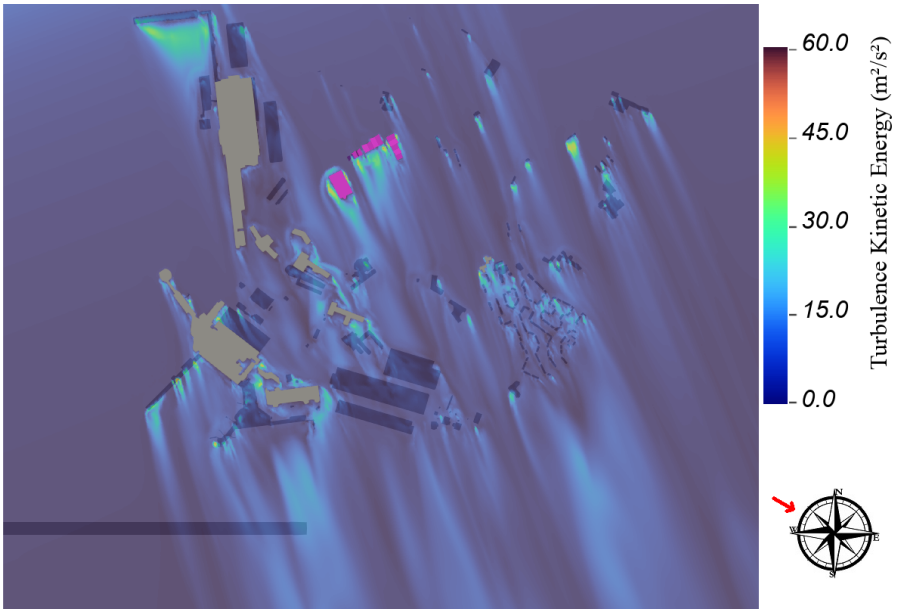


Figure 12: Turbulence Kinetic Energy Results at $Z = 10m$ Above the Ground - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 300.00°.

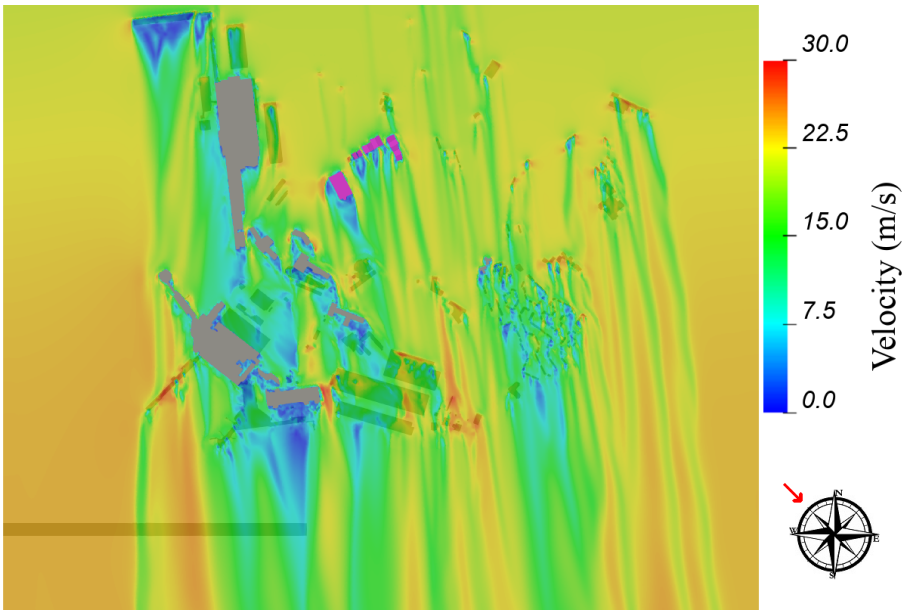


Figure 13: Flow Velocity Results at $Z = 10m$ Above the Ground and Along Runway 23R/05L - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 315.00°.

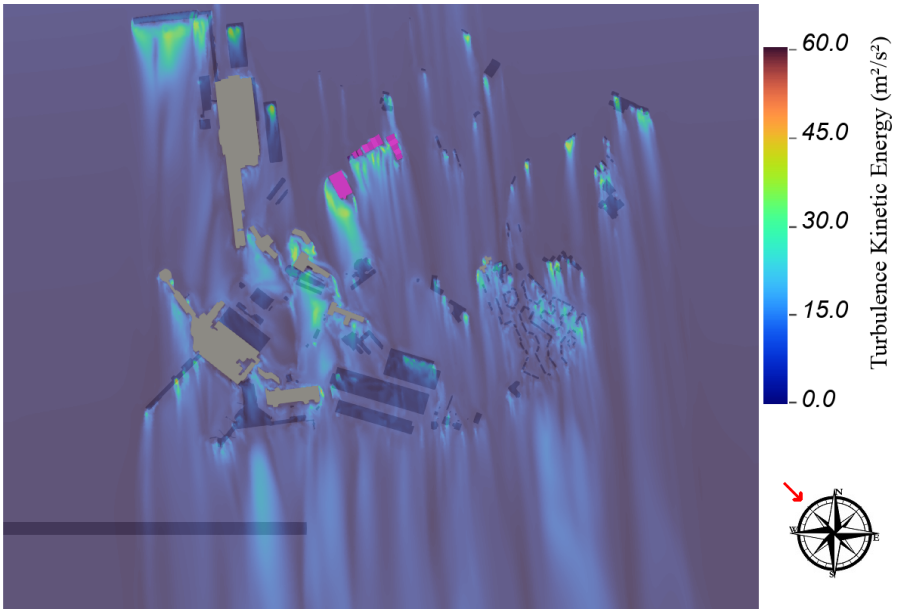


Figure 14: Turbulence Kinetic Energy Results at $Z = 10m$ Above the Ground - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 315.00°.

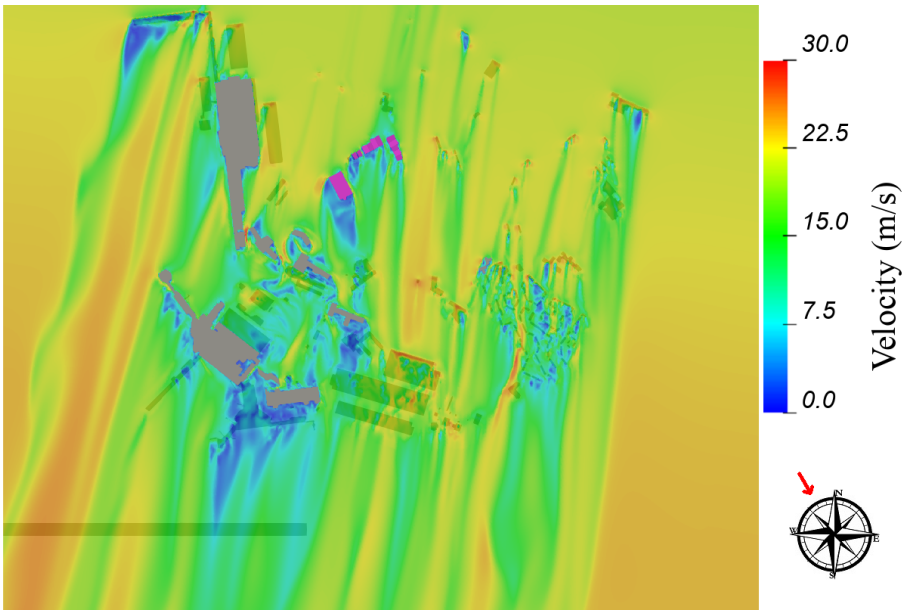


Figure 15: Flow Velocity Results at $Z = 10m$ Above the Ground and Along Runway 23R/05L - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 330.00°.

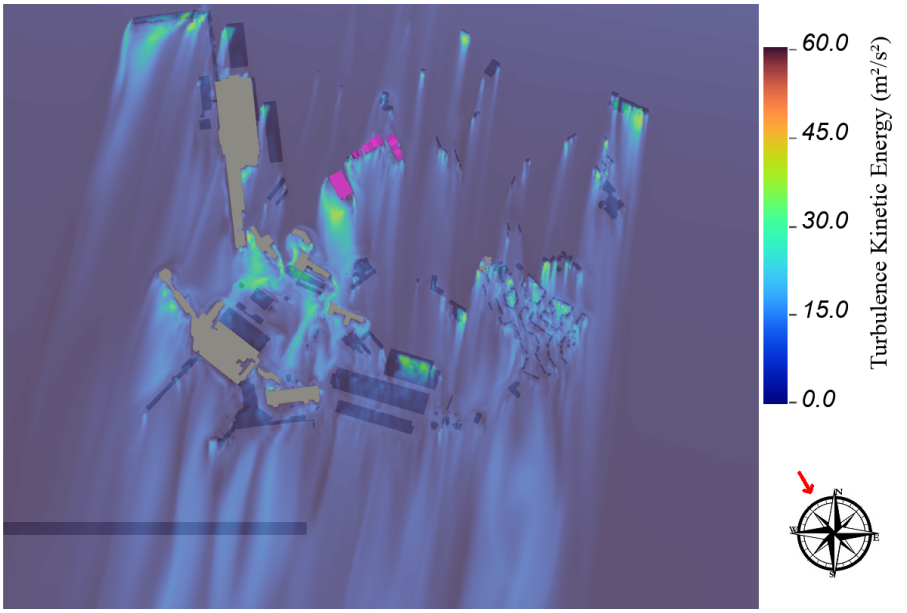


Figure 16: Turbulence Kinetic Energy Results at $Z = 10m$ Above the Ground - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 330.00°.

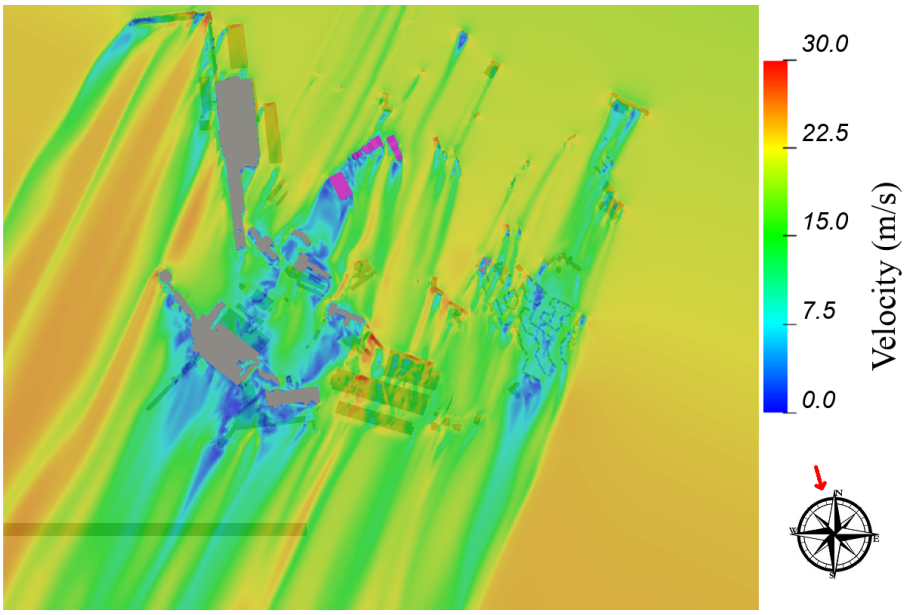


Figure 17: Flow Velocity Results at $Z = 10m$ Above the Ground and Along Runway 23R/05L - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 345.00°.

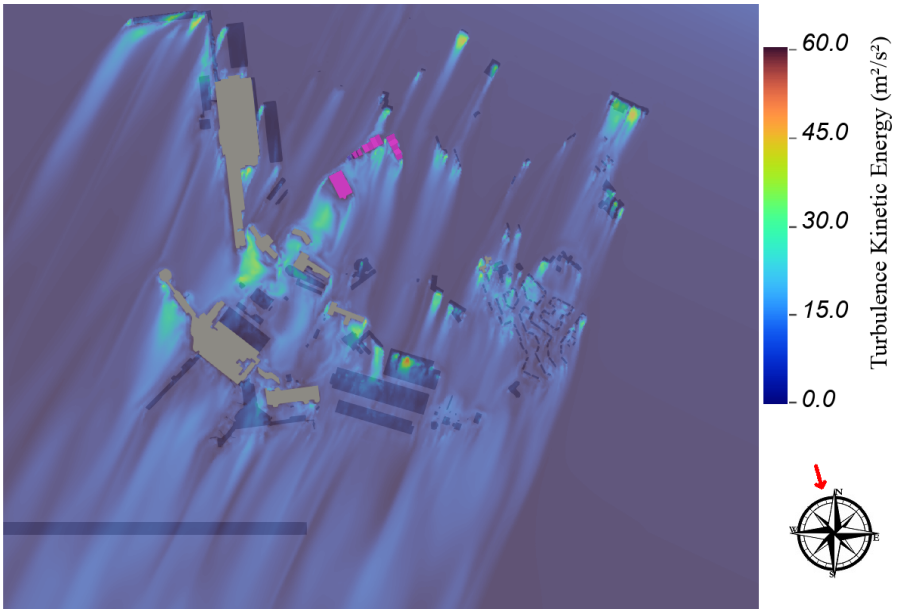


Figure 18: Turbulence Kinetic Energy Results at $Z = 10m$ Above the Ground - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 345.00°.

Figures 19 - 26 shows airflow velocity in a vertical slice along the runway, highlighting the effects of the new buildings on the local wind.

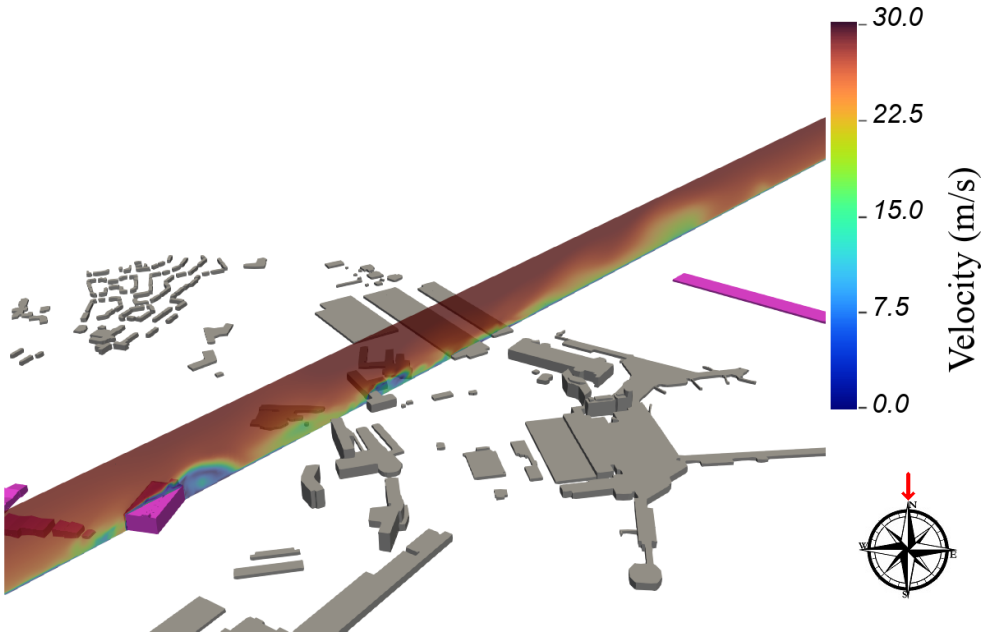


Figure 19: Flow Velocity on a 200m High Slice Across the Proposed Development - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 000.00°.

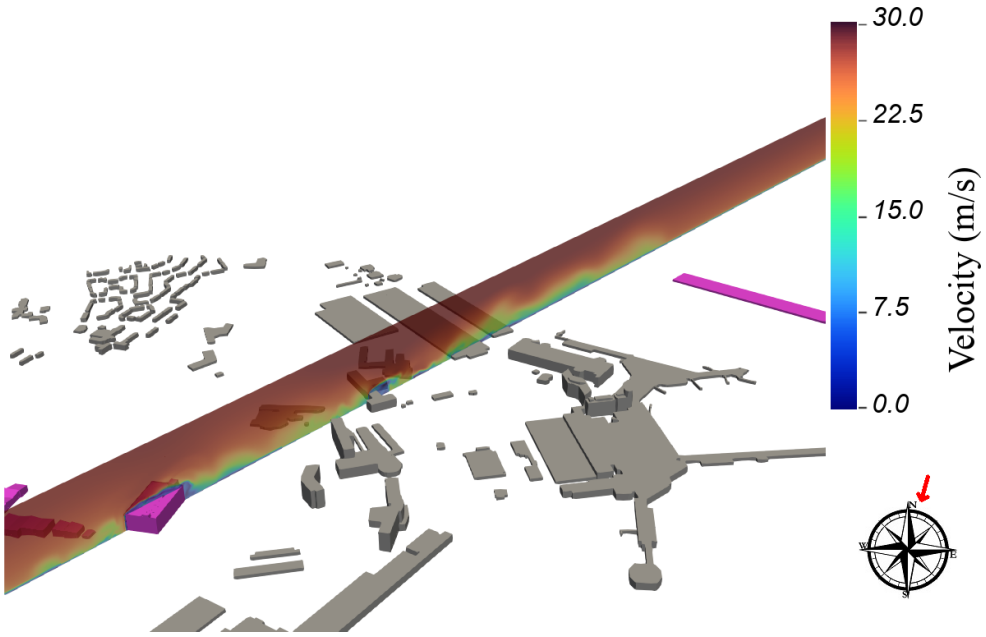


Figure 20: Flow Velocity on a 200m High Slice Across the Proposed Development - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 015.00°.

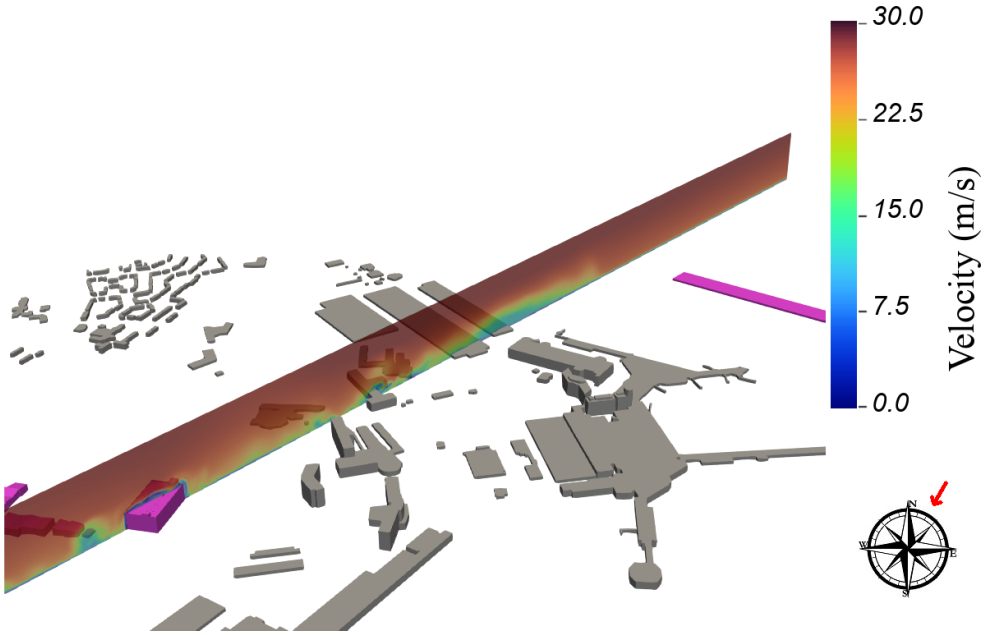


Figure 21: Flow Velocity on a 200m High Slice Across the Proposed Development - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 030.00°.

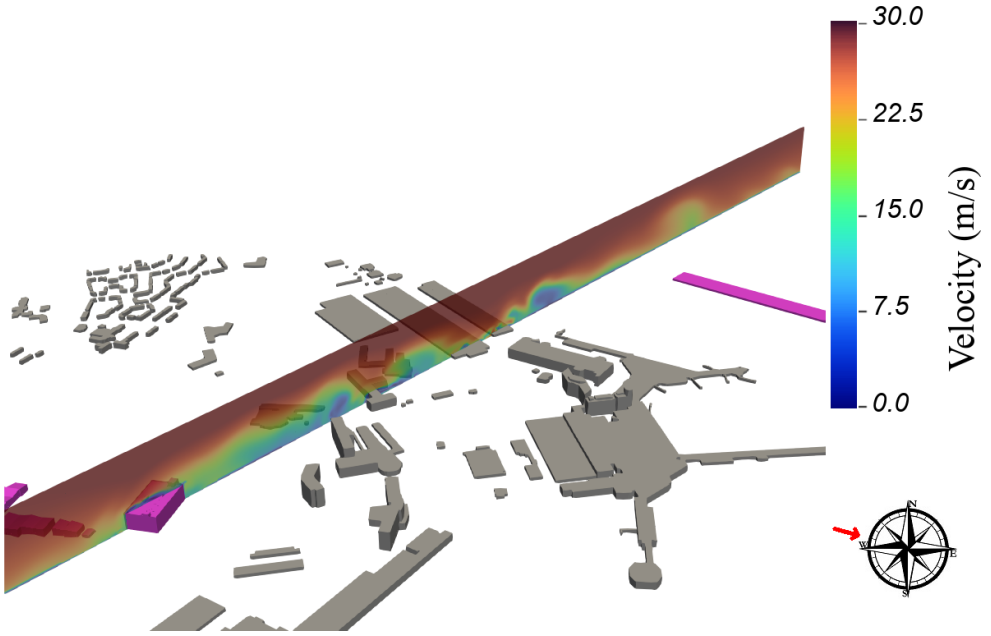


Figure 22: Flow Velocity on a 200m High Slice Across the Proposed Development - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 285.00°.

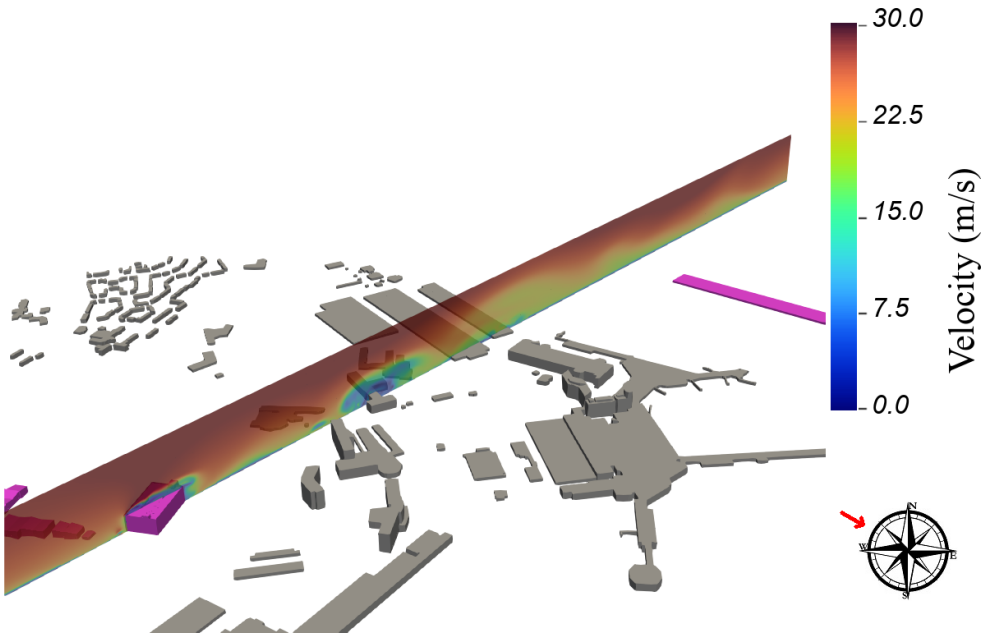


Figure 23: Flow Velocity on a 200m High Slice Across the Proposed Development - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 300.00°.

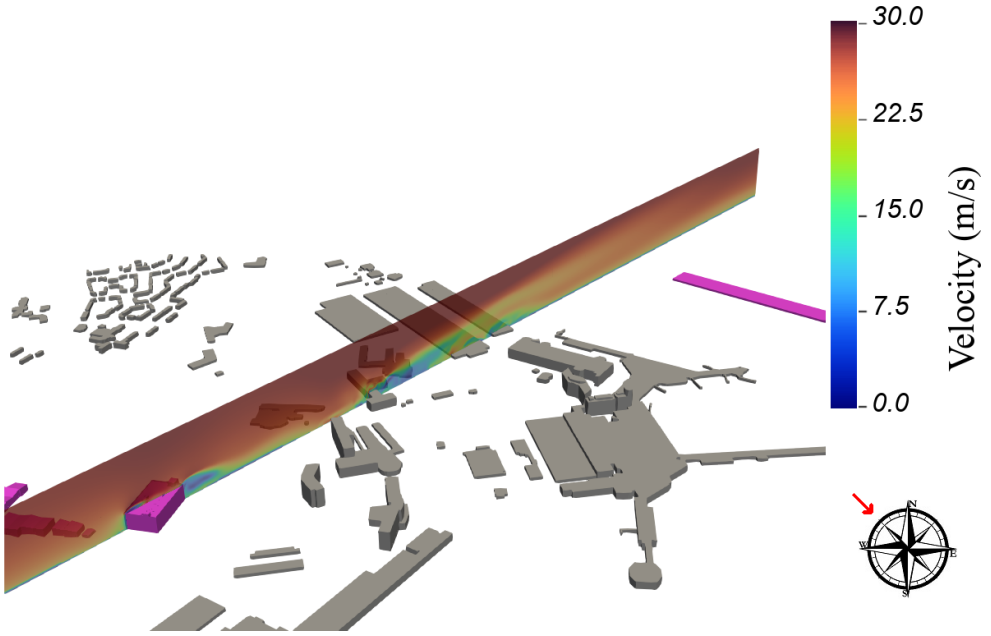


Figure 24: Flow Velocity on a 200m High Slice Across the Proposed Development - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 315.00°.

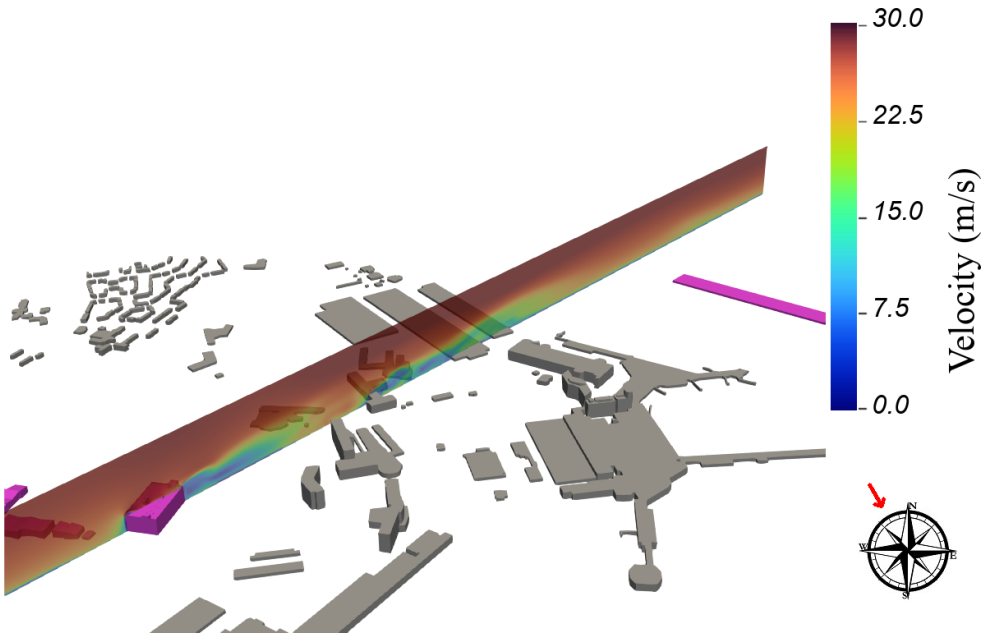


Figure 25: Flow Velocity on a 200m High Slice Across the Proposed Development - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 330.00°.

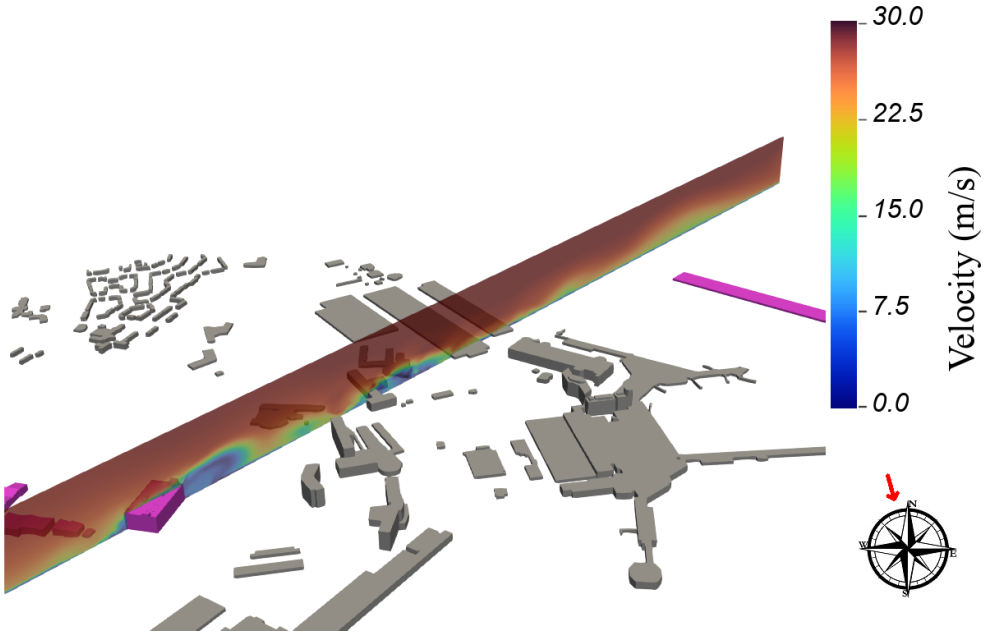


Figure 26: Flow Velocity on a 200m High Slice Across the Proposed Development - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 345.00°.

POSSIBLE LANDING SCENARIOS FOR RUNWAY 23R/05L:

In the wind shear and turbulence modelling study, wind speed and turbulence must be reported at the aircraft trajectory. The approaching angle for landing is usually between 2.7° and 4°, with 3° considered as the average.

In this study, 3° and 4° landing/takeoff degrees are analysed. It is assumed that the aircraft glides down with constant speed and its track angel is either 3° or 4°.

Six possible paths per each landing degrees are considered. Each path starts at 900m far from touch down zone and continues to ground level. Fluid velocity and turbulence values are collected along each path. In addition, every 100m across each possible aircraft trajectory, data sampling were performed per each landing path. The sample values are interpolated from values between the cellpoints. Landing paths and horizontal sampling lines are shown in Figures from 27 to 29.

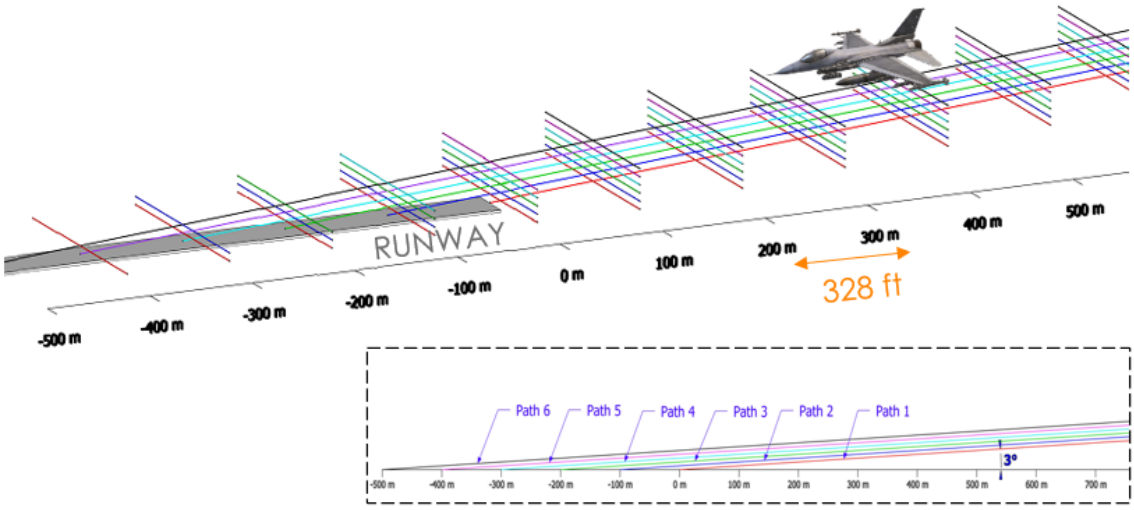


Figure 27: Landing Scenarios and Sampling Lines at 3° and 4° Approaching Angle.

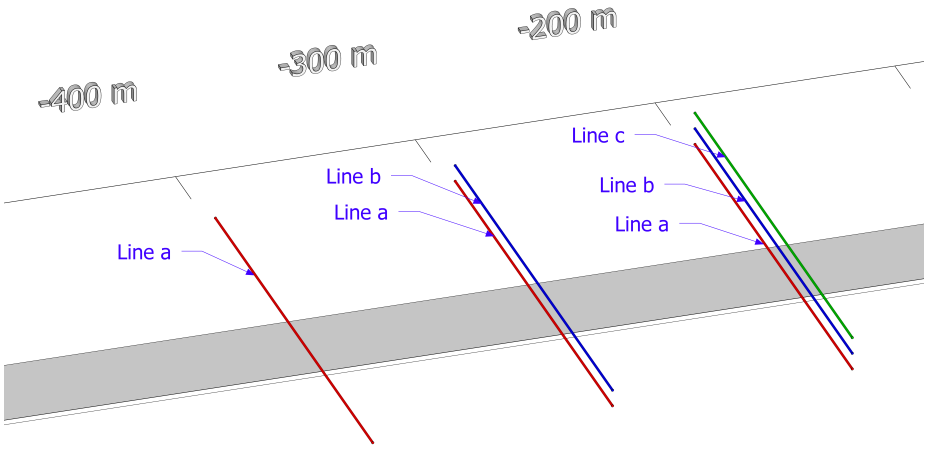


Figure 28: Sampling Lines Perpendicular to Possible Critical Aircraft Trajectories at 3° or 4° Approaching Angle.

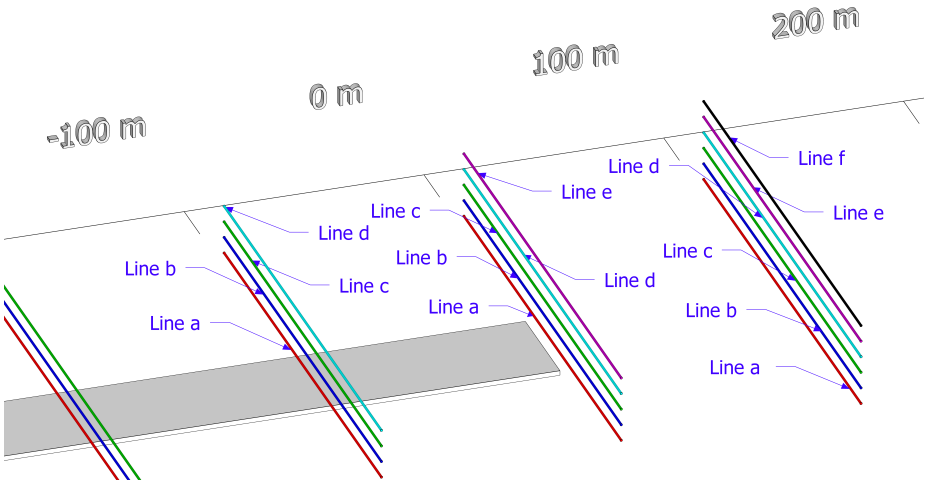


Figure 29: Sampling Lines Perpendicular to a Possible Critical Aircraft Trajectories at 3° or 4° Approaching Angle.

Reference Wind Speed at $10m$ Above Ground = 20m/s
Wind Direction = 0°

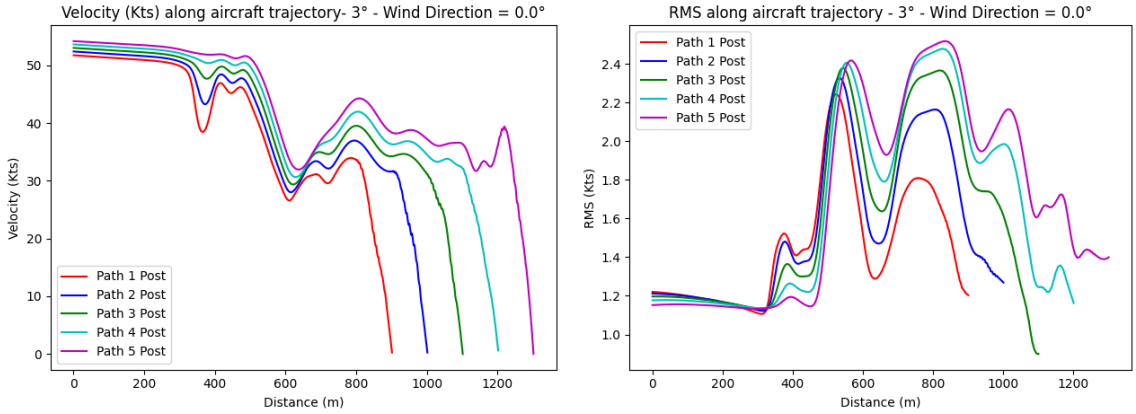


Figure 30: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 0°

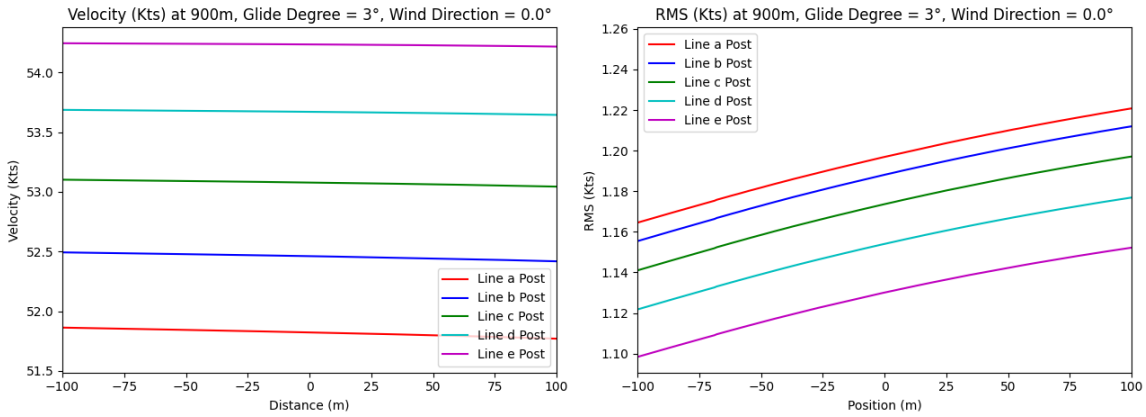


Figure 31: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 0°

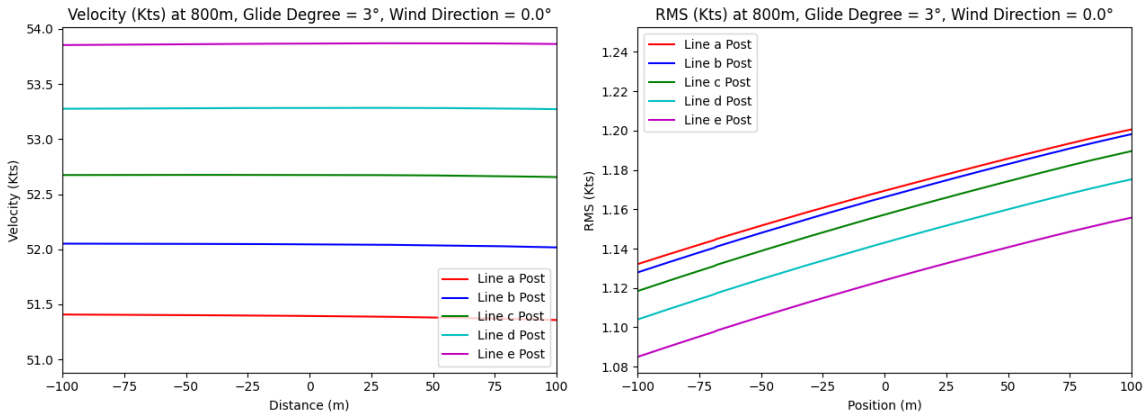


Figure 32: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 0°

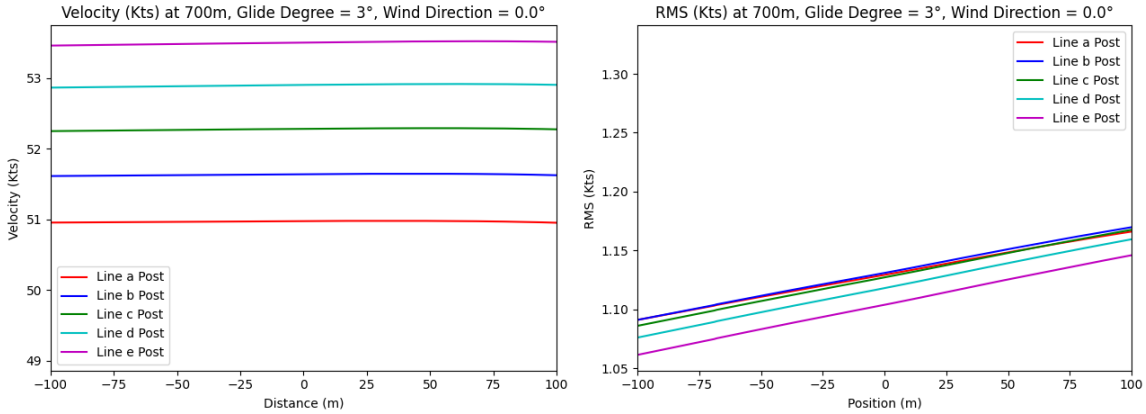


Figure 33: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 0°

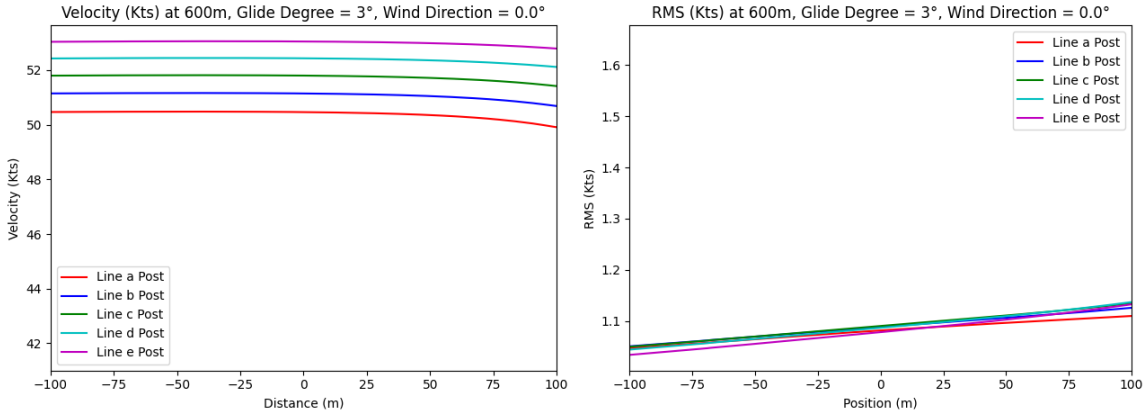


Figure 34: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 0°

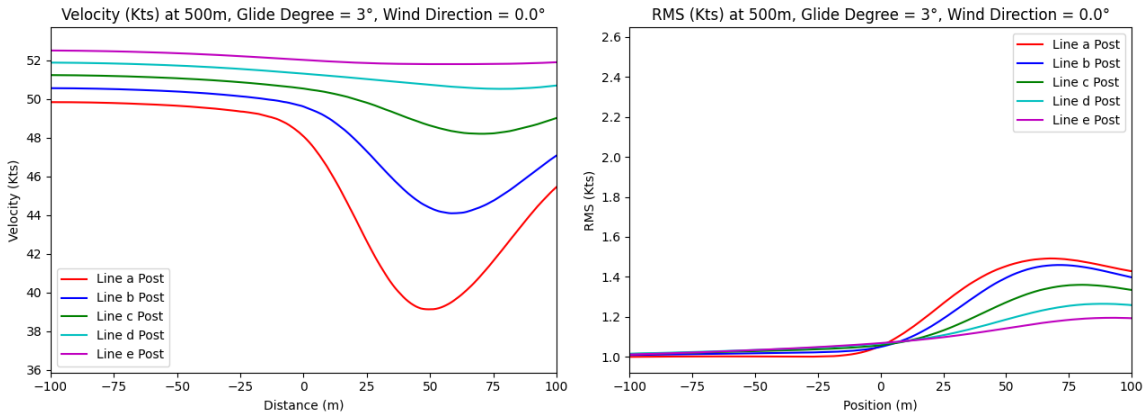


Figure 35: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 0°

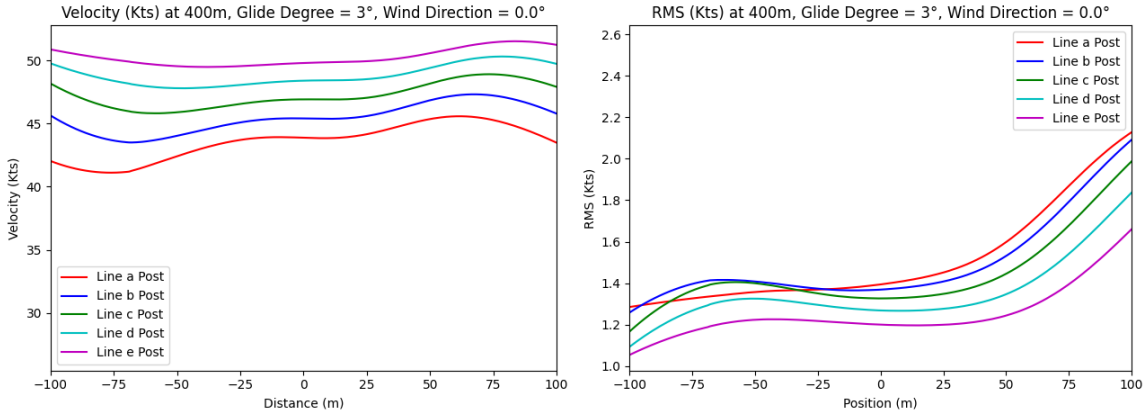


Figure 36: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 0°

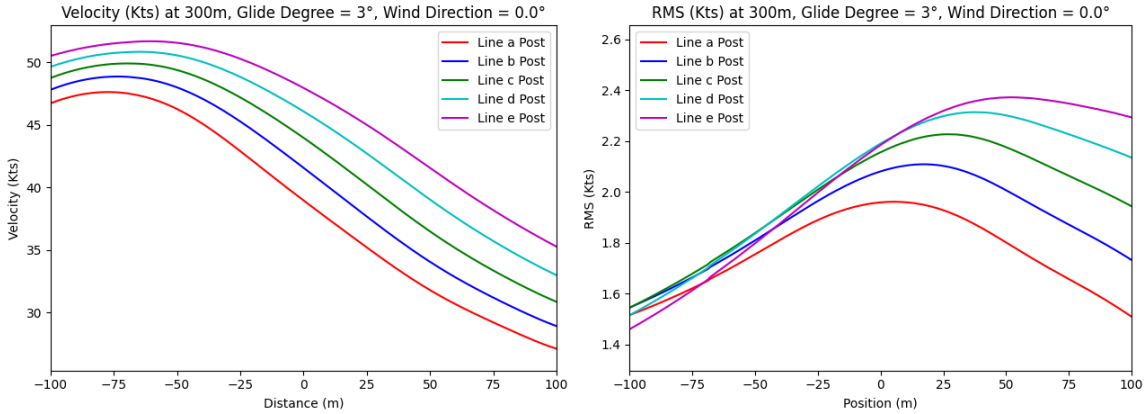


Figure 37: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 0°

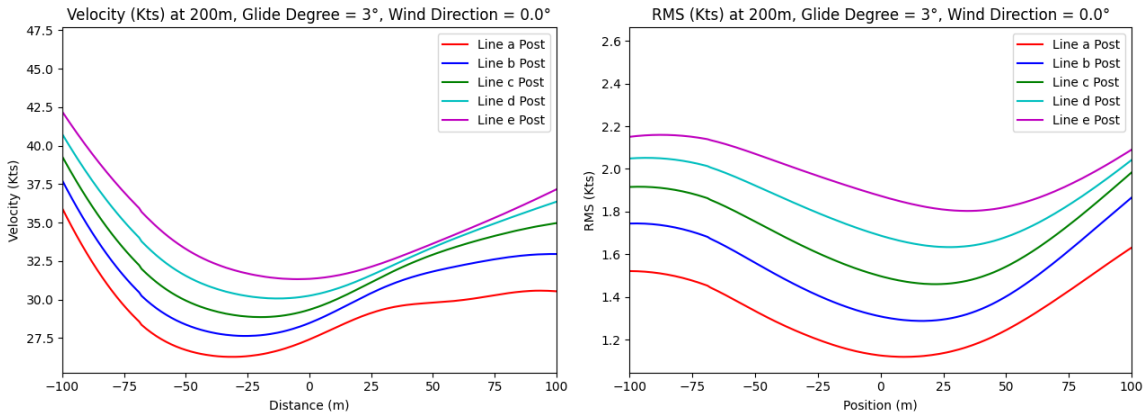


Figure 38: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 0°

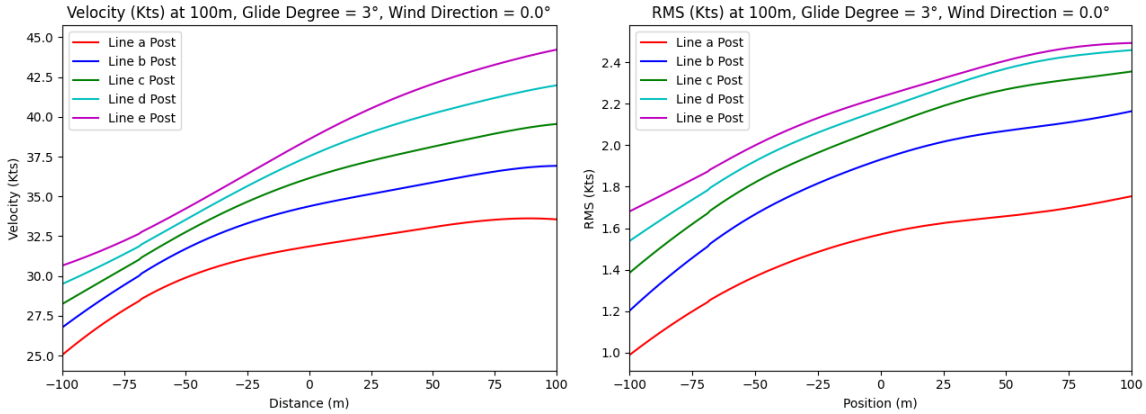


Figure 39: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 0°

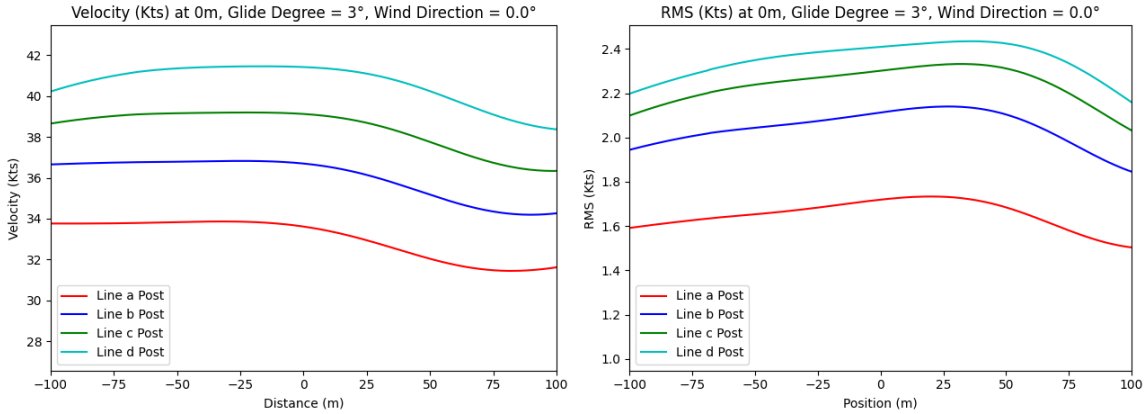


Figure 40: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 0°

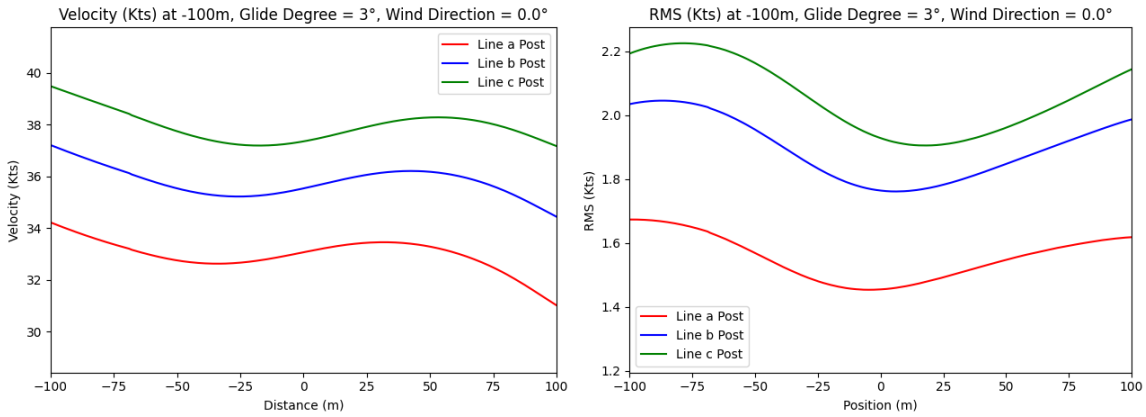


Figure 41: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 0°

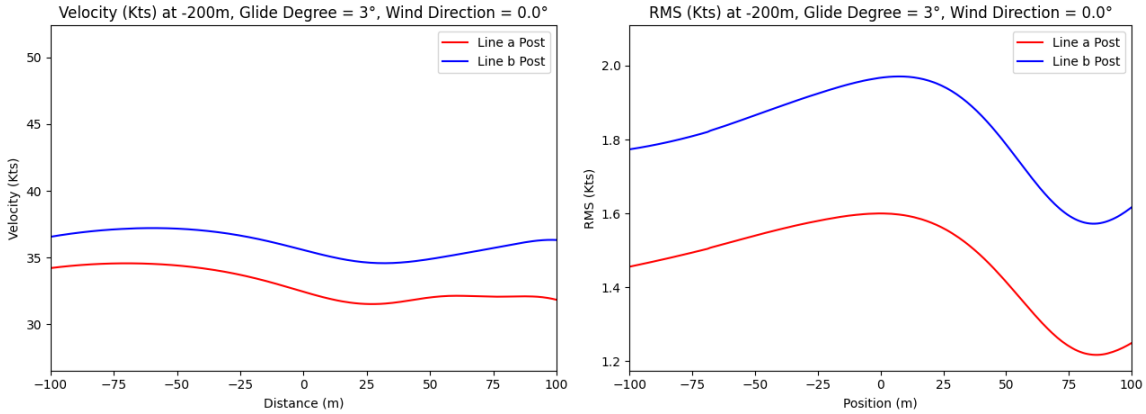


Figure 42: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 0°

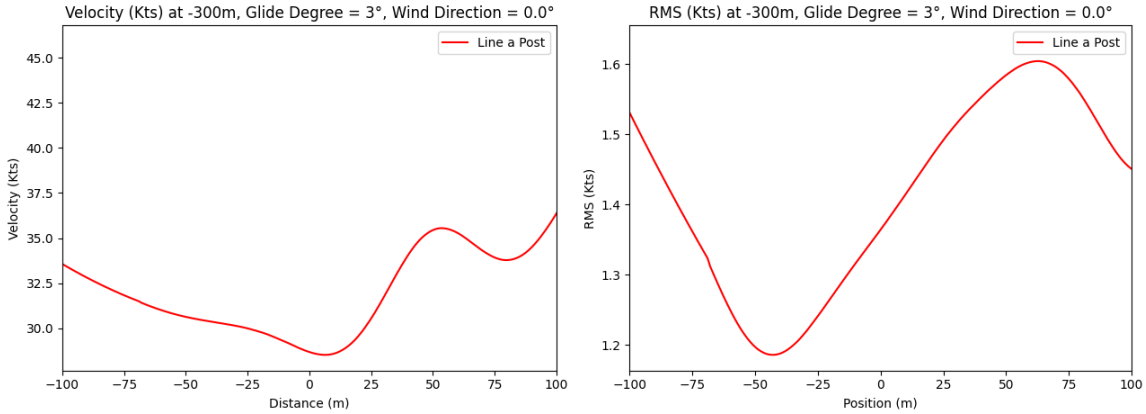


Figure 43: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 0°

Velocity magnitude and turbulence deviation values of CFD models along the runway centerline between chainages $-500m$ to $900m$, consistent with assessment area according to National Airport Safeguarding Framework (NASF), and up to a height of $60m$ above ground level for wind direction $0°$ with 20 m/s approaching speed are shown in Tables 1 and 2.

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	43.66	55.59	55.51	53.99	52.04	51.47	53.4	41.91	45.75	54.45	53.77	53.75	53.81	53.57	53.35
55	42.1	55.1	54.95	53.03	51.01	50.25	52.48	40.56	43.61	53.8	53.15	53.15	53.23	52.99	52.76
50	40.69	54.59	54.21	51.91	49.88	48.9	51.45	39.43	41.43	53.02	52.43	52.51	52.64	52.39	52.15
45	39.43	54.05	53.16	50.61	48.62	47.4	50.3	38.56	39.19	52.02	51.49	51.86	52.03	51.77	51.52
40	38.34	53.46	51.65	49.11	47.2	45.75	48.98	37.95	36.92	50.78	50.17	51.18	51.4	51.13	50.87
35	37.44	52.79	49.41	47.42	45.58	43.94	47.47	37.49	34.66	49.25	48.42	50.46	50.75	50.47	50.2
30	36.71	51.99	46.25	45.54	43.71	42.01	45.72	36.98	32.5	47.42	46.58	49.7	50.07	49.78	49.5
25	36.16	51	42.72	43.48	41.61	40.02	43.74	36.11	30.5	45.34	45.16	48.85	49.34	49.04	48.75
20	35.76	49.75	39.78	41.25	39.32	38.03	41.57	34.67	28.66	43.12	44.17	47.85	48.53	48.23	47.93
15	35.49	48.17	37.78	38.86	36.88	36.08	39.23	32.69	26.93	40.93	43.22	46.58	47.56	47.26	46.96
10	35.25	46.17	36.74	36.11	34.25	34.07	36.69	30.35	25.2	38.81	41.85	44.78	46.25	45.96	45.66
5	34.6	43.1	36.32	31.91	30.91	31.47	33.4	27.69	23.15	36.45	39.22	41.75	43.95	43.68	43.39

Table 1: Wind Speed in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 0°

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	3.47863	1.31961	1.04299	1.68567	1.89561	1.94167	2.13633	2.52399	2.39469	1.09553	1.09631	1.11461	1.13728	1.1662	1.18774
55	3.52925	1.41442	1.13937	1.80396	1.92997	2.02538	2.20655	2.45074	2.45817	1.21198	1.12489	1.12775	1.15284	1.1826	1.20476
50	3.53573	1.50383	1.27135	1.92821	1.97096	2.10481	2.27145	2.36467	2.47902	1.36446	1.16286	1.1354	1.16357	1.19398	1.21657
45	3.50029	1.58729	1.44375	2.04771	2.02167	2.17671	2.33368	2.27608	2.45304	1.53801	1.21575	1.13718	1.16911	1.19991	1.22263
40	3.42613	1.66588	1.6512	2.14615	2.0816	2.23485	2.39388	2.19496	2.37753	1.71547	1.28427	1.13292	1.16922	1.20005	1.22254
35	3.31659	1.74083	1.87627	2.20445	2.14436	2.26986	2.4482	2.12694	2.25473	1.87999	1.35653	1.12252	1.16374	1.19414	1.216
30	3.17444	1.81211	2.07977	2.20509	2.19731	2.27122	2.48627	2.07288	2.09338	2.01457	1.40982	1.10598	1.15252	1.18194	1.2027
25	3.00089	1.87624	2.19846	2.13768	2.22356	2.23081	2.49181	2.02685	1.90568	2.10222	1.42963	1.08362	1.13546	1.16324	1.1824
20	2.79404	1.92334	2.18896	2.00331	2.20549	2.14567	2.44682	1.96465	1.70166	2.12289	1.42142	1.05648	1.11254	1.13787	1.15481
15	2.54487	1.93512	2.05476	1.81604	2.12743	2.01523	2.33641	1.83874	1.4873	2.05867	1.39874	1.0273	1.08422	1.10597	1.11989
10	2.22416	1.87997	1.80119	1.59325	1.96702	1.82755	2.14134	1.60123	1.2635	1.89108	1.36401	1.00142	1.05272	1.06909	1.07864
5	1.75388	1.62987	1.42291	1.2243	1.59326	1.48203	1.726	1.23253	0.98328	1.53996	1.23159	0.96935	1.01145	1.01829	1.02107

Table 2: Turbulence deviation or RMS in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 0°

Wind Direction = 15°

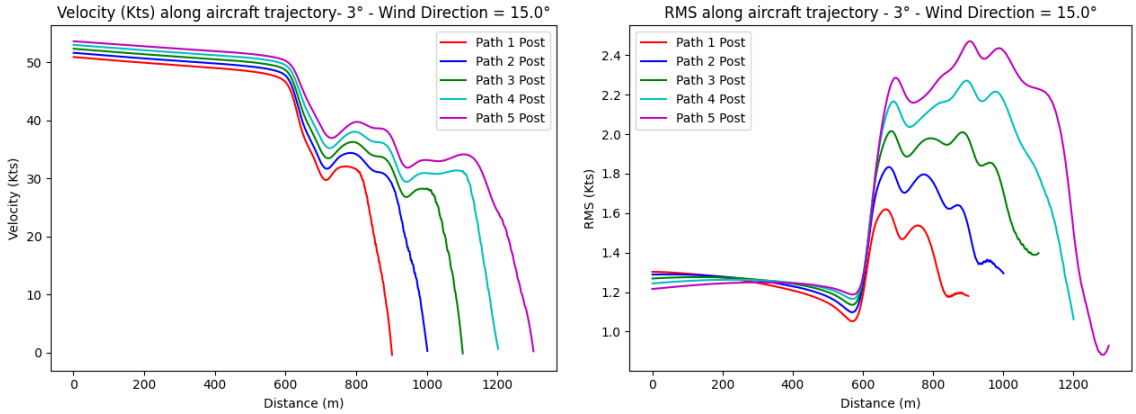


Figure 44: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 15°

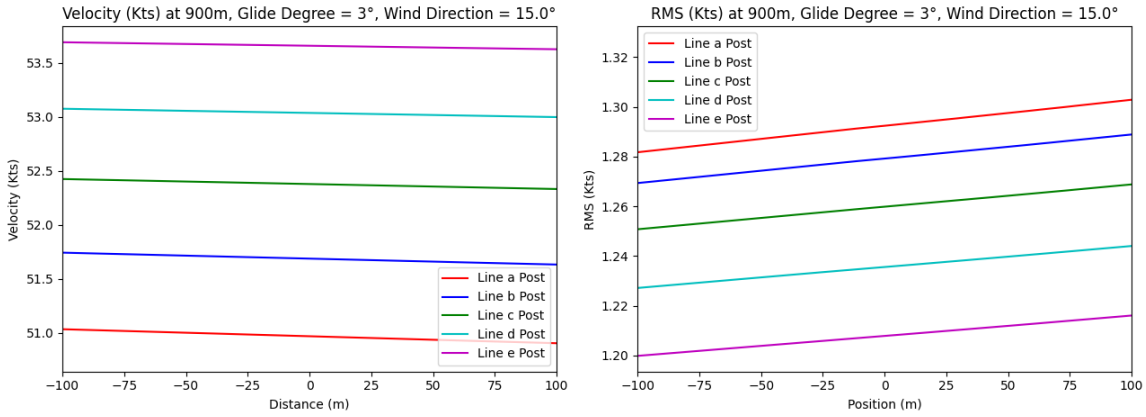


Figure 45: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 15°

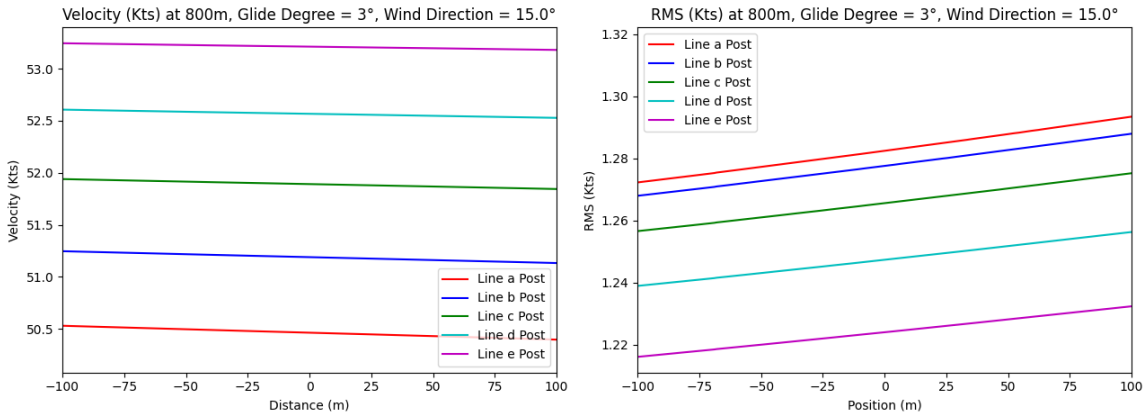


Figure 46: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 15°

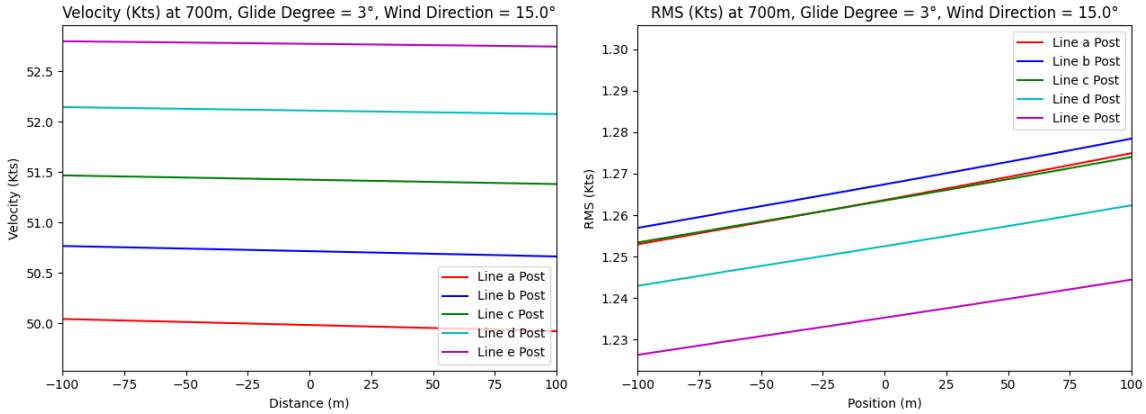


Figure 47: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 15°

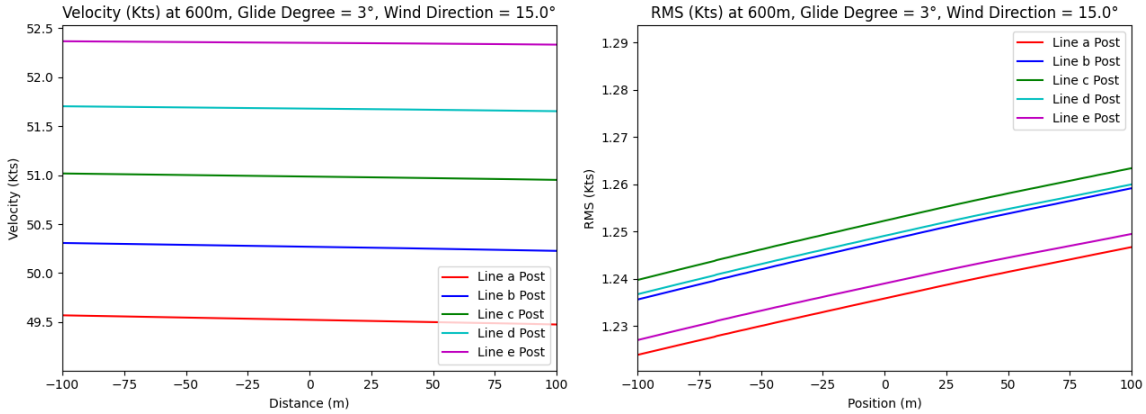


Figure 48: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 15°

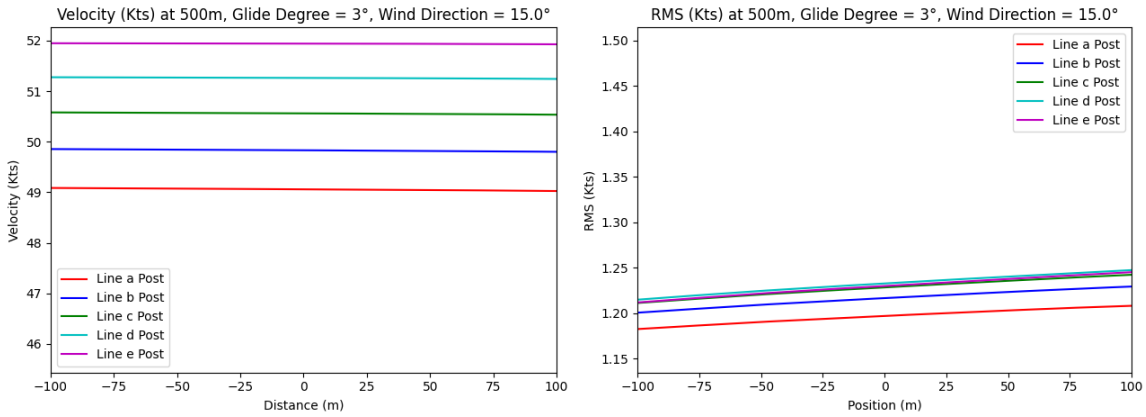


Figure 49: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 15°

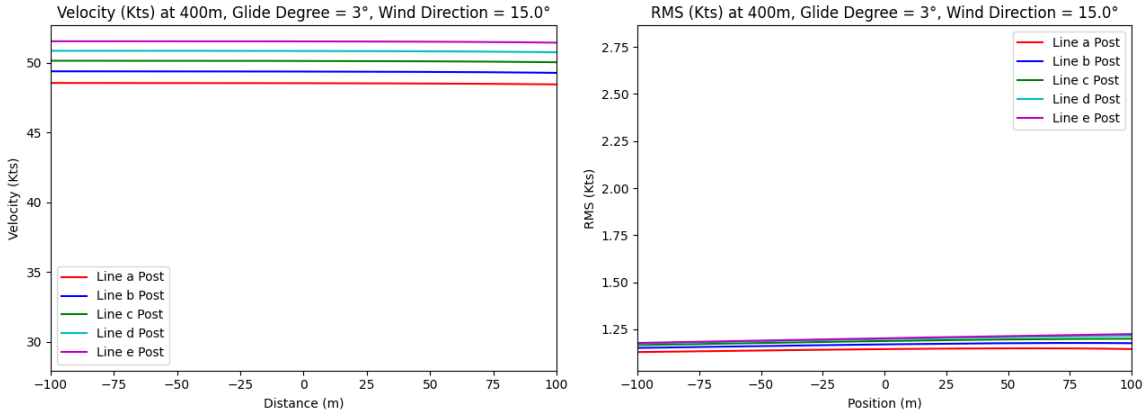


Figure 50: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 15°

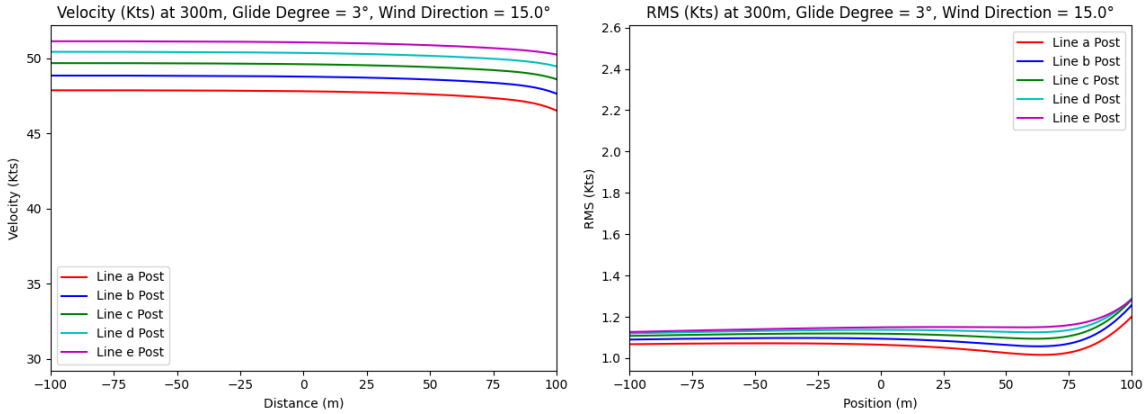


Figure 51: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 15°

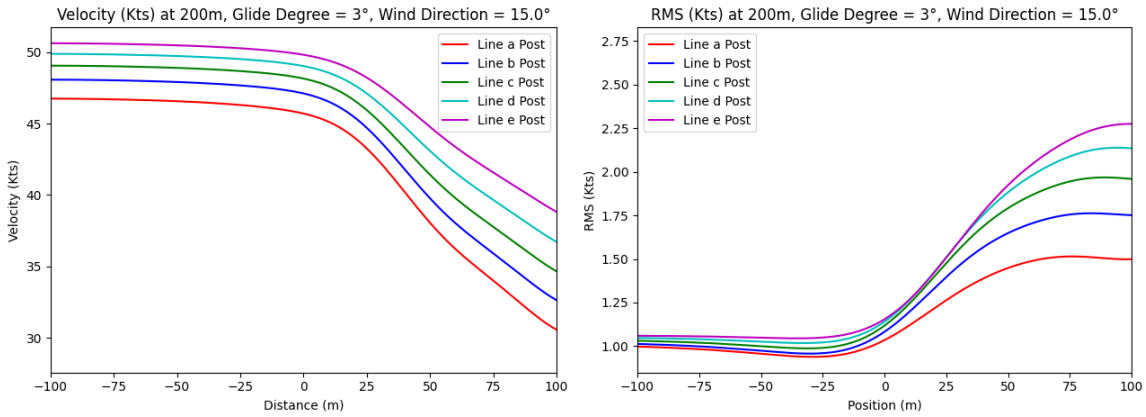


Figure 52: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 15°

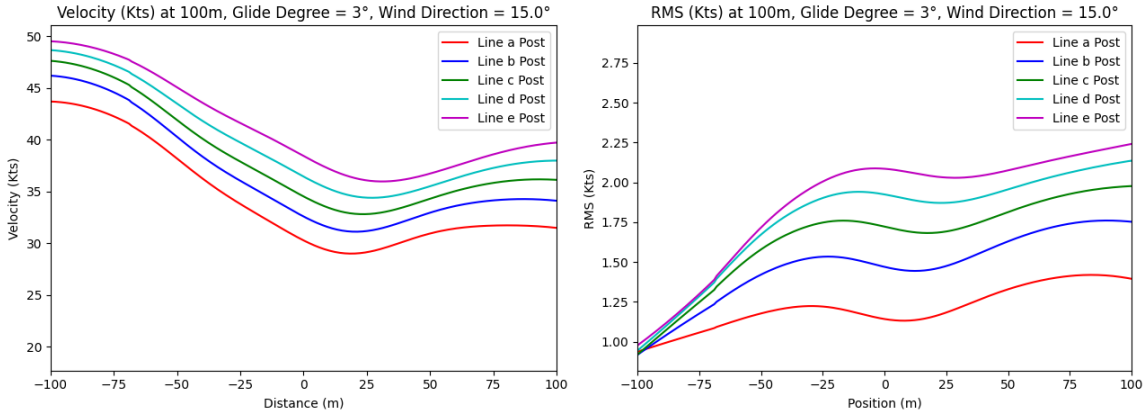


Figure 53: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 15°

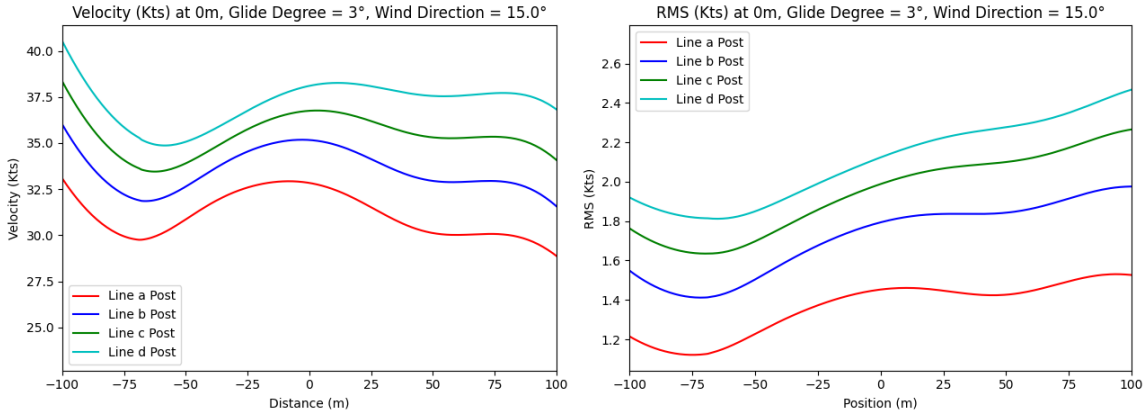


Figure 54: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 15°

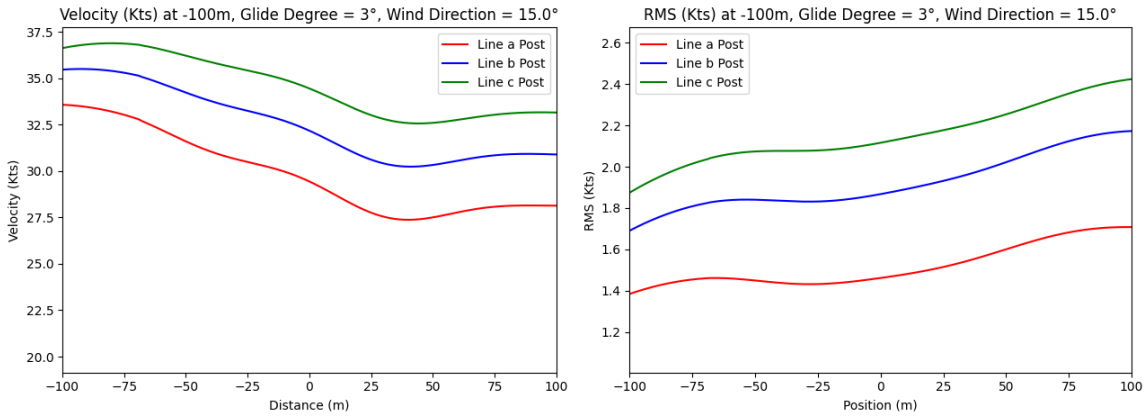


Figure 55: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 15°

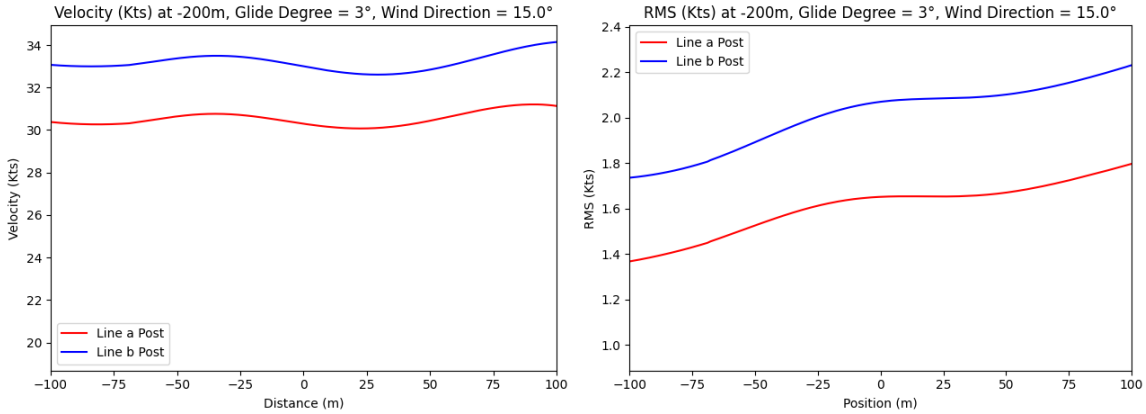


Figure 56: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 15°

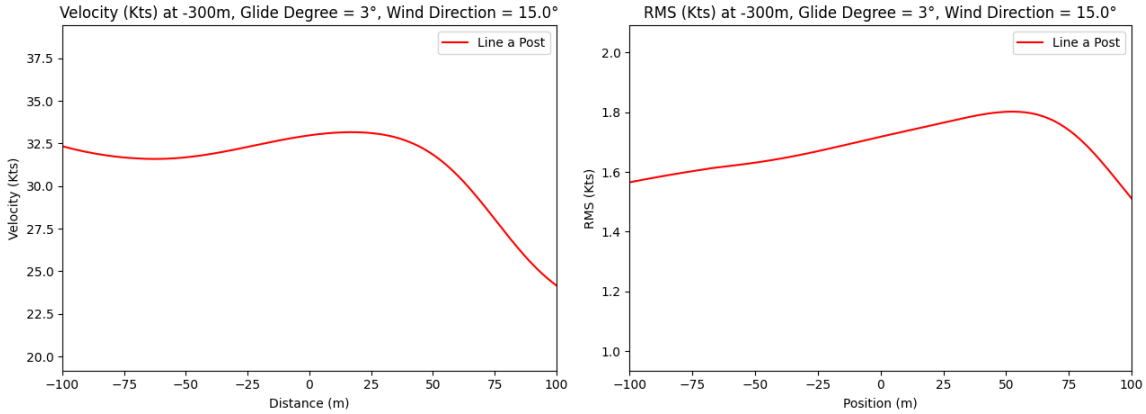


Figure 57: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 15°

Velocity magnitude and turbulence deviation values of CFD models along the runway centerline between chainages $-500m$ to $900m$, consistent with assessment area according to National Airport Safeguarding Framework (NASF), and up to a height of $60m$ above ground level for wind direction $15°$ with 20 m/s approaching speed are shown in Tables 3 and 4.

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	43.45	42.85	52.75	50.74	51.4	52.25	48.69	49.72	53.39	53.7	53.54	53.3	53.07	52.86	52.67
55	42.46	39.68	51.53	49.26	49.69	51.02	47.4	48.05	52.75	53.1	52.94	52.69	52.44	52.22	52.02
50	41.69	36.76	50.14	47.73	47.78	49.63	46.15	46.27	52.1	52.49	52.32	52.05	51.79	51.55	51.33
45	41.12	34.31	48.55	46.16	45.71	48.05	44.92	44.38	51.42	51.86	51.67	51.39	51.11	50.86	50.63
40	40.66	32.34	46.73	44.57	43.57	46.23	43.67	42.41	50.73	51.21	51.01	50.71	50.42	50.15	49.9
35	40.21	30.74	44.65	42.96	41.42	44.15	42.35	40.39	50.01	50.54	50.32	50.01	49.7	49.41	49.14
30	39.63	29.44	42.22	41.31	39.27	41.78	40.93	38.34	49.24	49.85	49.61	49.28	48.95	48.65	48.36
25	38.82	28.4	39.25	39.62	37.12	39.16	39.38	36.31	48.41	49.11	48.86	48.51	48.17	47.84	47.54
20	37.72	27.58	35.63	37.88	34.99	36.46	37.69	34.32	47.47	48.3	48.03	47.67	47.31	46.97	46.65
15	36.3	26.91	31.65	36.03	32.88	33.88	35.9	32.36	46.36	47.34	47.06	46.69	46.32	45.97	45.64
10	34.47	26.23	27.8	33.93	30.7	31.48	33.95	30.3	44.92	46.04	45.77	45.39	45.02	44.66	44.32
5	31.69	25.06	23.95	30.98	27.99	28.83	31.37	27.87	42.47	43.77	43.52	43.15	42.78	42.43	42.09

Table 3: Wind Speed in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 15°

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	2.34114	2.89152	2.54376	2.20942	2.18416	2.10031	2.24745	2.23549	1.22904	1.20051	1.21101	1.22243	1.23357	1.2451	1.25715
55	2.3355	2.86233	2.64443	2.34582	2.33629	2.23724	2.29634	2.34177	1.24316	1.21524	1.22873	1.24135	1.25347	1.26596	1.27899
50	2.33499	2.7779	2.71668	2.46194	2.46915	2.35855	2.32715	2.40966	1.25442	1.22419	1.24103	1.25492	1.2681	1.28168	1.29588
45	2.34525	2.66213	2.76037	2.5549	2.57964	2.46309	2.34259	2.43576	1.26391	1.22692	1.24727	1.26237	1.27658	1.29125	1.30665
40	2.36624	2.53337	2.77609	2.62168	2.66081	2.54738	2.34341	2.41753	1.27225	1.22313	1.24697	1.26308	1.27818	1.29382	1.31032
35	2.3916	2.39618	2.76521	2.65886	2.70569	2.60318	2.32775	2.35409	1.27861	1.21264	1.2397	1.25656	1.2723	1.28867	1.30603
30	2.41013	2.24971	2.72634	2.66238	2.70805	2.61552	2.29042	2.24747	1.27961	1.19527	1.22515	1.24238	1.25842	1.27517	1.29302
25	2.40776	2.09167	2.64921	2.62753	2.66201	2.56525	2.22254	2.10307	1.26882	1.17088	1.20296	1.22009	1.23599	1.25267	1.27055
20	2.36854	1.91664	2.51088	2.54871	2.56147	2.43966	2.11326	1.92668	1.23795	1.13936	1.17279	1.18921	1.20441	1.22042	1.23768
15	2.27392	1.71367	2.28882	2.41692	2.39807	2.23688	1.95379	1.71912	1.18034	1.10099	1.13442	1.14924	1.16288	1.17735	1.19308
10	2.09275	1.46302	1.97931	2.20595	2.14632	1.95084	1.73357	1.46757	1.09889	1.05819	1.08857	1.10014	1.11069	1.12203	1.1346
5	1.68846	1.13434	1.48194	1.76626	1.67952	1.50637	1.37806	1.13872	1.00554	1.0093	1.02657	1.03095	1.03484	1.0395	1.04517

Table 4: Turbulence deviation or RMS in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 15°

Wind Direction = 30°

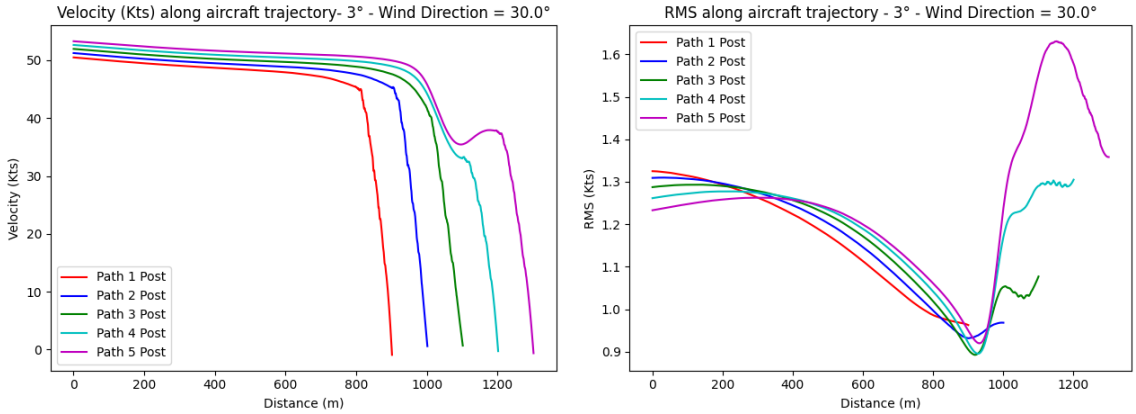


Figure 58: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 30°

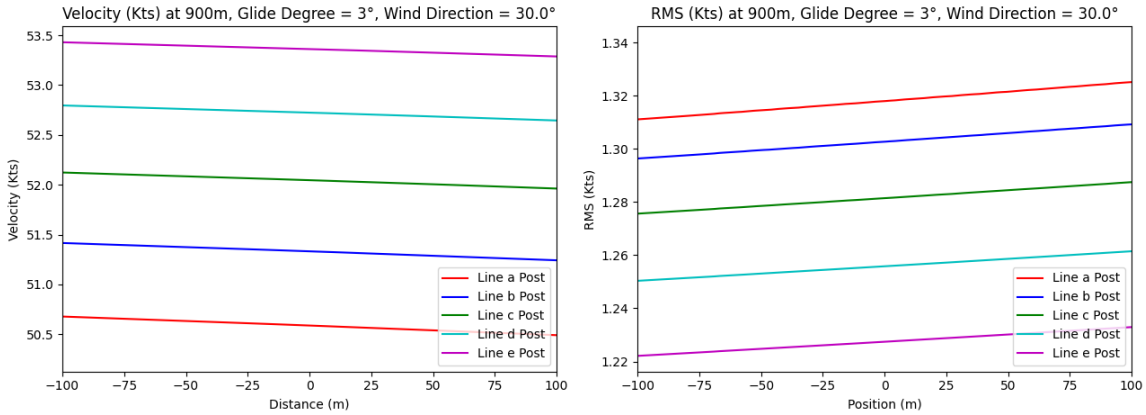


Figure 59: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 30°

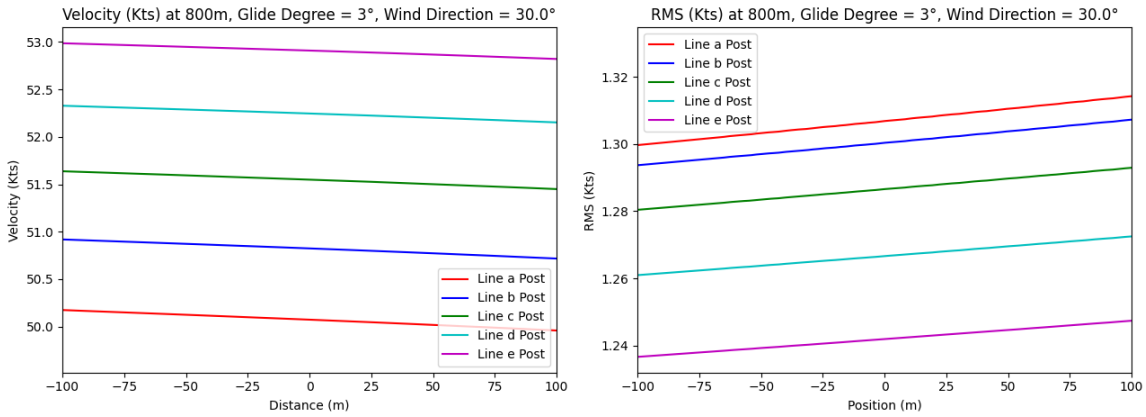


Figure 60: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 30°

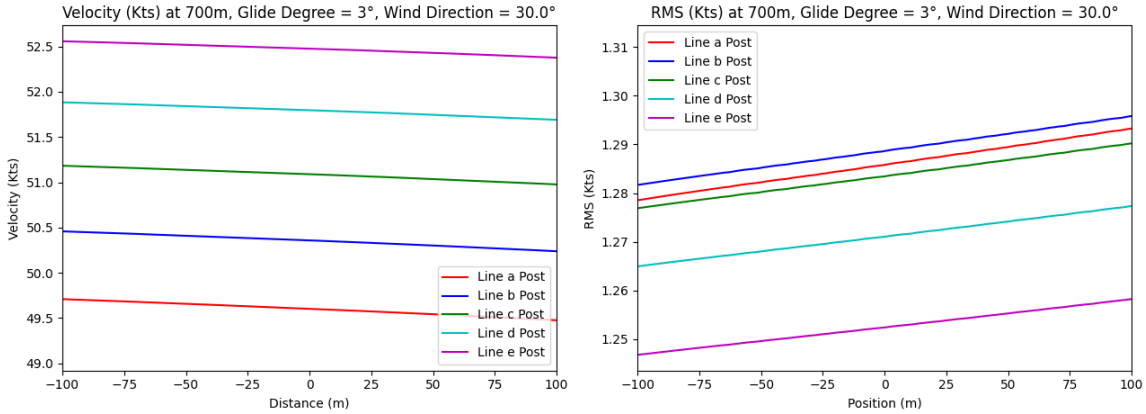


Figure 61: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 30°

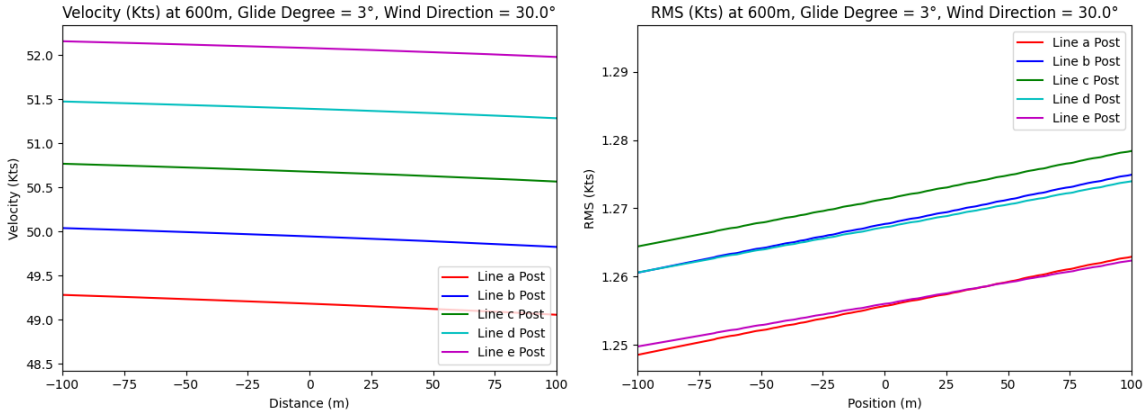


Figure 62: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 30°

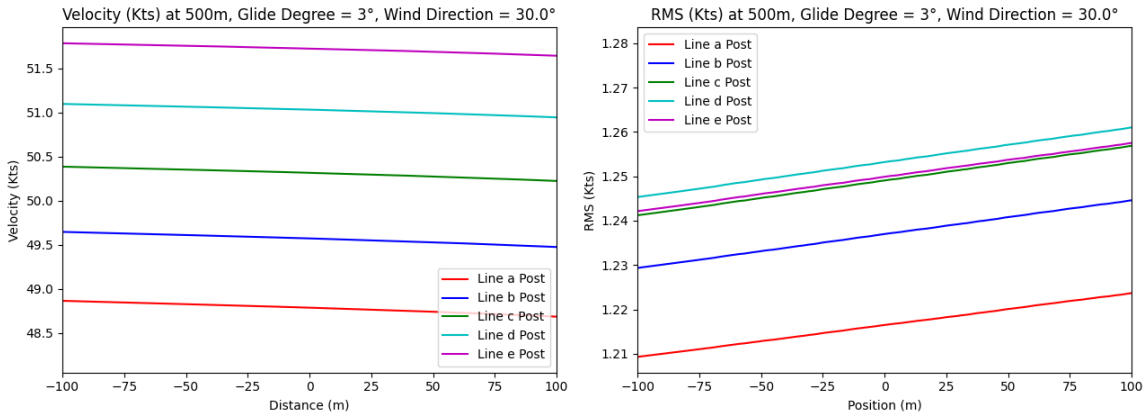


Figure 63: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 30°

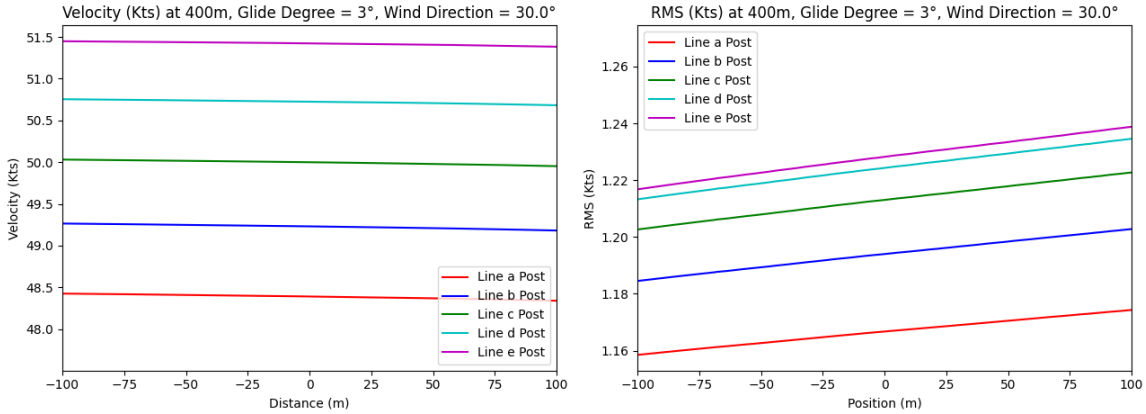


Figure 64: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 30°

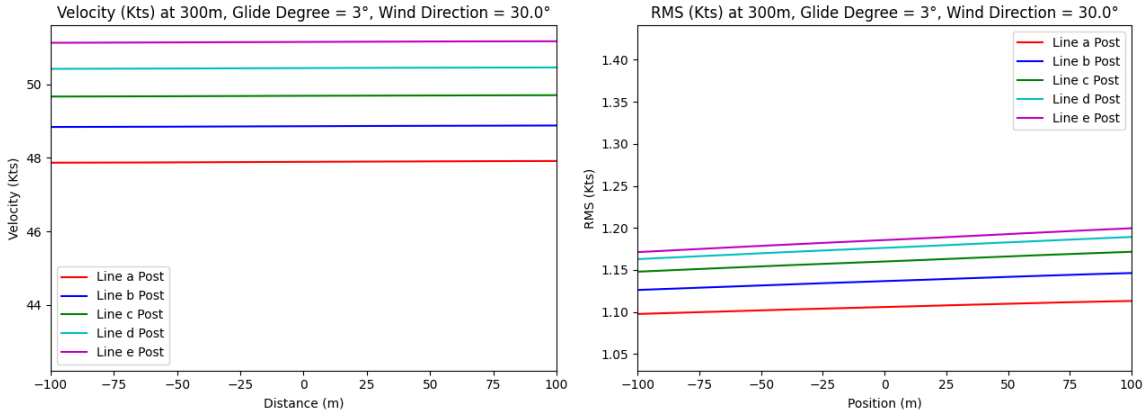


Figure 65: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 30°

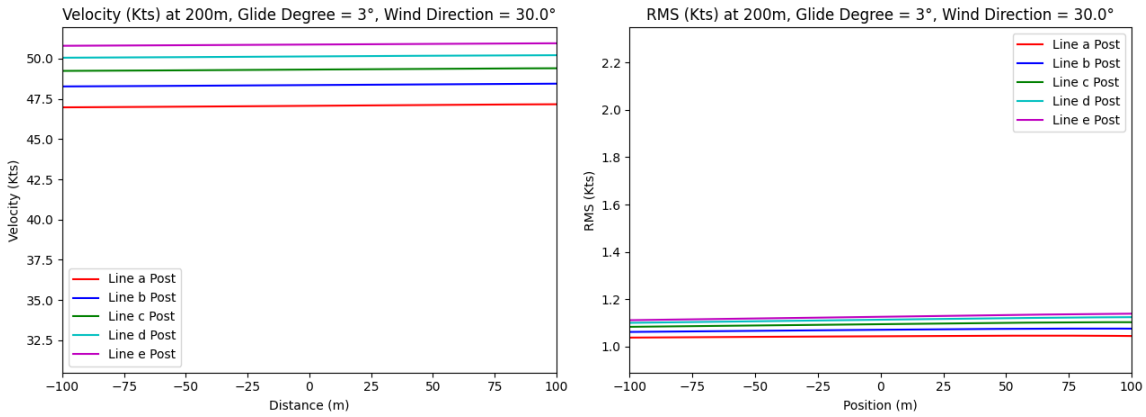


Figure 66: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 30°

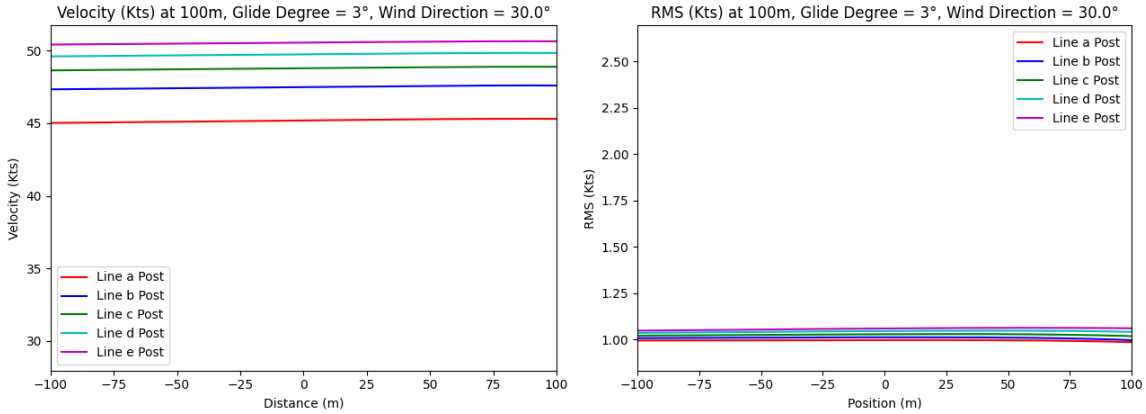


Figure 67: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 30°

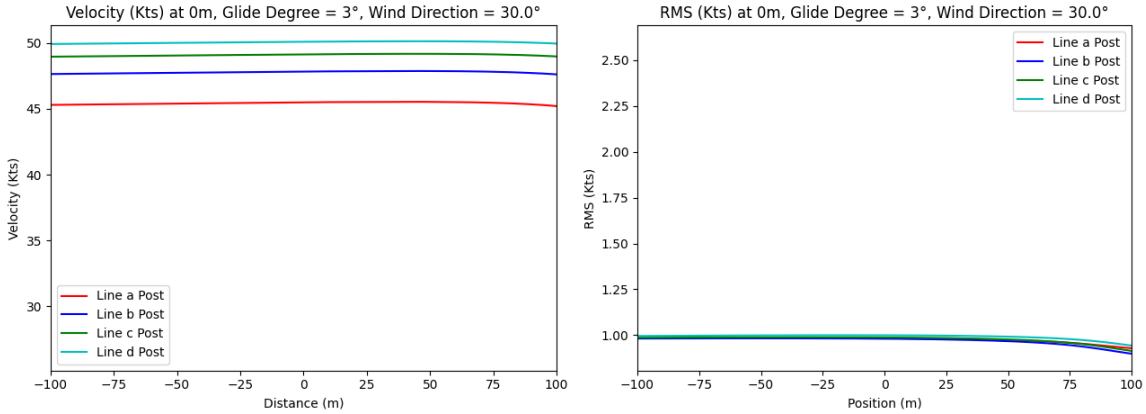


Figure 68: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 30°

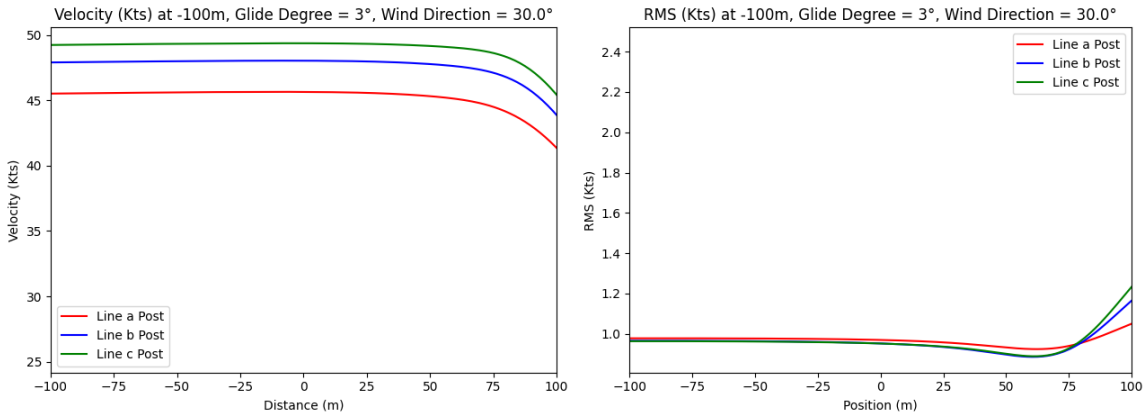


Figure 69: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 30°

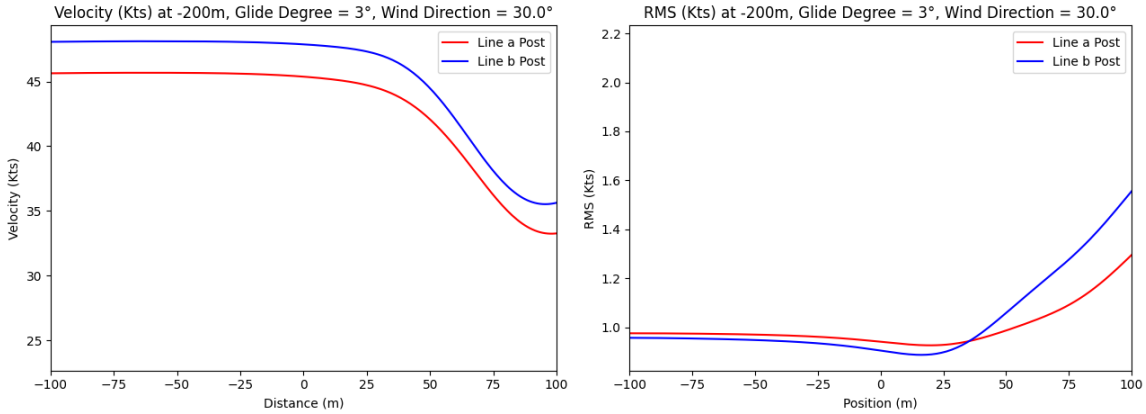


Figure 70: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 30°

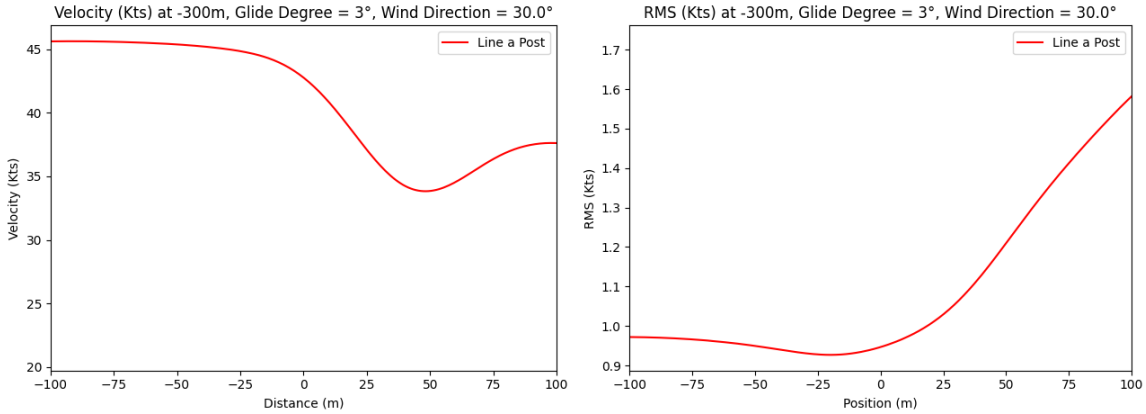


Figure 71: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 30°

Velocity magnitude and turbulence deviation values of CFD models along the runway centerline between chainages $-500m$ to $900m$, consistent with assessment area according to National Airport Safeguarding Framework (NASF), and up to a height of $60m$ above ground level for wind direction $30°$ with 20 m/s approaching speed are shown in Tables 5 and 6.

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	50.89	53.24	51.7	49.97	54.28	54.94	54.84	54.49	54.08	53.66	53.29	52.97	52.71	52.49	52.31
55	49.59	52.2	50.93	48.23	53.57	54.37	54.28	53.92	53.5	53.07	52.68	52.34	52.06	51.83	51.64
50	48.22	51.07	50.15	46.64	52.82	53.79	53.7	53.33	52.89	52.45	52.04	51.69	51.4	51.15	50.93
45	46.8	49.83	49.31	45.21	52.01	53.2	53.1	52.73	52.27	51.81	51.39	51.02	50.7	50.44	50.2
40	45.33	48.49	48.38	43.89	51.13	52.59	52.49	52.1	51.63	51.15	50.71	50.32	49.99	49.7	49.45
35	43.82	47.06	47.34	42.6	50.17	51.97	51.86	51.45	50.97	50.47	50.01	49.6	49.25	48.94	48.67
30	42.29	45.55	46.18	41.32	49.13	51.31	51.19	50.77	50.28	49.76	49.28	48.86	48.48	48.16	47.86
25	40.76	43.98	44.9	40	48.02	50.61	50.48	50.05	49.54	49.01	48.52	48.07	47.68	47.33	47.01
20	39.23	42.34	43.5	38.62	46.85	49.81	49.7	49.26	48.73	48.19	47.68	47.22	46.81	46.44	46.1
15	37.65	40.62	41.96	37.1	45.56	48.83	48.75	48.31	47.78	47.23	46.7	46.22	45.8	45.42	45.06
10	35.9	38.68	40.15	35.33	43.98	47.47	47.47	47.04	46.5	45.94	45.41	44.93	44.49	44.1	43.73
5	33.43	35.96	37.48	32.95	41.37	45.05	45.17	44.78	44.26	43.71	43.18	42.7	42.27	41.88	41.51

Table 5: Wind Speed in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 30°

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	2.45307	2.2242	1.73533	1.42515	1.05709	1.01521	1.05444	1.11396	1.16668	1.20072	1.21998	1.23368	1.24686	1.26059	1.2751
55	2.49913	2.31978	1.85184	1.50869	1.07929	1.02651	1.0694	1.13006	1.18357	1.21858	1.23887	1.25363	1.26789	1.28273	1.29835
50	2.52596	2.39491	1.95339	1.5811	1.10289	1.03218	1.0798	1.14156	1.19552	1.2312	1.25242	1.26829	1.28377	1.29994	1.317
45	2.53279	2.44845	2.03709	1.64324	1.13056	1.03197	1.08535	1.1481	1.20206	1.23797	1.25989	1.27679	1.29347	1.31101	1.32964
40	2.51854	2.47908	2.10081	1.69516	1.16396	1.02582	1.0859	1.1494	1.20279	1.23841	1.26069	1.2784	1.29614	1.31494	1.33504
35	2.48187	2.48513	2.1422	1.73482	1.20173	1.01373	1.08139	1.14528	1.19739	1.23208	1.25431	1.27255	1.29106	1.31084	1.33215
30	2.4214	2.46447	2.15837	1.75867	1.23784	0.99578	1.07182	1.13554	1.18558	1.21864	1.24032	1.25868	1.27758	1.29793	1.32002
25	2.33584	2.41454	2.14625	1.76171	1.2621	0.9723	1.05725	1.12002	1.16701	1.19767	1.21826	1.23627	1.25505	1.27541	1.2977
20	2.22295	2.33162	2.10163	1.73681	1.26285	0.94459	1.03799	1.09857	1.14132	1.16871	1.18759	1.20462	1.22263	1.24231	1.264
15	2.07617	2.20812	2.01723	1.67128	1.23017	0.91721	1.01542	1.07155	1.10837	1.13137	1.14766	1.16287	1.17916	1.19713	1.21715
10	1.87317	2.02005	1.87196	1.53785	1.16172	0.90453	0.99518	1.0417	1.06949	1.08612	1.09823	1.11	1.1229	1.1374	1.15383
5	1.51162	1.65049	1.55885	1.27617	1.04639	0.93407	0.98573	1.00877	1.01996	1.02522	1.02882	1.03298	1.03837	1.04516	1.05351

Table 6: Turbulence deviation or RMS in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 30°

Wind Direction = 285°

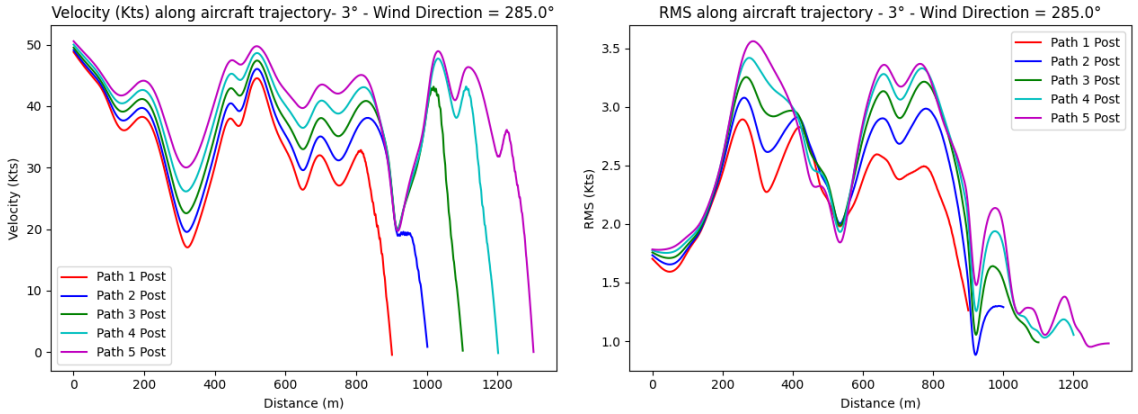


Figure 72: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 285°

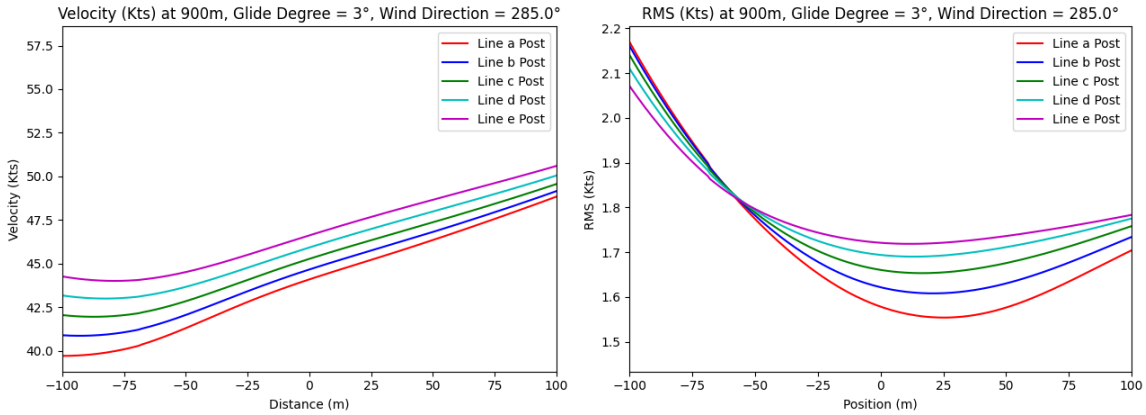


Figure 73: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 285°

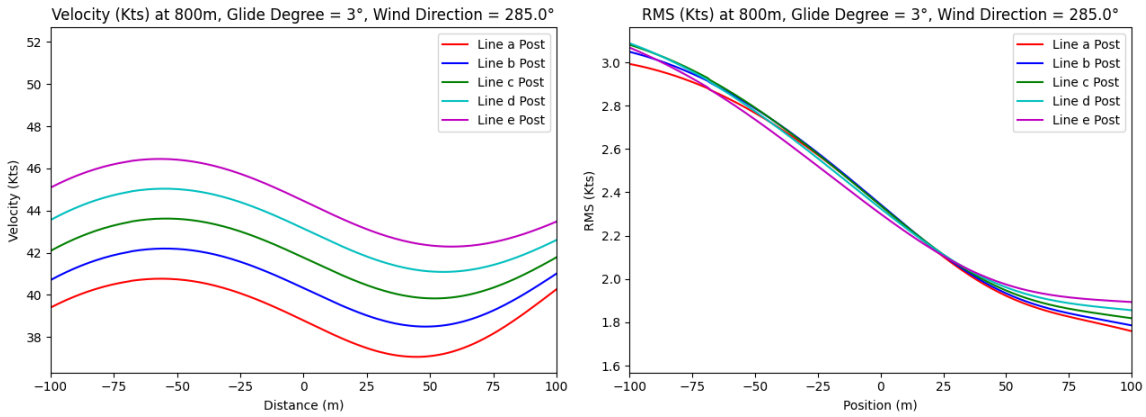


Figure 74: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 285°

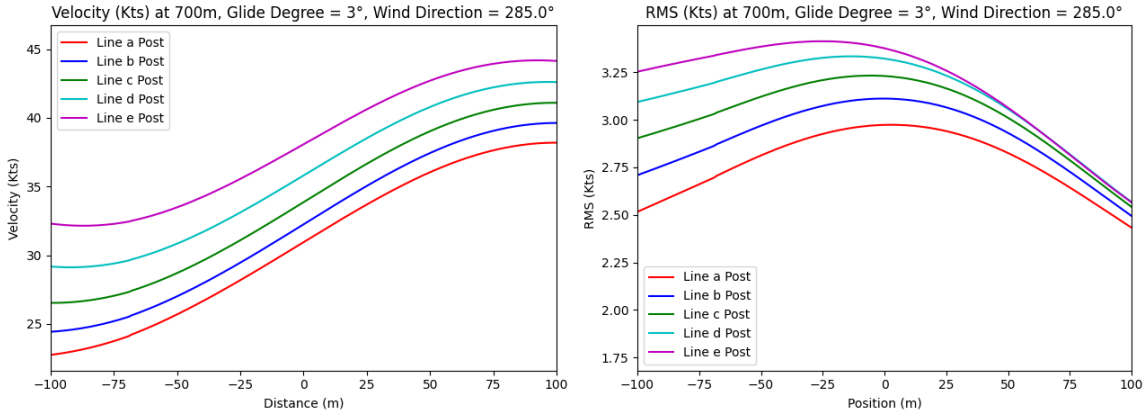


Figure 75: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 285°

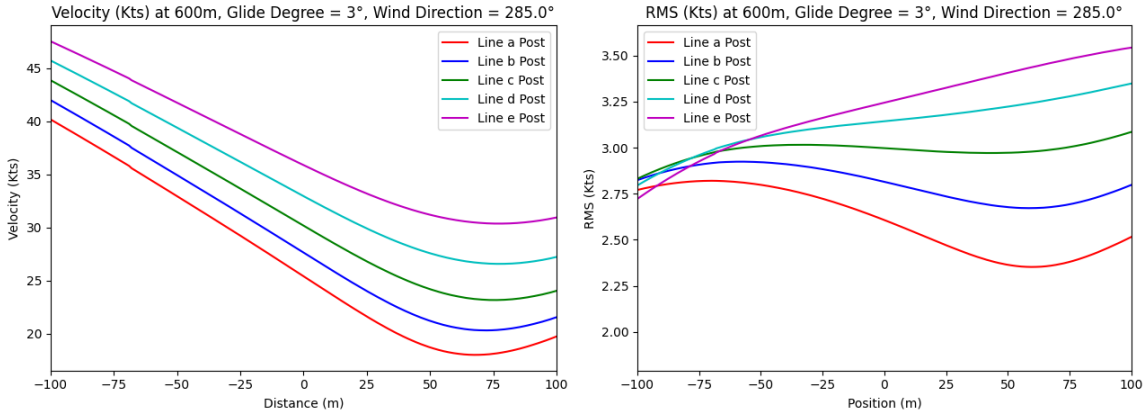


Figure 76: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 285°

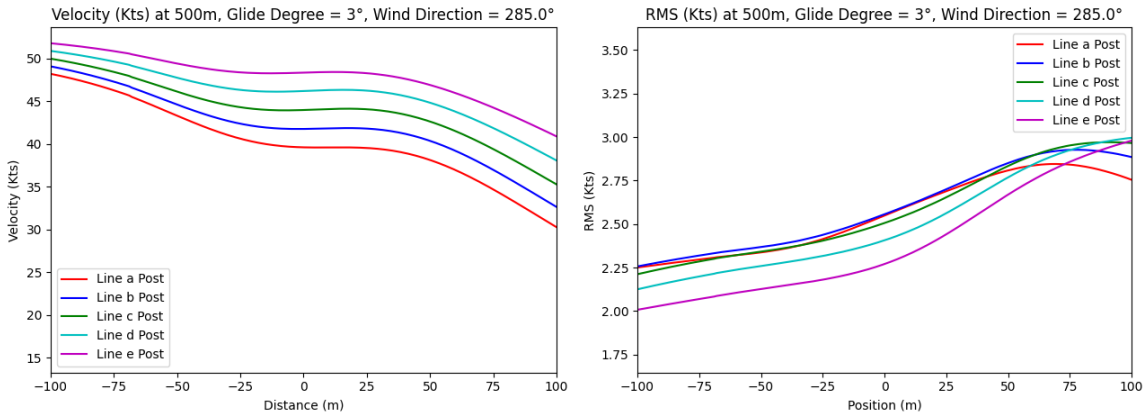


Figure 77: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 285°

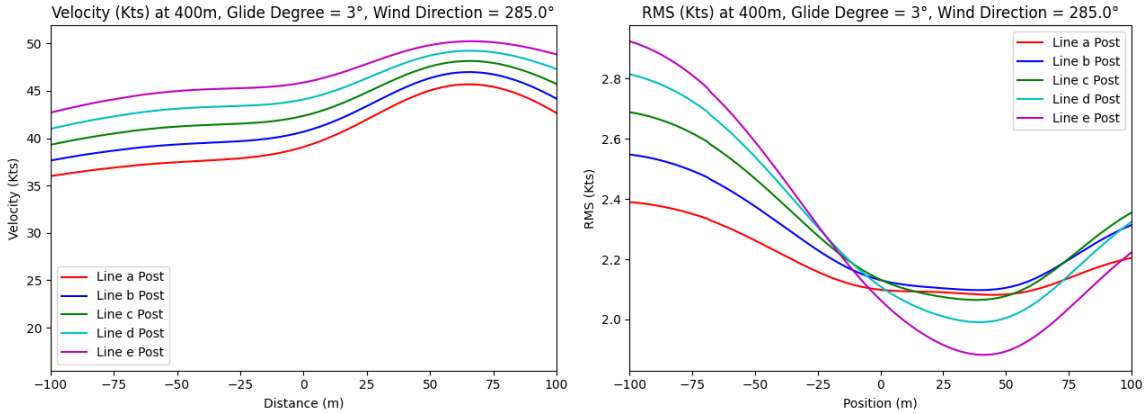


Figure 78: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 285°

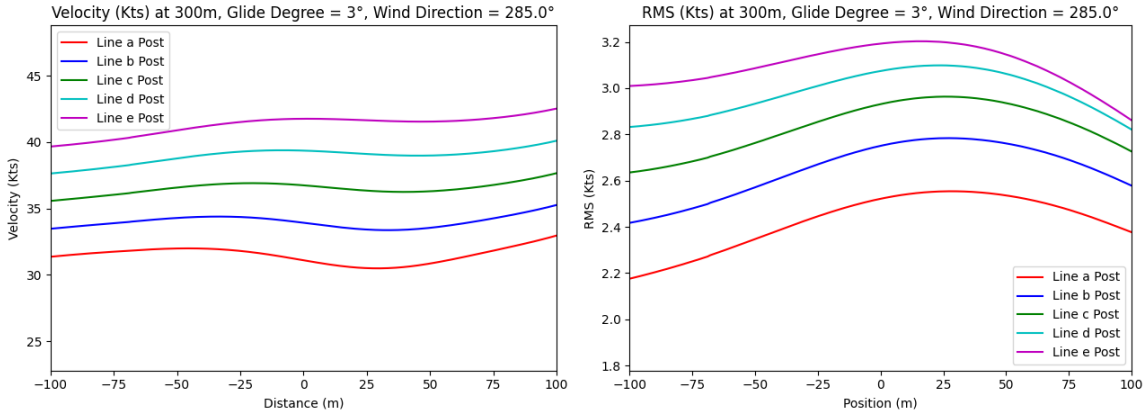


Figure 79: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 285°

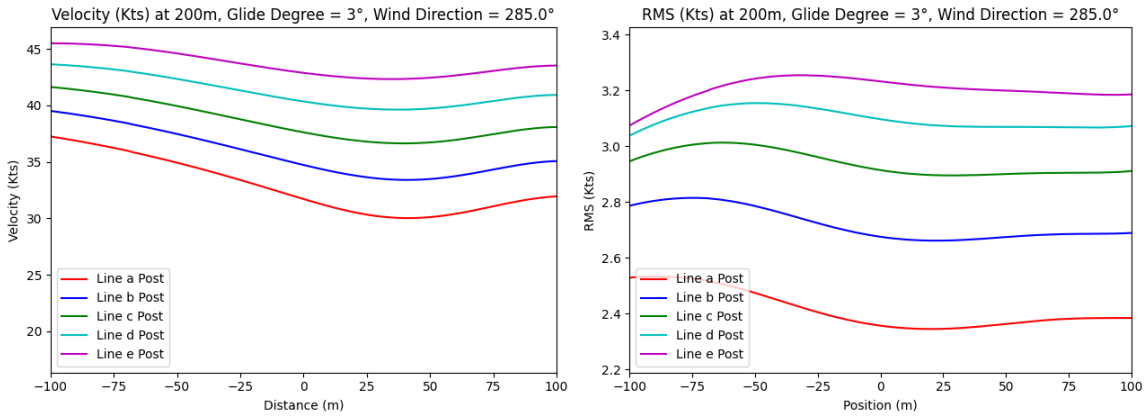


Figure 80: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 285°

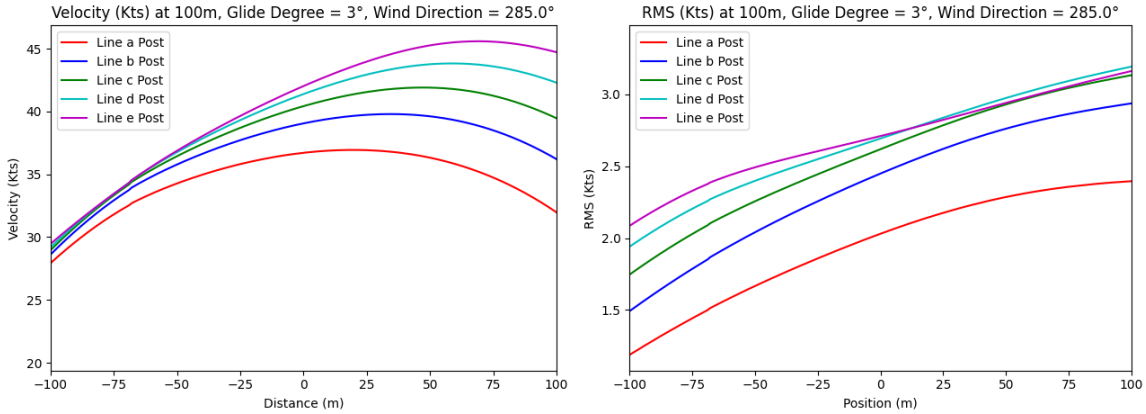


Figure 81: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 285°

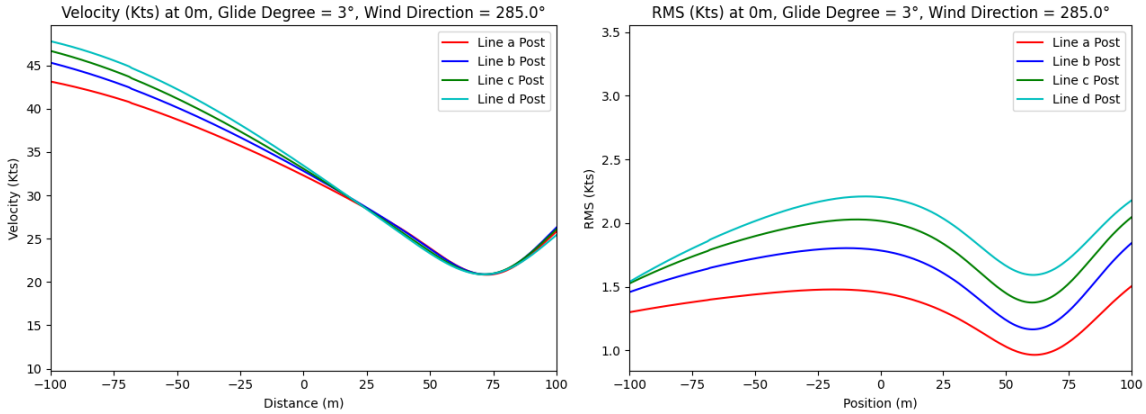


Figure 82: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 285°

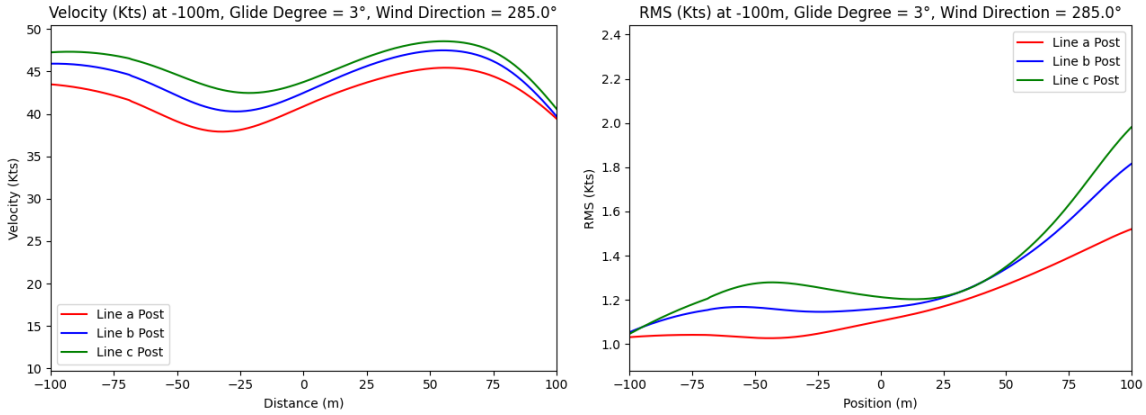


Figure 83: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 285°

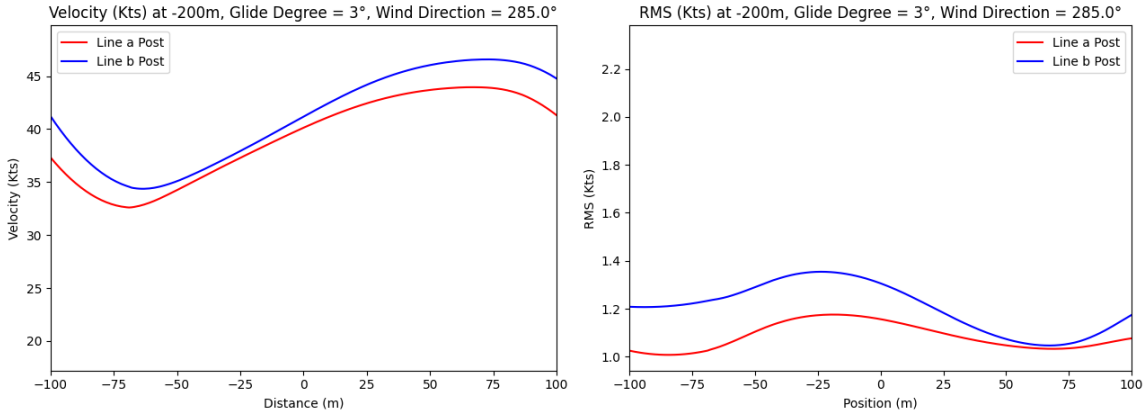


Figure 84: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 285°

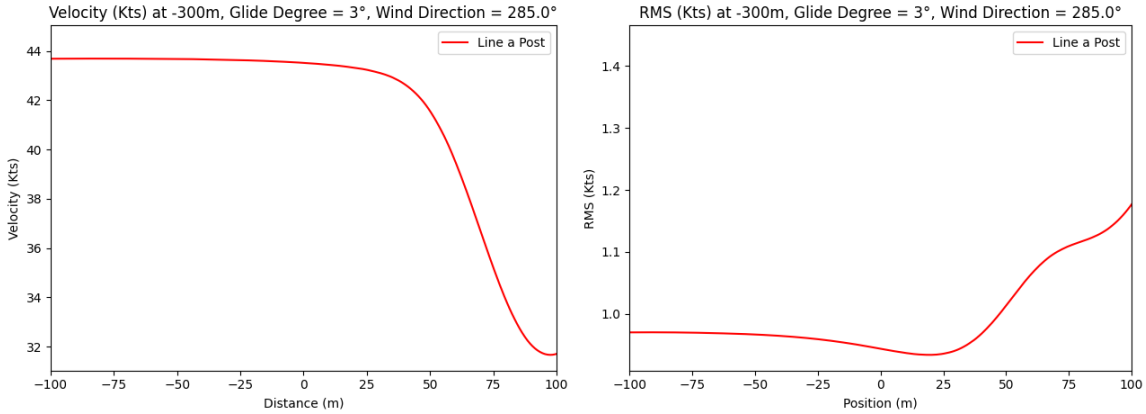


Figure 85: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 285°

Velocity magnitude and turbulence deviation values of CFD models along the runway centerline between chainages $-500m$ to $900m$, consistent with assessment area according to National Airport Safeguarding Framework (NASF), and up to a height of $60m$ above ground level for wind direction 285° with 20 m/s approaching speed are shown in Tables 7 and 8.

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	53.6	53.82	53.85	54.48	53.49	38.47	53.65	53.54	51.75	53.37	47.23	36.81	44.91	43.01	49.77
55	52.99	53.21	53.17	53.9	52.54	33.68	52.69	52.28	50.08	52.3	45.01	33.05	43.42	42.19	49.34
50	52.35	52.58	52.37	53.3	51.48	29.33	51.67	50.82	48.24	51.11	42.54	29.32	41.95	41.42	48.98
45	51.69	51.92	51.36	52.68	50.33	26.28	50.57	49.17	46.23	49.78	39.89	25.92	40.52	40.69	48.71
40	51	51.25	49.93	52.02	49.08	24.58	49.36	47.3	44.07	48.35	37.19	23.09	39.13	39.98	48.54
35	50.3	50.56	47.93	51.33	47.67	23.91	47.96	45.2	41.8	46.86	34.55	20.91	37.76	39.29	48.45
30	49.57	49.84	45.26	50.57	46.03	24.06	46.29	42.88	39.46	45.36	32.09	19.34	36.37	38.61	48.44
25	48.8	49.08	42	49.66	44.14	24.76	44.28	40.34	37.12	43.89	29.89	18.3	34.92	37.95	48.45
20	47.96	48.25	38.46	48.52	42.21	25.64	41.89	37.58	34.84	42.46	27.98	17.84	33.33	37.34	48.43
15	46.97	47.27	35.19	46.98	40.7	26.3	39.13	34.67	32.64	40.99	26.34	17.95	31.54	36.79	48.25
10	45.67	45.97	32.8	44.83	39.94	26.51	35.97	31.67	30.46	39.33	24.86	18.56	29.45	36.24	47.67
5	43.41	43.69	31.64	41.5	39.64	26.08	31.84	28.22	27.86	36.8	23.24	19.24	26.56	35.19	45.87

Table 7: Wind Speed in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 285°

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	1.15267	1.11033	1.05223	0.99945	1.39134	3.14279	2.0226	3.1015	2.4368	1.58828	2.804	3.65477	2.55975	1.87561	1.76716
55	1.17165	1.12824	1.07805	1.01502	1.54	3.06314	2.23367	3.20723	2.60264	1.76933	2.884	3.61155	2.57616	1.8395	1.74719
50	1.18622	1.14165	1.12227	1.02922	1.681	2.88609	2.44272	3.27184	2.73113	1.95505	2.94971	3.47392	2.56582	1.80578	1.7212
45	1.19566	1.14993	1.20656	1.04293	1.80361	2.69083	2.64139	3.29792	2.8193	2.1274	2.989	3.25464	2.53198	1.77702	1.69029
40	1.19943	1.15264	1.35229	1.05794	1.90628	2.53247	2.82127	3.28756	2.86345	2.26234	2.99087	2.98795	2.48026	1.75377	1.65514
35	1.19707	1.14951	1.54868	1.07722	1.98839	2.41903	2.97552	3.24224	2.85998	2.33985	2.94793	2.71101	2.41736	1.73337	1.6156
30	1.18818	1.1403	1.73815	1.10422	2.04685	2.33729	3.09696	3.16185	2.8067	2.35097	2.85816	2.44358	2.34922	1.70925	1.57062
25	1.17233	1.12482	1.8439	1.13943	2.07418	2.26169	3.1746	3.04319	2.70355	2.29635	2.72341	2.19406	2.27907	1.67162	1.51845
20	1.14906	1.10294	1.80951	1.17418	2.05443	2.16774	3.19032	2.87851	2.55182	2.1808	2.54519	1.96683	2.20343	1.60901	1.45757
15	1.11795	1.07494	1.63397	1.189	1.96948	2.03411	3.1179	2.65569	2.35036	2.00969	2.31958	1.75151	2.10718	1.50943	1.38756
10	1.07945	1.04313	1.38459	1.16623	1.79843	1.8267	2.91176	2.35331	2.08116	1.78557	2.02228	1.50848	1.95383	1.36012	1.30798
5	1.02359	1.00433	1.15649	1.07222	1.50209	1.48963	2.35878	1.83288	1.63962	1.4495	1.55344	1.18215	1.58913	1.15757	1.21298

Table 8: Turbulence deviation or RMS in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 285°

Wind Direction = 300°

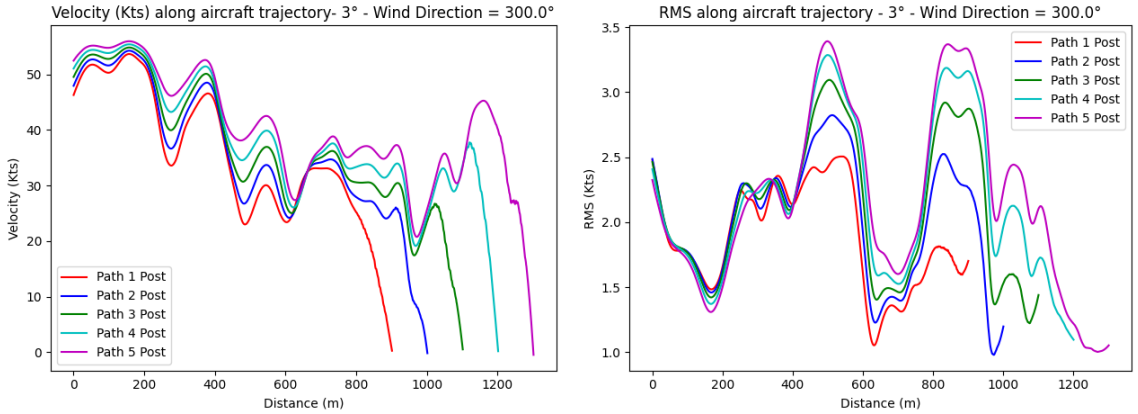


Figure 86: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 300°

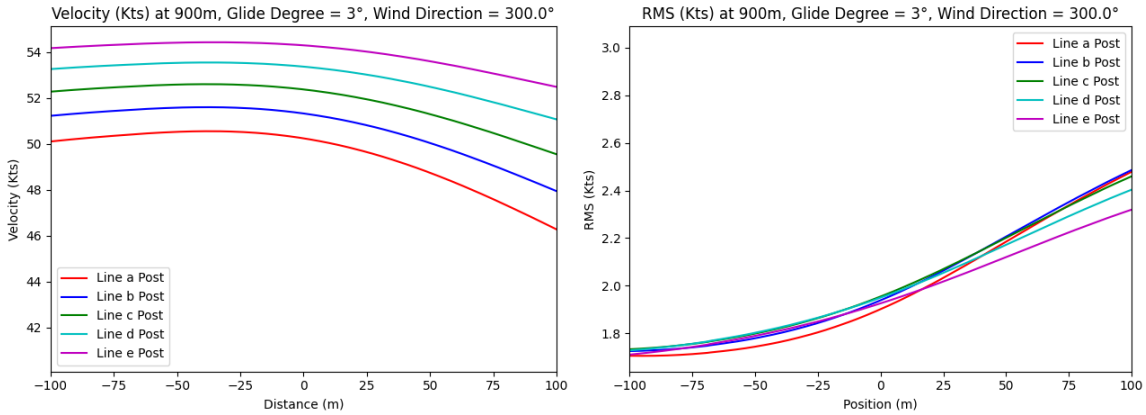


Figure 87: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 300°

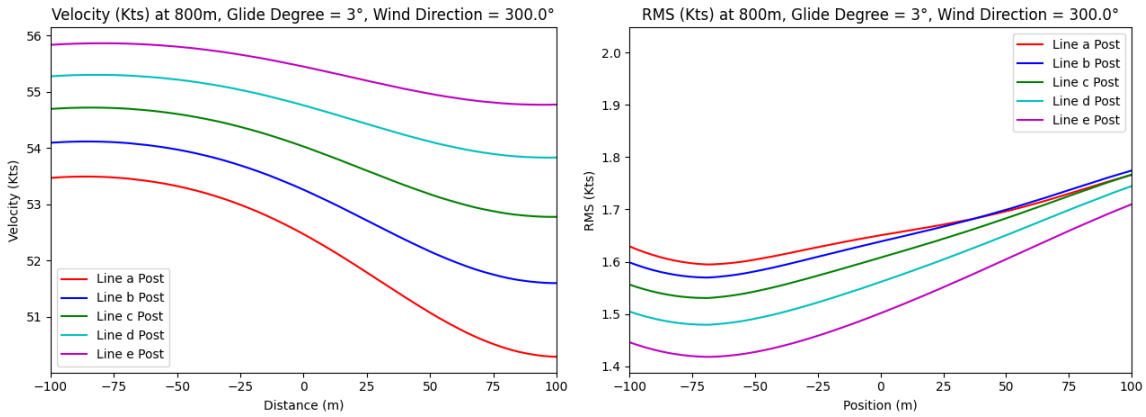


Figure 88: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 300°

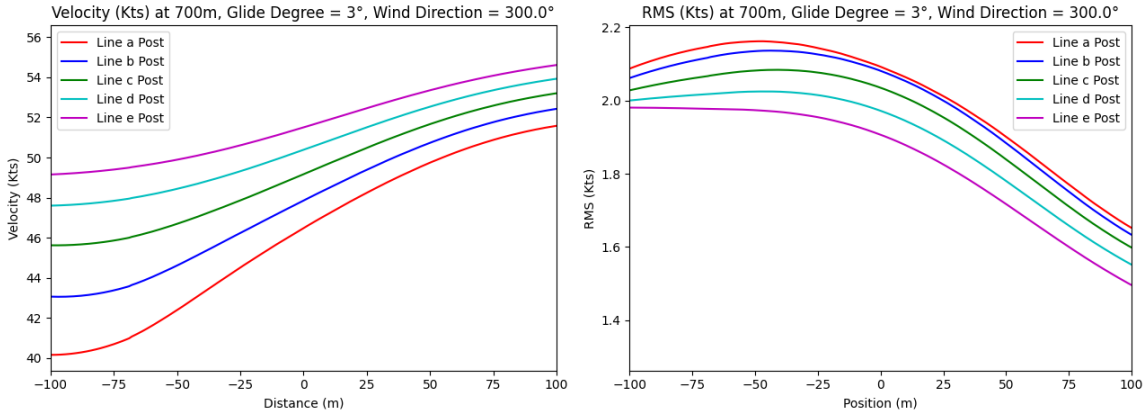


Figure 89: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 300°

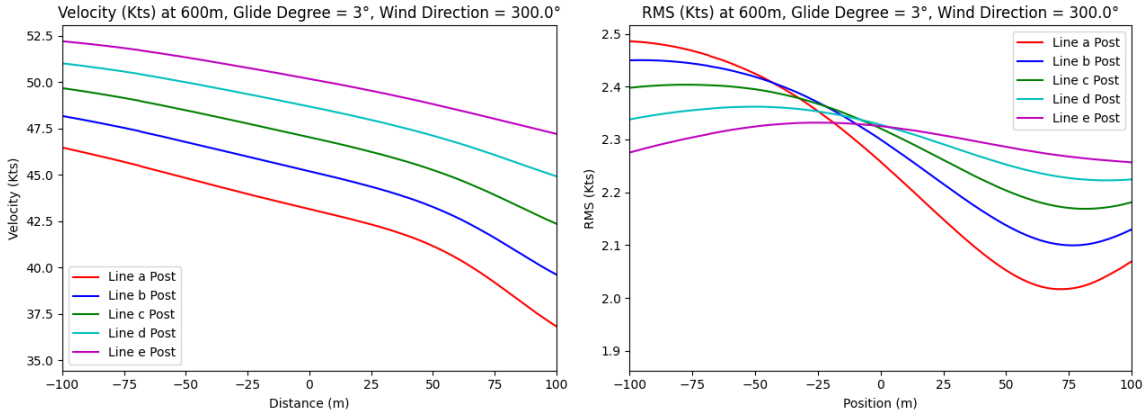


Figure 90: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 300°

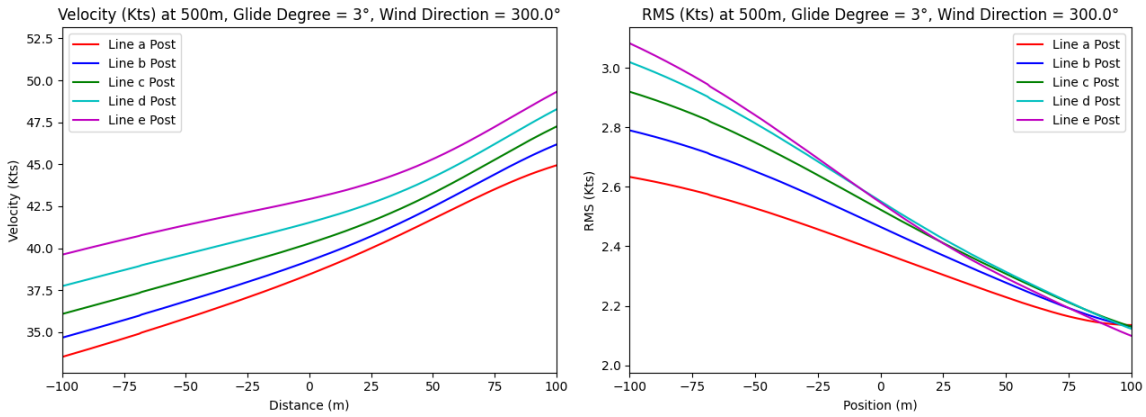


Figure 91: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 300°

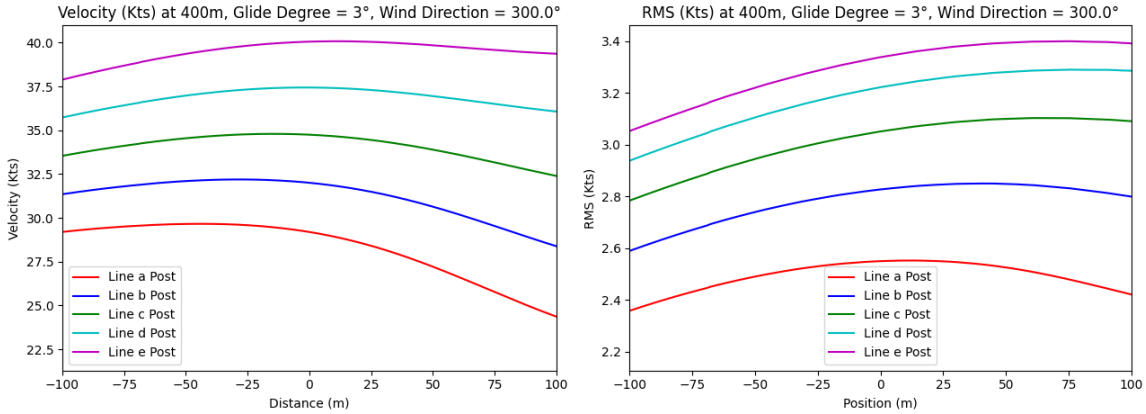


Figure 92: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 300°

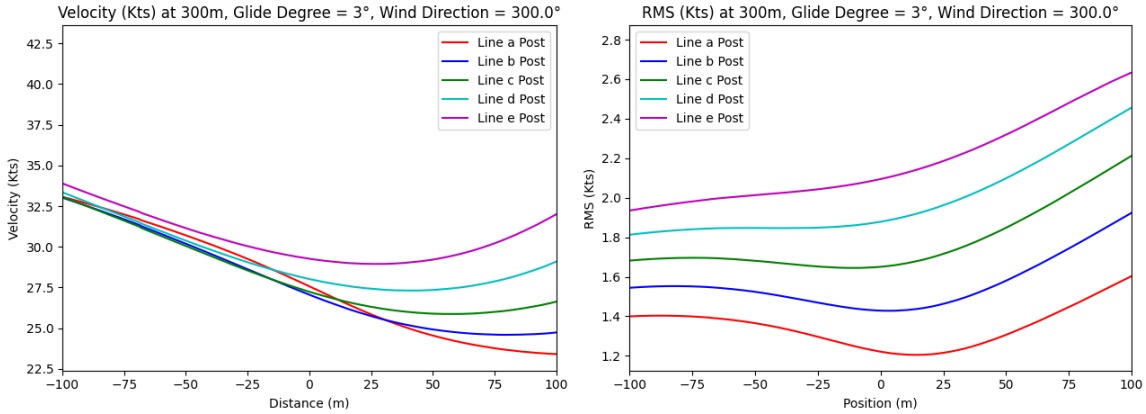


Figure 93: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 300°

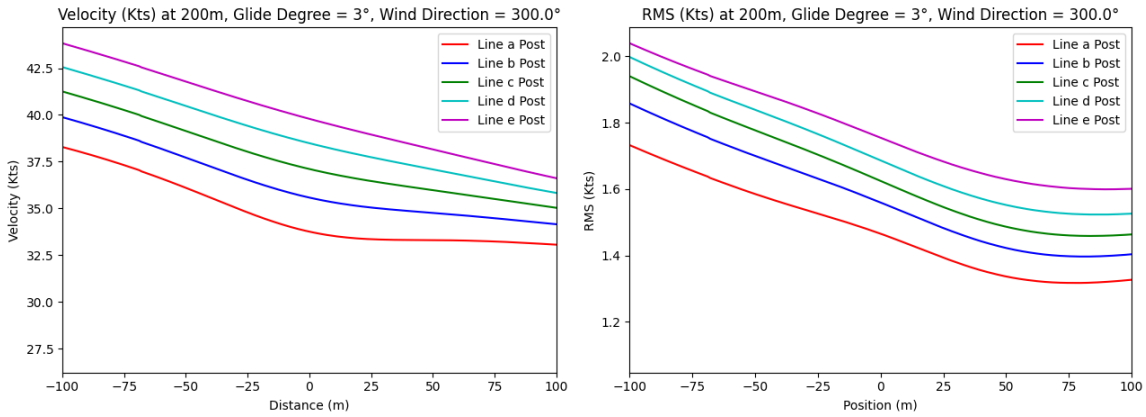


Figure 94: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 300°

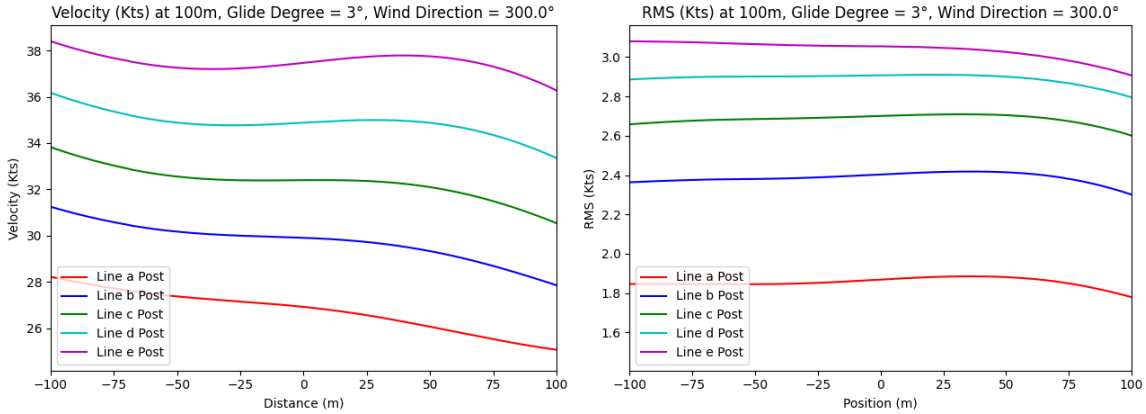


Figure 95: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 300°

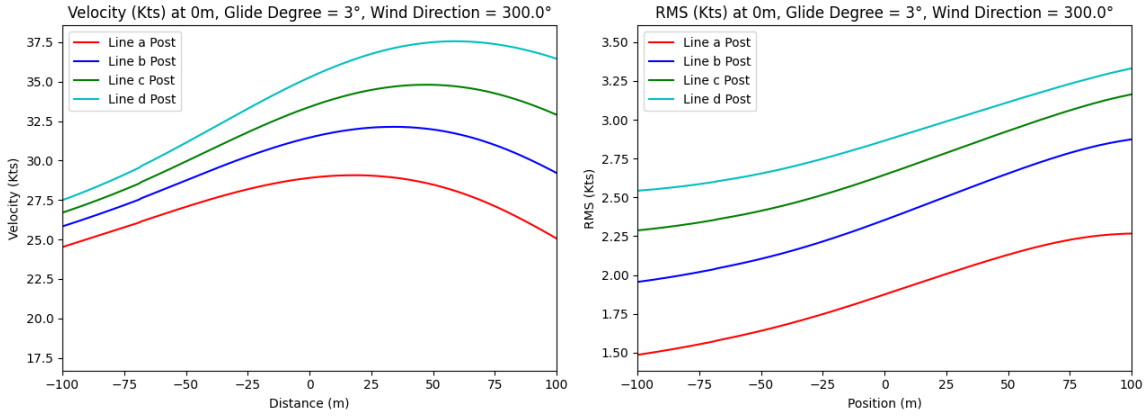


Figure 96: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 300°

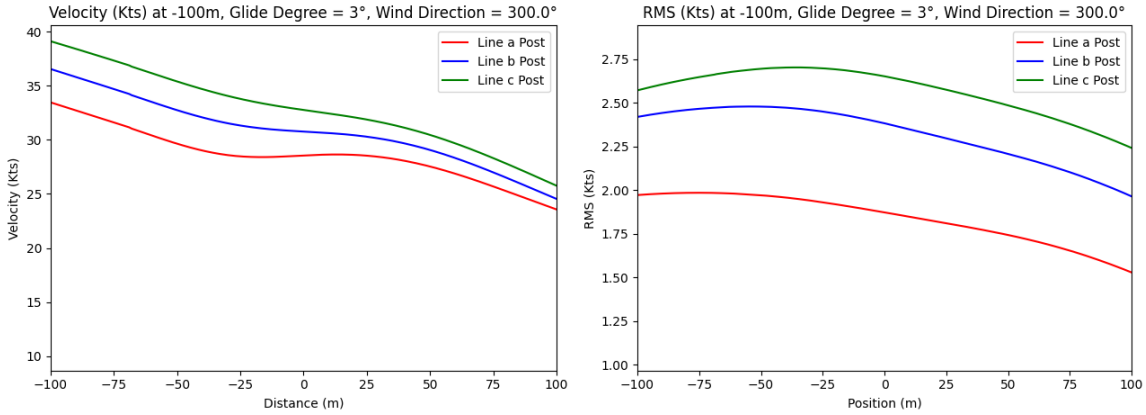


Figure 97: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 300°

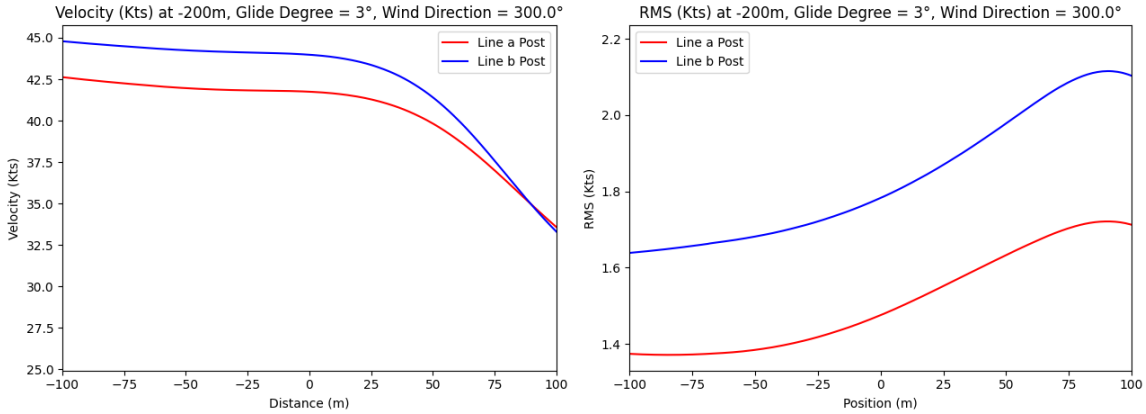


Figure 98: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 300°

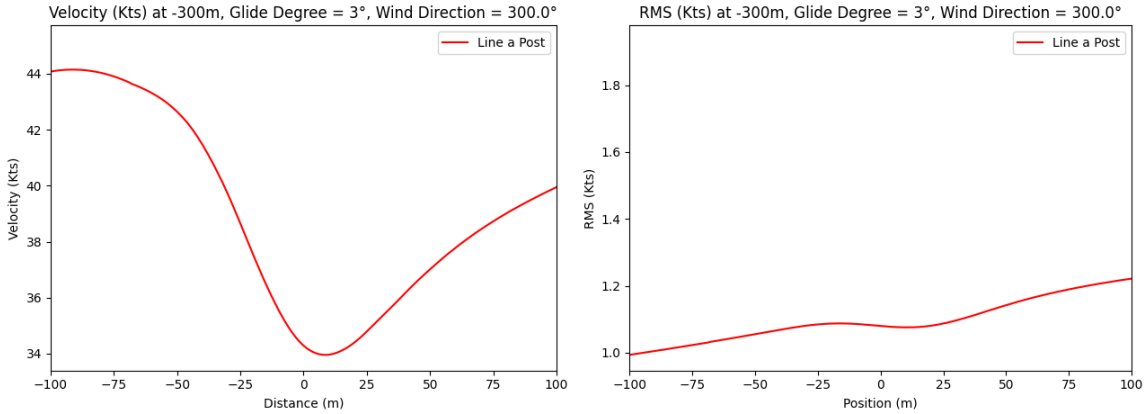


Figure 99: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 300°

Velocity magnitude and turbulence deviation values of CFD models along the runway centerline between chainages $-500m$ to $900m$, consistent with assessment area according to National Airport Safeguarding Framework (NASF), and up to a height of $60m$ above ground level for wind direction 300° with 20 m/s approaching speed are shown in Tables 9 and 10.

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	53.62	54.27	54.17	53.77	47.42	53.69	50.58	42.45	42.98	48.9	51.99	50.09	54.93	54.32	50.33
55	52.98	53.73	53.55	52.45	44.99	52.4	49.1	41.17	41.38	46.57	50.93	48.33	54.29	53.37	48.84
50	52.32	53.17	52.87	50.78	42.37	50.88	47.44	40.03	39.37	44.03	49.88	46.3	53.62	52.31	47.27
45	51.64	52.6	52.13	48.61	39.54	49.11	45.57	39	36.88	41.28	48.86	44	52.9	51.13	45.66
40	50.95	51.99	51.27	45.81	36.56	47.06	43.45	38.06	34.02	38.31	47.87	41.47	52.14	49.83	44.04
35	50.23	51.34	50.23	42.62	33.64	44.71	41.07	37.21	31.09	35.04	46.88	38.82	51.3	48.4	42.46
30	49.49	50.59	48.94	39.59	31.03	42.05	38.45	36.43	28.41	31.42	45.83	36.17	50.37	46.81	40.97
25	48.7	49.69	47.34	37	28.86	39.11	35.68	35.68	26.19	27.55	44.59	33.63	49.32	45.08	39.63
20	47.81	48.64	45.49	35	27.08	35.89	32.89	34.9	24.48	23.75	42.97	31.25	48.04	43.31	38.5
15	46.74	47.48	43.6	33.75	25.64	32.48	30.22	34.04	23.31	20.44	40.74	29.02	46.26	41.58	37.59
10	45.26	46.28	41.82	33.37	24.49	28.94	27.65	32.96	22.76	17.83	37.65	26.91	43.28	39.88	36.8
5	42.78	44.33	39.83	33.64	23.56	24.92	24.95	31.15	22.7	15.61	32.89	24.83	38.08	38.1	35.51

Table 9: Wind Speed in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 300°

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	1.01921	0.96122	1.01055	1.72965	2.8851	2.45886	2.28719	2.17552	2.64508	3.17344	1.94681	2.27999	1.46743	1.72808	2.43417
55	1.03765	0.97779	1.05841	1.95137	2.97274	2.70912	2.43853	2.07331	2.70138	3.31764	2.02462	2.26978	1.52507	1.75571	2.47441
50	1.05123	0.99306	1.11425	2.16545	3.01491	2.93736	2.59028	1.96681	2.74189	3.40025	2.08028	2.24598	1.57509	1.77106	2.48543
45	1.05925	1.00759	1.17795	2.377	3.0132	3.13145	2.73086	1.86025	2.75125	3.41785	2.11464	2.21068	1.61613	1.77282	2.46464
40	1.06111	1.02249	1.24888	2.57444	2.96604	3.28154	2.84627	1.75746	2.70553	3.36633	2.13081	2.16654	1.64509	1.7591	2.41035
35	1.05622	1.03971	1.3258	2.71568	2.87463	3.37964	2.92128	1.66308	2.58697	3.23888	2.13442	2.11483	1.65754	1.7267	2.32261
30	1.04388	1.06167	1.40433	2.75954	2.74874	3.42002	2.94069	1.58091	2.39671	3.02691	2.13399	2.05232	1.64938	1.67094	2.20396
25	1.0234	1.08823	1.47098	2.6999	2.59797	3.39859	2.89221	1.5122	2.15153	2.7269	2.14034	1.97086	1.62004	1.58698	2.05904
20	0.99463	1.11093	1.50144	2.55459	2.4229	3.30784	2.7704	1.45359	1.86842	2.35262	2.16136	1.86083	1.57848	1.47126	1.89111
15	0.96015	1.11441	1.47343	2.3462	2.21418	3.13372	2.57147	1.39556	1.55844	1.94024	2.18902	1.71186	1.54674	1.32092	1.69572
10	0.92961	1.0951	1.37952	2.07728	1.93945	2.84046	2.27066	1.31856	1.22588	1.52026	2.17835	1.50462	1.53578	1.13697	1.45825
5	0.93204	1.06725	1.21172	1.69204	1.50708	2.22738	1.74991	1.15123	0.898	1.05342	1.84444	1.17228	1.36786	0.99006	1.17337

Table 10: Turbulence deviation or RMS in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 300°

Wind Direction = 315°

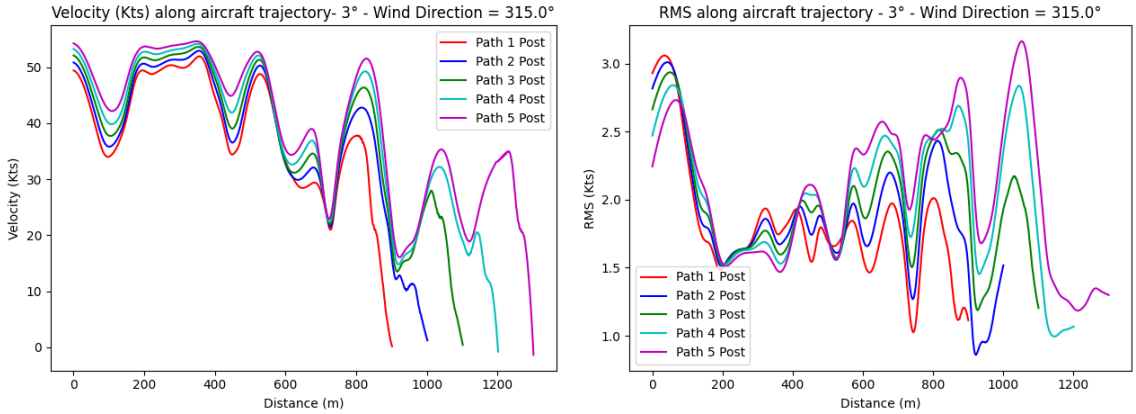


Figure 100: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

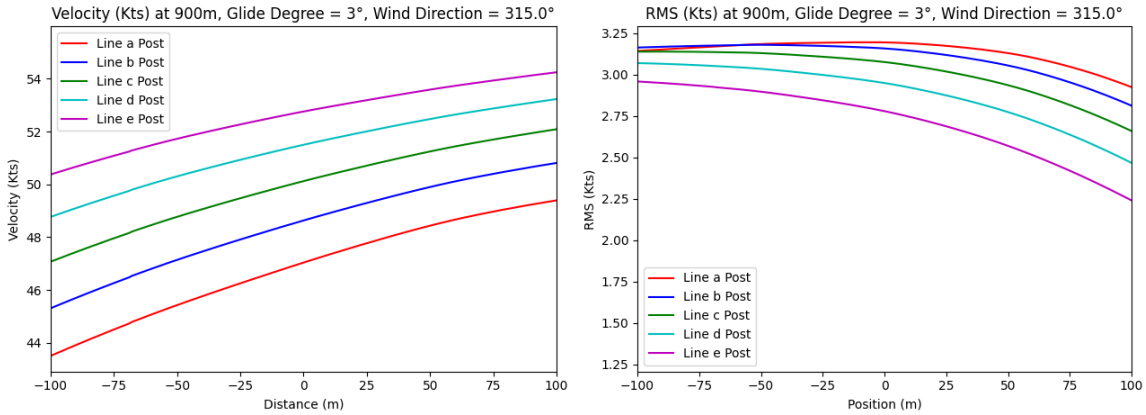


Figure 101: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

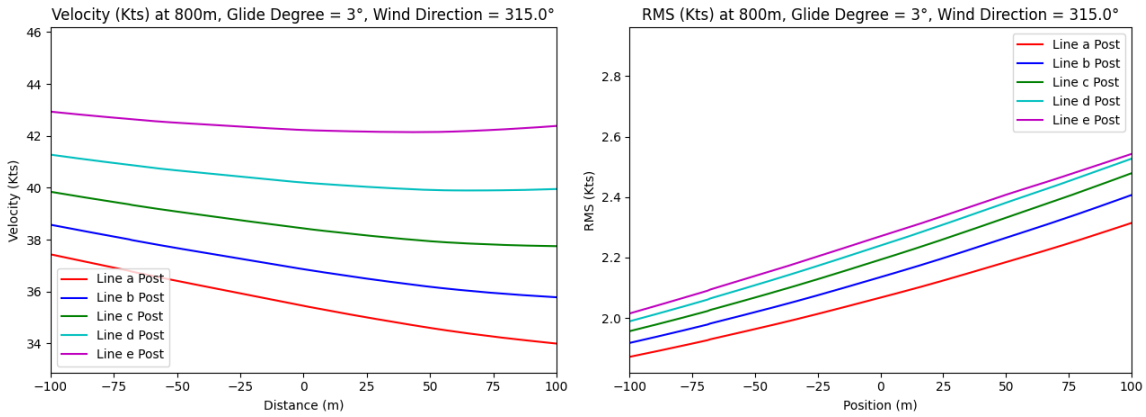


Figure 102: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

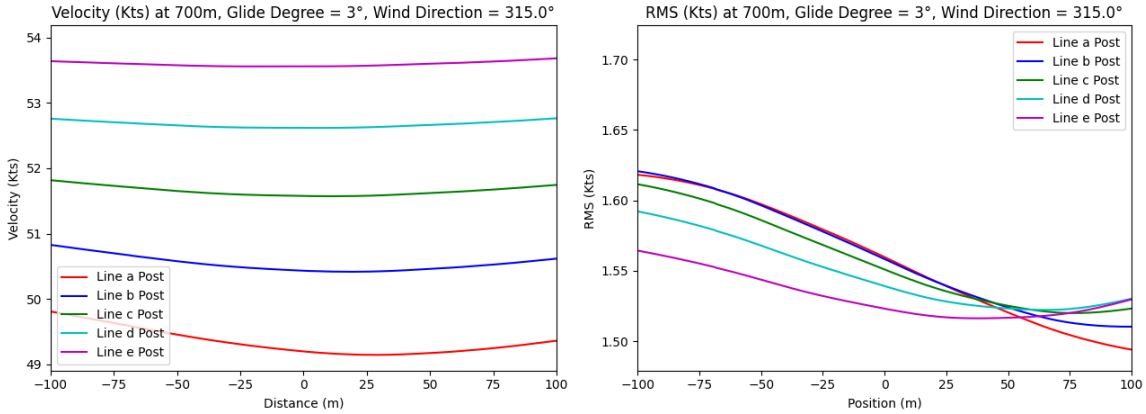


Figure 103: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

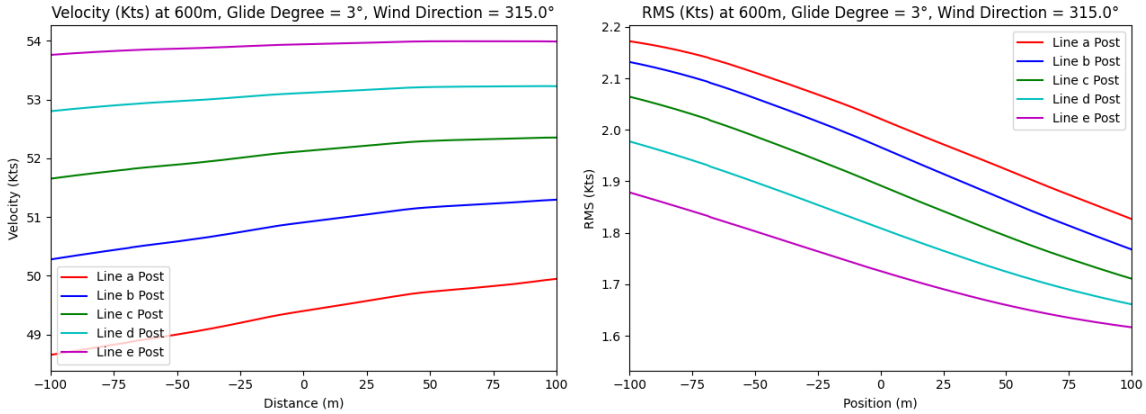


Figure 104: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

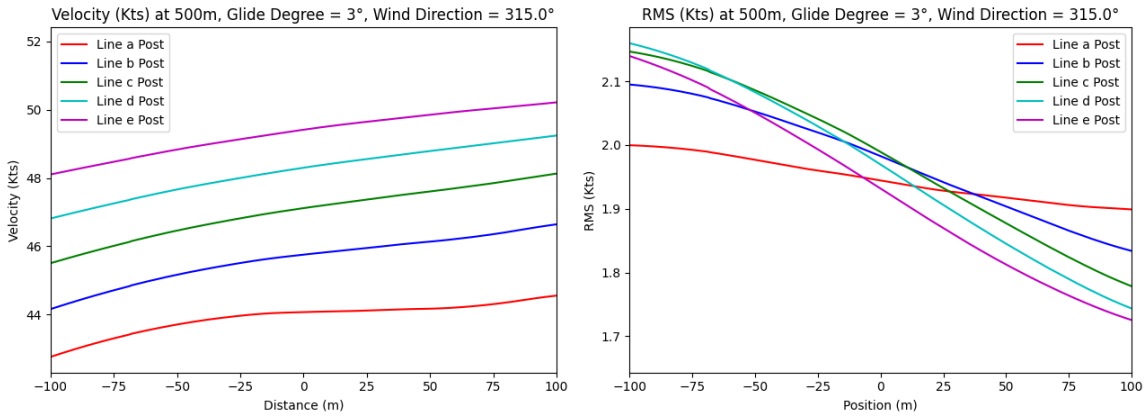


Figure 105: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

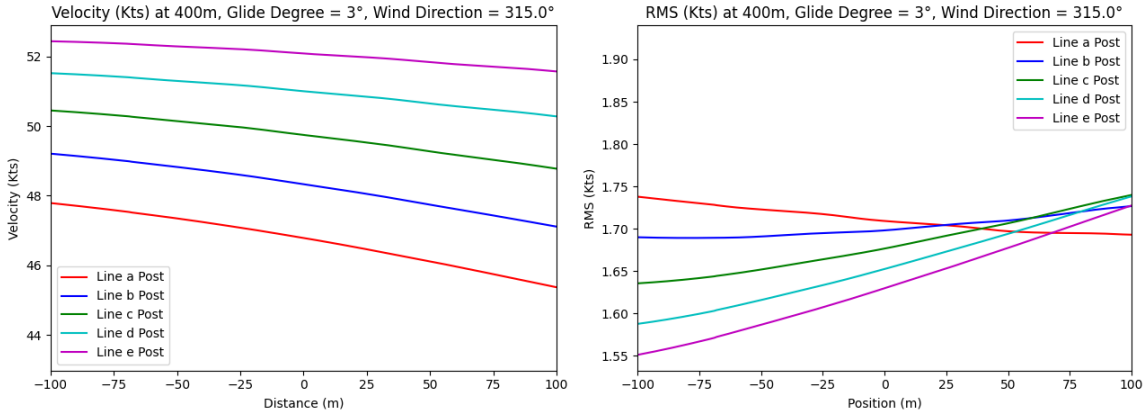


Figure 106: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

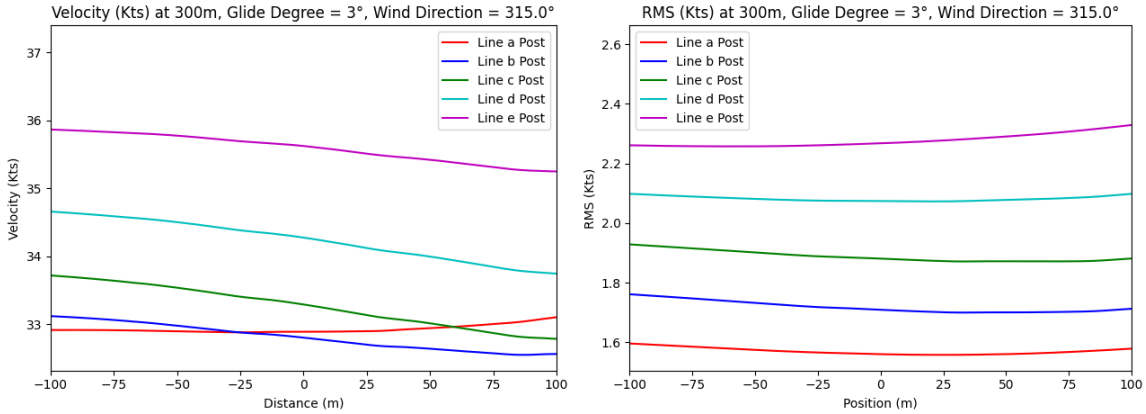


Figure 107: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

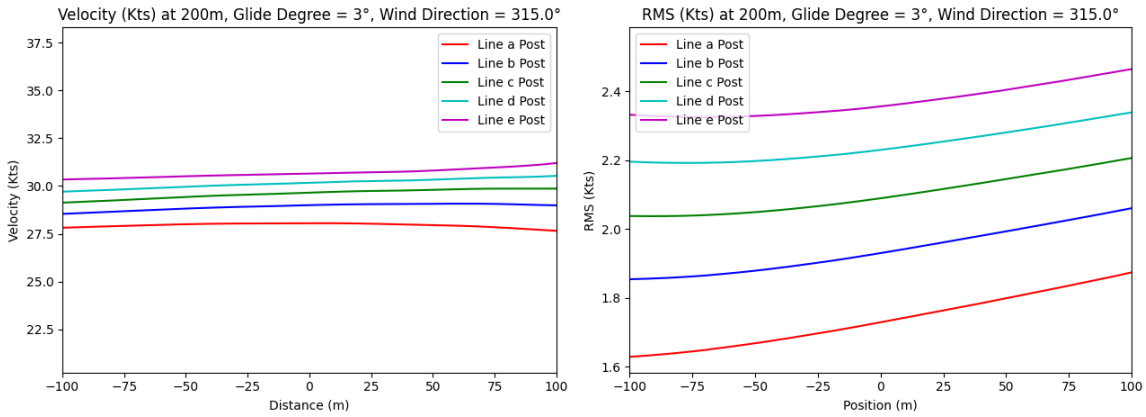


Figure 108: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

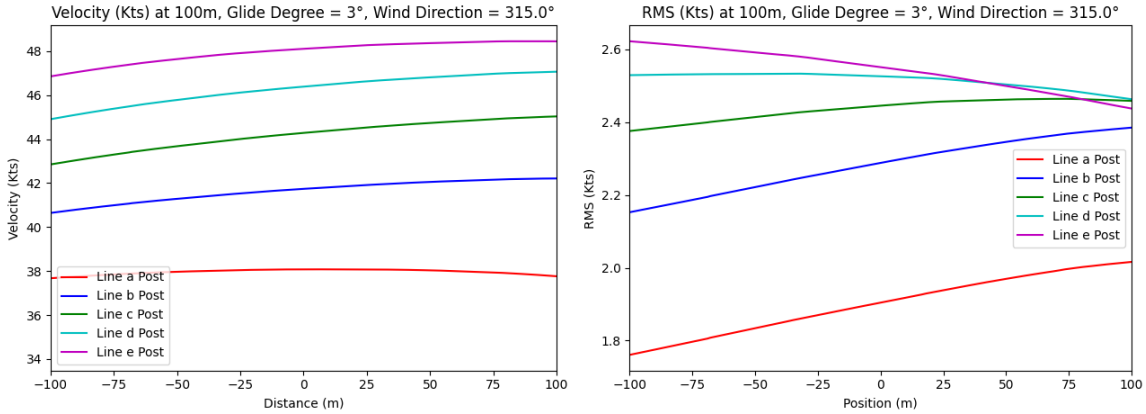


Figure 109: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

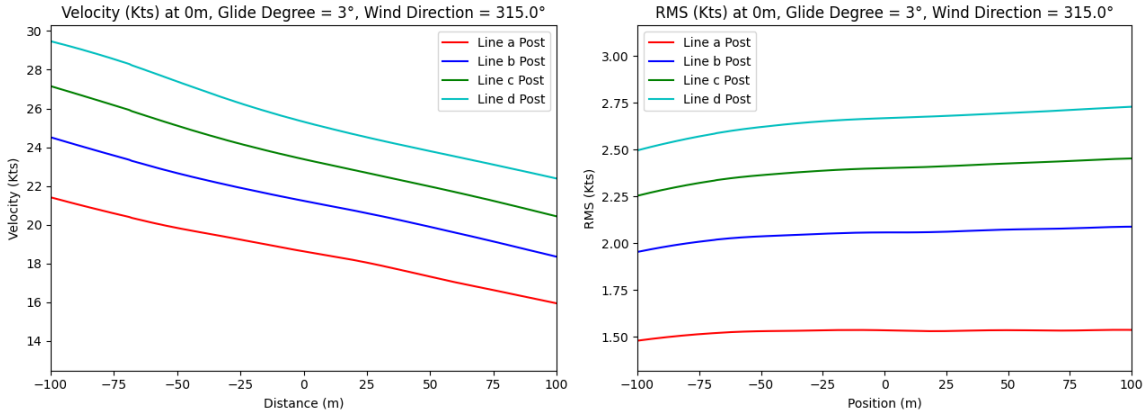


Figure 110: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

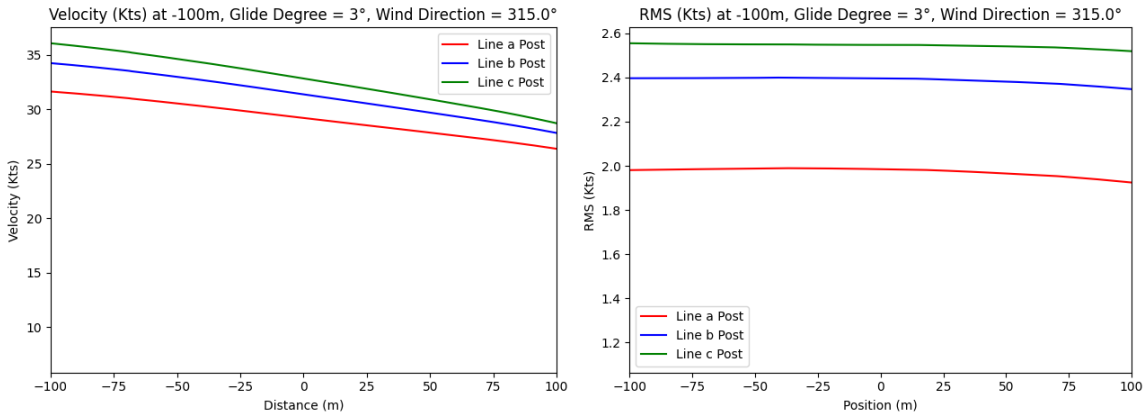


Figure 111: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

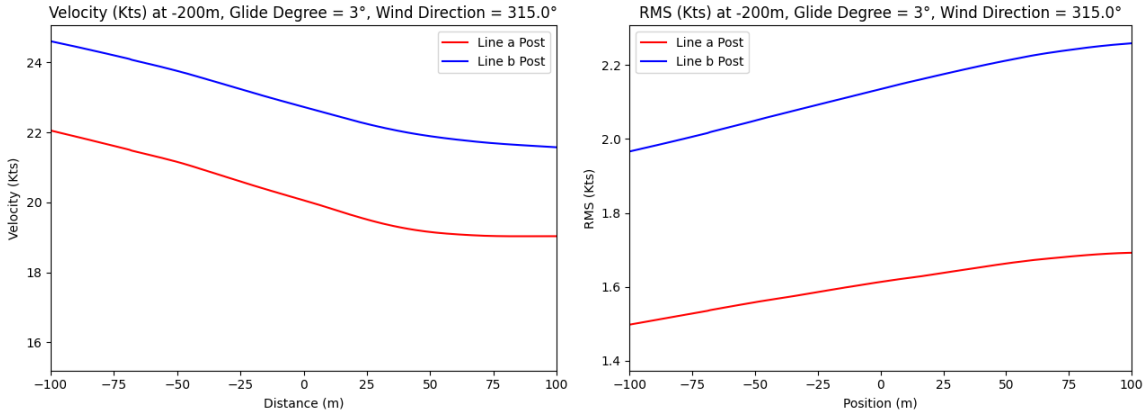


Figure 112: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

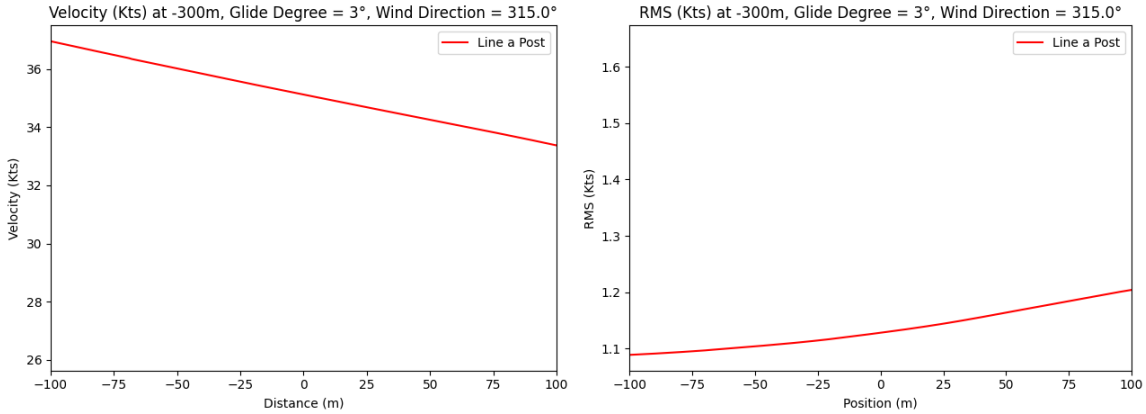


Figure 113: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

Velocity magnitude and turbulence deviation values of CFD models along the runway centerline between chainages $-500m$ to $900m$, consistent with assessment area according to National Airport Safeguarding Framework (NASF), and up to a height of $60m$ above ground level for wind direction 315° with 20 m/s approaching speed are shown in Tables 17 and 18.

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	54.46	56.61	46.77	42.54	40.95	40.97	51.51	40.2	44.91	54.72	52.69	55	54.09	41.14	52.66
55	53.45	56.25	45.43	41.11	38.52	39.54	51.06	38.14	42.79	54.01	51.72	54.37	53.26	38.91	51.5
50	52.29	55.86	44.07	39.58	36.35	37.38	50.7	36.15	40.59	53.2	50.77	53.68	52.34	36.91	50.22
45	51.07	55.44	42.67	37.87	34.56	34.52	50.4	34.36	38.44	52.26	49.85	52.92	51.32	35.1	48.81
40	49.88	54.97	41.25	35.93	33.12	31.4	50.1	32.89	36.47	51.16	48.9	52.03	50.2	33.45	47.25
35	48.81	54.44	39.83	33.7	31.96	28.53	49.72	31.79	34.77	49.86	47.74	50.94	48.96	31.97	45.55
30	47.85	53.81	38.42	31.21	30.98	26.08	49.15	31.01	33.45	48.37	46.18	49.55	47.57	30.72	43.69
25	47.01	53.04	37.03	28.59	30.15	23.98	48.21	30.39	32.67	46.75	44.03	47.75	45.97	29.7	41.69
20	46.25	52.09	35.7	26.03	29.39	22.08	46.78	29.74	32.61	45.07	41.28	45.45	44.15	28.9	39.55
15	45.46	50.91	34.56	23.65	28.64	20.2	44.73	28.85	33.22	43.35	38.33	42.62	42.14	28.26	37.27
10	44.38	49.39	33.78	21.38	27.76	18.18	41.94	27.52	33.95	41.41	35.93	39.23	39.97	27.65	34.77
5	42.14	46.88	33.37	18.92	26.31	15.84	37.53	25.2	33.23	38.48	34.3	34.99	37.56	26.66	31.51

Table 11: Wind Speed in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 315°

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	1.42021	1.21794	1.91303	2.58789	3.05061	2.55986	2.24909	2.90104	2.88527	1.62455	1.69824	1.55008	1.52715	2.53932	2.57402
55	1.45924	1.25101	1.90361	2.74928	2.9633	2.78704	2.27174	2.88469	2.86251	1.66632	1.71241	1.59297	1.53174	2.50771	2.74076
50	1.48347	1.28301	1.90532	2.89923	2.86283	3.00768	2.29391	2.83642	2.78527	1.69643	1.72059	1.63478	1.52892	2.45051	2.87026
45	1.49038	1.31623	1.91797	3.02491	2.77112	3.17353	2.31796	2.75897	2.65281	1.71765	1.73183	1.67919	1.5197	2.37312	2.96157
40	1.48033	1.35338	1.93325	3.11338	2.70154	3.23806	2.34548	2.65982	2.4738	1.73216	1.75437	1.72953	1.50589	2.2784	3.01488
35	1.45604	1.3971	1.93732	3.15052	2.65731	3.19816	2.37715	2.54807	2.26224	1.74005	1.79393	1.78585	1.48966	2.17106	3.03107
30	1.42051	1.4486	1.91589	3.12162	2.63406	3.07992	2.41192	2.43095	2.04022	1.73846	1.85178	1.84118	1.4717	2.05643	3.01081
25	1.37604	1.50541	1.85822	3.01593	2.61839	2.90645	2.44542	2.31003	1.84094	1.72206	1.91088	1.87885	1.44868	1.93734	2.95321
20	1.32535	1.55878	1.75755	2.83323	2.5864	2.68659	2.46659	2.18226	1.69044	1.6859	1.91931	1.87204	1.41197	1.81062	2.85374
15	1.27293	1.59212	1.61169	2.57626	2.50579	2.41323	2.45552	2.04023	1.5621	1.62798	1.80698	1.78559	1.34836	1.66503	2.7005
10	1.22707	1.57876	1.42066	2.22297	2.32768	2.05294	2.37441	1.85497	1.40078	1.54725	1.55252	1.5892	1.24022	1.47654	2.46037
5	1.14281	1.4343	1.19305	1.65935	1.89814	1.50971	1.98657	1.47603	1.18706	1.33723	1.21996	1.24337	1.10589	1.19934	1.96769

Table 12: Turbulence deviation or RMS in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 315°

Wind Direction = 330°

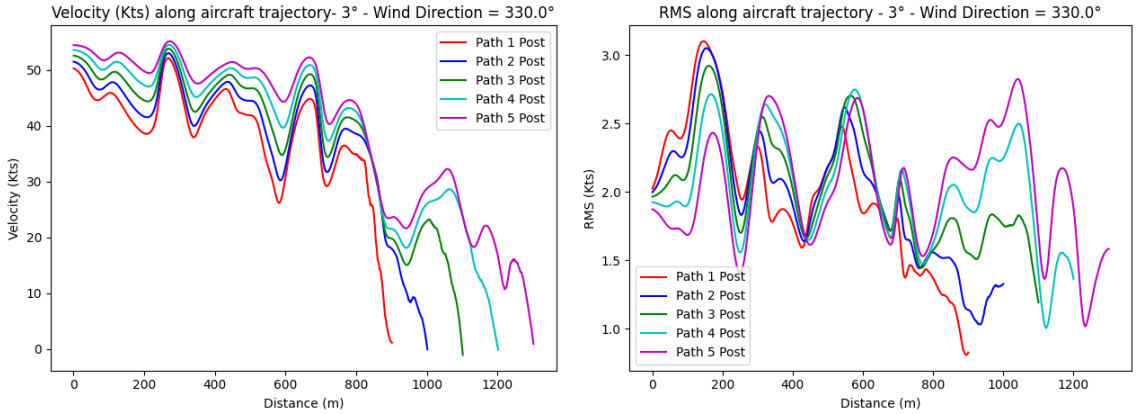


Figure 114: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

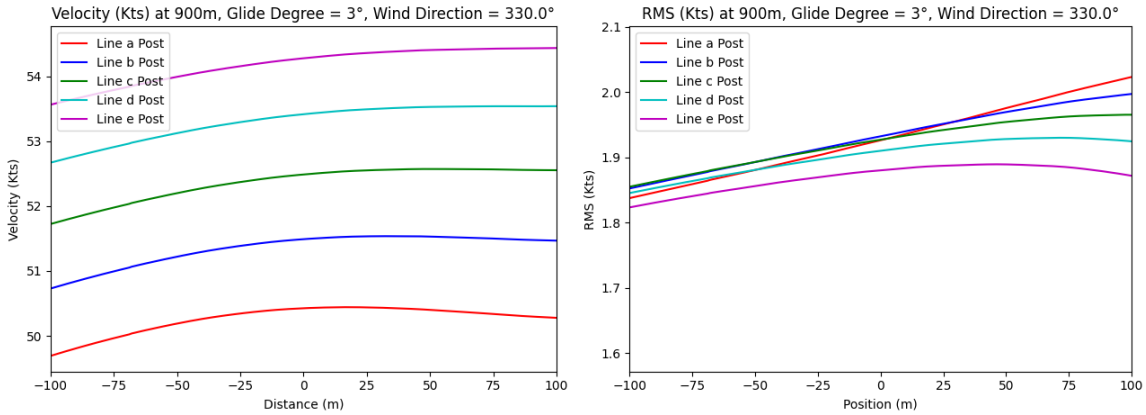


Figure 115: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

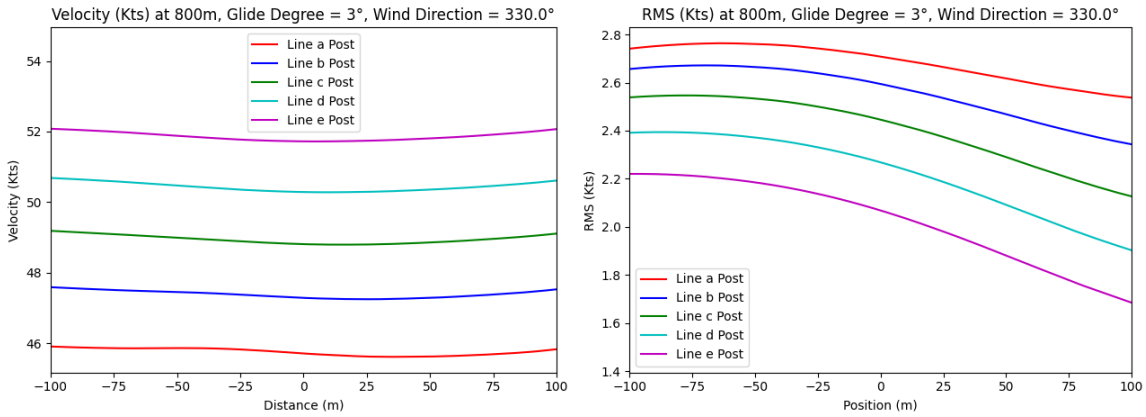


Figure 116: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

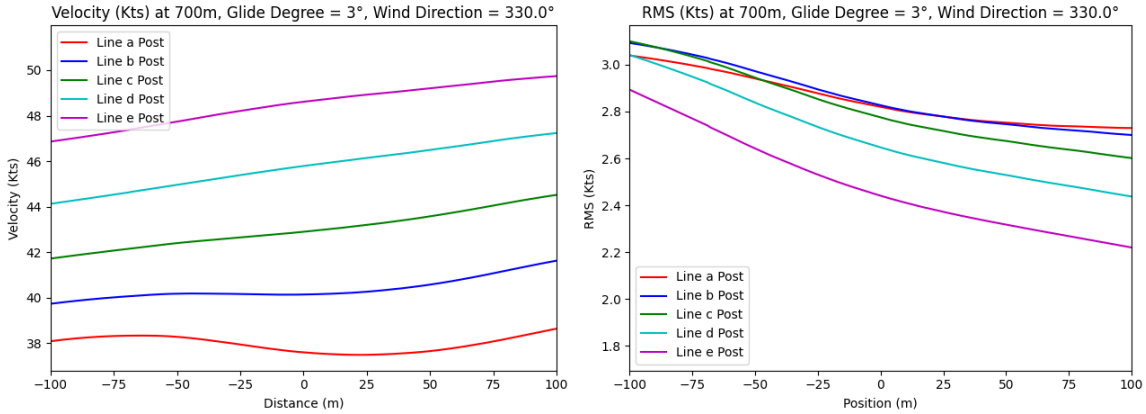


Figure 117: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

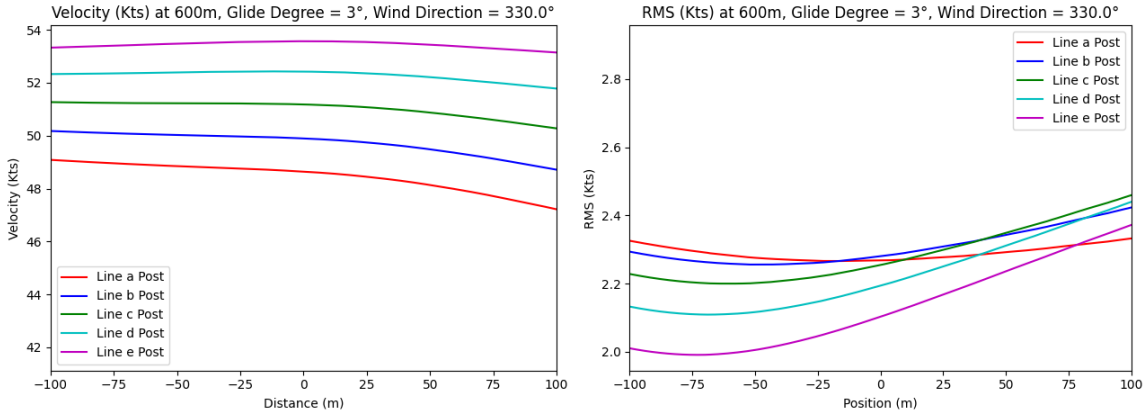


Figure 118: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

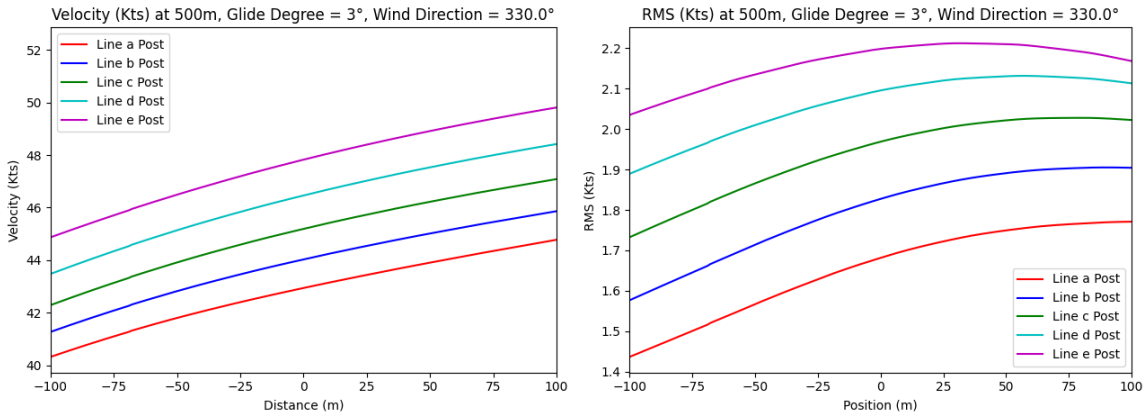


Figure 119: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

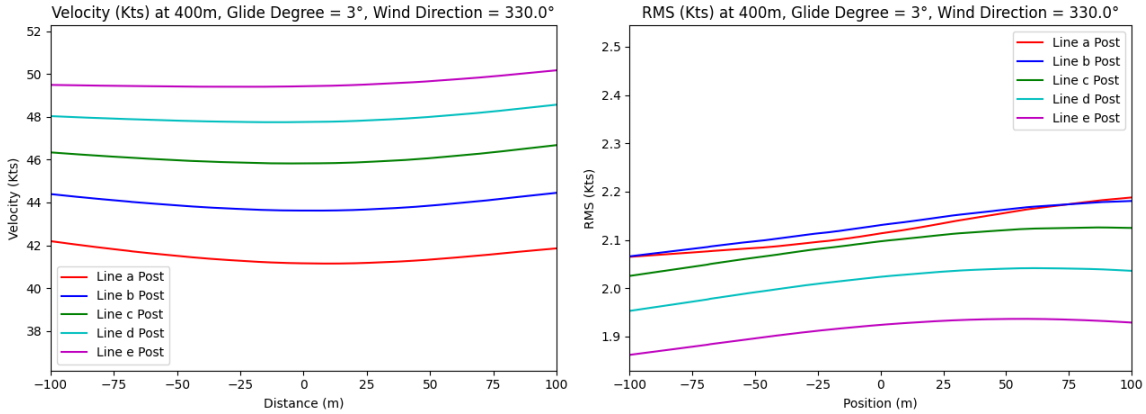


Figure 120: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

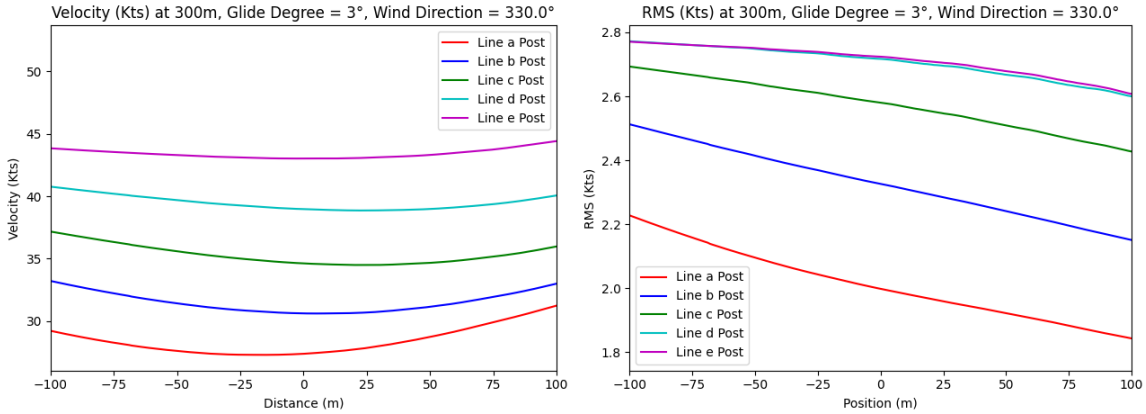


Figure 121: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

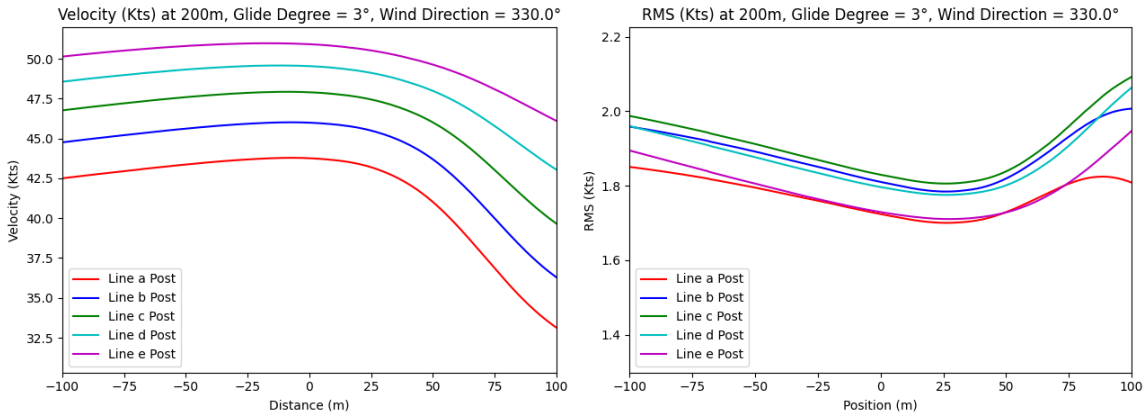


Figure 122: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

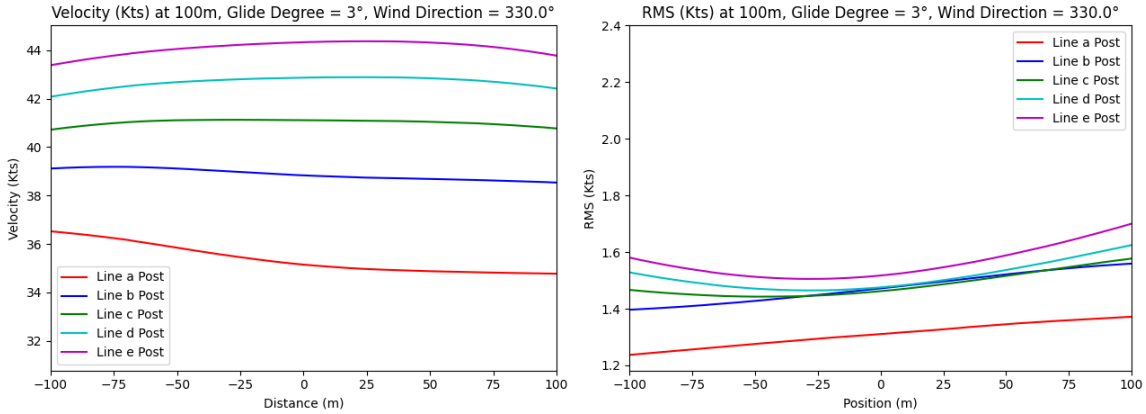


Figure 123: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

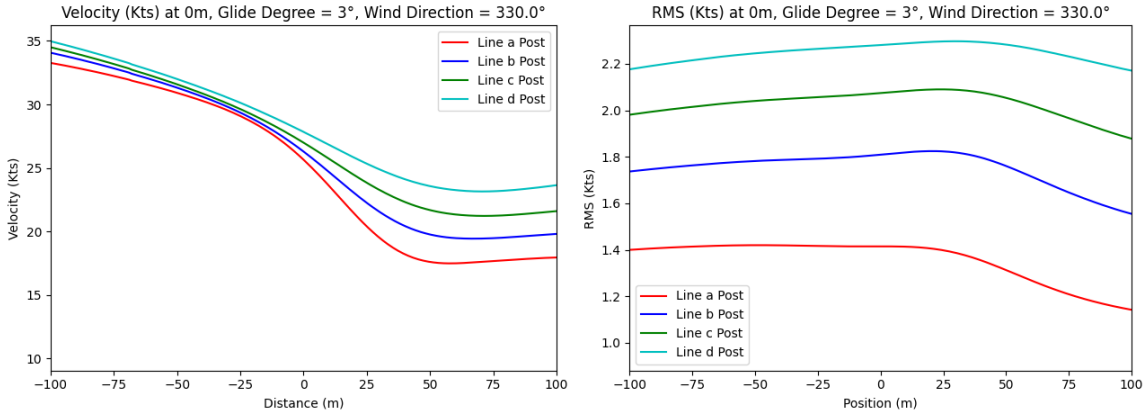


Figure 124: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

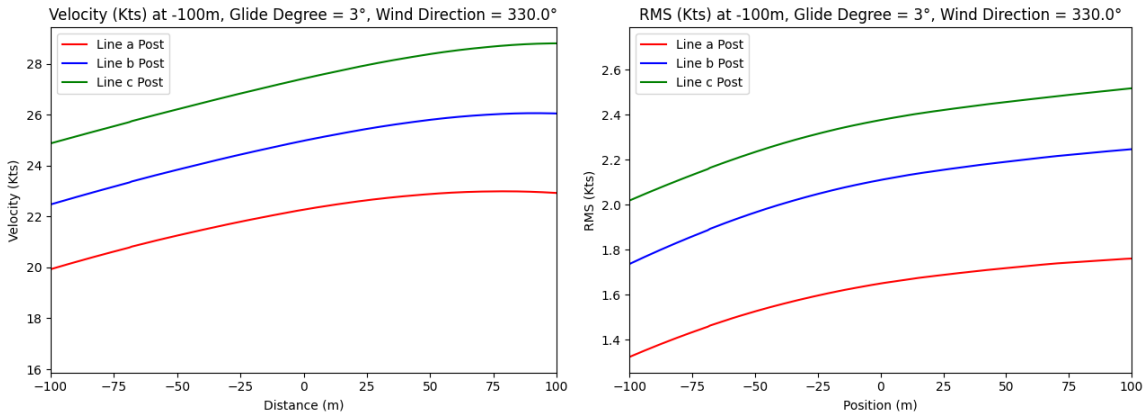


Figure 125: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

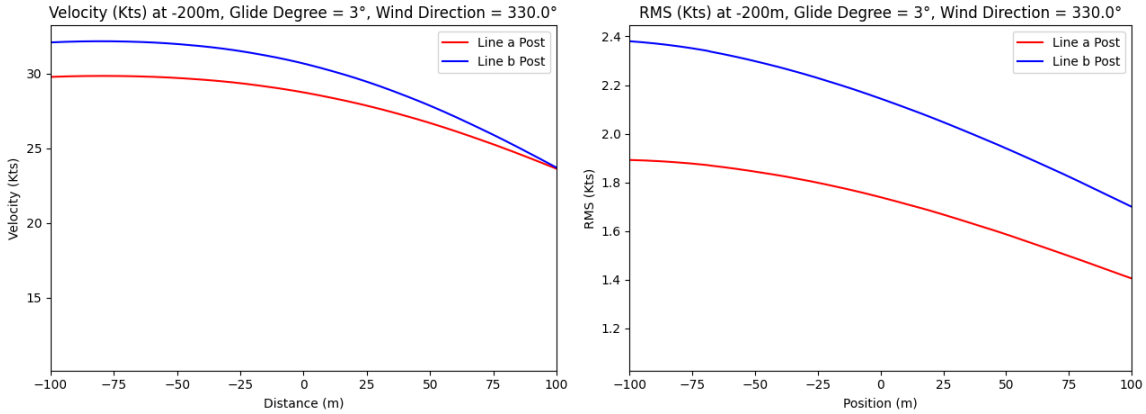


Figure 126: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

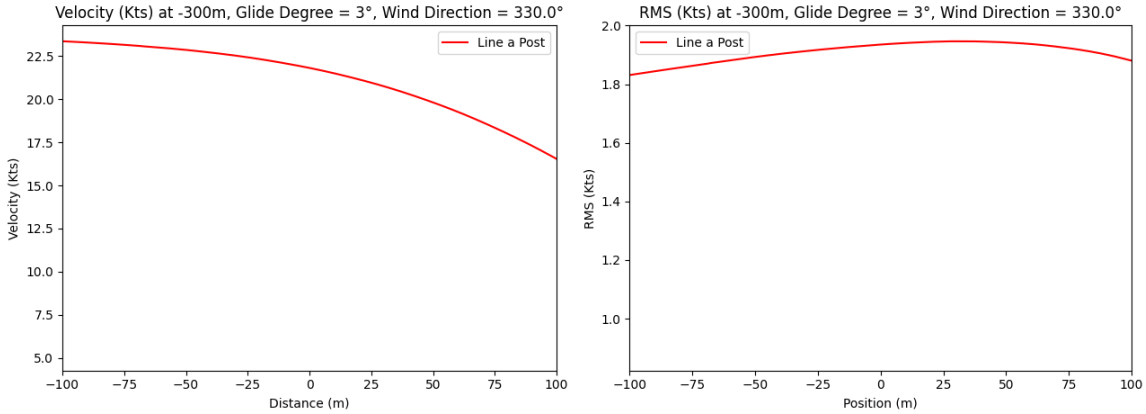


Figure 127: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

Velocity magnitude and turbulence deviation values of CFD models along the runway centerline between chainages $-500m$ to $900m$, consistent with assessment area according to National Airport Safeguarding Framework (NASF), and up to a height of $60m$ above ground level for wind direction 330° with 20 m/s approaching speed are shown in Tables 19 and 20.

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	42.3	44.55	45.28	42.1	49.81	42.5	51.75	54.73	55.01	54.23	53.15	54.87	50.9	51.34	53.06
55	39.9	42.66	42.95	38.93	48.07	40.25	50.62	53.81	53.76	53.32	51.91	53.81	48.62	49.92	52.07
50	37.33	40.9	40.51	35.57	46.17	37.92	49.45	52.75	52.1	52.27	50.61	52.6	46.13	48.46	50.99
45	34.89	39.33	37.92	32.17	44.09	35.51	48.25	51.5	49.91	51.07	49.27	51.23	43.45	46.9	49.8
40	32.73	37.98	35.14	29.06	41.83	33.03	47.06	49.96	46.99	49.67	47.95	49.76	40.62	45.22	48.52
35	30.95	36.87	32.17	26.55	39.4	30.48	45.88	47.98	43.19	48.05	46.7	48.26	37.75	43.41	47.14
30	29.66	36	29.11	24.74	36.78	27.92	44.71	45.45	38.96	46.15	45.57	46.86	34.98	41.48	45.67
25	28.97	35.35	26.09	23.6	34	25.47	43.51	42.43	35.22	43.94	44.55	45.69	32.43	39.49	44.12
20	28.88	34.84	23.31	23.15	31.18	23.27	42.17	39.18	32.59	41.38	43.59	44.8	30.14	37.52	42.51
15	29.31	34.38	20.85	23.33	28.46	21.37	40.53	35.97	31.06	38.5	42.44	44.1	28.06	35.62	40.81
10	30.08	33.74	18.67	23.79	25.82	19.67	38.31	32.96	30.29	35.21	40.7	43.29	26.13	33.75	38.93
5	30.66	32.3	16.48	23.64	22.79	17.87	34.56	29.89	29.29	30.62	37.3	41.12	23.93	31.49	36.49

Table 13: Wind Speed in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 330°

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	2.60065	3.5004	3.13582	3.44246	2.73983	3.37076	1.98402	1.49407	1.71844	1.56975	2.13418	2.19983	2.09864	1.79311	1.94662
55	2.66772	3.54868	3.26559	3.51137	2.81219	3.36281	1.98877	1.52649	1.92669	1.65438	2.17776	2.31852	2.32774	2.00627	1.98089
50	2.71363	3.55502	3.37182	3.45849	2.87002	3.3099	1.97795	1.56513	2.14517	1.75163	2.18456	2.40559	2.516	2.22028	2.00828
45	2.70396	3.52166	3.45224	3.28805	2.91131	3.2106	1.94978	1.62317	2.35628	1.85801	2.1538	2.45322	2.64912	2.42224	2.03146
40	2.62303	3.45252	3.50001	3.03527	2.93267	3.0646	1.90324	1.71436	2.53403	1.96585	2.08729	2.45326	2.7192	2.59645	2.05225
35	2.47325	3.35245	3.50293	2.75264	2.92891	2.87357	1.83944	1.84123	2.62717	2.06486	1.99013	2.40109	2.72684	2.72634	2.07055
30	2.2719	3.22481	3.44568	2.48025	2.89216	2.64454	1.76289	1.97868	2.57501	2.14312	1.87069	2.30039	2.68099	2.79883	2.08313
25	2.04521	3.07092	3.31657	2.24049	2.81195	2.39134	1.68273	2.07423	2.37814	2.18729	1.7412	2.16343	2.59219	2.8048	2.082
20	1.81628	2.88945	3.11225	2.04377	2.67943	2.12454	1.61387	2.08139	2.10096	2.18339	1.6204	2.00534	2.4631	2.73748	2.05328
15	1.59045	2.67311	2.83221	1.87318	2.48829	1.84105	1.57364	1.98526	1.80694	2.12019	1.53178	1.83674	2.28323	2.58745	1.97576
10	1.35295	2.39538	2.4547	1.68403	2.21851	1.52642	1.55829	1.78558	1.525	1.98259	1.48275	1.65926	2.02111	2.32751	1.81278
5	1.11555	1.93917	1.84579	1.39067	1.73072	1.12123	1.35345	1.40603	1.20725	1.5697	1.30778	1.42757	1.57192	1.84497	1.46924

Table 14: Turbulence deviation or RMS in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 330°

Wind Direction = 345°

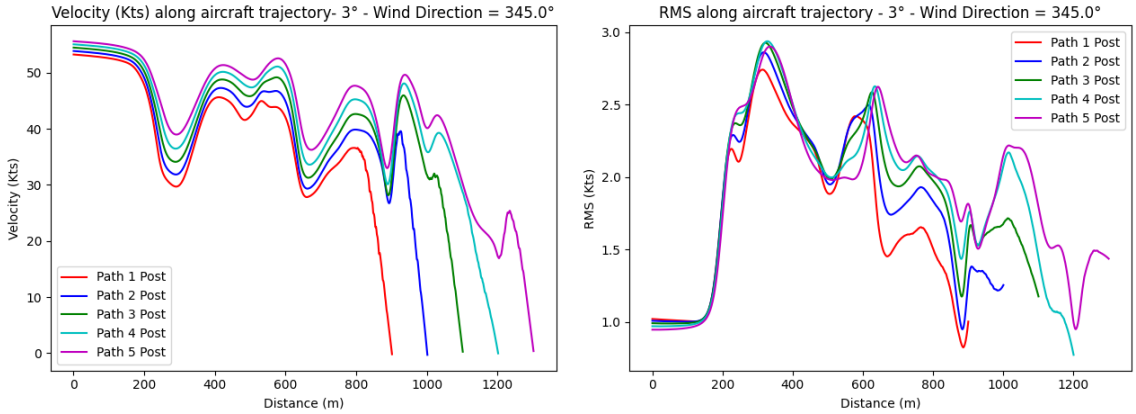


Figure 128: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

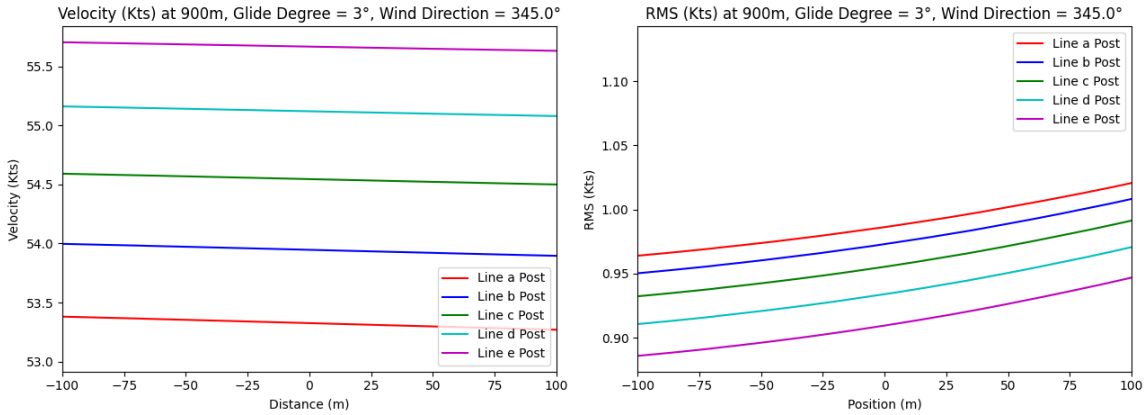


Figure 129: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

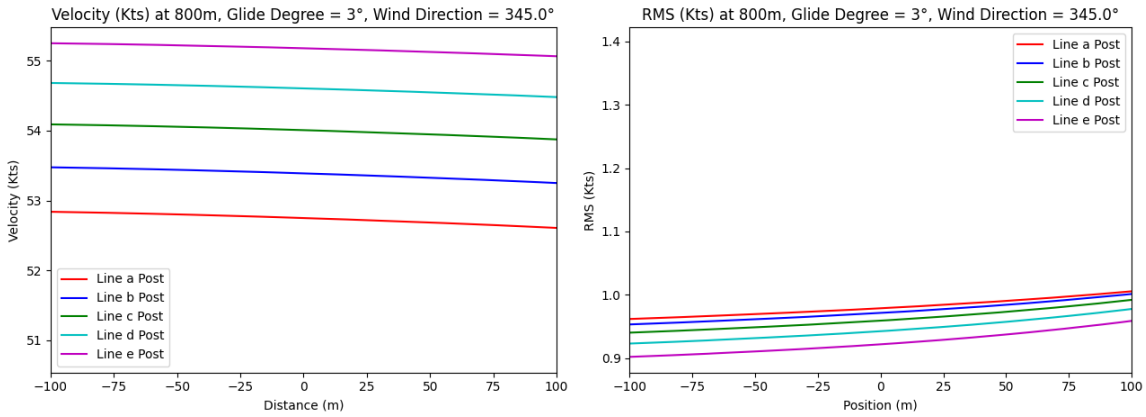


Figure 130: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

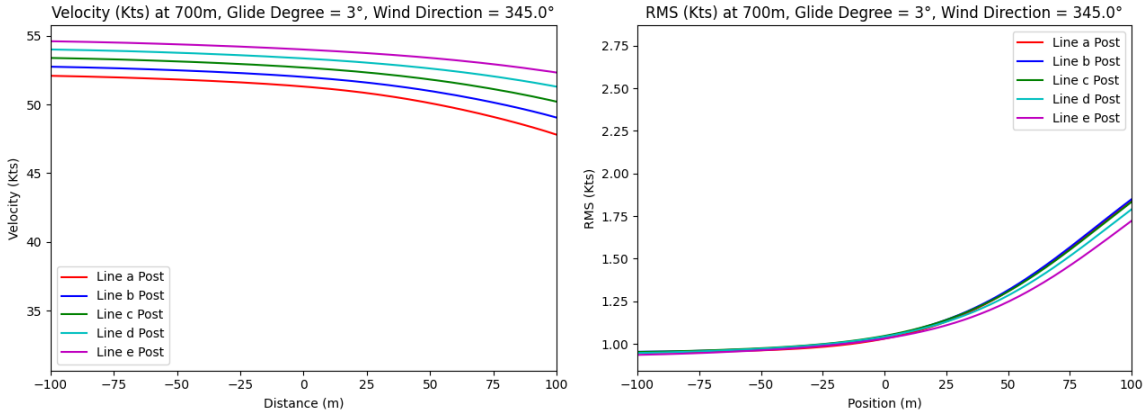


Figure 131: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

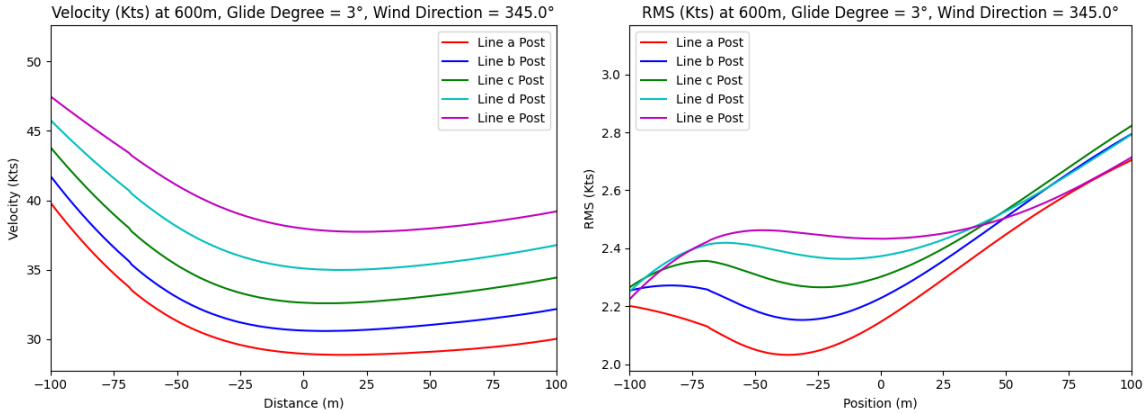


Figure 132: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

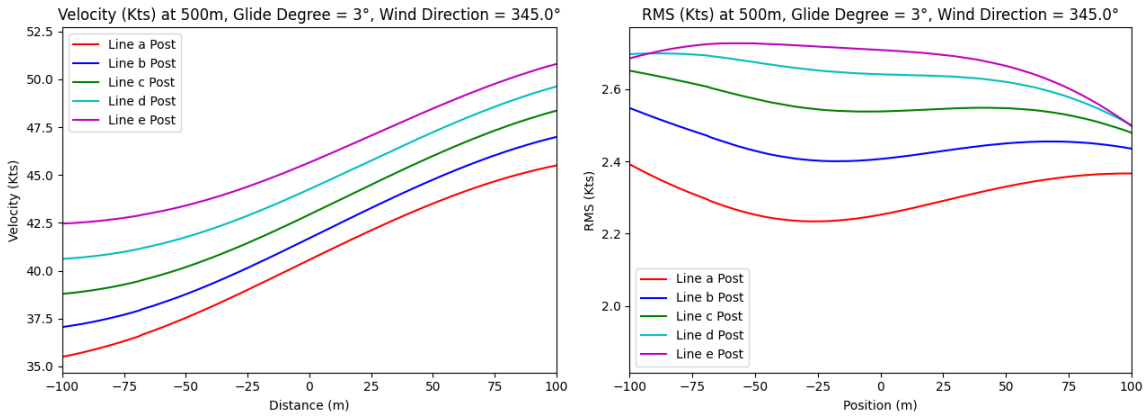


Figure 133: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

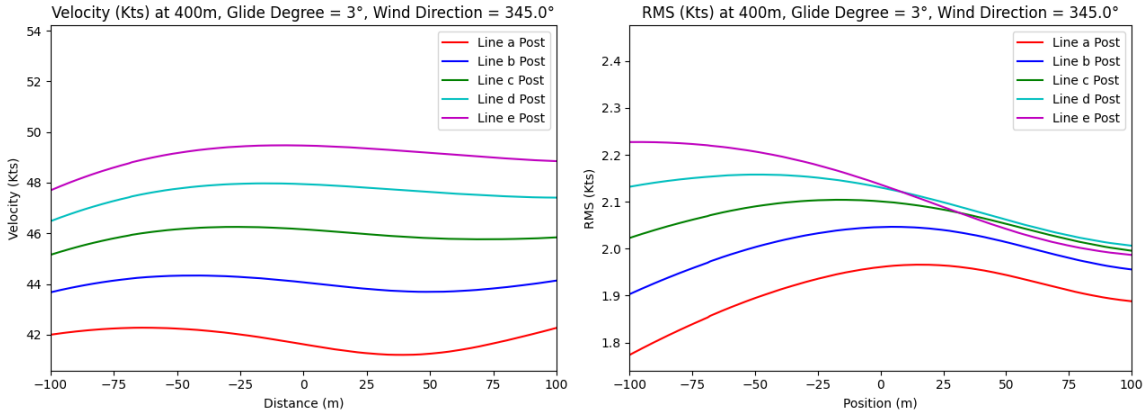


Figure 134: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

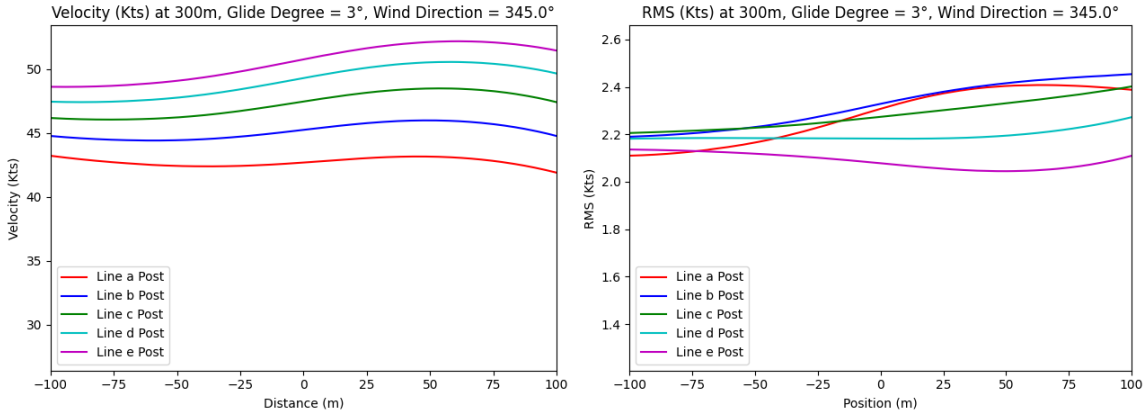


Figure 135: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

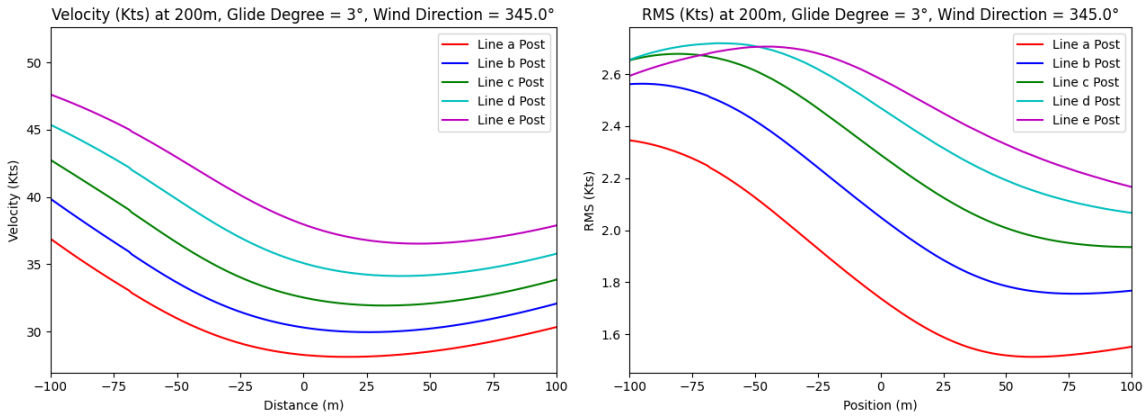


Figure 136: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

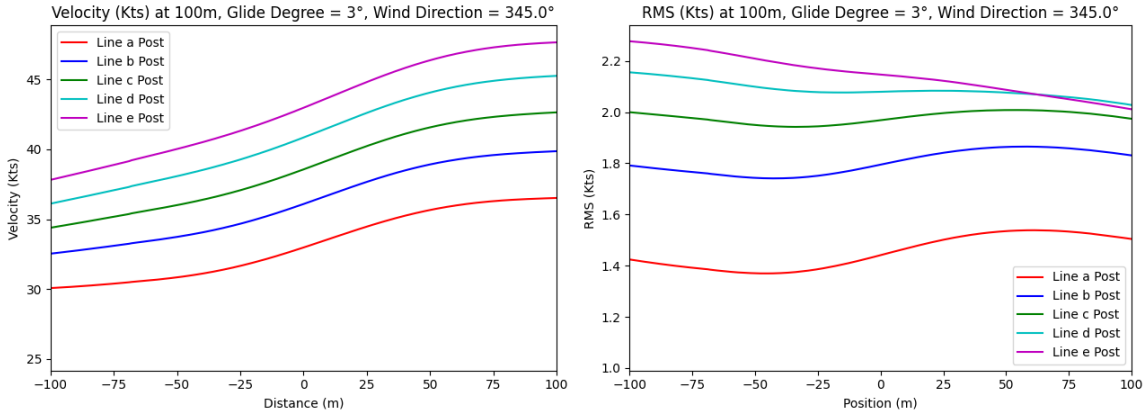


Figure 137: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

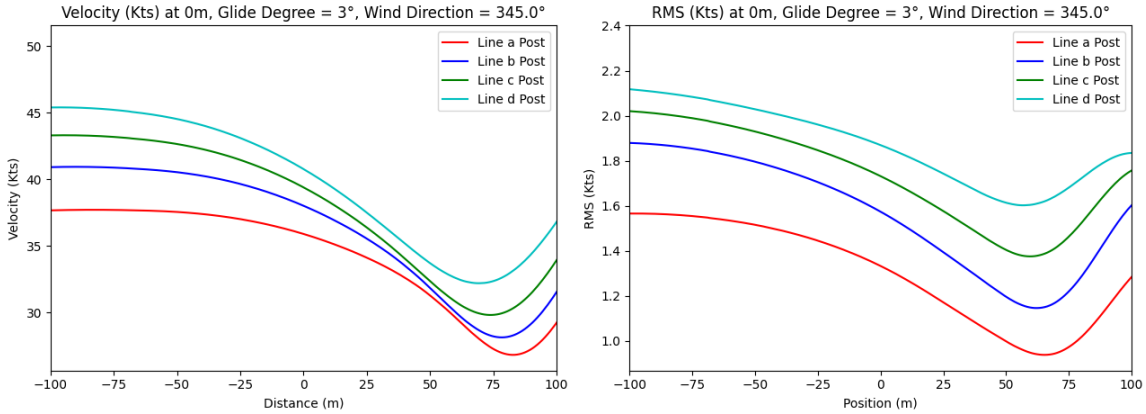


Figure 138: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

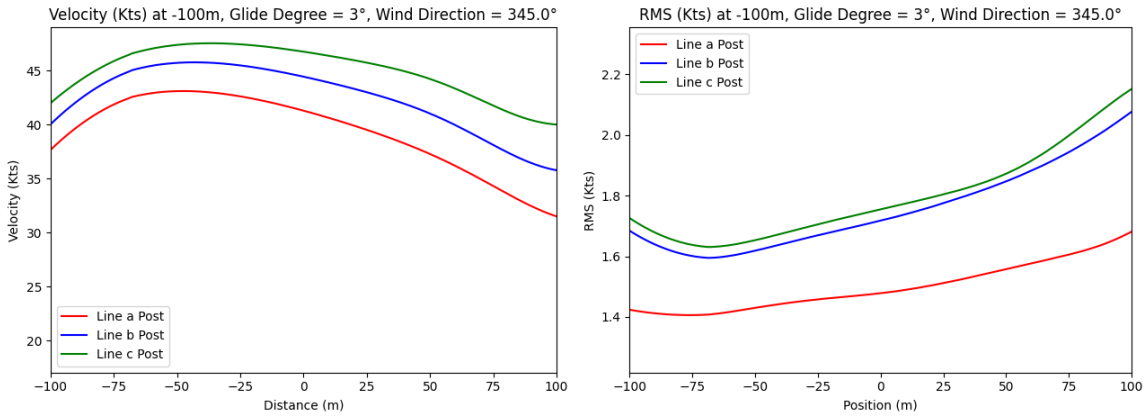


Figure 139: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

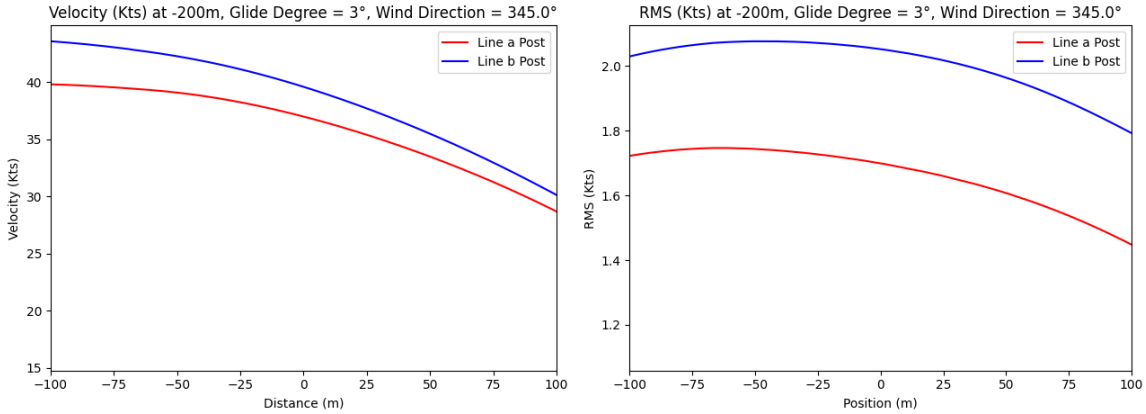


Figure 140: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

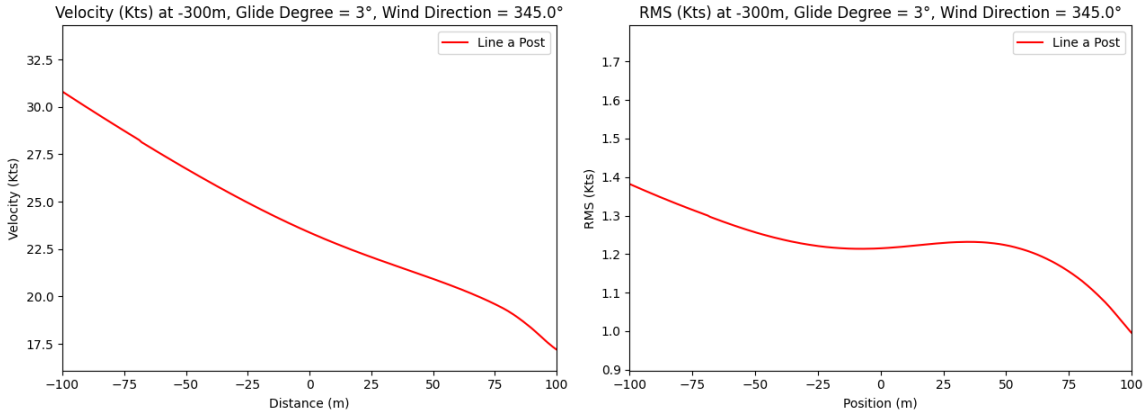


Figure 141: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

Velocity magnitude and turbulence deviation values of CFD models along the runway centerline between chainages $-500m$ to $900m$, consistent with assessment area according to National Airport Safeguarding Framework (NASF), and up to a height of $60m$ above ground level for wind direction 345° with 20 m/s approaching speed are shown in Tables 21 and 22.

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	37.92	46.08	33.61	47.24	56.78	53.69	56.34	50.48	55.94	53.1	53.39	43.01	52.82	54.78	54.79
55	36.54	44.83	30.78	45.46	56.26	52.46	55.72	48.6	55.26	52.04	52.44	40.54	51.87	54.2	54.23
50	35.36	43.64	28.53	43.61	55.61	51.06	54.92	46.45	54.49	50.91	51.43	38.15	50.86	53.62	53.64
45	34.34	42.56	26.65	41.7	54.75	49.47	53.91	44.1	53.58	49.7	50.35	35.86	49.8	53.01	53.03
40	33.48	41.56	25.06	39.75	53.62	47.59	52.64	41.72	52.45	48.39	49.19	33.65	48.67	52.39	52.4
35	32.77	40.64	23.74	37.8	52.15	45.29	51.1	39.45	51.01	46.97	47.95	31.5	47.44	51.75	51.75
30	32.2	39.73	22.65	35.91	50.18	42.46	49.28	37.32	49.17	45.43	46.61	29.49	46.08	51.08	51.07
25	31.75	38.76	21.73	34.15	47.36	39.25	47.17	35.34	46.92	43.76	45.16	27.65	44.48	50.36	50.35
20	31.37	37.63	20.91	32.59	43.6	36.11	44.83	33.52	44.32	41.93	43.58	26	42.49	49.55	49.54
15	31	36.21	20.06	31.25	39.42	33.41	42.3	31.84	41.55	39.86	41.86	24.49	39.99	48.59	48.58
10	30.45	34.38	19.03	30.07	35.42	31.11	39.62	30.16	38.73	37.41	39.9	23.04	37.05	47.25	47.26
5	29.15	31.55	17.55	28.65	31.33	28.71	36.35	28.04	35.48	33.91	37.15	21.55	33.34	44.87	44.91

Table 15: Wind Speed in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 345°

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	3.39911	2.35963	3.58938	2.86434	1.32009	1.59536	1.12821	2.17063	1.43708	1.69457	2.39049	2.53229	1.67582	0.96889	0.98138
55	3.39835	2.36503	3.49686	2.89426	1.39508	1.67046	1.26513	2.22651	1.57025	1.80562	2.45139	2.65275	1.7522	0.98494	0.99957
50	3.36976	2.34884	3.3535	2.89083	1.47559	1.72918	1.4233	2.26503	1.70472	1.89554	2.48937	2.75024	1.80716	0.99662	1.01394
45	3.31294	2.31469	3.1711	2.85332	1.56352	1.77195	1.58545	2.27979	1.84536	1.96032	2.50465	2.80918	1.83824	1.0036	1.02406
40	3.22763	2.26877	2.95583	2.78132	1.65962	1.8052	1.73661	2.2656	1.99693	1.99793	2.49801	2.8187	1.84381	1.00583	1.02975
35	3.11348	2.21875	2.71467	2.67555	1.7639	1.8361	1.86615	2.22076	2.15701	2.00769	2.47022	2.773	1.82308	1.00345	1.03098
30	2.96951	2.1726	2.45501	2.53897	1.87672	1.86248	1.96482	2.14604	2.30928	1.98978	2.42121	2.67105	1.77719	0.99683	1.02794
25	2.79364	2.13703	2.18356	2.3771	1.99783	1.86889	2.02224	2.04303	2.4213	1.94486	2.34899	2.51731	1.71068	0.98669	1.02102
20	2.58211	2.11264	1.90565	2.19666	2.10684	1.83818	2.0262	1.91044	2.45241	1.87495	2.24883	2.31692	1.6283	0.97448	1.01111
15	2.32779	2.08552	1.62427	2.00041	2.14926	1.75925	1.96314	1.74383	2.37067	1.78656	2.11229	2.06747	1.53281	0.96341	1.00026
10	2.01264	2.013	1.33364	1.77329	2.05459	1.60475	1.81519	1.53093	2.15847	1.6896	1.91979	1.74637	1.42709	0.9614	0.99391
5	1.56254	1.71922	0.99583	1.43064	1.64624	1.27942	1.48392	1.20252	1.7197	1.42579	1.56646	1.30921	1.20493	0.97113	0.98949

Table 16: Turbulence deviation or RMS in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 345°

10. APPENDIX B Pre-Development Results

This Appendix shows the CFD results of the wind assessment considering the Pre-Development scenario. Sample results of CFD models along runway 23R/05L and 10m above ground level are presented based on the following wind conditions:

- approach wind speed is 20m/s (38.9 Kts).
- approach wind directions for the runway 23R/05L is 315°, 330°, and 345°.

Figure 142 summaries the CFD model for the Pre-Development scenario. Further, Figure 143 shows the sampling locations of the simulation results where results are sampled at:

- A horizontal slice at 10m above the ground;
- A vertical slice across the proposed development.

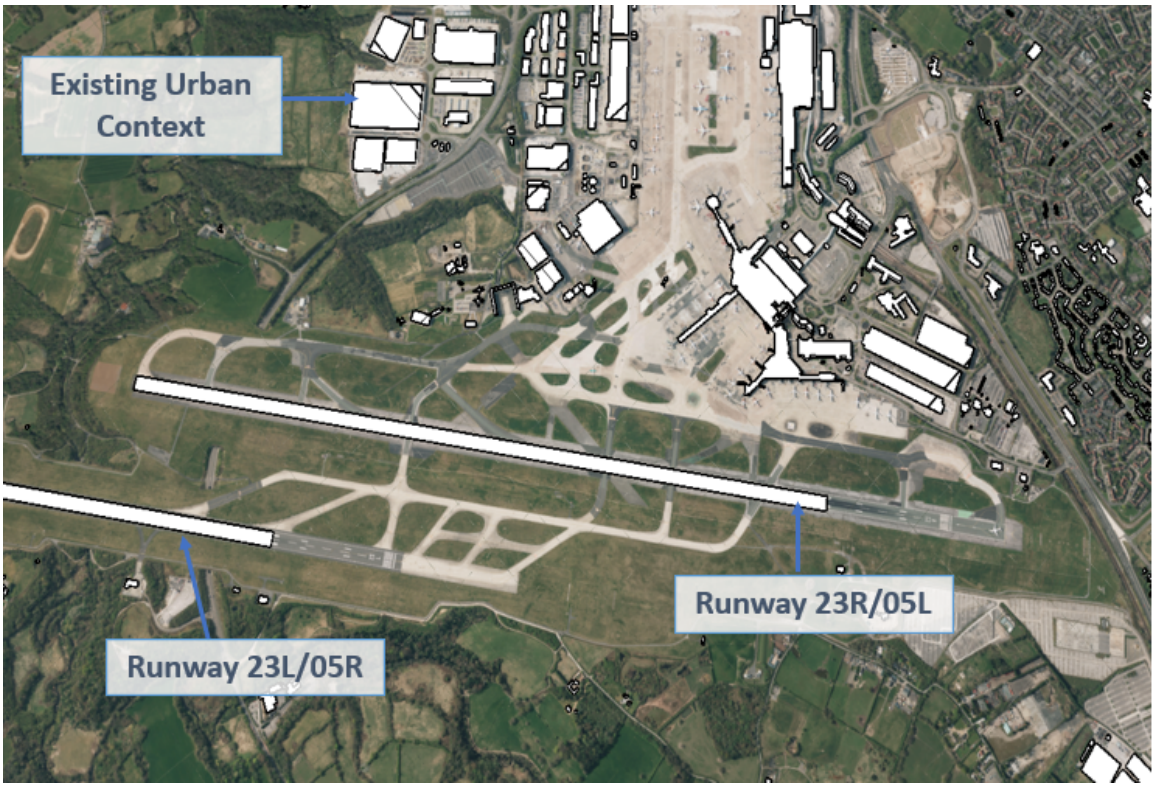


Figure 142: Summary of the CFD Model for the Pre-Development Scenario.

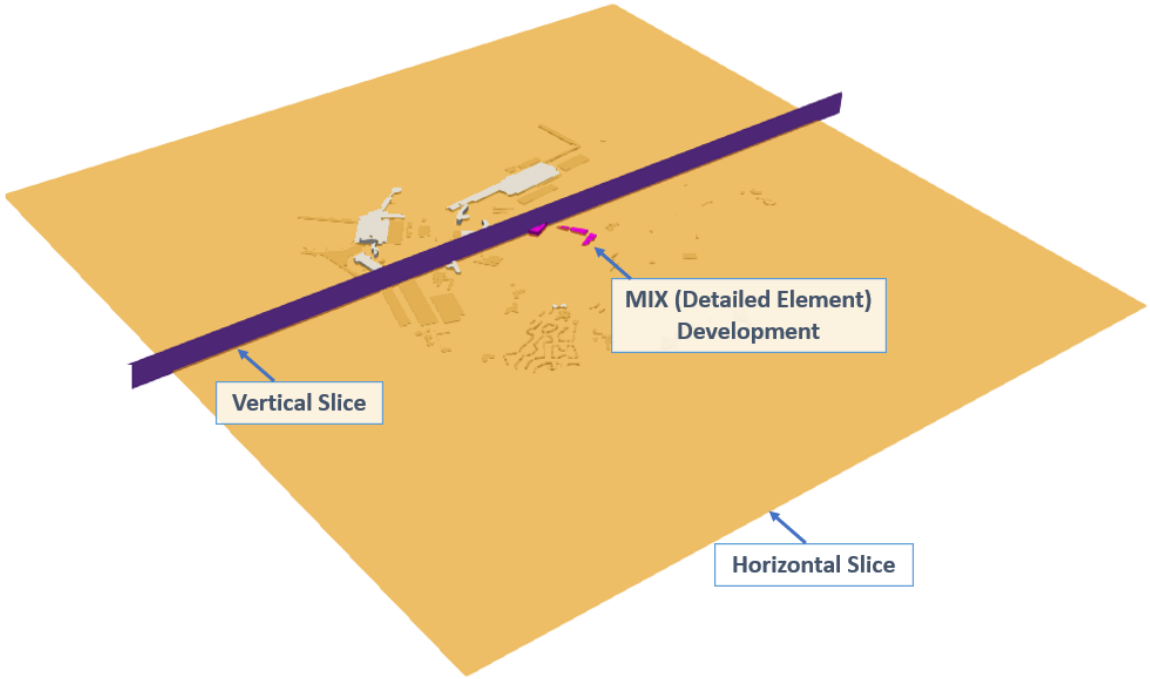


Figure 143: 3D View of the Sampling Locations.

FLOW VELOCITY and TURBULENCE RESULTS FOR RUNWAY 23R/05L (PRE-DEVELOPMENT):

Results of velocity and turbulence kinetic energy of the highest wind speed scenario (38.9 Kts) along runway 23R/05L and 10m above the ground are presented in Figures 144 to 149.

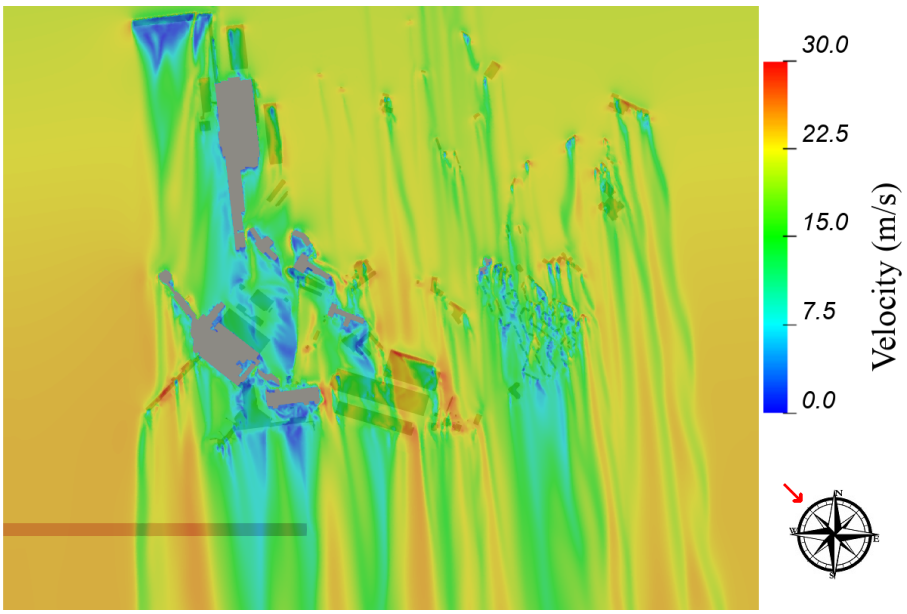


Figure 144: Flow Velocity Results at $Z = 10m$ Above the Ground and Along Runway 23R/05L - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 315.00°.

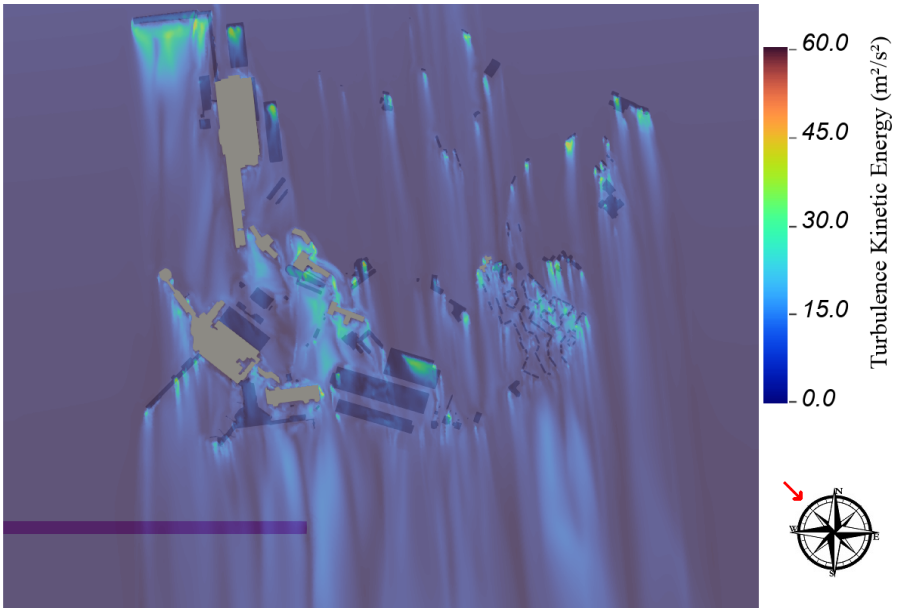


Figure 145: Turbulence Kinetic Energy Results at $Z = 10m$ Above the Ground - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 315.00°.

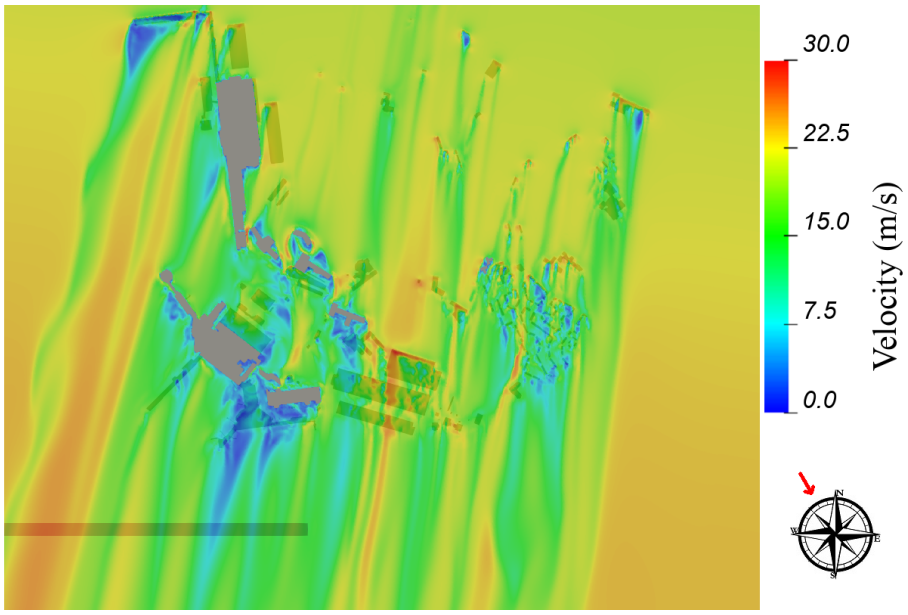


Figure 146: Flow Velocity Results at $Z = 10m$ Above the Ground and Along Runway 23R/05L - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 330.00°.

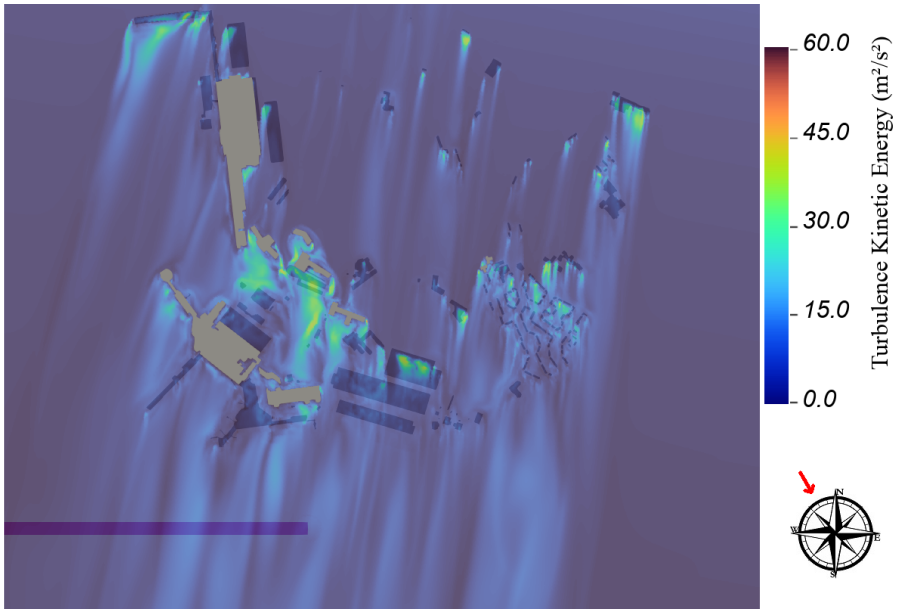


Figure 147: Turbulence Kinetic Energy Results at $Z = 10m$ Above the Ground - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 330.00°.

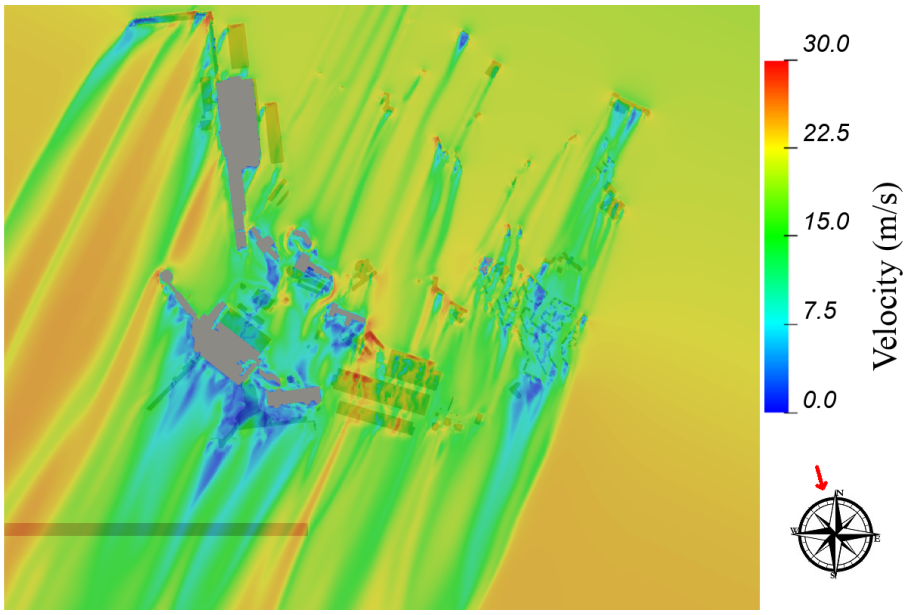


Figure 148: Flow Velocity Results at $Z = 10m$ Above the Ground and Along Runway 23R/05L - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 345.00°.

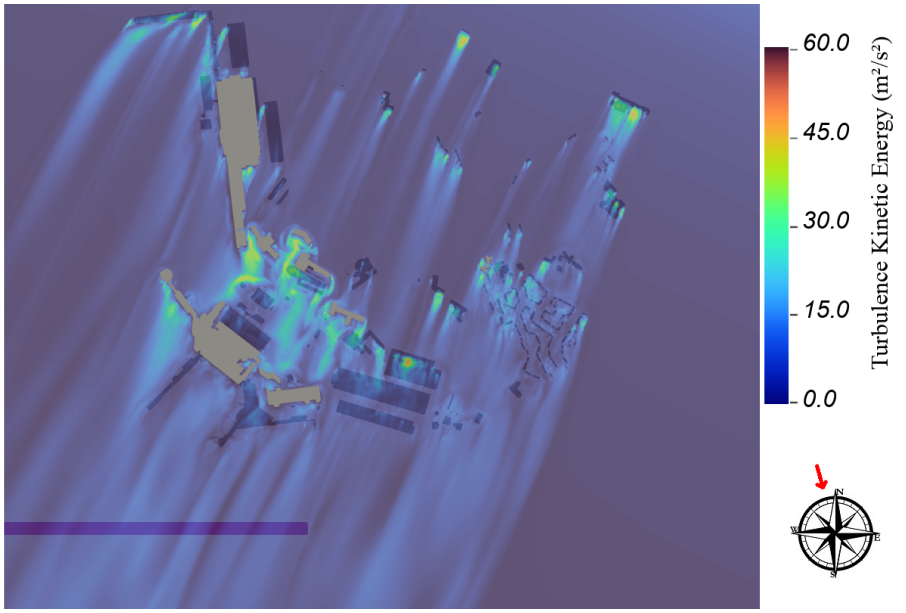


Figure 149: Turbulence Kinetic Energy Results at $Z = 10m$ Above the Ground - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 345.00°.

Figures 150 - 152 shows airflow velocity in a vertical slice along the runway, highlighting the effects of the new buildings on the local wind.

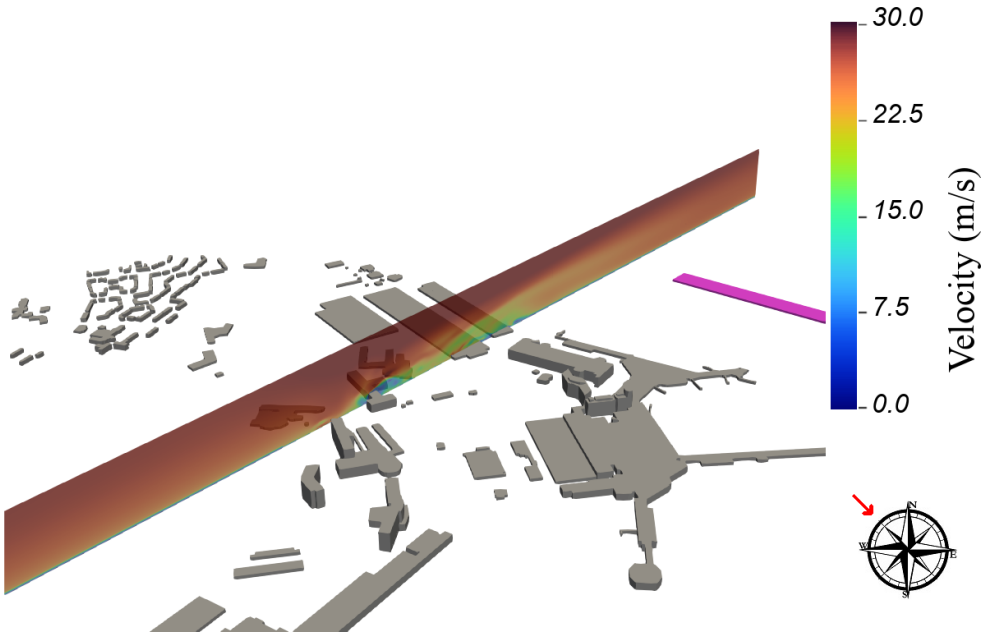


Figure 150: Flow Velocity on a 200m High Slice Across the Existing Conditions - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 315.00°.

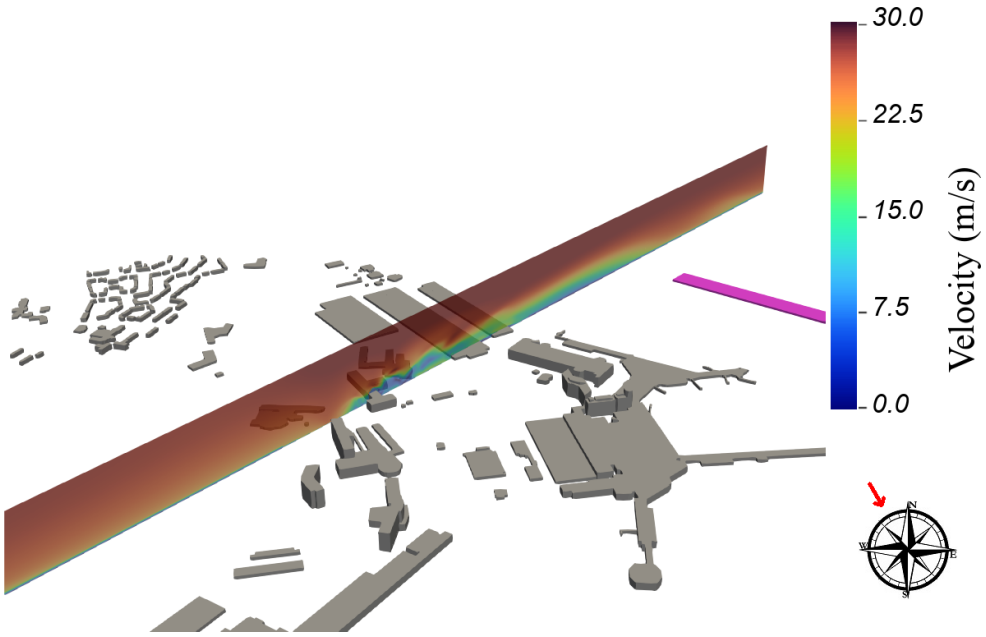


Figure 151: Flow Velocity on a 200m High Slice Across the Existing Conditions - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 330.00°.

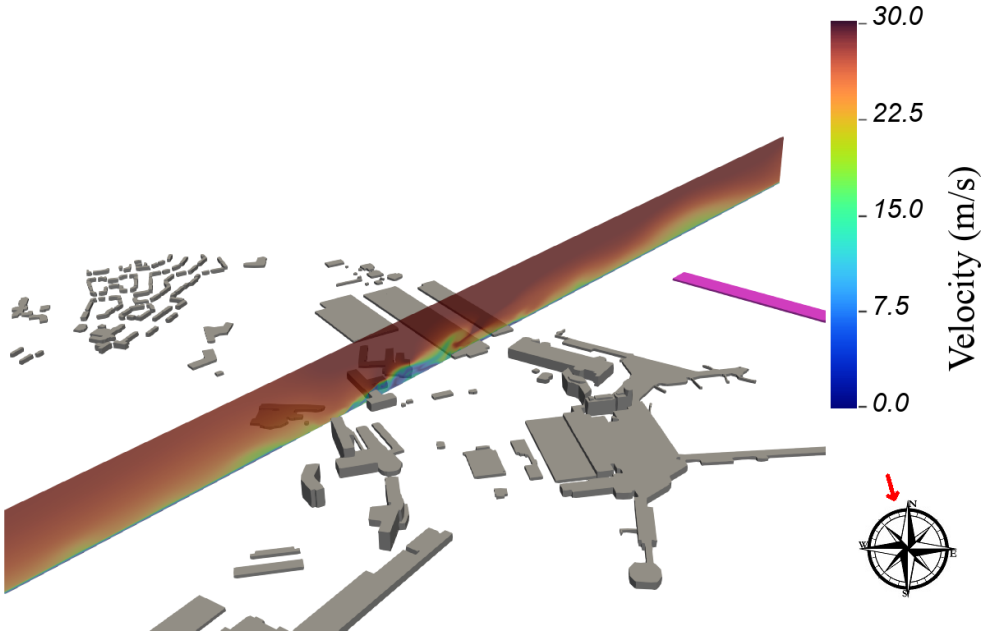


Figure 152: Flow Velocity on a 200m High Slice Across the Existing Conditions - Reference Wind Speed 38.9 Kts (20 m/s) - Wind Direction: 345.00°.

POSSIBLE LANDING SCENARIOS FOR RUNWAY 23R/05L:

In the wind shear and turbulence modelling study, wind speed and turbulence must be reported at the aircraft trajectory. The approaching angle for landing is usually between 2.7° and 4°, with 3° considered as the average.

In this study, 3° and 4° landing/takeoff degrees are analysed. It is assumed that the aircraft glides down with constant speed and its track angel is either 3° or 4°.

Six possible paths per each landing degrees are considered. Each path starts at 900m far from touch down zone and continues to ground level. Fluid velocity and turbulence values are collected along each path. In addition, every 100m across each possible aircraft trajectory, data sampling were performed per each landing path. The sample values are interpolated from values between the cellpoints. Landing paths and horizontal sampling lines are shown in Figures from 153 to 155.

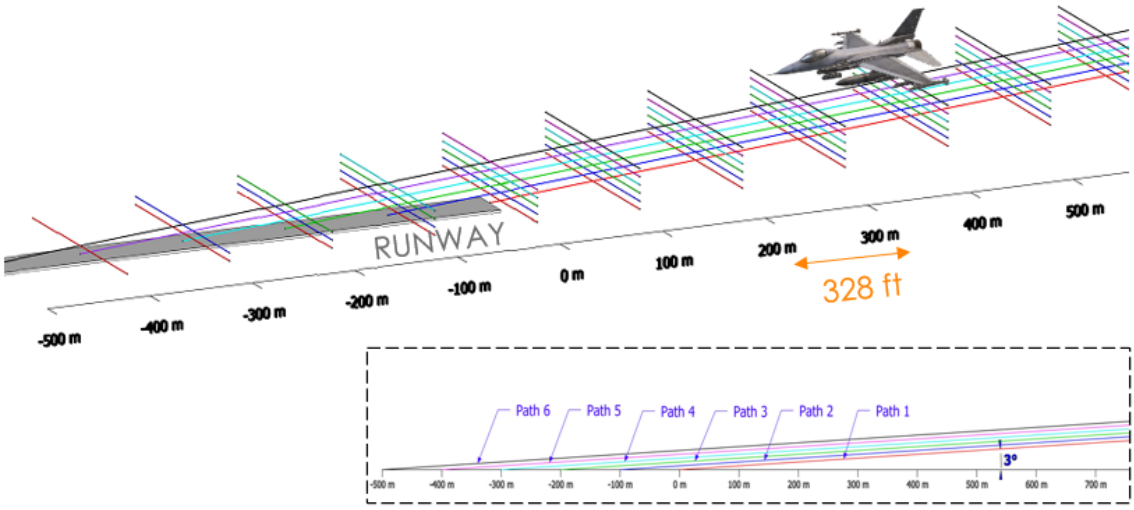


Figure 153: Landing Scenarios and Sampling Lines at 3° and 4° Approaching Angle.

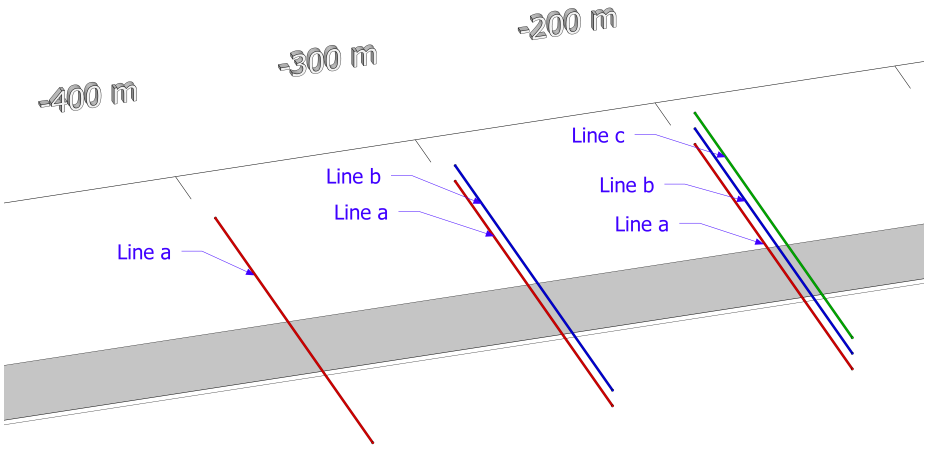


Figure 154: Sampling Lines Perpendicular to Possible Critical Aircraft Trajectories at 3° or 4° Approaching Angle.

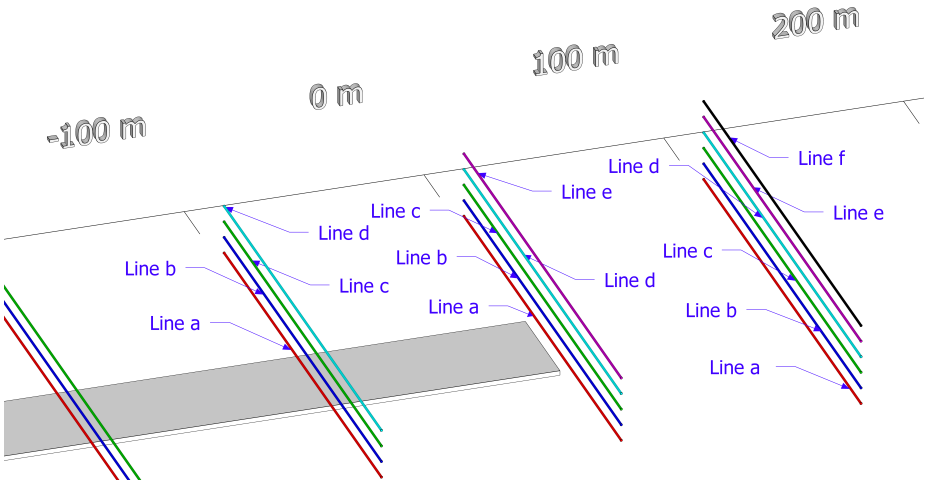


Figure 155: Sampling Lines Perpendicular to a Possible Critical Aircraft Trajectories at 3° or 4° Approaching Angle.

Reference Wind Speed at $10m$ Above Ground = 20m/s
Wind Direction = 315°

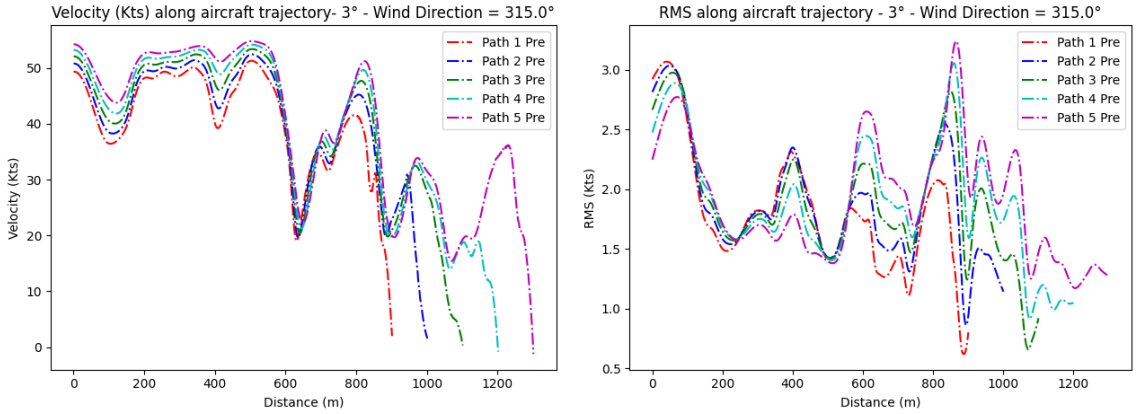


Figure 156: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

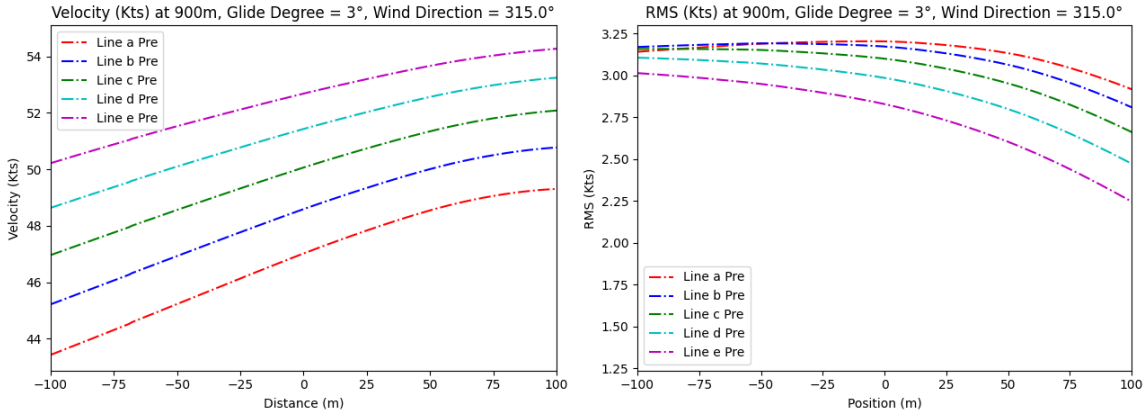


Figure 157: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

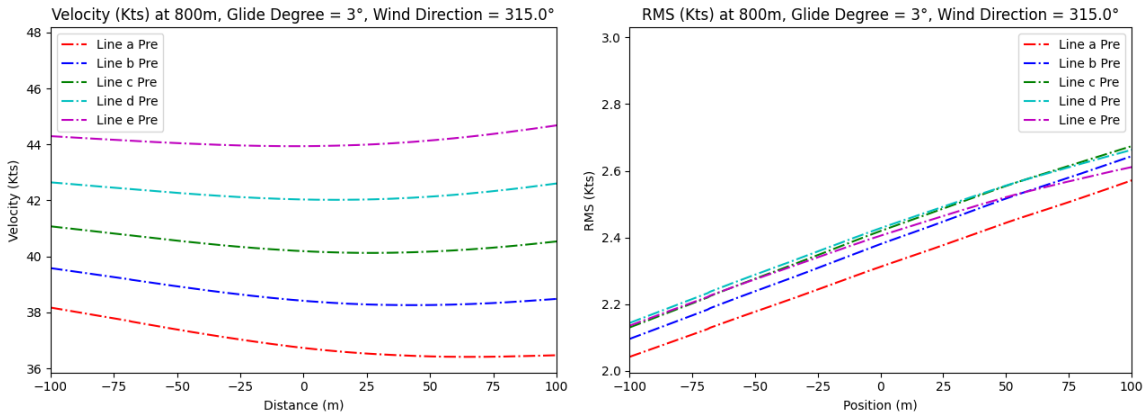


Figure 158: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

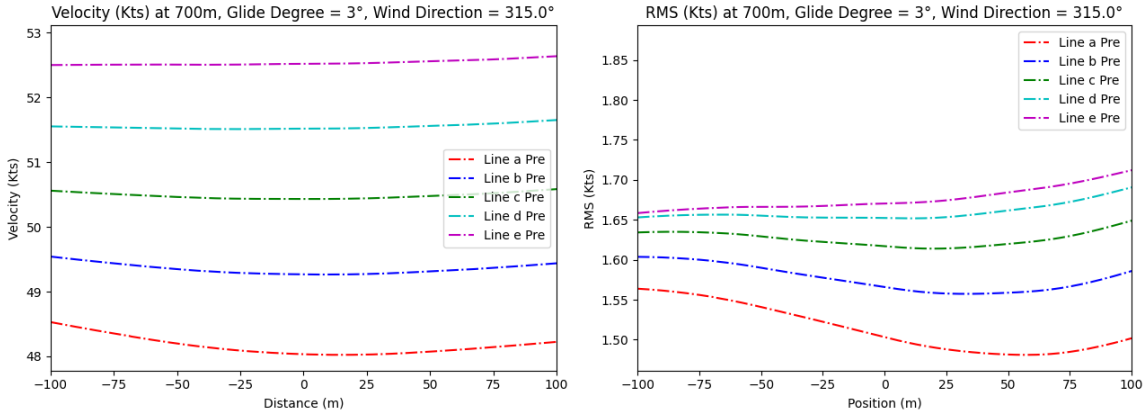


Figure 159: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

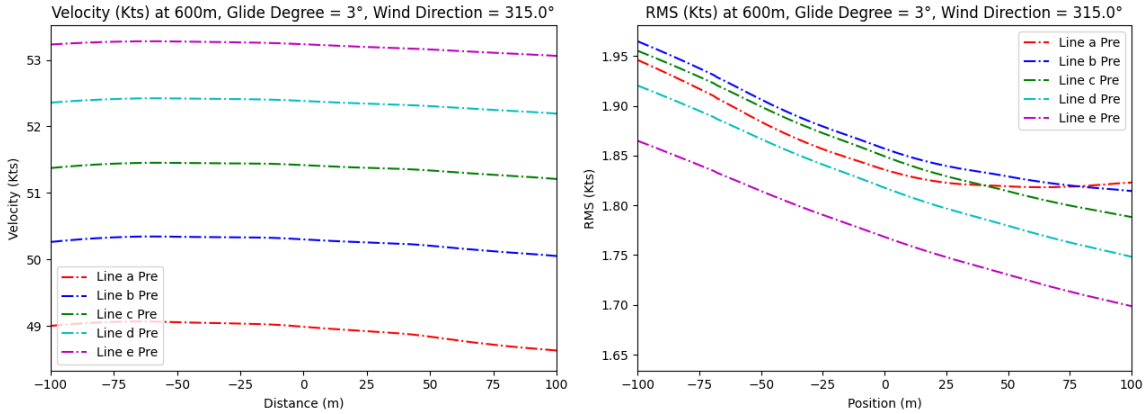


Figure 160: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

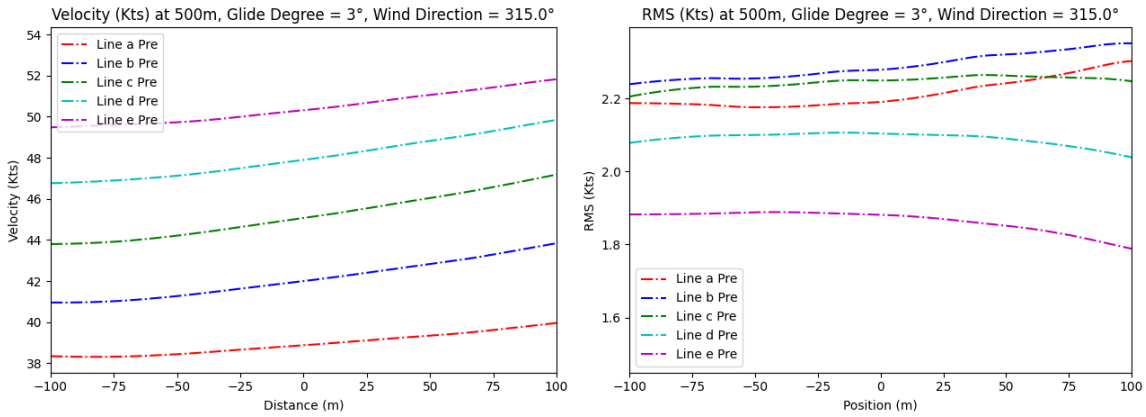


Figure 161: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

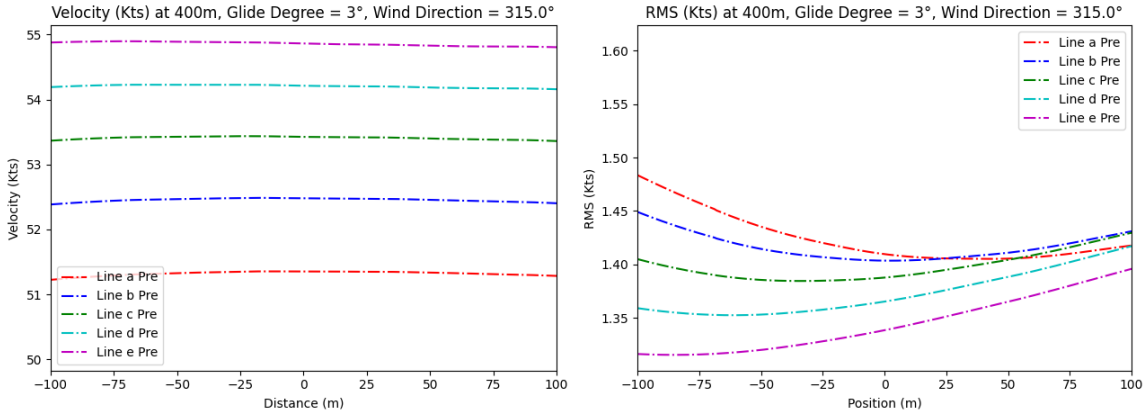


Figure 162: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

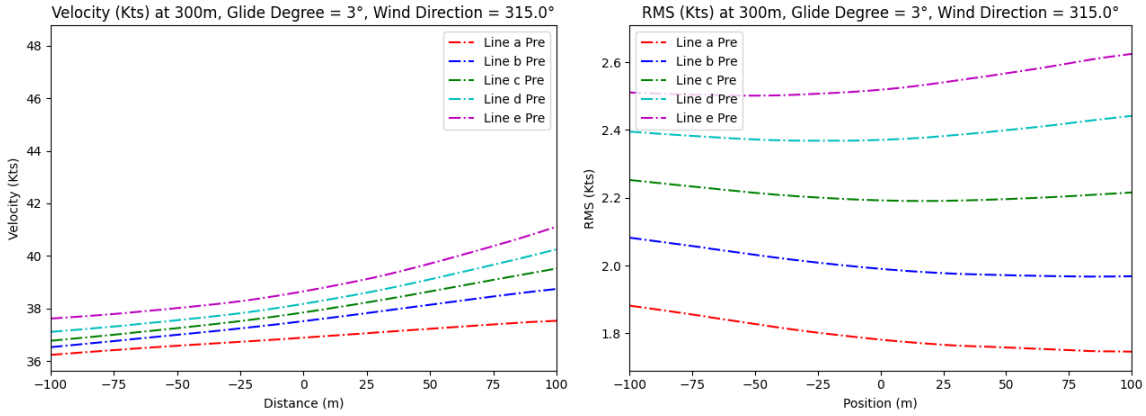


Figure 163: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

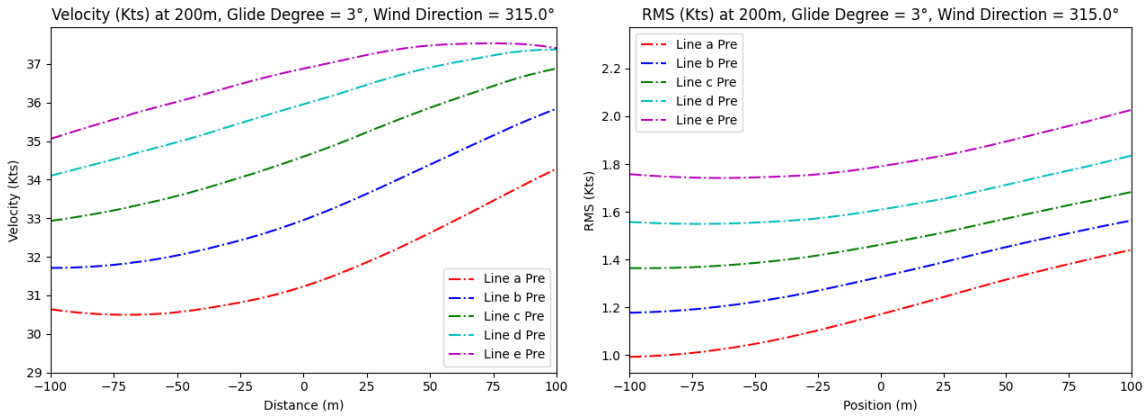


Figure 164: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

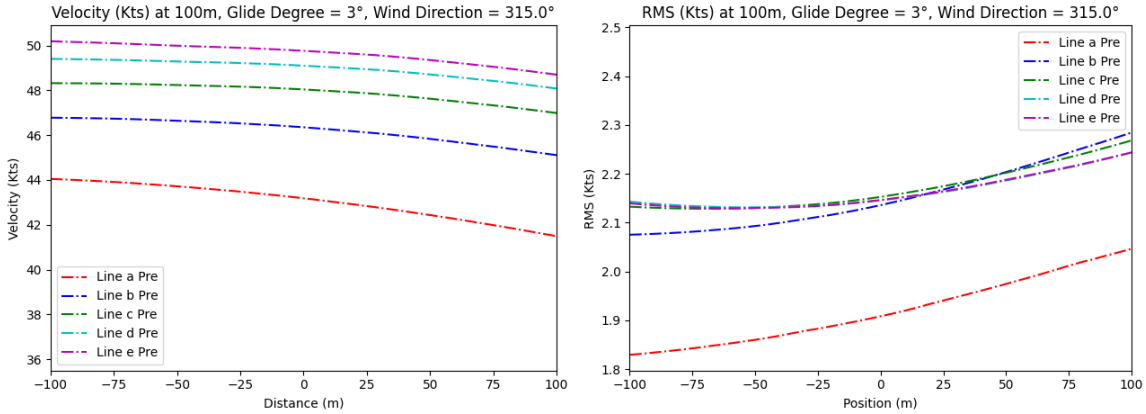


Figure 165: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

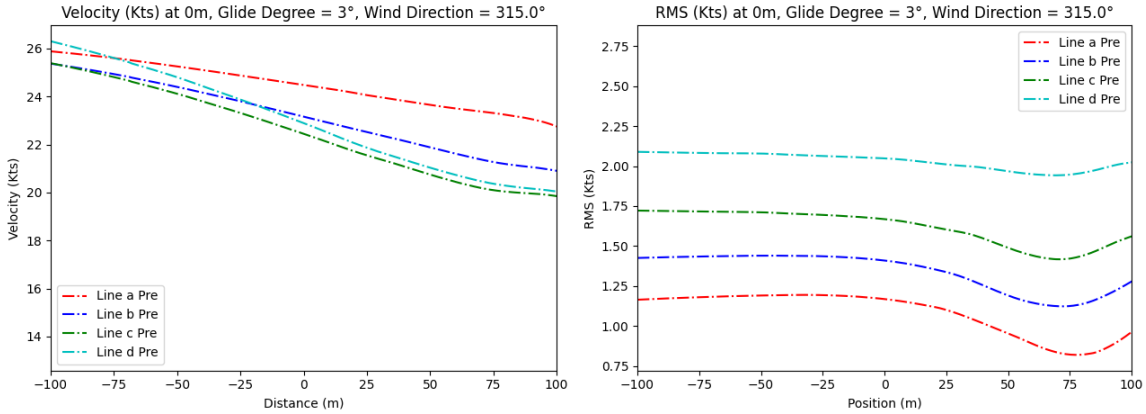


Figure 166: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

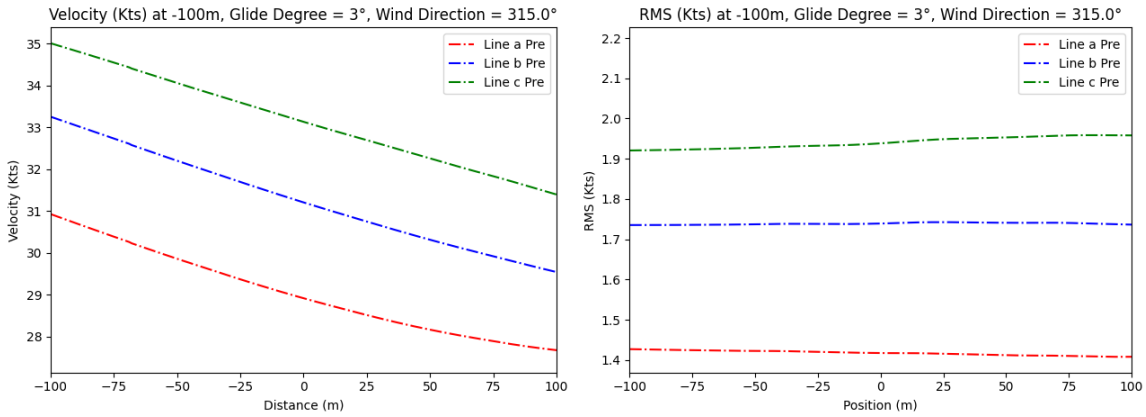


Figure 167: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

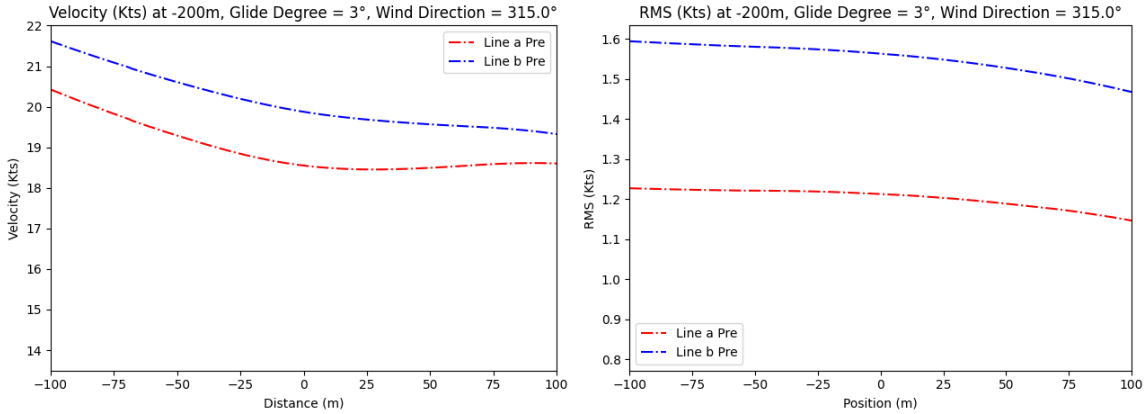


Figure 168: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

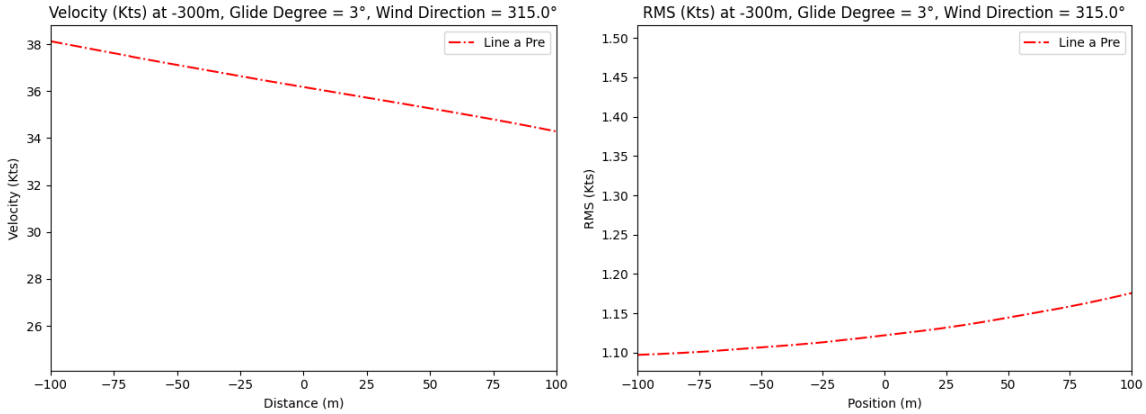


Figure 169: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 315°

Velocity magnitude and turbulence deviation values of CFD models along the runway centerline between chainages $-500m$ to $900m$, consistent with assessment area according to National Airport Safeguarding Framework (NASF), and up to a height of $60m$ above ground level for wind direction 315° with 20 m/s approaching speed are shown in Tables 17 and 18.

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	54.37	56.41	46.43	35.62	48.38	43.15	51.97	39.51	47.66	56.29	54.5	54.21	53.09	43.63	52.67
55	53.44	56.04	44.86	33.34	46.94	40.34	51.17	38.3	45.92	55.96	53.74	53.49	52.18	41.64	51.49
50	52.37	55.63	43.22	30.97	45.37	36.85	50.5	37.53	44.33	55.58	52.7	52.71	51.2	39.67	50.17
45	51.2	55.19	41.54	28.57	43.67	33.01	49.97	37.16	42.94	55.14	51.18	51.84	50.14	37.71	48.7
40	50.04	54.69	39.87	26.3	41.82	29.3	49.58	37.13	41.77	54.6	49.05	50.85	49.02	35.81	47.05
35	48.94	54.12	38.27	24.31	39.79	26.04	49.28	37.29	40.81	53.94	46.3	49.67	47.84	34.01	45.21
30	47.92	53.44	36.82	22.66	37.58	23.21	49	37.43	40.04	53.13	42.94	48.22	46.61	32.38	43.14
25	46.98	52.62	35.6	21.4	35.3	21.15	48.61	37.32	39.36	52.18	39.16	46.4	45.35	30.95	40.82
20	46.09	51.61	34.68	20.47	33.12	19.93	47.96	36.74	38.58	51.07	35.37	44	44.07	29.74	38.25
15	45.17	50.36	34.13	19.81	31.16	19.95	46.82	35.66	37.32	49.81	32.03	40.76	42.7	28.74	35.45
10	44	48.73	34.04	19.29	29.4	21.09	44.91	34.11	34.69	48.32	29.63	36.71	41.13	27.85	32.48
5	41.78	46.07	34.31	18.56	27.6	22.88	41.29	31.77	28.52	45.98	28.55	32.16	38.83	26.67	29.05

Table 17: Wind Speed in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 315°

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	1.40124	1.20834	2.01745	2.93364	2.56431	2.64446	2.42925	3.02841	2.65798	1.26177	1.30444	1.61207	1.71564	2.64175	2.57767
55	1.4444	1.24201	2.03742	2.94278	2.58919	2.99092	2.41806	2.89826	2.7746	1.30754	1.44925	1.66883	1.70435	2.67293	2.73998
50	1.47387	1.27438	2.05804	2.90221	2.59507	3.28034	2.39326	2.74081	2.82157	1.34645	1.64625	1.72037	1.67542	2.66613	2.86482
45	1.48755	1.30713	2.07202	2.80561	2.58051	3.41381	2.36028	2.56494	2.80079	1.37856	1.88218	1.76467	1.62739	2.6202	2.95257
40	1.48525	1.34222	2.06834	2.65771	2.54312	3.36172	2.32381	2.37418	2.71651	1.40388	2.11572	1.79867	1.5596	2.53662	3.00471
35	1.46853	1.38184	2.03628	2.47445	2.47904	3.1607	2.28786	2.17273	2.57553	1.42194	2.29059	1.81875	1.47327	2.42052	3.02395
30	1.43835	1.42733	1.96917	2.27525	2.38479	2.85435	2.25722	1.9733	2.38716	1.43144	2.35386	1.82184	1.37337	2.27969	3.01385
25	1.39419	1.47709	1.86576	2.07435	2.26052	2.45022	2.23981	1.79736	2.16342	1.43005	2.27039	1.80602	1.27083	2.12193	2.97666
20	1.3367	1.52394	1.72895	1.87639	2.11019	1.93579	2.2448	1.65942	1.92587	1.41426	2.03876	1.76185	1.1811	1.952	2.90542
15	1.26999	1.55384	1.56487	1.67461	1.9344	1.51887	2.27149	1.54775	1.7223	1.37946	1.69262	1.66399	1.11304	1.7673	2.77674
10	1.20387	1.54368	1.37558	1.44641	1.71585	1.21207	2.28271	1.42689	1.60629	1.32151	1.28569	1.4843	1.05611	1.55045	2.53868
5	1.1164	1.40614	1.16617	1.12986	1.39057	0.93563	2.023	1.20325	1.30101	1.21893	0.94885	1.17162	1.00258	1.25368	2.00222

Table 18: Turbulence deviation or RMS in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 315°

Wind Direction = 330°

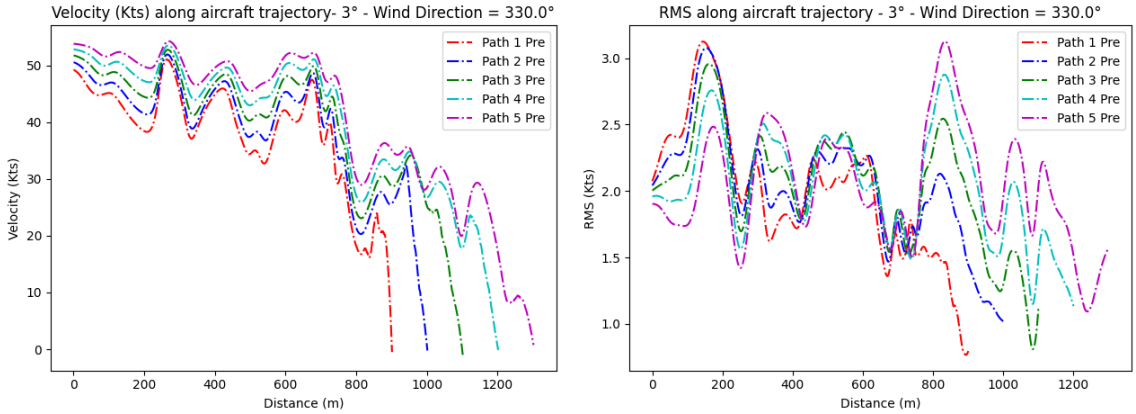


Figure 170: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

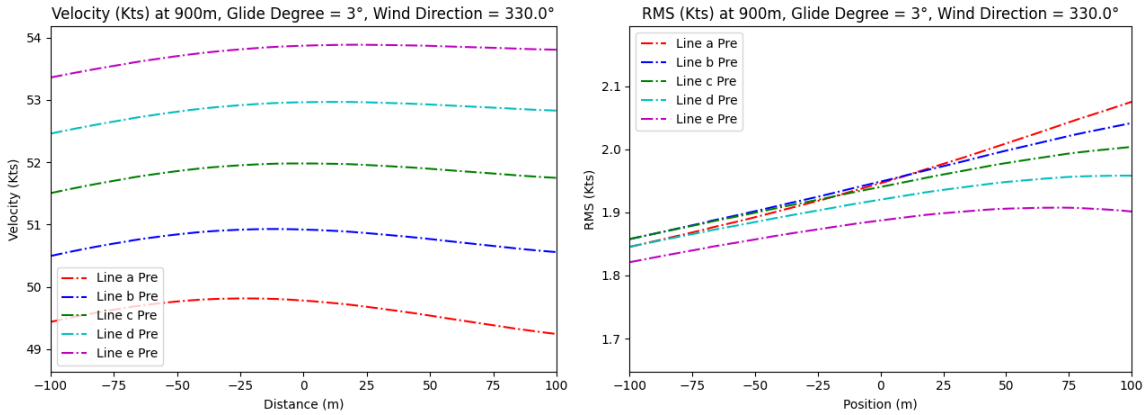


Figure 171: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

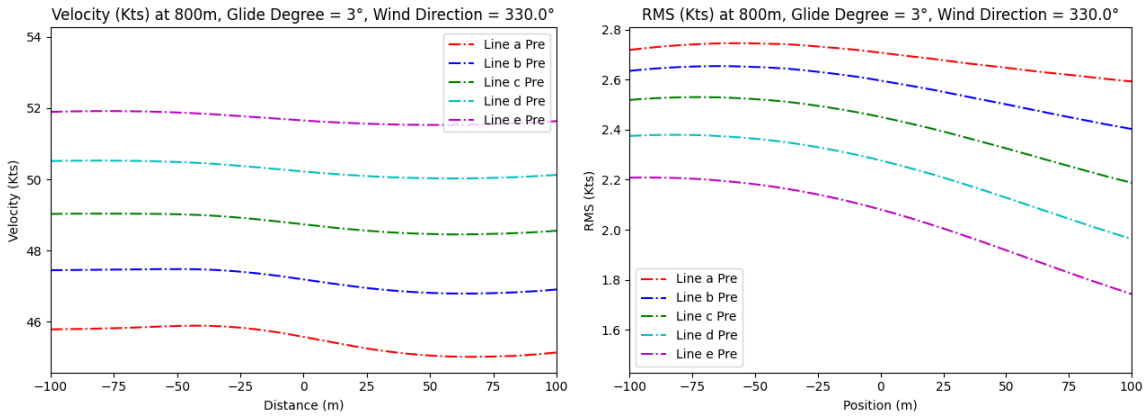


Figure 172: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

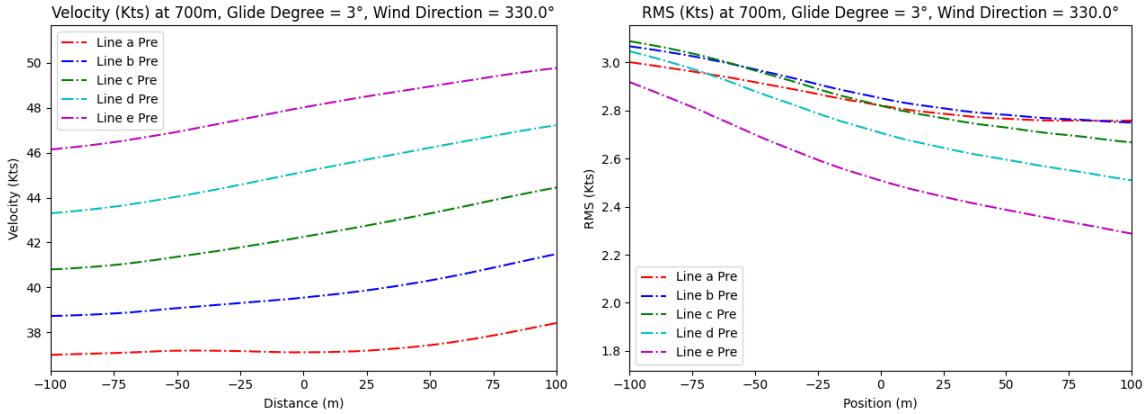


Figure 173: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

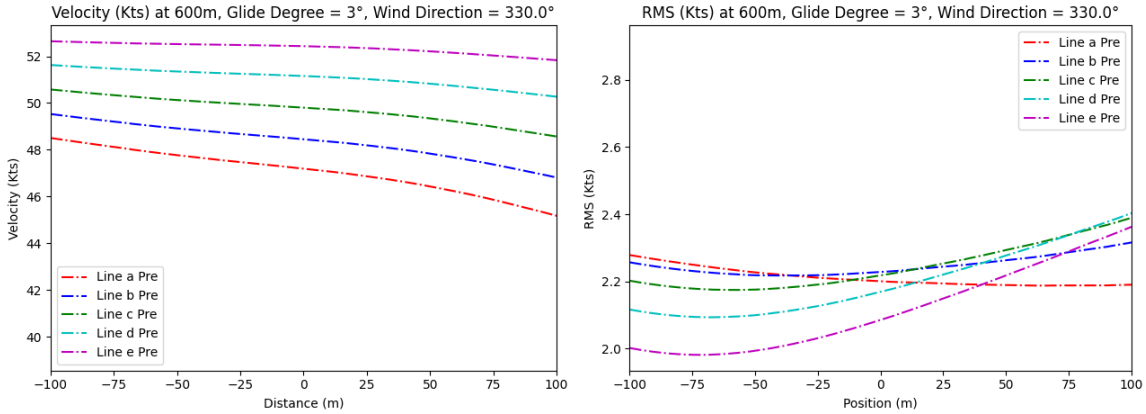


Figure 174: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

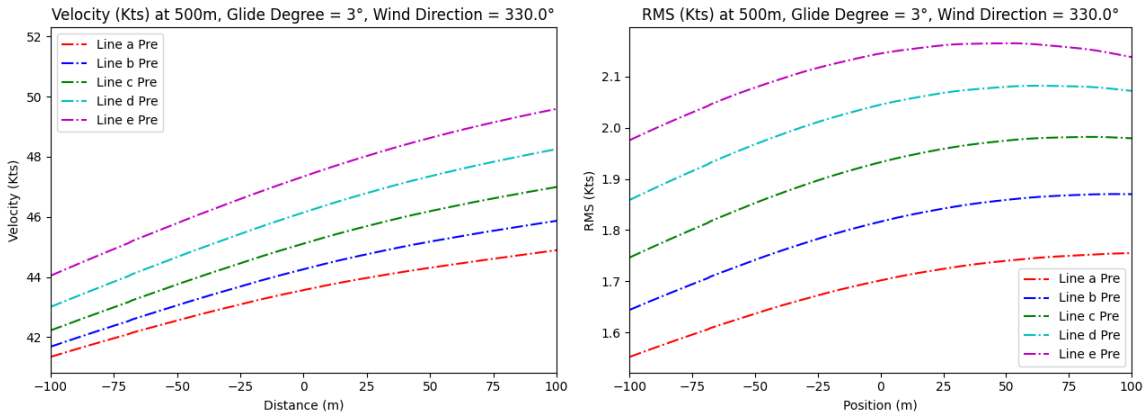


Figure 175: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

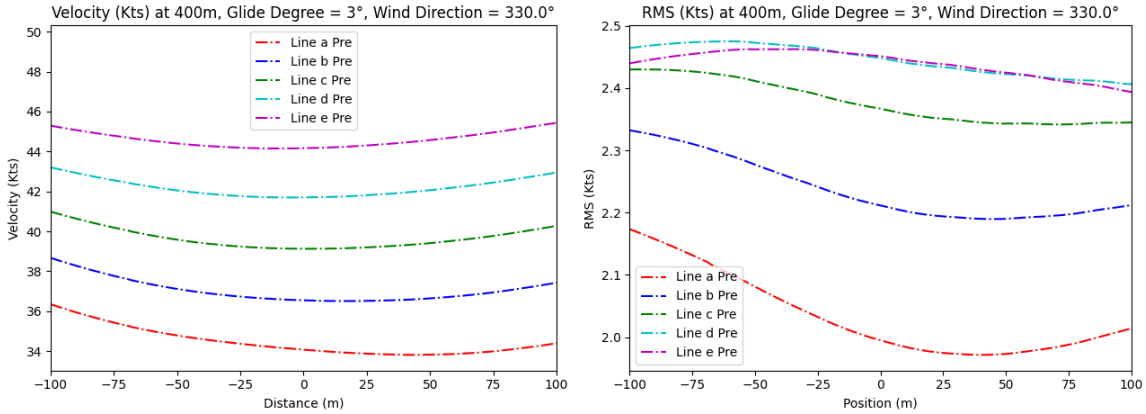


Figure 176: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

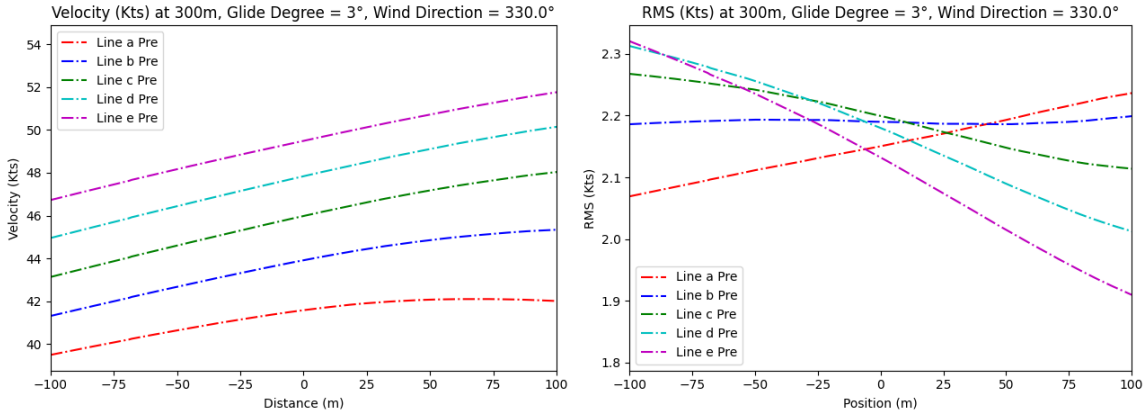


Figure 177: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

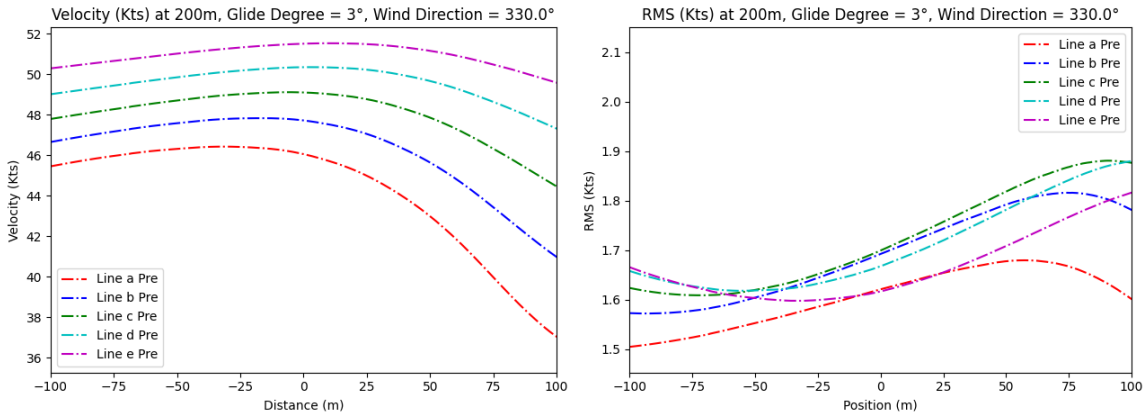


Figure 178: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

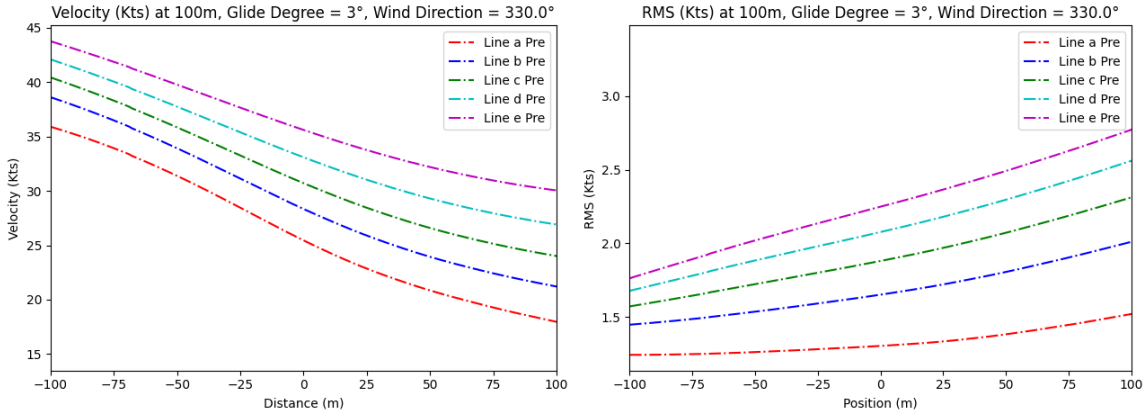


Figure 179: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

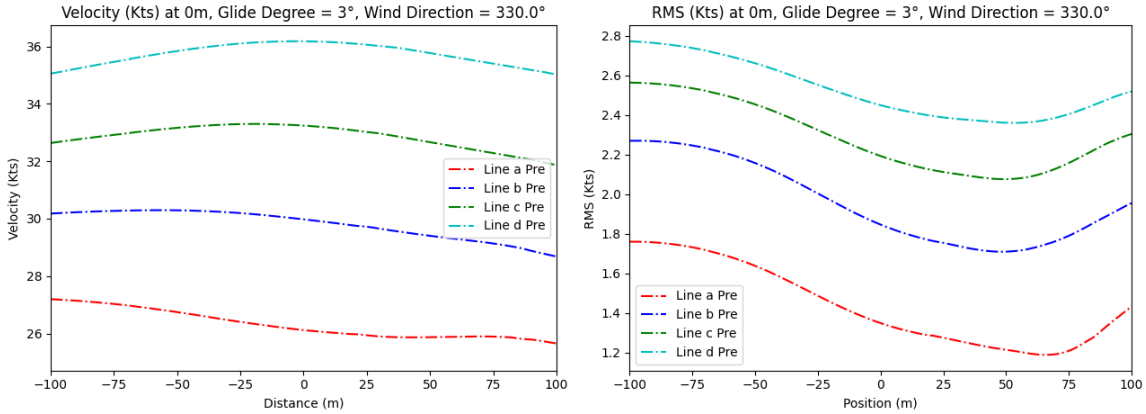


Figure 180: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

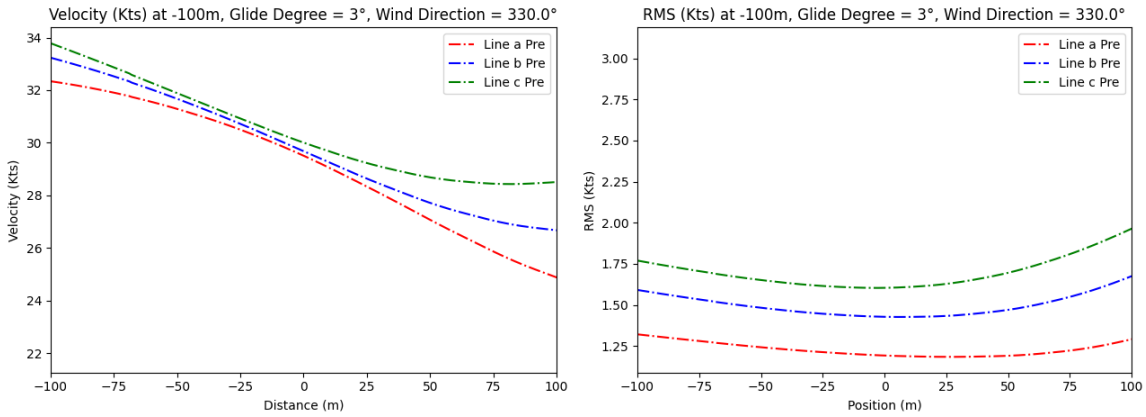


Figure 181: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

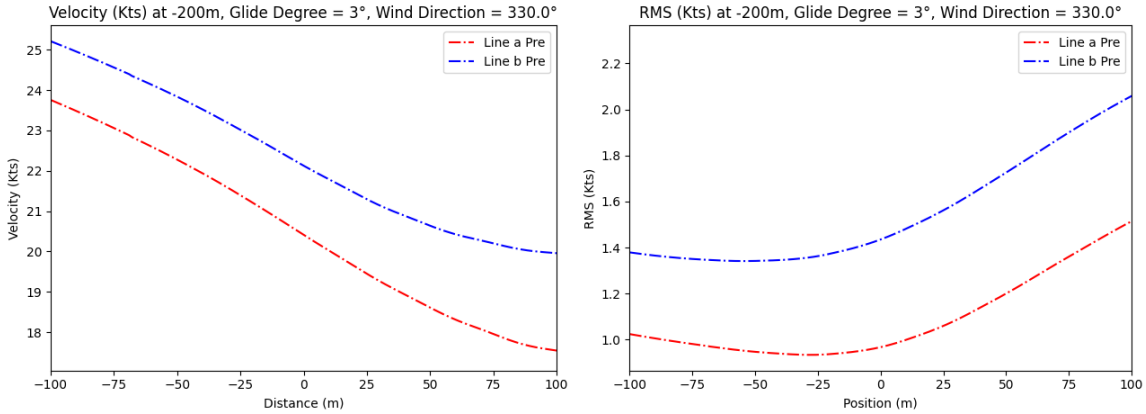


Figure 182: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

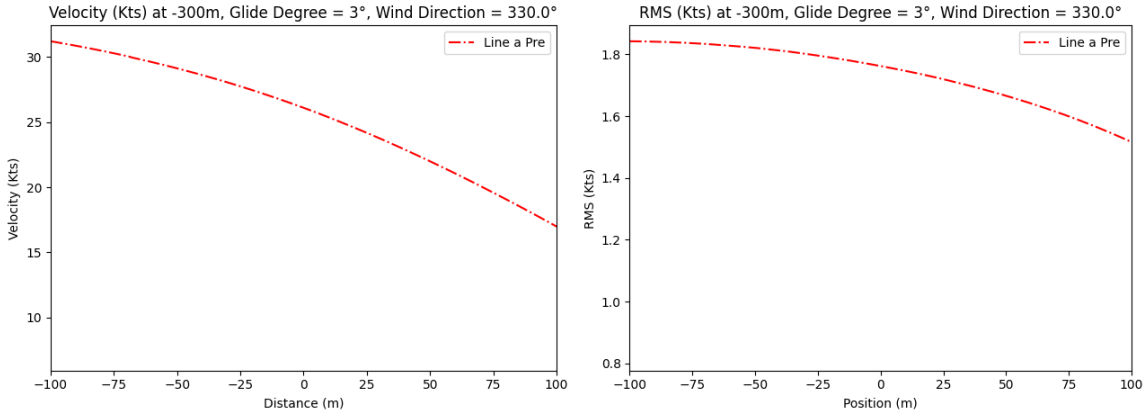


Figure 183: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 330°

Velocity magnitude and turbulence deviation values of CFD models along the runway centerline between chainages $-500m$ to $900m$, consistent with assessment area according to National Airport Safeguarding Framework (NASF), and up to a height of $60m$ above ground level for wind direction 330° with 20 m/s approaching speed are shown in Tables 19 and 20.

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	41.5	54.53	37.39	46.61	41.25	51.64	50.81	56.19	55.56	52.3	52.87	53.84	50.95	50.88	52.3
55	40.33	53.2	34.75	44.96	39.94	50.21	48.38	55.53	54.99	50.74	51.65	52.61	48.64	49.41	51.22
50	39.27	51.6	32.11	43.04	38.72	48.58	45.6	54.73	54.35	48.94	50.37	51.21	46.09	47.88	50.03
45	38.27	49.74	29.56	40.76	37.53	46.76	42.51	53.73	53.58	46.89	49.07	49.65	43.35	46.26	48.72
40	37.28	47.59	27.14	38.09	36.28	44.73	39.23	52.49	52.6	44.64	47.8	47.98	40.46	44.51	47.29
35	36.27	45.19	24.9	35.06	34.92	42.49	35.87	50.97	51.32	42.19	46.63	46.31	37.51	42.65	45.72
30	35.2	42.58	22.88	31.74	33.41	39.91	32.56	49.11	49.65	39.59	45.6	44.8	34.66	40.69	44.02
25	34.05	39.83	21.11	28.31	31.76	37.38	29.4	46.83	47.51	36.82	44.69	43.63	32.05	38.71	42.16
20	32.81	37.02	19.63	25.08	30.03	34.51	26.44	43.99	44.82	33.89	43.82	42.86	29.72	36.77	40.11
15	31.45	34.23	18.44	22.26	28.26	31.48	23.69	40.6	41.54	30.84	42.75	42.42	27.61	34.92	37.7
10	29.85	31.46	17.55	19.71	26.5	28.33	21	36.79	37.7	27.71	41.1	42	25.63	33.13	34.67
5	27.71	28.39	17.03	17.38	24.77	25.55	17.84	32.24	32.67	24.35	37.9	40.6	23.4	30.98	30.73

Table 19: Wind Speed in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 330°

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	2.71552	2.9087	3.13204	2.42589	2.68486	2.16066	2.5826	1.41279	1.49579	1.9238	2.15223	2.21888	2.16046	1.85262	1.98219
55	2.68613	3.13492	3.19755	2.62407	2.67539	2.33613	2.78846	1.45681	1.57939	2.08984	2.17485	2.3206	2.39876	2.06741	2.02148
50	2.6582	3.32063	3.22522	2.83312	2.66161	2.48529	2.95272	1.50771	1.66472	2.2406	2.16304	2.38526	2.58682	2.28091	2.05516
45	2.62763	3.45756	3.21387	3.02492	2.64053	2.60231	3.05199	1.57263	1.75298	2.35282	2.11791	2.40446	2.71	2.48037	2.08632
40	2.5871	3.53903	3.16278	3.16419	2.60529	2.683	3.07395	1.65495	1.84509	2.4087	2.04381	2.37048	2.76234	2.64984	2.11727
35	2.52751	3.55916	3.07198	3.21745	2.54642	2.72305	3.01971	1.74814	1.94127	2.3984	1.94834	2.28232	2.74854	2.77247	2.14858
30	2.43955	3.51424	2.94302	3.15945	2.4546	2.70868	2.89992	1.83365	2.03993	2.31972	1.84084	2.14996	2.68267	2.83507	2.17676
25	2.31472	3.40352	2.77747	2.98724	2.323	2.63335	2.72899	1.88333	2.13532	2.17639	1.73078	1.9912	2.57893	2.82936	2.19143
20	2.14529	3.22763	2.57368	2.72904	2.14863	2.48891	2.51935	1.86543	2.21075	1.9749	1.62767	1.82373	2.44098	2.74979	2.17482
15	1.92266	2.98434	2.32086	2.41248	1.92739	2.27063	2.27549	1.76357	2.23611	1.71959	1.54007	1.65702	2.25688	2.58785	2.10074
10	1.63165	2.6479	1.98579	2.01662	1.64114	1.88964	1.97876	1.58651	2.1679	1.40884	1.46955	1.48713	1.99142	2.31713	1.92253
5	1.24068	2.06055	1.49098	1.48376	1.26776	1.42295	1.48781	1.25631	1.75841	1.02628	1.29092	1.30423	1.5394	1.82967	1.50617

Table 20: Turbulence deviation or RMS in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 330°

Wind Direction = 345°

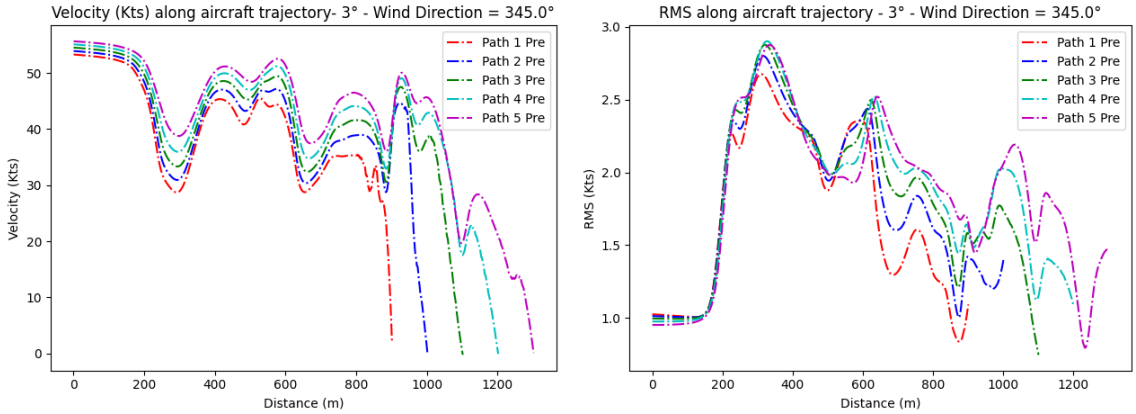


Figure 184: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

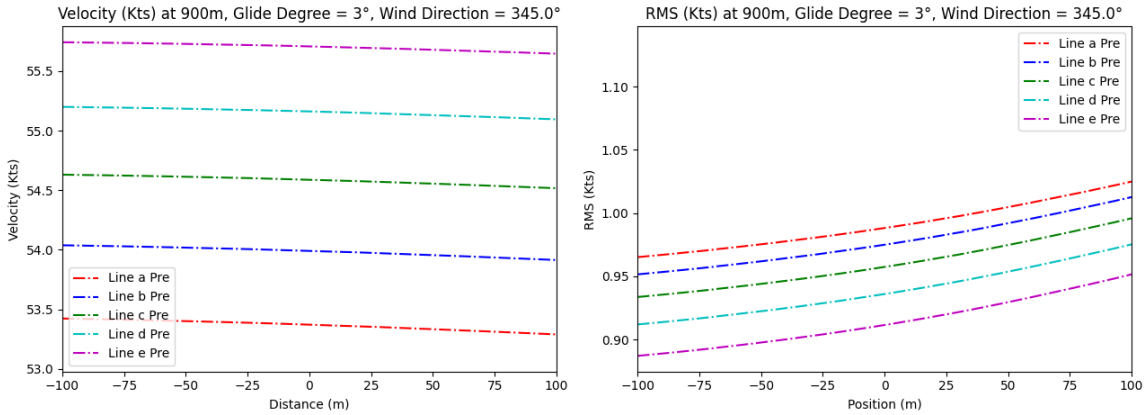


Figure 185: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

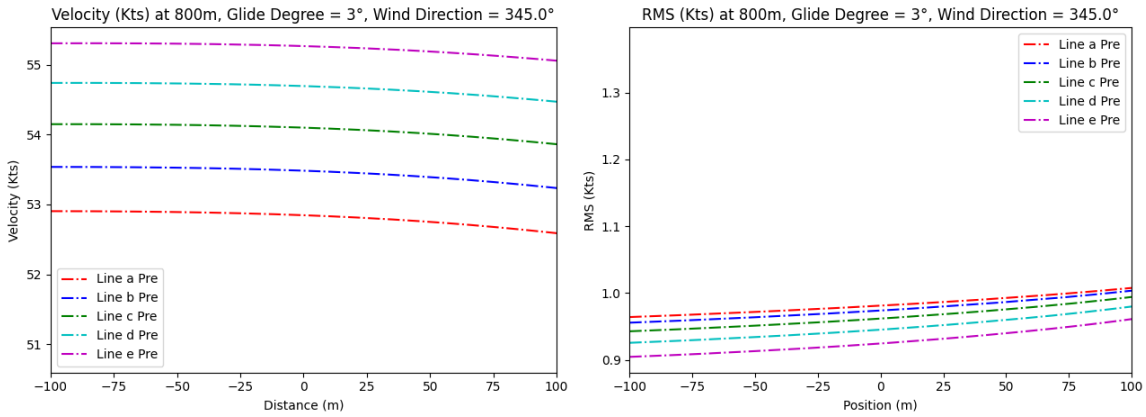


Figure 186: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

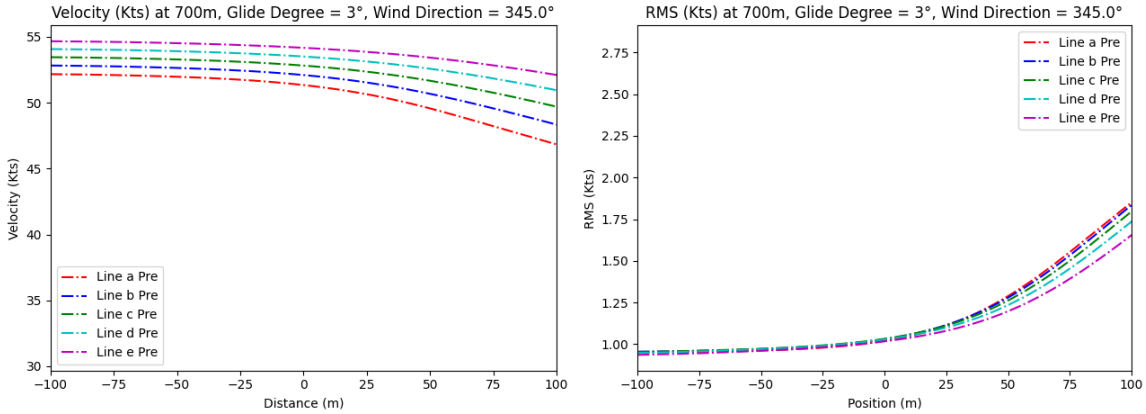


Figure 187: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

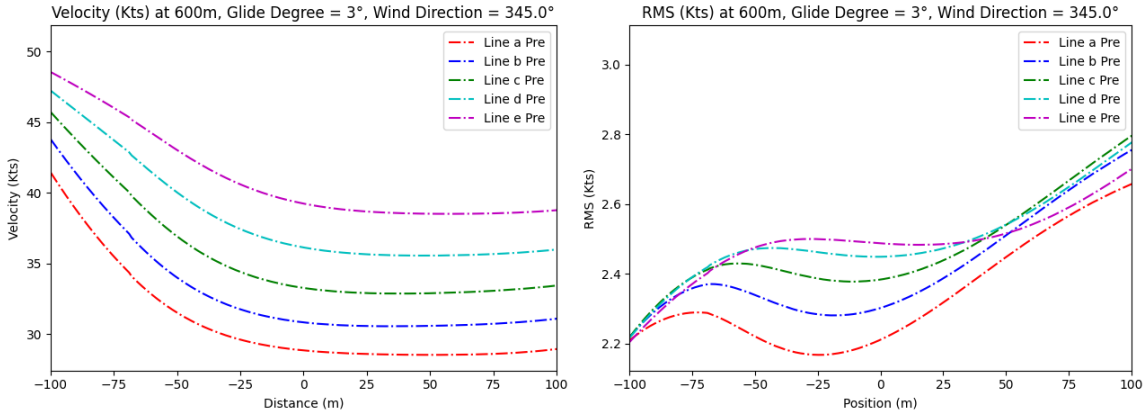


Figure 188: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

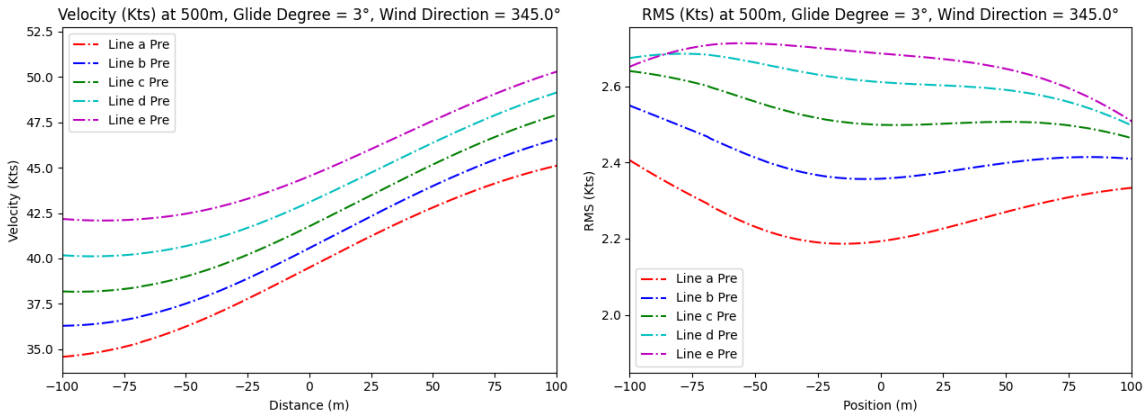


Figure 189: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

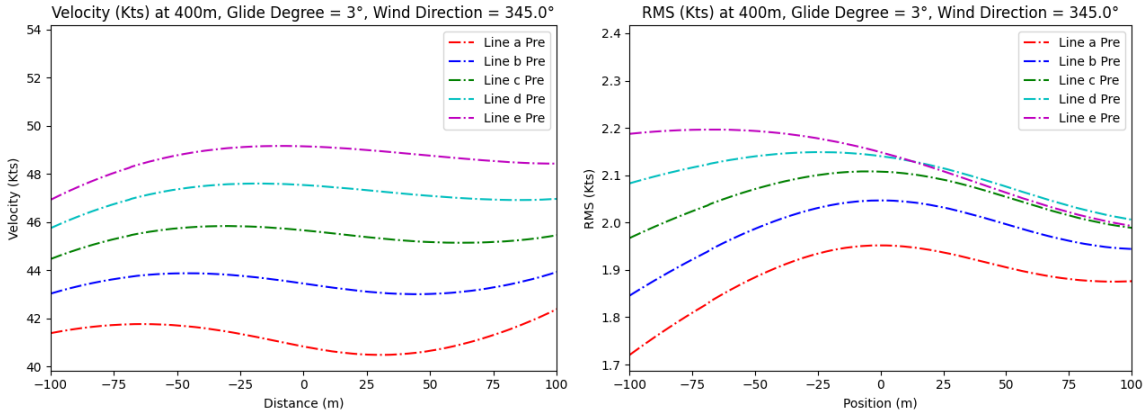


Figure 190: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

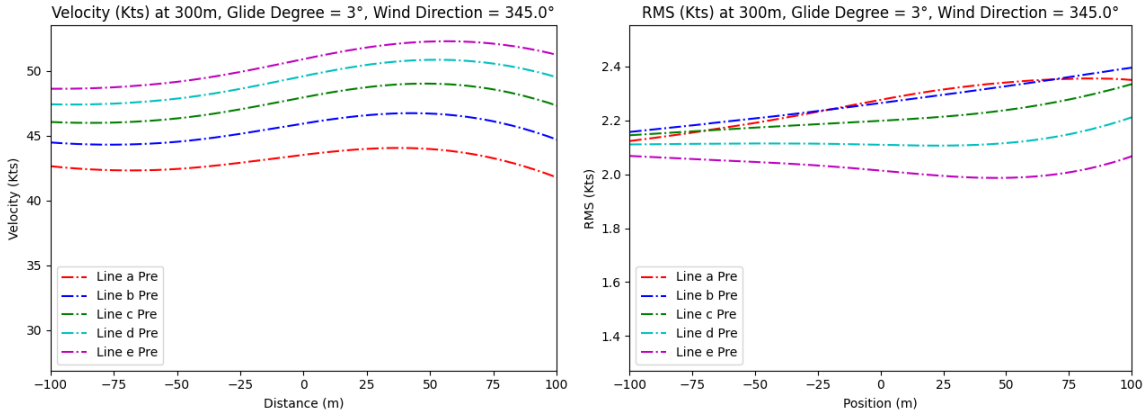


Figure 191: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

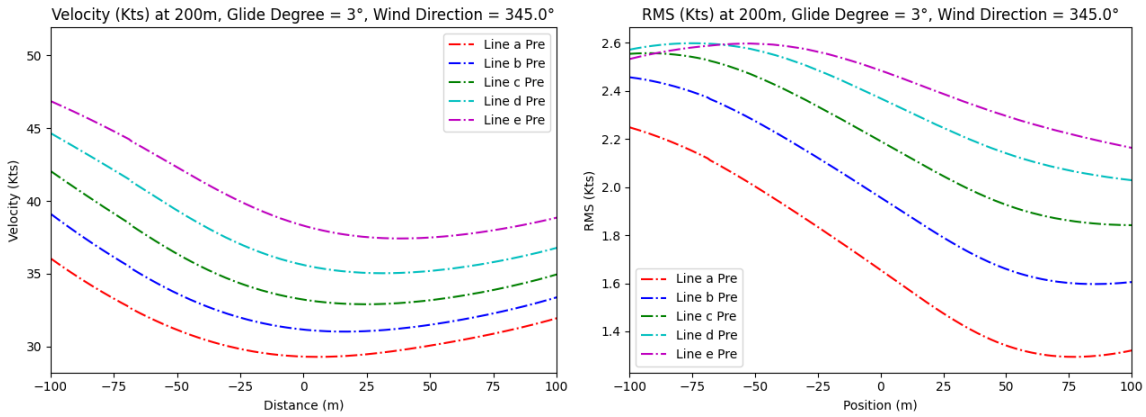


Figure 192: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

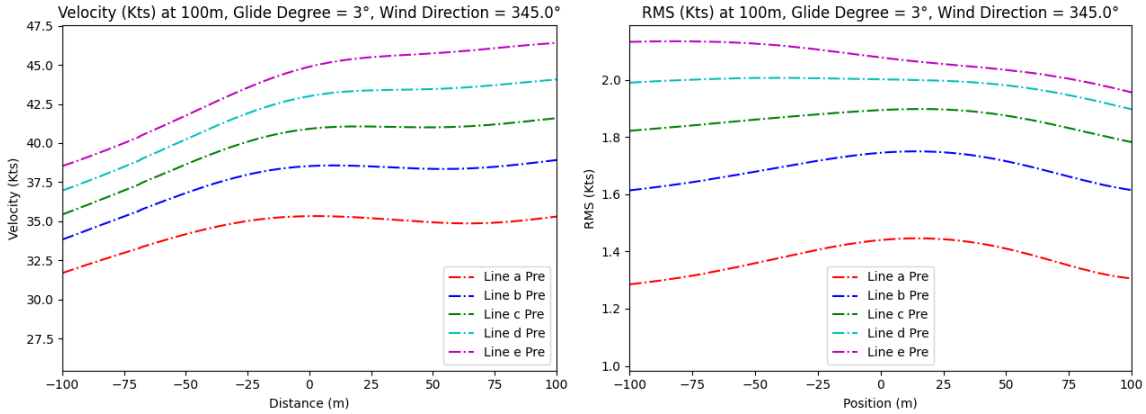


Figure 193: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

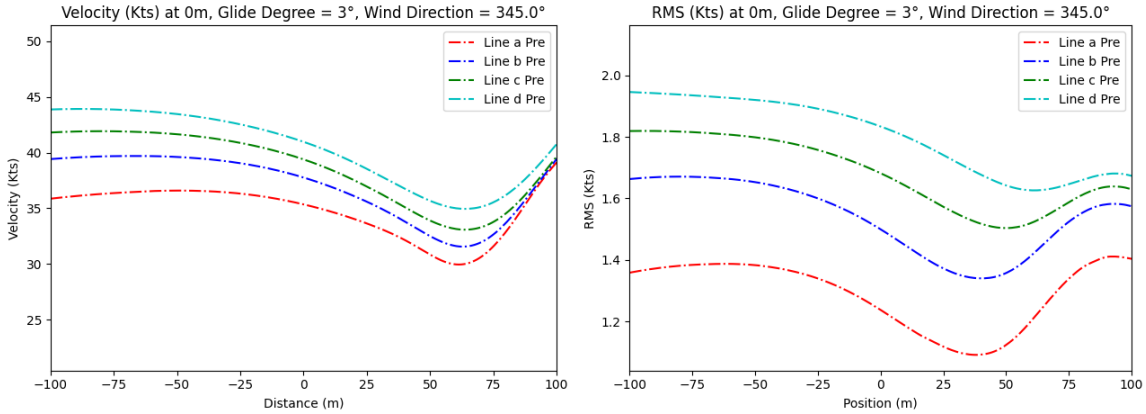


Figure 194: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

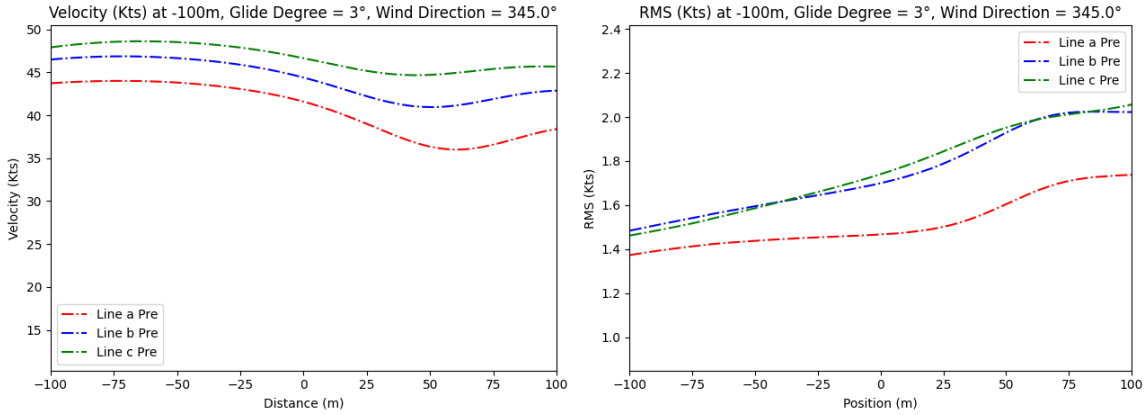


Figure 195: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

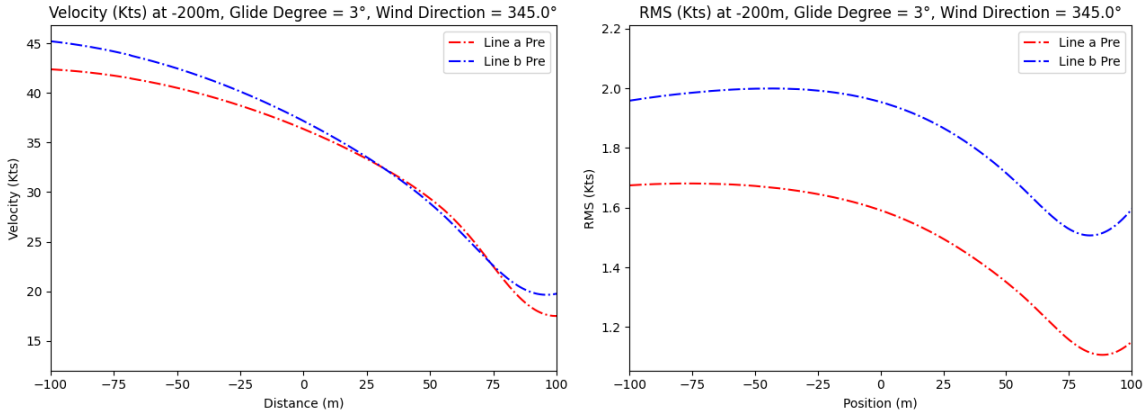


Figure 196: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

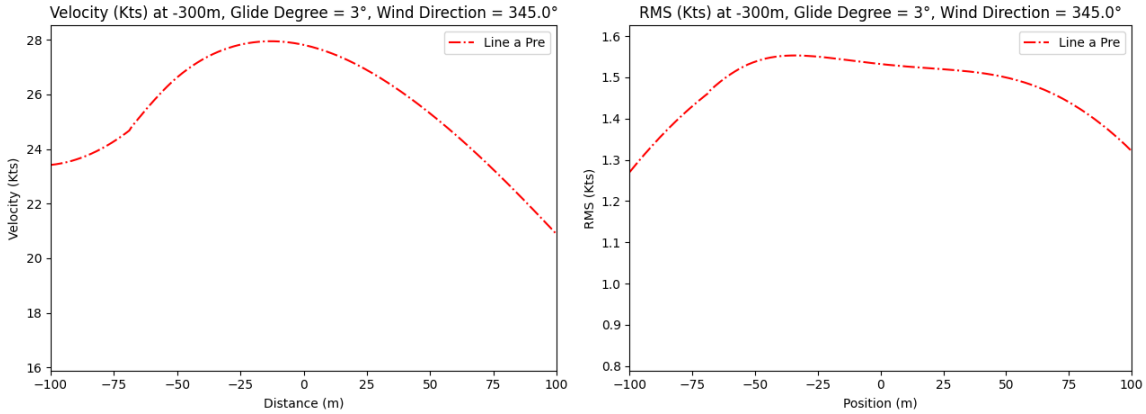


Figure 197: Velocity magnitude (Kts) and RMS (Kts) along a possible Critical Aircraft Trajectory. Reference wind speed 38.9Kts (20 m/s) - Landing/Takeoff degree 3° - Wind Direction 345°

Velocity magnitude and turbulence deviation values of CFD models along the runway centerline between chainages $-500m$ to $900m$, consistent with assessment area according to National Airport Safeguarding Framework (NASF), and up to a height of $60m$ above ground level for wind direction 345° with 20 m/s approaching speed are shown in Tables 21 and 22.

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	39.83	50.3	36.94	47.48	56.24	53.54	56.15	51.14	55.8	52.91	52.89	43.14	52.66	54.77	54.81
55	37.88	49.19	33.88	45.26	55.65	52.38	55.4	49.33	55.07	51.79	51.92	40.34	51.6	54.2	54.24
50	36.15	47.9	30.87	42.83	54.96	51.09	54.42	47.27	54.26	50.59	50.91	37.58	50.46	53.6	53.66
45	34.65	46.29	28.03	40.21	54.16	49.66	53.19	45	53.33	49.31	49.84	35	49.22	53	53.05
40	33.41	44.25	25.54	37.4	53.22	48.07	51.7	42.67	52.21	47.95	48.71	32.63	47.88	52.37	52.42
35	32.42	41.72	23.5	34.39	52.12	46.27	49.98	40.41	50.81	46.52	47.51	30.44	46.39	51.72	51.77
30	31.67	38.9	21.92	31.22	50.83	43.98	48.05	38.28	49.04	45.05	46.2	28.44	44.68	51.05	51.1
25	31.11	36.2	20.82	27.96	49.31	42.02	45.93	36.34	46.84	43.58	44.77	26.68	42.65	50.32	50.37
20	30.68	33.84	20.23	24.78	47.52	40.38	43.66	34.64	44.26	42.08	43.2	25.16	40.28	49.52	49.57
15	30.31	31.79	20.14	21.86	45.36	39.45	41.27	33.16	41.43	40.41	41.46	23.84	37.72	48.55	48.6
10	29.86	29.88	20.47	19.25	42.62	39.67	38.67	31.79	38.51	38.16	39.48	22.68	35.13	47.21	47.29
5	28.86	27.56	20.96	16.77	38.17	39.18	35.11	30.05	35.15	34.07	36.7	21.69	32.15	44.83	44.94

Table 21: Wind Speed in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 345°

	-500	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900
60	3.20691	2.33583	3.82861	2.71847	1.46651	1.50652	1.18918	2.08969	1.45705	1.7116	2.43309	2.51191	1.60287	0.97096	0.98595
55	3.20929	2.37012	3.70985	2.80322	1.56963	1.57377	1.35058	2.16667	1.58416	1.82077	2.48186	2.63885	1.68981	0.98701	1.00405
50	3.17105	2.4312	3.52003	2.85875	1.67355	1.63448	1.52713	2.22998	1.70899	1.90839	2.507	2.73753	1.75939	0.99869	1.01829
45	3.09706	2.52529	3.2743	2.88012	1.77333	1.68982	1.694	2.26927	1.83539	1.96978	2.50929	2.78969	1.80922	1.0057	1.02827
40	2.99338	2.64429	2.99733	2.85989	1.8633	1.73965	1.83051	2.27199	1.96807	2.00241	2.49015	2.78757	1.83789	1.00798	1.03378
35	2.86555	2.76128	2.71407	2.78948	1.9389	1.77797	1.92315	2.22898	2.1076	2.00578	2.45109	2.73104	1.84622	1.00566	1.03482
30	2.71742	2.83166	2.44202	2.65993	1.99681	1.77148	1.96434	2.1365	2.24432	1.98145	2.39283	2.62349	1.83474	0.99911	1.03152
25	2.55098	2.81904	2.19768	2.4652	2.03536	1.72859	1.95086	1.9948	2.35351	1.93251	2.31419	2.46902	1.80102	0.98903	1.02427
20	2.36614	2.72134	1.9925	2.20776	2.05456	1.67262	1.88297	1.80564	2.39684	1.86333	2.211	2.27072	1.74031	0.97677	1.01392
15	2.15829	2.55241	1.81518	1.90034	2.05337	1.62709	1.76495	1.57152	2.33592	1.78433	2.07491	2.02386	1.64806	0.96543	1.00247
10	1.90712	2.3034	1.61706	1.55036	2.01549	1.5524	1.59765	1.2929	2.14416	1.71629	1.88636	1.70541	1.51835	0.96262	0.99528
5	1.53402	1.84504	1.30677	1.11003	1.71135	1.37772	1.28518	0.99136	1.71929	1.44903	1.53812	1.28086	1.26538	0.97178	0.9903

Table 22: Turbulence deviation or RMS in Kts along the runway centerline between chainages -500m to 900m and up to a height of 60m above ground level. Wind Direction 345°

11. APPENDIX C Verification & Validation

It is important to verify and validate the CFD model for numerical studies by comparing the CFD results with experimental data. In this chapter, the CFD model used in the windshear and turbulence analysis is applied on a simplified geometry (a rectangular cylinder with an aspect ratio of 5:1). The flow field determined by the CFD model is then compared with experimental data from BARC (Benchmark on the Aerodynamics of a Rectangular 5:1 Cylinder). BARC addresses the high Reynolds number, external, unsteady flow around a stationary, sharp-edged rectangular cylinder, and the associated aerodynamic actions. BARC provides experimental data of flow field around blocks, which can be used to validate numerical results through comparisons of velocity.

Model Description

Physical Model

In the presented CFD model, the flow within the testing domain is assumed to be incompressible and Newtonian, with temperature and gravity effects neglected. The flow is governed by the Reynolds-averaged Navier-Stokes (RANS) formulation for mass and momentum where the turbulence is modeled using the k-ω SST turbulence model. The turbulence intensity in this group of study is 30%. The Reynolds number is 112,600.

Model Geometry

The geometry used in this chapter is a rectangular cylinder with an aspect ratio of 5:1, which is shown in Figure 198. Figure 199 shows the sampling location relative to the geometry.

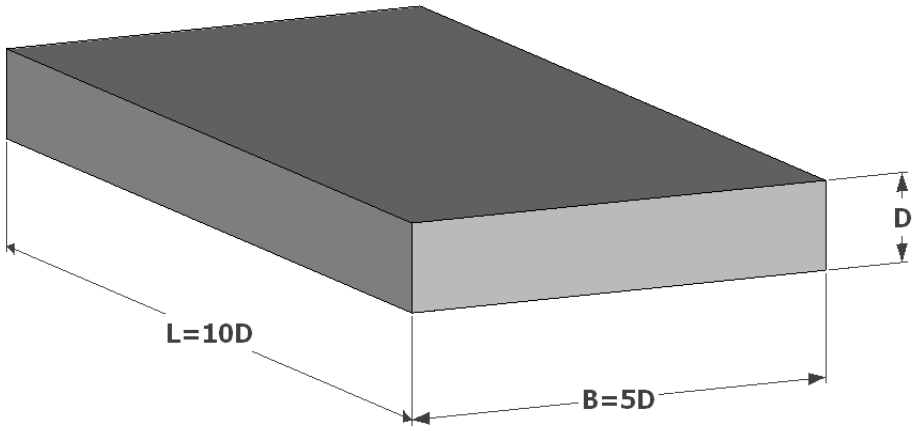


Figure 198: 3D View of the Geometry

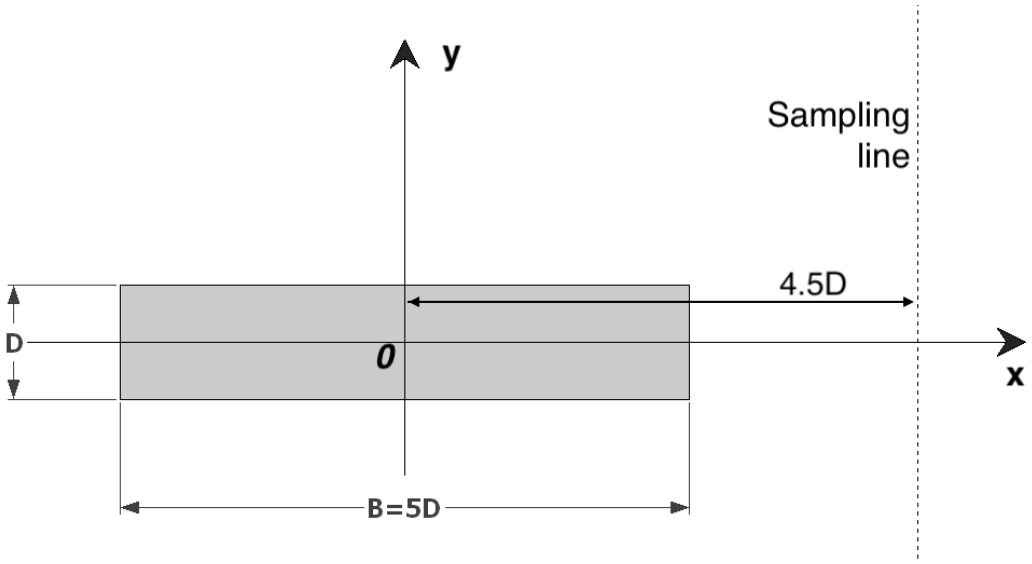


Figure 199: Sampling Location Relative to the Geometry

Computational Mesh

The computational mesh used in the simulations is created using OpenFOAM utilities snappyHexMesh and blockMesh. It is a hybrid mesh containing a structured background grid and an unstructured hexahedron-dominated mesh in the near-wall region. As shown in Figure 200, the largest cell has a depth of 2m, where the smallest has a depth of 0.0625m. The total cell count is approx. 1.7 million.

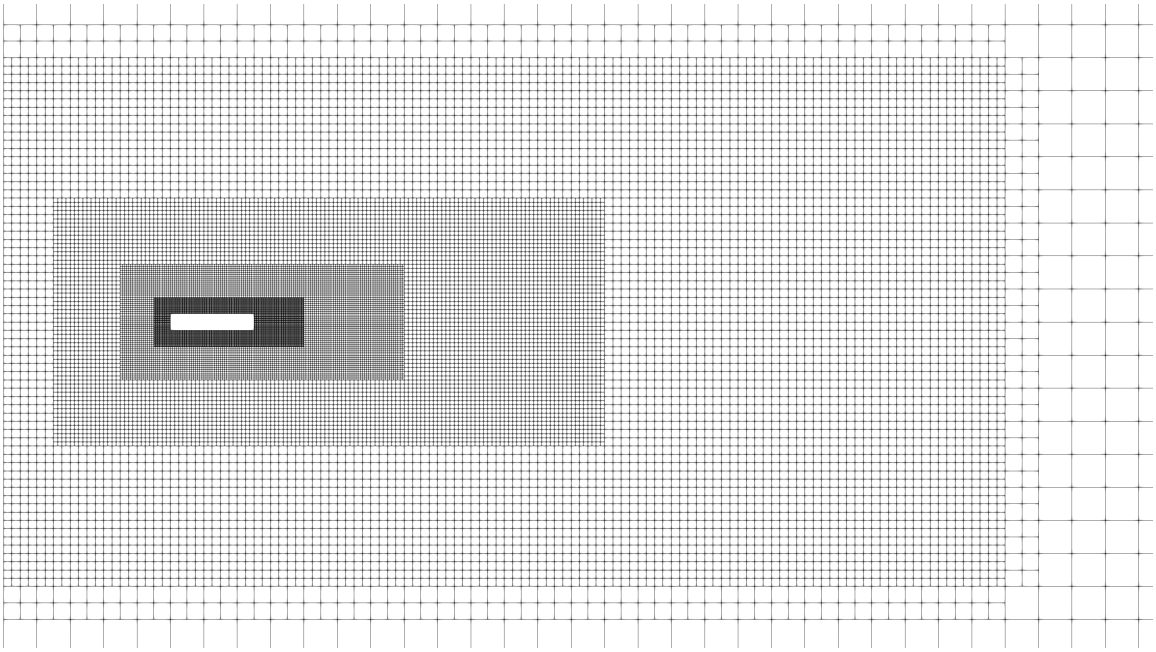


Figure 200: A Cross-Sectional View of the Computational Mesh

Boundary Conditions

Dimensions of the computational domain and the boundary conditions applied on each surfaces are shown in Figure 201.

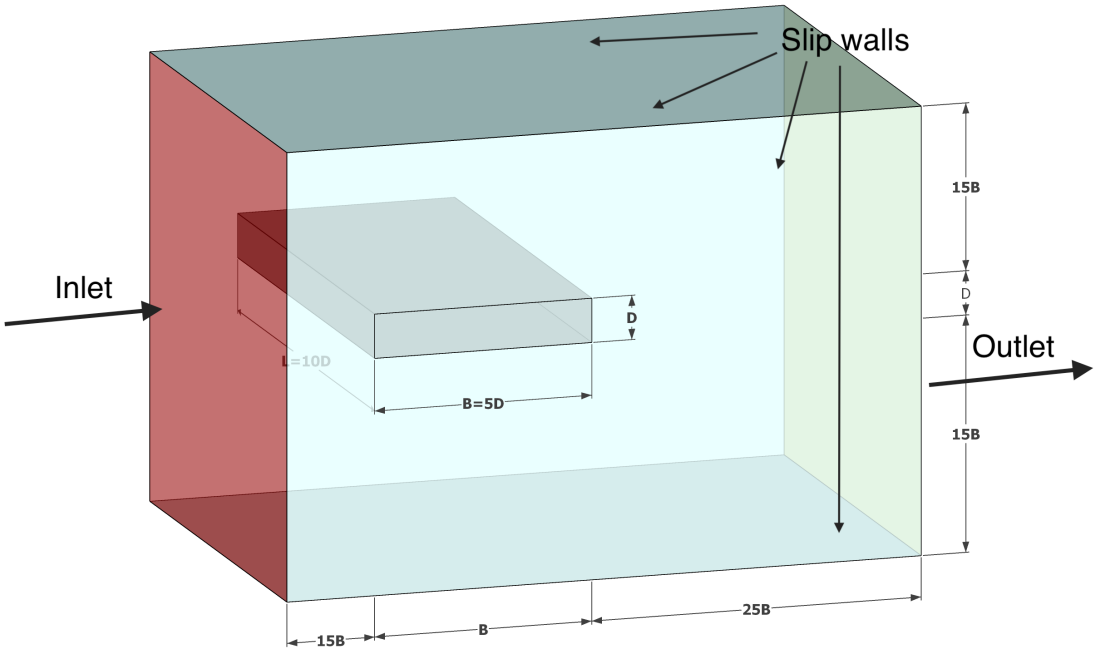


Figure 201: Computational Domain and Boundary Conditions

Numerical Configurations

In this chapter, all simulations employ the PIMPLE algorithm to perform the pressurevelocity coupling (pimpleFoam solver in OpenFOAM-V9). All terms in the RANS equations are discretized using the nominally second-order cell-centred finite volume method, where gradient and Laplacian terms are discretized using Gaussian integration with linear interpolation. Convection/advection terms are discretized using a second-order accurate linear-upwind scheme. The Euler scheme, which is a first-order implicit scheme, is implemented for the time discretization.

Results Validation

Figure 202 shows the velocity field around the cylinder. Figure 203 shows a comparison between the simulation results and the experimental data determined at the sampling location. The velocity results calculated by the presented CFD model agree well with the experimental benchmark data, which indicates that the presented CFD model can provide sufficiently accurate results for the windshear and turbulence analysis.

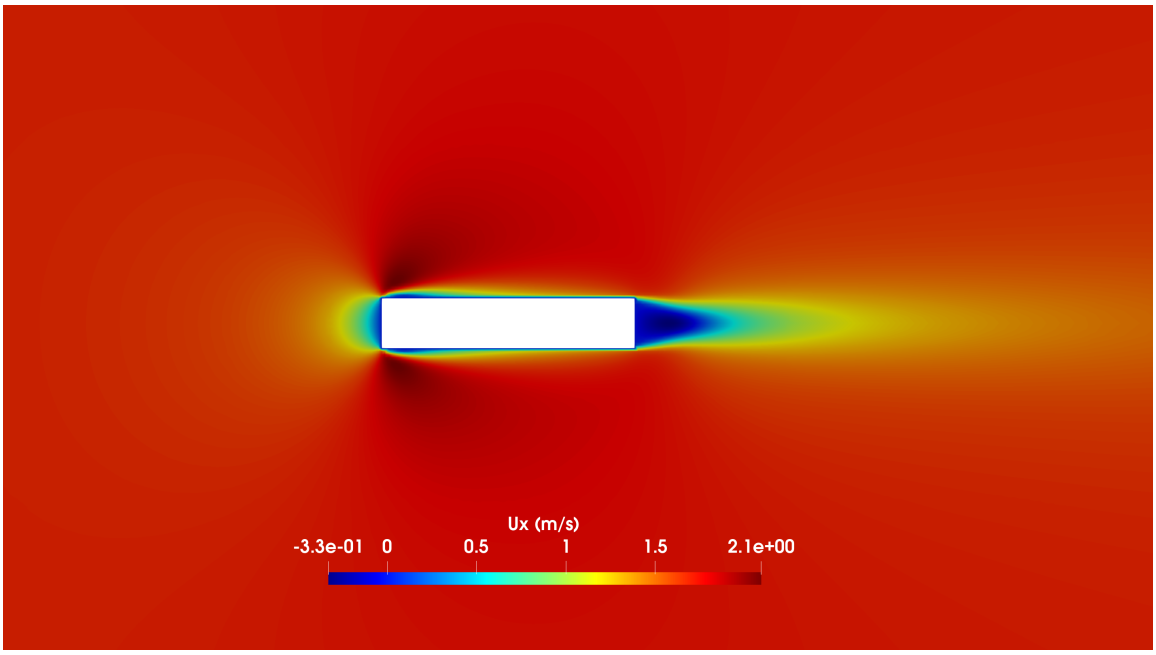


Figure 202: Velocity (m/s) in the x-direction

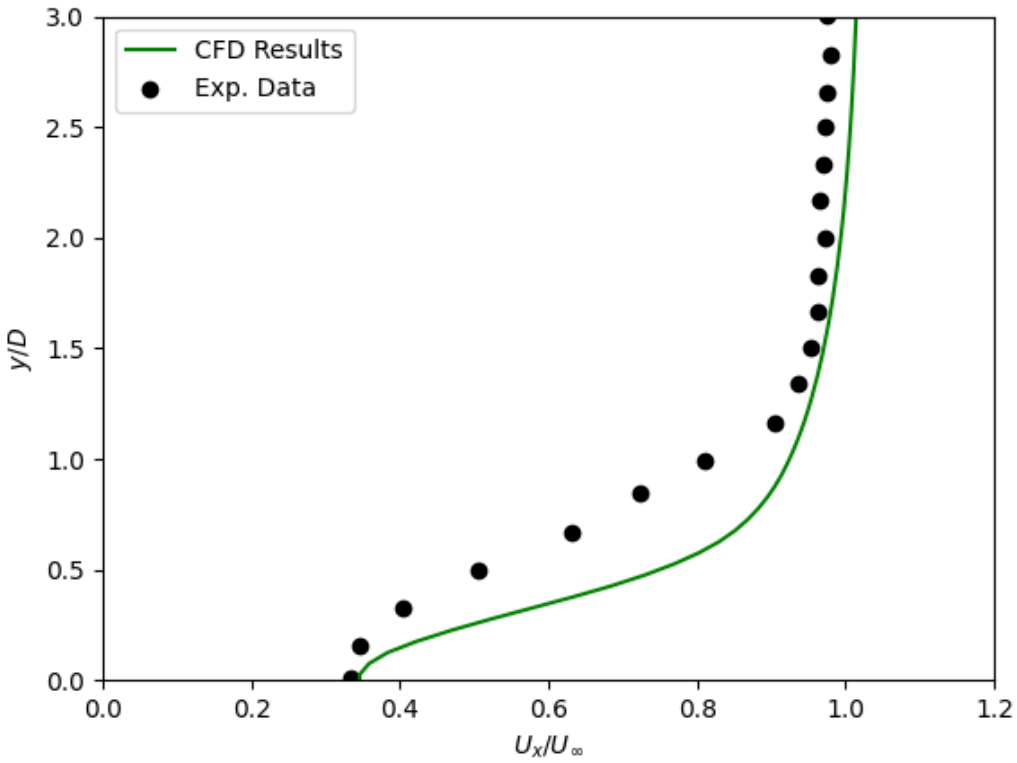


Figure 203: Comparison of velocity in the x-direction at x/D=4.5