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NLR-CR-2020-241 | August 2020

Study Wind Effects of the planned Nýi-Skerjafjörður Residential Area near Reykjavik Airport

CUSTOMER: ISAVIA

NLR – Royal Netherlands Aerospace Centre

EXECUTIVE SUMMARY

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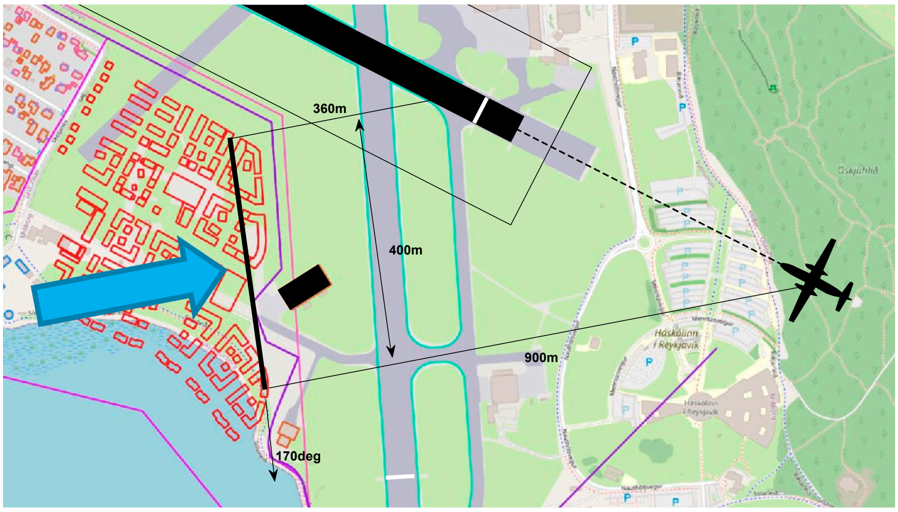

Problem area

There are plans to realize a new residential area (Nýi-Skerjafjörður) close to the airport of Reykjavik (BIRK). It is located east of the current residential area of Skerjafjörður, and will be built partly over the former runway 06, just outside the strip of the current main runway 01. The Nýi-Skerjafjörður residential area will consist of a variety of houses and apartment buildings, up to 17 meter above ground level.
Due to the proximity to the operational runways of the airport, it is possible that the new residential area affects the wind climate around the airport. It may partly block the wind, leading to shear-like phenomena, and lead to an increase of the turbulence level. Both effects may have an adverse safety impact on the airport operations.

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Description of work

The study has been based on three complementary analyses:

1. Assessment of the wind hindrance surfaces;
2. Assessment of the velocity deficit in the wake of the residential area;
3. Assessment of the turbulence intensity due to the change in terrain roughness.

The wind hindrance surfaces determine areas where there is no effect of wind hindrance to be expected and areas where possibly an adverse safety effect could occur. Criteria have been determined to assess the severity of the wake velocity deficit and the level of turbulence. The estimation of the velocity deficit and turbulence level has been performed, using empirical methods as developed by ESDU.

Results and conclusions

Based on the first analysis it is concluded that only approaches to runway 01 and runway 31 are potentially affected by the new residential area.
Based on the second analysis it is concluded that the wake velocity deficit encountered during the approaches is marginal and acceptable from a safety perspective. Based on the third analysis it is concluded that in general the turbulence level may increase, but not to a level that it can be considered as an adverse safety effect. However, for approaches to runway 31 under severe wind conditions the increase of turbulence intensity may be significant.
A safety analysis shows that the associated risk is tolerable. However, mitigating measures may be required to minimize and manage the risk. Possible measures are to brief pilots to be prepared for significant atmospheric turbulence during the final approach, under the given wind conditions, and monitoring the exposure to the expected level of turbulence and the associated pilot reports as part of the airport’s safety management system.
Risk acceptance should be part of a management decision.
However, it is concluded that the identified risk is manageable and should not block the development of the Nýi-Skerjafjörður residential area.

Applicability

The results of this study may be used in the process of acquiring a building permit for the Nýi-Skerjafjörður residential area, taking into account the operational safety aspects of building close to an airport. The results can also be used for consultations with the airport management.

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Contents

Abbreviations

ACRONYM	DESCRIPTION
AGL	Above Gound Level
AIP	Aeronautical Information Publication
AMSL	Above Mean Sea Level
BIRK	ICAO Code Reykjavik Airport
d	Height above zero plane
ESDU	Engineering Science Data Unit
EU	European Union
FAA	Federal Aviation Administration
ft	Foot
GNSS	Global Navigation Satellite System
H	Height of obstacle
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
kt	Knot
NDB	Non-directional Beacon
NLR	Netherlands Aerospace Centre
OLS	Obstacle Limitation Surface
RMS	Root Mean Square
RNAV	Area Navigation
RWY	Runway
THR	Threshold
VFR	Visual Flight Rules
z	Height above ground
z_0	Terrain roughness parameter

1 Introduction

There are plans to realize a new residential area close to the airport of Reykjavik (BIRK). This residential area is referred to as Nýi-Skerjafjörður. It is located east of the current residential area of Skerjafjörður, and will be built partly over the former runway 06, just outside the strip of the current main runway 01 and close to the crossing of runways 01 and 13. The Nýi-Skerjafjörður residential area will consist of a variety of houses and apartment buildings, up to 17 meter above ground level.
Due to the proximity to the operational runways of the airport, it is possible that the new residential area affects the wind climate around the airport. It may partly block the wind, leading to shear-like phenomena, and lead to an increase of the turbulence level. Both effects may have an adverse safety impact on the airport operations.

The present study evaluates the potential safety impact based on three complementary analyses:

1. Assessment of the wind hindrance surfaces;
2. Assessment of the velocity deficit in the wake of the residential area;
3. Assessment of the turbulence intensity due to the change in terrain roughness.

The study is set-up to first provide the necessary information about the airport lay-out and the new residential area. This is presented in Chapters 2 and 3, respectively.
The wind effects study is performed in Chapter 4. First, the assessment criteria are introduced and the study approach is presented. Subsequently, the three separate analyses are performed and documented in the dedicated sections. Finally, the results are summarized in Chapter 5 and the conclusions and recommendations, based on these results, are presented.

2 Reykjavik Airport (BIRK)

Reykjavik airport is the airport of Iceland's capitol city. It provides domestic hub services to and from the City of Reykjavik and environment. In addition several other functions are provided, such as ambulance flights, flight training, (international) business and tourist flights.
The airport operates four runways: 01/19 and 13/31. RWY01/19 has a length of 1567 meter and RWY13/31 a length of 1230 meter. The declared distances have been summarized in Table 2-1.
Based on the available reference field length the airport qualifies as an ICAO code 3 airport.

Table 2-1: Declared distances at Reykjavik Airport [AIP]

<table>
<tr><th>RWY Designator</th><th>TORA (M)</th><th>TODA (M)</th><th>ASDA (M)</th><th>LDA (M)</th><th>Remarks</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th></tr>
<tr><td>01</td><td>1567</td><td>1567</td><td>1567</td><td>1487</td><td rowspan="2"></td></tr>
<tr><td>19</td><td>1567</td><td>1567</td><td>1567</td><td>1567</td></tr>
<tr><td>13</td><td>1230</td><td>1230</td><td>1230</td><td>1230</td><td></td></tr>
<tr><td>13*</td><td>1375*</td><td>1375*</td><td>1375*</td><td></td><td rowspan="3">*TKOF from paved end inside RESA</td></tr>
<tr><td>31</td><td>1230</td><td>1230</td><td>1230</td><td>1165</td></tr>
<tr><td>31*</td><td>1349*</td><td>1349*</td><td>1349*</td><td></td></tr>
</table>

Runway 19 is the preferred runway and is equipped with a CAT I precision approach facility. Runway 19 qualifies therefore as a precision approach runway. Runways 01 and 13 are non-precision instrument runways, which are served by RNAV(GNSS), Localizer only (RWY13) or NDB (RWY13) instrument approach procedures. These runways will be mainly used for IFR traffic in case wind conditions do not allow use of runway 19, due to excessive cross- or tailwind.
Runway 31 is a non-instrument runway and is only used for VFR traffic (weather permitting).

Based on five years of traffic data (2015-2019) it has been observed that Reykjavik accommodated in total around 90,000 movements in this period, averaging 18,000 movements per year. In 2019 20,490 movements were realized. On average the traffic was distributed over the four runways as follows:

- RWY01: 30.3%;
- RWY13: 17.8%;
- RWY19: 38.2%;
- RWY31: 13.7%.

A large variety of aircraft use the airport, varying from small general aviation aircraft, like a Diamond DA-40 to medium-large commercial airliners, like the Boeing 757. Most frequent aircraft are the Fokker 50 (until 2016) and the Bombardier Dash-8 (after 2016), both twin-engine turbo-props with a seat capacity of around 50 passengers.

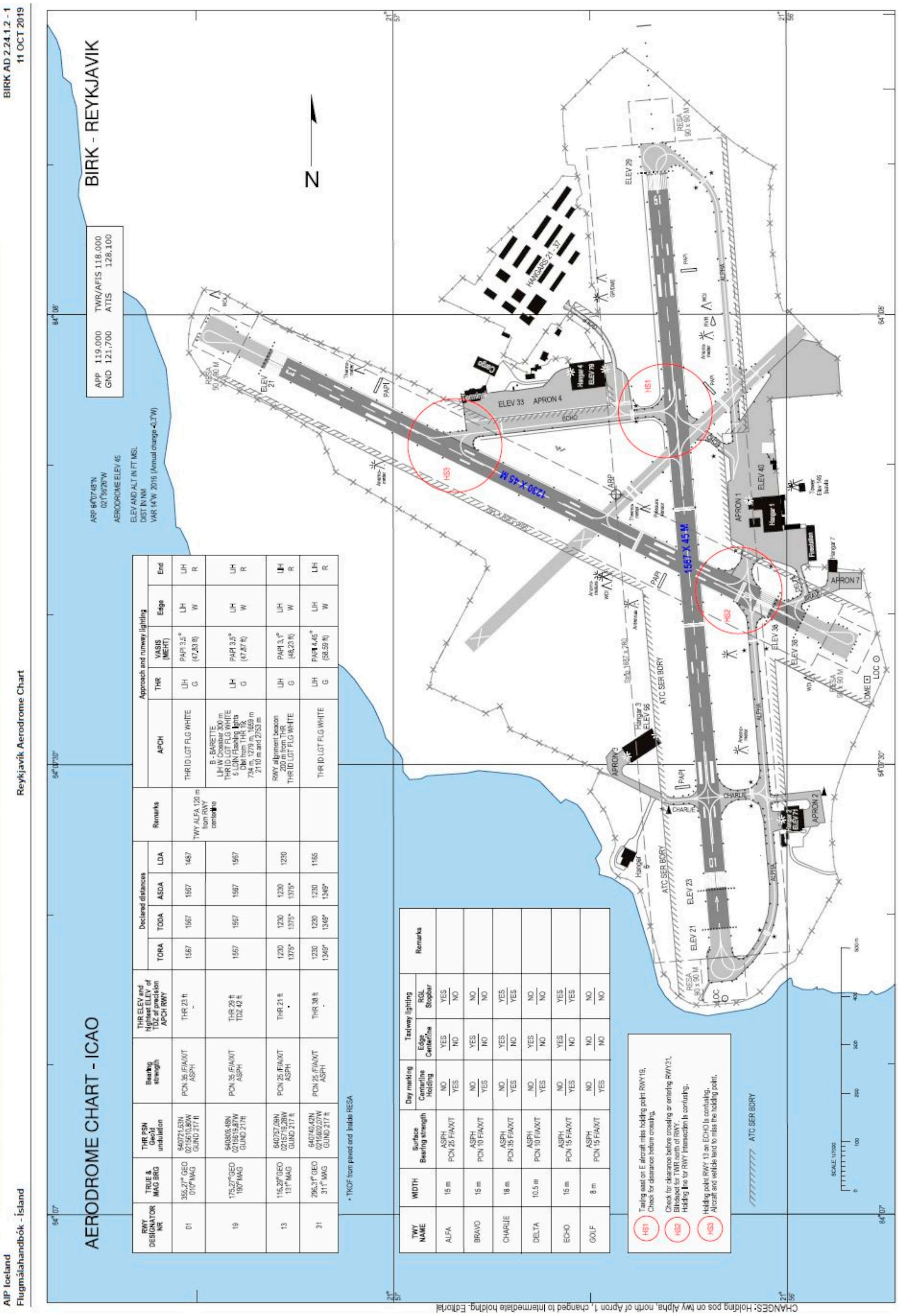


Figure 2-1: Reykjavik Airport (BIRK) Aerodrome Chart [1]

3 The Nýi-Skerjafjörður residential area plan

The City of Reykjavik plans to realize a new residential area close to the airport of Reykjavik (BIRK). The new residential area is located east of the current residential area of Skerjafjörður, and will be built partly over the former runway 06. For this purpose part of the current airport terrain is freed to get a residential destination.
The new residential area is referred to as Nýi-Skerjafjörður and is located just outside the strip of the current main runway 01, west of this runway and south of runway 13. The situation is visualized in Figure 3-1.

Figure 3-1: Location of the planned Nýi-Skerjafjörður residential area

The detailed lay-out of the plan and the subdivision in various lots is shown in Figure 3-2.
The relevant distances of the various lots to the runway centreline of RWY01 and RWY13 are given in Table 3-1.
It is shown that buildings closest to runway 01 (in lot 5 and 10) are located at slightly less than 190 meter from the runway centreline. The closest distance to runway 13 (houses in lot 1a) is around 200 meter.

It should be noted that the project incorporates two phases. The first phase is well defined in terms of building locations and height, as shown in Table 3-1. However, the second phase (Áfangi 2) is not yet fully defined, as shown in Figure 3-2, although the tentative building locations are shown in Figure 3-1. The highest building in the phase 2 area will be 24 meter AMSL. The characteristics of the buildings in phase 2 will be more or less similar to the buildings in the phase 1 area.

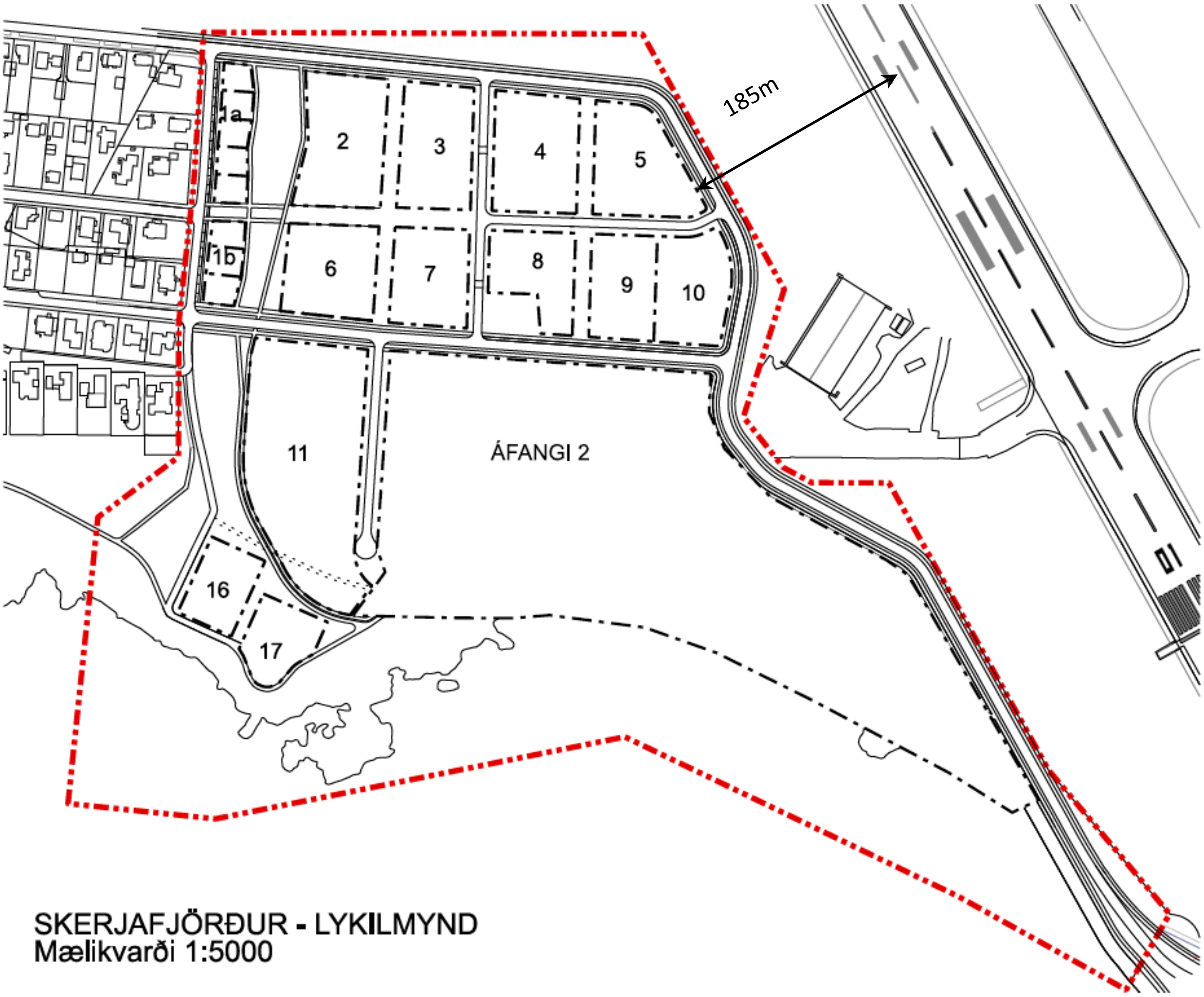


Figure 3-2: Lay-out of the Nýi-Skerjafjörður residential area

Table 3-1: Location of Nýi-Skerjafjörður residential area relative to the runways 01 and 13

Lot	Max. Height (m AMSL)	Distance to RWY01 (m)	Distance to RWY13 (m)
Lot 1	20	409-504	200-362
Lot 2	21.2	342-418	206-286
Lot 3	23.4	289-376	207-289
Lot 4	24.5	227-315	207-292
Lot 5	24	187-256	212-293
Lot 6	23	397-468	309-374
Lot 7	26	342-412	309-376
Lot 8	20.5	277-343	310-375
Lot 9	24	234-300	312-381
Lot 10	24	188-255	311-384
Lot 11	23	433-522	396-539
Lot 16	13	564-633	539-602
Lot 17	13.2	594-606	620-633

The buildings in Nýi-Skerjafjörður residential area are located within the area of the relevant Obstacle Limitation Surfaces, associated with these runways (see [2]); in particular the transitional surfaces (stretching 455 meter from the centreline of runway 01. Consequently height restrictions do apply to buildings in this area.
It is assumed that the maximum building height in the various lots complies with the regulatory obstacle restrictions to safeguard aviation safety.

However, compliance with the obstacle requirements does not ensure that all safety aspects are addressed. It is well-known that obstacles that do not interfere with the transitional surface still may have a significant effect on the wind disturbances that aircraft may experience during the final approach and landing (see [4]). In worst case this may result even in hazardous effects. For this reason the wind effects that may result from the realisation of the Nýi-Skerjafjörður residential area are further analysed and addressed in the next Chapter.

4 Wind effects study

4.1 Wind hindrance criteria

It is well known that build-up areas near the runway, and in particular in the area of the final approach and landing, may cause serious disturbances to the governing wind climate, such that the control of the aircraft may significantly be affected. This may cause increased workload and difficulties to accurately land the aircraft in the desired touchdown zone. In worst case it may to lead hard landings or even runway excursions.
Extensive research into the effects of wind hindrance due to obstacles around airports has been performed by NLR in the past [4]. The main motive for this study concerned the realisation of an engine test stand near the threshold of runway 27 of Schiphol. Although this construction did not penetrate any of the Obstacle Limitation Surfaces, it appeared that, soon after it was realised, under some wind conditions aircraft on final approach to runway 27 were severely hampered by the wind disturbance caused by the test stand. For this reason the Dutch aviation authority commissioned NLR to investigate the level of disturbances that the test stand could generate, and to determine criteria to assess future buildings at the airport terrain.
The study focussed not only on the test stand, but also on the effects of large buildings, such as hangars. Basically, the study found that three effects should be discriminated:

1. *Turbulence intensity*: buildings near the runway effectively change the terrain roughness around the airport. The terrain roughness is the main parameter determining the level of turbulence near the ground. An increase of the turbulence intensity may have an effect on aircraft controllability.
2. *Velocity deficit:* a large building (or group of buildings) may shield the approach path from the undisturbed wind, leading to a change of wind as function of altitude. This will be experienced by an aircraft as a windshear (a change of velocity over a given distance or time). The main parameter concerns the velocity deficit that may be caused by the building, and which is a measure of the severity of the effect.
3. *Wake vortices:* Buildings of a particular shape may shed wake vortices. These wake vortices may cause lateral-directional upsets of aircraft, similar to the wake vortices effects of two sequential aircraft. Such upsets may hamper the control of aircraft near the ground.

The results of the study led to a number of conclusions. First of all it was clearly demonstrated that wind effects may be significant for obstacles below the Obstacle Limitation Surfaces (OLS). Therefore, compliance with the OLS does not automatically ensure safety.
Secondly, it was concluded that building induced wind shear may cause a major effect on aircraft controllability due to the resulting wake velocity deficit and the associated increase of the turbulence level.

These results led to two main criteria to assess the severity of obstacle induced turbulence.

The first criterion concerned definition of so-called *wind hindrance surfaces*.
It was shown that even a worst-case stand-alone obstacle (i.e. an engine test stand) will not affect the response and landing performance of the aircraft significantly in case it does not penetrate an imaginary surface with a slope of 1:35 with the extended centreline as base. The segment where the wind disturbance plane is restrictive is bounded by a disk-shaped segment with origin in the centre of the runway threshold and radii of approximately 1200m perpendicular to runway centreline) and 900m in front of the runway threshold. The surface should cover the area of the high speed roll aft of the runway threshold.

The wind hindrance surface should be regarded as an assessment surface. For any obstacle not penetrating the wind hindrance surface it is guaranteed that no impact on the response and landing performance of the aircraft will occur. In case an obstacle penetrates the wind hindrance surface a specialist analysis is required to determine the severity of the effect, which still can be fully acceptable.
In the Netherlands the wind hindrance surfaces are used to comply with Article 9b[1] of the Commission Regulation (EU) Nr. 139/2014. Buildings with a width of 30 meters or more and penetrating the wind hindrance surface are not allowed unless a declaration of no objection has been issued, based on a specialist wind hindrance analysis.

The second criterion is related to the maximum allowable wake velocity deficit and the acceptable level of turbulence that may be caused by the increased terrain roughness.
The second criterion is summarized as follows.
For the segment that covers the landing phase from 200ft AGL to touchdown and the high speed roll out:

- With respect to the disturbance of a stand-alone block shaped obstacle the following criterion applies:
  - ***Along the aircraft track*** the speed deficit due to a wind disturbing structure must remain below 7 knots. The speed deficit change of ***7 knots*** must take place over a distance of at least 100m.
  - ***Across the aircraft track*** the speed deficit due to a wind disturbing structure must remain below 6 knots. The speed deficit change of ***6 knots*** must take place over a distance of at least 100m.
- With respect to impact of the surface roughness the following criterion applies:
  - ***The gust/turbulence components*** in horizontal direction caused by a wind disturbing structure in combination with the meso-scale surface roughness must remain below RMS values of ***4 knots.***

4.2 Study approach

The study approach will apply the wind hindrance criteria, as discussed in the previous section and as relevant for the building characteristics in the planned Nýi-Skerjafjörður residential area.

First it is assessed if and where the new buildings penetrate the wind hindrance surfaces for the various runways.
Secondly, for areas where penetrations are identified, it is estimated what the effects are on the change of wind in the boundary layer. This is translated into the wake velocity deficit that an aircraft may encounter during the final phase of the approach.
Thirdly, an assessment will be made to which extent the change in surface roughness may impact the turbulence intensity.

The potential impact of wake vortices, as mentioned in the previous section, is not further addressed in this study, because the shedding of significant wake vortices requires a specific shape of the buildings (such as an engine test stand). The characteristics of the buildings in the Nýi-Skerjafjörður residential area are such that they are expected not to generate such effects.

[1] Article 9 concerns: **Monitoring of aerodrome surroundings**; Member States shall ensure that consultations are conducted with regard to human activities and land use such as: (b) any development which may create obstacle-induced turbulence that could be hazardous to aircraft operations.

4.3 Wind hindrance surfaces

The wind hindrance surfaces for the four runways of Reykjavik airport are shown in Figure 4-1. It is shown that the Nýi-Skerjafjörður residential area is located only within the area of the wind hindrance surfaces associated with runway 01 and 31. It can therefore be concluded that operations on runway 13 and 19 will experience no safety effects due to the realization of Nýi-Skerjafjörður residential area.

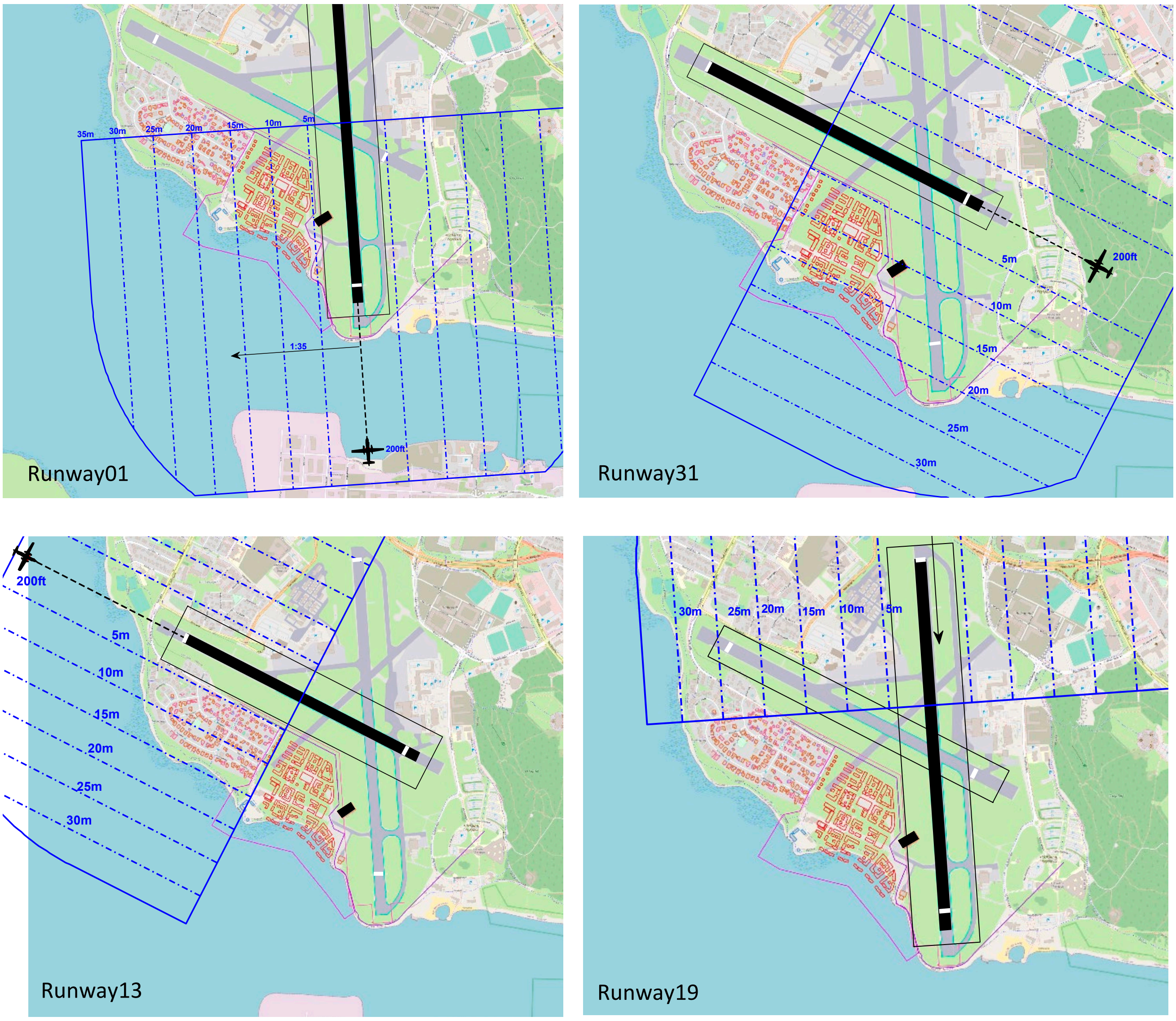


Figure 4-1: Wind hindrance surfaces for the four runways of Reykjavik Airport

For runway 01 the Nýi-Skerjafjörður residential area is located in an area of the wind hindrance surface where the iso-height contours vary between 5 and 15 meter above runway elevation 01, which is between 9 and 12 m AMSL in this area. It is evident that some of the buildings, in the lots closest to the runway (Lots 4, 5, 9 and 10), with building heights up to 24 m AMSL will penetrate the wind hindrance surface. The maximum penetration of the wind hindrance surface in these lots is between 6 and 8 meters and therefore requires further analysis.

For runway 31 the northern part of the Nýi-Skerjafjörður residential area (lots 1 to 10) is located in an area of the wind hindrance surface where the iso-height contours vary between 6 and 11 meter above runway elevation 13, which is around 11 meter AMSL in this area. It is evident that some of the buildings in these lots will penetrate the wind hindrance surface. The maximum penetration of the wind hindrance surface in these lots is around 4 to 5 meters and therefore requires further analysis.

4.4 Boundary layer wind effects

In order to assess the impact of the Nýi-Skerjafjörður residential area on the wind encountered during the final phase of the approach and landing a worst case approach scenario is applied. In the present stage of the investigation it is not possible to model all individual buildings and assess their individual contribution to the wind effects. For this reason the residential area is modelled as a fence of a certain width and height that blocks the undisturbed wind and has an effect on the change of wind as a function of altitude. The difference between the undisturbed wind and the disturbed wind at a certain altitude determines the velocity deficit caused by the build-up area. The velocity deficit is a measure of the severity of the effect, which can be assessed with the criteria as presented in section 4.1.

The estimation of the wind shelter that is provided by a solid or porous fence can be performed using the methodology as described in ESDU 97031 (see [5]).
This methodology is based on a combination of methods that provides best estimates at various distances behind the fence.
In general terms the method describes various areas behind the fence, as shown in Figure 4-2.

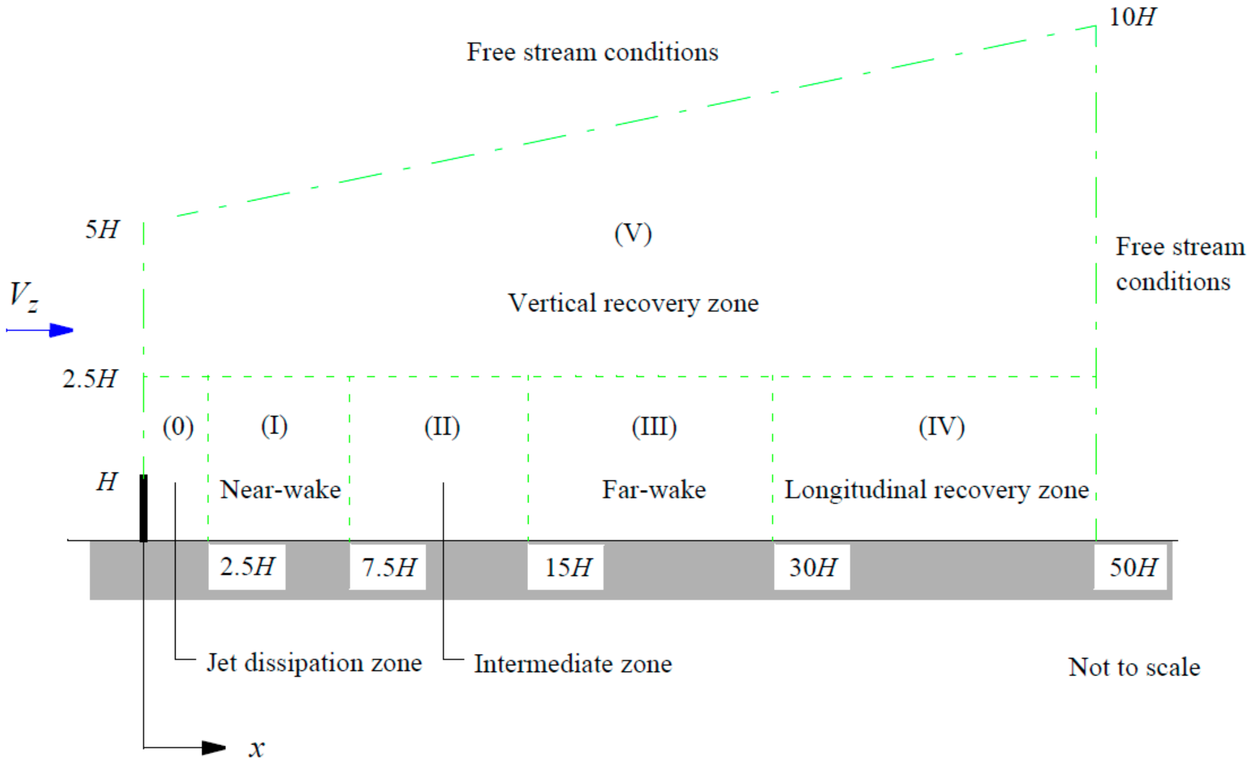


Figure 4-2: Various wake zones behind a fence [ESDU 97031]

The highest buildings in the Nýi-Skerjafjörður residential area have a height (H) of around 17 meter above ground.

The closest distance to the runway is around 190 meter (~11H). The distance to the point where the approach path has an altitude of 200ft is around 1100m (~65H) for runway 01 and 900m (~50H) for runway 31.
Therefore, the wind disturbance effects may be expected in the "intermediate zone" up to the area where the free stream conditions have fully recovered. In the area of the "Far wake" and "recovery zone" differences between the effects of a fence and a build-up area will largely disappear. Therefore, the method of modelling the residential area as a porous wall is an acceptable simplification.

The next question is how a fence can be defined, in terms of width, height and porosity, which is representative for the residential area. Because the study represents a worst case analysis, the height of the fence is taken as equal to the highest building in the area, and thus 24 meter AMSL (17 meter above ground).
The width is taken as the width of the residential area. The orientation of the fence is such that it is perpendicular to the bearing to the point of interest at the approach path, in order to capture the largest area of wind.
For approaches to runway 01 this leads to three scenarios, representative for three given wind directions.
For the various scenarios the location and dimension of the fence is shown for runway 01 in Figure 4-3.

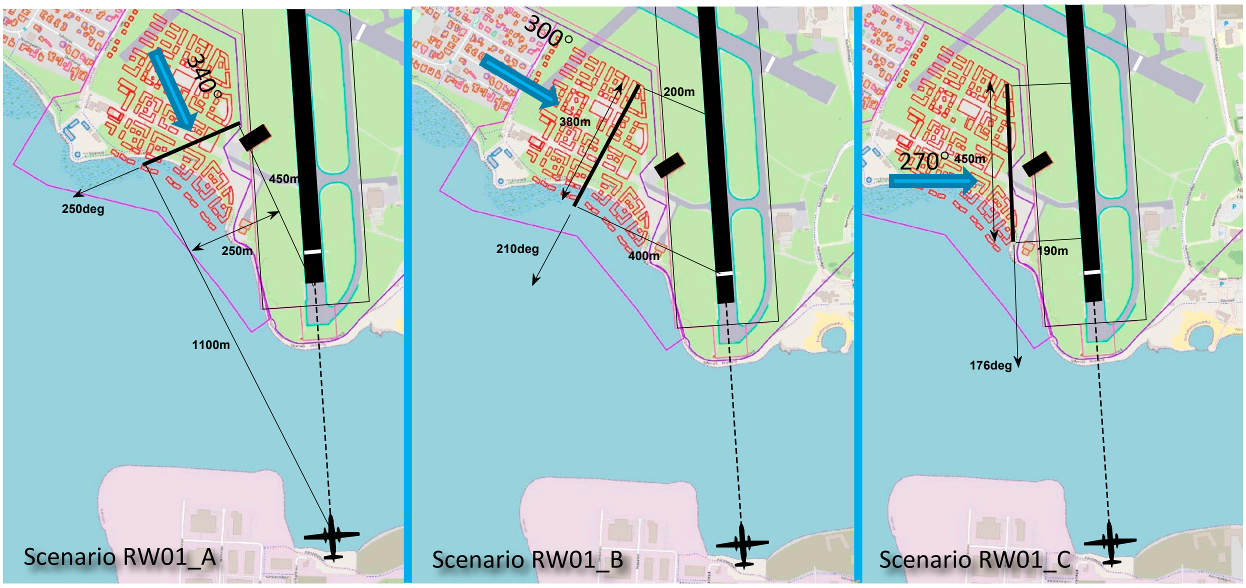


Figure 4-3: Representative wind scenarios for runway 01, with corresponding fence dimension and orientation

It is shown that three scenarios are sufficient to fully cover the exposure to wind effects of aircraft approaching to runway 01.

For runway 31 the exposure to wind effects can be sufficiently modelled with two scenarios, see Figure 4-4.

The next question to be addressed concerns the level of porosity of the fence in order to be representative of the residential area. For this some further explanation of the fence aerodynamics is required[2].
In general, the aerodynamic action of a fence is simple in principle. The fence exerts a drag force on the wind field, causing a net loss of momentum in the airflow, thus creating a sheltering effect. As the porosity of a fence is reduced (i.e. towards a solid fence), 'the bleed flow' decreases and the drag force increases. This is accompanied by a greater upward deflection of the approach flow and, below a certain porosity, a large region of separated flow in the lee of the fence is created.

[2] The following text in italic is quoted from ESDU 97031.

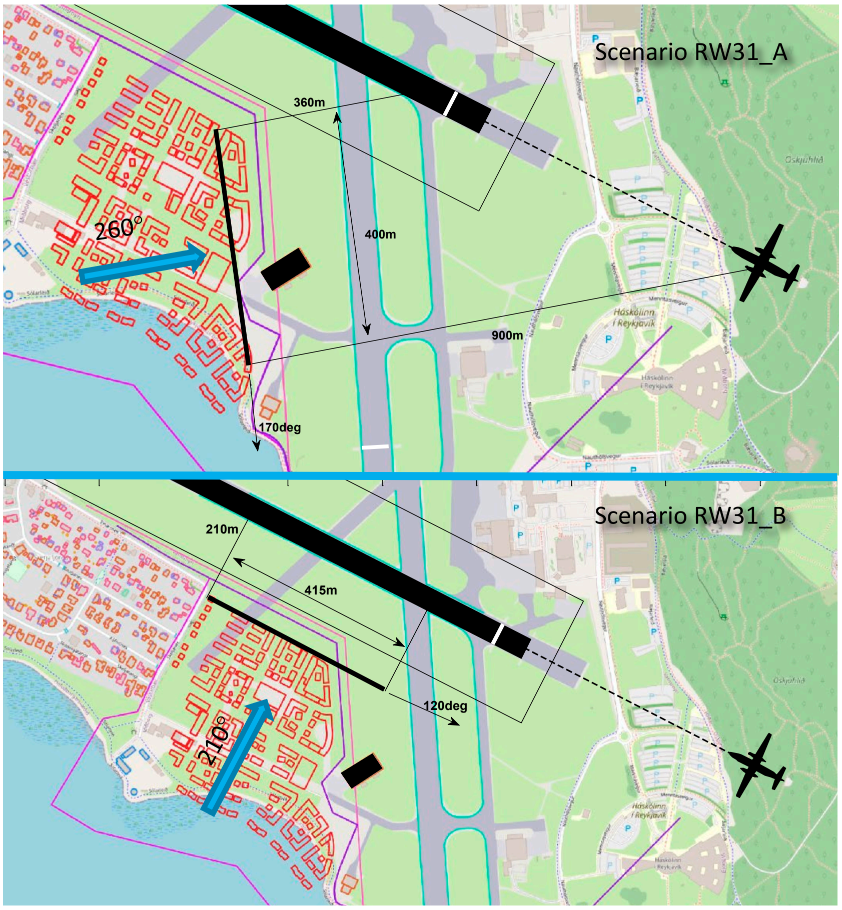


Figure 4-4: Representative wind scenarios for runway 31, with corresponding fence dimension and orientation

For a solid fence this separation region, or 'quiet zone' can be approximated to a triangular zone extending from the top of the fence to the ground at around 7.5H, depending on the turbulence intensity. The more solid the fence, the stronger is the turbulence in the separation bubble and the steeper the return of the displacement flow to the ground at its downstream reattachment point. As porosity increases (and hence bleed flow increases), the separation bubble diminishes in size and moves downstream. The separation bubble disappears at a porosity of about 0.35.

Based on experience it is known that a residential area has noticeable porosity, due to the inherent open spaces in between the buildings. In general, there is only a small or no separation bubble behind a residential area. For this reason it is assumed that, as a reasonable and representative porosity, a value of 25% can be used.

The final issue to be addressed concerns the wind speed that an aircraft may encounter for the wind directions corresponding to the specified scenarios. To identify worst case scenarios five years of traffic data (period 2015-1019) have been analysed. For each approach to one of the two relevant runways the instantaneous wind speed and direction has been determined by matching the traffic and weather data.
Based on this information the wind speed distribution for the various scenarios can be determined. This is illustrated in Figure 4-5, showing the empirical cumulative wind speed distribution, related to the three scenarios for runway 01 and the two scenarios for runway 31. The indicated wind directions associated with the various scenarios have been applied with +/- 15 degrees margin, so that each wind direction covers in fact a 30° wind sector.
It is shown that in pure crosswind conditions (in both cases the blue lines) the mean wind speed is less than in the cases with more headwind conditions. This is to be expected, because aircraft are subject to certain crosswind limitations. In general, runway assignment is such that the crosswind component does not exceed 15 kt.

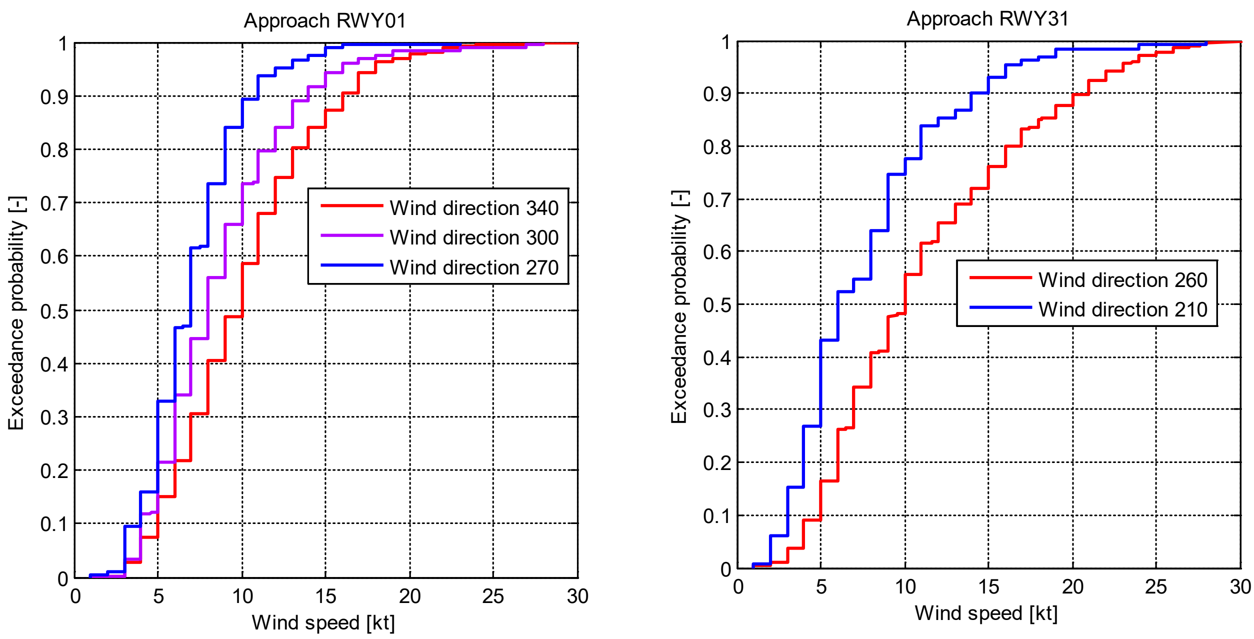


Figure 4-5: Empirical cumulative probability distribution of wind speed exceedance as function of wind direction, for approaches to runway 01 and runway 13, based on five years of traffic and weather data (2015-2019)

It is shown that for operations on runway 01 crosswind almost never exceeds 15kt. It is remarkable that for operations on runway 31 wind speed (and crosswind) is in general higher than for operations on runway 01, because runway 31 is a non-instrument runway and thus will only be used for VFR traffic.

The cumulative wind speed distributions are used to determine the worst case wind conditions. The reasonable maximum wind per scenario has been determined based on a 99% wind speed probability.
This leads per scenario to the following maximum wind speeds:

- Scenario RWY01_A: 23kt;
- Scenario RWY01_B: 23kt;
- Scenario RWY01_C: 15kt;
- Scenario RWY31_A: 28kt;
- Scenario RWY31_B: 19kt;

Using the ESDU methodology the wind speed in the earth boundary layer can be modelled, both in case the wind is fully undisturbed and in case the wind is disturbed by the porous fence.
Based on the given fence characteristics and the associated maximum wind the worst case wind disturbances are determined for each scenario.
The results are shown in Figure 4-6 through Figure 4-10.

Each figure shows four graphs. The left column shows the wind effect as function of distance to the threshold (negative values indicating before threshold crossing). The upper graph shows the undisturbed and disturbed wind, as encountered during the approach. The lower graph shows the encountered velocity deficit; the total deficit and the longitudinal and crosswind components. In this graph also the assessment criteria are shown (6kt for crosswind disturbances and 7kt for longitudinal disturbances).
The right column shows the same data, but now presented as function of altitude above the threshold.

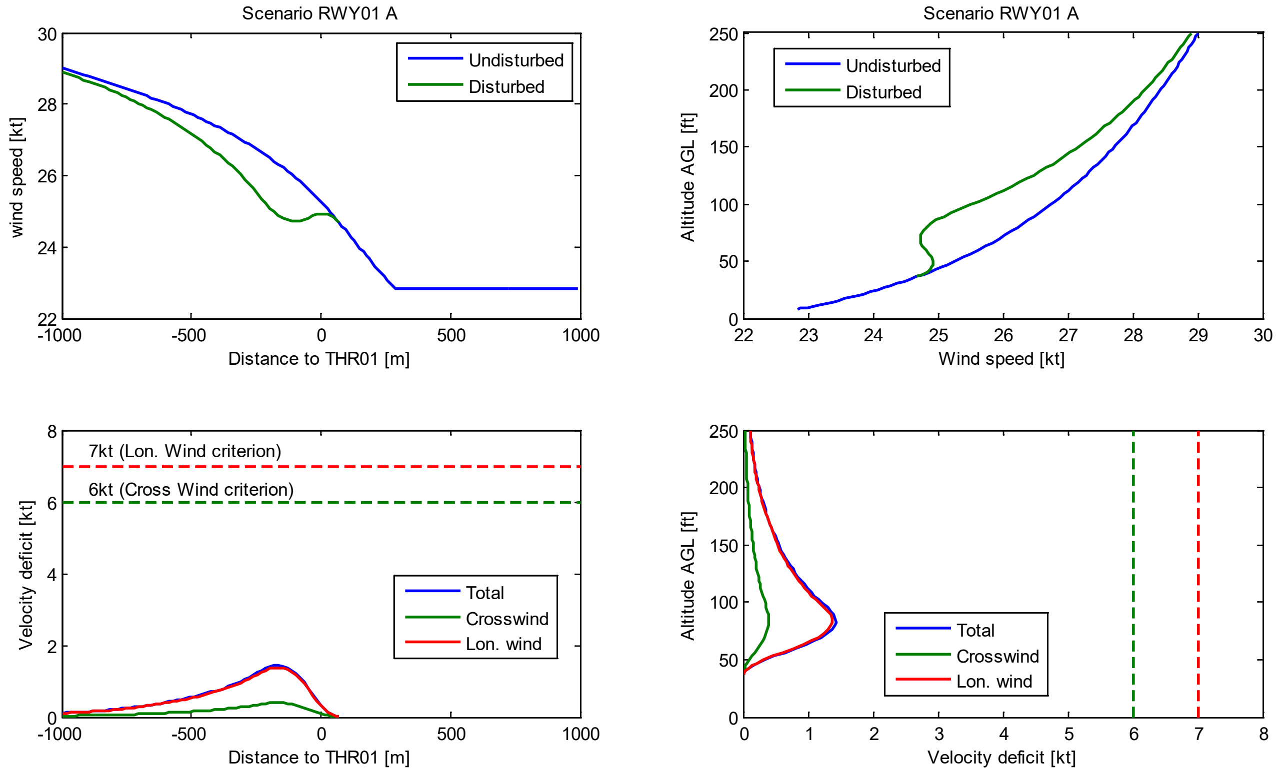


Figure 4-6: Worst case wind disturbance Scenario RWY01_A (wind speed: 23kt, wind direction: 340°)

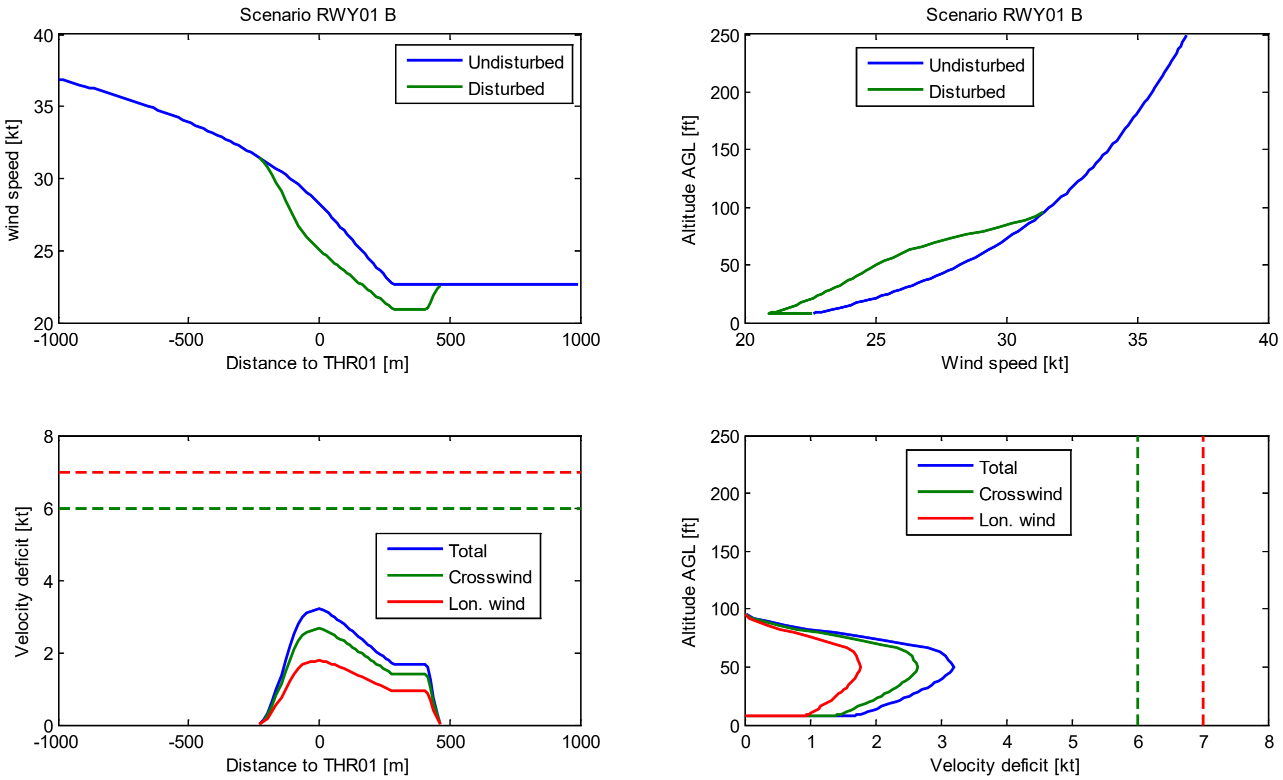


Figure 4-7: Worst case wind disturbance Scenario RWY01_B (wind speed: 23kt, wind direction: 300°)

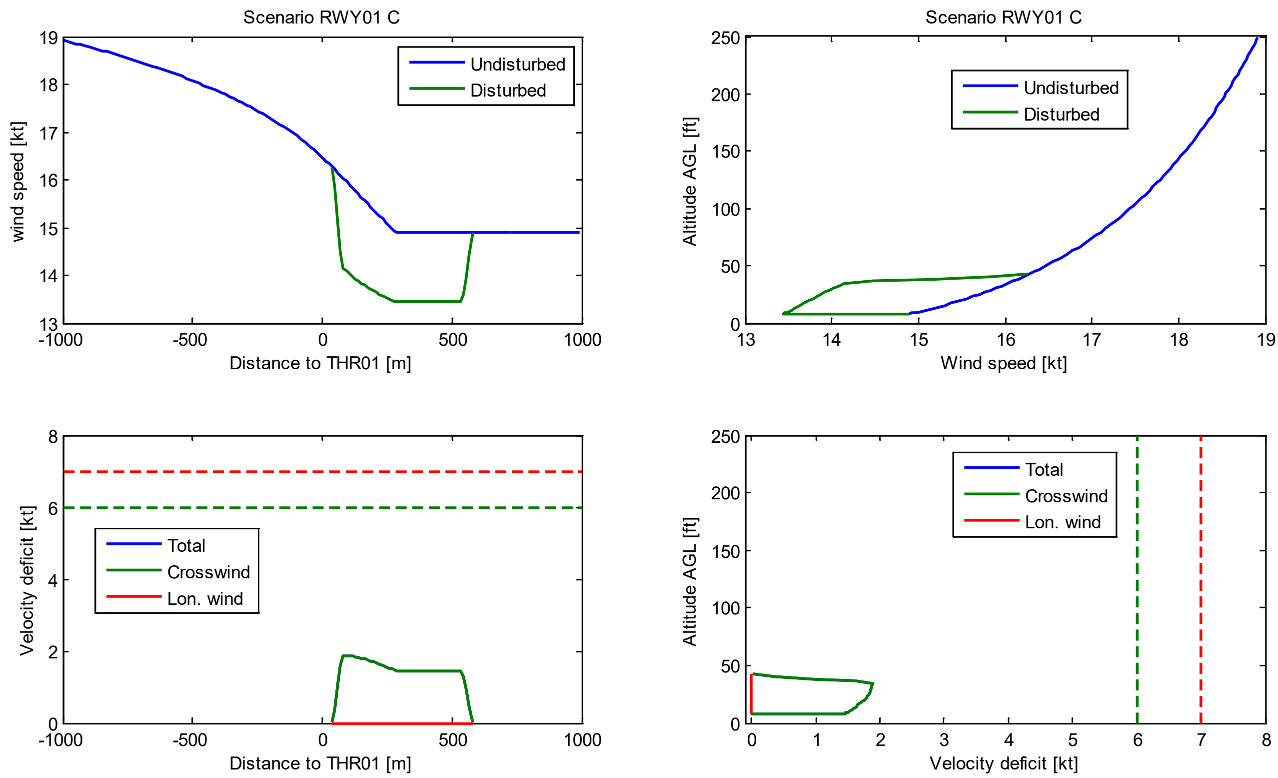


Figure 4-8: Worst case wind disturbance Scenario RWY01_C (wind speed: 15kt, wind direction: 270°)

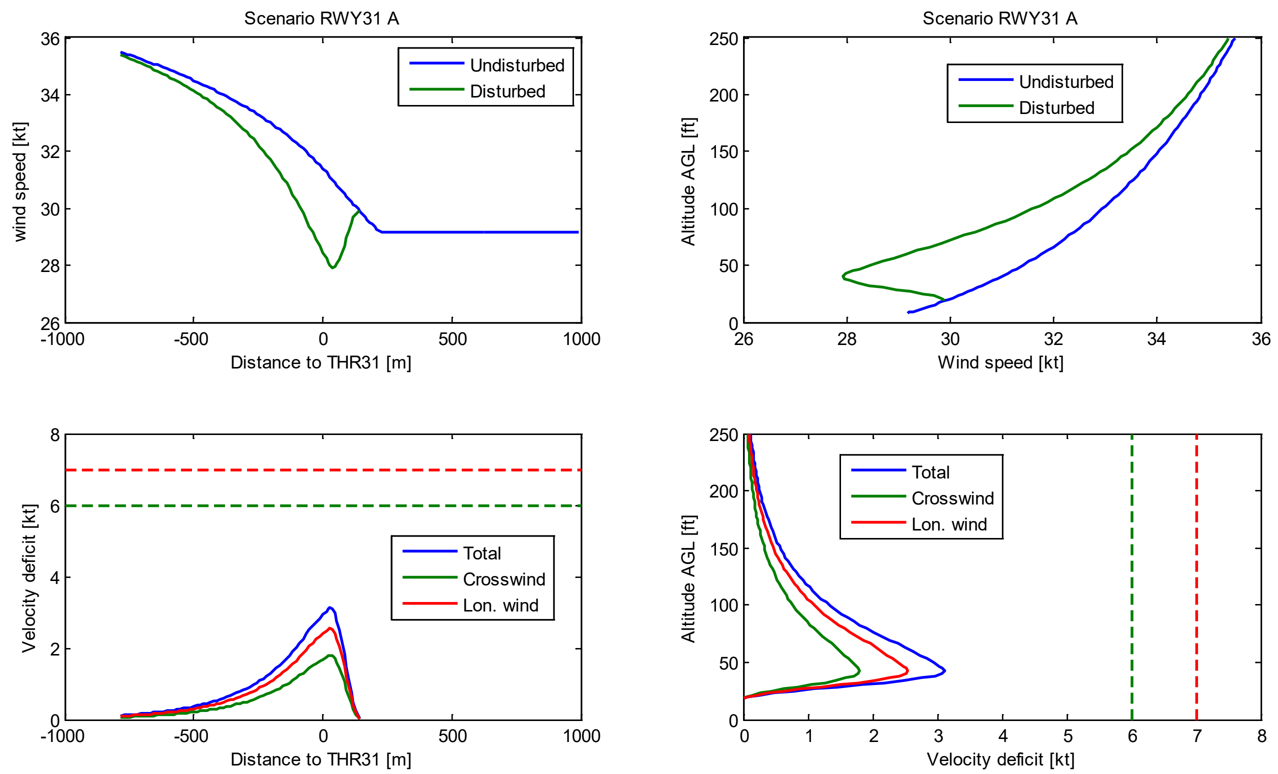


Figure 4-9: Worst case wind disturbance Scenario RWY31_A (wind speed: 28kt, wind direction: 260°)

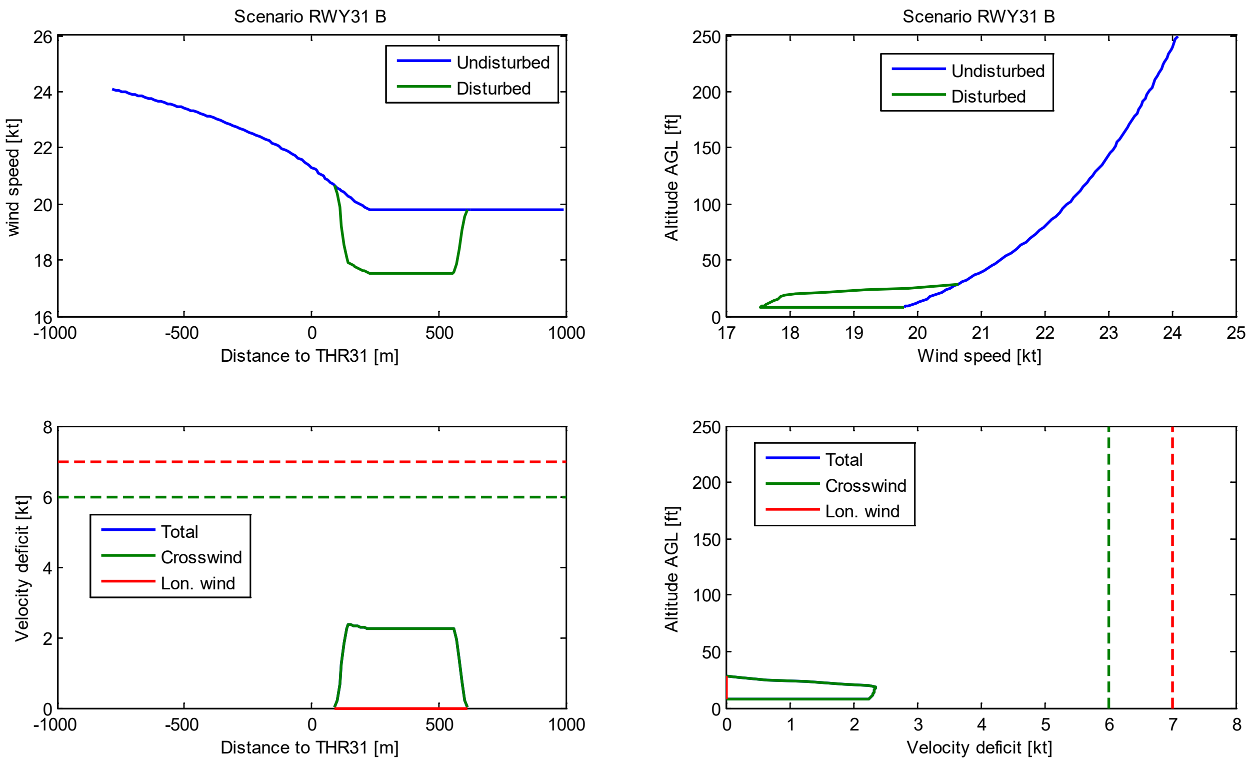


Figure 4-10: Worst case wind disturbance Scenario RWY31_B (wind speed: 19kt, wind direction: 210°)

The results of the analysis are summarized in Table 4-1.

Table 4-1: Summary of results of the wind disturbance analysis

Scenario	Fence width (m)	Wind direction (deg)	Wind speed (kt)	Max. Lon. Vel. Deficit (kt)	< 7kt	Max. Cross. Vel. Deficit (kt)	< 6kt
RWY01_A	250	340	23	1.4	yes	0.4	yes
RWY01_B	380	300	23	1.8	yes	2.7	yes
RWY01_C	450	270	15	0	yes	1.9	yes
RWY31_A	400	260	28	2.6	yes	1.8	yes
RWY31_B	415	210	19	0	yes	2.4	yes

It is shown that in all cases the wind disturbances remain well below the criteria as formulated in section 4.1.
It should be noted that these results represent worst case results, where the residential area is modelled as a porous fence with a constant height. In reality only a few buildings in the planned Nýi-Skerjafjörður residential area will reach that height. Therefore, it can be concluded the planned Nýi-Skerjafjörður residential area will not have a significant effect on the safety of the flight operations at Reykjavik Airport. It is possible that the wind effects, under certain high wind conditions, are noticeable to pilots, but the effects should be easily controllable and not differ much from shear-like phenomena that pilots will encounter on a routine basis.

4.5 Turbulence intensity

The planned Nýi-Skerjafjörður residential area affects the structure of the terrain adjacent to the runways of Reykjavik. The area where buildings are planned is former airport terrain that is fairly flat and therefore causes little viscous friction with the undisturbed wind (as far as the wind is not being disturbed by the adjacent Skerjafjörður residential area). This is expected to lead to a fairly low level of atmospheric turbulence. The realisation of Nýi-Skerjafjörður residential area will affect the so-called terrain roughness, which is one of the main parameters determining the turbulence intensity that aircraft will encounter during an approach.

In this section of the study it is investigated whether the potential increase of the turbulence level may cause adverse effects on aircraft approaching to Reykjavik airport.

The method used to determine the turbulence intensity is based on the procedure as described in ESDU 85020 [6]. It specifies the equations required to calculate the turbulence intensity, and the associated RMS of the turbulence velocities, based on a number of input parameters.

The main factors that affect turbulence in the atmospheric boundary layer (and hence the parameters that are required as input data) are:

- (i) surface roughness parameter, z_0 , see Table 4-2,
- (ii) the height above the zero plane (d),
- (iii) the local hourly-mean reference wind speed (at 10m above ground).

The height, z, at which the properties are determined is measured from the zero-plane displacement height, d, above the ground, so that height above ground is given by (z + d). Approximate values of d are given in Table 4-2 based on the assumption that the zero-plane is about one or two metres below the general height of the surrounding buildings or trees.

The worst case hourly-mean reference wind has been already determined with the scenarios as presented in the previous section. Therefore the main unknown is the impact that the planned Nýi-Skerjafjörður residential area may have on the local terrain roughness parameter z_0.
Based on the descriptions in Table 4-2 it is assumed that the planned Nýi-Skerjafjörður residential area is representative of a village/outskirt of a small town. This means that the terrain roughness parameter z_0 is around 0.1. Before reaching the aircraft the wind still crosses over the runway strip, which has a characteristic value z_0=0.003m ("*runway area of airports*") and in some cases over the sea with a characteristic value z_0=0.001m.
In light of the worst case approach it is assumed that z_0=0.05m is a representative value.

The next question is how the terrain roughness in the existing situation can be characterised. This depends on the wind direction. In case the wind direction is such that the wind is not partially shielded by the adjacent Skerjafjörður residential area then the wind crosses over the former runway 06 and thus over the "*runway area of airports*". In that case a typical value is z_0=0.003m.
In case the wind is (partly) shielded by the existing Skerjafjörður residential area the terrain roughness will increase. In that case the wind will cross partly over "*the outskirt of a small town*" (z_0=0.1m) and partly over the "*runway area of airports*" (z_0=0.003m). It seems reasonable to use in this case an intermediate value: z_0=0.03m, which would be representative for "*Open level country with few trees and hedges and isolated buildings*".

Using this approach the terrain roughness of the current situation can be linked to the scenarios in the previous sections:

- Scenario RWY01_A: z_0=0.03m (partly shielded by Skerjafjörður) ;
- Scenario RWY01_B: z_0=0.03m (partly shielded by Skerjafjörður) ;
- Scenario RWY01_C: z_0=0.003m (runway area of airport);
- Scenario RWY31_A: z_0=0.003m (runway area of airport);
- Scenario RWY31_B: z_0=0.003m (runway area of airport).

In case the Nýi-Skerjafjörður area is realized the terrain roughness increases in all cases to z_0=0.05m and d=1m.

Table 4-2: Typical Values of Terrain Parameters z_0 and d [6]

Terrain Description	z_0 (m)	d (m)
City centres Forests	0.7	15 to 25
Small towns Suburbs of large towns and cities Wooded country (many trees)	0.3	5 to 10
Outskirts of small towns Villages Countryside with many hedges, some trees and some buildings	0.1	0 to 2
Open level country with few trees and hedges and isolated buildings; typical farmland	0.03	0
Fairly level grass plains with isolated trees	0.01	0
Very rough sea in extreme storms (once in 50-yr extreme) Flat areas with short grass and no obstructions Runway area of airports	0.003	0
Rough sea in annual extreme storms Snow covered farmland Flat desert or arid areas Inland lakes in extreme storms	0.001	0

With the given input parameters the increase in turbulence intensity can be evaluated.

The results are illustrated for the five scenarios in Figure 4-11 through Figure 4-15.
Each figure consists of two graphs. The left graph shows the Root Mean Square (RMS) of the turbulence velocities as a function of the distance to the threshold. It shows the undisturbed case (current situation) and the disturbed case (with the Nýi-Skerjafjörður residential area). It also shows a line with constant 4kt, representing the criterion as formulated in section 4.1.
The right graph represents the same data, but then presented as a function of altitude.

The results are summarized in Table 4-3.

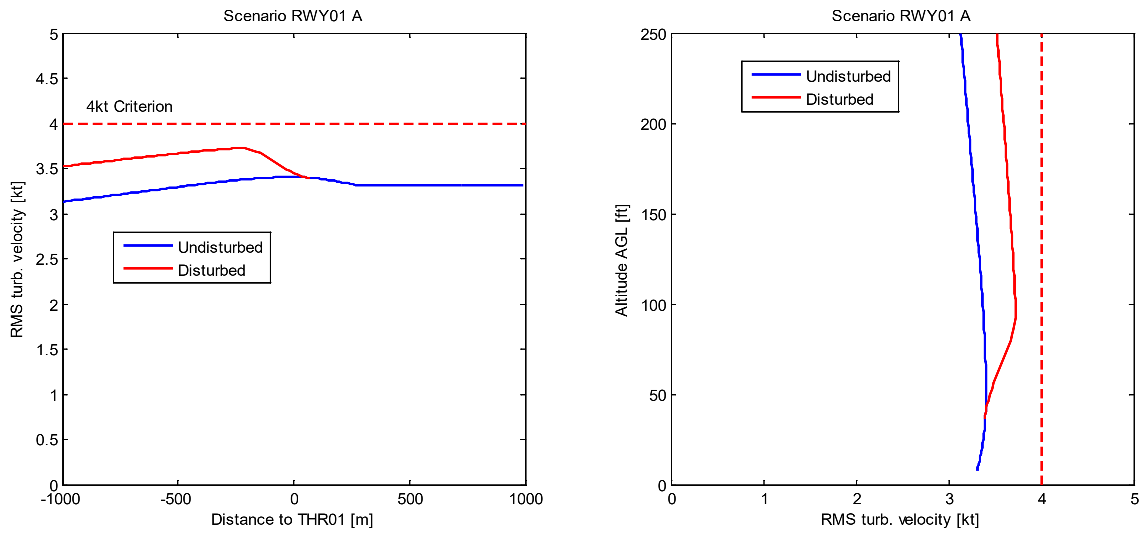


Figure 4-11: Worst case impact on turbulence level, Scenario RWY01_A (wind speed: 23kt, wind direction: 340°)

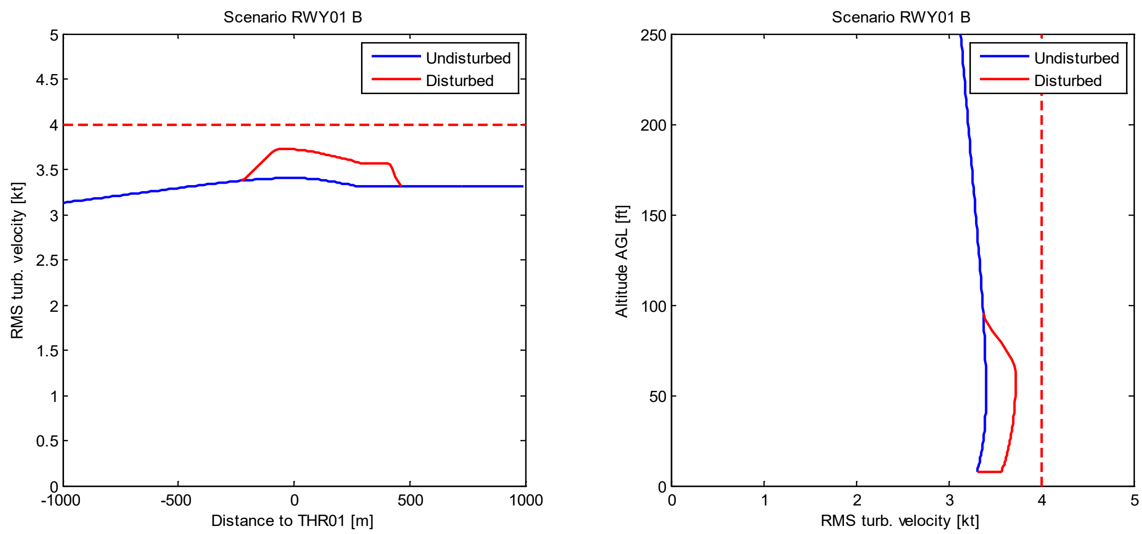


Figure 4-12: Worst case impact on turbulence level, Scenario RWY01_B (wind speed: 23kt, wind direction: 300°)

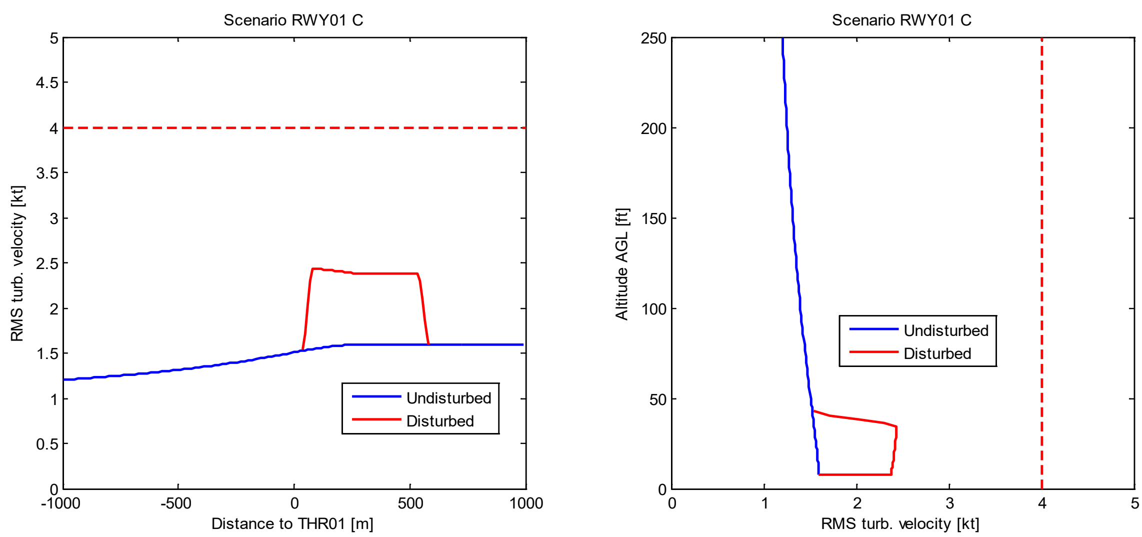


Figure 4-13: Worst case impact on turbulence level, Scenario RWY01_C (wind speed: 15kt, wind direction: 270°)

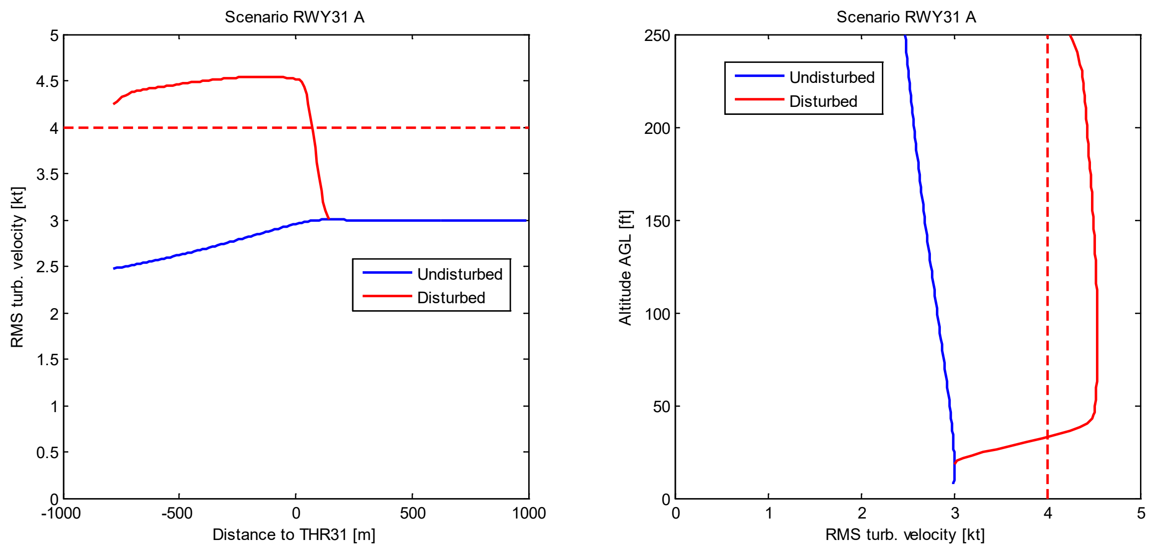


Figure 4-14: Worst case impact on turbulence level, Scenario RWY31_A (wind speed: 28kt, wind direction: 260°)

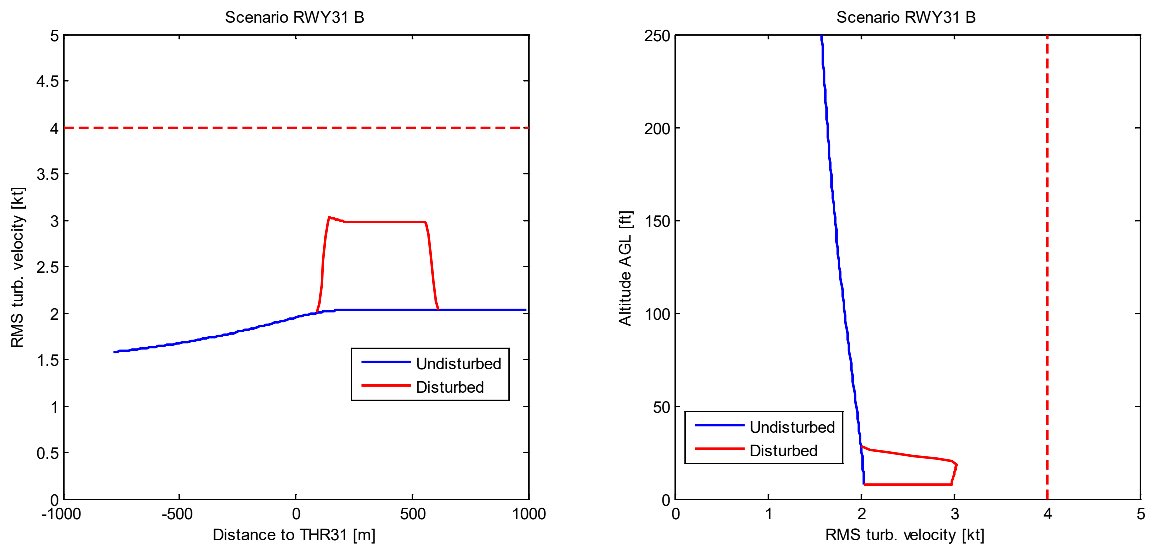


Figure 4-15: Worst case impact on turbulence level, Scenario RWY31_B (wind speed: 19kt, wind direction: 210°)

Table 4-3: Summary of results of the turbulence intensity analysis

Scenario	Wind direction (deg)	Wind speed (kt)	Max. undisturbed RMS Turb. Vel. (kt)	< 4kt	Max. disturbed RMS Turb. Vel. (kt)	< 4kt
RWY01_A	340	23	3.4	yes	3.7	yes
RWY01_B	300	23	3.4	yes	3.7	yes
RWY01_C	270	15	1.6	yes	2.4	yes
RWY31_A	260	28	3.0	yes	4.5	No
RWY31_B	210	19	2.0	yes	3.0	yes

It is shown that there is one scenario (RWY31_A) in which the additional turbulence generated by the Nýi-Skerjafjörður residential area may exceed the specified criterion, and thus signals a potential problem. Therefore, this specific case needs further analysis.

It should be noted that the identified exceedance occurs for aircraft approaching to runway 31, which is the least used runway of the airport. On average around 1150 approaches per year are performed on this runway.

Based on the available weather data it is shown that in case runway 31 is in use the exposure to the high wind conditions (28kt), as used in scenario RWY31_A, is very rare. On average only two aircraft per year are exposed to such conditions.
Further analysis shows that the 4kt-criterion could be violated for wind speed of 24kt or higher. Such conditions occur more frequently, on average once per month.

The question is what the safety impact is of this rather rare exceedance of the 4kt-criterion. In this context it is necessary to consider the involved safety risk in terms of severity and frequency of the occurrence. The guidelines for conducting such safety analysis are provided in the ICAO Safety Management Manual (ICAO Doc 9859 [7]). This document provides specifications to determine severity and frequency and to categorize the risk using a so-called risk matrix. This risk matrix and the associated definitions are provided in Appendix A.

Based on these definitions it is concluded that exceedance of the 4kt-criterion represents a “major” event, because the associated level of turbulence will lead to *a reduction in the ability of the operators to cope with adverse operating conditions as a result of an increase in workload or as a result of conditions impairing their efficiency.*
The frequency of the event is determined to be “occasional”, being around once per month. This leads to a risk index 4C, which is in the “tolerable” region (see Appendix A). However, such risk should be mitigated as much as possible and may require a management decision to determine its acceptability.

The risk itself cannot be easily mitigated directly, because under the given wind conditions (wind speed > 24kt and wind direction in the sector 255°-275°) no alternative landing runway is available at Reykjavik airport, due to crosswind or tailwind limitations. Therefore, the exposure cannot be reduced, other than halting the operations under such conditions. However, considering such mitigation is too strict, given the inherent uncertainties in the present analysis.
Alternative mitigations are to brief pilots to be prepared for significant atmospheric turbulence during the final approach, under the given wind conditions. Furthermore, it is recommended to monitor the exposure to the expected level of turbulence and the associated pilot reports as part of the airport’s safety management system.
These mitigations are expected to be sufficient to manage the identified risk.
It is therefore concluded that the identified risk is manageable and should not block the development of the Nýi-Skerjafjörður residential area.

5 Conclusions and recommendations

The present study has investigated the wind hindrance to the air operations at Reykjavik Airport due to the realisation of a new residential area (Nýi-Skerjafjörður) on a former part of the airport terrain.
The study has been based on three complementary analyses:

1. Assessment of the wind hindrance surfaces;
2. Assessment of the velocity deficit in the wake of the residential area;
3. Assessment of the turbulence intensity due to the change in terrain roughness.

Based on the first analysis it is concluded that only approaches to runway 01 and runway 31 are potentially affected by the new residential area.
Based on the second analysis it is concluded that the wake velocity deficit encountered during the approaches is marginal and acceptable from a safety perspective.
Based on the third analysis it is concluded that in general the turbulence level may increase, but not to a level that it can be considered as an adverse safety effect. However, for approaches to runway 31 under severe wind conditions (wind speed > 24 kt and from direction in the sector 255°-275°) the turbulence level may exceed the specified turbulence criterion.

A safety analysis shows that the associated risk is not unacceptable and should be regarded as tolerable. However, the associated risk is not acceptable without further mitigation measures and may require a management decision.
As a possible mitigation measure it is recommended to brief pilots to be prepared for significant atmospheric turbulence during the final approach, under the given wind conditions. Furthermore, it is recommended to monitor the exposure to the expected level of turbulence and the associated pilot reports as part of the airport's safety management system. These mitigations are expected to be sufficient to manage the identified risk.
It is therefore concluded that the identified risk is manageable and should not block the development of the Nýi-Skerjafjörður residential area.

6 References

Nr.	Document	Title
1	AIP	AIP Iceland, BIRK, 06 DEC 2019
2	ICAO Annex 14	ICAO Annex 14, Aerodromes, Vol I, Aerodrome Design and Operations, 8th Edition, July 2018
3	Nýi-Skerjafjörður	Nýi Skerjafjörður Tillaga Að Nýju Deiliskipulagi Sérskilmálar, ASK arkitektum, 26. Júní 2020
4	NLR-TP-2010-312	Wind criteria due to obstacles at and around airports, A.M.H. Nieuwpoort, J.H.M. Gooden and J.L. de Prins, July 2010
5	ESDU 97031	Estimation of shelter provided by solid and porous fence, March 2011
6	ESDU 85020	Characteristics of atmospheric turbulence near the ground Part II: single point data for strong winds (neutral atmosphere), August 2001
7	ICAO Doc 9859	Safety Management Manual (SMM), ICAO Doc 9859, Third Edition, 2013

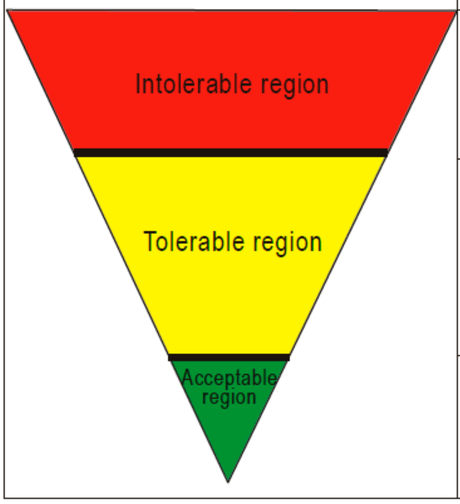
Appendix A ICAO Risk classification

ICAO Risk Matrix (ICAO Doc 9859)

Risk severity

Risk probability	Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent 5					
Occasional 4					
Remote 3					
Improbable 2					
Extremely improbable 1					

Risk Acceptability (ICAO Doc 9859)

Tolerability description	Assessed risk index	Suggested criteria
	5A, 5B, 5C, 4A, 4B, 3A	Unacceptable under the existing circumstances
	5D, 5E, 4C, 4D, 4E, 3B, 3C, 3D, 2A, 2B, 2C, 1A	Acceptable based on risk mitigation. It may require management decision.
	3E, 2D, 2E, 1B, 1C, 1D, 1E	Acceptable

ICAO Safety risk severity table

Severity	Meaning	Value
Catastrophic	— Equipment destroyed — Multiple deaths	A
Hazardous	— A large reduction in safety margins, physical distress or a workload such that the operators cannot be relied upon to perform their tasks accurately or completely — Serious injury — Major equipment damage	B
Major	— A significant reduction in safety margins, a reduction in the ability of the operators to cope with adverse operating conditions as a result of an increase in workload or as a result of conditions impairing their efficiency — Serious incident — Injury to persons	C
Minor	— Nuisance — Operating limitations — Use of emergency procedures — Minor incident	D
Negligible	— Few consequences	E

Safety risk probability table

Probability	Meaning	Value
Frequent	**ICAO:** Likely to occur many times (has occurred frequently) **FAA:** Expected to occur more than once per week or every 2500 departures/landings, whichever occurs sooner	5
Occasional	**ICAO:** Likely to occur sometimes (has occurred infrequently) **FAA:** Expected to occur about once every month or 250,000 departures/landings, whichever occurs sooner	4
Remote	**ICAO:** Unlikely to occur, but possible (has occurred rarely) **FAA:** Expected to occur about once every year or 2.5 million departures/landings, whichever occurs sooner	3
Improbable	**ICAO:** Very unlikely to occur (not known to have occurred) **FAA:** Expected to occur once every 10-100 years or 25 million departures/landings, whichever occurs sooner	2
Extremely improbable	**ICAO:** Almost inconceivable that the event will occur **FAA:** Expected to occur less than every 100 years	1

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