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Assessment of the impact of the proposed Creed wind turbine on the Sandwick SSR radar

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Administration page

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Executive summary

Background

The Western Isles Council (Comhairle nan Eilean Siar – CNES) has applied for planning consent for a single wind turbine of type Vestas V29/225, to serve a recycling centre near Stornoway, Isle of Lewis. The planning application has been more or less approved, but there is an outstanding objection from NATS.

The NATS objection is based on the turbines potential to disrupt the Sandwick Secondary Surveillance Radar (SSR) service. The proposed location for the turbine is 4.5 km from the SSR at Sandwick.

This document reports work undertaken by QinetiQ which quantifies the impact of the proposed wind farm on the Sandwick SSR system.

The proposed Turbine is a Vestas V29. This turbine has a hub height of 40 metres and a rotor diameter of 29 metres. As part of this study the impact of reducing the hub height or using a smaller turbine (17 metres rotor diameter) on the impact to the SSR has been investigated.

QinetiQ assessment

The QinetiQ impact assessment software has been used to predict the impact of the proposed Creed business park wind turbine on the SSR system at Sandwick. This assessment has taken account of the following aspects:

- *The turbine RCS.* A CAD model of the proposed turbines was created; a database of predicted RCS values was generated to provide a statistical model of how radar energy is reflected;
- *Interaction with the terrain.* The effects of terrain shielding and ground-reflections were included in the model. The NEMESIS software was used to generate this data;
- *SSR system parameters.* Factors such as transmitted powers, receiver sensitivities, gain time control (GTC) and antenna patterns were fully integrated into the modelling.

Predicted impacted airspace

The 90% zones are regarded as the likely impact zone from the turbines. For the largest turbine option (V29 on a 40 m tower) the zone is never higher than 400 m (1320 feet). Only aircraft arriving or departing from Stornoway airport would be low enough to enter this impact zone.

The difference between using a 30 m or a 40 m tower for the V29 turbine does not significantly change the results. The V17 turbine creates a significantly smaller impact zone which reaches up to 100 m (330 feet).

Larger impact zones are shown which give the maximum possible extent of the impact zones given the maximum scattering from the turbine. In the region between the smaller and larger zone boundaries interference effects have the potential to occur but the likelihood is extremely low. Also the high RCS levels are transitory in nature and any effect is likely to be very short lived.

List of contents

	Administration page	2
	Executive summary	3
	List of contents	4
1	Background and general information	5
	1.1 Introduction	5
	1.2 Details of the proposed wind farm	5
2	The QinetiQ SSR assessment tool	7
	2.1 SSR operation	7
	2.2 SSR assessment tool methodology	8
	2.3 Inputs to the SSR impact assessment tool	11
3	Results from the assessment	17
	3.1 Assumptions and inputs	17
	3.2 Impact zones	20
4	Conclusions	26
	4.1 QinetiQ assessment	26
	4.2 Predicted impacted airspace	26
5	References	27

1 Background and general information

1.1 Introduction

The Western Isles Council (Comhairle nan Eilean Siar - CNES) has applied for planning consent for a single wind turbine of type Vestas V29/225, to serve a recycling centre near Stornoway, Isle of Lewis. The planning application has been more or less approved, but there is an outstanding objection from NATS [1].

The NATS objection is based on the turbine's potential to disrupt the Sandwick Secondary Surveillance Radar (SSR) service. The proposed location for the turbine is 4.5 km from the SSR at Sandwick.

This document reports work undertaken by QinetiQ which quantifies the impact of the proposed wind farm on the Sandwick SSR system. The scope of the work is defined in [2]. It is the intention that the output from the work package can be used to inform CNES in any subsequent discussions with NATS.

1.2 Details of the proposed wind farm

The proposed turbine is a Vestas V29. This turbine has a hub height of 40 metres and a rotor diameter of 29 metres. As part of this study the impact of reducing the hub height or using a smaller turbine (17 metres rotor diameter) on the impact to the SSR has been investigated.

Relevant grid references are:

- NB 44200 32932 (the Sandwick SSR);
- NB 39890 31490 (the proposed wind turbine location at Creed Business park).

The relative positions are shown in Figure 1-1.



Figure 1-1: Map showing the location of the proposed wind turbine and the NATS SSR

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2 The QinetiQ SSR assessment tool

2.1 SSR operation

A monopulse secondary surveillance radar (MSSR) system is assumed in the following analysis. MSSR is used in conjunction with primary radar systems to provide additional information about targets. MSSR is a co-operative system, relying on aircraft replying to questions from ground-based transmitters.

The basic operating principle of MSSR is as follows. The rotating MSSR transmitter sends out an interrogating pulse-sequence in a known direction (the "up-link"). This pulse-sequence is received by an airborne transponder which immediately transmits an omni-directional reply (the "down-link"), giving information such as the height of the aircraft (information which is not possible to extract from primary radar detection) and flight identification. The ground-based interrogator transmits at 1030MHz while the airborne transponder transmits at 1090MHz. This basic operation is shown in Figure 2-1.

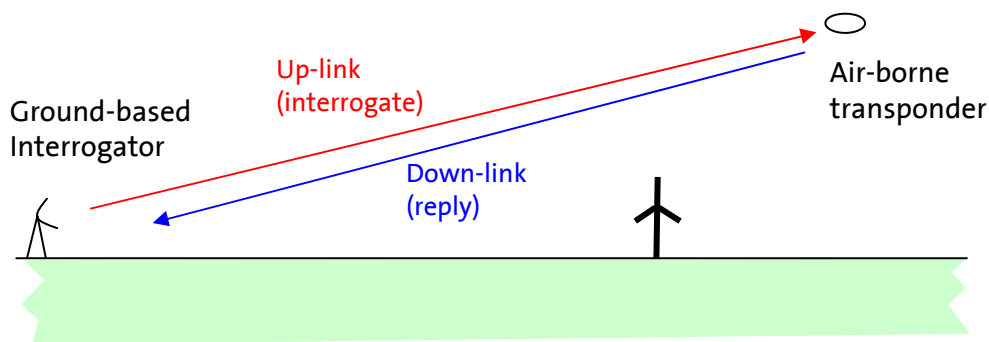


Figure 2-1: Geometry of MSSR transponder and interrogator

The effects on the operation of MSSR will be different for the up-link and the down-link. In the case of the up-link, the aircraft does not know how far away the interrogating MSSR station is, and hence the transponder is always maximally sensitive. For the down-link, however, there is a relationship between the expected signal strength and the elapsed time between interrogation and reply. Hence a Gain Time Control (GTC) law is used to eliminate weak signals which are likely to have resulted from reflections. This means that the up-link is more susceptible to being triggered as a result of weak reflections from e.g. wind turbines.

In order to minimise the impact of echoes, airborne transponders often employ weak echo suppression. This reduces the transponder sensitivity immediately after receiving a direct pulse, and gradually recovered until the next pulse is expected.

More information on the basic operating principles of SSR can be found in [3].

2.2 SSR assessment tool methodology

The QinetiQ SSR impact assessment tool [4] considers a wind turbine a fixed distance from a radar system. Reflections from the wind turbine can in principle disrupt the SSR operation for an aircraft in its vicinity. Depending on the timing and signal strength of the wind turbine reflections, the possible problems that could occur are split into two categories. The first is when the reflected signal and the direct signal cannot be separated by the receiving system. This can lead to problems such as:

- bearing errors;
- fading (a reduction in signal strength).

The second category of effects occurs when the reflected signal can be separated from the direct signal. If the reflected signal is strong enough it can create a false plot on the radar where no aircraft exists, or corrupt the code of the SSR signal.

The tool searches through the airspace and at each point the possibility of a problem occurring is calculated. The logic used is shown in Figure 2-2.

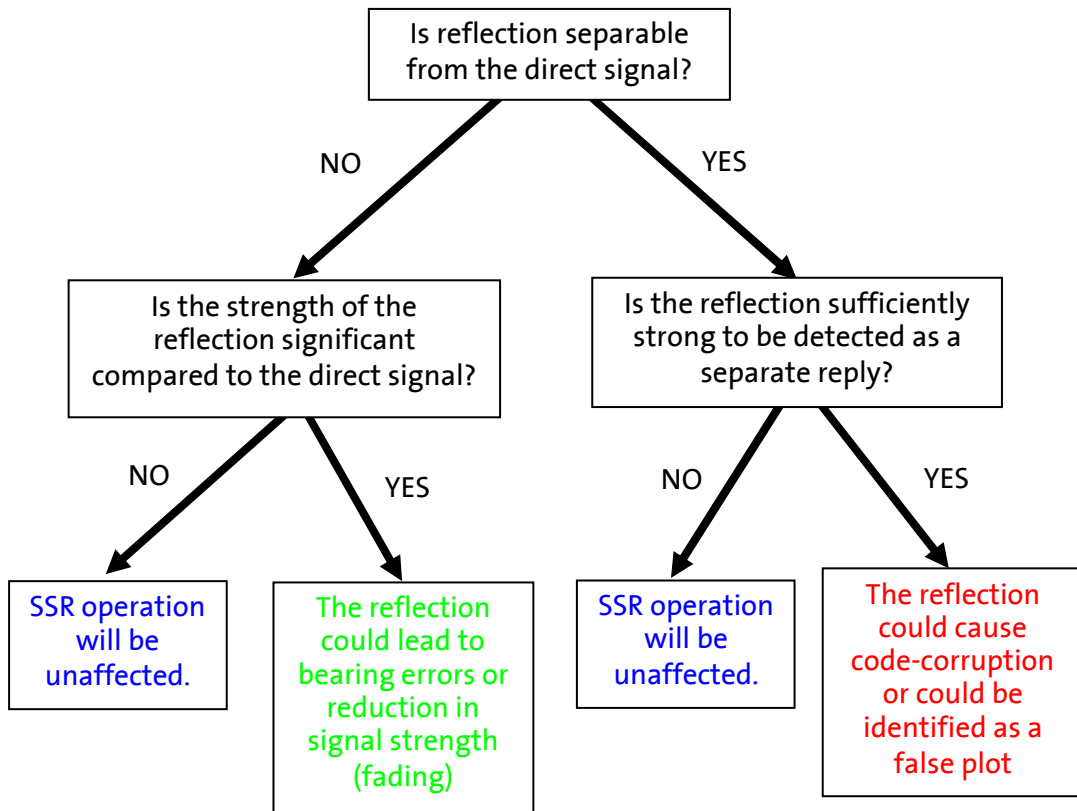


Figure 2-2: Impact assessment logic at a single point in the airspace

Figure 2-2 shows that there are three possibilities at every point in space. These are

1. SSR operation is unaffected (blue text in Figure 2-2);
2. The reflection is inseparable from the direct signal, possibly leading to problems such as bearing errors or fading (reduction in signal strength)

(green text in Figure 2-2). For simplicity this will be referred to as the **fading zone** in this report;

3. The reflection is separable from the direct signal, possibly leading to code-corruption or false-plots (red text in Figure 2-2). For simplicity this will be referred to as the **false-plot zone** in this report.

Thus the assessment tool quantifies the volume of air-space inside which problems might occur – for a turbine at a given range from the radar. It is important to stress that this does not mean problems *will* occur within this airspace, but it is safe to say problems *will not occur* outside the airspace (given the modelling assumptions discussed in this section). Insufficient information is known about the radar processing and hence care has been taken to ensure the volumes of affected airspace calculated are the outer envelopes of where problems *could* occur.

The outputs from the tool are best shown by illustration. Figure 2-3 shows the airspace in which false-plots could occur as a result of a reflected up-link (which is then received directly by the ground-based radar in addition to the reply from the direct up-link). The impact volume lies mainly between the wind farm and the radar. In addition to this, Figure 2-4 shows the fading impact zone. In this example the scales are the same as in the previous figure. Here the impact volume lies mainly behind the turbine (as viewed by the radar). To obtain the total impact volume, the two regions are added – as shown in Figure 2-5 – colouring the two parts differently for clarity. Two things can be said about this region of airspace:

1. For an aircraft outside of this airspace, no errors will be encountered with the operation SSR;
2. For an aircraft inside this volume, errors *might* occur with the operation of SSR.

The exaggerated vertical extent of these figures should be noted. Figure 2-6 plots the combined impact zones with the same extent in height, length and depth to highlight this point.

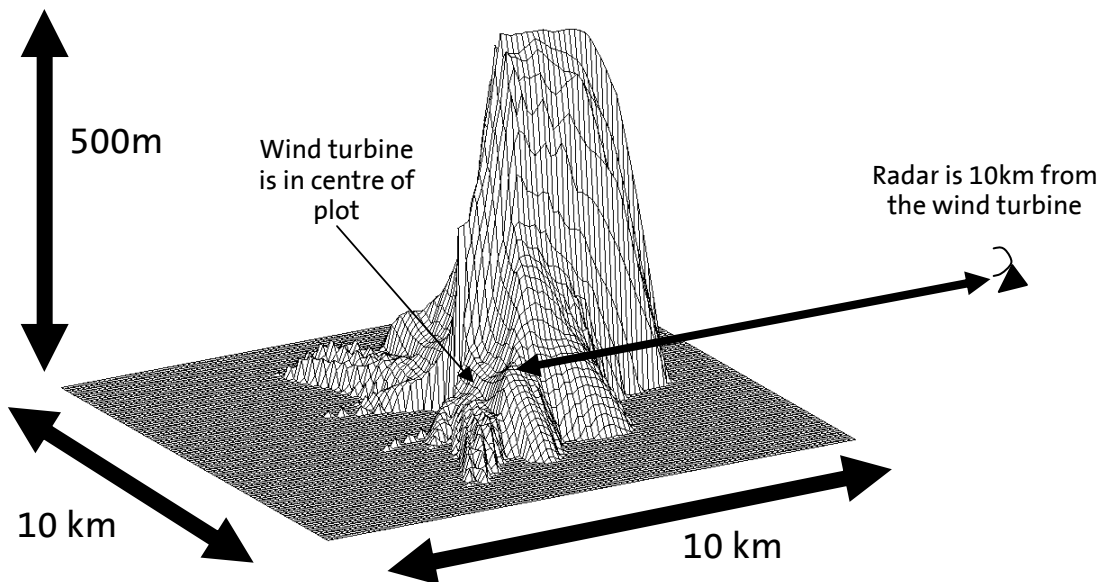


Figure 2-3: Example of false-plots impact zone

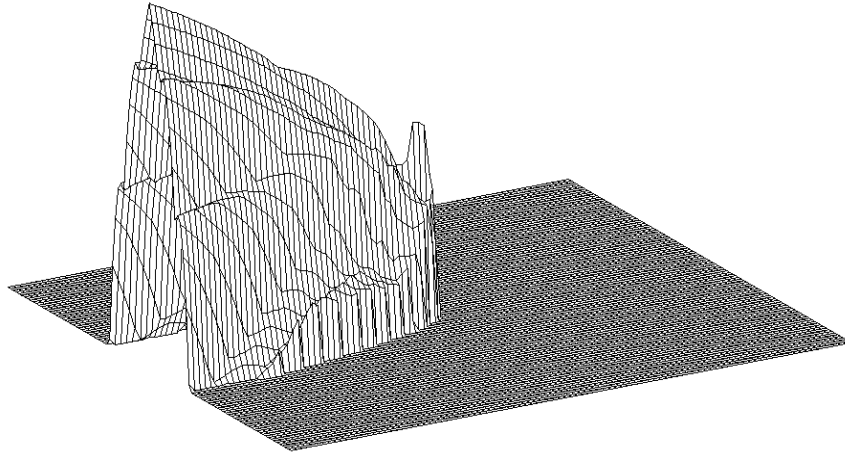


Figure 2-4: Example of bearing-error and fading impact zone

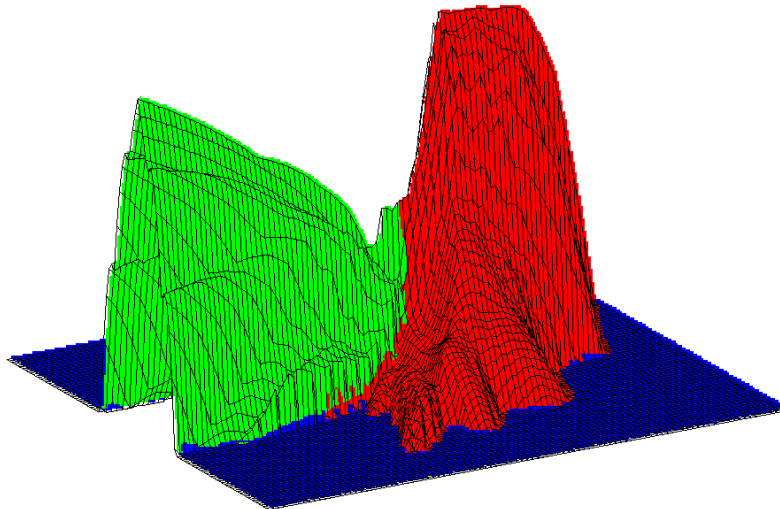


Figure 2-5: Example of combined impact zone

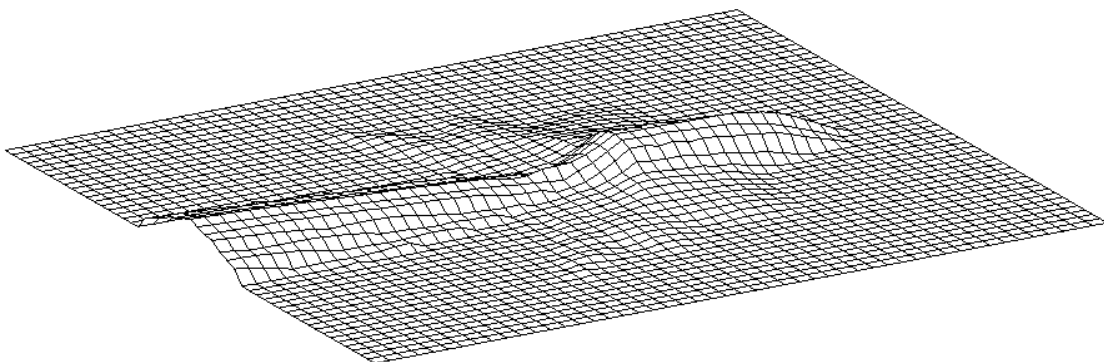


Figure 2-6: Example of combined impact zone without exaggerated vertical extent

2.3 Inputs to the SSR impact assessment tool

Two important steps in the assessment methodology have not yet been discussed. These are (1) the statistical representation of how the turbine scatters energy and (2) how the terrain affects the system. These two stages are shown in the flow-diagram in Figure 2-7 in the context of the assessment tool.

The two steps are discussed in the remainder of this sub-section.

2.3.1 Quantifying turbine reflections

The amount of energy scattered by an object is measured in terms of its Radar Cross-Section (RCS). To predict the RCS of the proposed turbine, a Computer Aided Design (CAD) model was generated based on the geometry of the V29. This was then scaled to get a representative model of a V17, so that the difference in impacts can be considered. The basic dimensions of the two turbine designs considered are shown in Table 2-1.

	V29	V17
Hub-height	40 m	23 m
Rotor-diameter	29 m	17 m
Maximum blade tip-height	54.5 m	31.5 m

Table 2-1: Summary of the turbine dimensions used.

Having made the CAD models, predictions were made of the turbines' RCS using a QinetiQ RCS prediction software tool called OCELLUS. OCELLUS has been validated for the RCS prediction of wind farms in DTI sponsored work in which the predictions were compared with the measurements from a scale model wind turbine blade and a 1.5MW turbine [5].

The RCS is a measure of how much energy is reflected from a wind turbine and is very sensitive to the turbine's configuration. For example, as the turbine blades rotate, the RCS is likely to change over several orders of magnitude. This fluctuating RCS means a variable impact on the operation of SSR (and indeed any electromagnetic system). In order to fully characterise the turbines' RCS, predictions of the two turbines were made:

- for yaw angles from 0 to 360 degrees. Yaw angle is defined as the angle of the rotor normal from the radar direction (see Figure 2-9);
- for blade positions from 0 to 120 degrees. Blade position is the angular offset of the rotor from a position with one of the blades horizontal and travelling downwards (see Figure 2-10).
- for scattering elevations from 0 to 90 degrees.

The resulting database of RCS values is sufficient to statistically capture the RCS variation of the wind turbine for any SSR scenario. When considering an aircraft at a point in space, the relevant RCS values are extracted from the database and reduced to a histogram of values which quantifies the likelihood of different reflection strengths. An example follows:

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- 100% value. This is the worst case where the RCS will never exceed this value. The impact volume calculated in this case should be considered the worst case.
- 90% value. This is still conservative, but 10% of the time the RCS of the wind turbine will be larger than this. The impact volume calculated in this case will be accurate for 90% of the time. 10% of the time the impact volume (outside of which there is no possibility of SSR problems) will be larger than this.

A final modification was made to the RCS database to correct the forward-scatter RCS values according to the distance between the ground-based radar and the wind turbine. The forward-scatter RCS is considered as a special-case since it is always in the near-field of the radar systems of interest¹. More information on forward-scatter RCS can be found in [6].

¹ Strictly, the RCS is not only a function of the variables discussed, but also of the range of both the receiver and transmitter from the wind turbine. For the scenarios of interest here, however, this dependence is weak for all RCS values apart from the forward-scatter.

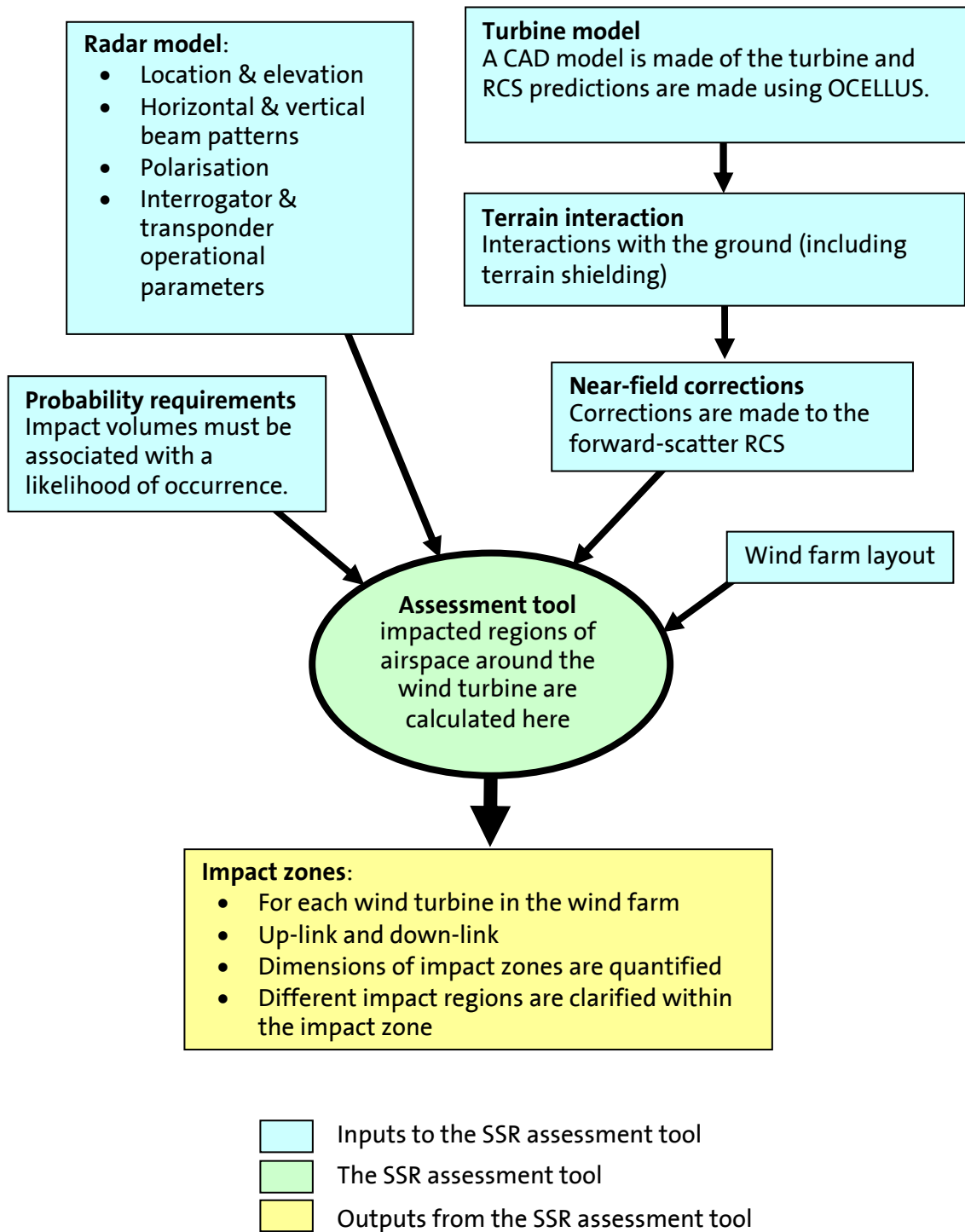


Figure 2-7: SSR assessment methodology

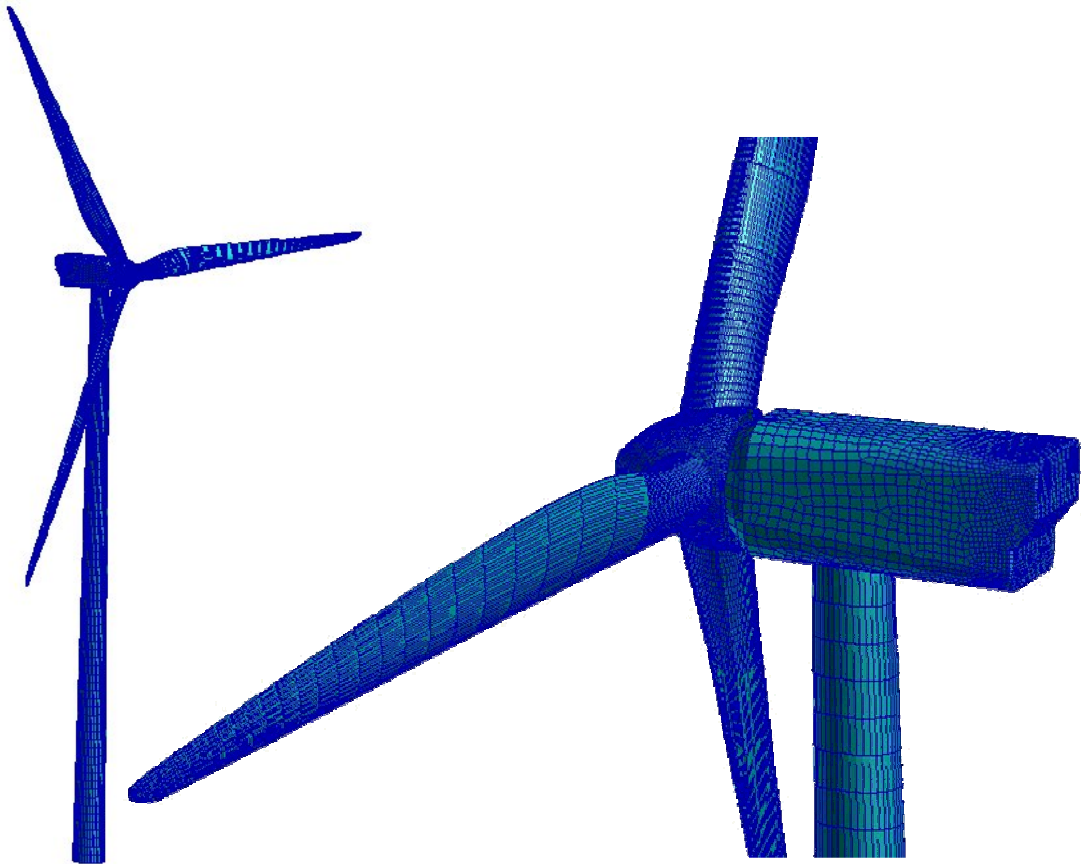


Figure 2-8: Model used for the wind turbine

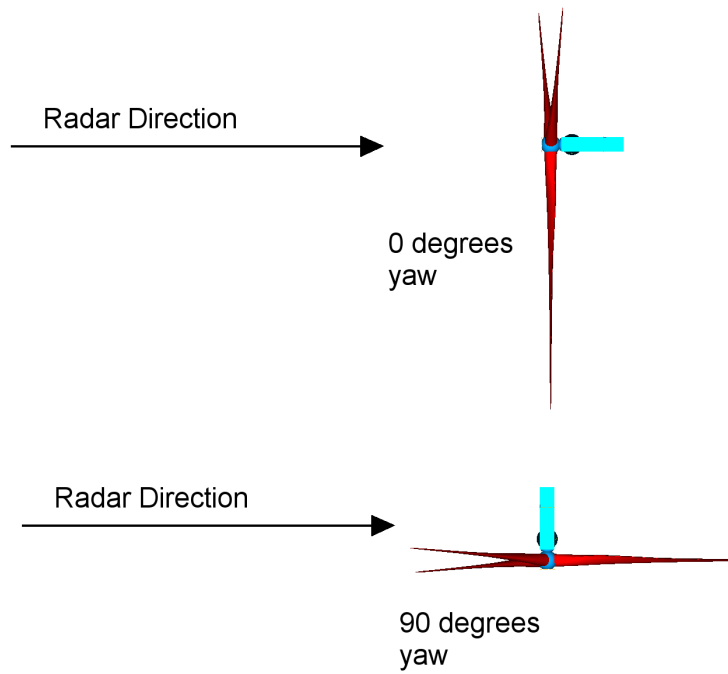


Figure 2-9; Diagram giving examples of yaw position orientations.

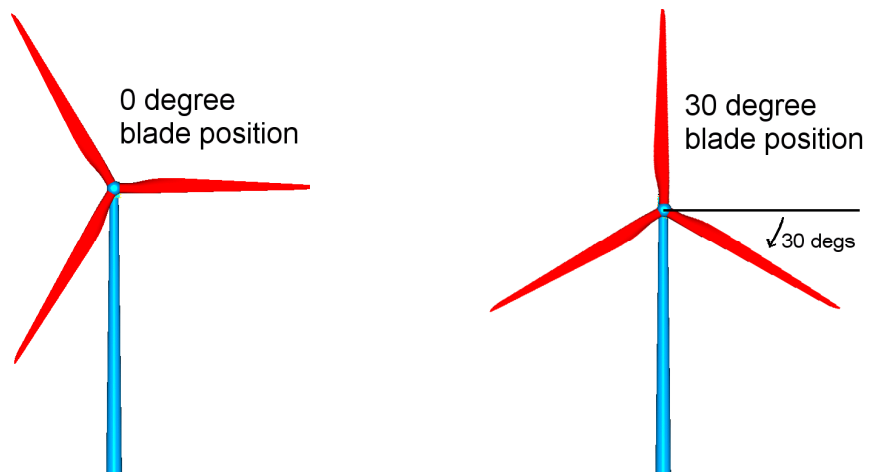


Figure 2-10; Diagram giving examples of blade position orientations.

2.3.2 Including terrain interactions

The discussion so far has neglected the interaction between the SSR system and ground. As is often the case, the proposed wind turbine locations are partially or wholly obscured by the terrain between the radar and the turbine. Furthermore, at SSR frequencies (around 1 GHz), energy can easily diffract around or over terrain features, meaning radars can “see” into optical blind-spots. This point is illustrated in Figure 2-11 showing a NEMESIS [7] prediction. NEMESIS is a QinetiQ proprietary tool for modelling terrain propagation.

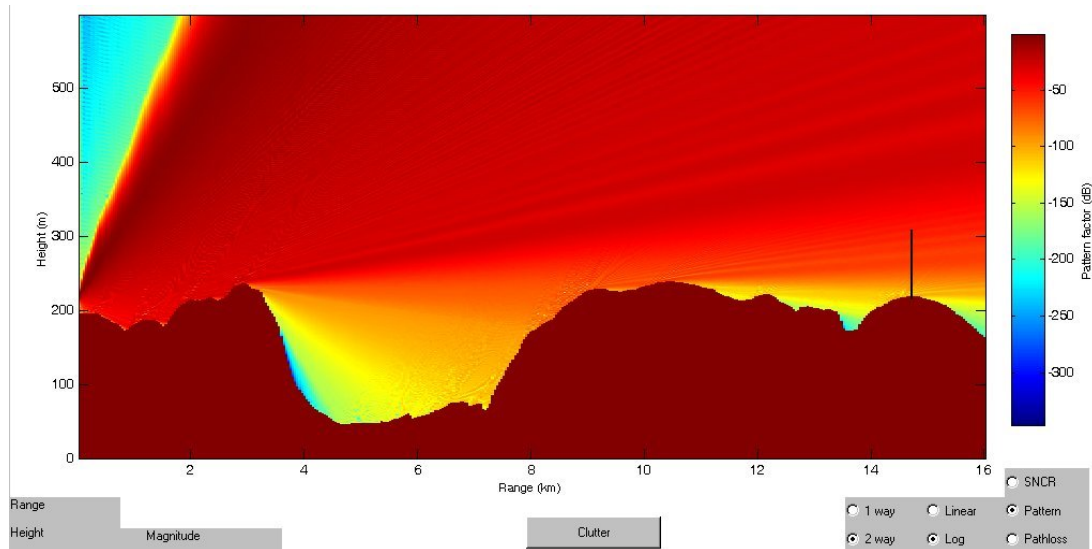


Figure 2-11: Illustration of terrain interaction using NEMESIS

In this case the radar (situated at the left of the plot) is illuminating a wind turbine 15km away. Some high terrain about 3 km away is partially blocking the line-of sight between the radar and the turbine. Nevertheless, an appreciable amount of energy is diffracted by the terrain – most noticeably into the valley between 4 and 8 km from the radar. The effect is also seen at the turbine where the signal strength varies over its height due to the partial blockage of the signal by the terrain.

Even when the blocking structure (in this case the hill at a range of 3km) is large, energy is diffracted around the blockage. The effects of diffraction and refraction are incorporated into QinetiQ’s terrain interaction calculations.

Conceptually, this reduction in signal strength can be incorporated into the model by reducing the RCS of the wind turbine. In other words an *effective* RCS is used, which takes into account any interaction with the terrain. NEMESIS calculations are carried out using the relevant terrain slice between the radar and each turbine in the wind farm.

It is assumed that the terrain has a negligible effect on signals travelling between the turbine and the aircraft. This is reasonable since for most airspace of interest there will be clear line-of-sight between the turbine and the aircraft.

3 Results from the assessment

3.1 Assumptions and inputs

A number of modelling assumptions are required for the impact assessment. Some of these are based on SSR system requirements; some are based on the likely operational set-up of the Sandwick radar. Results from a recent internet search of current in-service SSR transponders were used to ensure assumptions are up-to-date. A full list of modelling assumptions is given in Table 3-1.

The remainder of this sub-section discusses the choice of some of the modelling assumptions.

3.1.1 Carrier-to-interference ratio

The carrier-to-interference ratio, C/I, has been used to determine whether or not an interfering signal has sufficient strength to affect system operation. C/I is a ratio of the desired signal power to the unwanted (interfering) signal power. The larger the value of C/I the less likely the interfering signal is to affect the system. The quantity is normally quoted in decibels – e.g. if the direct signal is 1000 times more powerful than the interfering signal, C/I is $10 \times \log_{10}(1000) = 30\text{dB}$.

The “acceptable C/I threshold” used in the impact assessment is a statement of how sensitive the system’s operation is to interference. For example, if a C/I of more than 10 dB is tolerable, then interfering signals which are a tenth or less of the direct signal will not degrade performance.

The value of 20dB is used in the assessment of the Creed turbine. This is based on QinetiQ’s understanding of SSR’s operational requirements..

3.1.2 RCS likelihoods

Assessments have been made using two different RCS likelihoods corresponding to different levels of impact. These are

- 100% This is the worst case value. The RCS of the wind turbine will always be less than or equal to this sub-set of the database. Although the RCS will almost always be less than this value, this is the result of primary interest to NATS – i.e. the answer to the question *how bad could it be?*;
- 90% The impact zones calculated using this sub-set of the database will be sufficient to ensure problems are avoided 90% of the time. This is regarded as the *likely* impact of the wind turbine.

Interrogator (ground-based)	
Location	Sandwick, E144200, N932932
Interrogator power	2000W
Interrogator gain (peak)	500 (= 27dB)
Interrogator gain characteristics	Typical [3] vertical and azimuthal beam patterns are assumed
Interrogator minimum detectable signal	-85 dBm ²
Interrogator sensitivity	GTC is used (see section 2). A typical GTC law from [3] is employed.
Interrogator frequency	1030 MHz
Interrogator polarisation	VV (vertical transmit, vertical receive)
Signal separation threshold	0.4µs (if the temporal separation between two signals is smaller than this it is assumed the signals are inseparable)
Required C/I threshold	20dB (discussed in paragraph 3.1.1)
Mechanical tilt	None
Air-borne transponder	
Location	Anywhere in airspace
Transponder power	250W
Transponder gain (peak)	1
Transponder gain characteristics	Antenna is isotropic (transmits equal amounts of power in all directions)
Transponder minimum detectable signal	-74 dBm
Transponder sensitivity	Weak echo suppression is used (see section 2)
Transponder frequency	1090 MHz
Transponder polarisation	VV (vertical transmit, vertical receive)
Required C/I threshold	20dB (discussed in paragraph 3.1.1)
Wind turbine	
Dimensions	As supplied by customer
RCS	Full bistatic database used (see section 2)
Near-field	Near-field forward scatter RCS has been accounted (see section 2)
Location	E139890 N931490 (as supplied by CNES)
Terrain interaction	Terrain factors calculated for each turbine as described in section 2.
Other modelling assumptions	
RCS likelihood	Impact zones for values of 100% and 90% were calculated and are presented. The RCS likelihood is discussed in section 2 and in paragraph 3.1.2.

Table 3-1: Impact assessment assumptions

² dBm = “decibels reference to 1 mW”. For example, $3.98 \times 10^{-11} \text{ W} = 10 \times \log_{10}(3.98 \times 10^{-11} \text{ W} / 0.0001 \text{ W}) = -74 \text{ dBm}$.

3.1.3 Terrain effects

In addition to the RCS of the turbine, one of the most important factors in an impact assessment is the topography of the area. It is worth noting how the topography affects this assessment.

Figure 3-1 shows the Nemesis calculation results for the turbine location. The radar is at the left of the page and the approximate turbine location is marked with a black line. The results used in the SSR assessment are average propagation factors over the height of the turbine. The values used and the turbine configuration it applies to are shown in Table 3-2.

Turbine configuration	Tip height (metres)	Average PPF up the height of the turbine
V29 on a 40 m tower	54.5	-9.4
V29 on a 30 m tower	44.5	-10.2
V17 on a 23 m tower	31.5	-12.6

Table 3-2: Nemesis values used in simulation to take account of the terrain and the radar vertical beam pattern.

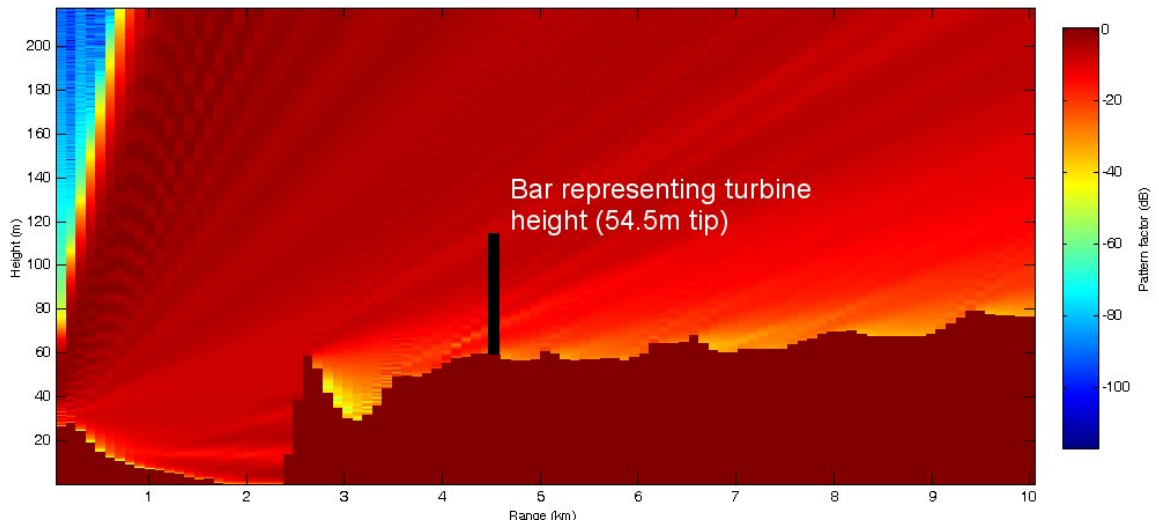


Figure 3-1: Nemesis calculation showing turbine location

3.2 Impact zones

The impact of the proposed wind turbine on the operation of the Sandwick SSR is presented here. The impact has been quantified in terms of impact zones – i.e. volumes of airspace in which an impact on the operation of SSR could be experienced. This does not mean problems *will* occur if an aircraft enters the impact zone – but rather there is a *finite probability of problems occurring* if an aircraft enters the zone.

Because of the system asymmetry of the up-link and down-link, impact zones have different dimensions. Only the up-link results will be considered here as these are the largest zones and therefore define a outer impact zone.

There are different results for the three turbine configurations considered: V29 turbine on a 40 m tower; a v29 on a 30 m tower; a V17 on a 23 metre tower.

The impact zones for RCS likelihoods of 90% and 100% are presented in Figure 3-2 to Figure 3-9 for the three turbine designs:

- The extent of the impact volumes (in easting and northing) are overlaid onto an ordnance survey map;
- The colour of the zone defines the height of the volume at that position;
- A key linking the colour shown to the height of the zone is shown in Figure 3-5.

A summary of the size of these zones is given in Table 3-3. These zones are areas within which false plots can occur. At this range the turbine does not create a significant blockage of the radar signal and no significant fading or bearing errors are predicted.

The 90% zones are regarded as the likely impact zone from the turbines. For the largest turbine option (V29 on a 40m tower) the zone is never higher than 400 m (1320 feet). Only aircraft arriving or departing from Stornoway airport would be low enough to enter this impact zone.

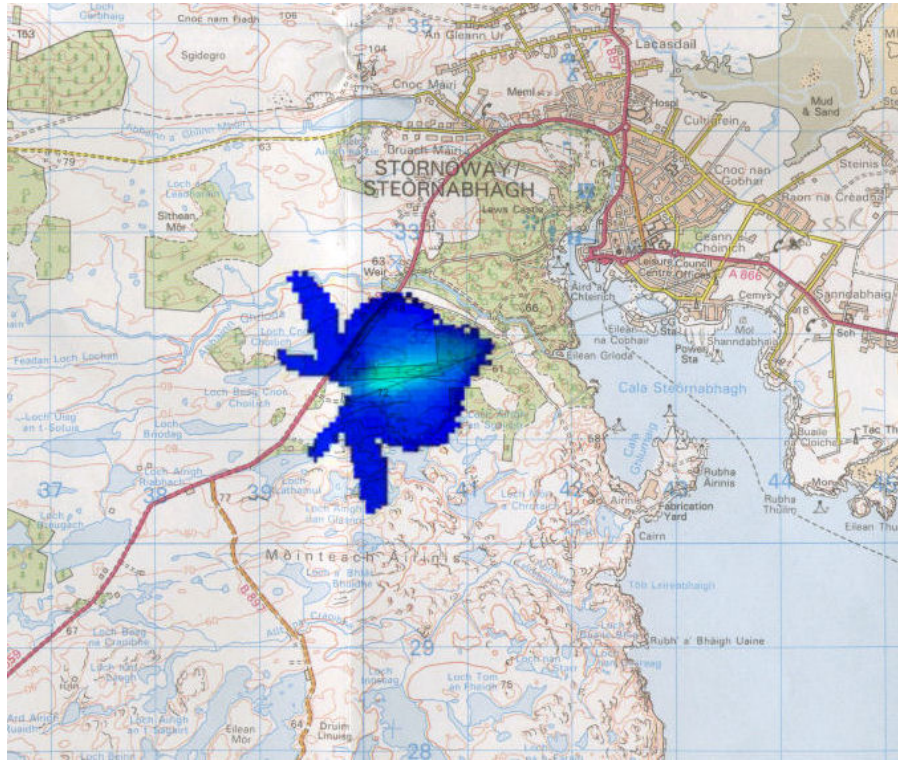
The difference between using a 30 m or a 40 m tower for the V29 turbine does not significantly change the results. The V17 turbine creates a significantly smaller impact zone which reaches up to 100 m (330 feet).

The 100% RCS zones (see figures 3-6 to 3-8) should be considered as the worst case situation (i.e. they were created using the largest RCS values). Two points are made about these zones:

1. although the zones are larger, the likelihood of problems occurring at the edges (the airspace bounded by the 90% and 100% zones) is very low;
2. due to the rapidly fluctuating nature of the RCS [6], operational impacts can be expected to be short-lived, with minimal (if any) inconvenience to the radar operator.

RCS %	Turbine	Maximum height (asl)	Max distance from turbine	Typical distance from turbine
100%	V29, 40m tower	1200 m	4.0 km	3.0 km
	V29, 30m tower	1100 m	3.5 km	2.5 km
	V17, 23m tower	500 m	1.5 km	1.0 km
90%	V29, 40m tower	400 m	1.5 km	0.5 km
	V29, 30m tower	300 m	1.5 km	0.5 km
	V17, 23m tower	100 m	0.5 km	0.1 km

Table 3-3; Approximate sizes of the radar impact zones around the turbine location.



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Figure 3-2; Impact zone for a Vestas V29 turbine on a 40 m tower using the 90% turbine scattering level.



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Figure 3-3; Impact zone for a Vestas V29 turbine on a 30 m tower using the 90% turbine scattering level.



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Figure 3-4; Impact zone for a Vestas V17 turbine on a 23 m tower using the 90% turbine scattering level.

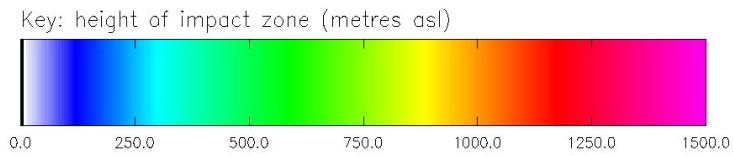
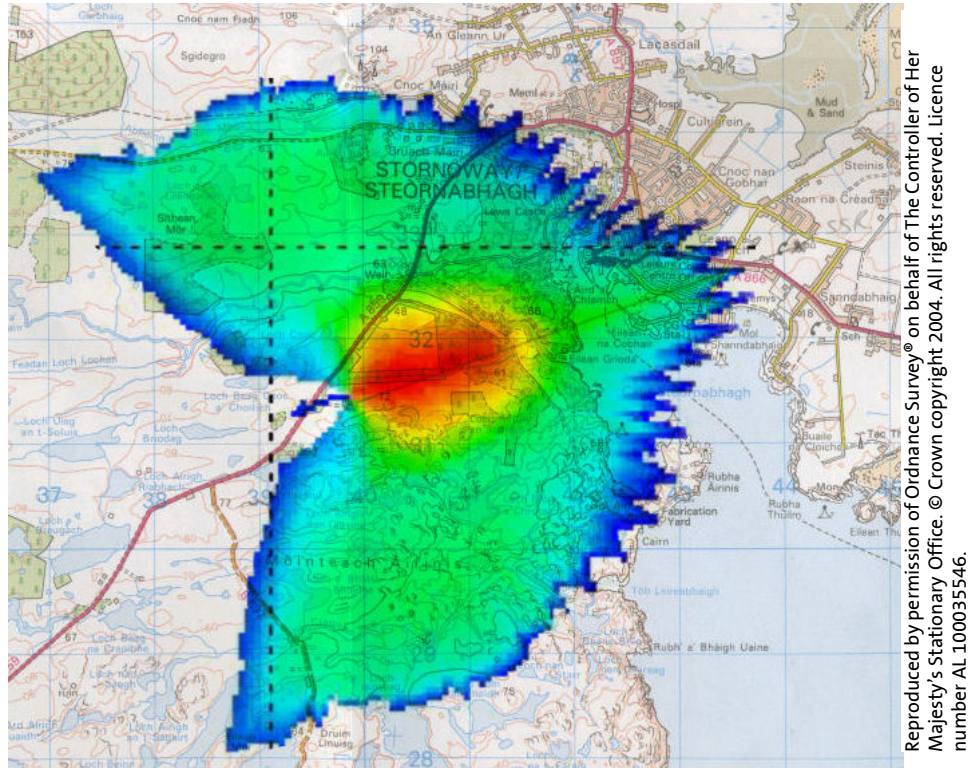
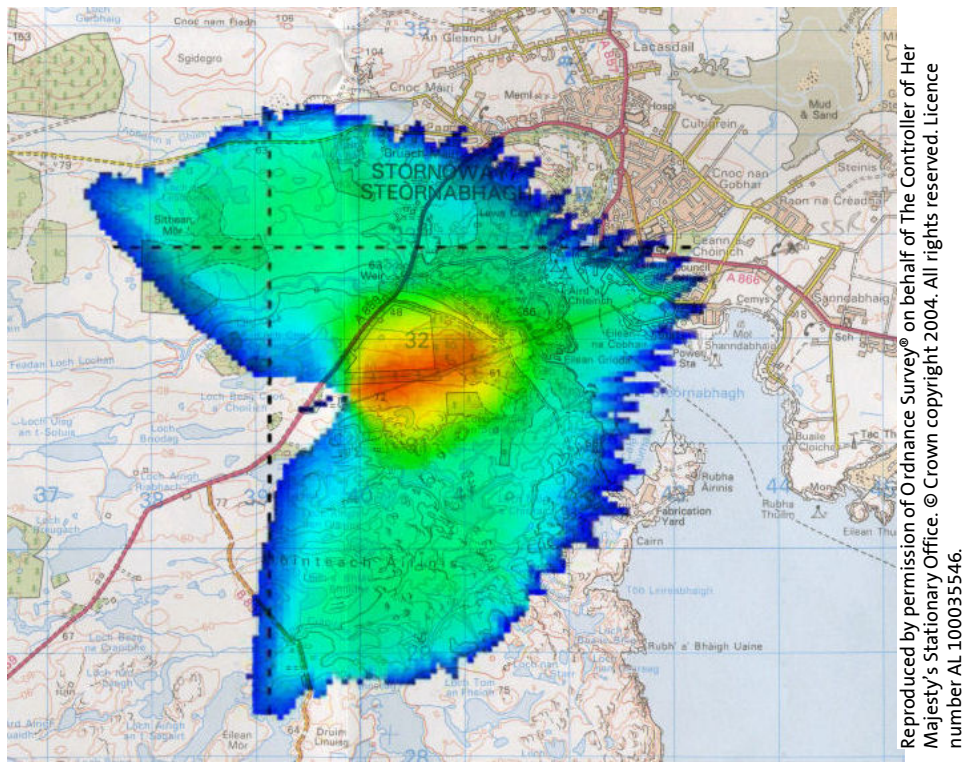


Figure 3-5; Key for Figures. Colour of the zone indicates its height above sea level



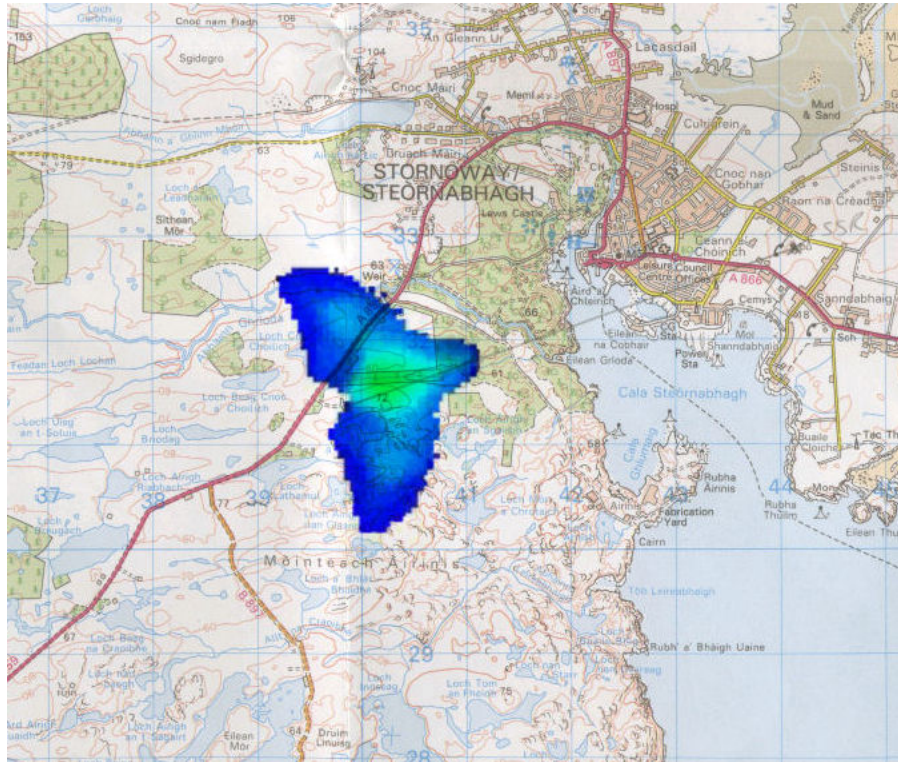
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Figure 3-6; Impact zone for a Vestas V29 turbine on a 40 m tower using the 100% turbine scattering level.



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Figure 3-7; Impact zone for a Vestas V29 turbine on a 30 m tower using the 100% turbine scattering level.



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Figure 3-8; Impact zone for a Vestas V17 turbine on a 23 m tower using the 100% turbine scattering level.

Key: height of impact zone (metres asl)

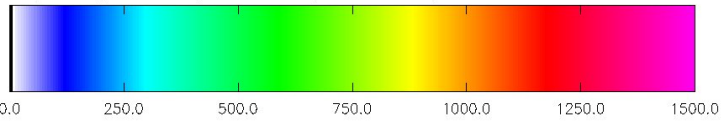


Figure 3-9; Key for Figures. Colour of the zone indicates its height above sea level

4 Conclusions

4.1 QinetiQ assessment

The QinetiQ impact assessment software has been used to predict the impact of the proposed Creed business park wind turbine on the SSR system at Sandwick. This assessment has taken account of the following aspects:

- *The turbine RCS.* A CAD model of the proposed turbines was created; a database of predicted RCS values was generated to provide a statistical model of how radar energy is reflected;
- *Interaction with the terrain.* The effects of terrain shielding and ground-reflections were included in the model. The NEMESIS software was used to generate this data;
- *SSR system parameters.* Factors such as transmitted powers, receiver sensitivities, gain time control (GTC) and antenna patterns were fully integrated into the modelling.

The results of the QinetiQ assessment are now described.

4.2 Predicted impacted airspace

The 90% zones are regarded as the likely impact zone from the turbines. For the largest turbine option (V29 on a 40m tower) the zone is never higher than 400 m (1320 feet). Only aircraft arriving or departing from Stornoway airport would be low enough to enter this impact zone.

The difference between using a 30 m or a 40 m tower for the V29 turbine does not significantly change the results. The V17 turbine creates a significantly smaller impact zone which reaches up to 100 m (330 feet).

The 100% RCS zones (see figures 3-6 to 3-8) should be considered as the worst case situation (i.e. they were created using the largest RCS values). Two points are made about these zones:

3. although the zones are larger, the likelihood of problems occurring at the edges (the airspace bounded by the 90% and 100% zones) is very low;
4. due to the rapidly fluctuating nature of the RCS [6], operational impacts can be expected to be short-lived, with minimal (if any) inconvenience to the radar operator.

5 References

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