East Anglia TWO Offshore Windfarm

Appendix 15.1

Airspace Analysis and Radar Modelling

Preliminary Environmental Information
Volume 3
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Revision Summary					
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Glossary of Acronyms

AARA	Air to Air Refuelling Area
ACT	Air Combat Training
AD	Air Defence
agl	Above Ground Level
AIC	Aeronautical Information Circulars
AIP	Aeronautical Information Publication
AIS	Aeronautical Information Services
ALARP	As low as reasonably practicable
amsl	Above Mean Sea Level
ANSP	Air Navigation Service Provider
ATA	Aerial Tactics Area
ATC	Air Traffic Control
ATS	Air Traffic Services
ATSOCAS	Air Traffic Services outside Controlled Airspace
CAA	Civil Aviation Authority
CAP	Civil Aviation Publication
CAS	Controlled Air Space
CNS	Communication Navigation & Surveillance
FL	Flight Level
GASIL	General Aviation Safety Information Leaflet
HAT	Highest Astronomical Tide
HMRs	Helicopter Main Route(s)
ICAO	International Civil Aviation Organisation
ILT	Inspectie Leefomgeving en Transport – the NL CAA
ITAR	International Traffic in Arms Regulations
LAT	Lowest Astronomical Tide
LoS	Line of Sight
LVNL	Luchtverkeersleiding Nederland – the NL equivalent of NATS
MAA	Military Aviation Authority
MoD	Ministry of Defence
MSD	Minimum Separation Distance
NAIZ	Non-Auto Initiation Zone
NATMAC	National Air Traffic Management Advisory Committee
NATS	NATS Holdings Limited (formerly National Air Traffic Services)
NERL	NATS (En Route) plc
NM	Nautical Mile
NL	Netherlands
NOTAMs	Notices to Airmen
NPS	National Policy Statement
NSL	NATS (Services) Limited
OLS	Obstacle Limitation Surfaces
PSRs	Primary Surveillance Radars
RAF	Royal Air Force
RLoS	Radar Line of Sight
RRH	Remote Radar Head
SAR	Search and Rescue
SARG	UK CAA Safety and Airspace Regulation Group
SARPs	Standards and Recommended Practices
SMS	Safety Management System
SSRs	Secondary Surveillance Radars
TMZ	Transponder Mandatory Zone

UARs	Upper Air Routes
VFR	Visual Flight Rules
ZAP	Zone Appraisal and Planning process

Glossary of Terminology

The Applicant	East Anglia TWO Limited
East Anglia TWO project	The proposed project consisting of up to 75 wind turbines, up to four offshore electrical platforms, up to one construction operation and maintenance platform, inter-array cables, platform link cables, up to one operational meteorological mast, up to two offshore export cables, fibre optic cables, landfall infrastructure, onshore cables and ducts, onshore substation, and National Grid infrastructure.
East Anglia TWO windfarm site	The offshore area within which wind turbines and offshore platforms will be located.
Offshore infrastructure	All of the offshore infrastructure including wind turbines, platforms, and cables.
Air to Air Refuelling Area (AARA)	Defined airspace in which the transfer of aviation fuel from a tanker aircraft to a receiving aircraft takes place.
Air Navigation Service Provider (ANSP)	A public or private legal entity managing air traffic on behalf of a company, region or country. NATS is the main ANSP in the UK.
Controlled Airspace (CAS)	Defined airspace in which pilots must follow Air Traffic Control instructions implicitly. In the UK, classes A, C, D and E are areas of controlled airspace.
Flight Information Region (FIR)	Airspace managed by a controlling authority with responsibility for ensuring air traffic services are provided to aircraft flying within it.
Flight Level (FL)	An aircraft altitude expressed in hundreds of feet at a standard sea-level pressure datum of 1013.25 hectopascals.
Highest Astronomical Tide (HAT)	The highest tidal level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions.
Lowest Astronomical Tide (LAT)	The lowest tidal level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions.
Mean Sea Level (msl)	The average level of the sea surface over a long period or the average level which would exist in the absence of tides.
Obstacle Limitation Surfaces (OLS)	A series of complex 3D surfaces described around an airport runway where the control of obstacles is necessary to protect aircraft.
Primary	A radar system that measures the bearing and distance of targets using the

Surveillance Radar (PSR)	detected reflections of radio signals.
Secondary Surveillance Radar (SSR)	A radar system that transmits interrogation pulses and receives transmitted responses from suitably equipped targets.
Uncontrolled Airspace	Defined airspace in which Air Traffic Control does not exercise executive authority but may provide basic information services to aircraft in radio contact. In the UK, class G is uncontrolled airspace.

15.1 Airspace Analysis and Radar Modelling

15.1 Introduction

1. This document is the appendix to ***Chapter 15 Civil and Military Aviation and Radar*** of the Preliminary Environmental Information Report for the proposed East Anglia TWO project. It provides detailed airspace analysis and radar modelling and outlines potential mitigation options.

2. The East Anglia TWO windfarm site covers an area of 255km^2 and is located 31km from Lowestoft and 32km from Southwold. The proposed East Anglia TWO project has an anticipated capacity of up to 900MW.

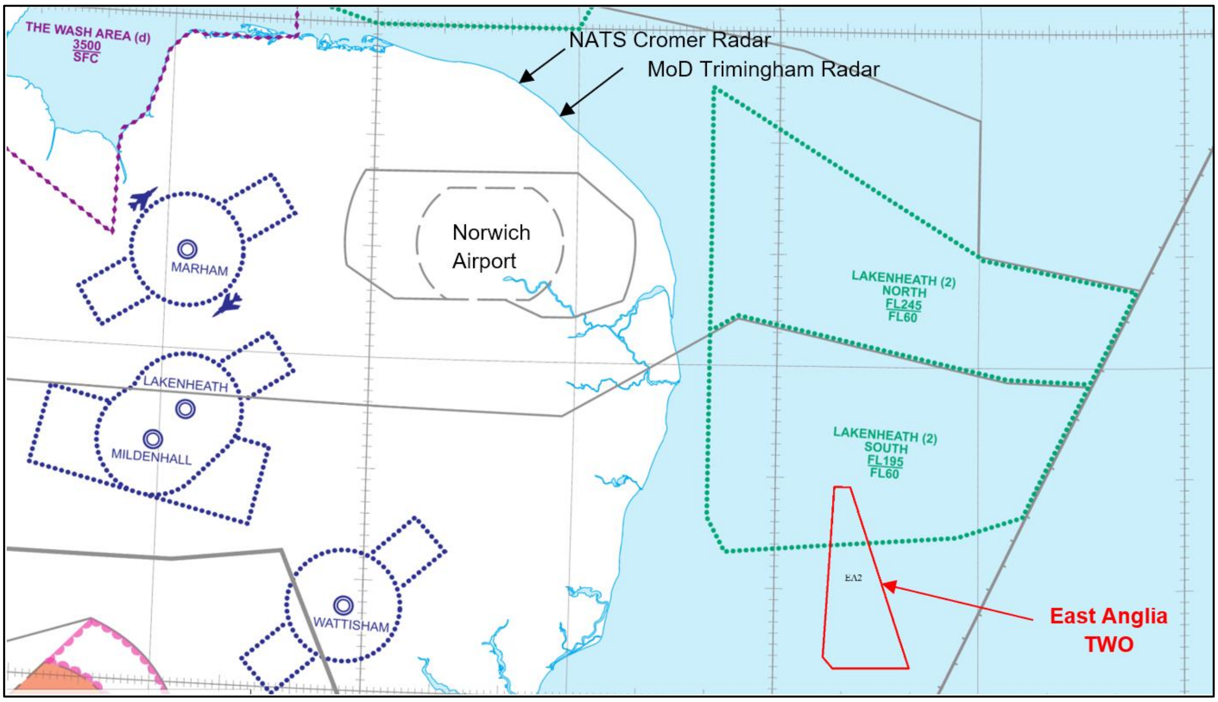

DiagramA15.1.1 Location of East Anglia TWO

15.2 Effects of Wind Turbines on Aviation

3. Wind turbines are a problem for aviation Primary Surveillance Radars (PSR) as the characteristics of a moving wind turbine blade are similar to an aircraft. The PSR is unable to differentiate between wanted aircraft targets and clutter targets introduced by the presence of turbines.

4. The significance of any radar impacts depends on the airspace usage and the nature of the Air Traffic Service (ATS) provided in that airspace. The

classification of the airspace in the vicinity of the East Anglia TWO windfarm site and the uses of that airspace (civil and military) are set out in this appendix.

5. Radar impacts may be mitigated by either operational or technical solutions or a combination of both. In either case, the efficacy and acceptability of any operational and / or technical mitigation options available can only be determined by protracted consultations with the radar operators / ATS providers.

6. Initial investigations address the identification of the maximum turbine sizes across the East Anglia TWO windfarm site that would not be detected by the Trimingham and Cromer PSRs. Subsequent analysis explores the potential technical mitigations which may be available in light of the findings of this document.

15.3 References

- Lockheed Martin TPS-77 radar: Lockheed Martin AN/TPS-77 Factsheet B013-03;
- MoD Trimingham radar positional data: Positional data pertaining to MoD Trimingham radar was received by email from MoD DES ADATS on 13/12/2013 12:33;
- NATS Cromer radar Site data: Ofcom Protected Radar list 2 October 2017;
- Raytheon ASR-10SS radar: Raytheon ASR-10SS Factsheet.

15.4 Data

7. The following data has been used to establish the drawings and calculations used in this report:

15.4.1 MoD Trimingham Radar

8. MoD Trimingham radar position from MoD DES ADATS:

- Grid Ref: TG 28846 38256 (E628846, N338256)
- Site Height: 69.8m above mean sea level (amsl)
- Antenna Aperture: 4.9m above ground level (agl)

9. MoD confirms that the Trimingham radar is a Lockheed Martin TPS-77 used in the Air Defence (AD) role.

10. MoD was unable to provide any technical information or specifications as these are ITAR (International Traffic in Arms Regulations) protected.

11. Additional data was derived from Lockheed Martin Factsheet B013-03.

15.4.2 NATS Cromer Radar

12. Position data from Ofcom Protected Radar list:

- Latitude: 52N5438
- Longitude: 001E2059
- Antenna Height: 17.5m agl

13. The radar is a Raytheon ASR10-SS used for en-route Air Traffic Control (ATC) and Southern North Sea operations.

14. Additional data was derived from Raytheon ASR10-SS factsheet.

15.4.3 East Anglia TWO

15. The boundary of the East Anglia TWO windfarm site was provided by the Applicant as a geo-referenced Shapefile:

- TCE_Wind_Farm_EA1N_EA2_20170615.shp

15.4.4 Turbines

16. Turbine data was provided to Cyrrus by the Applicant as per ***TableA15.1.1.*** This turbine data and the indicative layouts shown below were prepared to assist stakeholders visualise the windfarm. It is noted that there may be more turbines in the final layout, subject to the worst case limitations set out in ***Chapter 15 Table 15.2***.

TableA15.1.1 East Anglia TWO notional candidate turbines

Turbine MW	12	Up to 19
Max tip height (m above LAT)	244	300
Rotor Diameter (m)	220	250
Hub Height (m)	134	175
Blade length (m)	110	125
Inter-turbine spacing (inter-row – i.e. downwind) (m)	2420	2750
Inter-turbine spacing (inter-row – i.e. downwind) (RD)	11	11

17. **NOTE**: turbine heights in ***TableA15.1.1*** are above Lowest Astronomical Tide (LAT). Radar assessments are based on amsl, which is 1.21m above LAT at the centre of the East Anglia TWO windfarm site, therefore amsl calculations incorporate an additional buffer.

18. Indicative (visualisation) turbine layouts supplied by the Applicant are shown in the following diagrams:

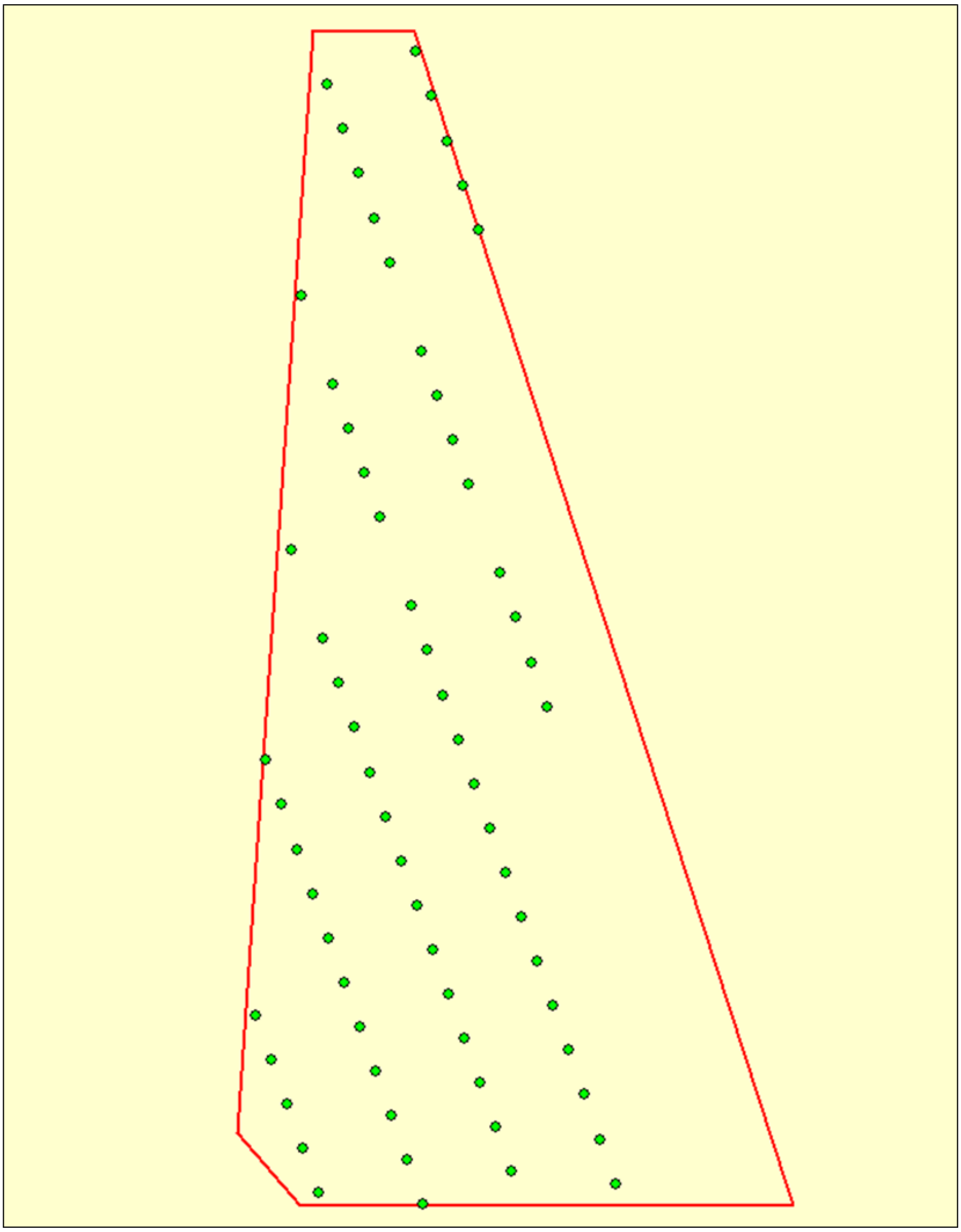

DiagramA15.1.2 Max Tip 244m Turbine Indicative Layout – 67 Turbines

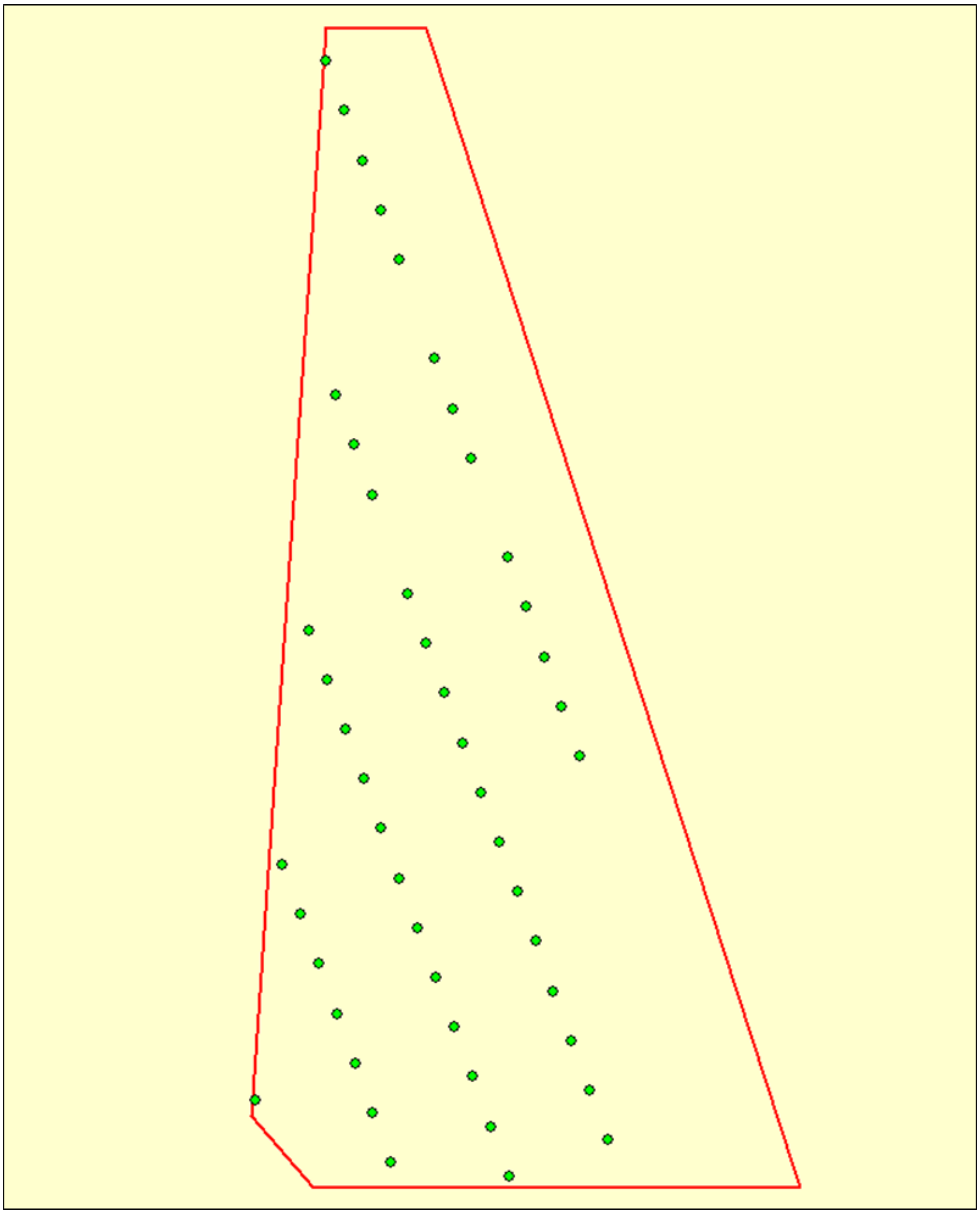

DiagramA15.1.3 Max Tip 300m Turbine Indicative Layout – 48 Turbines

15.4.5 Terrain Data

- ASTER Global Digital Elevation Model (GDEM) 1.5 arc seconds resolution.
- NextMap 25m Digital Terrain Model (DTM) in area around radars (Perpetual Licence).
- NextMap 25m Digital Surface Model (DSM) in area around radars (Perpetual Licence).

15.4.6 Analysis Tools

- ATDI ICS telecom EV v 15.1.2 x64 R1400 Radio Network analysis tool.

- Global Mapper v17.2 Geographic Information System (GIS) ATDI plugin for Global Mapper V1.00.
- AutoCAD 2017 and ZWCAD 2015 Professional.

15.4.7 Mapping Datum

19. Radar data was supplied in Ordnance Survey National Grid Reference (OSGB36) format.

20. Indicative turbine layout was supplied in geo-referenced Shapefile format.

21. UTM31N (WGS84 datum) is used as a common working datum for all mapping and geodetic references.

22. Mapping datum transformations are made using Global Mapper V17.2 (Blue Marble) or OS Grid Inquest (OSTN15).

23. All heights stated in this document are amsl (Newlyn Datum) unless stated otherwise.

15.5 Airspace Analysis

15.5.1 Introduction

24. This assessment is a review of potential impacts to aviation in the designated areas of the East Anglia TWO windfarm site. For the purpose of this assessment, a maximum tip height of 1000 feet amsl for the wind turbines has been assumed. 1000 feet is equivalent to 300m rounded to the nearest 50 feet.

25. All information has been referenced from the UK Aeronautical Information Publication (AIP) available online from source and is therefore the latest information available. Additional information was sourced from UK Civil Aviation Authority publications (as appropriate).

15.5.2 Scope

26. The scope of the assessment includes the East Anglia TWO windfarm site and the surrounding airspace relating to aviation, its use and potential impact. Each area is defined according to type of airspace, limitations and who the controlling authority is.

27. To best utilise airspace, the internationally acceptable use of "Flexible Use of Airspace" (FUA) may be used in some areas. FUA allows airspace to be shared between two entities, e.g. civilian flights and military training, allowing one entity to use the airspace when not in use by the other. The FUA requires formal arrangements between the entities with the designated Controlling Authority being responsible for arrangements within this airspace. The UK AIP

does not specifically define whether any of the airspace associated with the East Anglia TWO windfarm site is under FUA agreement. Where a potential impact is identified within a defined portion of airspace the discussion with those affected parties will extend to any FUA agreements.

15.5.3 Existing Environment

28. Airspace, in aviation terms, is defined as in two elements. The differentiation is required due to varying air pressure and to ensure aircraft are flying according to the same point of reference.

29. The first element is as an altitude amsl and designated in terms of feet. The barometric pressure used is typically a local pressure at the last point at which this pressure can be verified.

30. Above a certain altitude, the level at which an aircraft flies at is referred to as a Flight Level (FL) using a common international barometric pressure setting of 1013.2 hPa. The transition between an altitude and a FL is defined as a Transition Layer, consisting of a Transition Altitude and a Transition Level. The Transition Altitude will always be lower than the Transition Level and in the UK this is set at 3000 feet, with the exception of specified airspace. For example, the Transition Altitude for the Clacton Control Area (CTA) is 6000 feet. Refer UK AIP ENR 1.7 Altimeter Setting Procedures.

31. The table below defines each area and associated ATS routes, and designated areas that might be impacted by the East Anglia TWO windfarm site. Where potential impact has been identified then a meeting with the Controlling Authority may be required to understand how the associated airspace is utilised and whether the East Anglia TWO windfarm site would be a limiting factor to aviation operations. The remarks column relates to any remarks stated in the UK AIP with the associated airspace.

TableA15.1.2 Potentially Impacted Airspace

ATS Route/Designated Area	Use	Airspace Dimensions Upper Limit Lower Limit	Impact	Controlling Authority	Remarks
P7	Civilian ATS Route (RNAV)	FL460 FL85	Nil	NATS	
P44	Civilian ATS Route (RNAV)	FL245 FL105	Nil	NATS	
M183	Civilian	FL245	Nil	NATS	

ATS Route/Designated Area	Use	Airspace Dimensions Upper Limit Lower Limit	Impact	Controlling Authority	Remarks
	ATS Route (RNAV)	FL135			
L620	Civilian ATS Route (RNAV)	FL245 FL85	Nil	NATS	
Y4	Civilian ATS Route (RNAV)	FL245 FL95	Nil	NATS	
Lakenheath Aerial Tactics Area (ATA) South	Intense military air activity	FL195 FL60	Potential	MoD	Live firing at flares in the sea regularly takes place below the vertical limits of the ATA under 'Clear Range' procedures

15.5.3.1 Area Navigation Routes

32. The Area Navigation (RNAV) routes over the East Anglia TWO windfarm site defined in ***TableA15.1.2*** are depicted in ***DiagramA15.1.4***.

33. The routes are not directly affected, however radar surveillance of aircraft flying along the routes may be affected by the East Anglia TWO windfarm site.

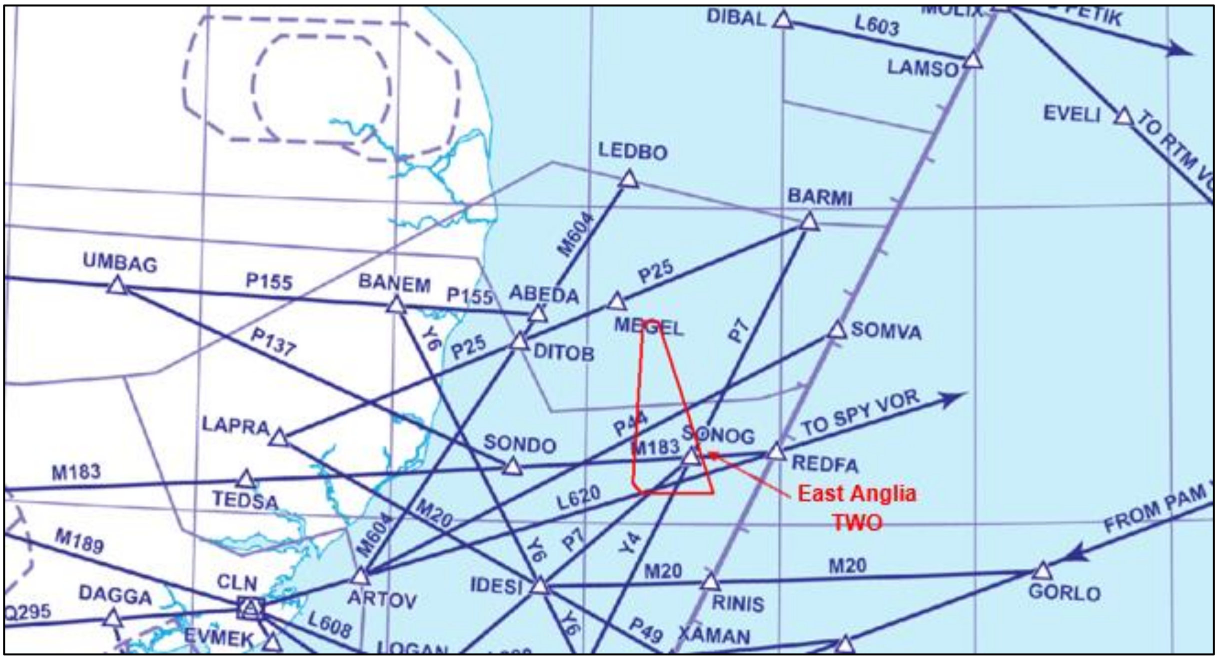

DiagramA15.1.4 RNAV Routes

15.5.3.2 Helicopter Main Routes (UK AIP ENR 1.6, 4.5.1.4.1)

34. The following Helicopter Main Routes (HMRs) are in the vicinity of the East Anglia TWO windfarm site:

- HMR 450 – This route lies significantly north of the East Anglia TWO windfarm site and is of no impact.
- HMR 20 – This is a south/north route and is of no impact.

35. Remaining HMRs further north of HMR 450 are of no consequence, as shown in ***DiagramA15.1.5***.

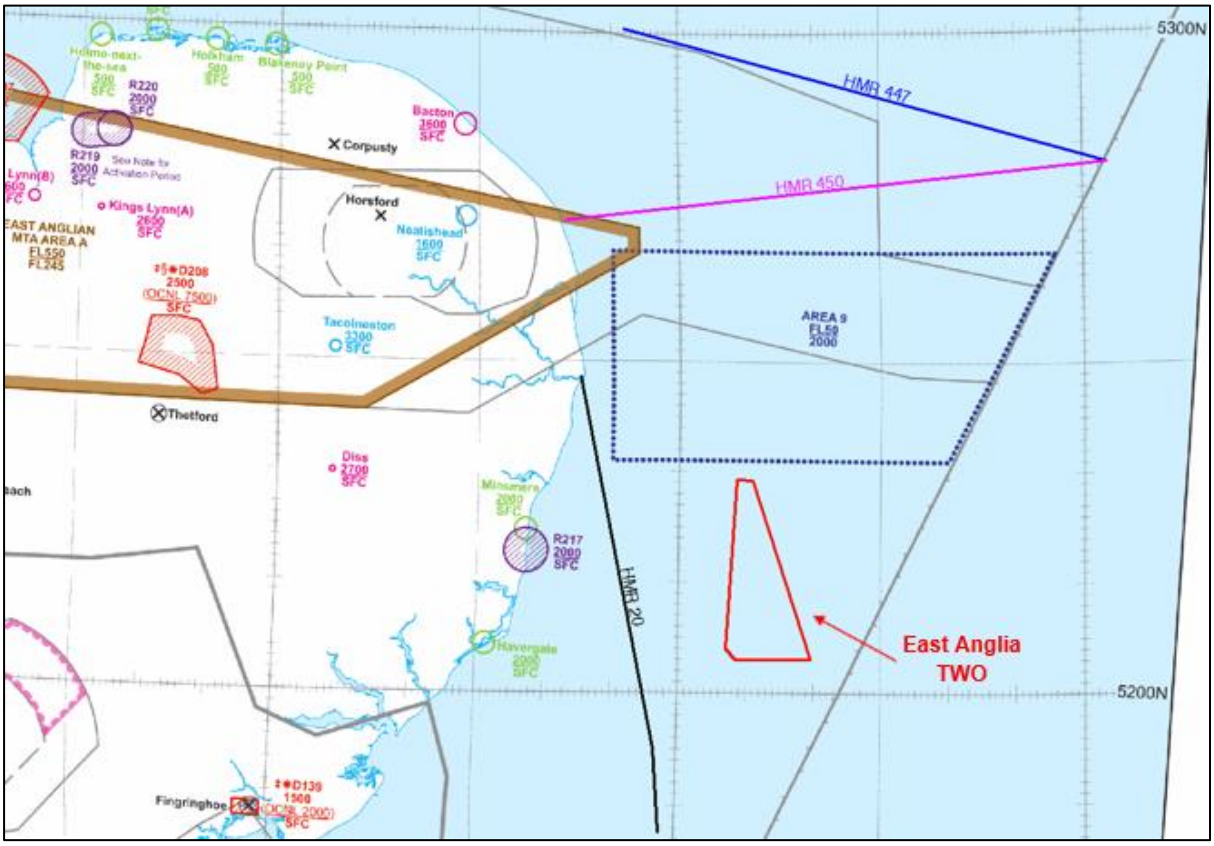

DiagramA15.1.5 Helicopter Main Routes and Area 9

15.5.3.3 Anglia Radar

36. The Anglia Radar defined area of responsibility, shown in ***DiagramA15.1.6***, is significantly further north of the East Anglia TWO windfarm site and is of no impact.

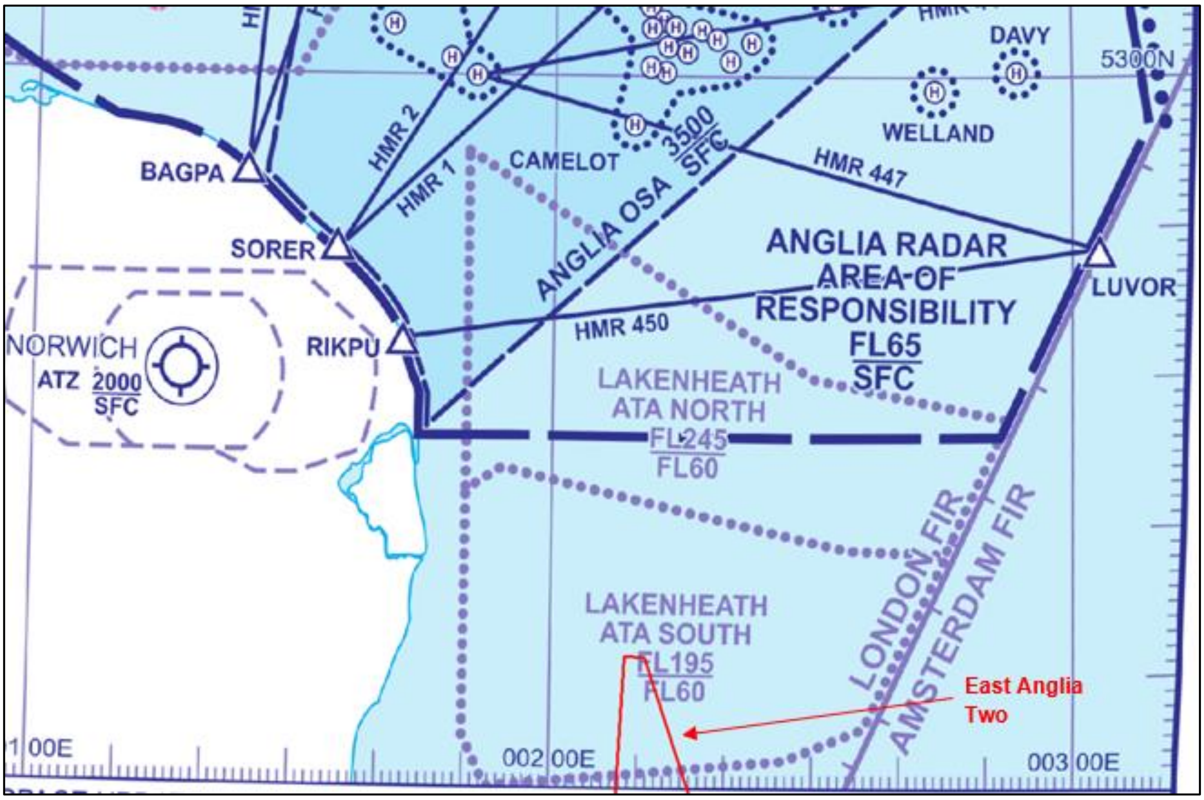

DiagramA15.1.6 Anglia Radar Area of Responsibility

15.5.3.4 ATS Airspace Classifications – Surface to FL195 (UK AIP ENR 6.1.4.1)

37. The following defined ATS Airspace are defined above the southern portion of the East Anglia TWO windfarm site:

- CLACTON CTA 5A – FL85 to FL195
- CLACTON CTA 6A – FL135 to FL195

38. The Clacton Control Areas (CTAs), shown in ***DiagramA15.1.7***, do not impact the East Anglia TWO windfarm site as the lower limits of these areas are well above the highest point of the wind turbines. The airspace surrounding the East Anglia TWO windfarm site to the north, excluding those defined in this appendix, are classified as Class G. This type of airspace does not normally have a controlling authority but may be subject to Visual Flight Rules (VFR) traffic and is further explained in ***section 15.5.5***.

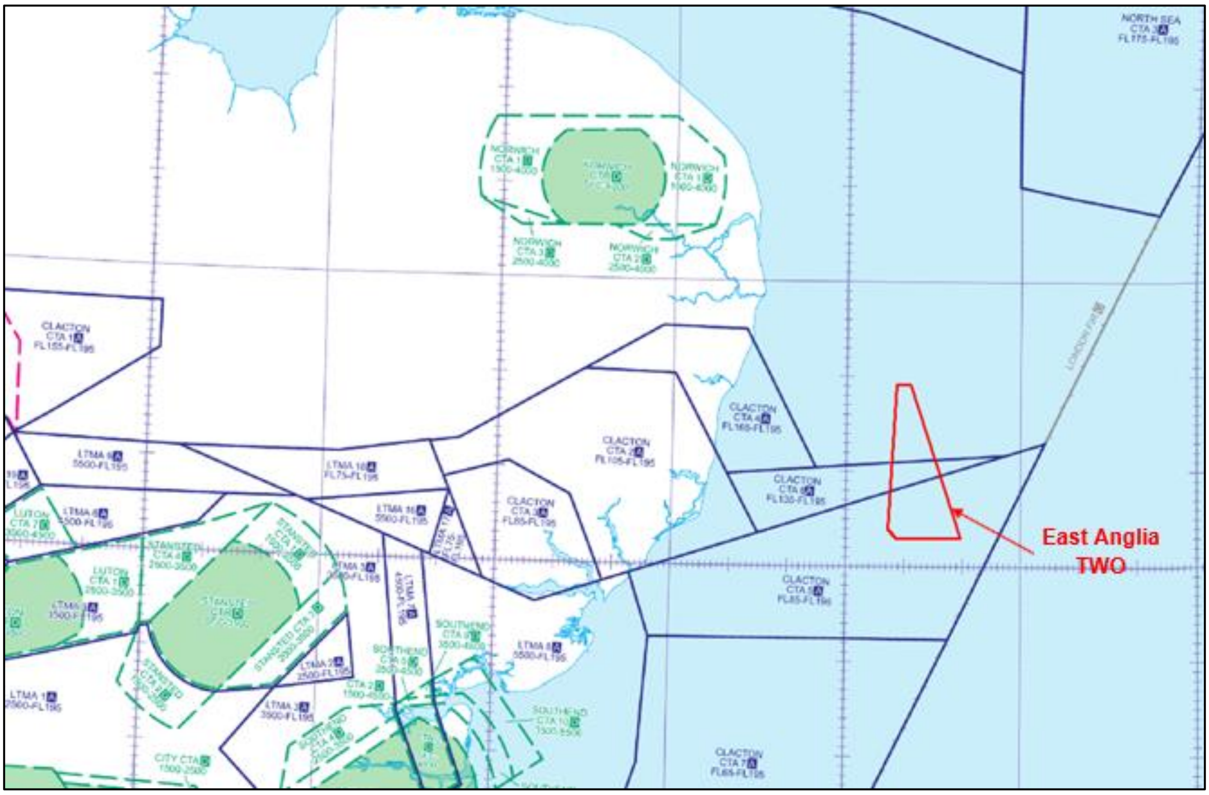

DiagramA15.1.7 Clacton CTAs

15.5.3.5 Military Low Flying Areas

39. Area 10 is the closest defined Low Level Flying area and is located at the south-eastern portion of the East Anglia land mass, for a small portion extending over the sea. The identified area does not extend significantly enough offshore to impact the East Anglia TWO windfarm site.

15.5.4 Potential Impacts

15.5.4.1 AARA Area 9

40. This area is a designated Air to Air Refuelling Area (AARA) with a defined lower limit of 2000 feet amsl, as indicated in ***DiagramA15.1.5***. The area is permanently available, but availability is managed through the MoD section at Swanwick. Due to the levels available in this area, it is assumed that refuelling activities are for military helicopters.

41. The East Anglia TWO windfarm site does not lie within the lateral boundaries of AARA Area 9 but since the entry and exit procedures for this area are not defined the possibility of aircraft exiting low-level to the south is possible. Once refuelling activity is complete the aircraft are able to route clear of this area exiting at either the lateral or vertical levels of the defined area. This includes descending below the 2000 feet limit.

15.5.4.2 ATA Lakenheath South

42. This area is designated as an Aerial Tactics Area (ATA) and is depicted in ***DiagramA15.1.1***. The UK AIP defines the area as that containing "Intense military activity" with additional advisory measures of pilots being strongly advised to avoid this area with a cautionary range of 15NM (nautical miles) from the edge of the area.

43. The addition of the 15NM cautionary range from the defined area is perhaps an indication that aircraft stray beyond the limitations of the lateral, and possibly vertical, range of the area.

15.5.5 Summary

44. The areas around the East Anglia TWO windfarm site appear to be relatively clear of any significant aviation activity. On the assumption that the wind turbines do not exceed a height of more than 1000 amsl the only potential impacts are those described above.

45. As the area is classified as a Class G airspace, i.e. not controlled by Air Traffic Control and not requiring specific procedures, there is a potential impact for a general aviation flight to be in this area (UK AIP ENR 1.4, 2.7 ATS Airspace Classification). The likelihood of general aviation traffic flying that far offshore is low. Additionally, there are specified 'rules of the air' that mitigate those aircraft capable of flying in the specified areas relating to visual metrological conditions which require aircraft flying below 3000 feet to have visibility of at least 5km and to be clear of cloud. Helicopters have a reduced visibility requirement of 1500m flight visibility if they fly at speeds below 140 knots. The culmination of these mitigations reduces the risk significantly.

15.6 Radar Line of Sight Assessment

15.6.1 Methodology

46. Initial Radar Line of Sight (RLoS) is determined by use of terrain data with radio propagation model. A 25m horizontal resolution DTM is used near the radar to provide accurate terrain mapping. ASTER DEM is used for the sea and other areas to provide background context. The two datasets are combined and used in both GIS and Radar Propagation models.

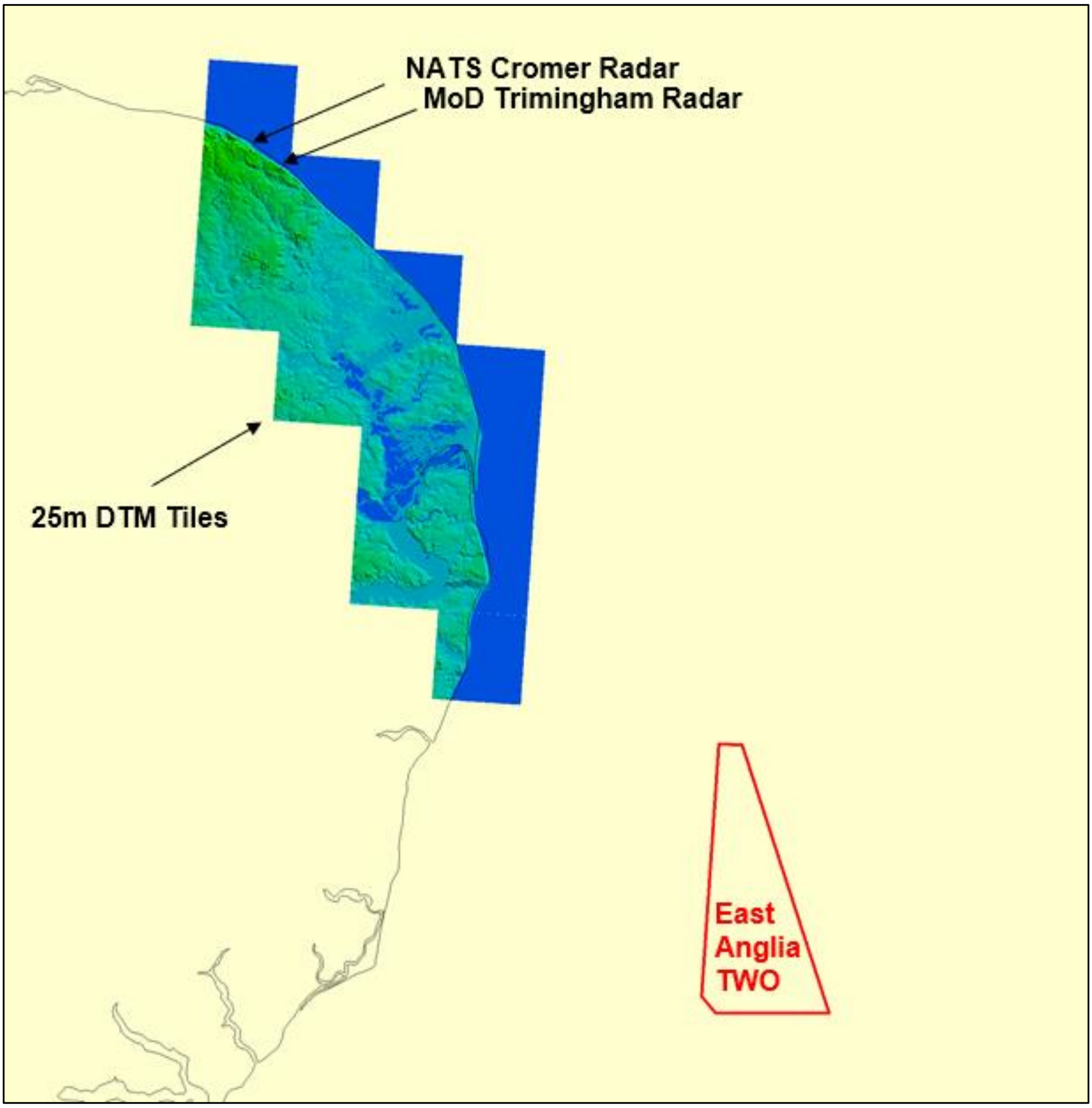

DiagramA15.1.8 High resolution DTM in vicinity of radars

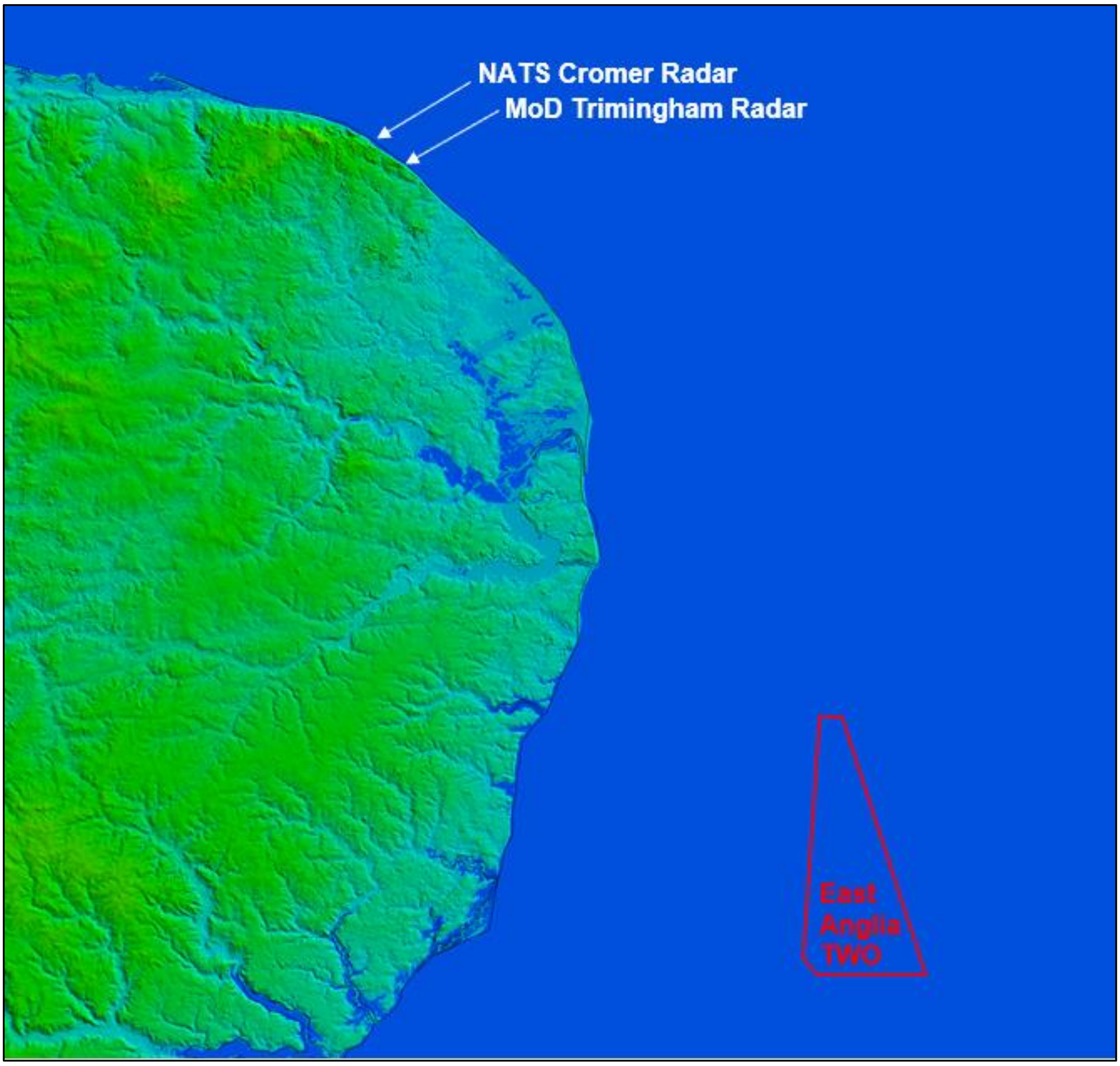

DiagramA15.1.9 DTM with ASTER DEM background

47. Initial coarse assessments are made using a GIS tool using a 4/3 earth curvature refraction model. This provides an illustrative overview of RLoS.

48. Detailed investigation and measurements are made using the same terrain data with ATDI ICS telecom, a radio propagation model.

15.7 MoD Trimingham Radar

15.7.1 Topography

49. The closest point of the East Anglia TWO windfarm site is 44NM (81.4km) from the Trimingham PSR.

50. There is some intervening terrain to provide screening of the East Anglia TWO windfarm site.

15.7.2 Radar Line of Sight

51. Initial assessments carried out established RLoS to turbine heights in the range 180m to 400m tip heights across the East Anglia TWO windfarm site.

52. ***DiagramA15.1.10*** illustrates the Trimingham RLoS elevations in metres above the East Anglia TWO windfarm site.

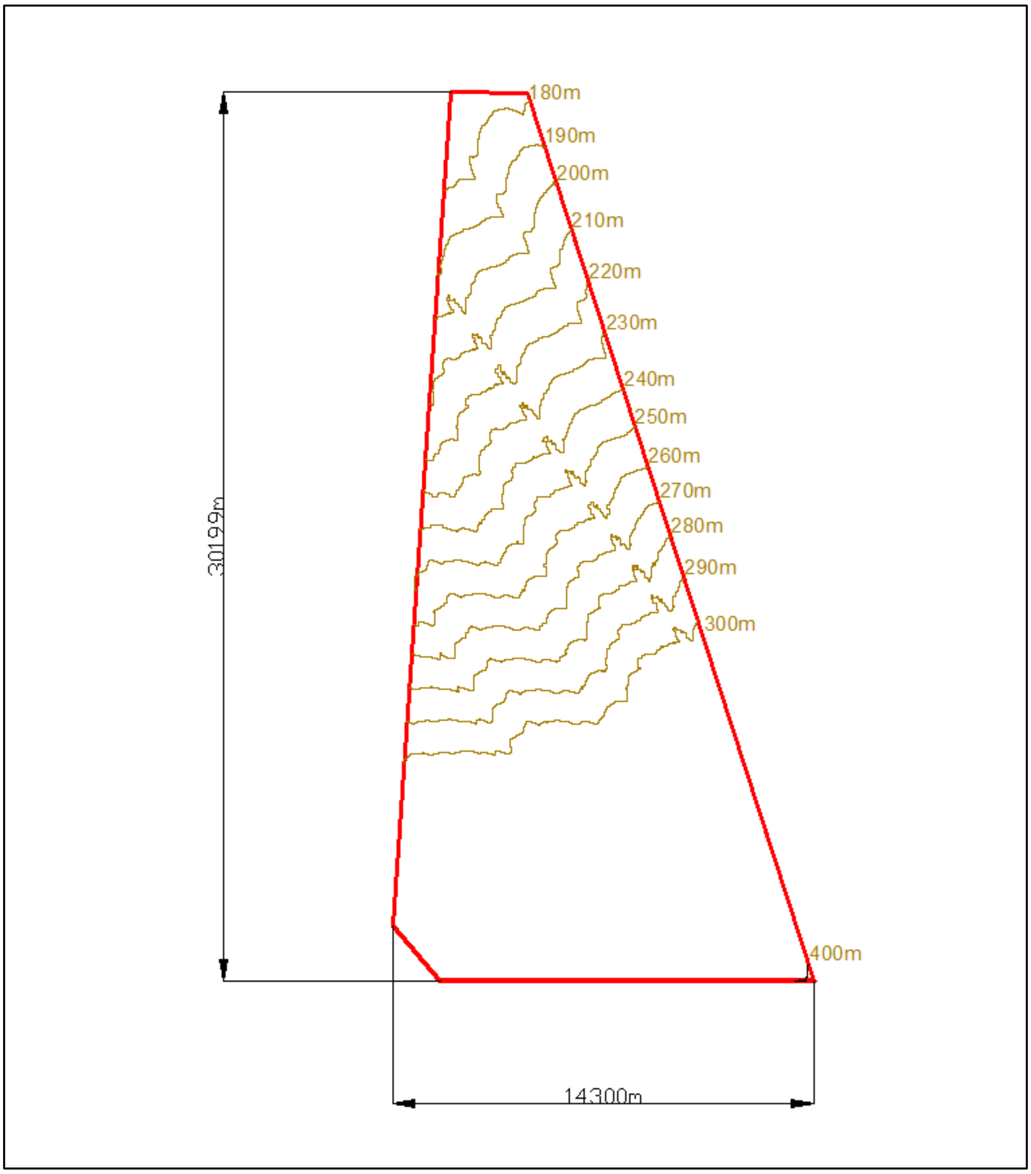

DiagramA15.1.10 Trimingham radar RLoS to East Anglia TWO

53. A 3D representation of the Trimingham PSR RLoS is shown in ***DiagramA15.1.11***.

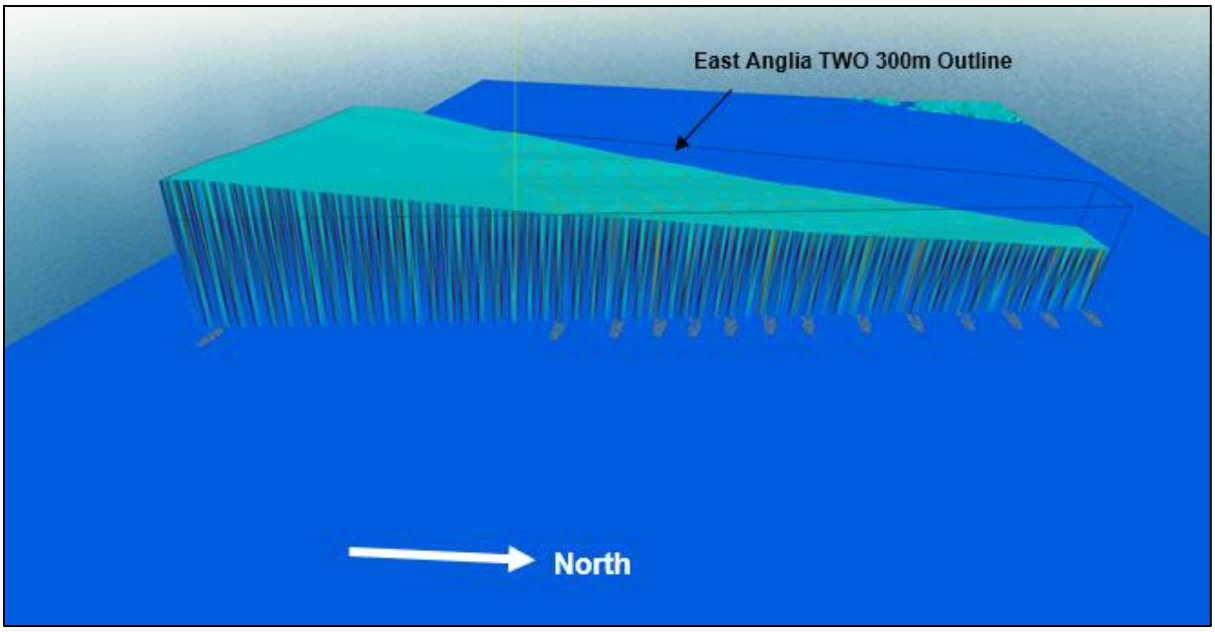

DiagramA15.1.11 3D representation of Trimingham PSR RLoS to East Anglia TWO, viewed from the east

54. The Cyan shaded volume in ***DiagramA15.1.11*** illustrates the volume where wind turbines do not have RLoS from MoD Trimingham radar. The black line illustrates a 300m high volume above the East Anglia TWO windfarm site.

55. The calculated RLoS from Trimingham radar to 244m turbines at the East Anglia TWO windfarm site is depicted in the following diagram:

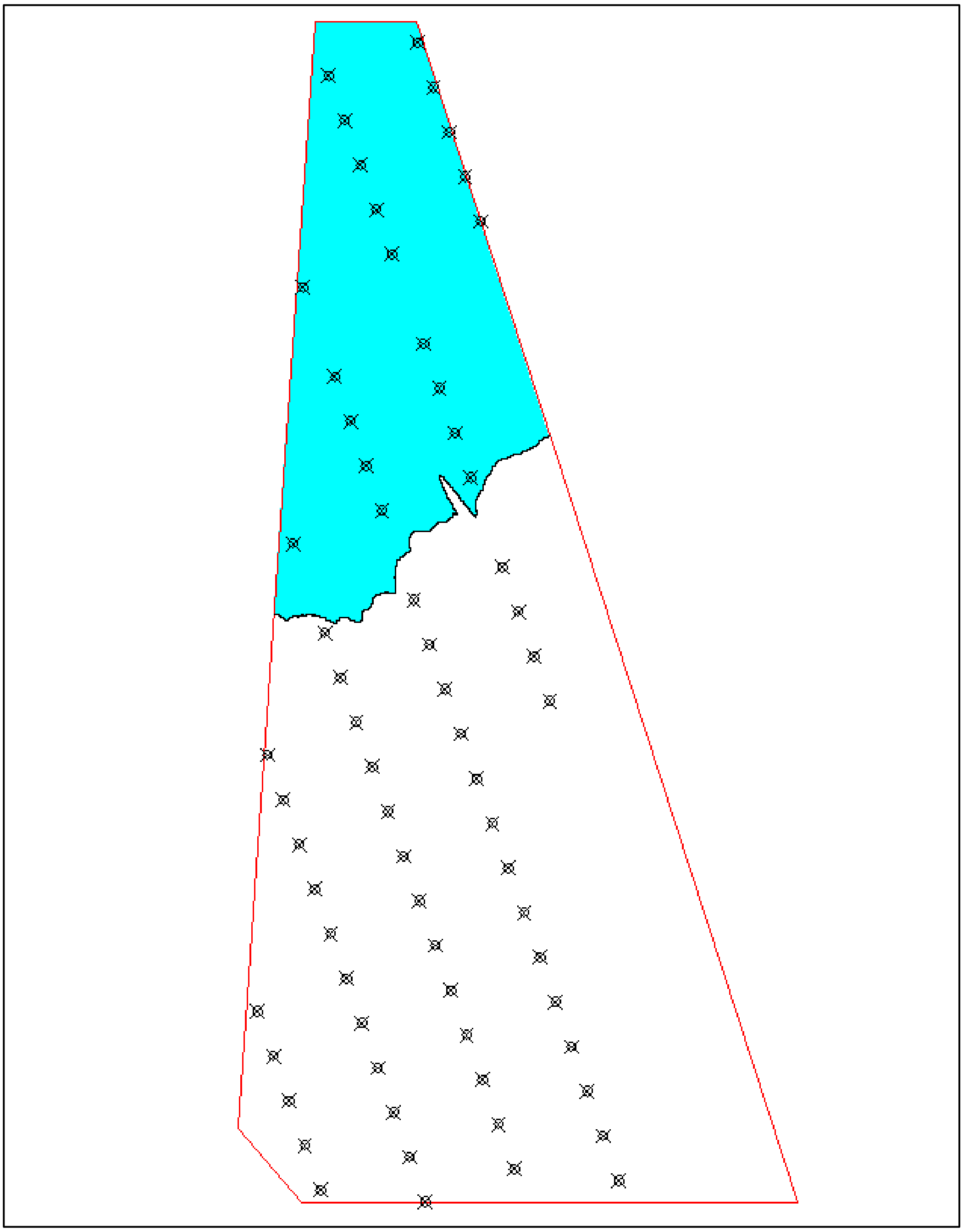

DiagramA15.1.12 Trimingham RLoS to 244m Turbines

56. The cyan shaded area depicts where Trimingham radar has RLoS to 244m turbines.

57. 20 of the 67 turbines in this indicative visualisation layout are in RLoS of Trimingham radar.

58. The calculated RLoS from Trimingham radar to 300m turbines at the East Anglia TWO windfarm site is depicted in the following diagram:

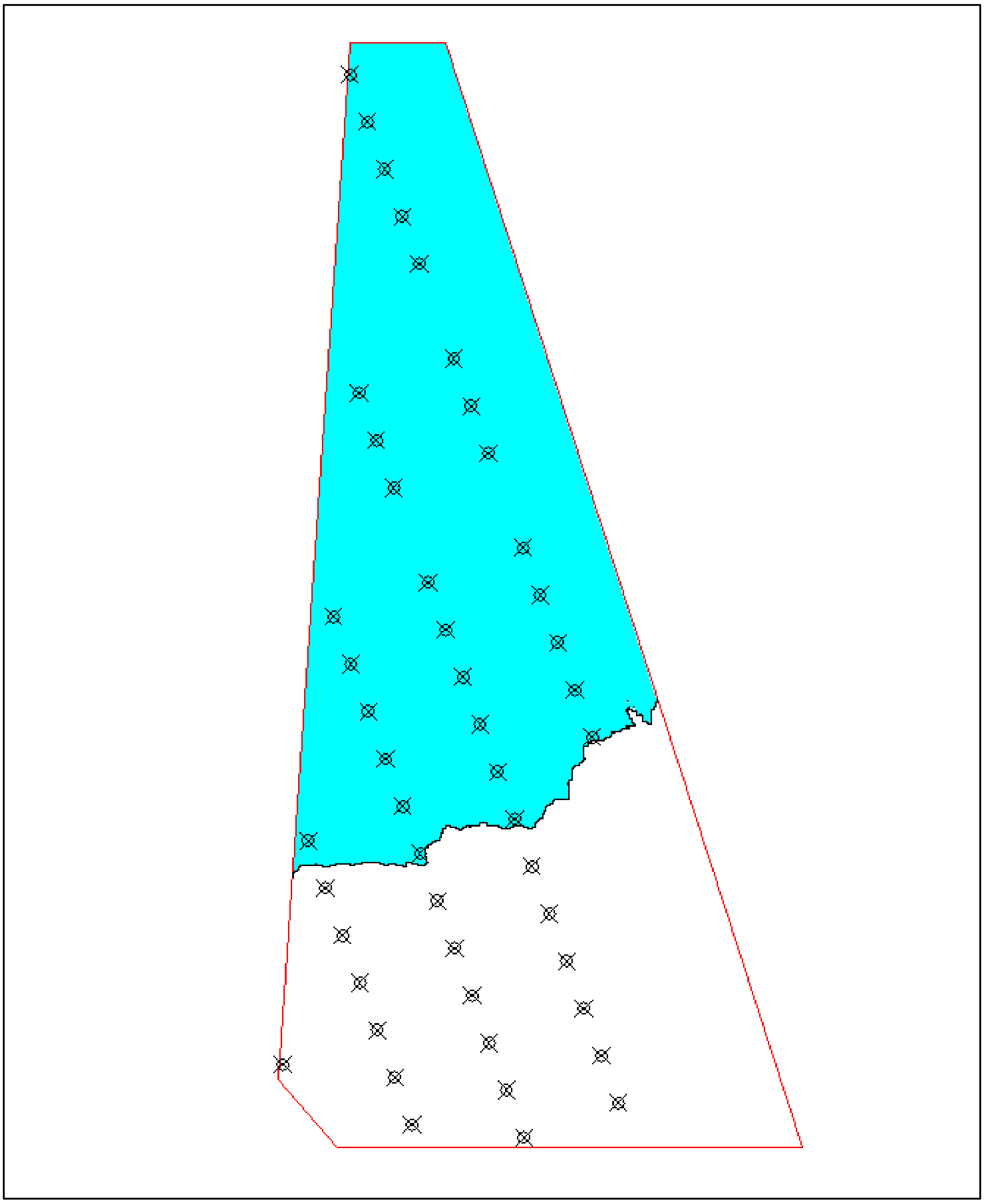

DiagramA15.1.13 Trimingham RLoS to 300m Turbines

59. The cyan shaded area depicts where Trimingham radar has RLoS to 300m turbines.

60. 29 of the 48 turbines in this indicative visualisation layout are in RLoS of Trimingham radar.

15.7.3 Closest Turbine

61. A radar propagation model was used to determine the maximum turbine height at the closest point of the East Anglia TWO windfarm site that would not be visible to Trimingham radar.

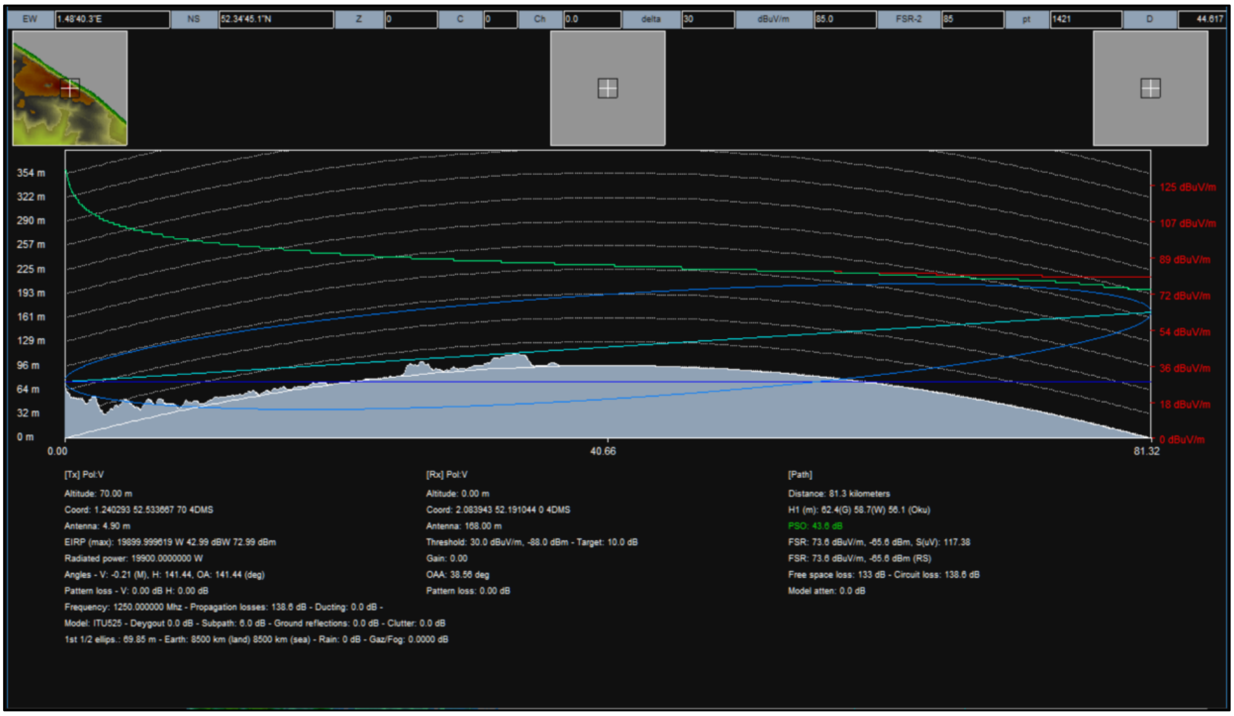

DiagramA15.1.14 Trimingham Radar Propagation Model to closest point of East Anglia TWO

62. The maximum turbine height that would not be detected by Trimingham radar at the closest point of the East Anglia TWO windfarm site is 168m amsl.

63. Visibility of a 168m tip height turbine at the East Anglia TWO windfarm site from Trimingham radar is shown in ***DiagramA15.1.15***.

DiagramA15.1.15 Trimingham radar visibility to 168m turbine – East Anglia TWO

64. The magenta shaded area in ***DiagramA15.1.15*** indicates the visibility of a 168m tip height turbine to Trimingham radar. The East Anglia TWO windfarm site boundary is depicted by the cyan line.

15.7.4 Potential Mitigation Options – TPS-77 NAIZ

65. The most common wind turbine mitigation technique applied to the TPS-77 radar is a Non-Automatic Initiation Zone, or NAIZ.

66. TPS-77 was acquired by the MoD on the basis that this type of AD PSR had enhanced or significantly improved resilience to wind turbine generated interference. In addition to the routine advanced processing of radar data that the TPS-77 is capable of, where areas of clutter and interference are deemed excessive, the system has an innovative means of removing radar returns that are distracting to system operators. A NAIZ can be configured within the radar system software which prevents newly detected radar tracks from being displayed within a specific 3-dimensional zone within the radar's coverage. Importantly for AD system operators, any moving radar tracks that enter a

NAIZ would continue to be tracked through the zone, regardless of the surrounding clutter which has been suppressed by the TPS-77 software. In sum, any track which first appears in a selected area (such as a range-azimuth cell(s) containing wind turbine(s)) would be suppressed but existing tracks which have entered that cell from elsewhere would be retained.

67. The NAIZ may be defined as a geographic polygon, or by range and sector angle from the radar. The NAIZ should be the minimum size necessary to prevent initiation of tracks from turbines that may be detected by the radar.

68. Consideration must be given not only to the NAIZ, but also to the area surrounding the NAIZ where aircraft tracks will be detected and initiated prior to the aircraft entering the NAIZ.

69. Trimingham radar has a scan rate of 5 Revolutions Per Minute (RPM), which equates to a time interval of 12 seconds between scans. Initial investigations consider a 5km buffer zone around the NAIZ to ensure detection of aircraft tracks prior to the target entering the NAIZ area. 5km equates to 16.2 seconds for an aircraft with a groundspeed of 600kts.

15.7.4.1 244m Turbines with NAIZ

70. ***DiagramA15.1.16*** illustrates a NAIZ based on range and sector angle to address the detection of turbines predicted in ***DiagramA15.1.12***.

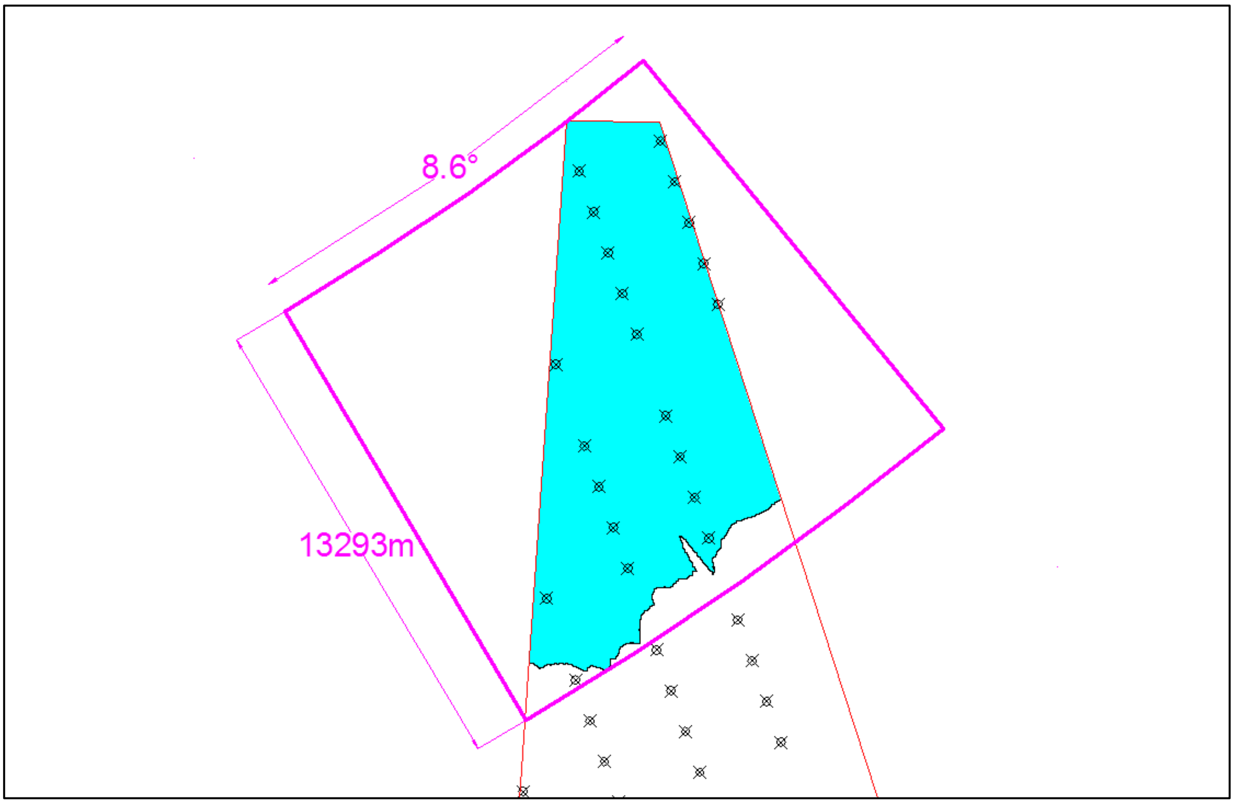

DiagramA15.1.16 Trimingham 244m turbine NAIZ

71. To encompass the 20 identified turbines, a NAIZ has been defined as depicted by the magenta outline in ***DiagramA15.1.16***.

72. A further 5km buffer is described around the NAIZ to ensure detection of established aircraft tracks entering the NAIZ. This is depicted in ***DiagramA15.1.17***.

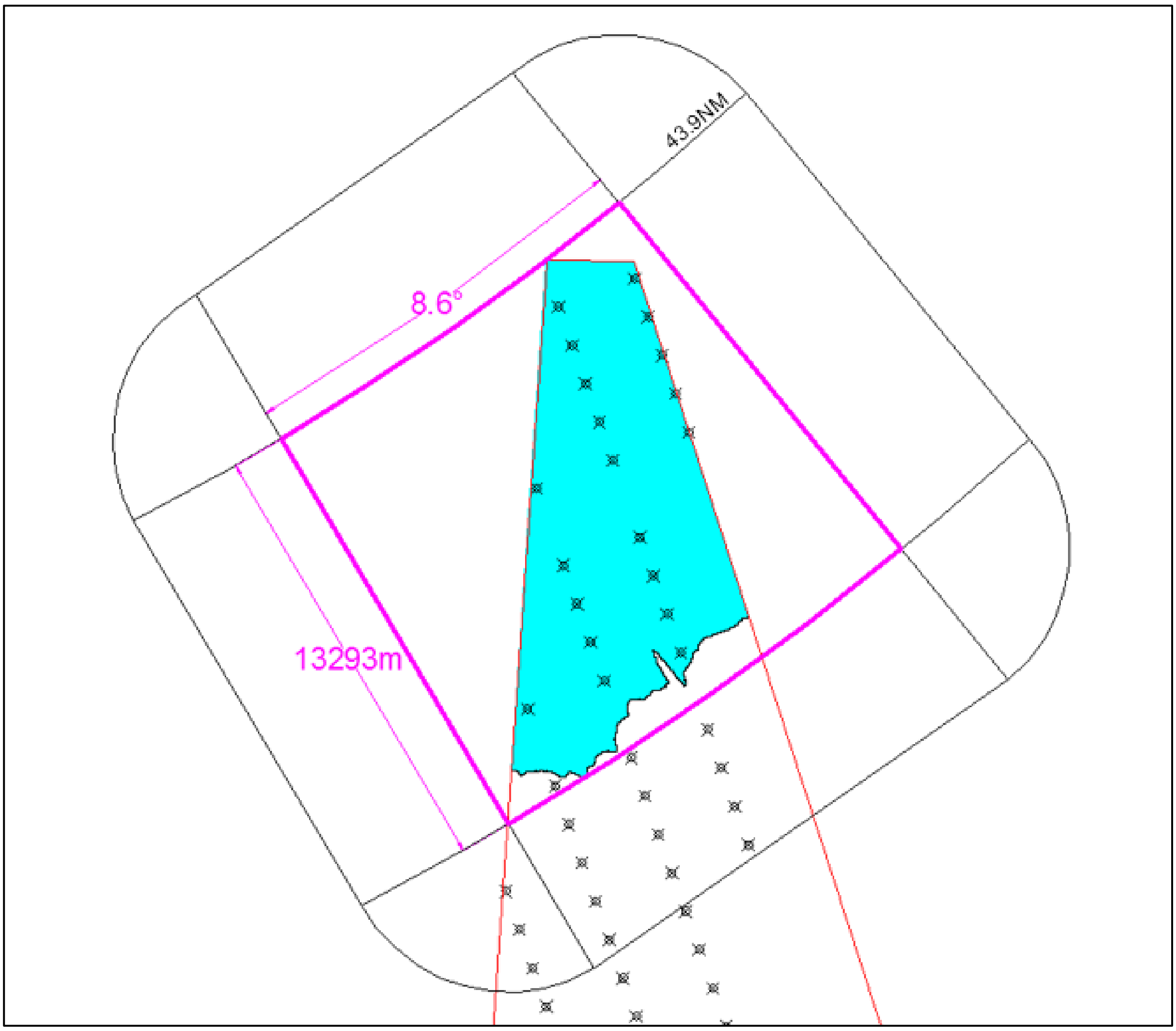

DiagramA15.1.17 Trimingham 244m turbine NAIZ buffer

73. Aircraft targets will continue to be tracked through the NAIZ provided they are detected within the NAIZ buffer area or have already formed a track.

74. Targets will be detected in the NAIZ buffer area provided they are within RLoS of Trimingham radar.

75. The RLoS altitudes within the NAIZ buffer area are depicted in ***DiagramA15.1.18***.

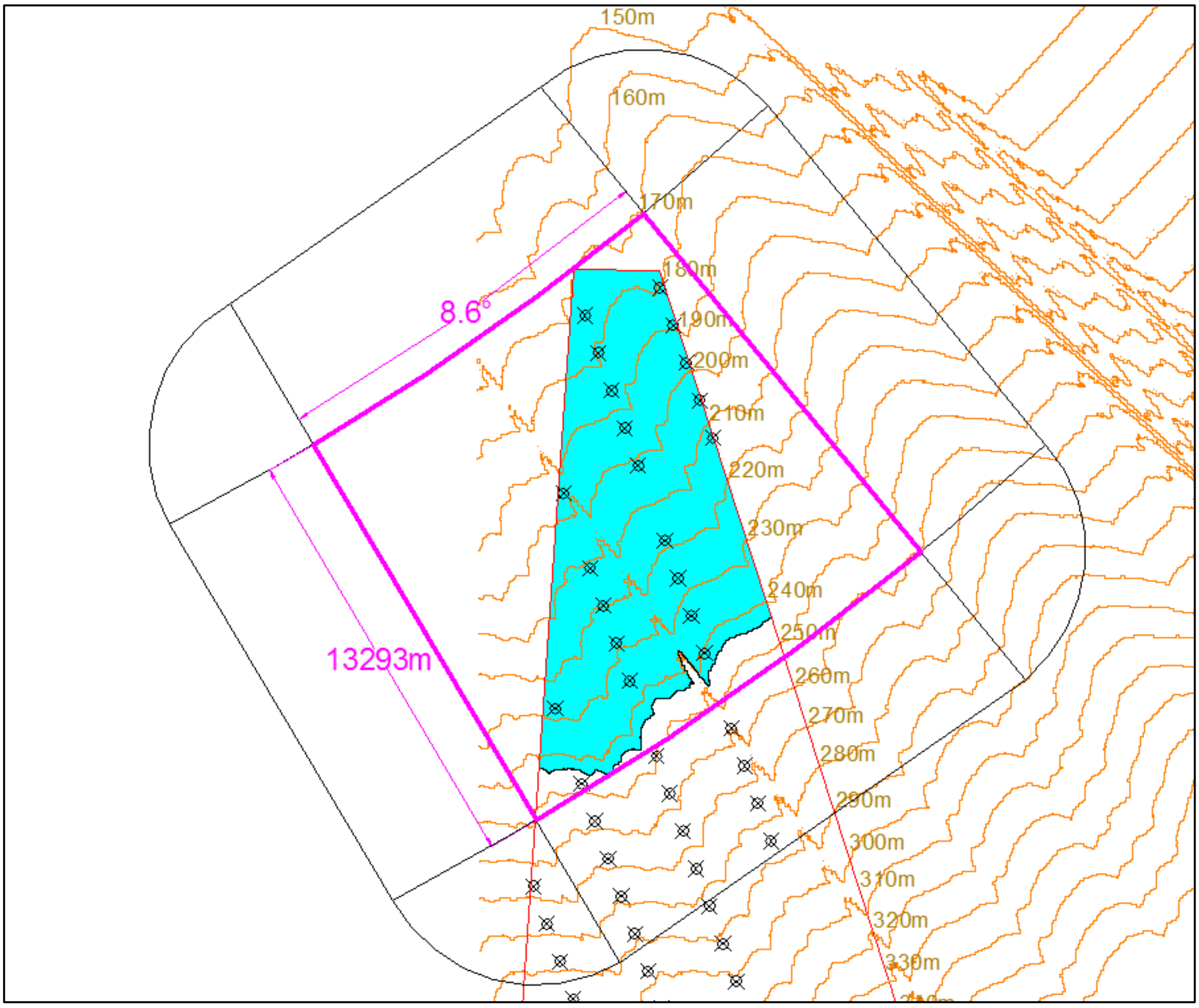

DiagramA15.1.18 Trimingham 244m turbine buffer RLoS contours

76. It can be seen that in the worst-case scenario an aircraft entering the NAIZ from the East would need to be at an altitude of 310m (1017') amsl to be detected and tracked through the NAIZ. Aircraft approaching the NAIZ from other directions would be detected at lower altitudes. Aircraft approaching the NAIZ from the North and West sectors would be detected and tracked at altitudes lower than the turbine tip heights.

77. The NAIZ effectively produces a worst-case 'dead volume' above the turbines of 66m (216').

15.7.4.2 300m Turbines with NAIZ

78. ***DiagramA15.1.19*** illustrates a NAIZ based on range and sector angle to address the detection of turbines predicted in ***DiagramA15.1.13***.

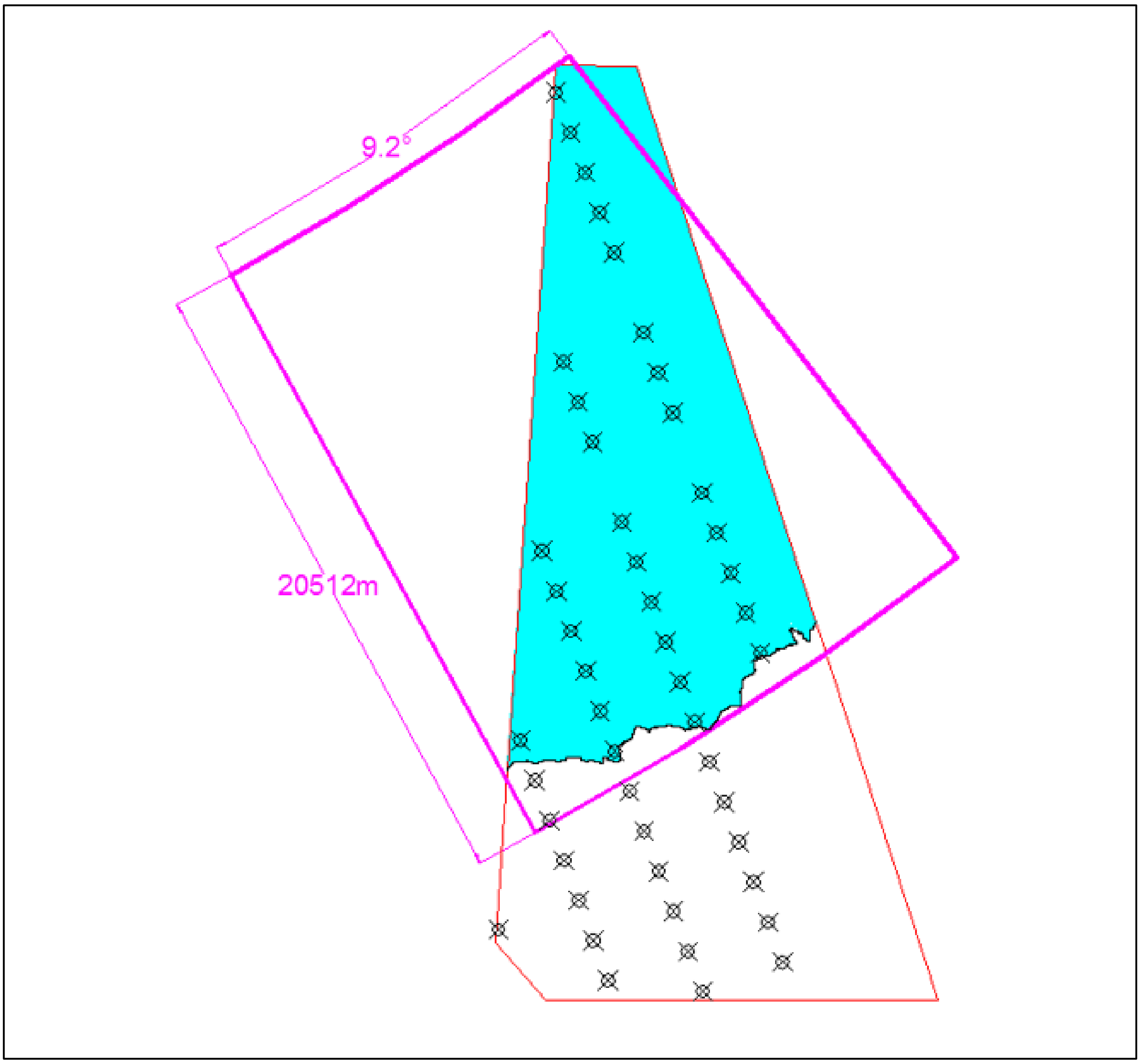

DiagramA15.1.19 Trimingham 300m turbine NAIZ

79. To encompass the 29 identified turbines, a NAIZ has been defined as depicted by the magenta outline in ***DiagramA15.1.19***.

80. A further 5km buffer is described around the NAIZ to ensure detection of established aircraft tracks entering the NAIZ. This is depicted at ***DiagramA15.1.20***.

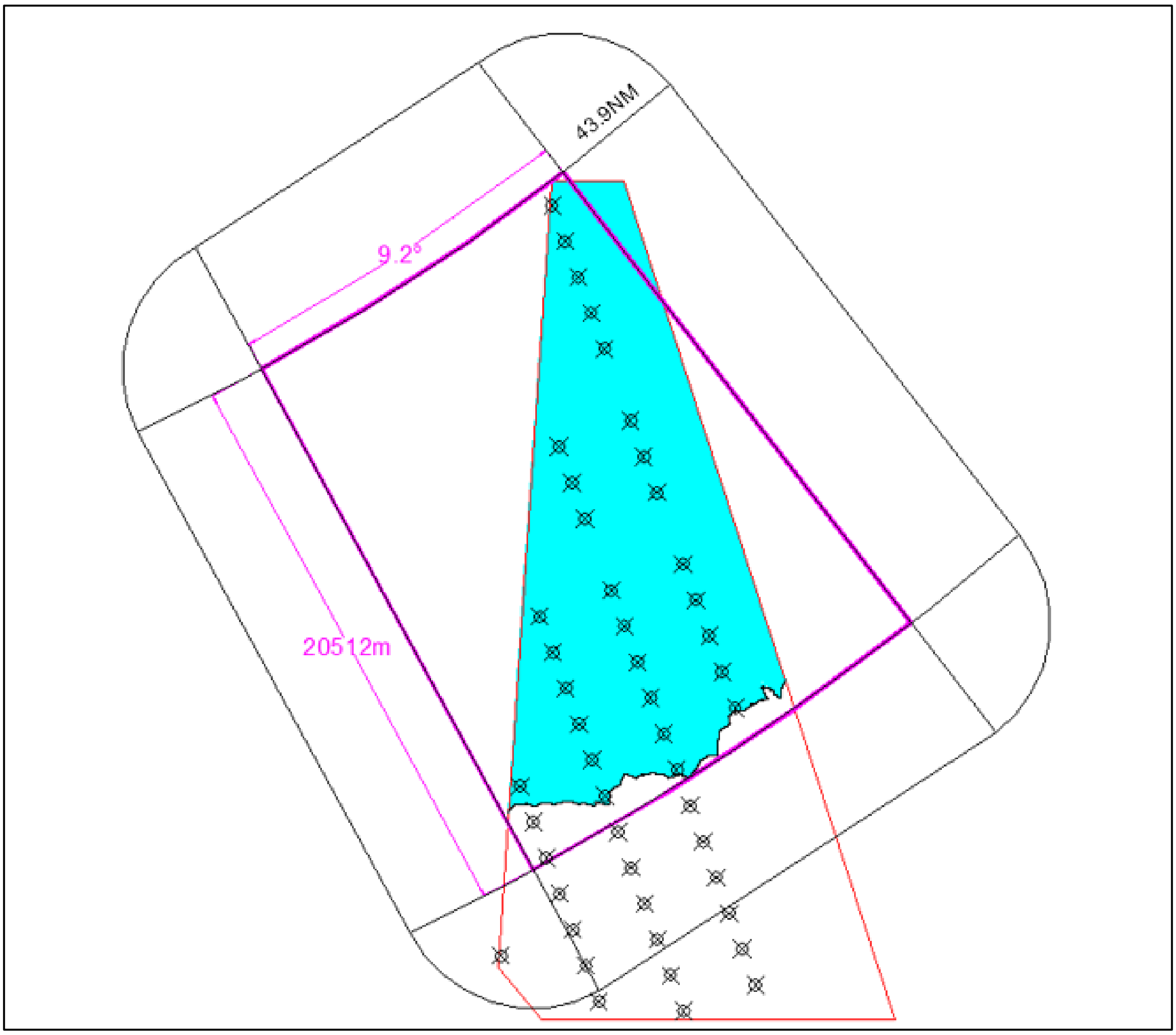

DiagramA15.1.20 Trimingham 300m turbine NAIZ buffer

81. Aircraft targets will continue to be tracked through the NAIZ provided they are detected within the NAIZ buffer area or have already formed a track.

82. Targets will be detected in the NAIZ buffer area provided they are within RLoS of Trimingham radar.

83. The RLoS altitudes within the NAIZ buffer area are depicted in ***DiagramA15.1.21***.

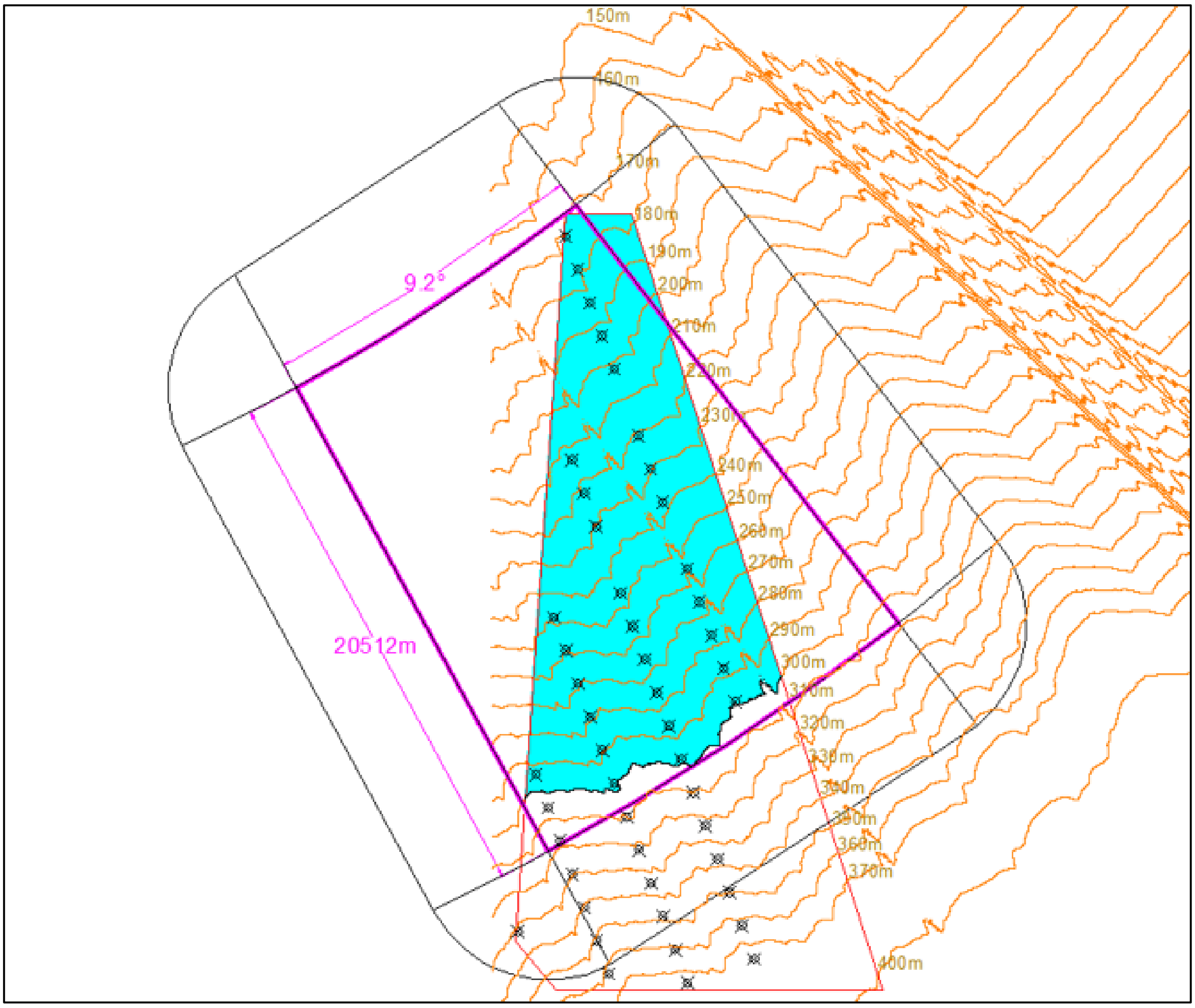

DiagramA15.1.21 Trimingham 300m turbine buffer RLoS contours

84. It can be seen that in the worst-case scenario an aircraft entering the NAIZ from the East would need to be at an altitude of 360m (1181’) amsl to be detected and tracked through the NAIZ. Aircraft approaching the NAIZ from other directions would be detected at lower altitudes. Aircraft approaching the NAIZ from the North and West sectors would be detected and tracked at altitudes lower than the turbine tip heights.

85. The NAIZ effectively produces a worst-case ‘dead volume’ above the turbines of 60m (197’).

86. Notwithstanding the above calculations, it would appear that the TPS-77 NAIZ has not met expected MoD performance requirements. In a statement dated 24 August 2018, the MoD announced:

> *"The MOD has recently conducted a trial looking at the real life impact of 2 offshore wind farms in the vicinity of the Humber Estuary on the TPS 77 radar that was situated at Remote Radar Head Staxton Wold. The trial determined that the wind farms had a detrimental effect on radar operations, specifically probability of detection and the aviation specification performance. The detrimental effect was not expected and the MOD needs to consider the findings of the trial further. As a result, the MOD must pause the receipt and assessment of any technical mitigation reports/submissions e.g. SERCO reports, relating to the TPS 77 radars and multi-turbine wind farms with immediate effect. Technical mitigation reports relating to single turbine developments will still be received and assessed by MOD."*

87. Coupled with the feedback received by East Anglia THREE in respect of potential NAIZ mitigations, SPR considers it unlikely that the MoD will agree to a NAIZ mitigation for the proposed East Anglia TWO project.

15.7.5 Potential Mitigation Options – Aveillant Theia Installation

88. In discussions with the MoD as to the feasibility of a NAIZ mitigation for East Anglia THREE, it became apparent that the MoD has very little appetite to accept NAIZ mitigations at the edge of Remote Radar Head Trimingham's cover. As a result, East Anglia THREE submitted an alternative AD mitigation proposal to the MoD in September 2017 under which it is proposed to install an extended range Aveillant Theia 3D Holographic Radar™ on the Norfolk coast. The Aveillant Theia is a 3D staring radar that sees both aircraft and wind turbines, characterising each and so discriminating between them (i.e. only reporting true targets) with no loss of performance. The Aveillant Theia would provide a radar feed to the MoD's AD Command and Control System, thus enabling provision of an air picture to the MoD without the interference of wind turbines.

89. In designing this alternative AD mitigation proposal for the MoD, the Applicant included consideration of the proposed East Anglia TWO and ONE North projects, and potentially other windfarms as illustrated in the image below:

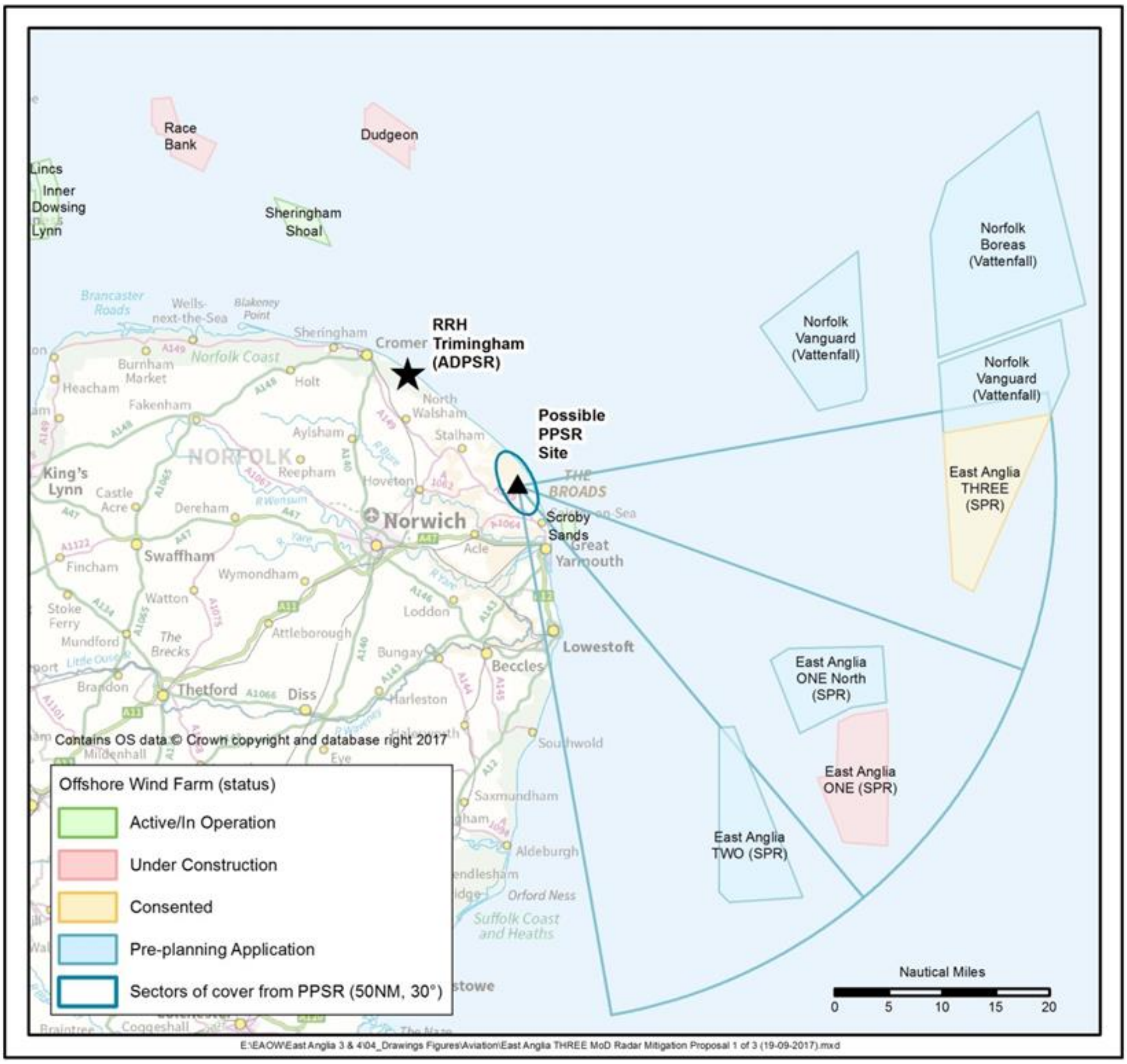

DiagramA15.1.22 Aveillant Theia sectors of cover

90. ScottishPower Renewables (SPR) (of which the Applicant is a wholly owned subsidiary) and Aveillant are engaged in discussions with the MoD with regards to this proposal. SPR has engaged Aveillant to undertake an extended range proving trial of the Theia in the first half of 2019, with the aim of moving to a full product qualification later in 2019 and into 2020. The MoD has been invited to observe / participate in these trials.

15.8 NATS Cromer Radar

15.8.1 Topography

91. The closest point of the East Anglia TWO windfarm site is 46NM (85.2km) from the Cromer PSR.

92. There is some intervening terrain to provide screening of the East Anglia TWO windfarm site.

15.8.2 Radar Line of Sight

93. Initial assessments carried out established RLoS to turbine heights in the range 180m to 400m tip heights across the East Anglia TWO windfarm site.

94. ***DiagramA15.1.23*** illustrates the Cromer PSR RLoS elevations in metres above the East Anglia TWO windfarm site.

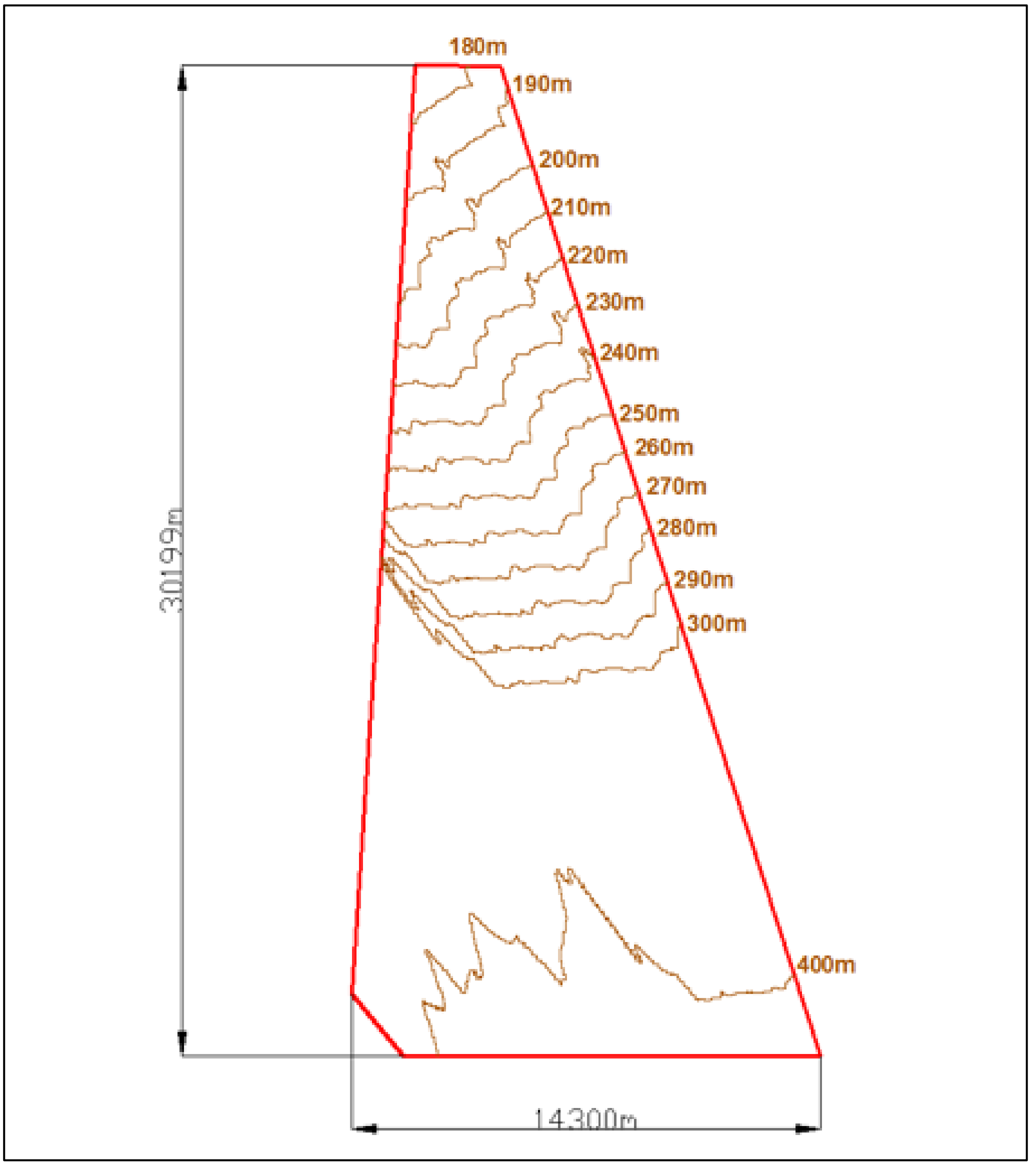

DiagramA15.1.23 Cromer radar RLoS to East Anglia TWO

95. A 3D representation of the Cromer PSR RLoS is shown in ***DiagramA15.1.24.***

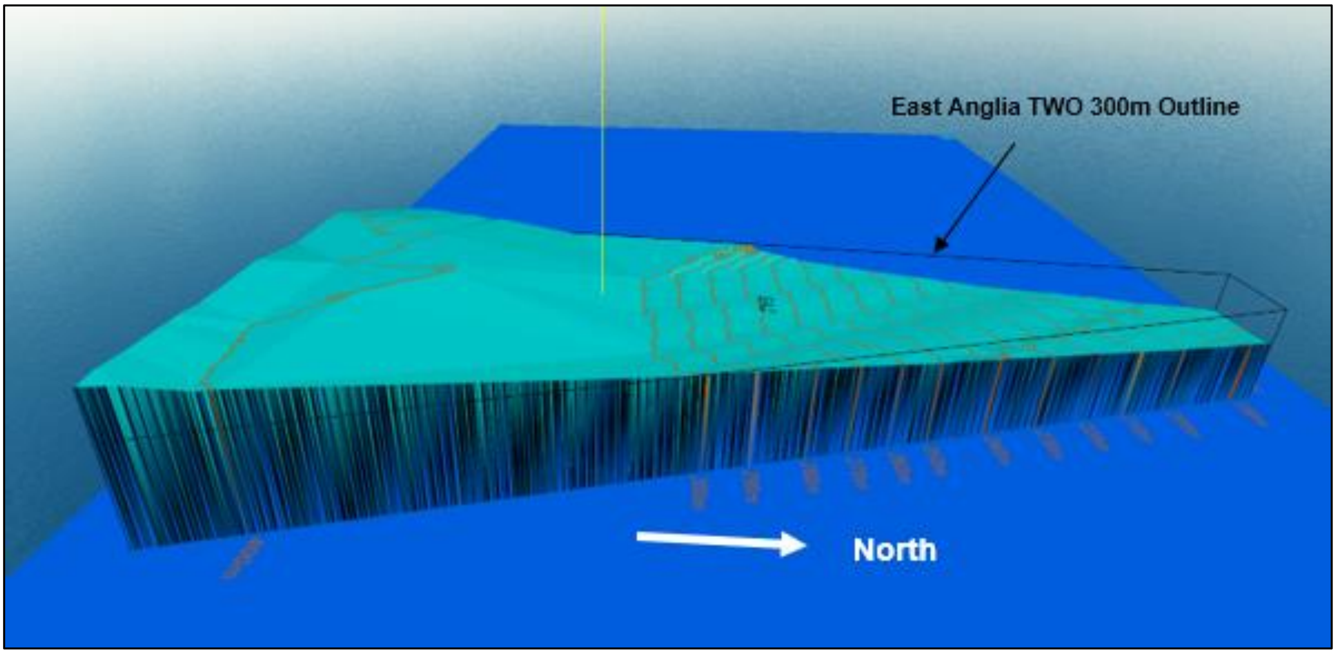

DiagramA15.1.24 3D representation of Cromer PSR RLoS to East Anglia TWO, viewed from the east

96. The cyan shaded volume in ***DiagramA15.1.24*** illustrates the volume where wind turbines up to 300m do not have RLoS to NATS Cromer radar. The black line illustrates a 300m high volume above the East Anglia TWO windfarm site.

97. The calculated RLoS from Cromer radar to 244m turbines in this indicative visualisation layout at the East Anglia TWO windfarm site is depicted in the following diagram:

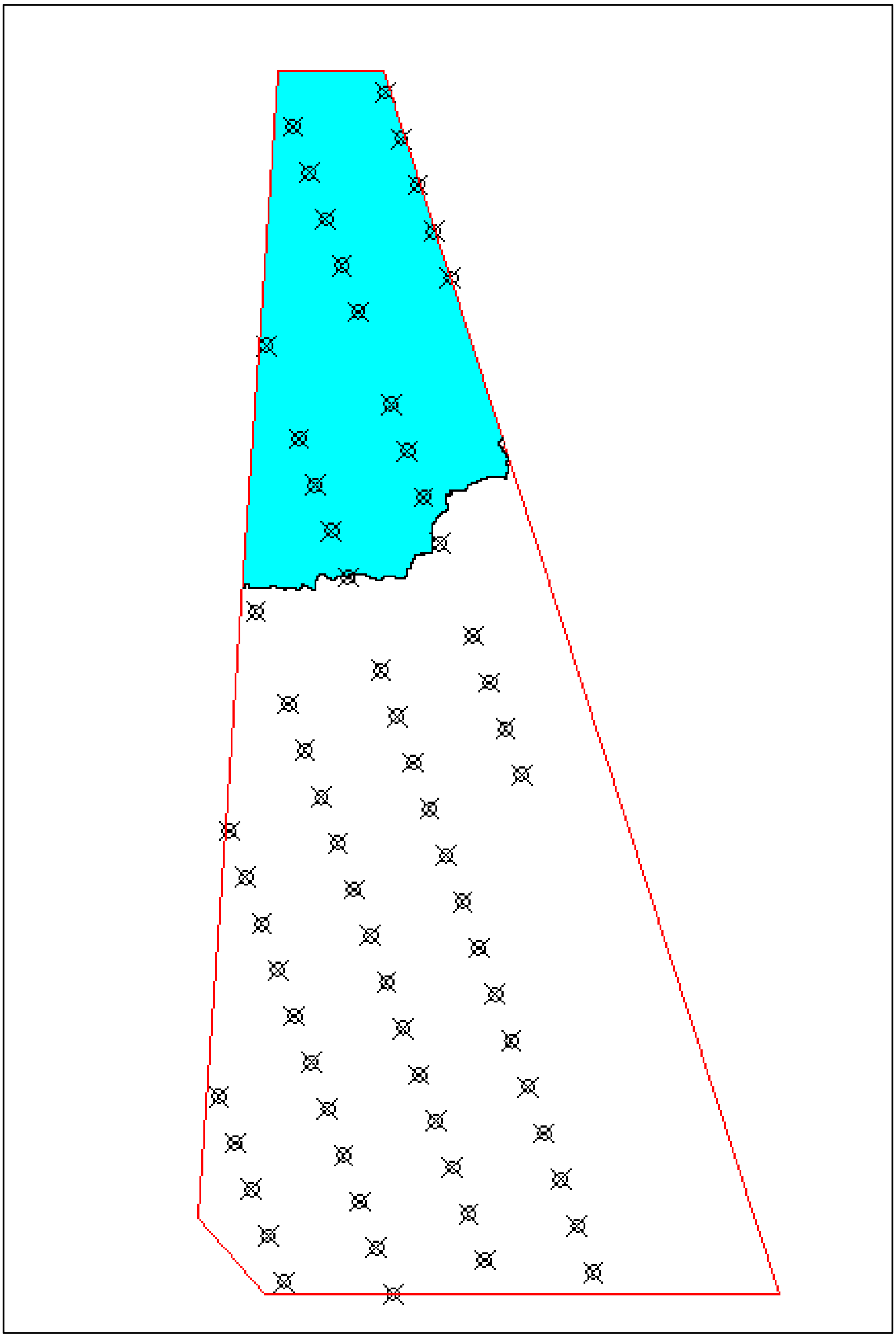

DiagramA15.1.25 Cromer RLoS to 244m Turbines

98. The cyan shaded area depicts where Cromer radar has RLoS to 244m turbines.

99. 18 of the 67 turbines in this indicative visualisation layout are in RLoS of Cromer radar.

100. The calculated RLoS from Cromer radar to 300m turbines at the East Anglia TWO windfarm site is depicted in the following figure:

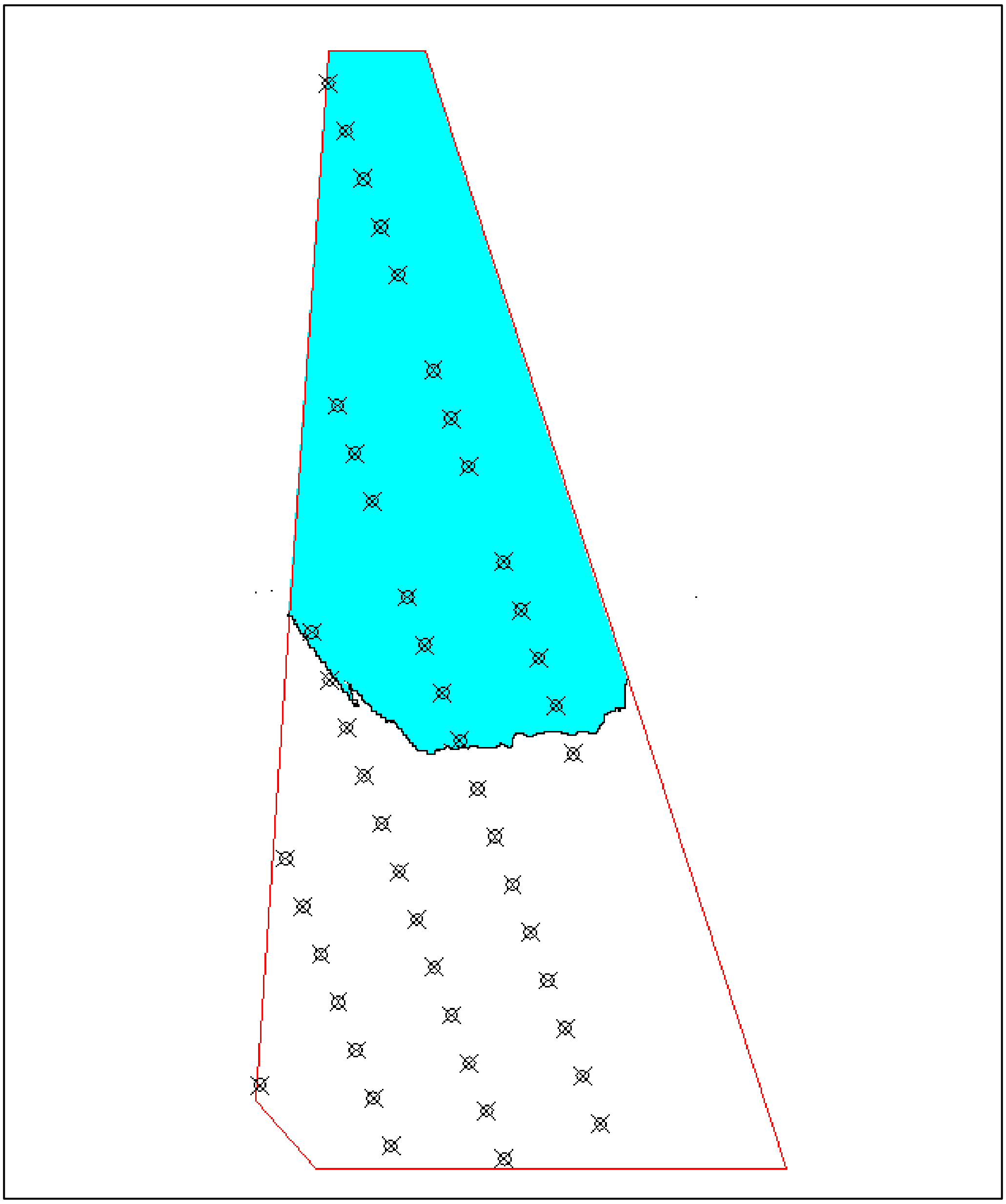

Diagram15.1.26 Cromer RLoS to 300m Turbines

101. The cyan shaded area depicts where Cromer radar has RLoS to 300m turbines.

102. 20 of the 48 turbines in this indicative visualisation layout are in RLoS of Cromer radar.

15.8.3 Closest Turbine

103. A radar propagation model was used to determine the maximum turbine height at the closest point of the East Anglia TWO windfarm site that would not be visible to Cromer radar.

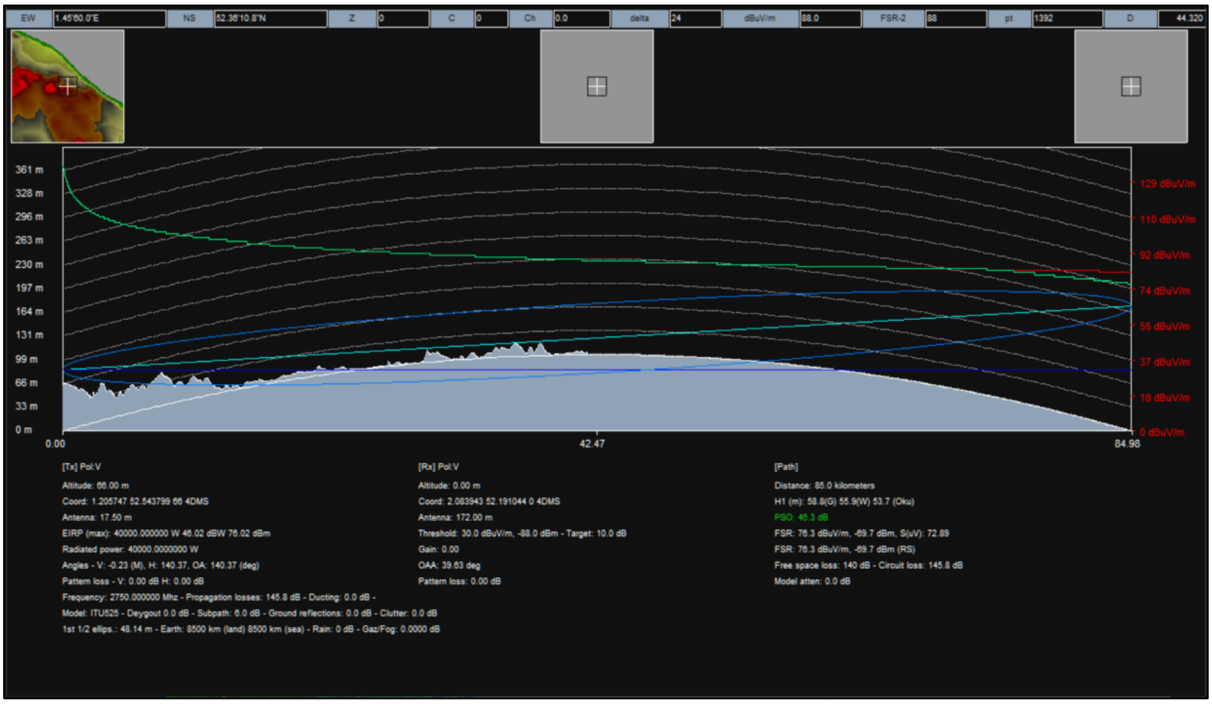

DiagramA15.1.27 Cromer Radar Propagation Model to closest point of East Anglia TWO

104. The maximum turbine height that would not be detected by Cromer radar at the closest point of the East Anglia TWO windfarm site is 172m amsl.

105. Visibility of a 172m tip height turbine at the East Anglia TWO windfarm site from Cromer radar is shown in ***DiagramA15.1.28***.

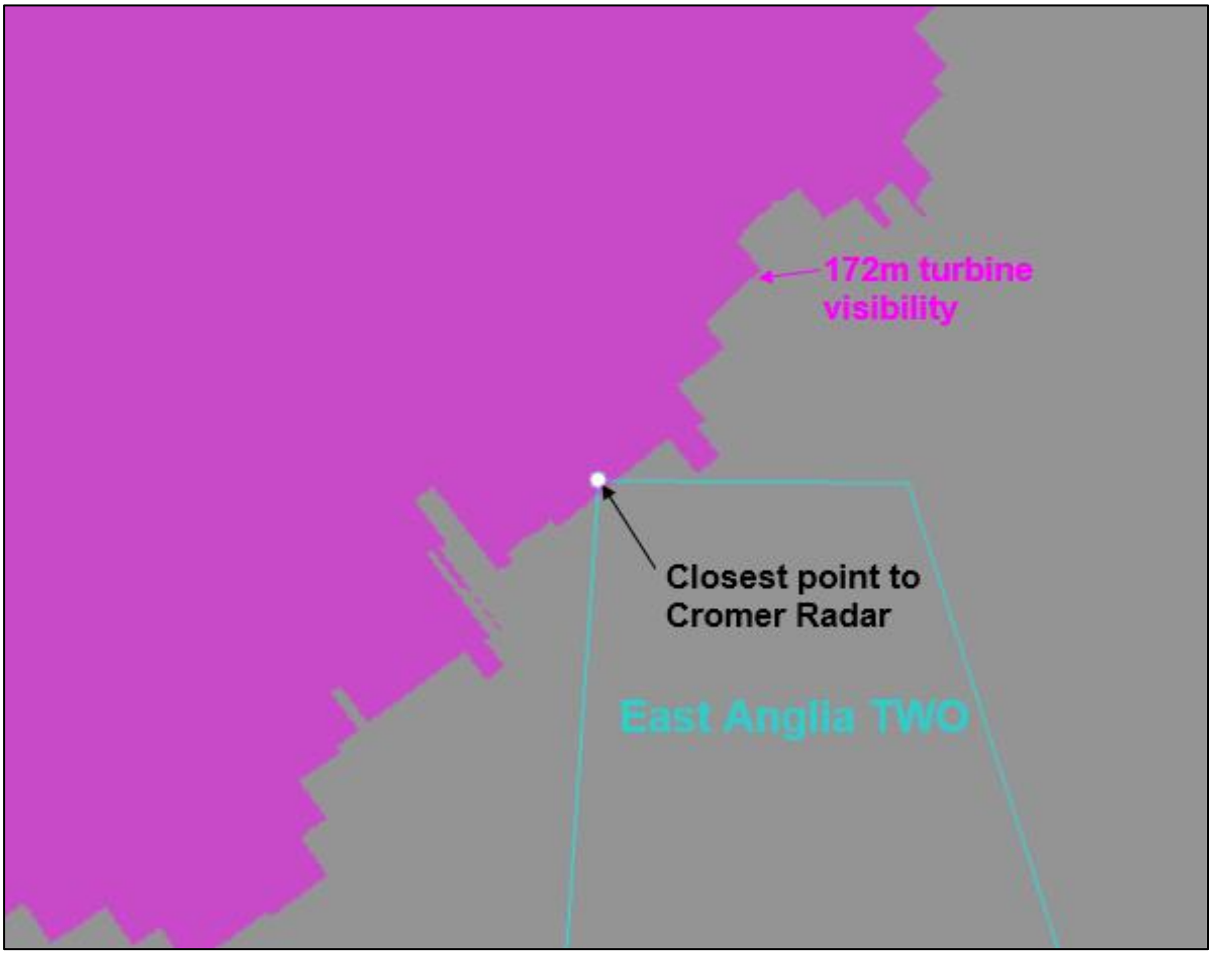

DiagramA15.1.28 Cromer radar visibility to 172m turbine – East Anglia TWO

106. The magenta shaded area in ***DiagramA15.1.28*** indicates the visibility of a 172m tip height turbine to Cromer radar. The East Anglia TWO windfarm site boundary is depicted by the cyan line.

15.8.4 Radar Probability of Detection

107. RLoS is only an indication as to whether the radar will ‘see’ a turbine. Depending on the radar configuration and the nature of the screening, the Probability of Detection (Pd) may be greater or less than the RLoS distance.

108. Pd may be calculated using a radio propagation model and the technical characteristics of the radar.

109. Cromer PSR is a Raytheon ASR-10SS. Parameters are taken from data published by Raytheon for a 16-Module radar.

110. Path loss calculations are made to a selection of turbines within the 244m and 300m indicative visualisation turbine layouts. Three parts of each turbine are

considered for the calculations, with the turbine blade pointing vertically: the turbine tip, the blade mid-point and the turbine nacelle. The calculations are made using the ITU526 propagation model.

15.8.4.1 244m Turbine Pd Modelling

111. The turbines and their associated location IDs selected for modelling are indicated in ***DiagramA15.1.29***. In order to establish the correlation between RLoS and Pd, the majority of turbine locations chosen are either within, or just beyond, RLoS from Cromer radar.

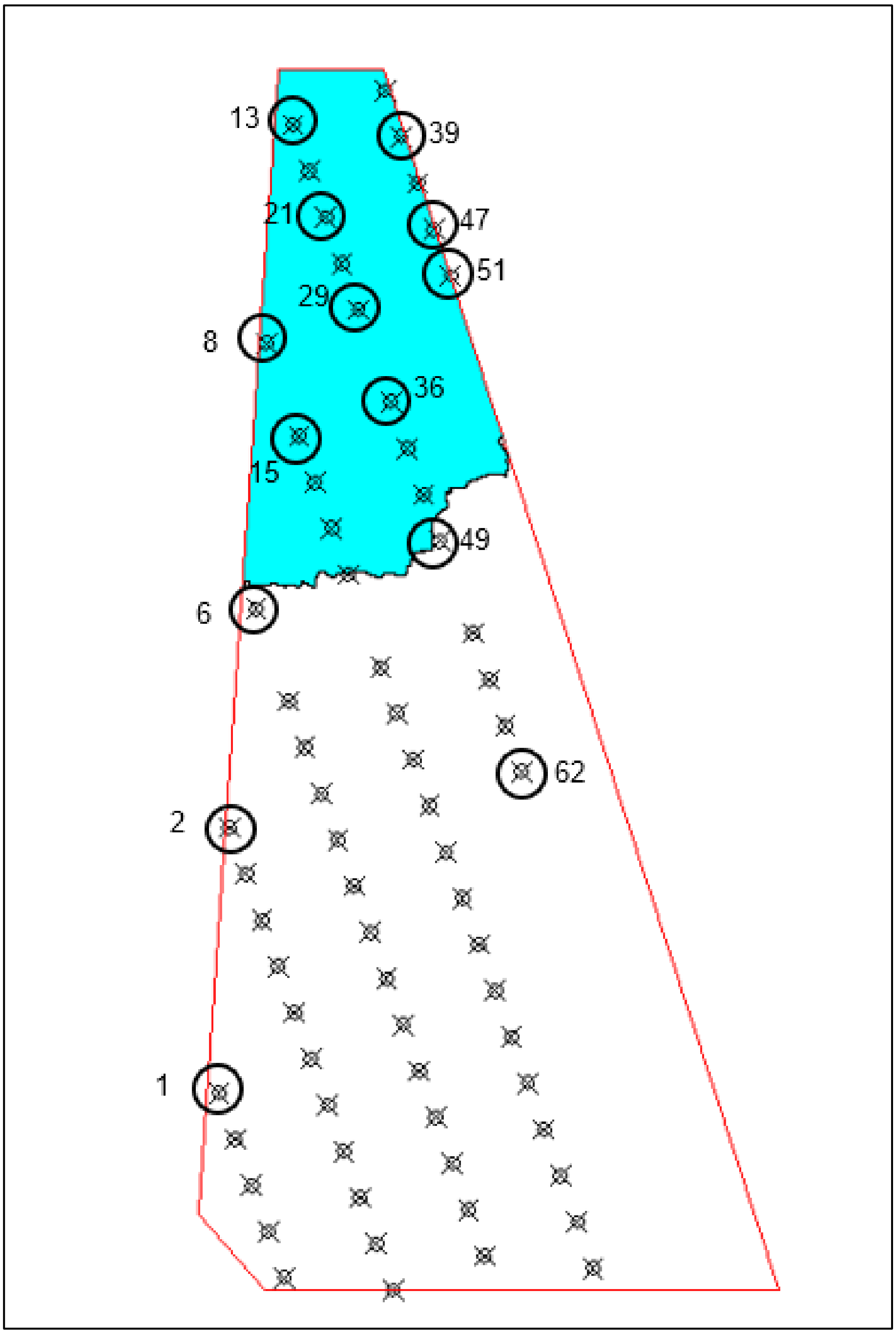

DiagramA15.1.29 244m turbine IDs selected for modelling

112. For each selected turbine location, the free space path loss from Cromer radar to the turbine together with the path loss to three points on the selected turbine was calculated. The results are presented in ***TableA15.1.3***.

TableA15.1.3 244m turbine path loss calculations

Cromer: Path Loss Calculations – 244m Max Tip Height				
Turbine ID	Equivalent Free Space path loss	Path loss to turbine tip	Path loss to blade mid-point	Path loss to turbine nacelle
	(dB)	(dB)	(dB)	(dB)
13	-139.9	-139.9	-157.7	-180.8
39	-140.1	-145.3	-168.1	-185.1
21	-140.1	-146.9	-167.2	-188.1
8	-140.3	-148.4	-171.4	-187.2
47	-140.4	-152.3	-173.1	-188.6
29	-140.4	-151.4	-173.8	-189.4
51	-140.5	-153.8	-176.8	-190.7
15	-140.5	-153.6	-176.4	-190.2
36	-140.7	-157.1	-179.2	-190.5
6	-140.8	-167.6	-186.0	-201.0
49	-141.0	-169.3	-184.8	-194.6
2	-141.2	-180.4	-196.4	-207.9
62	-141.4	-180.0	-191.3	-204.3
1	-141.7	-190.7	-203.8	-212.8

113. Path loss increases significantly for turbines located outside the cyan shaded area in ***DiagramA15.1.29*** depicting RLoS to 244m turbines (turbine IDs 6, 49, 2, 62, 1).

114. The amount of radar energy reflected will depend on the Radar Cross Section (RCS) of the turbine blade. For 110m turbine blades a nominal RCS of 120m^2 is used to determine the energy reflected from each of the three points on the turbine (tip, mid-point and nacelle).

115. Maximum on-axis antenna gain has been assumed, notwithstanding that the elevation angle from the radar to the turbine tips varies between -0.18° and -0.27°.

116. The parameters used for the Pd calculations are shown in ***DiagramA15.1.30***.

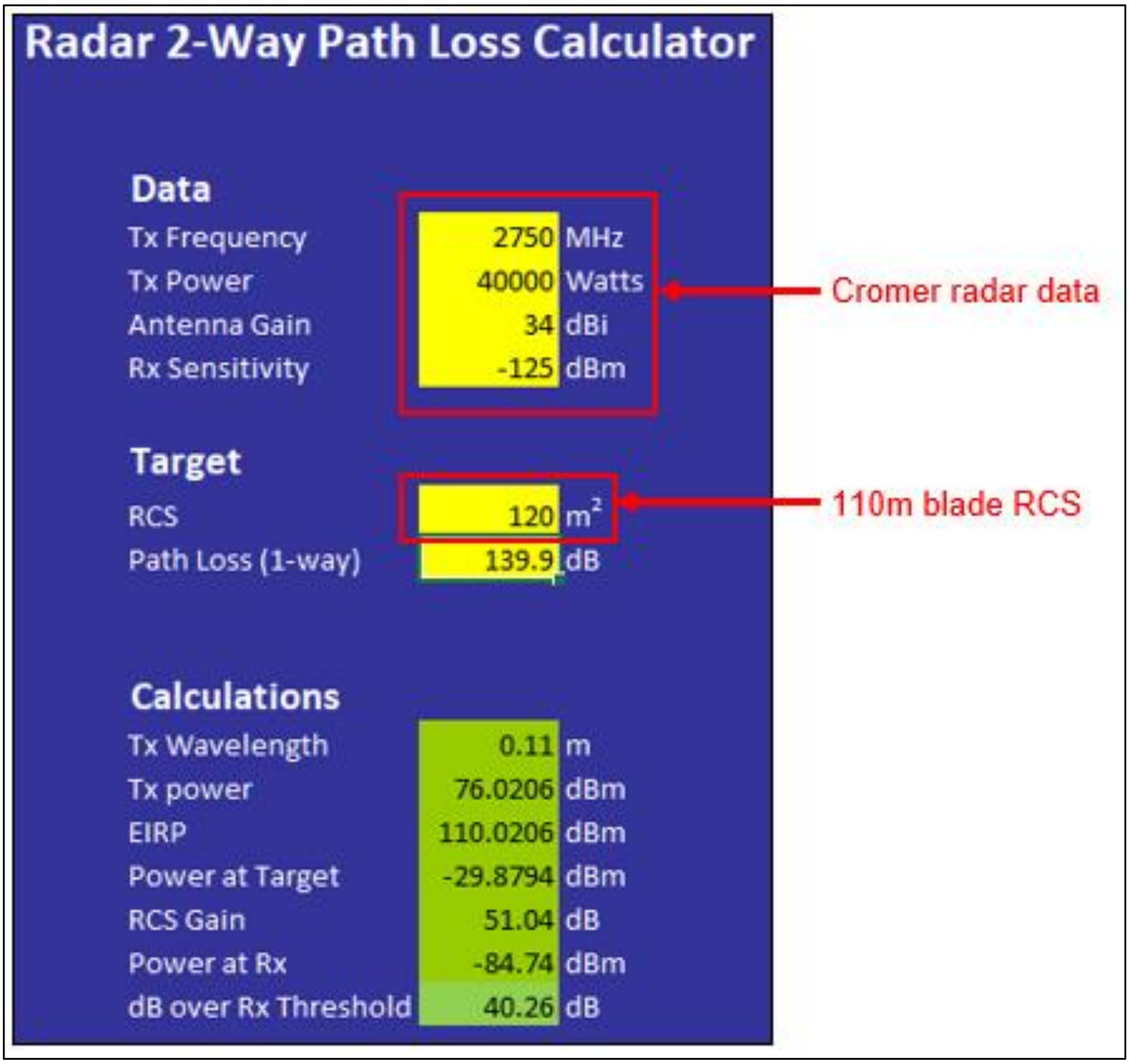

DiagramA15.1.30 Cromer radar Pd calculation for 244m turbines

117. The results of the Pd calculations for 244m turbines are presented in ***TableA15.1.4***.

TableA15.1.4 Cromer radar – 244m turbine Pd

Cromer: Probability of Detection – 244m Max Tip Height			
Turbine ID	Equivalent Free Space path loss	Path loss to turbine tip	dB over RX threshold RCS=120m²

Cromer: Probability of Detection – 244m Max Tip Height			
	(dB)	(dB)	(dB)
13	-139.9	-139.9	40.26
39	-140.1	-145.3	29.46
21	-140.1	-146.9	26.26
8	-140.3	-148.4	23.26
47	-140.4	-152.3	15.46
29	-140.4	-151.4	17.26
51	-140.5	-153.8	12.46
15	-140.5	-153.6	12.86
36	-140.7	-157.1	5.86
6	-140.8	-167.6	-15.14
49	-141.0	-169.3	-18.54
2	-141.2	-180.4	-40.74
62	-141.4	-180.0	-39.92
1	-141.7	-190.7	-61.33

118. The radar received signal level (dB over RX threshold) is colour coded to aid interpretation. Red is >-6dB below the receiver threshold and unlikely to be detected. Levels between -3dB and -6dB are shaded orange with a low probability of detection. Levels between -3dB and +3dB are shaded yellow with a possibility of detection. Levels above +3dB are shaded green, with a high probability of detection.

119. The results in ***TableA15.1.4*** represent worst-case, using maximum on-axis radar antenna gain, and indicate that turbines that are not in RLoS of Cromer radar are unlikely to be detected.

120. Cromer radar uses a modified Cosec^2 vertical antenna pattern which has reduced gain at low elevation angles to moderate the effects of ground clutter. The actual antenna gain at the turbine elevations (between -0.18° and -0.27°) is expected to be significantly lower than the on-axis gain.

121. If the antenna gain at -0.2° is assumed to be 10dB lower than the on-axis gain, then the Pd calculations may be revised as shown at ***TableA15.1.5***.

TableA15.1.5 Cromer radar – 244m turbine Pd with reduced antenna gain

Cromer: Probability of Detection – 244m Max Tip Height – Antenna gain reduced by 10dB			
Turbine ID	Equivalent Free Space path loss	Path loss to turbine tip	dB over RX threshold RCS=120m^2
	(dB)	(dB)	(dB)
13	-139.9	-139.9	20.26
39	-140.1	-145.3	9.46
21	-140.1	-146.9	6.26
8	-140.3	-148.4	3.26
47	-140.4	-152.3	-4.54
29	-140.4	-151.4	-2.74
51	-140.5	-153.8	-7.54
15	-140.5	-153.6	-7.14
36	-140.7	-157.1	-14.14
6	-140.8	-167.6	-35.14
49	-141.0	-169.3	-38.54
2	-141.2	-180.4	-60.74
62	-141.4	-180.0	-59.92
1	-141.7	-190.7	-81.33

122. With a 10dB reduction in antenna gain, Cromer radar is additionally unlikely to detect turbine IDs 51, 15 and 36 that are within RLoS of the radar.

123. The colour-coded results are illustrated in ***DiagramA15.1.31*** and suggest that all but the closest 10 of the 67 244m turbines are unlikely to be detected by Cromer radar.

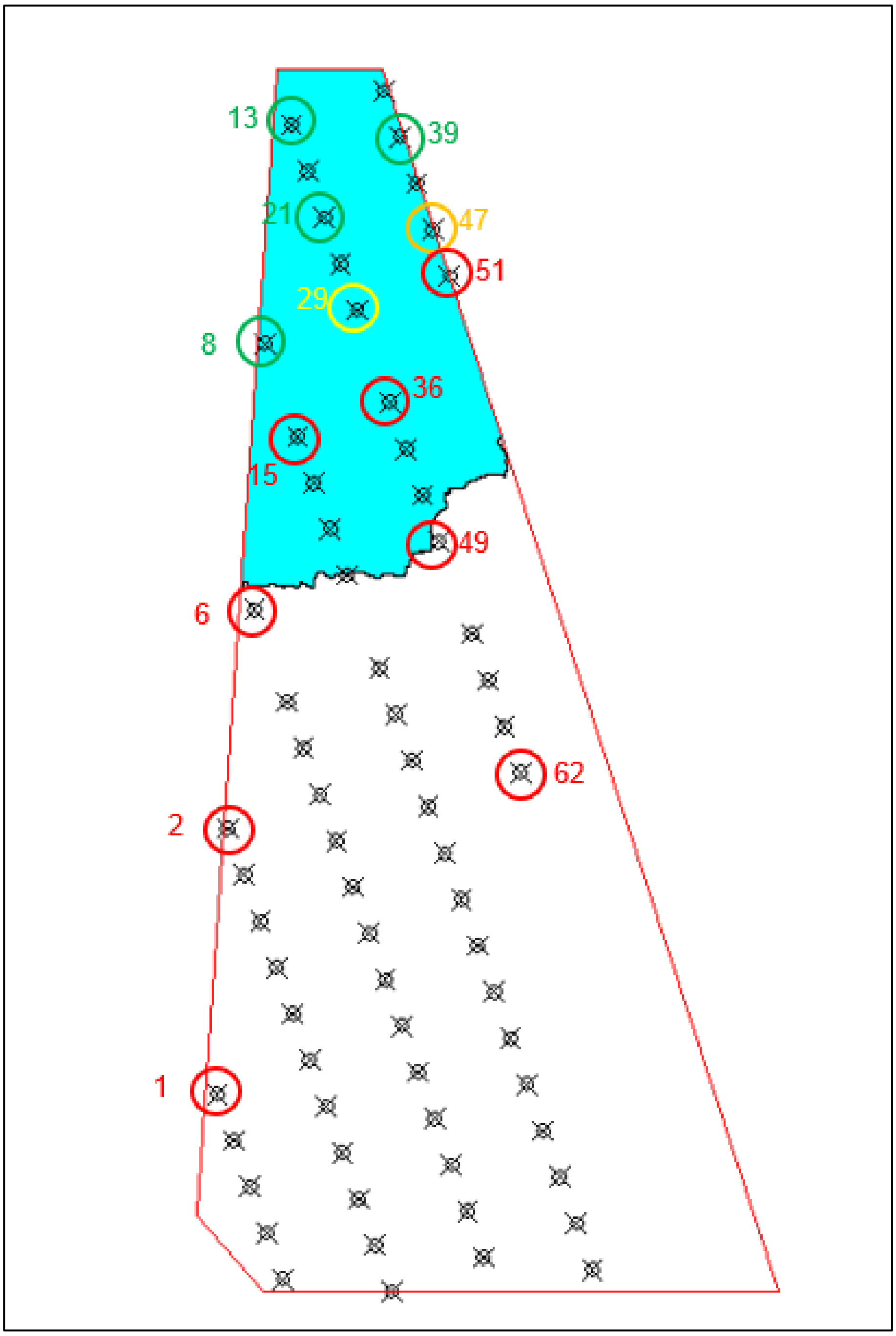

DiagramA15.1.31 Cromer radar Pd of 244m turbines with reduced antenna gain

124. The radar operating authority will be able to confirm the actual antenna gain at an elevation of -0.2°.

15.8.4.2 300m Turbine Pd Modelling

125. The turbines and their associated location IDs selected for modelling are indicated in ***DiagramA15.1.32***. To establish the correlation between RLoS and Pd, the majority of turbine locations chosen are either within, or just beyond, RLoS from Cromer radar.

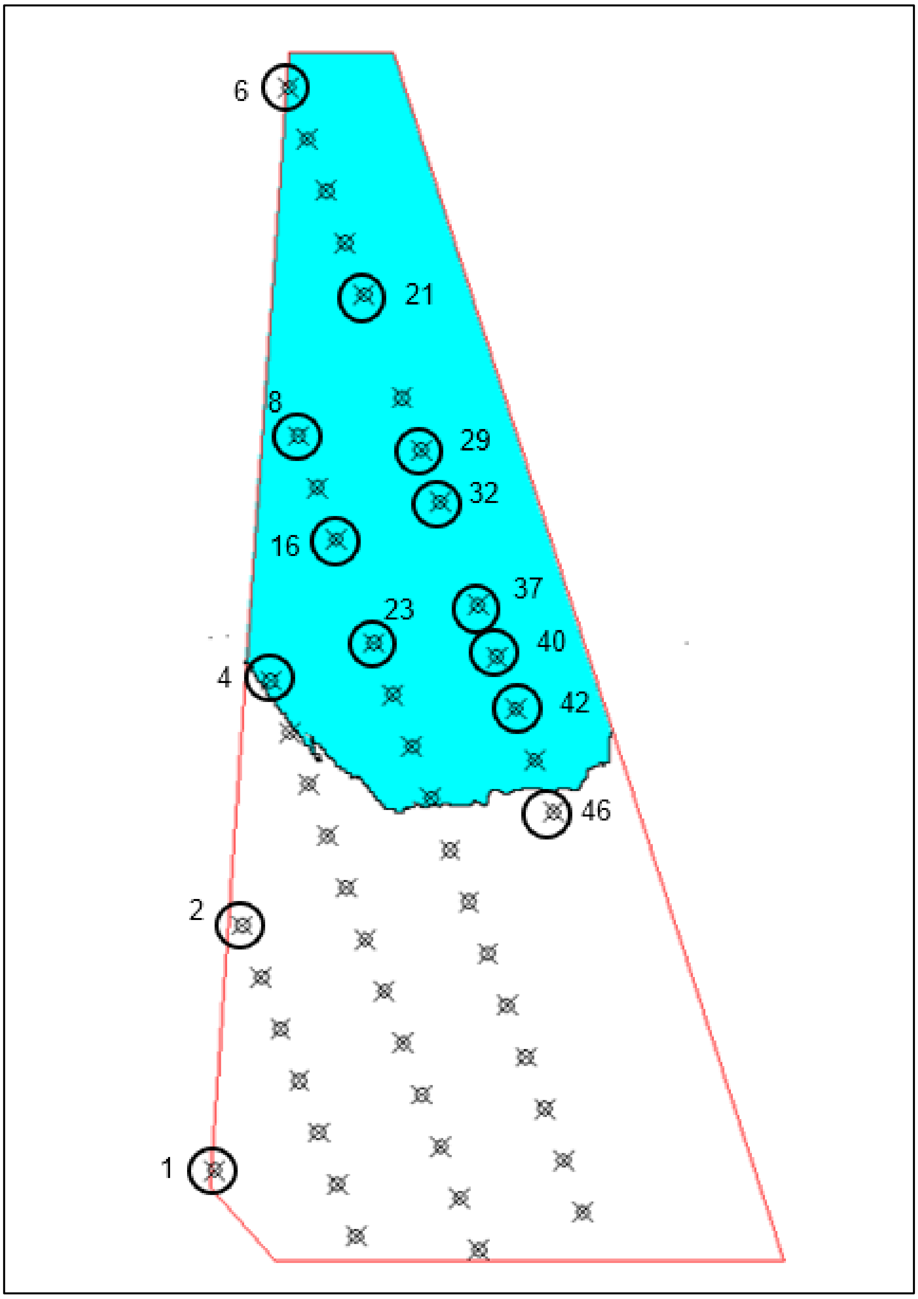

DiagramA15.1.32 300m turbine IDs selected for modelling

126. For each turbine location, the free space path loss from Cromer radar to the turbine together with the path loss to three points on the selected turbine was calculated. The results are presented in ***TableA15.1.6***.

TableA15.1.6 300m turbine path loss calculations

Cromer: Path Loss Calculations – 300m Max Tip Height				
Turbine ID	Equivalent Free Space path loss	Path loss to turbine tip	Path loss to blade mid-point	Path loss to turbine nacelle
	(dB)	(dB)	(dB)	(dB)
6	-139.9	-139.9	-140.0	-166.0
21	-140.4	-140.4	-153.4	-177.4
8	-140.6	-141.3	-156.4	-179.0
29	-140.8	-144.4	-161.6	-182.5
16	-140.8	-146.3	-169.4	-186.5
32	-140.9	-147.7	-170.3	-187.2
4	-141.0	-164.1	-175.1	-197.1
23	-141.1	-154.1	-176.1	-191.6
37	-141.1	-152.0	-175.4	-190.3
40	-141.3	-155.8	-178.6	-192.2
42	-141.3	-158.8	-180.8	-193.7
2	-141.4	-169.6	-183.5	-200.8
46	-141.5	-169.8	-186.2	-198.3
1	-141.8	-179.3	-197.4	-209.3

127. Path loss increases significantly for turbines either at the edge of, or located outside, the cyan shaded area in ***DiagramA15.1.32*** depicting RLoS to 300m turbines (turbine IDs 4, 2, 46, 1).

128. The amount of radar energy reflected will depend on the RCS of the turbine blade. For 125m turbine blades a nominal RCS of 140m^2 is used to determine the energy reflected from each of the three points on the turbine (tip, mid-point and nacelle).

129. Maximum on-axis antenna gain has been assumed, notwithstanding that the elevation angle from the radar to the turbine tips varies between -0.14° and -0.25°.

130. The parameters used for the Pd calculations are shown in ***DiagramA15.1.33***.

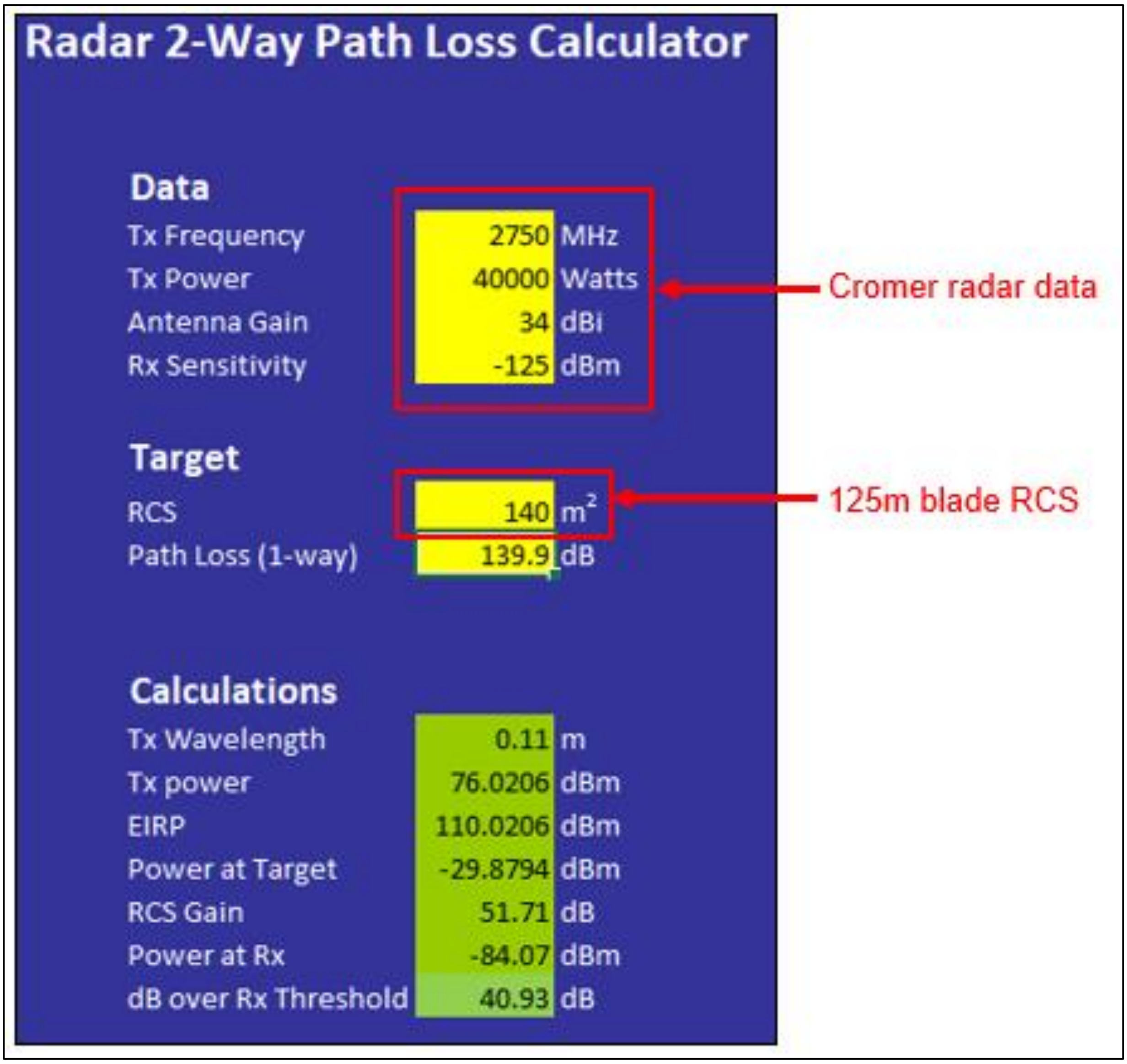

DiagramA15.1.33 Cromer radar Pd calculation for 300m turbines

131. The results of the Pd calculations for 300m turbines are presented in ***TableA15.1.7***.

TableA15.1.7 Cromer radar – 300m turbine Pd

Cromer: Probability of Detection – 300m Max Tip Height			
Turbine ID	Equivalent Free Space path loss	Path loss to turbine tip	dB over RX threshold RCS=120m^2
	(dB)	(dB)	(dB)
6	-139.9	-139.9	43.84
21	-140.4	-140.4	39.94

Cromer: Probability of Detection – 300m Max Tip Height			
8	-140.6	-141.3	38.13
29	-140.8	-144.4	31.93
16	-140.8	-146.3	28.13
32	-140.9	-147.7	25.33
4	-141.0	-164.1	-7.45
23	-141.1	-154.1	12.53
37	-141.1	-152.0	16.73
40	-141.3	-155.8	9.13
42	-141.3	-158.8	3.13
2	-141.4	-169.6	-18.47
46	-141.5	-169.8	-18.87
1	-141.8	-179.3	-37.87

132. The radar received signal level (dB over RX threshold) is colour coded to aid interpretation. Red is >-6dB below the receiver threshold and unlikely to be detected. Levels between -3dB and -6dB are shaded orange with a low probability of detection. Levels between -3dB and +3dB are shaded yellow with a possibility of detection. Levels above +3dB are shaded green, with a high probability of detection.

133. The results in ***TableA15.1.7*** represent worst-case, using maximum on-axis radar antenna gain, and indicate that turbines that are at or below RLoS of Cromer radar are unlikely to be detected.

134. Cromer radar uses a modified Cosec^2 vertical antenna pattern which has reduced gain at low elevation angles to moderate the effects of ground clutter. The actual antenna gain at the turbine elevations (between -0.14° and -0.25°) is expected to be significantly lower than the on-axis gain.

135. If the antenna gain at -0.2° is assumed to be 10dB lower than the on-axis gain, then the Pd calculations may be revised as shown at ***TableA15.1.8***.

TableA15.1.8 Cromer radar – 300m turbine Pd with reduced antenna gain

Cromer: Probability of Detection – 300m Max Tip Height – Antenna gain reduced by 10dB			
Turbine ID	Equivalent Free Space path loss	Path loss to turbine tip	dB over RX threshold RCS=120m^2

Cromer: Probability of Detection – 300m Max Tip Height – Antenna gain reduced by 10dB			
	(dB)	(dB)	(dB)
6	-139.9	-139.9	23.84
21	-140.4	-140.4	19.94
8	-140.6	-141.3	18.13
29	-140.8	-144.4	11.93
16	-140.8	-146.3	8.13
32	-140.9	-147.7	5.33
4	-141.0	-164.1	-27.45
23	-141.1	-154.1	-7.47
37	-141.1	-152.0	-3.27
40	-141.3	-155.8	-10.87
42	-141.3	-158.8	-16.87
2	-141.4	-169.6	-38.47
46	-141.5	-169.8	-38.87
1	-141.8	-179.3	-57.87

136. With a 10dB reduction in antenna gain, Cromer radar is additionally unlikely to detect turbine IDs 23, 40 and 42 that are within RLoS of the radar.

137. The colour-coded results are illustrated in ***DiagramA15.1.34*** and suggest that all but the closest 12 of the 48 300m turbines are unlikely to be detected by Cromer radar.

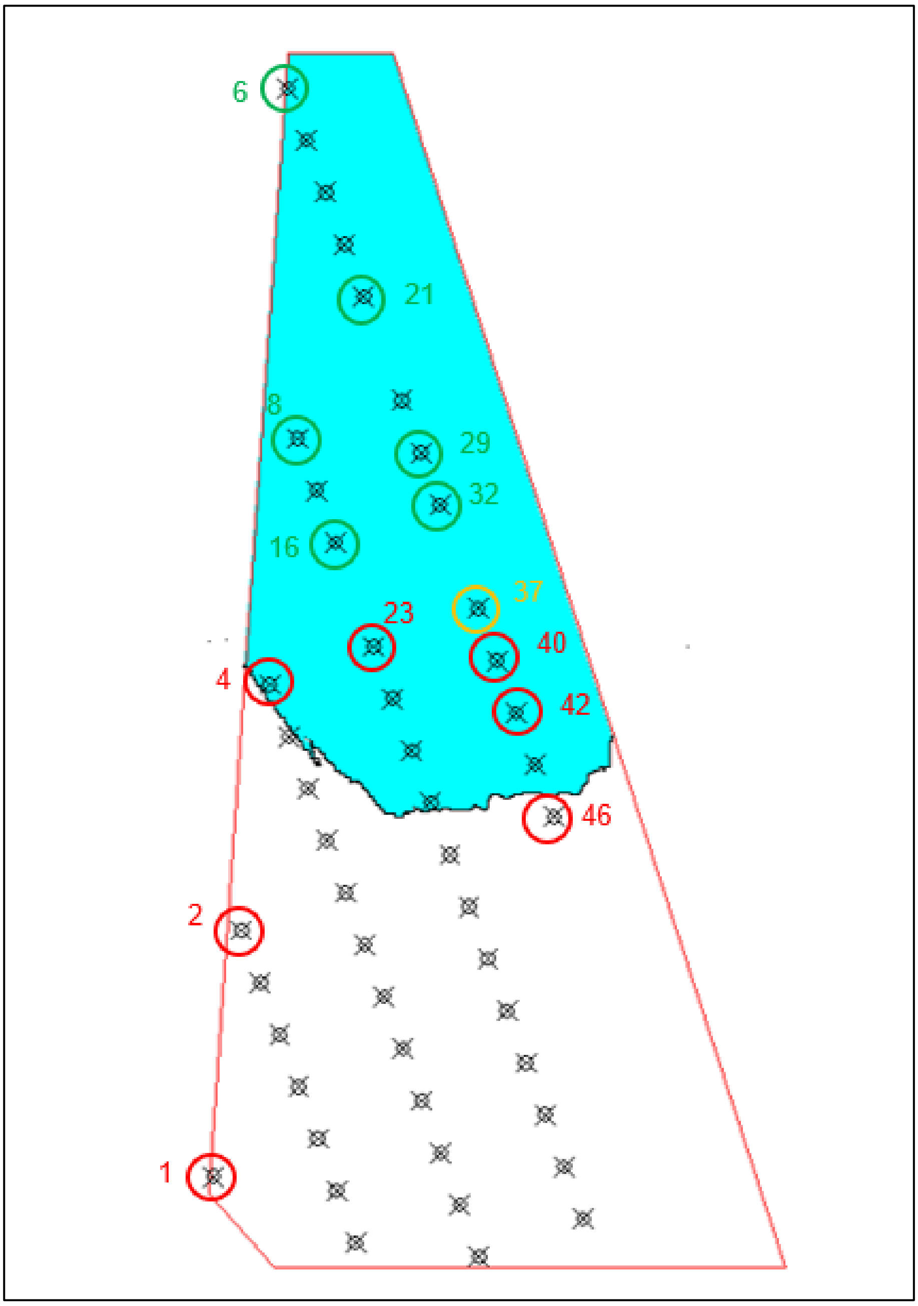

DiagramA15.1.34Cromer radar Pd of 300m turbines with reduced antenna gain

138. The radar operating authority will be able to confirm the actual antenna gain at an elevation of -0.2°.

15.8.5 Potential Mitigation Options

139. Probability of detection calculations indicate that Cromer radar will not detect 57 of the 67 turbines in the 244m turbine indicative visualisation layout,

provided that the antenna gain at the turbine elevation angles is at least 10dB lower than the maximum on-axis gain. This is depicted in ***DiagramA15.1.35***.

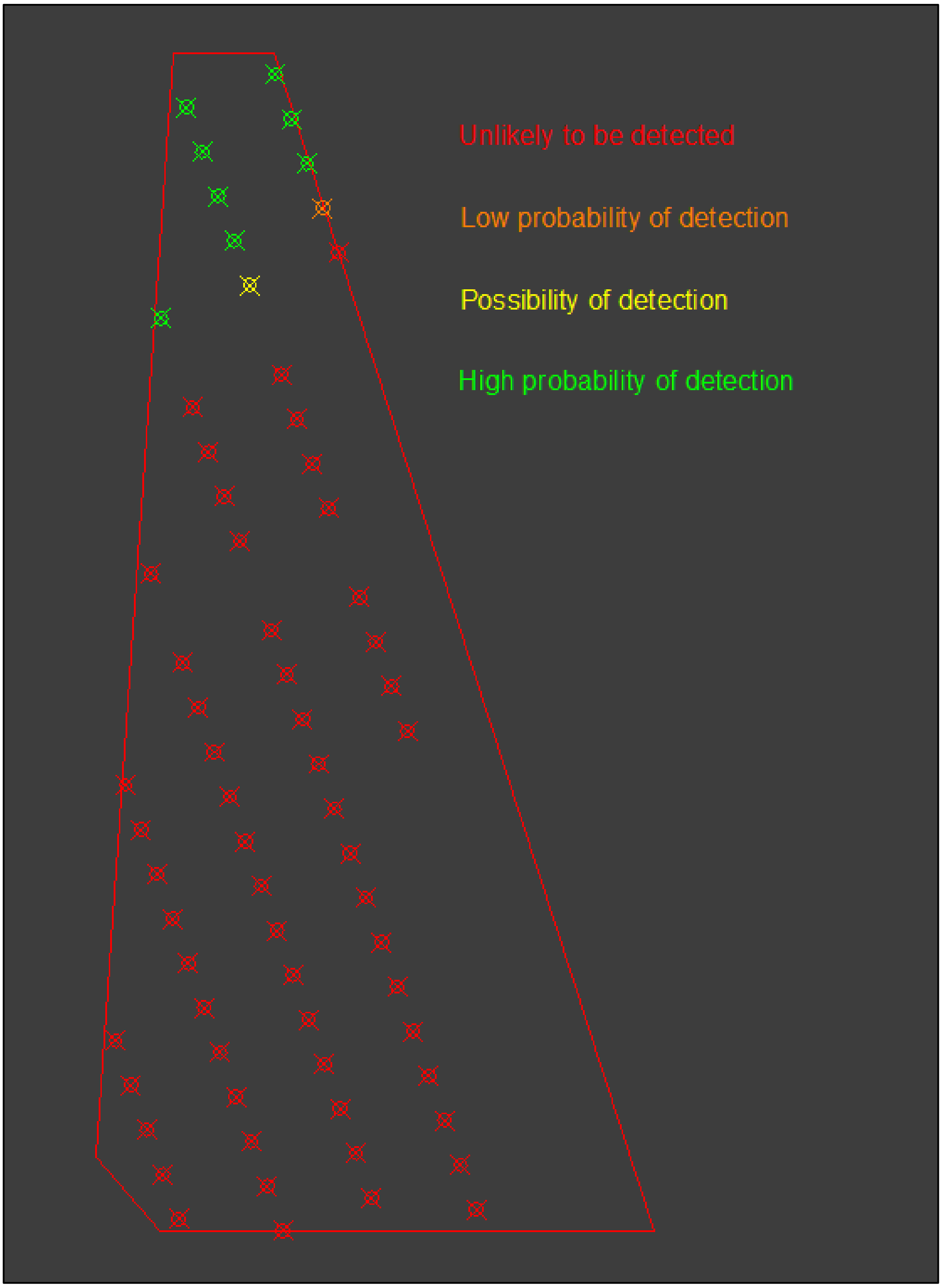

DiagramA15.1.35 Cromer radar – 57 of 67 244m turbines unlikely to be detected

140. Probability of detection calculations indicate that Cromer radar will not detect 36 of the 48 turbines in the 300m turbine indicative visualisation layout, provided that the antenna gain at the turbine elevation angles is at least 10dB lower than the maximum on-axis gain. This is depicted in ***DiagramA15.1.36***.

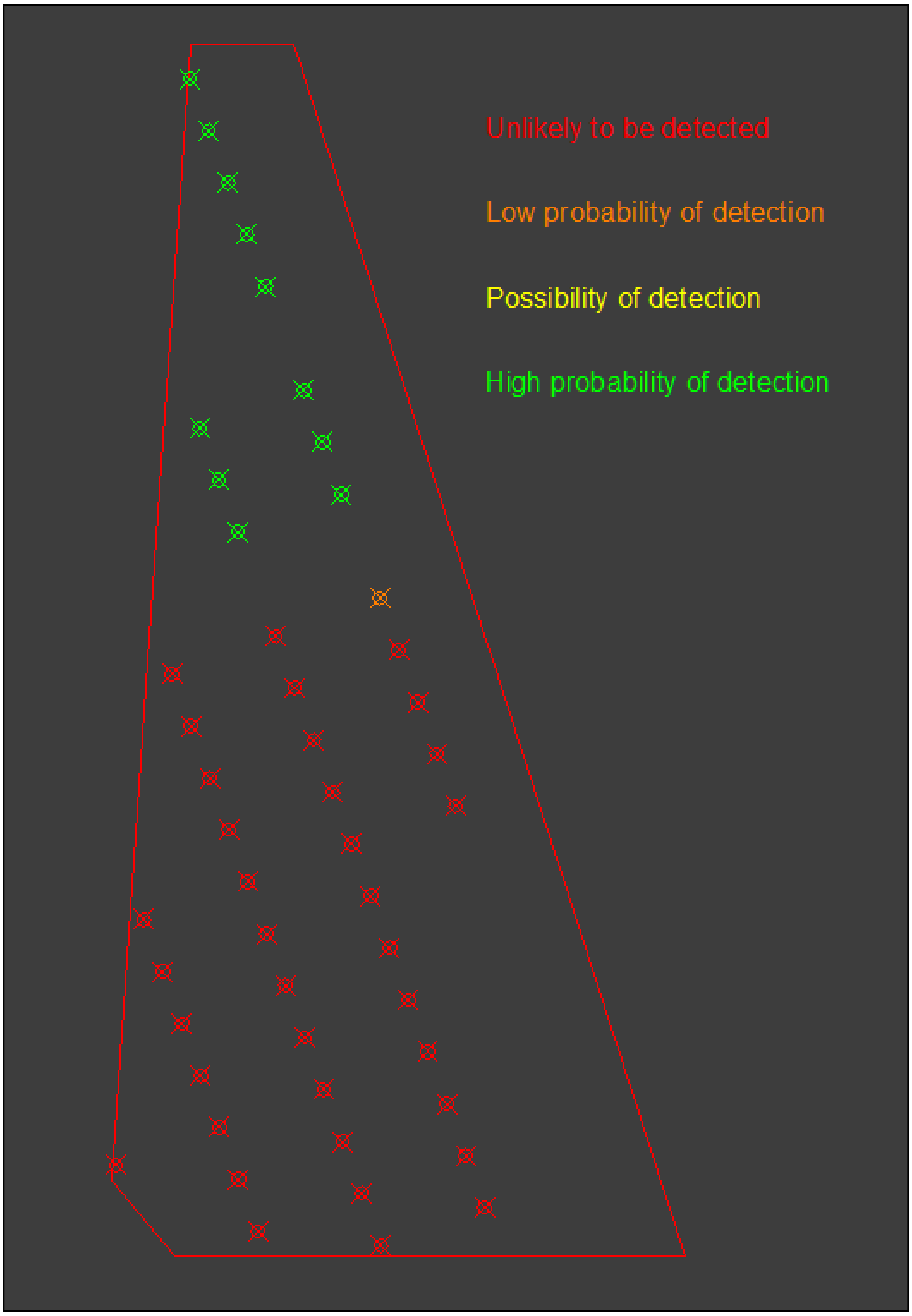

DiagramA15.1.36 Cromer radar – 36 of 48 300m turbines unlikely to be detected

141. Possible mitigation options for turbines that are detected by Cromer radar include blanking of the radar in the impacted area, blanking combined with infill from an alternative radar feed, or blanking combined with the imposition of a Transponder Mandatory Zone (TMZ).

142. The following paragraphs examine the alternative radar feeds which may be available to NATS in the vicinity of the East Anglia TWO windfarm site. The alternative radar sources investigated are NATS Claxby radar and NATS Debden radar.

143. Claxby radar has RLoS cover down to 7000 feet amsl above the East Anglia TWO windfarm site. The East Anglia TWO windfarm site lies between 112NM and 127NM from Claxby radar.

144. Claxby RLoS coverage in a sector encompassing the East Anglia TWO windfarm site boundary is depicted in ***DiagramA15.1.37***.

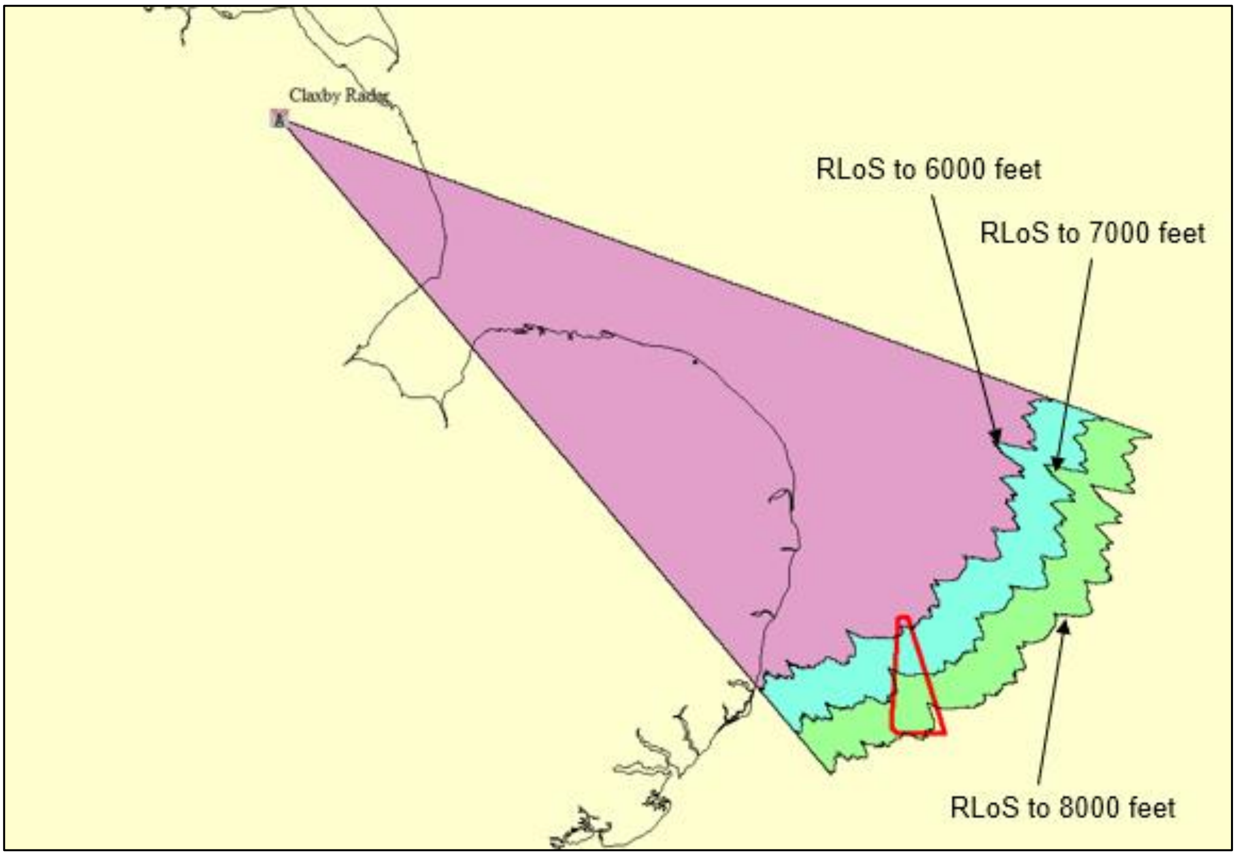

DiagramA15.1.37 Claxby radar RLoS coverage to 6000 feet, 7000 feet and 8000 feet

145. Debden radar has RLoS cover down to 3000 feet amsl above the East Anglia TWO windfarm site. The East Anglia TWO site lies between 69NM and 76NM from Debden radar.

146. Debden RLoS coverage in a sector encompassing the East Anglia TWO windfarm site boundary is depicted in ***DiagramA15.1.38***.

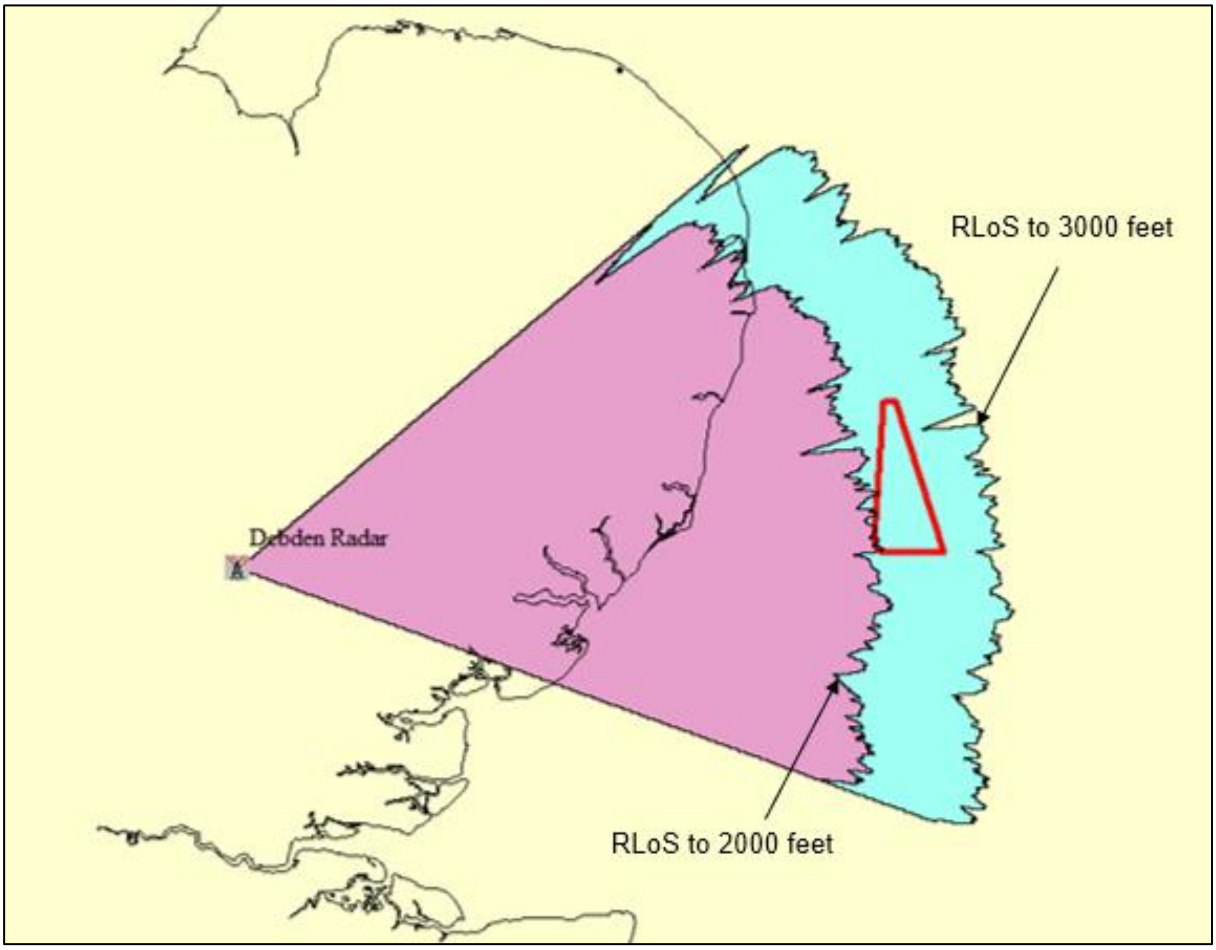

DiagramA15.1.38 Debden radar RLoS coverage to 2000 feet and 3000 feet

147. ***DiagramA15.1.37*** and ***DiagramA15.1.38*** illustrate the level of radar cover from Claxby and Debden radars should they be used for infill mitigation of Cromer radar.

148. Alternatively, a feed from the Aveillant Theia radar, discussed in ***section 15.7.5***, could be provided to NATS.