HEALD TOP FARM

NATS MANCHESTER APPROACH RADAR - ATC RADAR IMPACT ASSESSMENT

prepared by

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Contents

Abbreviations/Explanations

agl	above ground level
AIAA	Area of Intense Air Activity
amsl	above mean sea
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATS	Air Traffic Service
BCL	Buccaneer Consulting Limited (author of this Report)
BERR	(UK Govt Dept) Business, Enterprise & Regulatory Reform
CAA	Civil Aviation Authority
dB	Decibels – usual unit in measuring radar parameters
DTI	(UK Govt) Dept of Trade & Industry
Eurocontrol	European Organisation for the Safety of Air Navigation
ft	feet
Gain	Measure of antenna's ability to focus the electromagnetic energy
Gr/Gt	Gain of receiver/Gain of transmitter – for radar with 2 antennas
ha	hectare
ICAO	International Civil Aviation Organisation (a UN body that Promotes understanding, security and flight safety through cooperative regulation)
IFR	Instrument Flight Rules (simply, rules for flying in poor weather)
kg	kilograms
Km	kilometre
kts	Knots – nautical miles per hour. About 1.2 statute mph, 1.9kph
LARS	Lower Airspace Radar Service. Radar Advisory Service provided to aircraft flying at lower altitudes outside controlled airspace to assist with aircraft navigation and separation from other aircraft
LOS	Line of Sight
LPA	Local Planning Authority
m	metres
MDS	Minimum Discernible Signal, the sensitivity of a radar
MoD	Ministry of Defence
mph	Miles per hour
MTD	Moving Target Detector – improved MTI processing
MTI	Moving Target Indicator – radar processing to identify targets that have a velocity component
NATS	National Air Traffic Service
Pr	Power received back at radar after reflection from a target
PSR	Primary Surveillance Radar, a traditional type of radar
Pt	Power transmitted by radar
QinetiQ	Formerly the Defence Evaluation & Research Agency
RCS/ σ	Radar Cross Section – roughly equivalent to the reflecting area
RAF	Royal Air Force
SARPs	Standards and Recommended Practices
sq	square
SSR	Secondary Surveillance Radar – a cooperative beacon radar system
TMA	Terminal Manoeuvring Area - used by an airport to control inbound/outbound aircraft
VFR	Visual Flight Rules (simply, flying in clear weather)
VRP	Visual Reporting Point – landmark used for reporting aircraft position to ATC
λ	Wavelength
Watchman	The model of ATC PSR used by the MoD

Figures

EXECUTIVE SUMMARY

1. INTRODUCTION

The Civil Aviation Authority (CAA)/Eurocontrol methodology is used to analyse the impact of the turbine on the NATS radar. This analysis concludes that the Heald Top Farm turbine will not be detected by, poses no hazard to and will have no impact on the NATS Air Traffic Control (ATC) radar.

2. CIVIL AVIATION PUBLICATIONS

The relevant publication (CAP 764) is neither definitive about the impact nor is it concerned with single, small turbines. The CAA and the MoD (authors of an associated publication) refer to the problem being the blades of turbines in a wind farm. There are no CAA-published hazard reports or other published evidence of single, small turbines affecting radars or ATC operations - in the UK or elsewhere.

3. TURBINE LOCATION

At 43km the turbine is beyond the required consultation distance for an airport, away from Manchester's operational areas/routes and well below the Manchester TMA.

4. NATS OBJECTION

The NATS objection offers no evidence of any impact from this turbine despite referring to a 'result' in its Report. As presented the NATS objection is not valid but the Assessment does consider other published NATS:turbine issues.

5. EVIDENCE USED IN THIS ANALYSIS

This Analysis uses the most up-to-date and comprehensive evidence/references. This work has been conducted by the MoD, the CAA and QinetiQ, and by equivalent US/European Government agencies and research companies/organisations.

6. RADAR – WIND TURBINE TRIALS

All the published Trials undertaken into the perceived problem have been undertaken with large turbines (up to 4 x this one's size) and with large turbines in wind farms. There have been no trials - even that with which NATS was involved - conducted against nor have any of those trials undertaken drawn any results or conclusions for any potential impact of a single, small turbine.

All the international evidence indicates that single, small turbines located a short distance from an ATC radar will have no impact. As a result, international safeguarding criteria (exc the UK) are that small turbines beyond 20km are of no concern. The NATS desired safeguarding criteria are unnecessarily stringent.

7. LINE OF SIGHT

The turbine is line of sight to the radar but that dos not mean it will be detected. At its very low elevation some of the turbine is 'hidden' and this reduces the 'amount' that may reflect radar energy back. Low elevations are very significant for ATC radars and are discussed in Section 8.

8. ATC RADARS

ATC radars, like torches, are designed to focus their energy in the direction of likely targets and those targets, except at very short ranges of a few km, will be at several ‘000 ft. This design helps the radars to avoid unwanted reflections from the ground and from objects on and very close to the ground (called ‘clutter’) – like this turbine.

9. NATS MANCHESTER APPROACH ATC RADAR

NATS and Raytheon declined to provide details of the radar. So the parameters of the radar are deduced by comparison with similar radars. As all ATC radars are required to perform to international specifications and standards the assumptions/deductions made can be considered valid. This radar is very similar to many other modern ATC radars - like those described in Section 8 - for which data is available.

10. RADAR ‘PERFORMANCE’ CALCULATION

Using those radar parameters/data, a calculation can be made using the standard radar range equation (as used by NATS) to determine whether the turbine will be detected. The result is that at its very low elevation it will ‘reflect’ insufficient energy back to the radar for detection.

11. OTHER RADAR CONSIDERATIONS

The CAA considers that turbines might appear to the radar just as a large static return – clutter. Yet there are other much larger objects closer to the radar, terrain at the turbine site and other turbines not too far away that have not generated objections, suggesting that the radar’s capability at low elevations and its processing will both avoid and ‘neutralise’ clutter.

One of the processing techniques (the MoD refers to it as the *“most important”*) means that the radar automatically ‘desensitises’ itself in significant terrain clutter – like the hill on which the turbine will sit and other nearby terrain. As the turbine is in a hilly area and with other obstacles nearby the radar is likely to be desensitised enough so that it will not detect the turbine.

12. <u>OTHER AIR TRAFFIC CONTROL CONSIDERATIONS</u>

Closely spaced large turbines might well create a radar shadow but any shadow from a single, small turbine will be no different to that from a mobile phone mast or factory chimney. Simple geometry indicates and research shows that the shadow region from a small turbine is virtually non-existent.

There are radar operators which state that single turbines "*are unable to mimic the effects of a moving aircraft"*. Moreover, false targets are a day-to-day feature of ATC operations – eg microlight aircraft and gliders. The area of the turbine is a popular hang gliding site and the turbine will add nothing of any significance to NATS' false target rate.

The turbine is located well away from the airport, and clear of and well below any of Manchester's standard inbound/outbound routes. Real targets will always have a gain advantage over the turbine as they will always be in the peak of the radar beam - they will be detected.

NATS is concerned that a large wind farm will create significant clutter and might mask real aircraft returns, but that is not possible from a single, small turbine. Also, the turbine will be in an area already desensitised by terrain and will be even less likely to be detected.

Because the turbine is in the area of least radar 'brightness' (= gain = performance) while real aircraft will be in the peak of the beam, those real targets will always have an advantage over a single, small turbine and will always be detected.

As a modern radar, the NATS system uses many techniques to distinguish real aircraft from ground clutter – inc switching between beams to ensure real aircraft at operating altitudes are always detected 'over' ground clutter.

Individual small turbines cannot possibly generate turbine interactions like those seen and expected in wind farms/radar trials. There will be no false targets.

13. NATS TURBINE IMPACTS - ASSESSMENT CONCLUSIONS SUMMARISED

NATS concerns about the effects of turbines are re-visited and referenced to the evidence-based conclusions made in this Assessment. None of NATS concerns apply to a single, small turbine as it is most unlikely to be seen by the radar, and real targets will always have a significant gain advantage as they will be in the peak of the radar beam.

14. SUMMARY

Large turbines and multiples of them in wind farms may cause problems to ATC radars. However, there is no published evidence of single, small turbines generating any ill-effects - no adverse safety reports have been published by the CAA or anyone else.

14.1 Turbine Will Not Be Detected

The calculation is that the turbine will not be detected by the NATS radar at all and it cannot, therefore, produce any of the untoward effects anticipated. The radar will not be desensitised, false targets will not be generated and real aircraft will always be seen.

14.2 Trials Evidence Inferred by NATS Is Not Relevant to Single, Small Turbines

The objection and other NATS documents refer to the effects from Trials but those Trials were conducted solely against large turbines and wind farms of multiple turbines. Even a very recent NATS/Raytheon trial using the same radar as Manchester took place only against very large wind farms of very large turbines. The Trials do not show nor do they infer any effects from a single, small turbine.

14.3 No or Negligible Operational Impacts

In the extremely unlikely event that the turbine is detected it will pose no hazard to NATS operations at Manchester and will have no safeguarding implications.

- A single turbine is not a wind farm - it cannot generate false targets.

- The radar is new with modern software – the turbine will not show.

- The radar is designed to avoid low levels and its performance at and close to the horizon is significantly and deliberately degraded to avoid low level clutter – the turbine will not show.

- The turbine will be ‘in’ uncontrolled airspace and if detected at all, it will be handled as a transitory ‘target’ similar to those handled routinely in day-to-day ATC operations.

HEALD TOP FARM TURBINE – NATS ATC RADAR IMPACT ASSESSMENT

1. INTRODUCTION

Heald Top Farm proposes to erect a small 22m wind turbine (Rossendale BC ref 2012/0387, NATS ref 15745) but has received an objection from the UK National Air Traffic Services (NATS) for its Manchester Approach Control radar. This Report is to inform the planning decision making process and analyses the potential impact for a single, small turbine on the NATS radar.

The analysis is conducted in accordance with the methodology and data in Civil Aviation Authority (the CAA is the UK's specialist aviation regulator) publication CAP764 'CAA Policy & Guidance on Wind Turbines' (1). The methodology described in the 'Eurocontrol Guidelines on How to Assess the Impact of Wind Turbines on Surveillance Sensors' (2) is also used - Eurocontrol is the European Organisation for the Safety of Air Navigation.

The Report and analysis includes more basic information/explanations than required by radar specialists so that it can be understood by non-specialists. The analysis also covers non-radar Air Traffic considerations for completeness.

The methodology, logic and calculations have been accepted by other radar operators which have subsequently withdrawn their objections or not questioned/challenged the analysis (3a, b & c).

Note: The type of radar considered in this Report is properly called a PSR – Primary Surveillance Radar - to distinguish it from other radar types used by Air Traffic Control (ATC). For ease of understanding, though, in this Report the term 'ATC radar' will be used, while the specific term 'Manchester Approach radar' will be shortened to just 'Manchester radar'.

1.1 Assessment Conclusion

The results of the analysis demonstrate that, contrary to the objection (4) and associated TOPA (Technical & Operational Assessment) (5) the turbine will not be detected by, poses no hazard to and will have no impact on the NATS Manchester Approach Control radar.

1. CAA. 'CAP 764 – CAA Policy and Guidance on Wind Turbines'
2. Eurocontrol. 'Eurocontrol Guidelines on How to Assess the Impact of Wind Turbines on Surveillance Sensors'
3a. Northumberland CC Planning ref 12/00710/FUL, Camp House Whalton & Newcastle International Airport
3b. Northumberland CC Planning ref: 12/02032/RENE, Greenside Farm, Hartburn & Newcastle International Airport
3c. Mendip DC ref 2012/1158, MoD DIO ref 17113
4. NATS. E-mail NATS Safeguarding (Sarah J Allen), 2 Oct 2012
5. NATS. TOPA Heald Cross Farm Windfarm Development, Issue 1 NATS ref W(F)15745

2. CIVIL AVIATION PUBLICATIONS

2.1 CAA

The CAA publication CAP 764 [1] states:

*"The development of sites for wind turbines **has the potential** to cause a variety of negative effects on aviation. These include (but are not limited to): physical obstructions; the generation of unwanted returns on Primary Surveillance Radar (PSR); adverse affects on the overall performance of CNS equipment; and turbulence. Whilst it is generally the larger, commercial turbines that have the greatest impact on aviation, the installation of other equipment may also affect operations. Smaller turbines, and the preliminary activities for larger turbines (such as the erection of anemometer masts on potential development sites), **could have** a negative impact on aviation and so require assessment. Moreover, the cumulative effects of wind turbines on aviation need to be assessed if developments proliferate in specific areas."* [1 Ch 2, page 1, para 1.1] (BCL bold)

The CAA is also not definite about the effects stating only that radar returns from the blades *"**may** appear as aircraft on the display."* [1 Ch 2 page 2 para 2.3a] (BCL bold).

It is important to note that the CAA considers the problem to be "*generally the larger, commercial turbines that have the greatest impact on aviation"* [1 Chapter 2 page 1 para 1.1]. This is reinforced by many CAA comments on *"turbines"* (plural) in the section 'False Radar Returns (Clutter)' inc:

"*position of the wind turbines within a development"* [1 Ch2 page 2 para 2.3a]

"wind turbines may also increase the number of false targets" [1 Ch2 page 2 para 2.3a]

"The proportion of the volume behind the turbines that is shadowed depends on a number of factors such as the number of turbines, size of the turbines and their geographical distribution" [1 Ch2 page 3 para 2.3d]

"If the wind turbines are within radar LOS and aircraft are required to be detected at longer range behind the wind turbines" [1 Ch2 page 4 para 3.1b]. (LOS is Line of Sight)

2.2 NATS

From 2006 NATS has been assessing the impact of wind turbines on its new radars and it funded a study and participated in a trial to assess the impact of proposed modifications [60 & 61]. The study documents refer always to turbines (plural) and wind farms and the Trial was undertaken against a very large offshore wind farm. There is no reference whatsoever to a single, small wind turbine generating any of the expected problems. Given their numbers in the UK, had single, small turbines been so problematic it is reasonable to assume they would have been considered and studied.

1. CAA. 'CAP 764 – CAA Policy and Guidance on Wind Turbines'
60. UK NATS Wind Farm Study Phase L4 Analysis Report
61. Raytheon. 'Overview of Raytheon Wind Farm Mitigation Techniques and Test Results'

2.3 Eurocontrol

Eurocontrol's methodology also makes frequent references to 'wind farm' and 'wind farms' and this is reflected in: *"A simple way that an ANSP can ensure that planning authorities and developers understand what information is required prior to an assessment is by making available a pro forma which developers can complete and submit."* (2 page 25 para 3.1) ANSP is Air Navigation Service Provider. ANNEX – E is the pro-forma and the first information required is *"Wind Farm Name"* (2 page 70 Annex-E).

Additionally, Eurocontrol takes no account of turbines beyond 500m from the radar and below 30m in height. This turbine is considerably lower than the height below which Eurocontrol recommends no assessment is required (2 page 31 para 4.2.1).

2.4 UK Aviation Guidance by CAA & MoD

In addition to the CAA and Eurocontrol, guidance is provided in a document for which the CAA and MoD are joint authors and in which NATS is a *"principal stakeholder"* (6 page 22 table 2). This document 'Wind Energy and Aviation Interests – Interim Guidance' also refers to the problem being multiple turbines in wind farms:

"the blades of a single turbine will always appear in the same place. However, when a number of turbines are present in a farm, the combination of blades from different turbines can give the appearance of a moving object. This may cause air traffic controllers to perceive this as an unidentified aircraft and to take action to ensure that other aircraft avoid it (which may, in itself, cause other safety problems)" (6 page 16 para 3.5.2.2.3).

2.5 Turbines and Radar Incident Reports

There are no published hazard reports or other published evidence of small turbines affecting ATC radars or ATC operations. Specifically for the period Jul 09 to Jul 12, in 'Retrieval Request Safety Data Post No: 8311- Wind Turbines' on 17 Aug 2012 the CAA stated *"there no were reported occurrences between 01 Jul 2009 and 31 Jul 2011 involving wind turbines."* and "*Further to your request, we have found no occurrences involving wind turbines from July 2011"* (to present day) (7).

CAA & Eurocontrol Conclusions

The CAA and MoD accept that a single, small turbine cannot appear as an aircraft

A single, small turbine cannot, then, increase a Controller's workload

There is no published evidence or, in the case of the CAA, no evidence at all of turbines posing hazards during ATC operations, inc ATC radar operations

In the relevant civil aviation authorities' publications, inc NATS, the principal concern is wind farms and single, utility-scale turbines, not a single, small wind turbine

2. Eurocontrol. 'Eurocontrol Guidelines on How to Assess the Impact of Wind Turbines on Surveillance Sensors'
6. CAA & MoD. 'Wind Energy and Aviation Interests – Interim Guidelines' Wind Energy, Defence & Civil Aviation Interests Working Group
7. CAA. E-mail Denise Lillywhite to BCL 'Retrieval Request Safety Data Post No: 8311- Wind Turbines' dated 30 Aug 12

3. TURBINE LOCATION

The turbine is at SJ81274 82678, 34.2m agl, 009º/43.2km from the Manchester radar (Fig 1) and at an elevation from the radar of 0.31º [8]. It is located well below the Manchester TMA (Terminal Manoeuvring Area - airspace controlled by Manchester) which has a base of 3500ft (c1100m).

The TMA is controlled airspace around the airport in which aircraft are controlled for the first and last few minutes of a flight as they take off from and arrive to land at the airport. Close to the airport the controlled airspace will 'touch' the ground but further away it will be as high as necessary to accommodate a number of requirements. These include the number of aircraft arriving and departing at about the same time, the need to conserve aircraft fuel by operating at medium levels and above for as long as possible, and the need to avoid turbulence (more prevalent at low levels) to reduce aircraft fatigue and passenger discomfort.

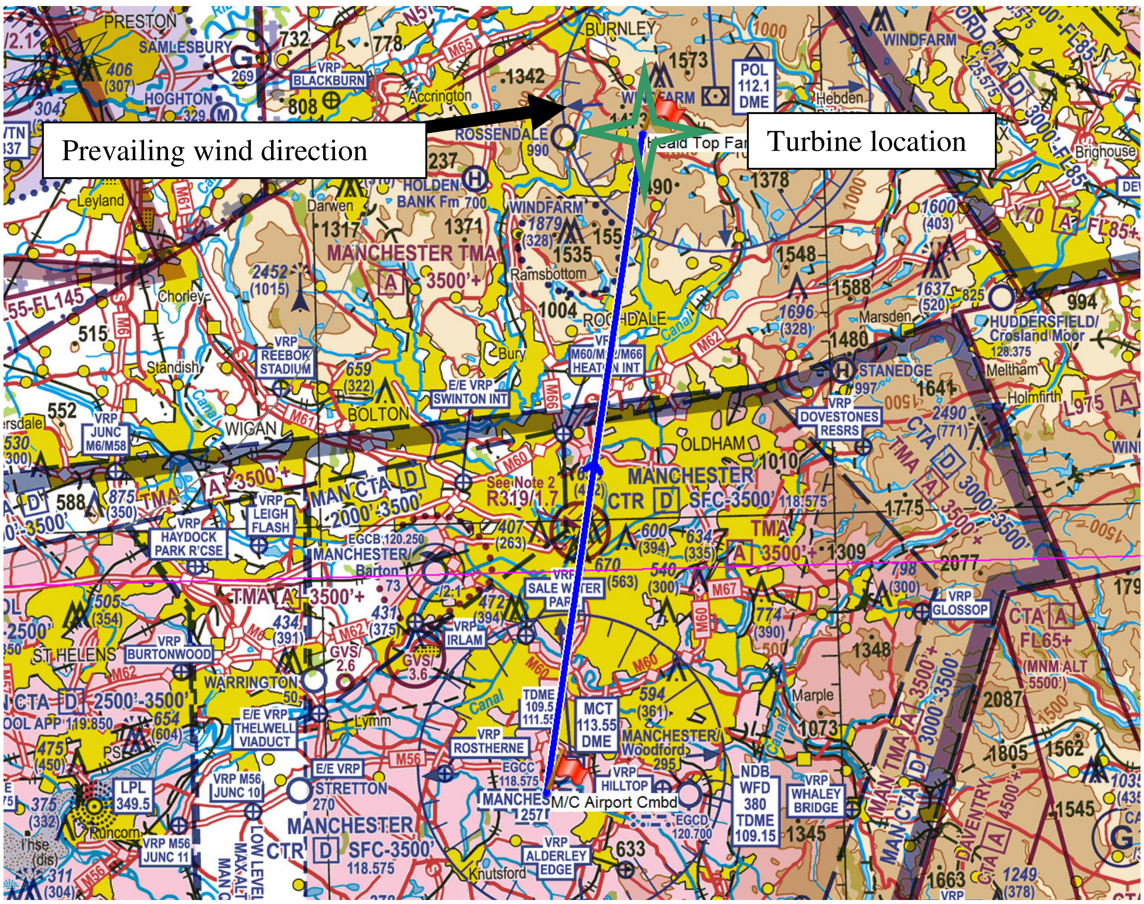


Fig 1. Map Showing Proposed Location Relative to NATS Manchester

While the NATS radar itself is on relatively low ground it is, as Fig 1 shows, near to high ground from 330º to 150º at a starting distance of c20km. Much of this high ground is at 400+m, much higher than the ground at the turbine location and also rather higher than the turbine tip. This high ground has implications for siting and set up of an ATC radar and will be considered further in Section 8.6 (page 31) & 9.3 (page 34).

8. NATS. NATS Safeguarding (A Auld) e-mail to BCL 19 December 2012

4. NATS OBJECTION

4.1 NATS Manchester Approach Radar

NATS is a UK-licensed operator which must operate in accordance with both national (CAA) and international (Eurocontrol & ICAO (International Civil Aviation Organisation)) Standards and Recommended Practices (SARPs). SARPs include the provision and capabilities of ATC radar services.

In addition to its National en-route ATC role, NATS also operates in a commercial manner providing ATC and other services to airports (inc Manchester airport) in the UK and overseas.

4.2 NATS Safeguarding

NATS has a *"comprehensive infrastructure of radars, communication systems and navigational aids throughout the UK, all of which could be compromised by the establishment of a wind farm"* (5 page 4 para 1.1)

In considering safeguarding issues with wind turbines NATS policy as stated is (9 page 4 para 2.4):

"NERL's first priority is the safety of aircraft in the airspace that we are licensed to operate. We are committed to ensuring the airspace under our control is optimised in terms of environmental performance and capacity, as we prepare to meet future demand. NERL is also developing environmentally efficient operations in partnership with airspace users."

It is understandable, then, that NATS will make its assessments on an absolutely worst case basis. This, however, takes no account of the specific characteristics of ATC radars at low elevations (see Section 8 page 25), of small turbines at low elevations and, so, the use of worst case is unrealistic.

4.3 NATS Turbine Policy

In its policy document on wind turbines NATS states: *"Wind Turbines have the potential to degrade the Communications Facilities, Navigation Aids and Surveillance radar systems employed by NERL, as recognised in CAP 764 and CAP 670".* (9 page 3 para 1.3)

So like the CAA (see page 2 para 2.1) NATS, too, is not definite - *"have the potential"* - about the effects of wind turbines on radar.

5. NATS. TOPA Heald Cross Farm Windfarm Development, Issue 1 NATS ref W(F)15745
9. NATS. 'Mitigating the effects of wind turbines on NATS En-Route Ltd (NERL) operations', . NATS En Route plc (NERL) ATM Policy Statement Issue 3.3. Brendan Kelly Head of NATS Operational Policy

Further in its policy document NATS is specific about the potential impacts and their reasons [9 page 13 para 5.11]:

"Technical Impact from wind-turbines on PSR
5.11. Like most large objects wind turbines reflect PSR pulses. Unlike most echoes, radar processing finds it very difficult to distinguish these from aircraft echoes for the following reasons:

a) Turbines have a reflectivity at least as large as most aircraft:
The design of modern turbines gives them an exceptionally large radar cross section (RCS). As a UK government report in 2003 stated "Any operating ATC radar must be sensitive enough to see the small aircraft, which tend to have RCS of about 1m2 to 10m2, where as the turbine return is up to 1000m2 in some instances." ..

b) Turbines occupy similar elevations to aircraft:
Whilst turbines generally reside at lower elevation than the majority of aircraft, their hill-top locations are higher than most other reflecting objects. Antenna tilt can be used as a tool to reduce the impact of turbines. However the impossibility of designing an antenna with a perfect low level cut-off coupled with the requirement for radar to see some low elevation targets in and around airports makes it impossible to remove turbines using antenna tilt without degrading radar performance.

c) Turbine blades are moving at the moment of reflection:
Moving turbine blades display the same characteristics as moving aircraft making it impossible for existing moving target detection algorithms to tell the difference.

d) Turbine returns are inconsistent:
The characteristics of turbine echoes are heavily dependent on turbine (and therefore wind) direction as well as the blade orientation at the moment of interrogation. Returns from an individual turbine are consequently inconsistent. This has a double impact on CFAR processing in that the large consistent portion of the echoes can build the threshold up to a level where small aircraft can be suppressed whilst the inconsistent flashes from the blades are passed as exceptional echoes.

e) Turbines are sited in large groups:
The inconsistent nature of the echoes also helps to defeat the post-plot extraction tracking algorithms. These algorithms will treat plots derived from different turbines within the same, or adjacent, development on consecutive scans as an aircraft which has moved, and moved within the limits imposed on scan-to-scan aircraft movement. Whilst this cuts down on the total number of false plots it means only the most aircraft-like tracks made up of turbine plots are presented to controllers. This difficulty in distinguishing between the two leads to turbines being displayed as if they are aircraft on controller's display with potentially unacceptable consequences in terms of controller distraction and workload.

9. NATS. 'Mitigating the effects of wind turbines on NATS En-Route Ltd (NERL) operations', . NATS En Route plc (NERL) ATM Policy Statement Issue 3.3. Brendan Kelly Head of NATS Operational Policy

This is further summarised by NATS [10] as:

- *"Causing shadows (an aircraft might not be picked up on radar)*
- *Causing clutter (i.e. where the large-scale moving blades show up as blips on the radar screen)."*

As a result of the absence of any data or evidence in the TOPA this Report will specifically address the concerns expressed by NATS and repeated above.

4.4 <u>NATS Objection</u>

In its TOPA NATS states: *"Section 0 of this document defines the assessments carried out against the development proposed in section 2, with the result detailed in section 4.1".* [5 page 4 para 1.1]

However the TOPA has no section 0, while section 4.1 on para 5 has no 'result' whatsoever and merely states: *"The proposed development has been examined by technical and operational safeguarding teams. A technical impact is anticipated, this has been deemed to be **<u>unacceptable</u>**."*

NATS further states [5 page 5 para 3.1.1]:

"Predicted impact on Manchester Approach Radar
Using the theory as described in Appendix A and development specific propagation profile it has been determined that the terrain screening available will not adequately attenuate the signal, and therefore this development is likely to cause false primary plots to be generated.
A reduction in the radar's probability of detection, for real aircraft, is also anticipated."

However, despite a specific reference to "*false primary plots to be generated*", Appendix A provides very little theory and actually gives only the standard radar range equation [5 page 6]. More importantly, the TOPA provides none of the data used in the equation nor does it provide the "*result detailed in section 0".* [5 page 4 para 1.1].

In the absence of input data and calculation results and with only a subjective "***<u>unacceptable</u>***" the NATS objection has no credence whatsoever and is not valid.

<u>NATS Objection Conclusion</u>

Without evidence, the NATS objection to this proposal has no credence whatsoever

10. NATS. Document 'What is NATS position on the development of wind farms?'
5. NATS. TOPA Heald Cross Farm Windfarm Development, Issue 1 NATS ref W(F)15745

5. EVIDENCE USED IN THIS ANALYSIS

This Assessment uses evidence and references from the most up-to-date, comprehensive and available published trials and studies conducted into the problem. This work has been conducted by the MoD, the CAA, QinetiQ and NATS. Until 2006 QinetiQ was first the MoD's Defence Evaluation & Research Agency, and later a world-leading defence & research company majority owned by the MoD. Later still, QinetiQ was floated on the UK stock market.

Reference will also be made to research conducted by equivalent US and European Government (inc aviation) agencies and by respected research companies.

6. RADAR – WIND TURBINE TRIALS

An extensive online search, inc the MoD, the British Wind Energy Association, the CAA and NATS has uncovered the Trials and Reports examined below. The Reports from the identified Trials are routinely cited by NATS, the CAA and the MoD (and international organisations) as highlighting the adverse effects of wind turbines on radar.

The Trials were conducted largely by the UK MoD with assistance from and participation by the UK civil aviation (and other) organisations. The Trials were conducted using a Watchman ATC radar – perhaps not too dissimilar to that at NATS Manchester Approach.

6.1 MoD Trial - RNAS Culdrose and Goonhilly Windfarm

Conducted in 1994 this Trial (11) used the Watchman ATC radar against a large wind farm comprising 14 x 45m turbines in 3 rows, in an area 600m x 600m – 14 turbines in less than 1 sq km. The turbines were close to the radar – 4miles/7km – at a shallow elevation angle (c 0.3º) and all in Line of Sight (LoS) to it.

The Trial was mostly conducted to investigate and measure technical aspects of radar performance but some of the findings relevant to this analysis are as follows:

"The wind farm lies from the radar at a bearing of 128-138º ... Because the prevailing wind direction is south westerly the turbines are often side on to the radar, consequently, a strong Doppler shift response is expected from the blades" (page 1 para 5)

"The turbine structure had an estimated RCS of approximately 9.3 sq m in circular polarization." (page 14 para 50), *"similar to a medium sized aircraft"* (page 6 para 20)

"It has been shown from the trials that the detection and tracking of aircraft over a wind farm area can be extremely difficult because of the problem of distinguishing between target responses and wind turbine responses. Over a large wind farm site this could cause a flight safety hazard" (page 15 para 58).

11. MoD. RAF Signals Engineering Establishment, 'Study into the Effects of Wind Turbines on Radar Performance', Technical Report 94010

"There is therefore a significant amount of time when the turbines are not causing interference" (11 page 16 para 60)

Flights for the trial were conducted at 500ft and 750 ft, and

"With the radar configured for normal operation, only a single missed detection occurred. This happened to be in line with the wind farm which may indicate slight loss due to obscuration" (11 page 14 para 46)

<u>Goonhilly Trial Conclusions by BCL</u>

The Trial makes no assumption and draws no conclusion that the effects observed from a wind farm of 14 turbines can be compared to those that may be caused by a single turbine c ½ the size of each of those used in the Trial

The phrase *"Over a large wind farm site this could cause a fight safety hazard"* states that the hazard is not definite and makes no inference that a single, small turbine will have the same effect

This Trial identifies likely RCS values for small-medium size wind turbines of 9.3sq m (9.73dBsm)

6.2 <u>MoD Trial Quixotic Zephyr</u>

Conducted in 2005, this Trial (12) used a Watchman ATC radar and was carried out in 3 stages, each using a large wind farm:

38 x 46m turbines at 13km,
103 x 45 turbines at 57km, elevation angle 0.18°
103 x 45m turbines at 10km, elevation angle 1°

All 3 stages were conducted with the turbines in full LoS of the radar, and flights were at altitudes that ensured detection occurred in the 'heart' of the appropriate radar beam. The 103 turbines covered an area of 10 sq km, 10 turbines per sq km.

The Trial's aim was

*"to determine the effects of **<u>wind turbine farms</u>** on ATC area and airfield Primary Surveillance Radars."* (page 2 para 6).

The Trial is regularly cited by NATS/CAA/MoD as demonstrating the adverse effects of turbines on ATC radars. Relevant findings from this trial follow.

11. MoD. RAF Signals Engineering Establishment, 'Study into the Effects of Wind Turbines on Radar Performance', Technical Report 94010
12. MoD. 'The Effects of Wind Turbine Farms on ATC Radar', AWC/WAD/72/665/Trials 10 May 05

*"The presence of a **wind turbine farm** in LoS of a Watchman Radar had a significant impact on its ability to support ATC. This took 2 main forms, obscuration and displayed clutter. These were a result of the strong radar reflections received from high RCS moving tgts, like wind turbines."* (12 page 13 para 28)

*"Overall, the presence of a **wind turbine farm** is not compatible with ATC operations in the vicinity of an airfield."* (12 page 13 para 28)

(The bold and underline of references to *'wind turbine farm'* and '*farms*' is BCL emphasis.)

In the section titled 'Major Recommendations' (page 14) the Report states:

"It is recommended that:

a. Planning applications for wind turbine farm developments be subject to scrutiny when in LoS of an airfield primary radar, regardless of range but in particular within 30nm of the radar head. *(para 19)*

b. ATS be limited within 5 nm of the boundary of a wind turbine farm. (Paragraph 20a)". (page 14 para 29)

Elsewhere the Report states

"However, during this Trial there were numerous occasions when a Watchman Operator was still able to distinguish between a reduced amplitude return from a real aircraft and the impermanent clutter returns from a wind turbine." (page B-6 para 6)

"Local Training. RAF airfields with an existing wind turbine farm interference problem have adopted local work-arounds to ensure that safety is not compromised. At RAF Valley, the location for Stage 1 of this Trial, this includes comprehensive training for local controllers to ensure that they are fully aware of the impact of the wind turbines on their picture. Training is only a valid mitigation for wind turbines where the developments are relatively small and avoid critical areas around the airfield. Therefore, local training would only be an appropriate mitigation for small wind turbine farms within the proposed Restricted Zone at Figure 4." (page B9 para 9c)

"The P&L wind turbine farm has an RCS estimated at 100[12] m^2, this figure could be as high as 10 000 – 100 000[13] m^2 for some of the proposed larger wind turbines." (page 9 para 20)

RCS is Radar Cross Section, a complex calculation/measurement but it approximates to the reflecting area of the object.

Flights for the trial were conducted at 2000 – 6000 ft to ensure the aircraft would be in the peak of the radar beam.

Given that the Trial aimed to observe and demonstrate the effects of wind farms on ATC radars the conclusions and recommendations of the Trial are not surprising.

12. MoD. 'The Effects of Wind Turbine Farms on ATC Radar', AWC/WAD/72/665/Trials 10 May 05

<u>Trial Quixotic Zephyr Conclusions by BCL</u>

There are no results or recommendations for single, small wind turbines

Even over a large wind farm "*there were numerous occasions"* when aircraft could be distinguished from turbine clutter

The effects were observed from very large windfarms – up to 103 turbines, at 10/sq km

The wind farm equates to over 100 military fighter jets or 15+ B747 jumbo jets in a small area

The Trial was conducted so the wind farm was in the peak of either the Short range or Long range beams. This relatively large elevation angle ensured maximum radar performance

It is commonly accepted that a 'wind farm' comprises more than one turbine – yet this proposal is for a single, small turbine

12. MoD. 'The Effects of Wind Turbine Farms on ATC Radar', AWC/WAD/72/665/Trials 10 May 05

6.3 DTI - Wind Farms Impact on Radar Aviation Interests

Conducted in 2003 the DTI (Dept of Trade & Industry, now BERR) Trial was largely about measuring and modelling the RCS of a single, large turbine (13). The Trial used a single, large turbine and an operational MoD Watchman ATC radar – not unlike the radar used at Manchester. The objectives (page iii) of the Trial included:

"Determine the effects of siting wind turbines adjacent to primary air traffic control radar;

Provide the information required for the generation of guidelines by civil, military and wind farm developer stakeholders;

Determine the extent to which detailed design of wind turbines influences their effects on radar systems"

The Trial used a single, large turbine 98m high and situated 5nm (8km) from the radar – 3 times larger and 5 times closer than the proposed turbine, and both factors are significant to radar, especially range (see Section 10, page 36 on). Key, relevant parts of the report are reproduced below.

Early in the Trial report QinetiQ states:

"*Cases are known where the presence of a wind farm adjacent to an airport is causing problems for the ATC of the airport. On the other hand, cases are also known where a wind turbine close to an airfield causes little or no problem to the airfield ATC."* (page 1 para 1.1.5)

Other relevant parts of the report are:

"*RCS returns of a whole turbine generally fall between 10 and 30dBsm (10m2 to 1000m2). These are large returns typical of aircraft returns the radar is designed to receive."* (page 75 para 8.2.2)

"Single wind turbines do not create a significant 'radar shadow'; Any shadow region is only dark to a distance of a few hundred metres behind the turbine." *(page 79 para 8.6.5)*

"Beyond this there is some reduction of the radar power, and a time-variation, but these will not prevent detection except possibly for very small targets." (page 79 para 8.6.5)

"In this example the turbine is facing the radar... The radar missed detection of the turbine 11 times in 50 scans." (page 51 para 6.5.3.1)

13. QinetiQ. 'Wind Farms Impact on Radar Aviation Interests', Final Report. FES W/14/00614/00/REP. DTI PUB URN 03/1294. 2003

Fig 6.12 of page 49 of the Report [13] is reproduced at Fig 2 (page 14, next page). This is a ‘screen shot’ of the radar display taken during the Trial, and of the screen shot the Report states:

“As an example of the radar picture at Marham an image with a range of 13nmi is shown in Figure 6-12. Here the wind turbine can be seen as a small yellow return, along with other clutter that appears to be from trees, road traffic and other large man-made structures, plus several aircraft targets.”

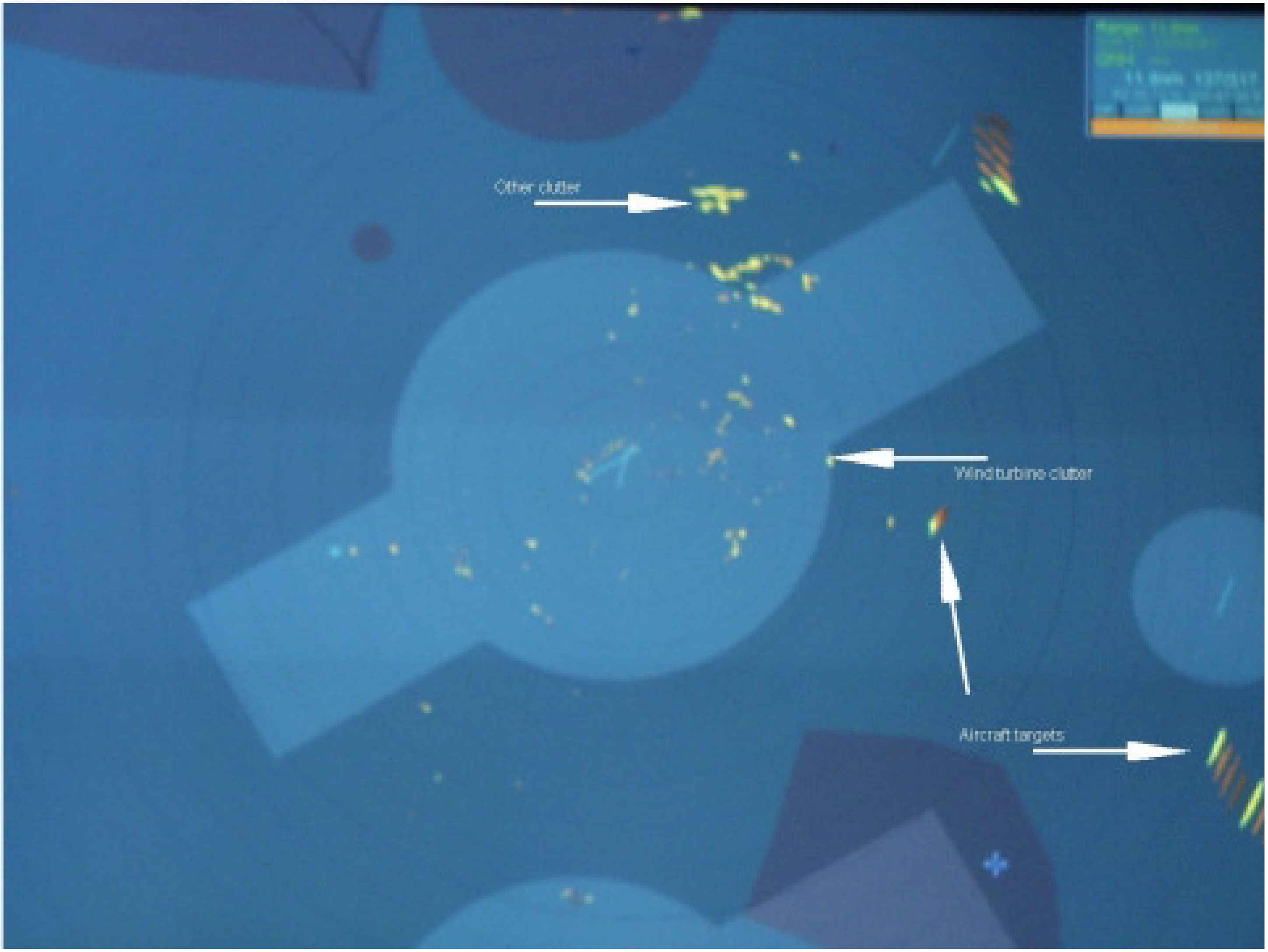
It is obvious from Fig 2 that the return from even a single large turbine (3 x the height of this proposal) is not as prominent as might otherwise have been thought, and that aircraft radar returns (‘blips’) can be clearly distinguished. It is also obvious that terrain and man-made clutter is an everyday part of ATC radar operations and displays.

The map of the same area at Fig 3 (page 15) shows some interesting comparisons with the radar display:

> There is no ‘other clutter’ beyond about 12.5km
>
> The tall mast at Great Massingham – 90m agl – doesn’t show as a return
>
> The 60+m mast at N Pickenham – 12km - might just be showing just to the W of the northern aircraft target

Does this perhaps indicate the degraded low level/low elevation coverage at anything other than very short ranges?

13. QinetiQ. ‘Wind Farms Impact on Radar Aviation Interests’, Final Report. FES W/14/00614/00/REP. DTI PUB URN 03/1294. 2003



<u>Captions on the Display Reproduced Below for Clarity</u>

Other clutter

Wind turbine clutter

Aircraft targets

Fig 2. ***"Figure 6-12; Screen shot from the recorded Marham data showing the turbine return and some air traffic."***

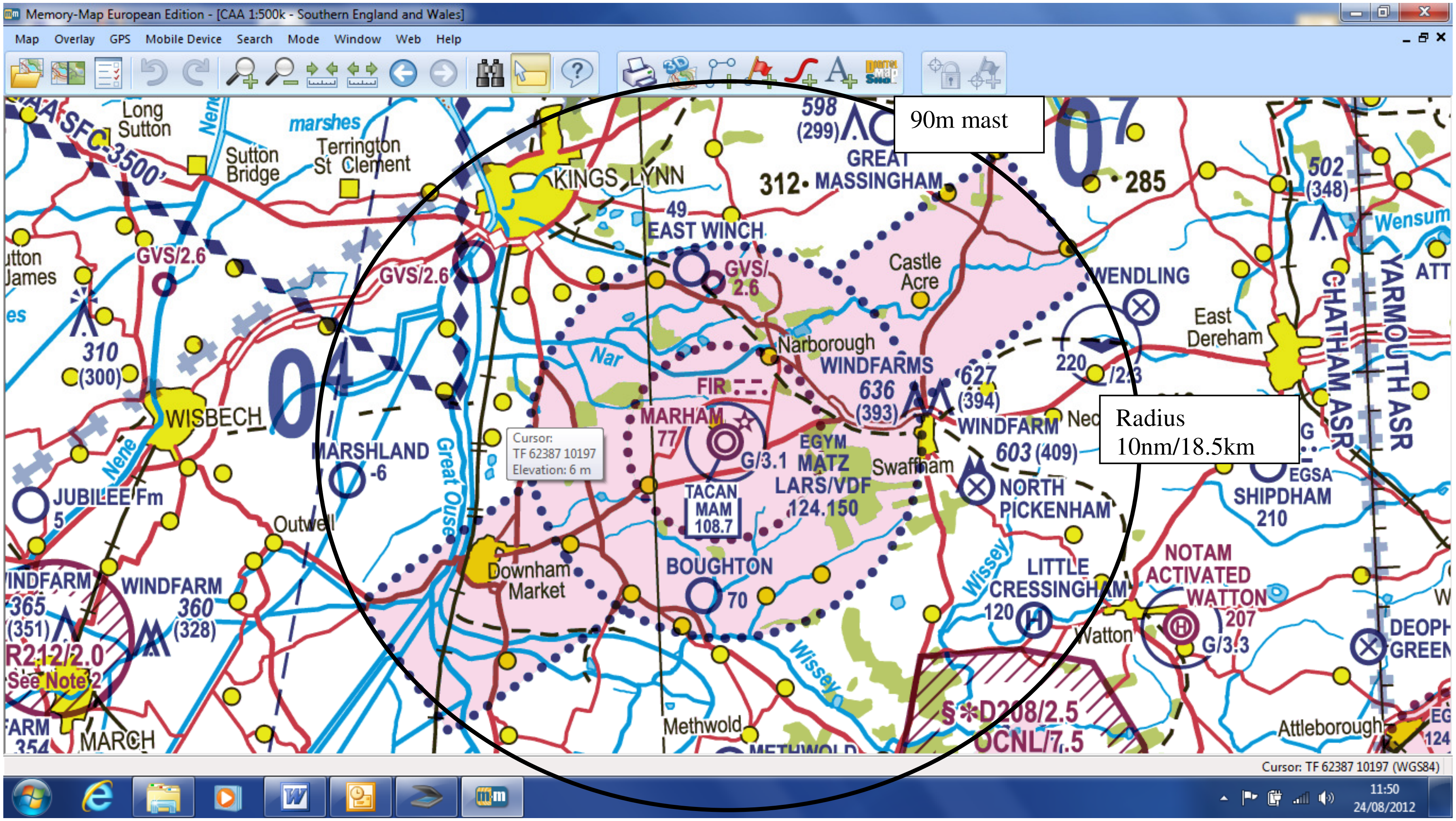


Fig 3. Aviation Map Showing Same Area as Radar Display at Fig 2

DTI Trial Conclusions by BCL

Single turbines *"do not create a significant 'radar shadow"*, so a single, small turbine shadow (if any) will be negligible – real aircraft will always be detected

Some wind turbines, inc large ones, close to airfields *"causes little or no problem to the airfield ATC"*

The effects of a small, single turbine will be even less pronounced and cannot possibly be compared to those of a turbine 4 x the size. Because:

- the large turbine close to Marham airfield shows on the radar as less pronounced than other general clutter, and much less than aircraft targets

- the Watchman ATC radar does not always detect a large turbine closer to the radar than the one proposed

Summary of All Trial Conclusions by BCL

Large, single turbines *"do not create a significant 'radar shadow"*, so a single small turbine shadow (if any at all) will be negligible – real aircraft will always be detected

All the Trials were conducted against wind turbines much larger than that proposed, and in combinations of turbines in wind farms of up to 103 turbines

Wind farms *"could cause a fight safety hazard"* – there are no conclusions or recommendations for single, small wind turbine

Trials were conducted with the turbines in the peak of the radar beam, not at low elevation angles where radar performance is much reduced

Even over a large wind farm "*there were numerous occasions"* when aircraft could be distinguished from turbine clutter

Some wind turbines, inc large ones, close to airfields *"causes little or no problem to the airfield ATC"*

The large turbine close to the airfield shows on the radar as less pronounced than other general clutter, and much less than aircraft targets

The radar does not always detect a large turbine much closer to the radar than the one proposed

6.4 US Experience & UK Trials

In addition to UK authorities Trial Quixotic Zephyr it is also cited by others, inc US Governmental authorities. In its assessment of the issues of wind turbines and radar (14) the US equivalent to the MoD (the Dept of Defense – DoD) summarised the Trial and used its observations to develop its own trials programme. More importantly, the US DoD stated of the UK Trial (14 page 36):

"they do not provide a sufficiently robust statistical database to enable quantitative computations to be performed in terms of actual reduction in probability of detection, increase in probability of loss of track, and increase in probability of false alarms. Only analytic tools able to incorporate wind turbine behavior as part of their input can accomplish that task. Such tools are currently unavailable."

It is not known whether such tools have become available but if they have there are no published results from trials or research using them. The Trials outlined above appear to be the most up-to-date trials available. As a result of its own work, then, the US Federal Aviation Authority (FAA - equivalent to UK CAA) and US DoD have virtually no radar concerns about turbines less than 61m high and beyond 6.1km of a radar (15) – turbines twice the height of this proposal.

6.5 International Safeguarding Criteria

In addition to the USA, other international criteria reinforce the view that the desired NATS criteria are far more stringent than any others.

Ireland - consideration of turbines only greater than 45m high or closer than 20km to a radar (17 & 18 page 40).

Eurocontrol - no account of turbines below 30m in height (2 page 31) while larger turbines that are beyond 15km and in radar line of sight (ie they could be detected) only require a simple assessment (2 page 31 papa 4.2.1).

In its relevant publication (19) the International Civil Aviation Organisation (ICAO) states *"This document establishes guidance material for determining whether the physical presence of a building may have an adverse effect on the availability or quality of CNS signals"* (19 Page 2 para 2.1). CNS = Communications, Navigation & Surveillance, and includes ATC radars. Later ICAO states this document *"applies a Building Restricted Area (BRA) for wind turbines of 15km around a PSR"* (19 Appendix 3 Table 4). and *"The BRA is considered to provide worst case protection"* (19 page 5 para 6.2) (BRA = Building Restricted Area)

14. US Dept of Defense, Office of the Director of Defense Research and Engineering. 'Report to the Congressional Defense Committees The Effect of Windmill Farms On Military Readiness 2006'
15. FAA Advisory Circular 70/7460 2K
17. Irish Government. SI 215 of 2005 Irish Aviation Authority (Obstacles to Aircraft in Flight) Order 2005.
18. Irish Wind Energy Association. Best Practice Guidelines for the Irish Wind Energy Association.
2. Eurocontrol. 'Eurocontrol Guidelines on How to Assess the Impact of Wind Turbines on Surveillance Sensors'
19. ICAO 'European Guidance Material on Managing Building Restricted Areas Sep 2009'

6.6 Operational Airport Experience

6.6.1 Filton Airport. The BAE Systems airfield at Filton has 3 large turbines 7km on the extended centreline of runway 27 and there is an additional proposal for 3 more. However, Filton did not object to the latest planning application (made well before the announcement of Filton's impending closure) and has experienced no ATC problems with the turbines.

'No special procedures or guidance have been established in the Bristol Filton Airport Manual of Air Traffic Services' (20 Ch 10 page 9 para 10.58)

'In the interim period between the commencement of operation of the existing REP phase I turbines in 2007 and the commissioning of the new S511 radar in 2009, the Civil Aviation Authority has not required the airport to institute any special measures to address the issue of the appearance of the existing wind turbines on radar.' (20 Ch 10 page 9 para 10.59)

6.6.2 Aberdeen Airport. A single large wind turbine is under the final approach at Aberdeen Airport.

'The turbine is believed to be partially visible to the NATS Plessey S511 radar on Perwinnes Hill, 7.2km SE of the wind turbine. Perwinnes Hill supplies primary and secondary data to controllers at Aberdeen Airport and to the Scottish Area Control Centre at Prestwick. Primary data from Perwinnes Hill received at Aberdeen Airport has already been processed, with both MTI and plot extraction applied to remove ground clutter and successive plots not meeting specified criteria for the formation of tracks. No returns from the area of the turbine have been noted by controllers at Aberdeen' (21 page 16).

- The Plessey s511 radar is older generation than that used at Manchester Airport which is equipped with more modern processing like MTD and plot extraction software (see Sections 9.2 page 34 and 11.5 page 42).

6.6.3 German Air Force Base Büchel. Büchel has several large wind turbine farms in LoS of the radar.

'the wind turbines observed at Büchel did not produce any interfering bursts of appearances on the screen.' (22 page 19 para 2.1.3)

- The ASR-S radar used at Büchel is thought to be equivalent to the ASR-10SS ATC radar used at Manchester.

20. BPC/Filton, 'Environmental Statement, The Bristol Port Company. Renewable Energy Project Phase II'
21. Spaven Consulting & Dutch Air Traffic Control Authority, LVNL. 'Wind Turbines and Radar: Operational Experience and Mitigation Measures. Report to a consortium of wind energy companies December 2001'
22. EADS, 'The Compatibility of Wind Turbines with Radars, Annual Report 2008'

6.6.4 Schiphol Airport.

"Fourteen turbines with a maximum blade height of 89m were constructed in the Amsterdam Western Harbour area, 10km north of Schiphol Airport, in 2000-2001. The turbines are all located within controlled airspace. They are positioned under the final approach path to runway 19L at Schiphol. This runway is only used for landings in daylight visual conditions (no night or instrument approaches permitted), but a surveillance radar approach is available which involves radar vectoring to a point approximately two nautical miles from touchdown." In addition, the radar at Schiphol, which is located on top of the elevated control tower at the airport, is estimated to be line of sight to 3 large turbine farms from 10-18mls distant.

'According to the Dutch air traffic control authority, LVNL, there have been no indications to date that any of the above wind turbines appear on their radar. LVNL is aware of the theoretical possibilities of diffraction, screening and false returns due to rotating turbine blades, but none of these effects have been experienced.' [21 page 23 para 7.1]

- Schiphol airport uses the ATCR-33K – this is a full, relatively modern (but not solid state) ATC radar not dissimilar to the Manchester radar. Like the Manchester radar, the ATCR-33K employs MTD processing and incorporates several clutter maps. These processes are effective at eliminating moving returns from road traffic around Schiphol as well as eliminating the wind turbines.

6.6.5 Las Palmas Airport, Gran Canaria. There are more than 20 x 40+m high turbines on the extended centreline of the only runway at Las Palmas Airport at just 10km range, yet they appear to offer no hazard to ATC operations. The author's approach (and others observed) was conducted without any deviation (author's observations 29 Nov 2012). Indeed, Las Palmas airport generates its own electricity from 2 x wind turbines located on the East side of the airport. [23 page 16]

6.6.6 Denmark. Denmark has one of the highest densities of wind turbines in the world, and it is virtually flat - most turbines are likely to be LoS to one or more radars. Yet *"consultations with the regulatory authority, Statens Luftfartsvaesen (SLV), the air traffic control provider, Flyvesikringstjenesten, and Danish wind industry companies and consultants, produced a unanimous response that wind turbines presented no difficulties to air traffic control radar operations"* [21 page 25 para 7.2].

6.6.6.i There are 71 wind turbines within 30km of Copenhagen International Airport at Kastrup. According to the Flyvesikringstjenesten engineering manager for the Kastrup *"Wind turbines consequently have "no effect whatsoever" on the radar display at Kastrup"* [21 page 25 para 7.2].

- Kastrup's primary radar (an ASR-8) - originally an older radar than Manchester but with updated track processing for plot extraction, etc.

21. Spaven Consulting & Dutch air traffic control authority, LVNL. 'Wind Turbines and Radar: Operational Experience and Mitigation Measures. Report to a consortium of wind energy companies December 2001'
23. AENA (Spanish National Air Traffic Service) La Palma airport Environmental Management Report 2006-08

6.6.7 Palm Springs, California. *"Air traffic controllers at Palm Springs are now able to vector traffic across the wind turbines without any detrimental effect on radar performance since the turbines no longer appear on the radar screen. No limitation of radar service is required"* [21 page 26 para 7.3].

- Palm Springs uses a modern ATC radar (ASR-9) - but one with a design slightly older than that at Manchester - with many of the same processing features.

6.7 International Air Traffic Control Hazard Reporting

A comprehensive internet search has uncovered no incidents involving ATC radars and wind turbines anywhere in the world – replicating the experience of the UK CAA [7]. In the absence of any incidents and knowing the results of UK & US Trials and other operational experience, international authorities have not tightened their own criteria suggesting that the safeguarding criteria desired by NATS are unnecessarily stringent.

21. Spaven Consulting & Dutch air traffic control authority, LVNL. 'Wind Turbines and Radar: Operational Experience and Mitigation Measures. Report to a consortium of wind energy companies December 2001'
7. CAA. E-mail Denise Lillywhite to BCL 'Retrieval Request Safety Data Post No: 8311- Wind Turbines' dated 30 Aug 12

7. LINE OF SIGHT

7.1 NATS LoS Diagram

NATS provided a LoS diagram produced from its ITRU propagation model. However, the diagram includes none of the input data and assumptions used in any computer model. The model seems to have used only terrain data whereas data using man-made obstructions would be more accurate. Like large turbines, man-made obstacles can have a significant and detrimental impact on the propagation of radar energy.

As presented, the NATS LoS diagram is of limited value for analysis and is considered no further.

7.2 LoS Analysis

This Report's Line of Sight analysis was conducted using Global Mapper v13, an MS Windows-based GIS model originally developed by the United States Geological Survey (USGS). The model includes the ‘usual’ GIS features and calculates radar LoS data, inc Fresnel Zone clearances, from user-defined inputs of frequency, refraction index, antenna/ receiver height, etc.

The initial calculations were made using OSGB Panorama data. Panorama uses terrain elevations from a 50m grid but it excludes surface details - man-made obstacles, buildings, etc. These can have a significant impact on radar performance so further analysis was conducted using the USGS Finished Shuttle Radar Topography Mission (SRTM) data. This data is spaced at c90m grid intervals but it does contain man-made obstacles and is considered more accurate than terrain-only data for electro-magnetic (communications, radar, etc) LoS assessments.

The model’s inputs include radar frequency and the desired Fresnel Zone clearance (as %).

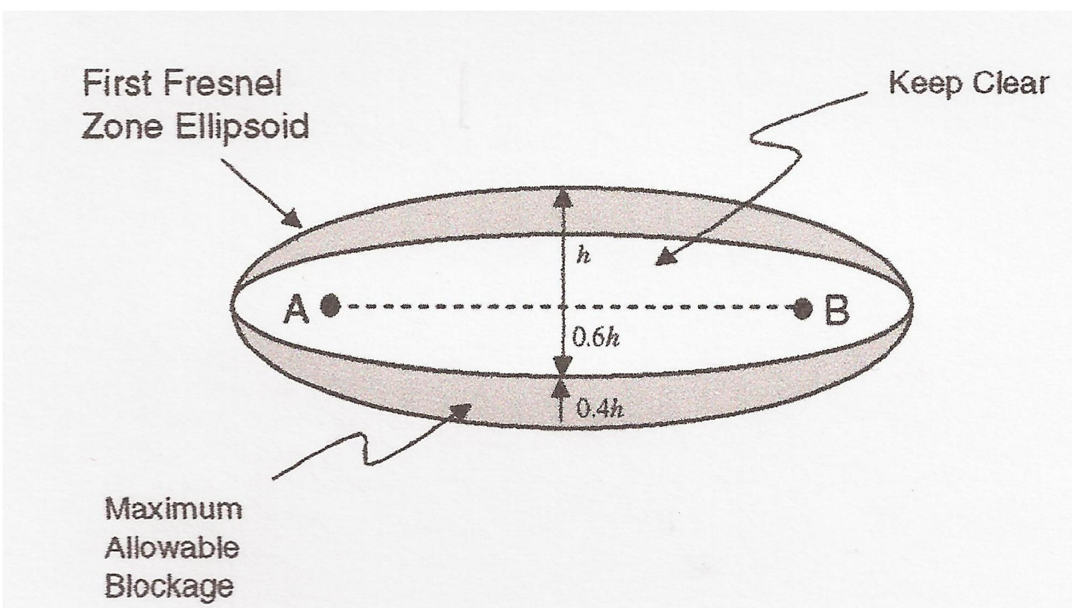


Fig 4. 1st Fresnel Zone (41)

41. Merrill Skolnik, The Radar Handbook

7.3 Fresnel Zone Analysis

The Fresnel Zone is a phenomenon of all electro-magnetic energy, which doesn't actually transmit in a direct straight line between 2 points. Electro-magnetic energy is actually transmitted as a very large number waves of energy in an ellipse between the transmitter (radar) and the receiver (turbine), on both the outbound and return paths.

A detailed description of the effect is not required for understanding this assessment, but simply the effect is caused by the different path lengths taken by waves in the ellipse. When an obstacle intrudes into the ellipse it causes reflections/deflections of some of the waves so that some arrive in the same phase and some arrive out of phase - those out of phase cause 'interference' and reduce the strength of the signal.

For completely accurate radar performance the radar ‘beam’ (actually an ellipse between the radar antenna and the target) must be clear of obstacles throughout the 1st Fresnel Zone [41 & 57].

A diagram illustrating the Fresnel Zone is at Fig 4 on the previous page.

It is also important to remember that any intrusion into the Fresnel Zone will cause a degradation of the radar signal on both the outbound and return paths of the radar signal.

The output diagram of the analysis to the turbine tip using SRTM data is shown at Fig 5 (page 23). The diagram shows the direct line of sight between the radar antenna and the tip of the turbine as a yellow highlighted, dashed line, while the limit of 100% of the 1st Fresnel Zone is the black dashed, curved line. The diagram shows that at 34.2m there are no obstacles intruding into the Fresnel Zone.

However, the turbine's impact (its reflecting area or the RCS - see Section 10.1.5 page 38) on the radar is considered to be produced by the whole structure - the tower, the hub and the blades.

Examination of the model at the height of the hub - Fig 6 page 24 - shows terrain/obstacle intrusion into the Fresnel Zone at c 39km with a consequent impact on the power transmitted to the hub - and then reflected back from it. Reducing the height of the turbine further in the model increases the 'intrusion' into the zone until at a turbine of 15m height there is sufficient loss of signal strength (nearly 3dB each way) to prevent detection.

Analysis of the potential impact of the turbine on the radar must, therefore, be limited to the impact of the top 19m which comprises the moving parts - the blades and hub. This impact will be considered further in consideration of the turbine's RCS Section 10.1.5 page 37.

41. Merrill Skolnik, 'The Radar Handbook'
57. UK OFCOM, 'Fixed-link Wind-turbine Exclusion Zone Method'

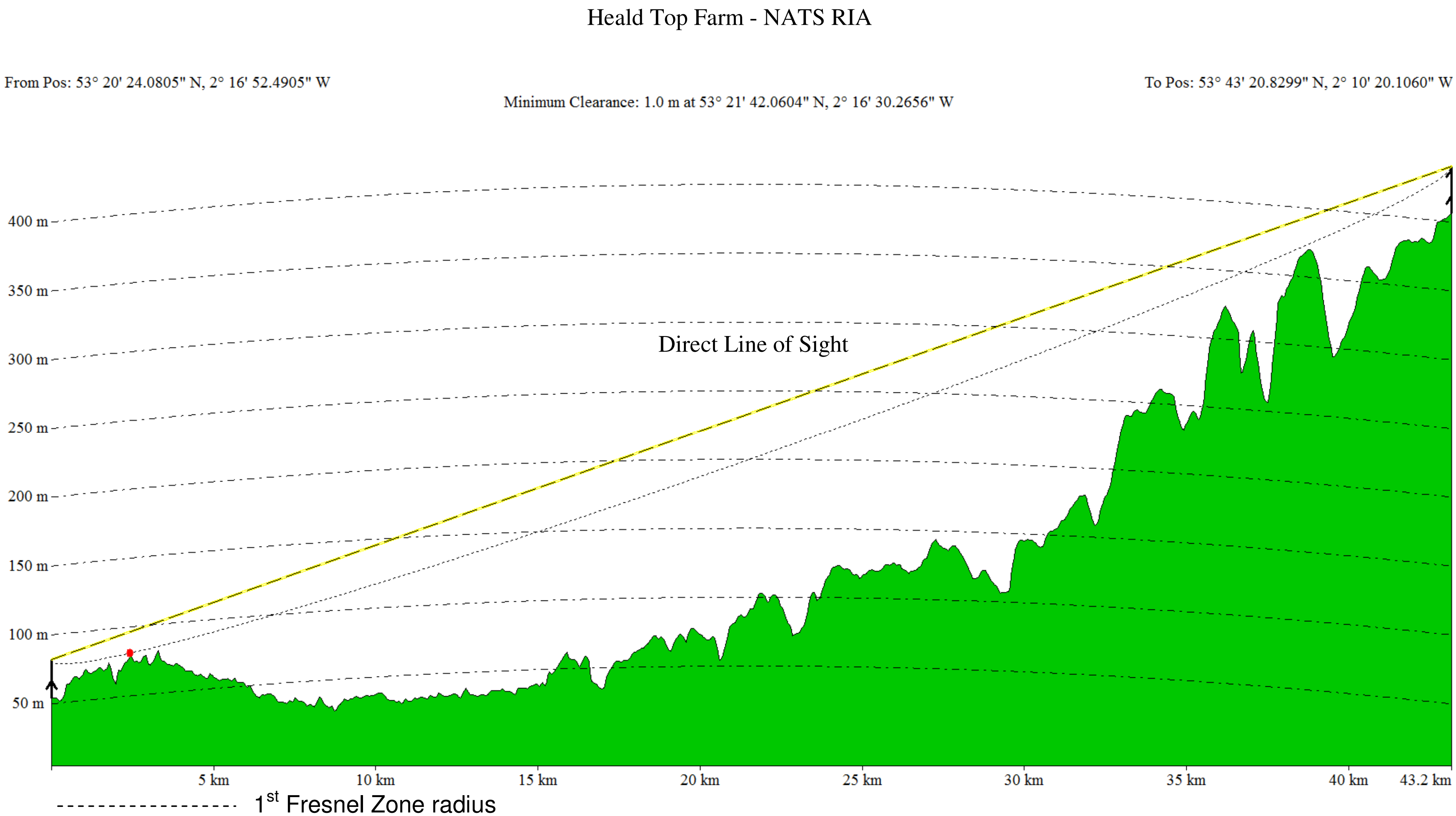


Fig 5. LoS to Turbine Tip

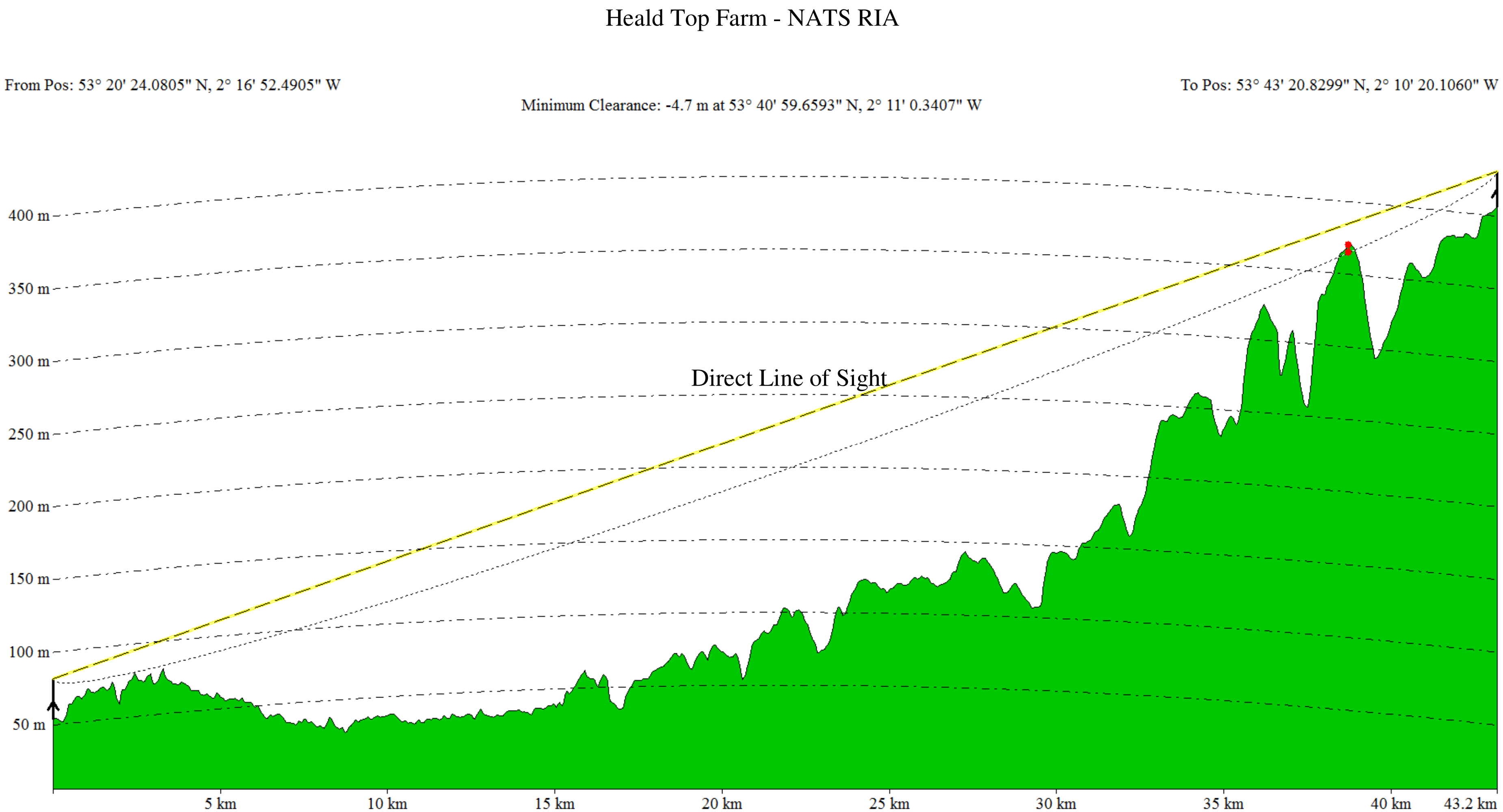


Fig 6. LoS to Turbine Hub at 24.6m

8. ATC RADARS

8.1 ATC Radar Operating Standards

Manchester is a CAA-licensed aerodrome and as such it must operate to both national (CAA) and international (ICAO) Standards and Recommended Practices (SARPs) applicable to aerodromes. These SARPs include the provision and capabilities of Air Traffic Services, especially the radars.

In the absence of data from NATS and the manufacturers (see Section 9 page 32) some assumptions have to be made about the ASR-10SS, but it is thought that it is not unlike a typical ATC radar such as the Watchman. Certainly as NATS is UK-licensed, the radar will have to operate to CAA and ICAO standards and criteria.

All radars are designed to focus their energy in the direction of likely targets and their performance is affected by 3 key factors – the radar's power, the radar's antenna gain (the ability of the radar to focus its energy in a particular direction (a bit like the lens of a torch)) and the target's elevation (See Section 10 page 36). ATC radars are not designed to detect low level targets, so the shape of the radar beam is designed to transmit as much of the energy as possible in the direction of likely targets.

Targets of interest to ATC radars are likely to be at 1000+m (except at a few km range from the airport), which is where the majority of aircraft will operate.

Furthermore, when radar beams 'impact' on objects (wanted and unwanted) a phenomenon called 'diffraction' occurs. This causes bending of the beam and a loss of radar power, and it can have a serious adverse effect on radar detection. ATC radars are designed and sited as much as possible to avoid diffraction, and by 'avoiding' low levels ATC radars avoid ground clutter (inc man-made objects) and diffraction.

8.2 MoD Watchman as Typical ATC Radar

ATC radars, like torches, are designed to focus their energy in the direction of likely targets but they are not designed to detect low level targets. ATC radars are designed to detect targets that are, except at very short ranges of a few km, at several '000 ft. So the shape of the radar beam is designed to transmit as much of the energy as possible in the direction of those likely targets.

To achieve this desired performance ATC radars use a 2 beam antenna [1 Appendix 7 (2006), 26 & 12 page B-5 para 5]. Watchman is a typical ATC radar with many used by the MoD and other civil operators (inc Manchester airport until 2011). It has an MoD-published [12 page B-5 para 5] elevation beam diagram (with 0° antenna tilt) - Fig 7 (next page).

This design helps the radars to avoid unwanted reflections from the ground and from objects on and very close to the ground (called 'clutter') - like this turbine - and to focus on those targets it wishes to detect at medium levels.

1. CAA. 'CAP 764 – CAA Policy and Guidance on Wind Turbines'
26. Raytheon. Product brochure ' Raytheon ASR-10SS Mk2 Series S-Band Solid-State Primary Surveillance Radar'
12. MoD. 'The Effects of Wind Turbine Farms on ATC Radar', AWC/WAD/72/665/Trials 10 May 05

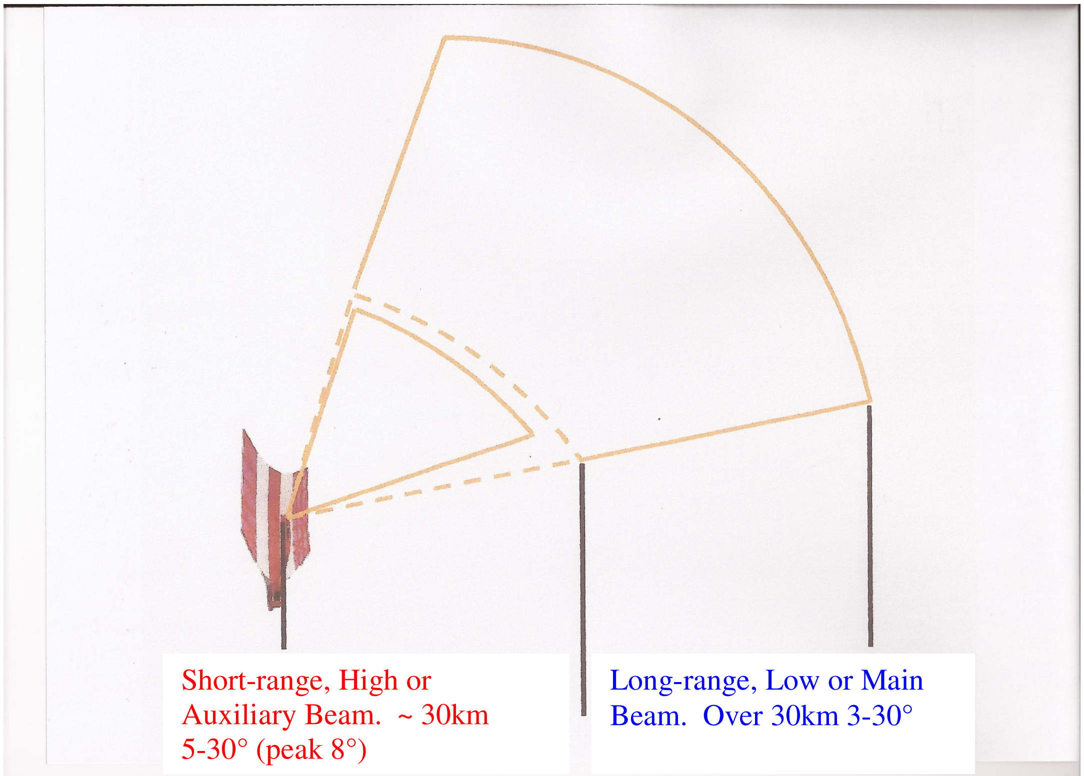


Fig 7. Watchman ATC Radar Beam Pattern (12)

As typical ATC radars, the ASR-10SS and the Watchman both use a Low (Long-range) beam and a High (Short-range) beam, with the Low beam used for transmission and reception. For the Watchman the Low beam is elevated to 3° (peak) above the horizon, while the High (Short-range) beam is elevated at 8° (peak) (12 page B-5 para 5 & 23 page 6 para 8).

Beyond the beam switch-over range (unknown at Manchester, but c36km for Watchman) the received signals are passed through the Long-range (Low) beam. At short target ranges up to the switch-over range, all received signals pass through the Short-range (High) beam which is used for reception only.

This configuration allows the radar to focus on the area in which it would typically expect aircraft to be located. It also reduces the amount of reflection received from ground clutter close to the radar, as the higher elevation of the High beam relative to the ground means that reflections received from low level targets and ground-based clutter are reduced in strength (24 page 6 para 8 & 1).

12. MoD. 'The Effects of Wind Turbine Farms on ATC Radar', AWC/WAD/72/665/Trials 10 May 05
23. MoD. 'M Spencer Proof of Evidence in Support of Objection by MoD'. Public Enquiry Local Planning Authority Reference: 20060040 Planning Inspectorate Reference: APP/R2928/A/07/2039188/NWF'
24. MoD. ADATS IPT TB3b. 'Feasibility Assessment of the Possible Tilt Options for the RAF Spadeadam Watchman Radar Systems'
1. CAA. 'CAP 764 – CAA Policy and Guidance on Wind Turbines'

With the peak of the Short-range (High) beam usually elevated to c8° above the horizon the antenna gain and power at low elevation angles is significantly reduced, thus reducing low level and ground reflections/clutter (1 & 23 page 6 para 8).

In describing this configuration and its benefits the MoD states: "*the antenna pattern is such that the gain reduces rapidly for targets at very low elevations. This region of the antenna can be exploited to control the returned signal strength of low elevation targets"* (24 page 3 para 6).

Also, by directing the energy upwards from low levels, ATC radars avoid an effect called diffraction, which can induce serious errors into radar detection. Diffraction is the bending of radar energy, usually by terrain and man-made objects on the terrain, and it produces inaccurate bearing measurements. Errors in bearing can have serious safety consequences for the separation of aircraft solely by radar.

An ATC radar is designed to detect and control aircraft at medium levels. The shaping/focus of the radar beam, the 2 beam configuration and the elevation of the beam (with consequent reductions in gain and power) all help to optimise the radar for that task. By reducing in strength reflections from low level targets and ground-based clutter, the radar avoids unwanted targets at low/ground level to avoid their being confused with wanted targets at medium levels. Overall, the design factors give the radar more desirable, more uniform and more accurate coverage.

For smaller wind turbines like this one, the angle of elevation subtended by the wind turbine to the radar will be low compared with an aircraft target, and the correspondingly lower antenna gain and power will reduce the probability of detection of the wind turbine (23 page 6 para 8).

1. CAA. 'CAP 764 – CAA Policy and Guidance on Wind Turbines'
23. MoD. 'M Spencer Proof of Evidence in Support of Objection by MoD'. Public Enquiry Local Planning Authority Reference: 20060040 Planning Inspectorate Reference: APP/R2928/A/07/2039188/NWF'
24. MoD. ADATS IPT TB3b. 'Feasibility Assessment of the Possible Tilt Options for the RAF Spadeadam Watchman Radar Systems'

8.3 <u>ATC Radar Loss of Gain and Power at Low Elevations</u>

The MoD produced a graph/table (24 page 4 fig 2 & table 3) (reproduced at Fig 8 below) showing the loss of antenna gain and power for targets at/close to the horizon and this is reinforced by the CAA (1 Appendix 7 (2006)). With a Beam switch-over range of 36km the proposed turbine will be in the Long-range (Low) beam of the radar – called the Main beam in the Watchman system (Figure 8 below).

It can be seen from the graph and the table that the loss of gain for a target at 0.31° is c6dB for the Low/Main beam (with a 0° antenna tilt). Similarly the reduction in power for the radar (from the graph/table) is -5dB for 0° tilt.

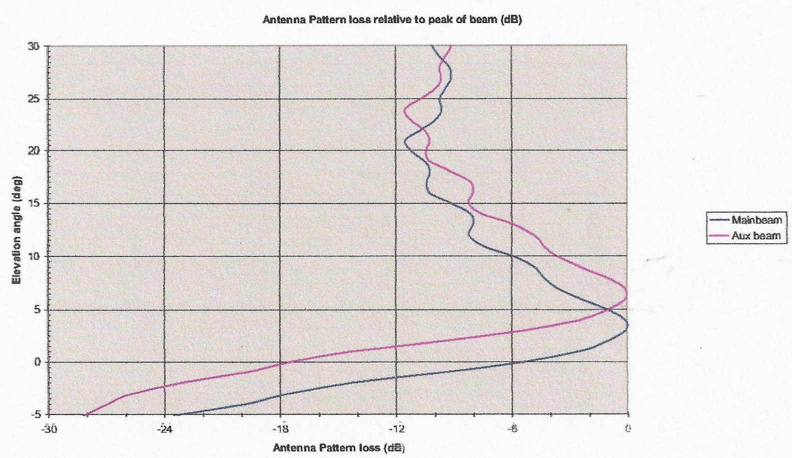


Figure 2 - Berry Hill relative antenna losses

9. Table 3 details the reduction in signal strength that may be expected if the Berry Hill antenna is tilted in ½° increments.

TILT WRT current setting	*MB antenna pattern loss*	*AB Antenna Pattern Loss*	Signal Strength reduction Main Beam	Signal Strength reduction Aux Beam
0.0	-5.4	-17.5	0.0	0.0
0.5	-7.3	-18.9	-3.8	-3.3
1.0	-9.5	-19.8	-8.2	-6.4
1.5	-12.0	-21.5	-13.2	-10.6
2.0	-14.3	-23.2	-17.8	-14.6
2.5	-16.1	-24.7	-21.4	-17.9
3.0	-17.5	-25.7	-24.2	-20.3
3.5	-18.8	-26.5	-26.7	-22.4
4.0	-19.8	-27.0	-28.8	-23.9

Table 3 - Berry Hill Signal Strength Reduction versus antenna tilt

Fig 8. Table Showing Watchman ATC Radar Beam Pattern Changes with Tilt/Elevation Angle (24)

24. MoD. ADATS IPT TB3b. 'Feasibility Assessment of the Possible Tilt Options for the RAF Spadeadam Watchman Radar Systems'
1. CAA. 'CAP 764 – CAA Policy and Guidance on Wind Turbines'

8.4 ATC Radar Processing

In addition to the design of the antenna/radar beam all ATC radars have software/signal processing techniques for distinguishing between wanted and unwanted radar returns. These techniques include processing to remove constant false alarms, for plot extraction, using advanced tracking algorithms, etc.

Probably the most common and oldest technique is Moving Target Indicator/Detection (MTI or MTD) processing which, according to the CAA, enables: *"discrimination of fast moving objects (assumed to be aircraft) from slow moving, or stationary objects (assumed to be clutter such as buildings or terrain); the slow moving or stationary objects can then be suppressed from display."* [1 chapter 2 page 2 para 2.3a]

While the MoD states: *"The lack of Doppler Shift on radar returns from the structure allows the MTI circuitry to filter the returns and prevent them from being displayed to the operator."* [12 page 7 para 20]

There are concerns that in a wind farm a radar may detect one blade of a turbine on one sweep of the radar and another blade on a different turbine on the next sweep. The radar may then 'believe' that the radar return is a real target, but obviously that cannot happen with a single turbine and its clutter is most unlikely to be detected or displayed. Because it cannot happen, some radar operators believe that:

"Single wind turbines are unable to mimic the effects of a moving aircraft" [25 & 6 page 16 para 3.5.2.2.3].

In its major study [12] the MoD refers to the ability of a modern software technique to overcome the extreme interference caused by a very large wind farm. This technique - Plot Extraction - will help the radar detect and track targets over the large area of the wind farm

"a sufficiently advanced plot extractor could significantly mitigate the effect of a wind turbine farm on a Watchman Radar" [12 page B-9 para 9a]

"In extreme situations a sufficiently intelligent plot extractor may be able to outperform an operator in distinguishing aircraft from clutter." [12 page 10].

Plot Extraction is software that predicts (within limits of 'normal' aircraft speed, manoeuvrability, etc) where an aircraft will be on subsequent sweeps of the radar. The ASR-10SS radar has such software – *"The system also offers a plot extractor and tracker"* [26], and *"CFAR, binary integration and adaptive thresholding provides unsurpassed false alarm control"* [26].

It is also important to note that the MoD refers to operations over *"wind turbine farms"* [12, various] where clutter is of concern. There is most unlikely to be any significant clutter from a single, small turbine.

1. CAA. 'CAP 764 – CAA Policy and Guidance on Wind Turbines'
12. MoD. 'The Effects of Wind Turbine Farms on ATC Radar', AWC/WAD/72/665/Trials 10 May 05
25. Newcastle International Airport. Northumberland County Council Planning Application 11/02509/RENE, and others
6. CAA & MoD. 'Wind Energy and Aviation Interests – Interim Guidelines' Wind Energy, Defence & Civil Aviation Interests Working Group
26. Raytheon. Product brochure ' Raytheon ASR-10SS Mk2 Series S-Band Solid-State Primary Surveillance Radar'

8.5 ATC Radar Simplified

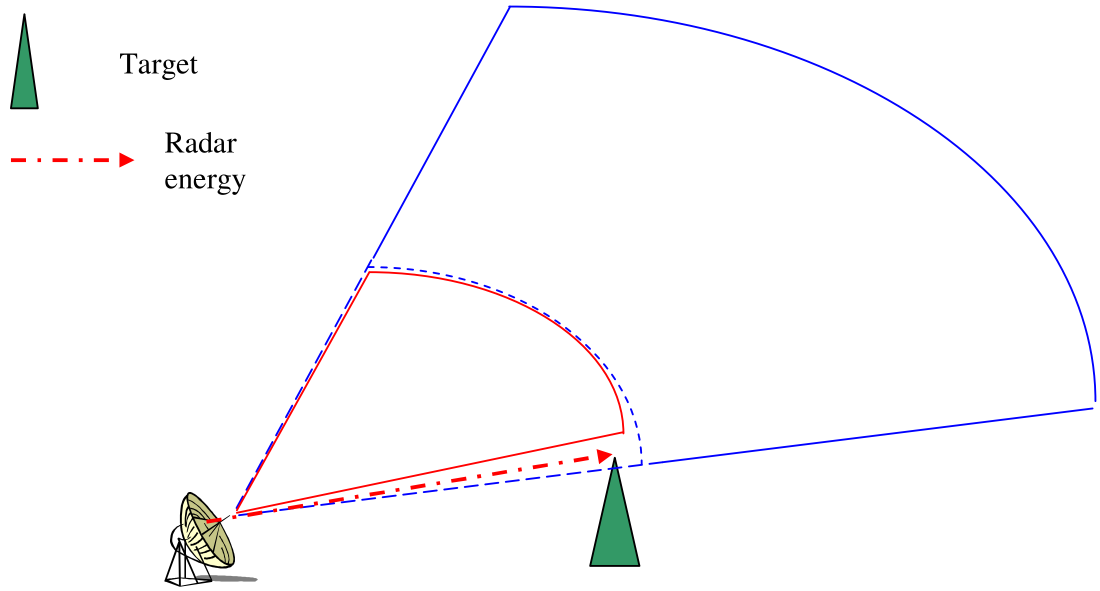


Fig 9. ATC Radar & Low Elevation Angle Targets

Fig 9 aims to show pictorially and simply the effect of the 2 beam arrangement, while a simple explanation follows.

Radar energy is transmitted, reflects off a target and is received back at the radar. The range of the target is determined by the time delay between transmission and reception of the energy. The energy travels at a fixed speed (the speed of light) and there is a simple relationship between speed and time to calculate the distance of the target.

If a radar is set to detect ONLY targets at long range it ignores any energy returned into that beam before a set time period; this is what the Long-range beam does. The Short-range beam 'listens' for energy returning from a target **before** that set time period.

In typical ATC radars all energy is transmitted through the Long-range beam, the Short-range beam is for receive-only.

So, with its higher elevation angle the Short-range beam will not receive energy from all short-range targets – only from those high enough to reflect energy back into the Short-range beam. This is one of the techniques used to avoid the radar detecting all the terrain, man-made objects on the terrain, etc

In Fig 9 the target will be illuminated by radar energy transmitted through the low elevation Long-range beam. But because the target is closer to the radar than the change over range (properly called the 'switch-over range') between the 2 beams, the radar would receive any returned energy through the Short-range beam. But energy is received back at the radar **only if the target is tall enough** to reflect energy back into the higher elevation, Short-range beam.

8.6 ATC Radar Beam Tilting

Beam tilting is also often employed to improve performance and reduce ground clutter by mechanically tilting the antenna. It is especially used in areas of significant terrain clutter to raise the beam over that clutter. The beam shaping and tilting (above the horizontal to reduce clutter from terrain and man-made objects) provides more uniform elevation coverage at medium and high levels, and also has the effect of reducing further the antenna gain at very low elevations.

"In very lay terms, tilting the radar achieves this because it shifts the part of the beam that is particularly good at picking up signals (known as the "gain") away from the returns being produced by the turbines. In effect, it makes the signals appear weaker to the radar". [27 page 9 para 38]

"To reduce the effects of clutter on radar it is possible to mechanically raise the radar beam so that it passes over the wind turbine development." [1 Ch 4 page 5 para 4.2.1]

*"**Effect of Mechanical Beam Tilting on ATS Provision.** Beam tilting results in a significant reduction in low-level radar coverage and so can only be viable in areas where low level coverage is not required for ATS provision."* [1 Ch 4 page 5 para 4.2.2] (ATS is Air Traffic Service).

MoD ATC radars (Watchman) "*are tilted by half or one degree"* [27 page 9 para 36] and this is presumably sufficient to avoid most low elevation, unwanted clutter. Any tilt applied at Manchester would presumably fulfil the same function, reducing the impact of the nearby high terrain.

In early ATC radars, returns from the ground – hills, etc and generally called 'clutter' – were unwanted but experienced and displayed. Modern ATC radars though – like the ASR-10SS – use a variety of software processing techniques to remove the ground clutter, but these techniques have the effect of desensitising the radar so that wanted targets may not be detected.

According to the US FAA [28 page 30 para 3.1.1] *"A common practice today to obtain better detection against ground clutter is to tilt the antenna up so that the peak of the beam is 3 to 4 degrees above the horizon (Figure 3-1). This reduces the ground clutter 15 to 20 dB so that much less improvement factor is required to see aircraft near the peak of the beam.*" Of lower elevation targets the FAA further states they *"are out of the peak of the beam and are hard to detect over clutter"* (= terrain), and *"uptilt will not help in detecting a small aircraft only 1,000 ft. high over strong clutter at 15 nmi"* (27km and close to the range of this turbine, but the turbine is much lower).

27. MoD. 'Mark Spencer, Rebuttal Proof of Evidence in Support of Objection by MoD'. Public Inquiry into Steadings, Ray and Green Rigg windfarms
1. CAA. 'CAP 764 – CAA Policy and Guidance on Wind Turbines'
28. U.S. Federal Aviation Administration (FAA) 'Next generation Airport Surveillance Radar (ASR()) Definition Study

The FAA further states *"Raising the search antenna mechanical tilt will elevate the vertical beam pattern throughout the 360 degree antenna rotation to reduce the effective antenna gain realized on the radar horizon."* [(29 page 6 para 4.1.2)]

9. NATS MANCHESTER APPROACH ATC RADAR

9.1 NATS Radar Details

Some details of the Manchester radar are known [(30 & 26)], having been provided by Manchester Airport for an earlier turbine assessment. Manchester Airport referred BCL to NATS for any operational parameters.

Following enquiries to NATS (and the manufacturers) seeking detailed information about the radar with which to make an assessment, NATS replied [(31a (& b))]: *"I can confirm that I can't provide the information you are requesting"* .

The reluctance to provide data is regrettable as Eurocontrol and the CAA are specific in the data requirements for assessing wind turbines, and these include the radar details [(2 page 27 para 3.2 & 1 App 2 page 2)] requested of NATS but not supplied.

As a result data already held by BCL was used, augmented by other details gained from comparisons with other modern, licensed ATC radars like the ASR-9, ATCR-33K and DASR-11. The Watchman radar was also used for comparison as it is fully licensed and full data is available.

All those radars studied are designed to meet ICAO standards/specifications and there is excellent correlation between all the information obtained. This information provides much of the data required to make an accurate analysis [(1 Appendix 7 (2006)), 24 page 4 fig 2 & table 3 etc)] (see Section 8 page 25 on).

As might well be expected of systems designed to meet the same international specification, the data correlates well between radars.

9.1.1 The radars compared all essentially equivalent - *"Current generation terminal and en route aircraft surveillance radars (ASR-9, ASR-11 and ARSR-4)"* [(32)].

29. FAA, 'Surveillance Engineering Study: Testing the FMH ASR-8 to Predict the Effects of the Cape Wind Turbine Project', 23 February 2010
30. Manchester Airport. Planning Dept (Natalie Garrad) e-mail to BCL 23 Aug 2012
26. Raytheon. Product brochure ' Raytheon ASR-10SS Mk2 Series S-Band Solid-State Primary Surveillance Radar'
31a. NATS. NATS Safeguarding (A Auld) e-mail to BCL 20 Dec 2012
31b. Raytheon (Rick Fagan ATC Radar Marketing Manager) e-mail exchange with BCL Oct 2012
2. Eurocontrol. 'Eurocontrol Guidelines on How to Assess the Impact of Wind Turbines on Surveillance Sensors'
1. CAA. 'CAP 764 – CAA Policy and Guidance on Wind Turbines'
24. MoD. ADATS IPT TB3b. 'Feasibility Assessment of the Possible Tilt Options for the RAF Spadeadam Watchman Radar Systems'
32. MIT, Lincoln Radar Laboratory, 'FAA Surveillance Radar Data as a Complement to The WSR-88d Network'*

9.1.2 Modern ATC radars are not designed to operate below the horizon (28 & 39), with an absolute minimum elevation of 0.3° (28 & 32). Again, these values closely match those of the Watchman radar (37).

9.1.3. Moreover at Ref 38 BAE Systems stated that with a horizontal angle of -0.02° (between its ATC radar and the turbines) *"it is highly unlikely that the radar will see the turbines"*. As in radar terms the difference between -0.02° and +0.3° is not significant (see Fig 8 page 28) this further supports the proposal that the radar is aimed at or above the horizon so that it cannot detect targets at or very near to the ground.

9.1.4 DASR-11 radar is much the same as the Manchester radar ASR-10 which *"uses the same electronics as the ASR-11 with software and hardware options"* (26).

9.1.5 The ASR-9 radar beam pattern compares well with that of Watchman - *"The ASR-9 low beam is optimised for low elevation targets (peak sensitivity at ~2.5 degs) at longer ranges generally beyond 15 - 20 nmi out to the maximum range of 60 nmi; the high beam (peak sensitivity at ~7 degs) is optimised for subclutter visibility of shorter range targets at higher elevations."* (33)

9.1.6. Reductions in gain and power at very low elevations are comparable with those of the Watchman radar. For 0° tilt the Ref (34) states *"Vertical elevation pattern with high roll-off below the horizon to eliminate the effects of ground multipath reflection on detection, accuracy and resolution".* This means that the performance of the antenna – and hence of the radar – drops off markedly from the horizon downwards. Indeed, data given in the Ref shows a drop of antenna gain at the horizon of between 4 and 14dB per degree of reducing elevation (34) (depending on the shape of beam actually produced).

9.1.7. Azimuth beamwidth of 1.5° (26, 28 & 34).

8.1.6. For all the radars compared the vertical beamwidth is very similar (depends on the shape of beam generated) and varies between 3.2° and 35° (26, 32 & 34).

9.1.8. Antenna gain 35dB (26, 28 & 34).

9.1.9. The sensitivity of the radars compared - the Minimum Discernible Signal strength (MDS) -109 dBm (dB milliwatts) is common. (28 page 7 para 4.1.3, 39 page 13 & 40 page 17-37 table 4).

28. U.S. Federal Aviation Administration (FAA) 'Next generation Airport Surveillance Radar (ASR()) Definition Study
39. US Naval Postgraduate School (Lt A Thongrod), ASR-9 Performance Evaluation of a Radar by Computer' Sep 1992
32. MIT, Lincoln Radar Laboratory, 'FAA Surveillance Radar Data as a Complement to The WSR-88d Network'*
37. MoD. E-mail MoD DIO to TGC 13 Feb 12, re S Somerset DC pre-planning application Hill View Farm
38. BAE Systems, e-mail re Fylde Borough Council Wyre Farm Planning Application 10/0594/FUL
26. Raytheon. Product brochure ' Raytheon ASR-10SS Mk2 Series S-Band Solid-State Primary Surveillance Radar'
33. National Aviation Reporting Center, 'Report on Radar Coverage and Propagation Conditions in the area of Chicago O'Hare International Airport, Nov 7, 2006'
34. SELEX Sistemi Integrati S.p.A. 'Antenna Systems brochure
40. Experimental pilot study on the effects of interference on a ARNS Radar System IWR 85/01/5352 VERSION 12000

The Manchester radar is relatively new and replaced an older Watchman radar about 2 years ago. It is a modern ATC radar operating in accordance with CAA/Eurocontrol /ICAO specifications and utilising 2 cosecant squared beams [1, 2, 28 & 26].

Raytheon ASR-10SS Primary Surveillance Radar (PSR – the ATC radar)
Position 381274 382678
ICAO S-band antenna
Frequency 2.7-2.9Ghz
Power output 25KW
Antenna gain 35dBi
Azimuth beamwidth 1.4°
Linear/circular polarisation
Vertical polar diagram similar to Watchman/CAA 'standard'
MDS of -109dBm
On the W side of the airfield at 28m agl (radome?)

9.2 ASR-10SS Radar Processing

In addition to the parameters above the radar has some of the most up-to-date processing available. As Raytheon states [26]:

"optimal target detection and for minimizing ground clutter" and *"unsurpassed false alarm control, including second-time-around returns due to anomalous propagation and birds".*

This processing is particularly well-suited to the processing of terrain and other existing obstacles near the turbine site (Section 11.1 page 40) and for effectively managing false targets (Section 12.3 page 49).

9.3 Manchester Radar Beam Tilting

From Refs 27, 1 & 28 (Section 8.6 page 31) one key reason for tilting an ATC radar antenna is to avoid local terrain thereby reducing unwanted 'clutter' on the radar display. With the Pennines to the N and E, from 16km range and nearly 600m above the radar height, the terrain elevations from the radar vary from 0.4° to 1.2°high (Fig 1 page 4)). It is quite likely, then, that NATS would seek to reduce clutter from this terrain - and to improve detection of aircraft - by tilting the Manchester radar (Section 8.6 page 31).

More closely, the track from the radar antenna to the turbine passes directly over the new 61m Manchester airport ATC tower and the 27m Radisson Blu hotel (c2km range). These will be close to (but probably more than) the minimum range of the radar and may not be detected/displayed. However, radar propagation will still be affected by the structures and they would cause significant diffraction and desensitisation of the radar beam (Sections 11 page 40 and 11.6 page 42).

1. CAA. 'CAP 764 – CAA Policy and Guidance on Wind Turbines'
2. Eurocontrol. 'Eurocontrol Guidelines on How to Assess the Impact of Wind Turbines on Surveillance Sensors'
28. U.S. Federal Aviation Administration (FAA) 'Next generation Airport Surveillance Radar (ASR()) Definition Study
26 Raytheon. Product brochure ' Raytheon ASR-10SS Mk2 Series S-Band Solid-State Primary Surveillance Radar'
27. MoD. 'Mark Spencer, Rebuttal Proof of Evidence in Support of Objection by MoD'. Public Inquiry into Steadings, Ray and Green Rigg windfarms
28. U.S. Federal Aviation Administration (FAA) 'Next generation Airport Surveillance Radar (ASR()) Definition Study

Simple geometry shows that at close range these objects would provide a significant obstacle width and to avoid adverse radar propagation effects over a large azimuth - and hence a large area - it would be usual to site the radar so it propagates over such obstacles. The radar is 28m agl so that to propagate over these 2 structures it is quite probable that the radar is also tilted.

Overall, it is quite probable that the Manchester radar beam is tilted (by mechanically tilting the antenna) to avoid both the local affects and (probably more importantly) the terrain effects. While it is not known precisely what the minimum elevation or tilt of the radar beam is at Manchester but it would be most unusual if it were below the horizon.

NATS claims radar coverage only to *"less than 200m above ground"* [(9 page 12 para 5.10)] it is quite likely to be stating a best case scenario and that would be over flat terrain, for a large target and at short range. Certainly NATS makes no claim of radar coverage at 35m agl - the height of this turbine.

With the beam already at/above the horizon at 0° tilt, the highly focussed and most effective part of the radar beam will be well above the proposed turbine (elevation 0.31°). Moreover as 1° of beam tilt (not quite enough to clear the Pennines) equates to 15m at 1km range - 600m at the range of this turbine - any tilt will take that highly focused and most effective part of the beam will above the tip of the turbine.

As the base of Manchester's controlled airspace in the area of the turbine is 1000+m 1° of tilt would put the focused part of the beam at the right elevation for controlling wanted targets.

9. NATS. 'Mitigating the effects of wind turbines on NATS En-Route Ltd (NERL) operations', . NATS En Route plc (NERL) ATM Policy Statement Issue 3.3. Brendan Kelly Head of NATS Operational Policy

10. RADAR 'PERFORMANCE' CALCULATION

Antenna gain and radar power are key factors in determining the ability of the radar to detect a target. Quite simply, reducing gain and/or power reduces the radar's performance, and both gain and power vary with the position of the target in the radar beam.

Gain is the radar antenna's ability - on transmit and receive - to focus energy to or from a particular direction and elevation. A higher gain antenna produces a more focussed beam which improves radar performance, whilst reducing the detection of unwanted targets and clutter outside that most focussed part of the beam.

Like a torch the power of a radar is focussed in a particular direction, and also like a torch power reduces towards the edges of the radar beam. Indeed, the radar beamwidth - both vertically and horizontally - is defined as the point at which power is reduced by half (the 3dB point). Moreover, that reduction in power - also like a torch and like the antenna gain - is gradual from the centreline of the beam to the edge.

Because of the surrounding high terrain (Section 9.3 page 34) it is assumed that the Manchester radar has a +ve tilt of at least 1°, so variables will be calculated using both the 0° and 1° tilt figures.

10.1 Radar Equation

Calculations to determine the maximum performance of the radar are performed in accordance with CAA & Eurocontrol guidelines [1 & 2 Annex B], with input from the most widely used internationally recognised textbook - 'The Radar Handbook' by M Skolnik [41 Page 2.4 papa 2.2], and from the NATS TOPA for this turbine radar assessment [5 page 6 Appendix A].

The calculations for radar detection can be performed with considerable precision. However, because of the nature of radar systems, the slightly diffuse edges of the radar beam, and transmission anomalies through the atmosphere, the calculations cannot be considered invariably correct. Anomalous propagation in the atmosphere, for example, can increase radar range significantly while rain can reduce it considerably.

Radar parameters for calculation are normally quoted in dB (decibels), which are 10 x the log(10) value. For example 10 in dB is 10dB, 100 is 20dB and 1000 is 30dB. Changes of 3dB are either doubling or halving a value, so that a gain or power of 30dB is half that of 33dB.

Rearranging the equation in terms of received power [2 Annex B, et al] it is easy to calculate the power returned to the radar in dB as follows:

$$Pr = Pt + Gt + Gr + (2 \times \lambda) + \sigma - (4\pi)^3 - Range^4 - \text{System losses}$$

Each factor will be examined in turn.

1. CAA. 'CAP 764 – CAA Policy and Guidance on Wind Turbines'
2. Eurocontrol. 'Eurocontrol Guidelines on How to Assess the Impact of Wind Turbines on Surveillance Sensors'
41. Merrill Skolnik. 'The Radar Handbook'
5. NATS. TOPA Heald Cross Farm Windfarm Development, Issue 1 NATS ref W(F)15745

10.1.1 Pr. The power of the radar return received back at the radar. If this power level exceeds the radar's sensitivity (called the MDS – Section 10.2 page 39) then the target will be displayed.

10.1.2 Pt. The radar's transmitted power. The radar's peak power is 25KW [26]/44dB but at the very bottom of the beam - ie the edge of the beamwidth – power, by definition, is reduced by at least 3dB and reduced further with any +ve tilt. At Fig 7 page 26 [24 page 4 fig 2 & table 3] the power reduction for 1° of tilt is 9.5dB.

0° tilt Pt = 44 - 3 =	**41.0dB**
1° tilt Pt = 44 - 9.5 =	**34.5dB**

10.1.3 Gt = Gr. The gain of the antenna is the ability of that antenna to focus radar energy into a relatively narrow beam. Full gain is 35dB but at very low elevation gain is likely to be reduced by between 5.4 and 8.2dB (Fig 8 page 28) [24 page 4 fig 2 & table 3, 35, 36 and others] depending on the tilt angle.

0° tilt G = 35 - 5.4 =	**29.6dB**
1° tilt G = 35 - 8.2 =	**26.8dB**

10.1.4 λ Wavelength of the S band radar is 10cm or -1dB

λ =	**-10dB**

10.1.5 RCS (σ). Radar Cross Section (RCS) of the turbine can be considered its reflecting area, although it is actually a complex topic depending on a variety of factors. NATS uses a value of 16dBsm for small turbines (less than 45m high) [42] While at Ref 11 [page 14 para 50] the MoD estimated a lower RCS for a turbine larger than that proposed (9 vice 16dBsm). While ADTI suggests that in practice the RCS of a large turbine as seen by an ATC radar is more likely to be 9dB lower than the peak [43 page 18] – about 1/10th of the maximum RCS.

Whatever value is used it is important only if the radar is actually pointing at the turbine and that is not always the case. Even when being closely observed in a trial and when the turbine is full LoS to the radar, the radar is likely to 'see' the turbine only 26% of the time [13 page 52 para 6.5.4.2].

"The joint probability that the radar will have transmitted in the direction of the turbine at the precise time that the peak of the blade RCS passes the reciprocal direction is very low." [44 page 3-6 para 3.3.1.4].

26 Raytheon. Product brochure ' Raytheon ASR-10SS Mk2 Series S-Band Solid-State Primary Surveillance Radar'
24. MoD. ADATS IPT TB3b. 'Feasibility Assessment of the Possible Tilt Options for the RAF Spadeadam Watchman Radar Systems'
35. U.S. Federal Aviation Administration (FAA) 'Next generation Airport Surveillance Radar (ASR()) Definition Study
36. SELEX Sistemi Integrati S.p.A. 'Antenna Systems brochure
42. National Air Traffic Services (NATS), S Lanarkshire Council Carluke Turbine Planning Application CL/11/0388
11. MoD. RAF Signals Engineering Establishment, 'Study into the Effects of Wind Turbines on Radar Performance', Technical Report 94010
43. ADTI/US Navy, 'Riviera Wind Farm Effect on Kingsville Naval Air Station' Jun 2010
13. QinetiQ, 'Wind Farms Impact on Radar Aviation Interests', Final Report. FES W/14/00614/00/REP. DTI PUB URN 03/1294. 2003
44. Alenia Marconi/DTI. 'Feasibility of Mitigating the Effects of Windfarms on Primary Radar' ETSU W/14/00623/REP, DTI PUB URN No. 03/976

Perhaps more importantly than any of the RCS discussion above is the finding from the US DoD study at Ref 14 which states: *"The RCS values indicated on Figure 21 are dominated by the tower and nacelle at the lower look-up angles. However, at the larger look-up angles, where scattering from the rotating blades dominates, the RCS values are comparable to or greater than typical RCS values for aircraft."* (page 31 Fig 21, & reinforced at 45 page 15)

As the US trials were for *"A total of 479 individual calibrated measurements of turbines"* (14 page 29) these Trials are significant and the results robust. So, at the very low elevation angle of this turbine the majority of the turbine RCS is from static components and will be 'filtered' from the radar display – if detected at all – by the radar software. (23 page 6 para 7, 45 page 27 & page 30 Table 2-1 & elsewhere, & 46 page 17 para 2.5 & page 23 para 3.3)

These findings are reinforced in a QinetiQ study for the MoD (46) which highlights the reducing RCS with reducing elevation angle (46 page 21 table 3.2 and others, & 45 page 52), and the reducing detection range with reducing elevation angle (46 page 22 Table 3.4 and others).

However from Section 7.3 page 22, when the LoS is calculated to the turbine hub the intrusion into the Fresnel Zone becomes so pronounced that not all the RCS of the turbine may be 'seen'. The US Navy/ADTI and QinetiQ suggest that the actual RCS 'viewed' could even be as low as -10dBsm (13 page 19 para 4.5.9) - so low a value that it could not possibly be detected by an ATC radar at this turbine's range. However, more likely values are between 5 and 10dBsm (43 page 18 & 13 page 21 para 4.5.13)

It would, then, be reasonable to use a smaller RCS in the calculation.

RCS = **9dBsm**

10.1.6 $(4\pi)^3$. A constant = 1985 or **33dB**

10.1.7 Range. Slant range = 43172m = **46.4dB**

10.1.8 System Losses. All electromagnetic systems suffer from losses – they do not, even on first commissioning, work exactly as designed. In radar systems, not only do the electronics become degraded but the cables deteriorate, and the radar feed/horn and antenna will not necessarily be perfectly aligned/focussed. There are also losses as the energy propagates through the atmosphere. For a system like the ASR-10SS losses are likely to be c13dB (41 various, 47 various, 48 Ch 2 page 10 para 2.7 on, & 49 page 13 & page 43 para 2.9).

Losses = **13dB**

14. US Dept of Defense, Office of the Director of Defense Research and Engineering. 'Report to the Congressional Defense Committees The Effect of Windmill Farms On Military Readiness 2006'
45. Vertical Axis Wind Turbine Radar Impact Assessment using the qr5. July 08
23. MoD. 'M Spencer Proof of Evidence in Support of Objection by MoD'. Public Enquiry Local Planning Authority Reference: 20060040 Planning Inspectorate Reference: APP/R2928/A/07/2039188/NWF'
46. QinetiQ (for MoD). 'Study into the radar impact of a Micro turbine' Nov 2007. QINETIQ/EMEA/TS/TR0707953/1.0
13. QinetiQ. 'Wind Farms Impact on Radar Aviation Interests', Final Report. FES W/14/00614/00/REP. DTI PUB URN 03/1294. 2003
43. ADTI/US Navy, 'Riviera Wind Farm Effect on Kingsville Naval Air Station' Jun 2010
41. Merrill Skolnik. 'The Radar Handbook'
47. Experimental pilot study on the effects of interference on a ARNS Radar System IWR 85/01/5352 VERSION 12000
48. James A. Scheer, 'The Radar Range Equation' ISBN : 9781891121524 January 19, 2010
49 M C Budge 'Radar Basics', 2011

10.1.9 Result.

9.1.9.i Pr at 0° tilt

Pr = 41 + 29.6+ 29.6 + (2 x -10) + 9 – 33 – (4 x 46.4) – 13

Pr at 0° tilt= -142.4 dBW (dB Watts) = -111.4 dBm (dB milliwatts)

9.1.9.ii. Pr at +1° tilt

Pr = 34.5 + 26.8+ 26.8 + (2 x -10) + 9 – 33 – (4 x 46.4) – 13

Pr at +1° tilt = -154.5 dBW = -124.5dBm

10.2 Discussion of Results

To be detected and displayed on the radar screen the returned signal must be greater than the Minimum Discernible Signal (MDS = sensitivity) strength of the radar (23 page 9 note 3). So, if the power received back at the radar from the turbine is much lower than the MDS of the radar the turbine will not be detected.

The MDS of the Manchester radar is assumed to be -109dBm and it can be seen that even at 0° tilt – best case scenario – the signal received back at the radar is below that minimum signal strength – the turbine will not be detected.

Once an antenna tilt is assumed the power received back at the radar falls further still, by over 10dB – it is a received power less than one tenth that with no antenna tilt.

10.2.1. MDS. However, the MDS itself is not an absolute but is, essentially, statistical in nature and related to system noise (41 page 1.7). It is understandable if Raytheon, Selex and other manufacturers provided the most advantageous figure and that the actual, operational performance value is higher than that quoted – ie the radar is less sensitive.

In discussing changes of just 1dB it is important to note one of the summaries from Eurocontrol *“The effect of 1 dB loss, …can start to produce degradation to the radar detection. ..both low & high-level cover have been eroded.”* (48 page 14-17 section 14-3 para 29).

Even assuming optimum radar performance and maximum ‘exposure’ of the turbine to the radar, the signal received back at the NATS radar from this turbine will be below the level that can be detected by the radar. The turbine will not be detected.

23. MoD. ‘M Spencer Proof of Evidence in Support of Objection by MoD’. Public Enquiry Local Planning Authority Reference: 20060040 Planning Inspectorate Reference: APP/R2928/A/07/2039188/NWF’
41. Merrill Skolnik. ‘The Radar Handbook’
48. Eurocontrol, ‘Experimental pilot study on the effects of interference on a ARNS Radar System’

Radar Equation Conclusions

The power received back at the radar from this proposed turbine will be too low for the turbine to be detected

If the turbine is not detected then none of the unwanted radar effects will be present

11. OTHER RADAR CONSIDERATIONS

Although the radar equation is extremely precise, radar performance itself is not an exact science. So, in addition to the calculation it is useful to examine what additional factors will ensure that the turbine will have no impact on the Manchester radar in the very unlikely event that it is detected.

11.1 Additional Obstructions

The CAA considers that turbines might well appear to the radar just as a large static return *"whether the blades are rotating or not, a wind turbine presents an obstruction to a radar signal in the same way as any other structure, e.g. a large building."* (1 Ch 2 page 3 para 2.3d)

An examination on Google Earth and the relevant OS maps along the track from the Manchester radar to the site of the proposed turbine shows many areas with very large buildings/commercial developments - Manchester city itself, Middleton and W of Rochdale for example. These developments house a large number of distribution centres/warehouses - with some of them showing metal flat sides of almost 1000sq m (30dBsm) to the radar. At only 25km and only a slightly lower elevation angle to the proposed turbine they might be considered significant if this turbine is considered so at almost twice the range. Yet NATS appears not to have objected to them even though they are full LoS to the Manchester radar.

Very near to the site itself there are several sets of high voltage electricity pylons - one set (pylons A) running parallel to the track (from radar to site) and 2 (pylons B & C) at 90° to it. Pylon set A is quite tall - perhaps 25+m high - and less than 100m from the track (from radar to site) and runs parallel to it for about 3 km. Pylons set B is also 25+m high and crosses the track about 250-300m before the turbine. Set C is smaller (15m high) and closer to the turbine at less than 100m. The line of Pylons A are significant because they will always be in the azimuth beamwidth of the radar (at 40+km that beamwidth will be 600+m) with at least one pylon very close by. That means that if the radar does 'see' that low the pylons will be processed by the radar as a single target.

There are also farm buildings on the track, about 500m before the site.

All of these obstacles will cause clutter and diffraction on the radar. Diffraction in particular causes bending of the beam and a loss of radar power, and it can have a serious adverse effect on radar detection.

1. CAA. 'CAP 764 – CAA Policy and Guidance on Wind Turbines'

11.2 Road Traffic

The effect of moving targets is problematic with A class roads and motorways when traffic often moves at the same speeds as turbine blade tips, and this was a particular problem with older generation radars. The A681 out of Bacup (visible as a main road on the map at Fig 1 page 4) runs in about the same direction as the track from the radar to the turbine and about 350m from it. Modern radars use better doppler and other processing to determine whether the target is actually moving over the ground. If the radar can 'see' to the very low elevations of the turbine then the traffic on the A681 is also likely to show as 'valid targets'. Or more likely the radar processing and settings are altered so the traffic - and the nearby turbine - will not show.

11.3 Other Nearby Turbines

In addition to the pylons there appears to be at least one small turbine operating 300m SW of this proposal. This is probably Rossendale BC 2010/0379 - a 24.5m turbine - to which NATS made no objection yet it is LoS to the Manchester radar.

Perhaps more significantly, not too far away is a consented proposal for a wind farm of 5 x 125m turbines (Calderdale Council ref 10/01057) all virtually full LoS to the radar. Yet NATS made no objection to this proposal.

11.4 Additional Clutter

The terrain, the pylons, the buildings, the existing turbine and the proposed wind farm will all affect radar propagation, reducing the signal strength on both the outbound and return paths (assuming propagation at very low elevations) (Section 7.3 page 22).

The radar returns from all these obstacles will be classed as 'clutter' [(1 Chapter 2 page 1 Note 1)] but are likely to be processed so they do not show on the display. They will, though, tend to reduce the radar's sensitivity reducing its ability in the area to detect small targets (Section 11.6 next page).

11.5 NATS Additional Clutter Response

During preliminary discussions between the Applicant and NATS (Ref 58) NATS seemed to admit that the radar already suffered from clutter in the area: *"in isolation we would have been happy with this turbine, it as an extension to this already problematic area of clutter that we object"* [(58)].

This concern is before the erection of 5 x large turbines or this single, small one and the clutter must only refer to the existing terrain, buildings and pylons. Surely, it is not reasonable for NATS to object buildings, electricity pylons, etc or is the concern about developments that might take place?

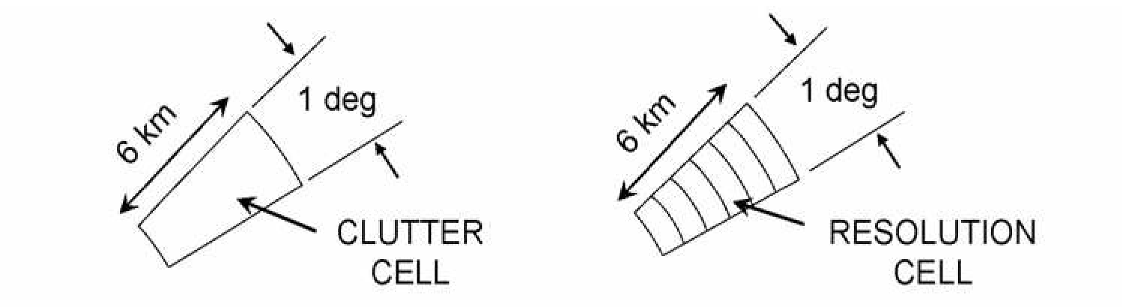
The mitigation offered by NATS to this "*problematic area of clutter"* was a suggestion of some spot blanking. Sadly, this is likely to be at a disproportionate cost for a single, small turbine. Or is the mitigation being discussed an attempt to mitigate the existing terrain/buildings or the proposed 5 x large turbine wind farm?

1. CAA. 'CAP 764 – CAA Policy and Guidance on Wind Turbines'
58. NATS. NATS Safeguarding (A Auld) e-mail to DC21 Ltd 5 Dec 2012

11.6 Radar Return Signal Processing of Terrain and Other Clutter

Radars are affected by unwanted clutter from terrain and man-made objects, and various techniques have been implemented to reduce such clutter. In very old systems this was achieved manually, but in more modern ones it is achieved through software processing. At Ref 49 the MoD explains this *"most important"* processing technique used by the Watchman radar (page 25 para 77) – Background Averaging.

The MoD states (49 page 25 paras 78/79) *"Background averaging involves the processor of the Watchman radar forming a map of clutter local to the radar in question. The map consists of "clutter cells" which are superimposed in a grid radiating out from the radar, as depicted in the left-hand image in Figure 5 below. For each clutter cell, the radar has a return signal amplitude set so that, in that clutter cell, only targets returning a signal with an amplitude in excess of that threshold amplitude will be displayed on the screen.*



79. The drawback of this approach is that the radar is effectively "desensitised" in the areas where there is clutter, and so will not display the smallest targets when they fly over clutter (AMEC/10/1, §18). This desensitisation can be significant, because actual aircraft tracking employs "resolution cells" that are smaller than the clutter cells in order accurately to establish the actual position of an aircraft. Accordingly, as shown in the right-hand image in Figure 5 above, several resolution cells could be affected by clutter in a single clutter cell, meaning that returns some distance away from the clutter are also masked." (49 page 25 paras 78/79)

In an area of significant clutter, like from a large wind farm, there is concern that a real aircraft return could be masked or the radar be reduced in sensitivity for one sweep of the radar or more (a light aircraft at 90kts completing a longitudinal transit of a large wind farm, for example).

However, the clutter return from a single, small turbine is likely to be no greater than that from a mobile phone mast and if it has any impact at all (most unlikely) it would be for less than one sweep of the radar as any real Manchester target would pass quickly over it.

49. MoD. 'Closing Submissions on Behalf of the MoD', Public Inquiry into Steadings, Ray and Green Rigg windfarms. 2007/08

More importantly, the area of this proposed turbine is one of hilly terrain and terrain provides significant clutter for radar (12 page E-1 para 2, & 48 page vi para 4 & page 14-17 para 30). The hill on which the turbine will stand will provide terrain 'returns' to the radar (46 page 27 para 3.6 & 48 page 14-17 paras 29/30) and desensitise it as described by the MoD – and it is far from the highest hill either in its area or in the Manchester ATC radar area.

Even in the absence of the turbine the radar will already be less sensitive in the area proposed, and when erected the turbine is even less likely to be detected.

<u>Other Radar Considerations Conclusions</u>

Aircraft will be detected as much as they currently are, because the significant high terrain near Manchester means the radar is already quite likely to be desensitised in the area of this proposal

This desensitisation will further reduce the likelihood of the turbine being detected

The turbine will add no significant further desensitisation to the radar

11.7 Radar Antenna Gain advantage

Sections 8.2 and 8.3 (page 25 on) encapsulate the MoD comments in Ref 23 (page 6 para 8) which, more specifically, are *"The correspondingly lower antenna gain will give the aircraft some advantage over the wind turbine for detection within the auxiliary beam region. This of course will only be true if the antenna gain to the aircraft plus the RCS of the aircraft substantially exceeds the antenna gain in the direction of the wind turbine plus the RCS of the wind turbine. In this situation the detection threshold of the radar can, in theory, be increased over the windfarm whilst maintaining sensitivity for detection of small targets which reside at elevation angles close to the radar peak of beam."*

While the effect is explained further as (50 page 18 para 7.2) *"It shows that the as aircraft altitude increases the "gain benefit" rises rapidly. Whether the gain is significant depends on the relative RCS of aircraft and wind turbine.. if the gain advantage approaches 15 dB, all other factors being equal then the RCS effect of the wind turbine will start to diminish."* While Skolnik states a 10-20dB advantage is required (41 page 1.7).

12. MoD. 'The Effects of Wind Turbine Farms on ATC Radar', AWC/WAD/72/665/Trials 10 May 05
48. Eurocontrol, 'Experimental pilot study on the effects of interference on a ARNS Radar System'
46. QinetiQ. 'Study into the Radar Impact of a Micro Turbine', QINETIQ/EMEA/TS/TR0707953/1.0, November 2007
23. MoD. 'M Spencer Proof of Evidence in Support of Objection by MoD'. Public Enquiry Local Planning Authority Reference: 20060040 Planning Inspectorate Reference: APP/R2928/A/07/2039188/NWF'
50. A Collinson, 'Proof of Evidence' Public Inquiry into Steadings, Ray and Green Rigg windfarms 2007/08'
41. Merrill Skolnik. 'The Radar Handbook'

Extrapolating the results from the US Navy/ADTI major study [43] of a wind farm of 75 x 80m turbines (over twice the height of this proposal) validates the gain advantage information above. It demonstrates that even a single, large wind turbine in the line-of-sight of the low beam of the radar at over 40km range should not produce target loss.

Similarly the US FAA demonstrated the same results in its research for a 130 x 130m turbine wind farm when the radar 'achieved' 99.49+% probability of detection of targets as low as 400ft over the wind farm [29 page 14 para 5.1]. This height of overflight is, of course, much lower (c 1000m lower) than that of any aircraft requiring a radar service from Manchester.

For operations in poor weather (properly called IMC, Instrument Flying Conditions) – when an ATC radar service is almost always used – the Surveillance Minimum Altitude for the area of the turbine is almost 3500ft [51 page 1 para 1.1 & 52] effectively inside the Manchester TMA [52]. This is *“the minimum safe levels allocated by a controller vectoring IFR flights”* ie the minimum safe level for ATC radar controlled flights.

The altitude at which aircraft will be radar controlled in the area of this turbine is well above the tip of the turbine. At this altitude - at over 1° elevation - the aircraft will be in the ‘peak’ of the radar beam and will ‘experience’ maximum radar antenna gain, whereas the turbine tip will be at almost minimum gain or even below it (see Section 8 page 25 on).

The difference in power and gain (the latter for each of the outbound and return paths) is at least 3 + 5.4 + 5.4 = 13.8dB even for 0° tilt, or 25.9dB for 1° tilt. While typical Manchester controlled aircraft are likely to have RCS of 20+dBsm [13 page 31 para 5.5.2]. When the difference between the RCS of the aircraft and that of the turbine is added to the additional power and gain experienced by the aircraft, that aircraft will have a minimum ‘gain advantage’ over the turbine of 13.8 + (20-9) = 25.8dB. This is much more than the 15dB required.

As 3dB is a change of 100% (a power level of 3dB more than before means power has doubled), the difference between the 15dB requirement for gain advantage and the 20dB or more gain advantage of this turbine over an aircraft under ATC radar control means the aircraft will easily be distinguished.

Indeed, that gain advantage will apply even if, in the unlikely event that, the radar ‘paints’ the aircraft for exactly the very short time it would be over the turbine.

Radar Gain Advantage Conclusions

Aircraft targets will always be easily detected as they have a very significant gain advantage over the turbine

An aircraft will pass over a very small turbine very quickly – in much less time than 1 sweep of the radar

43. ADTI/US Navy, ‘Riviera Wind Farm Effect on Kingsville Naval Air Station’ Jun 2010
29. FAA, 'Surveillance Engineering Study: Testing the FMH ASR-8 to Predict the Effects of the Cape Wind Turbine Project', 23 February 2010
51. CAA. ‘CAP777, ATC Surveillance Minimum Altitude Charts in UK Airspace’
52. NATS. UK NATS AIP (24 Sep 09) AD 2-EGCC-1-1, Manchester
13. QinetiQ. ‘Wind Farms Impact on Radar Aviation Interests’, Final Report. FES W/14/00614/00/REP. DTI PUB URN 03/1294. 2003

11.8 Turbine Probability of Detection

Although the rotating blades of a large turbine may present an intermittent target there is no surety that they will actually be detected. Indeed as one radar company states in its research: *"The joint probability that the radar will have transmitted in the direction of the turbine at the precise time that the peak of the blade RCS passes the reciprocal direction is very low"* [44 page 3-6 para 3.3.1.4].

Moreover, as QinetiQ demonstrated during its extensive Trail against a single very large turbine the turbine will not always be seen by the radar. Indeed, QinetiQ concluded *"For low probability of detection set wind turbines such that they are mainly yawed close to 90° from the radar direction"* [13 page 78 para 8.6.2]. This proposed single, small turbine's prevailing orientation into the wind will be 90° from radar (Fig 1 page 4).

Similarly the US FAA demonstrated the same results in its research for a 130 x 130m turbine wind farm when the radar 'achieved' 99.49+% probability of detection of targets as low as 400ft over the wind farm [29 page 14 para 5.1]. This height of overflight is, of course, much lower than that of any aircraft requiring radar service from Manchester.

Turbine Probability of Detection Conclusion

Even if radar energy is propagated at a very low elevation angle to 'see' the turbine, there is a very low probability of it being detected

44. Alenia Marconi/DTI. 'Feasibility of Mitigating the Effects of Windfarms on Primary Radar' ETSU W/14/00623/REP, DTI PUB URN No. 03/976
13. QinetiQ. 'Wind Farms Impact on Radar Aviation Interests', Final Report. FES W/14/00614/00/REP. DTI PUB URN 03/1294. 2003
29. FAA, 'Surveillance Engineering Study: Testing the FMH ASR-8 to Predict the Effects of the Cape Wind Turbine Project', 23 February 2010

11.9 Manchester Radar Beam Switching

As a further means of reducing unwanted low level radar returns and maintaining good aircraft tracking, the Manchester radar switches automatically between High and Low beams to achieve *"switchable high/low beam patterns"* [(26)].

The technique is explained in Ref 43 (the ASR-10SS at Manchester is equivalent to the DASR-11) as:

"The radar system is capable of scanning the skies for airborne targets using two different antenna patterns. The low beam is used to scan for targets that are further away and thus at a lesser elevation angle with respect to the antenna. The pattern is thus tailored to offer greater directivity at lesser elevation angles. As targets approach the radar, they begin encroaching upon regions of the low beam antenna pattern that do not offer as much gain, and are thus less likely to be detected. To avoid potential target loss, the radar system is able to switch to a high beam pattern, which offers more gain at greater elevation angles with respect to the radar. The DASR-11 ATC is able to switch between the two antenna patterns continuously." [(page 21)]

ASR-10SS Radar Beam Switching Conclusion

Real targets will always be detected and displayed because beam switching by the Manchester radar

- reduces ground clutter (inc small ground-based targets like the turbine), and

- improves real aircraft tracking

26. Raytheon. Product brochure ' Raytheon ASR-10SS Mk2 Series S-Band Solid-State Primary Surveillance Radar'
43. ADTI/US Navy, 'Riviera Wind Farm Effect on Kingsville Naval Air Station' Jun 2010

12. OTHER AIR TRAFFIC CONTROL CONSIDERATIONS

12.1 Radar Shadow

A few large turbines have already been approved in the area and are operating. It is extremely hard to imagine any shadow regions from these 'combining' to create a large shadow region, and their individual shadow regions are likely to be very small (13 page 79 para 8.6.5, page B-12 para B.5.4 & page B-16 para B.5.17). More importantly as the Reference indicates, the shadow region from a small turbine is virtually non-existent.

"This is unlikely to be a problem in practice for realistic aircraft" (13 page B-16 para B.5.17).

Radar Shadow Conclusion
A small, single turbine produces no shadow and real aircraft will always be detected

12.2 Pseudo-Wind Farm

In addition to unwanted radar interference from individual turbines there is also a concern that a combination of individually erected turbines might act as a pseudo-wind farm, exacerbating the interference effects.

In a wind farm each turbine can produce a return, it may have a Doppler (= velocity) component and there may be reflections between the blades. The radar may illuminate one blade of one turbine on one sweep and another blade of another turbine on the subsequent sweep, creating an apparently moving target (depending on radar parameters, turbine spacing, etc). However, radar software is able to distinguish between targets that move across the ground – like real aircraft - and those that are stationary – like the blades of a single, isolated turbine.

The design of a 'true' wind farm is a number of compromises between many factors, including the spacing between individual turbines. Typically, though, individual turbines in a wind farm are located 200m apart, to ensure that wind/turbulence interactions between the adjacent 50m blades are reduced to a minimum, as are the expensive components required to connect them together and to the electricity grid. Indeed, one of the largest wind farms in England (Scout Moor) comprises 26 large (100+m) turbines in an area of just 0.04 sq mile (8.5ha) - a density of 700 large turbines per sq mile. It is in wind farms with these dimensions that research and trials have taken place and in which some of the adverse effects have been observed.

13. QinetiQ. 'Wind Farms Impact on Radar Aviation Interests', Final Report. FES W/14/00614/00/REP. DTI PUB URN 03/1294. 2003

More importantly, these inter-reflections have occurred (if at all) between nearby large turbines when closely spaced in a wind farm, but have never been reported between turbines over longer distances. Moreover, it is most unlikely that any Planning Authority would permit adjacent large turbines at the relatively close spacing needed to replicate a wind farm, so the effect could not occur. The effects are, then, completely unlikely to occur between small wind turbines on individual rural sites.

As QinetiQ states of a single, small turbine near Exeter airport: *"being a single turbine, this would not lead to false tracks on a radar display since this effect needs adjacent turbines to give the turbine clutter the appearance of a moving object"* (59 page 8 papa 1.5.4).

Research into the local authorities covering the area has revealed a relatively small number of turbine applications/operating turbines – mostly small turbines. A wind farm has a density of c10 turbines per sq km, with turbines perhaps 200m apart, and it is almost impossible to imagine an LPA granting permission for several, individual turbines at that sort of spacing. Therefore, the area surrounding this proposal cannot be considered to equate to a wind farm. Even if all the turbines could be seen by the radar they could not replicate the adverse radar effects from wind farms.

This is presumably why the CAA, MoD and other radar operators conclude that *"Single wind turbines are unable to mimic the effects of a moving aircraft"* (25 & 4 page 16 para 3.5.2.2.3).

<u>Pseudo-Wind Farm Conclusions</u>

Individual, small turbines on separate rural sites cannot display interactions between blades and false aircraft will not be generated

A single small turbine cannot be confused with a real aircraft

59. QinetiQ. 'Technical Memo: Radar Impact Assessment of the Aishe Barton Wind Turbine' Mar 2009
25. Newcastle International Airport. Northumberland County Council Planning Application 11/02509/RENE, and others
4. CAA & MoD. 'Wind Energy and Aviation Interests – Interim Guidelines' Wind Energy, Defence & Civil Aviation Interests Working Group

12.3 Additional False Targets

The airspace in the vicinity of the turbine is uncontrolled - available for a variety of users inc pilots flying light aircraft, microlight aircraft, gliders, hang gliders and low flying military aircraft – all without any reference to Manchester ATC. A 20kg model aircraft with a 10ft wingspan could legally be flown in the area of the proposed turbine up to 400ft above ground level and at speeds of c150mph (more than the turbine tip rotation speed), and without any reference to local ATC (53). Flocks of birds, of course, could also be present.

Near to the proposed location (to the SW of it) is the Holden Bank Helicopter landing site and the Rossendale Gliding and Hang Gliding site. While the Fence helicopter site is nearby (to the NW) (see map at Fig 1 page 4), and light aircraft from Manchester Barton use the area for general flying. All of them can and will provide uncontrolled 'targets', which can be detected by radar and are most unlikely to have radio contact with Manchester or to expect an Air Traffic Service.

All of these have the potential to present transitory 'detections' on a radar and they could reasonably be considered the same as the transitory detection of a small turbine. ATC radar controllers deal with such transitory detections as a routine part of daily operations. So, if it did occur it would be similar to and will be dealt with in the same was as all other transitory targets.

Additional False Target Conclusion

Transitory radar targets are a routine part of everyday ATC operations and, if detected at all, the proposed turbine can be treated as any other transitory target

12.4 Additional Air Traffic Considerations

12.4.1 Visual Flight Rules. Under Visual Flight Rules (in the area below the TMA) pilots are responsible for terrain/obstacle clearance and are required to be 500ft above such terrain/obstacles (54 & 56). In the area of the turbine this equates to 1850+ft/570m above mean sea level (amsl), well above a turbine tip that is less than 435m amsl.

12.4.2 Instrument Flight Rules For operations in Instrument Flying Conditions aircraft would have to be at almost 1000m amsl - effectively in the Manchester TMA (51 page 1 para 1.1, 52 & 55) – again well above the turbine and in the peak of the radar beam.

12.4.3 Manchester Standard Flight Routes. An examination of the Manchester Standard Instrument Arrival and Departure routes (52) shows that only one route passes near the site and by then the aircraft will be at 5000ft (1500m). Any aircraft on that route will very quickly pass the turbine location and anyway the aircraft will also benefit from being right in the peak of the radar beam.

53. CAA 'CAP 658. Model Aircraft: A Guide to Safe Flying'
54. CAA. 'CAP 85 Aviation Law'
56. CAA, 'Guide to Visual Flight Rules (VFR) in the UK'
51. CAA. 'CAP777, ATC Surveillance Minimum Altitude Charts in UK Airspace'
52. NATS. UK NATS AIP (24 Sep 09) AD 2-EGCC-1-1, Manchester
55. NATS. UK AIP (12 Mar 09) ENR 1.6 — ATS Surveillance Services & Procedures

Additional Air Traffic Considerations Conclusions

The location is vertically well clear of controlled airspace and horizontally clear of instrument routes.

Below the Manchester controlled airspace pilots will be operating VFR and will be responsible for their own clearance/safety

In the TMA pilots will be well above the turbine where the radar will operate at maximum 'performance' and be easily able to identify them

13. NATS TURBINE IMPACTS - THIS ASSESSMENT'S CONCLUSIONS SUMMARISED

It is worthwhile summarising NATS expressed concerns on turbine impacts (9 page 13 para 5.11) and this assessment's evidence-based conclusions:

13.1 ***"a) Turbines have a reflectivity at least as large as most aircraft:***
The design of modern turbines gives them an exceptionally large radar cross section (RCS). As a UK government report in 2003 stated "Any operating ATC radar must be sensitive enough to see the small aircraft, which tend to have RCS of about 1m2 to 10m2, where as the turbine return is up to 1000m2 in some instances."

As a small, single turbine at a very low elevation angle this turbine has a smaller RCS than aircraft operating at Manchester - certainly less than 10dBsm (Section 10.1.5 page 37)

At the very bottom of the radar beam the turbine will also be at a significant gain disadvantage to aircraft which will be in the heart of the radar beam (Section 11.7 page 43)

13.2 ***"b) Turbines occupy similar elevations to aircraft:***
Whilst turbines generally reside at lower elevation than the majority of aircraft, their hill-top locations are higher than most other reflecting objects."

At 0.3° the turbine tip is at a much lower elevation than any aircraft which would be well over 1° in the Manchester TMA (flying at 1000+m) above the turbine site (Sections 3 page 4 & 11.7 page 43)

13.3 ***"c) Turbine blades are moving at the moment of reflection:***
Moving turbine blades display the same characteristics as moving aircraft making it impossible for existing moving target detection algorithms to tell the difference."

The turbine blades might move but there is a very low probability that the radar will be pointing at them when the blades show enough to reflect sufficient energy (Section 11.8 page 45)

Moreover, modern radars not only detect the velocity of a target but also whether it moves across the ground and a single turbine will not do that and cannot be perceived by the radar as doing that (Section 8.4 page 29)

That is why some radar operators believe that a single, small turbine cannot mimic an aircraft (Sections 8.4 page 29 & 12.2 page 47)

9. NATS. 'Mitigating the effects of wind turbines on NATS En-Route Ltd (NERL) operations', . NATS En Route plc (NERL) ATM Policy Statement Issue 3.3. Brendan Kelly Head of NATS Operational Policy

13.4 ***"d) Turbine returns are inconsistent:***
The characteristics of turbine echoes are heavily dependent on turbine (and therefore wind) direction as well as the blade orientation at the moment of interrogation. Returns from an individual turbine are consequently inconsistent."

Many targets are inconsistent - wanted and unwanted targets' RCS (reflectivity) changes as they fly and manoeuvre

Unwanted targets are a factor in day-to-day ATC radar operations and the area of this turbine may well have legal, unwanted targets (Section 12.3 page 49)

Modern radar processing is designed to minimise such transient targets, and again some radar operators believe that a single, small turbine cannot mimic an aircraft (Sections 8.4 page 29, 9.2 page 34 & 12.2 page 47)

13.5 ***"e) Turbines are sited in large groups:***
The inconsistent nature of the echoes also helps to defeat the post-plot extraction tracking algorithms. These algorithms will treat plots derived from different turbines within the same, or adjacent, development on consecutive scans as an aircraft which has moved, and moved within the limits imposed on scan-to-scan aircraft movement. Whilst this cuts down on the total number of false plots it means only the most aircraft-like tracks made up of turbine plots are presented to controllers. This difficulty in distinguishing between the two leads to turbines being displayed as if they are aircraft on controller's display with potentially unacceptable consequences in terms of controller distraction and workload."

This is a single, small turbine - returns from different turbines on different sweeps of the radar are impossible from a single, small turbine (Section 12.2 page 47)

9. NATS. 'Mitigating the effects of wind turbines on NATS En-Route Ltd (NERL) operations', . NATS En Route plc (NERL) ATM Policy Statement Issue 3.3. Brendan Kelly Head of NATS Operational Policy

14. SUMMARY

Large turbines and multiples of them in windfarms may cause problems to ATC radars. However, there are many, small 'approved' turbines - and some large ones - elsewhere in the UK and near to a number of airports. Yet there is no published evidence of single, small turbines generating any ill-effects - no adverse safety reports have been generated by the CAA and none have been published by other organisations.

This is perhaps why no trials have been conducted to assess the effects of a small, single turbine on ATC radars and why the civil aviation authorities' guidance essentially excludes or ignores them.

The NATS objection as stated in its TOPA is absolutely standard and provides no evidence that this turbine will have any impact on the Manchester radar. It refers to *"false primary plots to be generated"* but this was not a conclusion from any of the Trials. The effect is deemed to be unacceptable but this is a subjective assessment, as what is unacceptable to one person/organisation might well be acceptable to another.

14.1 Turbine Will Not Be Detected

- The likelihood of the NATS radar detecting this turbine at its very low elevation is extremely remote - there will be insufficient power returned to the radar for the turbine to be displayed.

- The calculation is that the turbine will not be detected by the NATS radar at all and it cannot, therefore, produce *"false primary plots*". The radar will not be desensitised, false targets will not be generated and real aircraft will always be seen.

14.2 Evidence from Trials Is Not Relevant to Single, Small Turbines

The NATS objection probably is based on the UK Trials conducted but those Trials were conducted solely against large turbines and wind farms of multiple turbines. The Trials do not show nor do they infer any effects from a single, small turbine. Indeed, what can be concluded from the Trials and the Reports is as follows:

- The impact of turbines is not absolute or definite – even for large turbines and in wind farms. Whatever effect is observed for a single turbine/wind farm and radar may not recur with a different turbine and/or radar

- A single turbine cannot appear as an aircraft, so

- There should be no increase in Controller workload

- Real aircraft will always be detected, because there is no radar shadow from a small turbine, and because there will always be significant gain advantage for real aircraft

- The high terrain close to NATS will already be desensitising the radar - there will be no additional desensitising effect from the small turbine

14.3 No or Negligible Operational Impacts

In the extremely unlikely event that the turbine is detected it will pose no hazard to ATC operations at NATS and will have no safeguarding implications.

- Single turbines on individual sites cannot be compared to a wind farm, and this single, small turbine could never be considered to exhibit the wind farm effects seen in the Trials – this turbine cannot generate false targets.

- The NATS radar is a relatively new, modern ATC radar with software specifically designed to eliminate stationary, ground-based targets and other unwanted clutter. As the turbine will not move over the ground it is most likely that it will be 'processed out' of the radar as an unwanted return.

- Like all ATC radars, the radar is designed to avoid low levels and its performance at and close to the horizon is significantly and deliberately degraded to avoid low level clutter (inc unwanted targets on or very close to the ground).

- In the most unlikely event that the turbine is detected at all, it will be handled as a transitory 'target' similar to those other transitory targets handled routinely in day-to-day ATC operations.

- The turbine's location is in uncontrolled airspace available for use by other users on a 'see and be seen' principle and without reference to any ATC, inc Manchester radar.

Buccaneer Consulting Ltd
6 January 2013