ANNEX B to
Tops Farm RIA

RADAR – WIND TURBINE TRIALS

B1. RADAR – WIND TURBINE TRIALS

In its objection (B1) the MoD states “Wind turbines have been shown to have detrimental effects on the performance of MOD ATC and Range Control radars”. As there are no published radar:turbine incident reports and no CAA hazard reports (properly called Mandatory Occurrence Reports) involving wind turbines and radar it is quite likely that the MoD is referring to “detrimental effects” observed during trials carried out into wind turbine:ATC radar interactions. These Trials will, then, be examined.

An extensive online search, inc the British Wind Energy Association website and the MoD, has uncovered the Trials and Reports examined below. A request made of the MoD on 5 Dec 12 (and others) “to provide sources of any trials or research conducted by the MOD into the effects that you describe” has produced no response. 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 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 PSR radar – perhaps not dissimilar to the radar at Warton.

B1.1 RNAS Culdrose & Goonhilly Windfarm

Conducted in 1994 this Trial \( (B2) \) 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 \( (B2) \) 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” \( (\text{page 1 para 5}) \)

“The turbine structure had an estimated RCS of approximately 9.3 sq m in circular polarization.” \( (\text{page 14 para 50}) \), “similar to a medium sized aircraft” \( (\text{page 6 para 20}) \)

“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” \( (\text{page 15 para 58}) \).

“There is therefore a significant amount of time when the turbines are not causing interference” \( (\text{page 16 para 60}) \)

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” \( (\text{page 14 para 46}) \)

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**Goonhilly Trial Conclusions**

The Trial draws no conclusion that there are “unacceptable effects” on the Watchman ATC PSR

The Trial also 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 ¾ the size of each of those used in the Trial

The phrase “Over a large wind farm site this could cause a flight 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 \( (9.73\text{dBsm}) \)

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B1.2 Trial Quixotic Zephyr

Conducted in 2005, this Trial used a Watchman ATC PSR 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. The103 turbines covered an area of 10 sq km, 10 turbines per sq km.

The Trial’s aim was

“to determine the effects of wind turbine farms 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 PSRs. Relevant findings from this trial are below.

“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.” (page 13 para 28)

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

(The bold and underline of references to ‘wind turbine farm’ and ‘farms’ is the author’s emphasis.)

In the section titled ‘Major Recommendations’ 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 (B3) 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.”

“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.”

“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.”

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 ‘heart’ of the radar beam. While understandable for trials purposes, these heights cannot replicate the effects of degraded radar performance at the very low elevation angles (see Section 7, pages 22 on) of the proposed turbine.

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.
Trial Quixotic Zephyr Conclusions

There is no evidence of or inference that a single, small wind turbine at a low elevation angle would produce similar “unacceptable interference“ effects.

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.

Local training of ATC personnel is a suitable mitigation for small wind farms, so would be most suitable for a small, isolated single turbine.

B1.3 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 \(^{(B4)}\). The Trial used a single, large turbine and an operational MoD Watchman ATC PSR radar – not unlike an older version of the radar used at Warton. 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 4 times closer than the proposed turbine, and both factors are significant to radar, especially range (see Section 8, page 33 on). Key, relevant parts of the report are reproduced below.

Early in the Trial report QinetiQ states:

“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)

Fig 6.12 of page 49 of the Report \(^{(B4)}\) is reproduced at Fig B1 (page B8, 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 B1 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 B2 (page B9) shows some interesting comparisons with the radar display:

\(^{\spadesuit}\) There is no ‘other clutter’ beyond about 12.5km

\(^{\spadesuit}\) The tall mast at Great Massingham to the N – 90m agl – doesn’t show as a return

\(^{\spadesuit}\) The 60+m mast at N Pickenham to the E - 12km - might just be showing just to the W of the northern aircraft target

\(^{\spadesuit}\) Masts can be detected by radar since even static mast tops move in strong winds. Moreover, at very low elevation angles turbines are ‘viewed’ by radar as largely static objects, like masts

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

\(^{(B4)}\) QinetiQ. ‘Wind Farms Impact on Radar Aviation Interests’, Final Report. FES W/14/00614/00/REP. DTI PUB URN 03/1294. 2003
Fig B1. “Figure 6-12; Screen shot from the recorded Marham data showing the turbine return and some air traffic.”
Fig B2. Aviation Map Showing Same Area as Radar Display at Fig 2
DTI Trial Conclusions

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 3 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 – hardly “unacceptable interference”
- the Watchman radar does not always detect a large turbine much closer to the radar than the one proposed

Summary of All Trial Conclusions

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 turbines.

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 RAF Marham airfield shows on the radar as less pronounced than other general clutter, and much less than aircraft targets – hardly “unacceptable interference”

The radar does not always detect a large turbine much closer to the radar than the one proposed.
B1.4 US Experience & UK Trials

In addition to the citing by UK authorities of Trial Quixotic Zephyr, it is also cited by others, inc US Governmental authorities. In its assessment of the issues of wind turbines and radar [B5] 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 [B5 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 [B6] – twice the height of this proposal and 5 times closer.

B2. INTERNATIONAL SAFEGUARDING CRITERIA

B2.1 International Review

Other international criteria reinforce the view that the UK criteria are far more stringent than any others. Most European agencies adopt ICAO standards [B7] of a 1:100 slope = 10m/km or an elevation angle of 0.65° - well above this turbine tip.

Elsewhere, Canada for example considers that “Lateral separation of at least 10 km should be maintained between wind turbines and areas where critical ATC operations take place.” [B8 page 9]

While Eurocontrol takes no account of turbines below 30m in height [B9 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 [B9 page 31 papa 4.2.1].

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B6. FAA Advisory Circular 70/7460 2K

B7. DTI/Strays. ‘Wind Turbines & Aviation Interests - European Experience & Practice’ ETSU W/14/006/REP. DTI URN 03/515


B9. Eurocontrol. ‘Eurocontrol Guidelines on How to Assess the Impact of Wind Turbines on Surveillance Sensors’
In its relevant publication (B10) the International Civil Aviation Organisation (ICAO, a UN body that promotes understanding, security and flight safety through cooperative aviation regulation) 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” (B10 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” (B10 Appendix 3 Table 4) and “The BRA is considered to provide worst case protection” (B10 page 5 para 6.2) (BRA = Building Restricted Area)

B3 OPERATIONAL AIRPORT EXPERIENCE

B3.1 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’ (B11 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.’ (B11 Ch 10 page 9 para 10.59)

In a meeting with an Air Traffic Controller at Birmingham Airport on 12 Dec 2013, the Controller had been at Bristol Airport when the turbines had been commissioned and had not seen them on the radar display (B12)

B3.2 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’ (B13 page 16)

B10. ICAO ‘European Guidance Material on Managing Building Restricted Areas Sep 2009’
B12. N Beattie ATC Watch Manager Birmingham Airport, 12 Dec 2013
B3.3 German AF 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.” (B14 page 19 para 2.1.3)

B3.4 Schiphol Airport

Schiphol airport is significant for this analysis because it uses the ATCR-33K – this is a full, relatively modern PSR (see Section 7 page 22 on) and uses a similar design to and common components with the Warton radar (B15).

“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.” (B13 page 23 para 7.1)

B3.5 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. (B16 page 16)

B15. SELEX Sistemi Integrati S.p.A, ‘ATCR-44S brochure’
B16. AENA (Spanish National Air Traffic Service) La Palma airport Environmental Management Report 2006-08
B4. 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 (B17). 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 (B7) suggesting that the safeguarding criteria desired by the MoD are unnecessarily stringent.

B5. ADDITIONAL RESEARCH

In addition to the trials undertaken and discussed earlier in this document there have been 3 other pieces of work conducted with wind turbines. These 3 and their relevance will be briefly examined.

B5.1 Study into the Radar Impact of a Micro Turbine

This study (B18) was designed to assess the RCS and any impact micro turbines might have on radar. It was focused on a turbine less than 4m high (not much taller than a lamppost) and in an urban environment “their (the turbines’) primary purpose is for installation on the roofs of houses rather than in remote fields” (B18 page 5 para 1.1.2). The study is, therefore, irrelevant to this Tops Farm Assessment.

B5.2 Proven Turbine RCS Study

Again conducted by QinetiQ, the study (B19) was designed to measure the RCS of a 12.4m tip height turbine. It is not much taller than a house and it made no reference to radar - ATC or otherwise; it is, therefore, irrelevant.

B5.3 Vertical Axis Wind Turbine Radar Impact Assessment

The final additional study (B20) was conducted into the radar impact of a vertical axis wind turbine only 5m high. Again, the very small scale of this turbine (much lower than a house) and the very different type to that proposed for Tops farm make the study irrelevant.

B17. CAA. E-mail Denise Lillywhite to BCL ‘Retrieval Request Safety Data Post No: 8311- Wind Turbines’ dated 30 Aug 12
B7. DTI/Stanys. ‘Wind Turbines & Aviation Interests - European Experience & Practice’ ETSU W/14/00624/REP. DTI URN 03/515
B18. QinetiQ for MoD. Study into the Radar Impact of a Micro Turbine. QinetiQ/EMEA/TS/TR0707953/1.0, Nov 2007

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B6. SUMMARY

Large turbines grouped into wind farms might well pose a hazard to ATC radars, and that is probably why all the research/trials work has concentrated on such turbines. Even then, the results are far from definite - “could cause a fight safety hazard” - or of no consequence - the presence of turbines “causes little or no problem to the airfield ATC” and large, single turbines “do not create a significant ‘radar shadow’”. Indeed, the radar does not always detect a large turbine much closer to the radar than the one proposed.

This proposal, though, is for a single, small turbine and there is no certainty it will even be detected. Even if it is detected - occasionally - the evidence from the trials against large turbines and those in wind farms is that a single small turbine will have no impact on an ATC radar.