Safeguarding Office

E2, Corporate & Technical Centre
4000 Parkway, Solent Business Park
Whiteley, Hampshire, PO15 7FL

Options for mitigating the impact of wind turbines on NERL's primary radar infrastructure

F1 Acceptance

Role	Responsibility	Name	Signature	Date
Author	Systems Engineer	A Auld		
Accepted	Deputy Eng. Manager (Surveillance)	J. Strong		

F2 Amendment History

Issue	Published	Reason
A	14/07/06	Initial document for selected internal NATS comment.
1.0	31/07/06	Issued
2.0	18/12/06	Re-issued with clarifications

F3 Distribution List

No.	Title	Location	Name
1	NERL Surveillance AM	Corporate & Technical Centre	S. Barber
2	Raytheon	RCL, Waterloo	B. Fournier
3	DTI	Renewable Energy 2010 Target Team	Z. Keeton

F4 Contents

F5 Related and referenced documents

The following documents are referenced in this document using square brackets, e.g. [1].

Ref	Document

F6 List of Abbreviations

AOD	Above Ordinance Datum
ASTERIX	All purpose STructured Eurocontrol suRveillance Information eXchange
ATC	Air Traffic Control
DTI	Department of Trade and Industry
LVA	Large Vertical Aperture
MRT	Multi-Radar Tracker
MoD	Ministry of Defence
NERL	NATS En-Route plc.
nPC	new Prestwick Centre
GPS	Global Positioning System
LF	Low Frequency (Rugby Time Source)
PSR	Primary Surveillance Radar
MSSR	Mono-pulse Secondary Surveillance Radar
EMS	European Mode-S
RDIF	Radar Data Interchange Format
RDTCU	Radar Data Time-stamping and Conversion System
RSL	Raytheon Systems Ltd.
RSS	Radar Site Services
ScACC	Scottish Area Control Centre
SSR	Secondary Surveillance Radar

1. Background

Although not specifically written with wind turbines in mind the DfT 2003 white paper ‘The Future of Air Transport’ opens with a statement summing up the balance which must be struck when examining the impact of wind turbines on ATC infrastructure:

“Air travel is essential to the United Kingdom's economy and to our continued prosperity … The challenge we face is to deal with the pressures caused by the increasing need to travel whilst at the same time meeting our commitment to protect the environment in which we live.”

NATS En Route Plc, NERL, is the air navigation service provider responsible for the safe and expeditious movement in the en-route phase of flight for all aircraft operating in controlled airspace in the UK. To undertake this responsibility NERL has a comprehensive infrastructure of radar, communication systems and navigational aids throughout the UK. Theory and practical experience has shown that any of these could be compromised by the establishment of a windfarm in the wrong place.

In order to safeguard this infrastructure NERL assess the potential impact of every proposed windfarm development in the UK. Inevitably these assessments have led to NERL objecting to a number of proposals and potentially becoming a roadblock to the realisation of hundreds of megawatts worth of renewable energy.

Assuming that the government commissioned energy review, due to report in July this year, continues to promote a policy of increasing the share of the nation’s energy demand met by renewable sources then NERL protecting its current level of service potentially stands in the way of the DTI attaining these targets.

2. Turbines impact on ATC

Although wind turbines have the potential to impact NERL's electronic infrastructure in a number of ways the potential for primary surveillance radar, PSR, to confuse turbines with aircraft is the reason for the majority of NERL objections and will be the focus of this document.

The function of an ATC surveillance technology, such as radar, is to accurately determine an aircraft's position and provide this information, in a timely fashion, to an air traffic controller in order that he can guide it towards its destination whilst maintaining separation from other aircraft.

If a radar mistakenly presents a turbine as a plot on his display a controller has little choice but to believe it to be an aircraft. Depending on the class of airspace and the service being provided a controller may have to re-route a real aircraft under his control to maintain horizontal separation from the turbine generated plot.

Even if the controller can assume that the plot comes from a turbine, or an aircraft safely below controlled airspace, numerous false plots can be distracting and have the potential to visually interfere with other information on the display. To maintain current levels of aircraft throughput whilst maintaining current levels of safety it is vital therefore that the number of false plots is kept to a minimum.

Although NERL only objects to 4% of all the applications (2006 to date) provided for assessment applications for large numbers of large turbines have a disproportionate impact on radar therefore it is likely that the fraction of megawatts objected to is significantly higher.

The impact of turbines on PSR is currently a roadblock to numerous developments and a technological solution mitigating this impact could potentially release hundreds of megawatts of renewable energy.

3. Why primary surveillance radar confuse turbines with aircraft

Throughout this paper 'radar' will refer to primary surveillance radar

3.1 Background

The introduction to Merrill Skolnik's Radar Handbook begins with the statement *"Radar is relatively simple in concept even though its practical implementation is not."* Before entering into a 1200 page treatise describing this practical implementation Skolnik provides the reader with a concise summary *"It operates by radiating electromagnetic energy and detecting the presence and character of the echo returned from reflecting objects."*

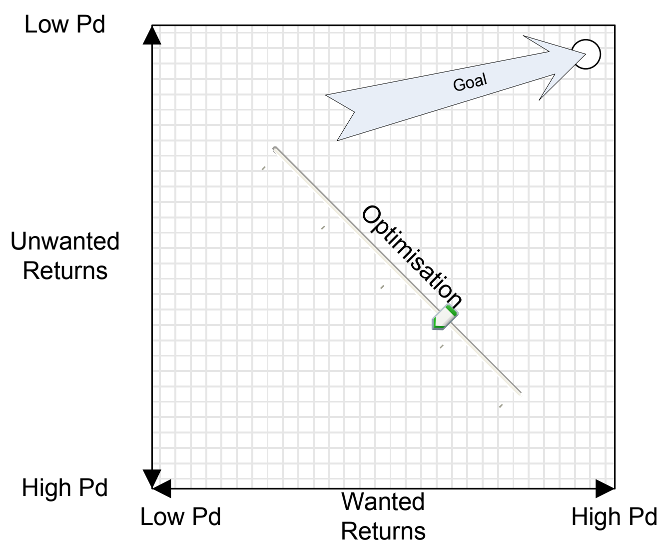
The term radar comes from the term 'RAdio Detection And Ranging' because further to detecting their presence radar uses the echo's time of arrival at its receiver to determine the range of the reflecting object from the receiver.

In rotating, monostatic, pulse radar, such as those operated by NERL, the energy is only radiated and received in the direction the radar is pointing and therefore a combination of a knowledge of the antenna's orientation and the calculated range provides a two-dimensional location of the reflecting object with respect to the radar.

Electromagnetic energy is fairly indiscriminate in what it reflects off and the skill in radar design and optimisation is maximising the ability to detect the echoes from aircraft whilst minimising the number of false alarms resulting from the energy reflected from other objects.

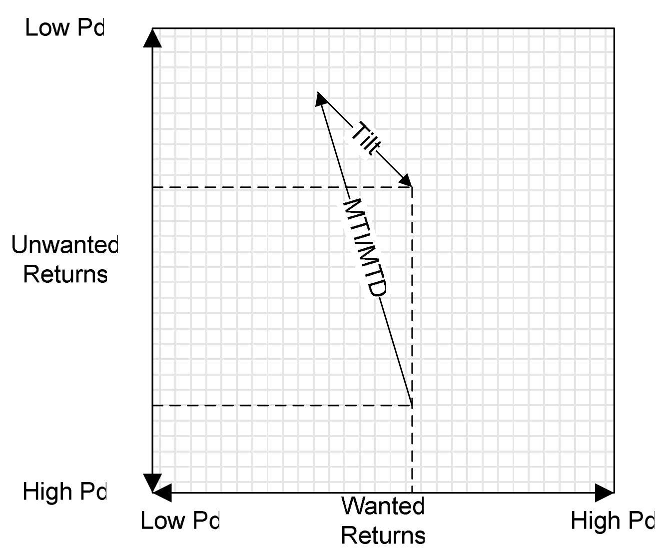
3.2 The balance inherent in radar design and optimisation

A radar designer/optimiser has a variety of techniques at his disposal when attempting to ensure a high probability of detection, pd, for wanted targets whist minimising the number of false alarms. The majority of these techniques have a similar effect on both types of targets forcing the engineer to attempt to find the balance that best suits the users of a particular radar service.



Moving target indication, MTI, and its subsequent evolution into moving target detection, MTD, was the radar design breakthrough allowing the greatest step towards the goal of detection without clutter. Although MTI reduces the pd of unwanted returns only at the expense of wanted returns it uses the instantaneous radial velocity of the reflecting object to weight this reduction in favour of removing returns from stationary objects.

Reducing Pd using this technique coupled with increasing it again with a less discriminatory technique such as antenna tilt allow the pd of radially moving targets, such as most aircraft, to remain similar whilst drastically reducing the pd of radially stationary targets such as buildings.



The reason that MTI/MTD succeeds where simpler techniques fail is the exploitation of a difference in what Skolnik refers to as the “character” of the unwanted echoes when compared to the wanted echoes. It is only through exploiting the character differences between turbine and aircraft echoes that turbine returns can be safely ignored without impacting aircraft detection.

3.3 The character of wind turbine echoes

The three main character differences exploited by radar systems and their users when discriminating between wanted and unwanted replies are:

1. Amplitude
   Radar antenna are designed to maximise the amplitude of replies from altitudes where aircraft are likely to be and due to their high reflectivity, known as radar cross section, aircraft tend to provide high amplitude echoes. Amplitude thresholding therefore is a simple but often very effective way of determining if an echo is wanted or not.

2. Instantaneous radial velocity
   As discussed in the previous section MTI and MTD are techniques where objects determined to be travelling towards or away from the radar are given a larger weight within detection algorithms therefore discriminating against stationary objects.

3. Scan-to-scan movement
   As there is an upper and lower limit of how far an aircraft can be expected to travel in the time taken for the radar revolve a variety of techniques mean that an echo which meets the criteria "potentially from a known moving target detected on the previous revolution" is more likely to be classed as a target.

Wind turbines, and in particular large groups of wind turbines, defeat these systems precisely because the characteristics of their echoes tend to be similar to those expected from real aircraft:

1. Amplitude
   Wind turbines are by and large built on hill tops and although this makes them lower in altitude than most aircraft they are generally higher in altitude than most unwanted reflectors. The shape and materials used in the construction of wind turbines have the side-effect of giving them a large reflectivity, comparable if not greater than that of most aircraft. The DTI sponsored study into wind turbine radar cross sections found that *"for some typical turbine configurations. RCS returns of a whole turbine generally fall between 10 and 30dBsm (10m^2 to 1000m^2)"* these figures range from typical for an aircraft to larger than anything expected from a jumbo jet.

2. Instantaneous radial velocity
   Another side-effect of wind turbine design is the need for the blades to rotate in order to extract energy from the wind. The same DTI sponsored study found that depending on blade orientation there were *"significant returns out to the Doppler frequency equivalent to the tip speed of the blades"* and with blade tip speeds for larger turbines in the region of 75 – 155 knots these returns are well within the expected range for real aircraft.

3. Scan-to-scan movement
   Wind turbines don't up-sticks and relocate during radar antenna revolutions however as the above characteristics depend heavily on blade orientation wind turbine echoes tend not pass the test of being from an aircraft on every rotation. Therefore a turbine may appear for a single rotation and another within the same farm appear on the following rotation, the radar has no way of determining that the two echoes emanate from two distinct intermittent sources rather than a single moving source. The larger the wind farm the greater the probability that echoes which can potentially be confused in this way appear on two consecutive scans.

Current techniques employed within conventional radar which attempt to exploit differences in the above characteristics are not sufficient to distinguish between echoes from wind turbines and those from real aircraft.

4. Proposed solutions for civil, en-route radar

By 2011 Raytheon ASR 10/23SS radar will be the sole PSR systems used for civil, en-route aircraft surveillance. In their attached report, Appendix A, Raytheon detail a variety of advanced mitigation techniques which they believe will remove the effects of wind turbines on these radar. A brief non-technical summary of each of the proposed techniques follows:

4.1 Con-current beam operation

The radar antenna sub-system is designed so that at short range the radar uses a beam which operates more efficiently at high elevation angles, the radar then switches to a low beam to maximise long range coverage. Depending on the reflecting object's elevation angle with respect to the radar its echo will appear with different characteristics in each beam.

In an attempt to exploit the short-range low-elevation angle characteristics of most turbines when compared to the majority of aircraft Raytheon propose making both beams available to the radar processing at all times so that rudimentary elevation filtering can be carried out. This should significantly improve the radar's ability to distinguish between aircraft flying above a wind farm and the turbines below.

4.2 Constant False Alarm Rate Processing

Constant False Alarm Rate, CFAR, processing raises the local amplitude threshold to a level equal to the average of the area around the position of a suspected target. In the presence of a number of geographically small but very large amplitude echoes, such as those from wind turbines, the threshold over a large area can be unduly raised.

Raytheon propose ignoring these anomalously high spikes and using a smoother averaging algorithm. The increase in the extra false alarms from using this technique is likely to be outweighed by the increase in the probability of detecting smaller aircraft in amongst large turbine echoes.

4.3 Radial speed dependent clutter maps

The local amplitude threshold is also raised by the constant reception of echoes in the same location scan after scan. Currently this system is only cognisant of the echoes calculated as having low radial velocities however the threshold is applied equally to all potential targets regardless of speed.

Raytheon propose radial speed dependent thresholds so that in any given area if a consistent echo is relieved, even if that echo is found to have a large radial velocity, then the threshold will be raised for any future echo with a similar velocity. This should help filter out targets which remain in one place but have a large, consistent, radial velocity.

4.3 Tracking Algorithms

By comparing the characteristics of the series of replies expected from real aircraft with those that could be expected from a number of turbines in close proximity Raytheon hope to exploit any differences found and prevent the turbines replies from being correlated into tracks and therefore prevent them being presented to controllers.

5. Costs and Schedules

NERL and Raytheon suggest the following phased approach to the complete implement of the complex of solutions required to mitigate the effects of the wind farms on ASR10/23SS radars, further details can be found in Appendix A. All costs, where provided, are rough order of magnitude cost, for budgetary purposes only.

5.1 Phase 1 - Feasibility Study

- Scrutinise existing, and propose new, mitigation options.

This phase has been completed and is summarised in this report.

5.2 Phase 2 - Mathematical Modelling

- Prepare a mathematical model of the radar
- Simulate the various mitigation options
- Analyse the results of the simulations
- Generate and present a report to the DTI recommending options for implementation

This phase is expected to take 14 months and cost approximately £960,000.

5.3 Phase 3a - Factory Testing

- Incorporate the chosen options into the ASR platform
- Ensure implemented options operate as expected under factory conditions

This phase is expected to take 9 months and cost approximately £220,000.

5.4 Phase 3b - Field Testing

- Install chosen options in test system
- Baseline performance without mitigation techniques employed
- Measure performance improvement with mitigation techniques employed
- Generate and present a report on the performance improvements

Assuming the existence of a suitable test system this phase is expected to take 11 months and cost approximately £430,000.

5.5 Phase 4 - Formal Qualification

- Collate evidence and generate the safety argument
- Gain approval from internal and external regulatory bodies

This phase is expected to take approximately 12 months, however costs, timescales and how much of the evidence collation can be carried out during phase 3 will depend heavily on which options are implemented.

5.6 Phase 5 - Roll-out

- Plan site order to maximises MW's released whilst minimising the operational impact
- Carry out software and hardware changes
- Optimisation and testing
- Accept system into operational service

This phase is expected to take approximately 3 months per radar, however costs and timescales will depend heavily on which options are implemented. It should be possible to run a number of modifications in parallel, which of NERL's 17 PSR systems can be modified in parallel will depend on resource availability and overlapping radar cover,

6. Conclusions

If NERL is to continue to maintain current levels of aircraft throughput whilst maintaining current levels of safety the impact of wind turbines on PSR systems will remain a roadblock to the realisation of hundreds of megawatts worth of renewable energy unless a technological solution can be found.

This work, if sanctioned, represents the single biggest opportunity currently available to provide that technological solution and allow the harmonious existence of a radar based en-route ATC service and large numbers of wind turbines in the UK.

Appendix A

Report On Advanced Mitigating Techniques to Remove the Effects of Wind Turbines and Wind Farms on the Raytheon ASR-10/23SS Radars