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Arup

Vistakon Wind energy project Development

Aviation Impact Assessment

September, 2011

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ADMINISTRATION PAGE

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Issue	Date	Detail of Changes
1	13 September, 2011	Initial Issue

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EXECUTIVE SUMMARY

- Vistakon is proposing to develop a single wind turbine on the eastern outskirts of Limerick City, Republic of Ireland. The proposed single wind turbine is planned to have a maximum blade tip height of 150.5m agl.
- Arup has commissioned Pager Power Ltd to undertake an Aviation Impact Assessment to assess the potential impacts of the proposed wind turbine on Aviation interests. The following have been concluded:
- The proposed wind turbine is likely to be within radar line of sight to both Shannon PSR/MSSR and Woodcock Hill MSSR;
- No additional shielding has been identified which would significantly change the line of sight results.
- It is likely that the proposed turbine will be detected by Shannon PSR.
- The effect of the proposed wind turbine on Shannon MSSR is negligible.
- The effect of the proposed wind turbine on Shannon PSR is minor; it is likely the proposed wind turbine will appear as clutter on Shannon Airport radar screens. However, due to the small size of the wind development (single turbine) this may be acceptable.
- The effect of the proposed wind turbine on Woodcock Hill MSSR is likely to be minor.
- The proposed wind turbine will not infringe the ICAO based protected surfaces of Shannon Airport and Coonagh airfield.
- It is likely that the IAA will require for the turbine to be lit.
- Consultation with Shannon Airport and the Irish Aviation Authority is recommended to determine the potential effects on Woodcock Hill MSSR and Shannon Airport Radar.

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1 INTRODUCTION

Vistakon is proposing to develop a single wind turbine on the eastern outskirts of Limerick City, Republic of Ireland. The proposed single wind turbine is planned to have a maximum blade tip height of 150.5m agl.

Arup has commissioned Pager Power Ltd to undertake an Aviation Impact Assessment to assess the potential impacts of the proposed wind turbine on Aviation interests. The following have been undertaken:

- Desk based investigation for aviation installations that could be affected by the proposed wind turbine;
- Radar line of sight regarding identified Primary and Secondary Surveillance Radar;
- Desk based assessment for overground obstructions that could shield the wind turbine;
- Radar detectability calculations for identified Primary Surveillance Radar;
- Physical Safeguarding Assessment;
- Assessment of impact on identified installations;

2 PROPOSED WIND ENERGY PROJECT DETAILS

2.1 Background

Vistakon is proposing to develop a single wind turbine on the eastern outskirts of Limerick City, Republic of Ireland. The proposed single wind turbine is planned to have a hub height of 100m above ground level (agl), a rotor diameter of 101m, resulting in a maximum blade tip height of 150.5m agl.

2.2 Name & Address

Name	Vistakon
Location	Eastern outskirts of Limerick City, Republic of Ireland
Developer Reference	Arup

Table 1 Wind Turbine Name & Address

2.3 Site Location & Height

Number of Turbines	1
Turbine coordinates (ING TM75)	163344.6 E 158172.67 N
Number of Blades per Turbine	3
Tower Design	Tapered Tubular
Generator Capacity /MW	3.00
Rotor Diameter /m	101.0
Rotor Radius /m	50.5
Wind Turbine Hub Height /m	100
Maximum Turbine Blade Tip Height /m	**150.5**
Land Height above datum/m	8

Table 2 Wind Turbine Location & Height

3 AVIATION INSTALLATIONS IDENTIFIED

3.1 Overview

An initial assessment was undertaken in order to identify potential aviation installations at issue as a result of the proposed wind turbine. These can be seen in the table below:

Location	Installation	Description	Distance to turbine (km/nm[1])	Grid Bearing of turbine relative to installation
Shannon Airport	**Aerodrome**	Two runways	26km/14.1nm	097°
	DVOR/DME	DVOR, DME	23.8km/12.8nm	103°
	PSR/MSSR	Primary Surveillance Radar / Monopulse Secondary Surveillance Radar	26.8km/14.5nm	097°
Coonagh (Limerick) Airfield	**Aerodrome**	Single runway	9.5km/ 5.1nm	085°
Woodcock Hill	**MMSR**	Monopulse Secondary Surveillance Radar	12.3km/6.7nm	116°

Table 3 Overview of identified aviation installations

Based on ICAO EUR DOC 015 Guidance the building restricted area for a VOR extends out to 15km for a wind turbine. As the Shannon Airport DVOR/DME is located approximately 23.8km of the proposed wind turbine it is unlikely to be affected. No further consideration has been given to the Shannon DVOR/DME within this report.

[1] 1nm = 1.852 km

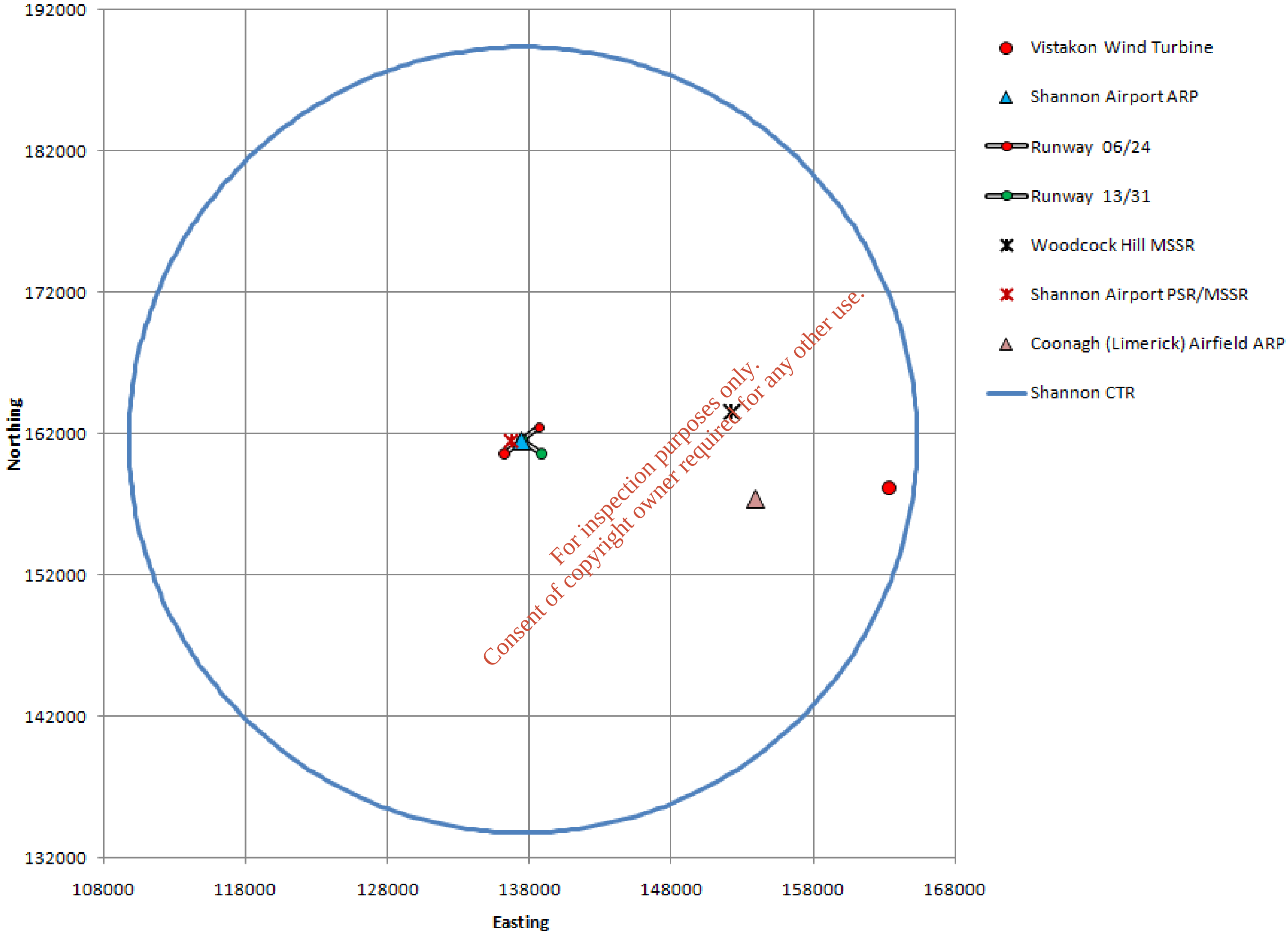


Figure 1 Aviation Installations identified

3.2 Shannon Airport

Shannon Airport is located approximately 21km northwest of Limerick. It is operated by Aer Rianta, and is part of the Dublin Airport Authority PLC (DAA). The DAA annual report states that almost 2.8 million passengers travelled through the airport in a typical year.

The diagram below shows the airport's runways, Primary Surveillance Radar (PSR), Monopulse Secondary Surveillance Radar (MSSR) and Woodcock Hill MSSR.

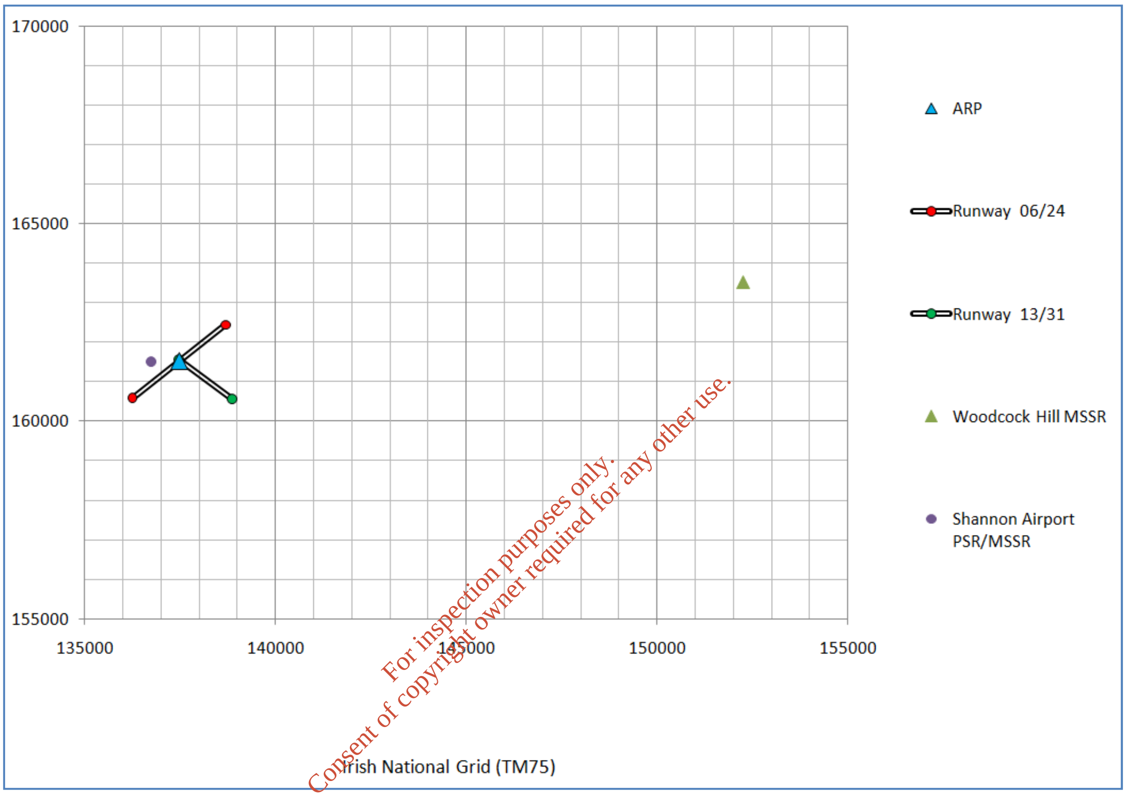


Figure 2 Shannon Runways and Radar including Woodcock Hill MSSR

The Airport has two substantial paved runways which are 3,199m x 45m and 1,720m x 45m in length.

According to the UK AIP the Shannon Control Zone is a circle with a 15nm radius centred at 5242207N 0085529W (Shannon ARP). Additionally, "...*the area within bearings from 045° True BRG clockwise to 180° True BRG from 523958N 0084053W to INT with boundary"* is uncontrolled airspace.

The airport has a variety of navigation equipment including visual markings and approach aids, radio navigation beacons, instrument landing system and radar.

Shannon Airport Radar Information	
Structure	Co-mounted PSR and MSSR on a freestanding tower
Location Description	Northwest of the main runway
Coordinates (Latitude/Longitude)	52 42 05.03N 08 56 11.74W
Coordinates (ING)	136734E 161510N
Terrain Elevation	5m
Antenna Height amsl[2]	30m (electrical centre of the antenna)
Antenna Type (PSR/SSR)	Thales Cosequant squared (AS 909 Linear Array)

Table 4 Shannon Radar Parameters

3.3 Coonagh (Limerick) Airfield

Coonagh airfield is located near Coonagh, approximately 3.5km northwest of Limerick. It is a licensed airfield by the Irish Aviation Authority (IAA) and is operated by Daniel Lehane, Portdrine, Cartloe, Co. Clare.

The airfield has a single asphalt runway designated 10/28 with dimensions 416x9m. It is located within a sector of uncontrolled airspace (SFC-1000ft) within the Shannon control zone.

3.4 Woodcock Hill Radar

Woodcock Hill MSSR is located approximately located 8km northwest of Limerick. It is understood that the radar is operated by the Irish Aviation Authority (IAA).

Woodcock Hill Radar Information	
Structure	MSSR located within a large concrete radome
Location Description	Located on top of Woodcock Hill
Coordinates (Latitude/Longitude)	52 43 15.77N 08 42 26.78W
Coordinates (ING)	152247E 163520N
Terrain Elevation	296m
Antenna Height amsl	316.9m (electrical centre of the antenna)

Table 5 Woodcock Hill Radar Parameters

[2] amsl: Above mean sea level

4 AIRSPACE AND AIR TRAFFIC

4.1 Airspace

Airspace may be classified as controlled or uncontrolled. Pilots need permission and a clearance to fly in controlled airspace. Pilots may fly at will in uncontrolled airspace. Airspace designations and classifications vary with altitude resulting in layers of airspace.

The diagram below shows the structure of airspace around Coonagh airfield and Vistakon turbine. It can be seen that both the airfield and the wind turbine are located entirely within uncontrolled airspace.

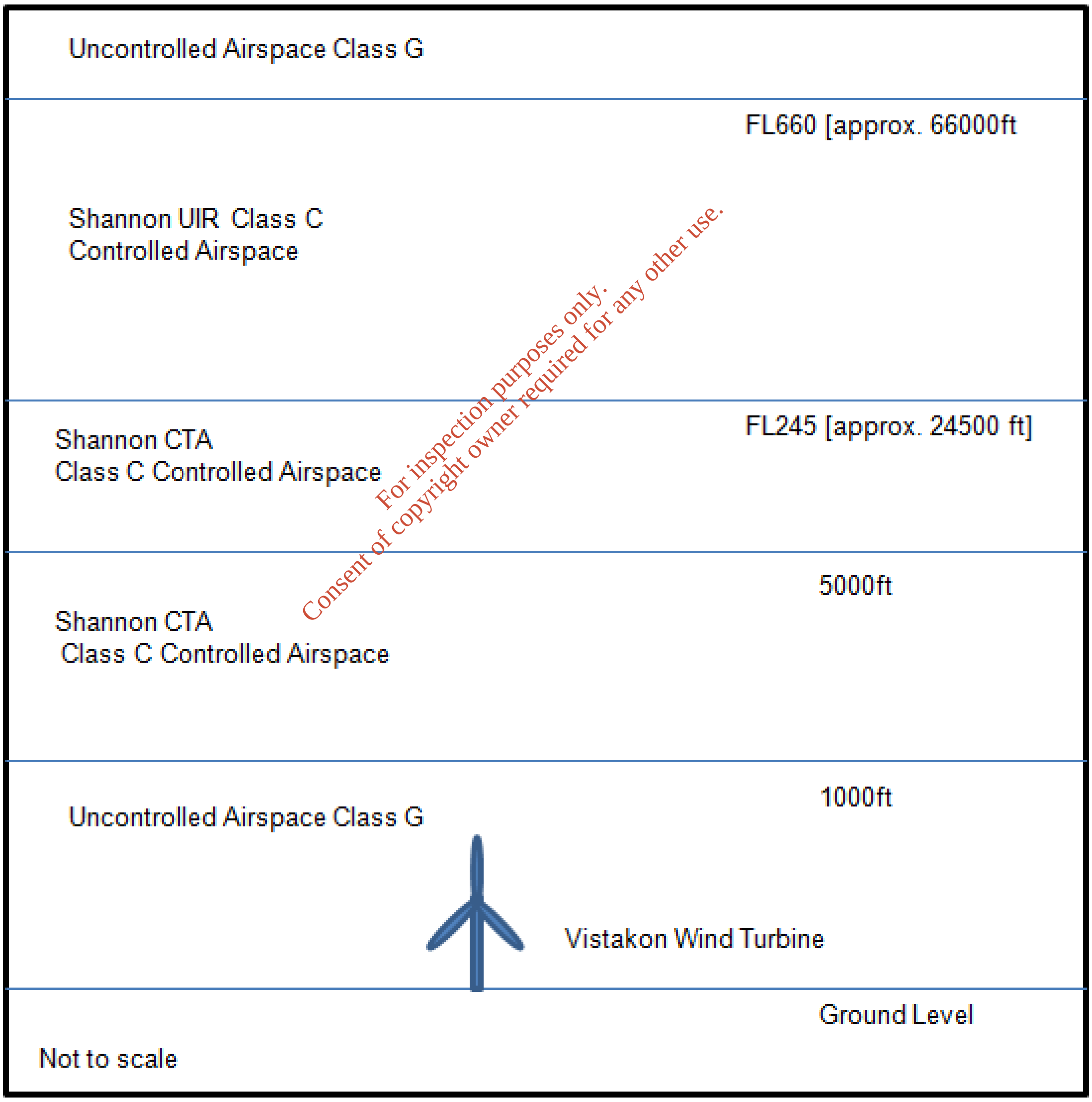


Figure 3 Airspace structure - Vistakon turbine

The airspace layers immediately above the wind energy project are detailed in the following table:

Lower Altitude	Upper Altitude	Name	Class	Controlled
Surface	1000 feet	Below Shannon CTA	G	No
1000 feet	5000 feet	Shannon CTA	C	Yes
5000 feet	FL245	Shannon CTA	C	Yes
FL245	FL 660	Shannon UIR	C	Yes
FL660	Unlimited	N/A	G	No

Table 6 Airspace Structure – Vistakon

4.2 Air Traffic

The majority of air traffic in the vicinity of Vistakon wind turbine is likely to consist of aircraft arriving at and departing from Shannon Airport and Coonagh airfield as well as general aviation aircraft.

Type of traffic permitted to use the identified aerodromes is as follows[3]:

- Shannon International EINN: International and national; VFR and IFR; scheduled, non scheduled, and private.
- Coonagh EICN: National; VFR; private.

Additionally, the turbine is located 5.285 km northwest of EIP9 (Limerick City Prison) where flying is prohibited. It should be noted that according to Coonagh airfield website regarding local procedures pilots are advised that: *"P9 - Limerick Prison prohibited area is not to be encroached at any time".*

[3] AIP Ireland, AD 1.3-1, 28 Jul 2011.

5 PHYSICAL OBSTRUCTION ANALYSIS

5.1 Overview

High ground and tall structures in any location may obstruct aerial navigation. There are various methods used to mitigate the effects of high ground and tall structures on aviation interests.

This section analyses the likely effects on aerial navigation of the proposed Vistakon wind turbine, accounting for tall structures and high ground that already exists in the region. It also assesses whether any change to existing mitigation measures is required to accommodate the proposed development.

The maximum blade tip height of the proposed wind turbine is 150.5m (494ft) agl. Adding the ground elevation at the base of each turbine, the wind turbine will have a maximum blade tip elevation of 159m (521ft).

5.2 Nearby Obstructions

The following obstructions are a selection identified in the region from aviation charts, including the Irish AIP, and where possible, cross referenced with OSi 1:50,000 maps.

- High terrain with maximum elevation of 1008 feet, located approximately 12.5km northwest of the proposed turbine.
- High terrain with maximum elevation of 1010 feet, located approximately 15km northwest of the proposed turbine.
- High terrain with maximum elevation of 670 feet, located approximately 10km south southeast of the proposed turbine.
- Chimneys with maximum elevation of 366 feet, located approximately 10.75km southeast of the proposed turbine.

5.3 ICAO Physical Safeguarding Surfaces

5.3.1 Overview

Wind turbines in close proximity to aerodromes can present concerns as physical obstructions. This relates to the infringement of any protected surfaces associated with the aerodrome.

Physical safeguarding at licensed aerodromes is managed using a series of imaginary surfaces which are projected from the aerodrome and its runways. The size and dimensions of these surfaces depend on runway length and a number of other factors.

The Vistakon wind turbine has been assessed against standard ICAO safeguarding surfaces – as defined by the International Civil Aviation Organisation (ICAO). These can be the following: Take-Off Climb Surfaces, Approach Surface, Transitional Surface, Inner Horizontal Surface, and Conical Surface Additionally, the Outer Horizontal Surface (OHS) has also been considered.

5.3.2 Shannon Airport

The Outer Horizontal Surface (OHS) is likely to extend at least 15,000m from the Aerodrome Reference Point (ARP). ohs is used for physical safeguarding of aerodromes in some countries, but not all, as it is not part of the core ICAO standard for physical safeguarding – although its use in some states is acknowledged. At a distance of 26km from the ARP the proposed wind turbine is most unlikely to cause any physical safeguarding concerns. Therefore the impact is determined as: **No impact.**

5.3.3 Coonagh Airfield

Based on ICAO standards there is not an OHS established for runways with length less than 1100m. The Conical Surface Radius for runway length <800m is likely to be 2,700m from the ARP. Thus, at a distance of 9.5km from the ARP it is most unlikely the proposed wind turbine will breach any protected surfaces. Therefore the impact is determined as: **No impact.**

5.4 Obstacle Assessment Surfaces for Shannon Airport Instrument Flight Procedures

The ICAO's Procedures for Aerial Navigation – Operations (PANS-OPS, ICAO Document 8168) gives details of Obstacle Assessment Surfaces (OAS) used for purposes of obstacle protection for different phases of various instrument flight procedures (used when not flying visually and hence unable to use the 'see and avoid' principle for safe flight). The maximum protection this document requires is 300m (984ft) below the planned flight path.

Detailed analysis of instrument flight procedures is beyond the scope of this report. However, having reviewed the published flight procedures it is unlikely there will be any physical safeguarding issues.

5.5 Other Physical Safeguarding Considerations

- The proposed wind turbine is 14.1nm from Shannon airport which has an elevation of 46 feet amsl; the tip height of the turbine is therefore 475 feet higher than the airport;
- The proposed wind turbine is 5.1nm from Coonagh airfield which has an elevation of 17 feet amsl; the tip height of the turbine is therefore 504 feet higher than the airfield.
- The Minimum Grid Area Altitude (MGAA) provides clearance by 1,000 feet in areas where the highest points are 5,000 feet or lower and clears all elevations by 2,000 feet in areas where the highest points are 5,001 feet or higher. Based on Jeppesen Aeronautical Chart (1:500,000, EI-2, ed.2010) the MGAA in the assessed area is 3,100 feet. The proposed wind turbine will have an elevation of 521 feet; therefore it will not affect the MGAA.
- According to the EINN AD 2.24-8A Shannon RWY 06, the turbine is planned to be located south of the Standard Instrument Departure (SID) route ABAGU 2A RWY06 and north of SID LUNIG 2A. Based on EINN AD 2.24-8A for Shannon RWY 06, the climb gradient is 3.3% for obstacle clearance (approximately 200feet climb per nautical mile). At a distance of 27.2nm (distance between end of RWY 06 to wind turbine) an aircraft is likely to be at approximately 5,000 feet or higher (subject to instruction from ATC). Therefore, there will be adequate vertical clearance between the turbine tip and an aircraft's height.

5.6 Obstruction Lighting (Aeronautical Ground Lighting)

Rules and regulations for fitting lights to wind turbines vary significantly throughout the world. Both the rules for determining whether lights should be fitted and what sort of lighting is fitted vary. Aeronautical Ground Lighting (AGL) is typically fitted to structures taller than 150m above ground level (agl) or structures close to airfields if they infringe a protected surface. In other instances, aviation stakeholders may request the fitting of aviation obstruction lights where it is deemed that the nature of local air traffic may require them as an additional safety precaution. In the case of this particular development it is likely that the IAA will require for the turbine to be lit.

5.7 Conclusions

- The physical obstruction to aerial navigation at Shannon Airport and Coonagh airfield by the proposed wind energy project will be negligible.
- It is likely the IAA will require the turbine to be lit.

6 RADAR ANALYSIS

6.1 Background

6.1.1 Radar Line of Sight

Wind turbine blades may display some characteristics that are similar to the targets which Air Traffic Control (ATC) Primary Surveillance Radar (PSR) are designed to detect and therefore may be displayed as clutter on radar screens. This normally occurs only if they are positioned in such a way that a returned signal would be detectable by the radar.

Radar line of sight analysis is used to determine the extent to which a planned wind turbine could be detected by a specific radar installation. The analysis takes into account:

- The curvature of the Earth
- Refraction of the radar signal by the atmosphere (Standard atmospheric refraction k of 4/3 has been used. This value is conservative, as k is generally smaller in a well mixed atmosphere. When wind turbines operate will result in atmospheric mixing.)
- The Effective Radar Height
- The Effective Turbine Height
- The height profile of the terrain between the radar and turbine

Further information has been attached in Appendix A of this report.

6.1.2 Additional Shielding from Overground Obstructions

Forestry and buildings can provide additional shielding to a wind turbine by reducing radar beam signal strength and consequently wind turbines detectability. A detailed assessment of such shielding is beyond the scope of this report. In order to assess its significance in more detail, an on-site survey would be required.

In this report 1:50,000 maps and aerial photography are used in combination with the line of sight analysis to identify any overground obstructions that could offer additional shielding to the proposed turbines.

6.1.3 Primary Surveillance Radar Detectability Analysis

Line of sight analysis does not account for variables which contribute to radar detectability such as signal propagation losses, range, and both radar and target characteristics. These factors may prevent detection of objects within radar line of sight.

Radar detectability analysis as described in the 1st edition of the Civil Aviation Authority's (CAA) CAP764 - Policy and Guidelines on Wind Turbines, besides the aforementioned variables, uses a number of radar parameters, such as receiver sensitivity and down tilt to determine whether a wind turbine will be detected by a radar. If the wind turbines are not detected by the radar, they will not appear as radar screen 'clutter'.

It should be noted that the analysis has been carried out using typical radar parameters taken from the calculation example of the 1st CAP764 edition understood to be based on a S-band airfield surveillance radar with one exception; the antenna gain value. A typical antenna gain value for Watchman radar, which is significantly higher than the value suggested by the CAA.

It should be noted that the calculations have not considered any additional obstruction by buildings and forestry.

6.2 Radar Line of Sight Analysis

6.2.1 Shannon PSR/MSSR

Line of sight analysis has been conducted for the co-mounted PSR/MSSR at Shannon Airport to the proposed wind turbine and to 4 locations within 50m of the current location to account for turbine micrositing. A summary of the visibility can be seen in the below table:

Turbine	Turbine Distance from Radar (m)	Turbine Visibility (m)	Description of Visibility
Proposed location	26,819	120m	Tower mostly visible, rotor entirely visible
50m East of current location	26,868	121.5m	Tower mostly visible, rotor entirely visible
50m West of current location	26,769	121m	Tower mostly visible, rotor entirely visible
50m South of current location	26,825	123.5m	Tower mostly visible, rotor entirely visible
50m North of current location	26,813	118m	Tower mostly visible, rotor entirely visible

Table 7 Shannon Airport PSR/MSSR line of sight results

The proposed wind turbine is likely to be within Shannon PSR/MSSR line of sight at all five locations.

The profile chart for the proposed location has been attached in Appendix B.

6.2.2 Woodcock Hill MSSR

Line of sight analysis has been conducted for the MSSR at Woodcock Hill to the proposed wind turbine and to 4 locations within 50m of the current location to account for turbine micrositing. A summary of the visibility can be seen in the below table:

Turbine	Turbine Distance from Radar (m)	Turbine Visibility (m)	Description of Visibility
Proposed location	12,319	150.5m	Tower entirely visible, rotor entirely visible
50m East of current location	12,364	150.5m	Tower entirely visible, rotor entirely visible
50m West of current location	12,274	150.5m	Tower entirely visible, rotor entirely visible
50m South of current location	12,341	150.5m	Tower entirely visible, rotor entirely visible
50m North of current location	12,297	150.5m	Tower entirely visible, rotor entirely visible

Table 8 Woodcock Hill MSSR line of sight results

It appears that the proposed wind turbine is likely to be within Woodcock Hill MSSR line of sight at all five locations.

The profile chart for the proposed location has been attached in Appendix B.

6.3 Additional Shielding from Overground Obstructions

6.3.1 Shannon PSR/MSSR

In the case of the Shannon Airfield PSR/MSSR - an inspection of aerial photography indicates that there is likely to be some additional shielding of the wind turbine from the radar, as there do appear to be buildings between the radar and the proposed wind energy project. These buildings are located near Laghile, Cratloe, Co. Clare, Ireland.

6.3.2 Woodcock Hill MSSR

In the case of the Woodcock Hill MSSR - an inspection of aerial photography indicates that there is unlikely to be additional shielding of the wind turbine from the radar, as there do not appear to be any obstructions of significance between the radar and the proposed wind energy project.

6.4 PSR Detectability Analysis

6.4.1 Shannon PSR

Radar detectability calculations were undertaken for all turbines considering Shannon PSR.

Turbine location	Radar Detection	Detection Margin (dBm)
Proposed location	*Detection likely*	19.67dbm above the sensitivity threshold
50m East of current location	*Detection likely*	19.67dbm above the sensitivity threshold
50m West of current location	*Detection likely*	19.67dbm above the sensitivity threshold
50m South of current location	*Detection likely*	19.75dbm above the sensitivity threshold
50m North of current location	*Detection likely*	19.4dbm above the sensitivity threshold

Table 9 Shannon PSR - Radar Detectability analysis results

The outcome of the analysis indicates that the proposed wind turbine is likely to be detected by the radar at all five locations. It appears that the margin between the predicted signal strength and the minimum detectable returned signal strength is >19dBm which enables us to decide with confidence that the wind turbines are likely to be detected. Such a large margin indicates that the results are tolerant of errors in the assumptions and inaccuracies in the source data.

Calculations for the proposed turbine location are attached in Appendix C.

6.5 Cumulative Radar Impact

Radar operators may be concerned by the possibility of contiguous areas of clutter in the vicinity of an aircraft's path. The issue is compounded if the vectoring of an aircraft to avoid one area of clutter would bring it close to another.

There may be a number of planned and existing wind energy projects in the region, some of which are commercially confidential. This analysis accounts for sites found on Jeppesen Aeronautical Chart (1:500,000, EI-2, ed.2010) aviation chart within 30km of the proposed site. It appears that there is currently one operational wind energy project located 26km east of the proposed site.

Based on the above information the cumulative impact is assessed as negligible.

7 TECHNICAL EFFECTS OF WIND TURBINES ON RADAR

7.1 Background

The UK Civil Aviation Authority Publication *CAP764 CAA Policy and Guidelines on Wind Turbines* and the Eurocontrol document *Guidelines on How to Assess the Potential Impact of Wind Turbines on Surveillance Sensors* outline the potential effects of wind turbines on radar.

7.1.1 CAP764 on PSR

This document identifies the following potential effects of wind turbines on PSR:

a) ***False Radar Returns (Clutter):*** *Moving targets impart a frequency shift in the reflected energy of the radar. The effect is known as Doppler shift. The Doppler shift induced by the rotation of the wind turbine blades can cause them to be misinterpreted as an aircraft once detected by the radar, as the radar uses the Doppler shift to distinguish between moving objects and stationary objects.*
In order to address the issue of clutter, some radars use techniques such as Moving Target Indication (MTI) and Moving Target Detection (MTD) that employ filters to detect the Doppler shift, enabling 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. The stationary parts of a wind turbine (nacelle and tower) can be filtered out using these techniques. However, the tips of the rotating turbine blades can move at similar speeds to aircraft such that the returns caused by the rotation of blades are not suppressed from output and may appear as aircraft on the display.
The position of the wind turbines within a development, and the rotation of turbine blades, can cause a 'twinkling' effect by illumination of fresh reflections from the turbine blades and fading the previous reflections, or even the formation of tracks, both of which can be very distracting for air traffic controllers, causing confusion when trying to distinguish between real aircraft and false returns. Additionally, the separation of other aircraft from these false returns may need to be maintained which can increase controller workload.
Additionally, high levels of clutter can obscure display symbology such as track labels making them difficult to read, and the real aircraft returns indistinguishable from other returns. Overall, false radar returns decrease the situational awareness of air traffic controllers, which could result in safety incidents.
The false plots caused by the wind turbine can also generate the effect known as 'track seduction' on radar screens. Track seduction is when the false plots generated by the wind turbine are selected as the updated plots and causes the effect of steering the true track away from the actual path of the aircraft. If on subsequent scans further 'alternative' plots are available to sustain the deviated path then the track is said to have been seduced. The criticality of such occurrence has to be taken into consideration depending on the density of traffic levels within the coverage and the false targets caused by the wind energy project.
Furthermore, it may also be possible that the wind turbines may also increase the number of false targets by being in the path of radar signals and reflecting the radar signals such that the plot indicated to the controller by the received signal would not represent the true aircraft position;

b) ***Loss of Receiver Sensitivity:*** *Wind turbines can cause conditions leading to the loss of sensitivity in detection to such an extent that the aircraft returns are completely lost.*
Radars use an adaptive algorithm to detect target returns against a background of noise, clutter and interference also referred to as CFAR (Constant False Alarm Rate). The received echo at the radar receiver comprises the wanted echo signal from the aircraft and

the unwanted power from internal receiver noise, as well as external clutter and interference. The role of this algorithm is to determine the power threshold above which any return can be considered to probably originate from a target. This threshold may rise and fall depending on the noise, clutter and interference present in various areas within coverage.

Clutter, including wind turbine clutter, can cause the threshold to rise resulting in complete loss of detection of lower energy targets. This can lead to a lowering of the probability of detection of aircraft in the region of the clutter.

This unwanted energy reflected back from the wind turbine will remain and affect the thresholds whether or not the turbines are rotating. Although the returns from the stationary parts of the wind turbine may be filtered out and prevented from being displayed by using the Doppler filtering techniques, the loss of detection capability due to the high receiver thresholds is difficult to prevent;

c) ***Plot Extractor/Filter Memory Overload:*** *On radars fitted with a plot extractor, every target picked up by the radar is processed and filtered. Due to the constraints of memory size, there is a limit to the number of plots and tracks a system can handle. Therefore, if a particular radar has a high number of false plots, its memory capacity may be reached and subsequent problems arise. Where such concerns exist, the developer must take such issues into consideration, by consultation with the ANSP;*

d) ***Presenting an Obstruction (Shadow):*** *In general, 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. The presence of a physical obstruction with a large RCS in the path of the radar beam is expected to create a region behind the turbine farm within which aircraft would be masked from detection, known as the shadow region. This shadow region is believed to be a direct result of the interference of large physical objects (components of the wind turbine towers), with the propagation of the radar beam. It is believed to only occur in the region directly behind the wind turbines up to a maximum of a few km. The effect on a wavefront partially obstructed by an obstacle is generally referred to as 'diffraction' and the effect causes a bending of the direction of propagation of the wave front. The energy that has been blocked by the turbine is lost by reflection in other directions. The energy that partially fills the shadow region behind the turbine is taken from the energy that passes the turbine unobstructed, hence the field strength behind the turbine is diminished over a region that shrinks with range behind the turbine. 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 with respect to the location of the radar. The operational effect of large structures in the coverage area of a radar are taken into consideration using current planning and assessment procedures, however the volume of the shadow region and its operational impact has to be given careful consideration in the planning process of a wind turbine implementation;*

e) ***Receiver Saturation:*** *Radar receivers require a large dynamic range in order to detect the reflected energy from both large and small aircraft. However, if an obstacle such as a wind turbine reflects a significant amount of power, the receiver can be pushed beyond its dynamic range and can become saturated. This effect is not limited to wind turbines and can be caused by any large obstacle; however, it is dependent upon the size and range of the obstacle from the receiver. It is acknowledged that the likelihood of wind turbine generated receiver saturation is low; however, any possibility of receiver saturation should be taken into consideration.*

7.1.2 Eurocontrol Guidelines on PSR

This document identifies the following potential PSR impacts:

- Reduction in probability of detection – similar to (b) above;
- Processing overload – similar to (c) above;
- Shadowing effects- similar to (d) above;
- False target reports – similar to (a) above;
- Range and azimuth errors – not mentioned in CAP764;
- Raised thresholds – similar to (b) above;
- Receiver saturation – similar to (e) above.

7.1.3 CAP 764 on SSR

This document identifies the following potential effects of wind turbines on secondary surveillance radar:

- ***False Targets Caused by SSR Signal Reflections:*** *Wind turbines, like any other large obstacle, can cause SSR reflections if they are sufficiently close to the SSR and are within radar LOS. In general terms, SSR energy may be reflected off the structures in both the uplink and downlink directions. This can result in an aircraft which is in a different direction to the way the radar is looking, replying through the reflected signal which results in the radar attributing that response to the original signal, and therefore outputting a false target in the direction where the radar is pointing i.e. at the obstruction. Traditional SSR (Mode A and C) is susceptible to this, but employs reflection processing and gain-time control (essentially speed/time calculations to confirm the validity of a response) to try to eliminate the reflections. However, these techniques are not always successful in eliminating high power reflections. Moreover, most reflection processing assumes a fixed-reflector orientation, which can be defeated by wind turbines due to the manner in which their orientation changes as the blades swing to face the wind. The selective and predictive tracking used by Mode Select (Mode S) radars makes them less susceptible to the effects of reflections (i.e. the reflection is not in the predicted location where the aircraft should be, so the selective interrogation will not be directed there); however, not all SSR radars are Mode S capable;*
- ***Presenting an Obstruction:*** *If the wind turbines are within radar LOS and aircraft are required to be detected at longer range behind the wind turbines, then shadowing effects similar to those described above for PSR at paragraph 2.3d can occur. Following discussion with service providers, and in the absence of recorded specific research, the CAA advises that 24 km (approx.) 13 NM) should be used as the trigger point for further discussions with the appropriate service provider who can make a more detailed, accurate assessment of the likely effect on their SSR. The majority of effects are likely to be within 10 km but, because the possibility exists for effects out to 24 km, the greater distance should be utilized for consultation. It must be noted that this is not intended as a range within which all turbines should be objected to.*

7.1.4 Eurocontrol Guidelines on SSR

This document identifies the following potential SSR impacts:

- Reduction in probability of detection and probability of Mode A and Mode code detection – similar to (b) above;
- SSR false target reports – similar to (a) above;
- Reduction in SSR 2D position accuracy;

7.2 Initial Assessment

An initial evaluation was undertaken for the identified radar installations in order to decide whether further consideration is required:

Radar	Eurocontrol Guidelines	UK
Shannon PSR	Turbine is planned to be located within Zone 3 (>15km of the radar and within radar line of sight). Simple assessment is required.	Turbine is located within 30km of a PSR equipped airport. Thus, further consideration is required.
Shannon MSSR	Turbine is planned to be located within Zone 4 (16km or not in radar line of sight). No assessment is required.	In the UK NATS safeguards SSR to a distance of 10km. At a distance larger than 24km it is most unlikely the Vistakon turbine will impact Shannon MSSR. No further consideration is given.
Woodcock Hill MSSR	Turbine is planned to be located within Zone 2 (500m-16km but within maximum instrumented range and in radar line of sight). Detailed assessment is required which is outside the scope of this report.	In the UK NATS safeguards SSR to a distance of 10km. Therefore, at an approximate distance of 12.3km, it is possible that any impact may be acceptable.

Table 10 Eurocontrol/UK - Shannon PSR/MSSR & Woodcock Hill MSSR

7.3 Assessment of Likely Impacts on Shannon Airport PSR

Based on the findings so far within this report, each of these potential impacts has been considered for the Shannon PSR. The most likely impacts are outlined below:

Technical Effect	Description
False Radar Returns (Clutter)	This is likely. Onscreen clutter will be generated by the wind turbine. However, because it is a single turbine the overall effect is unlikely to be significant.
Loss of Receiver Sensitivity / Probability of Detection	This is possible because the turbine will be detected by the radar. Small targets flying slowly in the vicinity of the turbine may be less likely to be detected as a result.
Plot Extractor/Memory Filter Overload	Unlikely to be significant.
Presenting an obstruction (Shadowing)	Shadowing effects are likely to be minor to negligible; it is likely that a small shadow zone will extend beyond the wind turbine at low altitude. This is unlikely to significantly affect aircraft arriving and departing Shannon.
Receiver saturation	It is unlikely due the size and distance of the development that the wind turbine will cause any receiver saturation effects.

PSR range and azimuth errors	Possible.

Table 11 Likely Technical Effects on Shannon Airport PSR

7.4 High Level Assessment of Likely Impacts on Woodcock Hill MSSR

Based on the findings so far within this report, the most likely Woodcock Hill MSSR impacts are outlined in the table below:

Technical Effect	Description
SSR Probability of detection and probability of Mode A and Mode C code detection	Unlikely that there will be any significant impact due to the height difference between MSSR and wind turbine.
False target reports	Unlikely.
SSR Reflections	Unlikely that there will be any significant impact due to the height difference between MSSR and wind turbine. Modern radar design and processing will make any potential impact less likely.
Presenting an Obstruction	Shadowing effects are likely to be negligible as the turbine tip is planned to be located 158m (518 feet) below the radar antenna.
SSR 2D position accuracy	Unlikely that there will be a significant impact.

Table 12 Likely Technical Effects on Woodcock Hill MSSR

The technical impact to Woodcock Hill MSSR based on distance and height separation may not be significant; however further investigation would be required to assess this in detail.

7.5 Operational Impact

The airspace above and around the proposed wind energy project is busy due to the Shannon Airport CTR/CTA, Class C. The proposed wind energy project is planned to be located within uncontrolled airspace so it is possible that unknown aircraft will appear in the vicinity of the proposed wind turbine. Although, the impact may be operationally acceptable to Shannon, Airport concerns may be raised.

An overview of technical mitigation options have been attached in Appendix D.

Any technical impact may be acceptable to the IAA. However, detailed analysis will be required to assess this which is outside the scope of this report.

8 CONCLUSIONS & RECOMMENDATIONS

- The proposed wind turbine is likely to be within radar line of sight to both Shannon PSR/MSSR and Woodcock Hill MSSR.
- No additional shielding has been identified which would significantly change the line of sight results.
- It is likely that the proposed turbine will be detected by Shannon PSR.
- The effect of the proposed wind turbine on Shannon MSSR is negligible.
- The effect of the proposed wind turbine on Shannon PSR is minor; it is likely the proposed wind turbine will appear as clutter on Shannon Airport radar screens. However, due to the small size of the development (single turbine) this may be acceptable.
- The effect of the proposed wind turbine on Woodcock Hill MSSR is minor.
- The proposed wind turbine will not infringe ICAO based protected surfaces of Shannon Airport and Coonagh airfield.
- It is likely the IAA will require the turbine to be lit.
- Consultation with Shannon Airport and the Irish Aviation Authority is recommended to determine the potential effects on Woodcock Hill MSSR and Shannon Airport Radar.

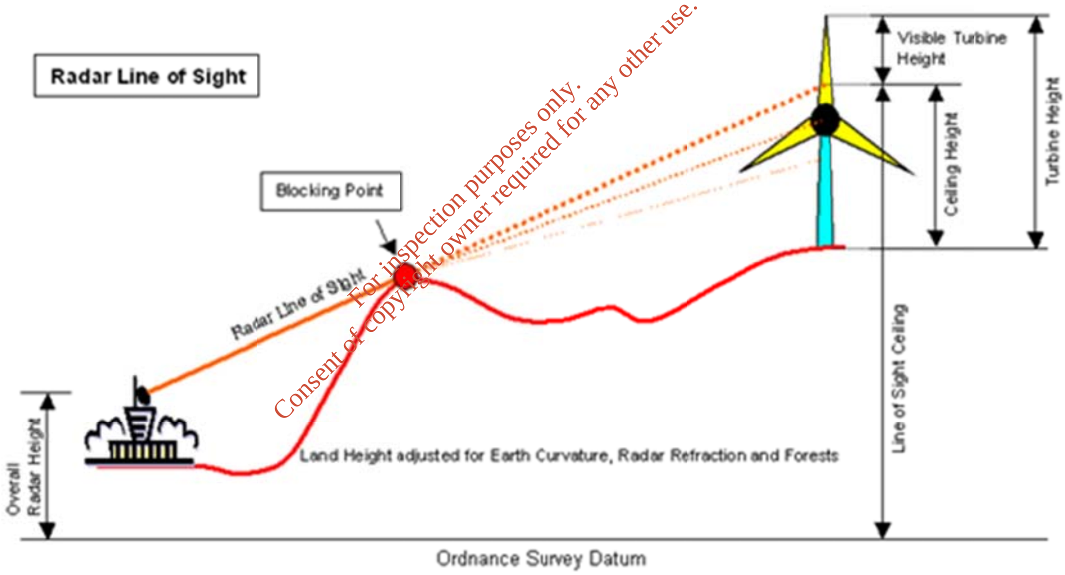
APPENDIX A - RADAR ANALYSIS GENERIC PRINCIPLES

Overview
Line of sight Analysis is used to determine the extent to which a planned wind turbine could be detected by a specific radar installation.

This analysis takes into account:

- The curvature of the Earth
- Refraction of the radar signal by the atmosphere
- The Effective Radar Height
- The Effective Turbine Height
- The height profile of the terrain between the radar and turbine

The following diagram shows how Radar Line of sight is determined, together with the various terms used in the analysis:



Radar Line of Sight

Overall Radar Height
The radar height determines the Line of sight angle. This in turn determines the Ceiling Height. The higher the radar, the lower the Line of sight Ceiling will be. The Overall Radar Height is the height of the radar radiation centre above mean sea level.

Turbine Height
Higher wind turbines are more likely to be detected by radar than lower ones. The Turbine Height is calculated by adding the hub height to the rotor radius.

Earth Curvature
Curvature of the Earth limits the distance at which objects can be detected, using visual and radar techniques.

The effect of Earth Curvature increases as the separation between radar and wind turbine increases.

The effect of Earth Curvature is calculated by determining the vertical separation of two lines running between the radar and wind turbine.

The first is the arc of the great circle that passes through the radar and wind turbine. This is the shortest arc between the two points.

The second is the chord between the radar and wind turbine. This line cuts through the Earth's surface.

Radar Signal Refraction
Radar Signals travel in straight lines in free space. Variations in the atmosphere cause bending of radar signals. This bending is caused by lower denser air having a higher refractive index than higher less dense air.

The result of this bending is that effective radar range is extended beyond the visible horizon. Radar system designers compensate for this effect by using a larger effective Earth Radius in their calculations. This compensation allows radar signals to be treated as straight lines, even though they are actually being refracted.

The Earth Radius is multiplied by a refraction constant k to give an increased effective Earth Radius. The standard figure used for k is 4/3. This value is known as Standard Refraction.

The Earth Curvature curve can then be adjusted, by recalculating each point using the adjusted Earth radius.

Attenuation by Forestry and Obstructions
Areas of land between the Radar and the Wind energy project may be covered with forest, buildings or structures that effectively attenuate radar signals. Where there are large areas of forestry, or built up areas, these may be considered, and included within the land profile charts.

Land Height Profile
A Land Height Profile is generated by determining the height of a series of equally spaced points along the line between the radar and a single wind turbine. The Digital Terrain Model (DTM) data used has the following characteristics:

DTM data source origin	SRTM
DTM data point interval	3 arc seconds
DTM height data resolution	1 metre

DTM Characteristics

Adjusted Land Height Profile
The Adjusted Land Height Profile can take Earth Curvature, Radar Refraction and any Buildings or Forestry into account.

It is calculated by adding the 'Land Height' curve and the 'Earth Curvature with compensation for Radar Refraction' curve.

Radar Line of sight
The Radar Line of sight is determined by taking the straight line which:

- Originates at the radiation centre of the radar
- Has the highest tangent with the Adjusted Land Height Profile
- Passes through or over the Wind Turbine

Line of sight Ceiling
The Line of sight Ceiling is the height, above mean sea level, of the point at which the Line of sight passes the wind turbine.

Ceiling Height
The Ceiling Height is the height, above ground level, of the point at which the Line of sight passes the wind turbine.

Visible Turbine Height
The Visible Turbine Height is the vertical distance between the point at which the Line of sight passes the wind turbine, and the top of the wind turbine.

[Visible Turbine Height] = [Turbine Height] - [Ceiling Height]

If the Line of sight passes below the top of the Wind Turbine then Visible Turbine Height is positive.

If the Line of sight passes above the top of the Wind Turbine then Visible Turbine Height is negative.

Predominant Blocking Point
The Predominant Blocking Point is defined as the point at which the Radar Line of sight is tangential to the Adjusted Land Height Profile.

The Blocking Point is the piece of land that physically prevents or limits the radar's detection of the wind turbine.

If a wind turbine lies in the shadow cast by the Predominant Blocking Point, the radar, discounting weak diffraction effects, cannot detect it.

Land Profile Charts
These show the Line of sight between the radar and a wind turbine. The horizontal scale shows the distance between the radar and the wind turbine in kilometres. 0km at the left hand side corresponds to the radar location. The right hand end of the scale represents the point in the wind energy project. The vertical scale shows land height in metres. All heights are with reference to the mean sea level.

APPENDIX B - RADAR LINE OF SIGHT CHARTS

Radar Impact Assessment
6970A Vistakon
Prepared for Arup Partners Ltd
by Pager Power Limited

Turbine Reference	1
Hub Height /m	100
Rotor Diameter /m	101
Turbine Height /m	150.5
Turbine Grid Reference	E163345 N158173
Turbine Land Height /m	8.3
Blocking Point Grid Reference	E148893 N159985
Blocking Point Adjusted Land Height /m	33.9
Distance from Turbine to Radar /km	26.8
Distance from Turbine to Blocking Point /km	14.6
Visible Turbine Height /m	120.2

Shannon Airport PSR

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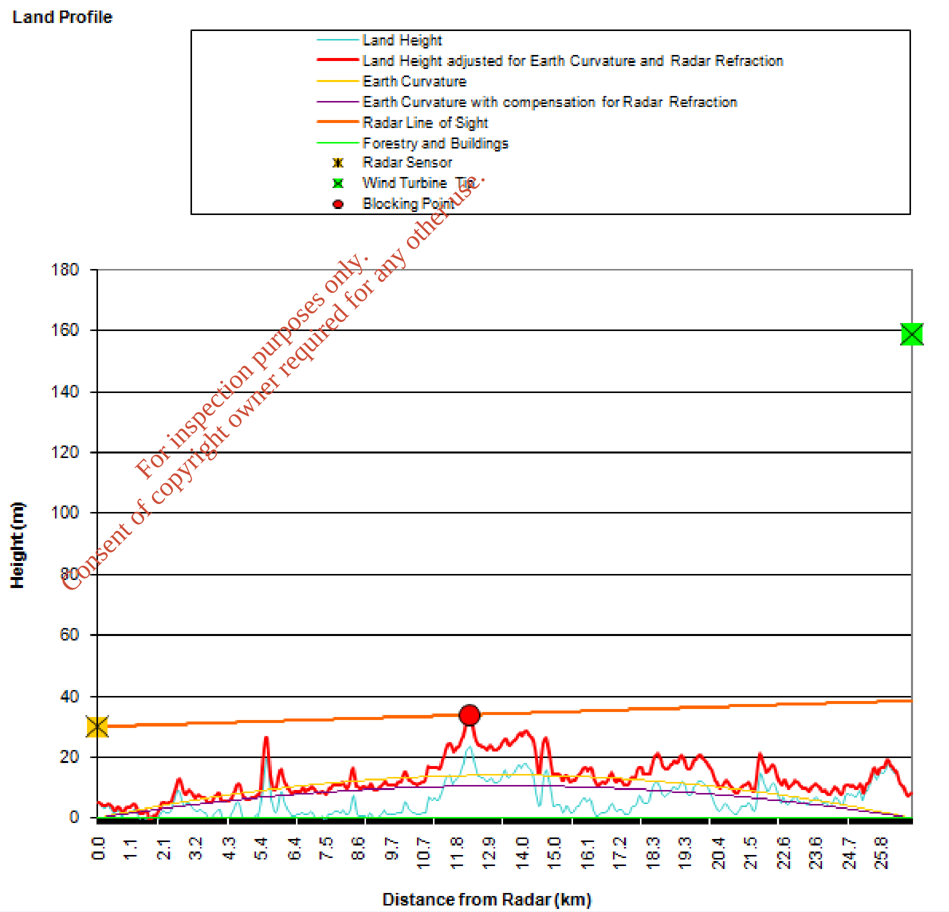
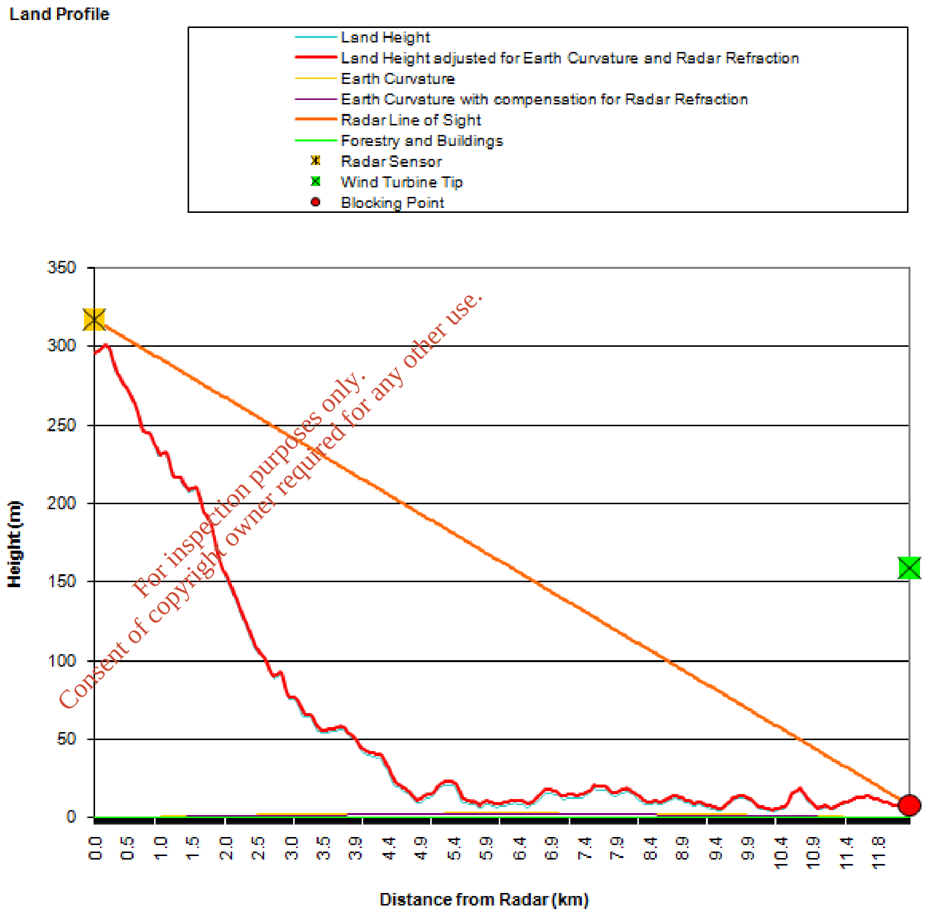


Radar Impact Assessment

6970A Vistakon
Prepared for Arup Partners Ltd
by Pager Power Limited

Turbine Reference	1
Hub Height /m	100
Rotor Diameter /m	101
Turbine Height /m	150.5
Turbine Grid Reference	E163345 N158173
Turbine Land Height /m	8.3
Blocking Point Grid Reference	E163345 N158173
Blocking Point Adjusted Land Height /m	8.3
Distance from Turbine to Radar /km	12.3
Distance from Turbine to Blocking Point /km	0.0
Visible Turbine Height /m	150.5

Woodcock Hill MSSR



APPENDIX C – RADAR DETECTABILITY CALCULATIONS

Wind Turbine Radar Detection Calculation - CAP 764 v1 Method [CAP76401]

Turbine Reference	1

Arup
Shannon Airport PSR

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A1.1 Input Parameters

Generic Wind Turbine

	Value	Units	Data Source
Height of Tower	50	m	CAP 764 v1
Tower Radar Cross Sectional Area	80	m^2	CAP 764 v1
Blade Length	30	m	CAP 764 v1
Blade Radar Cross Sectional Area	9	m^2	CAP 764 v1

Wind Turbine

	Value	Units	Data Source
Height of Tower	100.0	m	Customer
Blade Length (Rotor Radius)	50.5	m	
Number of Blades	3	N/A	Assumed
Location Easting	163345.0	m	
Location Northing	158173.0	m	
Base Elevation	8.3	m aod	DTM Terrain Database
Tip Height	150.5	m agl	
Tip Elevation	158.8	m aod	

Radar

	Value	Units	Data Source
Power Radiated	80.0	dBW	CAP 764 v1 Typical
Sensitivity	-130.0	dBW	Customer
Sensitivity	-100.0	dBm	
Down Tilt	0.0	degrees	CAP 764 v1 Typical
Frequency	2765.0	MHz	Customer
Receiver Loss	3.0	dB	CAP 764 v1 Typical
Speed Filter (0 = None 1=Operational)	1	N/A	
Location Easting	136734.44	m	Pager Power Online
Location Northing	161509.7	m	
Base Elevation	2.0	m aod	
Antenna Height	28.0	m agl	
Antenna Elevation	30.0	m aod	

Path details are in A1.4 below

Radar Antenna

Off-axis Elevation Angle	Gain (dBi)	Data Source
-3.0	16.5	Assumed Watchman Radar
-2.5	18.1	
-2.0	19.7	
-1.5	22.1	
-1.0	24.5	
-0.5	26.55	
0.0	28.6	
0.5	30.05	
1.0	31.5	
1.5	32.25	
2.0	33	
2.5	33.425	
3.0	33.85	
3.5	33.875	

A1.2 Assessment of the Radar Cross-Sectional Area of the Wind Turbine

	Value	Units
Static Element Scaling Factor	2.00	m
Static Element Radar cross-sectional area	320.00	m^2
Moving Element Scaling Factor	1.68	m
Moving Element Radar cross-sectional area	25.50	m^2

A1.3 Radar Antenna PLM Data

	Value	Units	28.66963466
Off-Axis elevation angle	0.02	degrees	28.6
Antenna gain towards turbine	28.7	dB	30.05

A1.4 Determine Elevation Angles and Separation Distance

	Value	Units
Length	26.8	km
Slope	0.02	degrees
Wavelength	0.11	metres
Free Space Path Loss (FSPL)	129.85	dB

A1.5 Divide Wind Turbine Structure into parts

Height m	Static RCS m^2	Moving RCS m^2
10	**32.0**	**#N/A**
20	**32.0**	**#N/A**
30	**32.0**	**#N/A**
40	**32.0**	**#N/A**
50	**32.0**	**0.1**
60	**32.0**	**2.5**
70	**32.0**	**2.5**
80	**32.0**	**2.5**
90	**32.0**	**2.5**
100	**32.0**	**2.5**
110	**#N/A**	**2.5**
120	**#N/A**	**2.5**
130	**#N/A**	**2.5**
140	**#N/A**	**2.5**
150	**#N/A**	**2.5**
160	**#N/A**	**0.1**
170	**#N/A**	**#N/A**
180	**#N/A**	**#N/A**
190	**#N/A**	**#N/A**
200	**#N/A**	**#N/A**

Static	
RCS /m	3.2
Start	0
Finish	100.0

Moving	
RCS /m	0.2525
Start	49.5
Finish	150.5

A1.6 Determine the radar return for each part of the turbine structure

Height m	Actual O/W Loss dB	FSPL dB	Additional Att. dB	Data Source
10	**166.1**	129.9	36.20	ITU-526
20	**153.0**	129.9	23.19	Pager Power Online
30	**148.4**	129.9	18.51	
40	**143.9**	129.9	14.03	
50	**139.5**	129.9	9.66	
60	**134.7**	129.9	4.84	
70	**131.6**	129.9	1.73	
80	**129.9**	129.9	0.00	
90	**129.9**	129.9	0.00	
100	**129.9**	129.9	0.00	
110	**129.9**	129.9	0.00	
120	**129.9**	129.9	0.00	
130	**129.9**	129.9	0.00	
140	**129.9**	129.9	0.00	
150	**129.9**	129.9	0.00	
160	**129.9**	129.9	0.00	
170	**129.9**	129.9	0.00	
180	**129.9**	129.9	0.00	
190	**129.9**	129.9	0.00	
200	**129.9**	129.9	0.00	

i Static parts (tower, nacelle etc)

	Value	Units
EIRP	**80.0**	dBW
Rx System Gain	**25.7**	dB

Height m	RCS m^2	Lbr dB	Latt dB	Lbr (act) dB	Pr dBm	Pr abs
10	32.00	214.32	36.20	286.72	-151.05	7.85158E-16
20	32.00	214.32	23.19	260.70	-125.03	3.1402E-13
30	32.00	214.32	18.51	251.34	-115.67	2.70992E-12
40	32.00	214.32	14.03	242.38	-106.71	2.13283E-11
50	32.00	214.32	9.66	233.64	-97.97	1.59572E-10
60	32.00	214.32	4.84	224.00	-88.33	1.46878E-09
70	32.00	214.32	1.73	217.78	-82.11	6.15116E-09
80	32.00	214.32	0.00	214.32	-78.65	1.36445E-08
90	32.00	214.32	0.00	214.32	-78.65	1.36445E-08
100	32.00	214.32	0.00	214.32	-78.65	1.36445E-08
110	#N/A	#N/A	0.00	#N/A	#N/A	0
120	#N/A	#N/A	0.00	#N/A	#N/A	0
130	#N/A	#N/A	0.00	#N/A	#N/A	0
140	#N/A	#N/A	0.00	#N/A	#N/A	0
150	#N/A	#N/A	0.00	#N/A	#N/A	0
160	#N/A	#N/A	0.00	#N/A	#N/A	0
170	#N/A	#N/A	0.00	#N/A	#N/A	0
180	#N/A	#N/A	0.00	#N/A	#N/A	0
190	#N/A	#N/A	0.00	#N/A	#N/A	0
200	#N/A	#N/A	0.00	#N/A	#N/A	0
Total					**-73.1**	4.87373E-08

ii Moving parts

EIRP and Rx System Gain as i above

Height m	RCS m^2	Lbr dB	Latt dB	Lbr (act) dB	Pr dBm	Pr abs
10	#N/A	#N/A	36.20	#N/A	#N/A	0
20	#N/A	#N/A	23.19	#N/A	#N/A	0
30	#N/A	#N/A	18.51	#N/A	#N/A	0
40	#N/A	#N/A	14.03	#N/A	#N/A	0
50	0.13	238.36	9.66	257.68	-122.01	6.29562E-13
60	2.53	225.35	4.84	235.03	-99.36	1.15896E-10
70	2.53	225.35	1.73	228.81	-93.14	4.85365E-10
80	2.53	225.35	0.00	225.35	-89.68	1.07663E-09
90	2.53	225.35	0.00	225.35	-89.68	1.07663E-09
100	2.53	225.35	0.00	225.35	-89.68	1.07663E-09
110	2.53	225.35	0.00	225.35	-89.68	1.07663E-09
120	2.53	225.35	0.00	225.35	-89.68	1.07663E-09
130	2.53	225.35	0.00	225.35	-89.68	1.07663E-09
140	2.53	225.35	0.00	225.35	-89.68	1.07663E-09
150	2.53	225.35	0.00	225.35	-89.68	1.07663E-09
160	0.13	238.36	0.00	238.36	-102.69	5.38317E-11
170	#N/A	#N/A	0.00	#N/A	#N/A	0
180	#N/A	#N/A	0.00	#N/A	#N/A	0
190	#N/A	#N/A	0.00	#N/A	#N/A	0
200	#N/A	#N/A	0.00	#N/A	#N/A	0
Total					**-80.3**	9.2688E-09

A1.7 Interpretation of the Results

	Value	Units	Assessment
Receiver Threshold	**-100.00**	dBm	
Speed Filter (0 = None 1=Operational)	**1**	N/A	
Received Power (Static)	**-73.12**	dBm	**Detection unlikely**
Received Power (Moving)	**-80.33**	dBm	**Detection likely**
Received Power (Static and Moving)	**-72.37**	dBm	**Detection likely**

1. Numbers on left indicate corresponding paragraph number in CAP 764

Tool last updated 08/12/10

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APPENDIX D - PRIMARY SURVEILLANCE RADAR MITIGATION

UK Civil Aviation Authority document CAP 764 describes a number of operational and technical mitigation options regarding Primary Surveillance Radar.

Operational mitigation options include:

- Routing aircraft around areas of wind energy project clutter
- Disregarding wind energy project clutter

Technical mitigation options are described in CAP 764 as follows:

- ***PSR Blanking:*** *PSR blanking is the means of ensuring that clutter caused by a wind turbine development is not presented to the controller by deliberately masking fixed areas on the radar display.*
- ***Effect of PSR Blanking on ATS Provision:*** *Regardless of the means of enabling PSR blanking, it is important to note that all radar returns – i.e. legitimate aircraft as well as wind turbine clutter are prevented from being presented to the air traffic controller. Therefore, this mitigation can only be used in areas in which the ATS provider or ANSP deems a total loss of data to be acceptable. As a result, the decision on where and when PSR blanking is appropriate is dependent on case-by-case analysis and is the prerogative of the ATS provider or ANSP.*
- ***In-Fill Radar:*** *Where PSR is blanked to avoid presentation of clutter to the air traffic controller, it is sometimes possible to enable the continued provision of radar coverage in the affected are by overlaying the returns from an unaffected alternative radar. The unaffected radar (for reasons such as terrain or distance) is known as the 'in-fill' radar, and the process is sometimes referred to as data-fusion or mosaicing. The process is reliant upon the capability of the ATC system to blank specific areas; receive data from an additional source; and fuse the data together and to display it to the controller in a usable format.*
- ***Effect of In-Fill on ATS Provision:*** *In-fill as a mitigation is effective, but often problematic due to the following considerations:*

  a) Data fusion is technically difficult and the service provider must be content that the risks are mitigated effectively;

  b) Service providers are understandably reluctant to rely on an in-fill radar that is not fully under their control, and so in-fill from external data sources will often require some form of guarantee to maintain the integrity of data for all but unforeseen, short-notice outages;

  c) In-fill mitigations based on the provision of new radars will be subject to the availability of appropriate operating frequencies, which are scarce, and may be subject to an Administered Incentive Pricing Scheme in the future, which will add to the financial considerations of the viability of this form of mitigation;

  d) Where the performance of an aeronautical radar station is affected by many wind turbine developments within its coverage, several in-fill radars may be required to cover the affected coverage areas, which could be costly and technically very complex.
- ***Shielding:*** *Where low-level radar coverage in the area of the wind turbine development is not required, it may be possible to use either terrain or a man-made object to prevent a radar from 'seeing' the wind turbines. The use of terrain may involve moving the turbines or radar (although the latter is likely to be far more problematic) to a suitable alternative location, where the physical characteristics ensure that the radar and the wind turbines are no longer in radar LOS. A man-made object could also be used (potentially constructed of Radar Absorbent Materials (RAM)) to create an artificial radar horizon. In either case, a detailed study of the radar performance requirements would be required.*
- ***Effect of Shielding on ATS Provision:*** *Shielding is only viable when the operational use of the radar is such that completely removing all radar coverage on specified radials at certain levels is deemed acceptable, i.e. where low level coverage in the vicinity of the wind turbine development is not required.*
- ***Use of Alternate Surveillance Techniques:*** *It is generally accepted that alternate surveillance techniques (such as Multilateration, Automatic Dependant Surveillance and Multistatic PSR) are less susceptible to effects induced by wind turbine developments. However the implementation of such*

systems should be considered with respect to their capability to deliver the required performance for the provision of a particular ATS, and the proportion of co-operative/non co-operative targets present in a particular operational environment where the service is being provided.

- ***Multilateration:*** *Multilateration is a form of co-operative and independent surveillance system which makes use of signals routinely transmitted by an aircraft to calculate the aircraft's position. Generally a multilateration system consists of a number of antennas receiving a signal from an aircraft and a central processing unit calculating the aircraft's position from the time difference of arrival of the signal at the different antennas. Active multilateration systems can also prompt replies from aircraft by interrogating the aircraft transponders, which includes transmitters as well as receivers.*
- ***Automatic Dependant Surveillance (ADS):*** *ADS is also a co-operative system that uses data gained from the aircraft's own systems (derived from sensors such as GPS etc.) and then transmits information to interested parties using datalink technology. ADS may be used across a range of applications from local airfield monitoring (ADS works down to low level) to long range airspace coverage.*
- ***Multistatic Primary Radar (MSPSR):*** *The term MSPSR refers to a sparse network of transmitters and either a single receiver or a network of receiver ground stations using static (i.e. non-rotating) antennas. These units receive signals reflected from the aircraft and prepare them for onward transmission to the centralized processing unit. The signal received via the reflected path is cross correlated with the direct signal from the transmitter(s) in order to locate the position of the target reflecting the signals.*
- ***Non Auto-Initiation Zones (NAIZ):*** *Some plot extracted PSR systems have the ability to create NAIZ, which are defined zones within which plot extracted tracks are prevented from initiating, whilst mature tracks are maintained and updated. NAIZ placed over the location of a wind turbine development ensure that turbine blades do not create false tracks, but established aircraft tracks entering the location continued to be updated.*
- ***Effect of NAIZ on ATS Provision:*** *Despite wind turbine blade returns being inhibited from processing and displaying, if the return signal strength of the wind turbine blades is equivalent to or greater than an established aircraft track, there is potential for ATC system processing to confuse the two returns, and switch the association of the established aircraft track from its real radar response to that of the wind turbine blade response. Switching of track association presents false information to the operator and may cause risk to flight safety. Moreover, NAIZ cannot identify the source of new potential tracks within the zone, and so will not enable initiation of a track on a radar response caused by an actual aircraft whose radar responses have only just begun to be received by the radar (i.e. climbing out of low level) before it enters the wind turbine development area. Therefore, the use of NAIZ are discouraged. When appropriate, their sizes must be minimal and proliferation avoided.*
- ***Advanced Tracking Algorithms:*** *Advanced Tracking Algorithms are classified as non-traditional tracking methods that make use of high capacity and high speed processing systems to perform multiple calculations to determine the most probable target positions. These non-deterministic approaches to target detection and tracking have yet to be fully accepted in the UK civil radar arena, where more traditional deterministic tracking methods are utilized.*
- ***Effect of Advanced Tracking Algorithms on ATS Provision:*** *Advanced tracking algorithms are non-deterministic. A radar may not have a solid detection of where an aircraft is and, to overcome this, tracking algorithms will predict (by extrapolation) the position of the aircraft based on the last known movement of the aircraft. The use of such advanced tracking algorithms to process plots over a wind turbine development affected area has to be given careful consideration as this process could associate false wind energy project plots, generating false or diverted tracks. As such, it may be difficult for any service provider to provide a robust safety assessment, including necessary verification evidence, for systems using advanced tracking algorithms. Nevertheless, this does not mean that it may not be possible in the future.*
- ***Use of SSR Only:*** *There may be instances whereby sole reliance on SSR is acceptable to the safe provision of an ATS; however, this can only be assessed on a case-by-case basis. It should also be noted that SSR is not the only co-operative surveillance technique (i.e. one that requires aircraft to be equipped with a transponder) available, hence techniques such as ADS-B and multilateration can also be used in situations where the sole use of a co-operative techniques is deemed acceptable.*
- ***Effect of SSR Only on ATS Provision:*** *The use of SSR only in the busy Approach environment (Terminal Control Areas) is not approved in the UK, as it is deemed unacceptable for an aircraft transponder to be a single point of failure, and the subsequent increased risk of conflictions with non-transponding – and therefore undetectable – aircraft. However, it may be justifiable to use SSR-only to maintain the identity of an aircraft transiting through small areas of airspace affected by the clutter*

caused by wind turbine developments. The use of SSR-only in the en route environment is more common; however, the same risks posed by non-transponding aircraft still exist but to a lesser extent and approval is still required from the CAA. Provision of surveillance systems according to airspace and ATS is described in CAP 670.

- ***Transponder Mandatory Zones (TMZ):*** *Transponder carriage requirements within UK airspace are changing to maximise the benefits offered by Mode S. However, under current regulations or proposals, not all UK airspace requires aircraft to be equipped with transponders, thus leaving large areas where transponders will not be mandatory. Nevertheless, it is recognised that, under certain circumstances and in certain areas, mandatory transponder carriage can provide significant safety benefits. Consequently, the CAA has the regulatory power to create TMZs. External bodies can also request TMZs; however, the ACP (CAP 725) must be followed. The ACP ensures that the requirement for a TMZ is fully justified and that the effect upon all airspace users is fully consulted and assessed. The responsibility for completing this assessment would not necessarily fall to the aviation stakeholder. Consideration of the feasibility of a TMZ as mitigation should include: effect on other airspace users; the creation of 'choke points' within Class G airspace; whether the affected ATC system is capable of PSR blanking; and the likelihood of the CAA approving SSR-only operations.*
- ***Offshore SSR Only and TMZ:*** *Despite offshore uncontrolled airspace being largely free of non transponder equipped aircraft, this cannot be taken to mean that SSR only operations, or TMZs, would enjoy an easier approval process. In many instances, the ability to identify non-transponding aircraft (for example, following equipment failure) will be required to maintain safety cases.*
- ***Effect of TMZ on ATS Provision:*** *TMZs are only viable when it is acceptable that the use of a non-co-operative surveillance technique (such as PSR) is not necessary for security reasons or for the detection of targets that are possibly undetected by SSR or other co-operative surveillance technique being used. It must be noted that, for Air Defence reasons, TMZs may not be suitable in all areas.*
- ***Mechanical Beam Tilting:*** *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.*
- ***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.*
- ***Electronic Beam Switching:*** *This achieves an effect similar to that of mechanical beam tilting, with the same resulting issue.*
- ***RAM:*** *RAM can significantly reduce an object's RCS in specific radar frequencies. The absorbed EM energy is dissipated as heat and very little energy is reflected. The use of RAM on wind turbines (referred to as 'stealth blades') to minimise their RCS is being developed and researched by many developers around the world and it could offer potential mitigation solutions in future.*
- ***Other Developments:*** *The provision of technical mitigation solutions is an area of considerable interest to the aviation and wind industries, and is attracting a significant amount of commercial and technical involvement. Technologies are at different stages of maturity and viability. Details of significant advances will be included on the CAA Wind Energy web pages.*