2015-02-25 - Rosedew Farm Solar Park - Aviation Glint and Glare Assessme...

AARDVaRC Ltd

Aviation Analysis, ...es Development & Visualisation, and Radio Communications

RAF St Athan, Cardiff Airport

Glint & Glare Assessment

for the proposed

Rosedew Farm Solar Park

Prepared for Rosedew Developments Ltd
by Charles Morelli BEng

25 February 2015

AARDVaRC Ltd, PO Box 10785, Sudbury, Suffolk, CO10 3AY
T: +44 (0) 1787 468539 E: charles@aardvarc.ltd.uk W: www.aardvarc.ltd.uk

1 Executive Summary

1.1 Background

Rosedew Developments Ltd is proposing a photovoltaic (PV) solar park (and associated works) on a site at Rosedew Farm, just southeast of the town of Llantwit Major/ Llanilltud Fawr, in the Vale of Glamorgan. The proposal consists of a number of photovoltaic (PV) panels facing due south (relative to True North) inclined at an angle of 25° to the horizontal. The site is approximately 8km west of Cardiff Airport and 2km west of RAF St Athan airfield.

AARDVaRC Ltd was retained to conduct a 'glint and glare' assessment (focussing on the phenomenon of specular reflections of sunlight) giving specific consideration to effects on operations at Cardiff Airport and RAF St Athan airfields with effects on other receptors also considered based on a general analysis.

Guidance from the Civil Aviation Authority (CAA) on the effects of solar park development on aviation advises developers to ensure that solar parks are compliant with the Air Navigation Order (ANO), and specifically Articles 137, 221 and 222, and advises of other nation's guidance for solar parks near airfields, e.g., that of the USA. However, a review of solar parks in 2010 (reproduced at the Annex to this report) at or near airfields around the world (see the Annex to this report) combined with several more recent solar park developments at or near UK airfields demonstrates the compatibility of solar parks and aviation.

In the United States the Federal Aviation Administration (FAA) cautions against relying on its original guidance document which is in the process of being updated due to practical experience and new information. The information in its document appears to be based on extracts from academic research for entirely different purposes without consideration of its applicability to solar reflections from dark solar panels. Furthermore, the document is meant for facilities actually on airfields (whereas the proposed solar park is not on an airfield), and any conclusions based on the information it provides are not supported by the FAA itself which implies that the FAA is aware of substantial shortcomings in that document.

When in shade but otherwise illuminated by an entire blue sky at midday, the ambient light level is typically 20,000 lux. This is much brighter than the 2,000 lux typical of specular reflections of sunlight from solar panels. When solar reflections may be seen, the sun must be shining and so ambient light levels will be high; therefore the worst case effects will be the nuisance caused by looking at or near reflecting panels. This will never be as harsh as looking towards the bright sun – perhaps when driving a car or landing an aircraft towards it, both relatively commonplace events and neither of which are considered to be safety issues.

The terms 'glint' and 'glare' are commonly used together: however, various sources use different definitions of 'glint' and 'glare' (they can mean either: specular and non-specular reflections of sunlight, or brief flashes and longer periods of brightness, respectively). This report focusses on the specular reflection of sunlight from solar panels and discusses the persistence of an observer's exposure to them where necessary; to avoid potential confusion, use of either term is minimised. Specular reflections of sunlight are much more intense – hence significant – than non-specular ones, so by focussing on the specular variety, the worst case is captured.

Sun positions for one year were predicted at 1-minute intervals and solar reflection directions calculated for each data point for later use. It must be noted that at any instant, reflected solar rays across the whole solar park will be parallel to each other, i.e., in a single discrete direction which changes slowly through the day and year.

1.2 Assessment Method

1.2.1 Rosedew Farm Solar Park

It was assumed that solar reflections may occur from any point within the solar park boundary. For detailed analysis, it was modelled by 20 points in 3 dimensions.

1.2.2 Receptors

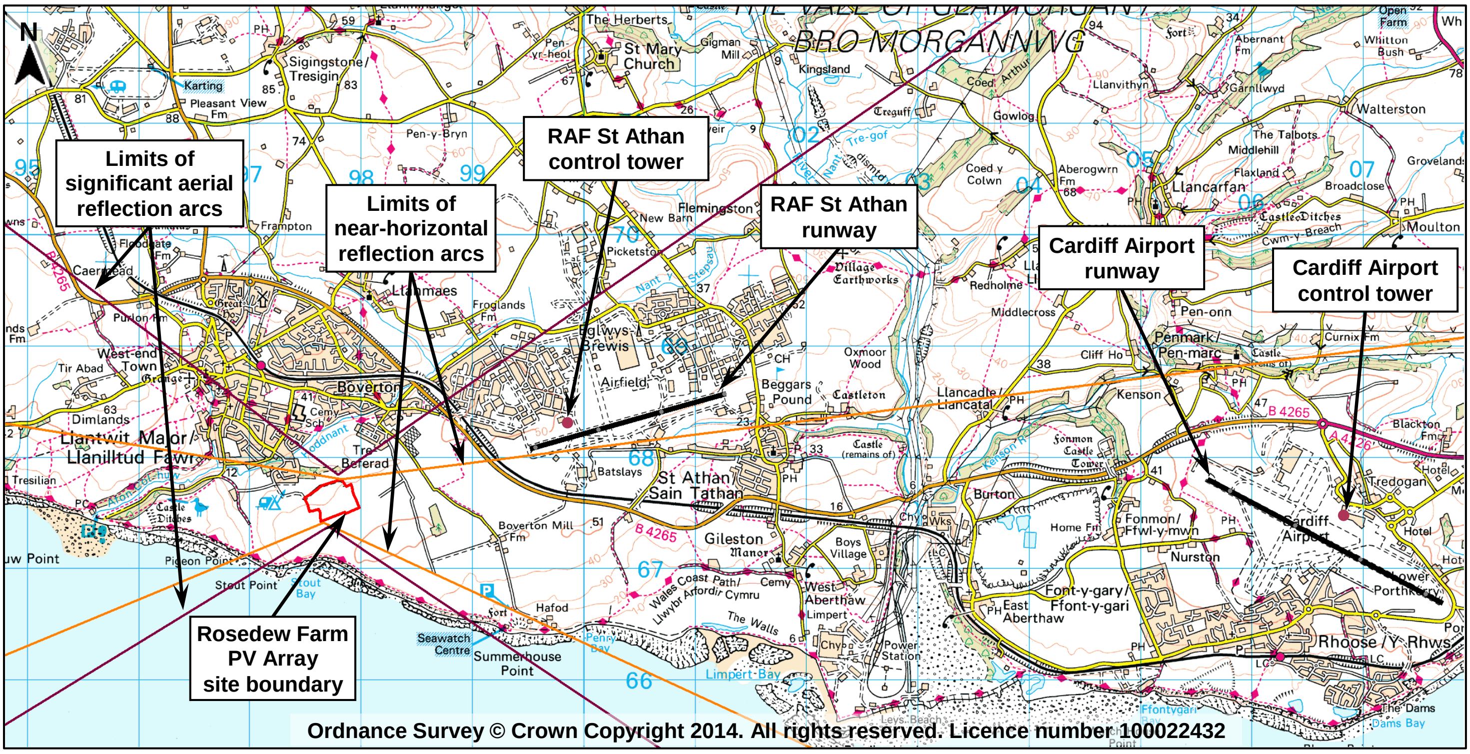
1.2.2.1 Background

Cardiff Airport – 8km east of the site, and RAF St Athan – 2km east of the site, were both specifically assessed, and a general assessment of other likely receptors was made. The approach paths for each runway landing direction and downwind legs of possible circuit patterns were assessed in detail, along with the visual control room (VCR or 'control tower'), at both airfields.

Other potential aerial receptors (e.g., aircraft taking-off, helicopter flight profiles and transiting traffic) were considered based on the results of the other analyses. General surface-based receptors (e.g., dwellings and roads) were also discussed based on the results of the analyses conducted.

1.2.2.2 Airfields and Solar Farm Locations

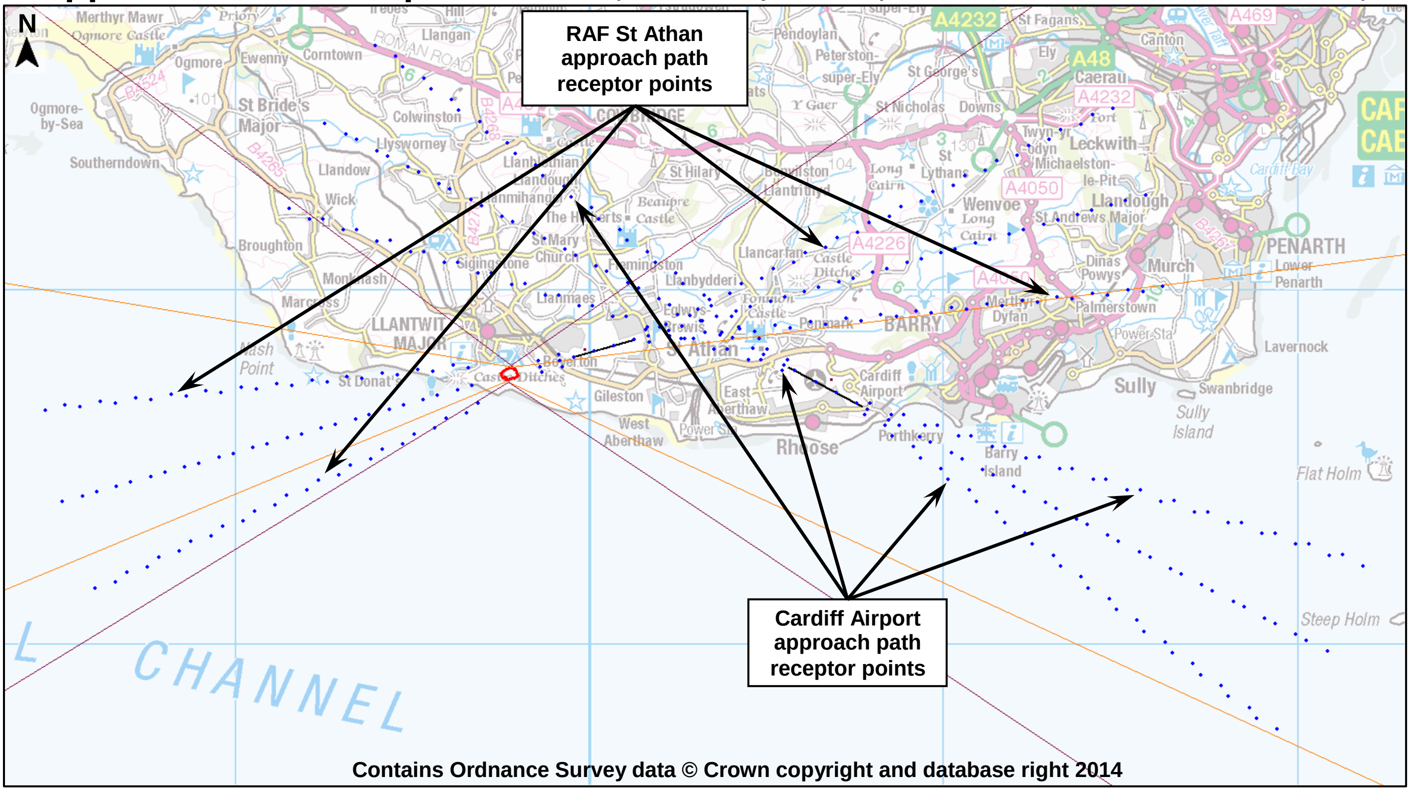
The airfields and solar farm locations are shown on the following chart. Also shown are 2 sets of solar reflection arcs identified in preliminary analysis: 'near-horizontal reflection' arcs (defined for this report as those directed from 5° below, to 10° above, the horizontal plane); and 'significant aerial reflection' arcs (defined for this report as those directed from the horizontal plane to 45° above it). Outside the respective reflection arcs, there is no possibility of observing reflections of the specified nature.



1.2.2.3 Receptor Points on Approach Paths to Runways

Receptor points on the approach paths were considered for both runway directions at each airfield as discussed above. The locations of the approach path receptor points used for detailed analysis are shown as blue dots on the chart below. For each approach path, 3 different glideslopes were considered (at 2°, 3° and 4°), so that each aerial receptor point was assessed at 3 different heights.

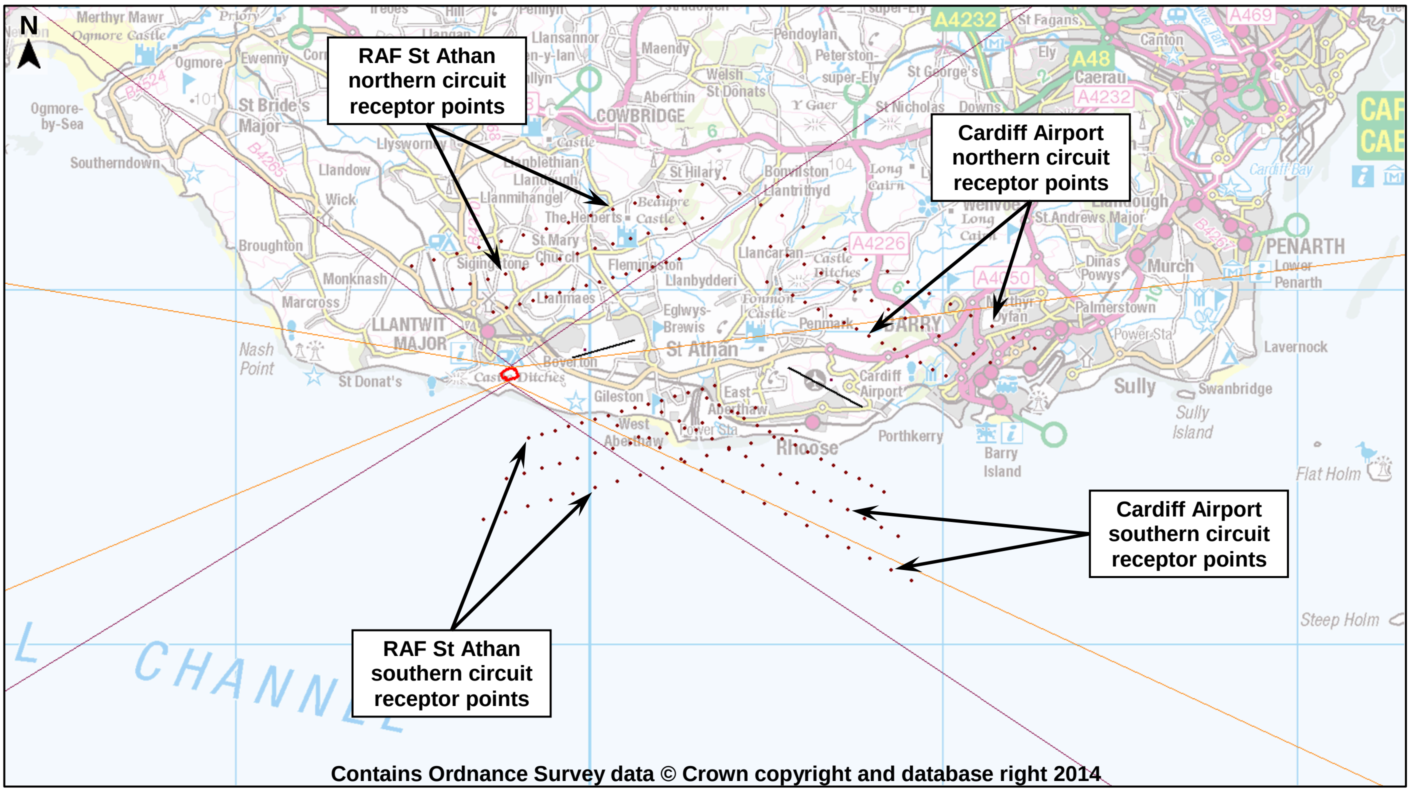
Approach Path Receptor Points (with runways, solar park and solar reflection arcs marked)



1.2.2.4 Receptor Points on Circuit Patterns to Runways

Receptor points on 3 assumed downwind legs paths were considered on either side of the runway at each airfield as discussed above. The locations of the downwind leg receptor points used are shown as brown dots on the chart below. For each downwind legs path, 3 different heights were considered (at 500ft, 1,000ft and 1,500ft above aerodrome level, so that each point was assessed at 3 different heights.

Circuit Receptor Points (with runways, solar park and solar reflection arcs marked)



1.2.3 Analysis

Solar reflections were calculated from the position of the sun on a minute-by-minute basis for a whole year at the solar farm location. Reflections occur within the plane of the incident ray and the reflecting surface's normal vector (the 'normal', perpendicular to the plane of the reflecting surface), and that the angle of reflection is equal and opposite to the angle of incidence relative to the normal.

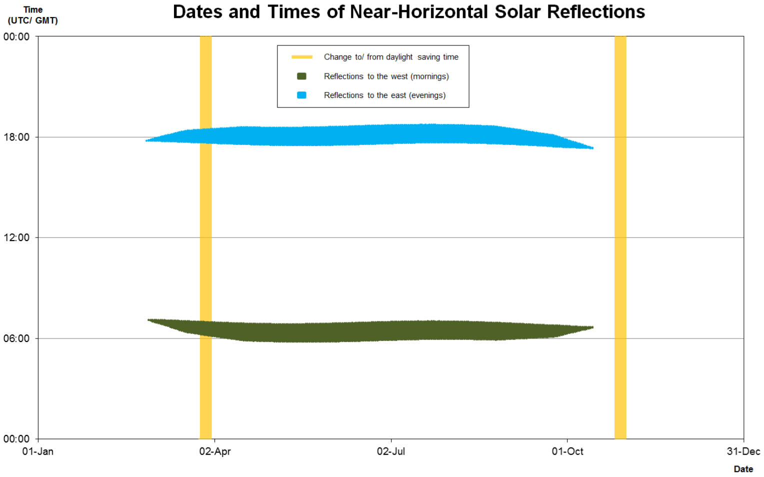
In preliminary analysis, the solar reflection arcs described in Section 1.2.2.2 above were calculated based on the calculated reflection directions.

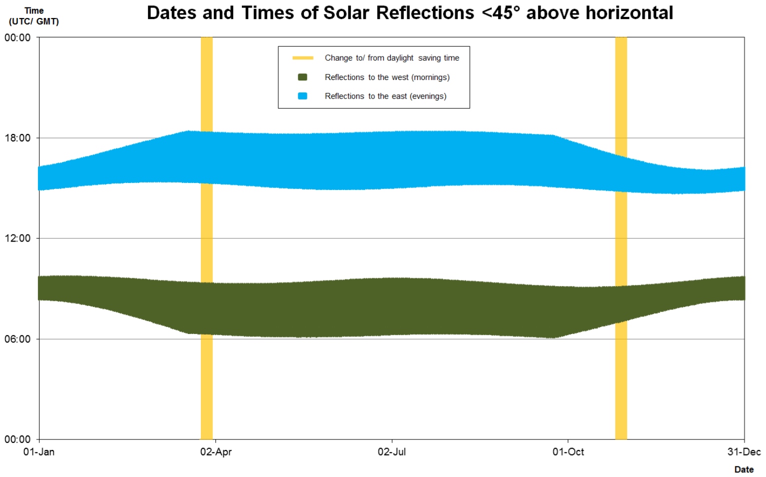
For the detailed analysis, the geometries between all solar farm points (described in Section 1.2.1 above) and all receptor points (described in Section 1.2.2 above) were calculated and compared to the calculated reflection directions in order to identify dates and times (and other pertinent properties) of reflections that could potentially affect each receptor point. Results were combined for each receptor group (e.g., all approach paths to a particular runway).

1.3 Results

1.3.1 Solar Reflections Dates and Times

The dates and times of ‘near-horizontal solar reflections’ (from 5° below, to 10° above, horizontal) and ‘significant aerial reflections’ (taken to be from horizontal to 45° above it) are shown in the following charts. Vertical yellow bands indicate the dates within which local time changes between Greenwich Mean Time (GMT) – equivalent to Universal Coordinated Time (UTC) for this report – and British Summer Time (BST).





Reflections more than 45° above the horizontal plane can only reach an aircraft from well below it and when very close to the solar farm (e.g., at 1,000ft above the solar farm, only when within 305m of a panel). They will be from a direction that is of little interest to a pilot (even when turning steeply) and will normally be blocked by the aircraft’s structure. However, they were considered for the detailed analysis and are discussed when they may reach an aircraft.

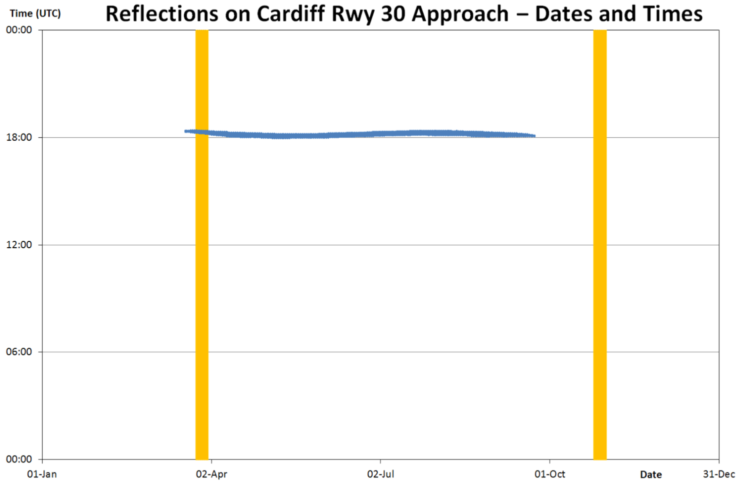
1.3.2 Solar Reflection Arcs

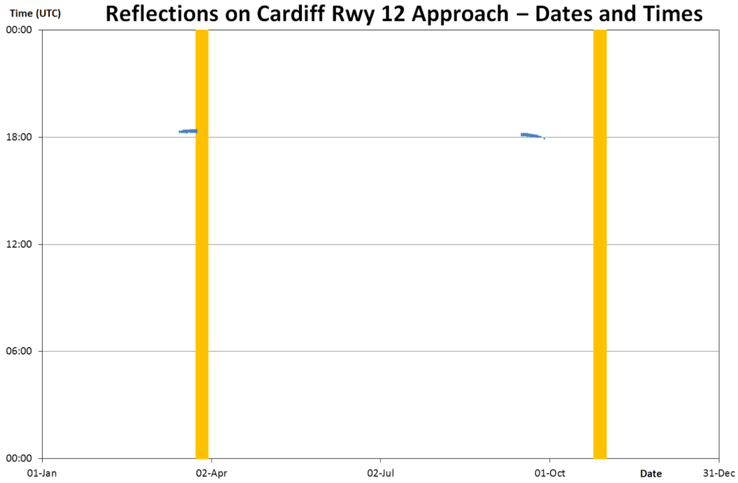
The solar reflection arcs around the solar farm for the solar reflections described in Section 1.3.1 above were calculated in the preliminary analysis to guide the detailed analysis. These are shown in the chart at section 1.2.2.2 above

1.3.3 Solar Reflections Affecting Cardiff Airport

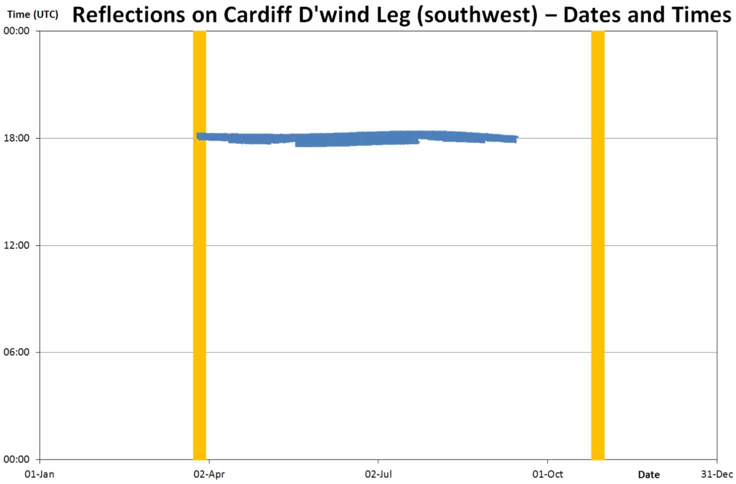
Solar reflections could only be observable by aircraft approaching to land at Cardiff Airport, on its downwind leg and at the VCR at the dates and times shown below. These are also used to inform discussion of dates and times when reflections may reach aircraft taking-off or in the remainder of visual circuit.

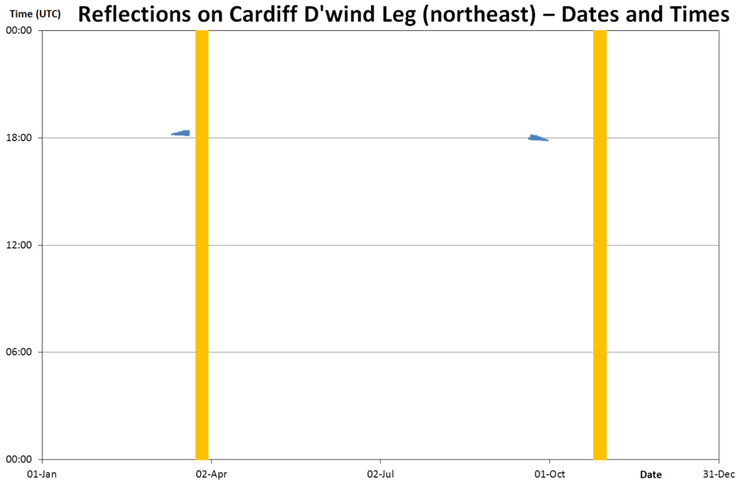
1.3.3.1 Approach Paths





1.3.3.2 Downwind Leg

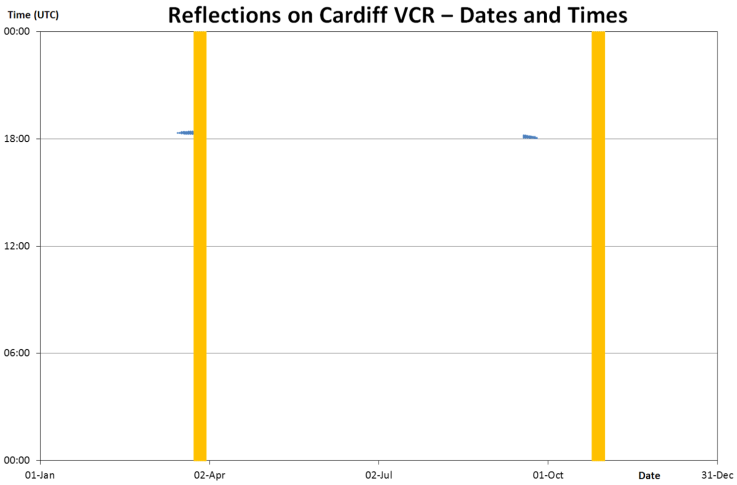




Some reflections may be received by aircraft at other points in the visual circuit, e.g., upwind and finals turns. These were not analysed in detail, but will be at dates and times close to those that may be experienced for the approach paths and downwind legs.

1.3.3.3 Airfield Surface receptors and the VCR

It is highly unlikely that surface receptors at Cardiff Airport will have any views of solar panels, and hence would never receive reflections. The VCR was analysed specifically, and if it has views of solar panels, reflections could occur as shown (other surface receptors with views of solar panels may receive reflections at similar dates and times).



1.3.4 Solar Reflections Affecting RAF St Athan

Solar reflections could only be observable by aircraft approaching to land at RAF St Athan, on its downwind leg and at the VCR at the dates and times shown below. These are also used to inform discussion of dates and times when reflections may reach aircraft taking-off or in the remainder of visual circuit.

1.3.4.1 Approach Paths

Rwy 26

No solar reflections can affect the Rwy 26 approaches as they are all well outside the solar reflection arcs (the only solar reflections in the azimuthal directions of the approach paths are steeply upwards and will pass well above them).

Rwy 08

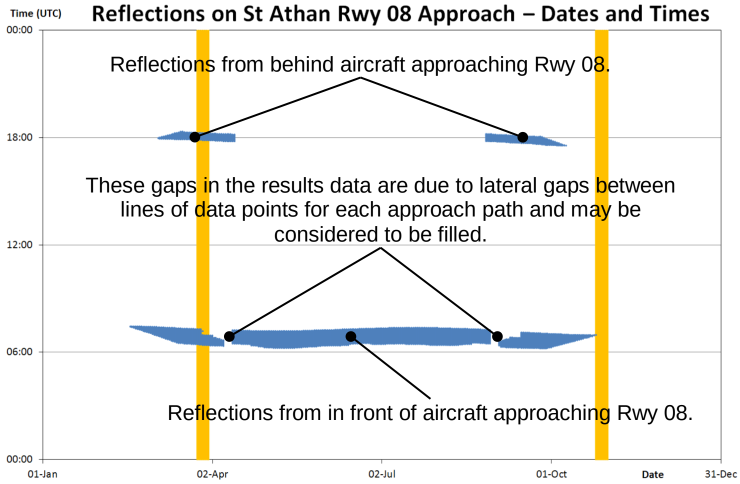
An aircraft approaching Rwy 08 from the left (i.e., north) of the runway's extended centreline will pass very close to, or overfly, the solar farm and reflections could occur from almost any direction at almost any time that the sun is up and illuminating the panels. However, as reflections from all parts of the solar farm will be parallel in a direction that only changes slowly with time, they can only affect a small part of the circuit at any instant and aircraft will quickly fly through them.

Aircraft approaching from the right of the runway's extended centreline will never receive solar reflections from in front of the aircraft but only as it passes abeam the solar farm (i.e., from the pilot's left shoulder) and thereafter from behind the aircraft.

Furthermore, they will not be from a direction of interest to a pilot in the circuit and aircraft overflying the solar farm in the circuit will effectively be transiting traffic and hence of low significance.

Before passing the solar farm, any reflections will be in the early mornings with the much brighter sun shining from close to any reflecting panels. After passing the solar farm, any reflections will be from behind an aircraft for the remainder of the approach, and hence insignificant.

Apart from aircraft within approximately 500m or 600m of the solar farm, solar reflections reaching aircraft approaching Rwy 08 will be as shown in the following chart.



When in very close proximity to the solar farm, reflections will be from increasingly below, then behind, the aircraft and it would almost invariably pass through any reflections in less than 20 seconds.

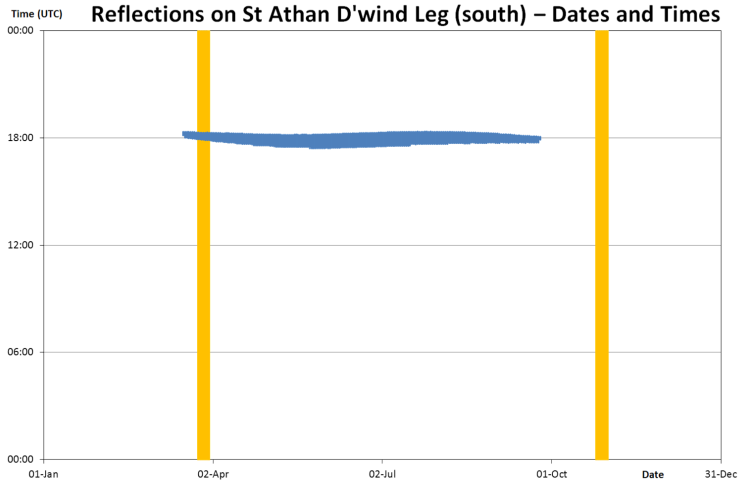
1.3.4.2 Downwind Leg

Northern Circuit Pattern

No reflections can affect the downwind leg of the northern circuit pattern at RAF St Athan.

Southern Circuit Pattern

Solar reflections may affect the downwind leg of the southern circuit pattern at RAF St Athan at the dates and times shown in the following chart.



Some reflections may be received by aircraft at other points in the visual circuit, e.g., upwind and finals turns. These were not analysed in detail, but will be at dates and times close to those that may be experienced for the approach paths and downwind legs.

1.3.4.3 Airfield Surface receptors and the VCR

No reflections can affect surface receptors at RAF St Athan, including the VCR, and aircraft on the ground or as they take-off or land at the airfield.

1.3.5 Transiting Traffic and Other Aerial Receptors

Effects on transiting traffic and other aerial receptors will be of low significance.

1.4 Conclusions

1.4.1 General Effects of Solar Reflections

1.4.1.1 General Characteristics

Solar reflections are commonplace occurrences for most people either from wet roads, expanses of water, or windows and mirrors of cars and buildings. Solar cells are designed to absorb light to generate electricity, not reflect it, and so are much less reflective than other sources of solar reflection.

Solar reflections can only occur when the sun is shining. It has no significance when the sun appears very close to – that is, in almost the same direction as – the reflecting object as seen by an observer (i.e., the observed angle between the sun and its reflection is close to 0°) as the much brighter sun will completely mask any reflections and the observer's eyes will be attuned to brightness when looking in that direction, thus reducing the observed intensity of any reflections.

Conversely, solar reflections are at their worst when an observer is facing the reflecting object, is in shade from the bright sun so that his/ her eyes aren't attuned to brightness, and the sun is behind the observer (i.e., the angle between observed reflections and the sun is close to 180°).

Solar reflections from PV panels may typically have intensities of 20 W/m² (about 2,000 lux). Ambient light levels on a sunny day in shade, but illuminated by the entire blue sky, are typically 20,000 lux so the worst problem that may be caused by reflections from solar panels is a nuisance from looking at or near them.

1.4.1.2 Characteristics of Solar Reflections from Rosedew Farm Solar Park

<u>Near-Horizontal Reflections</u>

Solar reflections from between 5° below the horizontal plane to 10° above it are described as 'near-horizontal'. Reflections within this vertical arc from the proposed solar park may be seen by receptors in general at or near ground level (including most – but not all – aircraft, particularly those at low level or at some distance from the solar park), they can only occur:

- in the mornings at receptors to the west of the solar park from February 27th to October 14th, from 05:47 to 07:06 GMT, or 06:47 to 08:06 BST (after the last Sunday in March);
- in the evenings at receptors to the east of the solar park from February 26th to October 14th, from 17:20 to 18:44 GMT, or 18:20 to 19:44 BST (after the last Sunday in March).

Unless immediately next to the solar panels, solar reflections can only be observed by receptors near ground level in the following azimuthal arcs from any solar panel (bearings are relative to True North):

- to the west: from 246.3° (approximately west-southwest) to 278.2° (slightly north of due west);

- to the east: from 081.6° (slightly north of due east) to 113.7° (approximately east-southeast).

The sun will never be more than 38° (approximately 2 to 2½ hand spans at arm's length) from any reflections observed by near-ground level receptors and usually much closer than this, so the worst case phenomenon described above can never occur and the reflections are often almost insignificant due to the proximity of the sun.

[The maximum angular distance between the sun and reflecting panels occurs at the most southerly extremes of the reflection arcs, and at the maximum altitude angle above horizontal (i.e., 10°). Elsewhere, the angular distance between the sun and reflecting panels will be much less than 38°.]

Effects of solar reflections may be further reduced by boundary fencing and hedges around the solar park and off-site, including any future tree planting.

Significant Aerial Reflections

Solar reflections from the horizontal plane up to 45° above it may be significant for aircraft operating at airfields near the proposed solar park. Reflections within this vertical band are described as 'significant aerial reflections'.

Such reflections may occur all year round:

- in the mornings at receptors to the west of the solar park from 06:05 to 09:43 GMT, or 07:05 to 10:43 BST (after the last Sunday in March until the last Sunday in October);
- in the evenings at receptors to the east of the solar park from 14:41 to 18:23 GMT, or 15:41to 19:23 BST (after the last Sunday in March until the last Sunday in October).

These reflections may occur in the following azimuthal arcs from any solar panel (bearings are relative to True North):

- to the west: from 237.4° (approximately southwest) to 305.8° (approximately northwest);
- to the east: from 054.2° (approximately northeast) to 122.6° (approximately southeast).

Aircraft would need to be in extremely close proximity to the solar park to receive reflections at steeper angles than 45°, although in some cases such reflections may occur in any azimuth at certain times. Aircraft 1000ft above the solar park could only observe such reflections within 305m of its boundary; this increases to within 610m for aircraft 2,000ft above it and within 914m for aircraft 3,000ft above it.

The first and last times of reflections on any day are later and earlier, respectively, than for 'near-horizontal' reflections because reflections below the horizontal plane are not considered for 'significant aerial reflections'.

1.4.2 Effects of Solar Reflections on Receptors

1.4.2.1 Effects on Cardiff Airport and RAF St Athan

Solar Reflections

Solar reflections may affect aircraft operating near Cardiff Airport and RAF St Athan at various times. Effects at either airfield on aircraft taking-off or landing, and surface receptors, e.g., the visual control rooms (control towers), will be negligible (at worst). Effects on aircraft approaching to land, climbing after take-off, in the visual circuit pattern or other phases of flight will be will be negligible (at worst).

Overall reflection impacts for Cardiff Airport and St Athan (including for transiting traffic) are assessed as negligible; no impact on any specific operation was assessed to be greater than negligible. This does not consider the very limited times when impacts are possible and the requirement for the sun to be shining: true impacts on the operations at Cardiff Airport and St Athan will therefore be even less than those assessed here.

Solar reflections from the sea will be much more significant on air traffic in the vicinity of the solar farm or Cardiff Airport and RAF St Athan than those from the solar panels, and is obviously acceptable.

Safeguarding of Runways and Technical Installations

The proposed solar park will not infringe any safeguarding criteria for this nature of development for the runways or technical installations (e.g., radio communications, navigation and surveillance equipment) at Cardiff Airport and St Athan.

Civil Aviation Authority Guidance for Solar Parks

The proposed development fulfils Civil Aviation Authority (CAA) guidance for solar parks with respect to Cardiff Airport and St Athan.

1.4.2.2 Effects on the Other Receptors

Effects on other nearby receptors, i.e., roads, railways and dwellings, will be negligible.

2 Contents

3 Glossary of Terms and Definitions

Altitude. The astronomical term for the vertical angle from an observer to a celestial object, measured from the horizontal plane. In this report, 'altitude' is also used to describe the vertical direction of reflected light (0° is horizontal, 90° is vertically upwards).

Note that there is scope for confusion between the astronomical and aviation terms, 'altitude'. In aviation terms it is the vertical distance of an aircraft above mean sea level, normally measured in feet using a barometric altimeter. Unless otherwise specified the astronomical definition is used: the aviation term is identified by referring to 'aircraft altitude' or 'flight altitude'. Where there remains scope for confusion, the term 'altitude angle' or 'astronomical altitude' may also be used.

amsl. Above Mean Sea Level, a datum for elevations or aircraft altitudes. For the purposes of this assessment, it is synonymous with 'AOD'.

AOD. Above Ordnance Survey Datum, a datum for elevations. For the purposes of this assessment, it is synonymous with 'amsl'.

Azimuth. The term for the horizontal angle from an observer to an object, measured clockwise (as viewed from above) relative to True North.

BNG. British National Grid, a Cartesian coordinate system of Eastings and Northings for Great Britain based on the Ordnance Survey Great Britain 1936 (OSGB36) datum.

BST. British Summer Time, one hour ahead of GMT (see below) and used as local time in the UK after the last Sunday in March and before the last Sunday in October.

Circuit. An airfield's traffic pattern in which an aircraft takes-off, turns to fly 'downwind' (i.e., parallel to the runway in the reverse direction for take-offs and landings) to position itself for final approach and landing. Aircraft may join or leave the circuit at any point, or may remain in the circuit for take-off and landing practice.

Equinox. At the equinoxes, the sun is on a line through the centre of the Earth perpendicular to its rotational axis, i.e., it is the point in time that it crosses the extended plane of the Equator (the 'equatorial plane'). There are 2 equinoxes each year, in Spring – the 'Vernal Equinox' (occurring about March 21st in the northern hemisphere), and in Autumn – the 'Autumnal Equinox' (occurring about September 23rd in the northern hemisphere).

An observer at the Equator (0° latitude) – and at an appropriate longitude – will see the sun's geometric centre rise due east and set due west of him/ her, or pass directly overhead, at either equinox. At other latitudes, this is not the case due to atmospheric refraction normally causing the sun to appear slightly higher than its true position. Also, actual sunrise and sunset times are for the highest point of the sun, not its centre.

The equinox dates and times for 2017 are March 20th at 10:28 (UTC), and September 22nd at 20:02 (UTC); these dates may vary by 1-2 days from year to year.

Note that although an equinox is defined specifically as an instant in time, the date on which the equinox occurs is commonly referred to as 'the equinox'.

Glare. Reflected diffuse lighting, e.g., from bright sky around the sun (glare may describe a range of brightness of reflections). Glare will generally be much dimmer than glint.

See *Glint* below for an alternative definition of *glare* that may also be used elsewhere.

Glint. Specular (direct) reflection of the sun. This is the principal issue regarding the potential for nuisance to an observer. Under certain conditions, e.g., a thin layer of high cloud dimming the sun, it may be difficult to distinguish between glint and glare (although the peak intensity of the glint would be reduced).

Whilst 'glint and glare' are often referred to together, the main issue with solar parks is normally only 'glint'. This assessment concerns itself specifically with 'glint' although the term 'glint and glare' may be used occasionally.

Note that other sources use different definitions of these terms: they may define 'glint' as short-lived periods of brightness, and 'glare' as prolonged periods of brightness. Both definitions may be found in different places on the internet, so care should be taken to avoid confusion.

GMT. Greenwich Mean Time, for the purposes of this report it may be considered equivalent to UTC (see below). GMT is local time in the UK before the last Sunday in March and after the last Sunday in October (see BST above).

Grid North. Grid North is the [northerly] direction of the easting grid lines (i.e., that run north to south) of the grid system in use: for this report, the British National Grid (BNG) system is used, and at all points on the British National Grid, Grid North is parallel to True North at the 2° West meridian of longitude.

Note that the difference between Grid North and True North varies from place to place. The local difference is stated in this report.

Hand span at arm's length. An easily visualised reference for observed angular arcs: an observer's hand held at arm's length with the fingers comfortably spread is assumed to subtend (typically) an arc of 15° to 20° between the tips of the small finger and thumb. Although a useful indicative measure, for the avoidance of doubt, the reader should 'calibrate' his/ her own hand span at arm's length against known angles before using this angular reference.

Local time. In the UK, local time is GMT from January 1st until early on the last Sunday in March and from early on the last Sunday in October until December 31st each year; otherwise local time is BST.

Normal. A line perpendicular to a planar surface (such as a solar cell).

PV Farm. A large-scale installation to convert sunlight into electricity using an array of photovoltaic (PV) cells. In this report the term may be used synonymously with 'Solar Farm' or 'Solar Park'.

Solar Farm. A large-scale installation to convert sunlight into usable energy, normally electricity. In this report the term may be used synonymously with 'PV Farm' or 'Solar Park'.

Solar Park. This term may be used synonymously with 'Solar Farm' or 'PV Farm'.

Solstice. The point in time when the sun is furthest from the equatorial plane, either to its north (Summer Solstice in the northern hemisphere) or south (Winter Solstice in the northern hemisphere). The solstices are when the sun appears to stop moving away from the equatorial plane, and begins moving back towards it. There are 2 solstices each year, sometimes referred to as 'midsummer' or 'midwinter', around June 21st and December respectively.

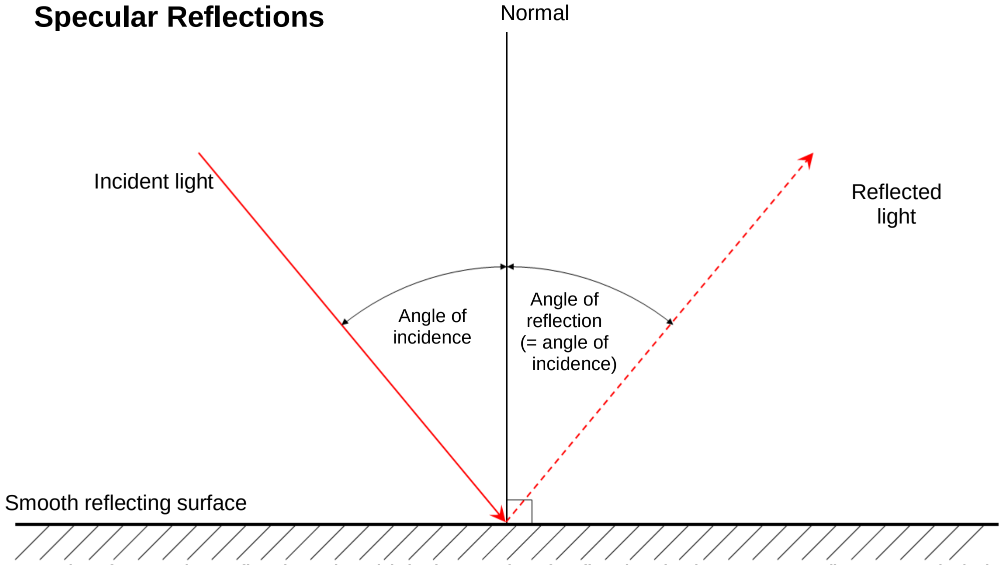
An observer at the Tropic of Cancer or of Capricorn (approximate latitudes 23° North and South respectively) at the appropriate solstice (e.g., the northern hemisphere's summer solstice at the Tropic of Cancer) – will see the sun's geometric centre rise due east and set due west of him/ her, or pass directly overhead, at either equinox. At other latitudes, this is not the case due to atmospheric refraction normally causing the sun to appear slightly higher than its true position. Also, actual sunrise and sunset times are for the highest point of the sun, not its centre.

The solstice dates and times for 2017 are June 21st at 04:24 (Summer Solstice in the northern hemisphere – when the sun is at its highest), and December 21st at 16:28 (Winter Solstice in the northern hemisphere – when the sun is at its lowest); these dates may vary by 1-2 days from year to year.

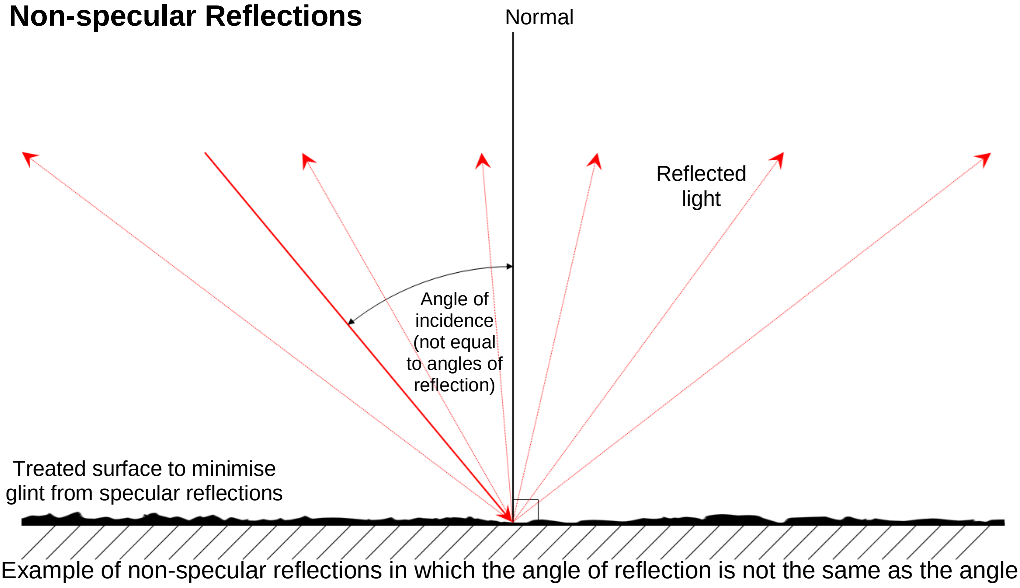
Note that although a solstice is defined specifically as an instant in time, the date on which the solstice occurs is commonly referred to as 'the solstice'.

Specular reflection. Specular, or direct, reflections may be observed from a polished mirror in which the angle of reflection is equal to the angle of incidence but on the opposite side to (and hence, in the same plane as) the normal line, as shown in the diagrams below.

'Non-specular reflections' are scattered reflections which may occur from a rough surface which causes the scattering effect.



Example of specular reflections in which the angle of reflection is the same as (but opposite) the angle of incidence – measured relative to the Normal line.



Example of non-specular reflections in which the angle of reflection is not the same as the angle of incidence: e.g., due to surface treatment of solar cells, such as a 'roughening' of the surface to minimise glint effects.

True North. The [northerly] direction of the meridian of longitude through a certain point, i.e., the direction of the northern polar axis.

Note that the difference between Grid North and True North varies from place to place. The local difference is stated in this report.

UTC. Coordinated Universal Time, for the purpose of this report, it is equivalent to GMT (see above). Unless otherwise specified, all times in this report are UTC.

Zenith. The point in the sky directly (i.e., vertically) an observer.

4 Introduction

4.1 The Solar Park

Rosedew Developments Ltd is proposing a photovoltaic (PV) solar park (and associated works) on a site at Rosedew Farm, just southeast of the town of Llantwit Major/ Llanilltud Fawr, in the Vale of Glamorgan. The proposal consists of a number of PV panels facing due south (relative to True North) inclined at an angle of 25° to the horizontal. The site is approximately 8km west of Cardiff Airport and 2km west of RAF St Athan airfield.

AARDVaRC Ltd was retained to conduct a desk-based investigation of the effects of 'glint and glare' on the airfields of Cardiff Airport and St Athan and their associated air traffic. The assessment and findings are described in this report considering the minute-by-minute position of the sun for a whole year. Effects on other, general, receptors are discussed at high level based on results of the analyses conducted.

The terms 'glint' and 'glare' are commonly used together and different definitions are used for the terms (see Section 3 above): to avoid confusion, these terms are avoided in this report where possible in favour of actual descriptions of phenomena. This assessment is specifically concerned with specular (or 'direct') reflections of sunlight: non-specular reflections (i.e., well scattered reflected light, or alternatively reflections of the bright sky around the sun) are much dimmer and of little concern and not generally considered. Where appropriate, differences between brief reflections and more sustained ones are considered.

4.2 Glint and Glare Effects on Aviation

4.2.1 Overview

There is little formal published guidance on the assessment of glint and glare from solar parks, either in the UK or overseas. It is noted that the definitions given by some aviation bodies for 'glint' and 'glare' differ from those often used in the solar power industry. 'Glint' may be defined either as the *specular reflection of light*, or as *short duration bright flashes of light* (or similar), from an object; 'glare' may be defined either as *non-specular (diffuse) reflection of light*, or as *longer periods of bright light* (or similar), from an object. Hence it is considered better to avoid these terms in technical discussions.

Here, the limited published guidance from the USA and the UK is considered.

4.2.2 United States: Federal Aviation Administration

In the United States, the Federal Aviation Administration (FAA) has published some guidance in the document Technical Guidance for Evaluating Selected Solar Technologies on Airports, dated November 2010 [1], although this document is caveated with the following text:

> 'NOTE: As of October 23, 2013, the FAA is reviewing multiple sections of the "Technical Guidance for Evaluating Selected Solar Technologies on Airports" based on new information and field experience, particularly with respect to compatibility and glare. All users of this guidance are hereby notified that significant content in this document may be subject to change, and the FAA

---

[1] http://www.faa.gov/airports/environmental/policy_guidance/media/airport_solar_guide_print.pdf, last accessed 24 February 2015.

cautions users against relying solely on this document at this time. Users should refer instead to the Interim Policy (http://federalregister.gov/a/2013-24729).'

[A previous version of the disclaimer read:

> 'NOTE: As of June 26, 2012, the FAA is reviewing Section 3.1.2 ("Reflectivity") of the "Technical Guidance for Evaluating Selected Solar Technologies on Airports" based on new information and field experience. All users of this guidance are hereby notified that significant content in this section may be subject to change, and the FAA cautions users against relying solely on this section at this time.'

Section 3.1.2 of this document considers the technical aspects of solar reflections and is discussed here.]

The webpage referenced by the current disclaimer does not provide much useful guidance, but offers a free online analysis tool and recommends analysis of solar reflections on a minute-by-minute basis for a whole year (as AARDVaRC has done). A reader may wish to use that tool, but AARDVaRC is unable to recommend the use of its results as evidence of the acceptability or otherwise of solar park developments near airfields as it has no knowledge of the algorithms used to generate the results and the tool also seems to be related to the technical advice in the above document which the FAA cautions against using.

In the FAA document, there appear to be major flaws in the discussion of the effects of solar radiation, discussed briefly here.

The FAA document states:

> 'Often 1000W/m² is used in calculations as an estimate of the solar energy interacting with a panel when no other information is available.'
> **[Note: W/m² (watts per square metre) is a unit of intensity, i.e., the power passing through a unit of area]**

And:

> 'According to researchers at Sandia National Lab, flash blindness for a period of 4-12 seconds (i.e., time to recovery of vision) occurs when 7-11 W/m² (or 650-1,100 lumens/m²) reaches the eye.'
> **[Note: 1 lumen/m² (lumen per square metre) ≡ 1 lux]**

And:

> 'Today's panels reflect as little as 2% of the incoming sunlight depending on the angle of the sun and assuming use of anti-reflective coatings. Using the previously mentioned value for solar irradiance, this would mean roughly 20 W/m² are reflected off of a typical PV panel.'

So it would seem that reflections from solar panels are bright enough to cause flash blindness lasting up to 12 seconds.

However, statements in Section 3.1.2 *Reflectivity* of the FAA document give reference to:

> 'Ho, Clifford, Cheryl Ghanbari, and Richard Diver. 2009. *Hazard Analysis of Glint and Glare From Concentrating Solar Power Plants. SolarPACES 2009*, Berlin Germany. Sandia National Laboratories'.

This reference states that the information about 'flash blindness' comes from research into how a pilots' eyesight might be affected by bright flashes from nuclear detonations which is rather divorced from reflections from dimly reflecting solar panels.

To understand the values of light levels quoted it is useful to put the data provided into context with a more commonplace example: a cricket match can be halted due to 'bad light' when the light levels fall to below 1,000 lux [2] (typically) at the wicket (with 650 lux acceptable at the boundary). Yet, the FAA document states that these [bad light] levels can cause 'flash blindness lasting up to 12 seconds'.

It seems reasonable to construe that those light levels can only cause flash blindness in the worst case: i.e., a flash occurring directly in front of eyes that have been in total darkness for some time beforehand. This does not correspond in any way to reflected sunlight from dark solar panels which can only occur with high ambient light levels. The realisation of this may be one reason as to why the FAA is unwilling to be held accountable for any conclusions drawn from its document.

When in shade but otherwise illuminated by an entire blue sky at midday, the light level is typically 20,000 lux (data from the Wikipedia website [3]), i.e., 215 W/m^2 (using a standard factor of 93 lux per W/m^2 for sunlight [4] that is equal – or at least very close – to the factor used in the FAA document). This is much higher than the 20W/m^2 that is quoted as the level of reflected light from solar panels. It is virtually impossible to conceive how 'flash blindness' could be experienced from solar panel reflections given such high ambient light levels that must be present for reflections to occur.

Considering the relatively low intensity of reflections from solar panels and the high ambient light levels that must be present, the worst case effects will be the nuisance caused by looking at, or near, reflecting panels. This will always be much less significant than looking into the bright sun (perhaps when driving a car or landing an aircraft towards it, neither of which are considered to be safety issues).

The disclaimer also states that new information and field experience has led to the review of the document, suggesting that it is perhaps the solar energy industry that is leading the development of appropriate ways to assess reflections from solar panels. There also seems to be little urgency given to understanding the issue of reflectance from solar panels for aviation by the FAA (since the document has been 'under review' for some time) suggesting that there is little concern regarding it.

In summary, this information appears to be based on extracts from academic research for entirely different purposes without consideration of its applicability to solar reflections from dark solar panels. Furthermore, this document is meant for facilities situated on airfields (whereas the proposed solar park is not on an airfield), and conclusions from the information in this document are not supported by the FAA itself.

4.2.3 United Kingdom: Civil Aviation Authority

In the UK, the Civil Aviation Authority (CAA) has published the document *Interim CAA Guidance - Solar Photovoltaic Systems*, dated 17 December 2010 [5]. It seems that, along with the FAA in the United States, the CAA does not consider the addressing of this issue to be particularly urgent.

[2] http://www.opticianonline.net/Articles/2003/09/12/6563/Lighting+the+sports+arena.htm, last accessed 24 February 2015.

[3] http://en.wikipedia.org/wiki/Daylight, last accessed 24 February 2015.

[4] http://en.wikipedia.org/wiki/Luminous_efficacy, last accessed 24 February 2015.

[5] http://www.caa.co.uk/docs/697/srg_asd_solarphotovoltaicsystguidance.pdf, last accessed 24 February 2015.

This document refers to the FAA document, but offers limited guidance and is principally for airports considering on-site solar parks. It refers to the legal requirements of the Air Navigation Order (ANO) and specifically notes that Local Planning Authorities should be cognisant of the following articles of the ANO with respect to any solar photo-voltaic development regardless of location.

- Article 137 – Endangering safety of an aircraft:

  A person must not recklessly or negligently act in a manner likely to endanger an aircraft, or any person in an aircraft.

- Article 221 – Lights liable to endanger:

  (1) A person must not exhibit in the United Kingdom any light which:

  (a) by reason of its glare is liable to endanger aircraft taking off from or landing at an aerodrome; or

  (b) by reason of its liability to be mistaken for an aeronautical ground light is liable to endanger aircraft.

  (2) If any light which appears to the CAA to be a light described in paragraph (1) is exhibited, the CAA may direct the person who is the occupier of the place where the light is exhibited or who has charge of the light, to take such steps within a reasonable time as are specified in the direction:

  (a) to extinguish or screen the light; and

  (b) to prevent in the future the exhibition of any other light which may similarly endanger aircraft.

  (3) The direction may be served either personally or by post, or by affixing it in some conspicuous place near to the light to which it relates.

  (4) In the case of a light which is or may be visible from any waters within the area of a general lighthouse authority, the power of the CAA under this article must not be exercised except with the consent of that authority.

- Article 222 – Lights which dazzle or distract:

  A person must not in the United Kingdom direct or shine any light at any aircraft in flight so as to dazzle or distract the pilot of the aircraft.

These are all considered in this report.

4.2.4 Examples of Solar parks near Airfields

There are a number of known solar parks at or near airfields. A review [6] shows various examples (see the Annex to this report: *Caddington PV Solar park - Review of the PV Reflection Studies in the Public Domain* dated 22 December 2010) of such instances from around the world with many examples from the United States. Since this review was written there have been a number of further developments, particularly in the UK, e.g., on Gatwick Airport, near Newquay Airport, and near Exeter Airport demonstrating the compatibility of solar parks and aviation.

---

[6] Originally downloaded from (last accessed 30 April 2014 but apparently no longer available at this URL): http://www.emsraynerenewableenergy.co.uk/downloads/GlintGlareStudyReview.pdf, hence it is provided in the Annex to this report.

4.3 Map Datums and Time Zones

Unless otherwise stated, locations are given as British National Grid OSGB36 Eastings/ Northings coordinates and azimuths/ bearings are given as Grid bearings.

The entire UK is in the Greenwich Mean Time (GMT) time zone, but daylight saving time (i.e., British Summer Time, BST) is currently used from the last Sunday of March to the last Sunday of October. Unless otherwise specified, all times in this report are given in coordinated universal time (UTC) – equivalent to GMT for the purposes of this assessment.

The term 'local time' refers to BST when daylight saving time is in use, otherwise it refers to GMT. Where specific examples are used, the dates for daylight saving time are for 2017 as typical for the operational life of the proposed PV farm.

4.4 AARDVaRC Ltd

AARDVaRC Ltd was founded in April 2010 to provide expert aviation, defence and other technical consultancy services to the renewable energy and other industries. Although these services are particularly focussed on renewable technologies, this expertise is equally applied to other industries, e.g., *AARDVaRC* provided its expert aviation and defence services for the recently consented Cherry Orchard tower development in south London.

*AARDVaR*C's technical expertise lends itself to a wide range of technical issues relating to renewable energy development. Hence, the company has developed an analytical model to assess solar reflections from large-scale solar park developments, particularly – but not solely – for aviation impact assessment.

4.5 The Author

Charles Morelli holds a BEng degree in Aeronautical Engineering from Bath University. He was commissioned into the Royal Regiment of Artillery, serving as a Forward Observation Officer managing battlefield indirect fire and electronic warfare assets for the local commander before taking helicopter flying duties in the Army Air Corps. Here he served as second-in-command of an anti-tank helicopter squadron, and was the Army Aviation subject matter expert and project manager compiling flying regulations for the newly formed Joint Helicopter Command (JHC). Since leaving the Army in 2004, he has focussed on technical and specialist aviation analysis for renewable energy developments working in 2 consultancy companies until founding *AARDVaRC* in 2010.

The author has an in-depth knowledge of the aviation industry, electromagnetic propagation (including reflections of light/ glint/ glare), wave theory, and of communications, navigation and surveillance (CNS) equipment. He has conducted detailed assessments of technical, aviation and electromagnetic issues for many renewable energy and other developments.

He has developed many specialist analytical tools, e.g., to support his solar reflection assessments (conducted by AARDVaRC) for the Westmill (nr Swindon), Parkhouse (nr Salisbury) solar parks, and the Strete Farm solar array with specific concerns raised by Exeter Airport – all now operational and supplying electricity to the grid. Issues included effects on airfields, smaller nearby aerodromes – including a glider site, dwellings, and adjacent main roads.

Charles is also a glider pilot and holds a Private Pilot's Licence (PPL) for light single-engined aeroplanes. Other interests and hobbies include amateur astronomy, renewable energy technology and cycling.

5 Rosedew Farm Photovoltaic Array

5.1 The Development

The Rosedew Farm solar PV array (or 'solar park') and associated works are proposed on a site just southeast of the town of Llantwit Major/ Llanilltud Fawr, in the Vale of Glamorgan. The proposal is for a number of PV panels of varying length (with supporting infrastructure) across the site, aligned to face due south (relative to True North) and inclined at 25° to the horizontal.

The PV cells on the solar panels will be less than 3m high: in the detailed geometrical analyses below they were modelled as 2.5m above ground.

5.2 Site Information

5.2.1 Grid and True North

Grid North (for the British National Grid – BNG, based on the OSGB36 datum) at this location is 1.1° west of True North, i.e., True bearings are 1.1° less than Grid bearings and the PV panels are aligned on a Grid bearing of 181.1°. Grid bearings are used throughout this report unless otherwise specified. Charts and other pictorial representations in this report are typically aligned with Grid North at the top for consistency with OS mapping used: associated graphical representations of the directions of solar reflections, etc., are adjusted accordingly.

Due to the small difference between True North and Grid North at this location, it will normally be adequate for the reader to assume – for simplicity – that they are coincident for the purposes of this report.

5.2.2 Local Sun Data

Sun position data used in this report was predicted to a precision of 0.1° in altitude and azimuth at 1 minute time intervals for all of 2017 – as a typical year in the operation of the solar park – at WGS84 longitude: 003° 28' West, latitude: 51° 24' North (the nearest whole arc-minute of longitude/ latitude to the site).

The sun is modelled as a point in the sky, but in reality has an angular diameter as viewed from the Earth of approximately 0.5° (i.e., 0.25° around the central point). Atmospheric effects – specifically refraction – typically cause the sun to appear approximately 0.5° higher in the sky than its true position: the predicted sun data accounts for this using 'standard refraction', although there may be small variations due to weather effects. The actual angular size of the sun and possible variations in its position due to weather effects are accommodated in this report.

The path of the sun across the sky changes gradually from year to year. Significant changes over the life of the solar park are corrected each leap year so the calculated sun data for 2017 is valid for the project's whole period of operation.

5.3 Site Boundary

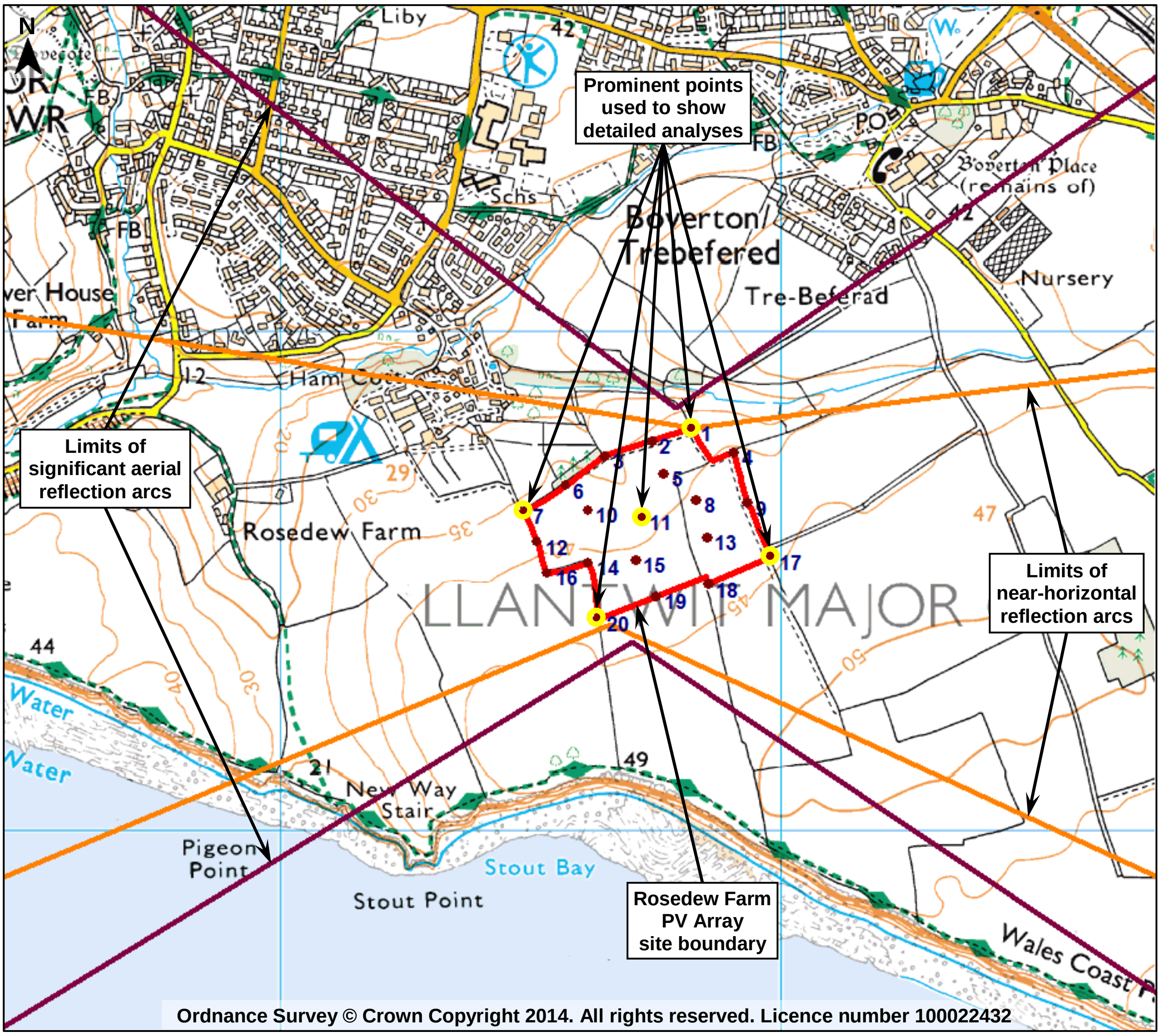
The site boundary is marked on the site chart in Section 5.3.1 below. It was assumed that solar reflections can come from anywhere within the site boundary (although this is worse than the actual case: no panels will be sited right at the boundary).

For detailed geometrical analysis, the azimuth and altitude angles between 20 significant points in the solar park and each receptor point were considered. These significant points are described next.

5.3.1 Site Chart

The site boundary is marked as the red line overlaid on a background 1:25,000-scale OS Explorer map in the following chart (reflections are assumed to originate from anywhere within this area).

Points at the 20 numbered dots were used for detailed geometrical analyses; analyses of those with yellow circles are shown as examples later (these are typical of the most significant points on the solar park; coordinates for these 5 points are given in Section 5.3.2 below). The limits of the 'near-horizontal' solar reflection arcs (orange lines) and of the arcs in which reflections may be directed at less than 45° above horizontal (purple lines), calculated in the initial analysis (as described later), are also shown.



5.3.2 Significant Points on the Solar Park

20 significant points were chosen on and within the site boundary for detailed geometrical analyses. A number of points were used so that – combined with a number of closely spaced receptor points and appropriate buffers – there were no gaps when the geometries of the solar park points and receptor points were considered.

Of the 20 points, 5 were chosen as prominent points for which the geometrical analyses are shown in this report. Coordinates and panel elevations above mean sea level (amsl, equivalent to Above OS Datum – *AOD* – for the purposes of this report) are given for these in the following table (Point IDs are as in the chart above). Terrain elevations are from OS Digital Terrain Model (DTM) data, and solar panels were assumed to be 2.5m high.

Point ID	Easting	Northing	Terrain elevation /m (AOD)	Modelled Panel height /m	Panel elevation /m (AOD)	Notes
1	297825	167805	35		37.5	Northernmost point
7	297490	167640	37		39.5	Westernmost point
11	297724	167627	39	2.5	41.5	Approximately central point
17	297982	167549	44		46.5	Easternmost point
20	297638	167426	44		46.5	Southernmost point

Although only a selection of solar park points are shown, all data were used in the analyses to generate the results given in this report.

5.4 Initial Analysis

5.4.1 Background

To aid the selection of the most significant receptors, an initial general assessment of solar reflections was conducted to identify arcs within which effects may occur. This was done for ‘near-horizontal’ or ‘near-ground level’ reflections (taken to be no higher than 10° above horizontal and no lower than 5° below horizontal).

In each case, it was found that solar reflections occur in 2 arcs: to the east and to the west. Reflections within the +10°/ -5° altitude band will never occur outside these azimuthal arcs.

Further early analysis was conducted to establish arcs within which solar reflections may occur from horizontal up to an altitude angle of 45° above horizontal, the ‘significant aerial reflection arcs’. Generally solar reflections at steeper altitude angles than this will be of little significance to pilots (discussed later).

Although this initial analysis is helpful, it does not eliminate the need to conduct detailed analyses on all receptor points considered using the entire data set for solar reflections, as described later (the detailed analyses consider all possible reflections, and were not limited to those that may occur within the reflection arcs described here). The solar reflection arcs in relation to all the aerial receptor points identified are shown in the charts at Section 6.4 below.

5.4.2 Solar Reflection Arcs

The ‘near-horizontal reflection arcs’ are marked by orange lines on the charts at Appendix 1 (the first chart shows the arcs overlaid on an OS 1:50,000-scale Landranger map to show the arcs in the vicinity of the solar park, the second shows the arcs overlaid on an OS 1:500,000-scale map to show the arcs in the wider region). The ‘significant aerial reflection arcs’ (which bounds all reflections directed upwards at less than 45° above horizontal) is marked by purple lines on the charts at Appendix 1.

It was assumed for simplicity that solar reflections may be directed more steeply upwards than 45° above horizontal in any azimuthal direction (this assumption is significantly worse than reality: see the chart in Section 7.3.2 below to see the actual case). However, since slopes of greater than 45° represent gradients of 100% (1:1) or more, such reflections could only be observed when aircraft are as close as (measured horizontally) – or closer than – their height is above (measured vertically) a solar panel; i.e., an aircraft 1,000ft above the level of a solar panel must be within 1,000ft (305m) of that panel to have any chance of observing solar reflections directed so steeply upwards.

6 Key Receptors

6.1 Background

6.1.1 General

Cardiff Airport – approximately 7km from the proposed solar park – and RAF St Athan – approximately 2km from the proposed solar park – airfields are considered by the developer to be the most sensitive receptors of glint and glare effects in the vicinity of the proposed solar park. These are specifically assessed in detail in this report.

When approaching to land, aircraft are at their most sensitive to solar reflections, as they will be descending towards the ground from low levels with the solar park (in some cases, although not for the Rosedew Farm site) close to the touchdown point resulting in little angular change between the solar park and aircraft as it approaches. Other flight profiles are unlikely to combine all these factors: at other times aircraft will be moving rapidly through any solar reflections so that effects will be transient, although these are discussed below. However, the airfield circuit patterns, particularly 'downwind leg' flight paths on either side of the runway at each airfield have also been assessed in detail.

The visual control room (VCR or 'control tower') at each airfield are also potentially significant receptors of solar reflections and so are considered. Effects on aircraft taking-off, in the circuit or in transit are also discussed, based on the results of other analyses.

Effects on other general receptors (i.e., nearby roads, built-up areas and isolated dwellings) are also considered at a high level based on the results of other analyses conducted..

6.1.2 Data Sources

Airfield data was taken from the United Kingdom Aeronautical Information Publication (UK AIP) entries for Cardiff Airport and the UK Military (Mil) AIP for RAF St Athan. Where necessary, this data was supplemented with other public domain material, e.g., Ordnance Survey Digital Terrain Model (DTM) terrain elevation data and freely available photographs and mapping.

6.1.3 Runway Nomenclature

Runways are referenced with numbers depending on the runway direction as follows.

- The runway number is the approximate heading (rounded to the nearest 10°) divided by 10, e.g., Rwy 12 is aligned on a heading of 120° (strictly, a *magnetic* heading, but that is not relevant for the purposes of this report, other than to note that Grid or True headings given later are not the source data for runway identification), so the runway in the opposite direction of Rwy 12 is aligned on a heading of 300° (i.e., Rwy 30).
- A physical runway surface is referred to by both runway directions, e.g., Rwy 12/ 30 refers to the strip that serves both Rwy 12 and Rwy 30.

6.1.4 Runway Approach Paths

For this analysis, it was assumed that:

- aircraft approaching to land may touchdown between the runway threshold and a third of the runway length beyond it;

- approaches may be displaced by up to 10° either side of the runway extended centreline, measured from the touchdown point;
- aircraft may be displaced by up to 1° above or below the nominal 3° glideslope typical for fixed wing aircraft.

Therefore, multiple approach paths to each runway were modelled for geometric analysis in relation to the solar panels, as follows.

- Touchdown points were taken as: the runway threshold and a point one third of the runway length beyond the landing runway threshold (i.e., 2 possible touchdown points on each runway).
- Approach paths were taken to be along each runway's extended centreline, and also 10° to each side of the extended centreline (i.e., 3 possible approach directions), measured from each possible touchdown point.
- Glideslopes were assumed to be 3° as typical, and also 2° and 4° for each approach path to allow for possible variations.

This gives a total of 18 approach variations modelled for each runway approach.

Helicopter operations may differ significantly from fixed wing operations, so these are specifically discussed.

6.1.5 Runway Circuit Patterns

6.1.5.1 Outline of Typical Circuit Patterns

Circuit patterns are established to facilitate aircraft manoeuvring in close proximity to the airfield for aircraft departing and arriving, and also for training purposes, allowing repeated approach and landing practice. The description of the various parts of the circuit pattern originates from the assumption that the take-off and landing direction is into the wind. All turns are normally in the same direction for visual circuit patterns, this describes the circuit direction (i.e., a 'left hand' or a 'right hand' circuit).

For visual circuits, after take-off, an aircraft will make typically make either one (the 'upwind turn') or two turns (the 'crosswind leg' is flown between the turns) to the left or right to fly in the opposite direction to take-off and landing, parallel to – and some displaced some distance to the side – of the runway.

After passing some distance beyond the landing point on the downwind leg, one (the 'finals turn') or two turns (the 'base leg' is flown between the turns), after which the aircraft is positioned on its 'final approach' to the landing point on the runway.

6.1.5.2 Analysis of Circuit Patterns

The actual circuit patterns have not been confirmed for either airfield, so various possibilities have been evaluated. The detailed analyses conducted are for the 'downwind leg' of possible circuit patterns, and have been considered either side of each airfield's runway.

For the detailed assessment, 3 possible flight paths have been considered for each downwind leg (and on either side of each airfield's runway). The 3 possible flight paths are 1.0nm (1.9km), 1.5nm (2.8km), and 2.0nm (3.7km), from – and parallel to – the respective runway's extended centreline, beginning and ending 1.0nm, 1.5nm and 2.0nm beyond the runway threshold in each direction (the distance beyond the runway threshold is the same as the distance from the runway centreline, i.e., the start and finish pints are at an angle of 45° from the runway centreline measured at the thresholds). Each possible downwind leg was represented by 15 evenly-spaced points along its length.

Each possible downwind leg was considered at 3 heights: 500ft (152m), 1,000ft (305m) and 1,500ft (457m) above the airfield's reference elevation. So for each downwind leg, 9 possible variations are considered: 3 flight paths at 3 altitudes, giving a total of 135 receptor points. This was repeated 4 times: once for either side of each airfield's runway.

6.1.6 Phases of Flight other than Approach, Landing and Circuit Patterns

Other phases of flight (i.e., take-off, helicopter flight profiles, and transiting air traffic) are less sensitive than approach and landing as aircraft are further from the ground (as opposed to descending towards the ground at low level) and do not fly directly towards the solar park or its reflections continuously. It is not practicable to conduct detailed analysis specific for each phase of flight; however, other analyses already conducted were sufficient to support discussion of effects.

Being of lower sensitivity than landing aircraft, discussion of solar reflection effects on other phases of flight at each airfield, including helicopter traffic, is conducted separately based on the results of the various analyses already conducted.

Other phases of flight are grouped as follows.

- Aircraft Taking-Off. Aircraft taking-off follow similar paths to the final approach, except in the opposite direction and normally climbing more steeply than the approach path.
- Helicopter flight profiles. Helicopters are much more versatile than aeroplanes when manoeuvring after take-off or before landing and are not restricted to the flight profiles used by aeroplanes. They often adopt more direct approach and departure profiles when flying visually.
- Transiting Air Traffic. Transiting air traffic may pass the solar park site in almost any direction.

6.1.7 Identification of Solar Reflection Receptors

6.1.7.1 Outline

For dim solar reflections from dark solar panels to be a significant nuisance, panels must be close to the direction of a viewer's main interest for extended periods. There is no conceivable possibility of 'flash blindness' from brief exposure to solar reflections from solar panels given the high ambient light levels required for significant reflections to occur (as discussed in Section 4.2.2 above), so brief exposure to reflected sunlight from solar panels may be less significant than prolonged exposure.

In the case of a solar park viewed from an aircraft, such prolonged exposure can normally only occur when a pilot is flying in a straight line in the general direction of the solar park (i.e., descending). The only likely instance being where the solar park is close to a runway and the aircraft is descending to land there.

Aircraft approaching to land at Cardiff Airport and RAF St Athan do not meet these criteria with respect to the Rosedew Farm site as it is significantly displaced from their runways, and neither do aircraft taking-off, manoeuvring in the vicinity of the airfields, or transiting through the local airspace. However, of these, aircraft approaching to land are most sensitive and are considered in detailed analyses whereas other air traffic is not considered in such depth – excepting the downwind leg of the airfields' circuit patterns (although it is discussed).

6.1.7.2 Runway Touchdown Points and Approach Heading Data

Runway touchdown points (in each case, the runway threshold and an inset touchdown point, 1/3 of the runway length in from the threshold) assumed for this assessment are tabulated later for each airfield. Runway headings are calculated from this information.

Runway threshold data is from the UK Mil AIP; WGS 84 latitude/ longitude coordinates converted to British National Grid (BNG) eastings and northings (in the OSGB36 coordinate system). Inset landing point locations and approach headings were calculated from threshold location data. Terrain elevations are from the UK Mil AIP for threshold elevation data (also used for inset touchdown points), converted to metres above OS datum (AOD). Approach headings are relative to British National Grid North for consistency in the geometrical analyses.

6.1.7.3 Downwind Legs of Runway Circuit Patterns

The downwind legs of the various possible circuit patterns were calculated from the runway threshold locations and the respective airfield's reference elevation.

6.1.7.4 VCR Location Data

In addition to the touchdown points, the VCR is the only other surface receptor considered at either airfield. VCR location data was extracted from the UK AIP/ Mil AIP, mapping and photographs; coordinates and elevation data used are given for each airfield's VCR respectively in Sections 6.2.3 and 6.3.3 below and VCR locations marked on the respective charts in Sections 6.2.5 and 6.3.5 below.

6.1.7.5 Approach Path Receptor Points

Each runway's approach path receptor points used for detailed analyses were taken for approaches to its touchdown points as specified in Section 6.1.4 above. Approaches considered were: along each runway's extended centreline, and displaced 10° to the left and right of centreline (measured from the respective touchdown point). Three glideslopes were considered for each approach path: 2°, 3° and 4° (3° is typical).

6.1.7.6 Downwind Leg Receptor Points

The downwind leg was considered on either side of each airfield's runway as specified in Section 6.1.5 above. On either side of each runway, possible downwind legs were considered at 3 distances from the runway centreline, and at 3 different heights above the airfield reference elevation.

6.1.7.7 Selected Receptor Point Locations

Ten receptor points (5 for each airfield) were chosen to use as examples of the detailed analyses conducted. It is emphasised that the detailed receptor-specific analyses were not limited to these points, nor to solar reflections that occur only in the arcs described earlier: the complete data sets were used throughout. It is only due to the practicalities of space that a selection of data is presented in this report.

6.2 Cardiff Airport

6.2.1 Overview

Cardiff Airport is located 7km north of the town of Rhoose, Vale of Glamorgan and has a single visual and instrument runway strip (Rwy 12/30), 2,392m long and aligned from approximately west-northwest to east-southeast. Its visual circuit is normally on the north side of the runway, but in this report it is assumed that it may be established on either side. Its airspace is closely coordinated with the nearby RAF St Athan which lies within Cardiff Airport's Control Zone (CTR).

It is confirmed that the proposed solar park will not infringe any safeguarding criteria for this nature of development for Cardiff Airport's runways or CNS installations so these are not considered further in this assessment.

6.2.2 Runway Data

Two runway touchdown points were considered for each runway in this assessment: the runway thresholds, and inset touchdown points 1/3 of the runway length in from the thresholds (most aircraft would be expected to touchdown between these points). Runway headings and lengths are summarised and shown graphically in Section 6.2.5 below.

The lengths of the runway and its headings (relative to True North) are shown in the following table as calculated from UK Mil AIP data.

Runway Strip	Runway Length	Runway	Runway Heading /° (True)
Rwy 12/30	2,392m	Rwy 12	117
		Rwy 30	297

Data for RHADS runway touchdown points as assumed for this assessment are shown in the following table (BNG data is shown).

Runway strip	Runway	Touchdown point	Easting	Northing	Elevation /m AOD	Approach (Grid) Heading		
						10° right of centreline	On centreline	10° left of centreline
Rwy 12/30	Rwy 12	Threshold	305799	167700	62.5	287.8°	297.8°	307.8°
		Inset (1/3 Rwy length)	306383	167392	62.5			
	Rwy 30	Inset (1/3 Rwy length)	306967	167084	64.9	107.8°	117.8°	127.8°
		Threshold	307552	166775	64.9			

6.2.3 Visual Control Room

The Cardiff Airport Visual Control Room (VCR, or 'control tower') was identified and its height noted. Its location is marked on the chart in Section 6.2.5 and given below.

BNG coordinates used for the Cardiff Airport VCR are as follow:

306820 E, 167470 N, 82m AOD.

Controllers' eye level for this analysis of was assumed to be 82m AOD.

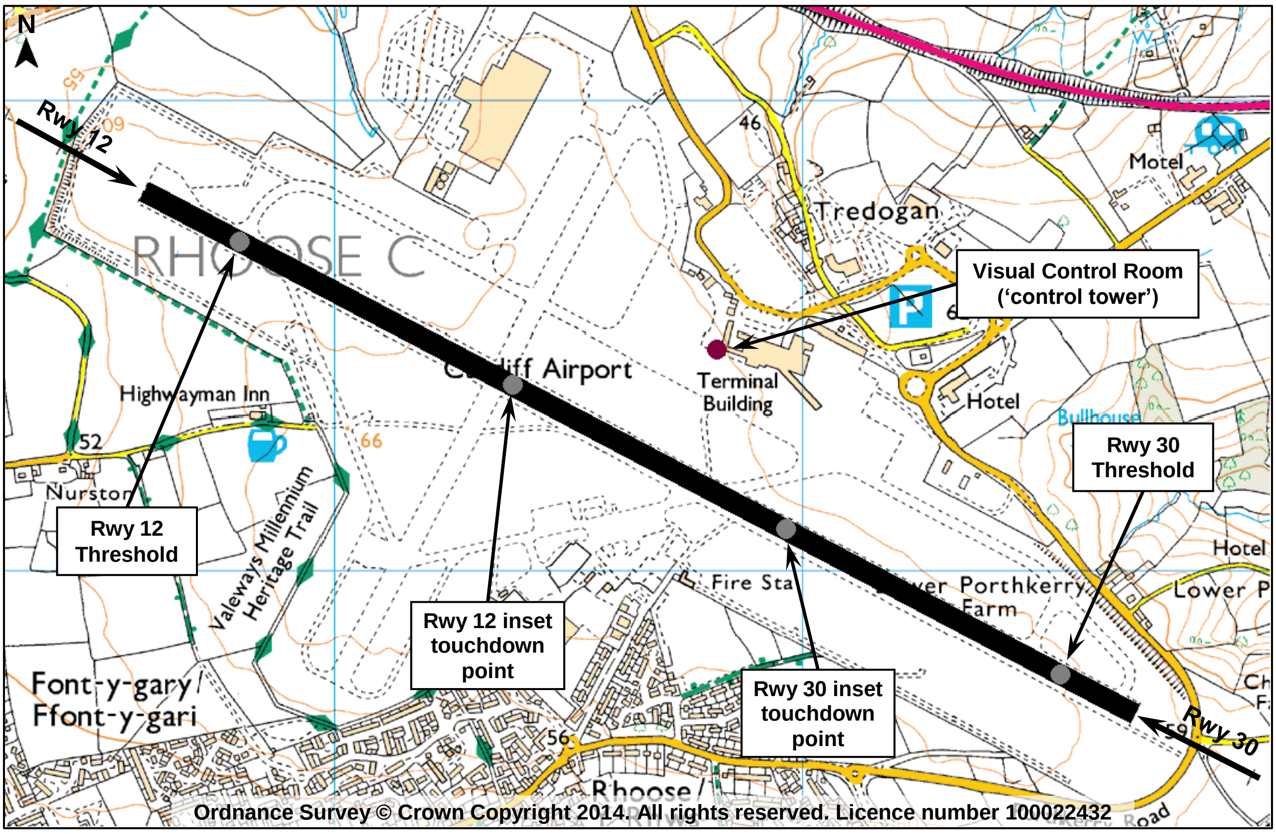
Detailed geometrical analysis is shown for this receptor later in this report.

6.2.4 Helicopter Traffic

There are no special instructions published in the UK Mil AIP for helicopter operations, but helicopter traffic will be discussed in general later.

6.2.5 Airfield Chart

The following chart shows the runway layout superimposed on an OS Explorer 1:25,000 scale background map. Surface receptor points on the airfield considered later in this report are marked: i.e., the VCR and the touchdown points for each runway (runway thresholds and inset touchdown points).



6.2.6 Cardiff Airport Runway Approach Path Receptor Points

Receptor points for detailed analysis were chosen at 1,000m intervals to a distance of 15km from each touchdown point as described in Section 6.1.4 above and as shown on the chart at Section 6.5 below.

6.2.7 Cardiff Airport Circuit Pattern Receptor Points

In the absence of accurate circuit pattern information, circuit patterns were assumed to be established on either side of the runway and were modelled as described in Section 6.1.5 above and as shown on the chart at Section 6.6 below.

6.2.8 Cardiff Airport Selected Receptor Point Locations

BNG coordinates are given in the following table for 5 receptor points (the VCR; points at 3km from the runway threshold for each landing direction, on the runway's extended centreline and 3° glideslope; and the mid-points of the downwind legs, 1nm north and south of the runway centreline, 1,000ft above airfield elevation). Those listed are shown later with solar panel/ receptor point geometry as worked examples to support the detailed analyses of the approaches.

Runway/ VCR	Receptor Description	Easting	Northing	Altitude/ Elevation
VCR	Control tower	306820	167470	82m (269ft)
Rwy 12 Approach	3km from the threshold touchdown point, on centreline and 3° glideslope	303146	169100	222m (727ft)
Rwy 12 left-hand (northern) circuit	Mid-point of the downwind leg, 1nm from centreline, 1,000ft above the airfield.	307540	168876	372m (1220ft)
Rwy 30 Approach	3km from the threshold touchdown point, on centreline and 3° glideslope	310205	165375	224m (735ft)
Rwy 30 left-hand (southern) circuit	Mid-point of the downwind leg, 1nm from centreline, 1,000ft above the airfield.	305811	165600	372m (1220ft)

6.3 RAF St Athan

6.3.1 Overview

RAF St Athan is located 3km east of Llantwit Major, Vale of Glamorgan and has a single visual and instrument runway strip (Rwy 26/08), 1,828m long and aligned from approximately west-southwest to east-northeast. A visual circuit is established for St Athan based aircraft (and visiting aircraft in emergency) to the north of the runway – however, the flight path for circuit traffic has not been confirmed in the time available to produce this report, so various possible circuit patterns were considered, and on either side of the runway for completeness.

RAF St Athan is entirely inside Cardiff Airport's control zone (CTR)with its own local flying zone within the Cardiff CTR. It is home to the University of Wales Air Squadron as its only resident flying unit, which conducts ab initio pilot training. The South Wales Police helicopter also operates from the airfield, on the south side of the runway.

It is confirmed that the proposed solar park will not infringe any safeguarding criteria for this nature of development for St Athan's runways or CNS installations so these are not considered further in this assessment.

6.3.2 Runway Data

Two runway touchdown points were considered for each runway in this assessment: the runway thresholds, and inset touchdown points 1/3 of the runway length in from the thresholds (most aircraft would be expected to touchdown between these points). Here, runway headings and lengths are summarised and shown graphically in Section 6.3.5 below.

The lengths of the runways and their headings (relative to True North) are shown in the following table as calculated from UK Mil AIP data.

Runway Strip	Runway Length	Runway	Runway Heading /° (True)
Rwy 26/08	1828m	Rwy 08	253°
		Rwy 26	073°

Data for RAF St Athan runway touchdown points assumed for this assessment are shown in the following table.

Runway strip	Runway	Touchdown point	Easting	Northing	Elevation /m AOD	Approach (Grid) Heading		
						10° right of centreline	On centreline	10° left of centreline
Rwy 26/08	Rwy 08	Threshold	299564	168092	49.1	064.2°	074.2°	084.2°
		Inset (1/3 Rwy length)	300130	168252	49.8			
	Rwy 26	Inset (1/3 Rwy length)	300695	168413	46.2	244.2°	254.2°	264.2°
		Threshold	301261	168573	40.7			

6.3.3 Visual Control Room

The RAF St Athan Visual Control Room (VCR, or 'control tower') was identified and its height noted. Its location is given below and marked on the chart in Section 6.3.5 below.

BNG coordinates used for the RAF St Athan VCR are as follow:

299850 E, 168310 N, 62m AOD.

Controllers' eye level for this analysis of was assumed to be 62m AOD.

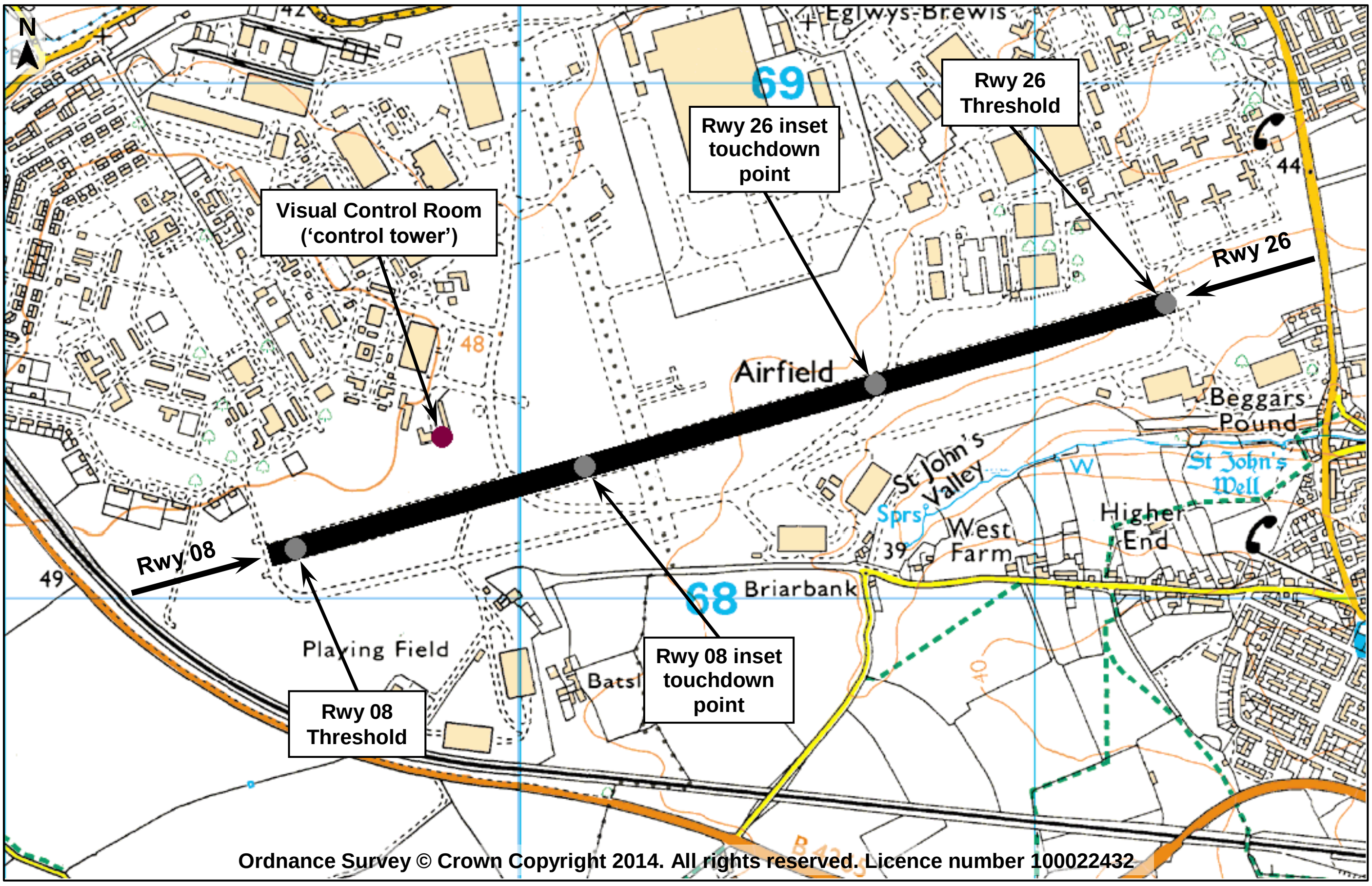
Detailed geometrical analysis is shown for this receptor later in this report.

6.3.4 Helicopter Traffic

There are no special instructions published in the UK Mil AIP for helicopter operations, but helicopter traffic will be discussed in general later.

6.3.5 Airfield Chart

The following chart shows the runway layout superimposed on an OS Explorer 1:25,000 scale background map. Surface receptor points on the airfield considered later in this report are marked: i.e., the VCR and the touchdown points for each runway (runway thresholds and inset touchdown points).



6.3.6 RAF St Athan Runway Approach Path Receptor Points

Receptor points for detailed analysis were chosen at 1,000m intervals to a distance of 15km from each touchdown point as described in Section 6.1.4 above and as shown on the chart at Section 6.5 below.

6.3.7 RAF St Athan Circuit Pattern Receptor Points

In the absence of accurate circuit pattern information, circuit patterns were assumed to be established on either side of the runway and were modelled as described in Section 6.1.5 above and as shown on the chart at Section 6.6 below.

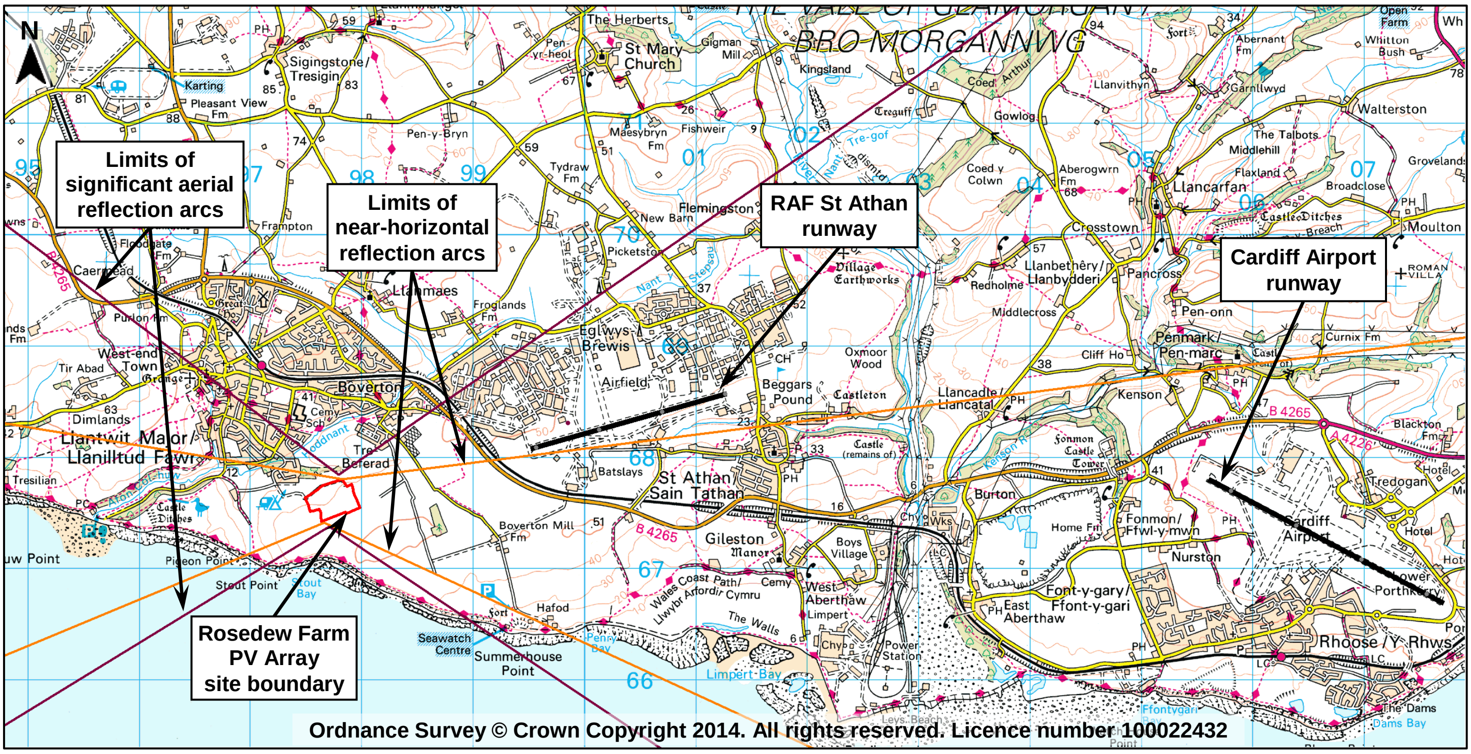
6.3.8 RAF St Athan Selected Receptor Point Locations

BNG coordinates are given in the following table for 5 receptor points (the VCR; points at 3km from the runway threshold for Rwy 26 approaches and at 4km from the runway for Rwy 08 approaches (as the point 3km from the threshold on this approach is a special case – discussed later – due to its proximity to the solar farm), on the runway's extended centreline and 3° glideslope; and the mid-points of the downwind legs, 1nm north and south of the runway centreline, 1,000ft above airfield elevation). Those listed are shown later with solar panel/ receptor point geometry as worked examples to support the detailed analyses of the approaches.

Runway/ VCR	Receptor Description	Easting	Northing	Altitude/ Elevation
VCR	Control tower	299850	168310	62m (203ft)
Rwy 08 Approach	4km from the threshold touchdown point, on centreline and 3° glideslope	295715	167002	261m (855ft)
Rwy 08 left-hand (northern) circuit	Mid-point of the downwind leg, 1nm from centreline, 1,000ft above the airfield.	299908	170114	355m (1163ft)
Rwy 26 Approach	3km from the threshold touchdown point, on centreline and 3° glideslope	304148	169390	200m (656ft)
Rwy 26 left-hand (southern) circuit	Mid-point of the downwind leg, 1nm from centreline, 1,000ft above the airfield.	300917	166550	355m (1163ft)

6.4 Summary of Airfield and Solar Farm Locations

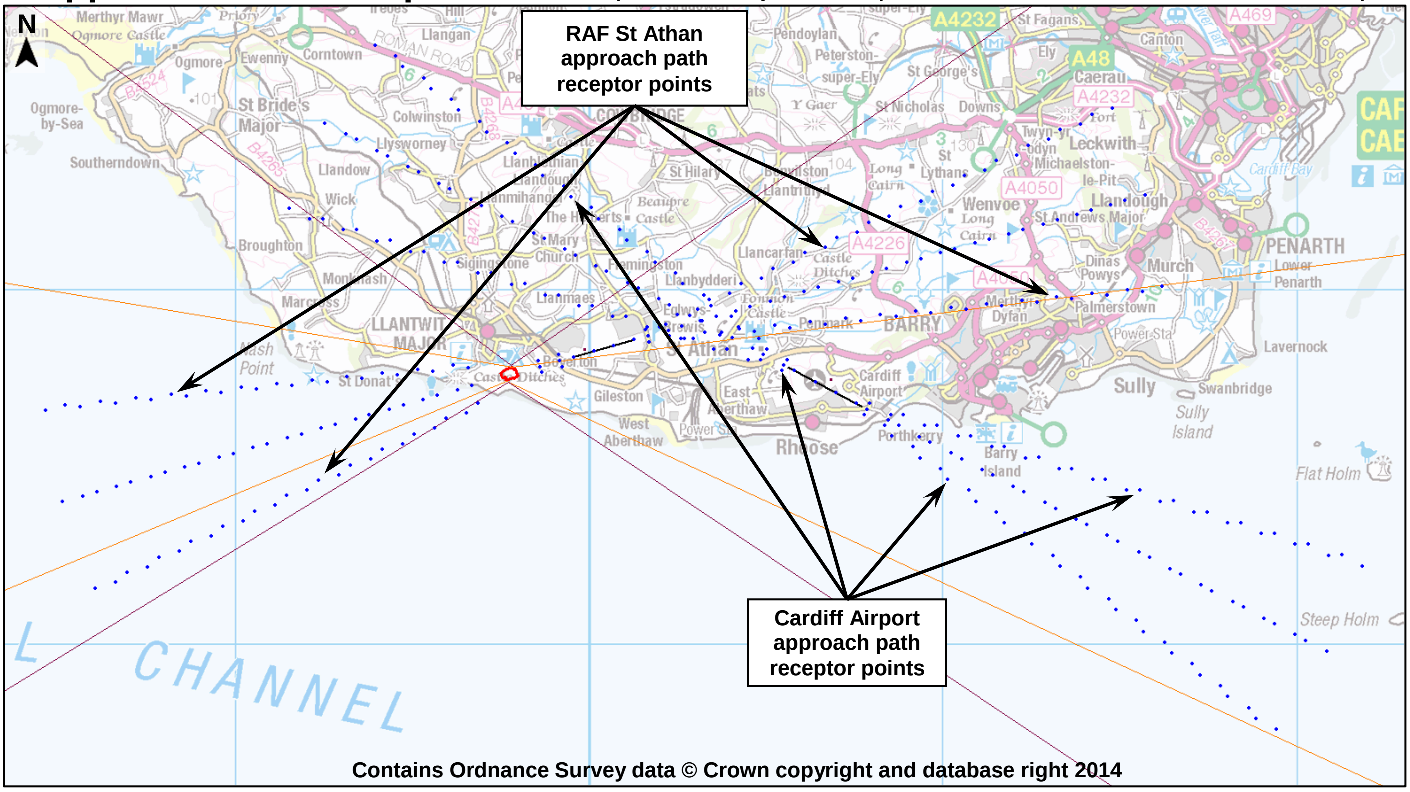
The locations of the proposed Rosedew Farm solar farm boundary, and of Cardiff Airport and RAF St Athan airfields' runways are shown on the following chart overlaid on a background OS 1:50,000 scale Landranger map. Also shown are the limits of the 'near-horizontal' solar reflection arcs (orange lines) and the arcs where reflections may be directed at less than 45° above horizontal (purple lines), calculated for the initial analysis (as described later).



6.5 Summary of Airfield Approach Path Receptors

Approach path receptor points for detailed analysis were chosen at 1,000m intervals to a distance of 15km from each touchdown point for Cardiff Airport and RAF St Athan approaches as shown on the following chart (marked as blue dots) overlaid on a background OS 1:250,000 scale map.

Approach Path Receptor Points (with runways, solar park and solar reflection arcs marked)



In close proximity to the solar farm (within 500m of it), the approach path points have been omitted from the chart as an alternative method for assessment is required in this area (as discussed later).

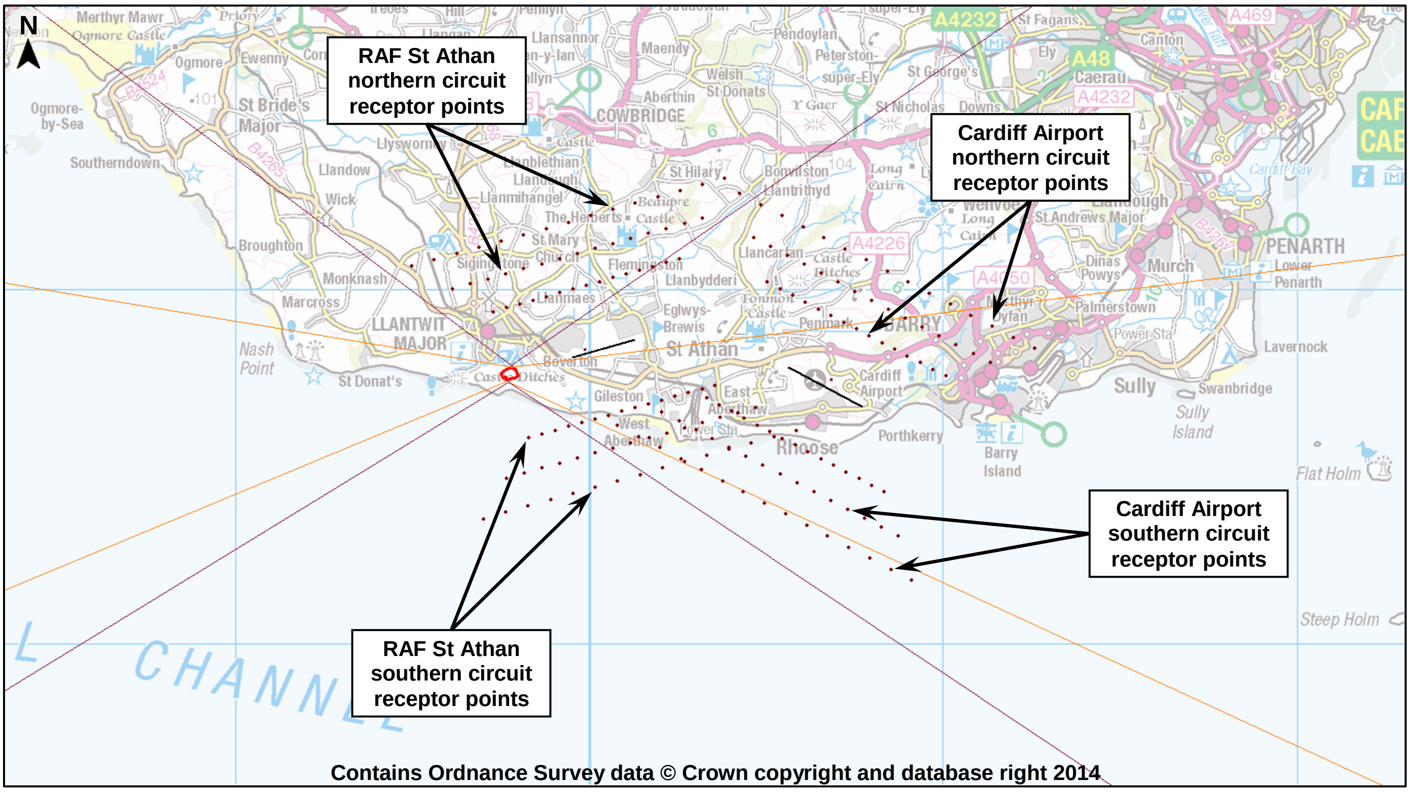
6.6 Summary of Airfield Circuit Pattern Receptors

Circuit pattern receptor points for detailed analysis were chosen for the ‘downwind leg’ on either side of each airfield’s runway. As the locations of the downwind leg flight paths are not accurately known, 3 ‘legs’ were taken on either side of each runway. These were parallel to the respective runway at 1nm (1.9km), 1.5nm (2.8km) and 2.0nm (3.7km) from the runway centreline.

For each leg, 15 receptor points were chosen starting and ending at a point 45° from the thresholds of the respective runways (i.e., 1.0nm beyond or before the runway for the legs 1.0nm from the centrelines, 1.5nm for the legs 1.5nm from the centrelines, and 2.0nm for the legs 2.0nm from the centrelines).

These are marked as the brown dots parallel to the runways overlaid on a background OS 1:250,000 scale map in the chart below.

Circuit Receptor Points (with runways, solar park and solar reflection arcs marked)



6.7 Other Receptors

Other receptors are only considered at high level based on other analyses conducted: no specific detailed analysis is conducted for them. Receptors discussed are: built-up areas nearby and various other dwellings, the B4265 and minor roads, and the railway to the east of the site. No other potentially significant receptors have been identified that may be affected by solar reflections.

7 Glint and Glare Assessment

7.1 Outline

The terms 'glint' and 'glare' are commonly used together, and different definitions are used by various sources referring either to the specular (direct) and non-specular (diffuse) reflections of sunlight, or to brief and prolonged bright reflections of light, respectively. To avoid confusion, the terms 'glint' and 'glare' will be avoided where possible in this section. This section considers specular reflections and the duration of those reflections as they affect receptors will be considered where necessary.

Specular reflections are much brighter – hence more significant – than non-specular ones: this report focusses on the specular variety. The difference in significance between bright flashes and longer periods of brightness is less clear: where an impact of brightness may be significant, it may be exacerbated by sudden and brief exposure to it with no possibility of becoming accustomed to it (e.g., while driving at night on a dark country lane and suddenly seeing the bright headlights of an oncoming vehicle directly ahead). However, continuous flying or driving directly towards the low sun may be considered a greater nuisance than a fleeting glimpse of the sun as it passes in front, say, of a manoeuvring aircraft or car. These aspects are considered later where appropriate.

PV cells are designed to absorb light and are therefore dark in colour and not very reflective – much less reflective than, say, a body of water or standard glass (e.g., windows and car windscreens). To further minimise nuisance from reflections, additional treatment is commonly added to the surface of PV cells to scatter reflected light in a non-specular manner (i.e., in many directions hence attenuating rapidly).

Effects of specular solar reflections from the PV panels are considered here. These effects diminish with distance from the solar park due to scattering effects that are even associated with specular reflections (e.g., diffraction effects) and atmospheric attenuation. This is a commonplace phenomenon: solar reflection off car windscreens (which is more reflective than solar panels) a few metres away are much more of a nuisance than similar reflections tens or hundreds of metres away.

Where appropriate, another everyday) example (to pilots and non-pilots alike is used to gauge likely effects: the nuisance of looking at or very near to the sun. The sun is many, many times brighter than reflections from dark solar panels and there is no attenuating effect with distance similar to that for reflections from solar panels.

7.2 Sun Data

7.2.1 Overview

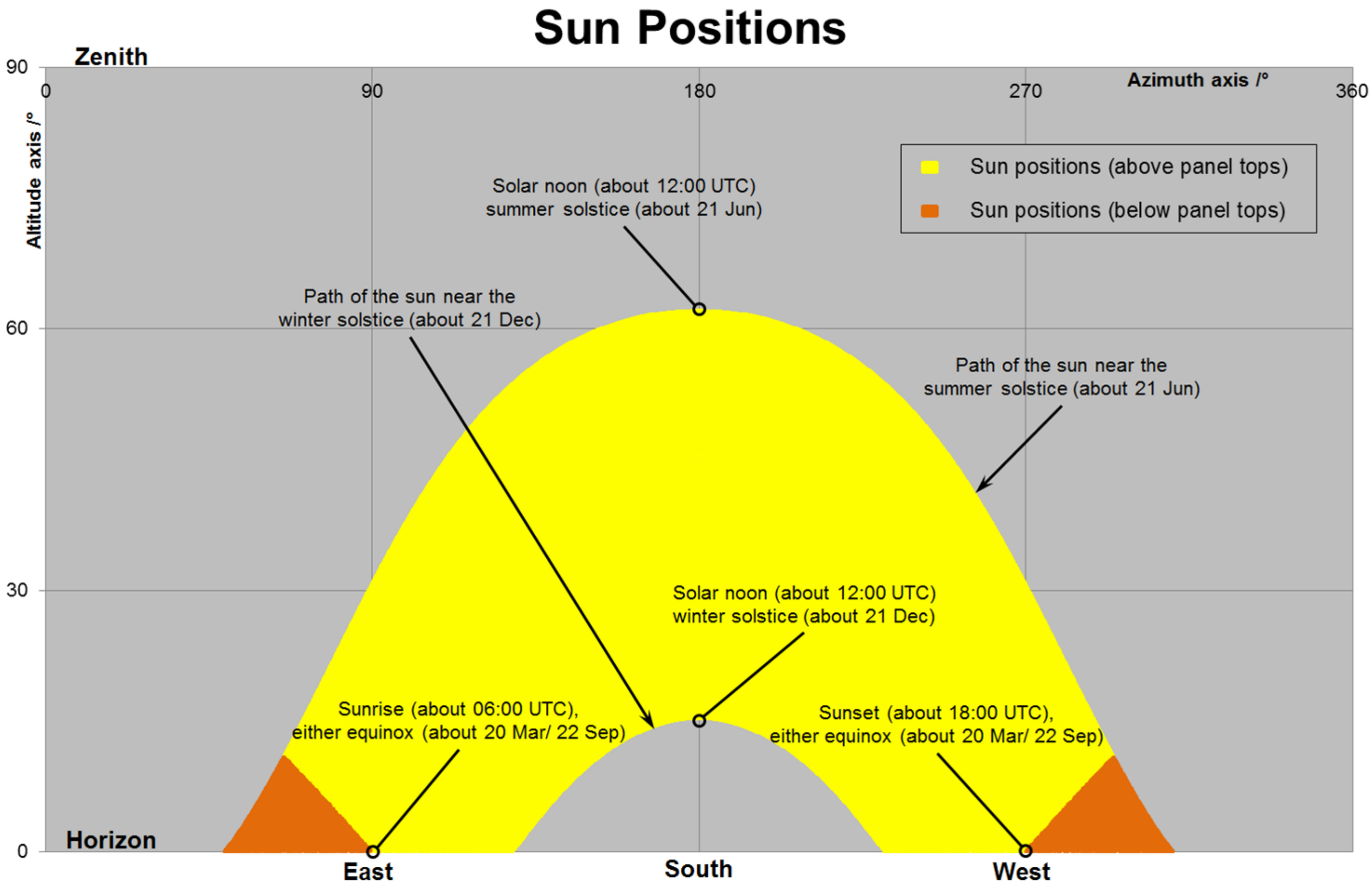
The sun's position was plotted on a minute-by-minute basis for a whole year. In this section, it's position in the sky and the times when it is above the horizon through the year are considered. From this data, the directions of solar reflections were calculated, with dates and times of those reflections.

7.2.2 Positions of the Sun

The position of the sun in the sky varies with the time of day and seasonally. The chart below shows the various positions the sun occupies in the sky at various times (although date and time information is not depicted in the axes of this chart, 6 date/ time data points are specified on the chart – those at the equinoxes occurring twice) at the solar park.

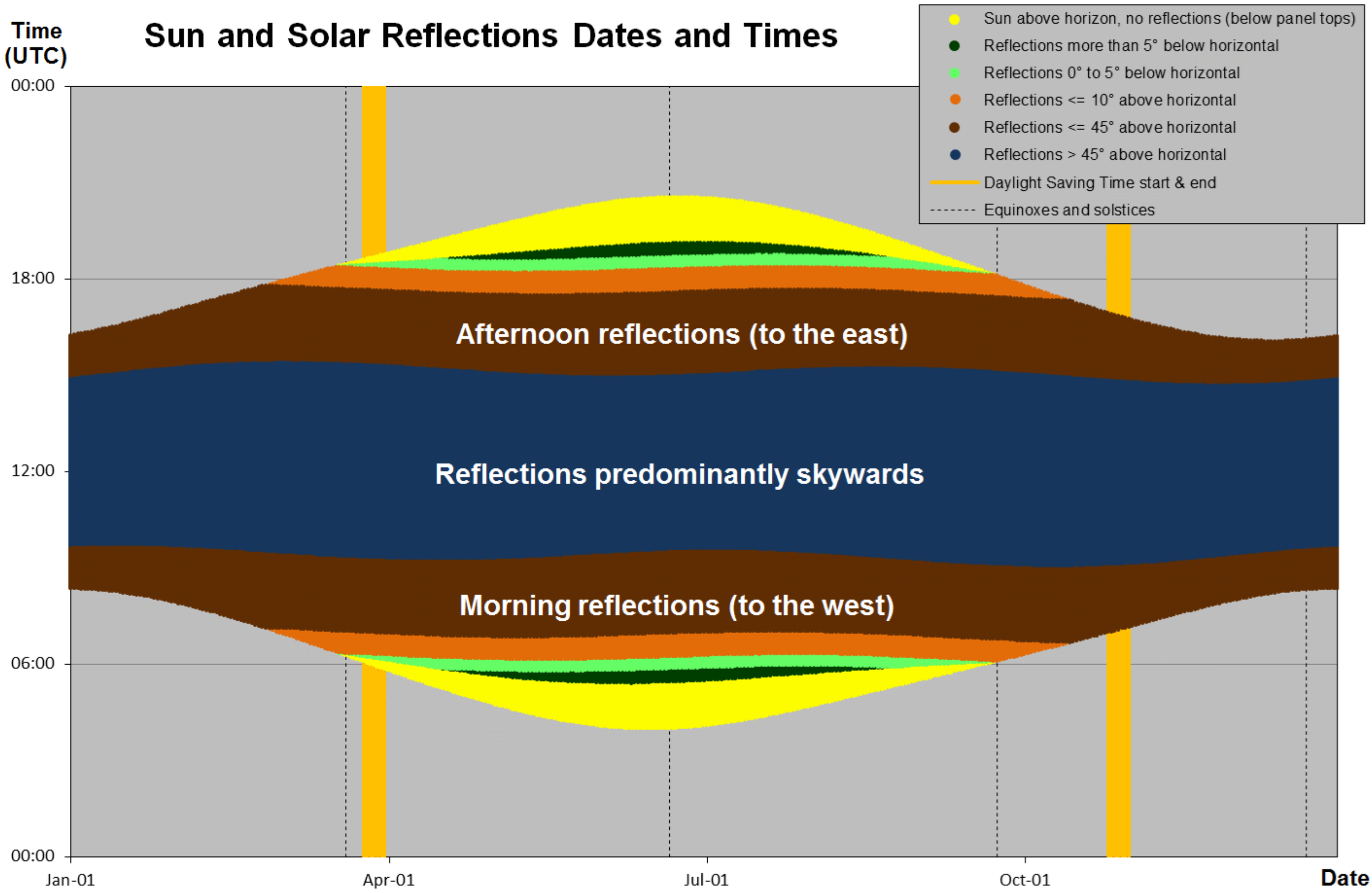
The daily movement is westwards from east, starting at 0° altitude (sunrise) in an arc with increasing altitude reaching its highest point about midday, and then continuing the westward arc with reducing altitude until sunset in the west at 0° altitude again; azimuths are given as True bearings. Apart from the innermost and outermost arcs, the sun passes through similar points in the sky twice each year.

The inside boundary of the arc is the sun's path at around the Winter Solstice (about 21 December), the outer boundary is the sun's path at around the Summer Solstice (about 21 June). At the equinoxes, the sun rises and sets at almost due east and west respectively, i.e., its path is then roughly in the middle of the arc shown.



7.2.3 Dates and Times when the Sun is Above the Horizon

All dates and times that the sun is above the horizon are shown graphically in the following chart. The chart also shows the altitude bands of reflected sunlight from the proposed solar park at these times (also where no reflections are possible when the sun is shining on the undersides of the solar panels), which are referred to later in this assessment.



7.3 Solar Reflections

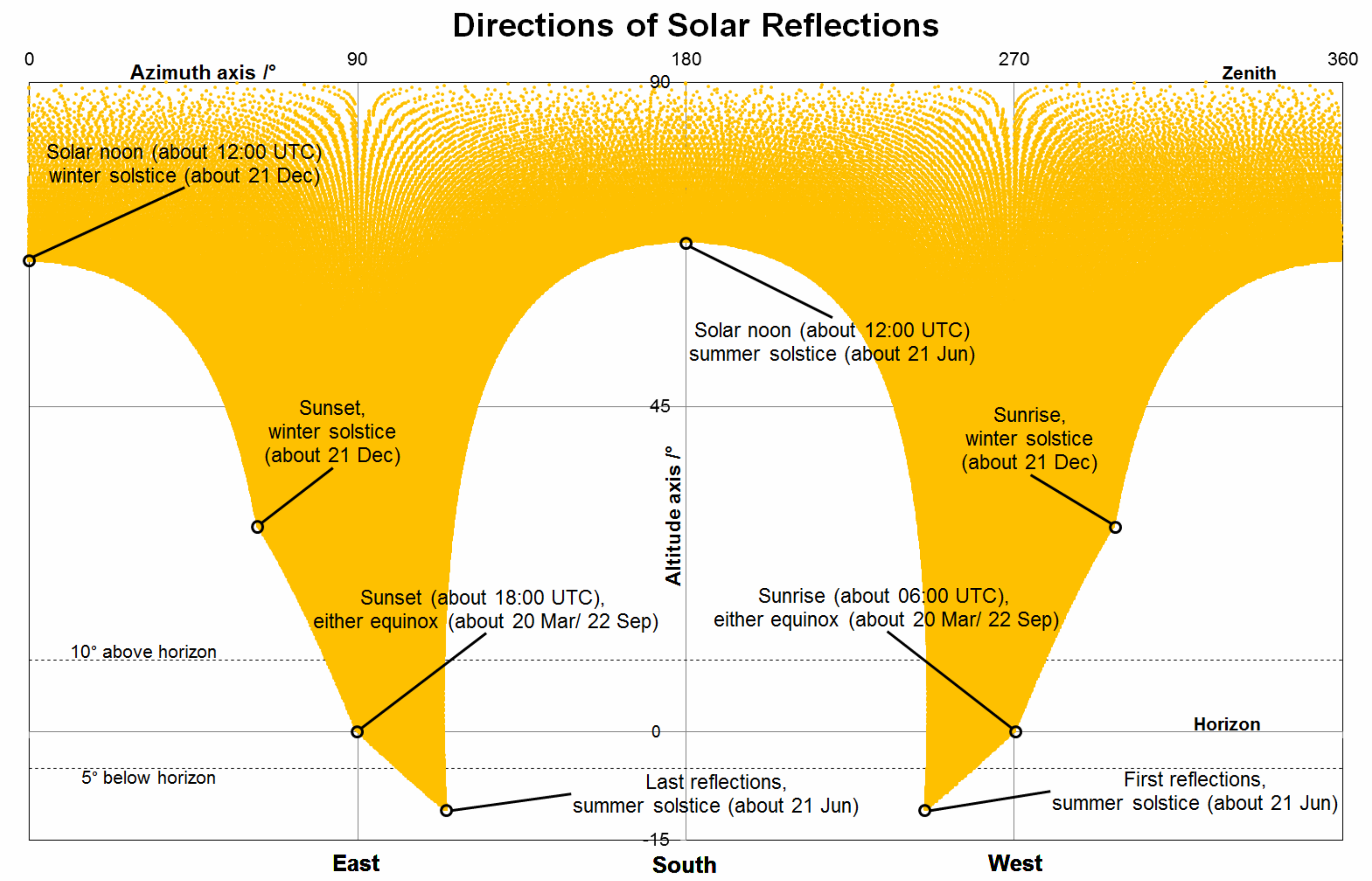
7.3.1 Overview

At any instant, solar reflections from all of the panels in the solar park will be parallel to each other, the direction determined by the position of the sun and the orientation of the panels. In this section, the directions of all reflections, and the dates and times when they occur, are considered.

7.3.2 Directions of Solar Reflections

As well as the time of day and year, the direction of solar reflections (in altitude and azimuth) depends on the latitude (from which the position of the sun at any instant can be calculated) and the orientation of the panels. The chart below shows the directions of all solar reflections calculated at 1 minute intervals through the year; azimuths are given as True bearings. Apart from the points on the curved arcs on the outside of the shaded area, reflections are in similar directions twice each year.

The gaps at the top of the chart are due to the stretching of the zenith from a single point to the length of the axis and the 60 second intervals between data points.



For the purposes of this assessment, solar reflections directed at more than 45° above horizontal are generally considered insignificant for pilots. Earlier (in Section 5.4.2) it was assumed that solar reflections directed upwards at more than 45° above horizontal may occur in any azimuth: the above chart shows that it is possible to specify this even more precisely: only reflections above approximately 70° (the higher of the altitude angles of solar reflections at the summer and winter solstices – see Appendix 2) occurs in all azimuths. Below approximately 60° altitude angle (the lower of the altitude angles of reflections at the summer and winter solstices – again, see Appendix 2), solar reflections are confined to 2 azimuthal arcs.

The remaining solar reflections (below the 45° altitude line) are clearly confined in 2 arcs: one approximately westerly (occurring in the morning), the other approximately easterly (occurring in the evening). There is no indication of dates and times of solar reflections in the axes of the chart above, so 10 date/ time data points are shown (8 points are marked but the equinox points occur twice in a year).

7.3.3 Dates and Times of Solar Reflections

The dates and times of reflections at various altitude angles are shown in the chart at Section 7.2.3 above.

7.4 General Effects of Solar Reflections

Solar reflections are a commonplace experience for almost everyone: perhaps from wet road surfaces, expanses of water or windows of buildings and vehicles. It does not normally present an excessive nuisance or distraction, including to drivers or pilots (based on the author's personal experience as a driver and professional pilot, and observation of common experience). They can only occur when the sun is shining. Various sources agree that solar panels are amongst the least reflective surfaces.

It must be understood that for a given orientation of a reflecting surface, at any instant solar reflections are directed in a single discrete direction which is a function of sun position and orientation of the surface.

[As the sun is larger than a fixed point, the reflected light will have a similar, small, angular extent (slightly increased by small scattering effects such as diffraction – even for 'specular' reflections), but this understanding is valid for most practical purposes, and necessary for describing the solar reflection phenomenon in simple terms. Throughout this analysis, the small angular extent of solar reflections at any instant is accommodated by the use of angular 'buffers' around any specified reflection.]

Solar reflections are worst when the observed angle between the sun and the reflecting object is at its maximum (i.e., 180°, so that when facing the reflecting object the sun is directly behind an observer), particularly if the observer (and much of the surrounding vista) is in shade so that his/ her eyes aren't attuned to brightness.

Consider two examples of this worst case.

- Driving westwards in a car in an urban area in the early morning; the car (with its occupants) is in the shade of tall buildings behind. Solar reflections may be observed from low windows of a building directly in front of the driver when the building (but not the car) is illuminated by the sun through a gap in tall buildings behind.
- Sitting in a dimly lit, west-facing room in the early morning, observing solar reflections from the windows of neighbouring buildings to the west.

In these examples, the relative brightness of the solar reflections (compared to ambient brightness) is at a maximum, compounded by the observer's eyes not being attuned to brightness.

Conversely, solar reflections are insignificant when the observed angle between the sun and its refection is at a minimum – i.e., close to 0° – so that the sun is in almost the same direction as the reflecting object and its brightness masks that of the reflections (for this angle to be 0°, the observer must be looking at the sun along the reflective plane – in this case along the plane of a PV panel, e.g., looking due east along a panel towards the sunrise around either equinox).

The sun may be said to be close to the reflecting object if the angle between them as viewed by an observer is less than, say, about 45° (if the sun was directly to the side of, or directly above, an observer as he/ she faced a reflecting object, the angle would be 90°). In this instance, when facing the reflecting object, an observer's eyes will be attuned to brightness, so the apparent intensity of the reflections will be low and of reduced significance (even if the sun is screened, perhaps by a visor). As the angle reduces to less than, say, 20°, the sun may be described as being very close to its reflections and will be the predominant nuisance to an observer facing that direction.

[It may be useful to have some measure for angular distances: a typical hand span at arms' length subtends approximately 15° to 20° from the tip of the little finger to the tip of the thumb. Therefore an angle of 20° (measured vertically, horizontally, or obliquely) is typically about 1 or 1½ hand spans; an angle of 45° is about 2 or 3 hand spans. For smaller angles, the angular diameter of the sun or moon may be used – approximately 0.5° whether low or high in the sky (the 'large' sun or moon when low in the sky is an optical illusion).]

Where an observer's gaze must be focussed in a particular direction (e.g., the road ahead for drivers, or the touchdown point on a runway for pilots approaching to land), the position of the sun relative to the direction of gaze must also be considered. As the sun is always much brighter than any reflections from solar panels, if the sun is a similar angular distance or closer to the direction of gaze than the reflecting panels (even if not directly between them), the sun's brightness will be the predominant cause of any nuisance, not the solar reflections. In such an instance the reflections will not significantly compound the issue, just as a quiet, but otherwise distracting noise is of little consequence when there is a much louder noise present.

Since solar reflections from various surfaces are a common experience – including for drivers and pilots – they are not considered to affect safety unless, perhaps, the reflections are of the worst kind (as described above). Even in such a scenario there is little evidence of any safety implications: looking towards solar reflections from solar panels is always much less severe than looking near to the sun, which is occasionally necessary for both drivers and pilots.

As the angle from the focus of view to any brightly reflecting object or bright light source increases, perhaps to 20°-30°, it may be possible to screen the light source effectively using a visor, blinds or a curtain. Bright light sources cause little nuisance when at moderate angles from the focus of view (say, greater than 45°, although this is subjective and depends on other factors).

At angles close to or greater than 90° from the focus of view (i.e., to the side or behind the observer's direction of vision), bright lights or reflections have little or no effect and if any minor nuisance was caused, an observer would naturally turn his/ her head slightly to remove the nuisance completely.

It should be noted that in general, a fixed receptor point will be subjected to solar reflections from a solar park once per day over 2 periods per year either side of the summer solstice. There is a special case in which the two periods meet at the summer solstice to merge into a longer, single annual period of daily solar reflections.

Receptors to the north of, and on the same level as, south-facing solar panels will only see the underside of those surfaces – and hence will never observe solar reflections – unless substantially above the level of the solar panels: this is apparent from inspection of the Directions of Solar Reflections chart at Section 7.3.2 above. The closer a receptor is to due north (from the solar panel) and the steeper the panel's inclination, the higher the receptor must be above it (in angular terms) to see its top surface and hence have any possibility of seeing solar reflections.

7.5 Outline Assessment Method

7.5.1 General

The basic method for the solar reflections analysis was to apply the physical principle that reflections occur within the plane of the incident ray and the reflecting surface's normal vector (the 'normal', perpendicular to the plane of the reflecting surface), and that the angle of reflection is equal and opposite to the angle of incidence relative to the normal.

For simplicity, it was assumed that the solar cells will cause the specular reflection of light. However, it should be noted that this is much worse than reality since solar cells are designed to absorb sunlight and not reflect it (reflected sunlight is solar energy that won't be converted to electricity and is therefore wasted).

Solar cells may be further treated to reduce the intensity of specular (direct) reflections, and instead to scatter light in many directions as diffuse reflections reducing any nuisance to an observer. The assumption of purely specular reflections allows the 'worst case' to be assessed, hence only specular reflections are analysed in detail.

When reflected, the wave properties of light will cause small diffraction effects (i.e., the bending of rays as they pass through an aperture: the reflecting surface is effectively an aperture). For visible light, diffraction effects are small and accommodated by 'buffers' applied in this analysis. However, diffraction has a small scattering effect and contributes to the reduction of solar reflection intensity with distance from the reflector.

7.5.2 Tasks

The following tasks were conducted:

- identification of the bands of vertical angles (altitudes) within which solar reflections may reach aerial, ground-based or 'near-ground level' (e.g., 'near-horizontal') receptors and apply appropriate buffers to accommodate various factors such as the angular size of the sun, atmospheric effects, uncertainties in receptor location (e.g., aircraft deviating from the nominal flight path), etc.;
- calculation of dates and times when reflections would be directed within those altitude bands, to calculate the horizontal arcs containing those reflections, and to plot these from all points in the solar park;
- identification of specific receptor points for detailed geometrical analysis with the solar park using results from the solar reflection calculations and identify dates and times when reflections match the specific geometries identified (with appropriate buffers).

7.5.3 Assumptions

Due to the volume of data generated (e.g., the sun is normally above the horizon for more than 250,000 minutes in a year, and solar reflection data was calculated at 1 minute intervals with more than 1,000 receptor points specifically analysed), the following general assumptions were made to reduce the data to a manageable quantity for both analysis and presentation in this report (these allow the data to be broken down into various levels of significance, they were not used to discard results), based on the author's experience as a professional pilot, common experience, and other factors.

- Approach paths are assumed to be straight lines to the point of touchdown to simplify geometrical analysis.
- Solar reflections reaching an aircraft approaching to land on any runway are generally of low significance unless within 45° (vertically, horizontally, or obliquely) of the touchdown point, which is taken to be where the pilot's gaze is focussed. However, these are considered when they may occur.
- Solar reflections reaching an aircraft are of less significance if they come from an angle of greater than 45° below horizontal (i.e., if they are directed upwards more steeply than 45°) as it is a direction of limited interest to a pilot and is likely to be frequently blocked by the aircraft structure. This is valid for aircraft when approaching to land and in most other phases of flight including turning (banking in a turn may expose more of the ground to view, but directions steeply below a pilot remain of little concern to the pilot during the turn).
- Where an aircraft may fly directly over or close to the solar park there will be large variations in the possible solar-panel-to-aircraft geometries. So in such cases it is assumed that solar reflections may reach the aircraft from any of the possible directions shown in the chart in Section 7.3.2 above; i.e., the solar park is effectively assumed to have no boundaries (which is obviously worse than the reality). Other assumptions (above) concerning the significance of reflections in particular directions are considered in such cases.

7.6 General Analysis

7.6.1 Outline

For reflectors facing south at low to moderate angles of inclination, near-horizontal reflections (i.e., those that may affect receptors at or near ground level) are confined to 2 arcs: the eastern arc is from just north of due east to approaching southeast, the western arc is from just north of due west to approaching southwest. As reflections at higher altitude angles are considered, these arcs increase in size.

Reflections to the west occur in the morning (with the sun in the east), and reflections to the east occur in the afternoon and evening (with the sun in the west). This is shown in the Directions of Solar Reflections chart at Section 7.3.2 above, and as the solar reflection arcs from the proposed solar park in the charts at Appendix 1.

In general, reflections will be directed at a particular altitude angle twice each day: westwards in the morning and eastwards in the afternoon or evening.

Again in general, a specific receptor that is subjected to solar reflections will normally receive them over 2 periods each year (normally spread over a number of days), once before and once after the summer solstice; these periods may merge into one period straddling the summer solstice. Reflections occur at roughly the same times of day in each period.

In the winter with the sun low, reflections are generally skyward with no reflections near-horizontal: the earliest and latest dates for near-horizontal reflections are determined by site latitude and angle of inclination of the south-facing reflector. In the UK there are generally no reflections near to the horizontal to the north or south from solar parks; reflections towards the west and southwest, and east and southeast normally occur only early or late in the day, respectively.

7.6.2 Altitude Bands of Concern

The land near the Rosedew Farm site is undulating although there are some steep localised slopes nearby, notably to the north of the site. It is therefore extremely unlikely that any ground-based off-site receptor will be higher or lower than approximately 5° as viewed from the solar farm.

In addition, reflections directed downwards are generally insignificant at any distance from a solar park (on flat ground reflections at 1° below horizontal from a height of 3m fall to the ground within 200m) and are likely to be blocked by fences, hedges or even other PV panels.

From this it is reasonable to assume that, unless very close to the solar panels, solar reflections will only be significant to ground-based receptors at vertical angles of between approximately horizontal (0°) and 5° above horizontal (+5°). A further 5° buffer was then added to allow for other factors, such as the angular size of the sun, weather effects, etc.

Therefore, reflections within a vertical band of 5° below (-5°) to 10° above (+10°) horizontal were considered to be the most significant and that is the main vertical band of interest for reflections. This altitude band will be described as 'near-horizontal' or 'near ground level' in this assessment. It should be noted that when very close to the solar panels (e.g., within say, 10m to 20m), solar reflections may be observed from a surface-based receptor above or below these vertical arcs – this is considered where necessary in this report.

However, although most aerial receptors will also be within this near-horizontal band, they may receive solar reflections from steeper angles than this when close to the solar park. Therefore a further vertical band of interest for reflections affecting aircraft is considered: from horizontal to 45° above horizontal (solar reflections reaching an aircraft from steeper angles is considered insignificant and can only be observed in very close proximity to the solar park, depending on the height of the aircraft above it, e.g., 3,000ft above the solar panels, reflections at greater than 45° above horizontal could only reach aircraft within 915m of the solar park, although perhaps in any azimuthal direction).

7.6.3 Key Almanac Dates

In order to understand better the phenomenon of solar reflections, it is necessary to consider certain dates. Some key dates to consider are: the solstices (summer and winter), the equinoxes (vernal and autumnal), and the earliest and latest times of the year when reflections may occur within the near-horizontal band (at both the top and the bottom of the range of altitude angles) and when solar reflections pass through an altitude angle of 45°. The direction of the sun and of reflected rays at key dates and times are given in the table at Appendix 2.

The angle of incidence of the sun's rays (the same as the angle of reflectance) relative to the normal vector through the PV plane is also shown for each data point in Appendix 2, with the observed angle between the sun and its reflections at a receptor.

7.6.4 Results

7.6.4.1 Overview

The limits of the 'near-horizontal reflection arcs', outside of which reflections will not be observed by ground-based – or near ground (and most aerial) – receptors (and within which it may be observed at certain times, given line-of-sight to the panels in the solar park), were plotted for all points on the solar park: this is shown on the charts at Appendix 1 as the orange-outlined 'bow-tie' shape. These arcs are valid for all receptors close to the horizontal plane through the solar park, e.g., aircraft approaching to land at Cardiff Airport and RAF St Athan (excepting aircraft approaching St Athan's Rwy 08 which may pass close to the solar farm well above the horizontal plane through the solar park – this case is discussed later).

The arcs represent the zone within which solar reflections will be directed to near ground level and do not consider blocking by terrain, hedges, buildings, and woods, etc. It will be impossible to see such reflections from near ground level outside these arcs: they are confined to areas between approximately (to the east) east-northeast to southeast, and (to the west) west-northwest to southwest. The eastern and western arcs are virtually symmetrical about the True North line.

Also shown on the charts at Appendix 1 are the arcs within which solar reflections are confined to less than 45° above horizontal: the 'significant aerial reflection arcs' (the purple outlined 'bow-tie shape'), which may be significant to aircraft more than 10° above the solar panels (usually when aircraft may be relatively close to the solar park).

For simplicity it is assumed that reflections directed upwards at angles greater than 45° above horizontal occur in all azimuths (but see the chart in Section 7.3.2 above for precise data as this assumption is worse than the actual case). So aircraft in very close proximity to the solar park – relative to their height above it (i.e., within 915m of the solar park boundary if 3,000ft above it, within 305m if 1,000ft above it) – will be more than 45° above some or all solar panels: at specific times, such aircraft may receive reflections directed steeply upwards more steeply than 45° above horizontal, and it is assumed that these can occur in all directions around the solar park.

The table at Appendix 2 lists the directions of the sun and of its reflections from the PV array at various times and dates through the year. The table is not exhaustive but shows key examples including where solar reflections cross through 45° above horizontal and other instances where reflections are outside the +10°/-5° range from the horizontal to highlight certain aspects, and providing additional data for peer review. All times given are UTC (i.e., GMT). Bold text indicates reflections within the +10°/-5° vertical limits. Although only a selection of data is shown, the whole data set was used for supporting analyses.

Appendix 3 uses 'near-horizontal solar reflections, and those at less than 45° above horizontal to highlight aspects of the solar reflection phenomenon.

- The first chart at Appendix 3 ('Direction of Reflections') shows how the direction of near-horizontal reflections (to the east and west) changes through the year. Reflections are directed furthest north early and late in the year (but only at the top of the vertical band of interest), to east and west at the equinoxes, and furthest south about the summer solstice.
- The second chart ('Daily Reflection Limits') shows how the horizontal solar reflection arcs grow (on one day for illustration only: the summer solstice) with a widening vertical band of interest. There is little change in the horizontal arcs as the vertical band of interest reduces to -2.5°/ +5° from -5°/ +10°, but they grow more significantly as the vertical band increases from -5°/ +10° to -10°/ +20°. On any one day reflections close to ground level are confined to a very narrow horizontal arc (i.e., at near-horizontal angles, the predominant change in the direction of reflection is vertical as the sun moves across the sky on any one day).

  [The arcs for reflections at up to 45° above horizontal as shown at Appendix 1 illustrate how much more the azimuthal reflection directions changes as reflection altitude angles of up to 45° are considered.]

- The third chart ('Solar Reflection Arcs') shows the full horizontal arcs in which various reflections can occur from any point in the solar park (this is plotted for all points in the solar park on the charts in Section 5.3.1 above and Appendix 1).
- The fourth chart ('Arcs for Observation of Solar Reflections at a Receptor') shows the reciprocal arcs to the third chart: these are the directions from which various reflections reach an observer (assuming the solar park is also within those arcs). This may be used as a template to assess whether reflections could affect a particular location: if placed at that location, unless any panels of the solar park are visible within the appropriate arcs, solar reflections will never be observed.

Appendix 4 summarises graphically the dates and times when:

- solar reflections may occur at near-horizontal angles (5° below horizontal to 10° above horizontal): the chart shows the reflections as marked by the light brown and light green shaded areas on the chart at Section 7.2.3 above;
- significant aerial solar reflections (taken to be reflections directed upwards from 0° to 45° above horizontal) the chart shows the reflections as marked by the light and dark brown shaded areas on the chart at Section 7.2.3 above.

7.6.4.2 Near-Horizontal Reflections

Dates and Times of Reflections

Dates and times that solar reflections may occur within the near-horizontal reflection arcs are summarised in the following table. Note that a receptor at a fixed point will generally observe reflections for much shorter periods than the times stated: typically (unless very close to the solar park site) for about 4 to 5 minutes a day over two periods of the year of perhaps from several days to two or three weeks, one before and one after the summer solstice.

	Morning (westerly) reflections	**Evening (easterly) reflections**
Dates of reflections	February 27th to October 14th	February 26th to October 14th
Times of reflections	05:47 GMT/ 06:47 BST to 07:06 GMT/ 08:06 BST	17:20 GMT/ 18:20 BST to 18:44 GMT/ 19:44 BST

Notes.

- After 31 March until the last reflections near ground level for the year, daylight saving time is always used in the UK (it is used from the last Sunday in March, i.e., March 26th in 2017, and never before March 25th) so local time will be BST.

  After midsummer, reflections only occur near to ground level when local time is BST, i.e., never after the last Sunday in October (October 29th in 2017, and never before October 25th).
- The maximum time taken for reflections to pass through the vertical band of interest on any particular day is always less than 68 minutes – near the summer solstice – reducing to nothing before early-march and after mid-October.
- On any one day, solar reflections near ground level are confined to 2 narrow horizontal arcs (as illustrated in Appendix 3). Near the summer solstice, they are directed only to the east-southeast and west-southwest (approximately); at the equinoxes, they are directed only to the east and west (approximately).

This is shown graphically in the chart at Section 7.2.3 above, marked by the light green and light brown shaded areas.

Directions of Reflections

Near-horizontal solar reflections (i.e., from 5° below, to 10° above, horizontal) can occur in 2 arcs: to the west in the mornings, and to the east in the evenings. The northern and southern azimuthal limits of this 'near-horizontal reflection arcs' are summarised in the following table.

These are the bearings of the orange lines forming the near-horizontal reflection arcs shown in Appendix 1.

	Westerly (morning) reflections	**Easterly (evening) reflections**
Northern azimuth limit of reflection arcs	279.3° (Grid)/ 278.2° (True)	082.8° (Grid)/ 081.6° (True)
Southern azimuth limit of reflection arcs	247.4° (Grid)/ 246.3° (True)	114.8° (Grid)/ 113.7° (True)

These can be also seen from the chart in Section 7.3.2 above.

7.6.4.3 Solar Reflections up to 45° Above the Horizontal Plane

Overview

It is normally sufficient to consider only near-horizontal solar reflections for aerial receptors unless either very high or particularly close to the solar park. Aircraft operating near Cardiff Airport or RAF St Athan may sometimes satisfy one of these conditions, so reflections from the horizontal plane up to 45° above it are considered here as part of the general analysis.

It is assumed that some reflections above 45° may occur in any azimuth at the appropriate time, but that they are of little significance to a pilot. To receive solar reflections such steep angles – perhaps from any azimuthal direction, an aircraft must either be almost directly above the solar park, e.g., within 305m of its boundary for aircraft 1,000ft above it, or at very high level: in either case, any reflections will be of little concern to a pilot who will have little interest in the ground steeply below him/ her.

Dates and Times of Reflections

Dates and times that solar reflections may occur anywhere within the vertical arcs between the horizontal plane and 45° above it are summarised in the following table.

	Morning (westerly) reflections	**Evening (easterly) reflections**
Dates of reflections	All year	
Times of reflections	06:05 GMT/ 07:05 BST to 09:43 GMT/ 10:43 BST	14:41 GMT/ 15:41BST to 18:23 GMT/ 19:23 BST

Notes.

- The earliest time in the morning and latest time in the evening that solar reflections can occur are respectively later and earlier than for near-horizontal reflections because reflections below the horizontal plane were not considered in this part of the analysis, whereas it was for near-horizontal reflections.

- Ignoring below-horizontal reflections only affects the earliest and latest times of reflections after the vernal equinox and before the autumnal equinox since the sun has to be above and to the north of the panels for below horizontal reflections – see Appendix 2).

This is shown graphically in the chart at Section 7.2.3 above, marked by the light and dark brown shaded areas.

Directions of Reflections

Solar reflections from the horizontal plane up to 45° above it can occur in 2 arcs: to the west in the mornings, and to the east in the evenings. Northern and southern azimuthal limits of these arcs are summarised in the following table. These are the bearings of the purple lines forming the 'less than 45°' reflection arcs in Appendix 1.

	Westerly (morning) reflections	**Easterly (evening) reflections**
Northern azimuth limit of reflection arcs	306.9° (Grid)/ 305.8° (True)	055.4° (Grid)/ 054.2° (True)
Southern azimuth limit of reflection arcs	238.5° (Grid)/ 237.4° (True)	123.8° (Grid)/ 122.6° (True)

These can be also seen from the chart in Section 7.3.2 above.

7.6.5 Discussion

Only limited data is shown in Appendix 2 but the full data set was used throughout this assessment. The following points from the analyses are noteworthy.

- For reflections to occur, the sun must be above the horizon and shining on the PV panels' tops, i.e., above the plane of the panels, otherwise no reflections occur. Obviously solar reflections only occur when the weather is sunny.
- At any instant, all specular reflections from any point in the solar park (discounting minor effects such as diffraction and the small angular diameter of the sun) will be directed in single, discrete altitude angle and azimuth. Reflections from all solar panels will be parallel to each other.
- Reflections cannot be seen unless an observer has a view of the tops of the PV panels: therefore receptors on the north side of a row of solar panels cannot receive solar reflections unless substantially above the level of the solar panels. The near-horizontal solar reflection arcs shown in Appendix 1 extend slightly to the northern side of the solar farm only because they include reflections up to 10° above horizontal.
- Reflections generally occur within the vertical limits at 2 periods each day: in the morning (in a westerly direction with the sun in the east) and evening (in an easterly direction with the sun in the west). In between reflections are skywards.
- At 12:16 UTC/ 13:16 BST at the Summer Solstice (June 21st), the sun is closest to the normal vector of the array and reflections are in almost the same direction as the sun (i.e., high to the south).
- Near-horizontal reflections occur in the most southerly directions around the Summer Solstice; although the most southerly reflections may not occur on exactly the summer solstice, any difference is small (of the order of 0.1°).

- There are never reflections near-horizontal further north than just north of due east and due west. There are never reflections at less than 45° above horizontal further north than approximately northeast and northwest.
- There are never reflections near-horizontal further south than approximately east-southeast and west-southwest. There are never reflections at less than 45° above horizontal further south than approximately east-southeast and west-southwest.
- Reflections directed upwards at more than approximately 65° above horizontal may occur in all azimuths (although for the purposes of this report, it is assumed that this may apply to all reflections above 45°).
- At midsummer, reflections pass through the +10°/-5° band in less than 68 minutes; they pass through the band +45°/ 0° altitude band in approximately 200 minutes. At other times of year, reflections will be within this band for shorter periods.
- The length of time each day that reflections persist at near-horizontal altitudes reduces from a maximum near midsummer to zero in late-February/ mid-October.
- There are no near-horizontal reflections before February 26th or after October 14th.
- At noon at midwinter, the sun is low to the south; reflections are high to the north.
- Halving the altitude band defined as 'near-horizontal reflections' from +10°/-5° to +5°/-2.5° doesn't greatly reduce the reflection arcs over a year, although the first and last reflections of the year will occur slightly later and earlier. However, a doubling to +20°/-10° gives a more significant increase in the reflection arcs.

  Considering the +45°/ 0° altitude band gives a yet more significant increase in the reflection arcs to the north and a slight reduction to the south.
- Reflections at or below horizontal will generally fall quickly to the ground, onto hedges and fences, or even adjacent rows of PV cell panels. This also applies to some extent to reflections just above horizontal.
- The sun is never more than 38° (approximately 2 to 2½ hand spans at arm's length) from any near-horizontal reflections and usually much closer than this (the maximum angle occurs close to midsummer at the top of the vertical band of interest, i.e., close to 10° above horizontal). Therefore whenever such reflections are observed, there will be very high ambient brightness from the sun.

7.7 Specific Receptor Analysis

The geometries (altitude and azimuth angles, and distances) between the Airfields' selected receptor points (summarised in Section 6.4 above) and each of the significant solar park points (specified in Section 5.3 above) were calculated and are tabulated here. The maximum and minimum altitude and azimuth angles for each receptor point was taken with an appropriate buffer as bounding values for comparison with the solar reflections data to establish dates and times when reflections are within those limits.

A buffer of ±1° in azimuth and altitude angle was used for all receptor points. This allows for factors such as the angular size of the sun, variations in the sun's observed position due to weather (hence atmospheric refraction effects) or in the alignment of the panels, and fills any gaps between receptor points (the use of multiple analysis points across the solar park also serves this function).

Where charts are shown later in this section to mark dates and times of reflections, they have 2 vertical orange stripes. These mark the dates within which local time changes from GMT to BST (the last Sunday in March, i.e., varying between 25 and 31

March from year to year) and from BST to GMT (the last Sunday in October, i.e., varying between 25 and 31 October).

It may be helpful to refer to Appendix 2 when considering the direction of the sun and solar reflections at a particular date and time. Although only limited data is shown there, it should assist in understanding the nature of the phenomenon at any instant.

7.7.1 Geometries between the Solar Park and Airfield Receptor Points

7.7.1.1 Overview

The geometries – i.e., azimuths, altitude angles, and horizontal distances – between selected points on the solar park and receptor points are shown below. Although only selected examples are shown here for brevity, all geometries between all solar park points and all approach path points described earlier were considered in the analysis.

In the tables, azimuths are given first as grid bearings with true bearings in parentheses. For the geometrical calculations, pilot's eye height is taken as 2m above an aircraft's assumed position.

7.7.1.2 Geometries between Selected Solar Park and Receptor Points

Geometries are tabulated below between Points 1, 7, 11, 17, and 20 on the solar park and receptor points (see Section 6 above for more details of the receptor points) at:

- the VCR (control tower) at each airfield;
- 3km from touchdown (at the runway thresholds) – less for the approach to RAF St Athan's Rwy 08 which is at 4km from touchdown – on the extended centreline and on the 3° glideslope to each airfield's runways; and,
- the mid-point of the downwind legs, 1nm to the north and south of each airfield's runway, 1,000ft above airfield elevation.

Cardiff Airport																
Point on PV Farm	VCR (Control Tower)			Rwy 12, on centreline, 3° glideslope, 3km from touchdown at the runway threshold			Mid-point of northern circuit's downwind leg, 1nm from centreline, 1,000ft above airfield			Rwy 30, on centreline, 3° glideslope, 3km from touchdown at the runway threshold			Mid-point of southern circuit's downwind leg, 1nm from centreline, 1,000ft above airfield		
	Alt /°	Az /°	Dist /m	Alt /°	Az /°	Dist /m	Alt /°	Az /°	Dist /m	Alt /°	Az /°	Dist /m	Alt /°	Az /°	Dist /m
1	0.30	092.1 (091.0)	9001	1.93	076.3 (075.2)	5476	1.96	083.7 (082.6)	9774	0.85	101.1 (100.0)	12616	2.31	105.4 (104.3)	8285
7	0.27	091.0 (089.9)	9332	1.79	075.5 (074.4)	5841	1.88	083.0 (081.8)	10125	0.82	100.1 (099.0)	12915	2.22	103.8 (102.6)	8567
11	0.27	091.0 (089.8)	9097	1.84	074.8 (073.7)	5619	1.91	082.8 (081.6)	9895	0.83	100.2 (099.1)	12683	2.27	104.1 (102.9)	8337
17	0.24	090.5 (089.4)	8838	1.86	073.3 (072.1)	5392	1.93	082.1 (081.0)	9649	0.82	100.1 (098.9)	12415	2.31	104.0 (102.8)	8068
20	0.23	089.7 (088.6)	9182	1.74	073.1 (071.9)	5757	1.86	081.7 (080.5)	10007	0.80	099.3 (098.1)	12733	2.23	102.6 (101.4)	8374

RAF St Athan															
Point on PV Farm	**VCR (Control Tower)**			**Rwy 08, on centreline, 3° glideslope, 4km from touchdown at the runway threshold**			**Mid-point of northern circuit's downwind leg, 1nm from centreline, 1,000ft above airfield**			**Rwy 26, on centreline, 3° glideslope, 3km from touchdown at the runway threshold**			**Mid-point of southern circuit's downwind leg, 1nm from centreline, 1,000ft above airfield**		
	Alt /°	**Az /°**	**Dist /m**	**Alt /°**	**Az /°**	**Dist /m**	**Alt /°**	**Az /°**	**Dist /m**	**Alt /°**	**Az /°**	**Dist /m**	**Alt /°**	**Az /°**	**Dist /m**
1	0.73	076.0 (074.9)	2087	5.65	249.2 (248.0)	2258	5.82	042.0 (040.9)	3110	1.43	075.9 (074.8)	6519	5.43	112.1 (110.9)	3337
7	0.57	074.2 (073.0)	2453	6.69	250.2 (249.1)	1886	5.20	044.3 (043.2)	3460	1.33	075.3 (074.1)	6884	5.01	107.6 (106.5)	3596
11	0.58	072.2 (071.0)	2233	5.95	252.7 (251.6)	2104	5.40	041.3 (040.1)	3310	1.36	074.7 (073.5)	6662	5.31	108.6 (107.5)	3370
17	0.50	067.8 (066.7)	2017	5.25	256.4 (255.3)	2332	5.48	036.9 (035.8)	3208	1.37	073.4 (072.2)	6435	5.67	108.8 (107.6)	3100
20	0.42	068.2 (067.1)	2382	6.21	257.6 (256.4)	1969	5.00	040.2 (039.0)	3518	1.29	073.2 (072.1)	6800	5.19	104.9 (103.8)	3394

7.7.2 Analysis of Solar Reflections on Airfield Receptors

7.7.2.1 Runway Touchdown Points, Approach Paths, Circuit Patterns' Downwind Legs and VCRs

The detailed analyses for each airfield focus on the approach paths to all the runways, the touchdown points, the downwind legs of the circuit patterns and the VCR. Solar panel-to-receptor point geometries – already calculated – with a buffer of 1° in altitude and azimuth applied were combined for each 'receptor group' (i.e., all approach paths to each runway were grouped, and the VCR treated as a 'group' in itself) and compared to the reflection geometries to identify when solar reflections could affect any of those receptor groups (as well as other relevant properties of those reflections).

The following results do not specify which parts of the specified 'receptor group' may be affected, instead just specifying that a part of the receptor group may receive solar reflections within the dates and times shown. The specific receptor group considered at each stage is stated below.

Where solar reflections may affect an aircraft in a particular location (e.g., a localised part of an approach path), they will be confined to that local vicinity and will not be observable from other parts of the receptor group until some considerable time has passed due to the slow movement of the sun.

Notably, except for the approach to Rwy 08 at RAF St Athan (which involves aircraft flying close to or directly above the solar farm) all receptor points considered in detailed analyses are within the 'near-horizontal' band (i.e., less than 10° above horizontal) for solar reflections.

7.7.2.2 Discussion of Other Airborne Receptors

Other phases of flight are not as sensitive to solar reflections as approach and landing may be for the following reasons.

- An aircraft will not be flying directly towards the solar panels (as it may do when approaching to land if panels are close to the runway), so the aircraft will quickly pass through any reflections and effects will be transient.
- The pilot's focus of gaze will not be towards, or close to, the solar park as it may be when approaching to land if panels are close to the runway.
- An aircraft will either be on the ground (during the take-off roll – although there is unlikely to be any view of the solar park from aircraft on the ground); climbing rapidly away from the ground with the pilot's focus of vision being the sky into which he/ she is climbing (just after take-off), i.e., away from any reflecting panels; or well away from the ground (all other phases of flight). It will not be flying towards the ground at low level.

Therefore, no further detailed analysis has been conducted on these phases of flight other than the airfield circuit patterns: it would not be practicable to analyse every possibility. Instead, they are discussed generally here based on the findings from analyses already described: where the situation at one of the airfields requires specific discussion, this is given later when each airfield is analysed.

<u>Aircraft Taking-Off</u>

The runway at RAF St Athan is outside the near-horizontal solar reflection arcs and it was confirmed that no solar reflections can reach aircraft on the ground at St Athan (only the undersides of panels could be visible from St Athan's runway, assuming there is line-of-sight which has not been confirmed in this analysis).

Whilst Cardiff Airport is within the reflections arcs, it is highly unlikely that there would be any view of the solar panels 8km away from aircraft on the ground. If panels are observable from the runway, for reflections to reach an observer, they would have to be reflected almost directly along the rows of solar panels. This can only occur when the sun is setting almost due west (around the equinoxes) and therefore the sun would be shining in almost exactly the same direction as any reflecting panels. At such a distance from the panels, any solar reflections are unlikely to be noticeable, and the much brighter sun would be the principle cause of any nuisance.

Effects of solar reflections when climbing away after lift-off are discussed later for each airfield.

Circuit Traffic

The downwind legs of the possible circuit patterns have been analysed in detail. Parts of the airfield circuits that have not been subject to such analysis are discussed later in conjunction with the downwind leg analysis for each airfield's runway and the approach path analyses in both runway directions for each airfield.

Helicopter Traffic

There are no special procedures published for helicopters at either airfield so these are discussed at high level later for each airfield.

Other Flight Procedures

Visual and instrument flight procedures are discussed briefly for each airfield.

Transiting Traffic

Transiting traffic may operate to or from either, or neither, airfield. The following points are generally pertinent to aircraft in transit.

- Reflections may be observable at certain times in the mornings to the west of the solar park and in the evenings to the east of it.
- As the geometry between the solar park and the flight path of a transiting aircraft is generally quite different from those on approaches to runways, solar reflections may be experienced by such traffic outside the reflection arcs shown in the charts at Appendix 1 at various times of day through the year (but only when very close to the solar park relative to height above it).
- Aircraft will normally be relatively high with reflections from steeply below an aircraft that will often be blocked by the aircraft structure (or from behind the pilot).
- Solar reflections will not come from a direction of specific and immediate interest to the pilot (there is no reason why a pilot in transit would normally need to stare in the direction of the solar park, reducing any nuisance from solar reflections).
- Such aircraft will not be descending towards the solar park so effects of solar reflections will be transient. E.g., the entire site is 500m across at its widest point, so such so at a slow 60kts (31m/s) groundspeed an aircraft will cross it in no more than 17 seconds (worst case). Aircraft crossing the site after take-off or preparing to land at either airfield may well be travelling at perhaps 4 times this speed, in which case reflections could only be visible for less than 5 seconds.
- The arcs for significant aerial reflections (within which reflections are directed upwards at less than 45° – see Appendix 1 and elsewhere) applies for all aircraft in the vicinity of the site unless extremely close to or over it.
- For an aircraft transiting at a height of 1,000ft above the solar park, reflections directed upwards at more than 45° can only reach it within 305m of solar panels

(or within 610m at 2,000ft), perhaps from any azimuthal direction. At 10,000ft, reflections above 45° can only be seen within approximately 3km of the solar park.

The arcs for near-horizontal reflections apply to aircraft at a height of, say 5,000ft above the solar panels within 9.3km/ 5.0nm of them; within this distance (and still at 5,000ft above, but beyond 1.7km/ 0.9nm from, solar panels) the significant aerial reflection arcs (i.e., up to 45° above horizontal) apply.

- For solar reflections to occur, there must be high levels of ambient brightness, reducing the apparent brightness – and hence significance – of any reflections.

Effects will therefore be of low significance for transiting traffic.

7.7.2.3 Solar Reflections from the Sea

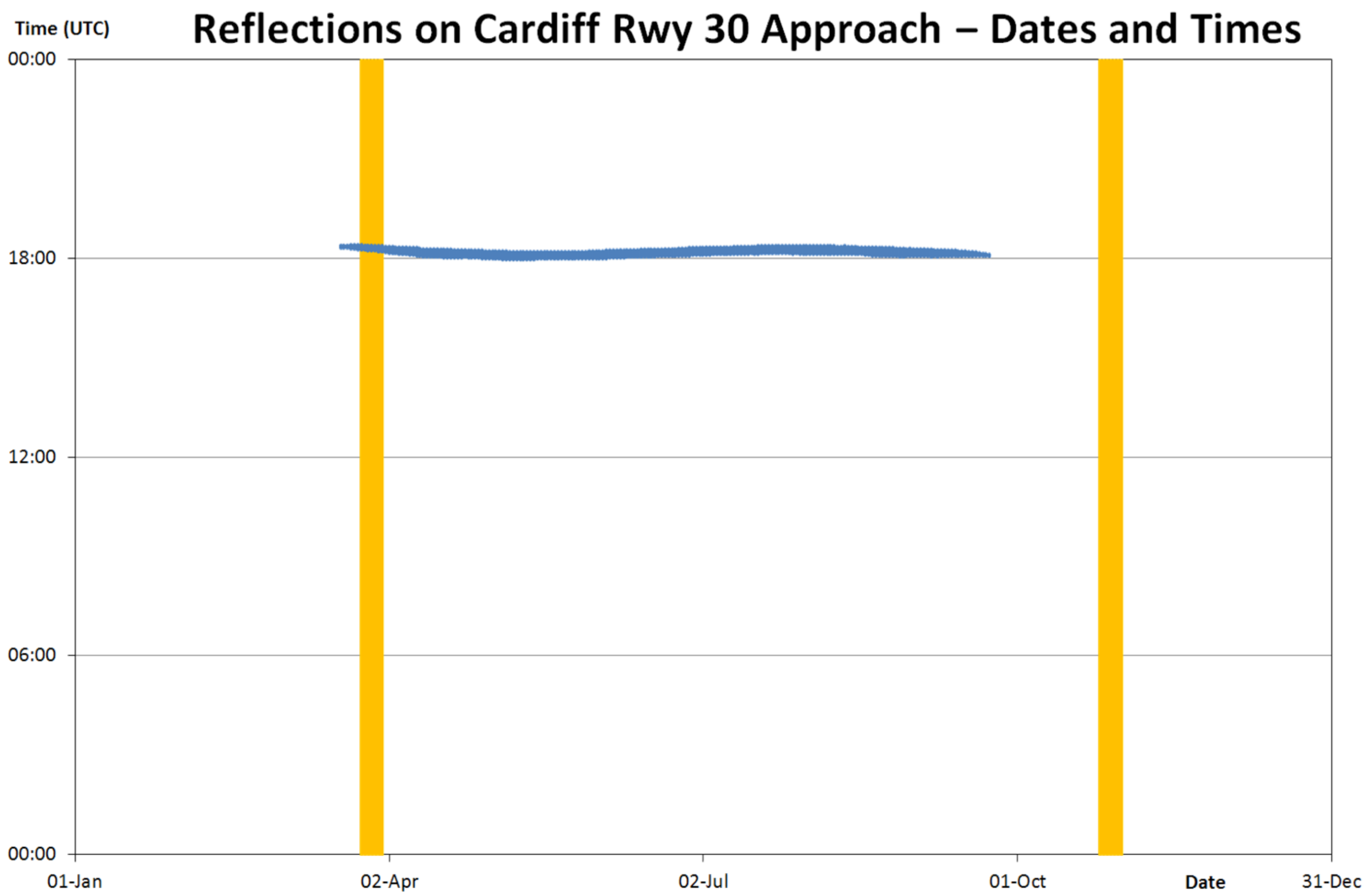
The sea has similar reflecting qualities to solar PV cells and has a much greater expanse than the solar farm. Due to the airfields' proximity to the sea, both Cardiff Airport and RAF St Athan air traffic will be subjected to solar reflections from the sea much more commonly and for longer periods than could occur from the proposed solar farm. This is considered later in considering the effects of reflections from the solar panels on aircraft.

7.7.3 Cardiff Airport Receptors

7.7.3.1 Rwy 30 Approaches

Aircraft landing on Rwy 30 will occasionally (i.e., evenings around June/ July) have to approach almost directly into the low sun, regardless of any solar reflections. This is not considered a safety issue, so there is similarly no safety concern regarding the effects of much dimmer solar reflections.

Solar reflections could only be observable by aircraft approaching to land on Rwy 30 at the dates and times shown below.



These dates and times are summarised in the table below.

Solar Reflection Occurrences	
Dates of reflections	March 17th to September 25th
Times of reflections	17:57GMT/ 18:57BST to 18:25GMT/ 19:25BST

Other Factors

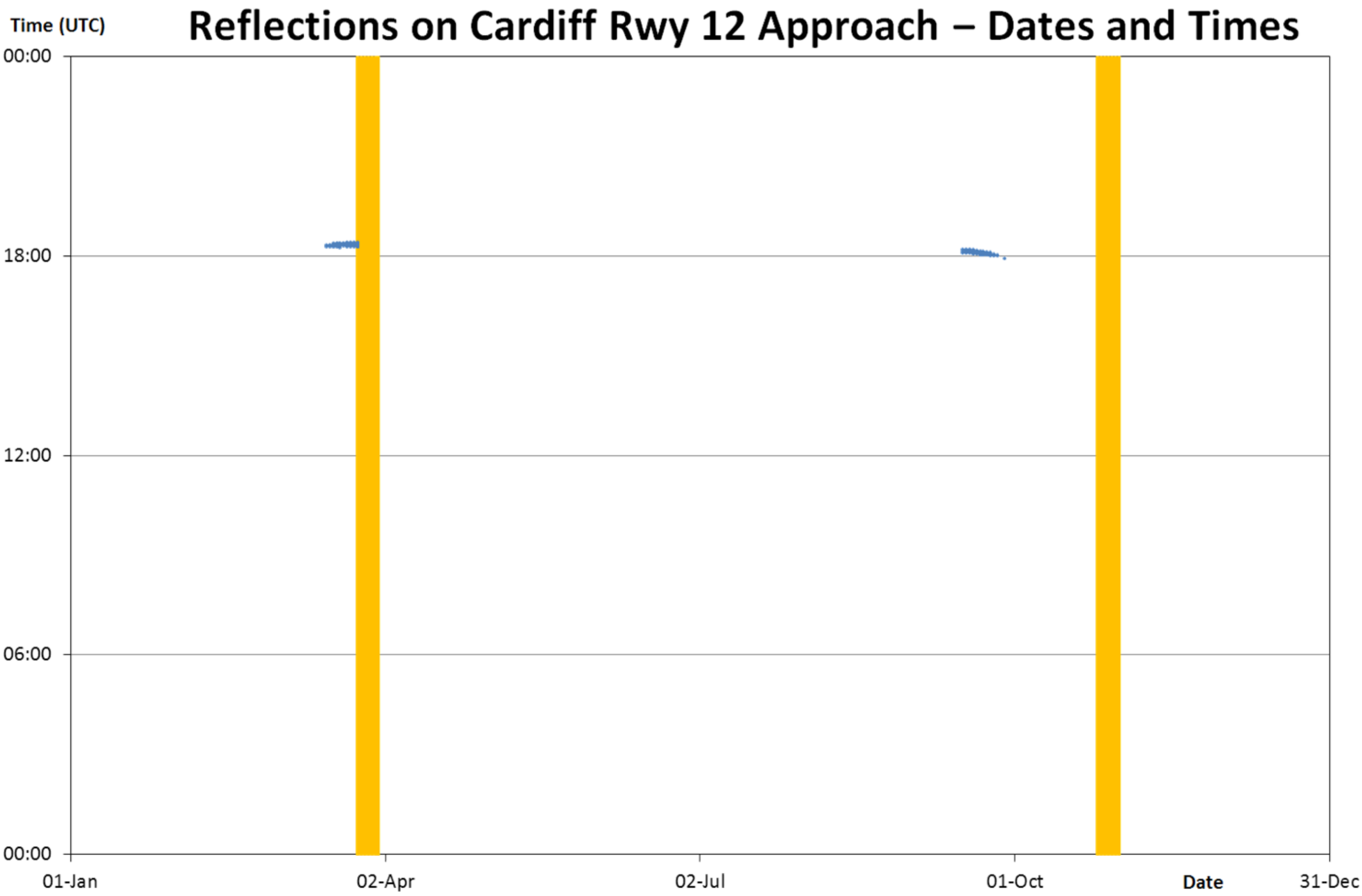
The sun will always be shining from no more than 26° (about 1½ hand span at arm's length) from any solar reflections, which will be well to the left of and well beyond the pilot's aiming point on the runway ahead. Its proximity to any reflecting panels is such that the sun will be the predominant nuisance when any solar reflections occur.

On this approach, pilots will experience solar reflections from the much greater expanse of sea, in front of the aiming point and also from close to the solar farm. This is clearly not a safety issue, so neither will the solar farm be one.

7.7.3.2 Rwy 12 Approaches

Aircraft landing on Rwy 12 will occasionally (i.e., mornings around December and January) have to approach almost directly into the low sun, regardless of any solar reflections. This is not considered a safety issue, so there is similarly no safety concern regarding the effects of much dimmer solar reflections.

Solar reflections could only be observable by aircraft approaching to land on Rwy 12 at the dates and times shown below.



These dates and times are summarised in the table below.

Solar Reflection Occurrences		
	Before the summer solstice	**After the summer solstice**
Dates of reflections	March 16th to 25th	September 16th to 28th (local time is always BST between these dates)
Times of reflections	18:15 GMT/ 19:15 BST to 18:24 GMT/ 19:24 BST	18:56 BST to 19:12 BST

Other Factors

The sun will always be less than 5° (less than half a hand span at arm's length) from any reflecting panels as viewed by aircraft approaching this runway, and will only be visible from well behind and to the right of approaching aircraft.

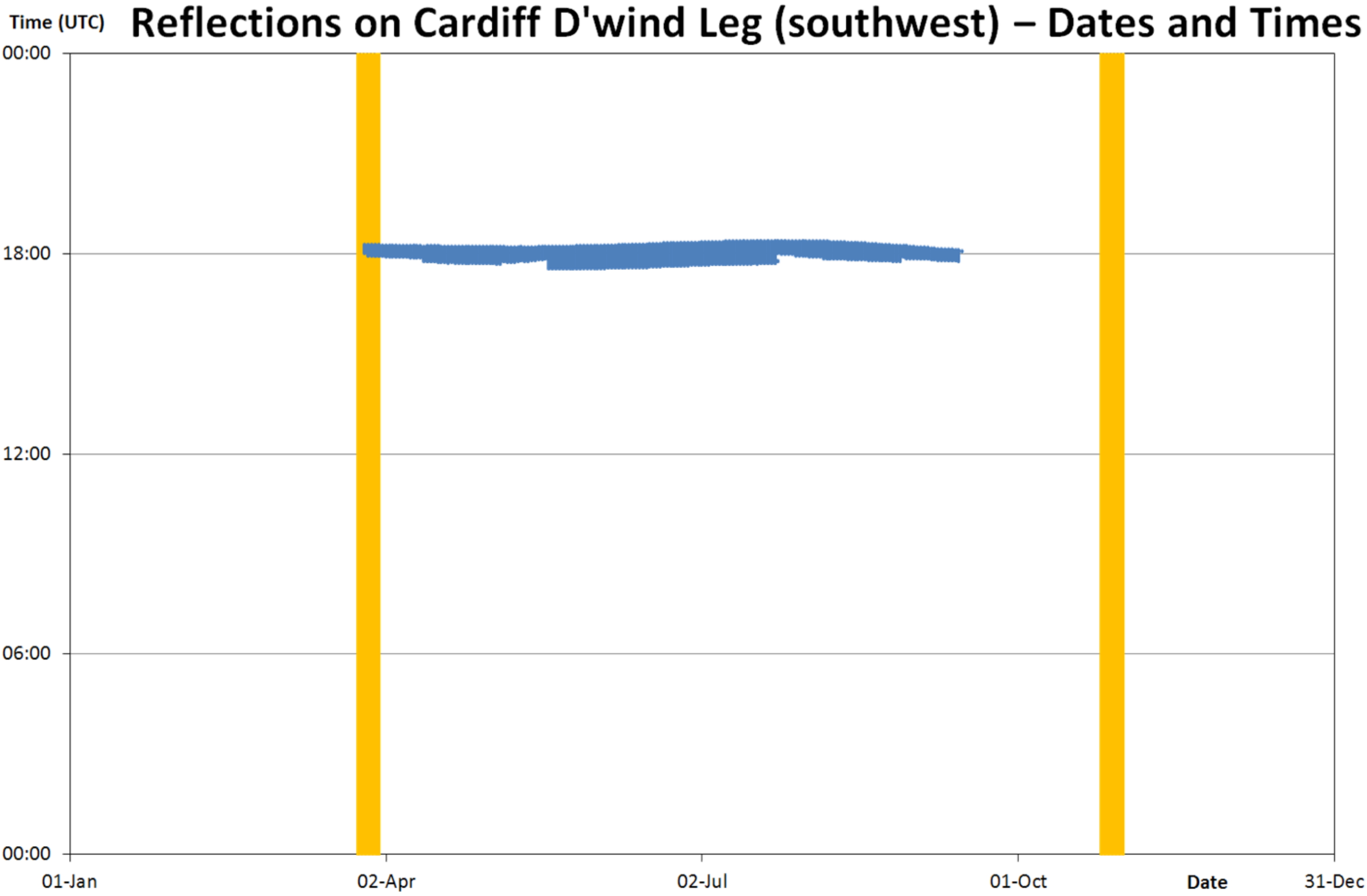
7.7.3.3 Rwy 30/ 12 Southern Circuit Pattern

General

This is not the normal visual circuit at Cardiff Airport, but may be used occasionally.

Downwind Leg

Solar reflections could only reach aircraft on the downwind leg of a southerly/ southwesterly circuit on either Rwy 30 or Rwy 12 at the dates and times shown below.



These dates and times are summarised in the table below.

Solar Reflection Occurrences	
Dates of reflections	March 27th to September 15th
Times of reflections	17:32 GMT/ 18:32 BST to 18:23 GMT/ 19:23 BST

However, the earliest local time for such reflections is 17:54.

The sun will always be less than 38° from any reflecting panels as viewed by aircraft on the downwind leg.

Solar reflections from the sea, including the sea near the solar farm, will affect this downwind leg much more than those from the solar panels.

The upwind turn/ crosswind leg and finals turn/ base leg for each runway direction is considered next.

Rwy 30 Left Hand Circuit

As an aircraft lifts-off and climbs away from Rwy 30 it may receive solar reflections which may occur briefly from in front of the aircraft until the latter part of the upwind turn when the solar farm will be almost abeam to the right of the aircraft and progressively moving further behind it. As the aircraft is climbing in the upwind turn (towards the solar farm and also the sun when reflections may occur), the sun will appear very close (in angular terms) to any reflecting panels due to its distance from the solar farm (5km or more, typically) and being almost due west of the site. The resulting high ambient brightness and transience of any solar reflections will minimise any effects form glint and glare.

The solar farm and any reflections will be behind the aircraft throughout the downwind leg until the latter parts of the finals turn when reflections will be as for the approach to Rwy 30, discussed above.

Rwy 12 Right Hand Circuit

The solar farm is behind an aircraft taking-off from Rwy 12 and will remain so until the latter part of the upwind turn, when any reflections will similar to those discussed above for the downwind leg.

As an aircraft approaches the finals turn, the solar farm and any reflections will move progressively behind the aircraft's left side where it will remain through final approach (when reflections will be as discussed above for the approach path) and touchdown.

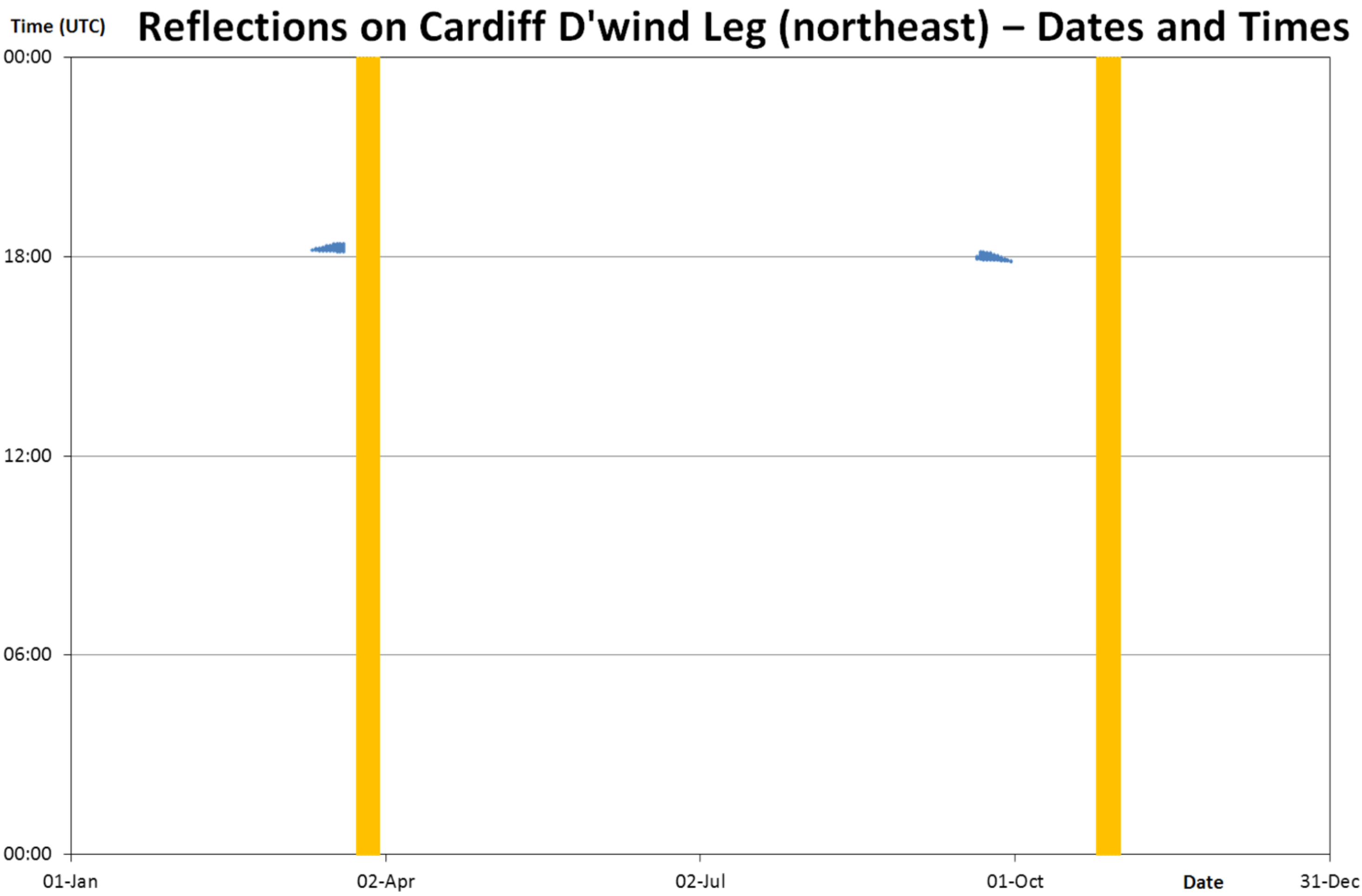
7.7.3.4 Rwy 30/ 12 Northern Circuit Pattern

General

This is published as the normal circuit direction for all visual air traffic at Cardiff Airport. No circuit height or circuit path data is published in the UK AIP.

Downwind Leg

Solar reflections could only reach aircraft on the downwind leg of a northerly/ northeasterly circuit on either Rwy 30 or Rwy 12 at the dates and times shown below.



These dates and times are summarised in the table below.

Solar Reflection Occurrences		
	Before the summer solstice	**After the summer solstice**
Dates of reflections	March 12th to 21st (local time is always GMT between these dates)	September 20th to 30th (local time is always BST between these dates)
Times of reflections	18:09 GMT to 18:23 GMT	18:51 BST to 19:09 BST

The sun will always be less than 7° (less than half a hand span at arm's length) from any reflecting panels as viewed by aircraft on the downwind leg. Such reflections will be insignificant and probably virtually unnoticeable due to the proximity (in angular terms) of the much brighter sun to reflecting panels and the distance from the panels (8km or more).

The upwind turn/ crosswind leg and finals turn/ base leg for each runway direction is considered next.

Rwy 30 Right Hand Circuit

As an aircraft lifts-off and climbs away from Rwy 30 it may receive solar reflections briefly. It will turn away from the solar farm and hence any reflections as it begins its upwind turn. Any reflections will then be from well behind the aircraft until the latter parts of the finals turn(s). Thereafter, any reflections affecting the aircraft will be similar to those for the approach to Rwy 30 discussed above.

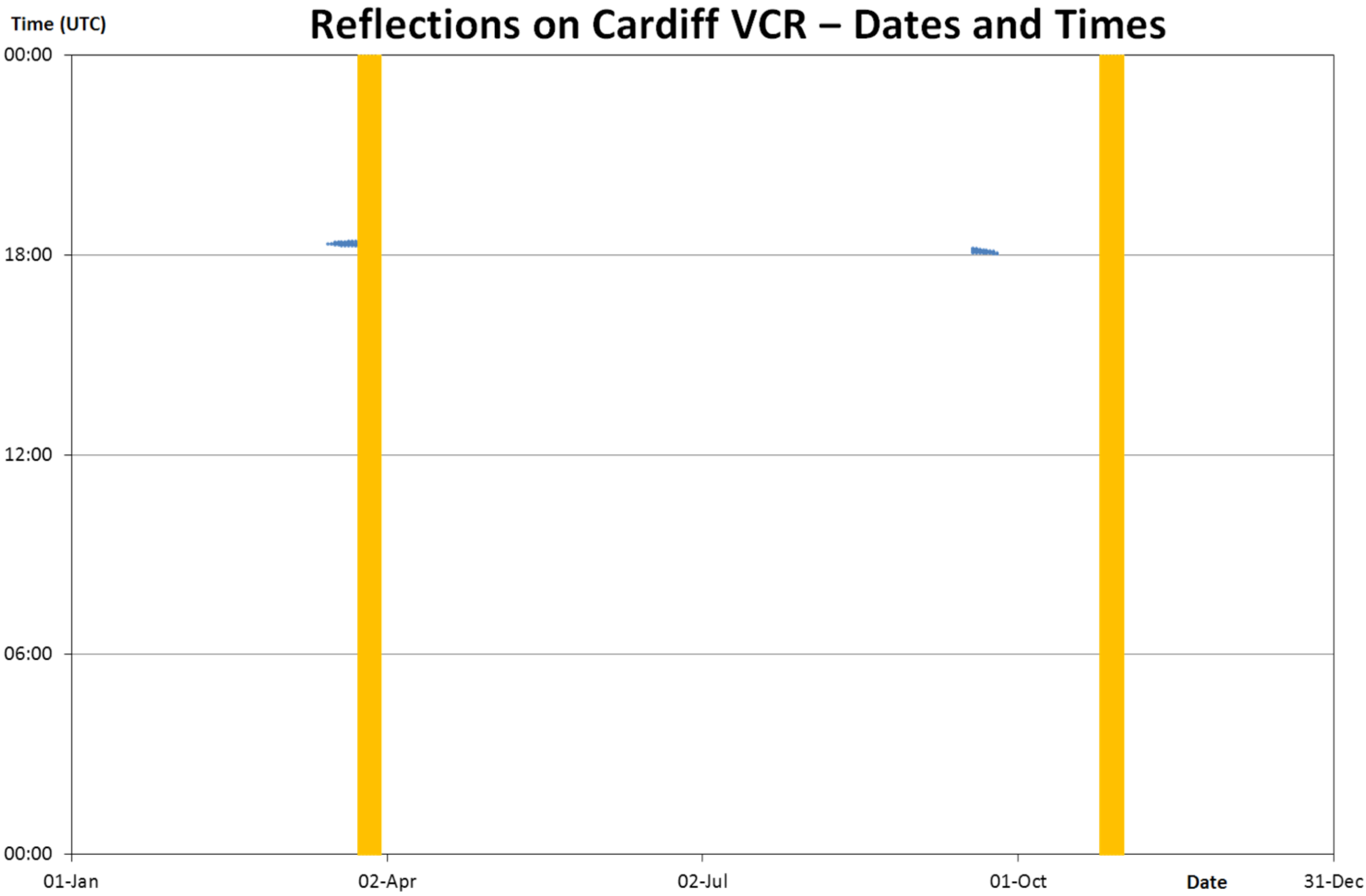
Rwy 12 Left Hand Circuit

The solar farm is behind an aircraft taking-off from Rwy 12 and will remain so until the latter part of the upwind turn, when any reflections will similar to those discussed above for the downwind leg.

As an aircraft approaches the finals turn, it will move outside the solar reflection arcs until the latter stages of the finals turn when any reflections will be from behind the aircraft (i.e., as for the approach to Rwy 12 discussed above).

7.7.3.5 Visual Control Room ('Control Tower')

If any solar panels are visible from the control tower at Cardiff Airport (this is considered extremely unlikely given the distance and many opportunities for hedgerows, other vegetation and buildings, etc., to block such views), solar reflections could only be observable from it at the dates and times shown below.



These dates and times are summarised in the table below.

Solar Reflection Occurrences		
	Before the summer solstice	**After the summer solstice**
Dates of reflections	March 16th to 24th (local time is always GMT between these dates)	September 18th to 25th (local time is always BST between these dates)
Times of reflections	18:16 GMT to 18:24 GMT	19:02 BST to 19:12 BST

Other Factors

The sun will always be less than 4° (less than half a hand span at arm's length) from any reflecting panels as viewed from the control tower (i.e., in almost exactly the same direction as the sun). The much brighter sun will be the predominant cause of any nuisance and any solar reflections will be almost unnoticeable next to it.

7.7.3.6 Other Cardiff Airport Receptors

Helicopter Traffic

Helicopters may fly similar flight paths to fixed wing aircraft in which case their analysis will be as discussed elsewhere. However, the additional flexibility due to the nature of helicopters allows other options.

Where helicopters are permitted to use their inherent flexibility, they tend to fly almost directly to an airfield and then fly a very short and localised terminal manoeuver before landing, and on departure would fly a similar procedure (in the opposite direction). The approach or departure would then be as for transiting traffic discussed in Section 7.7.2.2 above, and the initial take-off and final landing manoeuvres at Cardiff Airport will be well outside the reflection arcs, so would not be affected by solar reflections from the Rosedew Farm site.

Aircraft taking-Off

Only aircraft taking off on Rwy 30 could be affected (aircraft departing on Rwy 12will be facing away from the solar farm). It is extremely unlikely (although it has not been confirmed in this analysis) that there will be any views of solar panels form an aircraft during their ground roll on the runway at Cardiff Airport. If any panels are visible, reflections could only occur with the sun setting almost due west in almost exactly the same direction as any reflecting panels, and would be almost unnoticeable against the much brighter sun.

After lift-off, views of the solar panels will increase. However, an aircraft departing straight ahead will quickly leave the solar reflections arc after which reflections will not be possible until the aircraft would effectively be 'transiting traffic'. Reflections received in this brief time can still only occur with the sun very close to any reflecting panels.

Other flight procedures

Solar reflections effects on other flight procedures will be similar to those for transiting traffic as discussed in Section 7.7.2.2 above. These include instrument approach procedures published in the UK AIP (excepting final approach segments which have effectively been analysed above). Instrument flight procedures do not require pilots to look outside the aircraft, reducing any impact from solar reflections.

7.7.4 RAF St Athan Receptors

7.7.4.1 Rwy 26 Approaches

No solar reflections can affect the Rwy 26 approaches (they are all well outside the solar reflection arcs so this is as expected: the only solar reflections in the azimuthal directions of the approach paths are steeply upwards and will pass well above them).

7.7.4.2 Rwy 08 Approaches

General

Aircraft landing on Rwy 08 will occasionally (i.e., mornings around April and August/ September) have to approach almost directly into the low sun, regardless of any solar reflections. This is not considered a safety issue, so there is similarly no safety concern regarding the effects of much dimmer solar reflections.

On approach to Rwy 08, aircraft may pass very close to – or overfly – the solar farm particularly if approaching from left (north) of centreline. In this instance the analytical method breaks down due to large angular gaps between the receptor points closest to the solar farm relative to the points on the solar farm. In very close proximity to the solar farm, reflections may be experienced from almost any direction that they can occur see Section 7.3.2 above (at the appropriate dates and times).

Therefore, the following analysis results for this specific approach do not include receptor points within 500m of the solar farm (this resulted in 9 approach path locations, i.e., 27 points – since each location was considered for 3 glideslopes/ altitudes – being omitted from this particular analysis): reflections affecting approaching aircraft within this area are discussed below.

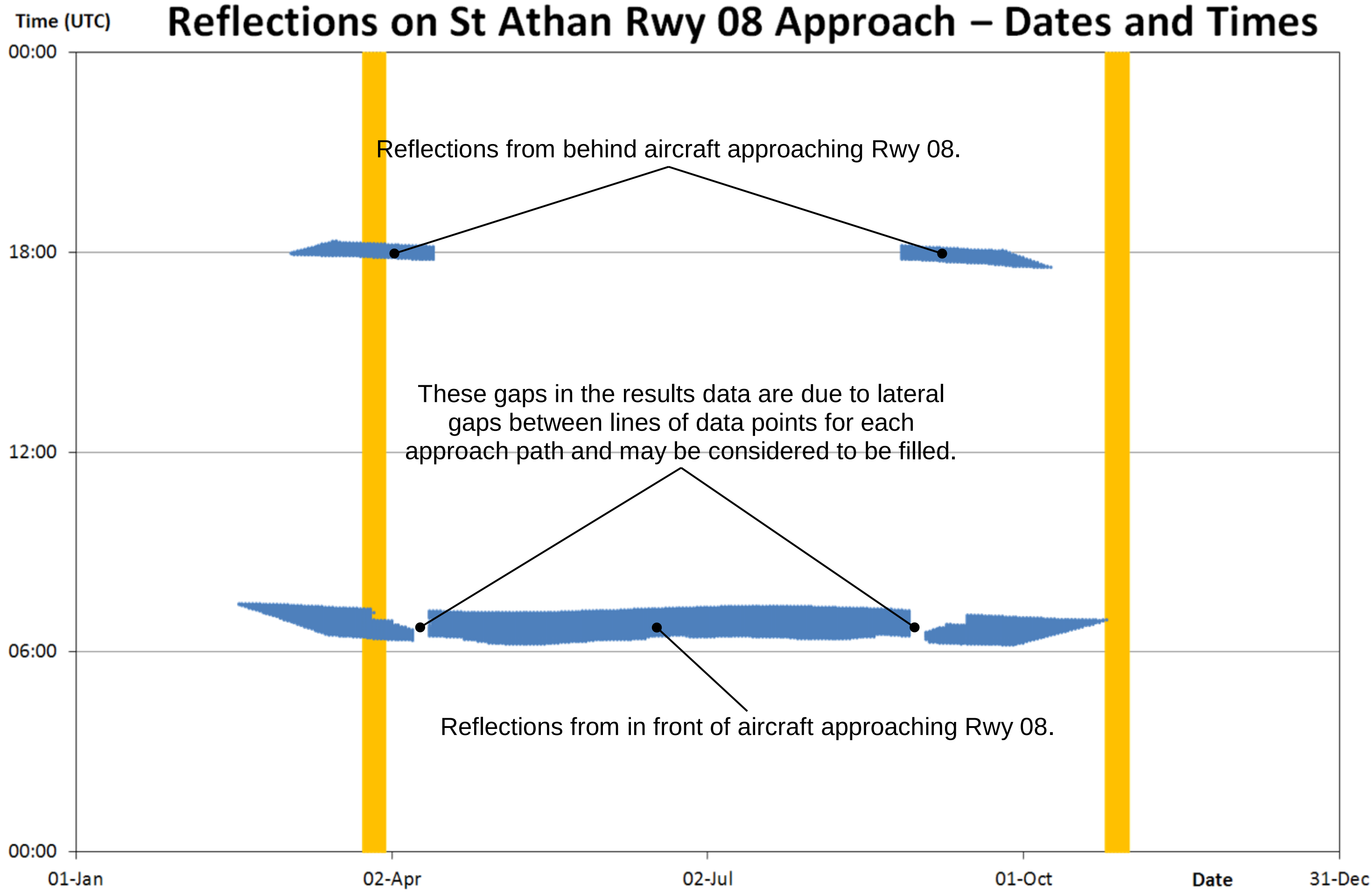
Given this, solar reflections could only be received (from in front of or behind) aircraft approaching to land on Rwy 08 (but more than 1km from it) at the dates and times shown on the following page.

Evening reflections shown can only be received from behind aircraft approaching to land on Rwy 08 and will be insignificant. The morning reflections shown will not be received by aircraft approaching from 10° to the right of the runway's extended centreline (such aircraft approach from outside the solar reflection arcs until the solar farm passes abeam the left side of the aircraft).

Aircraft approaching along or from the left of the extended centreline may receive solar reflections as described until within approximately 500m of the solar panels. The gaps in the morning reflections shown are due to gaps between receptor point lines (i.e., each separate approach path) and can be considered filled.

Within about 500m or 600m of the solar farm (particularly if above if approaching more steeply than the nominal 3° glideslope) – at about 3km from touchdown, it will be more than 10° above horizontal as viewed from the solar panels so may receive solar reflections outside the dates and times for 'near-horizontal' reflections.

As such an aircraft gets even closer to the solar farm, it will be more than 45° above horizontal as viewed from the solar panels so may receive solar reflections outside the dates and times for 'significant aerial' reflections. Any such reflections will then be from steeply below the aircraft, are likely to be hidden by the aircraft's structure, and the aircraft will pass through such reflections very quickly. The nature of reflections will be similar to those for transiting aircraft discussed in Section 7.7.2.2 above.



These dates and times are summarised in the tables below.

Morning Solar Reflection Occurrences (from in front of approaching aircraft)	
Dates of reflections (to the west)	February 17th to October 25th
Times of reflections (to the west)	06:12 GMT/ 07:12 BST to 07:26 GMT/ 08:26 BST

Evening Solar Reflection Occurrences (from behind approaching aircraft)		
	Before the summer solstice	**After the summer solstice**
Dates of reflections	March 4th to April 14th	August 27th to October 9th (local time is always BST between these dates)
Times of reflections	17:47 GMT/ 18:47 BST to 18:20 GMT/ 19:20 BST	18:32 BST to 19:12 BST

As an aircraft flies very near the solar farm, the most significant reflections it may receive will be in the mornings from less than 45°below the horizontal (as discussed in

Section 7.5.3 above. Dates and times of these reflections are shown in the second chart at Appendix 4 and summarised in Section 7.6.4.3 above; these may only be received within the 'significant aerial reflection' arcs as shown in the charts at Appendix 1 (and elsewhere).

In very close proximity to the solar farm, (i.e., within approximately 200m of its boundary), aircraft approaching Rwy 08 may receive reflections from more than 45° below the horizontal, it is assumed from almost any possible reflecting angle (see Section 7.3.2 above) at the appropriate time for the specific direction (see Section 7.2.3 above). These reflections are of little significance as discussed in Section 7.5.3 above.

<u>Other Factors</u>

The morning sun will be shining from very close to any reflecting panels as viewed by aircraft a long distance from touchdown. In close proximity to the solar farm, reflections may be viewed later in the mornings from well below the aircraft (and well below the runway aiming point ahead which will be the pilot's visual focal point; also, the much brighter sun will shining be from generally in front of the aircraft when reflections are from the front, so there will be high levels of ambient brightness).

Any solar reflections will be from behind approaching aircraft when within 2km to 2.5km of touchdown and will then be totally insignificant.

Solar reflections cannot affect aircraft approaching from 10° to the right of the centreline until the solar farm (and any reflections from it) are 90° or more from the aircraft's direction of travel (i.e., from behind).

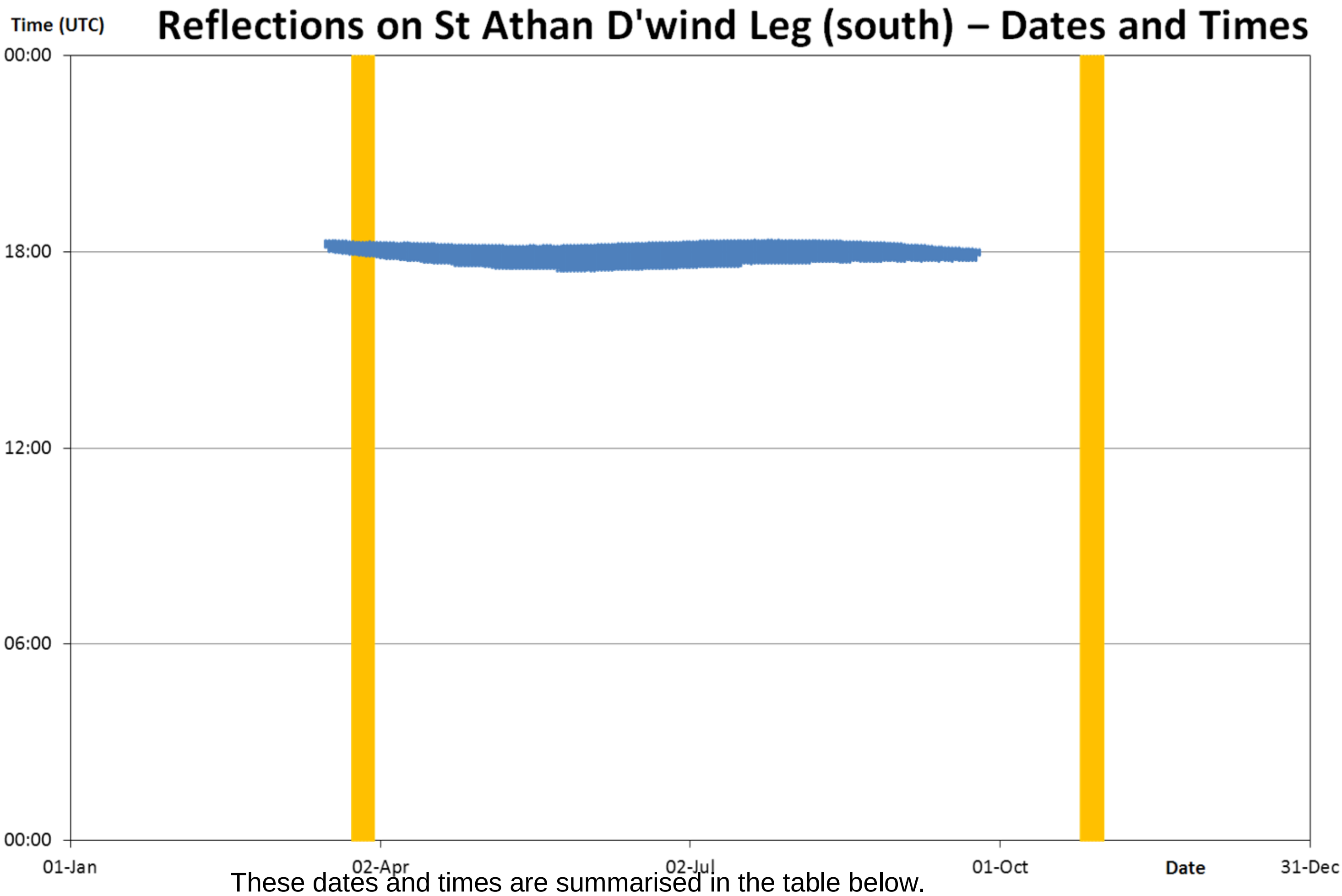
7.7.4.3 Rwy 26/ 08 Southern Circuit Pattern

General

This is the published circuit direction for all air traffic at RAF St Athan (normally only available to St Athan-based traffic). Fast jet traffic published circuit height is 1,200ft above aerodrome elevation, and 800ft for light aircraft. Either type may use a 500ft circuit height in bad weather.

Downwind Leg

Solar reflections could only reach aircraft on the downwind leg of a southerly circuit on either Rwy 26 or Rwy 08 at the dates and times shown below.



These dates and times are summarised in the table below.

Solar Reflection Occurrences	
Dates of reflections	March 17th to September 25th
Times of reflections	17:24 GMT/ 18:24 BST to 18:21 GMT/ 19:21 BST

The sun will always be less than 41° from any reflecting panels as viewed by aircraft on the downwind leg.

Solar reflections from the expanse of sea will be much more significant than any from the solar farm.

The upwind turn/ crosswind leg and finals turn/ base leg for each runway direction is considered next.

Rwy 26 Left Hand Circuit

As an aircraft lifts-off from Rwy 26, there is no possibility of receiving solar reflections. Shortly after take-off, an aircraft may be subjected to solar reflections briefly, from well below the aircraft (and the aircraft's nose is likely to be high as it climbs after take-off). Such reflections will be quickly move further below and behind an aircraft during the upwind turn. Then, any reflections affecting the aircraft will be from behind it and hence insignificant.

During the latter parts of the finals turn, the solar farm will be in front of the aircraft, but it will have moved outside the reflections arcs so cannot receive any reflections from here onwards.

Rwy 08 Right Hand Circuit

The solar farm is behind an aircraft taking-off from Rwy 08, and in any case there is no possibility of solar reflections affecting it until the latter part of the upwind turn, when reflections will similar to those discussed above for the downwind leg.

As an aircraft executes the finals turn, it may move outside the solar reflection arcs, or it may remain inside with a possinbility of turnng through the solar farm and observing solar reflections briefly forom in front of the aircraft. As an aircraft is established on final approah, any reflections will be from almost directly below it, or from behind and will be insignificant for the remainder of the approach.

7.7.4.4 Rwy 26/ 08 Northern Circuit Pattern

General

Use of the northern circuit is not a published procedure at RAF St Athan, so is expected to be used only exceptionally.

Downwind Leg

Solar reflections will not affect the assumed downwind leg of circuit patterns to the north at any distance from the runway or at any height. An aircraft will not be more than 10° above the horizontal plane from any solar panels at any point on the downwind leg in a realistic circuit pattern, so the near-horizontal arcs apply here.

The upwind turn/ crosswind leg and finals turn/ base leg for each runway direction is considered next.

Rwy 08 Left Hand Circuit

This is not the published direction for Rwy 08 circuits at RAF St Athan, so such circuits would be exceptional.

The solar farm is behind an aircraft taking-off from Rwy 08, and in any case there is no possibility of solar reflections affecting it at any point before joining the downwind leg.

As an aircraft executes the finals turn, in the latter parts of the turn, it may receive solar relfections from steeply below the aircraft. When established on final approach, any reflections will be from behind the aircraft.

Rwy 26 Right Hand Circuit

This is not the published direction for Rwy 26 circuits at RAF St Athan, so such circuits would be exceptional.

As an aircraft lifts-off from Rwy 26, there is no possibility of receiving solar reflections. Shortly after take-off, an aircraft may be subjected to solar reflections briefly, from well below the aircraft (and the aircraft's nose is likely to be high as it climbs after take-off). Such reflections will quickly move further below and behind an aircraft during the upwind turn until the aircraft moves out of the reflection arcs. Then, no further reflections will affect the aircraft for the remainder of the circuit.

7.7.4.5 Visual Control Room ('Control Tower')

No solar reflections can occur at the VCR as it is well outside the solar reflection arcs (the only solar reflections in its azimuthal direction are steeply upwards and will pass well above it).

7.7.4.6 Other RAF St Athan Receptors

Helicopter Traffic

Helicopters may fly similar flight paths to fixed wing aircraft in which case their analysis will be as discussed elsewhere. However, the additional flexibility due to the nature of helicopters allows other options.

Where helicopters are permitted to use their inherent flexibility, they tend to fly almost directly to an airfield and then fly a very short and localised terminal manoeuver before landing, and on departure would fly a similar procedure (in the opposite direction). The approach or departure would then be as for transiting traffic discussed in Section 7.7.2.2 above, and the initial take-off and final landing manoeuvres at RAF St Athan will be either outside or on the northern limit the near-horizontal reflection arcs so would not be affected by solar reflections from the Rosedew Farm site (here reflections are significantly above the horizontal – being on the north side of all solar panels – although less than 10°, and would pass above a helicopter at very low level (such as the South Wales Police helicopter).

Aircraft taking-Off

- Rwy 26. Those taking-off on Rwy 26 may receive have reflections after lift-off from well below the aircraft and in a direction of little or no interest to a pilot (who will be focussing his/ her gaze on the airspace ahead and above, into which the aircraft is climbing, and the aircraft will quickly climb through the zone of reflections. Effects of these reflections will be similar to those on transiting traffic. Such reflections may occur in the afternoon and evening.
- Rwy 08. Aircraft taking-off on Rwy 08 will be flying away from the solar park and in any case, will be outside the reflection arcs throughout the take-off: there will be no effects.

Other flight procedures

Solar reflections effects on other flight procedures will be similar to those for transiting traffic as discussed in Section 7.7.2.2 above. These include instrument approach procedures published in the UK Mil AIP (excepting final approach segments which have effectively been analysed above). Instrument flight procedures do not require pilots to look outside the aircraft, reducing any impact from solar reflections.

7.7.5 Discussion of Solar Reflections Effect on Other Receptors

7.7.5.1 General Observations

The discussions in this section are informed by inspection of freely available aerial and street-level photography, as well as large-scale mapping.

Wherever reflections may occur at receptors discussed below, they will be within dates and times given for near-horizontal reflections in Section 7.6.4.2 above, with the much brighter sun shining from near the reflecting panels (in angular terms), occurring in the early mornings for receptors within the near-horizontal reflection arcs to the west of the site, and in the early evenings for receptors within the near-horizontal reflection arcs to the east of the site.

Reflections should pass over any static, point receptor in less than 5 minutes (unless almost adjacent to the solar park).

7.7.5.2 Roads

The roads identified within the solar reflection arcs in the vicinity are the B4265 to the east of the site and some unclassified roads. These roads are all very unlikely to have any views of solar panels. Should there be any views of solar panels – and hence possibly solar reflections – from these roads, they will be fleeting glimpses with the much brighter sun shining from a similar direction to any reflecting panels.

Effects will therefore be of low significance.

7.7.5.3 Railway

The railway to the east of the solar farm, mostly adjacent to the B4265 within the solar reflection arcs until a considerable distance from the solar farm, is highly unlikely to have any views of solar panels, or reflections from them. If reflections were visible, they could only occur with the much brighter sun being in almost exactly the same direction as any reflecting panels, hence they would be almost unnoticeable.

Effects will therefore be of low significance.

7.7.5.4 Minor Settlements and Isolated Dwellings

There are few settlements (and no built-up areas) that may have views of solar panels and hence which may be affected by solar reflections. Those that may receive solar reflections may do so as discussed in Section 7.7.5.1 above.

Notably, the camping and caravanning site near the north west corner of the solar farm site will have no views of solar panels' tops, and hence no possibility of receiving solar reflections.

Any effects will be of low significance.

7.8 Assessment of Solar Reflection Impacts

7.8.1 Background and Comparison to Commonplace Examples

At times, pilots landing on certain runways at Cardiff Airport and RAF St Athan will have to land directly into the sun, so this fact is used as the basis for impact assessment. It is almost impossible to convey any meaningful quantification of intensity in a report such as this (even video representation would be very limited for this purpose); however, it is reasonable to state that however bright any solar reflections are, they will always be much less bright than the sun (typically about 2% of the sun's brightness).

There are a number of airfields where runways are near (or extend into) areas of water when solar reflections may occur suddenly and late in an approach; it may also occur from a wet tarmac runway just before touchdown. This author is not aware of concerns ever having been raised in such cases, nor of any requirement to assess such examples of 'glint and glare'.

The table below defines the impact levels used in this section: a 10-point scale (actually an 11-point scale in theory but not in practice, as is explained in the table) is considered necessary to accommodate the subtleties involved in assessing the impact of solar reflections, although the impact descriptions given are reduced to a 5-point scale. Only impacts of Level 5 (i.e., 'small') and higher are significant.

Level of Impact	Impact Description	Definition
0	Nil/ no impact	Absolutely zero impact. In practice, such a level of impact from any nature of development is virtually impossible to justify, so this level is normally unused.
1		Effects not observable unless significant effort is taken to notice them, so there is practically no impact.
2		Effects may be observable with little effort but with no practical impact on the task in hand and will quickly be dismissed from an observer's awareness.
3	Negligible	Observable effects that may persist in an observer's consciousness but have no effect on his/ her execution of the task in hand.
4		Effects that are readily and continuously noticeable that do not affect the execution of the task in hand.
5	Small	Effects that may cause an observer to take some almost unconscious action with no noticeable effect on the task in hand.
6		Effects that may cause an observer to take some conscious action that does not interfere with the execution of the task in hand.
7	Medium	Effects that require a noticeable change in the execution of the task in hand to manage.
8		Effects that require a deliberate and noticeable change in the execution of the task in hand to manage.
9	Large	Effects that require a considerable effort to manage in the execution of the task in hand.
10		Effects that require an excessive effort to manage in the execution of the task in hand.

Landing (or driving a road vehicle) directly into the sun is deemed to have a Level 6 (small) impact: it is certainly noticeable, but a pilot just does it and copes by squinting, looking slightly sideways, or perhaps wearing sunglasses or using a visor: this takes little or no effort to manage. There is no concern regarding flight safety: this author knows of no airfields that would close a runway because the sun happens to be in that direction. Effects of reflections from dark solar panels must be less than this, even considering the 'planned' nature of approaches (or departures) into the sun.

A commonplace non-aviation example of reaction to sudden bright light sources is how car-drivers' react to the main beam headlights of oncoming traffic suddenly appearing from around a corner on a dark country road. Although some drivers might react with annoyance by flashing their own lights, if this option was not available drivers would squint and maybe try to look sideways to minimise the nuisance (as well as adjusting their driving to accommodate the change in the environmental conditions). Again, there is no question of safety being compromised and most commentators are likely to agree that reflections from dark solar panels on a bright day must be less severe than the sudden dazzling effect of looking into car headlights on a dark night.

However, the latter example has some similarities to the possibility of solar reflections occurrences as it would be a sudden change in the environment prompting a reaction, but as it is less severe than flying (or driving) directly towards a low sun, it must only qualify for a Level 5 (small) impact. If the headlights are viewed from even slightly to the side rather than directly in front, it would be reasonable to reduce the impact to Level 4 (negligible).

Where an impact is significant (i.e., level 5 and above) it may be reasonable to add 1 to the level of impact when there is a sudden change in the environment (e.g., headlights directly in front of a driver): in this instance, the immediate impact from the headlights suddenly appearing would be Level 6 (small), reducing to Level 5 (small) after the initial change. This wouldn't normally apply to impacts that are negligible unless there is some other factor to make this appropriate.

It is worth considering that when an observer's eyes are attuned to ambient brightness (as will always be the case when solar reflections may be observed by a pilot approaching to land), the impact – e.g., from the example of the car's headlights – would again be substantially reduced.

The following standard assumption is used as a reasonable starting point for the assessment of solar reflection impact.

> In bright daylight where solar reflections come from a dark solar panel directly ahead of an observer with neither the observer nor the observer's focus of view in deep shade and when the sun is not particularly close to the reflecting solar panel, a Level 4 (*negligible*) impact is attributed. Other factors should then be considered to modify this level of impact (either upwards or downwards on the scale).

Where such reflections are a significant angular distance away from directly in front of an observer, or the sun is either very close to the reflecting object, or from more directly in front of the observer, any impact should be less than this.

7.8.2 Impact on Cardiff Airport

7.8.2.1 Rwy 30 Approach

Any reflections would be in the distance to the side of the pilot's view of the runway ahead with the sun in a similar direction so impact is assessed as Level 3 (*negligible)*.

No increment is necessary to accommodate any change to the environment as reflections may be encountered.

7.8.2.2 Rwy 12 Approach

Any reflections would be from well behind and to the right of an approaching aircraft with the sun in a similar direction so impact is assessed as Level 2 (*nil)*.

No increment is necessary to accommodate any change to the environment as reflections may be encountered.

7.8.2.3 Circuit Patterns

Any reflections will occur with high levels of ambient brightness with the sun shining from close to any reflecting panels impact is assessed as Level 3 (*negligible)*.

No increment is necessary to accommodate any change to the environment as reflections may be encountered.

7.8.2.4 Visual Control Room (Control Tower)

Reflections will reach the VCR from almost exactly the same direction as the setting sun so impact is assessed as Level 2 (nil).

No increment is necessary to accommodate any change to the environment as reflections may be encountered.

7.8.2.5 Impact on Phases of Flight Other Than Final Approach and Landing

Impacts on other phases of flight will vary, but there will always be high levels of ambient brightness when reflections can occur and solar reflections will either:

- be transient in nature;
- occur with the sun shining sufficiently close to reflecting panels or the main direction of a pilot’s view to minimise the significance of effects; or,
- from a direction of little interest to a pilot: e.g., steeply below, or behind, an aircraft.

In no instance will the impact be greater than Level 3 (*negligible*). The worst case impacts (i.e., Level 3, negligible) for other phases of flight will be for transiting traffic overflying the solar park as reflections may be visible from different directions at various times of day throughout the year.

No increment is necessary to accommodate any change to the environment as reflections may be encountered in other phases of flight as impacts are only negligible.

7.8.2.6 Overall Impact on Cardiff Airport

Given the impact levels of the most significant impacts on, the overall impact of solar reflections from the proposed solar park on Cardiff Airport is assessed to be no greater than Level 3 (*negligible*).

This impact assessment ignores the limited dates and times in which solar reflections can occur. It only considers the impact level when they do occur. Extending this to encompass the overall impact of solar reflections across airfield operations through an entire day (and year), the overall impact must be even less than this due to the limited periods of impact (and the requirement for the sun to be shining).

7.8.3 Impact on RAF St Athan

7.8.3.1 Rwy 26 Approach

No reflections will reach aircraft approaching Rwy 26 so impact is assessed as Level 1 (*nil*).

No increment is necessary to accommodate any change to the environment as reflections may be encountered.

7.8.3.2 Rwy 08 Approach

The worst case is for an aircraft approaching along, or from left of the runway's centreline. Any reflections will occur with high levels of ambient brightness, either with the sun shining from close to any reflecting panels, or else reflections will be from well below the aircraft and occur for a short time only so impact is assessed as Level 4 (negligible).

No increment is necessary to accommodate any change to the environment as reflections may be encountered.

7.8.3.3 Circuit Patterns

Any reflections will occur with the sun shining from close to any reflecting panels so the worst case impact is assessed as Level 3 (*negligible)*.

No increment is necessary to accommodate any change to the environment as reflections may be encountered.

7.8.3.4 Impact on the Visual Control Room (Control Tower)

No reflections will reach the VCR so impact is assessed as Level 1 (*nil*).

No increment is necessary to accommodate any change to the environment as reflections may be encountered.

7.8.3.5 Impact on Phases of Flight Other Than Final Approach and Landing

Impacts on other phases of flight will vary, but there will always be high levels of ambient brightness when reflections can occur and solar reflections will either:

- be transient in nature;
- occur with the sun shining sufficiently close to reflecting panels or the main direction of a pilot's view to minimise the significance of effects; or,
- from a direction of little interest to a pilot: e.g., steeply below, or behind, an aircraft.

In no instance will the impact be greater than Level 3 (negligible). The worst case impacts (i.e., Level 3, negligible) for other phases of flight will be for transiting traffic overflying the solar park as reflections may be visible from different directions at various times of day throughout the year.

No increment is necessary to accommodate any change to the environment as reflections may be encountered in other phases of flight as impacts are only negligible.

7.8.3.6 Overall Impact on RAF St Athan

Given the impact levels of the most significant impacts on aircraft (i.e., those approaching Rwy 08), the overall impact of solar reflections from the proposed solar park on RAF St Athan is assessed to be no greater than Level 4 (*negligible*).

This impact assessment ignores the limited dates and times in which solar reflections can occur. It only considers the impact level when they do occur. Extending this to encompass the overall impact of solar reflections across airfield operations through an entire day (and year), the overall impact must be even less than this due to the limited periods of impact (and the requirement for the sun to be shining).

7.8.4 Impact on Other Receptors

Caution is applied in assessing the impact on other receptors which have not been considered as rigorously as the airfields, so in the absence of evidence presented to the contrary, a 'worst case' impact was assumed.

In no instance will the impact on other receptors, including roads and dwellings, be greater than Level 3 (*negligible*): only the near-horizontal reflections need be considered, so the much brighter sun will always be shining from close to (in angular terms) any reflecting panels.

Due to the negligible impact and high ambient brightness when reflections may occur, no increment to the level of impact is considered necessary to accommodate any change to the environment as reflections may be encountered.

7.9 Discussion of Solar Reflections with respect to the Air Navigation Order

7.9.1 Background

In Section 4.2.3 above, the CAA's concerns that solar park development should be in accordance with the requirements of the ANO were specified, specifically relating to 3 articles within the ANO (Articles 137, 221 and 222). These are discussed more fully here.

The CAA guidance also refers to that from the US Federal Aviation Administration (FAA), however the 'current' FAA guidance is under review and caveated such that the FAA has distanced itself from being held accountable for its use; it is discussed briefly in Section 4.2.2 above. It appears that the solar PV industry and operational experience of the benign nature of glint and glare from solar parks near airfields has taken the lead in its assessment in the USA.

7.9.2 Article 137 – Endangering safety of an aircraft

The commissioning of this assessment shows that the developer is taking reasonable measures to ensure that it is not recklessly or negligently acting in a manner likely to endanger an aircraft, or any person in an aircraft. Flight safety considerations are discussed next in relation to Articles 221 and 222.

7.9.3 Article 221 – Lights liable to endanger

This article prohibits lights that are liable to endanger aircraft taking off from or landing at an aerodrome due to their glare, or that may endanger aircraft if liable to be mistaken for aeronautical ground lights.

7.9.3.1 Glare Effects

The difference from the definitions of terms used in this report is noted: glare (as defined in Section 3 above) from the solar park is unlikely to dazzle pilots; glint (as defined in Section 3 above) has been discussed in depth. As almost every pilot will have had to land or take off into the sun on occasion, the much dimmer solar reflections (whether in the form of brief flashes or more prolonged exposure) from a solar park is unlikely to significantly affect a pilot other than perhaps as a nuisance.

The specular reflections of sunlight from the proposed solar park are not considered to be a significant nuisance for the reasons given in this assessment and there will be no impact on flight safety.

7.9.3.2 Misidentification as Aeronautical Ground Lights

The solar panels do not emit light, and solar reflections are only possible during the day with the sun above the horizon. Therefore, solar reflections will not be a cause of misidentification of aeronautical ground lights.

Cultural and other lighting may be very dimly reflected by solar panels at night. Such reflected lights are unlikely to be mistaken as the reflections will be so dim and if misidentification was likely, the source lights would not be permitted under this article.

Furthermore, surface lights from near-horizontal angles would generally be reflected by the inclined panels at high angles unless (almost close to due east or west of the panels) and would therefore only be noticeable to pilots for short periods as they fly through the reflection. Screening from hedges is likely to block either the source of such lights or near-horizontal reflections from the panels.

If reflections at low angles were observed (to east or west), the light sources would also be visible to the west or east very close to the dim reflection and would be much more prominent.

Therefore it is virtually inconceivable that reflections from the solar panels could be misidentified as aeronautical ground lights.

7.9.4 Article 222 – Lights which dazzle or distract

This report has considered the effects of specular reflections of sunlight, which will be the most intense form of reflected light and found effects to be negligible. There is no question that effects of solar reflections during bright daylight with the sun near to the reflecting panels could approach the dazzling effect of, say, looking towards the sun, into a laser beam, or even of suddenly looking into the bright headlights of another car at night.

Therefore the proposed solar park cannot be construed as ‘lights which dazzle or distract’.

7.9.5 Summary

The articles of the Air Navigation Order that CAA guidance directs solar park developers to are all satisfied by the proposed solar park.

7.10 Other Considerations

7.10.1 Proximity of the Sun

For most aerial and surface receptors of solar reflections, when they occur, the sun will be shining relatively close to the reflecting object (as it appears to the observer). This reduces the impact of solar reflections as their relative intensity will be reduced by the ambient light level, an observer’s eyes will be attuned to brightness further reducing any nuisance from reflections, and the sun is likely to be the predominant nuisance to an observer.

7.10.2 Effects of Trees, Hedges and Fencing around the Solar Park

Existing and future treelines, hedgerows and fencing around the solar park (particularly to the east and west) will reduce solar reflections in 2 ways as follows.

- When between the solar park and a receptor, they will generally block ‘near-horizontal’ reflections, especially from panels nearest to the hedge. As the height of the hedge increases, reflections from further inside the solar park are progressively blocked.
- Hedges on the far side of the solar park will cast long shadows over the panels nearest to them when the sun is low in the sky (when ‘near-horizontal’ reflections are most likely to occur), so preventing them from reflecting and hence reducing overall reflection effects on a receptor.

These long shadows will not significantly reduce the solar park's output as the sun will be low in the sky (hence there would be little electrical generation potential) and long shadows are only cast for short periods after sunrise or before sunset.

This reasoning may also apply to many aerial receptors, as most of these may be considered close to the horizontal plane through the solar park.

7.10.3 Non-Reflective Panels

Solar panels are very dark in colour – much darker than normal glass – as they are designed to absorb light to convert it to useful energy rather than reflect it (reflected light is wasted), and their surfaces may be further treated to scatter any reflected light rather than cause specular reflections. There are various sources of public domain information to support this.

It is therefore considered that any solar reflections from the solar panels will be significantly dimmer than other common sources of such reflections and insignificant compared to the brightness of the sun (which will always be observed close to any solar reflections from the panels).

8 Conclusions

8.1 General Effects of Solar Reflections

8.1.1 General Characteristics

Solar reflections are commonplace occurrences for most people either from wet roads, expanses of water, or windows and mirrors of cars and buildings. Solar cells are designed to absorb light to generate electricity, not reflect it, and so are much less reflective than other sources of solar reflection.

Solar reflections can only occur when the sun is shining. It has no significance when the sun appears very close to – that is, in almost the same direction as – the reflecting object as seen by an observer (i.e., the observed angle between the sun and its reflection is close to 0°) as the much brighter sun will completely mask any reflections and the observer's eyes will be attuned to brightness when looking in that direction, thus reducing the observed intensity of any reflections.

Conversely, solar reflections are at their worst when an observer is facing the reflecting object, is in shade from the bright sun so that his/ her eyes aren't attuned to brightness, and the sun is behind the observer (i.e., the angle between observed reflections and the sun is close to 180°).

Solar reflections from PV panels may typically have intensities of 20 W/m² (about 2,000 lux). Ambient light levels on a sunny day in shade, but illuminated by the entire blue sky, are typically 20,000 lux so the worst problem that may be caused by reflections from solar panels is a nuisance from looking at or near them.

8.1.2 Characteristics of Solar Reflections from Rosedew Farm Solar Park

8.1.2.1 Near-Horizontal Reflections

Solar reflections from between 5° below the horizontal plane to 10° above it are described as 'near-horizontal'. Reflections within this vertical arc from the proposed solar park may be seen by receptors in general at or near ground level (including most – but not all – aircraft, particularly those at low level or at some distance from the solar park), they can only occur:

- in the mornings at receptors to the west of the solar park from February 27th to October 14th, from 05:47 to 07:06 Greenwich Mean Time (GMT), or 06:47 to 08:06 British Summer Time (BST – after the last Sunday in March);
- in the evenings at receptors to the east of the solar park from February 26th to October 14th, from 17:20 to 18:44 GMT, or 18:20 to 19:44 BST (after the last Sunday in March).

Unless immediately next to the solar panels, solar reflections can only be observed by receptors near ground level in the following azimuthal arcs from any solar panel (bearings are relative to True North):

- to the west: from 246.3° (approximately west-southwest) to 278.2° (slightly north of due west);
- to the east: from 081.6° (slightly north of due east) to 113.7° (approximately east-southeast).

The sun will never be more than 38° (approximately 2 to 2½ hand spans at arm's length) from any reflections observed by near-ground level receptors and usually much closer than this, so the worst case phenomenon described above can never occur and the reflections are often almost insignificant due to the proximity of the sun.

[The maximum angular distance between the sun and reflecting panels occurs at the most southerly extremes of the reflection arcs, and at the maximum altitude angle above horizontal (i.e., 10°). Elsewhere, the angular distance between the sun and reflecting panels will be much less than 38°.]

Effects of solar reflections may be further reduced by boundary fencing and hedges around the solar park and off-site, including any future tree planting.

8.1.2.2 Significant Aerial Reflections

Solar reflections from the horizontal plane up to 45° above it may be significant for aircraft operating at airfields near the proposed solar park. Reflections within this vertical band are described as 'significant aerial reflections'.

Such reflections may occur all year round:

- in the mornings at receptors to the west of the solar park from 06:05 to 09:43 GMT, or 07:05 to 10:43 BST (after the last Sunday in March until the last Sunday in October);
- in the evenings at receptors to the east of the solar park from 14:41 to 18:23 GMT, or 15:41to 19:23 BST (after the last Sunday in March until the last Sunday in October).

These reflections may occur in the following azimuthal arcs from any solar panel (bearings are relative to True North):

- to the west: from 237.4° (approximately southwest) to 305.8° (approximately northwest);
- to the east: from 054.2° (approximately northeast) to 122.6° (approximately southeast).

Aircraft would need to be in extremely close proximity to the solar park to receive reflections at steeper angles than 45°, although in some cases such reflections may occur in any azimuth at certain times. Aircraft 1000ft above the solar park could only observe such reflections within 305m of its boundary; this increases to within 610m for aircraft 2,000ft above it and within 914m for aircraft 3,000ft above it.

The first and last times of reflections on any day are later and earlier, respectively, than for 'near-horizontal' reflections because reflections below the horizontal plane are not considered for 'significant aerial reflections'.

8.2 Effects of Solar Reflections on Receptors

8.2.1 Effects on Cardiff Airport and RAF St Athan

8.2.1.1 Solar Reflections

Solar reflections may affect aircraft operating near Cardiff Airport and RAF St Athan at various times. Effects at either airfield on aircraft taking-off or landing, and surface receptors, e.g., the visual control rooms (control towers), will be negligible (at worst). Effects on aircraft approaching to land, climbing after take-off, in the visual circuit pattern or other phases of flight will be will be negligible (at worst).

Overall reflection impacts for Cardiff Airport and St Athan (including for transiting traffic) are assessed as negligible; no impact on any specific operation was assessed to be greater than negligible. This does not consider the very limited times when impacts are possible and the requirement for the sun to be shining: true impacts on the operations at Cardiff Airport and St Athan will therefore be even less than those assessed here.

Solar reflections from the sea will be much more significant on air traffic in the vicinity of the solar farm or Cardiff Airport and RAF St Athan than those from the solar panels, and is obviously acceptable.

8.2.1.2 Safeguarding of Runways and Technical Installations

The proposed solar park will not infringe any safeguarding criteria for this nature of development for the runways or technical installations (e.g., radio communications, navigation and surveillance equipment) at Cardiff Airport and RAF St Athan.

8.2.1.3 Civil Aviation Authority Guidance for Solar Parks

The proposed development fulfils Civil Aviation Authority (CAA) guidance for solar parks with respect to Cardiff Airport and RAF St Athan.

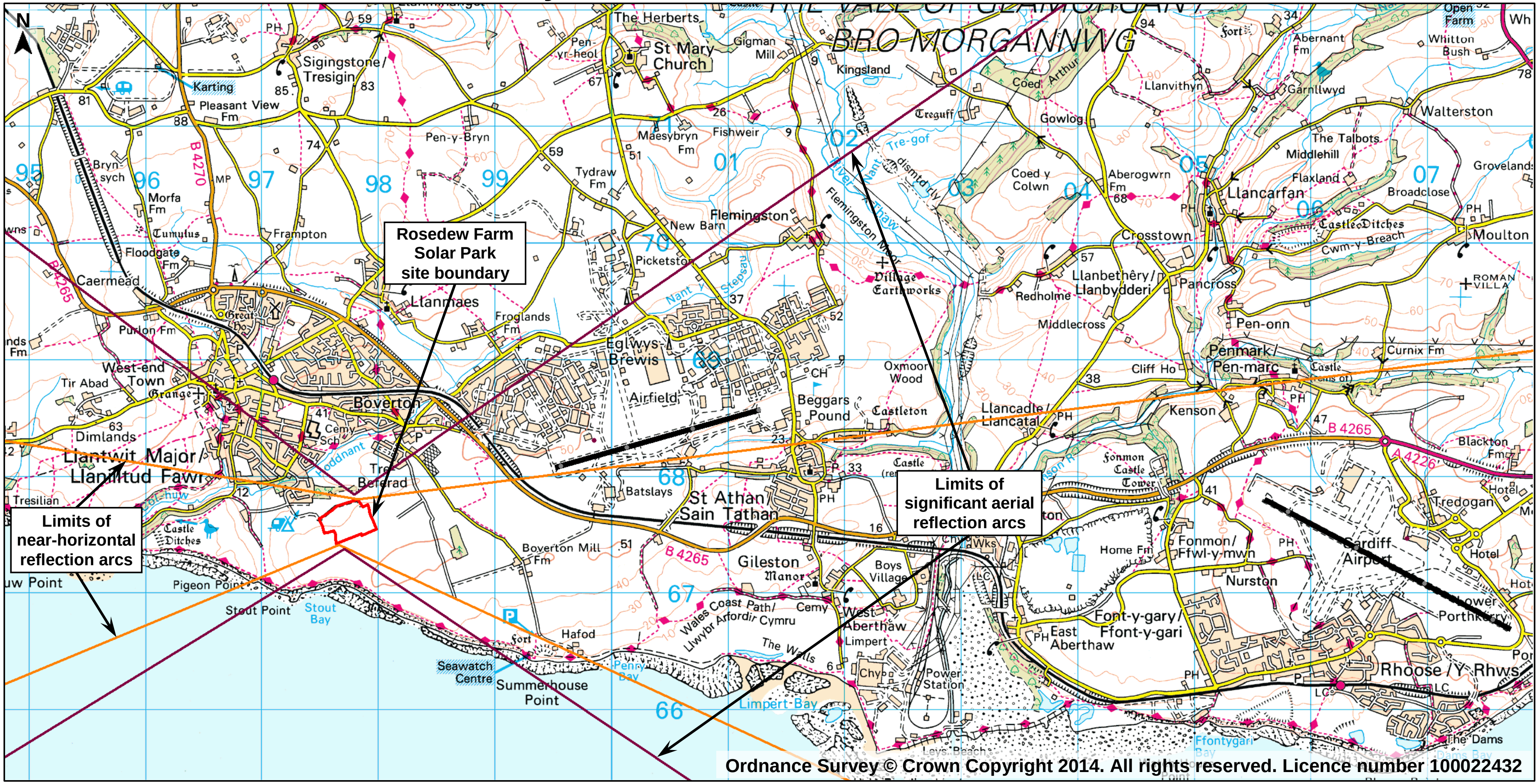
8.2.2 Effects on the Other Receptors

Effects on other nearby receptors, i.e., roads, railways and dwellings, will be negligible.

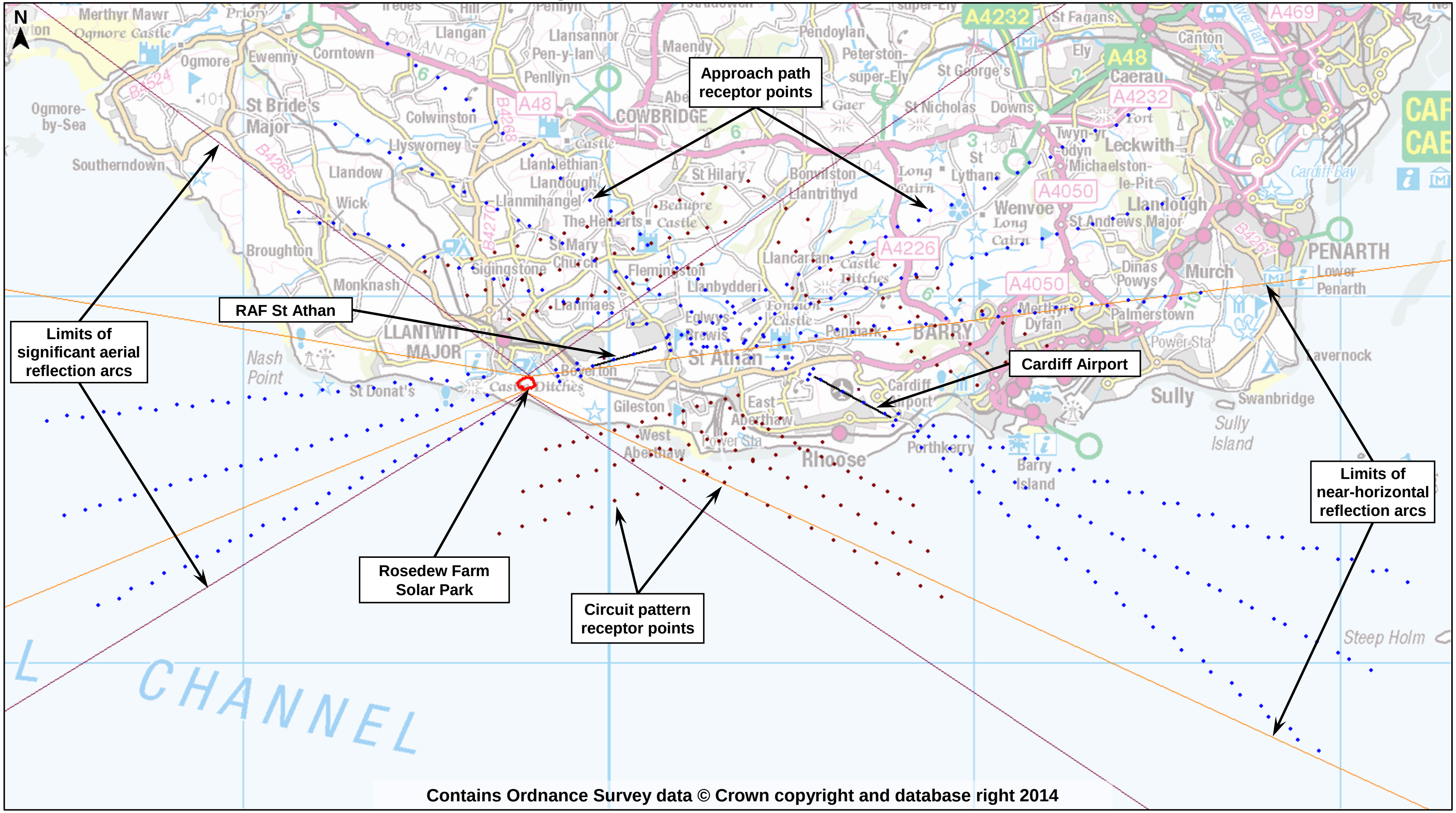
AARDVaRC Ltd
Aviation Analysis, Renewables Development & Visualisation, and Radio Communications

Appendix 1 – Chart of Solar Park and Reflection Arcs

Solar Reflection Arcs In the Vicinity of Rosedew Farm



Solar Reflection Arcs in the Wider Region



Appendix 2 – Data for Key Almanac Dates/ Times

Table of Reflection Analysis Results

The following table (7 pages) shows a selection of sun positions and corresponding directions for reflected sunlight from solar panels inclined to face 'True South' at 25° to the horizontal. It shows points of interest throughout the year. Reflections considered to be within the 'near-horizontal' (altitude angles from +10° to -5° measured from the horizontal plane) are marked in bold in the appropriate Altitude/ Azimuth columns.

The points of interest shown are for the following dates:

- the first and last days of the year when reflections are as low as 10° above horizontal, in the morning and evenings;
- the first and last days of the year when reflections reach 5° below horizontal (more specifically, the day before/ after reflections are below this angle for the first and last time in the year), in the morning and evenings;
- the equinoxes and solstices.

The times of interest for each of the above dates are:

- sunrise and sunset;
- first and last reflections from the top surfaces of the solar panels (when the sun does not directly illuminate them at sunrise and sunset);
- morning and afternoon/ evening times when reflections pass through altitude angles of -5°, 0°, +5°, +10° and +45° (relative to the horizontal plane);
- mid-morning (i.e., 09:00 UTC), mid-afternoon (i.e., 15:00 UTC), and solar noon when the sun is due south (i.e., on an azimuth – or True bearing – of 180°).

These are intended to provide illustrative data to assist in

Reflections at more than 45° above horizontal are generally considered to be insignificant for aerial receptors as discussed in the main report.

The angle of incidence is relative to the normal line through the plane of the PV cells and is equal to the angle of reflectance. Azimuths are given as True bearings.

Where daylight saving time (BST) is in use, this is stated in the date column and UTC times are marked in red. When BST is in use, add 1 hour to the UTC time for local time, otherwise, UTC is effectively equivalent to local time (GMT).

Interpolation between data points given below will give approximate results for other dates and times, but should be used with caution as the variation in results through the day and the year is complex and non-linear.

Date	Time (UTC)	Direction of Sun		Direction of Reflection		Angle of Incidence /°	Observed angle between sun and reflections /°	Notes
		Altitude /°	Azimuth /°	Altitude /°	Azimuth /°			
26 Feb	07:07	0.0	103.2	10.1	278.6	84.5	11.1	Sunrise.
	09:00	15.5	126.4	37.6	281.9	61.1	57.9	Mid-morning.
	09:30	19.1	133.2	44.9	283.5	55.3	69.5	Reflections approximately 45° above horizontal.
	12:27	30.1	180.1	80.1	0.5	34.9	110.2	Sun almost due south.
	15:00	21.7	221.3	50.6	74.9	50.9	78.1	Mid-afternoon.
	15:23	19.2	226.7	45.0	76.5	55.1	69.7	Reflections 45° above horizontal.
	17:47	0.1	257.0	**10.0**	**81.6**	**84.5**	**11.1**	Sunset. First evening reflection of the year within altitude range.
27 Feb	07:05	0.1	102.6	**9.7**	**278.1**	**84.6**	**10.8**	Sunrise. First morning reflection of the year within altitude range.
	07:06	0.2	102.8	**9.9**	**278.2**	**84.4**	**11.1**	Last morning reflection within altitude range.
	09:00	15.8	126.2	37.6	281.4	60.9	58.3	Mid-morning.
	09:30	19.4	133.1	45.0	283.1	55.0	70.0	Reflections 45° above horizontal.
	12:27	30.5	180.1	80.5	0.5	34.5	111.0	Sun almost due south.
	15:00	22.0	221.5	50.6	75.5	50.7	78.5	Mid-afternoon.
	15:23	19.5	227.0	45.0	77.1	55.0	70.1	Reflections 45° above horizontal.
	17:47	0.3	257.3	**9.9**	**82.0**	**84.4**	**11.2**	First evening reflection within altitude range.
	17:49	0.0	257.7	**9.4**	**82.0**	**84.8**	**10.3**	Sunset. Last evening reflection (within altitude range).
20 Mar	06:18	0.0	89.4	No reflection				Sunrise.
	06:19	0.1	89.6	No reflection				Just before first reflection (PV cells not illuminated).
	06:20	0.3	89.8	**0.0**	**269.6**	**89.8**	**0.4**	First morning reflection (within altitude range).
	06:41	3.2	93.9	**5.0**	**270.1**	**85.5**	**9.1**	Reflections 5° above horizontal.
	07:01	6.3	97.8	**10.0**	**270.2**	**81.0**	**18.0**	Last morning reflection within altitude range.
	09:00	23.5	123.0	39.7	271.2	55.1	69.8	Mid-morning.
	09:21	26.2	127.9	44.9	271.3	50.7	78.6	Reflections approximately 45° above horizontal.
	12:21	38.7	179.9	88.7	356.6	26.3	127.4	Sun almost due south.
	15:00	28.8	226.8	50.3	88.5	46.4	87.3	Mid-afternoon.
	15:21	26.3	232.0	45.0	88.8	50.6	78.8	Reflections 45° above horizontal.
	17:42	6.3	262.4	**9.9**	**90.0**	**81.1**	**17.8**	First evening reflection within altitude range.
	18:02	3.3	266.3	**5.0**	**90.2**	**85.4**	**9.1**	Reflections 5° above horizontal.
	18:23	0.3	270.4	**-0.1**	**90.5**	**89.9**	**0.2**	Last evening reflection (within altitude range).
	18:24	0.2	270.6	No reflection				Just after last reflection (PV cells not illuminated).
	18:25	0.1	270.8	No reflection				Sunset (PV cells not illuminated).

Date	Time (UTC)	Direction of Sun		Direction of Reflection		Angle of Incidence /°	Observed angle between sun and reflections /°	Notes
		Altitude /°	Azimuth /°	Altitude /°	Azimuth /°			
17 Apr (**BST**)	05:16	0.0	72.3	No reflection				Sunrise (PV cells not illuminated).
	05:51	4.9	79.0	No reflection				Just before first reflection (PV cells not illuminated).
	05:52	5.1	79.2	**-4.9**	**259.1**	**89.9**	**0.2**	First morning reflection of the year near bottom of altitude range.
	06:12	8.1	83.1	**0.0**	**259.4**	**85.6**	**8.9**	Reflections horizontal.
	06:33	11.4	87.1	**5.1**	**259.4**	**80.9**	**18.2**	Reflections approximately 5° above horizontal.
	06:53	14.5	91.0	**10.0**	**259.4**	**76.5**	**27.1**	Last morning reflection within altitude range.
	09:00	33.5	118.3	41.1	257.1	48.1	83.7	Mid-morning.
	09:16	35.6	122.3	45.0	256.4	44.7	90.7	Reflections 45° above horizontal.
	12:13	49.3	179.9	80.7	180.4	15.7	148.6	Sun almost due south.
	15:00	37.1	235.0	47.6	104.4	42.3	95.5	Mid-afternoon.
	15:11	35.7	237.8	45.0	103.8	44.6	90.8	Reflections 45° above horizontal.
	17:34	14.5	269.1	**9.9**	**100.6**	**76.5**	**27.0**	First evening reflection within altitude range.
	17:54	11.4	273.0	**5.0**	**100.7**	**80.9**	**18.1**	Reflections 5° above horizontal.
	18:15	8.2	277.1	**-0.1**	**100.8**	**85.6**	**8.9**	Reflections almost horizontal.
	18:35	5.2	280.9	**-4.9**	**101.0**	**89.9**	**0.3**	First evening reflection of the year near bottom of altitude range.
	18:36	5.0	281.1	No reflection				Just after last reflection (PV cells not illuminated).
	19:12	0.0	288.1	No reflection				Sunset (PV cells not illuminated).

Date	Time (UTC)	Direction of Sun		Direction of Reflection		Angle of Incidence /°	Observed angle between sun and reflections /°	Notes
		Altitude /°	Azimuth /°	Altitude /°	Azimuth /°			
18 Apr (**BST**)	05:14	0.0	71.7	No reflection				Sunrise (PV cells not illuminated).
	05:50	5.1	78.7	No reflection				Just before first reflection (PV cells not illuminated).
	05:51	5.2	78.9	-5.1	258.8	89.9	0.1	First morning reflection.
	05:52	5.4	79.1	**-4.8**	**258.8**	**89.7**	**0.7**	First morning reflection within altitude range.
	06:12	8.4	82.9	**0.0**	**259.0**	**85.4**	**9.3**	Reflections horizontal.
	06:32	11.5	86.8	**4.9**	**259.1**	**80.9**	**18.1**	Reflections approximately 5° above horizontal.
	06:52	14.6	90.7	**9.9**	**259.1**	**76.5**	**27.0**	Last morning reflection within altitude range.
	09:00	33.8	118.1	41.1	256.6	48.0	84.1	Mid-morning.
	09:16	36.0	122.1	45.0	255.8	44.4	91.2	Reflections 45° above horizontal.
	12:13	49.6	179.9	80.4	180.4	15.4	149.2	Sun almost due south.
	15:00	37.4	235.3	47.5	105.0	42.1	95.7	Mid-afternoon.
	15:10	36.1	237.9	45.0	104.4	44.3	91.4	Reflections 45° above horizontal.
	17:34	14.8	269.4	**9.9**	**101.1**	**76.4**	**27.3**	First evening reflection within altitude range.
	17:54	11.7	273.3	**5.0**	**101.1**	**80.8**	**18.4**	Reflections 5° above horizontal.
	18:14	8.6	277.1	**0.1**	**101.1**	**85.2**	**9.6**	Reflections almost horizontal.
	18:35	5.4	281.2	**-5.0**	**101.4**	**89.8**	**0.4**	Last evening reflection (within altitude range).
	18:36	5.3	281.4	-5.2	101.4	90.0	0.1	Last evening reflection.
	18:37	5.1	281.6	No reflection				Just after last reflection (PV cells not illuminated).
	19:14	0.0	288.8	No reflection				Sunset (PV cells not illuminated).

Date	Time (UTC)	Direction of Sun		Direction of Reflection		Angle of Incidence /°	Observed angle between sun and reflections /°	Notes
		Altitude /°	Azimuth /°	Altitude /°	Azimuth /°			
21 Jun: Summer Solstice (**BST**)	03:59	0.0	49.4	No reflection				Sunrise (PV cells not illuminated).
	05:25	10.8	65.6	No reflection				Just before first reflection (PV cells not illuminated).
	05:26	10.9	65.8	-10.8	245.7	89.9	0.1	First morning reflection.
	05:51	14.5	70.4	**-5.0**	**246.3**	**84.9**	**10.3**	First morning reflection within altitude range.
	06:13	17.8	74.4	**0.0**	**246.5**	**80.3**	**19.4**	Reflections horizontal.
	06:35	21.1	78.4	**5.0**	**246.6**	**75.7**	**28.6**	Reflections 5° above horizontal.
	06:56	24.3	82.3	**9.8**	**246.4**	**71.3**	**37.5**	Last morning reflection within altitude range.
	09:00	43.4	107.9	37.8	241.0	44.2	91.6	Mid-morning.
	09:33	48.2	116.3	44.9	237.5	36.8	106.3	Reflections approximately 45° above horizontal.
	12:16	62.1	180.1	67.9	179.9	2.9	174.2	Sun almost due south.
	14:58	48.2	243.6	44.9	122.5	36.8	106.4	Reflections approximately 45° above horizontal.
	15:00	48.0	244.1	44.6	122.4	37.2	105.7	Mid-afternoon.
	17:35	24.4	277.7	**9.9**	**113.6**	**71.2**	**37.7**	First evening reflection within altitude range.
	17:57	21.0	281.7	**4.9**	**113.4**	**75.8**	**28.3**	Reflections approximately 5° above horizontal.
	18:18	17.8	285.5	**0.1**	**113.4**	**80.2**	**19.5**	Reflections almost horizontal.
	18:40	14.6	289.5	**-4.9**	**113.7**	**84.7**	**10.5**	Last evening reflection within altitude range.
	19:05	11.0	294.1	-10.6	114.3	89.8	0.4	Last evening reflection.
	19:06	10.8	294.3	No reflection				Just after last reflection (PV cells not illuminated).
	20:32	0.0	310.5	No reflection				Sunset (PV cells not illuminated).

Date	Time (UTC)	Direction of Sun		Direction of Reflection		Angle of Incidence /°	Observed angle between sun and reflections /°	Notes
		Altitude /°	Azimuth /°	Altitude /°	Azimuth /°			
24 Aug (**BST**)	05:16	0.0	71.4	No reflection				Sunrise (PV cells not illuminated).
	05:53	5.2	78.6	No reflection				Just before first reflection (PV cells not illuminated).
	05:54	5.3	78.8	-5.1	258.7	89.9	0.2	First morning reflection.
	05:55	5.5	79.0	**-4.8**	**258.7**	**89.6**	**0.8**	First morning reflection within altitude range.
	06:15	8.5	82.8	**0.0**	**258.9**	**85.3**	**9.4**	Reflections horizontal.
	06:35	11.6	86.7	**4.9**	**259.0**	**80.9**	**18.2**	Reflections approximately 5° above horizontal.
	06:55	14.7	90.6	**9.8**	**259.0**	**76.5**	**27.1**	Last morning reflection within altitude range.
	09:00	33.4	117.4	40.4	256.7	48.6	82.8	Mid-morning.
	09:19	36.0	122.1	45.0	255.8	44.4	91.2	Reflections 45° above horizontal.
	12:16	49.6	179.9	80.4	180.4	15.4	149.2	Sun almost due south.
	15:00	37.6	234.4	48.2	104.9	41.6	96.8	Mid-afternoon.
	15:14	35.8	238.0	44.8	104.0	44.6	90.8	Reflections approximately 45° above horizontal.
	17:37	14.6	269.2	**9.9**	**100.8**	**76.5**	**27.1**	First evening reflection within altitude range.
	17:57	11.5	273.1	**5.0**	**100.8**	**80.9**	**18.2**	Reflections 5° above horizontal.
	18:17	8.4	277.0	**0.1**	**100.9**	**85.3**	**9.3**	Reflections almost horizontal.
	18:38	5.2	281.0	**-5.0**	**101.1**	**89.9**	**0.2**	Last evening reflection of the year at bottom of altitude range.
	18:39	5.1	281.2	No reflection				Just after last reflection (PV cells not illuminated).
	19:15	0.0	288.2	No reflection				Sunset (PV cells not illuminated).

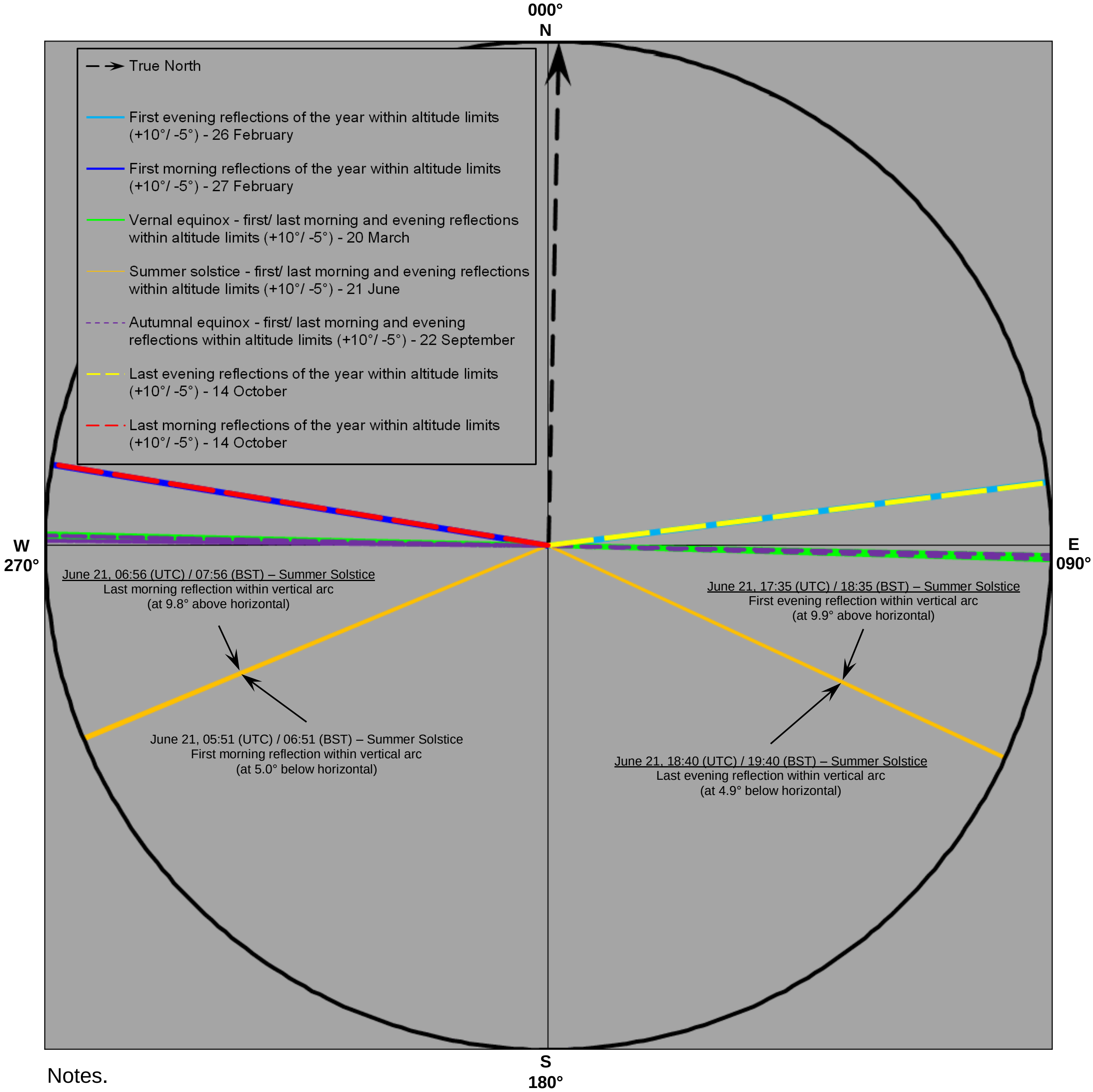
Date	Time (UTC)	Direction of Sun		Direction of Reflection		Angle of Incidence /°	Observed angle between sun and reflections /°	Notes
		Altitude /°	Azimuth /°	Altitude /°	Azimuth /°			
25 Aug (**BST**)	05:18	0.1	72.1	No reflection				Sunrise (PV cells not illuminated).
	05:53	4.9	78.9	No reflection				Just before first reflection (PV cells not illuminated).
	05:54	5.1	79.1	**-5.0**	**259.1**	**89.9**	**0.1**	Last morning reflection of the year at bottom of altitude range.
	06:15	8.3	83.1	**0.1**	**259.2**	**85.4**	**9.2**	Reflections almost horizontal.
	06:35	11.4	87.0	**5.0**	**259.3**	**80.9**	**18.1**	Reflections 5° above horizontal.
	06:55	14.5	90.9	**9.9**	**259.4**	**76.5**	**27.0**	Last morning reflection within altitude range.
	09:00	33.2	117.7	40.5	257.1	48.7	82.7	Mid-morning.
	09:18	35.6	122.1	44.8	256.3	44.7	90.5	Reflections approximately 45° above horizontal.
	12:16	49.2	180.0	80.8	180.0	15.8	148.4	Sun due south.
	15:00	37.3	234.2	48.2	104.4	41.8	96.5	Mid-afternoon.
	15:14	35.5	237.8	44.9	103.5	44.8	90.4	Reflections approximately 45° above horizontal.
	17:37	14.3	269.1	9.8	100.5	76.7	26.6	First evening reflection within altitude range.
	17:57	11.2	273.0	**4.9**	**100.5**	**81.1**	**17.8**	Reflections approximately 5° above horizontal.
	18:17	8.1	276.8	**0.0**	**100.6**	**85.5**	**9.0**	Reflections horizontal.
	18:37	5.1	280.7	**-4.8**	**100.8**	**89.9**	**0.3**	Last evening reflection (within altitude range).
	18:38	4.9	280.9	No reflection				Just after last reflection (PV cells not illuminated).
	19:13	0.0	287.7	No reflection				Sunset (PV cells not illuminated).
22 Sep: Autumnal Equinox (**BST**)	06:02	0.0	89.0	No reflection				Sunrise (PV cells not illuminated).
	06:04	0.3	89.3	No reflection				Just before first reflection (PV cells not illuminated).
	06:05	0.4	89.5	**-0.1**	**269.4**	**89.8**	**0.3**	First morning reflection (within altitude range).
	06:26	3.4	93.7	**5.0**	**269.8**	**85.4**	**9.3**	Reflections approximately 5° above horizontal.
	06:46	6.4	97.6	**9.9**	**269.9**	**81.0**	**18.0**	Last morning reflection within altitude range.
	09:00	25.6	126.3	43.4	271.0	51.9	76.2	Mid-morning.
	09:06	26.3	127.8	44.9	271.1	50.7	78.7	Reflections approximately 45° above horizontal.
	12:07	38.8	180.2	88.8	7.4	26.2	127.6	Sun almost due south.
	15:00	27.1	230.5	46.6	88.7	49.3	81.4	Mid-afternoon.
	15:07	26.2	232.2	44.8	88.8	50.8	78.5	Reflections approximately 45° above horizontal.
	17:27	6.3	262.3	**9.9**	**89.9**	**81.0**	**17.9**	First evening reflection within altitude range.
	17:47	3.3	266.2	**5.0**	**90.1**	**85.4**	**9.2**	Reflections 5° above horizontal.
	18:08	0.3	270.3	**0.0**	**90.4**	**89.9**	**0.3**	Last evening reflection (within altitude range).
	18:09	0.2	270.5	No reflection				Just after last reflection (PV cells not illuminated).
	18:10	0.0	270.7	No reflection				Sunset (PV cells not illuminated).

Date	Time (UTC)	Direction of Sun		Direction of Reflection		Angle of Incidence /°	Observed angle between sun and reflections /°	Notes
		Altitude /°	Azimuth /°	Altitude /°	Azimuth /°			
14 Oct (**BST**)	06:38	0.0	102.6	**9.6**	**278.2**	**84.7**	**10.6**	Sunrise. First morning reflection (within altitude range).
	06:40	0.3	102.9	**10.0**	**278.1**	**84.3**	**11.4**	Last morning reflection of the year within altitude range.
	09:00	19.0	132.3	44.2	282.9	55.7	68.7	Mid-morning.
	09:03	19.3	133.0	44.9	283.1	55.1	69.7	Reflections approximately 45° above horizontal.
	12:00	30.3	180.0	80.3	0.0	34.7	110.6	Sun due south.
	14:56	19.3	226.8	45.0	76.7	55.1	69.9	Reflections 45° above horizontal.
	15:00	18.9	227.7	44.1	77.0	55.8	68.5	Mid-afternoon.
	17:20	0.1	257.0	**10.0**	**81.6**	**84.5**	**11.1**	First evening reflection within altitude range.
	17:21	0.0	257.2	**9.8**	**81.7**	**84.6**	**10.7**	Sunset. Last evening reflection of the year within altitude range.
15 Oct (**BST**)	06:40	0.1	103.2	10.1	278.5	84.4	11.3	Sunrise.
	09:00	18.7	132.6	44.2	283.4	55.8	68.3	Mid-morning.
	09:03	19.0	133.3	44.9	283.7	55.3	69.4	Reflections approximately 45° above horizontal.
	12:00	30.0	180.1	80.0	0.5	35.0	110.0	Sun almost due south.
	14:56	19.0	226.7	44.9	76.3	55.3	69.4	Reflections approximately 45° above horizontal.
	15:00	18.5	227.6	43.9	76.5	56.1	67.8	Mid-afternoon.
	17:19	0.0	256.6	10.2	81.3	84.4	11.2	Sunset.
21 Dec: Winter Solstice	08:19	0.0	128.7	28.6	297.2	74.7	30.6	Sunrise.
	09:00	4.3	136.9	37.3	301.1	67.9	44.1	Mid-morning.
	09:37	7.9	144.6	45.0	305.8	62.2	55.5	Reflections 45° above horizontal.
	12:12	15.2	180.0	65.2	0.0	49.8	80.4	Sun due south.
	14:47	7.9	215.4	45.0	54.2	62.2	55.5	Reflections 45° above horizontal.
	15:00	6.7	218.1	42.4	56.0	64.1	51.7	Mid-afternoon.
	16:05	0.0	231.3	28.6	62.8	74.7	30.6	Sunset.

Appendix 3 – Direction and Limit of Reflections

Direction of Reflections

The following diagram shows the extent of reflections between +10° and -5° to the horizontal on key dates throughout the year from any particular point in the array. It can be seen that the southernmost extent of near-horizontal reflections occurs at (or about) midsummer, with reflections at other dates further to the north.



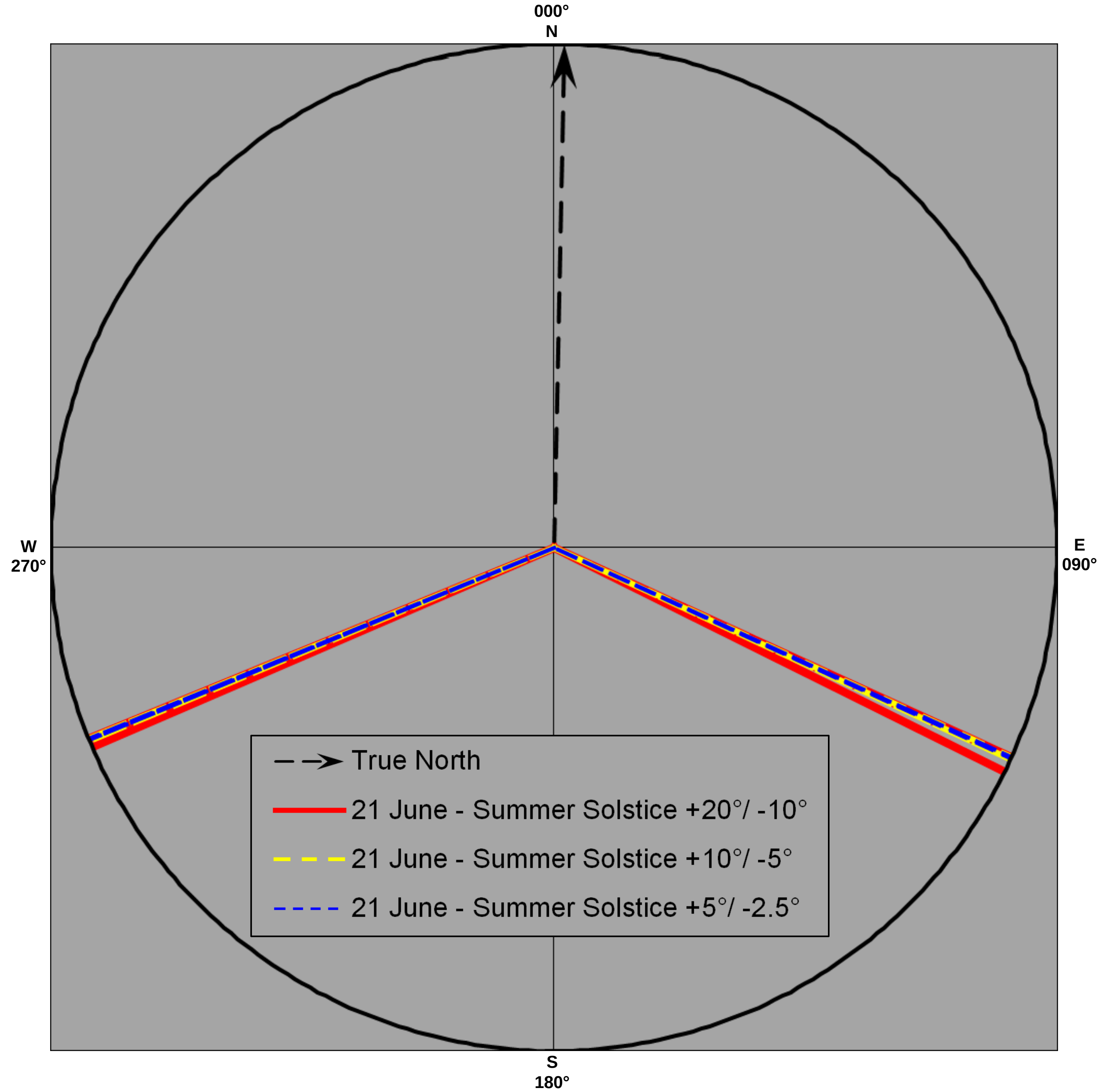
Notes.

- The chart is aligned with Grid North (British National Grid, OSGB36); the local offset for True North is marked.
- For the summer solstice, arcs are marked in accordance with the table at Appendix 2 as an example (the directions of the first and last reflections within the vertical arcs are shown).

Daily Reflection Limits

The following diagram shows how the extent of reflections within altitude bounds vary in one day, depending on astronomical altitude bands selected. Altitude bands shown are: within +20°/-10°, within +10°/-5°, and within +5/-2.5°, of the horizontal. The examples shown for illustration are at the summer solstice.

This assessment generally used the +10°/-5° criterion as shown by the yellow dashed lines.

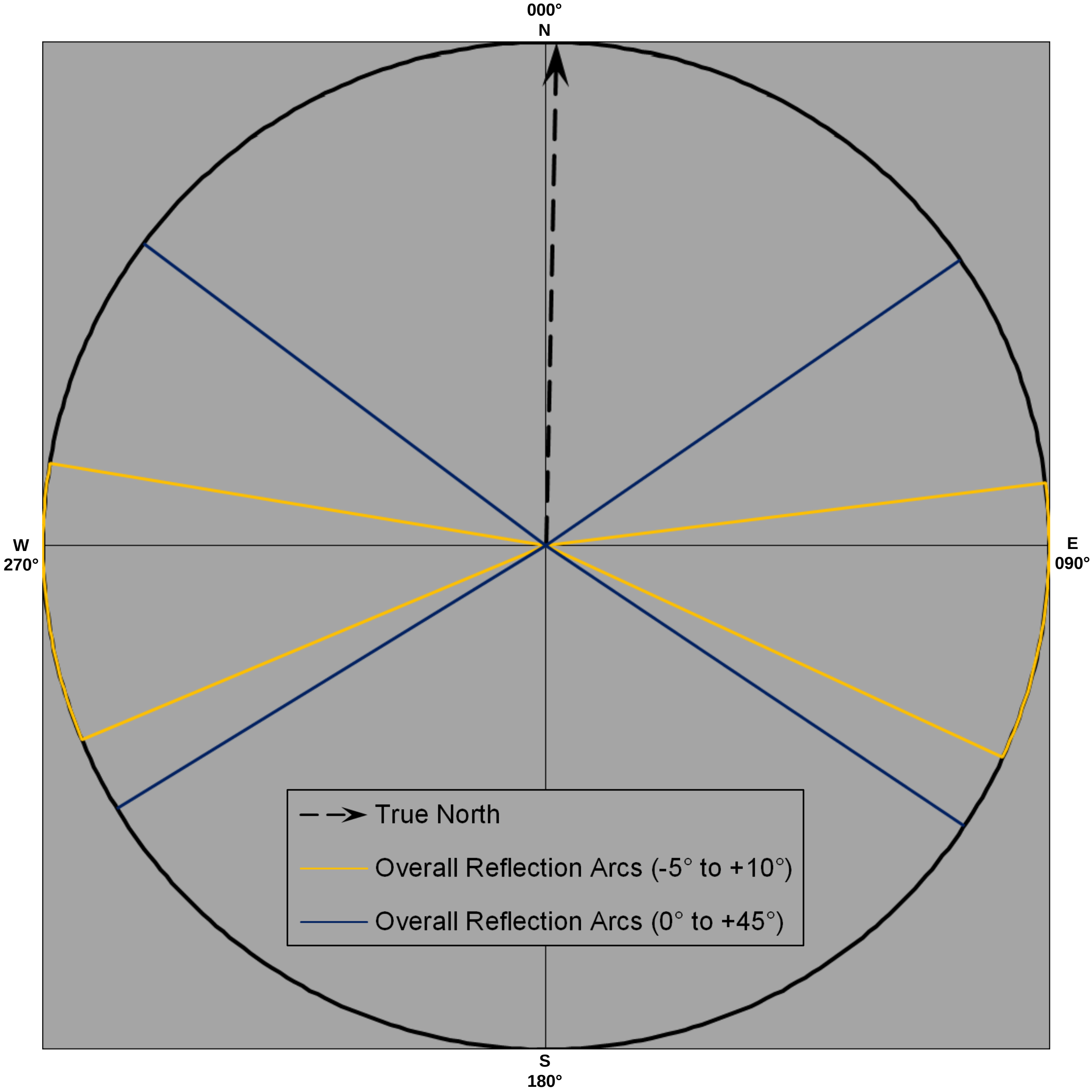


Solar Reflection Arcs

This diagram shows the following:

- gold arcs within which solar reflections will be directed at 'near-horizontal' altitude angles (i.e., between vertical arcs of +10° and -5° to the horizontal), and
- blue arcs within which solar reflections will be directed from 0° to 45° above horizontal,

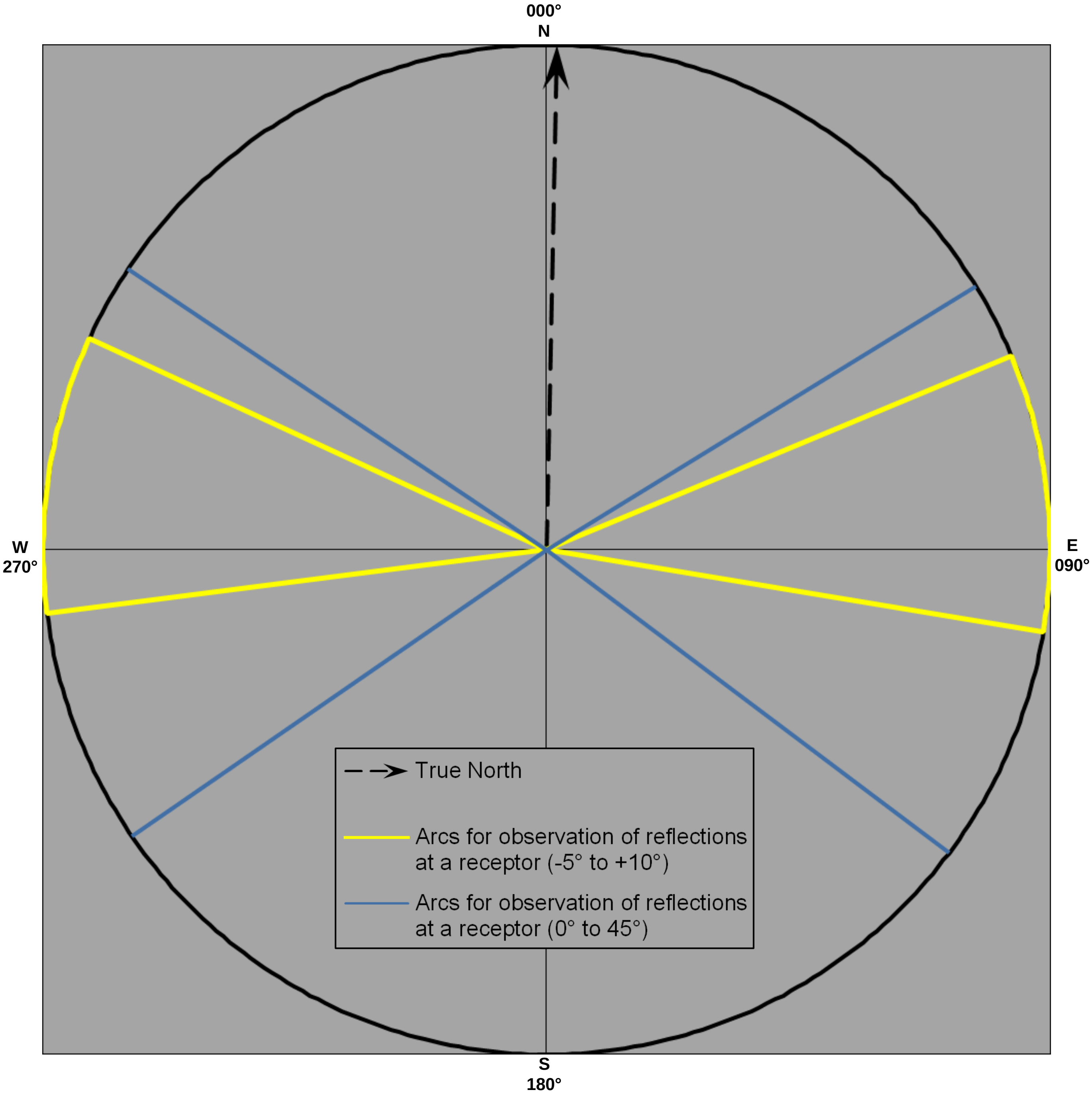
from any point in the solar park and at any time of day throughout the year. These were applied to all points in the solar park to generate the respective solar reflection arcs.



Arcs for Observation of Solar Reflections by a Receptor

The following diagram shows the arcs within which solar reflections from the solar park can be observed by a receptor at near-horizontal (i.e., from 5° below to 10° above horizontal) – represented by the yellow arcs, or at less than 45° below horizontal relative to the solar park – represented by the blue arcs, assuming there are solar panels visible in those directions. The lines are on the reciprocal bearings to those in the previous chart (Solar Reflection Arcs). The reciprocals may also be applied to the solar reflection arcs at other altitudes to find such arcs for those bands.

Solar reflections can never be observed at a receptor (within the appropriate vertical band) unless solar panels are visible within the respective arcs.

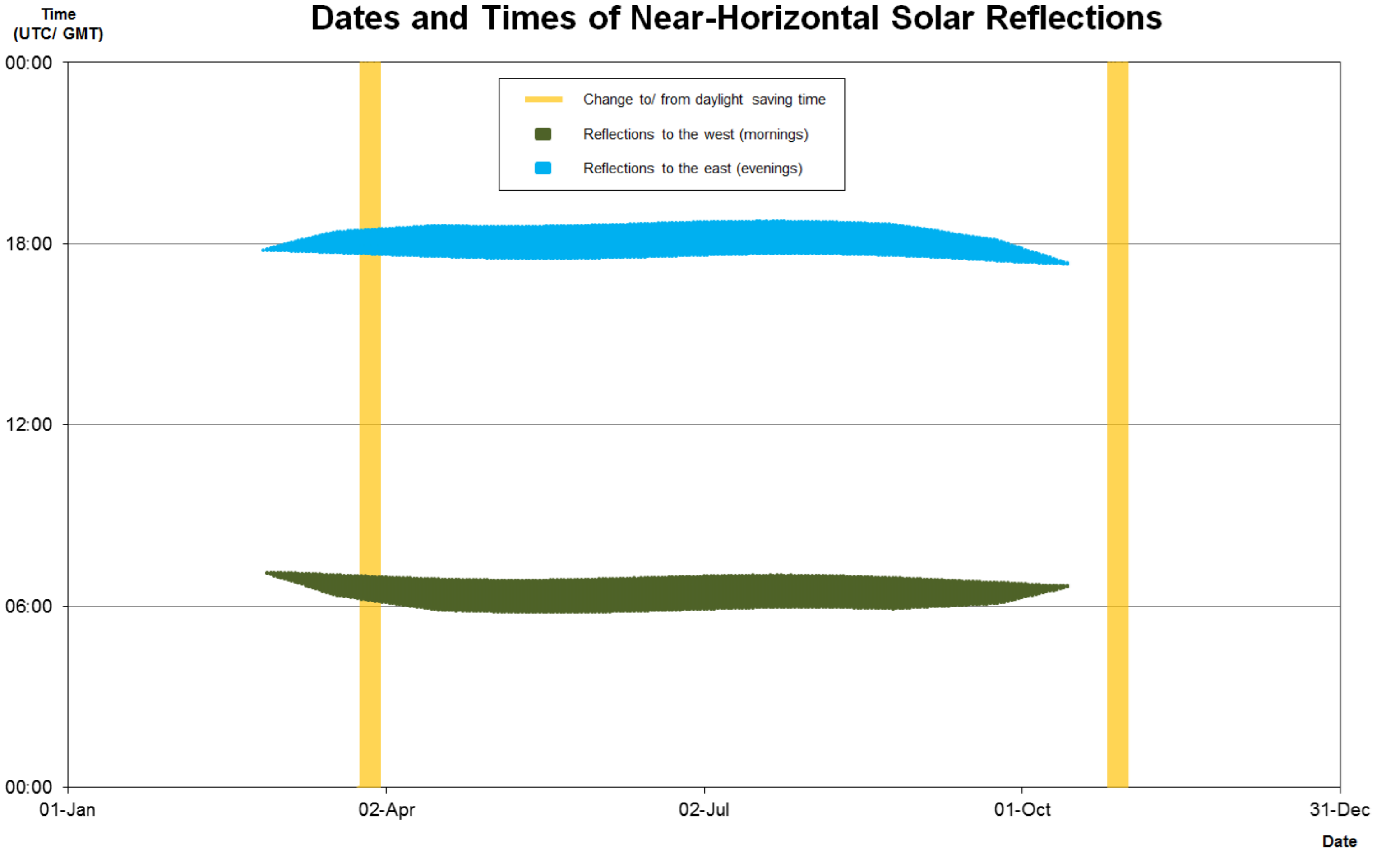


Aviation Analysis, Renewables Development & Visualisation, and Radio Communications

Appendix 4 – Dates and Times of Significant Solar Reflections

Summary of Near-Horizontal Solar Reflections

This chart shows the dates and times that solar reflections may occur at near-horizontal altitude angles, potentially affecting all surface receptors and most aerial ones. The vertical yellow bars mark dates within which the change from GMT to BST may take place (on the last Sunday of March, i.e., between March 25th and 31st) and also from BST to GMT (on the last Sunday of October, i.e., between October 25th and 31st). Times shown are UTC (GMT). For BST (between the vertical yellow bars), add 1 hour to the times shown.



Summary of Solar Reflections below 45°

This chart shows the dates and times that solar reflections may occur from within the horizontal plane to 45° above it, potentially affecting some aerial receptors that are either very high or close to the solar park; only aircraft extremely close to the solar park could be affected by reflections at angles greater than 45° above horizontal. The vertical yellow bars mark dates within which the change from GMT to BST may take place (on the last Sunday of March, i.e., between March 25th and 31st) and also from BST to GMT (on the last Sunday of October, i.e., between October 25th and 31st). Times shown are UTC (GMT). For BST (between the vertical yellow bars), add 1 hour to the times shown.