

# Solar Photovoltaic Glint and Glare Study

Solar Farm, N Wales

The Sirius Group

July, 2020



## PLANNING SOLUTIONS FOR:

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## ADMINISTRATION PAGE

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## EXECUTIVE SUMMARY

### Report Purpose

Pager Power has been retained to assess the possible effects of glint and glare from a proposed solar photovoltaic (PV) installation to be located on Anglesey in north Wales.

This assessment pertains to the possible effects upon aviation activity at RAF Valley, which is located approximately 1.5km south west of the proposed solar development. In particular, the runway approach paths, and the Air Traffic Control (ATC) Tower have been assessed.

### Pager Power

Pager Power has undertaken over 450 glint and glare assessments in the UK, Europe and further afield. The company's own glint and glare guidance is based on industry experience and extensive consultation with industry stakeholders including airports and aviation regulators.

### Overall Conclusions and Recommendations

No impact upon the ATC Tower or the approach paths for runway 01, 19 and 31 is expected. No significant impact is expected for the approach path to runway 13. The results of this report should be made available to the MOD and further consultation is advised. No mitigation is recommended.

### Guidance and Studies

Guidelines exist in the UK (produced by the CAA<sup>1</sup>) and in the USA (produced by the FAA<sup>2</sup>) with respect to solar developments and aviation activity, however a specific methodology for aviation assessments has not been produced to date. Therefore, Pager Power has reviewed existing guidelines and the available studies (discussed below) in the process of defining its own glint and glare assessment guidance. This guidance document defines the process for determining the impact upon aviation activity. Pager Power's approach is to undertake geometric reflection calculations and, where a solar reflection is predicted, undertake solar intensity calculations in line with the Sandia National Laboratories' FAA methodology. The scenario in which a solar reflection can occur is identified and discussed, and a comparison is made against the available solar panel reflection studies to determine the overall impact.

The available studies have measured the intensity of reflections from solar panels with respect to other naturally occurring and manmade surfaces. The results show that the reflections produced are of intensity similar to or less than those produced from still water and significantly less than reflections from glass and steel<sup>3</sup>.

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<sup>1</sup> Civil Aviation Authority.

<sup>2</sup> Federal Aviation Administration.

<sup>3</sup> SunPower, 2009, SunPower Solar Module Glare and Reflectance (appendix to Solargen Energy, 2010).

## Glint and Glare

The definition of glint and glare used by Pager Power is as follows:

- Glint – a momentary flash of bright light;
- Glare – a continuous source of bright light.

## Analysis Results

### Assessment Results – Runway 01, 19 and 31 Approaches

No solar reflection is geometrically possible towards the approach paths for runways 01 and 31. A solar reflection is possible towards runway 19 however it occurs outside the pilot's primary field of vision (see Section 8).

No impact on these runway approaches is expected.

### Assessment Results – Runway 13 Approach

A solar reflection is possible towards up to 1.3 miles of the 2-mile approach path (from 0.7 miles to 2-miles from the runway threshold). However only the Pager Power model predicts a solar reflection from 0.7-1.2 miles.

From 1.3 miles to 2-miles, all predicted glare intensities have a 'low potential for temporary after-image' (green) which is acceptable considering the associated guidance. No impact is anticipated for pilots on this section of the approach path.

From 1.2 to 1.3 miles, the predicted glare intensity is 'potential for temporary after-image' (yellow) which is not acceptable considering the FAA guidance. Pager Power however recommends a pragmatic approach and therefore consideration of the technical and operational impact has been undertaken. This is presented below:

- Yellow glare is possible for 14 minutes per year. This represents a very small proportion of time compared to average daylight hours in any one year (less than 0.1%);
- The weather would have to be clear at sunny at the very specific times when the glare was possible to be experienced. A pilot would also have to be on the approach path at these times;
- Its maximum duration would be for less than five minutes on the few days when the glare is possible;
- The 'yellow' glare only marginally passes the 'yellow'/'green' threshold on the intensity chart. Green glare (or glare with 'low potential for temporary after-image') is acceptable for approaching aircraft;
- Whilst not outside a pilot's field of vision completely, the 'yellow' glare would occur on the edge of this boundary (50 degrees from the runway centre line) and at a point on the approach path where the reflecting solar panels would originate significantly off to the left of pilot, who would be focussing on the runway.

Considering the above, no significant impact is expected for the approach path to runway 13.

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## ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 48 countries within South Africa, Europe, America, Asia and Australasia.

The company comprises a team of experts to provide technical expertise and guidance on a range of planning issues for large and small developments.

Pager Power was established in 1997. Initially the company focus was on modelling the impact of wind turbines on radar systems. Over the years, the company has expanded into numerous fields including:

- Renewable energy projects.
- Building developments.
- Aviation and telecommunication systems.

Pager Power prides itself on providing comprehensive, understandable and accurate assessments of complex issues in line with national and international standards. This is underpinned by its custom software, longstanding relationships with stakeholders and active role in conferences and research efforts around the world.

Pager Power's assessments withstand legal scrutiny and the company can provide support for a project at any stage.

## 1 INTRODUCTION

### 1.1 Overview

Pager Power has been retained to assess the possible effects of glint and glare from a proposed solar photovoltaic (PV) installation to be located on Anglesey in north Wales.

This assessment pertains to the possible effects upon aviation activity at Anglesey Airport/RAF Valley (hereafter referred to as RAF Valley only), which is located approximately 1.5km south west of the proposed solar development. In particular, the runway approach paths, and the Air Traffic Control (ATC) Tower have been assessed. A report has therefore been produced that contains the following:

- Details of the proposed solar development;
- Explanation of glint and glare;
- Overview of relevant guidance;
- Overview of relevant studies;
- Identification of aviation concerns and receptors;
- Assessment methodology;
- Glint and glare assessment for:
  - Aircraft approach paths for the relevant runways;
  - Air Traffic Control (ATC) Tower.
- Results discussion.

The relevant technical analysis is presented in each section. Following the assessment, conclusions and recommendations are made.

Please note that any reference to visual impact made within this report should be read in the context of potential glint and glare. In addition, this report is solely desk based and no site visit has taken place.

### 1.2 Pager Power's Experience

Pager Power has undertaken over 450 Glint and Glare assessments internationally. The studies have included assessment of civil and military aerodromes, railway infrastructure and other ground-based receptors including roads and dwellings.

### 1.3 Glint and Glare Definition

The definition of glint and glare can vary however, the definition used by Pager Power is as follows:

- Glint – a momentary flash of bright light typically received by moving receptors or from moving reflectors.
- Glare – a continuous source of bright light typically received by static receptors or from large reflective surfaces.

These definitions are aligned with those of the Federal Aviation Administration (FAA) in the United States of America. The term 'solar reflection' is used in this report to refer to both reflection types i.e. glint and glare.

## 2 PROPOSED DEVELOPMENT LOCATION AND DETAILS

### 2.1 Proposed Development Location

The general location of the proposed development is shown in the aerial image of Figure 1<sup>4</sup> below (red icon).

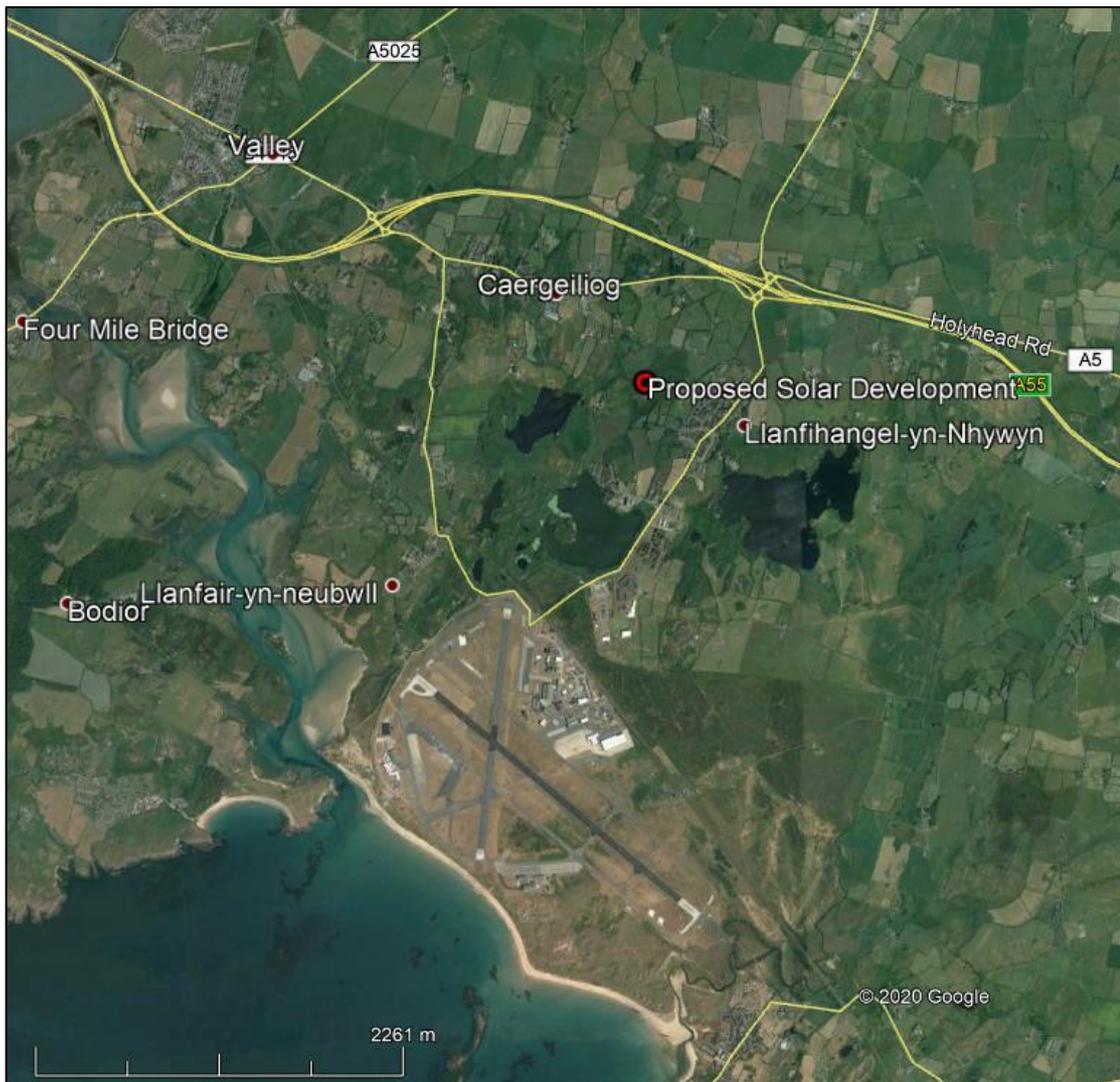


Figure 1 Proposed development general location – aerial image

<sup>4</sup> Source: Aerial image copyright © 2020 Google.

## 2.2 Proposed Solar Panel Layout

The layout of the solar panels within the proposed development is shown in Figure 2<sup>5</sup> below (blue hatched area).

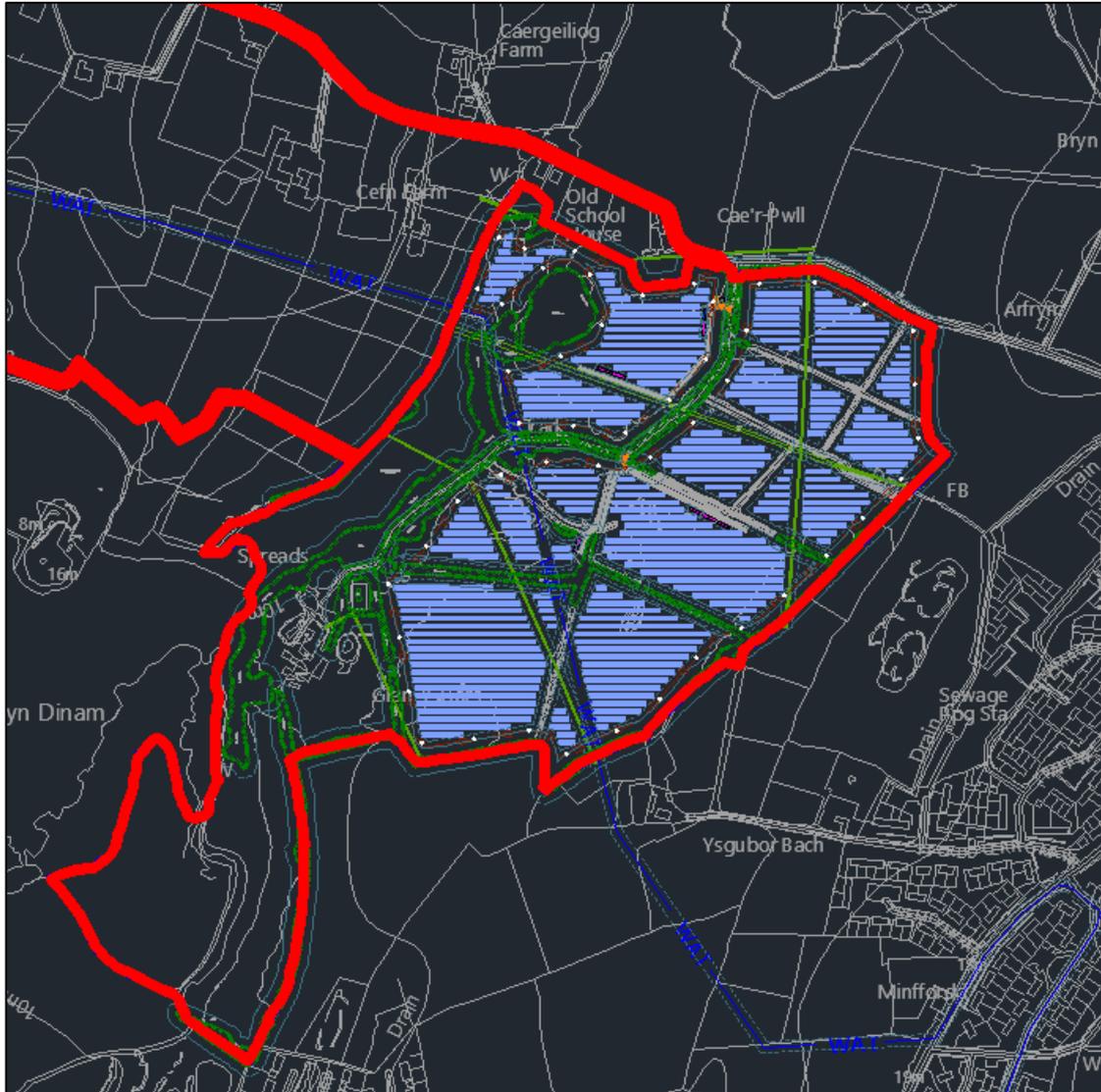


Figure 2 Proposed solar panel layout

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<sup>5</sup> Source: low carbon (edited).

### 2.3 Proposed Solar Panel Layout – Aerial Image

The layout of the solar panels within the proposed development overlaid on an aerial image is shown in Figure 3<sup>6</sup> below.



Figure 3 Proposed solar panel layout – aerial image

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<sup>6</sup> Source: low carbon (edited) and aerial image copyright © 2020 Google.

## 2.4 Proposed Solar Panel Side Profile

The side profile of the proposed solar panels is shown in Figure 4<sup>7</sup> below. The solar panels will be south facing and have an elevation angle of 25 degrees.

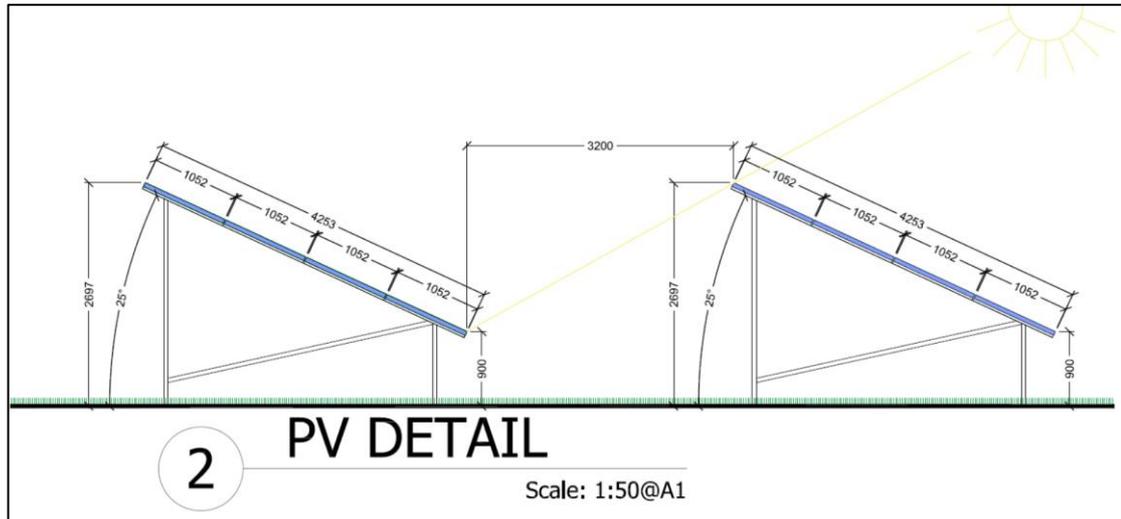


Figure 4 Proposed solar panel side profile

Specific details about the solar panel areas assessed within this report can be seen in Section 5 and Appendix G.

<sup>7</sup> Source: low carbon (edited).

## 3 RAF VALLEY DETAILS

### 3.1 Overview

The following section presents details regarding RAF Valley.

### 3.2 Airport Information

RAF Valley is predominantly operated by the MOD. It is expected the aerodrome is used by fixed wing propeller and jet aircraft, as well as helicopters.

### 3.3 Runway Details

RAF Valley has two runways. This is presented below:

1. 01/19 measuring 1,572 by 45m (asphalt);
2. 13/31 measuring 2,290 by 45m (asphalt).

The runways are shown on the aerodrome chart in Figure 5<sup>8</sup> on the following page.

### 3.4 Air Traffic Control Tower

The Air Traffic Control Tower (ATC Tower) is located to the northeast of the runway intersection and is highlighted in Figure 5 on the following page.

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<sup>8</sup> Source: Military AIP. Last accessed 17.07.20.

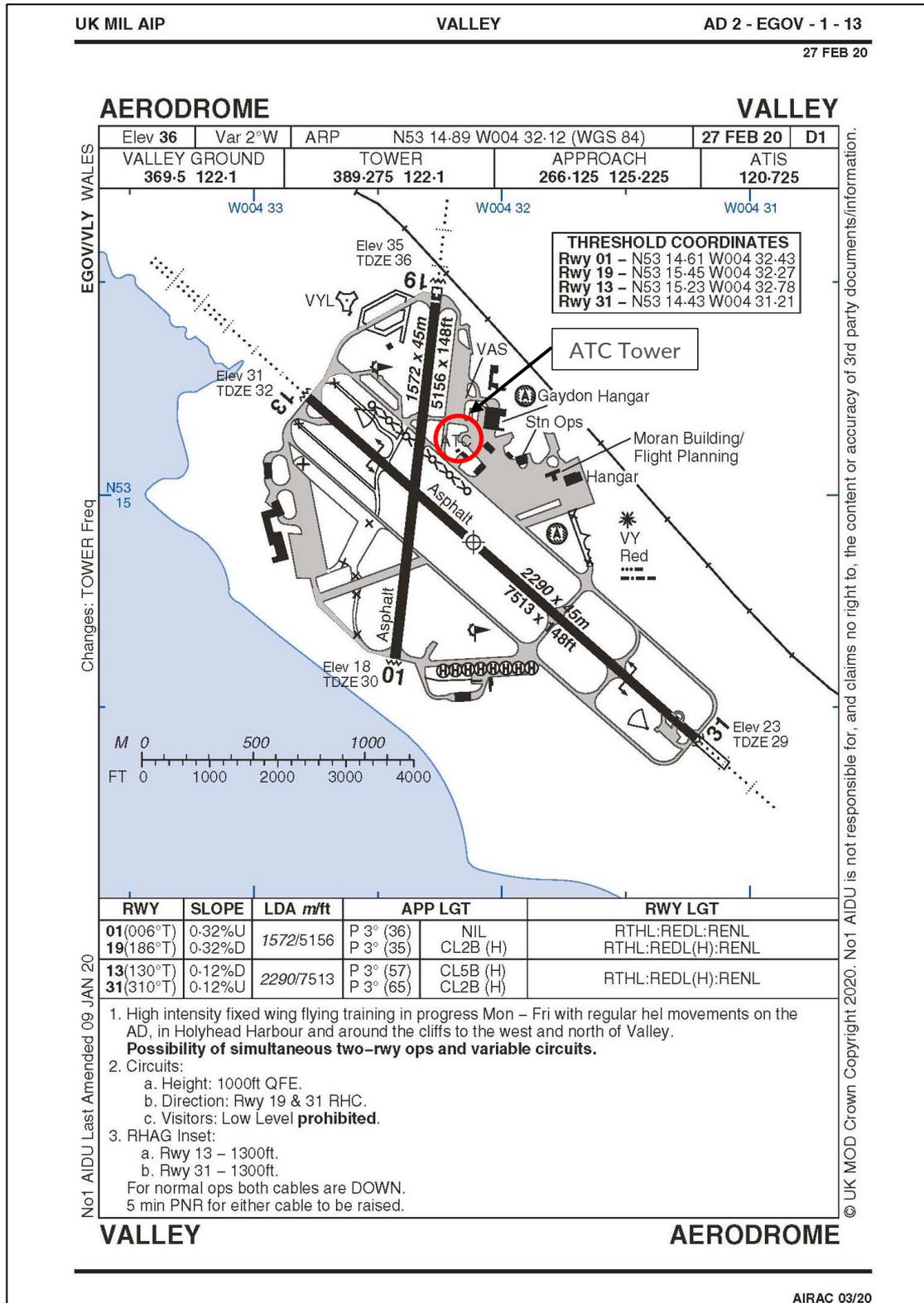


Figure 5 RAF Valley aerodrome chart

The relative location of the proposed development to RAF Valley is presented in Figure 6<sup>9</sup> below.



Figure 6 Relative location of RAF Valley to the proposed development

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<sup>9</sup> Source: low carbon (edited) and aerial image copyright © 2020 Google.

## 4 GLINT AND GLARE ASSESSMENT METHODOLOGY

### 4.1 Overview

The following sub-sections provides a general overview with respect to the guidance studies and methodology which informs this report.

### 4.2 Guidance and Studies

Appendix A and B present a review of relevant guidance and independent studies with regard to glint and glare issues from solar panels and glass. The overall conclusions from the available studies are as follows:

- Specular reflections of the Sun from solar panels and glass are possible;
- The measured intensity of a reflection from solar panels can vary from 2% to 30% depending on the angle of incidence;
- Published guidance shows that the intensity of solar reflections from solar panels are equal to or less than those from water and similar to those from glass. It also shows that reflections from solar panels are significantly less intense than many other reflective surfaces, which are common in an outdoor environment.

### 4.3 Background

Details of the Sun's movements and solar reflections are presented in Appendix C.

### 4.4 Methodology

The assessment methodology is based on guidance, studies, previous discussions with stakeholders and Pager Power's practical experience. Information regarding the methodology of Pager Power's and Sandia National Laboratories' methodology is presented below.

#### 4.4.1 Pager Power's Methodology

The glint and glare assessment methodology has been derived from the information provided to Pager Power through consultation with stakeholders and by reviewing the available guidance. The methodology for the aviation glint and glare assessment is as follows:

- Identify receptors in the area surrounding the proposed development;
- Consider direct solar reflections from the proposed development towards the identified receptors by undertaking geometric calculations;
- Consider the visibility of the reflectors from the receptor's location. If the reflectors are not visible from the receptor then no reflection can occur;
- Based on the results of the geometric calculations, determine whether a reflection can occur, and if so, at what time it will occur;
- Consider the solar reflection intensity, if appropriate;
- Consider both the solar reflection from the proposed development and the location of the direct sunlight with respect to the receptor's position;

- Consider the solar reflection with respect to the published studies and guidance;
- Determine whether a significant detrimental impact is expected in line with Appendix D.

Within the Pager Power model, the reflector area is defined, as well as the relevant receptor locations. The result is a chart that states whether a reflection can occur, the duration and the panels that can produce the solar reflection towards the receptor.

Where a solar reflection is identified for an aviation approach path receptor, intensity calculations are completed in line with the Sandia National Laboratories methodology (discussed in the following section).

#### **4.4.2 Sandia National Laboratories' Methodology**

Sandia National Laboratories developed the Solar Glare Hazard Analysis Tool (SGHAT) which is no longer available. Pager Power has since reviewed the Sandia National Laboratories model and is developing its own intensity calculation model in line with Sandia National Laboratories' methodology. Whilst strictly applicable in the USA and to solar photovoltaic developments only, the methodology and associated guidance is widely used by UK aviation stakeholders. The following text is taken from the SGHAT model methodology.

*'This tool determines when and where solar glare can occur throughout the year from a user-specified PV array as viewed from user-prescribed observation points. The potential ocular impact from the observed glare is also determined, along with a prediction of the annual energy production.'*

The result was a chart that states whether a reflection can occur, the duration and predicted intensity for aviation receptors.

Pager Power has undertaken many aviation glint and glare assessments with both models (SGHAT and Pager Power's) producing similar results. Therefore, where the Pager Power geometrical analysis indicates that a solar reflection is geometrically possible, an intensity calculation in line with Sandia National Laboratories' methodology has also been completed<sup>10</sup>.

#### **4.5 Assessment Methodology and Limitations**

Further technical details regarding the methodology of the geometric calculations and limitations are presented in Appendix E and Appendix F.

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<sup>10</sup> Currently using the Forge Solar model, based on the Sandia methodology.

## 5 IDENTIFICATION OF RECEPTORS

### 5.1 Overview

The following section presents the relevant receptors assessed within this report.

### 5.2 Airborne Receptors- Approaching Aircraft

It is Pager Power's methodology to assess whether a solar reflection can be experienced on the approach paths for the associated runways. RAF Valley has two operational runways with four associated approach paths, one for each bearing.

A geometric glint and glare assessment has been undertaken for all aircraft approach paths for each runway (existing and proposed). This is considered to be the most critical stage of the flight. The Pager Power approach for determining receptor (aircraft) locations on the approach path is to select locations along the extended runway centre line from 50ft above the runway threshold out to a distance of 2 miles. The height of the aircraft is determined by using a 3-degree descent path relative to the runway threshold height. The receptor details for each runway approach are presented in Appendix G.

Figure 7 on the following page shows the assessed aircraft receptor locations<sup>11</sup>.

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<sup>11</sup> Source: Aerial image copyright © 2020 Google.



Figure 7 Runway approach receptor locations

### 5.3 Air Traffic Control Tower

It is standard practice to determine whether a solar reflection can be experienced by personnel within the ATC Tower. The ATC Tower is located north east of the intersection of the runways.

Figure 8 below shows the location of the ATC Tower<sup>12</sup>.



Figure 8 ATC Tower location

The detailed receptor details are presented in Appendix G.

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<sup>12</sup> Source: Aerial image copyright © 2020 Google.

## 6 ASSESSED REFLECTOR AREA

### 6.1 Overview

The following section presents the modelled reflector area.

### 6.2 Reflector Area

A number of representative panel locations are selected within the proposed reflector area. The number of modelled reflector points being determined by the size of the reflector area and the assessment resolution. The bounding co-ordinates for the proposed solar development have been extrapolated from the site maps. All ground heights and panel elevation data has been provided by the developer. The data can be found in Appendix G.

A resolution of 10m has been chosen for this assessment. This means that a geometric calculation is undertaken for each identified receptor every 10m from within the defined area. This resolution is sufficiently high to maximise the accuracy of the results – increasing the resolution further would not significantly change the modelling output.

The reflector area assessed is shown in Figure <sup>13</sup> below (blue area). The area has been overlaid on aerial imagery.

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<sup>13</sup> Source: Aerial image copyright © 2020 Google.



Figure 9 Assessed reflector area

## 7 GLINT AND GLARE ASSESSMENT RESULTS

### 7.1 Overview

The following section presents an overview of the glare for the identified receptors.

The Pager Power model has been used initially. Where solar reflections have been predicted, intensity calculations in line with Sandia National Laboratories' methodology have been undertaken. The intensity calculations determine the potential for an after-image (or worse) occurring. The designation used by the model is presented in Table 1 below along with the associated colour coding.

Coding Used	Intensity Key
Glare beyond 50°	 Glare beyond 50 deg from pilot line-of-sight  Low potential for temporary after-image  Potential for temporary after-image  Potential for permanent eye damage
Low potential	
Potential	
Potential for permanent eye damage	

Table 1 Glare intensity designation

This coding has been used in the table where a reflection has been calculated and is in accordance with Sandia National Laboratories' methodology. The relative width of the colour band is related to the estimated percentage of each type of glare<sup>14</sup>.

In addition, the intensity model allows for assessment of a variety of solar panel surface materials. In the first instance, a surface material of 'smooth glass without an anti-reflective coating' is assessed. This is the most reflective surface and allows for a 'worst case' assessment. Other surfaces that could be modelled include:

- Smooth glass with an anti-reflective coating;
- Light textured glass without an anti-reflective coating;
- Light textured glass with an anti-reflective coating; or
- Deeply textured glass.

If significant glare is predicted, modelling of less reflective surfaces could be undertaken.

The tables in the following subsections summarise the time (am or pm) and intensity for a solar reflection be experienced by a receptor. Appendix H presents the results charts.

<sup>14</sup> Where two or more glare intensities are predicted for a particular receptor throughout the year.

## 7.1 Geometric Calculation Results Overview – ATC Tower

The results of the geometric calculation for the ATC Tower is presented in Table 2 below.

Receptor	Pager Power Results		Glare Type	Comment
	Reflection possible toward the ATC Tower? (GMT)			
	am	pm		
ATC Tower	No	No	n/a	No solar reflection geometrically possible No impact possible.

Table 2 Geometric analysis results for the ATC tower

## 7.2 Geometric Calculation Results Overview – Approach for Runway 01

The results of the geometric calculations for the approach towards runway 01 are presented in Table 3 below.

Receptor	Pager Power Results		Glare Type	Comment
	Reflection possible toward the Runway 01 Approach? (GMT)			
	am	pm		
Threshold - 2 miles	No	No	n/a	No solar reflection geometrically possible No impact possible.

Table 3 Geometric analysis results for the Runway 01 Approach

### 7.3 Geometric Calculation Results Overview – Approach for Runway 19

The results of the geometric calculations for the approach towards runway 19 are presented in Table 4 below.

Receptor	Pager Power Results		Glare Type	Comment
	Reflection possible toward the Runway 19 Approach? (GMT)			
	am	pm		
Threshold – 2miles	Yes	No	n/a	Solar reflection geometrically possible however the solar reflection will originate outside of a pilot’s field of vision.  No impact possible. Discusses further in Section 8.3.

Table 4 Geometric analysis results for the Runway 19 Approach

## 7.4 Geometric Calculation Results Overview – Approach for Runway 13

The results of the geometric calculations for the approach towards runway 13 are presented in Table 5 below.

Receptor	Pager Power Results		Glare Type	Comment
	Reflection possible toward the Runway 13 Approach? (GMT)			
	am	pm		
Threshold – 0.6 miles	No	No	n/a	No solar reflection geometrically possible No impact possible.
0.7-1.2 miles	Yes	No	n/a	Solar reflection geometrically possible however predicted only from the Pager Power model. Discussed further in Section 8.4
1.2-1.3 miles	Yes	No		Solar reflection with potential for temporary after-image predicted. Discussed further in Section 8.4.
1.3- 2- miles	Yes	No		Solar reflection with low potential for temporary after-image predicted. Discussed further in Section 8.4.

Table 5 Geometric analysis results for the Runway 13 Approach

## 7.5 Geometric Calculation Results Overview – Approach for Runway 31

The results of the geometric calculations for the approach towards runway 31 are presented in Table 6 below.

Receptor	Pager Power Results		Glare Type	Comment
	Reflection possible toward the Runway 31 Approach? (GMT)			
	am	pm		
Threshold - 2 miles	No	No	n/a	No solar reflection geometrically possible No impact possible.

Table 6 Geometric analysis results for the Runway 31 Approach

## 8 GEOMETRIC ASSESSMENT RESULTS AND DISCUSSION

### 8.1 Overview

The results of the aviation glint and glare calculations are presented in the following sub-sections.

### 8.2 ATC Tower

The result of the geometric modelling has shown that a solar reflection from the proposed development towards the ATC is not geometrically possible.

No impact is expected.

### 8.3 Runway 01, 19 and 31 Approaches

The result of the geometric modelling has shown that a solar reflection from the proposed development towards the approach paths for runways 01 and 31 are not geometrically possible.

A solar reflection is possible towards runway 19 however it occurs outside the pilot's primary field of vision (50 degrees either side of the runway centre line and 30 degrees downward).

No impact on these runway approaches is expected.

### 8.4 Runway 13 Approach

The analysis has shown that solar reflections are predicted towards up to 1.3 miles of the 2-mile approach path (from 0.7 miles to 2-miles from the runway threshold). However only the Pager Power model predicts a solar reflection from 0.7-1.2 miles.

From 1.3 miles to 2-miles, all predicted glare intensities have a 'low potential for temporary after-image' (green) which is acceptable considering the associated guidance. No impact is anticipated for pilots on this section of the approach path.

From 1.2 to 1.3 miles, the predicted glare intensity is 'potential for temporary after-image' (yellow) which is not acceptable considering the FAA guidance. Pager Power however recommends a pragmatic approach and therefore a further technical and operational assessment is required.

#### 8.4.1 Results Discussion

Figures 10<sup>15</sup> and 11<sup>16</sup> on the following pages show the results of the modelling and the glare location on the approach path relative to the assessed solar panel area. The following is true:

- Yellow glare is possible for 14 minutes per year. This represents a very small proportion of time compared to average daylight hours in any one year (less than 0.1%);

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<sup>15</sup> Forge modelling results

<sup>16</sup> Source: Aerial image copyright © 2020 Google.

- The weather would have to be clear at sunny at the very specific times when the glare was possible to be experienced. A pilot would also have to be on the approach path at these times;
- Its maximum duration would be for less than five minutes on the few days when the glare is possible;
- The 'yellow' glare only marginally passes the 'yellow'/'green' threshold on the intensity chart. Green glare (or glare with 'low potential for temporary after-image') is acceptable for approaching aircraft;
- Whilst not outside a pilot's field of vision completely, the 'yellow' glare would occur on the edge of this boundary (50 degrees from the runway centre line) and at a point on the approach path where the reflecting solar panels would originate significantly off to the left of pilot, who would be focussing on the runway.

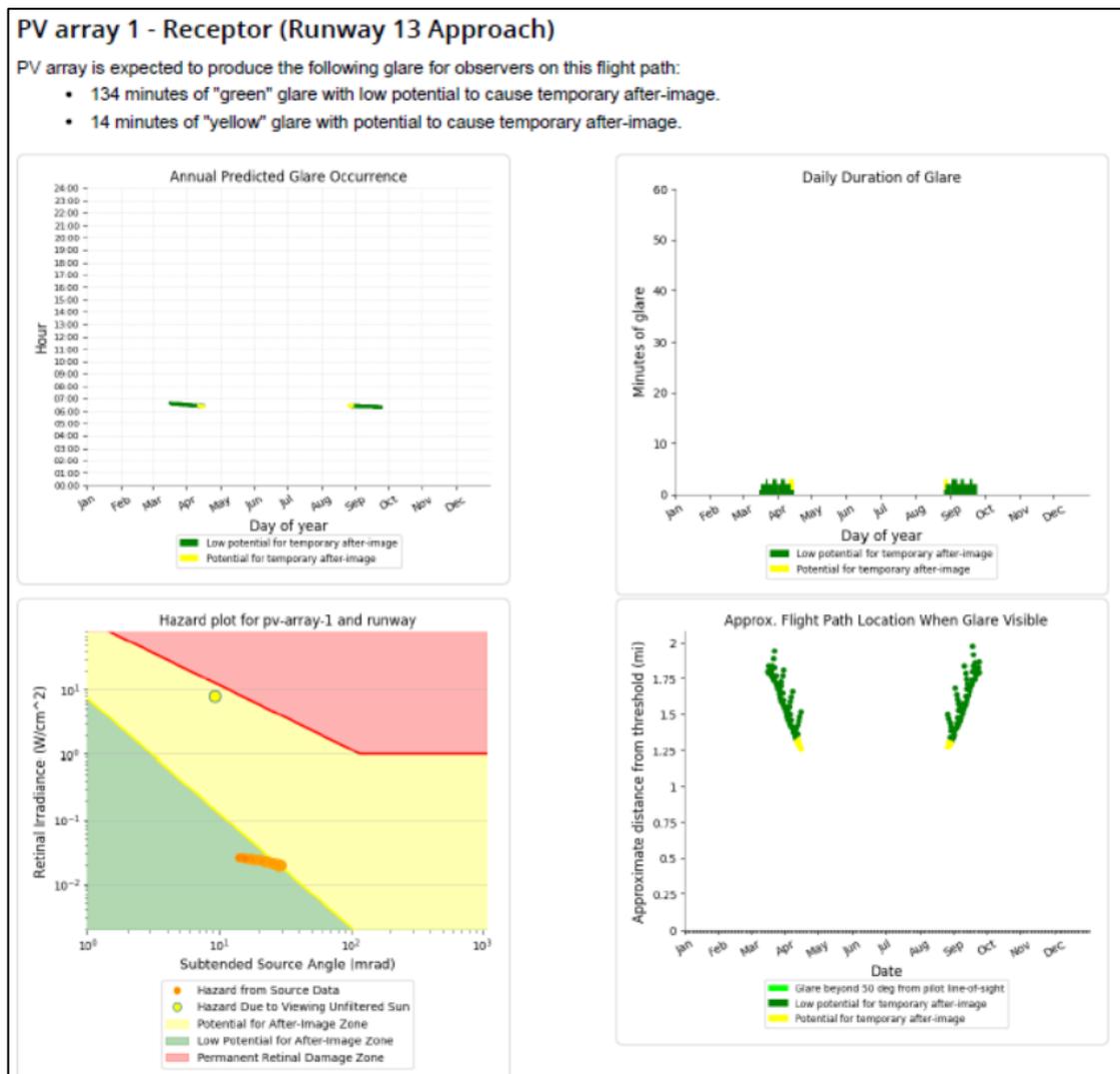


Figure 10 Glare modelling results for runway 13

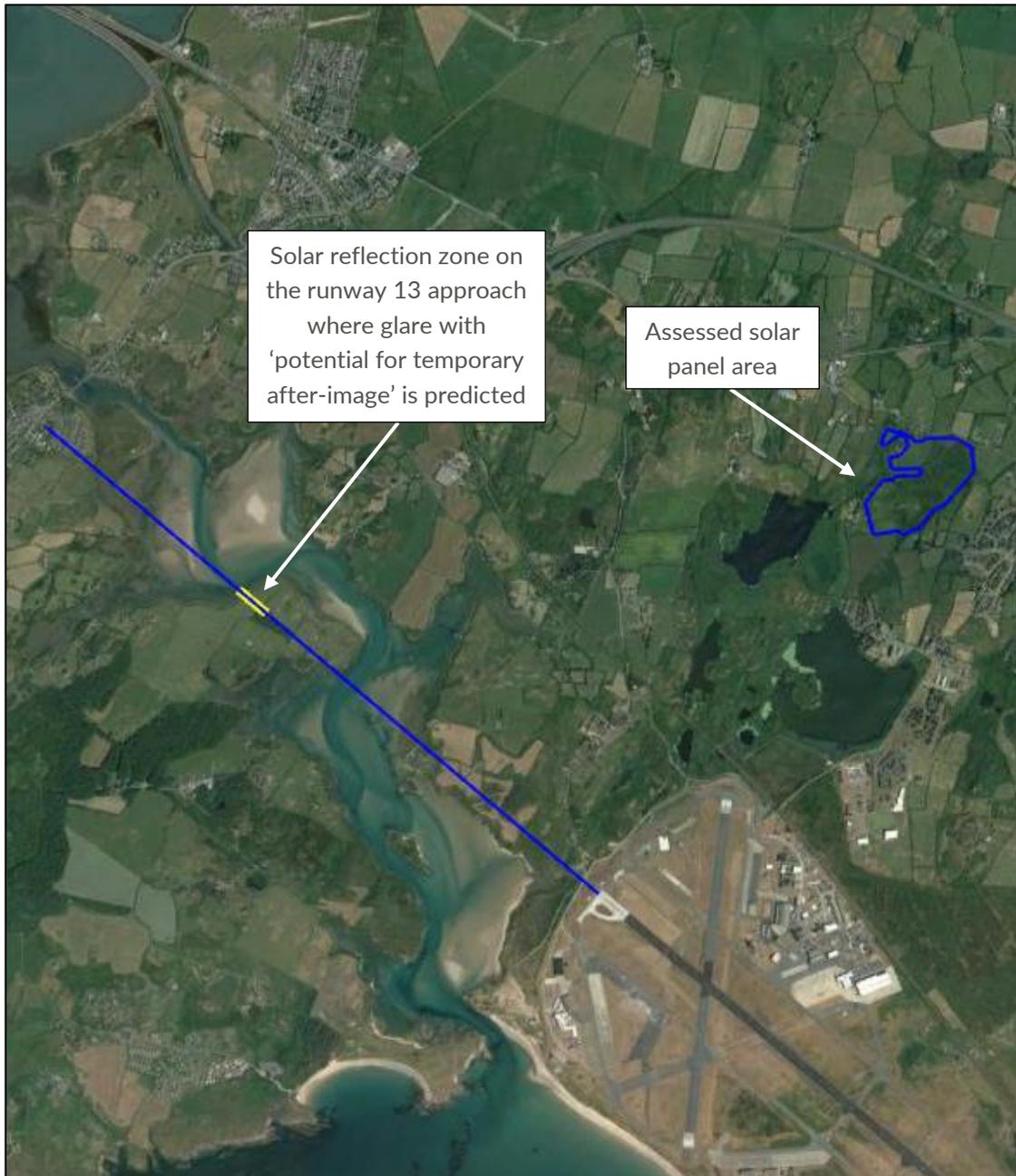


Figure 11 Section of approach path for runway 13 where 'yellow' glare is predicted

#### 8.4.2 Overall Conclusions for the Runway 13 Approach

Considering the points made above, no significant impact upon pilots on the 2-mile approach path to runway 13 expected. The results should however be made available to the MOD and further consultation is advised. No mitigation is recommended.

## 9 OVERALL CONCLUSIONS

### 9.1 Assessment Results – ATC Tower

No solar reflection is geometrically possible towards the ATC Tower.

No impact is expected.

### 9.2 Assessment Results – Runway 01, 19 and 31 Approaches

No solar reflection is geometrically possible towards the approach paths for runways 01 and 31. A solar reflection is possible towards runway 19 however it occurs outside the pilot's primary field of vision.

No impact on these runway approaches is expected.

### 9.3 Assessment Results – Runway 13 Approach

A solar reflection is possible towards up to 1.3 miles of the 2-mile approach path (from 0.7 miles to 2-miles from the runway threshold). However only the Pager Power model predicts a solar reflection from 0.7-1.2 miles.

From 1.3 miles to 2-miles, all predicted glare intensities have a 'low potential for temporary after-image' (green) which is acceptable considering the associated guidance. No impact is anticipated for pilots on this section of the approach path.

From 1.2 to 1.3 miles, the predicted glare intensity is 'potential for temporary after-image' (yellow) which is not acceptable considering the FAA guidance. Pager Power however recommends a pragmatic approach and therefore consideration of the technical and operational impact has been undertaken. This is presented below:

- Yellow glare is possible for 14 minutes per year. This represents a very small proportion of time compared to average daylight hours in any one year (less than 0.1%);
- The weather would have to be clear at sunny at the very specific times when the glare was possible to be experienced. A pilot would also have to be on the approach path at these times;
- Its maximum duration would be for less than five minutes on the few days when the glare is possible;
- The 'yellow' glare only marginally passes the 'yellow'/'green' threshold on the intensity chart. Green glare (or glare with 'low potential for temporary after-image') is acceptable for approaching aircraft;
- Whilst not outside a pilot's field of vision completely, the 'yellow' glare would occur on the edge of this boundary (50 degrees from the runway centre line) and at a point on the approach path where the reflecting solar panels would originate significantly off to the left of pilot, who would be focussing on the runway.

Considering the above, no significant impact is expected for the approach path to runway 13.

#### 9.4 Overall Conclusions and Recommendations

No impact upon the ATC Tower or the approach paths for runway 01, 19 and 31 is expected. No significant impact is expected for the approach path to runway 13. The results of this report should however be made available to the MOD and further consultation is advised. No mitigation is recommended.

## APPENDIX A – OVERVIEW OF GLINT AND GLARE GUIDANCE

### Overview

This section presents details regarding the relevant guidance and studies with respect to the considerations and effects of solar reflections from solar panels, known as ‘Glint and Glare’.

This is not a comprehensive review of the data sources, rather it is intended to give an overview of the important parameters and considerations that have informed this assessment.

### UK Planning Policy

UK National Planning Practice Guidance dictates that in some instances a glint and glare assessment is required however, there is no specific guidance with respect to the methodology for assessing the impact of glint and glare.

The planning policy from the Department for Communities and Local Government (paragraph 27<sup>17</sup>) states:

*‘Particular factors a local planning authority will need to consider include... the effect on landscape of glint and glare and on **neighbouring uses and aircraft safety**.’*

The National Planning Policy Framework for Renewable and Low Carbon Energy<sup>18</sup> (specifically regarding the consideration of solar farms) states:

*‘What are the particular planning considerations that relate to large scale ground-mounted solar photovoltaic Farms?’*

*The deployment of large-scale solar farms can have a negative impact on the rural environment, particularly in undulating landscapes. However, the visual impact of a well-planned and well-screened solar farm can be properly addressed within the landscape if planned sensitively.*

*Particular factors a local planning authority will need to consider include:*

- *the proposal’s visual impact, the effect on landscape of glint and glare (see guidance on landscape assessment) and on **neighbouring uses and aircraft safety**;*
- *the extent to which there may be additional impacts if solar arrays follow the daily movement of the sun;*

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<sup>17</sup> <http://planningguidance.planningportal.gov.uk/blog/guidance/renewable-and-low-carbon-energy/>

<sup>18</sup> Reference ID: 5-013-20140306, paragraph 13-13, <http://planningguidance.planningportal.gov.uk/blog/guidance/renewable-and-low-carbon-energy/particular-planning-considerations-for-hydropower-active-solar-technology-solar-farms-and-wind-turbines/>

*The approach to assessing cumulative landscape and visual impact of large scale solar farms is likely to be the same as assessing the impact of wind turbines. However, in the case of ground-mounted solar panels it should be noted that with effective screening and appropriate land topography the area of a zone of visual influence could be zero.'*

## **Aviation Assessment Guidance**

The UK Civil Aviation Authority (CAA) issued interim guidance relating to Solar Photovoltaic Systems (SPV) on 17 December 2010 and was subject to a CAA information alert 2010/53. The formal policy was cancelled on September 7<sup>th</sup>, 2012<sup>19</sup> however the advice is still applicable<sup>20</sup> until a formal policy is developed. The relevant aviation guidance from the CAA is presented in the section below.

### **CAA Interim Guidance**

This interim guidance makes the following recommendations (p.2-3):

*'8. It is recommended that, as part of a planning application, the SPV developer provide safety assurance documentation (including risk assessment) regarding the full potential impact of the SPV installation on aviation interests.*

*9. Guidance on safeguarding procedures at CAA licensed aerodromes is published within CAP 738 Safeguarding of Aerodromes and advice for unlicensed aerodromes is contained within CAP 793 Safe Operating Practices at Unlicensed Aerodromes.*

*10. Where proposed developments in the vicinity of aerodromes require an application for planning permission the relevant LPA normally consults aerodrome operators or NATS when aeronautical interests might be affected. This consultation procedure is a statutory obligation in the case of certain major airports, and may include military establishments and certain air traffic surveillance technical sites. These arrangements are explained in Department for Transport Circular 1/2003 and for Scotland, Scottish Government Circular 2/2003.*

*11. In the event of SPV developments proposed under the Electricity Act, the relevant government department should routinely consult with the CAA. There is therefore no requirement for the CAA to be separately consulted for such proposed SPV installations or developments.*

*12. If an installation of SPV systems is planned on-aerodrome (i.e. within its licensed boundary) then it is recommended that data on the reflectivity of the solar panel material should be included in any assessment before installation approval can be granted. Although approval for installation is the responsibility of the ALH<sup>21</sup>, as part of a condition of a CAA Aerodrome Licence, the ALH is required to obtain prior consent from CAA Aerodrome Standards Department before any work is begun or*

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<sup>19</sup> [http://www.caa.co.uk/docs/697/srg\\_asd\\_solarphotovoltaicsystguidance.pdf](http://www.caa.co.uk/docs/697/srg_asd_solarphotovoltaicsystguidance.pdf)

<sup>20</sup> Reference email from the CAA dated 19.05.2014.

<sup>21</sup> Aerodrome Licence Holder.

approval to the developer or LPA is granted, in accordance with the procedures set out in CAP 791 Procedures for Changes to Aerodrome Infrastructure.

13. During the installation and associated construction of SPV systems there may also be a need to liaise with nearby aerodromes if cranes are to be used; CAA notification and permission is not required.

14. The CAA aims to replace this informal guidance with formal policy in due course and reserves the right to cancel, amend or alter the guidance provided in this document at its discretion upon receipt of new information.

15. Further guidance may be obtained from CAA's Aerodrome Standards Department via [aerodromes@caa.co.uk](mailto:aerodromes@caa.co.uk).'

### **FAA Guidance**

The most comprehensive guidelines available for the assessment of solar developments near aerodromes were produced initially in November 2010 by the United States Federal Aviation Administration (FAA) and updated in 2013.

The 2010 document is entitled 'Technical Guidance for Evaluating Selected Solar Technologies on Airports'<sup>22</sup> and the 2013 update is entitled 'Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports'<sup>23</sup>.

Key points from the 2010 FAA guidance are presented below.

- The potential impacts of reflectivity are glint and glare (referred to henceforth just as glare) which can cause a brief loss of vision (also known as flash blindness).
- Reflectivity from solar panels could cause flash blindness<sup>24</sup> episodes on pilots or air traffic controllers when 7-11 W/m<sup>2</sup> reaches the eye.
- Today's solar panels reflect as little as 2% of the incoming sunlight meaning roughly 20 W/m<sup>2</sup> are reflected off a typical PV panel.
- PV solar panels reflect less light than other substances such as snow, vegetation and water.
- Reflections from PV panels are specular because of their smooth surfaces – meaning that reflected light from a specific source is reflected in a single direction.
- Glare analysis can include one or more of:
  - A qualitative analysis of potential impact in consultation with the Control Tower, pilots and airport officials;

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<sup>22</sup> [http://www.faa.gov/airports/environmental/policy\\_guidance/media/airport\\_solar\\_guide\\_print.pdf](http://www.faa.gov/airports/environmental/policy_guidance/media/airport_solar_guide_print.pdf)

<sup>23</sup> <http://www.gpo.gov/fdsys/pkg/FR-2013-10-23/pdf/2013-24729.pdf>

<sup>24</sup> Flash Blindness, as described in the FAA guidelines, can be described as a temporary visual interference effect that persists after the source of illumination has ceased. This occurs from many reflective materials in the ambient environment.

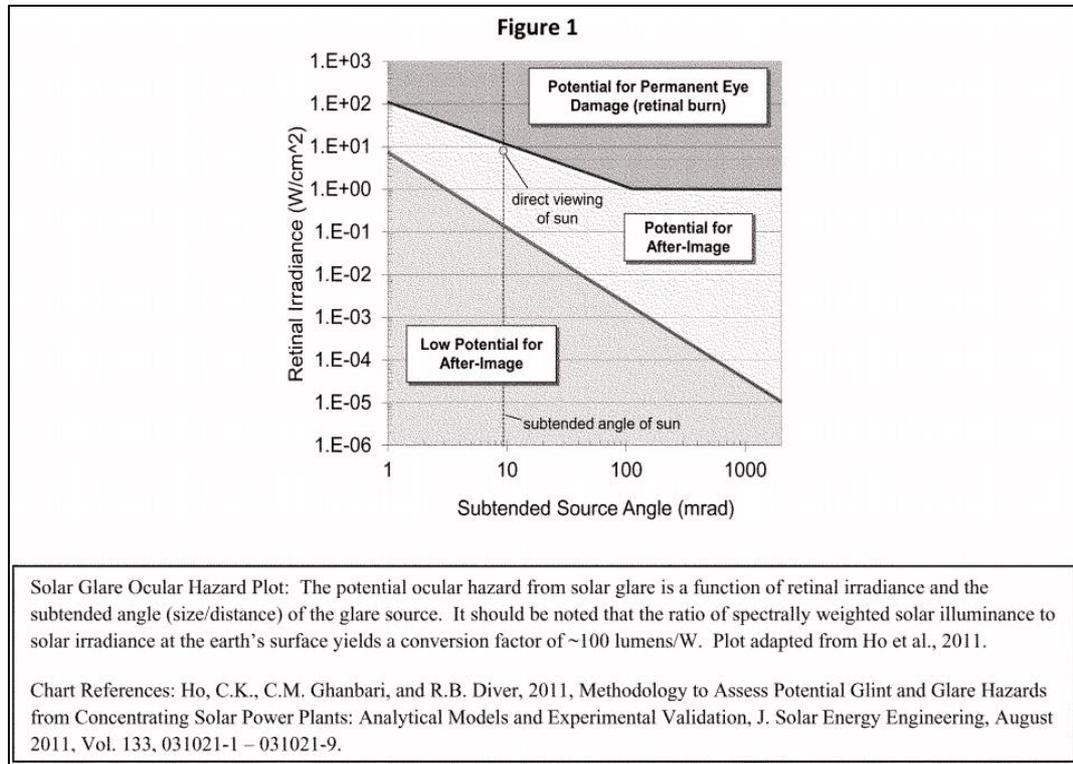
- A demonstration field test with solar panels at the proposed site in coordination with FAA Tower personnel;
  - A geometric analysis to determine days and times when an impact is predicted.
- The extent of reflectivity analysis required to assess potential impacts will depend on the specific project site and system design.
- Reflection in the form of glare is present in current aviation operations. The existing sources of glare come from glass windows, auto surface parking, rooftops, and water bodies. Figure 16 (not shown) shows the percent of incoming sunlight that is reflected off of a variety of surfaces. At airports, existing reflecting surfaces may include hangar roofs, surface parking, and glassy office buildings. To minimize unexpected glare, windows of air traffic control towers and airplane cockpits are coated with anti-reflective glazing and operators will wear polarized eye wear. Potential glare from solar panels should be viewed in this context. Any airport considering a PV installation should first review existing sources of glare at the airport and the effectiveness of measures used to mitigate that glare.
- Geometric studies are the most technical approach for reflectivity issues that are difficult to assess. Studies of glare can employ geometry and the known path of the sun to predict when sunlight will reflect off of a fixed surface (like a solar panel) and contact a fixed receptor (e.g., control tower). At any given site, the sun not only moves across the sky every day, but its path in the sky changes during various times of year. This in turn alters the destination of the resultant reflections since the angle of reflection for the solar panels will be the same as the angle at which the sun hits the panels. The larger the reflective surface, the greater the likelihood of glare impacts.
- Solar installations are presently operating at a number of airports including megawatt-sized solar facilities covering multiple acres. Project managers from six airports where solar has been operational for one to three years were asked about glare complaints. Air traffic controllers were contacted from three of those airports and asked to comment on the effect of glare on their daily operations. To date, there have been no serious complaints from pilots or air traffic control due to glare impacts from existing airport solar PV installations.

*Any potential problems in this area have apparently been resolved prior to construction through one or a combination of the strategies described above. The anecdotal evidence suggests that either considerable glare is not occurring during times of operation or if glare is occurring, it is not a negative effect and is a minor part of the landscape to which pilots and tower personnel are exposed.*

From October 2013, the FAA is reviewing multiple sections of the guidance based on new information and field experience. An overview of the 2013 FAA interim guidance is presented below.

- Solar energy systems located on an airport that is not federally-obligated or located outside the property of a federally-obligated airport are not subject to this policy.
- Proponents of solar energy systems located off-airport property or on non-federally-obligated airports are strongly encouraged to consider the requirements of this policy when siting such system.

- FAA adopts the Solar Glare Hazard Analysis Plot shown...below as the standard for measuring the ocular impact of any proposed solar energy system on a federally-obligated airport. This is shown in the figure below.



Solar Glare Hazard Analysis Plot (FAA)

- **No potential for glint or glare in the existing or planned Airport Traffic Control Tower (ATC) cab, and**
- **No potential for glare or “low potential for after-image” ... along the final approach path for any existing landing threshold or future landing thresholds (including any planned interim phases of the landing thresholds) as shown on the current FAA-approved Airport Layout Plan (ALP). The final approach path is defined as two (2) miles from fifty (50) feet above the landing threshold using a standard three (3) degree glidepath.**
- Ocular impact must be analysed over the entire calendar year in one (1) minute intervals from when the sun rises above the horizon until the sun sets below the horizon.

The two bullets highlighted above state there should be ‘no potential for glare’ at that ATC Tower and ‘no’ or ‘low potential for glare’ on the approach paths.

### **Air Navigation Order (ANO) 2009**

In some instances, an aviation stakeholder can refer to the ANO 2009 with regard to safeguarding. Key points from the document are presented below.

#### ***Endangering safety of an aircraft***

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

#### ***Lights liable to endanger***

221.

*(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.*

#### ***Lights which dazzle or distract***

*222. 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.'*

The document states that no 'light', 'dazzle' or 'glare' should be produced which will create a detrimental impact upon aircraft safety.

## APPENDIX B – OVERVIEW OF GLINT AND GLARE STUDIES

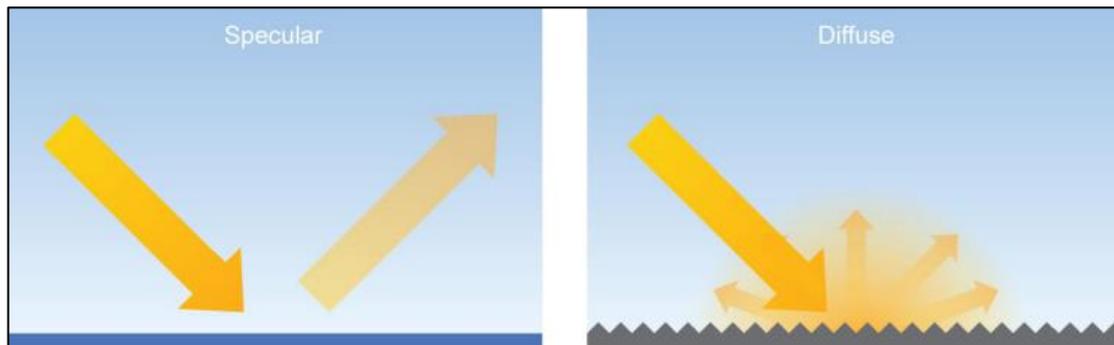
### Overview

Studies have been undertaken assessing the type and intensity of solar reflections from various surfaces including solar panels and glass. An overview of these studies is presented below.

The guidelines presented are related to aviation safety. The results are applicable for the purpose of this analysis.

### Reflection Type from Solar Panels

Based on the surface conditions reflections from light can be specular and diffuse. A specular reflection has a reflection characteristic similar to that of a mirror; a diffuse will reflect the incoming light and scatter it in many directions. The figure below, taken from the FAA guidance<sup>25</sup>, illustrates the difference between the two types of reflections. Because solar panels are flat and have a smooth surface most of the light reflected is specular, which means that incident light from a specific direction is reradiated in a specific direction.



*Specular and diffuse reflections*

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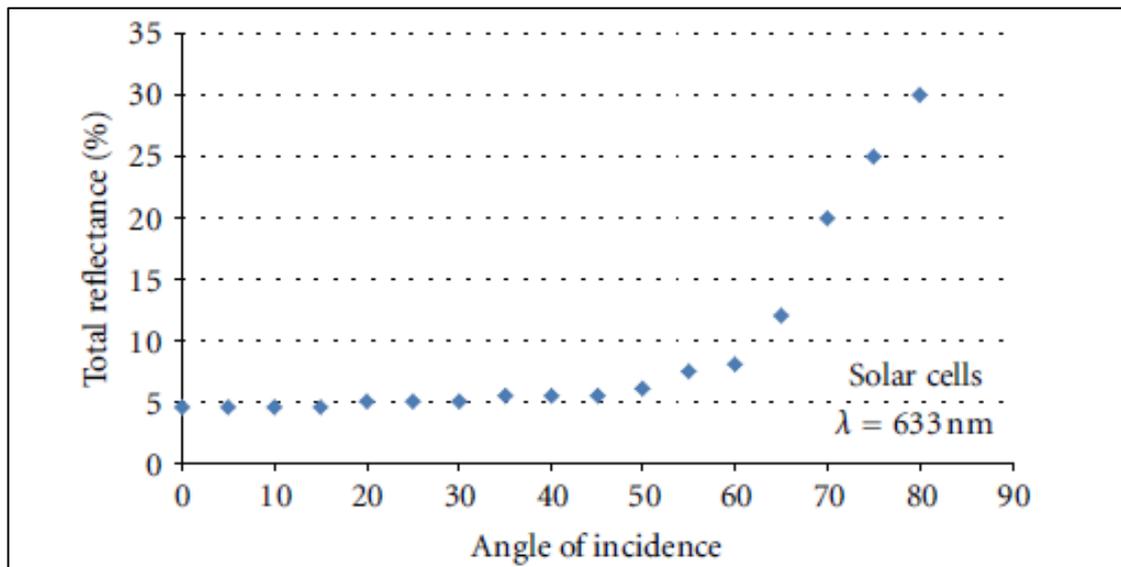
<sup>25</sup> Source: Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration, November 2010.

## Solar Reflection Studies

An overview of content from identified solar panel reflectivity studies is presented in the subsections below.

### Evan Riley and Scott Olson, “A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems”

Evan Riley and Scott Olson published in 2011 their study titled: *A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems*<sup>26</sup>. They researched the potential glare that a pilot could experience from a 25 degree fixed tilt PV system located outside of Las Vegas, Nevada. The theoretical glare was estimated using published ocular safety metrics which quantify the potential for a postflash glare after-image. This was then compared to the postflash glare after-image caused by smooth water. The study demonstrated that the reflectance of the solar cell varied with angle of incidence, with maximum values occurring at angles close to 90 degrees. The reflectance values varied from approximately 5% to 30%. This is shown on the figure below.



Total reflectance % when compared to angle of incidence

The conclusions of the research study were:

- The potential for hazardous glare from flat-plate PV systems is similar to that of smooth water;
- Portland white cement concrete (which is a common concrete for runways), snow, and structural glass all have a reflectivity greater than water and flat plate PV modules.

<sup>26</sup> Evan Riley and Scott Olson, “A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems,” *ISRN Renewable Energy*, vol. 2011, Article ID 651857, 6 pages, 2011. doi:10.5402/2011/651857

**FAA Guidance- “Technical Guidance for Evaluating Selected Solar Technologies on Airports”<sup>27</sup>**

The 2010 FAA Guidance included a diagram which illustrates the relative reflectance of solar panels compared to other surfaces. The figure shows the relative reflectance of solar panels compared to other surfaces. Surfaces in this figure produce reflections which are specular and diffuse. A specular reflection (those made by most solar panels) has a reflection characteristic similar to that of a mirror. A diffuse reflection will reflect the incoming light and scatter it in many directions. A table of reflectivity values, sourced from the figure within the FAA guidance, is presented below.

Surface	Approximate Percentage of Light Reflected <sup>28</sup>
Snow	80
White Concrete	77
Bare Aluminium	74
Vegetation	50
Bare Soil	30
Wood Shingle	17
Water	5
Solar Panels	5
Black Asphalt	2

*Relative reflectivity of various surfaces*

Note that the data above does not appear to consider the reflection type (specular or diffuse).

An important comparison in this table is the reflectivity compared to water which will produce a reflection of very similar intensity when compared to that from a solar panel. The study by Riley and Olsen study (2011) also concludes that still water has a very similar reflectivity to solar panels.

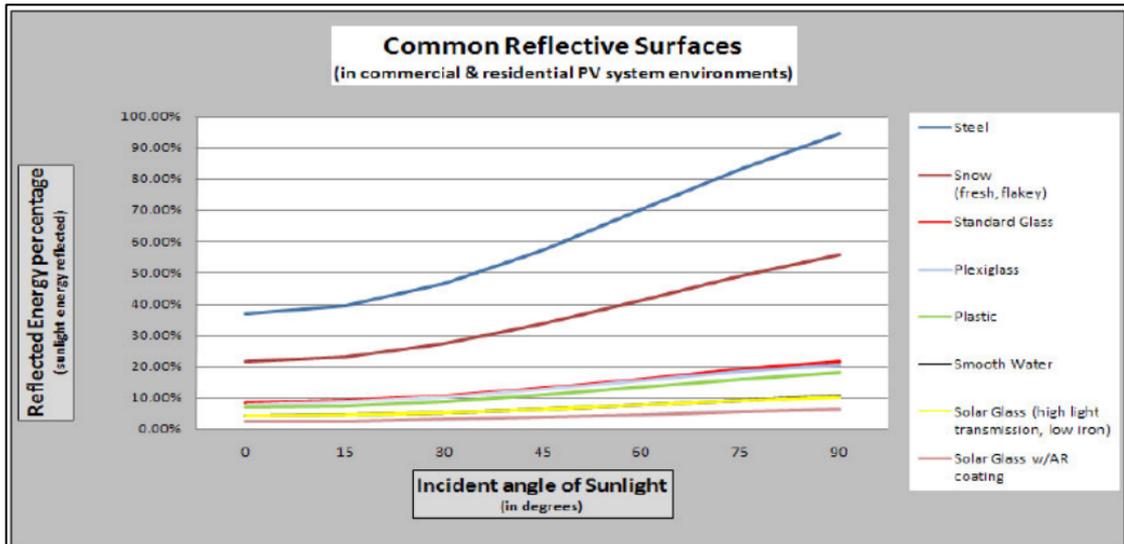
<sup>27</sup> Source: Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration, November 2010.

<sup>28</sup> Extrapolated data, baseline of 1,000 W/m<sup>2</sup> for incoming sunlight.

### SunPower Technical Notification (2009)

SunPower published a technical notification<sup>29</sup> to 'increase awareness concerning the possible glare and reflectance impact of PV Systems on their surrounding environment'.

The figure presented below shows the relative reflectivity of solar panels compared to other natural and manmade materials including smooth water, standard glass and steel.



Common reflective surfaces

The results, similarly to those from Riley and Olsen study (2011) and the FAA (2010), show that solar panels produce a reflection that is less intense than those of 'standard glass and other common reflective surfaces'.

With respect to aviation and solar reflections observed from the air, SunPower has developed several large installations near airports or on Air Force bases. It is stated that these developments have all passed FAA or Air Force standards with all developments considered "No Hazard to Air Navigation". The note suggests that developers discuss any possible concerns with stakeholders near proposed solar farms.

<sup>29</sup> Source: Technical Support, 2009. SunPower Technical Notification – Solar Module Glare and Reflectance.

## APPENDIX C – OVERVIEW OF SUN MOVEMENTS AND RELATIVE REFLECTIONS

### Overview

The Sun's position in the sky can be accurately described by its azimuth and elevation. Azimuth is a direction relative to true north (horizontal angle i.e. from left to right) and elevation describes the Sun's angle relative to the horizon (vertical angle i.e. up and down).

The Sun's position can be accurately calculated for a specific location. The following data being used for the calculation:

- Time;
- Date;
- Latitude;
- Longitude.

The combination of the Sun's azimuth angle and vertical elevation will affect the direction and angle of the reflection from a reflector.

## APPENDIX D – GLINT AND GLARE IMPACT SIGNIFICANCE

### Overview

The significance of glint and glare will vary for different receptors. The following section presents a general overview of the significance criteria with respect to experiencing a solar reflection.

### Impact significance definition

The table below presents the recommended definition of ‘impact significance’ in glint and glare terms and the requirement for mitigation under each.

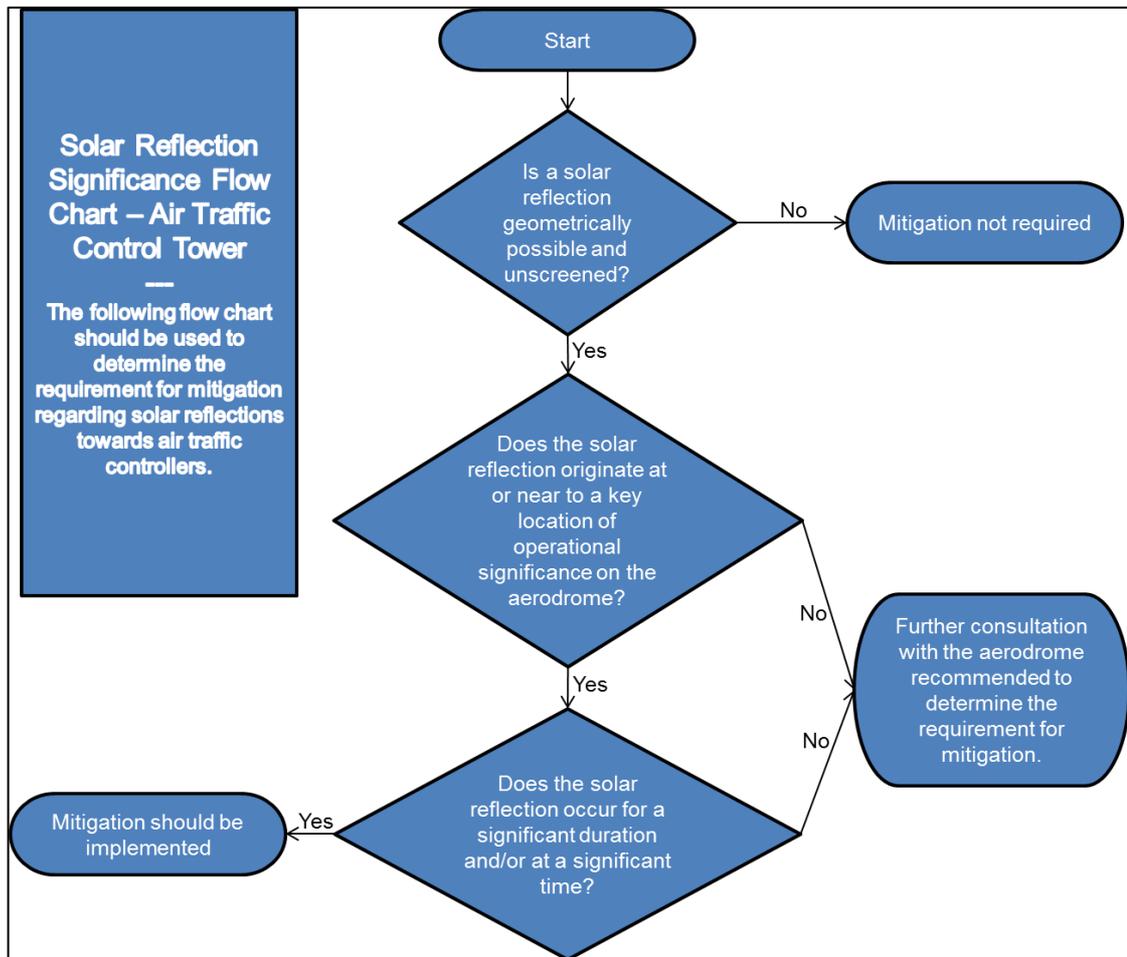
Impact Significance	Definition	Mitigation Requirement
No Impact	A solar reflection is not geometrically possible or will not be visible from the assessed receptor.	No mitigation required.
Low	A solar reflection is geometrically possible however any impact is considered to be small such that mitigation is not required e.g. intervening screening will limit the view of the reflecting solar panels.	No mitigation required.
Moderate	A solar reflection is geometrically possible and visible however it occurs under conditions that do not represent a worst-case.	Whilst the impact may be acceptable, consultation and/or further analysis should be undertaken to determine the requirement for mitigation.
Major	A solar reflection is geometrically possible and visible under conditions that will produce a significant impact.  Mitigation and consultation is recommended.	Mitigation will be required if the proposed development is to proceed.

*Impact significance definition*

The flow charts presented in the following sub-sections have been followed when determining the mitigation requirement for aviation receptors.

## Assessment Process – ATC Tower

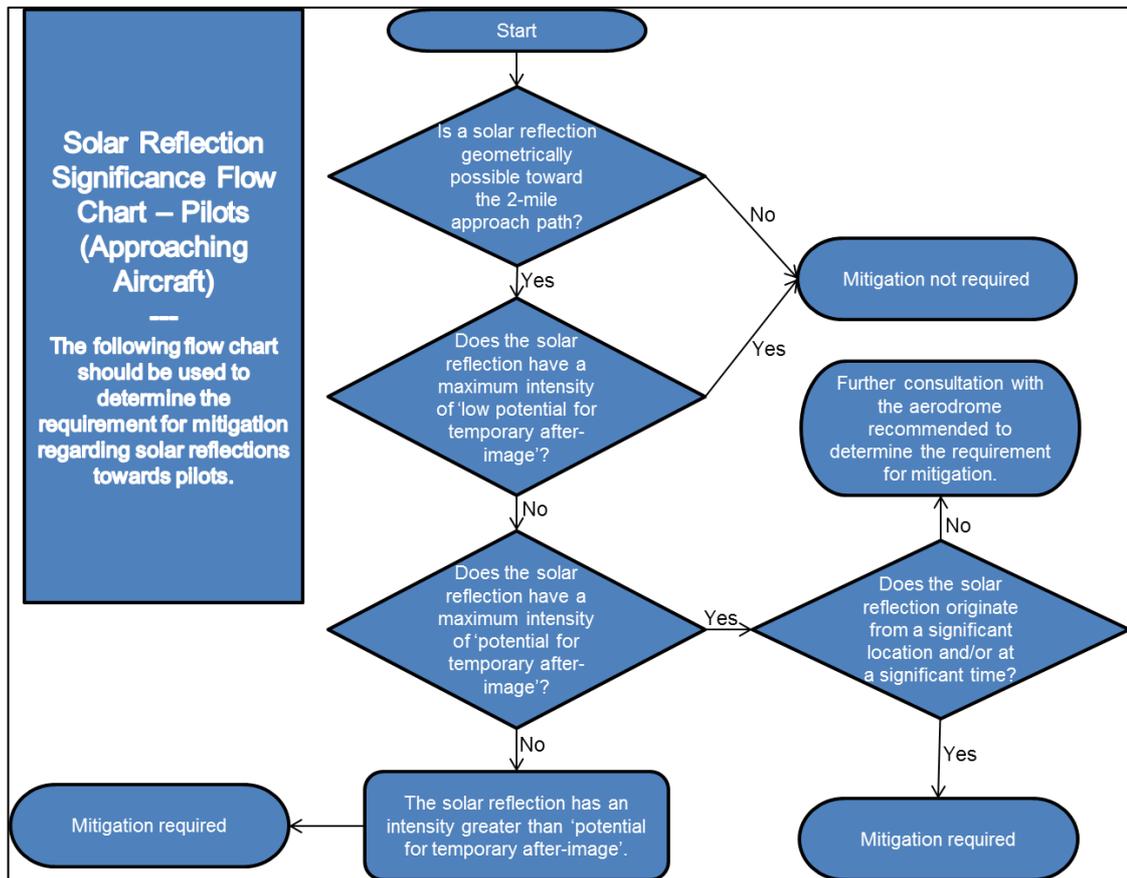
The charts relate to the determining the potential impact upon the ATC Tower.



ATC Tower mitigation requirement flow chart

## Assessment Process – Approaching Aircraft

The charts relate to the determining the potential impact upon approaching aircraft.



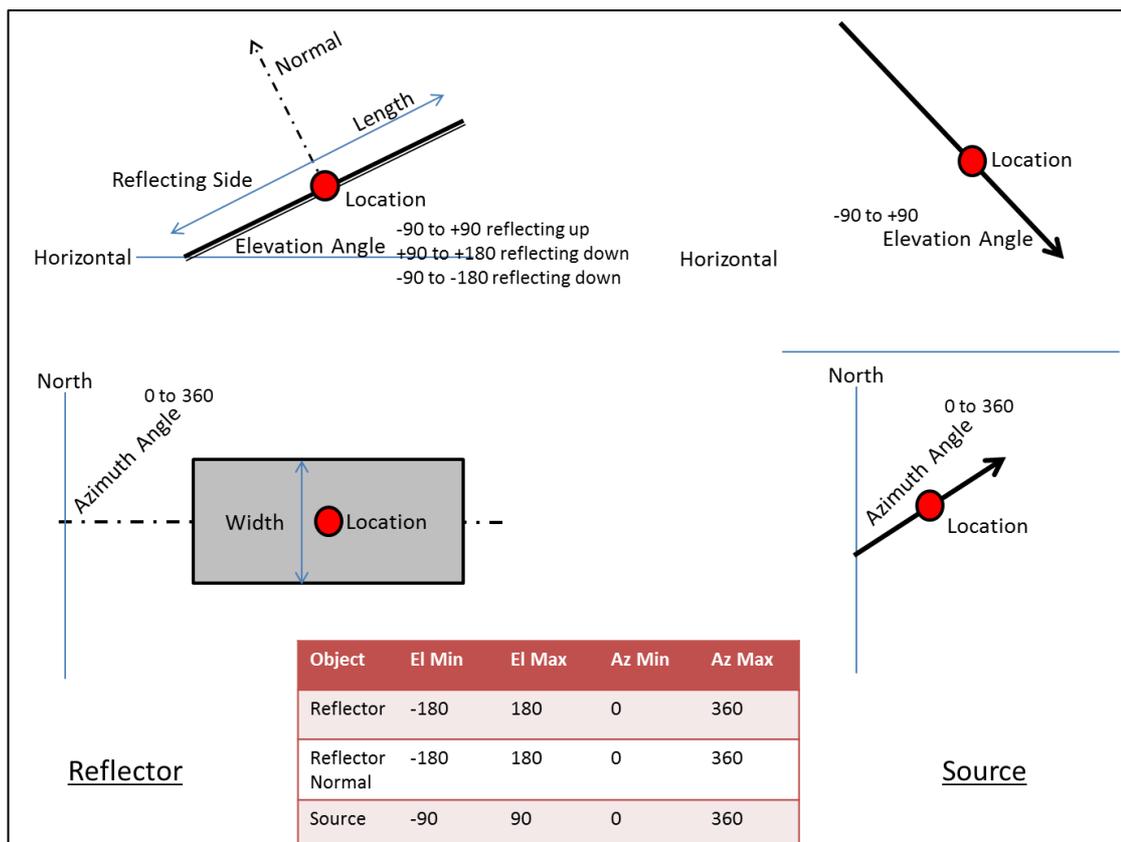
Approaching aircraft receptor mitigation requirement flow chart

## APPENDIX E – PAGER POWER’S REFLECTION CALCULATIONS METHODOLOGY

The calculations are three dimensional and complex, accounting for:

- The Earth’s orbit around the Sun;
- The Earth’s rotation;
- The Earth’s orientation;
- The reflector’s location;
- The reflector’s 3D Orientation.

Reflections from a flat reflector are calculated by considering the normal which is an imaginary line that is perpendicular to the reflective surface and originates from it. The diagram below may be used to aid understanding of the reflection calculation process.



The following process is used to determine the 3D azimuth and elevation of a reflection:

- Use the Latitude and Longitude of reflector as the reference for calculation purposes;
- Calculate the Azimuth and Elevation of the normal to the reflector;
- Calculate the 3D angle between the source and the normal;

- If this angle is less than 90 degrees a reflection will occur. If it is greater than 90 degrees no reflection will occur because the source is behind the reflector;
- Calculate the Azimuth and Elevation of the reflection in accordance with the following:
  - The angle between source and normal is equal to angle between normal and reflection;
  - Source, Normal and Reflection are in the same plane.

## APPENDIX F – ASSESSMENT LIMITATIONS AND ASSUMPTIONS

### Pager Power's Model

It is assumed that the panel elevation angle provided by the developer represents the elevation angle for all of the panels within the solar development.

It is assumed that the panel azimuth angle provided by the developer represents the azimuth angle for all of the panels within the solar development.

Only a reflection from the face of the panel has been considered. The frame or the reverse of the solar panel has not been considered.

The model assumes that a receptor can view the face of every panel within the proposed development area whilst in reality this, in the majority of cases, will not occur. Therefore any predicted reflection from the face of a solar panel that is not visible to a receptor will not occur.

A finite number of points within the proposed development are chosen based on an assessment resolution so we can build a comprehensive understanding of the entire development. This will determine whether a reflection could ever occur at a chosen receptor. The calculations do not incorporate all of the possible panel locations within the development outline.

A single reflection point on the panel has been chosen for the geometric calculations. This will suitably determine whether a reflection can be experienced at a location and the general time of year and duration of this reflection. Increased accuracy could be achieved by increasing the number of heights assessed however this would only marginally change the results and is not considered significant.

Whilst line of sight to the development from receptors has been considered, only available street view imagery and satellite mapping has been used. In some cases this imagery may not be up to date and may not give the full perspective of the installation from the location of the assessed receptor.

Any screening in the form of trees, buildings etc. that may obstruct the Sun from view of the solar panels is not considered unless stated.

### Sandia National Laboratories' (SGHAT) Model

The following text is taken from the Solar Glare Hazard Analysis Tool (SGHAT) Technical Reference Manual<sup>30</sup> which was previously freely available. The following is presented for reference.

### 3. Assumptions and Limitations

Below is a list of assumptions and limitations of the models and methods used in SGHAT:

- The software currently only applies to flat reflective surfaces. For curved surfaces (e.g., focused mirrors such as parabolic troughs or dishes used in concentrating solar power systems), methods and models derived by Ho et al. (2011) [1] can be used and are currently being evaluated for implementation into future versions SGHAT.
- When enabled, PV array single- or dual-axis tracking does not account for backtracking or the effects of panel shading and blocking.
- SGHAT does not rigorously represent the detailed geometry of a system; detailed features such as gaps between modules, variable height of the PV array, and support structures may impact actual glare results. However, we have validated our models against several systems, including a PV array causing glare to the air-traffic control tower at Manchester-Boston Regional Airport and several sites in Albuquerque, and the tool accurately predicted the occurrence and intensity of glare at different times and days of the year.
- SGHAT assumes that the PV array is aligned with a plane defined by the total heights of the coordinates outlined in the Google map. For more accuracy, the user should perform runs using minimum and maximum values for the vertex heights to bound the height of the plane containing the solar array. Doing so will expand the range of observed solar glare when compared to results using a single height value.
- SGHAT does not consider obstacles (either man-made or natural) between the observation points and the prescribed solar installation that may obstruct observed glare, such as trees, hills, buildings, etc.
- The variable direct normal irradiance (DNI) feature (if selected) scales the user-prescribed peak DNI using a typical clear-day irradiance profile. This profile has a lower DNI in the mornings and evenings and a maximum at solar noon. The scaling uses a clear-day irradiance profile based on a normalized time relative to sunrise, solar noon, and sunset, which are prescribed by a sun-position algorithm [2] and the latitude and longitude obtained from Google maps. The actual DNI on any given day can be affected by cloud cover, atmospheric attenuation, and other environmental factors.
- The ocular hazard predicted by the tool depends on a number of environmental, optical, and human factors, which can be uncertain. We provide input fields and typical ranges of values for these factors so that the user can vary these parameters to see if they have an impact on the results. The speed of SGHAT allows expedited sensitivity and parametric analyses.

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<sup>30</sup> [https://share.sandia.gov/phlux/static/references/glint-glare/SGHAT\\_Technical\\_Reference-v5.pdf](https://share.sandia.gov/phlux/static/references/glint-glare/SGHAT_Technical_Reference-v5.pdf)

## APPENDIX G – RECEPTOR AND REFLECTOR AREA DETAILS

### ATC Receptor Details

The co-ordinates and overall altitude of the ATC Tower has been taken from the military AIP obstacle list. The ground elevation been taken from Pager Power’s database<sup>31</sup> based on the co-ordinates given for the ATC Tower. The details are presented in the table below.

Longitude (°)	Latitude (°)	Ground Height	ATC Tower Height	Overall Assessed Height
-4.53640	53.25171	9.61m	14.64m	24.25m

*ATC Tower receptor details*

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<sup>31</sup> Based on OS Panorama 50m DTM

## The Approach Surface for Aircraft Landing on Runway 01

The table below presents the data for the assessed locations for aircraft on approach to runway 01. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (17.95ft amsl).

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Threshold	-4.54045	53.24351	20.7
Receptor 02	-4.54071	53.24207	29.1
Receptor 03	-4.54098	53.24063	37.6
Receptor 04	-4.54125	53.23919	46.0
Receptor 05	-4.54151	53.23775	54.4
Receptor 06	-4.54178	53.23631	62.9
Receptor 07	-4.54204	53.23487	71.3
Receptor 08	-4.54231	53.23343	79.8
Receptor 09	-4.54258	53.23199	88.2
Receptor 10	-4.54284	53.23055	96.6
Receptor 11 – 1 mile	-4.54311	53.22911	105.1
Receptor 12	-4.54337	53.22767	113.5
Receptor 13	-4.54364	53.22623	121.9
Receptor 14	-4.54391	53.22479	130.4
Receptor 15	-4.54417	53.22336	138.8
Receptor 16	-4.54444	53.22192	147.2
Receptor 17	-4.54470	53.22048	155.7
Receptor 18	-4.54497	53.21904	164.1
Receptor 19	-4.54524	53.21760	172.5
Receptor 20	-4.54550	53.21616	181.0
Receptor 21 – 2 miles	-4.54577	53.21472	189.4

*Assessed receptor (aircraft) locations on the approach path for runway 01*

## The Approach Surface for Aircraft Landing on Runway 19

The table below presents the data for the assessed locations for aircraft on approach to runway 19. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (34.74ft amsl).

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Threshold	-4.53786	53.25754	25.8
Receptor 02	-4.53759	53.25898	34.3
Receptor 03	-4.53733	53.26042	42.7
Receptor 04	-4.53706	53.26186	51.1
Receptor 05	-4.53679	53.26330	59.6
Receptor 06	-4.53653	53.26474	68.0
Receptor 07	-4.53626	53.26618	76.4
Receptor 08	-4.53599	53.26762	84.9
Receptor 09	-4.53573	53.26906	93.3
Receptor 10	-4.53546	53.27050	101.7
Receptor 11 – 1 mile	-4.53520	53.27194	110.2
Receptor 12	-4.53493	53.27338	118.6
Receptor 13	-4.53466	53.27482	127.0
Receptor 14	-4.53440	53.27626	135.5
Receptor 15	-4.53413	53.27770	143.9
Receptor 16	-4.53386	53.27914	152.3
Receptor 17	-4.53360	53.28058	160.8
Receptor 18	-4.53333	53.28202	169.2
Receptor 19	-4.53307	53.28346	177.6
Receptor 20	-4.53280	53.28490	186.1
Receptor 21 – 2 miles	-4.53253	53.28633	194.5

*Assessed receptor (aircraft) locations on the approach path for runway 19*

### The Approach Surface for Aircraft Landing on Runway 13

The table below presents the data for the assessed locations for aircraft on approach to runway 13. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (30.79ft amsl).

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Threshold	-4.54636	53.25379	24.6
Receptor 02	-4.54820	53.25473	33.1
Receptor 03	-4.55004	53.25567	41.5
Receptor 04	-4.55189	53.25661	49.9
Receptor 05	-4.55373	53.25755	58.4
Receptor 06	-4.55557	53.25849	66.8
Receptor 07	-4.55742	53.25942	75.2
Receptor 08	-4.55926	53.26036	83.7
Receptor 09	-4.56110	53.26130	92.1
Receptor 10	-4.56295	53.26224	100.5
Receptor 11 – 1 mile	-4.56479	53.26318	109.0
Receptor 12	-4.56663	53.26412	117.4
Receptor 13	-4.56848	53.26506	125.8
Receptor 14	-4.57032	53.26600	134.3
Receptor 15	-4.57216	53.26694	142.7
Receptor 16	-4.57401	53.26787	151.1
Receptor 17	-4.57585	53.26881	159.6
Receptor 18	-4.57769	53.26975	168.0
Receptor 19	-4.57954	53.27069	176.4
Receptor 20	-4.58138	53.27163	184.9
Receptor 21 – 2 miles	-4.58322	53.27257	193.3

*Assessed receptor (aircraft) locations on the approach path for runway 13*

### The Approach Surface for Aircraft Landing on Runway 31

The table below presents the data for the assessed locations for aircraft on approach to runway 31. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (23.1ft amsl).

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Threshold	-4.52024	53.24045	22.3
Receptor 02	-4.51840	53.23951	30.7
Receptor 03	-4.51655	53.23857	39.1
Receptor 04	-4.51471	53.23763	47.6
Receptor 05	-4.51287	53.23669	56.0
Receptor 06	-4.51103	53.23575	64.5
Receptor 07	-4.50919	53.23481	72.9
Receptor 08	-4.50734	53.23387	81.3
Receptor 09	-4.50550	53.23293	89.8
Receptor 10	-4.50366	53.23199	98.2
Receptor 11 – 1 mile	-4.50182	53.23105	106.6
Receptor 12	-4.49998	53.23012	115.1
Receptor 13	-4.49813	53.22918	123.5
Receptor 14	-4.49629	53.22824	131.9
Receptor 15	-4.49445	53.22730	140.4
Receptor 16	-4.49261	53.22636	148.8
Receptor 17	-4.49077	53.22542	157.2
Receptor 18	-4.48892	53.22448	165.7
Receptor 19	-4.48708	53.22354	174.1
Receptor 20	-4.48524	53.22260	182.5
Receptor 21 – 2 miles	-4.48340	53.22166	191.0

*Assessed receptor (aircraft) locations on the approach path for runway 31*

### Modelled Reflector Area

ID	Longitude (°)	Latitude (°)	Ground Height amsl	Assessment Data
1	-4.52714	53.27247	Ground height taken from Based on OS Panorama 50m DTM. An additional 2m has been added to represent the approximate mid pint of the solar panels above ground level.	The azimuth angle of the solar panels has been assessed at 180 degrees. The panel elevation angle has been assessed at 25 degrees.
2	-4.52664	53.27234		
3	-4.52625	53.27235		
4	-4.52559	53.27215		
5	-4.52535	53.27196		
6	-4.52483	53.27198		
7	-4.52448	53.27209		
8	-4.52266	53.27211		
9	-4.52152	53.27173		
10	-4.52136	53.27074		
11	-4.52333	53.26941		
12	-4.52408	53.26919		
13	-4.52505	53.26849		
14	-4.52613	53.26819		
15	-4.52636	53.26838		
16	-4.52807	53.26822		
17	-4.52859	53.26951		
18	-4.52745	53.27039		
19	-4.52668	53.27043		
20	-4.52668	53.27057		
21	-4.52500	53.27059		
22	-4.52486	53.27088		
23	-4.52684	53.27085		
24	-4.52702	53.27130		
25	-4.52626	53.27142		
26	-4.52575	53.27177		

ID	Longitude (°)	Latitude (°)	Ground Height amsl	Assessment Data
27	-4.52597	53.27217	As above.	As above.
28	-4.52648	53.27222		
29	-4.52719	53.27183		
30	-4.52754	53.27184		
31	-4.52738	53.27220		

Modelled reflector area



Modelled reflector area image

## APPENDIX H – GEOMETRIC CALCULATION RESULTS – PAGER POWER RESULTS

The charts for the receptors are shown on the following pages. Each chart shows:

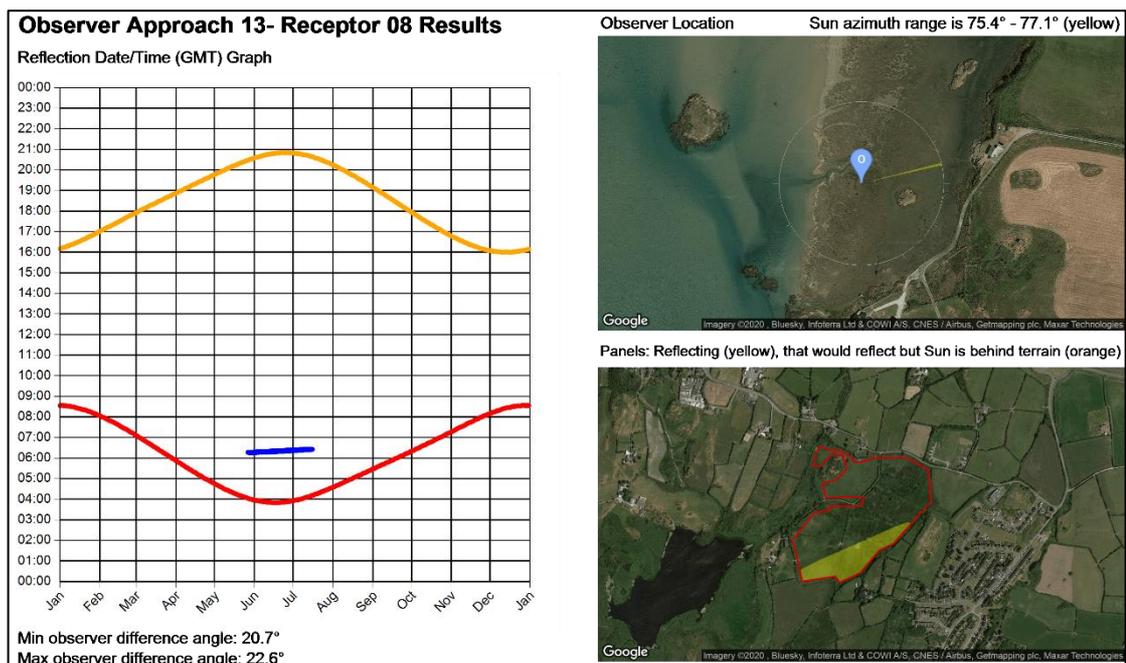
- The receptor (observer) location – top right image. This also shows the azimuth range of the Sun itself at times when reflections are possible. If sunlight is experienced from the same direction as the reflecting panels, the overall impact of the reflection is reduced as discussed within the body of the report;
- The reflecting areas – bottom right image. The reflecting area is shown in yellow. If the yellow panels are not visible from the observer location, no issues will occur in practice. Additional obstructions which may obscure the reflector area from view are considered separately within the analysis;
- The reflection date/time graph – left hand side of the page. The blue line indicates the dates and times at which geometric reflections are possible. This relates to reflections from the yellow areas only.

Only the key results are shown.

### Runway 13 Approach

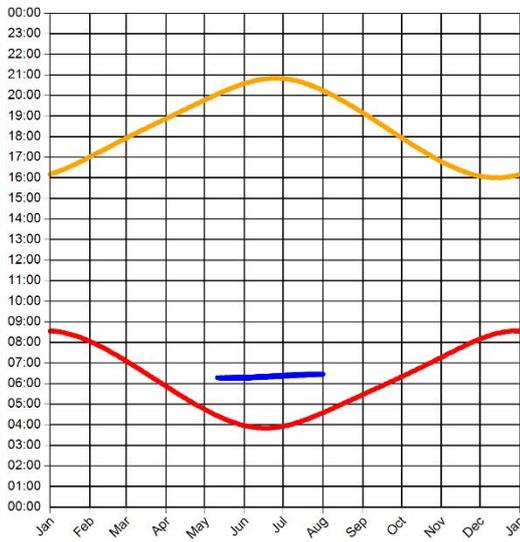
#### Observer Approach 13- Receptor 01-07

No valid reflections found.



## Observer Approach 13- Receptor 09 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 18.3°  
Max observer difference angle: 22.9°

Observer Location Sun azimuth range is 75.4° - 79.6° (yellow)

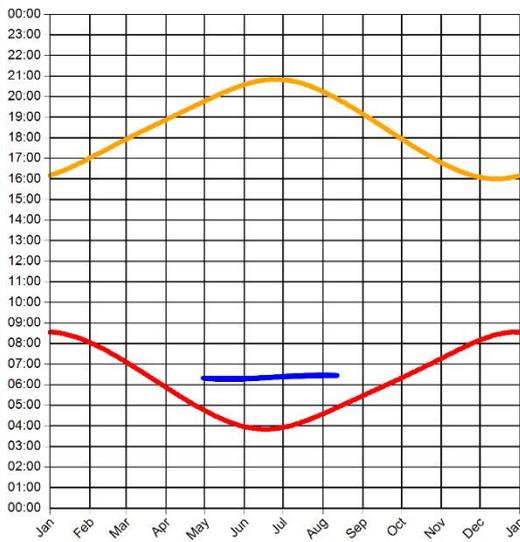


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 13- Receptor 10 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 16°  
Max observer difference angle: 22.8°

Observer Location Sun azimuth range is 75.7° - 81.8° (yellow)

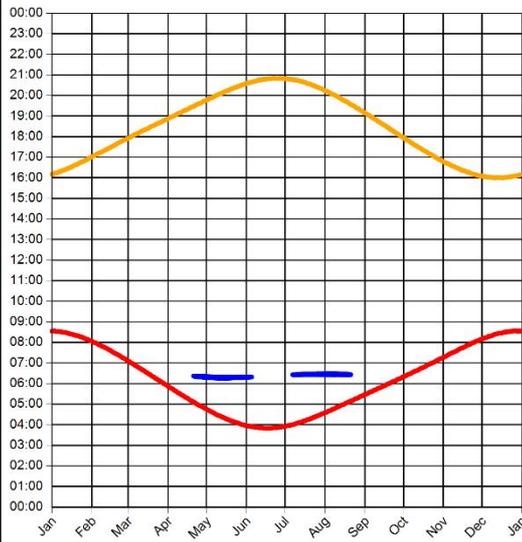


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 13- Receptor 11 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 13.8°  
Max observer difference angle: 22.2°

Observer Location Sun azimuth range is 76.5° - 83.8° (yellow)

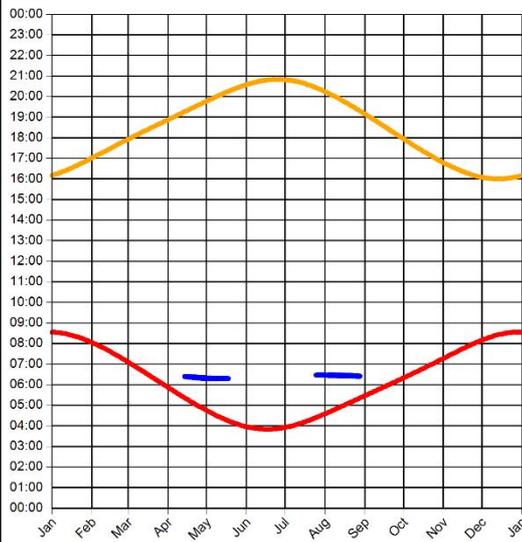


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 13- Receptor 12 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 11.8°  
Max observer difference angle: 20°

Observer Location Sun azimuth range is 78.6° - 85.4° (yellow)

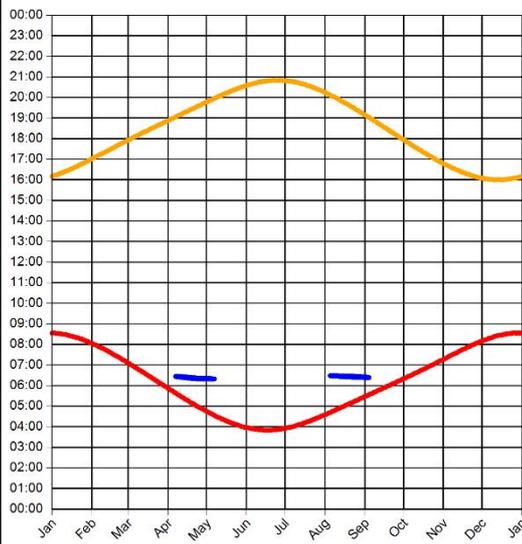


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 13- Receptor 13 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 9.8°  
Max observer difference angle: 18°

Observer Location Sun azimuth range is 80.6° - 87.2° (yellow)

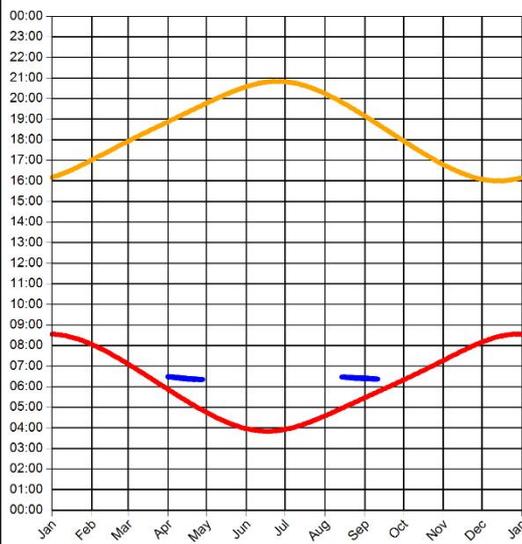


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 13- Receptor 14 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 8°  
Max observer difference angle: 16°

Observer Location Sun azimuth range is 82.4° - 88.9° (yellow)

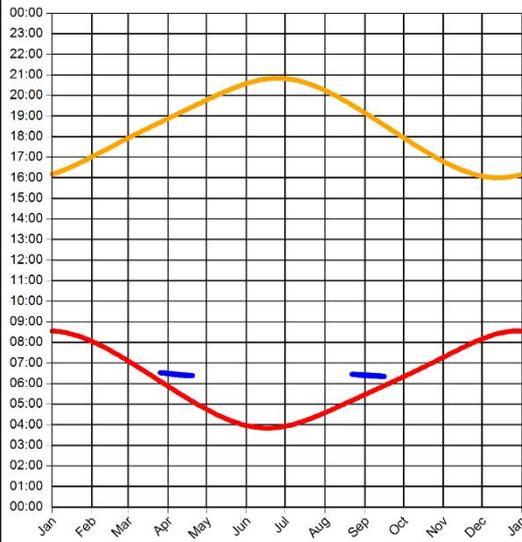


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 13- Receptor 15 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 6.3°  
Max observer difference angle: 14.1°

Observer Location Sun azimuth range is 84.1° - 90.2° (yellow)

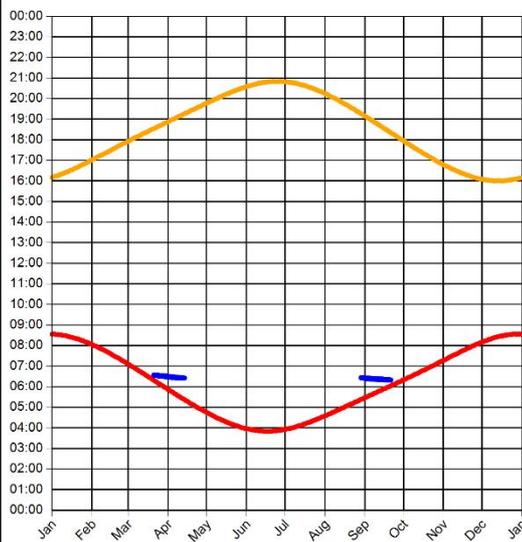


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 13- Receptor 16 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 4.8°  
Max observer difference angle: 12.3°

Observer Location Sun azimuth range is 85.7° - 91.6° (yellow)

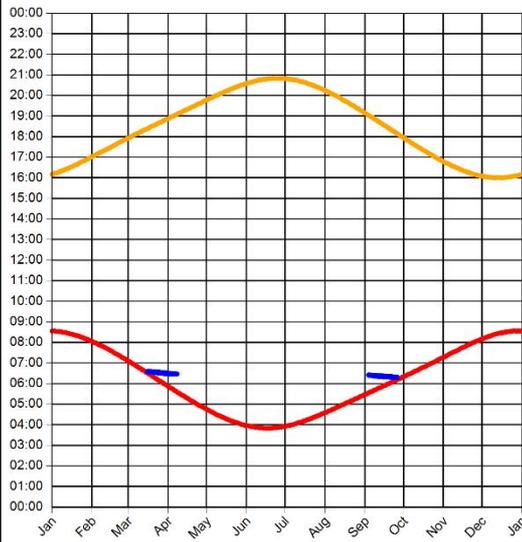


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 13- Receptor 17 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 3.3°  
Max observer difference angle: 10.7°

Observer Location Sun azimuth range is 87.2° - 92.8° (yellow)

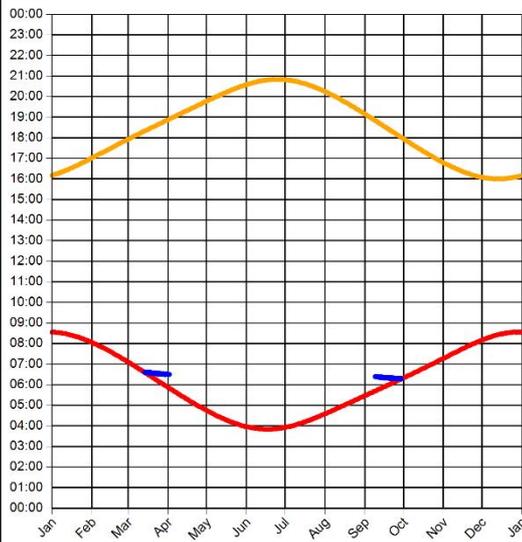


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 13- Receptor 18 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 2.8°  
Max observer difference angle: 9°

Observer Location Sun azimuth range is 88.5° - 93.4° (yellow)

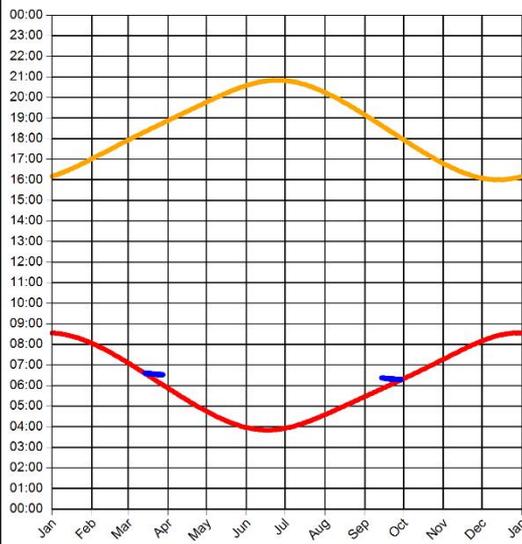


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 13- Receptor 19 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 2.7°  
Max observer difference angle: 7.5°

Observer Location Sun azimuth range is 89.7° - 93.4° (yellow)

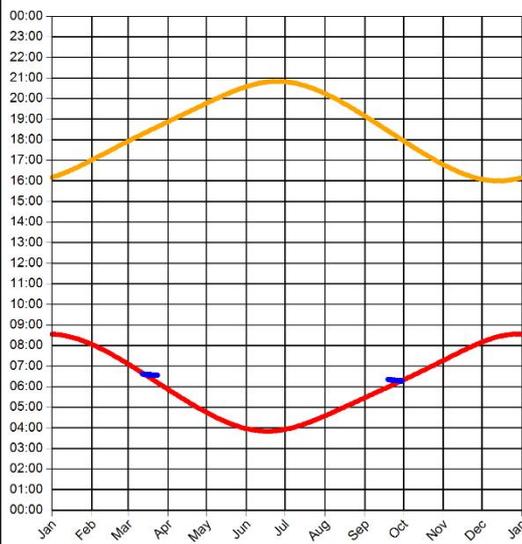


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 13- Receptor 20 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 2.2°  
Max observer difference angle: 6.1°

Observer Location Sun azimuth range is 90.9° - 93.8° (yellow)

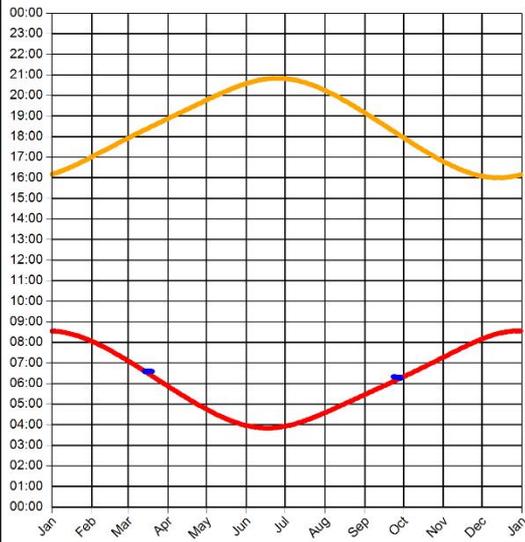


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 13- Receptor 21 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 2.4°  
 Max observer difference angle: 4.9°

Observer Location Sun azimuth range is 92° - 93.3° (yellow)



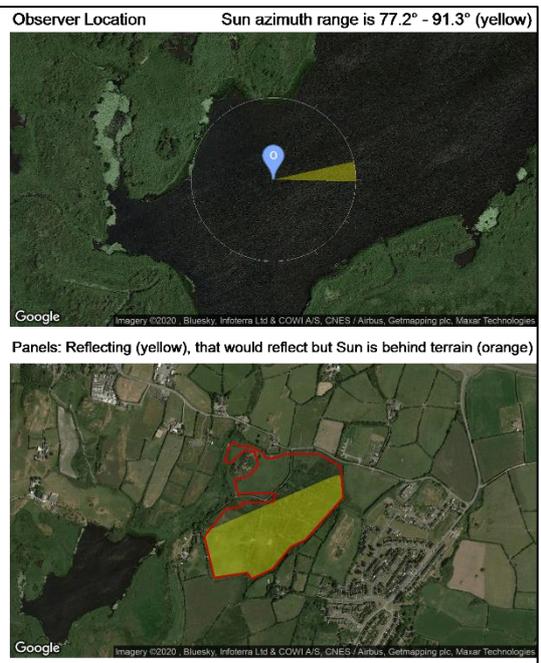
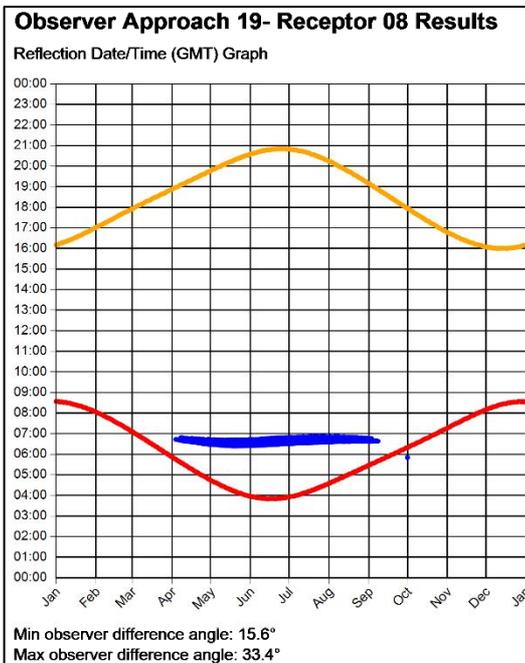
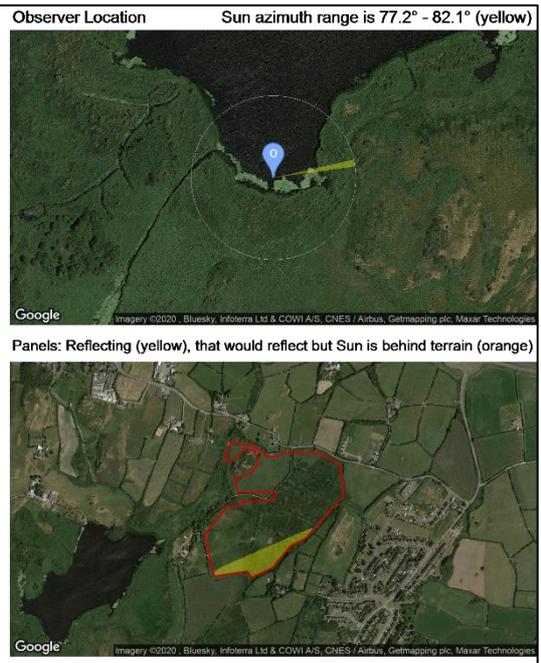
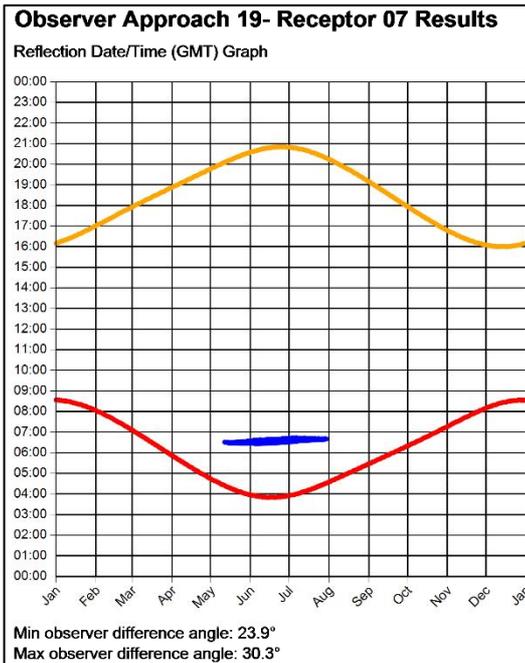
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Runway 19 Approach

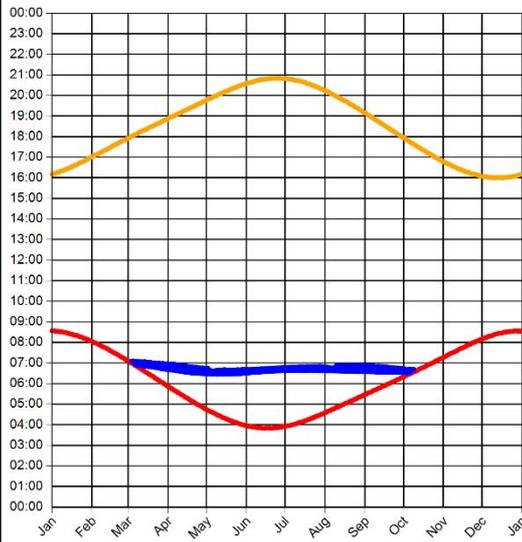
### Observer Approach 19- Receptor 01 - 06

No valid reflections found.



## Observer Approach 19- Receptor 09 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 7.5°  
Max observer difference angle: 32.4°

Observer Location Sun azimuth range is 78.5° - 101° (yellow)

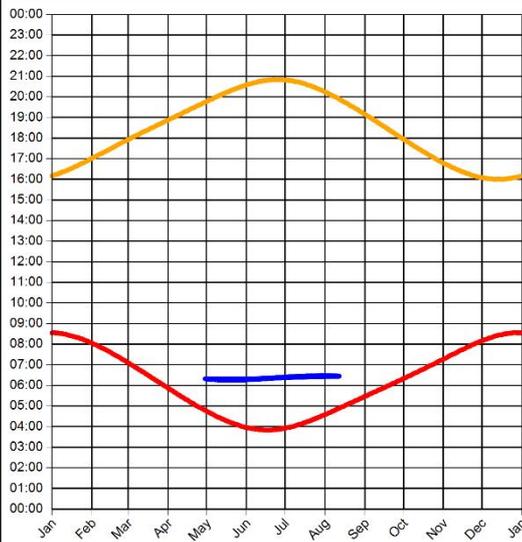


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 13- Receptor 10 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 16°  
Max observer difference angle: 22.8°

Observer Location Sun azimuth range is 75.7° - 81.8° (yellow)

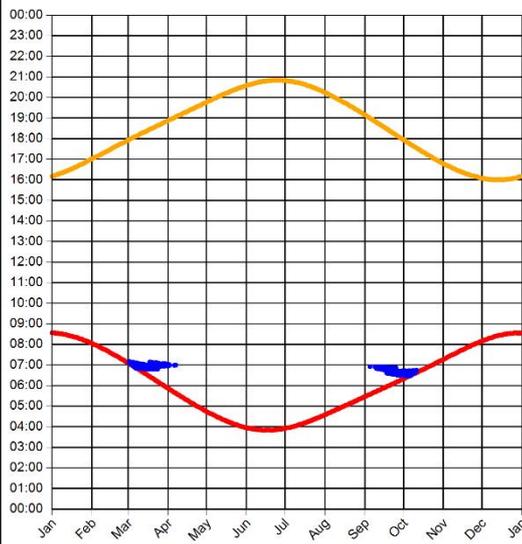


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 19- Receptor 11 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 6.1°  
Max observer difference angle: 24°

Observer Location Sun azimuth range is 93.7° - 102.3° (yellow)

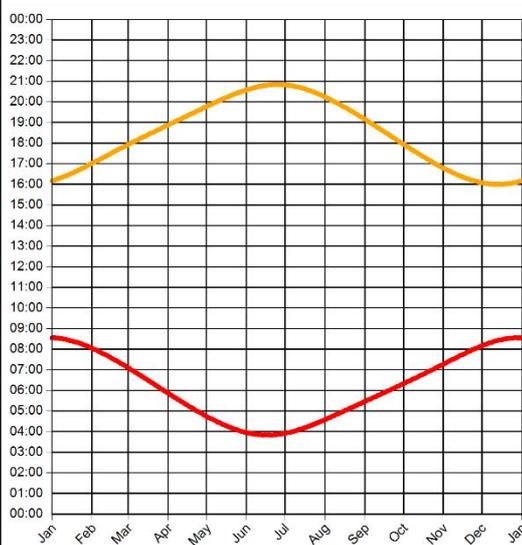


Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 19- Receptor 12 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 6.1°  
Max observer difference angle: 24°



Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)



## Observer Approach 19- Receptor 13 - 21

No valid reflections found.

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