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Solar Photovoltaic Glint and Glare Study

Stansted PV Scheme

Manchester Airport Group

February 2022





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1	November 2021	Initial issue
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EXECUTIVE SUMMARY

Report Purpose

Pager Power has been retained to assess the possible effects of glint and glare from a solar photovoltaic (PV) development known as **Stansted PV Scheme** located immediately southeast of London Stansted Airport in Stansted Mountfitchet, Essex, UK. The assessment pertains to the possible impact upon aviation activity associated with London Stansted Airport. The runway approach paths and the Air Traffic Control (ATC) Tower have been assessed.

Pager Power

Pager Power has undertaken over 750 glint and glare assessments in the UK, Europe and internationally. 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

No impacts are predicted upon personnel in the ATC tower and no mitigation is required.

No significant impacts are predicted upon pilots on approach to the runways assessed at London Stansted Airport.

Glare is possible towards positions within the visual circuits at Stansted Airport. The glare intensity is mostly 'low potential for temporary after-image', which is acceptable even for pilots on final approach. Two out of eighty modelled locations show some glare with 'potential for temporary after-image' (see Figure 9 and Figure 10 on pages 34 and 35 of this report). There are no formal intensity criteria for aircraft in the circuit. It is likely that this level of glare can be operationally accommodated, although this should be discussed with the safeguarding team at London Stansted Airport to understand their position.

Guidance and Studies

Guidelines exist in the UK (produced by the Civil Aviation Authority) and in the USA (produced by the Federal Aviation Administration) with respect to solar developments and aviation activity. The UK CAA guidance is relatively high-level and does not prescribe a formal methodology. Pager Power has reviewed existing guidelines and the available studies in the process of defining its own glint and glare assessment guidance document and methodology[1]. This methodology defines a comprehensive process for determining the impact upon ground-based receptors (including dwellings, roads and railways) and aviation activity. This was published following a literature review, stakeholder consultation and engagement with solar developers. Broadly, the process is to undertake geometric reflection calculations and, where a solar reflection is predicted, consider the screening (existing and/or proposed) between the receptor and the reflecting solar panels. The scenario in which a solar reflection can occur for all receptors is then

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[1] Pager Power Glint and Glare Guidance, Third Edition (3.1), April 2021.

identified and discussed, and a comparison is made against the available solar panel reflection studies to determine the overall impact.

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[2].

Assessment Results - London Stansted Airport

ATC Tower

The modelling indicates that solar reflections from the proposed development towards the ATC tower are not geometrically possible.

No impacts are therefore predicted upon personnel in the ATC tower and no mitigation is required.

Runway 04 Approach

The modelling indicates that solar reflections with 'low potential for temporary after-image' are predicted towards pilots between 0.1 miles and 1.4 miles from the runway 04 threshold. This is acceptable considering the associated guidance (Appendix D).

No significant impacts upon pilots approaching runway 04 are expected, and no mitigation is required.

Runway 22 Approach

The modelling indicates that solar reflections with 'low potential for temporary after-image' are predicted towards pilots between 1.6 miles and 2 miles from the runway 22 threshold. This is acceptable considering the associated guidance (Appendix D).

No significant impacts upon pilots approaching runway 22 are expected, and no mitigation is required.

04 Left-Hand Circuit/22 Right-Hand Circuit

The modelling has shown that solar reflections with a 'low potential for temporary after-image' are predicted towards a section of the 04 left-hand circuit and 22 right-hand circuit. Considering the associated guidance pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for circuit paths.

No significant impacts upon the 04 left-hand circuit and 22 right-hand circuit are expected, and no mitigation is required.

04 Right-Hand Circuit/22 Left-Hand Circuit

The modelling has shown that solar reflections with a maximum of 'low potential for temporary after-image' are predicted towards a section of the 09 right-hand and 27 left hand circuit. Considering the associated guidance pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for circuit paths.

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[2] SunPower, 2009, SunPower Solar Module Glare and Reflectance (appendix to Solargen Energy, 2010).

No significant impacts upon this section of the 04 right-hand circuit and 22 left-hand circuit are therefore predicted.

The modelling has shown that solar reflections with a maximum of 'potential for temporary after-image' are predicted towards a section of the 09 right-hand and 27 left hand circuit. Considering the associated guidance pertaining to approach paths, this level of glare also requires further consideration where circuit paths are concerned. It is likely that this level of glare can be operationally accommodated, although this should be discussed with the safeguarding team at London Stansted Airport to understand their position.

LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 51 countries within Europe, Africa, 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 solar photovoltaic (PV) development known as **Stansted PV Scheme** located immediately east of London Stansted Airport in Stansted Mountfitchet, Essex, UK. The assessment pertains to the possible impact upon aviation activity associated with London Stansted Airport. The runway approach paths and the Air Traffic Control (ATC) Tower have been assessed.

This report contains the following:

- Solar development details.
- Explanation of glint and glare.
- Overview of relevant guidance.
- Overview of relevant studies.
- Overview of Sun movement.
- Assessment methodology.
- Identification of aviation concerns and receptors.
- Glint and glare assessment for identified receptors.
- Results discussion.

1.2 Pager Power's Experience

Pager Power has undertaken over 750 Glint and Glare assessments in the UK and 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 is as follows[3]:

- 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.

The term 'solar reflection' is used in this report to refer to both reflection types i.e. glint and glare.

[3]These definitions are aligned with those of the Federal Aviation Administration (FAA) in the United States of America.

2 SOLAR DEVELOPMENT LOCATION AND DETAILS

2.1 Proposed Development

Figure 1[4] below shows the proposed development plan[5]. The white areas represent the panel areas. Further details regarding the solar panel areas assessed within this report can be seen in Section 6 and Appendix G.

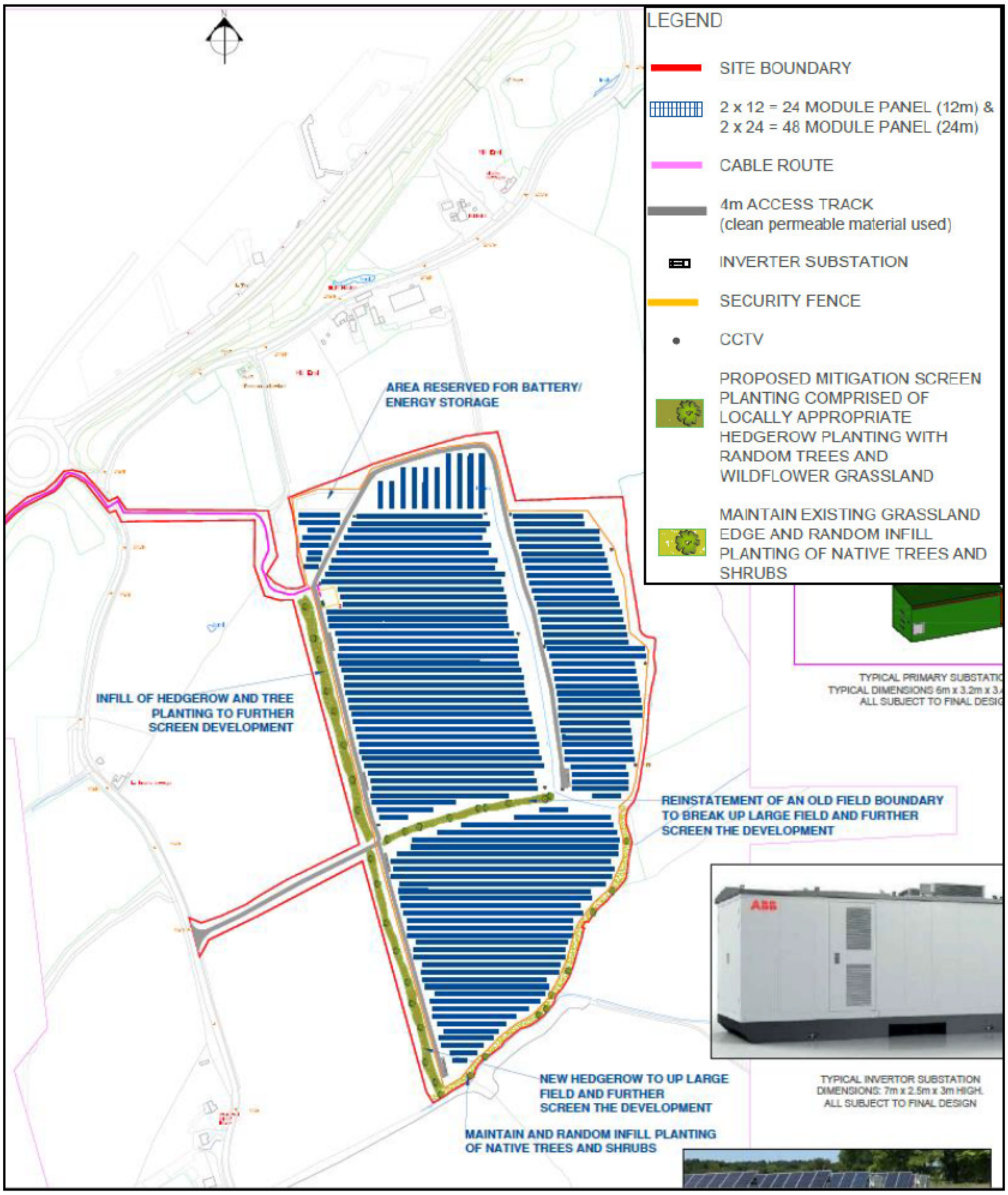

Figure 1 *Proposed development layout*

2.2 Proposed Development Location - Aerial Image

The location of the proposed development is shown overlaid on aerial imagery in Figure 2[6] below. The blue areas denote the solar panel areas.

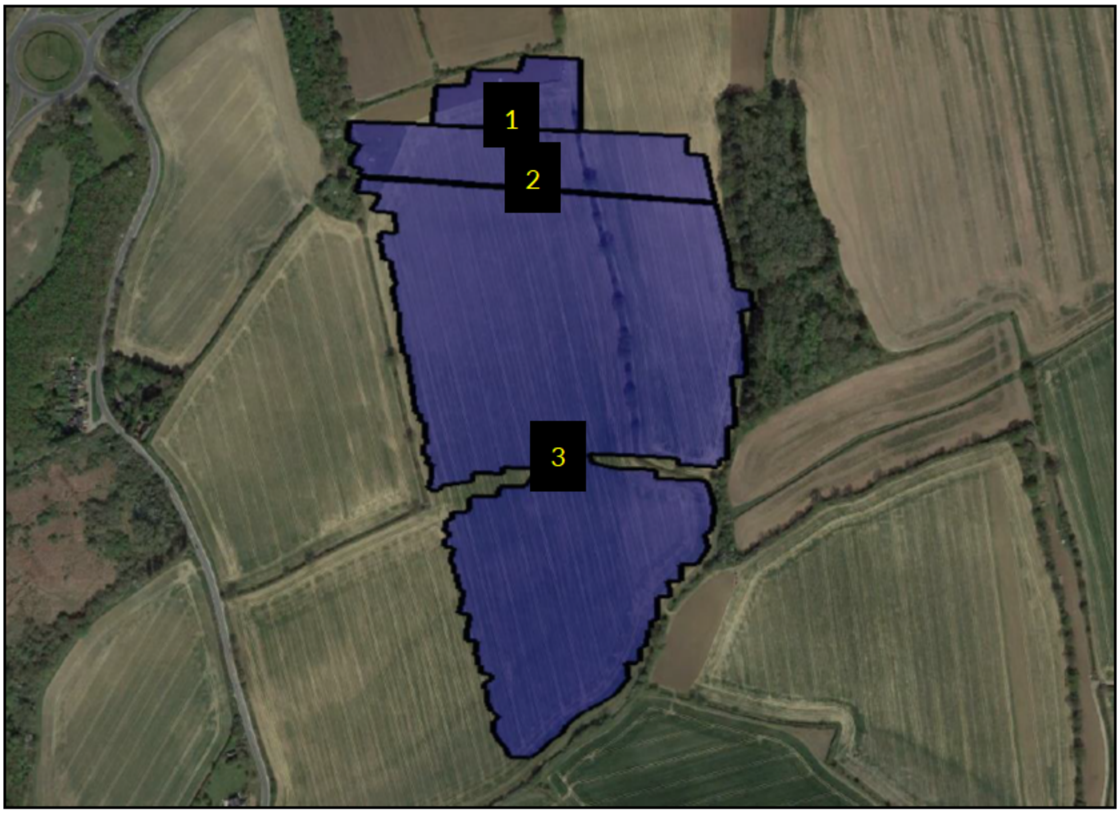

Figure 2 *Proposed development layout – aerial image*

2.3 Solar Panel Details

The solar panel details used in the assessment are presented in Table 1 below.

Solar Panel Details	
Azimuth angle (°)	Panel areas 1 & 2: 90 (East-facing) Panel area 3: 180 (South-facing)
Elevation angle (°)	25
Assessed height (m agl[7])	2[8]

Table 1 *Solar panel details*

[4] Provided by Manchester Airport Group
[5] This layout plan is expected to be updated to reflect the latest panel details.
[6] Source: Aerial image copyright © 2021 Google.
[7] metres above ground level
[8] Average heights are used for the modelling. This average is taken from a minimum of 0.8m up to a maximum of 3.2m.

3 LONDON STANSTED AIRPORT DETAILS

3.1 Overview

The following section presents details regarding London Luton Airport.

3.2 Airport Information

London Stansted Airport is a Civil Aviation Authority (CAA) licensed aerodrome used predominately by fixed wing propeller and jet aircraft, as well as helicopters.

3.3 Runway Details

London Stansted Airport has one runway, the details of which are presented below:

1. 04/22 measuring 3,049m by 46m (asphalt).

The runway is shown on the aerodrome chart in Figure 3[9] on the following page.

3.4 Air Traffic Control Tower

The Air Traffic Control Tower (ATC Tower) is located 1.2km to the east-southeast of the approximate centre point of runway 04/22 and is highlighted in Figure 3 on the following page.

The relative location of the approach paths and the ATC Tower to the proposed development is shown in Figure 4[10] on page 16.

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[9] Source: NATS AIP. Last accessed 04.11.21.

[10] Copyright @ 2021 Google.

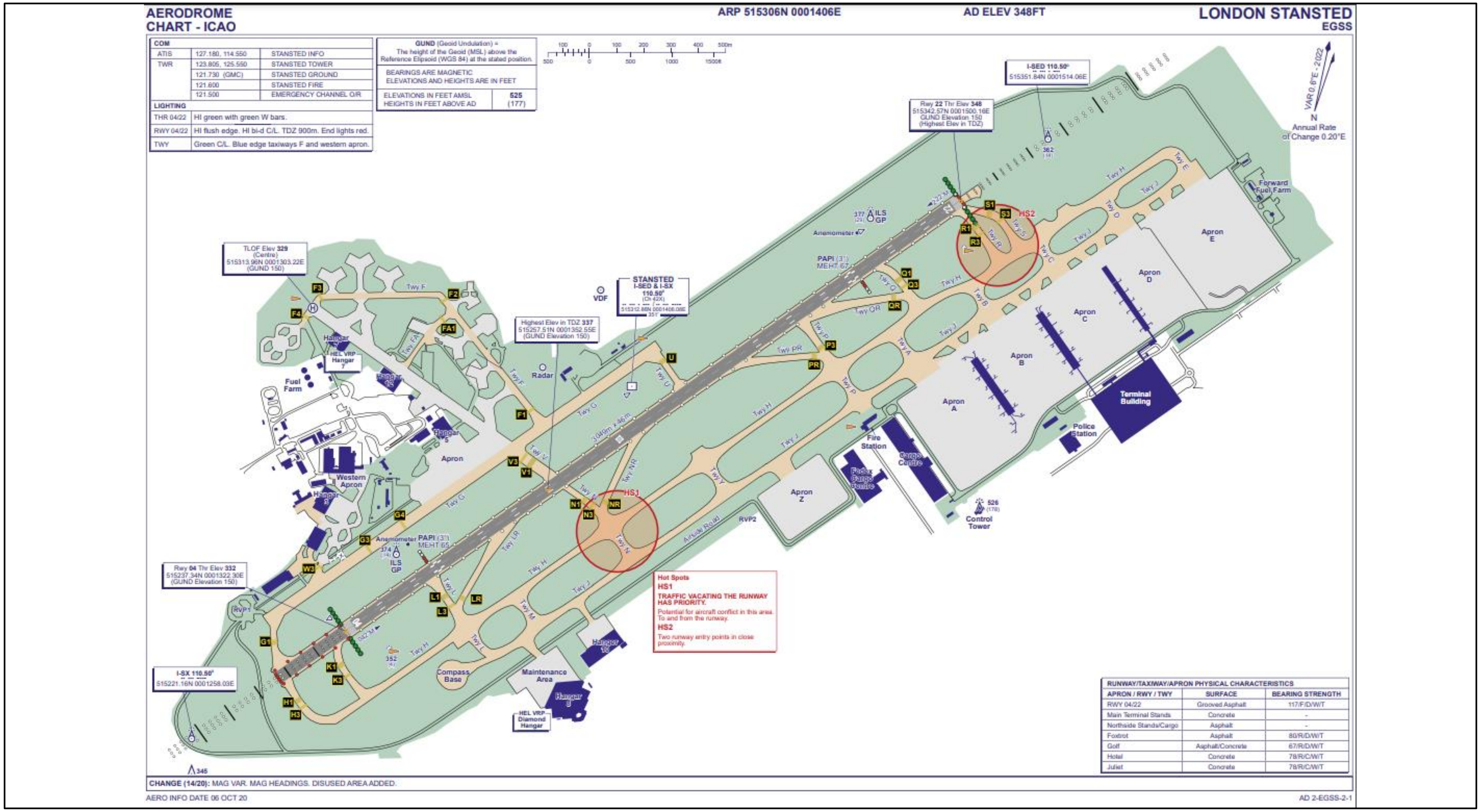

Figure 3 *London Stansted Airport aerodrome chart*

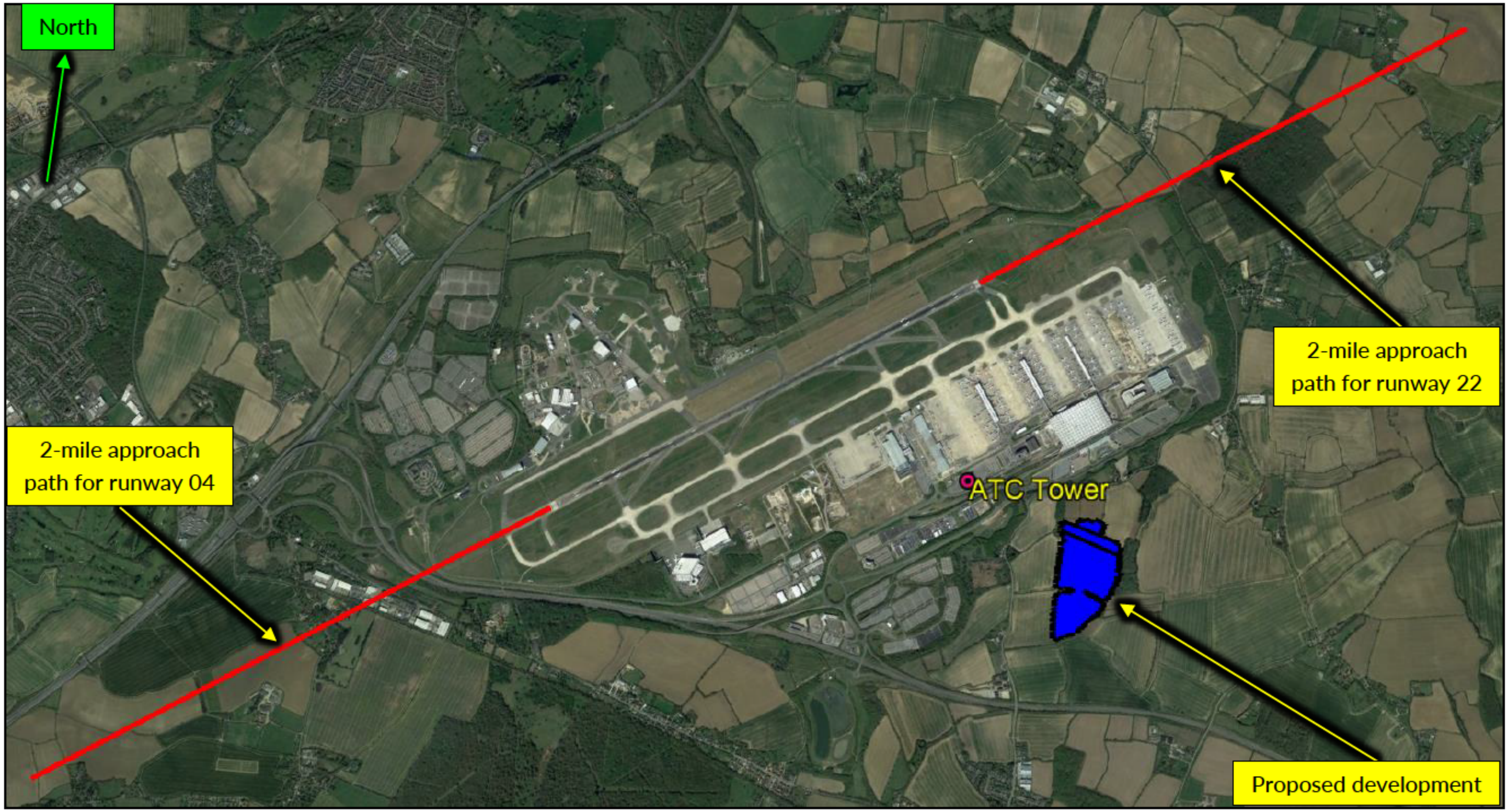

Figure 4 *Relative location of the proposed development to London Stansted Airport*

4 GLINT AND GLARE ASSESSMENT METHODOLOGY

4.1 Overview

The following sub-sections provide 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

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 and studies. The methodology for a glint and glare assessments is as follows:

- Identify receptors in the area surrounding the solar development.
- Consider direct solar reflections from the solar development towards the identified receptors by undertaking geometric calculations.
- Consider the visibility of the panels from the receptor's location. If the panels 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 both the solar reflection from the solar 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 the process presented in Appendix D.

4.4.2 Sandia National Laboratories' Methodology

Sandia National Laboratories developed the Solar Glare Hazard Analysis Tool (SGHAT) which is no longer available. 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. Intensity calculations in line with Sandia National Laboratories' methodology has been completed[11]. Where required, cross checks have been completed.

4.5 Assessment Methodology and Limitations

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

[11] 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 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 at London Stansted Airport is located approximately 560m west of the proposed development.

Figure 5[10] below shows a 3D representation of the ATC Tower.

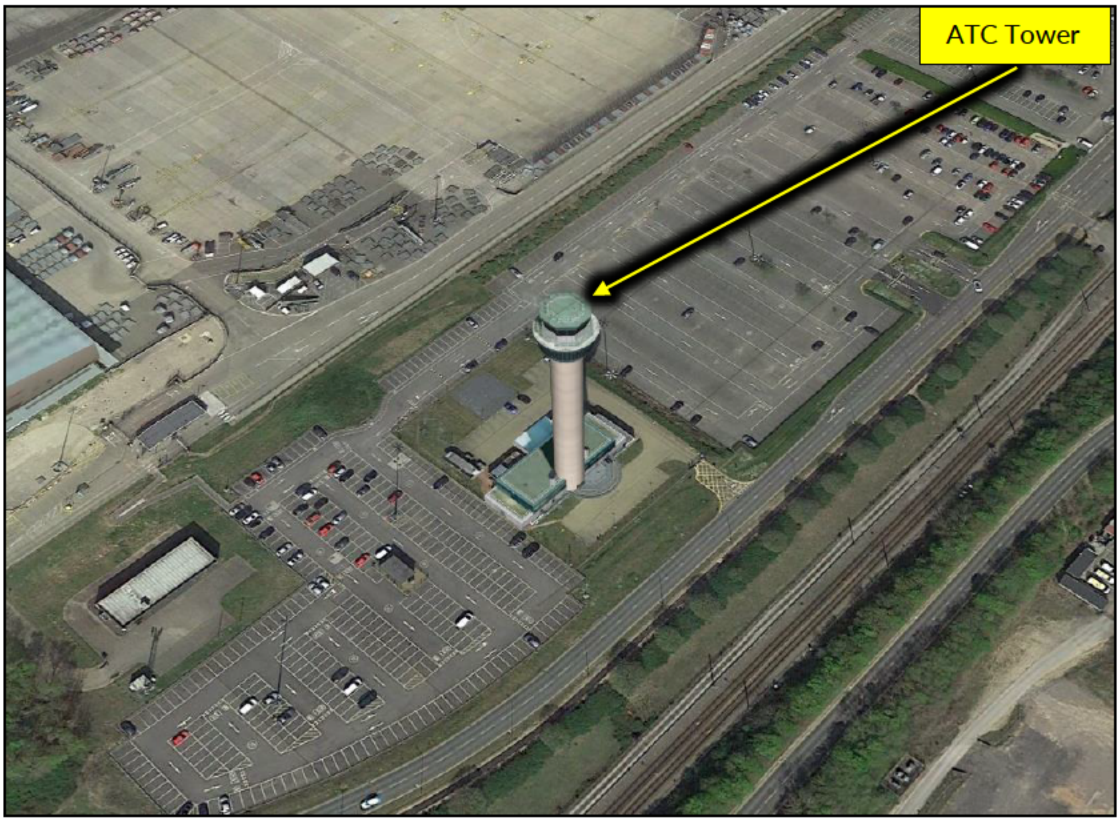

Figure 5 *London Stansted Airport ATC Tower location*

5.3 Airborne Receptors – Approaching Aircraft

London Stansted Airport has one operational runway with two approach paths, one for each bearing. It is Pager Power's methodology to assess whether a solar reflection can be experienced on the approach paths for the associated runways. This is considered to be the most critical stage of the flight.

A geometric glint and glare assessment has been undertaken for all aircraft approach paths for the aerodromes assessed in this report. 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 6[10] on the following page shows the assessed 2-mile approach paths (red lines) for each bearing and the receptor locations assessed as purple points.

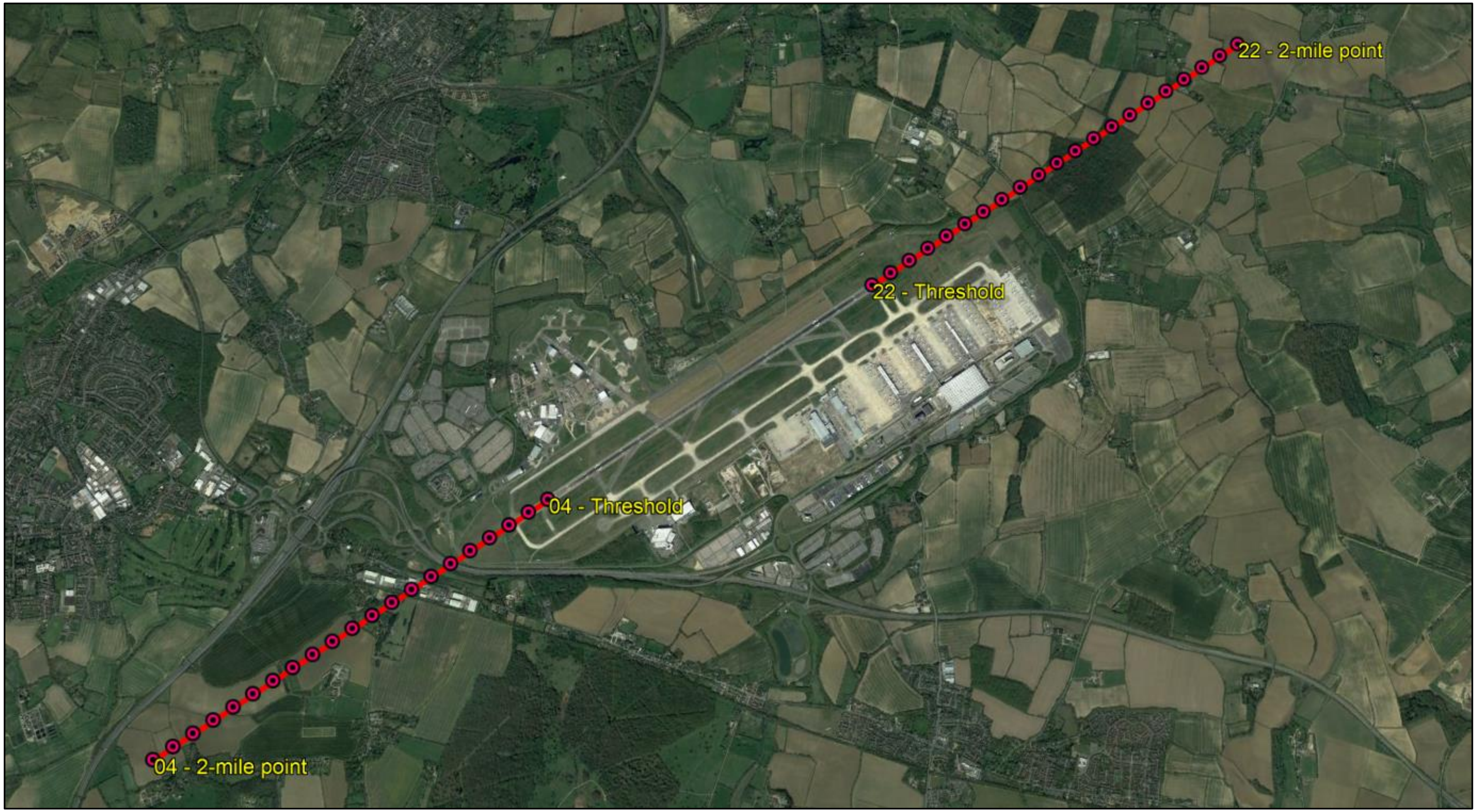

Figure 6 *Runway 04/22 approach paths*

5.4 Airborne Receptors – Aircraft Circuit

Stansted Airport has requested an assessment of general aviation aircraft flying a left and right-hand circuit of runway 04/22.

When light aircraft arrive or depart from an aerodrome, they fly in a standard pattern. A typical circuit is shown in Figure 7 below.

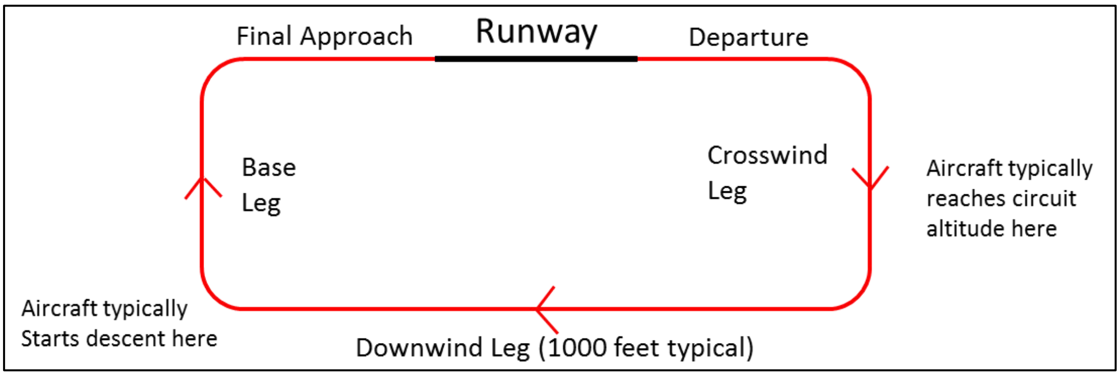

Figure 7 *Typical circuit diagram*

The way circuits are flown varies from airport to airport, pilot to pilot and aircraft to aircraft. The assessed circuit has the following characteristics:

- Circuit altitude 1,000ft (304.8m) above the lowest runway threshold;
- Circuit originates and terminates at the runway ends[12];
- The circuit considers an ascent and descent angle of 5°.

It is assumed that aircraft will be at 1,000ft above mean sea level on the base leg.

A circuit width of 1 nautical mile (nm) has been modelled for the 1,000ft circuit. In total, 40 individual aircraft receptor locations have been assessed which are spaced equally around the circuit from threshold to threshold.

Figure 8[10] on the following page shows the modelled circuit points. Points from 1 to 40 belong to the Approach 04 left-hand and Approach 22 right-hand side circuits while points from 41 to 80 belong to the Approach 04 right-hand and 22 left-hand side circuit. The receptor details are presented in Appendix G.

[12] Runway thresholds.

Figure 8 *Assessed aircraft circuit receptors*

6 ASSESSED REFLECTOR AREAS

6.1 Overview

The following section presents the modelled reflector areas.

6.2 Reflector Areas

A number of representative panel locations are selected within the proposed reflector areas with the number of modelled reflector points being determined by the size of the reflector areas and the assessment resolution. The bounding co-ordinates for the proposed solar development have been extrapolated from the site plans.

A resolution of 10m has been chosen for this assessment. This means that a geometric calculation is undertaken for each identified receptor from a point 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 number of modelled reflector points are 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 plans. The data can be found in Appendix G.

The assessed reflector areas are shown in Figure 2[10] on page 13 of this report.

7 GLINT AND GLARE ASSESSMENT – TECHNICAL RESULTS

7.1 Overview

The Pager Power and Forge model has been used to determine whether reflections are possible. Intensity calculations in line with the Sandia National Laboratories methodology have been undertaken for aviation receptors. These calculations are routinely required for solar photovoltaic developments on or near aerodromes. The intensity model calculates the expected intensity of a reflection with respect to the potential for an after-image (or worse) occurring. The designation used by the model is presented in Table 2 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	Low potential for temporary after-image
Potential	Potential for temporary after-image
Potential for permanent eye damage	Potential for permanent eye damage

Table 2 *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.

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. In this case, significant glare was initially predicted by the modelling, and consequently smooth glass with an anti-reflective coating has been utilised.

7.2 Summary of Results

The modelling output showing the precise predicted times and the reflecting panel areas are shown in Appendix H.

7.3 Geometric Calculation Results Overview – London Stansted Airport

The results of the geometric calculations for the receptors at London Stansted Airport are presented in Table 3 to Table 5 below.

Receptor(s)	Pager Power Results Reflections possible towards the receptor(s)? (GMT) am	pm	Glare Type (Forge)	Comment
ATC Tower	No.		N/A	No solar reflection geometrically possible. No impact possible.
Runway 04 approach (receptors 2 – 15)	Yes.	No.		Solar reflections (from panel area 3) with a maximum of 'low potential for temporary after-image' are predicted for 4,925 minutes over the year lasting for up to just over 30 minutes on any one day. Discussed further in Section 8.2.2
Runway 22 approach (receptors 17 – 21)	No.	Yes.		Solar reflections (from panel areas 1&2) with a maximum of 'low potential for temporary after-image' predicted for 2,910 minutes over the year lasting for up to just over 35 minutes on any one day. Discussed further in Section 8.2.3

Table 3 *Geometric analysis results for the ATC Tower and the approach paths at London Stansted Airport*

Receptor(s)	Pager Power Results		Glare Type (Forge)	Comment
	Reflections possible towards 04LH/22RH circuit? (GMT)			
	am	pm		
1 – 24.	No.		N/A.	No solar reflection geometrically possible. No impact possible.
25 – 40.	Yes.	No.		Solar reflections (from panel area 3) with a maximum of 'low potential for temporary after-image' predicted for up to 3,654 minutes over the year lasting for up to 30 minutes on any one day. Discussed further in Section 8.2.4

Table 4 *Geometric analysis results for 04LH/22RH circuit at London Stansted Airport*

Receptor(s)	Pager Power Results		Glare Type (Forge)	Comment
	Reflections possible towards 04RH/22LH circuit? (GMT)			
	am	pm		
41 – 46.	No.		N/A.	No solar reflection geometrically possible. No impact possible.
47 – 53.	No.	Yes.		Solar reflections (from panel areas 1&2) with a maximum of 'low potential for temporary after-image' predicted for up to 5,249 minutes over the year lasting for up to 55 minutes on any one day. Discussed further in 8.2.5.

Receptor(s)	Pager Power Results		Glare Type (Forge)	Comment
	Reflections possible towards 04RH/22LH circuit? (GMT)			
	am	pm		
54.	No.	Yes.		Solar reflections (from panel area 2) with a maximum of 'low potential for temporary after-image' predicted for 1,422 minutes over the year lasting for up to 35 minutes on any one day. Discussed further in Section 8.2.5.
				Solar reflections (from panel area 3) with a maximum of 'potential for temporary after-image' predicted for 1,391 minutes over the year lasting for up to just over 20 minutes on any one day. Discussed further in Section 8.2.5.
55.	No.	Yes.		Solar reflections (from panel area 3) with a maximum of 'potential for temporary after-image' predicted for 4,494 minutes over the year lasting for up to just over 100 minutes on any one day. Discussed further in Section 8.2.5.

Receptor(s)	Pager Power Results		Glare Type (Forge)	Comment
	Reflections possible towards 04RH/22LH circuit? (GMT)			
	am	pm		
56.	No.	Yes.		Solar reflections (from panel area 3) with 'potential for temporary after-image' predicted for 72,242 minutes over the year lasting for up to just over 200 minutes on any one day. Discussed further in Section 8.2.5.
57.	Yes.	Yes.		Solar reflections (from panel area 3) with 'potential for temporary after-image' predicted for 73,396 minutes over the year lasting for up to 250 minutes on any one day. Discussed further in Section 8.2.5.
58 – 59.	Yes.	No.		Solar reflections (from panel area 3) with 'potential for temporary after-image' predicted for up to 23,337 minutes over the year lasting for up to 200 minutes on any one day. Discussed further in Section 8.2.5.

Receptor(s)	Pager Power Results — Reflections possible towards 04RH/22LH circuit? (GMT)		Glare Type (Forge)	Comment
	am	pm		
60 – 73.	No.		N/A.	No solar reflection geometrically possible. No impact possible.
74 – 80.	Yes.	No.		Solar reflections (from panel area 3) with 'potential for temporary after-image' predicted for up to 3,654 minutes over the year lasting for up to 30 minutes on any one day. Discussed further in Section 8.2.5.

Table 5 *Geometric analysis results for 04RH/22LH circuit at London Stansted Airport*

8 GEOMETRIC ASSESSMENT RESULTS AND DISCUSSION

8.1 Overview

The result of the glint and glare calculations and a discussion for each receptor is presented in the following sub-sections.

8.2 London Stansted Airport

8.2.1 ATC Tower

The modelling indicates that solar reflections from the proposed development towards the ATC tower are not geometrically possible.

No impacts are therefore predicted upon personnel in the ATC tower and no mitigation is required.

8.2.2 Runway 04 Approach

The modelling indicates that solar reflections with 'low potential for temporary after-image' are predicted towards pilots between 0.1 miles and 1.4 miles from the runway 04 threshold. This is acceptable considering the associated guidance (Appendix D).

No significant impacts upon pilots approaching runway 04 are expected, and no mitigation is required.

8.2.3 Runway 22 Approach

The modelling indicates that solar reflections with 'low potential for temporary after-image' are predicted towards pilots between 1.6 miles and 2 miles from the runway 22 threshold. This is acceptable considering the associated guidance (Appendix D).

No significant impacts upon pilots approaching runway 22 are expected, and no mitigation is required.

8.2.4 04 Left-Hand Circuit/22 Right-Hand Circuit

The modelling has shown that solar reflections with a 'low potential for temporary after-image' are predicted towards a section of the 04 left-hand circuit and 22 right-hand circuit (circuit receptors 25 – 40). Considering the associated guidance pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for circuit paths.

No significant impacts upon the 04 left-hand circuit and 22 right-hand circuit are expected, and no mitigation is required.

8.2.5 04 Right-Hand Circuit/22 Left-Hand Circuit

The modelling has shown that solar reflections with a maximum of 'low potential for temporary after-image' are predicted towards a section of the 09 right-hand and 27 left hand circuit (circuit receptors 47 – 53, 56 – 59, and 74 – 80). Considering the associated guidance pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for circuit paths.

No significant impacts upon this section of the 04 right-hand circuit and 22 left-hand circuit are therefore predicted.

The modelling has shown that solar reflections with a maximum of ‘potential for temporary after-image’ are predicted towards a section of the 09 right-hand and 27 left hand circuit (circuit receptors 54 and 55). Considering the associated guidance pertaining to approach paths, this level of glare also requires further discussion when judging the requirement for mitigation where circuit paths are concerned.

Figure 9 and Figure 10 on the following pages show the output of the technical modelling for the section of the 04 right-hand and 22 left hand circuit where yellow glare has been predicted.

The figure shows:

- Dates and times at which glare is possible under worst-case conditions (top left panel);
- Daily duration of glare throughout the year (top right panel);
- Annual glare reflections on PV footprint specific to panel area 1 (bottom left panel);
- Glare intensity plot (bottom right panel).

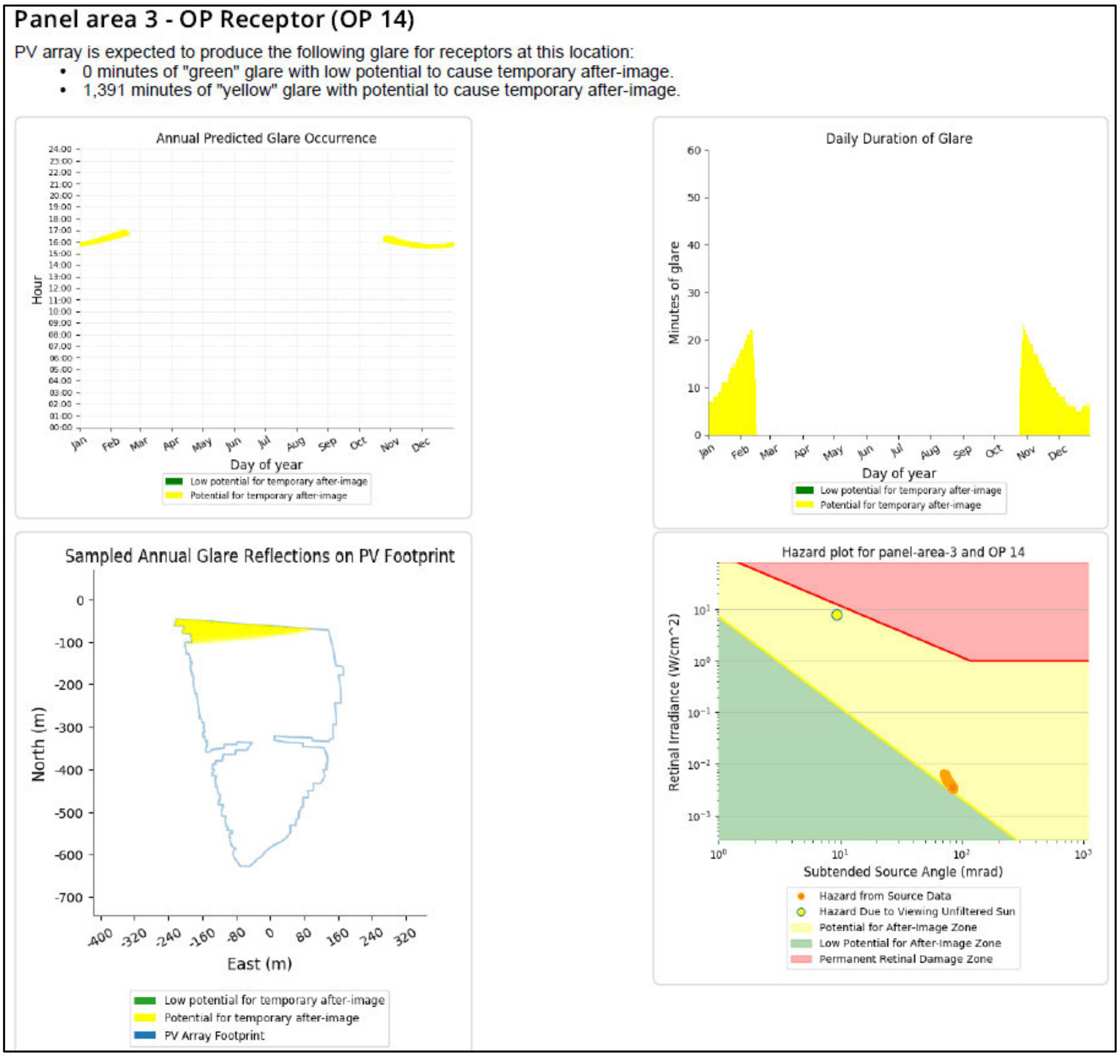

Figure 9 *Modelling output: Receptor 54 for 04R/22L Circuit*

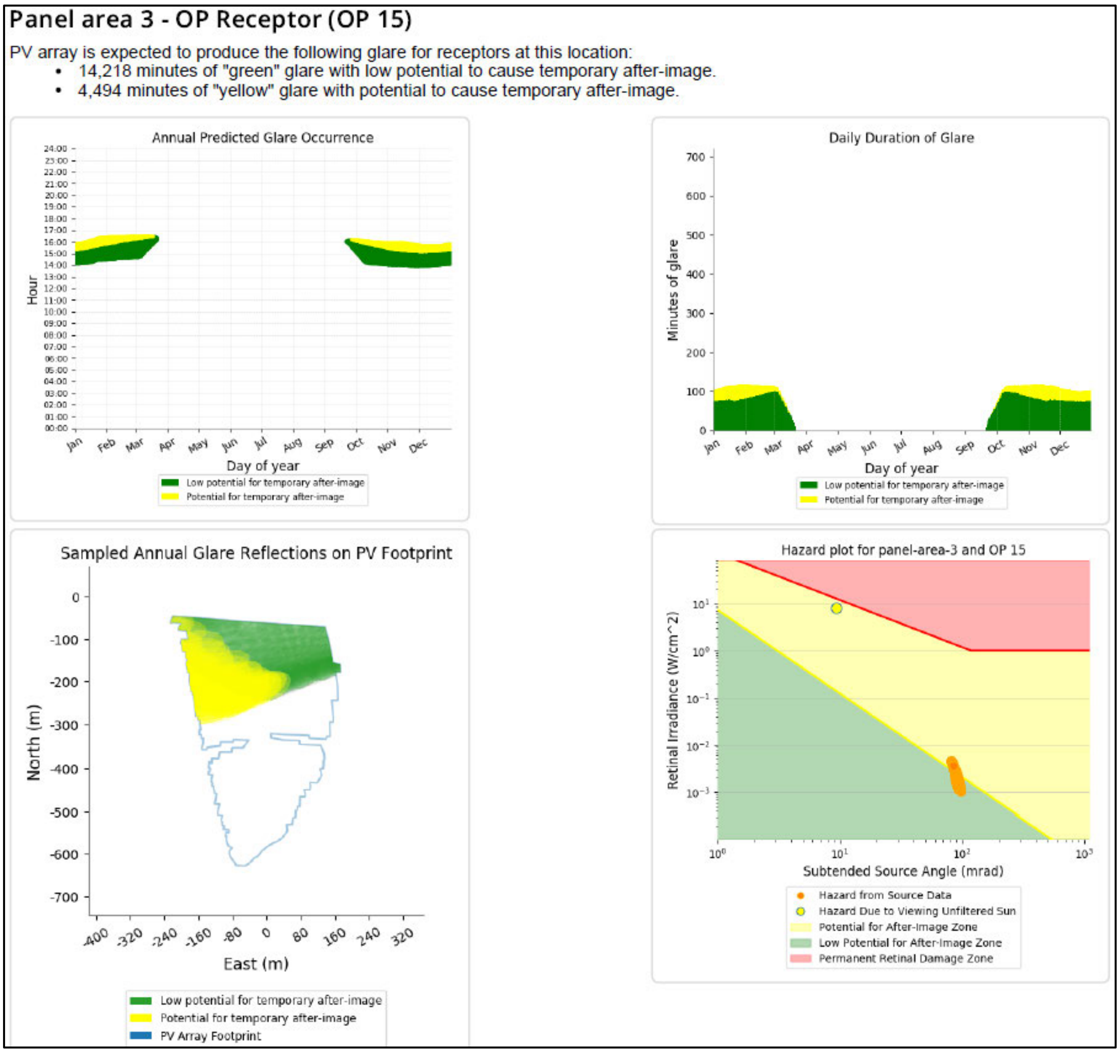

Figure 10 *Modelling output: Receptor 55 for 04R/22L Circuit*

It is likely that this level of glare can be operationally accommodated, although this should be discussed with the safeguarding team at London Stansted Airport to understand their position.

9 OVERALL CONCLUSIONS

9.1 Assessment Results - London Stansted Airport

9.1.1 ATC Tower

The modelling indicates that solar reflections from the proposed development towards the ATC tower are not geometrically possible.

No impacts are therefore predicted upon personnel in the ATC tower and no mitigation is required.

9.1.2 Runway 04 Approach

The modelling indicates that solar reflections with 'low potential for temporary after-image' are predicted towards pilots between 0.1 miles and 1.4 miles from the runway 04 threshold. This is acceptable considering the associated guidance (Appendix D).

No significant impacts upon pilots approaching runway 04 are expected, and no mitigation is required.

9.1.3 Runway 22 Approach

The modelling indicates that solar reflections with 'low potential for temporary after-image' are predicted towards pilots between 1.6 miles and 2 miles from the runway 22 threshold. This is acceptable considering the associated guidance (Appendix D).

No significant impacts upon pilots approaching runway 22 are expected, and no mitigation is required.

9.1.4 04 Left-Hand Circuit/22 Right-Hand Circuit

The modelling has shown that solar reflections with a 'low potential for temporary after-image' are predicted towards a section of the 04 left-hand circuit and 22 right-hand circuit (circuit receptors 25 – 40). Considering the associated guidance pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for circuit paths.

No significant impacts upon the 04 left-hand circuit and 22 right-hand circuit are expected, and no mitigation is required.

9.1.5 04 Right-Hand Circuit/22 Left-Hand Circuit

The modelling has shown that solar reflections with a maximum of 'low potential for temporary after-image' are predicted towards a section of the 04 right-hand and 22 left hand circuit (circuit receptors 47 – 53, 56 – 59, and 74 – 80). Considering the associated guidance pertaining to approach paths, which states that this level of glare is acceptable, it can be concluded that this level of glare is also acceptable for circuit paths.

No significant impacts upon this section of the 04 right-hand circuit and 22 left-hand circuit are therefore predicted.

The modelling has shown that solar reflections with a maximum of 'potential for temporary after-image' are predicted towards a section of the 09 right-hand and 27 left hand circuit (circuit receptors 54 and 55). Considering the associated guidance pertaining to approach paths, this level of glare also requires further consideration where circuit paths are concerned. It is likely that this level of glare can be operationally accommodated, although this should be discussed with the safeguarding team at London Stansted Airport to understand their position.

9.2 Overall Conclusions

No impacts are predicted upon personnel in the ATC tower and no mitigation is required.

No significant impacts are predicted upon pilots on approach to the runways assessed at London Stansted Airport.

Glare is possible towards positions within the visual circuits at Stansted Airport. The glare intensity is mostly 'low potential for temporary after-image', which is acceptable even for pilots on final approach. Two out of eighty modelled locations (circuit receptors 54 and 55) show some glare with 'potential for temporary after-image' (see Figure 9 and Figure 10 on pages 34 and 35 of this report). There are no formal intensity criteria for aircraft in the circuit. It is likely that this level of glare can be operationally accommodated, although this should be discussed with the safeguarding team at London Stansted Airport to understand their position.

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

The National Planning Policy Framework under the planning practice guidance for Renewable and Low Carbon Energy[13] (specifically regarding the consideration of solar farms, paragraph 013) 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;*

…

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.'

[13] Renewable and low carbon energy, Ministry of Housing, Communities & Local Government, date: 18 June 2015, accessed on: 17/06/2020

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 7th, 2012[14] however the advice is still applicable[15] 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[16], 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 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.

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[14] Archived at Pager Power
[15] Reference email from the CAA dated 19/05/2014.
[16] Aerodrome Licence Holder.

15. Further guidance may be obtained from CAA's Aerodrome Standards Department via 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'*[17] and the 2013 update is entitled '*Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports'*[18]. In April 2018 the FAA released a new version (Version 1.1) of the '*Technical Guidance for Evaluating Selected Solar Technologies on Airports'*[19].

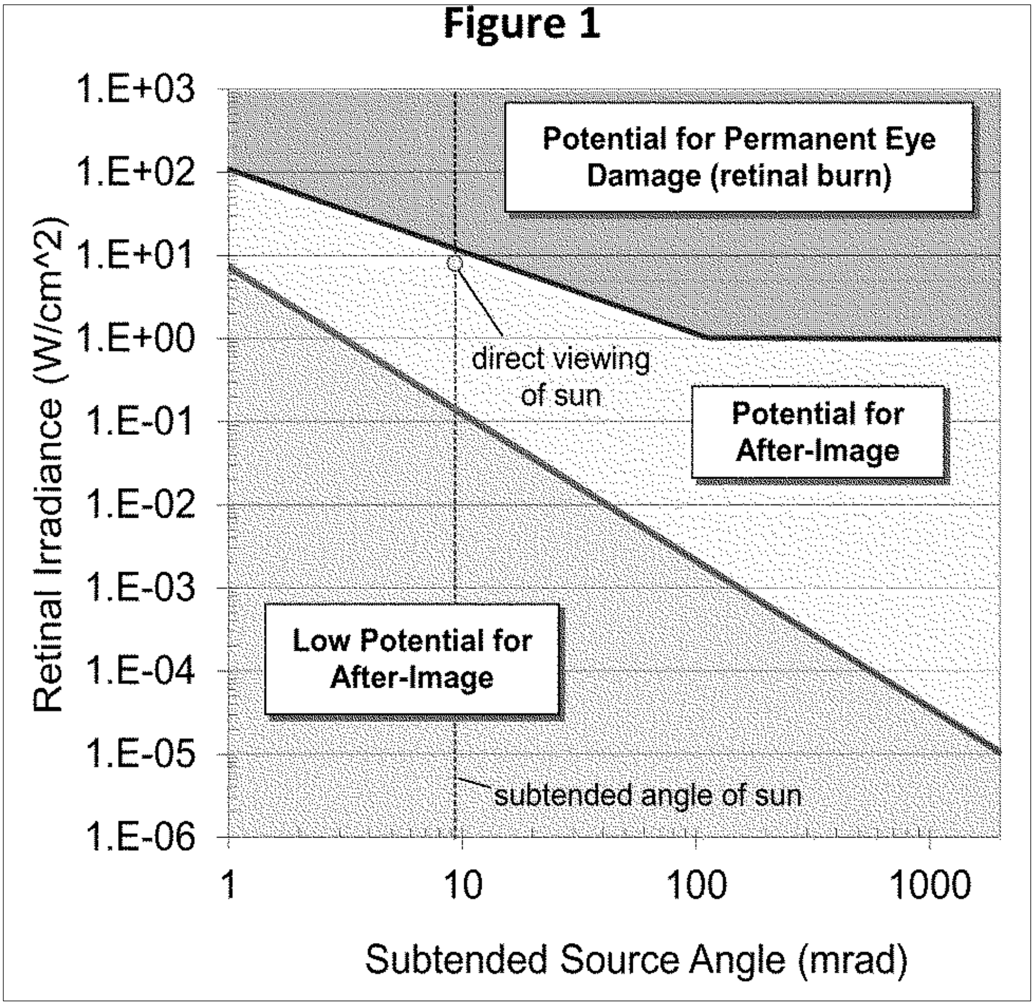
An overview of the methodology presented within the 2013 interim guidance and adopted by the FAA is presented below. This methodology is not presented within the 2018 guidance.

- *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…. 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.*

[17] Archived at Pager Power

[18] Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports, Department of Transportation, Federal Aviation Administration (FAA), date: 10/2013, accessed on: 20/03/2019

[19] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019



Solar Glare Hazard Analysis Plot (FAA)

- *To obtain FAA approval to revise an airport layout plan to depict a solar installation and/or a "no objection" … the airport sponsor will be required to demonstrate that the proposed solar energy system meets the following standards:*
- *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 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

Key points from the 2018 FAA guidance are presented below.

- *Reflectivity refers to light that is reflected off surfaces. The potential effects of reflectivity are glint (a momentary flash of bright light) and glare (a continuous source of bright light). These two effects are referred to hereinafter as "glare," which can cause a brief loss of vision, also known as flash blindness*[20].
- *The amount of light reflected off a solar panel surface depends on the amount of sunlight hitting the surface, its surface reflectivity, geographic location, time of year, cloud cover, and solar panel orientation.*
- *As illustrated on Figure 16*[21]*, flat, smooth surfaces reflect a more concentrated amount of sunlight back to the receiver, which is referred to as specular reflection. The more a surface is polished, the more it shines. Rough or uneven surfaces reflect light in a diffused or scattered manner and, therefore, the light will not be received as bright.*
- *Because the FAA has no specific standards for airport solar facilities and potential glare, the type of glare analysis may vary. Depending on site specifics (e.g., existing land uses, location and size of the project) an acceptable evaluation could involve one or more of the following levels of assessment:*
    - *A qualitative analysis of potential impact in consultation with the Control Tower, pilots and airport officials;*
    - *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.*
- ***1. Assessing Baseline Reflectivity Conditions** – 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. 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. Operators also wear polarized eye wear. Potential glare from solar panels should be viewed in this context. Any airport considering a solar PV project should first review existing sources of glare at the airport and the effectiveness of measures used to mitigate that glare.*
- ***2. Tests in the Field** – Potential glare from solar panels can easily be viewed at the airport through a field test. A few airports have coordinated these tests with FAA Air Traffic Controllers to assess the significance of glare impacts. To conduct such a test, a sponsor can take a solar panel out to proposed location of the solar project, and tilt the panel in different directions to evaluate the potential for glare onto the air traffic control tower. For the two*

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[20] 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.
[21] First figure in Appendix B.

- *known cases where a field test was conducted, tower personnel determined the glare was not significant. If there is a significant glare impact, the project can be modified by ensuring panels are not directed in that direction.*
- ***3. Geometric Analysis** – Geometric studies are the most technical approach for reflectivity issues. They are conducted when glare is difficult to assess through other methods. 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 moves across the sky every day and its path in the sky changes throughout 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.*
- *Facilities placed in remote locations, like the desert, will be far from receptors and therefore potential impacts are limited to passing aircraft. Because the intensity of the light reflected from the solar panel decreases with increasing distance, an appropriate question is how far you need to be from a solar reflected surface to avoid flash blindness. It is known that this distance is directly proportional to the size of the array in question22 but still requires further research to definitively answer.*
- ***Experiences of Existing Airport Solar Projects** – Solar installations are presently operating at a number of airports, including megawatt-sized solar facilities covering multiple acres. Air traffic control towers have expressed concern about glint and glare from a small number of solar installations. These were often instances when solar installations were sited between the tower and airfield, or for installations with inadequate or no reflectivity analysis. Adequate reflectivity analysis and alternative siting addressed initial issues at those installations.*

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

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[22] 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.

(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

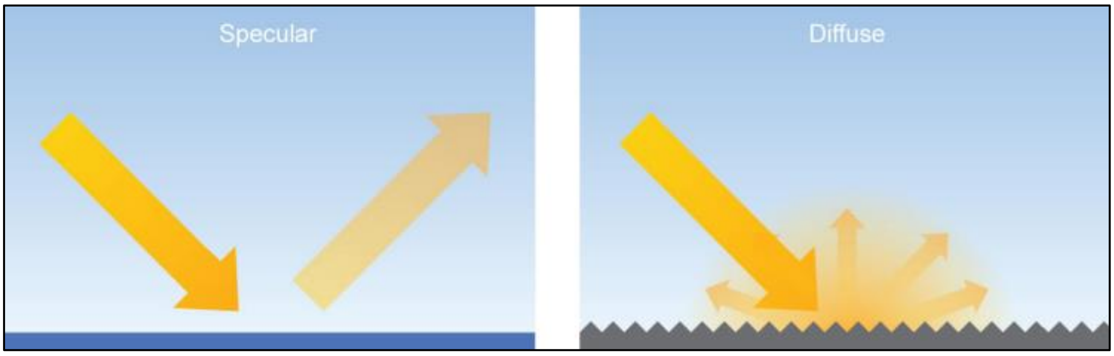
Overview

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[23], 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

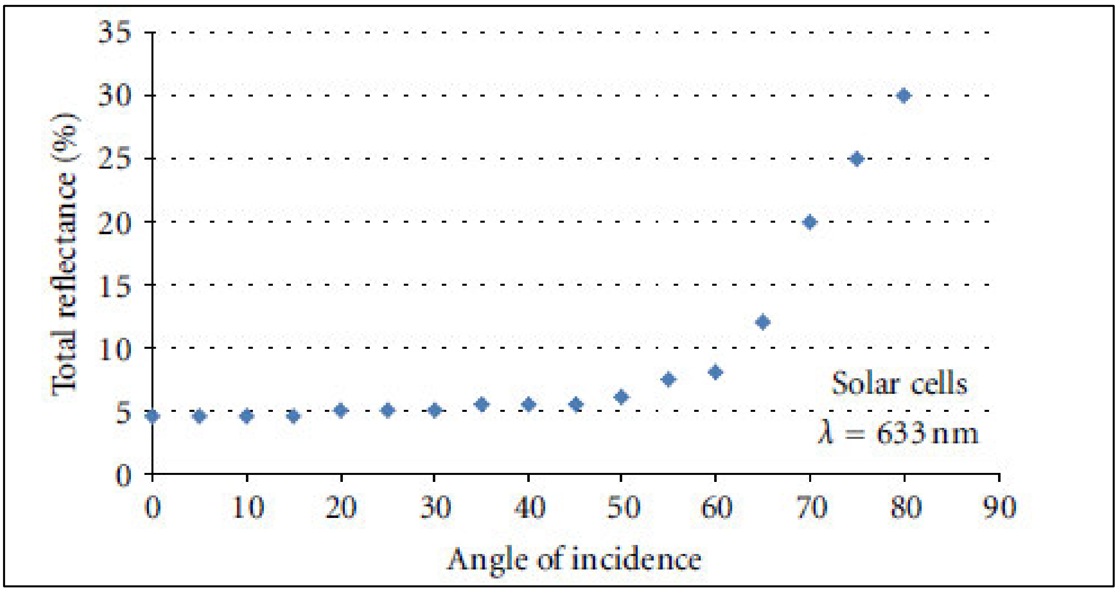
[23] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

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*[24]". 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.

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[24] 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"[25]

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[26]
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).

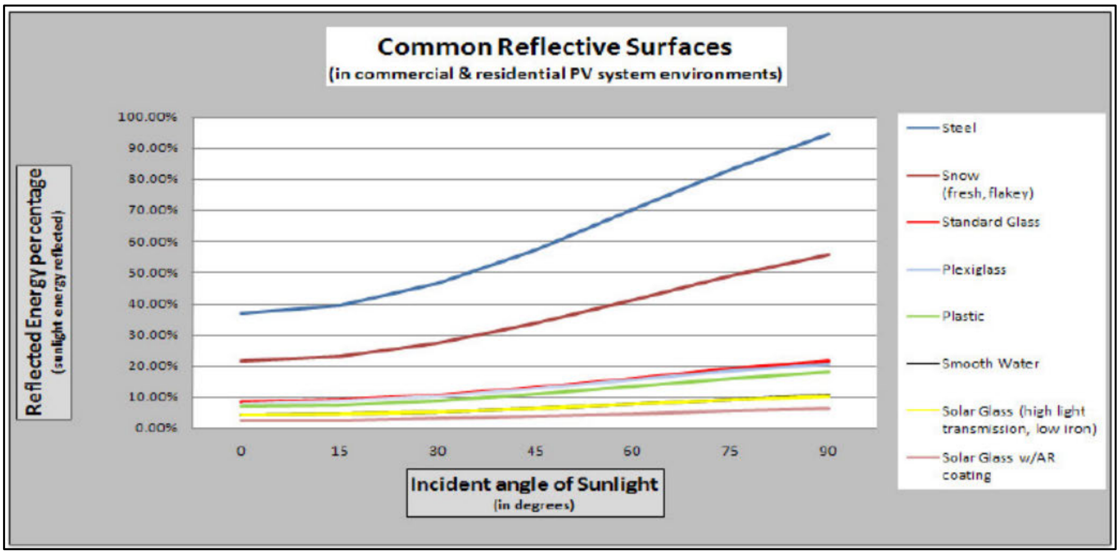
An important comparison in this table is the reflectivity compared to water which will produce a reflection of very similar intensity when compared to that from a solar panel. The study by Riley and Olsen study (2011) also concludes that still water has a very similar reflectivity to solar panels.

[25] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.
[26] Extrapolated data, baseline of 1,000 W/m^2 for incoming sunlight.

SunPower Technical Notification (2009)

SunPower published a technical notification[27] 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.

[27] Source: Technical Support, 2009. SunPower Technical Notification – Solar Module Glare and Reflectance.

APPENDIX C – OVERVIEW OF SUN MOVEMENTS AND RELATIVE REFLECTIONS

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).

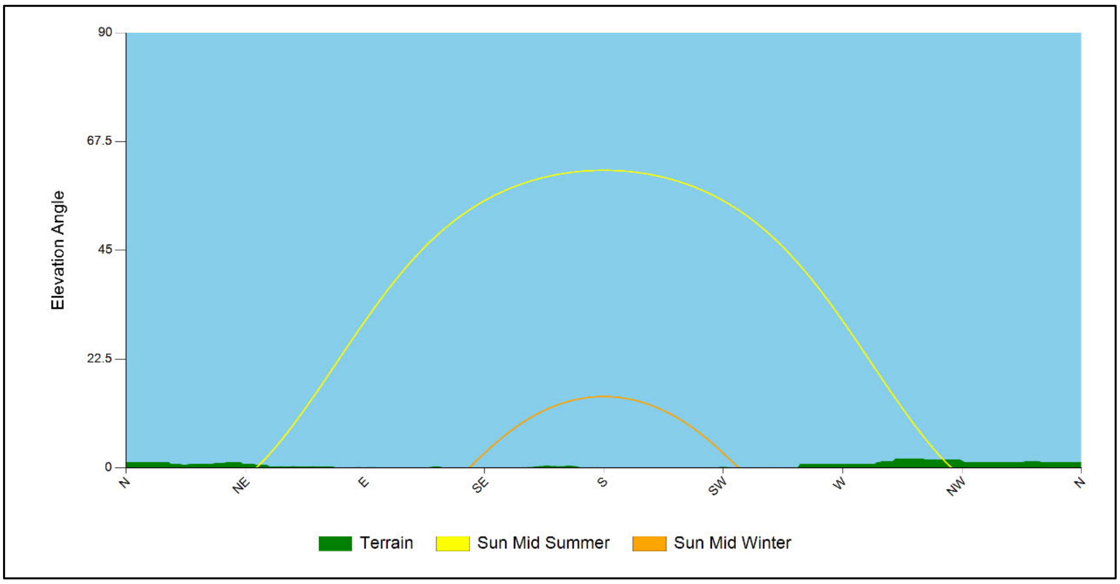
The Sun's position can be accurately calculated for a specific location. The following data being used for the calculation:

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

The following is true at the location of the solar development:

- The Sun is at its highest around midday and is to the south at this time.
- The Sun rises highest on 21 June (longest day).
- On 21 December, the maximum elevation reached by the Sun is at its lowest (shortest day).

The combination of the Sun's azimuth angle and vertical elevation will affect the direction and angle of the reflection from a reflector. The figure below shows terrain at the horizon as well as the sunrise and sunset curves throughout the year. This is based on the location longitude: -0.264791 and latitude: 51.884967.



Terrain at the visible horizon and Sun path

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

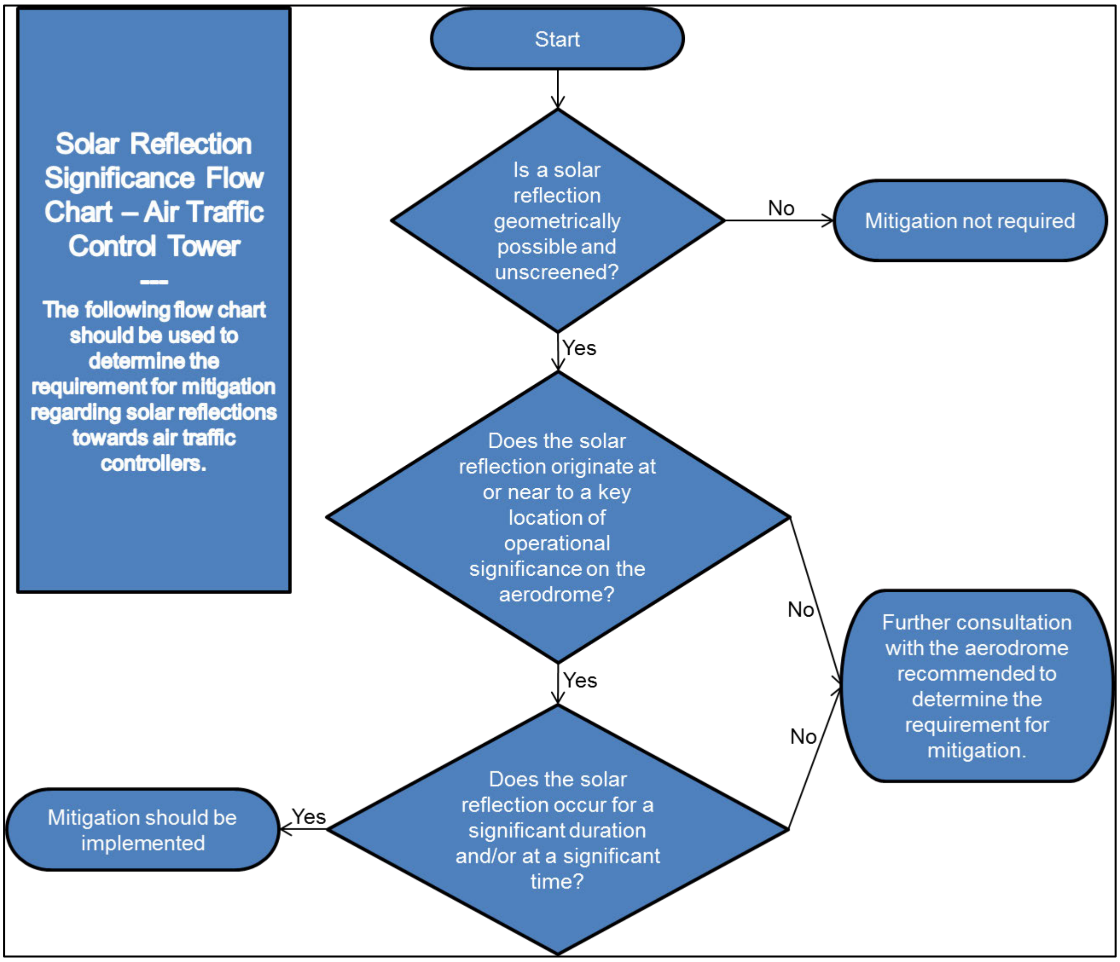
The table below presents the recommended definition of 'impact significance' in glint and glare terms and the requirement for mitigation under each.

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 solar development is to proceed.

Impact significance definition

Assessment Process – ATC Tower

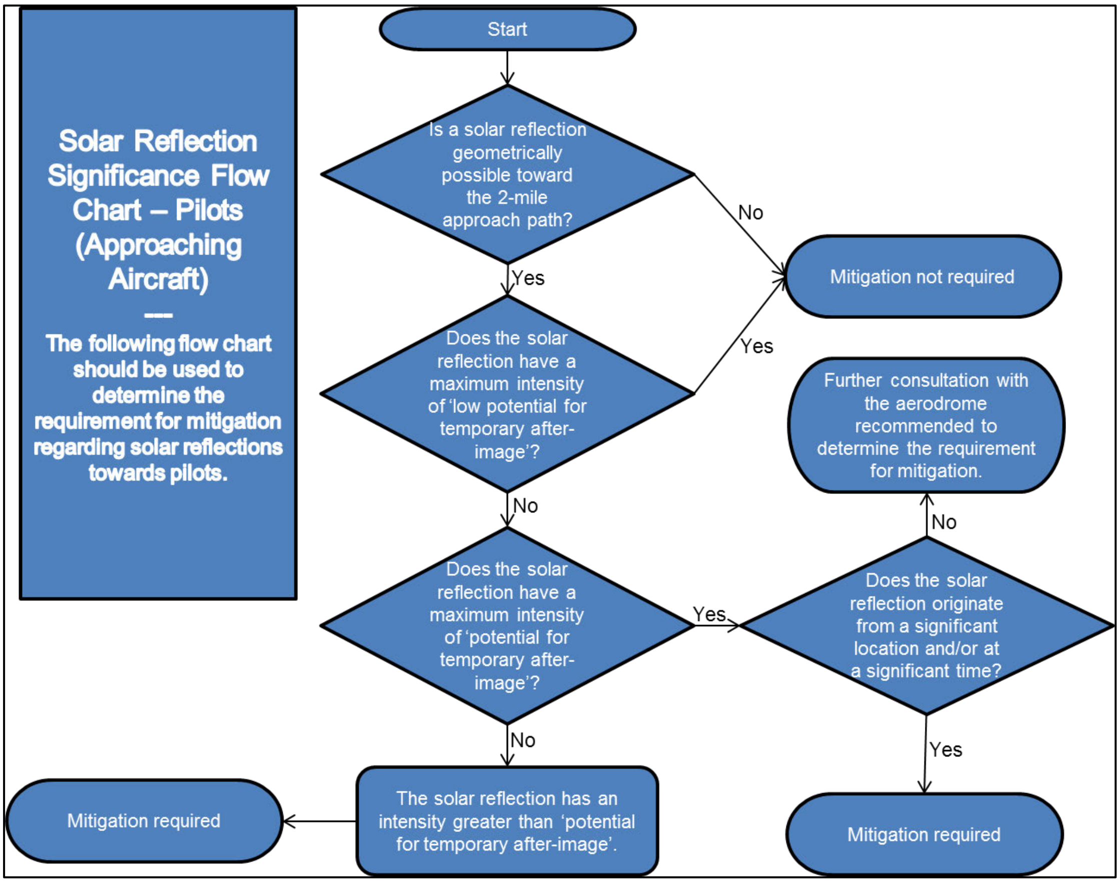
The charts relate to the determining the potential impact upon the ATC Tower.



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

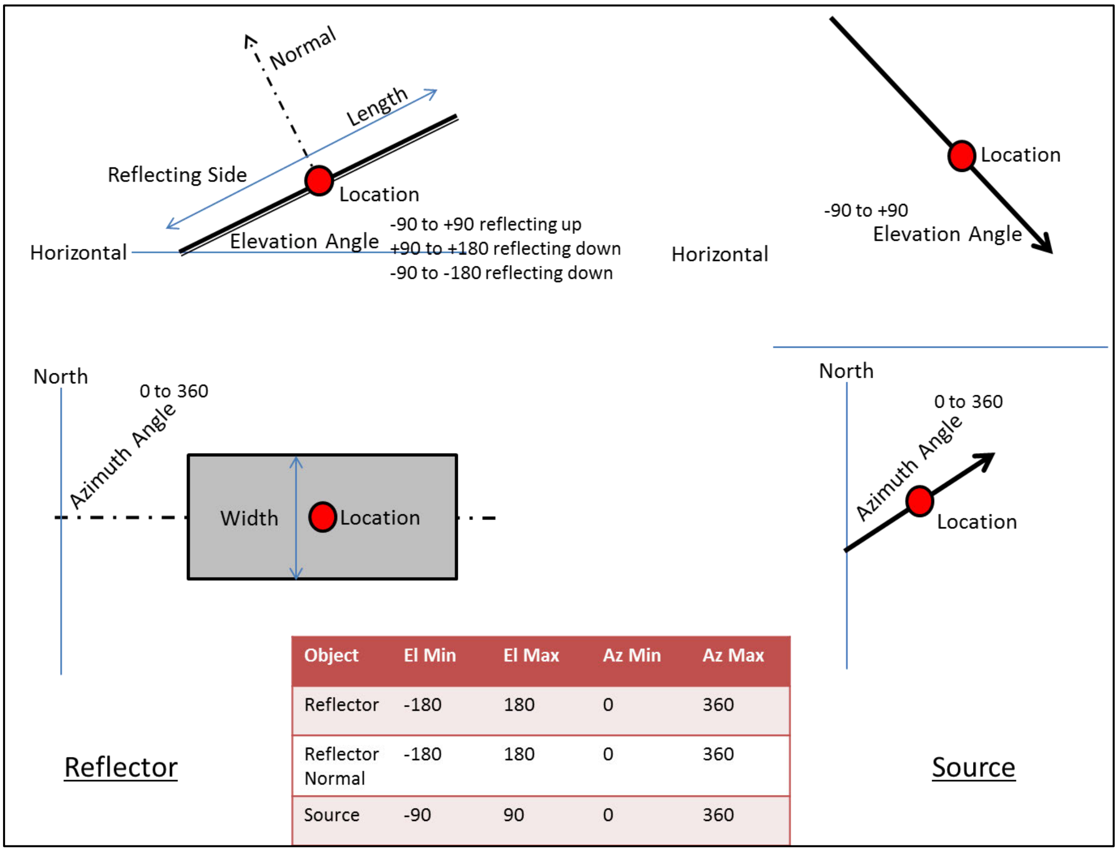
APPENDIX E – REFLECTION CALCULATIONS METHODOLOGY

Pager Power 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.



Object	El Min	El Max	Az Min	Az Max
Reflector	-180	180	0	360
Reflector Normal	-180	180	0	360
Source	-90	90	0	360

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

The model considers 100% sunlight during daylight hours which is highly conservative.

The model does not account for terrain between the reflecting solar panels and the assessed receptor where a solar reflection is geometrically possible.

The model considers terrain between the reflecting solar panels and the visible horizon (where the sun may be obstructed from view of the panels)[28].

It is assumed that the panel elevation angle assessed represents the elevation angle for all of the panels within each solar panel area defined.

It is assumed that the panel azimuth angle assessed represents the azimuth angle for all of the panels within each solar panel area defined.

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

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

A finite number of points within each solar panel area defined is chosen based on an assessment resolution so that a comprehensive understanding of the entire development can be formed. This determines whether a solar reflection could ever occur at a chosen receptor. The model does not consider the specific panel rows or the entire face of the solar panel within the development outline, rather a single point is defined every 'x' metres (based on the assessment resolution) with the geometric characteristics of the panel. A panel area is however defined to encapsulate all possible panel locations. See the figure below which illustrates this process.

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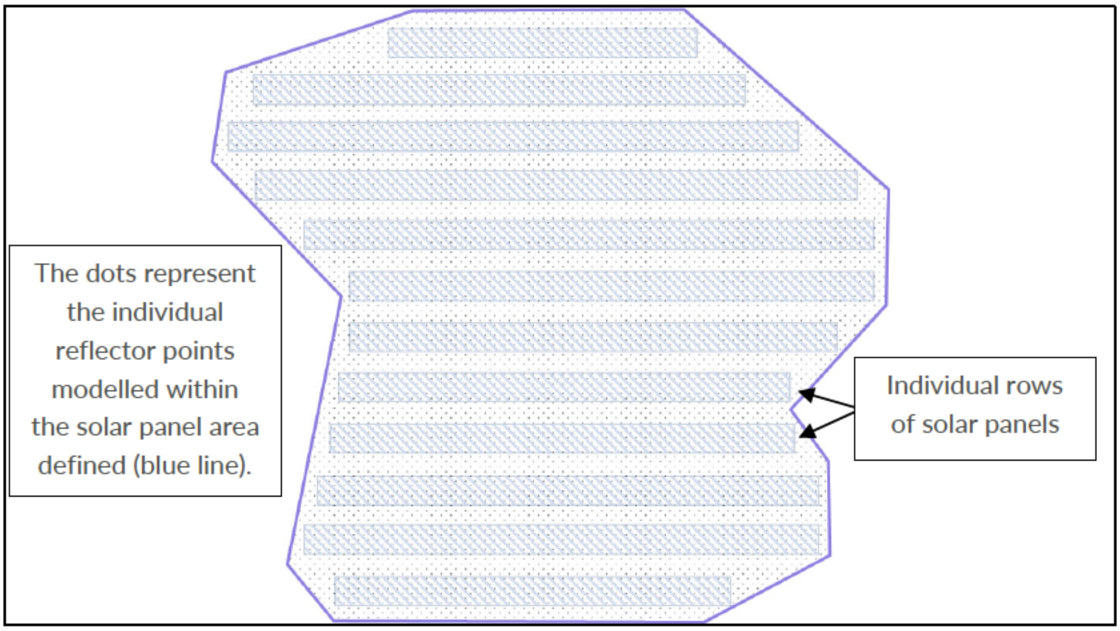
[28] UK only.



Solar panel area modelling overview

A single reflection point is chosen for the geometric calculations. This suitably determines whether a solar reflection can be experienced at a receptor location and the time of year and duration of the solar 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.

The available street view imagery, satellite mapping, terrain and any site imagery provided by the developer has been used to assess line of sight from the assessed receptors to the modelled solar panel area, unless stated otherwise. 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 within the modelling unless stated otherwise. The terrain profile at the horizon is considered if stated.

Sandia National Laboratories' (SGHAT) Model

The following text is taken from the Solar Glare Hazard Analysis Tool (SGHAT) Technical Reference Manual[29] which was previously freely available. The following is presented for reference.

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[29] https://share.sandia.gov/phlux/static/references/glint-glare/SGHAT_Technical_Reference-v5.pdf

Summary of assumptions and abstractions required by the SGHAT/ForgeSolar analysis methodology

1. Times associated with glare are denoted in Standard time. For Daylight Savings, add one hour.
2. Result data files and plots are now retained for two years after analysis completion. Files should be downloaded and saved if additional persistence is required.
3. The algorithm 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.
4. Several calculations utilize the PV array centroid, rather than the actual glare spot location, due to algorithm limitations. This may affect results for large PV footprints. Additional analyses of array sub-sections can provide additional information on expected glare. This primarily affects analyses of path receptors.
5. Random number computations are utilized by various steps of the annual hazard analysis algorithm. Predicted minutes of glare can vary between runs as a result. This limitation primarily affects analyses of Observation Point receptors, including ATCTs. Note that the SGHAT/ForgeSolar methodology has always relied on an analytical, qualitative approach to accurately determine the overall hazard (i.e. green vs. yellow) of expected glare on an annual basis.
6. The subtended source angle (glare spot size) is constrained by the PV array footprint size. Partitioning large arrays into smaller sections will reduce the maximum potential subtended angle, potentially impacting results if actual glare spots are larger than the sub-array size. Additional analyses of the combined area of adjacent sub-arrays can provide more information on potential glare hazards. (See previous point on related limitations.)
7. The algorithm 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.
8. The algorithm 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.
9. 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 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.
10. 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.
11. The system output calculation is a DNI-based approximation that assumes clear, sunny skies year-round. It should not be used in place of more rigorous modeling methods.
12. Hazard zone boundaries shown in the Glare Hazard plot are an approximation and visual aid. Actual ocular impact outcomes encompass a continuous, not discrete, spectrum.
13. Glare locations displayed on receptor plots are approximate. Actual glare-spot locations may differ.
14. Glare vector plots are simplified representations of analysis data. Actual glare emanations and results may differ.
15. PV array tracking assumes the modules move instantly when tracking the sun, and when reverting to the rest position.

APPENDIX G – RECEPTOR AND REFLECTOR AREA DETAILS

Terrain Height

All ground heights are interpolated based on OS Panorama data.

ATC Receptor Details

The co-ordinates and overall altitude of the ATC Tower has been extrapolated from available maps and imagery. The ground height has been taken from Pager Power's database[30] based on the co-ordinates of the ATC Tower. The details are presented in the table below.

Longitude (°)	Latitude (°)	Ground Height Altitude (m) (amsl)	ATC Tower Height (m)	Overall Assessed Height (m)
0.254483	51.885311	96.70	63.32	160.02

ATC Tower receptor details

The Approach Path for Aircraft Landing on Runway 04

The table below presents the data for the assessed locations for aircraft on approach to runway 04. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.24m) above the runway threshold (101.2m/332.0ft amsl).

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Threshold	0.22286	51.87704	116.4
Receptor 02	0.221264	51.87598	124.9
Receptor 03	0.21967	51.87492	133.3
Receptor 04	0.21807	51.87386	141.7
Receptor 05	0.21647	51.87280	150.2
Receptor 06	0.21488	51.87174	158.6
Receptor 07	0.21328	51.87068	167.0
Receptor 08	0.21168	51.86962	175.5
Receptor 09	0.21009	51.86855	183.9

[30] Based on OS Panorama 50m DTM

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Receptor 10	0.20849	51.86749	192.3
Receptor 11 – 1 mile	0.20689	51.86643	200.8
Receptor 12	0.20529	51.86537	209.2
Receptor 13	0.20370	51.86431	217.6
Receptor 14	0.20210	51.86325	226.1
Receptor 15	0.20050	51.86219	234.5
Receptor 16	0.19891	51.86113	242.9
Receptor 17	0.19731	51.86007	251.4
Receptor 18	0.19571	51.85901	259.8
Receptor 19	0.19412	51.85794	268.2
Receptor 20	0.19252	51.85688	276.7
Receptor 21 – 2 miles	0.19092	51.85582	285.1

Assessed receptor (aircraft) locations on the approach path for runway 04

The Approach Path for Aircraft Landing on Runway 22

The table below presents the data for the assessed locations for aircraft on approach to runway 22. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.24m) above the runway threshold (106.1m/348.0ft amsl).

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Threshold	0.25004	51.89516	121.3
Receptor 02	0.25164	51.89622	129.7
Receptor 03	0.25324	51.89728	138.2
Receptor 04	0.25484	51.89834	146.6
Receptor 05	0.25643	51.89940	155.0
Receptor 06	0.25803	51.90046	163.5
Receptor 07	0.25963	51.90152	171.9
Receptor 08	0.26123	51.90258	180.3

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Receptor 09	0.26283	51.90365	188.8
Receptor 10	0.26442	51.90471	197.2
Receptor 11 – 1 mile	0.26602	51.90577	205.7
Receptor 12	0.26762	51.90683	214.1
Receptor 13	0.26922	51.90789	222.5
Receptor 14	0.27081	51.90895	231.0
Receptor 15	0.27241	51.91001	239.4
Receptor 16	0.27401	51.91107	247.8
Receptor 17	0.27561	51.91213	256.3
Receptor 18	0.27720	51.91319	264.7
Receptor 19	0.27880	51.91426	273.1
Receptor 20	0.28040	51.91532	281.6
Receptor 21 – 2 miles	0.28200	51.91638	290.0

Assessed receptor (aircraft) locations on the approach path for runway 22

04 Left-Hand & 22 Right-Hand Circuit

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Circuit 01 - 04 Left	0.25004	51.89516	106.1
Circuit 02 - 04 Left	0.25282	51.89701	130.6
Circuit 03 - 04 Left	0.25559	51.89885	155.1
Circuit 04 – 04 Left	0.25836	51.90070	179.6
Circuit 05 - 04 Left	0.25910	51.90301	204.1
Circuit 06 - 04 Left	0.25895	51.90553	228.6
Circuit 07 - 04 Left	0.25778	51.90776	253.1
Circuit 08 - 04 Left	0.25479	51.90947	277.6

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Circuit 09 - 04 Left	0.25180	51.91118	302.1
Circuit 10 - 04 Left	0.24875	51.91281	326.6
Circuit 11 - 04 Left	0.24468	51.91271	351.1
Circuit 12 - 04 Left	0.24060	51.91261	375.6
Circuit 13 - 04 Left	0.23745	51.91127	400.1
Circuit 14 - 04 Left	0.23467	51.90943	410.9
Circuit 15 - 04 Left	0.23190	51.90758	410.9
Circuit 16 - 04 Left	0.22913	51.90573	410.9
Circuit 17 - 04 Left	0.22636	51.90388	410.9
Circuit 18 - 04 Left	0.22359	51.90204	410.9
Circuit 19 - 04 Left	0.22081	51.90019	410.9
Circuit 20 - 04 Left	0.21804	51.89834	410.9
Circuit 21 - 04 Left	0.21527	51.89649	410.9
Circuit 22 - 04 Left	0.21250	51.89465	410.9
Circuit 23 - 04 Left	0.20972	51.89280	410.9
Circuit 24 - 04 Left	0.20695	51.89095	410.9
Circuit 25 - 04 Left	0.20418	51.88910	410.9
Circuit 26 - 04 Left	0.20141	51.88726	410.9
Circuit 27 - 04 Left	0.19863	51.88541	410.9
Circuit 28 - 04 Left	0.19586	51.88356	395.2
Circuit 29 – 04 Left	0.19394	51.88152	370.7
Circuit 30 - 04 Left	0.19410	51.87900	346.2

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
Circuit 31 - 04 Left	0.19425	51.87649	321.7
Circuit 32 - 04 Left	0.19711	51.87474	297.2
Circuit 33 - 04 Left	0.20010	51.87302	272.7
Circuit 34 - 04 Left	0.20310	51.87131	248.2
Circuit 35 - 04 Left	0.20679	51.87077	223.7
Circuit 36 - 04 Left	0.21087	51.87086	199.2
Circuit 37 - 04 Left	0.21454	51.87150	174.7
Circuit 38 - 04 Left	0.21732	51.87335	150.2
Circuit 39 - 04 Left	0.22009	51.87519	125.7
Circuit 40 - 04 Left	0.22286	51.87704	101.2

04 left-hand side circuit

04 Right-Hand & 22 Left-Hand Circuit

ID	Longitude (°)	Latitude (°)	Assessed Altitude (metres amsl)
Circuit 41 - 04 Right	0.25004	51.89516	106.1
Circuit 42 - 04 Right	0.25282	51.89701	130.6
Circuit 43 - 04 Right	0.25559	51.89885	155.1
Circuit 44 - 04 Right	0.25836	51.90070	179.6
Circuit 45 - 04 Right	0.26204	51.90134	204.1
Circuit 46 - 04 Right	0.26611	51.90143	228.6
Circuit 47 - 04 Right	0.26981	51.90089	253.1
Circuit 48 - 04 Right	0.27280	51.89918	277.6
Circuit 49 - 04 Right	0.27579	51.89746	302.1

ID	Longitude (°)	Latitude (°)	Assessed Altitude (metres amsl)
Circuit 50 - 04 Right	0.27865	51.89571	326.6
Circuit 51 - 04 Right	0.27881	51.89320	351.1
Circuit 52 - 04 Right	0.27896	51.89068	375.6
Circuit 53 - 04 Right	0.27704	51.88864	400.1
Circuit 54 - 04 Right	0.27427	51.88679	410.9
Circuit 55 - 04 Right	0.27150	51.88494	410.9
Circuit 56 - 04 Right	0.26873	51.88310	410.9
Circuit 57 - 04 Right	0.26595	51.88125	410.9
Circuit 58 - 04 Right	0.26318	51.87940	410.9
Circuit 59 - 04 Right	0.26041	51.87755	410.9
Circuit 60 - 04 Right	0.25764	51.87571	410.9
Circuit 61 - 04 Right	0.25486	51.87386	410.9
Circuit 62 - 04 Right	0.25209	51.87201	410.9
Circuit 63 - 04 Right	0.24932	51.87016	410.9
Circuit 64 - 04 Right	0.24655	51.86832	410.9
Circuit 65 - 04 Right	0.24378	51.86647	410.9
Circuit 66 - 04 Right	0.24100	51.86462	410.9
Circuit 67 - 04 Right	0.23823	51.86277	410.9
Circuit 68 - 04 Right	0.23546	51.86093	395.2
Circuit 69 - 04 Right	0.23231	51.85959	370.7
Circuit 70 - 04 Right	0.22823	51.85949	346.2
Circuit 71 - 04 Right	0.22415	51.85939	321.7

ID	Longitude (°)	Latitude (°)	Assessed Altitude (metres amsl)
Circuit 72 - 04 Right	0.22111	51.86102	297.2
Circuit 73 - 04 Right	0.21811	51.86273	272.7
Circuit 74 - 04 Right	0.21512	51.86444	248.2
Circuit 75 - 04 Right	0.21396	51.86667	223.7
Circuit 76 - 04 Right	0.21380	51.86919	199.2
Circuit 77 - 04 Right	0.21454	51.87150	174.7
Circuit 78 – 04 Right	0.21732	51.87335	150.2
Circuit 79 – 04 Right	0.22009	51.87519	125.7
Circuit 80 - 04 Right	0.22286	51.87704	101.2

04 Right-hand side circuit

Modelled Reflector Data

The tables below and on the following pages present the coordinate data for the modelled reflector areas used in the assessment.

Area 1

Vertex number	Longitude (°)	Latitude (°)
01	51.88492	0.26608
02	51.88557	0.26608
03	51.88560	0.26526
04	51.88546	0.26519
05	51.88548	0.26448
06	51.88534	0.26443
07	51.88533	0.26398
08	51.88498	0.26392

Panel Area 1 data

Area 2

Vertex number	Longitude (°)	Latitude (°)
01	51.88430	0.26804
02	51.88472	0.26789
03	51.88474	0.26761
04	51.88489	0.26765
05	51.88501	0.26273
06	51.88483	0.26271
07	51.88481	0.26289
08	51.88468	0.26275
09	51.88461	0.26275
10	51.88460	0.26288
11	51.88454	0.26288

Panel Area 2 data

Area 3

Vertex number	Longitude (°)	Latitude (°)
1	51.88438	0.26282
2	51.88437	0.26316
3	51.88433	0.26316
4	51.88431	0.26312
5	51.88429	0.26311
6	51.88427	0.26309
7	51.88424	0.26306
8	51.88422	0.26306
9	51.88420	0.26337
10	51.88414	0.26338
11	51.88408	0.26340
12	51.88402	0.26340
13	51.88402	0.26317
14	51.88394	0.26315

Vertex number	Longitude (°)	Latitude (°)
15	51.88391	0.26319
16	51.88386	0.26319
17	51.88383	0.26321
18	51.88378	0.26321
19	51.88377	0.26332
20	51.88370	0.26332
21	51.88369	0.26335
22	51.88362	0.26334
23	51.88361	0.26339
24	51.88356	0.26339
25	51.88353	0.26335
26	51.88348	0.26335
27	51.88345	0.26337
28	51.88340	0.26338
29	51.88337	0.26340
30	51.88332	0.26340
31	51.88331	0.26345
32	51.88316	0.26344
33	51.88311	0.26345
34	51.88304	0.26347
35	51.88300	0.26350
36	51.88294	0.26350
37	51.88293	0.26356
38	51.88286	0.26356
39	51.88284	0.26358
40	51.88280	0.26359
41	51.88276	0.26359
42	51.88273	0.26360
43	51.88269	0.26361
44	51.88263	0.26363

Vertex number	Longitude (°)	Latitude (°)
45	51.88255	0.26364
46	51.88250	0.26365
47	51.88246	0.26367
48	51.88241	0.26366
49	51.88240	0.26374
50	51.88233	0.26373
51	51.88232	0.26381
52	51.88225	0.26381
53	51.88220	0.26381
54	51.88212	0.26385
55	51.88212	0.26379
56	51.88202	0.26378
57	51.88202	0.26385
58	51.88194	0.26385
59	51.88194	0.26392
60	51.88189	0.26391
61	51.88184	0.26392
62	51.88174	0.26387
63	51.88170	0.26388
64	51.88170	0.26403
65	51.88175	0.26405
66	51.88178	0.26450
67	51.88186	0.26451
68	51.88186	0.26494
69	51.88191	0.26494
70	51.88190	0.26532
71	51.88190	0.26546
72	51.88178	0.26532
73	51.88174	0.26527
74	51.88174	0.26490

Vertex number	Longitude (°)	Latitude (°)
75	51.88165	0.26488
76	51.88165	0.26448
77	51.88151	0.26444
78	51.88151	0.26421
79	51.88144	0.26421
80	51.88144	0.26411
81	51.88134	0.26410
82	51.88133	0.26416
83	51.88128	0.26416
84	51.88127	0.26410
85	51.88120	0.26409
86	51.88119	0.26423
87	51.88112	0.26420
88	51.88105	0.26419
89	51.88102	0.26423
90	51.88095	0.26422
91	51.88095	0.26428
92	51.88090	0.26427
93	51.88087	0.26429
94	51.88081	0.26430
95	51.88080	0.26437
96	51.88067	0.26434
97	51.88065	0.26432
98	51.88059	0.26430
99	51.88058	0.26447
100	51.88045	0.26442
101	51.88035	0.26441
102	51.88034	0.26457
103	51.88027	0.26454
104	51.88022	0.26454

Vertex number	Longitude (°)	Latitude (°)
105	51.88020	0.26457
106	51.88013	0.26457
107	51.88012	0.26462
108	51.88005	0.26461
109	51.88004	0.26478
110	51.87998	0.26478
111	51.87998	0.26468
112	51.87990	0.26467
113	51.87990	0.26471
114	51.87983	0.26470
115	51.87975	0.26473
116	51.87969	0.26479
117	51.87966	0.26489
118	51.87960	0.26481
119	51.87953	0.26480
120	51.87944	0.26487
121	51.87936	0.26498
122	51.87929	0.26504
123	51.87928	0.26535
124	51.87935	0.26551
125	51.87943	0.26563
126	51.87950	0.26580
127	51.87958	0.26589
128	51.87965	0.26602
129	51.87972	0.26618
130	51.87979	0.26642
131	51.87987	0.26661
132	51.88001	0.26678
133	51.88008	0.26677
134	51.88014	0.26675

Vertex number	Longitude (°)	Latitude (°)
135	51.88015	0.26694
136	51.88029	0.26697
137	51.88029	0.26705
138	51.88044	0.26706
139	51.88046	0.26712
140	51.88053	0.26712
141	51.88053	0.26720
142	51.88074	0.26721
143	51.88074	0.26739
144	51.88081	0.26739
145	51.88088	0.26735
146	51.88088	0.26755
147	51.88097	0.26756
148	51.88104	0.26754
149	51.88103	0.26779
150	51.88111	0.26788
151	51.88119	0.26795
152	51.88132	0.26789
153	51.88133	0.26800
154	51.88147	0.26801
155	51.88150	0.26804
156	51.88163	0.26802
157	51.88179	0.26792
158	51.88181	0.26720
159	51.88189	0.26719
160	51.88190	0.26666
161	51.88195	0.26623
162	51.88204	0.26622
163	51.88202	0.26668
164	51.88201	0.26724

Vertex number	Longitude (°)	Latitude (°)
165	51.88200	0.26751
166	51.88194	0.26752
167	51.88192	0.26809
168	51.88198	0.26812
169	51.88198	0.26823
170	51.88228	0.26822
171	51.88228	0.26834
172	51.88237	0.26834
173	51.88274	0.26829
174	51.88274	0.26850
175	51.88305	0.26849
176	51.88333	0.26842
177	51.88333	0.26860
178	51.88350	0.26857
179	51.88353	0.26832
180	51.88388	0.26823
181	51.88418	0.26810
182	51.88428	0.26806
183	51.88451	0.26288

Panel Area 3 data

APPENDIX H – DETAILED MODELLING RESULTS – FORGE RESULTS

Overview

The Forge charts for the aviation receptors where significant impacts are predicted are shown on the following pages. In detail, each chart shows:

- The reflection date/time graph – top left image. The chart shows the time at which glare at the corresponding intensities can occur;
- Duration of glare – top right image. The chart shows the duration for the corresponding glare intensities;
- The reflecting areas – bottom left image. Indicative only;
- Glare intensity graph – bottom right image. Shows you the intensity of glare produced and the categorisation it falls within.

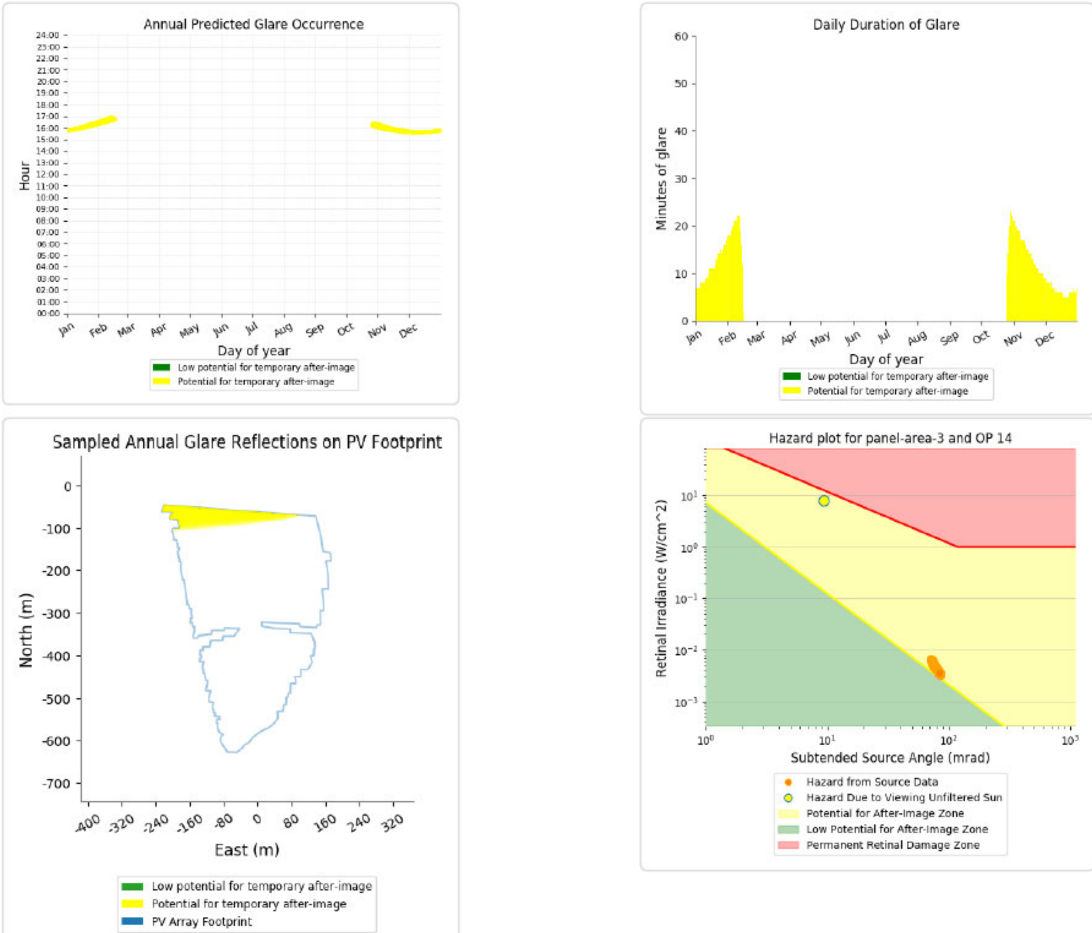
The charts for the remaining receptors can be provided on request.

Receptor 54 for 04R/22L Circuit

Panel area 3 - OP Receptor (OP 14)

PV array is expected to produce the following glare for receptors at this location:

- 0 minutes of "green" glare with low potential to cause temporary after-image.
- 1,391 minutes of "yellow" glare with potential to cause temporary after-image.

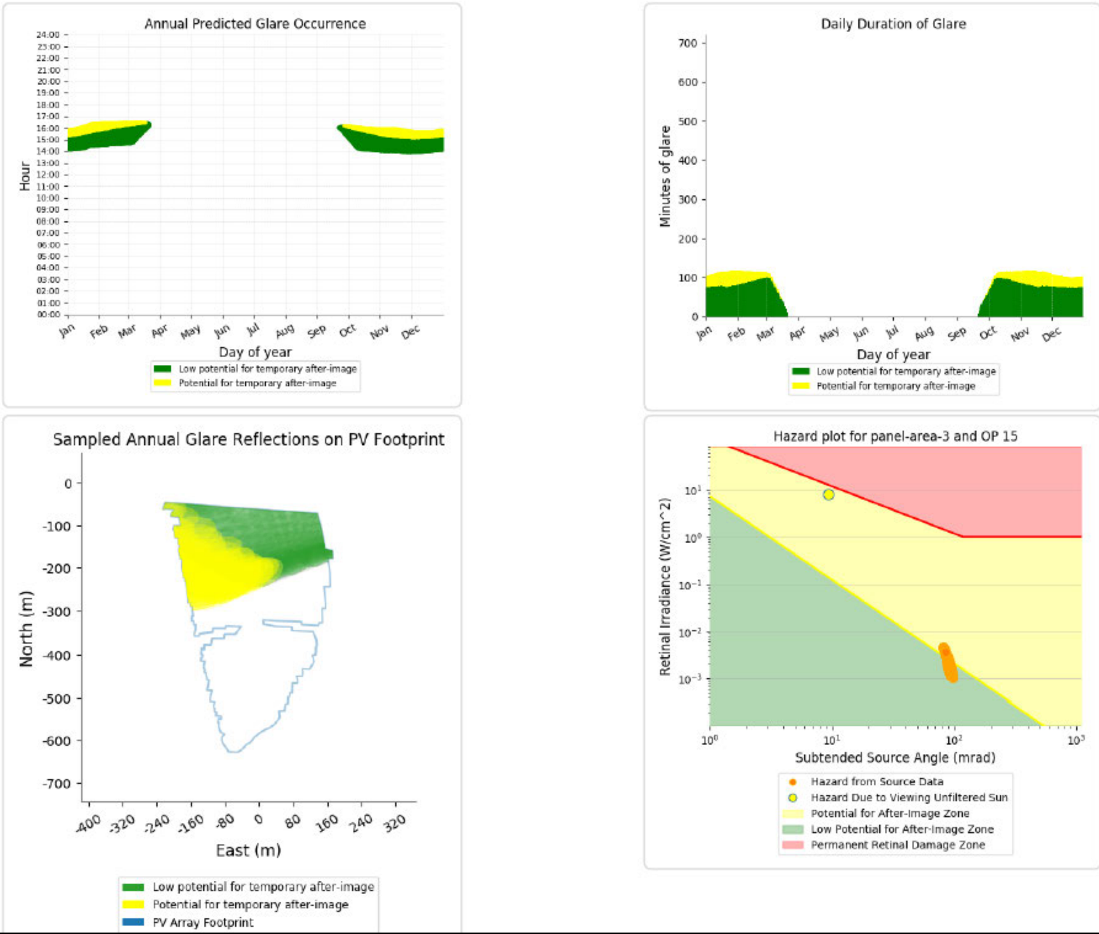


Receptor 55 for 04R/22L Circuit

Panel area 3 - OP Receptor (OP 15)

PV array is expected to produce the following glare for receptors at this location:

- 14,218 minutes of "green" glare with low potential to cause temporary after-image.
- 4,494 minutes of "yellow" glare with potential to cause temporary after-image.



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