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Urban & Renewables

Solar Photovoltaic Glint and Glare Study

Plot E2

Airport City LP Ltd

September, 2021







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EXECUTIVE SUMMARY

Report Purpose

Pager Power has been retained to assess the possible glint and glare effects from a proposed building development located north Manchester Airport, Manchester, UK. The proposed building development will be located approximately 1.2km north of the ATC[1] Tower. This assessment pertains to the possible effects upon aviation activity.

ATC Tower Results

The analysis has shown that no solar reflections generating from the proposed building development are geometrically possible towards the ATC Tower.

Therefore, no impact is anticipated, and no mitigation is required.

Approaches 05L, 23L & 05R Results

The analysis have shown that no solar reflections from the proposed building development towards any of the assessed receptor points associated with approaches 05L, 23L and 05R are geometrically possible.

Therefore, no impact is anticipated, and no mitigation is required.

Approach 23R Results

The analysis has shown that solar reflections from the proposed building development towards planes approaching threshold 23R are possible within 0.2 miles of the threshold itself. These reflections would originate outside the primary field of view of a pilot. Therefore, no impact is anticipated, and no mitigation is required.
Therefore, no impact is anticipated, and no mitigation is required.

Circuit paths

The analysis has shown that solar reflections from the proposed building development towards planes travelling across the circuit paths are only possible between 0.2 miles to threshold (23R) for planes circuiting 05L paths (both right and left). These reflections would originate outside the primary field of view of a pilot. Therefore, no impact is anticipated, and no mitigation is required.

Therefore, no impact is anticipated, and no mitigation is required.

Recommendation

Overall, no impact is expected towards aviation receptors associated with Manchester Airport. The results should be made available to the safeguarding team at Manchester Airport.

[1] Air traffic control

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ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 51 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 glint and glare effects generating from a proposed building development located north Manchester Airport, Manchester, UK. The proposed building development will be located approximately 1.2km north of the ATC[2] Tower. This assessment pertains to the possible effects upon aviation activity. This assessment pertains to the possible effects upon aviation activity. The analysis contains the following:

- Details of the solar development.
- Explanation of glint and glare.
- Overview of relevant guidance.
- Overview of relevant studies.
- Identification of aviation and ground-based concerns and receptors.
- Assessment methodology.
- Glint and glare assessment for:
    - Locations on the approach paths for runway 05L/23R and 05R/23L;
    - ATC Tower;
    - Both directions of the identified circuit patterns.
- Results discussion.

1.2 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] Air traffic control

2 PROPOSED DEVELOPMENT LOCATION AND DETAILS

2.1 Proposed Development

The proposed building development and its location relative to Manchester Airport are shown in Figure 1[3] and in Figure 2[4] below.

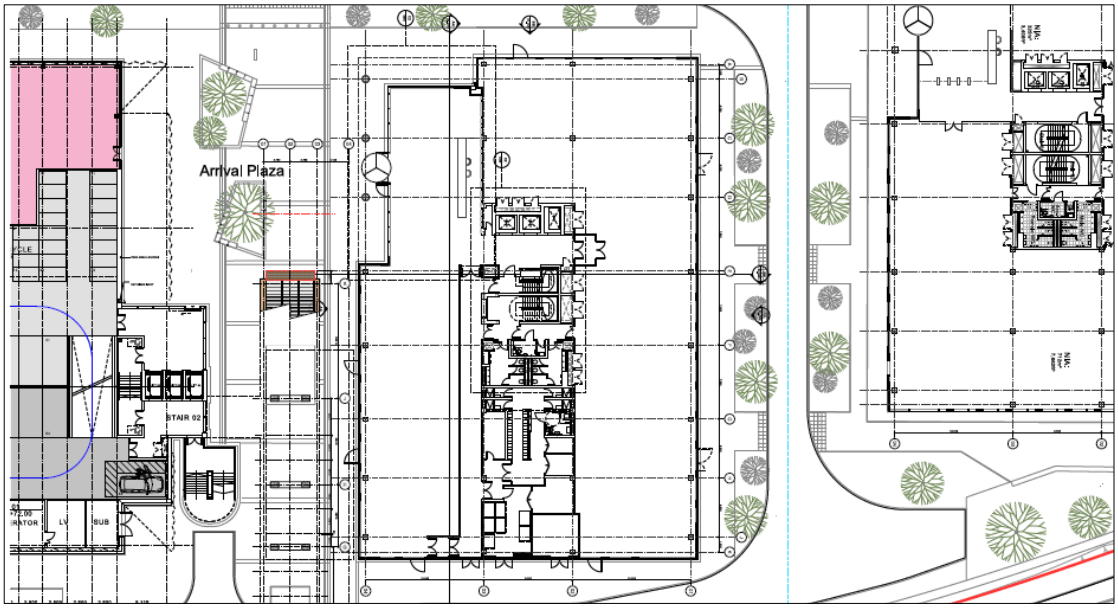


Figure 1 – Proposed building development



Figure 2 – Proposed development location relative to Manchester Airport

[3] E Plot Site Plan, Airport City Manchester, date: 12/01/2018, Drawing No.: E2_00_1200, cropped.
[4] Source: Copyright © 2021 Google.

2.2 Proposed Building Development Characteristics

The proposed building development has been divided into 8 wall areas (Figure 3[5] below). An example of the composition of the façade and the elevation of the building is shown in Figure 4[6].



Figure 3 – Areas considered for the assessment

[5] Source: Copyright © 2021 Google.

[6] E2 West Elevation - General Arrangement Drawing, Plot E2 - Airport City, Manchester, 5plus architects, date: 12/12/2017, cropped.

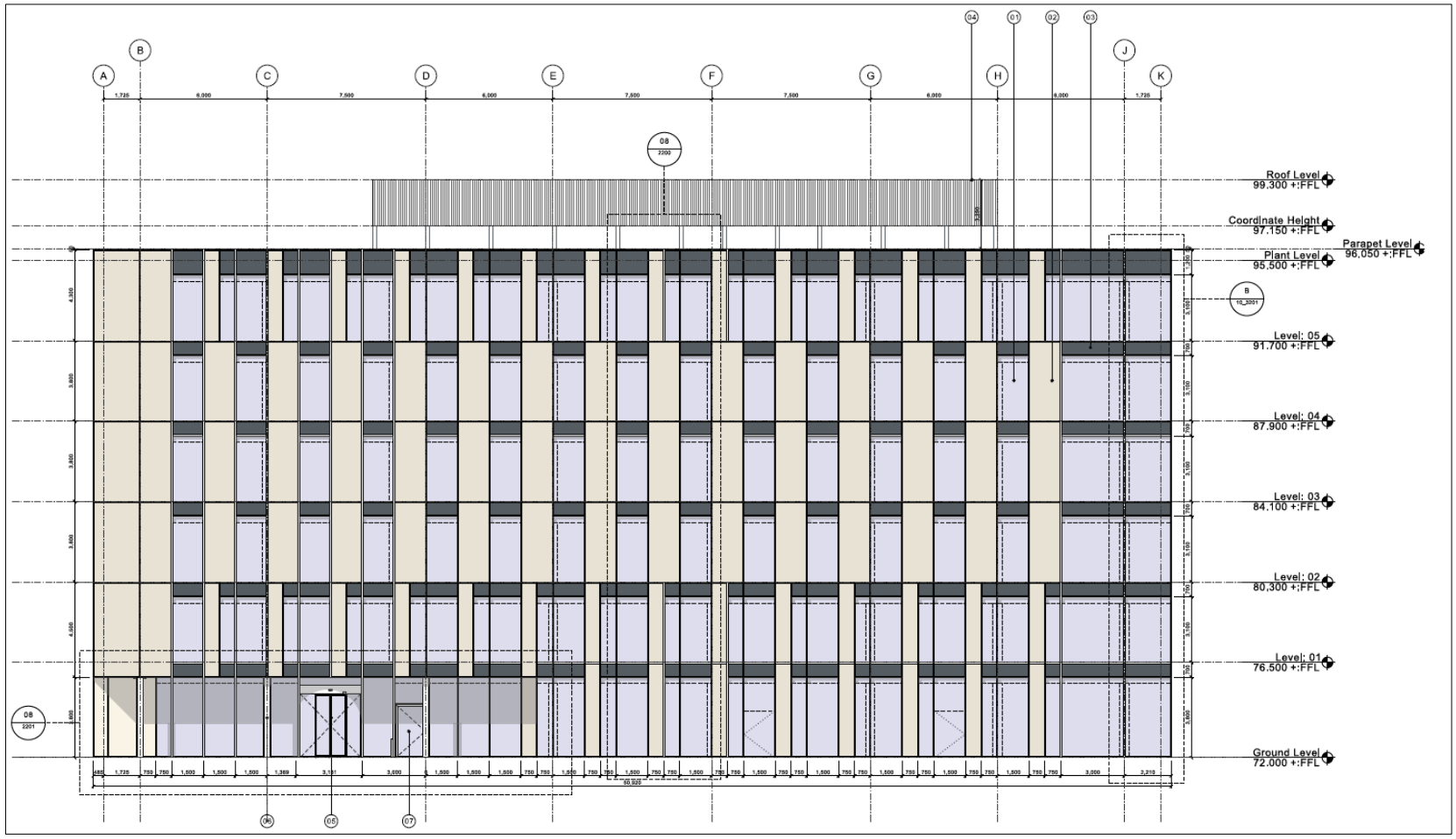


Figure 4 – Building elevation

3 MANCHESTER AIRPORT DETAILS

3.1 Airport Information

Manchester Airport is a Civil Aviation Authority (CAA) licensed aerodrome.

Manchester Airport has two operational runways. The runway details are presented below:

- 05L/23R measuring 3,048m by 45m (concrete and asphalt);
- 05R/23L measuring 3,050m by 45m (concrete and asphalt).

The runways are shown on the aerodrome chart in Figure 5 on the following page[7]. The ATC tower location is circled (red circle yellow area) for reference.

[7] Source: NATS AIP EG AD 2 EGCC 2-1 12/09/2019, accessed September 2019.

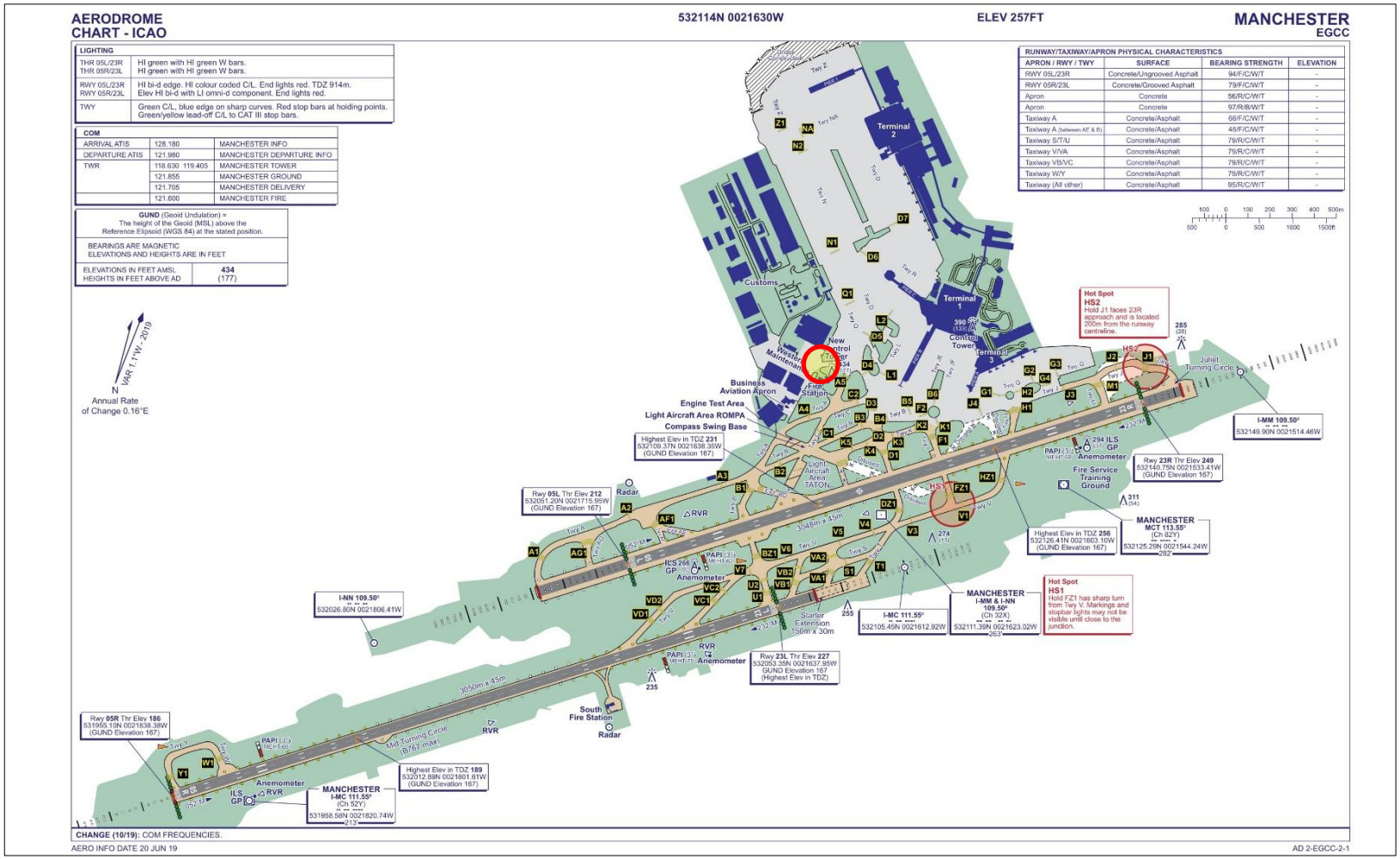


Figure 5 – Aerodrome chart of Manchester Airport

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. Note that a glint and glare assessment is typically undertaken for solar panels or for large reflective surfaces such as glass. The proposed development will feature surfaces which can cause specular reflections.

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, for reference. The overall conclusions from the available studies are as follows:

- Specular reflections of the Sun from solar panels and glass are possible;
- Published guidance shows that the intensity of solar reflections from glass are equal to or less than those from plexiglass and similar to those from plastic.

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;
- 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 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 freely 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. 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[8].

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.

[8] Currently using the Forge Solar model, based on the Sandia methodology.

5 IDENTIFICATION OF RECEPTORS

5.1 Overview

This assessment has been carried out with specific reference to potential impacts at Manchester Airport. The assessment has considered the Air Traffic Control (ATC) tower and the approaches towards both runways in accordance with the recommended guidance and circuit paths.

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 has a height of 60m and operates a twenty-four-hour service. It is located approximately 1.2km north of the ATC Tower.

Figure 6 below[9] shows a zoomed in aerial image of the ATC tower.



Figure 6 – ATC tower location

[9] Source: Copyright © 2021 Google.

5.3 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. Manchester Airport has two asphalt runways with four approach paths.

A geometric glint and glare assessment has been undertaken for aircraft on approach towards both runways in both directions. 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[10] relative to the runway threshold height.

Figure 7 on the following page[11] shows the assessed aviation receptor locations incorporated into the assessment.

The receptor details are presented in Appendix G.

[10] This is the same glide path angle as described in the NATS AIP for Manchester Airport at the time of writing.
[11] Copyright © 2021 Google.

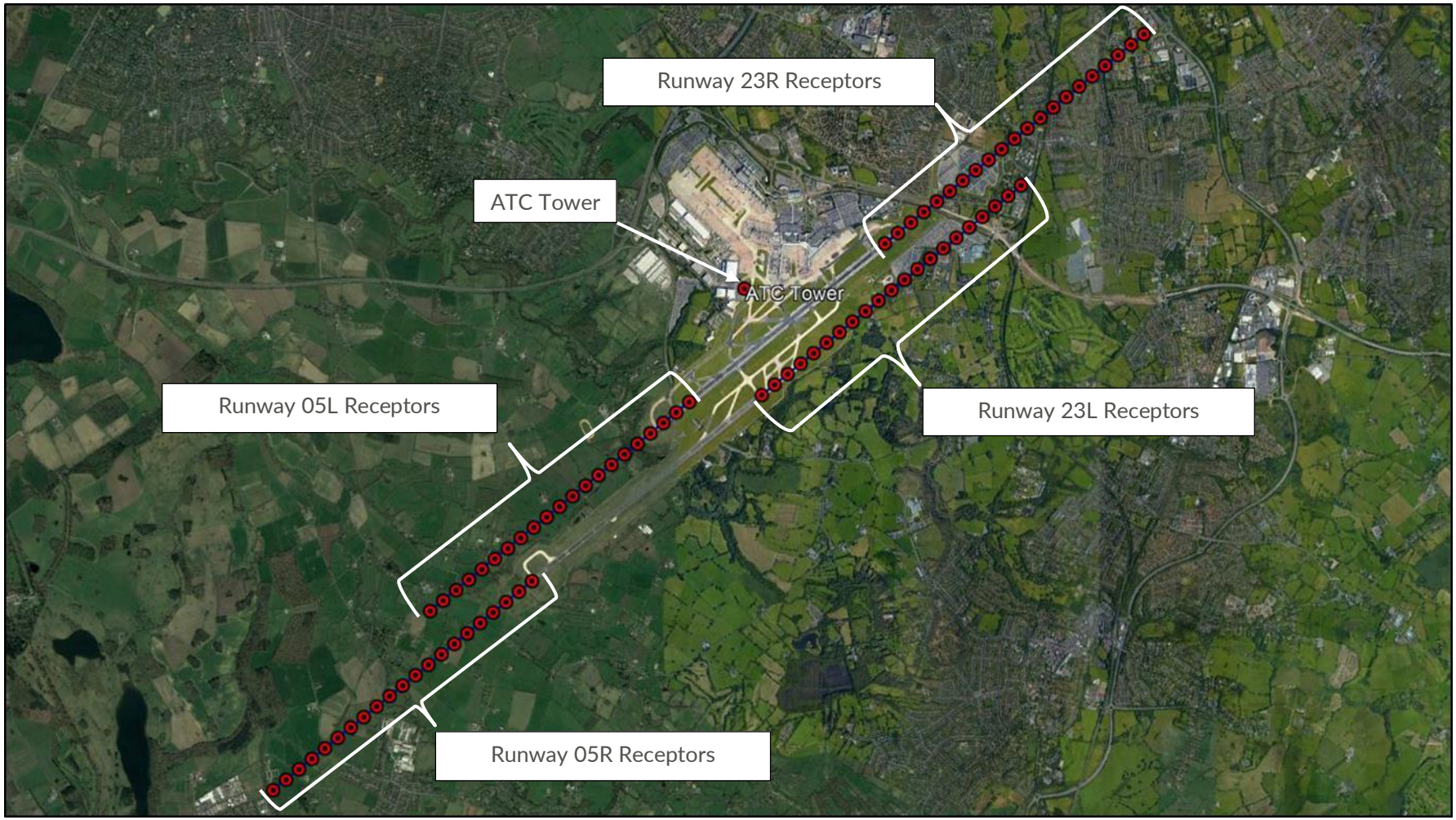


Figure 7 – Approach for runways 05L, 05R, 23R and 23L, ATC tower and receptor locations

5.4 Airborne Receptors – Aircraft Circuits

Manchester Airport has requested assessment of general aviation aircraft flying both directions of approach 05L, 05R, 23L and 23R.

When light aircraft arrive or depart from an aerodrome, they may fly in a standard pattern. A typical circuit is shown in Figure 8 below.

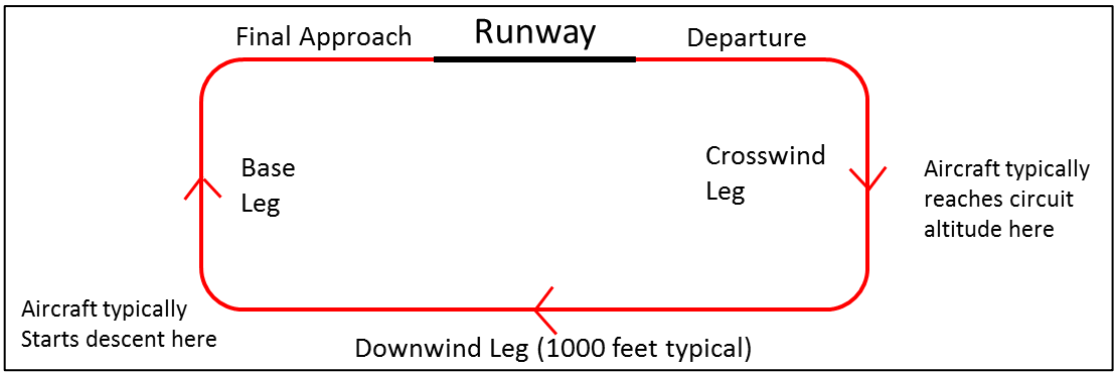


Figure 8 – *Typical circuit diagram*

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 9[13] on the following page shows the modelled circuit points as white placemarks. Points on the red circuit path belong to runway 05L-23R while points on the blue path belong to runway 05R-23L. The receptor details are presented in Appendix G.

[12] Runway thresholds.
[13] Copyright © 2021 Google.

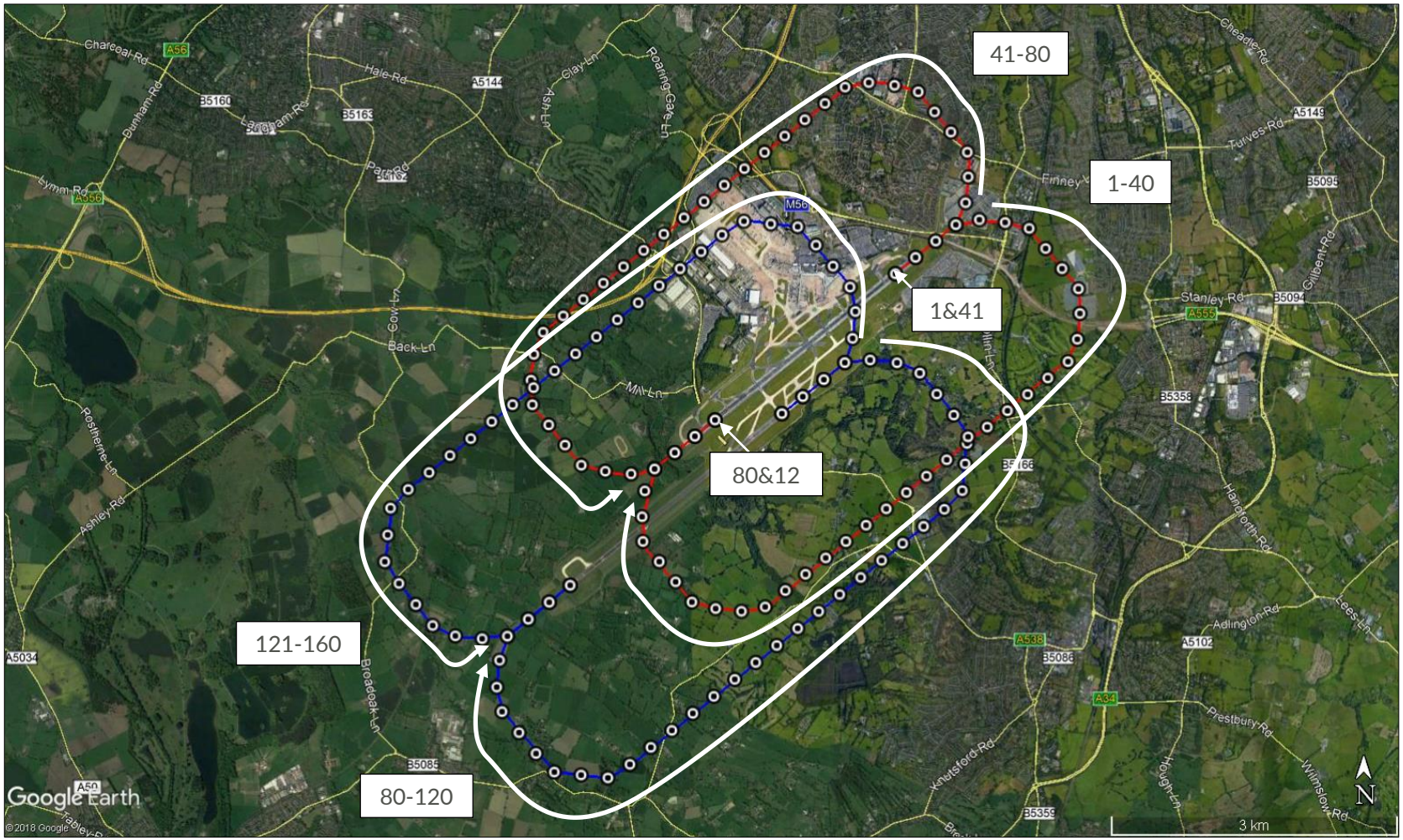


Figure 9 – Circuits paths for runways 05L-23R (red line) and 05R-23L (blue line)

6 ASSESSED REFLECTOR AREAS

6.1 Reflecting Façades

The following section presents the data for the reflectors.

A number of representative reflector points are selected based on the external vertical walls of the proposed development where the glass façade is present and likely to be visible to the identified receptors.

The number of reflector points is determined by the size of the reflector area and the selected vertical and/or horizontal resolution[14].

The reflector wall endpoint co-ordinates have been extrapolated from site plans. Individual reflector points have been taken every 2m vertically by 2m horizontally between the assessed heights stated for each reflector wall.

The model assumes that the entire exterior wall is smooth i.e. no exterior features that may alter the reflective surface, and perpendicular (90 degrees) to the horizontal (ground).

Overall, the modelling results are considered conservative. Further assumptions are presented in Appendix E.

6.2 Proposed Development Reflector Details

The reflective surfaces (façades only) on the proposed development are numerous glass window panels facing the railway line. The portion of the modelled façade which can produce a specular reflection is predicted to be less than 70% of the total surface area (see Figure 4 on page 12 Section 2.2 for further details). Only specular reflections are considered significant. The remaining surfaces would be expected to produce diffuse reflections and are not significant.

6.3 Modelled Façade Details

Eight external walls have been assessed. The façade defining point has been extrapolated. The specific details of the assessed reflectors are presented in Appendix F.

The reflector areas assessed are shown in Figure 10 on the following page.

[14] A horizontal resolution of 2m means a reflector point is defined every 2m along the horizontal plane of the wall. A 2m vertical resolution means that a reflector point is defined every 2m along the vertical plane of the wall. Both horizontal and vertical resolutions determine the overall resolution for a wall.

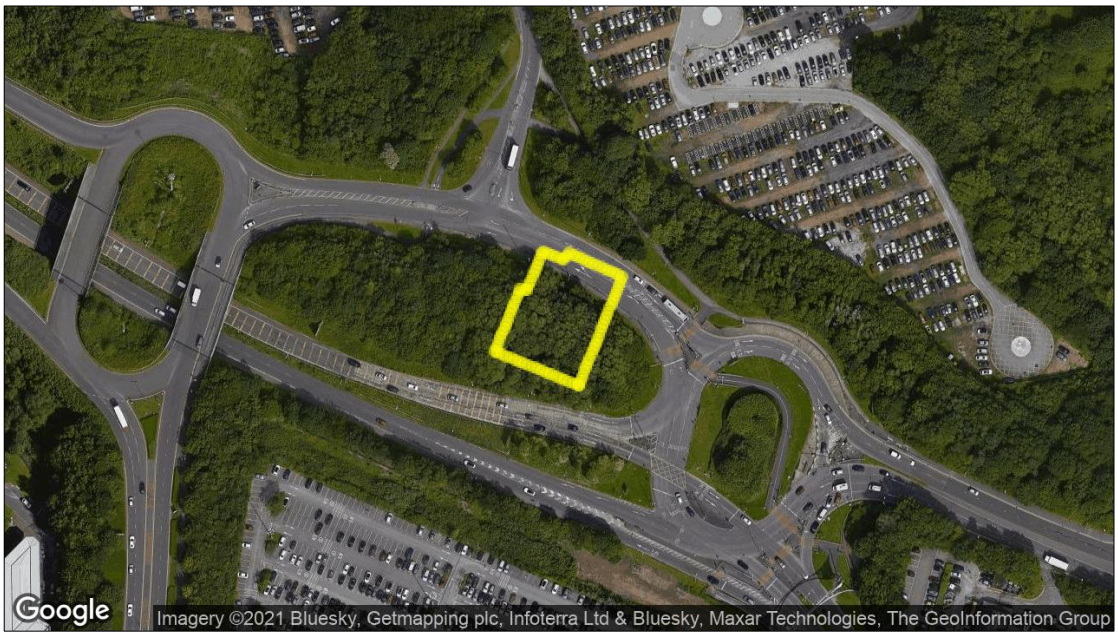


Figure 10 – Assessed reflector areas

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. Where glare is predicted, 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 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	Low potential for temporary after-image
Potential	Potential for temporary after-image
Potential for permanent eye damage	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[15]. In addition, the intensity model allows for assessment of a variety of reflector surface materials. A surface material of 'smooth glass without an anti-reflective coating' is assessed.

7.2 Summary of Results

The tables in the following subsections summarise the months and times during which a solar reflection could be experienced by a receptor.

This does not mean that reflections would occur continuously between the times shown.

The range of times at which reflections are geometrically possible is generally greater than the length of time for any particular day. This is because the times of day at which reflections could start and stop vary throughout the days/months.

The results of the analysis are presented in the following sections. Appendix H presents the results charts.

[15] Where two or more glare intensities are predicted for a particular receptor throughout the year.

7.3 Geometric Calculation Results Overview – ATC Tower

The results of the geometric calculation for the ATC tower are presented in Table 2 below. Discussed in 8.1.

Airfield Receptor	Predicted reflection times towards the ATC Tower (GMT)		Glare Type	Comment
	am	pm		
ATC tower	None.	None.	None.	Solar reflections are not predicted towards the ATC Tower.

Table 2 – Geometric analysis results for the ATC tower

7.4 Geometric Calculation Results Overview – Runway 05L

The results of the geometric calculations for aircraft approaching runway 05L are presented in Table 3 below. Discussed in 8.2.

Runway Approach	Predicted reflection times towards Runway 05L (GMT)		Glare Type	Comment
	am	pm		
Threshold – 2.0 miles	None.	None.	None.	Solar reflections are not possible.

Table 3 – Geometric analysis results for runway 05L

7.5 Geometric Calculation Results Overview – Runway 23R

The results of the geometric calculations for aircraft approaching runway 23R are presented in Table 4 below. Discussed in section 8.3.

Runway Approach	Predicted reflection times towards Runway 23R (GMT)		Glare Type	Comment
	am	pm		
Threshold	Between 06:29 and 06:40 during mid-March. Between 06:08 and 06:19 during the beginning of October.	Between 18:37 and 18:42 during the end of March. Between 18:28 and 18:32 during mid- September.	Glare beyond 50°	Solar reflections are possible. However, they will be outside pilot's field of view. No impact is expected in practice.
0.1 mile	Between 06:56 and 07:06 during late February.	At circa 18:59 during mid- April.	Glare beyond 50°	Solar reflections are possible. However, they will be outside pilot's field of view. No impact is expected in practice.
0.2 mile	Between 07:20 and 07:28 during mid-February.	Between 19:19 and 19:21 during mid- April. Between 19:24 and 19:25 during late August.	Glare beyond 50°	Solar reflections are possible. However, they will be outside pilot's field of view. No impact is expected in practice.
0.3 mile – 2.00 miles	None.	None.	None.	Solar reflections are not possible.

Table 4 – Geometric analysis results for runway 23R

7.6 Geometric Calculation Results Overview – Runway 05R

The results of the geometric calculations for aircraft approaching runway 05R are presented in Table 5 below. Discussed in 8.2.

Runway Approach	Predicted reflection times towards Runway 05R (GMT)		Glare Type	Comment
	am	pm		
Threshold – 2.0 miles	None.	None.	None.	Solar reflections are not possible.

Table 5 – Geometric analysis results for runway 05R

7.7 Geometric Calculation Results Overview – Runway 23L

The results of the geometric calculations for aircraft approaching runway 23L are presented in Table 6 below. Discussed in 8.2.

Runway Approach	Predicted reflection times towards Runway 23L (GMT)		Glare Type	Comment
	am	pm		
Threshold – 2.0 miles	None.	None.	None.	Solar reflections are not possible.

Table 6 – Geometric analysis results for runway 23L

7.8 Geometric Calculation Results Overview – Circuit Path 05R

7.8.1 05R right-hand side circuit

The results of the geometric calculations for aircraft circling both directions of the 05R right-hand side circuit are presented in Table 7 below. Discussed in 8.4.

Circuit Point	Predicted reflection times towards planes both directions of 05R right-hand side circuit (GMT)		Glare Type	Comment
	am	pm		
1 – 40	None.	None.	None.	Solar reflections are not possible.[16]

Table 7 – Geometric analysis results for planes circling both directions of 05R right-hand side circuit

7.8.2 05R left-hand side circuit

The results of the geometric calculations for aircraft circling both directions of the 05R left-hand side circuit are presented in Table 8 below. Discussed in 8.4.

Runway Approach	Predicted reflection times towards planes circling both directions of 05R left-hand side circuit (GMT)		Glare Type	Comment
	am	pm		
41 – 80	None.	None.	None.	Solar reflections are not possible.[16]

Table 8 – Geometric analysis results for planes circling both directions of the 05R right-hand side circuit

[16] Forge has predicted glare with low potential for after-image towards some receptors. This small discrepancy with Pager Power results might be due to the difference in the algorithm.

7.9 Geometric Calculation Results Overview – Circuit Path 05L

7.9.1 05L right-hand side circuit

The results of the geometric calculations for planes circling both directions of the 05L right-hand side circuit are presented in Table 9 below. Discussed in section 8.4.

Runway Approach	Predicted reflection times towards planes circling both directions of 05L right-hand side circuit (GMT)		Glare Type	Comment
	am	pm		
81	Between 06:31 and 06:42 during mid-March. Between 06:11 and 06:21 during the beginning of October.	Between 18:35 and 18:40 during the end of March. Between 18:27 and 18:31 during mid- September.	Glare beyond 50°	Solar reflections are possible. However, they will be outside pilot's field of view. No impact is expected in practice.
82	Between 07:13 and 07:22 during mid-February.	Between 19:13 and 19:16 during mid- April. Between 19:15 and 19:17 during late August.	Glare beyond 50°	Solar reflections are possible. However, they will be outside pilot's field of view. No impact is expected in practice.
83 – 120	None.	None.	None.	Solar reflections are not possible.

Table 9 – Geometric analysis results for aircraft circling both directions of the 05L right-hand side circuit

7.9.2 05R left-hand side circuit

The results of the geometric calculations for planes circling both directions of the 05R left-hand side circuit are presented in Table 10 below. Discussed in section 8.4.

Runway Approach	Predicted reflection times towards planes circling both directions of the 05R left-hand side circuit (GMT)		Glare Type	Comment
	am	pm		
121	Between 06:31 and 06:42 during mid-March. Between 06:11 and 06:21 during the beginning of October.	Between 18:35 and 18:40 during the end of March. Between 18:27 and 18:31 during mid- September.	Glare beyond 50°	Solar reflections are possible. However, they will be outside pilot's field of view. No impact is expected in practice.
122	Between 07:13 and 07:22 during mid-February.	Between 19:13 and 19:16 during mid- April. Between 19:15 and 19:17 during late August.	Glare beyond 50°	Solar reflections are possible. However, they will be outside pilot's field of view. No impact is expected in practice.
123 – 160	None.	None.	None.	Solar reflections are not possible.

Table 10 – Geometric analysis results for planes circling both directions of the 05R left-hand side circuit

8 GEOMETRIC ASSESSMENT RESULTS AND CONCLUSION

8.1 ATC Tower Results

The analysis has shown that solar reflections generating from the proposed building development towards the ATC tower are not geometrically possible. Furthermore, the proposed building development will not be visible from the ATC tower since other buildings are obstructing views.

8.2 Approaches 05L, 23L & 05R Results

Both Pager Power and Forge analysis have shown that solar reflections from the proposed building development towards any of the assessed receptor points associated with approaches 05L, 23L and 05R are geometrically not possible.

Therefore, no impact is anticipated in practice, and no mitigation is required.

8.3 Approach 23R Results

Pager Power analysis has shown that solar reflections from the proposed building development towards planes approaching threshold 23R are possible between 0.2 miles to threshold. However, Forge analysis has not predicted reflection. This is because Forge software takes into consideration if the solar reflections occur within the field of view of a pilot or not (50° both sides of the approach bearing). In this case the reflective area will be located outside the field of view of a pilot.

Therefore, no impact is anticipated in practice, and no mitigation is required.

8.4 Circuit paths

Pager Power analysis has shown that solar reflections from the proposed building development towards planes travelling across the circuit paths are only possible between 0.2 miles to threshold for planes circuiting 05L paths (both right and left). However, Forge analysis has not predicted reflection. This is because Forge software takes into consideration if the solar reflections occur within the field of view of a pilot or not (50° both sides of the approach bearing). In this case the reflective area will be located outside the field of view of a pilot.

Therefore, no impact is anticipated in practice, and no mitigation is required.

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[17] (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.'

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[18] however the advice is still applicable[19]

[17] Renewable and low carbon energy, Ministry of Housing, Communities & Local Government, date: 18 June 2015, accessed on: 17/06/2020
[18] Archived at Pager Power
[19] Reference email from the CAA dated 19/05/2014.

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[20], 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.

15. Further guidance may be obtained from CAA's Aerodrome Standards Department via aerodromes@caa.co.uk.'

FAA Guidance

[20] Aerodrome Licence Holder.

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'*[21] and the 2013 update is entitled '*Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports'*[22]. In April 2018 the FAA released a new version (Version 1.1) of the '*Technical Guidance for Evaluating Selected Solar Technologies on Airports'*[23].

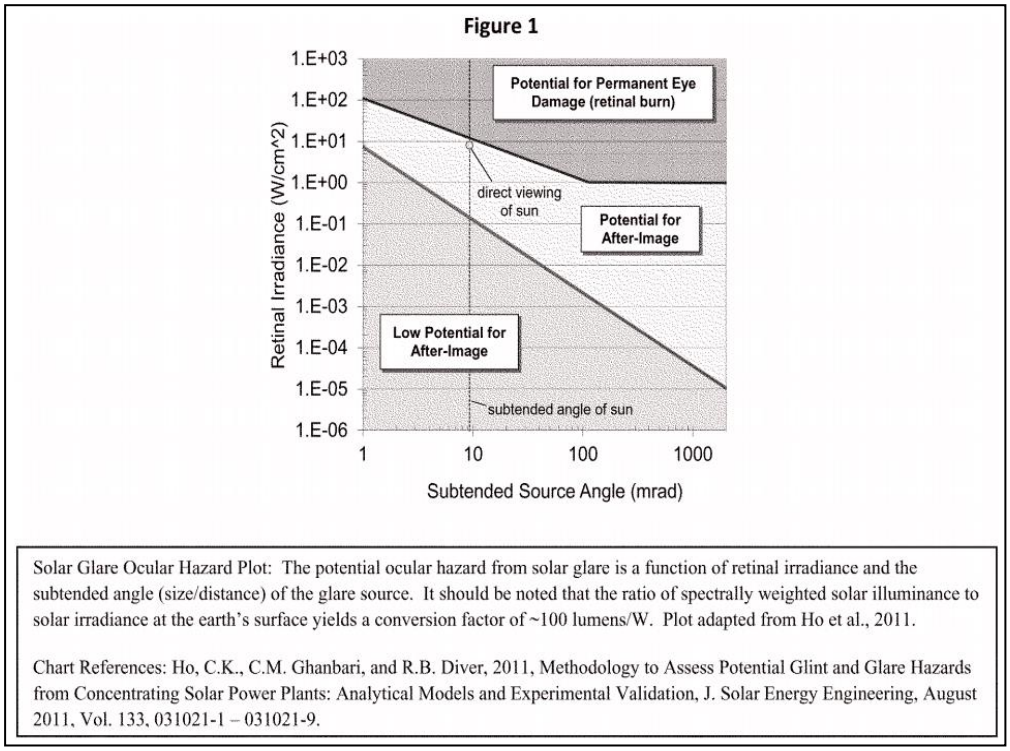
An overview of the methodology presented within the 2013 interim guidance and adopted by the FAA is presented below. This methodology is not presented within the 2018 guidance.

- *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.*

[21] Archived at Pager Power

[22] 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

[23] 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[24].

- *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*[25]*, 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 known cases where a field test was conducted, tower personnel determined the glare was*

[24] 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.
[25] First figure in Appendix B.

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 question26 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
(b) by reason of its liability to be mistaken for an aeronautical ground light is liable to endanger aircraft.

[26] 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.

(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.

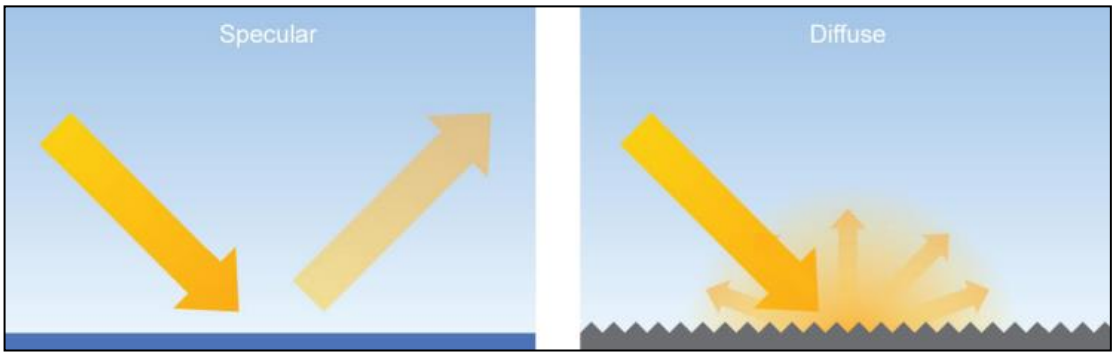
APPENDIX B – OVERVIEW OF GLINT AND GLARE STUDIES

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[27], 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

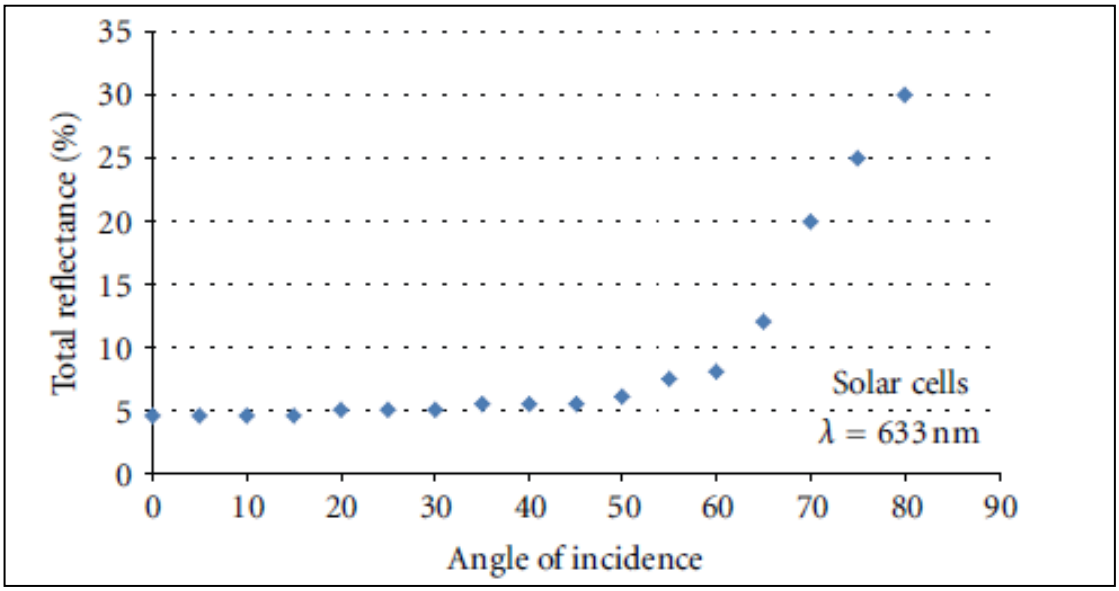
[27] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

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*[28]". 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.

[28] 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"[29]

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[30]
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.

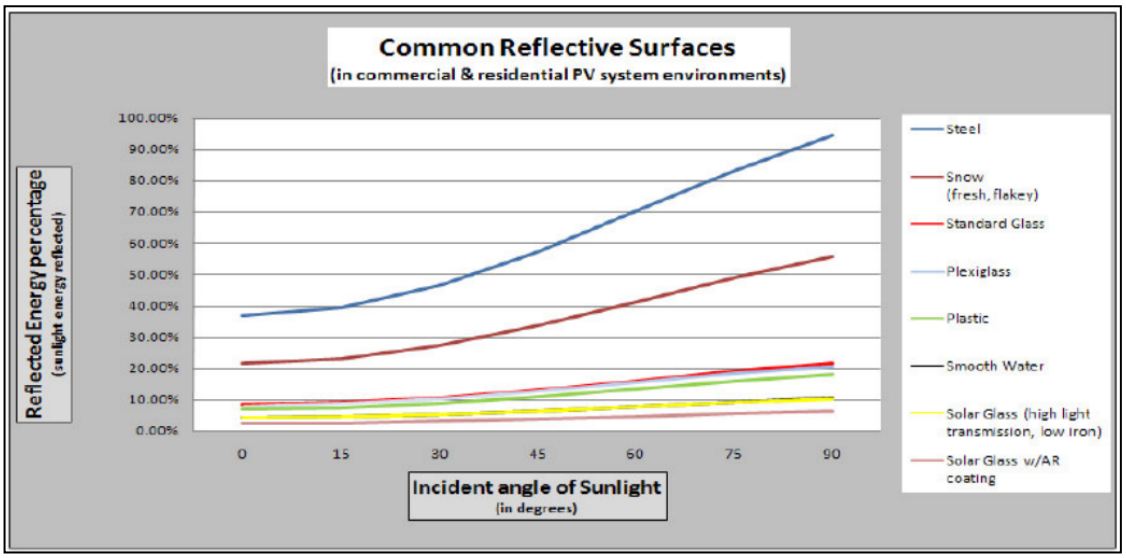
[29] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

[30] Extrapolated data, baseline of 1,000 W/m^2 for incoming sunlight.

SunPower Technical Notification (2009)

SunPower published a technical notification[31] 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.

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

APPENDIX C – OVERVIEW OF SUN MOVEMENTS AND RELATIVE REFLECTIONS

Overview

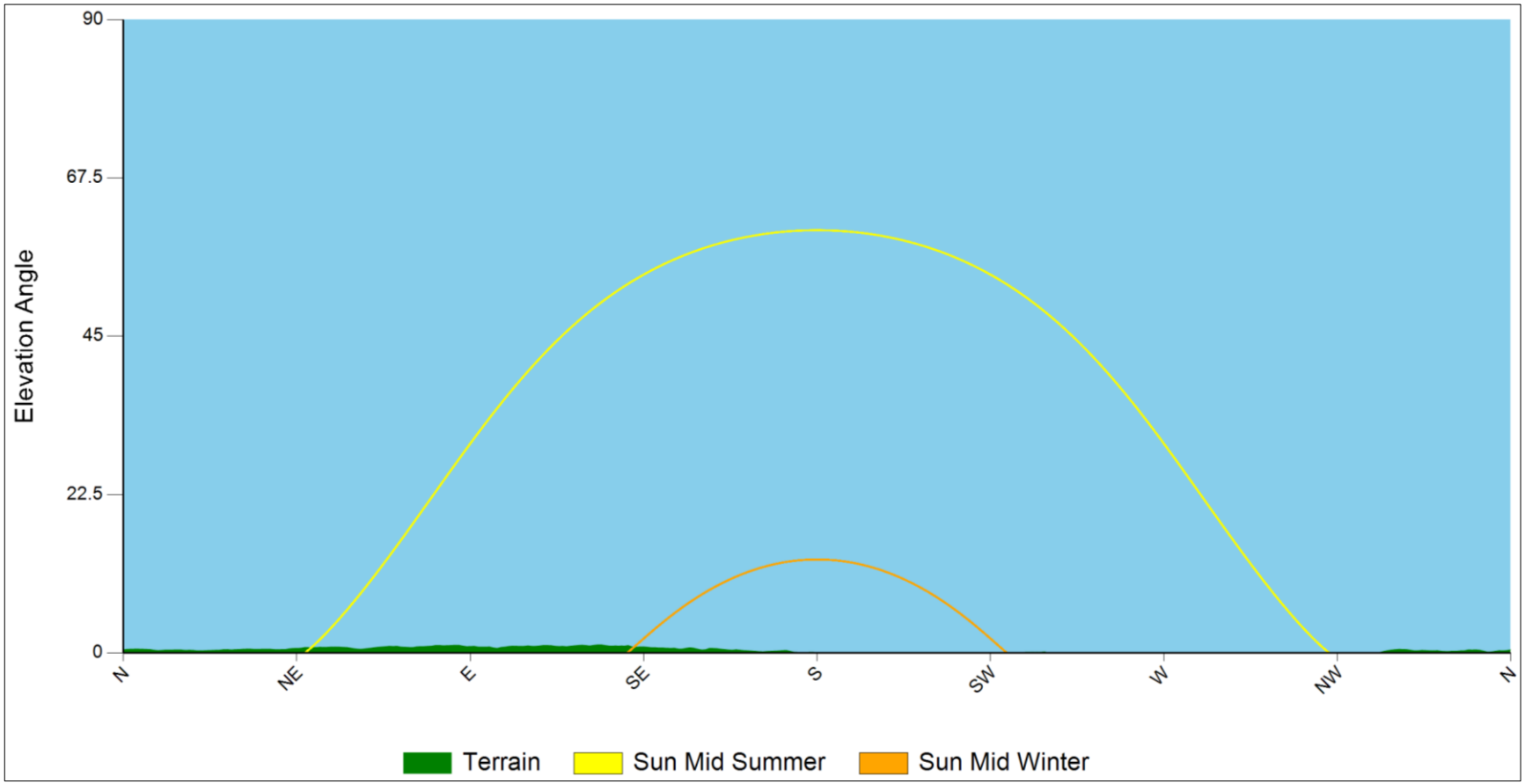
The Sun's position in the sky can be accurately described by its azimuth and elevation. Azimuth is a direction relative to true north (horizontal angle i.e. from left to right) and elevation describes the Sun's angle relative to the horizon (vertical angle i.e. up and down).

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.

Terrain Sun Curve – From lon:-2.273325 lat:53.367855



Terrain profile at horizon and sunrise/sunset curve at proposed development location

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.

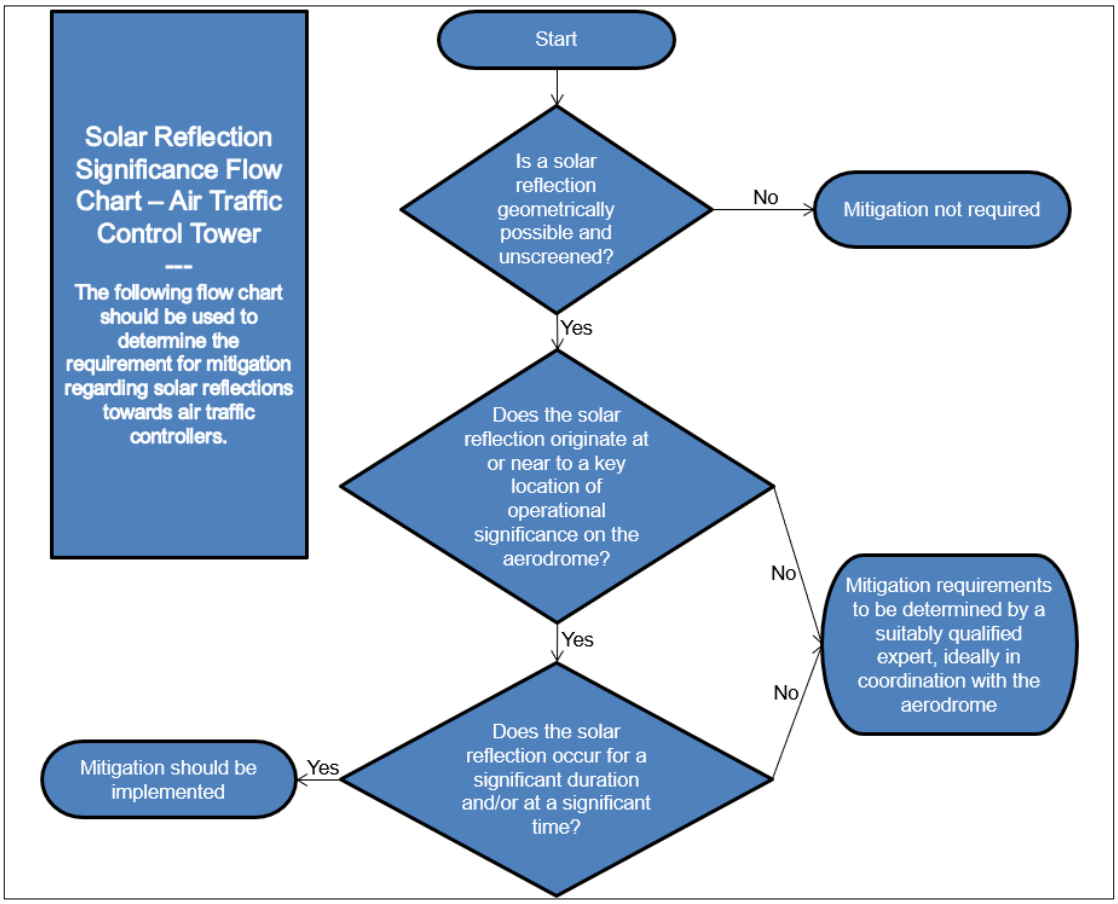
Impact Significance	Definition	Mitigation Requirement
No Impact	A solar reflection is not geometrically possible or will not be visible from the assessed receptor.	No mitigation required.
Low	A solar reflection is geometrically possible however any impact is considered to be small such that mitigation 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 the relevant receptors.

Assessment Process – ATC Tower

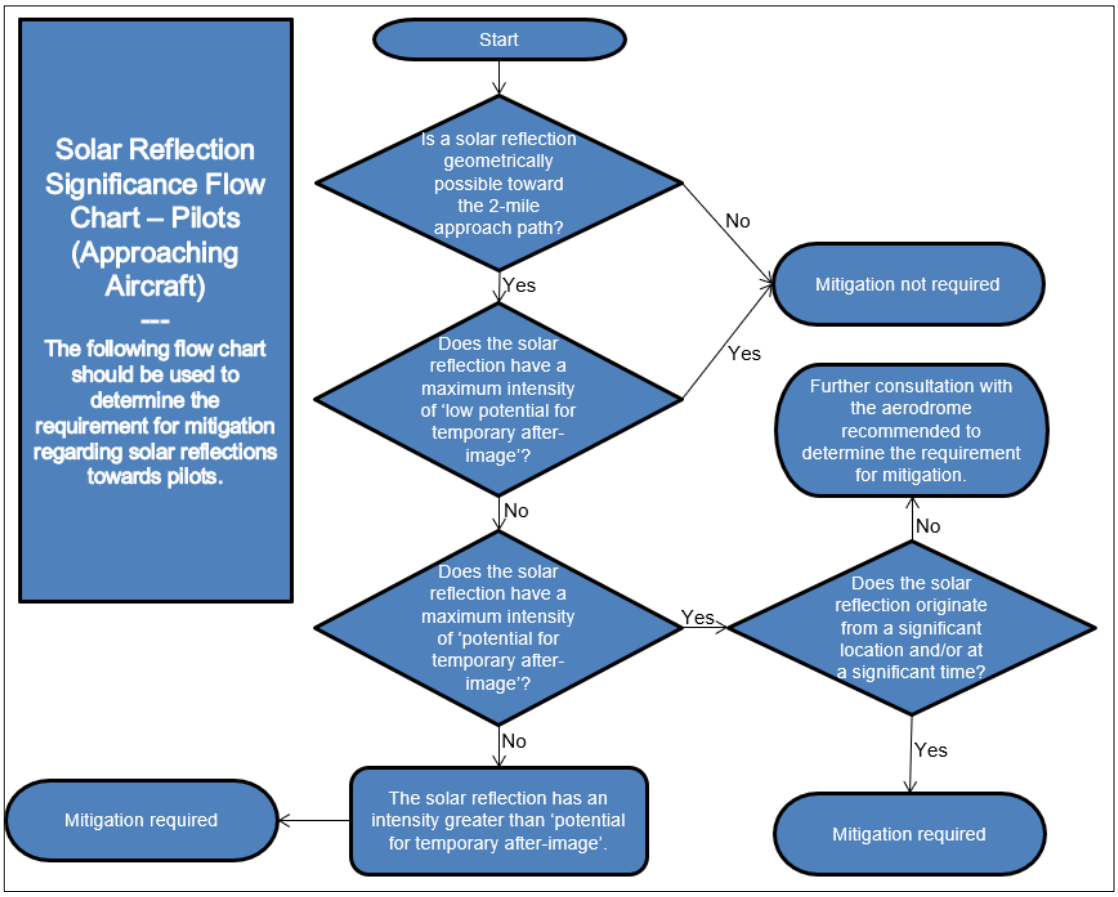
The charts relate to the determining the potential impact upon the ATC tower (for solar panels – presented for reference).



ATC Tower mitigation requirement flow chart

Assessment Process – Approaching Aircraft

The charts relate to the determining the potential impact upon approaching aircraft (for solar panels – presented for reference).



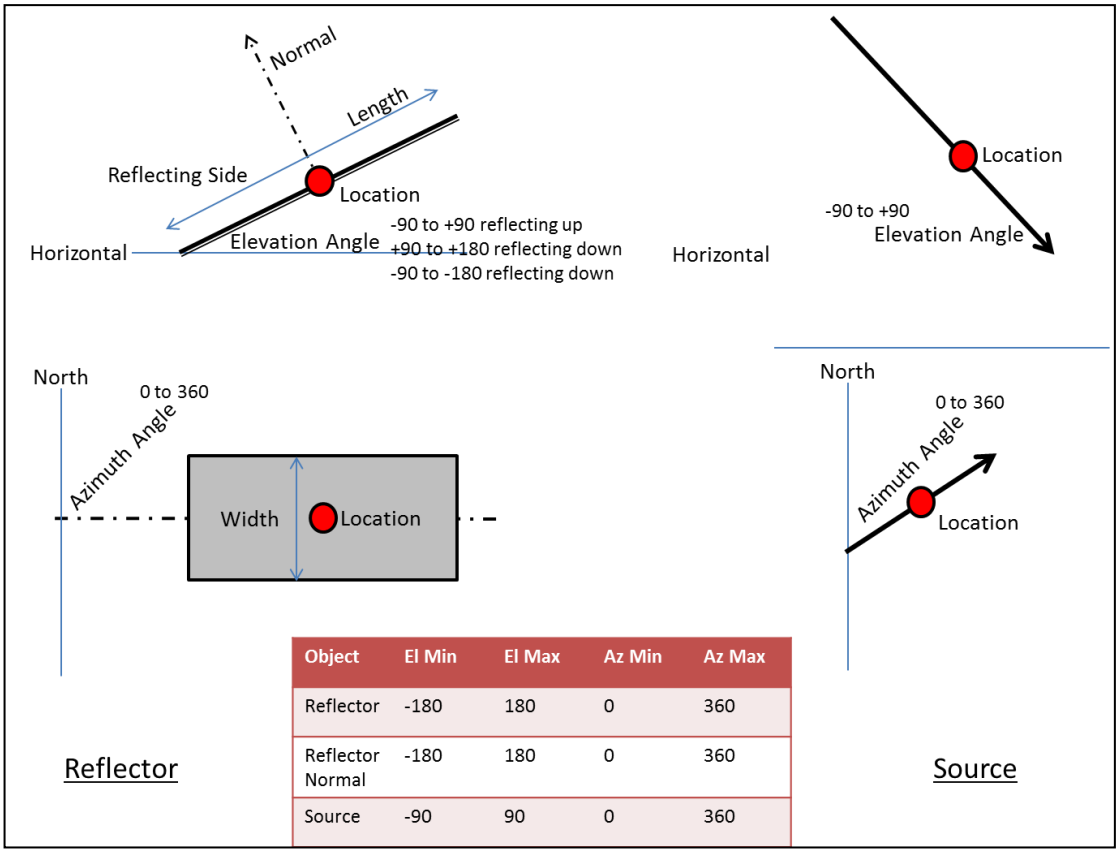
Approaching aircraft receptor mitigation requirement flow chart

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.



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 assumes that a receptor can view every wall of the proposed building development whilst in reality this, in the majority of cases, will not occur. Therefore, any predicted solar reflection from the building façade that is not visible to a receptor will not occur in practice.

A finite number of points within each façade 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 reflective surface (i.e. window) or the entire face of the reflective surface within the development outline, rather a single point is defined every 'x' metres (based on the resolution) with the geometric characteristics of the wall. A wall area is however defined to encapsulate all possible reflective surfaces locations. See the figure below which illustrates this process.

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 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 proposed building is not within the modelling unless stated otherwise. The terrain profile at the horizon is considered if stated.

Forge's Sandia National Laboratories' (SGHAT) Model

The following text is taken from Forge[32] and is presented for reference.

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.

[32] Source: https://www.forgesolar.com/help/#assumptions

APPENDIX G – RECEPTOR AND REFLECTOR AREA DETAILS

ATC Tower Receptor Details

Longitude (°)	Latitude (°)	Ground Height (m amsl)	ATC Tower Height (m agl)	Overall Assessed Height (m amsl)
-2.2797167	53.3574	69.47m	62.81	127.28m[33]

ATC Tower receptor details

The Approach Path for Aircraft Landing on Runway 05L

The table below presents the data for the assessed locations for aircraft on approach to runway 05L. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (64.62m/212ft amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m amsl)
0	-2.28776	53.34756	Threshold	79.9
1	-2.28965	53.34665	160.9	88.3
2	-2.29154	53.34574	321.9	96.7
3	-2.29343	53.34482	482.8	105.1
4	-2.29531	53.34391	643.7	113.5
5	-2.29720	53.34300	804.7	122.0
6	-2.29909	53.34209	965.6	130.4
7	-2.30097	53.34118	1126.5	138.8
8	-2.30286	53.34027	1287.5	147.2
9	-2.30475	53.33936	1448.4	155.7
10	-2.30663	53.33845	1609.3	164.1
11	-2.30852	53.33754	1770.3	172.5
12	-2.31041	53.33663	1931.2	180.9
13	-2.31230	53.33572	2092.1	189.4

[33] Overall height minus 5m to account for cab level.

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m amsl)
14	-2.31418	53.33481	2253.1	197.8
15	-2.31607	53.33390	2414.0	206.2
16	-2.31796	53.33299	2575.0	214.6
17	-2.31984	53.33208	2735.9	223.0
18	-2.32173	53.33117	2896.8	231.5
19	-2.32362	53.33026	3057.8	239.9
20	-2.32550	53.32935	2 miles	248.3

Assessed receptor (aircraft) locations on the approach path for runway 05L

The Approach Path for Aircraft Landing on Runway 23R

The table below presents the data for the assessed locations for aircraft on approach to runway 23R. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (75.90m/249ft amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m amsl)
0	-2.25928	53.36132	Threshold	91.1
1	-2.25739	53.36223	160.9	99.6
2	-2.25550	53.36314	321.9	108.0
3	-2.25362	53.36405	482.8	116.4
4	-2.25173	53.36496	643.7	124.8
5	-2.24984	53.36587	804.7	133.2
6	-2.24795	53.36678	965.6	141.7
7	-2.24606	53.36769	1126.5	150.1
8	-2.24417	53.36860	1287.5	158.5
9	-2.24228	53.36951	1448.4	166.9
10	-2.24040	53.37042	1609.3	175.4
11	-2.23851	53.37133	1770.3	183.8
12	-2.23662	53.37224	1931.2	192.2
13	-2.23473	53.37315	2092.1	200.6

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m amsl)
14	-2.23284	53.37406	2253.1	209.1
15	-2.23095	53.37498	2414.0	217.5
16	-2.22907	53.37589	2575.0	225.9
17	-2.22718	53.37680	2735.9	234.3
18	-2.22529	53.37771	2896.8	242.7
19	-2.22340	53.37862	3057.8	251.2
20	-2.22151	53.37953	2 miles	259.6

Assessed receptor (aircraft) locations on the approach path for runway 23R

The Approach Path for Aircraft Landing on Runway 05R

The table below presents the data for the assessed locations for aircraft on approach to runway 05R. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (56.69m/186ft amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m amsl)
0	-2.31066	53.33197	Threshold	71.9
1	-2.31255	53.33106	160.9	80.4
2	-2.31443	53.33015	321.9	88.8
3	-2.31632	53.32924	482.8	97.2
4	-2.31820	53.32833	643.7	105.6
5	-2.32009	53.32742	804.7	114.0
6	-2.32198	53.32650	965.6	122.5
7	-2.32386	53.32559	1126.5	130.9
8	-2.32575	53.32468	1287.5	139.3
9	-2.32763	53.32377	1448.4	147.7
10	-2.32952	53.32286	1609.3	156.2
11	-2.33141	53.32195	1770.3	164.6
12	-2.33329	53.32104	1931.2	173.0
13	-2.33518	53.32012	2092.1	181.4

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m amsl)
14	-2.33706	53.31921	2253.1	189.8
15	-2.33895	53.31830	2414.0	198.3
16	-2.34083	53.31739	2575.0	206.7
17	-2.34272	53.31648	2735.9	215.1
18	-2.34461	53.31557	2896.8	223.5
19	-2.34649	53.31466	3057.8	232.0
20	-2.34838	53.31374	2 miles	240.4

Assessed receptor (aircraft) locations on the approach path for runway 05R

The Approach Path for Aircraft Landing on Runway 23L

The table below presents the data for the assessed locations for aircraft on approach to runway 23L. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (69.19m/227ft amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m amsl)
0	-2.27721	53.34815	Threshold	84.4
1	-2.27532	53.34906	160.9	92.9
2	-2.27343	53.34997	321.9	101.3
3	-2.27155	53.35089	482.8	109.7
4	-2.26966	53.35180	643.7	118.1
5	-2.26777	53.35271	804.7	126.5
6	-2.26588	53.35362	965.6	135.0
7	-2.26400	53.35453	1126.5	143.4
8	-2.26211	53.35544	1287.5	151.8
9	-2.26022	53.35635	1448.4	160.2
10	-2.25833	53.35726	1609.3	168.7
11	-2.25645	53.35817	1770.3	177.1
12	-2.25456	53.35908	1931.2	185.5
13	-2.25267	53.35999	2092.1	193.9

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m amsl)
14	-2.25079	53.36090	2253.1	202.3
15	-2.24890	53.36181	2414.0	210.8
16	-2.24701	53.36273	2575.0	219.2
17	-2.24512	53.36364	2735.9	227.6
18	-2.24324	53.36455	2896.8	236.0
19	-2.24135	53.36546	3057.8	244.5
20	-2.23946	53.36637	2 miles	252.9

Assessed receptor (aircraft) locations on the approach path for runway 23L

The right-hand side of Runway 05R

The table below presents the data for the assessed locations for aircraft circuiting the right-hand side of runway 05R.

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
1	-2.27721	53.34815	56.69
2	-2.27390	53.34975	81.44
3	-2.27059	53.35136	106.20
4	-2.26727	53.35296	130.95
5	-2.26329	53.35320	155.70
6	-2.25905	53.35294	180.45
7	-2.25546	53.35197	205.20
8	-2.25277	53.34999	229.95
9	-2.25009	53.34801	254.70
10	-2.24784	53.34596	279.45
11	-2.24829	53.34343	304.21
12	-2.24873	53.34090	328.96
13	-2.25154	53.33913	353.71
14	-2.25485	53.33753	378.46
15	-2.25816	53.33593	383.13

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
16	-2.26147	53.33433	383.13
17	-2.26479	53.33273	383.13
18	-2.26810	53.33112	383.13
19	-2.27141	53.32952	383.13
20	-2.27472	53.32792	383.13
21	-2.27803	53.32632	383.13
22	-2.28134	53.32472	383.13
23	-2.28465	53.32312	383.13
24	-2.28796	53.32152	383.13
25	-2.29127	53.31991	383.13
26	-2.29459	53.31831	383.13
27	-2.29790	53.31671	383.13
28	-2.30121	53.31511	366.21
29	-2.30468	53.31383	341.45
30	-2.30892	53.31410	316.70
31	-2.31316	53.31437	291.95
32	-2.31606	53.31610	267.20
33	-2.31874	53.31808	242.45
34	-2.32142	53.32006	217.70
35	-2.32227	53.32236	192.95
36	-2.32182	53.32489	168.19
37	-2.32059	53.32717	143.44
38	-2.31728	53.32877	118.69
39	-2.31397	53.33037	93.94
40	-2.31066	53.33197	69.19

Assessed receptor (aircraft) locations on the right-hand side of runway 05R circuit path

The left-hand side of Runway 05R

The table below presents the data for the assessed locations for aircraft circuiting the left-hand side of runway 05R.

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
41	-2.27721	53.34815	56.69
42	-2.27390	53.34975	81.44
43	-2.27059	53.35136	106.20
44	-2.26727	53.35296	130.95
45	-2.26605	53.35523	155.70
46	-2.26560	53.35776	180.45
47	-2.26645	53.36007	205.20
48	-2.26913	53.36204	229.95
49	-2.27181	53.36402	254.70
50	-2.27471	53.36576	279.45
51	-2.27895	53.36602	304.21
52	-2.28319	53.36629	328.96
53	-2.28666	53.36502	353.71
54	-2.28997	53.36341	378.46
55	-2.29328	53.36181	383.13
56	-2.29659	53.36021	383.13
57	-2.29991	53.35861	383.13
58	-2.30322	53.35701	383.13
59	-2.30653	53.35541	383.13
60	-2.30984	53.35380	383.13
61	-2.31315	53.35220	383.13
62	-2.31646	53.35060	383.13
63	-2.31977	53.34900	383.13
64	-2.32308	53.34740	383.13
65	-2.32639	53.34580	383.13

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
66	-2.32971	53.34420	383.13
67	-2.33302	53.34259	383.13
68	-2.33633	53.34099	366.21
69	-2.33914	53.33923	341.45
70	-2.33958	53.33670	316.70
71	-2.34003	53.33417	291.95
72	-2.33778	53.33211	267.20
73	-2.33510	53.33014	242.45
74	-2.33241	53.32816	217.70
75	-2.32882	53.32719	192.95
76	-2.32458	53.32692	168.19
77	-2.32059	53.32717	143.44
78	-2.31728	53.32877	118.69
79	-2.31397	53.33037	93.94
80	-2.31066	53.33197	69.19

Assessed receptor (aircraft) locations on the left-hand side of runway 05R circuit path

The right-hand side of Runway 05L

The table below presents the data for the assessed locations for aircraft circuiting the right-hand side of runway 05L.

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
81	-2.25928	53.36132	75.90
82	-2.25610	53.36286	99.69
83	-2.25291	53.36440	123.49
84	-2.24973	53.36594	147.28
85	-2.24818	53.36801	171.08
86	-2.24775	53.37044	194.87
87	-2.24789	53.37277	218.67

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
88	-2.25047	53.37467	242.46
89	-2.25305	53.37657	266.26
90	-2.25562	53.37848	290.05
91	-2.25938	53.37909	313.85
92	-2.26345	53.37934	337.64
93	-2.26719	53.37893	361.44
94	-2.27038	53.37739	383.13
95	-2.27356	53.37585	383.13
96	-2.27675	53.37431	383.13
97	-2.27993	53.37277	383.13
98	-2.28312	53.37123	383.13
99	-2.28630	53.36969	383.13
100	-2.28949	53.36815	383.13
101	-2.29267	53.36661	383.13
102	-2.29586	53.36507	383.13
103	-2.29904	53.36353	383.13
104	-2.30223	53.36200	383.13
105	-2.30541	53.36046	383.13
106	-2.30860	53.35892	383.13
107	-2.31178	53.35738	373.96
108	-2.31497	53.35584	350.16
109	-2.31643	53.35374	326.37
110	-2.31686	53.35131	302.57
111	-2.31664	53.34899	278.78
112	-2.31406	53.34709	254.98
113	-2.31148	53.34519	231.19
114	-2.30890	53.34329	207.39

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
115	-2.30511	53.34272	183.59
116	-2.30103	53.34247	159.80
117	-2.29732	53.34294	136.00
118	-2.29413	53.34448	112.21
119	-2.29095	53.34602	88.41
120	-2.28776	53.34756	64.62

Assessed receptor (aircraft) locations on the right-hand side of runway 05L circuit path

The left-hand side of Runway 05L

The table below presents the data for the assessed locations for aircraft circuiting the left-hand side of runway 05L.

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
121	-2.25928	53.36132	75.90
122	-2.25610	53.36286	99.69
123	-2.25291	53.36440	123.49
124	-2.24973	53.36594	147.28
125	-2.24601	53.36641	171.08
126	-2.24193	53.36615	194.87
127	-2.23814	53.36559	218.67
128	-2.23556	53.36368	242.46
129	-2.23298	53.36178	266.26
130	-2.23040	53.35988	290.05
131	-2.23018	53.35756	313.85
132	-2.23061	53.35513	337.64
133	-2.23208	53.35304	361.44
134	-2.23526	53.35150	383.13
135	-2.23845	53.34996	383.13
136	-2.24163	53.34842	383.13

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
137	-2.24482	53.34688	383.13
138	-2.24800	53.34534	383.13
139	-2.25119	53.34380	383.13
140	-2.25437	53.34226	383.13
141	-2.25756	53.34072	383.13
142	-2.26074	53.33918	383.13
143	-2.26393	53.33764	383.13
144	-2.26711	53.33611	383.13
145	-2.27030	53.33457	383.13
146	-2.27348	53.33303	383.13
147	-2.27667	53.33149	373.96
148	-2.27985	53.32995	350.16
149	-2.28359	53.32953	326.37
150	-2.28767	53.32979	302.57
151	-2.29142	53.33040	278.78
152	-2.29400	53.33230	254.98
153	-2.29658	53.33420	231.19
154	-2.29916	53.33610	207.39
155	-2.29929	53.33844	183.59
156	-2.29886	53.34087	159.80
157	-2.29732	53.34294	136.00
158	-2.29413	53.34448	112.21
159	-2.29095	53.34602	88.41
160	-2.28776	53.34756	64.62

Assessed receptor (aircraft) locations on the left-hand side of runway 05L circuit path

Reflector Details

The table below shows the vertical reflector co-ordinates, heights assessed and azimuth angles of the modelled façades.

Reflector Wall	Start Co-Ordinates (Longitude/ Latitude) (°)	End Co-Ordinates (Longitude/ Latitude) (°)	Assessed Height	Assessment Resolution	Azimuth Angle
1-2	-2.27320 53.36761	-2.27372 53.36773	The lowest reflector height has been taken as 72m amsl. The highest reflector height has been taken as 96m amsl.	Reflection points have been taken every 2m vertically by 2m horizontally.	22.1°
2-3	-2.27372 53.36773	-2.27356 53.36796			112.3°
3-4	-2.27356 53.36796	-2.27352 53.36796			185.8°
4-5	-0.28695 51.49194	-2.27342 53.36810			112.8°
5-6	-2.27342 53.36810	-2.27329 53.36807			200.3°
6-7	-2.27329 53.36807	-2.27326 53.36810			130.9°
7-8	-2.27326 53.36810	-2.27293 53.36801			203.9°
8-1	-2.27293 53.36801	-2.27320 53.36761			291.9°

Block A: Bounding reflector details

APPENDIX H – GEOMETRIC CALCULATION RESULTS – PAGER POWER RESULTS

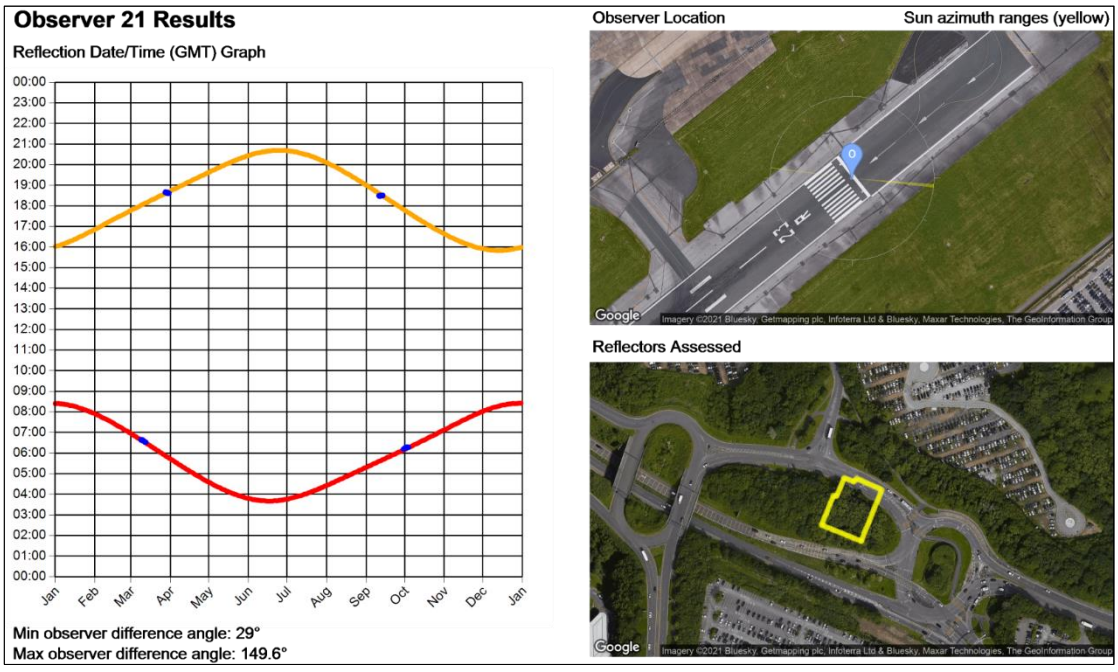
The charts for the receptors are shown on the following pages. Each chart shows:

- 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 red. If the red 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 red areas only;
- In the same graph the red line shows the time at which the sun is rising while the red line shows when the sun is setting for each specific month.

ATC Tower

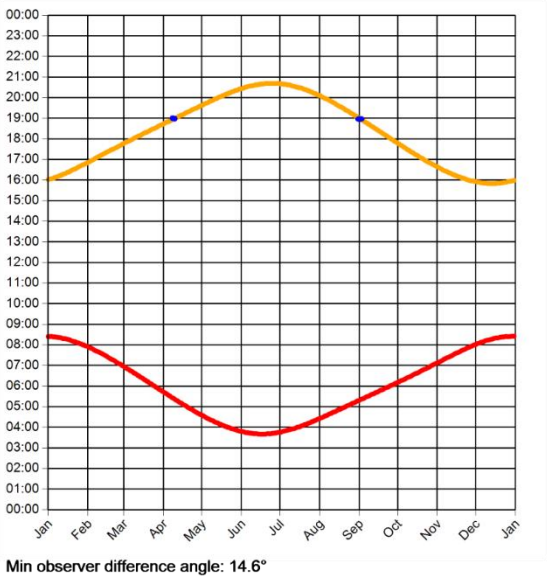
No reflections are possible.

Approaches 05R-23L & 05L-23R



Observer 22 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 14.6°
Max observer difference angle: 15.4°

Observer Location — Sun azimuth range is 284.3° - 284.9° (yellow)

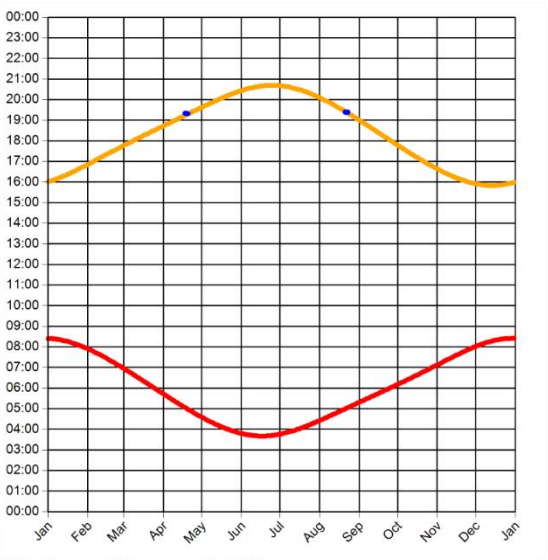


Reflectors Assessed



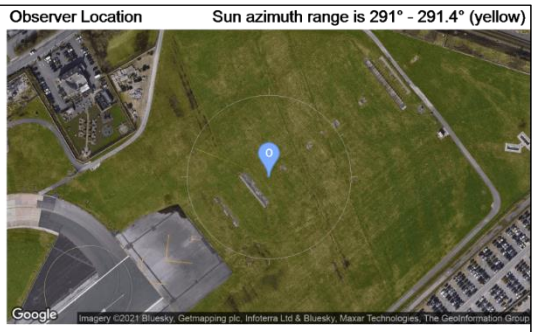
Observer 23 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 1.5°
Max observer difference angle: 1.9°

Observer Location — Sun azimuth range is 291° - 291.4° (yellow)



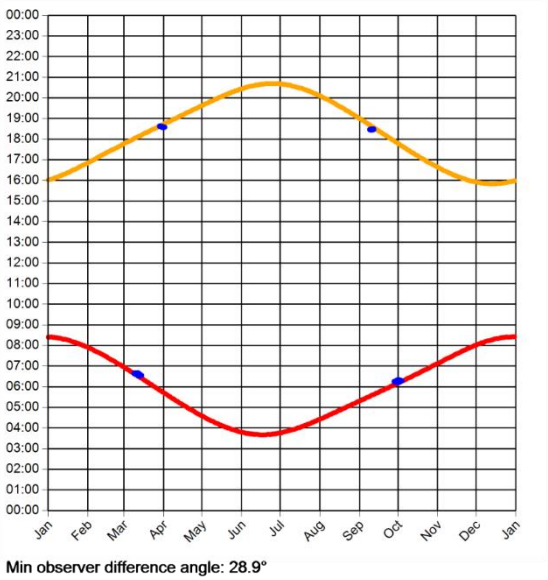
Reflectors Assessed



Circuits 05R-23L & 05L-23R

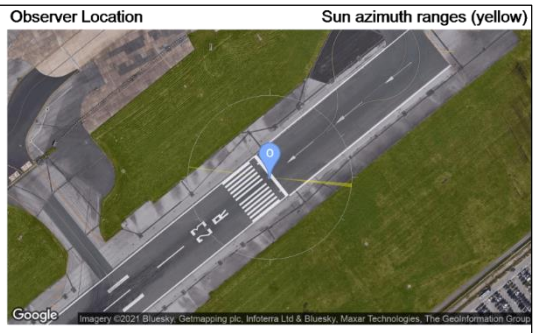
Observer 81 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 28.9°
Max observer difference angle: 149.7°

Observer Location — Sun azimuth ranges (yellow)

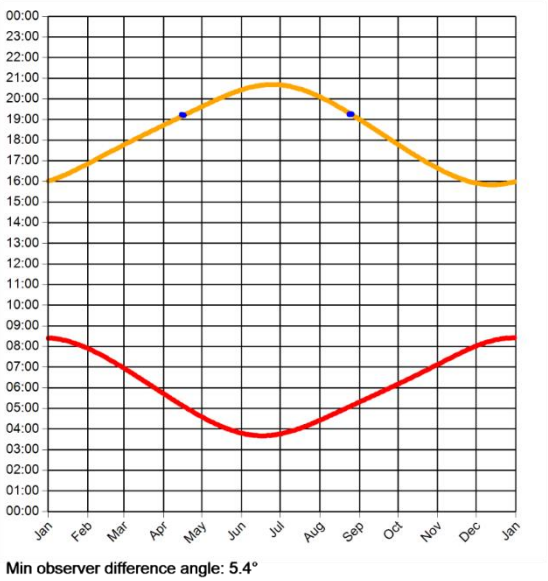


Reflectors Assessed



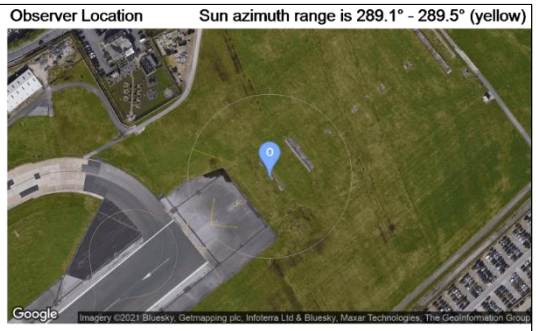
Observer 82 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 5.4°
Max observer difference angle: 5.9°

Observer Location — Sun azimuth range is 289.1° - 289.5° (yellow)

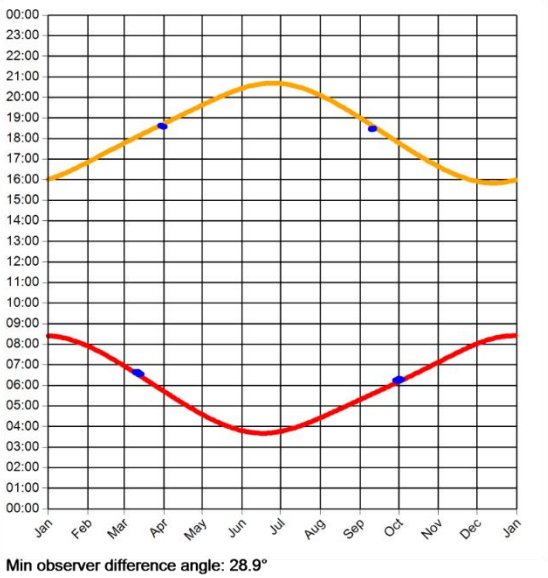


Reflectors Assessed



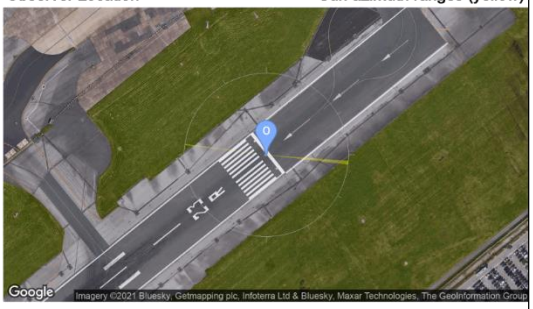
Observer 121 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 28.9°
Max observer difference angle: 149.7°

Observer Location — Sun azimuth ranges (yellow)

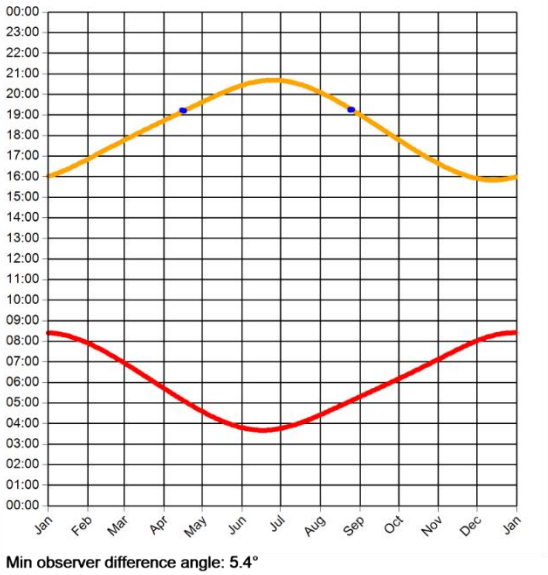


Reflectors Assessed



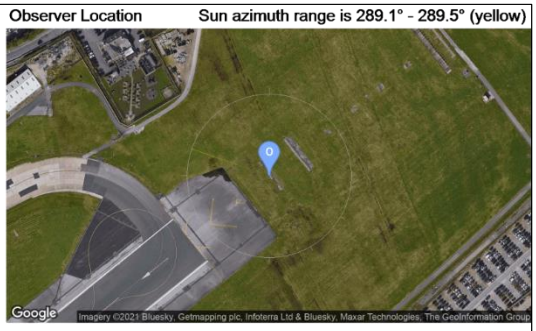
Observer 122 Results

Reflection Date/Time (GMT) Graph



Min observer difference angle: 5.4°
Max observer difference angle: 5.9°

Observer Location — Sun azimuth range is 289.1° - 289.5° (yellow)



Reflectors Assessed



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