

Solar Photovoltaic Glint and Glare Study

Workman LLP

Building 402

March 2022

PLANNING SOLUTIONS FOR:

- Solar
- Telecoms
- Railways
- Defence
- Buildings
- Wind
- Airports
- Radar
- Mitigation

www.pagerpower.com



ADMINISTRATION PAGE

Job Reference:	11320A
Date:	March 2022
Author:	Hannah McNaul
Telephone:	01787 319001
Email:	hannahm@pagerpower.com

Reviewed By:	Andrea Mariano; Danny Scrivener
Email:	andrea@pagerpower.com; danny@pagerpower.com

Issue	Date	Detail of Changes
1	March 2022	Initial issue

Confidential: The contents of this document may not be disclosed to others without permission.

Copyright © 2022 Pager Power Limited

Stour Valley Business Centre, Brundon Lane, Sudbury, CO10 7GB

T: +44 (0)1787 319001 E: info@pagerpower.com W: www.pagerpower.com

All aerial imagery (unless otherwise stated) is taken from Google Earth. Copyright © 2022 Google.

EXECUTIVE SUMMARY

Report Purpose

Pager Power has been retained to assess the possible effects of glint and glare from solar panels on the rooftop of a proposed development Building 402 located approximately 550m northwest of the Air Traffic Control (ATC) Tower at Manchester Airport. The building's roof will consist of glass rooflights and solar panels, which require a glint and glare assessment with respect to aviation activity associated with Manchester Airport.

A specific layout for the rooflights and solar panels has not yet been determined and therefore this assessment has provided guidance to develop a layout which is acceptable in accordance with the appropriate safeguarding criteria.

Overall Conclusions

A layout of rooflights and solar panels which ensures no glare is predicted towards the ATC Tower is possible. The primary constraint is ensuring rooflights or solar panels that follow the pitch of the roof are not located within three small areas of sections A, C and D (see Section 8.1). The removal of solar panels will ensure that glare towards the ATC tower is not produced; alternatively a change in elevation angle may also provide a solution.

No significant impacts upon approaching aircraft or aircraft using the visual circuits are predicted for any potential rooflight and solar panel layout.

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. There is no existing planning guidance for the assessment of solar reflections from solar panels towards aviation receptors. Pager Power has, however, produced guidance for glint and glare and solar photovoltaic developments, with the third edition originally published in 2020¹.

Pager Power's approach 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. For aviation activity, where a solar reflection is predicted, solar intensity calculations are undertaken in line with the Sandia National Laboratories' FAA methodology². The scenario in which a solar reflection can occur for all receptors is then identified and discussed, and a comparison is made against the available solar panel reflection studies to determine the overall impact.

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

² Formerly mandatory for on-airfield solar developments in the USA under the FAA's interim policy, superseded in 2021 with a policy that effectively requires individual airports to sign off on their on-airfield development as they see fit.

LIST OF CONTENTS

Administration Page	2
Executive Summary	3
Report Purpose	3
Overall Conclusions	3
Guidance and Studies	3
List of Contents	4
List of Figures	6
List of Tables	7
About Pager Power	8
1 Introduction	9
1.1 Overview	9
1.2 Pager Power's Experience	9
1.3 Glint and Glare Definition	9
2 Proposed Development Location and Details	11
2.1 Proposed Development Location	11
2.2 Assessment Parameters	12
2.3 Building Elevations	12
3 Manchester Airport Details	14
3.1 Overview	14
3.2 Airport Information	14
3.3 Runway Details	14
4 Glint and Glare Assessment Methodology	16
4.1 Guidance and Studies	16
4.2 Background	16
4.3 Pager Power's Methodology	16
4.4 Assessment Limitations	17
5 Identification of Receptors	18

5.1	Overview.....	18
5.2	Aviation Receptors.....	18
6	Assessed Reflector Areas.....	22
6.1	Reflector Areas	22
7	Glint and Glare Assessment – Technical Results	24
7.1	Overview.....	24
7.2	Summary of Results	24
7.3	Geometric Calculation Results Overview – ATC Tower	25
7.4	Geometric Calculation Results Overview – Runway Approaches.....	25
7.5	High Level Assessment – Visual Circuits.....	26
8	Geometric Assessment Results Discussion.....	27
8.1	ATC Tower.....	27
8.2	05R and 05L Approach Paths	28
8.3	23L and 23R Approach Paths	28
8.4	Visual Circuits (High-Level)	28
9	Overall Conclusions	29
9.1	Overall Conclusions and Recommendations	29
	Appendix A – Overview of Glint and Glare Guidance.....	30
	Overview.....	30
	UK Planning Policy	30
	Aviation Assessment Guidance	30
	Appendix B – Overview of Glint and Glare Studies.....	37
	Overview.....	37
	Reflection Type from Solar Panels.....	37
	Solar Reflection Studies	38
	Appendix C – Overview of Sun Movements and Relative Reflections.....	41
	Appendix D – Glint and Glare Impact Significance	42
	Overview.....	42
	Impact Significance Definition.....	42
	Assessment Process – ATC Tower	43

Assessment Process for Approaching Aircraft.....	44
Appendix E – Reflection Calculations Methodology	45
Pager Power's Reflection Calculations Methodology	45
Appendix F – Assessment Limitations and Assumptions.....	47
Pager Power's Model.....	47
Forge's Sandia National Laboratories' (SGHAT) Model	49
Appendix G – Receptor and Reflector Area Details	50
ATC Receptor Details.....	50
Approach Receptors for Runway 05L.....	50
Approach Receptors for Runway 23R	51
Approach Receptors for Runway 05R	52
Approach Receptors for Runway 23L.....	53
Reflector Area Data	54
Appendix H – Detailed Pager Power Modelling Results.....	55
Overview.....	55

LIST OF FIGURES

Figure 1 Proposed development masterplan	11
Figure 2 North Elevation	12
Figure 3 South Elevation	13
Figure 4 East and West Elevations.....	13
Figure 5 Indicative section	13
Figure 6 Aerodrome chart – Manchester Airport	14
Figure 7 Location of proposed development relative to the proposed development..	15
Figure 8 ATC Tower location.....	18
Figure 9 Runway approach paths – aerial image.....	19
Figure 10 Typical circuit diagram.....	20
Figure 11 Circuits paths for runways 05L-23R (red line) and 05R-23L (blue line)	21

Figure 12 Modelled reflector areas	22
Figure 13 Reflecting areas.....	27

LIST OF TABLES

Table 1 Technical details	22
Table 2 Glare intensity designation.....	24
Table 3 Geometric calculation results overview – ATC Tower	25
Table 4 Geometric calculation results overview – runway approaches	25
Table 5 High-level assessment – visual circuits.....	26

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 solar panels on the rooftop of a proposed development Building 402 located approximately 550m northwest of the Air Traffic Control (ATC) Tower at Manchester Airport. The building's roof will consist of glass rooflights and solar panels, which require a glint and glare assessment with respect to aviation activity associated with Manchester Airport.

The specific receptors requiring assessment are the approach paths, the ATC Tower, and aircraft in the visual circuits. 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 receptors.
- Glint and glare assessment for identified receptors.
- Results discussion.

Following this, a summary of findings and overall conclusions and recommendations from the desk-based analysis is presented. No site survey has taken place at this stage.

1.2 Pager Power's Experience

Pager Power has undertaken over 800 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 follows³:

- 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 the 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 PROPOSED DEVELOPMENT LOCATION AND DETAILS

2.1 Proposed Development Location

Figure 1⁴ below shows the proposed development masterplan.

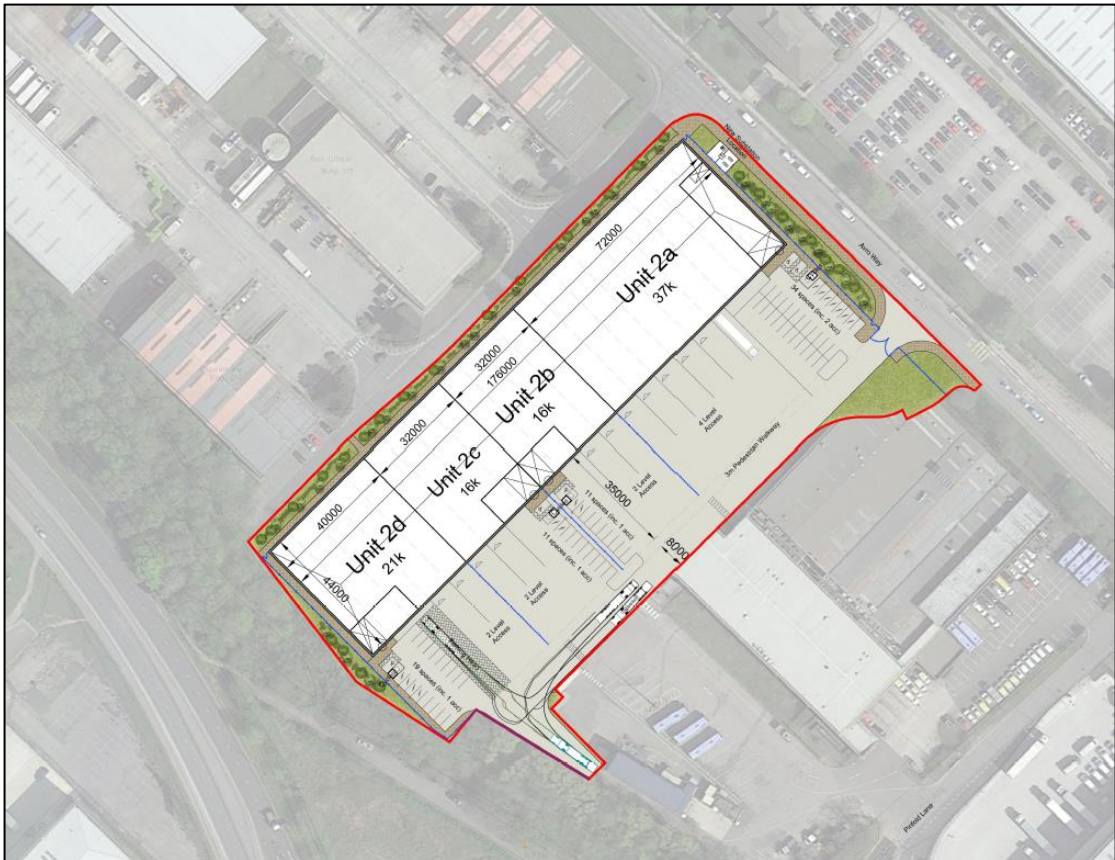


Figure 1 Proposed development masterplan

⁴ Source: 020943-RPS-SI-XX-DR-A-0110 (Proposed Block Plan)

2.2 Assessment Parameters

The rooftop of the proposed development will consist of multiple rooflights, covering approximately 20% of the roof surface area, and solar panels that will be installed on other parts of the rooftop.

The rooflights and solar panels have the potential to produce specular reflections and could be located over any parts of the roof. As such, the assessment has considered the entire rooftop to contain reflective surfaces, which would be considered the worst-case with respect to glint and glare.

The reflector areas and technical details used in this assessment are presented in Section 6.

2.3 Building Elevations

The building elevations are shown in Figures 2 to 5⁵ below and on the following page.

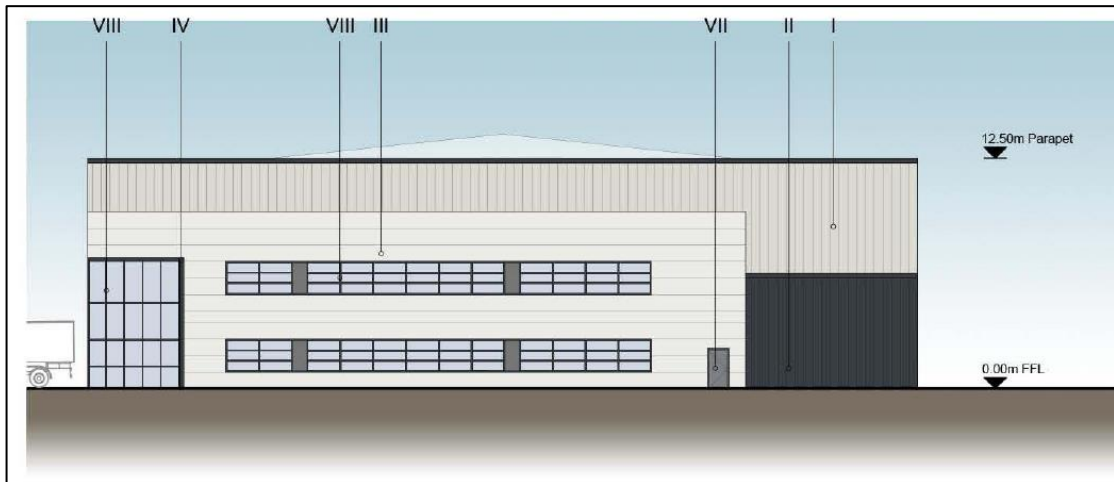


Figure 2 North Elevation

⁵ Source: 020943-RPS-SI-XX-DR-A-0111 (Proposed Elevations)

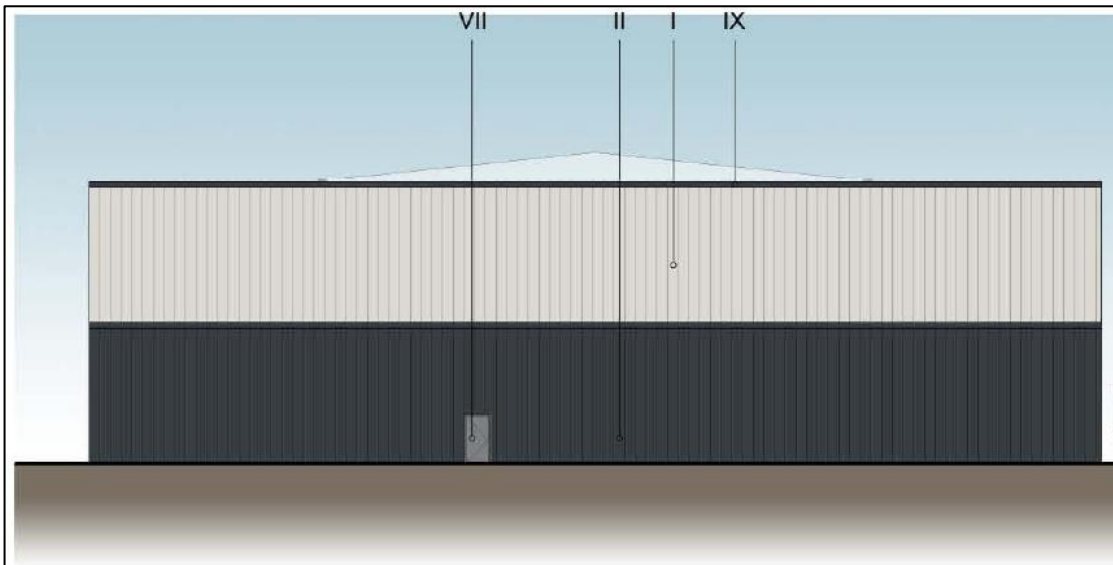


Figure 3 South Elevation

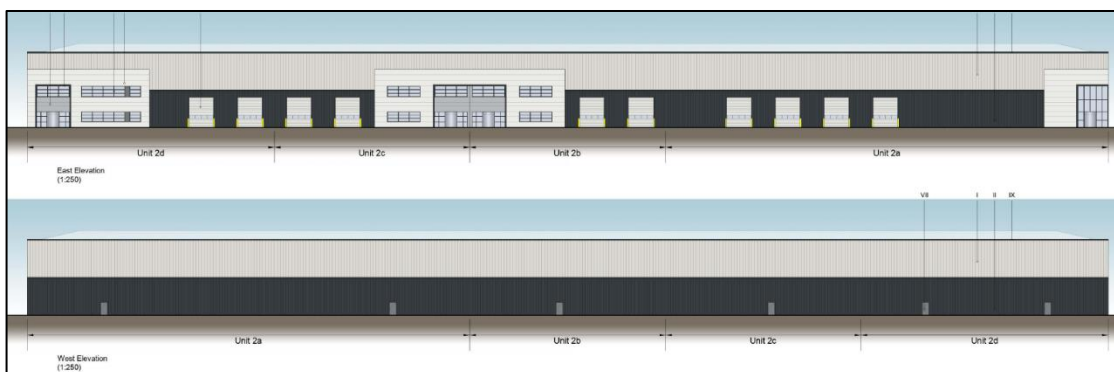


Figure 4 East and West Elevations

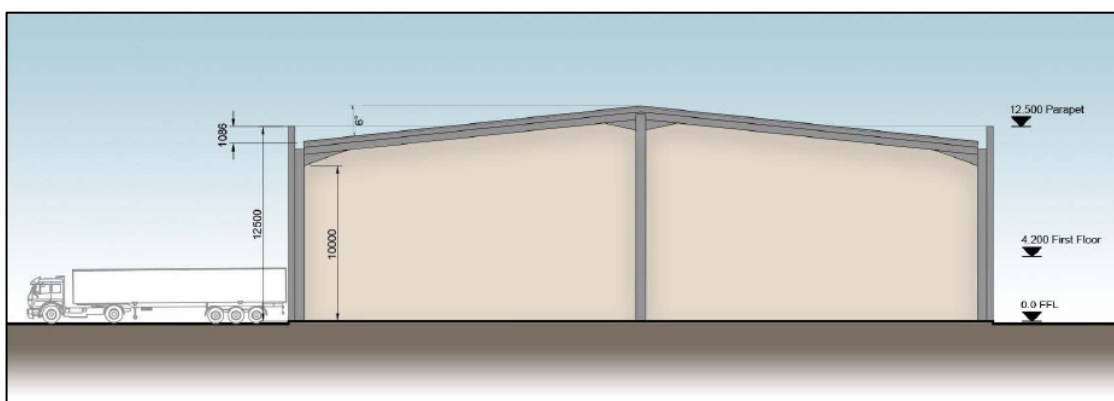


Figure 5 Indicative section

3 MANCHESTER AIRPORT DETAILS

3.1 Overview

The following section presents general details regarding Manchester Airport.

3.2 Airport Information

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

3.3 Runway Details

The runway details are presented below:

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

The runways are shown in Figure 6⁶ (aerodrome chart) below.

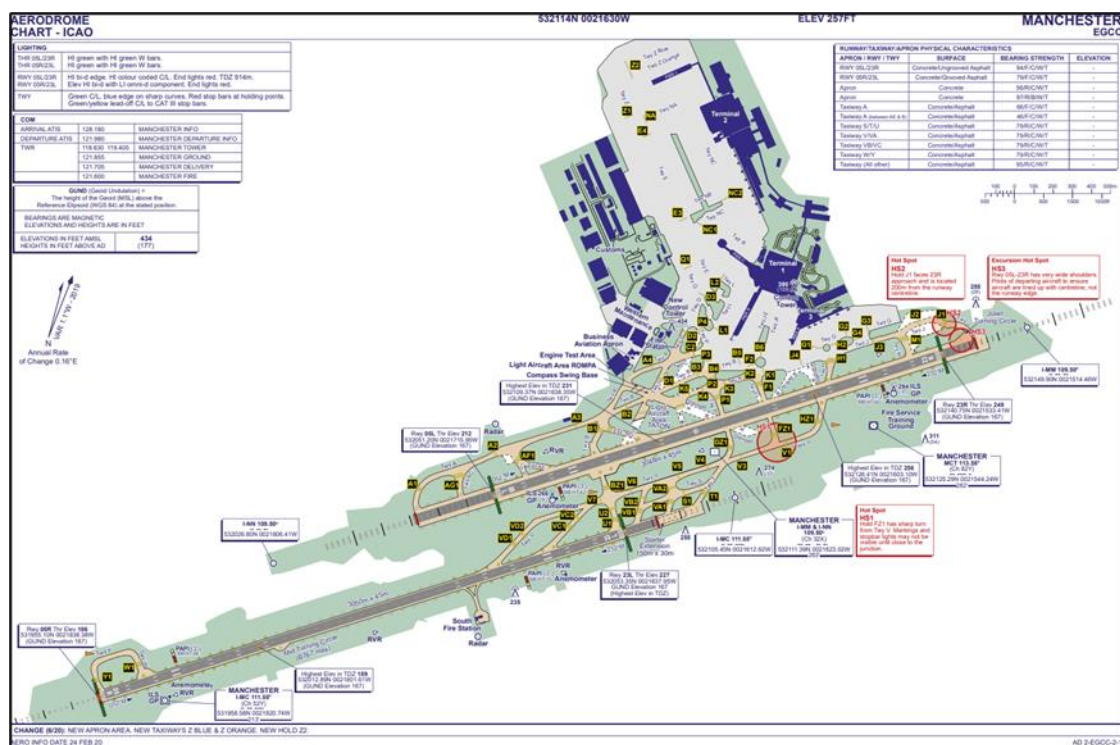


Figure 6 Aerodrome chart – Manchester Airport

The proposed development building footprint relative to Manchester Airport is shown in Figure 7 on the following page.

⁶ Source: NATS AIP for Manchester Airport (last accessed March, 2022).



Figure 7 Location of proposed development relative to the proposed development

4 GLINT AND GLARE ASSESSMENT METHODOLOGY

4.1 Guidance and Studies

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

- Specular reflections of the Sun from solar panels 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. It also shows that reflections from solar panels are significantly less intense than many other reflective surfaces, which are common in an outdoor environment.

4.2 Background

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

4.3 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 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 – including intensity calculations where appropriate.
- Determine whether a significant detrimental impact is expected in line with the process presented in Appendix D.

Within the Pager Power model, the solar development 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.

4.3.1 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. Intensity calculations in line with Sandia National Laboratories' methodology has been completed.

4.4 Assessment Limitations

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

5 IDENTIFICATION OF RECEPTORS

5.1 Overview

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

5.2 Aviation Receptors

5.2.1 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 location is illustrated in Figure 8 below.

Coordinate data, taken from the NATS AIP, is presented in Appendix G.



Figure 8 ATC Tower location

5.2.2 Airborne Receptors - Approaching Aircraft

Manchester Airport has two operational runways, each with two associated 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 both aircraft approach paths for each runway. 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 9 below shows the assessed aircraft approach paths.



Figure 9 Runway approach paths – aerial image

5.2.3 Aircraft Circuits

Manchester Airport requires assessment of general aviation aircraft flying both directions in the visual circuits for 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 10 below.

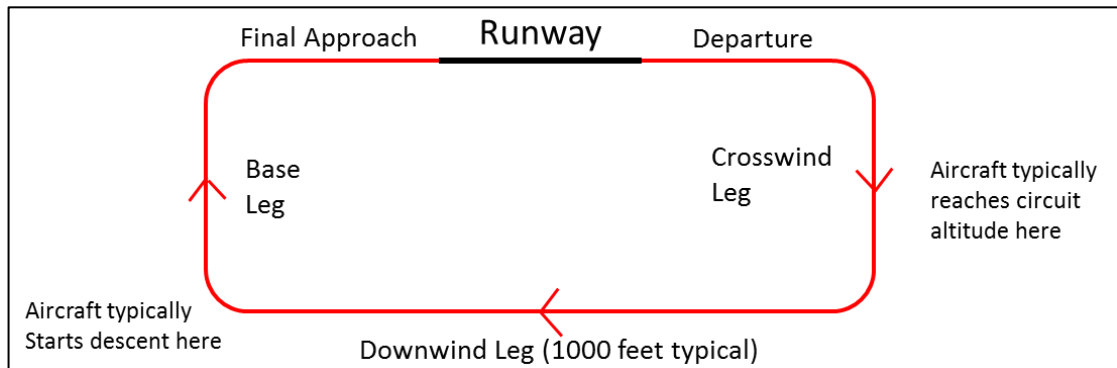


Figure 10 Typical circuit diagram

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 ends⁷;
- 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.

Figure 11 on the following page shows the circuits paths for Manchester Airport. The red circle paths belong to Runway 05L-23R while the blue paths belong to Runway 05R-23L. The visual circuits have been considered at a high-level within this report.

⁷ Runway thresholds.



Figure 11 Circuits paths for runways 05L-23R (red line) and 05R-23L (blue line)

6 ASSESSED REFLECTOR AREAS

6.1 Reflector Areas

The entire rooftop has been considered as a reflective area to remain conservative. The unit is split into four distinctive reflector areas, which are shown in Figure 12 below.

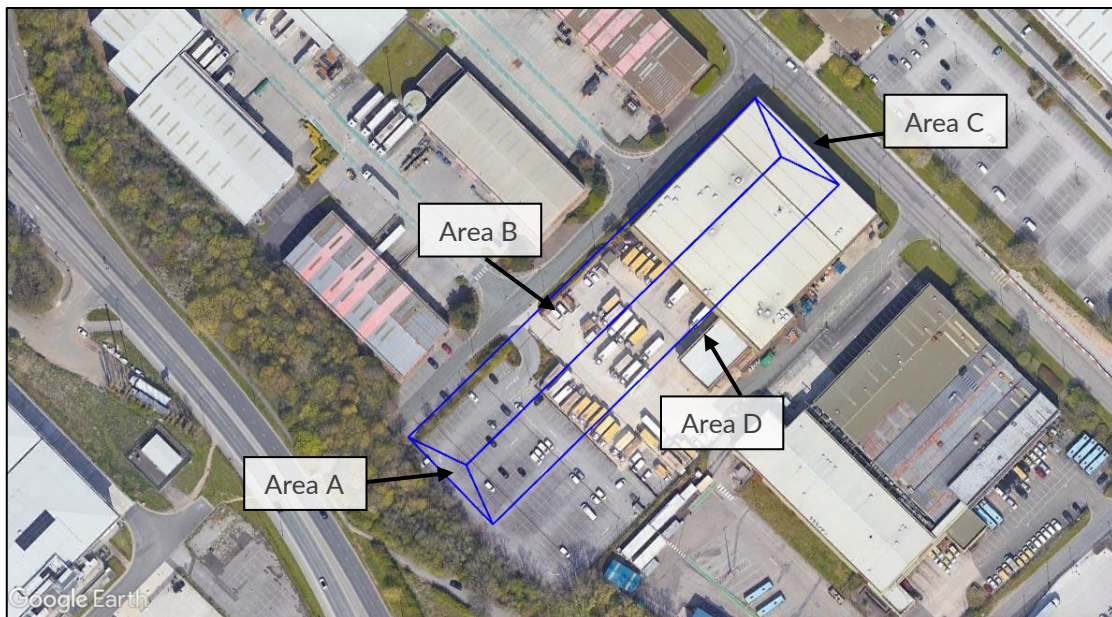


Figure 12 Modelled reflector areas

The technical details used in this assessment are presented in Table 1 below.

Technical Details				
Areas	A	B	C	D
Roof azimuth angles (°)	225	315	45	135
Assessed height (m amsl ⁸)	13			
Elevation angle (°)	6			

Table 1 Technical details

A number of representative locations are selected within the rooftop areas. The number of modelled reflector points is determined by the size of the reflector area and the assessment resolution. The bounding coordinates for the rooftop areas have been extrapolated from the

⁸ Above mean sea level

site plans and can be found in Appendix G. All ground heights have been based on OSGB36 Panorama terrain data.

A resolution of 2m has been chosen for Pager Power model in this assessment. This means that a geometric calculation is undertaken for each identified receptor every 2m 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.

7 GLINT AND GLARE ASSESSMENT – TECHNICAL RESULTS

7.1 Overview

The Pager Power and Forge models have been used to determine whether reflections are possible. Where solar reflections have been predicted, intensity calculations in line with the Sandia National Laboratories methodology have been undertaken for reference purposes. 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 for temporary after-image  Potential for temporary after-image  Potential for permanent eye damage
Low potential	
Potential	
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' has been assessed. Surfaces that can be modelled include:

- Smooth glass with an anti-reflective coating (ARC);
- Light textured glass without an anti-reflective coating;
- Light textured glass with an anti-reflective coating;
- Deeply textured glass.

7.2 Summary of Results

The tables in the following subsections summarise the results of the assessment. The predicted glare times are based solely on bare-earth terrain i.e. without consideration of screening from buildings and vegetation. The final column summarises the glare intensity designation defined in the previous sub-section.

The significance of any predicted impact is discussed in the subsequent report sections. The modelling output showing the precise predicted times and the reflecting panel area is shown in Appendix H.

7.3 Geometric Calculation Results Overview – ATC Tower

The results of the geometric calculations for the ATC Tower are presented in Table 3 below.

Receptor	Reflection possible towards ATC Tower? (GMT)		Glare Type (Forge)	Comment
	am	pm		
ATC Tower	No.	Yes.		Solar reflections with 'low potential for temporary after-image' are predicted to originate from parts of Areas A, C and D. Discussed further in Section 8.1.

Table 3 Geometric calculation results overview – ATC Tower

7.4 Geometric Calculation Results Overview – Runway Approaches

The results of the geometric calculations for the runway approaches are presented in Table 4 below.

Runway	Reflection possible towards the runway approaches? (GMT)		Glare Type (Forge)	Comment
	am	pm		
05L	No.	No.	N/A	No solar reflections geometrically possible. No impacts predicted.
05R				
23R	No.	Yes.		Solar reflections with 'low potential for temporary after-image' are predicted towards the entire 2-mile approach. Low impact is predicted.
23L				

Table 4 Geometric calculation results overview – runway approaches

7.5 High Level Assessment – Visual Circuits

The results of the high level assessment of the visual circuits are presented in Table 5 below.

Receptor	Glare Type	Comment
Visual Circuits	Expected to be green glare at worst, as per the modelling analysis of the approach paths.	Solar reflections may be possible towards pilots along the visual circuit paths. Glare intensities are predicted to be no worse than those predicted towards pilots on approach considering the relative distance of the approach paths from the proposed development compared to the visual circuits. Low impact predicted.

Table 5 *High-level assessment – visual circuits*

8 GEOMETRIC ASSESSMENT RESULTS DISCUSSION

8.1 ATC Tower

The analysis has shown that solar reflections are predicted towards the ATC Tower from three sections of Areas A, C and D if the rooflights and solar panels both follow the 6-degree pitch of the rooftop. The reflecting areas are shown in Figure 13 below. Any predicted glare towards an ATC tower is not acceptable in accordance with the associated guidance and industry best practice and is therefore likely to cause an objection to be raised by Manchester Airport.

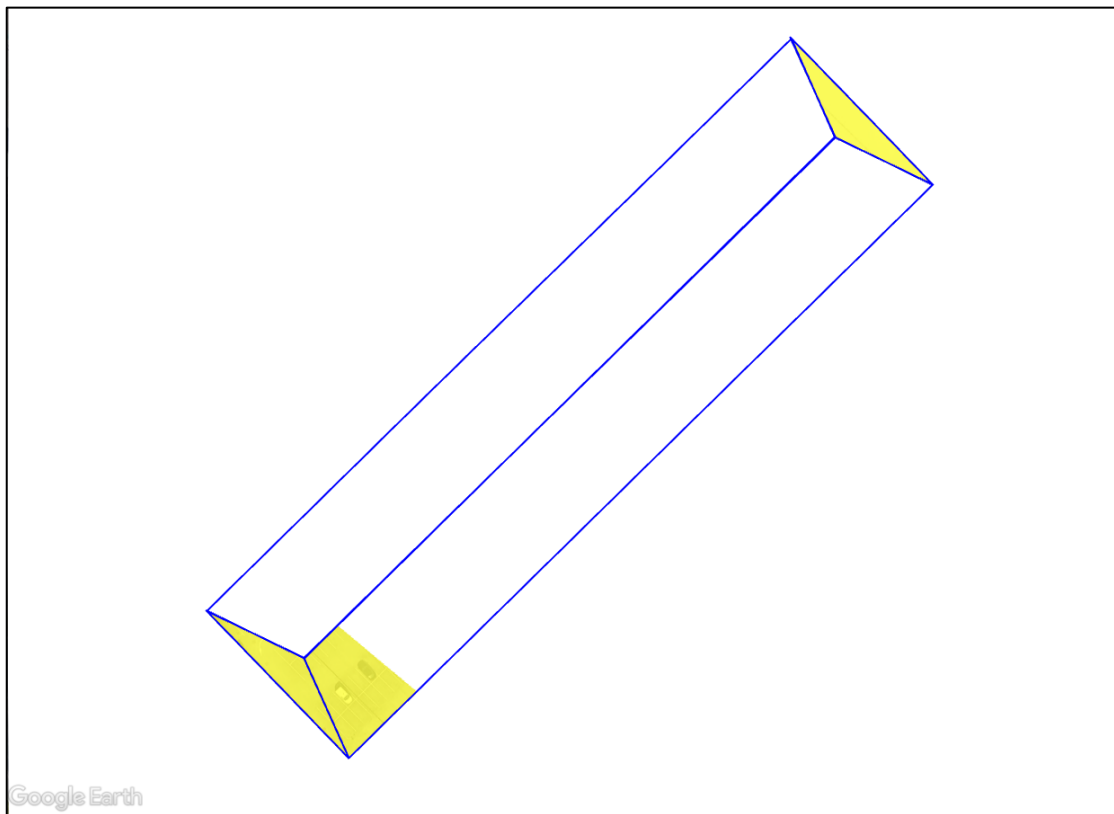


Figure 13 Reflecting areas

In accordance with the associated guidance and industry best practice, mitigation is recommended. One possible mitigation solution would be to remove the panels within the reflecting area; although a change in the elevation angle may also provide a suitable solution.

Therefore, ensuring the layout of the rooflights and solar panels is developed in accordance with the above will guarantee that no impacts are predicted upon the ATC Tower.

8.2 05R and 05L Approach Paths

The modelling has shown that solar reflections are not geometrically possible towards aircraft along the 2-mile approach paths for runways 05L and 05R.

No impacts are therefore predicted upon aircraft approaching runways 05L and 05R for any potential rooflight and solar panel layout.

8.3 23L and 23R Approach Paths

The modelling has shown that solar reflections predicted towards pilots along the 2-mile approach paths for runway 23R and 23L will have a maximum of 'low potential for temporary after-image'. This level of glare is acceptable considering the associated guidance and industry best practice.

A low impact is therefore predicted upon aircraft approaching runways 23R and 23L for any potential rooflight and solar panel layout.

8.4 Visual Circuits (High-Level)

Considering the analysis results for the approach paths (which are a more sensitive receptor), no significant impact upon the visual circuits is anticipated as any visible solar reflection is expected to be of acceptable intensity under the associated guidance and industry best practice.

9 OVERALL CONCLUSIONS

9.1 Overall Conclusions and Recommendations

A layout of the rooflights and solar panels which ensures no glare is predicted towards the ATC Tower is possible. The primary constraint is ensuring rooflights or solar panels that follow the pitch of the roof are not located within three small areas of sections A, C and D (see Section 8.1). The removal of solar panels will ensure that glare towards the ATC tower is not produced; alternatively a change in elevation angle may also provide a solution.

No significant impacts upon approaching aircraft or aircraft using the visual circuits are predicted for any potential rooflight and solar panel layout.

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 Energy⁹ (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, 2012¹⁰ however the advice is still

⁹ Renewable and low carbon energy, Ministry of Housing, Communities & Local Government, date: 18 June 2015, accessed on: 17/06/2020

¹⁰ Archived at Pager Power

applicable¹¹ 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 ALH¹², 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.'

¹¹ Reference email from the CAA dated 19/05/2014.

¹² Aerodrome Licence Holder.

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*'¹³ and the 2013 update is entitled '*Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports*'¹⁴. In April 2018 the FAA released a new version (Version 1.1) of the '*Technical Guidance for Evaluating Selected Solar Technologies on Airports*'¹⁵.

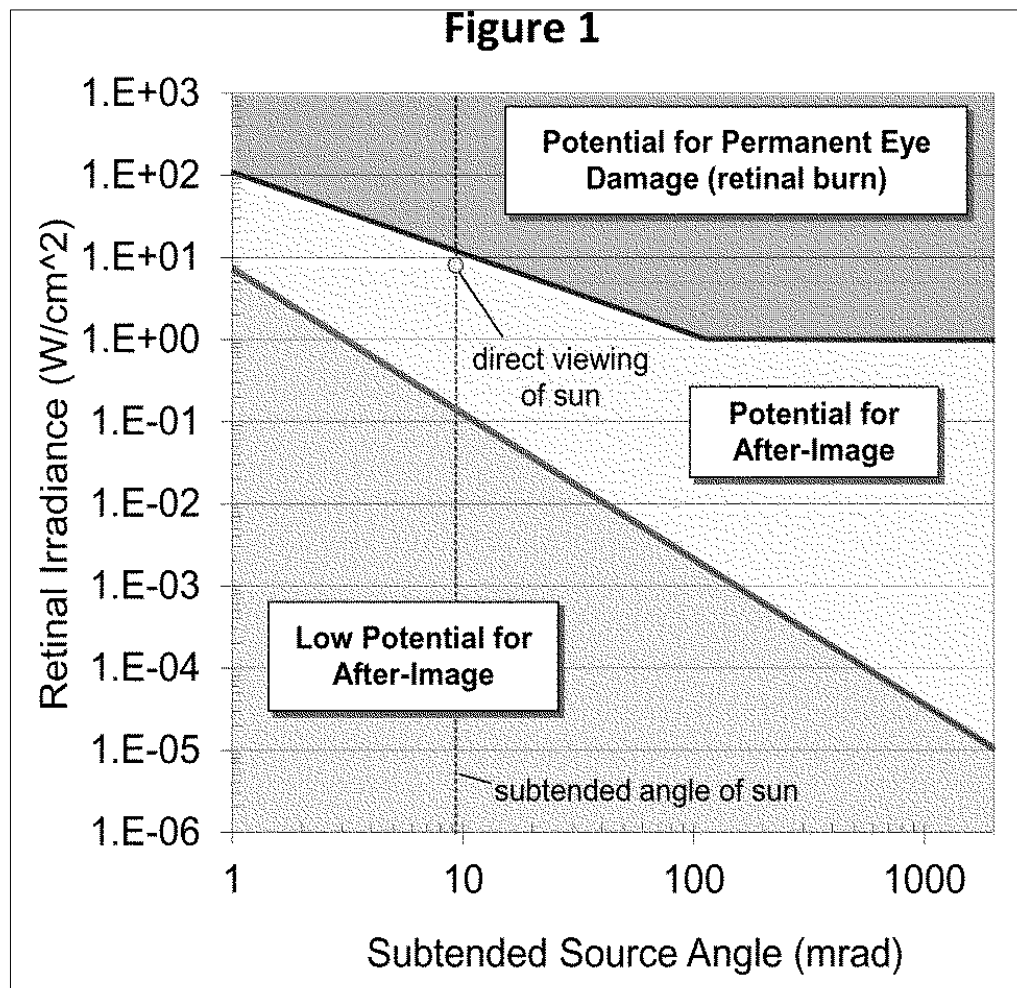
An overview of the methodology presented within the 2013 interim guidance and adopted by the FAA is presented below. This methodology is not presented within the 2018 guidance.

- *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 on the next page.*

¹³ Archived at Pager Power

¹⁴ 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

¹⁵ 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 on the next page.

- 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 blindness¹⁶.
- 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 16¹⁷, 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

¹⁶ 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.

¹⁷ First figure in Appendix B.

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 question¹⁸ 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

¹⁸ 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

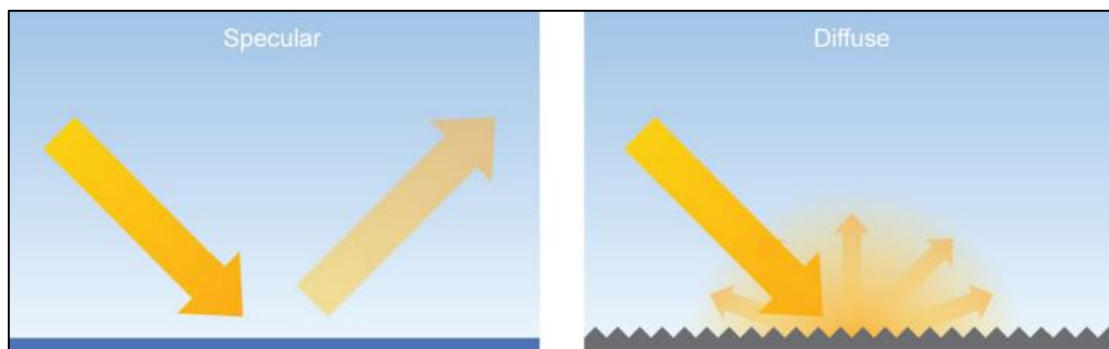
Overview

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 guidance¹⁹, 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

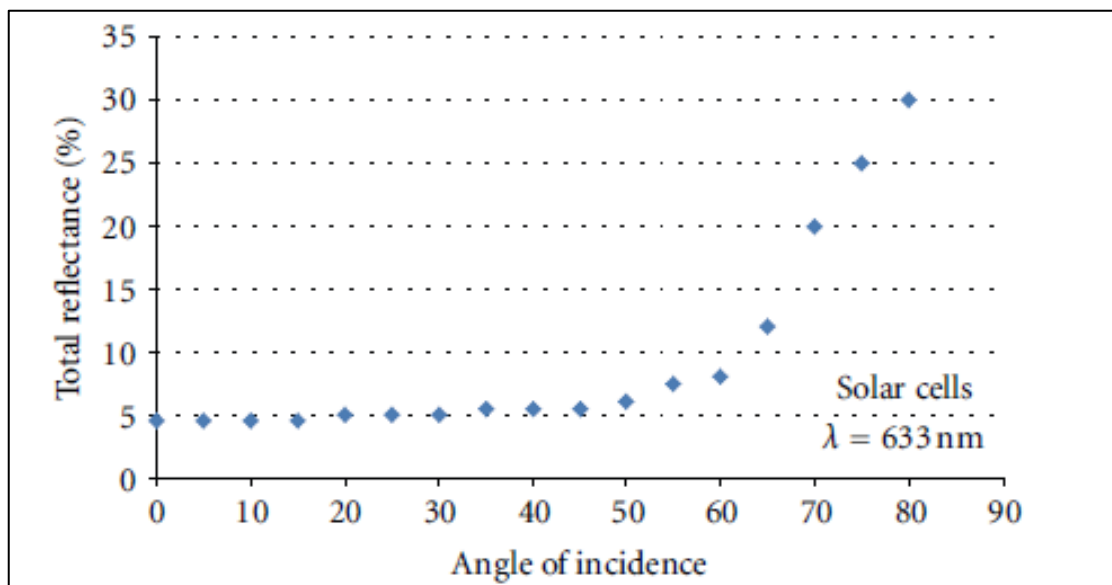
¹⁹ Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

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*²⁰. 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.

²⁰ 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"²¹

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 ²²
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.

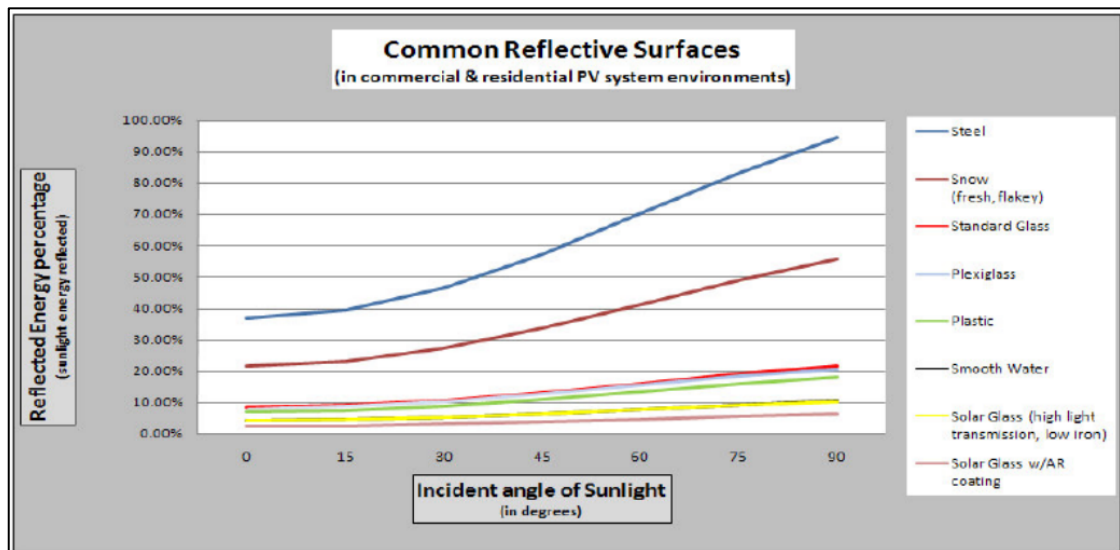
²¹ Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

²² Extrapolated data, baseline of 1,000 W/m² for incoming sunlight.

SunPower Technical Notification (2009)

SunPower published a technical notification²³ 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.

²³ 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).

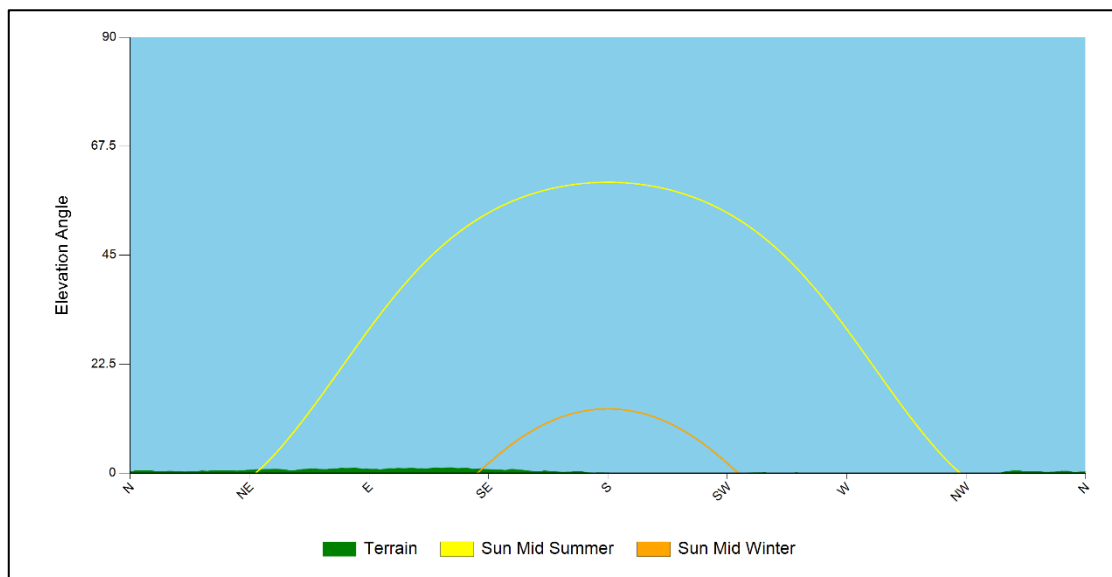
The Sun's position can be accurately calculated for a specific location. The following data being used for the calculation:

- 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.



Terrain elevation at the horizon

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

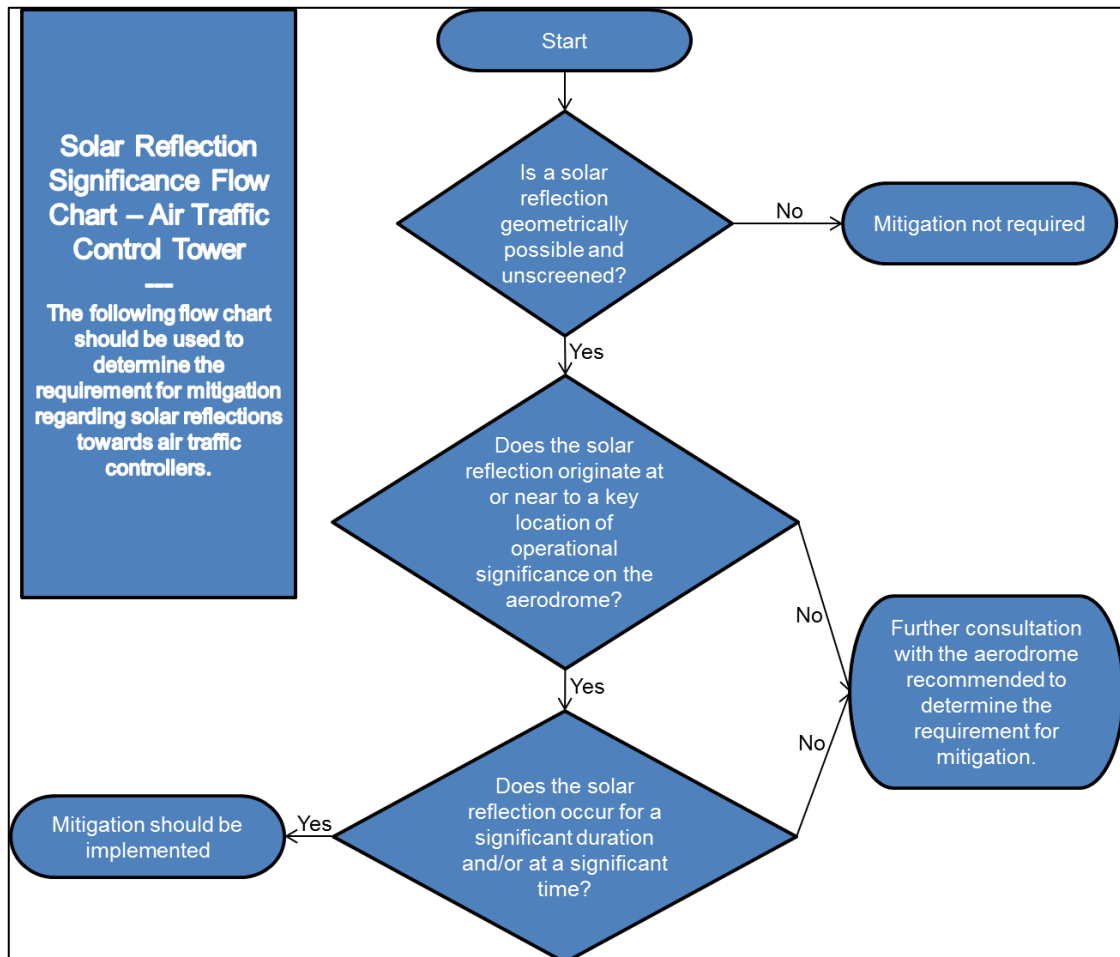
The table below presents the recommended definition of 'impact significance' in glint and glare terms and the requirement for mitigation under each.

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.
High	A solar reflection is geometrically possible and visible under conditions that will produce a significant impact. Mitigation and consultation are recommended.	Mitigation will be required if the proposed solar development is to proceed.

Impact significance definition

Assessment Process – ATC Tower

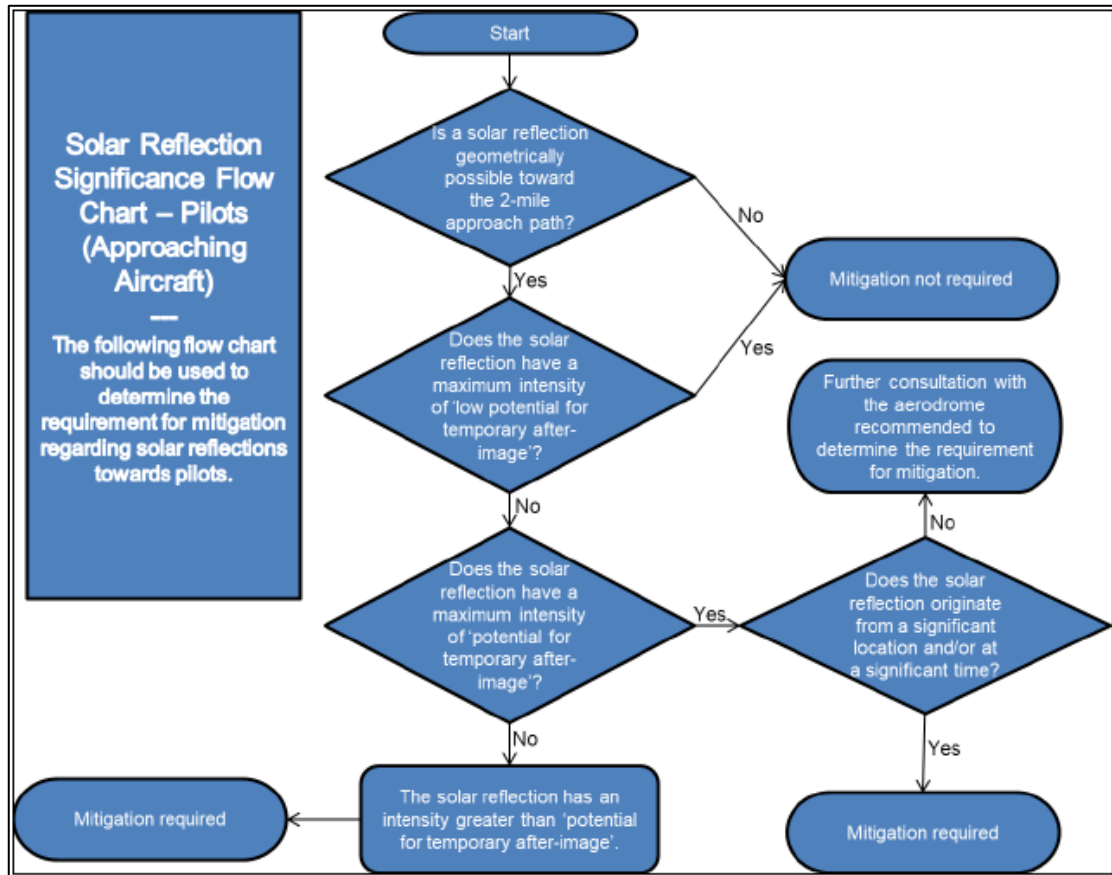
The charts relate to the determining the potential impact upon the ATC Tower.



ATC Tower mitigation requirement flow chart

Assessment Process for Approaching Aircraft

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



Approaching aircraft receptor mitigation requirement flow chart

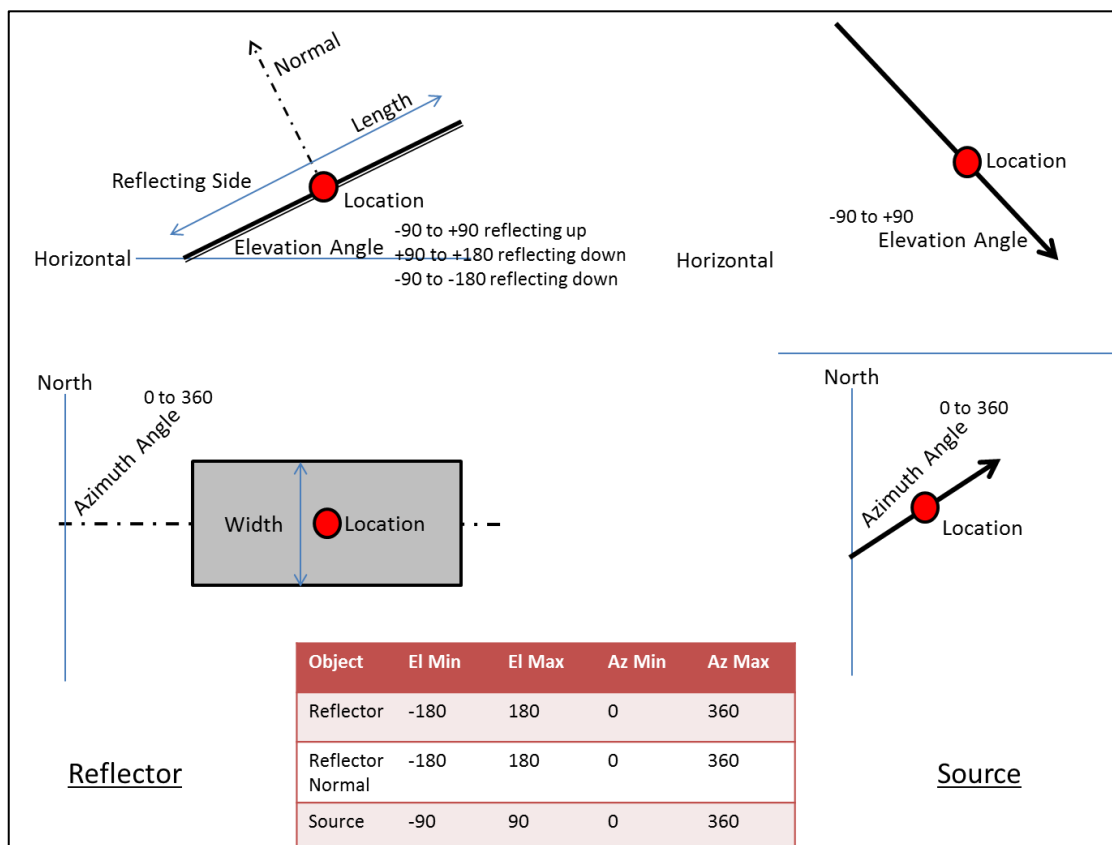
APPENDIX E – REFLECTION CALCULATIONS METHODOLOGY

Pager Power'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.



Reflection calculation process

The following process is used to determine the 3D Azimuth and Elevation of a reflection:

- Use the Latitude and Longitude of reflector as the reference for calculation purposes;
- Calculate the Azimuth and Elevation of the normal to the reflector;
- Calculate the 3D angle between the source and the normal;
- If this angle is less than 90 degrees a reflection will occur. If it is greater than 90 degrees no reflection will occur because the source is behind the reflector;
- Calculate the Azimuth and Elevation of the reflection in accordance with the following:
 - The angle between source and normal is equal to angle between normal and reflection;
 - Source, Normal and Reflection are in the same plane.

APPENDIX F – ASSESSMENT LIMITATIONS AND ASSUMPTIONS

Pager Power's Model

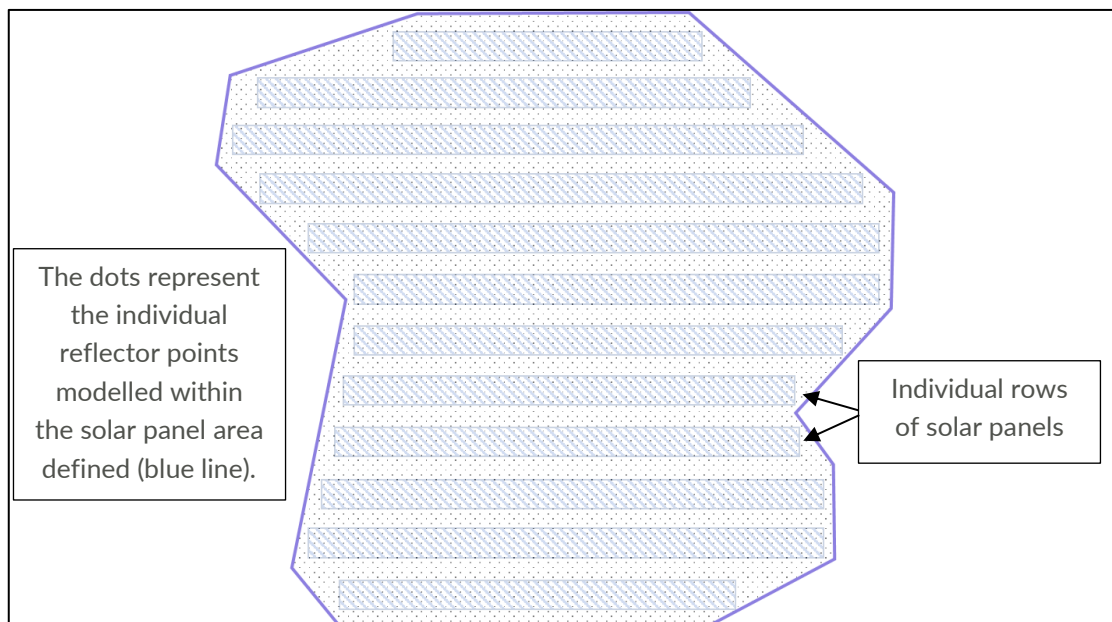
It is assumed that the panel elevation angle provided by the developer represents the elevation angle for all of the panels within each solar panel area defined.

It is assumed that the panel azimuth angle provided by the developer 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 of the solar panel has not been considered.

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



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.

Forge's Sandia National Laboratories' (SGHAT) Model²⁴

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.

²⁴ <https://www.forgesolar.com/help/#assumptions>

APPENDIX G – RECEPTOR AND REFLECTOR AREA DETAILS

ATC Receptor Details

Receptor	Longitude (°)	Latitude (°)	Assessed Altitude (m amsl)
ATC Tower	-2.2797167	53.3574000	126.91

ATC tower receptor details

Approach Receptors for Runway 05L

The table below presents the data for the assessed locations for aircraft on approach to runway 05L.

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m amsl)
1	-2.2877640	53.3475560	Threshold	79.86
2	-2.2896436	53.3466471	0.1 miles	88.29
3	-2.2915230	53.3457382	0.2 miles	96.73
4	-2.2934024	53.3448293	0.3 miles	105.16
5	-2.2952818	53.3439204	0.4 miles	113.59
6	-2.2971610	53.3430114	0.5 miles	122.03
7	-2.2990402	53.3421024	0.6 miles	130.46
8	-2.3009193	53.3411933	0.7 miles	138.90
9	-2.3027983	53.3402843	0.8 miles	147.33
10	-2.3046772	53.3393752	0.9 miles	155.77
11	-2.3065560	53.3384660	1 mile	164.20
12	-2.3084348	53.3375569	1.1 miles	172.63
13	-2.3103135	53.3366477	1.2 miles	181.07
14	-2.3121921	53.3357385	1.3 miles	189.50
15	-2.3140706	53.3348292	1.4 miles	197.94
16	-2.3159490	53.3339199	1.5 miles	206.37
17	-2.3178274	53.3330106	1.6 miles	214.81

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m amsl)
18	-2.3197057	53.3321013	1.7 miles	223.24
19	-2.3215839	53.3311919	1.8 miles	231.67
20	-2.3234620	53.3302825	1.9 miles	240.11
21	-2.3253401	53.3293731	2 miles	248.54

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

Approach Receptors for Runway 23R

The table below presents the data for the assessed locations for aircraft on approach to runway 23R.

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m amsl)
1	-2.2592806	53.3613194	Threshold	91.14
2	-2.2573996	53.3622276	0.1 miles	99.57
3	-2.2555184	53.3631359	0.2 miles	108.00
4	-2.2536372	53.3640440	0.3 miles	116.44
5	-2.2517559	53.3649522	0.4 miles	124.87
6	-2.2498746	53.3658603	0.5 miles	133.31
7	-2.2479931	53.3667684	0.6 miles	141.74
8	-2.2461116	53.3676765	0.7 miles	150.17
9	-2.2442300	53.3685845	0.8 miles	158.61
10	-2.2423483	53.3694925	0.9 miles	167.04
11	-2.2404666	53.3704005	1 mile	175.48
12	-2.2385847	53.3713084	1.1 miles	183.91
13	-2.2367028	53.3722163	1.2 miles	192.35
14	-2.2348208	53.3731242	1.3 miles	200.78
15	-2.2329387	53.3740321	1.4 miles	209.21
16	-2.2310566	53.3749399	1.5 miles	217.65
17	-2.2291743	53.3758477	1.6 miles	226.08

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m amsl)
18	-2.2272920	53.3767555	1.7 miles	234.52
19	-2.2254096	53.3776632	1.8 miles	242.95
20	-2.2235271	53.3785709	1.9 miles	251.39
21	-2.2216445	53.3794786	2 miles	259.82

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

Approach Receptors for Runway 05R

The table below presents the data for the assessed locations for aircraft on approach to runway 05R.

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m amsl)
1	-2.3106611	53.3319722	Threshold	71.93
2	-2.3125394	53.3310629	0.1 miles	80.37
3	-2.3144177	53.3301537	0.2 miles	88.80
4	-2.3162959	53.3292443	0.3 miles	97.24
5	-2.3181740	53.3283350	0.4 miles	105.67
6	-2.3200520	53.3274256	0.5 miles	114.10
7	-2.3219300	53.3265162	0.6 miles	122.54
8	-2.3238079	53.3256068	0.7 miles	130.97
9	-2.3256856	53.3246973	0.8 miles	139.41
10	-2.3275633	53.3237878	0.9 miles	147.84
11	-2.3294410	53.3228783	1 mile	156.27
12	-2.3313185	53.3219687	1.1 miles	164.71
13	-2.3331960	53.3210591	1.2 miles	173.14
14	-2.3350734	53.3201495	1.3 miles	181.58
15	-2.3369507	53.3192399	1.4 miles	190.01
16	-2.3388279	53.3183302	1.5 miles	198.45
17	-2.3407051	53.3174205	1.6 miles	206.88

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m amsl)
18	-2.3425821	53.3165108	1.7 miles	215.31
19	-2.3444591	53.3156010	1.8 miles	223.75
20	-2.3463360	53.3146912	1.9 miles	232.18
21	-2.3482129	53.3137814	2 miles	240.62

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

Approach Receptors for Runway 23L

The table below presents the data for the assessed locations for aircraft on approach to runway 23L.

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m amsl)
1	-2.2772083	53.3481528	Threshold	84.43
2	-2.2753284	53.3490614	0.1 miles	92.86
3	-2.2734484	53.3499700	0.2 miles	101.30
4	-2.2715683	53.3508786	0.3 miles	109.73
5	-2.2696881	53.3517872	0.4 miles	118.17
6	-2.2678078	53.3526957	0.5 miles	126.60
7	-2.2659275	53.3536042	0.6 miles	135.03
8	-2.2640471	53.3545126	0.7 miles	143.47
9	-2.2621666	53.3554211	0.8 miles	151.90
10	-2.2602860	53.3563295	0.9 miles	160.34
11	-2.2584054	53.3572378	1 mile	168.77
12	-2.2565246	53.3581462	1.1 miles	177.21
13	-2.2546438	53.3590545	1.2 miles	185.64
14	-2.2527629	53.3599628	1.3 miles	194.07
15	-2.2508820	53.3608710	1.4 miles	202.51
16	-2.2490009	53.3617792	1.5 miles	210.94
17	-2.2471198	53.3626874	1.6 miles	219.38

No.	Longitude (°)	Latitude (°)	Distance from RWY Threshold	Assessed Altitude (m amsl)
18	-2.2452386	53.3635956	1.7 miles	227.81
19	-2.2433573	53.3645037	1.8 miles	236.25
20	-2.2414759	53.3654118	1.9 miles	244.68
21	-2.2395944	53.3663199	2 miles	253.11

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

Reflector Area Data

Area A

ID	Longitude	Latitude	ID	Longitude	Latitude
1	-2.29043	53.36016	3	-2.29027	53.35997
2	-2.29074	53.36025			

Reflector area data – area A

Area B

ID	Longitude	Latitude	ID	Longitude	Latitude
1	-2.29074	53.36025	3	-2.2887	53.36118
2	-2.28885	53.36137	4	-2.29043	53.36016

Reflector area data – area B

Area C

ID	Longitude	Latitude	ID	Longitude	Latitude
1	-2.28885	53.36137	3	-2.2887	53.36118
2	-2.28838	53.36108			

Reflector area data – area C

Area D

ID	Longitude	Latitude	ID	Longitude	Latitude
1	-2.29027	53.35997	3	-2.2887	53.36118
2	-2.29043	53.36016	4	-2.28838	53.36108

Reflector area data – area D

APPENDIX H – DETAILED PAGER POWER MODELLING RESULTS

Overview

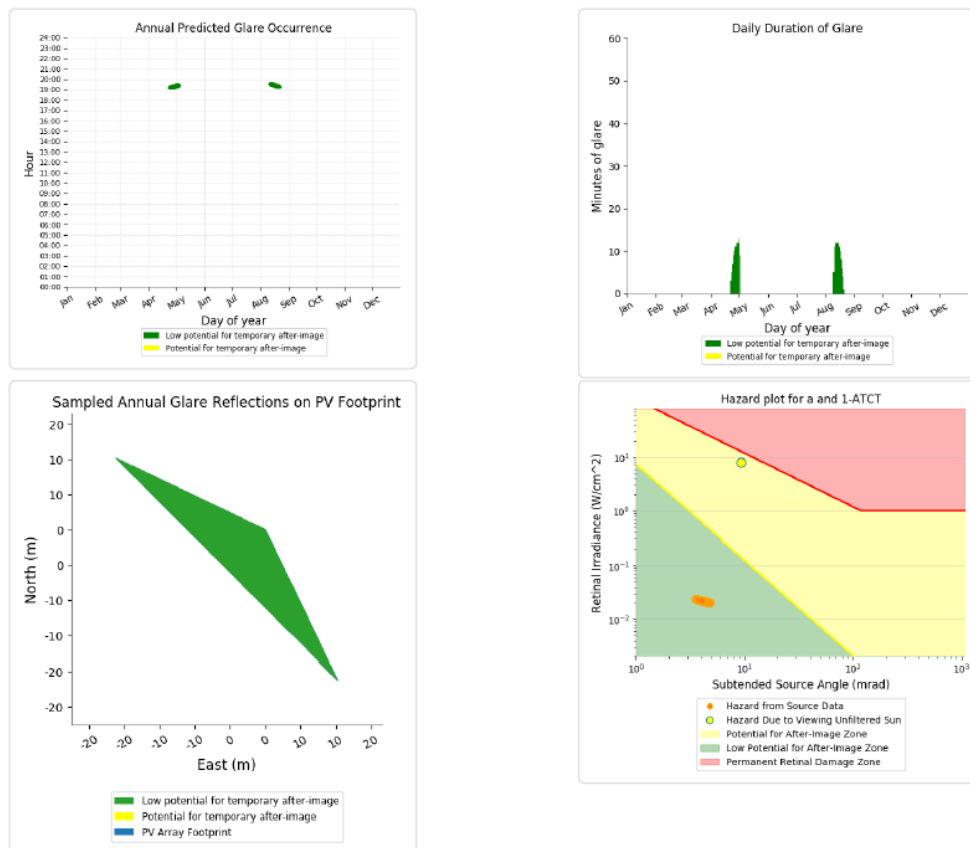
The charts from the Forge modelling for the potentially affected receptors are shown on the following pages for completeness. Each chart shows:

- 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.

A - OP Receptor (1-ATCT)

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

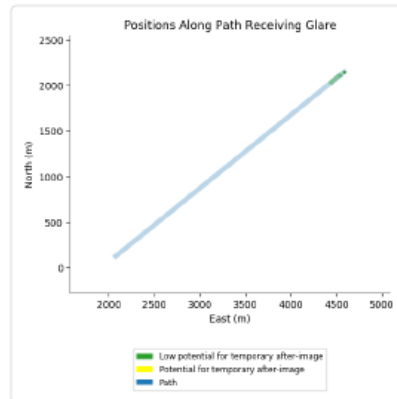
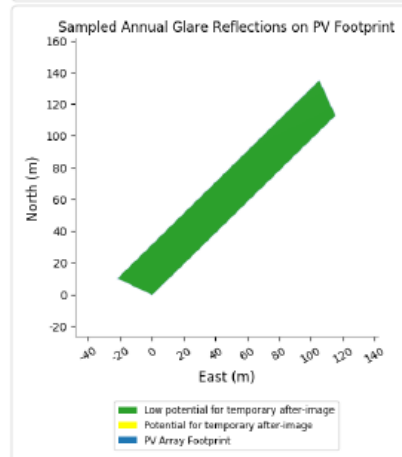
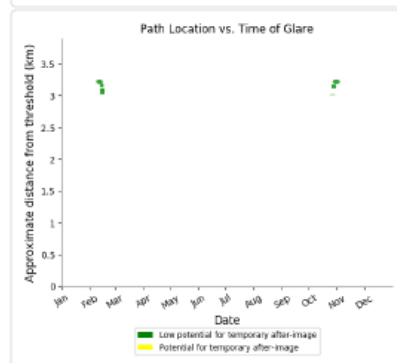
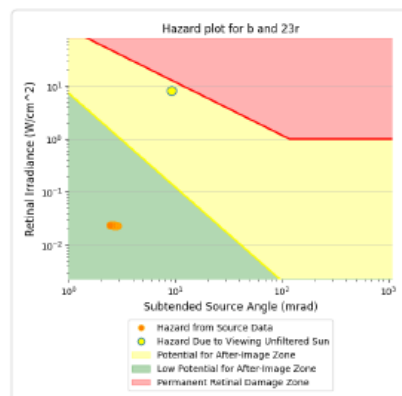
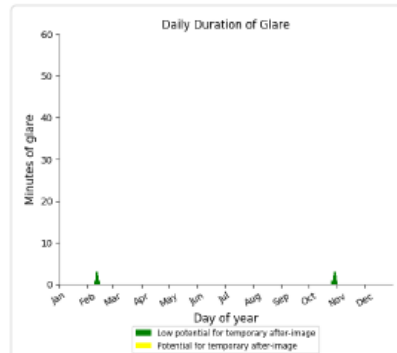
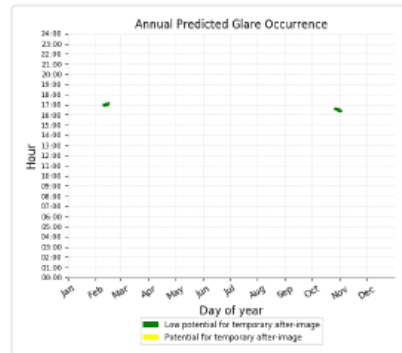
- 207 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.



B - Receptor (23R)

PV array is expected to produce the following glare for observers on this flight path:

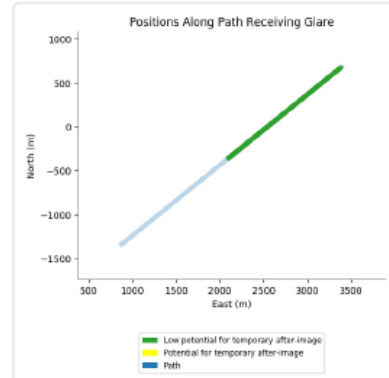
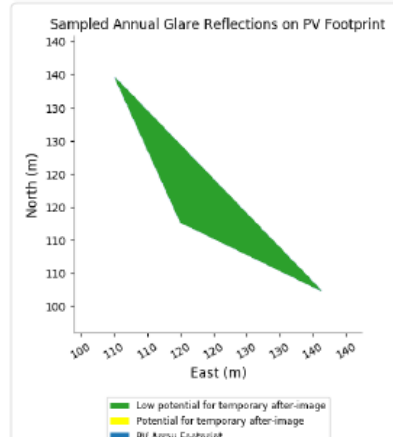
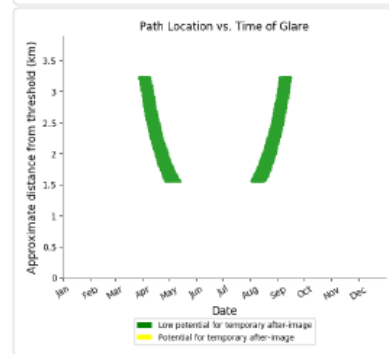
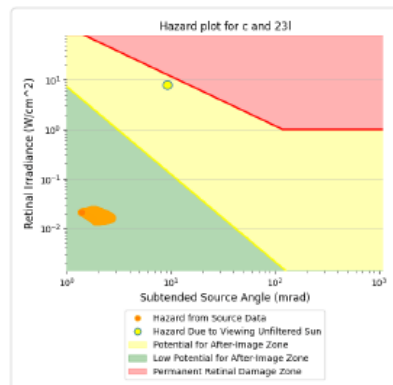
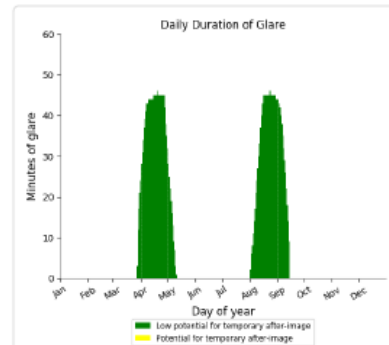
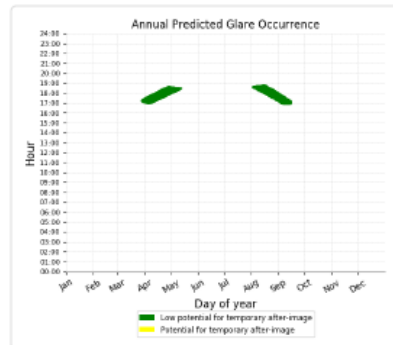
- 26 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.



C - Receptor (23L)

PV array is expected to produce the following glare for observers on this flight path:

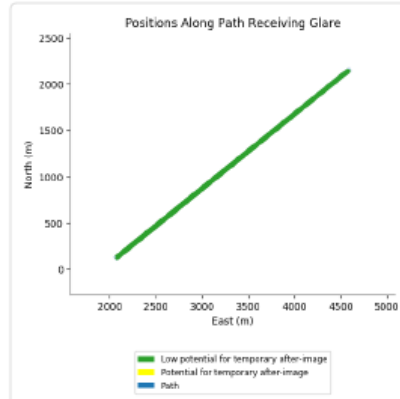
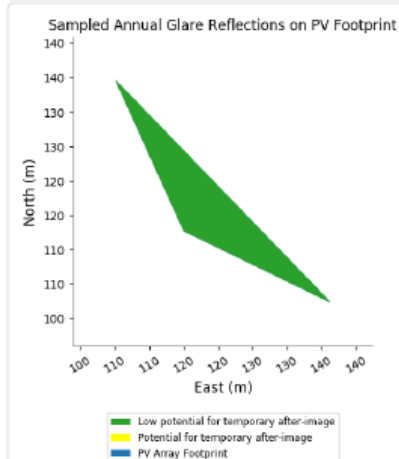
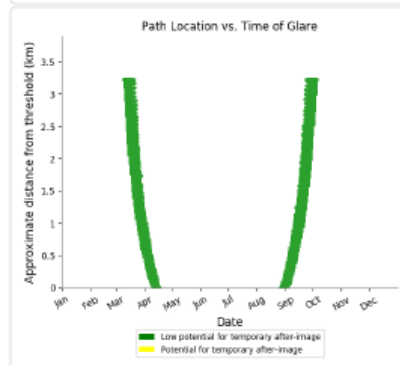
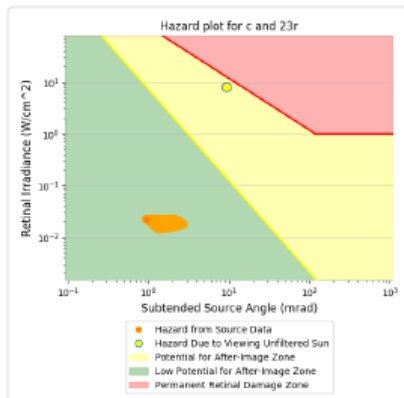
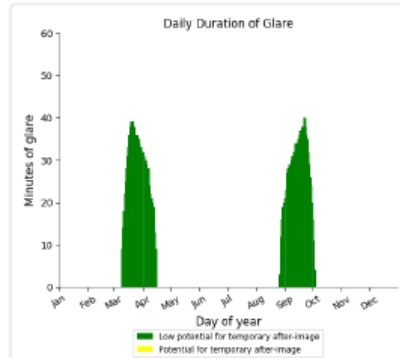
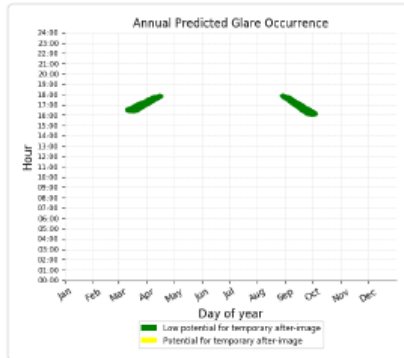
- 2,936 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.



C - Receptor (23R)

PV array is expected to produce the following glare for observers on this flight path:

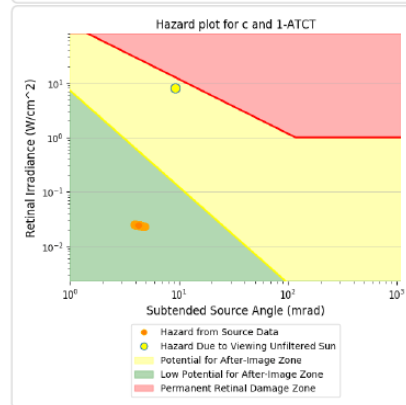
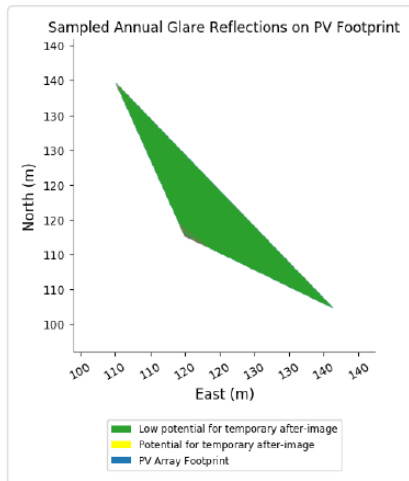
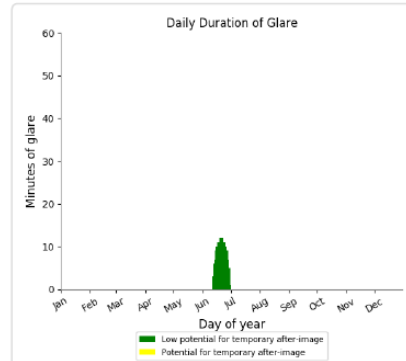
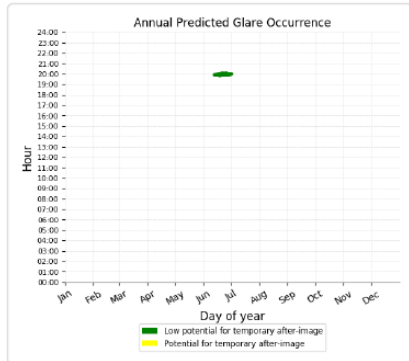
- 2,233 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.



C - OP Receptor (1-ATCT)

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

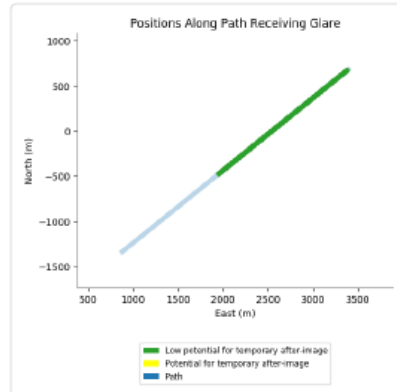
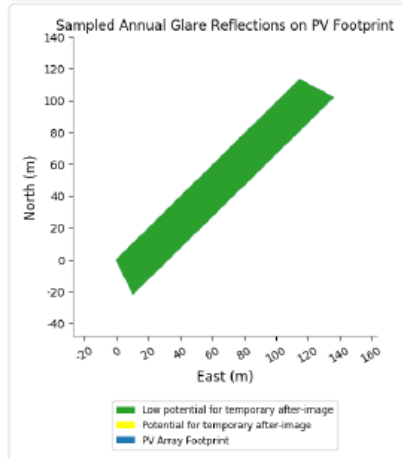
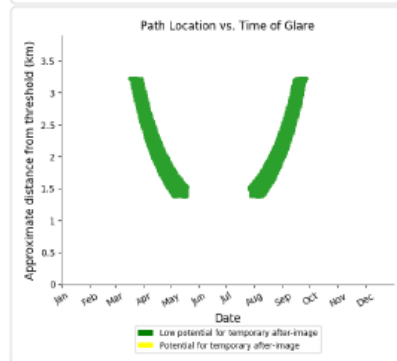
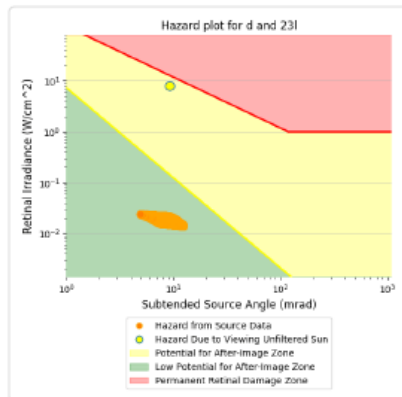
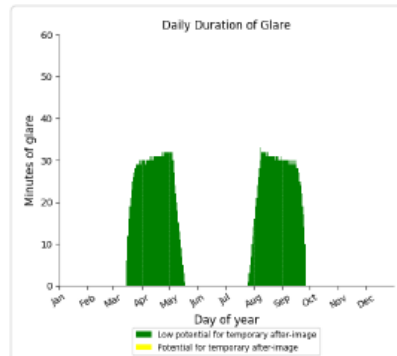
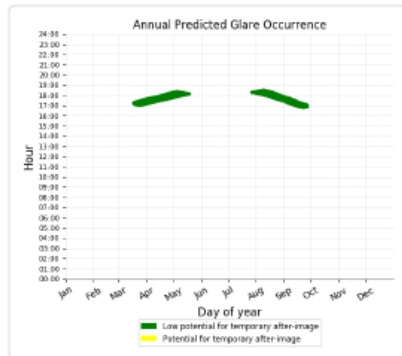
- 180 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.



D - Receptor (23L)

PV array is expected to produce the following glare for observers on this flight path:

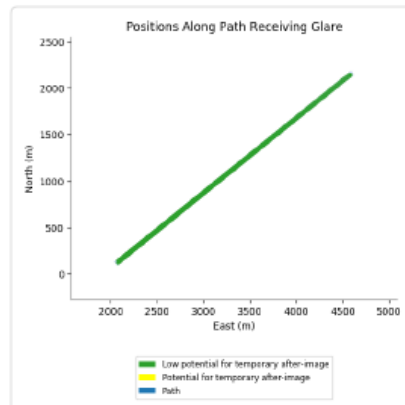
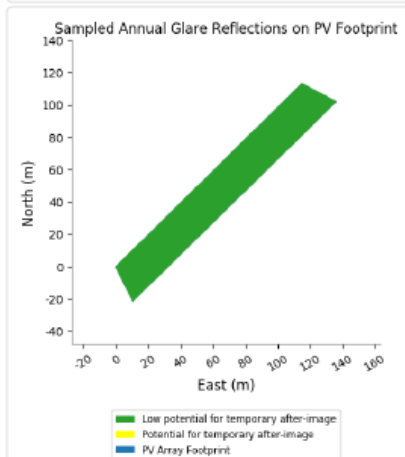
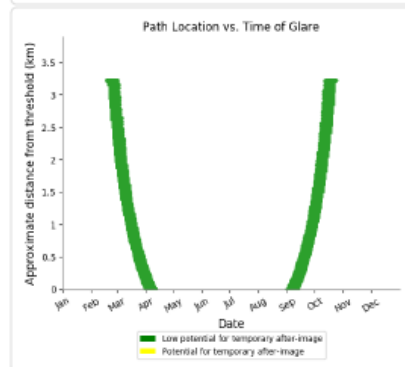
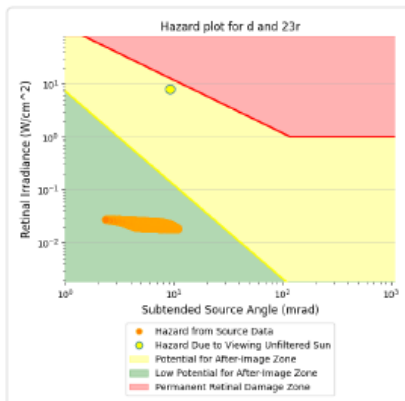
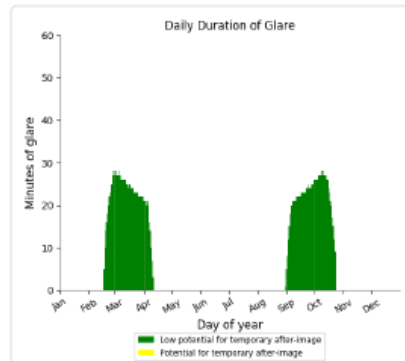
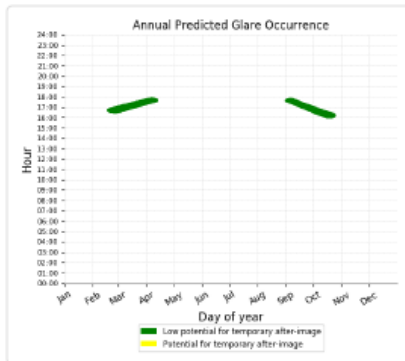
- 3,259 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.



D - Receptor (23R)

PV array is expected to produce the following glare for observers on this flight path:

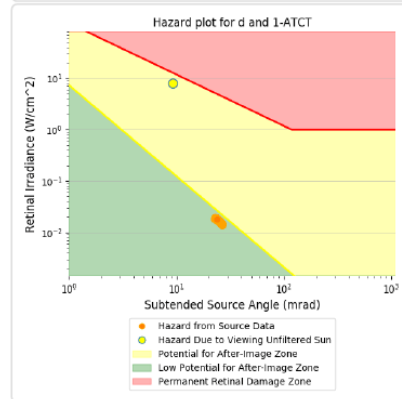
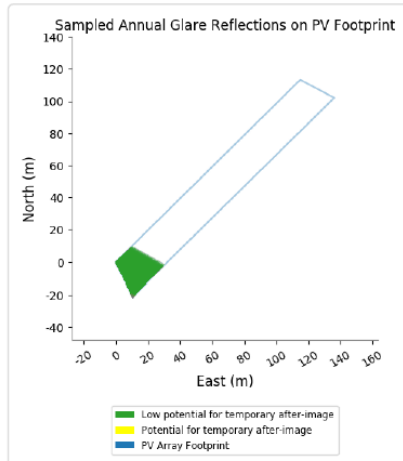
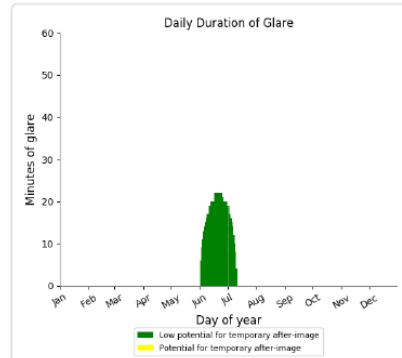
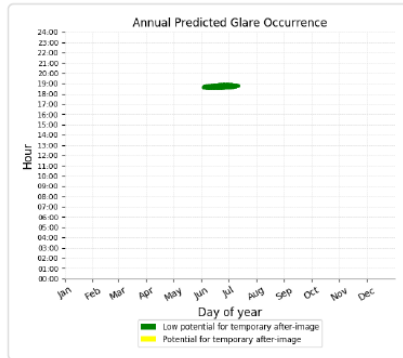
- 2,346 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.



D - OP Receptor (1-ATCT)

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

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





Pager Power Limited
Stour Valley Business Centre
Sudbury
Suffolk
CO10 7GB

Tel: +44 1787 319001 **Email:** info@pagerpower.com **Web:** www.pagerpower.com