



# Wind Power Aviation Consultants Ltd

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## Wind Farm Aviation Lighting and Mitigation Report for Craiginmoddie Wind Farm Version 3

**Our Reference: WPAC/047/21 Version 3**

**Your Reference: EKUK-SS-380**

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## Reference Documents

- A. Civil Aviation Publication (CAP) 764 Civil Aviation Authority (CAA) Policy and Guidance on Wind Turbines Version 6, Feb 2016
- B. CAP 764 Version 7 (Draft) issued for comment in June 2020 (to be released shortly)
- C. Air Navigation Order (ANO) Article 222
- D. CAA Policy Statement: Lighting of Onshore Wind Turbine Generators in the United Kingdom with a maximum blade tip height at or in excess of 150m Above Ground Level dated 01/06/17
- E. NatureScot General pre-application and scoping advice for onshore wind farms dated Sep 2020
- F. International Civil Aviation Organisation (ICAO) Annex 14 Vol 1 Chapter 6
- G. CAA SARG Approval Letter dated 23/12/22 (Appendix C)

## Scope

1. This report is divided into two parts. Part 1 proposes a lighting design that is compliant with existing and draft (but soon to be ratified) regulations and guidance contained within References A to D and F as discussed with the CAA and the MOD. It explains the rationale behind the lighting design taking into account the requirement to minimise the number of turbines illuminated with aviation obstruction lights whilst maintaining flight safety and provides a detailed assessment of the brilliance of the lighting when viewed from a number of viewpoints provided by the LVIA consultant after consultation with the relevant stakeholders including NatureScot and the Local Planning Authority. Part 2 of the report identifies and explains those mitigation measures that can be utilised to minimise the environmental effect of the lights including an assessment of the historical meteorological data from which to predict the luminous intensity requirements for the lights. The entire report can be considered to fulfil the requirements for an Aviation Lighting Landscape and Visual Impact Mitigation Plan (ALLVIMP) as proposed by NatureScot in their response to a recent Wind Farm Inquiry.

## Part 1 Turbine Lighting Layout Design

### Introduction

2. WPAC have designed a number of CAA and MOD compliant lighting layouts for wind farms and have also been in constant dialogue with the CAA regarding the proposed change to CAP 764 in terms of aviation lighting requirements. Whilst Reference A is technically the current publication for policy and guidance on this issue, Reference B was released for comment and is already being used by the CAA as the current *de facto* policy. Recent discussions with the CAA clarified that the draft regulations will not be changing in terms of the overarching policy but the wording may be slightly amended in the interests of clarity. This is Version 3 of the report which reflects the receipt of the CAA approval letter for the proposed lighting layout. The CAA approval letter (Reference G) is at Appendix C.





## CAA-ANO Red 2000/200cd Lighting

5. The CAA requires:

- That all perimeter turbines be lit unless removing a light will leave a gap of less than 900m total between the remaining lit turbines.
- That any turbine within 200m of a 'string perimeter' be lit unless the distance between adjacent turbines is less than 900m total.
- That any unlit turbine does not exceed a 10° up-slope from adjacent lit turbines. Note: the highest turbines on the site are lit. Accordingly, all the non-perimeter turbines do not require lights.

Applying these criteria dictates that all of the twelve perimeter turbines of the Craiginmoddie site will require ANO visible red lighting. This requires that without a CAA dispensation, 12 of the 14 turbines will have to be fitted with lights, however see paragraph 10 later in the report which proposes a reduced lighting layout.

**Turbines with 2000/200cd Lights: T1, T2, T3, T5, T6, T7, T8, T9, T10, T11, T12 and T13**

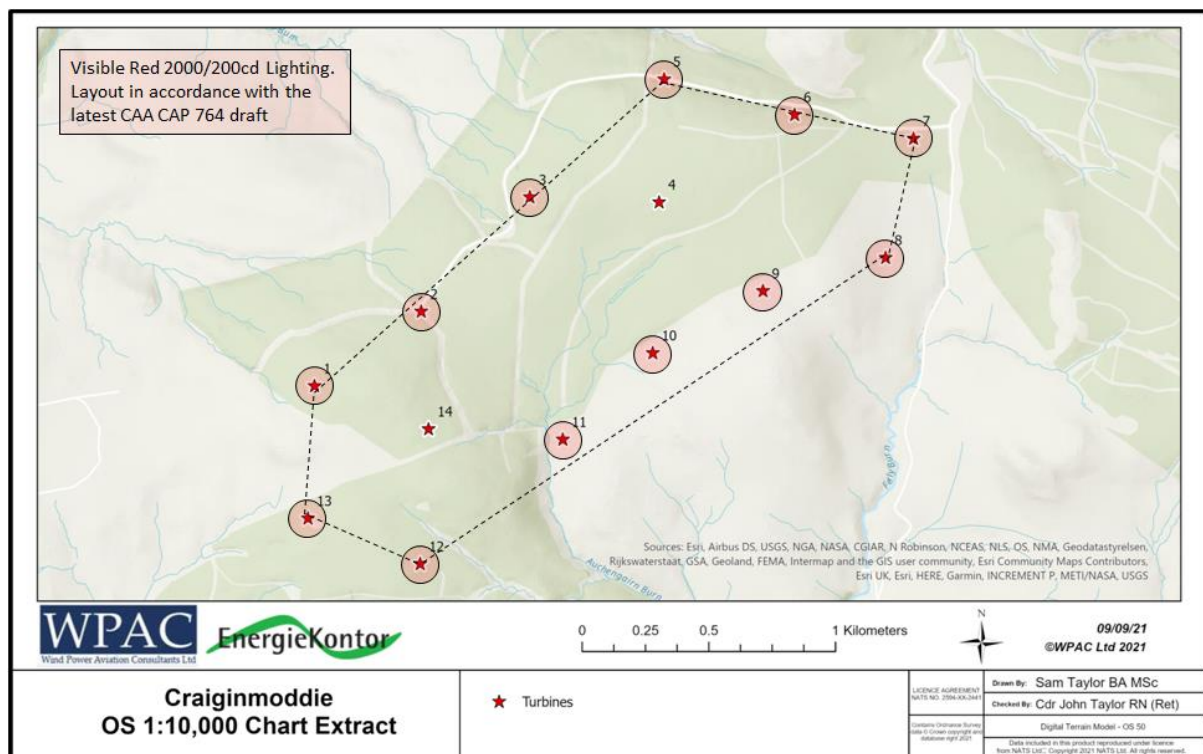


Figure 2 CAA-ANO CAP 764 Compliant Lighting Arrangement



## MOD Low Flying & Lighting

6. Military low flying is conducted at various heights by day and at night. Aircraft are fitted with a range of Night Vision Devices (NVDs) and aircrew can also wear Night Vision Goggles. Most of these devices use Infra-Red light (heat) to see objects since heat radiation persists during the hours of darkness.

7. In many circumstances, aircrew using such devices can see wind turbines at night at several miles range - weather (atmospheric heat profile) dependant. Nonetheless, whilst low flying at night, it is important that aircrew can guarantee to see the turbines at 5km range. Fast jets operate at up to nine nautical miles per minute: that is 18 kilometres per minute or one kilometre in a little over 3 seconds. Early detection is important especially if the aircraft is manoeuvring hard and the air temperature profile causes the turbines to blend into the background. Suitable lighting is necessary for flight safety.

8. MOD IR lights have been developed to be invisible to the public at large but very detectable to aircrew night vision aids. As such the MOD IR lights can have a wide beam width and flash continuously without disturbing the environment.

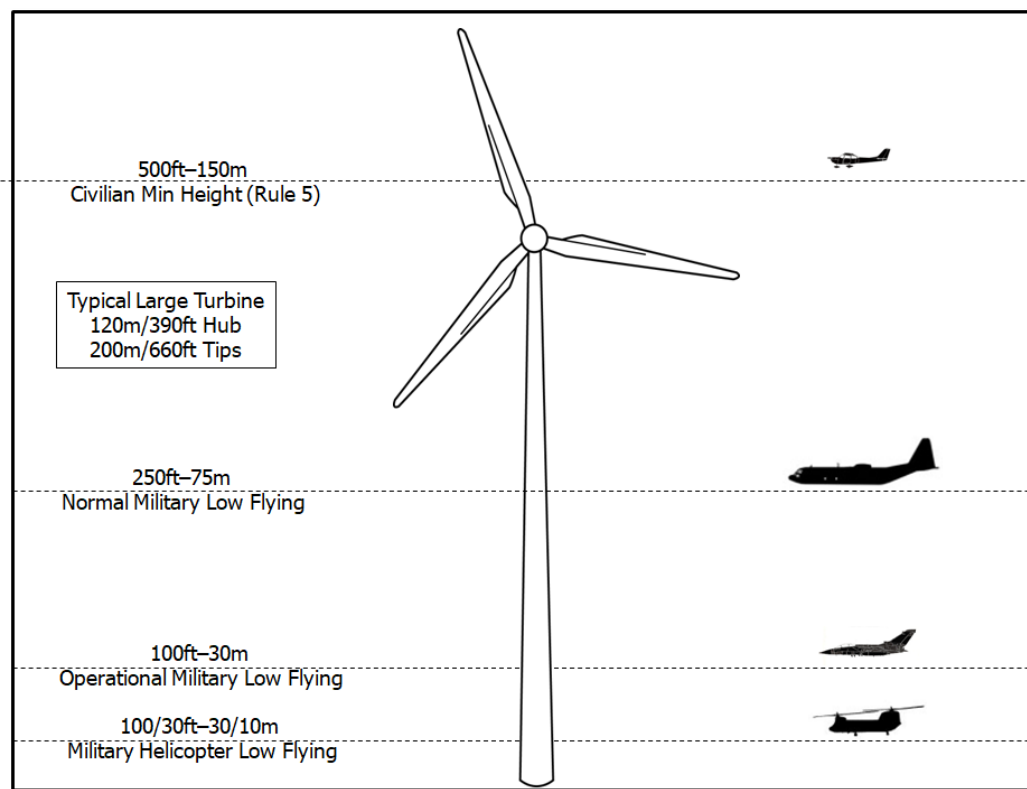


Figure 3 MOD Low Flying Vs Wind turbines in context

## MOD IR Lighting

9. The MOD requires:

- That all 'compound-perimeter' (see diagram) turbines be lit unless removing a light will leave a gap of less than 500m between the remaining perimeter lit turbines. Note: at this site, the 'string' and 'compound' perimeters differ at turbines 7 and 8.
- That any dominant turbine, by location or height, be lit. Note: here, the corner and highest turbines are lit.
- That a central turbine be lit to provide 'depth perception' to approaching aircraft. Note: Craiginmoddie meets the MOD small site criteria and does need central turbines to be lit

Applying these criteria dictates that all of the compound perimeter turbines of the Craiginmoddie site will require IR lighting. Twelve turbine hub lights in total.

**Turbines with Infra-Red: T1, T2, T3, T5, T6, T7, T8, T9, T10, T11, T12 and T13**

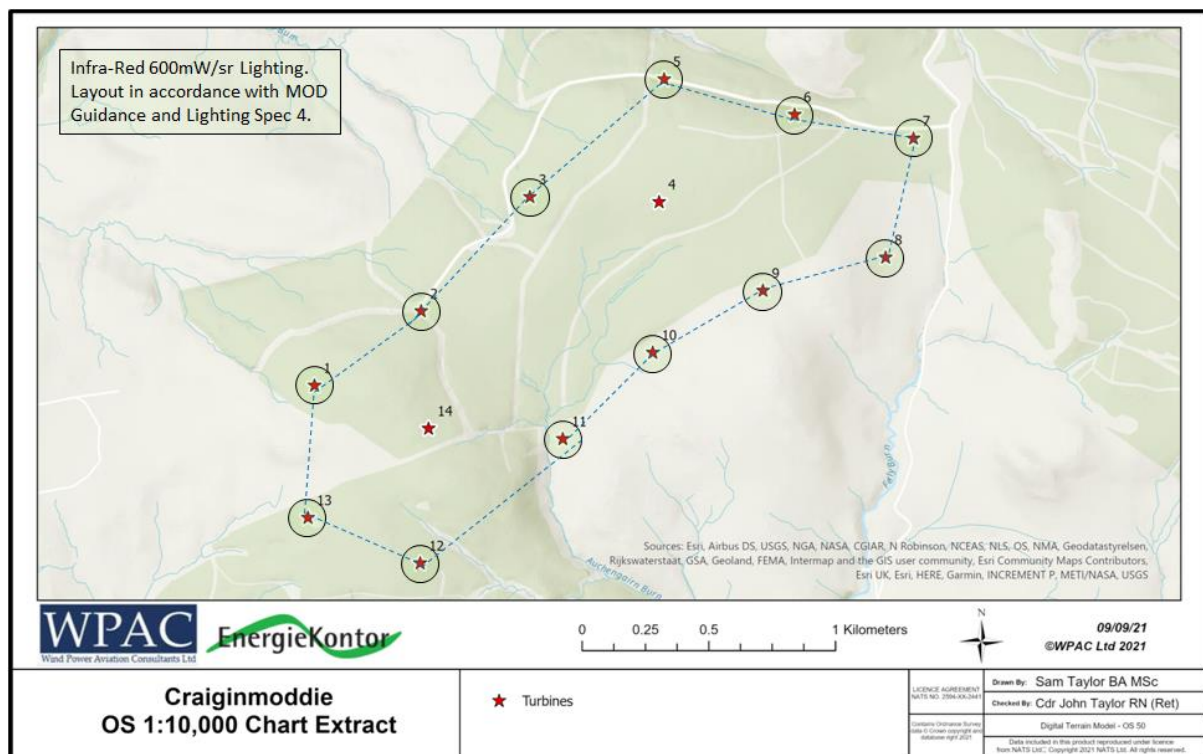


Figure 4 MOD IR Guidance Compliant Lighting Arrangement

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## Combined CAA Visible Lighting and MOD Infra-Red Lighting

| Craiginmoddie Lighting Proposal |         |          |        |            |           |          |
|---------------------------------|---------|----------|--------|------------|-----------|----------|
| Turbine                         | Easting | Northing | Tip Ht | ANO Red    | Infra-Red | Mid Mast |
| 1                               | 230600  | 598605   | 200m   | 2000/200cd | 600mW     | Possibly |
| 2                               | 231021  | 598899   | 200m   | 2000/200cd | 600mW     |          |
| 3                               | 231450  | 599350   | 200m   | 2000/200cd | 600mW     |          |
| 4                               | 231960  | 599330   | 200m   |            |           |          |
| 5                               | 231980  | 599815   | 200m   | 2000/200cd | 600mW     | Possibly |
| 6                               | 232495  | 599675   | 200m   | 2000/200cd | 600mW     |          |
| 7                               | 232964  | 599581   | 200m   | 2000/200cd | 600mW     | Possibly |
| 8                               | 232854  | 599111   | 200m   | 2000/200cd | 600mW     |          |
| 9                               | 232370  | 598980   | 200m   | 2000/200cd | 600mW     |          |
| 10                              | 231935  | 598735   | 200m   | 2000/200cd | 600mW     |          |
| 11                              | 231580  | 598394   | 200m   | 2000/200cd | 600mW     |          |
| 12                              | 231017  | 597903   | 200m   | 2000/200cd | 600mW     | Possibly |
| 13                              | 230574  | 598083   | 200m   | 2000/200cd | 600mW     |          |
| 14                              | 231050  | 598435   | 200m   |            |           |          |

Table 1 Combined CAA & MOD Lighting Table

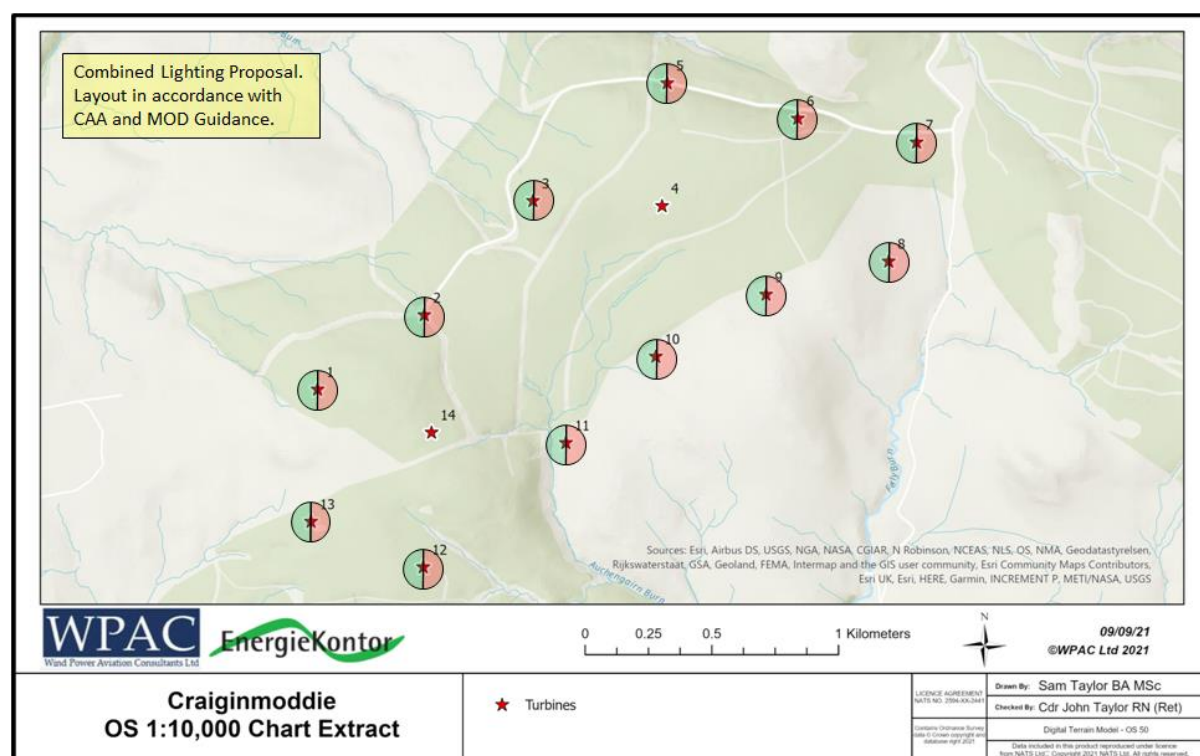


Figure 5 Combined CAA and MOD Lighting Diagram



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## Alternate Combined Lighting Arrangement

10. Detailed discussions with the CAA have indicated that the ANO lights on Turbines T6, T9 and T11 can be removed. The layout below has now been approved by the CAA as per their dispensation approval letter at Appendix C which also confirms that there is no requirement for mid mast lighting.

| Craiginmoddie Reduced Lighting Layout |         |          |        |            |           |
|---------------------------------------|---------|----------|--------|------------|-----------|
| Turbine                               | Easting | Northing | Tip Ht | ANO Red    | Infra-Red |
| 1                                     | 230600  | 598605   | 200m   | 2000/200cd | 600mW     |
| 2                                     | 231021  | 598899   | 200m   |            | 600mW     |
| 3                                     | 231450  | 599350   | 200m   | 2000/200cd | 600mW     |
| 4                                     | 231960  | 599330   | 200m   |            |           |
| 5                                     | 231980  | 599815   | 200m   | 2000/200cd | 600mW     |
| 6                                     | 232495  | 599675   | 200m   |            | 600mW     |
| 7                                     | 232964  | 599581   | 200m   | 2000/200cd | 600mW     |
| 8                                     | 232854  | 599111   | 200m   | 2000/200cd | 600mW     |
| 9                                     | 232370  | 598980   | 200m   |            | 600mW     |
| 10                                    | 231935  | 598735   | 200m   | 2000/200cd | 600mW     |
| 11                                    | 231580  | 598394   | 200m   |            | 600mW     |
| 12                                    | 231017  | 597903   | 200m   | 2000/200cd | 600mW     |
| 13                                    | 230574  | 598083   | 200m   | 2000/200cd | 600mW     |
| 14                                    | 231050  | 598435   | 200m   |            |           |

Table 2

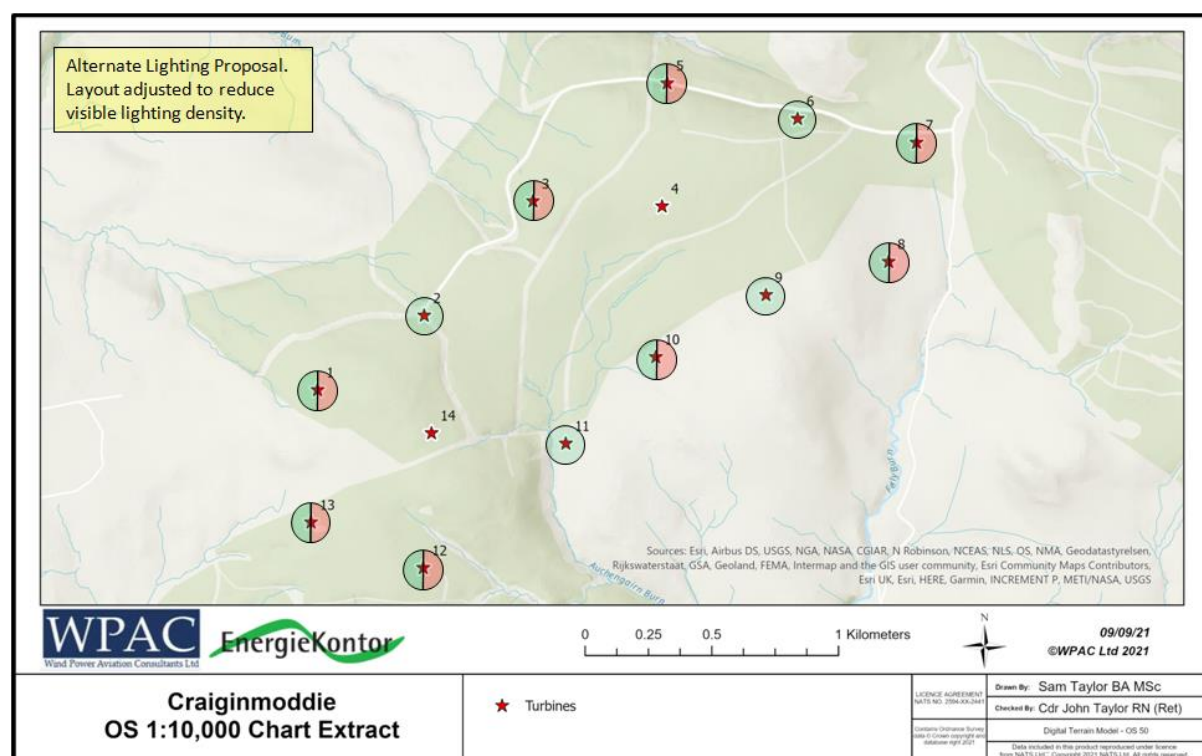


Figure 6



## ANO Light Specifications

11. The ANO 2000/200cd Lights will conform to the ICAO specification as set out in Annex 14 Table 6-3. The lights will also be controlled such that when the met visibility is greater than 5km in all directions from all turbine hubs, the lights will be reduced to 200cd (10% of normal power). This reduction in power will not apply to MOD IR Lights.

ICAO Annex 14 Table 6-3 (excerpt)

| Benchmark intensity | Minimum requirements          |                       |                       |                          |               | Recommendations              |                       |                       |                          |               |
|---------------------|-------------------------------|-----------------------|-----------------------|--------------------------|---------------|------------------------------|-----------------------|-----------------------|--------------------------|---------------|
|                     | Vertical elevation angle (b)  |                       |                       | Vertical beam spread (c) |               | Vertical elevation angle (b) |                       |                       | Vertical beam spread (c) |               |
|                     | 0°                            |                       | -1°                   |                          |               | 0°                           | -1°                   | -10°                  |                          |               |
|                     | Minimum average intensity (a) | Minimum intensity (a) | Minimum intensity (a) | Minimum beam spread      | Intensity (a) | Maximum intensity (a)        | Maximum intensity (a) | Maximum intensity (a) | Maximum beam spread      | Intensity (a) |
| 2000                | 2000                          | 1500                  | 750                   | 3°                       | 750           | 2500                         | 1125                  | 75                    | N/A                      | N/A           |

a) 360° horizontal. All intensities are expressed in Candela. For flashing lights, the intensity is read into effective intensity, as determined in accordance with the Aerodrome Design Manual (Doc 9157), Part 4.

b) Elevation vertical angles are referenced to the horizontal when the light unit is levelled.

c) Beam spread is defined as the angle between the horizontal plane and the directions for which the intensity exceeds that mentioned in the "intensity" column.

Table 3 ICAO Annex 14 Table 6-3 Medium Intensity Lighting Specifications.

## IR Light Specifications

12. The IR lights will conform to the MOD specification as set-out in MOD Lighting Guidance.

### **MOD Specification IR.**

**IR wavelength** – 750 to 900nm.

But ideally concentrated within 800 to 850nm for optimum detection by all military NVG types.

**IR intensity** – 600mW/sr minimum at peak flash but not above 1200mW/sr.

(Note: Typically a 300mW/sr steady burn LED IR light will generate 600mW/sr at peak flash)

This will generate a 7-8 nm NVG pick-up range - remaining above 5nm as the light ages.

**Horizontal Pattern** – unrestricted 360 deg.

**Vertical Pattern** – Minimum flash intensity of 600 mW/sr between +30 deg and -15 deg elevation.

– up to 50% reduction between +25 to +30 deg and -10 to -15 deg is acceptable.

– Maximum intensity of 1200 mW/sr for all angles of elevation.

– Vertical overspill is acceptable.

**Flash Pattern** – 60 flashes per min at 100-500 ms duration (ideally 250ms)

**Synchronisation** – all lights to be visually synchronised across a wind farm site

Table 4 MOD Specification for IR Obstacle Lights

## Assessment of Aviation Lighting and Potential Mitigation Measures Designed into the Lights

13. Having defined a layout of turbines to be lit with visible lighting, an assessment has been undertaken to calculate the brilliance of the lights when seen from a number of viewpoints. The standard aviation lights to be fitted to the nacelle of the turbines are required to fulfil certain design criteria in terms of brilliance and coverage as per Table 3. They are designated 'medium intensity obstruction lights' and have a **minimum** luminous intensity of 2000 candela<sup>1</sup> at horizontal and slightly above. The LED lights are also required to be able to shine a beam that reduces in intensity above and below the horizontal also as shown in Figure 3. One manufacturer of such obstruction lights, CEL, have tested their light, the CEL MI-2KR<sup>2</sup> in a calibration chamber and produced results showing precisely how much the beam reduces in brilliance at any specified elevation angle. The results are provided to every 0.1°. These lights are already fitted in a number of locations around the UK.

14. Figure 7 demonstrates the reduction in luminous intensity below the horizontal and also above 1° in elevation. The various coloured lines are the candela measured from different angles in the horizontal in order to measure the performance all around the light.

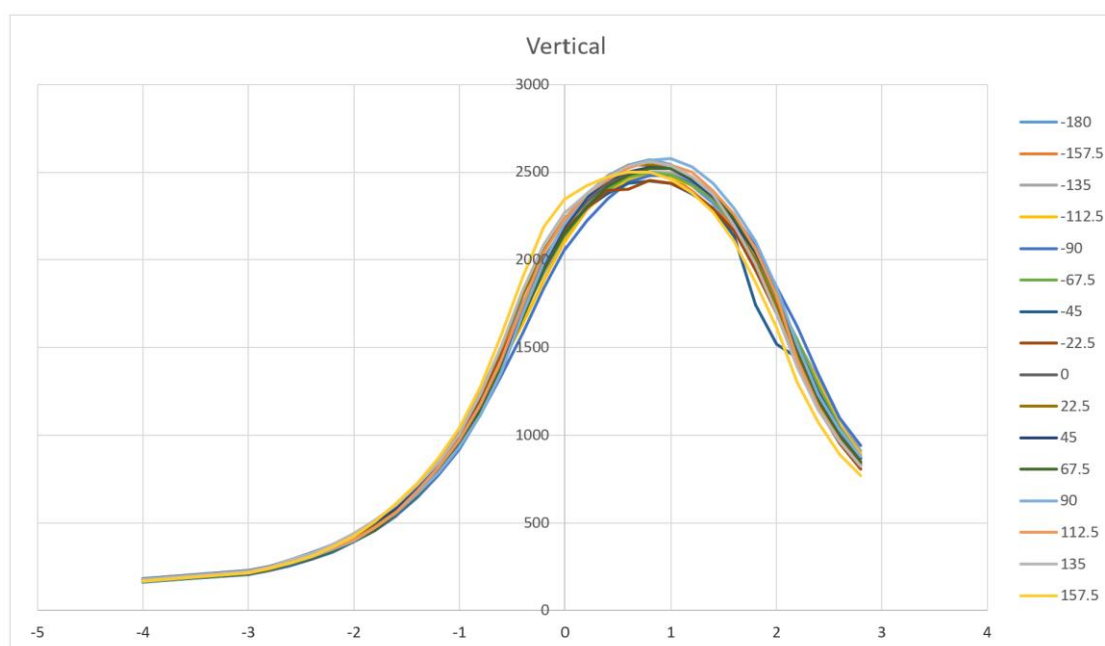


Figure 7 (MI GAM Light Measurement Results)

15. WPAC have utilised their propagation modelling system (Rview) to calculate the precise angle of elevation between the turbine light and a viewpoint assuming a height of eye of 1.5 metres and a

<sup>1</sup> Candela is the SI Unit of luminous intensity and refers to the amount of light emitted in a particular direction.

<sup>2</sup> The Technical Specification is at: <https://www.contarnex.com/led-obstruction-lighting/medium-intensity-led-obstacle-warning-lighting.php>

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turbine hub height of 122.5 metres as required. The system utilises a standard atmospheric model and an earth model that uses actual earth curvature between the turbine light and the viewpoint. Ordnance Survey OS50 DTM is used as the terrain model. The calculations have been undertaken for each designated lit turbine against all Craiginmoddie Wind Farm viewpoints. The locations of the viewpoints are shown in Figure 8 and Table 5. The assessment has been undertaken utilizing the reduced turbine lighting layout shown in Figure 8 as this layout has now been approved by the CAA.

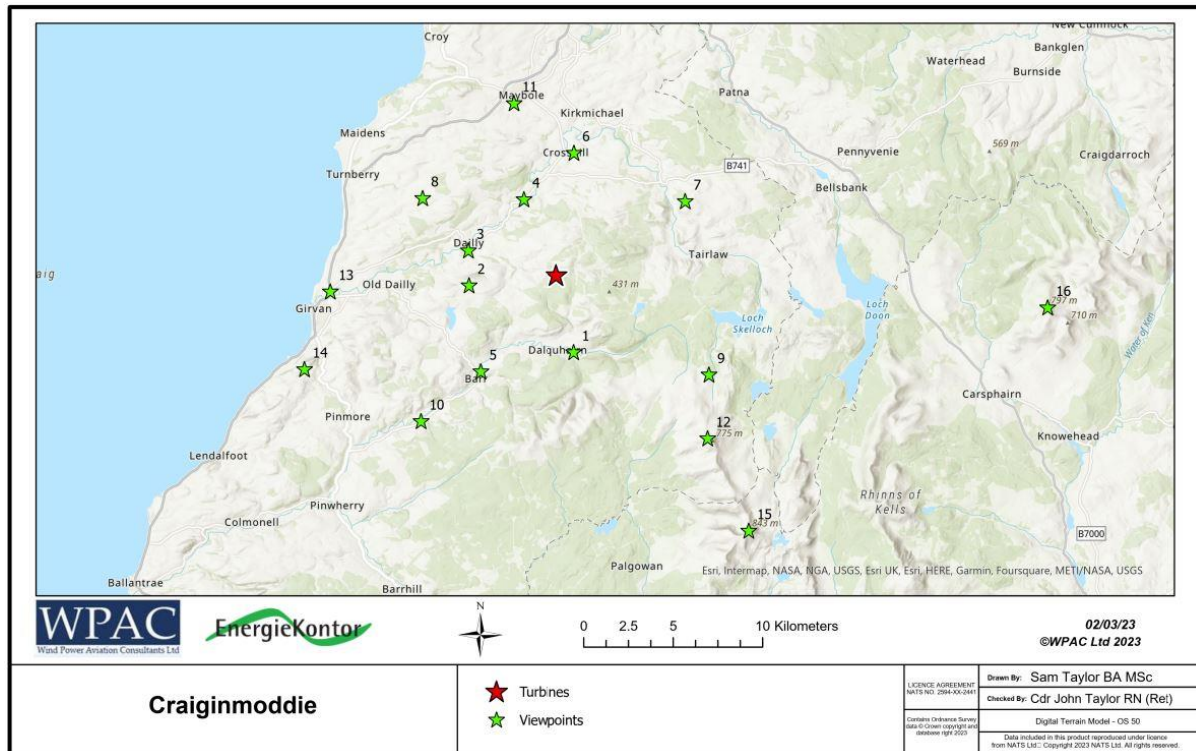


Figure 8 Viewpoint Locations



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| Viewpoint Number | Viewpoint Name                               | Grid Reference |
|------------------|----------------------------------------------|----------------|
| 1                | South Balloch                                | NX 32966 95514 |
| 2                | Hadyard Hill                                 | NX 27066 99244 |
| 3                | Dailly                                       | NS 27028 01195 |
| 4                | B741 near Ruglen                             | NS 30135 04050 |
| 5                | Barr                                         | NX 27726 94440 |
| 6                | Crosshill                                    | NS 32985 06641 |
| 7                | Colonel Hunter Blair Monument, Kildoach Hill | NS 39202 03942 |
| 8                | North Threave                                | NS 24472 04115 |
| 9                | Cornish Hill                                 | NX 40532 94263 |
| 10               | B734 near Cairnwhin                          | NX 24380 91664 |
| 11               | Maybole War Memorial                         | NS 29578 09413 |
| 12               | Shalloch on Minnoch                          | NX 40459 90702 |
| 13               | A77 north of Girvan                          | NX 19309 98902 |
| 14               | Byne Hill                                    | NX 17862 94562 |
| 15               | Merrick                                      | NX 42755 85549 |
| 16               | Cairnsmore of Carsphairn                     | NX 59465 98009 |

Table 5 Viewpoints

16. The next stage in the process is to take the candela figures radiated towards a viewpoint and taking into account the distance, calculate the lumens per square metre (also known as Lux) that will be experienced by the human eye at the viewpoint. The figure produced is in micro-lumens per square metre or  $\text{lumen}^{(10^{-6})}/\text{m}^2$  or  $\text{lux}^{(10^{-6})}$ . These are perfect clear-air figures and therefore worst case results from an LVIA perspective. Figures obtained by this method enable comparisons to be made with commonly understood light sources such as stars or planets. In practice the light intensity at the observation points will be further attenuated by scatter and absorption by airborne dust, droplets and aerosols in the atmosphere. This attenuation is typically in the order of 10 to 20% but can be as high as 75% at the more distant observation ranges.

17. The results for every lit turbine from all of the viewpoints are shown in the results tables in Appendix A to this report. Viewpoints where lights are obstructed by terrain are shaded in green, when the viewpoint is too close to a turbine to get an accurate assessment it is shaded red. **To take into account any limitations within the terrain model we have highlighted in purple any viewpoints where the line of sight is under 10 metres above ground level but above 1.5 metres and should therefore, still be screened by terrain but may be visible within the vicinity of the viewpoint.**





## Interpreting the Results

18. The results show that there is a significant decrease in the luminous intensity (candela) of the light emanating towards those viewpoints which are at lower angles of elevation in relation to the turbine hub. However, when considering the perception of the light from a viewpoint in general, the distance between the light and the viewpoint is likely to be the dominant factor and the resultant figure in micro-lux is the most relevant figure to consider. This report provides the results and anticipates that the Landscape and Visual Impact Assessment (LVIA) consultants will be able to put them into the correct context for visualisations in terms of background environmental lighting and atmospheric conditions. Table 6 shows the turbine with the greatest potential perceived luminous intensity expressed in micro-lumens per m<sup>2</sup> (Lux <sup>(10-6)</sup>) at each viewpoint.

| Viewpoint | Brightest Lit Turbine | Distance (km) | microlumens per m <sup>2</sup> (lux <sup>10-6</sup> ) | Microlumens at 10% | Obscured |
|-----------|-----------------------|---------------|-------------------------------------------------------|--------------------|----------|
| 1         | 5                     | 4.4           | 9.0                                                   | 0.9                |          |
| 2         | 13                    | 3.7           | 28.2                                                  | 2.8                |          |
| 3         | 5                     | 5.1           | 5.5                                                   | 0.5                |          |
| 4         |                       |               |                                                       |                    | X        |
| 5         | 13                    | 4.6           | 7.7                                                   | 0.8                |          |
| 6         | 5                     | 6.9           | 4.3                                                   | 0.4                |          |
| 7         | 5                     | 8.3           | 17.2                                                  | 1.7                |          |
| 8         | 10                    | 9.2           | 6.3                                                   | 0.6                |          |
| 9         | 8                     | 9.1           | 26.5                                                  | 2.7                | M        |
| 10        | 12                    | 9.1           | 4.3                                                   | 0.4                |          |
| 11        | 5                     | 9.9           | 4.2                                                   | 0.4                |          |
| 12        | 8                     | 11.3          | 17.2                                                  | 1.7                |          |
| 13        |                       |               |                                                       |                    | X        |
| 14        | 13                    | 13.2          | 5.2                                                   | 0.5                |          |
| 15        | 8                     | 16.8          | 8.5                                                   | 0.8                |          |
| 16        | 7                     | 26.5          | 3.5                                                   | 0.4                | M        |

Table 6 Brightest Turbine Hub Light from each Viewpoint (measured in micro-lumens)

19. In order to place the values in microlumens per m<sup>2</sup> (lux<sup>10-6</sup>) in context, Table 7 provides some examples of approximate values placed on a number of environmental comparators, however these are just an illustration to place the results in a real world environment. The actual perceived brightness will depend upon a number of factors including bulb manufacturer, bulb type, specific construction (single/multiple colour LEDs etc) atmospheric conditions, absorption spectrum, individual eye characteristics and capabilities.

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| Comparison Object                           | Approximate Illuminance (micro-lumens per m <sup>2</sup> ) |
|---------------------------------------------|------------------------------------------------------------|
| Car Halogen main beam approaching 1km       | Up to 1,000,000 (can vary significantly between cars)      |
| International Space Station (400km up)      | 1000 (depends upon relative position of sun)               |
| Car Brake Light at 0.5km                    | 400                                                        |
| Car Brake Light at 0.7km                    | 200                                                        |
| Car Brake Light at 1.0km                    | 100                                                        |
| Car Brake Light at 2.0km                    | 25                                                         |
| Car Brake Light at 5.0km                    | 4                                                          |
| Car Brake Light at 10km                     | 1                                                          |
| Front Cycle Light at 0.5km                  | 140 (Modern high power white LED)                          |
| Front Cycle Light at 0.7km                  | 70                                                         |
| Front Cycle Light at 1.0km                  | 35                                                         |
| Front Cycle Light at 2km                    | 9                                                          |
| Front Cycle Light at 5km                    | 2                                                          |
| White LED Street Light at 0.5km             | 500 (Viewed from the horizontal)                           |
| White LED Street Light at 0.7km             | 250                                                        |
| White LED Street Light at 1.0km             | 120                                                        |
| White LED Street Light at 2.0km             | 30                                                         |
| White LED Street Light at 5.0km             | 8                                                          |
| Sodium Street Light at 0.5km                | 300 (Viewed from the horizontal)                           |
| Sodium Street Light at 0.7km                | 150                                                        |
| Sodium Street Light at 1.0km                | 75                                                         |
| Sodium Street Light at 2.0km                | 20                                                         |
| Sodium Street Light at 5.0km                | 5                                                          |
| Brightest Star in the Sky (Sirius)          | 13                                                         |
| Airliner flying at 30,000ft)                | Nav Lights 0.4 to 5; anti-collision lights 2 to 20         |
| Typical bright star (e.g. Orion)            | 0.5 to 2.0                                                 |
| Faintest light visible from street lit area | 0.4                                                        |
| Visible limit for fully dark-adapted eyes   | 0.02                                                       |

Table 7 Comparisons of approximate micro-lumens values



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20. If there is a requirement to consider the brightest turbine in terms of emitted candela rather than micro-lumens, Table 8 provides data on which turbine emits the most candela towards each viewpoint but takes no account of the distance between light and viewpoint.

| Viewpoint | Brightest Lit Turbine | Distance (km) | Candela | Candela at 10% | Obscured |
|-----------|-----------------------|---------------|---------|----------------|----------|
| 1         | 5                     | 4.4           | 176.2   | 17.6           |          |
| 2         | 8                     | 5.8           | 756.5   | 75.7           |          |
| 3         | 8                     | 6.2           | 185.3   | 18.5           |          |
| 4         |                       |               |         |                | X        |
| 5         | 7                     | 7.3           | 291.3   | 29.1           | M        |
| 6         | 1                     | 8.4           | 228.1   | 22.8           |          |
| 7         | 5                     | 8.3           | 1192.2  | 119.2          |          |
| 8         | 10                    | 9.2           | 529.8   | 53.0           |          |
| 9         | 8                     | 9.1           | 2185.2  | 218.5          | M        |
| 10        | 7                     | 11.7          | 529.8   | 53.0           |          |
| 11        | 10                    | 10.9          | 483.7   | 48.4           |          |
| 12        | 3                     | 12.5          | 2393.4  | 239.3          |          |
| 13        |                       |               |         |                | X        |
| 14        | 10                    | 14.7          | 982.0   | 98.2           | M        |
| 15        | 1                     | 17.8          | 2471.1  | 247.1          |          |
| 16        | 7                     | 26.5          | 2495.1  | 249.5          |          |

Table 8 Brightest Turbine Hub Light measured in Candela emitted towards a viewpoint

NB – where candela results are the same, the closest turbine has been selected as the brightest.

## Mid Mast Lights

21. The CAA are considering their position in relation to the requirement for lights at the mid point between the turbine hub and the ground and will make a case by case decision about the requirement. In this specific case, the CAA response approving the lighting layout has been received and is included in Appendix C to this report, it states that mid mast lighting is not required in this location and the results have therefore been removed from the report.



## Part 2 Mitigation

22. The lights (IR and visible red lights) will be switched on between Evening Civil Twilight and Morning Civil Twilight in accordance with the UK Almanac; approximately 11 hours per day averaged over the year.

23. The primary mitigation consideration in addition to the already described reduction in brilliance due to elevation angle, is taken from Reference D which states:

*'If the horizontal meteorological visibility in all directions from every wind turbine generator in a group is more than 5 km, the intensity for the light positioned as close as practicable to the top of the fixed structure required to be fitted to any generator in the windfarm and displayed may be reduced to not less than 10% of the minimum peak intensity specified for a light of this type'.*

24. It is therefore possible to take advantage of the CAA SARG Policy Statement dated 01/06/2017 and incorporate the option to reduce the hub height lighting to not less than 10% of the minimum peak intensity specified for the installation in good weather. In essence, reducing the 2000cd obstruction lights to 200cd in meteorological visibilities greater than 5km.

### Intensity Reduction (ANO Lighting: 2000cd down to 200cd)

25. It will be necessary to calculate how much time the lights would spend at 2000cd and at 200cd. To assess historical visibility on this west coast area, the closest meteorological station to Craiginmoddie is at Prestwick Airport. The visibility will not be identical at the two locations but similar. Below is a table of visibilities throughout the year and averaged over a 30-year period.

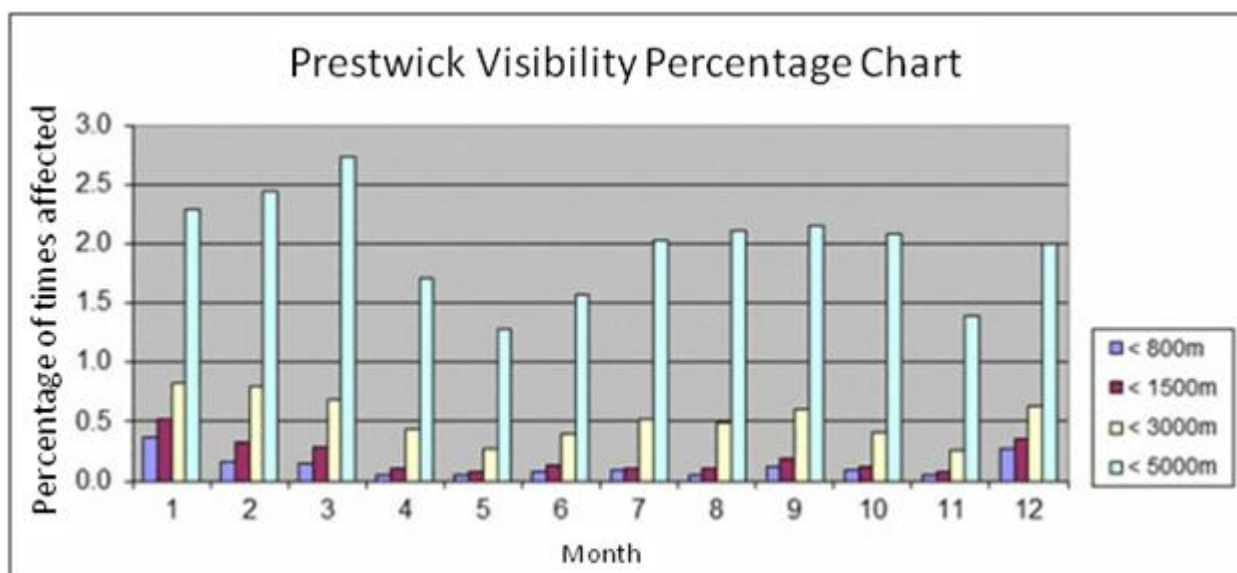


Table 8 Visibility Table for Prestwick Airport (Light Blue is 5km Indicator)

26. This Met Office table shows us that the visibility is below 5km for an average of 2% of the time. This suggests that the lights will be at **2000cd for 2% of the time and 200cd for 98% of the time.**



27. Whilst Prestwick is not Craiginmoddie, met visibility improves with height since the concentration of particles (dust, haze) and liquid droplets (water, aerosols) reduces with height and the air also becomes thinner. It could be argued that the Craiginmoddie visibility would be better than that at Prestwick and the lights would spend even more time at 200cd as opposed to 2000cd.

### Obstruction Light: Weather (Cloud) Obscuration.

28. On occasion, the visibility in the area of Craiginmoddie will drop significantly due to the presence of cloud on the hills. If the Craiginmoddie turbines are in cloud, then the obstruction lights will not be seen. In a similar vein, if the turbines are partially shrouded in cloud, then the light intensity will be much reduced.

29. The average height at the base of the Craiginmoddie turbines is around 900-1100ft above mean sea level (amsl). The hub heights will be around 1300-1500ft amsl. (Note: the obstruction lights are turbine hub mounted and all the turbines are sited on similar height terrain).

30. It is now possible to compare these two heights: **turbine base average 1000ft amsl** and **turbine hub average 1400ft amsl** with the actual cloud bases recorded by the Met Office at Prestwick airport, again, over a 30-year period, shown at Table 9.

31. The light blue columns (400-500ft) indicate that, on around 80 occasions a month, the cloud-base will be well below the turbine base heights (1000ft). The lights will be completely obscured and not be seen.

32. The burgundy columns (600-1000ft) indicate that the cloud base will range from approximately 400ft to 800ft below turbine hub height on around 500 occasions a month. Again, the hub mounted lights will be obscured, even when the cloud base is towards the upper level (1000ft amsl) but still 400ft below the hub mounted light.

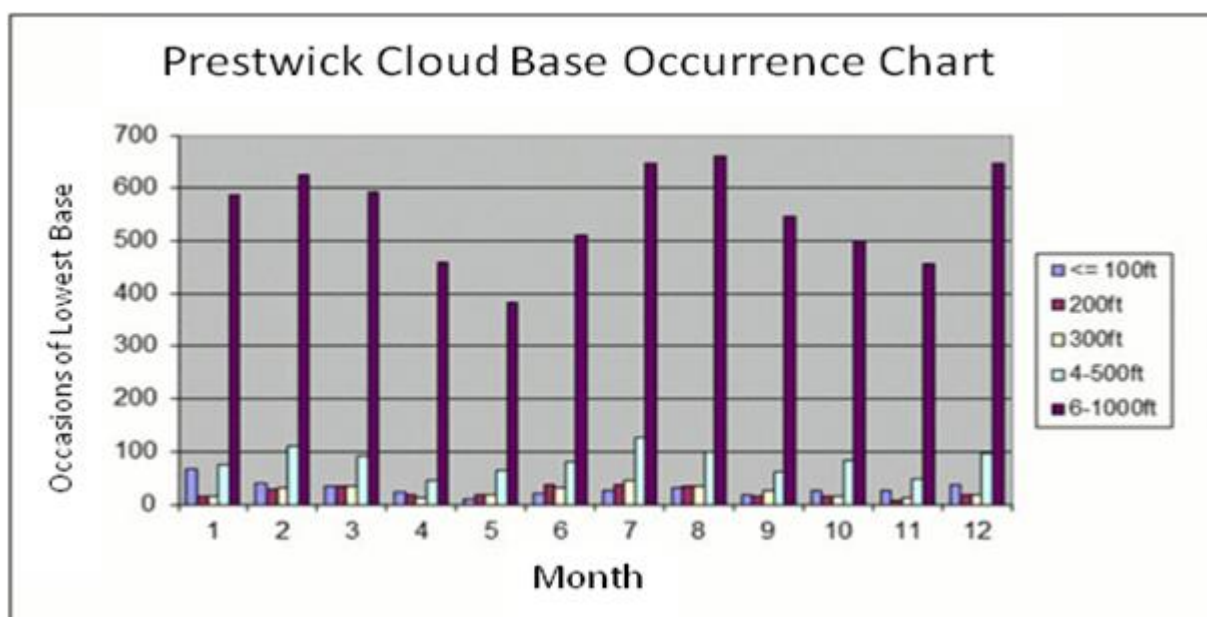


Table 9 Cloud Base Table for Prestwick Airport

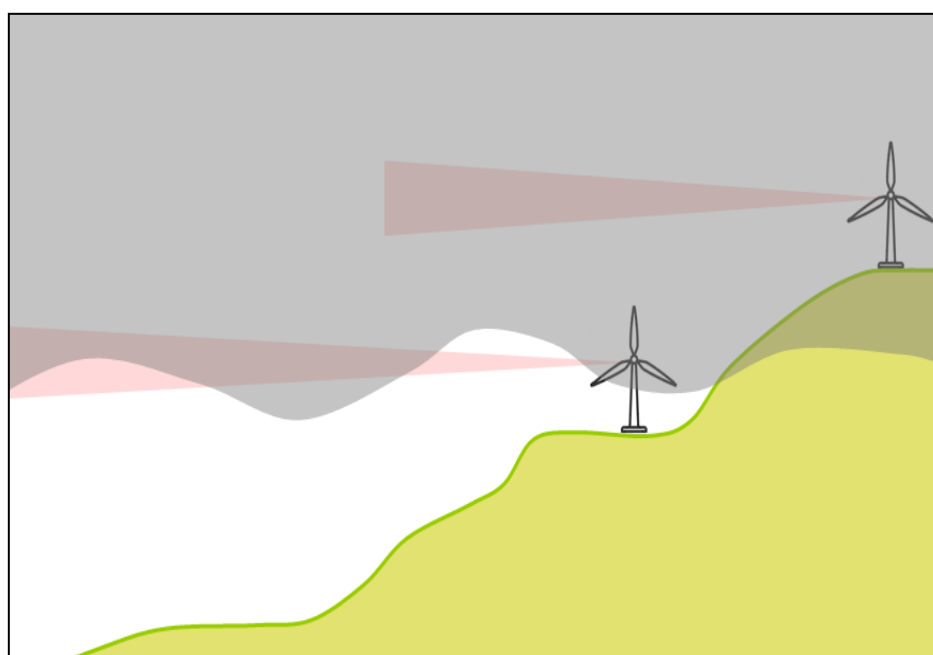


Figure 9 Turbine Visible Light Obscuration by Cloud – Full and Partial

33. Whilst Prestwick is not Craiginmoddie, Met Office statistics show that cloud-bases reduce in the region of hills. It could be argued that at Craiginmoddie the cloud-base would, on the whole, be lower than at Prestwick thus providing even greater degree of light obscuration on more occasions per month.

### Weather Obscuration Conclusion

34. It is most important not to try and combine the two different observations, visibility and cloud-base, into a single statement. Informal advice direct from Met Office and Airport forecasters indicate that the information so gathered, should be presented as follows:

*Meteorological observations suggest that the turbine hubs will be obscured on several hundred occasions a month by cloud. (Obstruction lights not visible by the public)*

*When not obscured by cloud, the visibility in the area of the turbines can be expected to exceed 5km for up to 98% of the time. (Obstruction lights switched down to 200cd)*

### Conclusion/Notes

35. The Craiginmoddie site does not benefit appreciably from the dispensations available in the latest CAA CAP 764 and MOD Obstruction Lighting Guidance to reduce the number of obstruction lights required at the turbine site. However, the CAA has agreed to remove the visible ANO mid mast lighting requirement.

Accordingly, the 14-turbine site requires 8 visible-red and 12 infra-red hub mounted obstruction lights.

In addition, the site is in an area where it will positively benefit from weather obscuration of its visible ANO lighting. This obscuration benefit is potentially quite significant.

The lights will be regularly obscured by cloud and when not obscured set at 200cd for 98% of the time.

### Technical Mitigation

36. One other form of potential mitigation commonly discussed is the installation of an Aircraft Detection Lighting System (ADLS). There are two possible methods of detecting an aircraft approaching a wind farm that will automatically turn on the aviation obstruction lights, firstly through the use of a suitable primary surveillance radar (PSR) or secondly, the use of aircraft installed Electronic Conspicuity (EC) equipment with a suitable receiver at the wind farm. There are some significant technical and regulatory issues to be overcome before any such system can be installed and operated in the UK.

37. In the case of PSR, this is already in use at wind farms in Europe; as an example the Terma Scanter 5002 radar is installed at a number of sites as shown in Figure 10. The main regulatory constraint is that although such systems are in use in Europe, in the UK, where airspace tends to be shared between users, the CAA have yet to mandate the performance parameters that such a system must be capable of fulfilling. For example, the coverage requirement will need to be defined in terms of maximum range of detection and activation (which may vary depending upon the speed of the aircraft), base of cover (above ground level) and almost certainly a maximum height coverage to avoid unnecessary activations, which a PSR on its own cannot ascertain. An initial set of draft requirements was promulgated in 2018 but these were for discussion with aviation stakeholders and it cannot be assumed that these are going to be the final criteria. Even if the standards are defined, it may be that any single radar will not be capable of delivering the required coverage where a wind farm is located on a hill and aircraft may approach below the wind farm from any direction. It may then become necessary to install multiple radars in order to achieve the required coverage at low level. This in itself may lead to limitations due to mutual interference in what is already a crowded part of the electromagnetic spectrum, (although the Terma radar does have some anti-interference capabilities) but the additional radars may affect other systems working in the same frequency band. There would also be additional planning issues to consider, such as the visual impact of additional aeries, and rotating arrays. Technical constraints also mean that it will be necessary to position the radars some distance outside the windfarm as shown in the example below in order to avoid turbines screening the radar and to provide the required height coverage.



Figure 10 Terma 5002 Radar at a Wind Farm in Germany

38. The one major advantage of PSR is that it will detect any aircraft, both those transponding and those that are not, known as non-co-operative targets. Depending upon how the regulatory process

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moves forwards, this may have a major effect on which systems to use for ADLS. In response to a recent planning inquiry paper the CAA responded stating in a letter dated 21 April 2021: *For the UK, there are some challenges to be resolved. The cost/benefit of the use of primary surveillance radar for the active detection of aircraft, spectrum availability, incentive pricing cost and geographical separation required before frequencies can be re-used potentially makes this a less than optimal solution.*

39. The alternate system is one based upon a reliance on aircraft carried Electronic Conspicuity (EC) transponders. Currently light aircraft flying clear of regulated airspace in the UK below 10,000ft are not required to carry a transponder (one example being Secondary Surveillance Radar or SSR). Most aircraft do, but not all. The CAA has been encouraging fitment by all aircraft and hope to have a regulatory system in place within the next few years requiring all flying machines to be fitted. Unfortunately this is not a simple process. This issue has been running for at least 20 years so far, however some limited progress is now being made. In the same response to a recent planning inquiry paper the CAA stated: *'At the same time, the lack of interoperability between the wide variety of electronic conspicuity devices currently available may require careful consideration of the specification of any passive system receivers and how they are deemed compliant to be deployed and operated.'* The letter goes on to state: *'We concur that not every situation may require ADLS to be fitted and operated; Article 222 or 223 requirements of the Air Navigation Order will remain, and the CAA may agree a specific solution under Section 7 of Article 222 and Section 11 of Article 223. However, ADLS could potentially provide an acceptable means of compliance that could provide greater certainty for developers when developing planning proposals on CAA acceptance and assist with discussions with communities during planning consultation.'* What this letter is saying is that ADLS using EC is technically feasible but that until the regulatory actions concerning the mandatory carriage of a compatible EC system have been completed and signed into law, and the coverage requirements agreed, nothing can be done unless a planning condition to require the retrospective installation of a system is considered appropriate. The length of time that this is likely to take is difficult to estimate, however, realistically it is likely to be within a two to five year timeframe as it is a small part of a much wider airspace modernisation programme currently under way. Additionally, the CAA also issued a Guidance Notice dated 26/10/21 entitled: *'Electronic continuity specifications: enabling interoperability between airspace users'*. This announced the establishment of a task force to jointly develop electronic conspicuity specifications to enable interoperability between airspace users. It goes on to state: *'The adoption of EC specifications will not be mandated UK wide. Users of other systems can continue to benefit from the functionality that those products offer'*. This does not mean that an EC triggered ADLS system will not be feasible, but the regulatory challenges mentioned above may take longer to resolve.

40. What is clear is that once the carriage of compatible transponders is mandated and all aircraft fitted with them, this is likely to be a realistic way of triggering an ADLS system. Such systems are passive at the wind farm and will not, therefore cause any interference. As shown in Figure 11 they require unobtrusive small aerials, approximately 1.2 metres long that are very reliable and relatively inexpensive to install and operate.



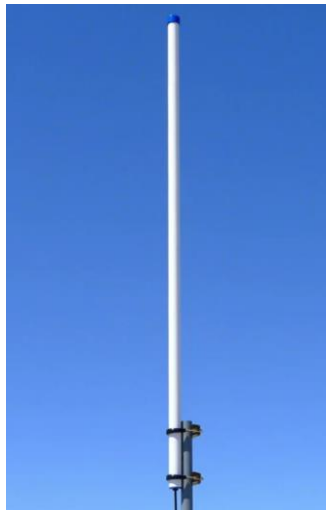


Figure 11 ADSB/SSR Passive Aerial

41. Bearing the above in mind, it would be prudent to ensure that any lighting installed on the turbines is compatible with any future EC triggered ADSL system, so that when the regulatory process and aircraft equipage has been completed, it will be a relatively cheap and simple exercise to retro-fit such a system. Alternately, the ADSB/SSR aerials and system could be installed when the wind farm is constructed, ready for activation when required. It may therefore be suitable for use as the basis of a planning condition requiring the activation of the system once the regulatory and equipage hurdles have been overcome.

42. An ADSL system may not be suitable for every location, depending upon the nature of aviation operations at night in the area around the wind farm and the activation criteria that are finally mandated by the CAA. If located close to the approach for a major airport for example, the lights might be required to be turning on and off continuously, however, in a location like Craiginmoddie, with limited night low level civilian traffic, the lights will rarely be activated. The EC activated ADLS system will be able to differentiate between civil traffic and SAR/HEMS/military traffic using NVD and not therefore activate when these types of aviation operations are taking place within the activation zone for the system. The infra-red lights that these types of operations rely on will always be on at night, but of course are invisible to the naked eye and will have no effect on the visual impact of the development.

## Comment

43. In recent months various briefing documents have been in circulation suggesting that visible obstruction lights are not required in the current aviation environment. The CAA have briefed WPAC that they do not support this position and would consider prosecuting organisations that do not follow the existing guidance and regulations. However, change will come; this will be led by the CAA and be centred on the new draft CAP 764 (as adhered to in this report) and the future development of ADLS.

44. From the direct experience of WPAC staff who have over 40 years of day/night low flying over land and sea both with and without NVG/Ds, the inclusion of adequate visible red lighting is important to cater for both routine operations and the inevitable unplanned outcome. Pilots uncertain of their

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location together with emergency situations and system failures of critical night low flying equipment are circumstances that require a degree of visible obstruction lighting on large wind turbines.

45. In addition, future green energy aircraft (hydrogen/electric and battery powered) will fly considerably lower and slower than current aircraft and will be significantly limited in track variation by much shorter ranges. Good visible obstruction lighting will become more, not less important in this low direct flight environment.

46. Finally, an aircraft colliding with a wind turbine is thankfully an extremely rare event but one with enormous potential consequences. A standard risk assessment as part of an aviation safety case would conclude that even a very low probability of a significant dangerous event is still unacceptable and must be mitigated, in this case by the fitting of visible obstruction lights.

## Conclusion

47. This report has assessed the requirements for both visible, CAA approved aviation lighting and MOD approved Infra-Red lighting for the Craiginmoddie Wind Farm. The resulting layout is set out in Figure 8 and makes use of both CAA/ANO Red lights and MOD IR lights. The proposed layouts were sent to the CAA and MOD DIO for approval and the CAA response approving the proposed layout is included at Appendix C.

48. The report also reports the brilliance of lights that will be visible taking into account the elevation angle between the turbine obstruction light and the viewpoints and the distance between each turbine and each viewpoint. The report shows that for up to 98% of the time, the lights will only be required to operate at 10% luminous intensity which will significantly reduce obstruction light effects in the area. Further interpretation of these results can be undertaken by a Landscape and Visual Impact Assessment expert.

49. The report then identifies additional mitigation options that, should the regulatory process allow, enable the visible medium intensity turbine lights to be switched off for the vast majority of the time and activated only on those rare occasions in this location when an aircraft activates the system. A suitably worded planning condition may enable the future lighting effects to be mitigated to the extent of becoming almost non-existent.

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## Authors

**Cdr John Taylor RN (Ret)** – after a career in the Royal Navy specialising in Air Traffic Control (ATC), Airspace Management and Air Defence which culminated in leading both the ATC and Fighter Control Specialisations, John worked for Lockheed Martin UK for three years as a Principal Consultant and Business Area Manager responsible for Air Traffic Management Consultancy, including the provision of advice to wind farm developers. In 2008 he founded WPAC Ltd and since then he and his team have provided aviation advice in relation to over 2000 wind farm and wind turbine sites, given evidence at a number of planning inquiries and enabled many sites to overcome aviation objections where it was feasible to do so. He and his team have also provided advice to a number of Local Planning Authorities, Renewable UK and the Aviation Fund Management Board, including organising workshops and the provision of guidance documents. John also advises planners and developers in relation to physical and technical safeguarding of non-wind farm developments in the vicinity of aviation facilities.

**Sqn Ldr Mike Hale RAF (Rtd)** has over 45 years, piloting, instructing and examining experience on numerous military fast jet aircraft through to a range of civilian and military general aviation training aircraft and gliders. He has held many posts including Flying Instructor, Training Officer, Flight Commander, Squadron Commander and Principal Tornado AD Force Examiner. He has amassed over 10,000 flying hours of experience when operating at many locations around the world. In parallel to his flying duties, Mike held the post of Officer Commanding the MOD Low Flying Operations Squadron (OC LFOS). In this post he was both Low Level Airspace Manager for the MOD & Wind-Farm Subject Matter Expert for the Defence Infrastructure Organization (DIO). During that period, he assessed over 14,000 wind-farm pre-applications and 2000 full applications against low flying, weapons range, specialist airspace, local community and aerodrome safeguarding criteria. Mike also instigated two Qinetiq ground based Infra Red obstruction lighting trials. These were followed by instigating and managing the MOD Infra Red/Low Intensity (Henlow) flight trials and the CAA/MOD/Trinity-House/RUK off-shore IR/Morse (North Hoyle) flight trials. In conjunction, Mike organised numerous and various supporting trials including night vision equipment compatibility and detailed lighting beam overspill analysis (where light is emitted outside the required specification envelope). In 2012, he was awarded an MBE for generating a proactive and mutually successful working relationship between the Wind Power Industry and the MOD Air Staff.



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# Wind Power Aviation Consultants Ltd

Wind Farm Aviation Lighting and Mitigation Report for Craiginmoddie Wind Farm Version 3

Our Ref: WPAC/047/21 V3

Date: 03/03/23

## Appendix A Aviation Lighting Results Tables

| Turbine | Distance (km) | Elevation Angle | Candela | Candela at 10% | Microlumens per square metre (lux <sup>10-6</sup> ) | Microlumens per square metre (lux <sup>10-6</sup> ) at 10% | Obscured |
|---------|---------------|-----------------|---------|----------------|-----------------------------------------------------|------------------------------------------------------------|----------|
| 1       | 3.893         | -3.8            | 180.8   | 18.1           | 11.9                                                | 1.2                                                        | X        |
| 3       | 4.125         | -4.3            | 151.7   | 15.2           | 8.9                                                 | 0.9                                                        | X        |
| 5       | 4.413         | -3.9            | 176.2   | 17.6           | 9.0                                                 | 0.9                                                        |          |
| 7       | 4.067         | -4.1            | 165.1   | 16.5           | 10.0                                                | 1.0                                                        | X        |
| 8       | 3.599         | -4.7            | 125.0   | 12.5           | 9.7                                                 | 1.0                                                        | M        |
| 10      | 3.382         | -5.1            | 75.0    | 7.5            | 6.6                                                 | 0.7                                                        |          |
| 12      | 3.083         | -5.4            | 75.0    | 7.5            | 7.9                                                 | 0.8                                                        | X        |
| 13      | 3.51          | -4.2            | 158.4   | 15.8           | 12.9                                                | 1.3                                                        | X        |

Viewpoint 1 South Balloch

| Turbine | Distance (km) | Elevation Angle | Candela | Candela at 10% | Microlumens per square metre (lux <sup>10-6</sup> ) | Microlumens per square metre (lux <sup>10-6</sup> ) at 10% | Obscured |
|---------|---------------|-----------------|---------|----------------|-----------------------------------------------------|------------------------------------------------------------|----------|
| 1       | 3.591         | -2.5            | 291.3   | 29.1           | 22.6                                                | 2.3                                                        |          |
| 3       | 4.385         | -1.9            | 448.4   | 44.8           | 23.3                                                | 2.3                                                        |          |
| 5       | 4.947         | -1.4            | 690.6   | 69.1           | 28.2                                                | 2.8                                                        |          |
| 7       | 5.908         | -1.3            | 756.5   | 75.7           | 21.7                                                | 2.2                                                        |          |
| 8       | 5.79          | -1.3            | 756.5   | 75.7           | 22.6                                                | 2.3                                                        |          |
| 10      | 4.896         | -1.4            | 690.6   | 69.1           | 28.8                                                | 2.9                                                        |          |
| 12      | 4.172         | -1.9            | 448.4   | 44.8           | 25.8                                                | 2.6                                                        |          |
| 13      | 3.695         | -2.1            | 384.9   | 38.5           | 28.2                                                | 2.8                                                        |          |

Viewpoint 2 Hadyard Hill

| Turbine | Distance (km) | Elevation Angle | Candela | Candela at 10% | Microlumens per square metre (lux <sup>10-6</sup> ) | Microlumens per square metre (lux <sup>10-6</sup> ) at 10% | Obscured |
|---------|---------------|-----------------|---------|----------------|-----------------------------------------------------|------------------------------------------------------------|----------|
| 1       | 4.412         | -5.6            | 75.0    | 7.5            | 3.9                                                 | 0.4                                                        |          |
| 3       | 4.791         | -5.0            | 105.0   | 10.5           | 4.6                                                 | 0.5                                                        |          |
| 5       | 5.141         | -4.4            | 145.0   | 14.5           | 5.5                                                 | 0.5                                                        |          |
| 7       | 6.152         | -3.8            | 180.8   | 18.1           | 4.8                                                 | 0.5                                                        |          |
| 8       | 6.188         | -3.7            | 185.3   | 18.5           | 4.8                                                 | 0.5                                                        |          |
| 10      | 5.489         | -4.1            | 165.1   | 16.5           | 5.5                                                 | 0.5                                                        |          |
| 12      | 5.172         | -3.9            | 176.2   | 17.6           | 6.6                                                 | 0.7                                                        | X        |
| 13      | 4.718         | -4.4            | 145.0   | 14.5           | 6.5                                                 | 0.7                                                        | X        |

Viewpoint 3 Dailly



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| Turbine | Distance (km) | Elevation Angle | Candela | Candela at 10% | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) at 10% | Obscured |
|---------|---------------|-----------------|---------|----------------|----------------------------------------------------------------|-----------------------------------------------------------------------|----------|
| 1       | 5.465         | -4.5            | 138.4   | 13.8           | 4.6                                                            | 0.5                                                                   | X        |
| 3       | 4.88          | -4.7            | 125.0   | 12.5           | 5.2                                                            | 0.5                                                                   | X        |
| 5       | 4.619         | -4.4            | 145.0   | 14.5           | 6.8                                                            | 0.7                                                                   | X        |
| 7       | 5.289         | -3.9            | 176.2   | 17.6           | 6.3                                                            | 0.6                                                                   | X        |
| 8       | 5.638         | -3.2            | 207.8   | 20.8           | 6.5                                                            | 0.7                                                                   | X        |
| 10      | 5.612         | -2.7            | 256.4   | 25.6           | 8.1                                                            | 0.8                                                                   | X        |
| 12      | 6.21          | -3.1            | 212.3   | 21.2           | 5.5                                                            | 0.6                                                                   | X        |
| 13      | 5.983         | -3.6            | 189.8   | 19.0           | 5.3                                                            | 0.5                                                                   | X        |

Viewpoint 4 B741 near Ruglen

| Turbine | Distance (km) | Elevation Angle | Candela | Candela at 10% | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) at 10% | Obscured |
|---------|---------------|-----------------|---------|----------------|----------------------------------------------------------------|-----------------------------------------------------------------------|----------|
| 1       | 5.06          | -4.0            | 171.7   | 17.2           | 6.7                                                            | 0.7                                                                   |          |
| 3       | 6.162         | -3.2            | 207.8   | 20.8           | 5.5                                                            | 0.5                                                                   |          |
| 5       | 6.855         | -2.4            | 309.1   | 30.9           | 6.6                                                            | 0.7                                                                   | X        |
| 7       | 7.339         | -2.5            | 291.3   | 29.1           | 5.4                                                            | 0.5                                                                   | M        |
| 8       | 6.936         | -2.6            | 273.5   | 27.4           | 5.7                                                            | 0.6                                                                   | M        |
| 10      | 6.014         | -3.0            | 216.8   | 21.7           | 6.0                                                            | 0.6                                                                   |          |
| 12      | 4.777         | -4.0            | 171.7   | 17.2           | 7.5                                                            | 0.8                                                                   |          |
| 13      | 4.624         | -4.1            | 165.1   | 16.5           | 7.7                                                            | 0.8                                                                   |          |

Viewpoint 5 Barr

| Turbine | Distance (km) | Elevation Angle | Candela | Candela at 10% | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) at 10% | Obscured |
|---------|---------------|-----------------|---------|----------------|----------------------------------------------------------------|-----------------------------------------------------------------------|----------|
| 1       | 8.382         | -2.9            | 228.1   | 22.8           | 3.2                                                            | 0.3                                                                   |          |
| 3       | 7.451         | -3.2            | 207.8   | 20.8           | 3.7                                                            | 0.4                                                                   |          |
| 5       | 6.9           | -3.3            | 203.3   | 20.3           | 4.3                                                            | 0.4                                                                   |          |
| 7       | 7.06          | -3.2            | 207.8   | 20.8           | 4.2                                                            | 0.4                                                                   |          |
| 8       | 7.531         | -3.0            | 216.8   | 21.7           | 3.8                                                            | 0.4                                                                   |          |
| 10      | 7.975         | -2.3            | 332.9   | 33.3           | 5.2                                                            | 0.5                                                                   | X        |
| 12      | 8.957         | -2.5            | 291.3   | 29.1           | 3.6                                                            | 0.4                                                                   | X        |
| 13      | 8.891         | -2.6            | 273.5   | 27.4           | 3.5                                                            | 0.3                                                                   | X        |

Viewpoint 6 Crosshill





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| Turbine | Distance (km) | Elevation Angle | Candela | Candela at 10% | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) at 10% | Obscured |
|---------|---------------|-----------------|---------|----------------|----------------------------------------------------------------|-----------------------------------------------------------------------|----------|
| 1       | 10.123        | -0.9            | 1087.1  | 108.7          | 10.6                                                           | 1.1                                                                   |          |
| 3       | 9.01          | -0.9            | 1087.1  | 108.7          | 13.4                                                           | 1.3                                                                   |          |
| 5       | 8.318         | -0.8            | 1192.2  | 119.2          | 17.2                                                           | 1.7                                                                   |          |
| 7       | 7.611         | -1.0            | 982.0   | 98.2           | 17.0                                                           | 1.7                                                                   |          |
| 8       | 7.977         | -0.6            | 1442.9  | 144.3          | 22.7                                                           | 2.3                                                                   | X        |
| 10      | 8.94          | -0.4            | 1721.2  | 172.1          | 21.5                                                           | 2.2                                                                   | X        |
| 12      | 10.172        | -0.4            | 1721.2  | 172.1          | 16.6                                                           | 1.7                                                                   | X        |
| 13      | 10.429        | -0.8            | 1192.2  | 119.2          | 11.0                                                           | 1.1                                                                   |          |

Viewpoint 7 Colonel Hunter Blair Monument, Kildoach Hill

| Turbine | Distance (km) | Elevation Angle | Candela | Candela at 10% | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) at 10% | Obscured |
|---------|---------------|-----------------|---------|----------------|----------------------------------------------------------------|-----------------------------------------------------------------------|----------|
| 1       | 8.241         | -2.2            | 356.7   | 35.7           | 5.3                                                            | 0.5                                                                   |          |
| 3       | 8.45          | -2.1            | 384.9   | 38.5           | 5.4                                                            | 0.5                                                                   |          |
| 5       | 8.652         | -1.9            | 448.4   | 44.8           | 6.0                                                            | 0.6                                                                   |          |
| 7       | 9.627         | -1.7            | 529.8   | 53.0           | 5.7                                                            | 0.6                                                                   |          |
| 8       | 9.762         | -1.7            | 529.8   | 53.0           | 5.6                                                            | 0.6                                                                   |          |
| 10      | 9.2           | -1.7            | 529.8   | 53.0           | 6.3                                                            | 0.6                                                                   |          |
| 12      | 9.024         | -1.9            | 448.4   | 44.8           | 5.5                                                            | 0.6                                                                   |          |
| 13      | 8.58          | -2.0            | 413.2   | 41.3           | 5.6                                                            | 0.6                                                                   |          |

Viewpoint 8 North Threave

| Turbine | Distance (km) | Elevation Angle | Candela | Candela at 10% | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) at 10% | Obscured |
|---------|---------------|-----------------|---------|----------------|----------------------------------------------------------------|-----------------------------------------------------------------------|----------|
| 1       | 10.84         | -0.2            | 1981.9  | 198.2          | 16.9                                                           | 1.7                                                                   | M        |
| 3       | 10.41         | -0.1            | 2083.6  | 208.4          | 19.2                                                           | 1.9                                                                   | M        |
| 5       | 10.196        | 0.0             | 2185.2  | 218.5          | 21.0                                                           | 2.1                                                                   | M        |
| 7       | 9.25          | 0.0             | 2185.2  | 218.5          | 25.5                                                           | 2.6                                                                   | M        |
| 8       | 9.08          | 0.0             | 2185.2  | 218.5          | 26.5                                                           | 2.7                                                                   | M        |
| 10      | 9.691         | 0.0             | 2185.2  | 218.5          | 23.3                                                           | 2.3                                                                   | M        |
| 12      | 10.187        | -0.1            | 2083.6  | 208.4          | 20.1                                                           | 2.0                                                                   | M        |
| 13      | 10.666        | -0.1            | 2083.6  | 208.4          | 18.3                                                           | 1.8                                                                   | M        |

Viewpoint 9 Cornish Hill



# Wind Power Aviation Consultants Ltd

Wind Farm Aviation Lighting and Mitigation Report for Craiginmoddie Wind Farm Version 3

Our Ref: WPAC/047/21 V3

Date: 03/03/23

| Turbine | Distance (km) | Elevation Angle | Candela | Candela at 10% | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) at 10% | Obscured |
|---------|---------------|-----------------|---------|----------------|----------------------------------------------------------------|-----------------------------------------------------------------------|----------|
| 1       | 9.32          | -2.1            | 384.9   | 38.5           | 4.4                                                            | 0.4                                                                   | X        |
| 3       | 10.443        | -1.7            | 529.8   | 53.0           | 4.9                                                            | 0.5                                                                   | X        |
| 5       | 11.144        | -1.5            | 633.3   | 63.3           | 5.1                                                            | 0.5                                                                   | X        |
| 7       | 11.677        | -1.7            | 529.8   | 53.0           | 3.9                                                            | 0.4                                                                   |          |
| 8       | 11.281        | -1.8            | 483.7   | 48.4           | 3.8                                                            | 0.4                                                                   |          |
| 10      | 10.348        | -1.9            | 448.4   | 44.8           | 4.2                                                            | 0.4                                                                   |          |
| 12      | 9.109         | -2.2            | 356.7   | 35.7           | 4.3                                                            | 0.4                                                                   |          |
| 13      | 8.92          | -2.2            | 356.7   | 35.7           | 4.5                                                            | 0.4                                                                   | X        |

Viewpoint 10 B734 near Cairnwhin

| Turbine | Distance (km) | Elevation Angle | Candela | Candela at 10% | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) at 10% | Obscured |
|---------|---------------|-----------------|---------|----------------|----------------------------------------------------------------|-----------------------------------------------------------------------|----------|
| 1       | 10.856        | -2.0            | 413.2   | 41.3           | 3.5                                                            | 0.4                                                                   |          |
| 3       | 10.236        | -2.1            | 384.9   | 38.5           | 3.7                                                            | 0.4                                                                   |          |
| 5       | 9.894         | -2.0            | 413.2   | 41.3           | 4.2                                                            | 0.4                                                                   |          |
| 7       | 10.399        | -2.0            | 413.2   | 41.3           | 3.8                                                            | 0.4                                                                   |          |
| 8       | 10.81         | -1.9            | 448.4   | 44.8           | 3.8                                                            | 0.4                                                                   |          |
| 10      | 10.935        | -1.8            | 483.7   | 48.4           | 4.0                                                            | 0.4                                                                   |          |
| 12      | 11.6          | -1.8            | 483.7   | 48.4           | 3.6                                                            | 0.4                                                                   | M        |
| 13      | 11.374        | -1.8            | 483.7   | 48.4           | 3.7                                                            | 0.4                                                                   | X        |

Viewpoint 11 Maybole War Memorial

| Turbine | Distance (km) | Elevation Angle | Candela | Candela at 10% | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) at 10% | Obscured |
|---------|---------------|-----------------|---------|----------------|----------------------------------------------------------------|-----------------------------------------------------------------------|----------|
| 1       | 12.636        | 1.3             | 2393.4  | 239.3          | 15.0                                                           | 1.5                                                                   |          |
| 3       | 12.488        | 1.3             | 2393.4  | 239.3          | 15.3                                                           | 1.5                                                                   |          |
| 5       | 12.447        | 1.4             | 2347.5  | 234.8          | 15.2                                                           | 1.5                                                                   |          |
| 7       | 11.619        | 1.5             | 2276.4  | 227.6          | 16.9                                                           | 1.7                                                                   |          |
| 8       | 11.338        | 1.6             | 2205.4  | 220.5          | 17.2                                                           | 1.7                                                                   |          |
| 10      | 11.713        | 1.5             | 2276.4  | 227.6          | 16.6                                                           | 1.7                                                                   |          |
| 12      | 11.875        | 1.4             | 2347.5  | 234.8          | 16.6                                                           | 1.7                                                                   |          |
| 13      | 12.337        | 1.4             | 2347.5  | 234.8          | 15.4                                                           | 1.5                                                                   |          |

Viewpoint 12 Shalloch on Minnoch



# Wind Power Aviation Consultants Ltd

Wind Farm Aviation Lighting and Mitigation Report for Craiginmoddie Wind Farm Version 3

Our Ref: WPAC/047/21 V3

Date: 03/03/23

| Turbine | Distance (km) | Elevation Angle | Candela | Candela at 10% | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) at 10% | Obscured |
|---------|---------------|-----------------|---------|----------------|----------------------------------------------------------------|-----------------------------------------------------------------------|----------|
| 1       | 11.295        | -2.3            | 332.9   | 33.3           | 2.6                                                            | 0.3                                                                   | X        |
| 3       | 12.149        | -1.9            | 448.4   | 44.8           | 3.0                                                            | 0.3                                                                   | X        |
| 5       | 12.704        | -1.7            | 529.8   | 53.0           | 3.3                                                            | 0.3                                                                   | X        |
| 7       | 13.672        | -1.3            | 756.5   | 75.7           | 4.0                                                            | 0.4                                                                   | X        |
| 8       | 13.547        | -1.2            | 822.4   | 82.2           | 4.5                                                            | 0.4                                                                   | X        |
| 10      | 12.627        | -1.4            | 690.6   | 69.1           | 4.3                                                            | 0.4                                                                   | X        |
| 12      | 11.751        | -2.1            | 384.9   | 38.5           | 2.8                                                            | 0.3                                                                   | X        |
| 13      | 11.295        | -2.3            | 332.9   | 33.3           | 2.6                                                            | 0.3                                                                   | X        |

Viewpoint 13 A77 north of Girvan

| Turbine | Distance (km) | Elevation Angle | Candela | Candela at 10% | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) at 10% | Obscured |
|---------|---------------|-----------------|---------|----------------|----------------------------------------------------------------|-----------------------------------------------------------------------|----------|
| 1       | 13.364        | -1.2            | 822.4   | 82.2           | 4.6                                                            | 0.5                                                                   |          |
| 3       | 14.407        | -1.1            | 902.2   | 90.2           | 4.3                                                            | 0.4                                                                   | M        |
| 5       | 15.064        | -0.9            | 1087.1  | 108.7          | 4.8                                                            | 0.5                                                                   | X        |
| 7       | 15.914        | -0.9            | 1087.1  | 108.7          | 4.3                                                            | 0.4                                                                   | M        |
| 8       | 15.667        | -0.9            | 1087.1  | 108.7          | 4.4                                                            | 0.4                                                                   | M        |
| 10      | 14.679        | -1.0            | 982.0   | 98.2           | 4.6                                                            | 0.5                                                                   | M        |
| 12      | 13.573        | -1.1            | 902.2   | 90.2           | 4.9                                                            | 0.5                                                                   |          |
| 13      | 13.191        | -1.1            | 902.2   | 90.2           | 5.2                                                            | 0.5                                                                   |          |

Viewpoint 14 Byne Hill

| Turbine | Distance (km) | Elevation Angle | Candela | Candela at 10% | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) | Microlumens per square metre (lux <sup>10<sup>-6</sup></sup> ) at 10% | Obscured |
|---------|---------------|-----------------|---------|----------------|----------------------------------------------------------------|-----------------------------------------------------------------------|----------|
| 1       | 17.838        | 1.1             | 2471.1  | 247.1          | 7.8                                                            | 0.8                                                                   |          |
| 3       | 17.84         | 1.1             | 2471.1  | 247.1          | 7.8                                                            | 0.8                                                                   |          |
| 5       | 17.878        | 1.2             | 2439.4  | 243.9          | 7.6                                                            | 0.8                                                                   |          |
| 7       | 17.11         | 1.2             | 2439.4  | 243.9          | 8.3                                                            | 0.8                                                                   |          |
| 8       | 16.792        | 1.3             | 2393.4  | 239.3          | 8.5                                                            | 0.8                                                                   |          |
| 10      | 17.057        | 1.3             | 2393.4  | 239.3          | 8.2                                                            | 0.8                                                                   |          |
| 12      | 17.041        | 1.2             | 2439.4  | 243.9          | 8.4                                                            | 0.8                                                                   |          |
| 13      | 17.478        | 1.2             | 2439.4  | 243.9          | 8.0                                                            | 0.8                                                                   |          |

Viewpoint 15 Merrick



## Wind Power Aviation Consultants Ltd

Wind Farm Aviation Lighting and Mitigation Report for Craiginmoddie Wind Farm Version 3

Our Ref: WPAC/047/21 V3

Date: 03/03/23

| Turbine | Distance<br>(km) | Elevation<br>Angle | Candela | Candela<br>at 10% | Microlumens per<br>square metre (lux <sup>10-6</sup> ) | Microlumens per<br>square metre (lux <sup>10-6</sup> )<br>at 10% | Obscured |
|---------|------------------|--------------------|---------|-------------------|--------------------------------------------------------|------------------------------------------------------------------|----------|
| 1       | 28.871           | 0.5                | 2452.1  | 245.2             | 2.9                                                    | 0.3                                                              | M        |
| 3       | 28.047           | 0.6                | 2475.5  | 247.6             | 3.1                                                    | 0.3                                                              | M        |
| 5       | 27.544           | 0.6                | 2475.5  | 247.6             | 3.3                                                    | 0.3                                                              | M        |
| 7       | 26.548           | 0.7                | 2495.1  | 249.5             | 3.5                                                    | 0.4                                                              | M        |
| 8       | 26.634           | 0.7                | 2495.1  | 249.5             | 3.5                                                    | 0.4                                                              | M        |
| 10      | 27.54            | 0.6                | 2475.5  | 247.6             | 3.3                                                    | 0.3                                                              | M        |
| 12      | 28.448           | 0.6                | 2475.5  | 247.6             | 3.1                                                    | 0.3                                                              | M        |
| 13      | 28.891           | 0.6                | 2475.5  | 247.6             | 3.0                                                    | 0.3                                                              | M        |

Viewpoint 16 Cairnsmore of Carsphairn



## Appendix B – Abbreviations and Definitions

|                           |                                                                                |
|---------------------------|--------------------------------------------------------------------------------|
| ADSB.....                 | Automatic Dependent Surveillance Broadcast                                     |
| AGL.....                  | Above Ground Level (Height)                                                    |
| ANO.....                  | Air Navigation Order                                                           |
| AMSL.....                 | Above Mean Sea Level (Elevation)                                               |
| ASG.....                  | Aviation Steering Group                                                        |
| CAA.....                  | Civil Aviation Authority                                                       |
| CAP.....                  | Civil Aviation Publication (Referrers to Specific Documents)                   |
| cd.....                   | Candela, a measure of light intensity                                          |
| DIO.....                  | Defence Infrastructure Organisation                                            |
| HNTA.....                 | Helicopter Night Training Area                                                 |
| In Flight Visibility..... | The distance a pilot can see ahead to fly & navigate the aircraft              |
| IR.....                   | Infra-Red                                                                      |
| Kts.....                  | Knots: a measure of airspeed (10 kts = 12mph = 19 kph)                         |
| LED.....                  | Light Emitting Diode                                                           |
| MOD.....                  | Ministry of Defence                                                            |
| mW/sr.....                | milliWatts per steradian: electromagnetic energy output related to solid angle |
| Nm.....                   | Nautical Mile                                                                  |
| NVD .....                 | Night Vision Devices - Aircraft Mounted                                        |
| NVG.....                  | Night Vision Goggles - Operator Worn                                           |
| Radar Altimeter.....      | An altimeter that uses radar to accurately measure height above ground         |
| QFE .....                 | Setting on Altimeter that gives Height above Airfield                          |
| RoAR.....                 | Rules of the Air Regulations                                                   |
| Rule 5.....               | The Low Flying Rule – part of RoAR                                             |
| Rule 28.....              | VFR Rules Outside Controlled Airspace – part of the RoAR                       |
| ReUK.....                 | Renewables UK – The UK Wind Industry Body                                      |
| SAR Box.....              | Night Training Area for Search and Rescue Helicopter Units                     |
| SSA.....                  | Sector Safety Altitude                                                         |
| SSR.....                  | Secondary Surveillance Radar                                                   |
| UKAB.....                 | United Kingdom Air Prox Board – Investigates Aircraft Near Misses              |
| VFR.....                  | Visual Flight Rules (Flight without ATC on a see-and-be-seen basis)            |
| VMC.....                  | Visual Meteorological Conditions (Weather suitable for VFR flight)             |



## Appendix C CAA Approval Letter

### Safety and Airspace Regulation Group Safety and Business Delivery



Mike Hale  
Aviation Consultant  
Wind Power Aviation Consultants Ltd.  
38 Hadrian Way  
Chilworth  
Southampton  
SO16 7HX

23 December 2022  
Ref Windfarms/Craiginmoddie

Dear Mike,

### Proposed Obstacle Lighting Scheme for Craiginmoddie Wind Farm

Reference: Craiginmoddie Wind Farm Updated Brief, e-mailed 6 December 2022

1. Thank you for the e-mail at reference. The attached report discusses the proposed obstacle lighting plan for the Craiginmoddie Wind Farm. This is a revision to my letter dated 21 December 2022, taking account of the further reduced lighting proposal contained within the brief above.
2. The proposed Craiginmoddie Wind Farm consists of 14 turbines, with tip heights in excess of 150m, which brings them within scope of the Air Navigation Order (ANO) Article 222 obstacle lighting requirements.
3. We have considered the report carefully and take note of the intent to address concerns relating to adverse visual impacts of aviation lighting on non-aviation receptors while ensuring that the lighting installed on the turbines meets air safety requirements.
4. We note the local terrain aspects and some mitigation provided by the provision of infra-red lighting for those operators who carry Night Vision Device capability.
5. Under provisions given in the Air Navigation Order (ANO) Article 222 section 6, the CAA provides for the following variation:
  - medium intensity steady red (2000 candela) lights on the nacelles of turbines T01, T03, T05, T07, T08, T10, T12 and T13;
  - a second 2000 candela light on the nacelles of the above turbines to act as alternates in the event of a failure of the main light;

#### Civil Aviation Authority

1W Aviation House Beehive Ring Road Crawley West Sussex RH6 0YR [www.caa.co.uk](http://www.caa.co.uk)  
Telephone 0330 138 3166 [andy.wells@caa.co.uk](mailto:andy.wells@caa.co.uk)



- the lights on these turbines to be capable of being dimmed to 10% of peak intensity when the lowest visibility as measured at suitable points around the wind farm by visibility measuring devices exceeds 5km;
- infra-red lights to MoD specification installed on the nacelles of turbines T01, T02, T03, T05, T06, T07, T08, T09, T10, T11, T12, and T13.

6. Intermediate level 32 candela lights are not required to be fitted on the turbine towers.
7. If the proposed design of the wind farm changes (other than variations due to micro-siting etc.) this is likely to require a revision to this aviation obstacle lighting variation.
8. Please let me know if you have any further queries.

Yours sincerely,



Andy Wells, Manager Rulemaking and Safety Publications

Continued (2 of 2 pages)