Wind Power Aviation Consultants Ltd

Wind Farm Aviation Lighting and Mitigation Report for Knockcronal Wind Farm

Our Reference: WPAC/046/21
Your Reference:
Email tasking E Bathgate (ITPE) of 15/08/21

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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

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.

Lighting Layout Starting Point and Assumptions

3. Statkraft has proposed the 9 turbine Knockcronal wind farm on the southern slops of Halfmark Rig approximately one kilometre to the north of Linfern Loch in Ayrshire. This location sits under

unregulated airspace which is designated Class G by the CAA and away from any civil or military airfields.

4. The proposed site is located in MOD Low Flying Area (LFA) 16 and Tactical Training Area (TTA) 20 by day. This converts to Night Allocated Region (NAR) 2B during the hours of darkness. Although primarily a fast jet training area, the airspace is also used by NATO tactical aircraft and helicopters day and night.

    - Accordingly, the site will be assessed as Class G 'en-route' insofar as obstruction lighting is concerned in accordance with the latest (still draft) CAA CAP 764.
    - To accommodate MOD requirements, the site will be assessed for NVG compatible lighting in accordance with MOD published obstruction lighting specifications.
    - Where possible, the recommended lighting configuration will be optimised to reduce light impact on the local area.
    - The Knockcronal wind turbine proposal is for 9 turbines at 180 to 200m to tip see Figure 1 below.

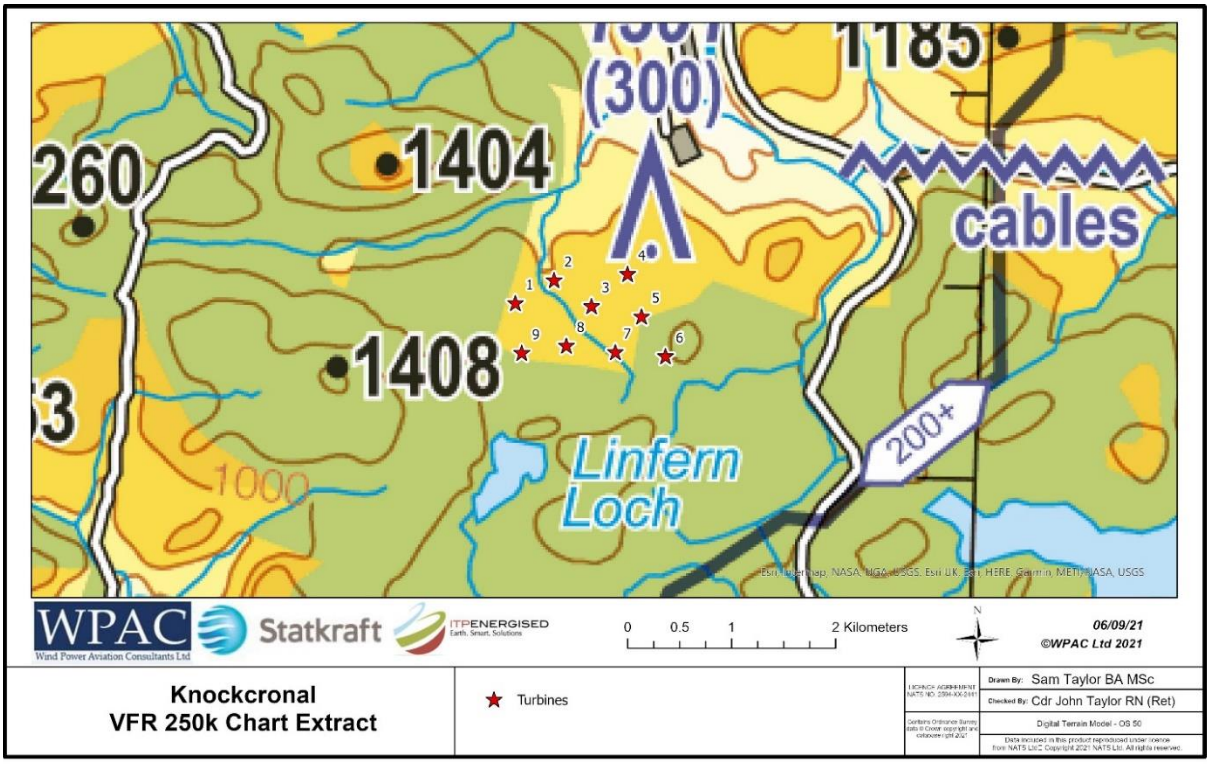

Figure 1 Knockcronal Layout on an aviation chart extract

CAA-ANO Red 2000/200cd Lighting

5. The CAA requires:

   - That all 'string-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, not all non-perimeter turbines require lights.

6. Applying these criteria dictates that all of the 'string perimeter' and close set turbines of the Knockcronal site will require ANO lighting; six turbine hub lights in total.

Turbines with 2000/200cd Lights: T1, T2, T4, T6, T7, and T9

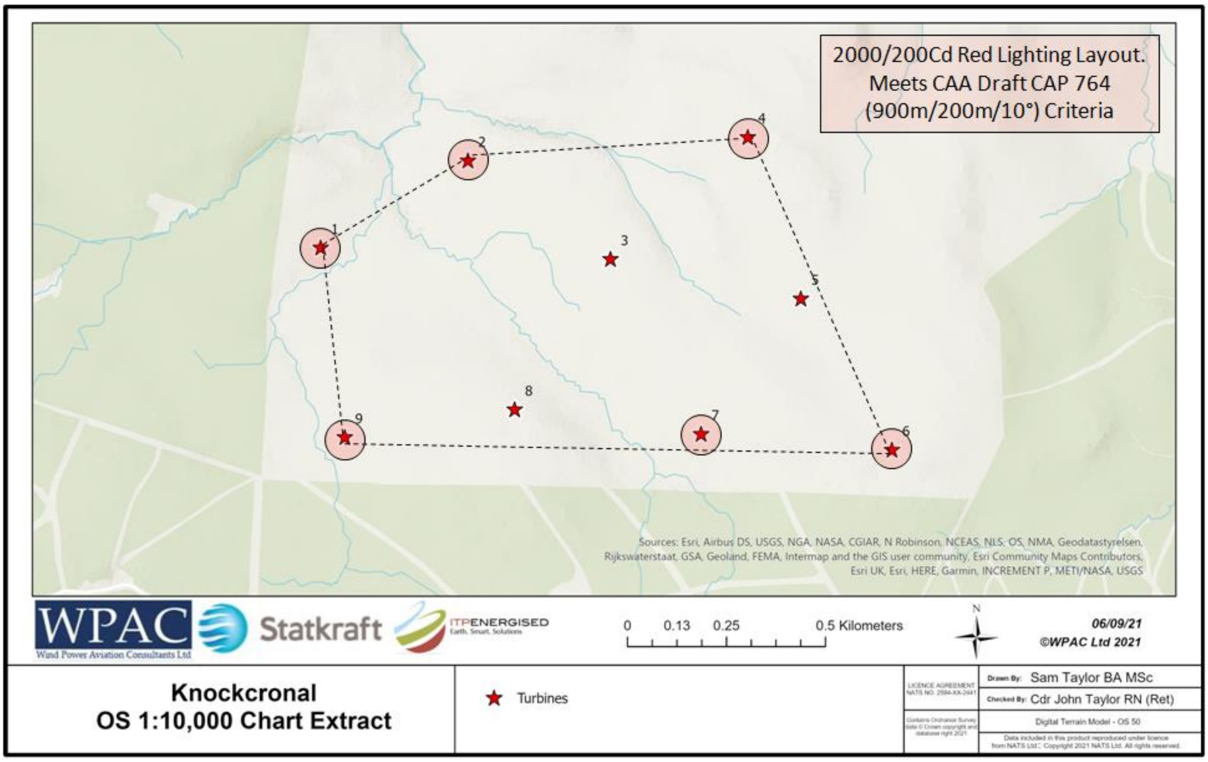

Figure 2 CAA-ANO CAP 764 Compliant Lighting Arrangement

MOD Low Flying & Lighting

7. 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.

8. 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 up the 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.

9. 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.

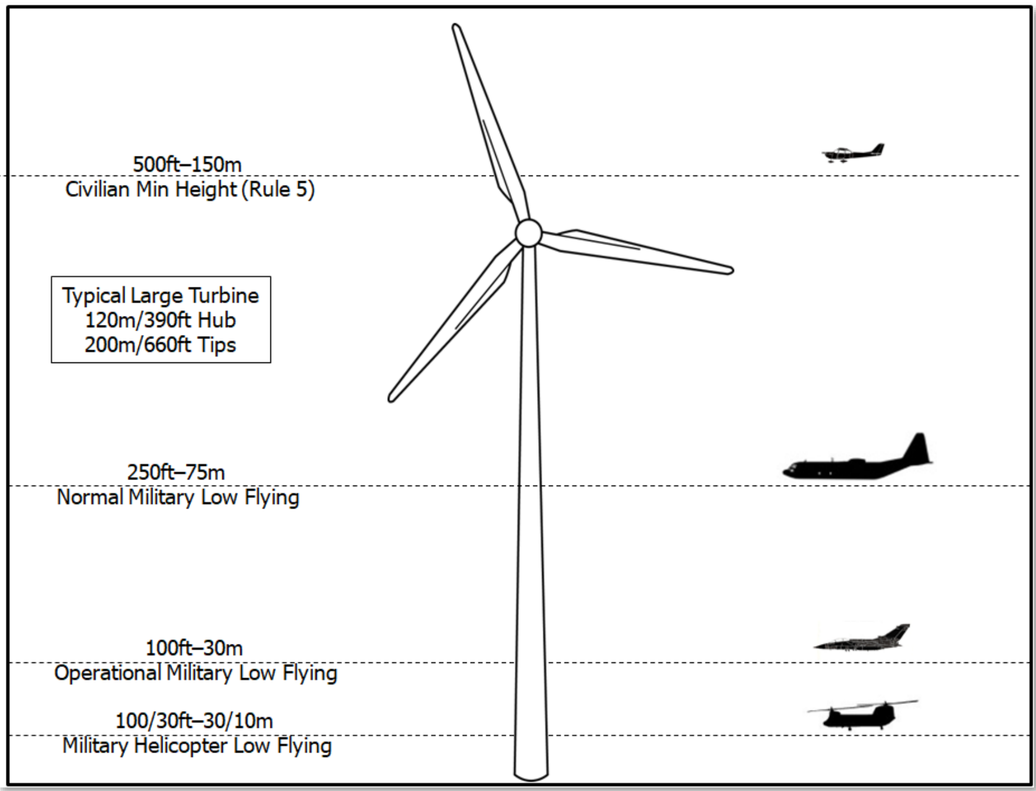

Figure 3 MOD Low Flying Vs Wind turbines in context

Hazards, 38 Hadrian Way, Chilworth, Southampton SO16 7HX

MOD IR Lighting

10. 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.

- 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: Knockcronal meets the MOD small site criteria and does need centrals turbines to be lit

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

Turbines with Infra-Red: T1, T2, T4, T5, T6, T7, T8 and T9

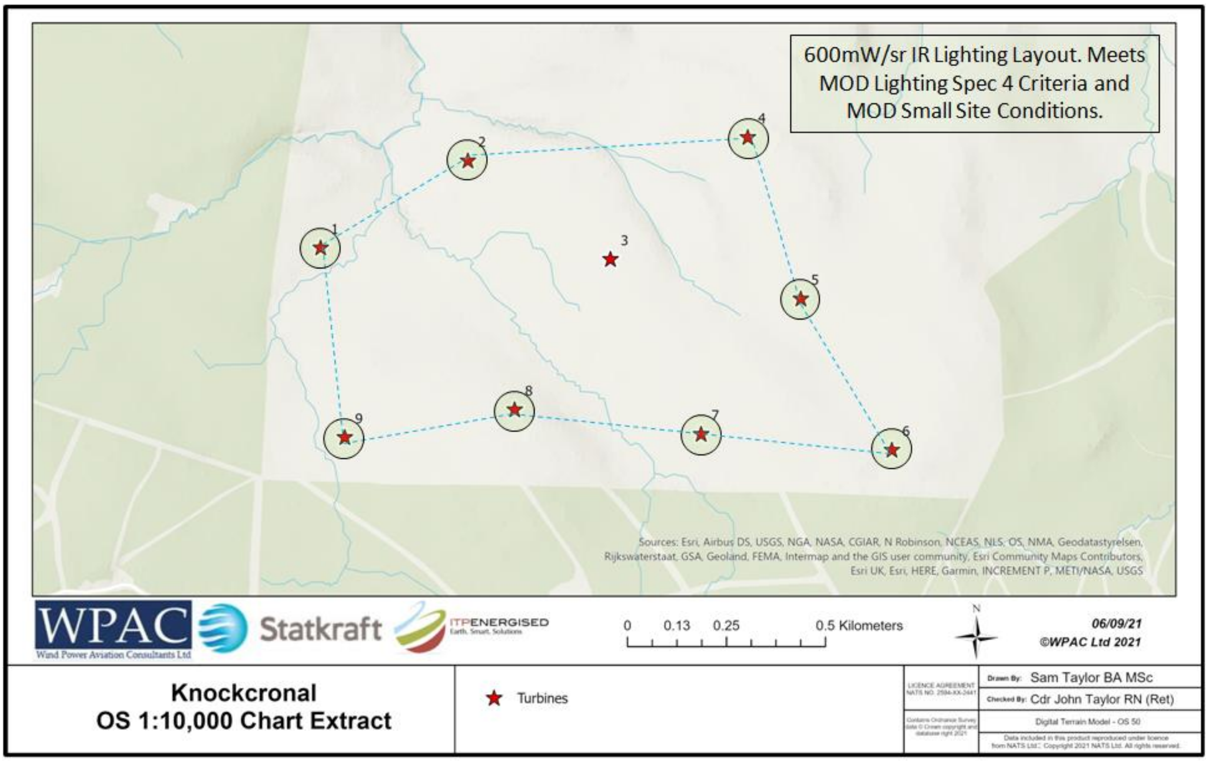

Figure 4 MOD IR Guidance Compliant Lighting Arrangement

Combined CAA Visible Lighting and MOD Infra-Red Lighting

Knockcronal Lighting Proposal						
Turbine	Easting	Northing	Tip Ht	ANO Red	Infra-Red	Mid Mast
1	236759	599643	200m	2000/200cd	600mW	Possibly
2	237131	599863	200m	2000/200cd	600mW	
3	237491	599614	200m			
4	237838	599922	200m	2000/200cd	600mW	Possibly
5	237972	599514	180m		600mW	
6	238202	599132	180m	2000/200cd	600mW	Possibly
7	237720	599172	180m	2000/200cd	600mW	
8	237249	599234	200m		600mW	
9	236820	599164	200m	2000/200cd	600mW	Possibly

Table 1 Combined CAA & MOD Lighting Table

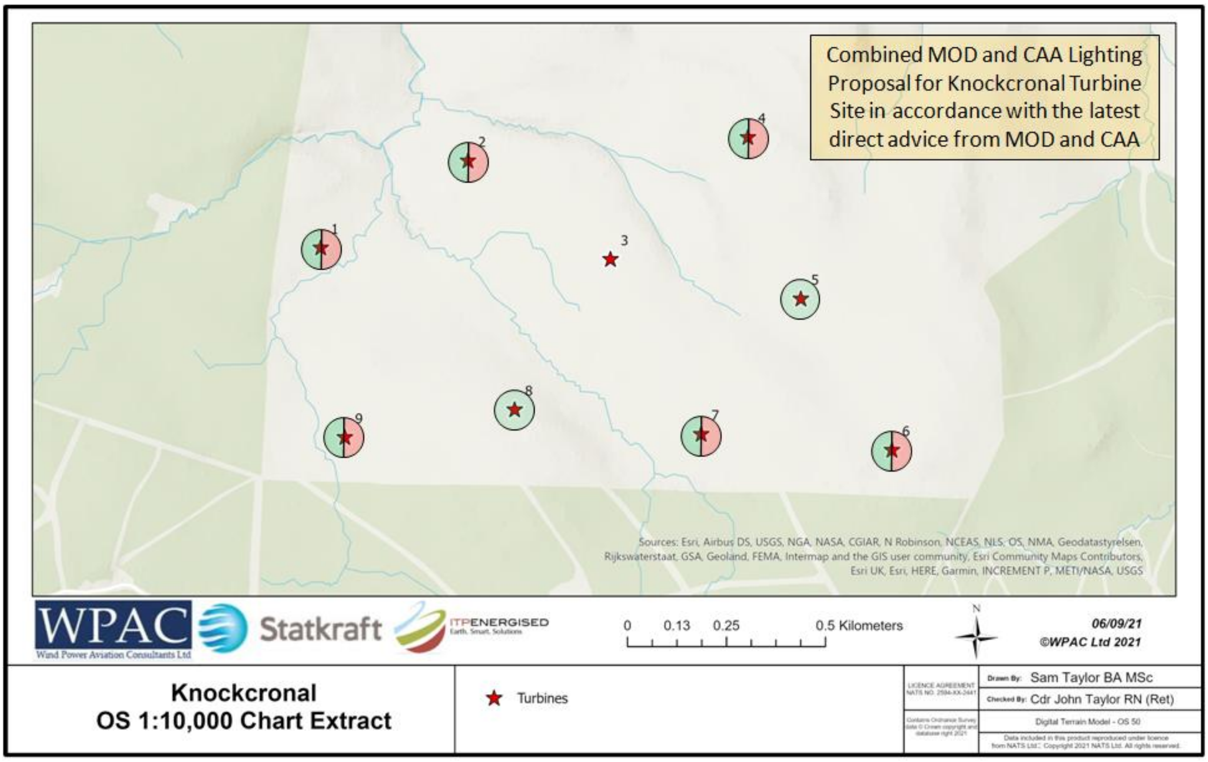

Figure 5 Combined CAA and MOD Lighting Diagram

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

Table 6-2. Light distribution for low-intensity obstacle lights

	Minimum intensity (a)	Maximum intensity (a)	Vertical beam spread (f)	
			Minimum beam spread	Intensity
Type A	10 cd (b)	N/A	10°	5 cd
Type B	32 cd (b)	N/A	10°	16 cd
Type C	40 cd (b)	400 cd	12° (d)	20 cd
Type D	200 cd (c)	400 cd	N/A (e)	N/A

Note.— This table does not include recommended horizontal beam spreads. 6.2.1.3 requires 360° coverage around an obstacle. Therefore, the number of lights needed to meet this requirement will depend on the horizontal beam spreads of each light as well as the shape of the obstacle. Thus, with narrower beam spreads, more lights will be required.

Table 3: ICAO Annex Table 6-2 Low Intensity Obstacle Lights.

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 2. They are designated 'medium intensity obstruction lights' and have a minimum luminous intensity of 2000 candela[1] 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 Table 3 above. One manufacturer of such obstruction lights, CEL, have tested their light, the CEL MI-2KR[2] 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.

[1] Candela is the SI Unit of luminous intensity and refers to the amount of light emitted in a particular direction.

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

14. Figure 6 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.

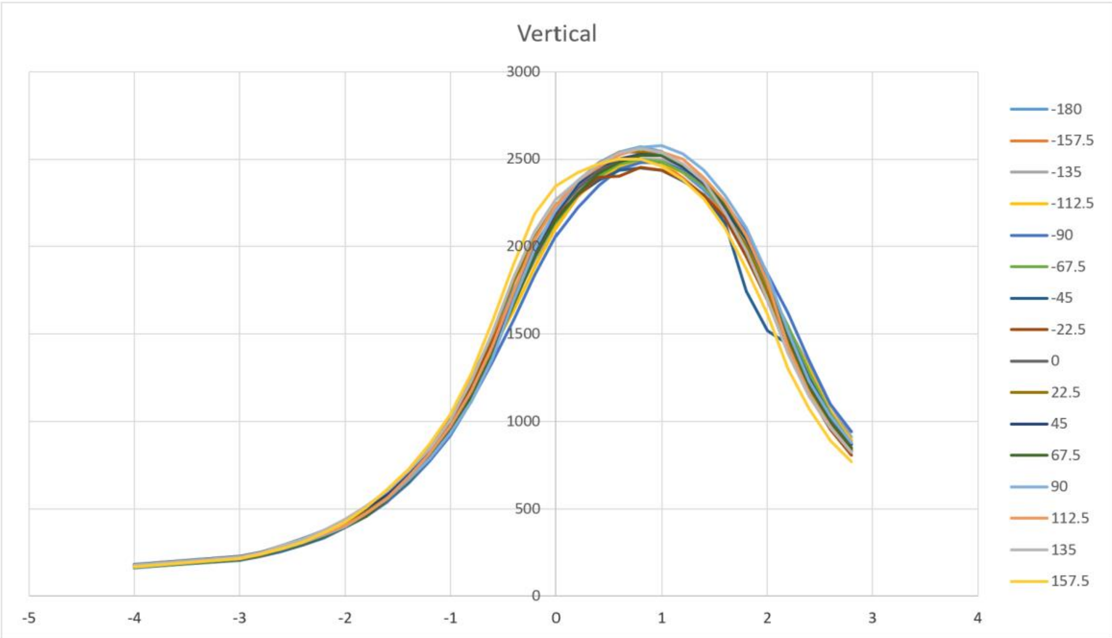

Figure 6 (MI GAM Light Measurement Results)

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 turbine hub height of 102.5 and 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 Knockcronal Wind Farm viewpoints. The locations of the viewpoints are shown in Figure 7 and Table 5.

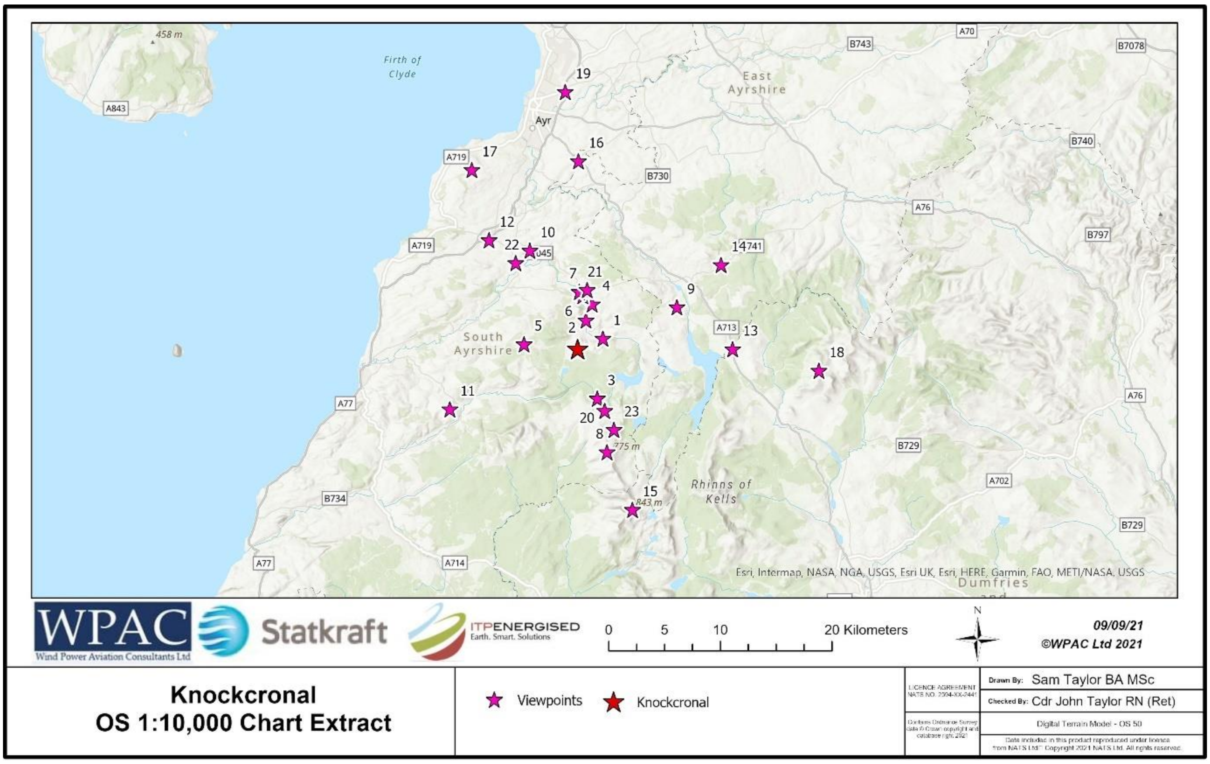

Figure 7 Viewpoint Locations and Lit Turbines

Viewpoint Number	Viewpoint Name	Easting	Northing
1	Minor Road near Tairlaw	240104	600868
2	Minor Road near Craig	238581	602491
3	Minor Road near Stinchar Bridge	239597	595494
4	Craigengower Monument	239137	603928
5	NCN7, near Palmullan Bridge	233036	600354
6	Straiton, minor road south of settlement	238293	604673
7	Straiton	237983	605039
8	Shalloch on Minnoch	240467	590705
9	Craigengillan GDL, Shear Hill	246726	603675
10	B7045, west of Kirkmichael	233558	608730
11	Auchensoul Hill	226394	594542
12	Maybole	229905	609666
13	A713 Eriff	251721	599914
14	B741 near Clawfin	250682	607455
15	Merrick	242746	585542
16	A713 and B742 Road Junction	237908	616734
17	Brown Carrick Hill	228363	615950
18	Cairnsmore of Carsphairn	259446	597989
19	A77, Ayr	236730	622935
20	Cornish Hill	240261	594403

21	B741 nr Largs Farm	238690	605212
22	B7023 north of Gartlea Farm	232293	607622
23	Loch Girvan Eye	241088	592703

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 that will be experienced by the human eye at the viewpoint. The figure produced is in micro-lumens per square metre or lumen(10^{-6})/m^2). These are perfect clear-air figures and therefore are maximum visibility 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% can be as high as 75% at the more distant observation ranges. The results for all of the lit turbines are shown in the following tables. **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 5 metres above ground level but above 1.5 metres and should therefore, still be screened by terrain.**

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	3.562	-3	217	22	17.1	1.7	X
2	3.138	-4.5	119	12	12.1	1.2	
4	2.456	-6.2	105	11	17.4	1.7	
6	2.575	-3	217	22	32.7	3.3	X
7	2.926	-3.3	204	20	23.8	2.4	X
9	3.7	-3	217	22	15.9	1.6	X

Viewpoint 1 Minor Road near Tairlaw

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	3.381	-4.2	130	13	11.4	1.1	
2	3.001	-4.8	110	11	12.2	1.2	
4	2.674	-5.8	105	11	14.7	1.5	
6	3.38	-4.7	112	11	9.8	1	
7	3.429	-4.7	112	11	9.5	1	
9	3.764	-4.2	130	13	9.2	0.9	

Viewpoint 2 Minor Road near Craig

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	5.027	-0.3	1851	185	73.2	7.3	
2	5.017	-0.3	1851	185	73.5	7.4	
4	4.765	-0.5	1582	158	69.7	7	
6	3.896	-0.8	1192	119	78.5	7.9	
7	4.129	-0.8	1192	119	69.9	7	
9	4.602	-0.6	1443	144	68.1	6.8	

Viewpoint 3 Minor Road near Stinchar Bridge

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	4.901	-0.7	1317	132	54.8	5.5	
2	4.533	-0.7	1317	132	64.1	6.4	
4	4.211	-1.1	902	90	50.9	5.1	
6	4.886	-1	982	98	41.1	4.1	
7	4.963	-1.1	902	90	36.6	3.7	
9	5.298	-0.9	1087	109	38.7	3.9	

Viewpoint 4 Craigengower Monument

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	3.79	-1.1	902	90	62.8	6.3	
2	4.124	-1	982	98	57.7	5.8	
4	4.821	-1.1	902	90	38.8	3.9	
6	5.309	-1.1	902	90	32	3.2	
7	4.831	-1.2	822	82	35.2	3.5	
9	3.967	-1.4	691	69	43.9	4.4	

Viewpoint 5 NCN7 near Palmullan Bridge

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	5.259	-1.5	622	62	22.5	2.2	X
2	4.948	-1.9	448	45	18.3	1.8	X
4	4.773	-3.5	194	19	8.5	0.9	
6	5.542	-3.1	213	21	6.9	0.7	
7	5.531	-3	217	22	7.1	0.7	X
9	5.703	-1.8	484	48	14.9	1.5	X

Viewpoint 6 Straiton minor road south of settlement

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	5.533	-2	413	41	13.5	1.3	X
2	5.246	-1.9	448	45	16.3	1.6	X
4	5.119	-2.1	385	39	14.7	1.5	X
6	5.911	-2.2	357	36	10.2	1	X
7	5.873	-1.9	448	45	13	1.3	X
9	5.989	-2	413	41	11.5	1.2	X

Viewpoint 7 Straiton

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	9.677	2.2	1477	148	15.8	1.6	
2	9.747	2.2	1477	148	15.5	1.6	
4	9.585	2.1	1612	161	17.5	1.8	
6	8.726	2.3	1350	135	17.7	1.8	
7	8.901	2.2	1477	148	18.6	1.9	
9	9.212	2.2	1477	148	17.4	1.7	

Viewpoint 8 Shalloch on Minnoch

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	10.752	-0.6	1443	144	12.5	1.2	X
2	10.325	-0.6	1443	144	13.5	1.4	
4	9.648	-0.8	1192	119	12.8	1.3	
6	9.659	-0.8	1192	119	12.8	1.3	
7	10.069	-0.8	1192	119	11.8	1.2	
9	10.885	-0.7	1317	132	11.1	1.1	

Viewpoint 9 Craigengillan GDL, Shear Hill

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	9.634	-0.8	1192	119	12.8	1.3	X
2	9.56	-1.9	448	45	4.9	0.5	
4	9.793	-2	413	41	4.3	0.4	
6	10.662	-1.9	448	45	3.9	0.4	
7	10.425	-1.9	448	45	4.1	0.4	
9	10.107	-1.4	691	69	6.8	0.7	X

Viewpoint 10 B7045, west of Kirkmichael

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	11.552	1.2	2439	244	18.3	1.8	X
2	11.983	1	2503	250	17.4	1.7	X
4	12.646	0.1	2257	226	14.1	1.4	X
6	12.669	-0.5	1582	158	9.9	1	
7	12.236	-0.5	1582	158	10.6	1.1	
9	11.405	0	2185	219	16.8	1.7	X

Viewpoint 11 Auchensoul Hill

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	12.142	0.6	2475	248	16.8	1.7	X
2	12.178	-1	982	98	6.6	0.7	X
4	12.565	-1.5	622	62	3.9	0.4	
6	13.409	-1.5	622	62	3.5	0.3	
7	13.084	-1.3	756	76	4.4	0.4	X
9	12.574	-0.1	2083	208	13.2	1.3	X

Viewpoint 12 Maybole

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	14.964	-0.1	2083	208	9.3	0.9	X
2	14.59	-0.4	1721	172	8.1	0.8	X
4	13.883	-0.6	1443	144	7.5	0.7	
6	13.542	-0.6	1443	144	7.9	0.8	
7	14.021	-0.6	1443	144	7.3	0.7	
9	14.92	-0.5	1582	158	7.1	0.7	M

Viewpoint 13 A713 Eriff

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	15.965	-0.5	1582	158	6.2	0.6	
2	15.533	-0.5	1582	158	6.6	0.7	
4	14.89	-0.6	1443	144	6.5	0.7	
6	15.001	-0.6	1443	144	6.4	0.6	
7	15.383	-0.6	1443	144	6.1	0.6	
9	16.152	-0.5	1582	158	6.1	0.6	

Viewpoint 14 B741 near Clawfin

Hazards, 38 Hadrian Way, Chilworth, Southampton SO16 7HX

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	15.319	2.2	1477	148	6.3	0.6	X
2	15.382	2.2	1477	148	6.2	0.6	X
4	15.195	1.9	1870	187	8.1	0.8	X
6	14.33	2	1747	175	8.5	0.9	X
7	14.527	2.1	1612	161	7.6	0.8	X
9	14.855	2.2	1477	148	6.7	0.7	X

Viewpoint 15 Merrick

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	17.13	-1	982	98	3.3	0.3	
2	16.889	-1	982	98	3.4	0.3	
4	16.812	-1.1	902	90	3.2	0.3	
6	17.604	-1.1	902	90	2.9	0.3	
7	17.563	-1.1	902	90	2.9	0.3	
9	17.604	-1.1	902	90	2.9	0.3	

Viewpoint 16 A713 and B742 Road Junction

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	18.342	-0.3	1851	185	5.5	0.6	X
2	18.321	-0.4	1721	172	5.1	0.5	
4	18.619	-0.4	1721	172	5	0.5	
6	19.485	-0.4	1721	172	4.5	0.5	
7	19.211	-0.5	1582	158	4.3	0.4	
9	18.796	-0.4	1721	172	4.9	0.5	X

Viewpoint 17 Brown Carrick Hill

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	22.747	1	2503	250	4.8	0.5	
2	22.394	1	2503	250	5	0.5	
4	21.694	1	2503	250	5.3	0.5	
6	21.275	1	2503	250	5.5	0.6	
7	21.758	0.9	2509	251	5.3	0.5	
9	22.656	0.9	2509	251	4.9	0.5	

Viewpoint 18 Cairnsmore of Carsphairn

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	23.292	-0.9	1087	109	2	0.2	M
2	23.075	-0.9	1087	109	2	0.2	M
4	23.04	-1	982	98	1.8	0.2	X
6	23.848	-1	982	98	1.7	0.2	X
7	23.784	-1	982	98	1.7	0.2	M
9	23.771	-1	982	98	1.7	0.2	

Viewpoint 19 A77, Ayr

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	6.303	0.6	2475	248	62.3	6.2	
2	6.294	0.6	2475	248	62.5	6.2	
4	6.027	0.4	2429	243	66.9	6.7	
6	5.158	0.4	2429	243	91.3	9.1	
7	5.404	0.4	2429	243	83.2	8.3	
9	5.874	0.4	2429	243	70.4	7	

Viewpoint 20 Cornish Hill

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	5.894	-2.2	357	36	10.3	1	X
2	5.572	-2.5	291	29	9.4	0.9	
4	5.358	-2.9	228	23	7.9	0.8	
6	6.1	-2.6	273	27	7.3	0.7	
7	6.117	-2.6	273	27	7.3	0.7	
9	6.33	-2.5	1119	112	27.9	2.8	

Viewpoint 21 B741 nr Largs Farm

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	9.144	-0.2	1982	198	23.7	2.4	X
2	9.144	-1	982	98	11.7	1.2	X
4	9.489	-2	1747	175	19.4	1.9	X
6	10.344	-1.5	622	62	5.8	0.6	X
7	10.043	-1.6	576	58	5.7	0.6	X
9	9.593	-0.2	1982	198	21.5	2.2	X

Viewpoint 22 B7023 north of Gartlea Farm

Turbine	Distance	Elevation	Candela	Candela at 10%	Microlumens	Microlumens at 10%	Obscured
1	8.179	0.6	2475	248	37	3.7	
2	8.181	0.6	2475	248	37	3.7	X
4	7.917	0.5	2452	245	39.1	3.9	M
6	7.047	0.5	2452	245	49.4	4.9	
7	7.293	0.5	2452	245	46.1	4.6	X
9	7.743	0.4	2429	243	40.5	4.1	

Viewpoint 23 Loch Girvan Eye

Interpreting the Results

17. 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, the distance between the light and the viewpoint is the dominant factor and the resultant figure in micro-lumens is the most relevant figure to consider. This report provides the results and anticipates that the Landscape and Visual Impact Assessment (LVIA) consultants 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 at each viewpoint.

Viewpoint	Brightest Lit Turbine	Distance (km)	Microlumens	Microlumens at 10%	Obscured
1	4	2.456	17.4	1.7	
2	4	2.674	14.7	1.5	
3	6	3.896	78.5	7.9	
4	2	4.533	64.1	6.4	
5	1	3.79	62.8	6.3	
6	4	4.773	8.5	0.9	
7					X
8	4	9.585	17.5	1.8	
9	2	10.325	13.5	1.4	M
10	2	9.56	4.9	0.5	
11	7	12.236	10.6	1.1	
12	4	12.565	3.9	0.4	
13	6	13.542	7.9	0.8	
14	2	15.533	6.6	0.7	
15					X
16	2	16.889	3.4	0.3	
17	2	18.321	5.1	0.5	
18	6	21.275	5.5	0.6	
19	9	23.771	1.7	0.2	
20	6	5.158	91.3	9.1	
21	9	6.33	27.9	2.8	
22					X
23	6	7.047	49.4	4.9	

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

18. In order to place the values in microlumens 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.

Comparison Object	Approximate Illuminance (micro-lumens per m²)
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

19. 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 distance between light and viewpoint.

Viewpoint	Brightest Lit Turbine	Distance (km)	Candela	Candela at 10%	Obscured
1	2	3.138	119	12	
2	1	3.381	130	13	
3	2	5.017	1851	185	
4	2	4.533	1317	132	
5	2	4.124	982	98	
6	6	5.542	213	21	
7					X
8	4	9.585	1612	161	
9	2	10.325	1443	144	
10	2	9.56	448	45	
11	7	12.236	1582	158	
12	4	12.565	622	62	
13	6	13.542	1443	144	
14	2	15.533	1582	158	
15					X
16	2	16.889	982	98	
17	2	18.321	1721	172	
18	7	21.758	2509	251	
19	9	23.771	982	98	
20	2	6.294	2475	248	
21	9	6.33	1119	112	
22					X
23	1	8.179	2475	248	

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 Results

Visibility Tables for the Mid-Tower lights

20. 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. Whilst is it possible that mid mast lights will not be required in this case, theoretically a small number of the turbines identified as requiring hub lights will also require 32 candela red lights as described in paragraph 7. Commercially available 32cd mid-mast lights are over engineered and emit considerably more light than the minimum required by ICAO Annex E. Lighting manufacturers are working on a new generation of 32cd lights that carefully match the

ICAO Annex E requirement without excessive light intensity or light that 'spills' downward but it should be assumed that the existing lights will have to be used if required.

21. The calculations for the mid-mast lights are based upon the parameters of the CEL -LI-32-230-F LED red low intensity aircraft warning light manufactured by Contarnex Europe Ltd . The full technical specification is available[3] . The light has been tested in a calibrated test chamber and the results are shown in the graph below (Figure 8); the manufacturer has provided the luminous intensity figures for every 0.5° in elevation. Although less precise than the 2000cd medium intensity red lights referred to in the main report, there is still some reduction in intensity the further below horizontal the viewpoint is in relation to the light. It should be noted that although classified as a 32cd low intensity red light, the maximum output peaks at around 74cd at an elevation angle of +4.0°, however, this is likely to be well above the elevation angle between any light and any potential viewpoint. The concession to reduce light intensity in good visibility does not apply to these lights. Finally it should also be noted that due to the lower elevation of the mid mast light (half hub height), there is more opportunity for terrain screening between the light and a viewpoint.

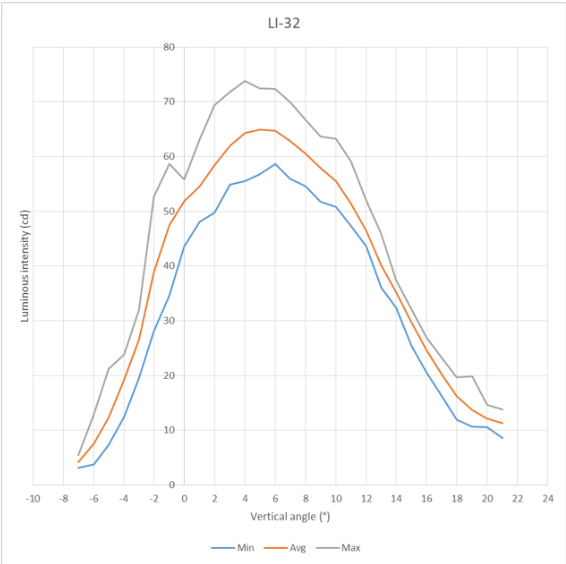

Figure 8: Mid mast lights results

22. The results tables for the mid mast lights are provided in Appendix B to this report.

[3] https://www.contarnex.com/led-obstruction-lighting/datasheets/Low-Intensity/1-READY%20-%202nd%20Generation/CEL-LI-32-230-F-low-intensity-led-obstruction-warning-light.pdf

Part 2 Mitigation

23. 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.

24. 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'.

25. 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. It should be noted that this does not apply to any low intensity 32cd lights installed halfway up the turbine towers.

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

26. 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 is at Prestwick Airport. The visibility will not be identical at the locations but very similar. Below is a table of visibilities throughout the year and averaged over a 30-year period.

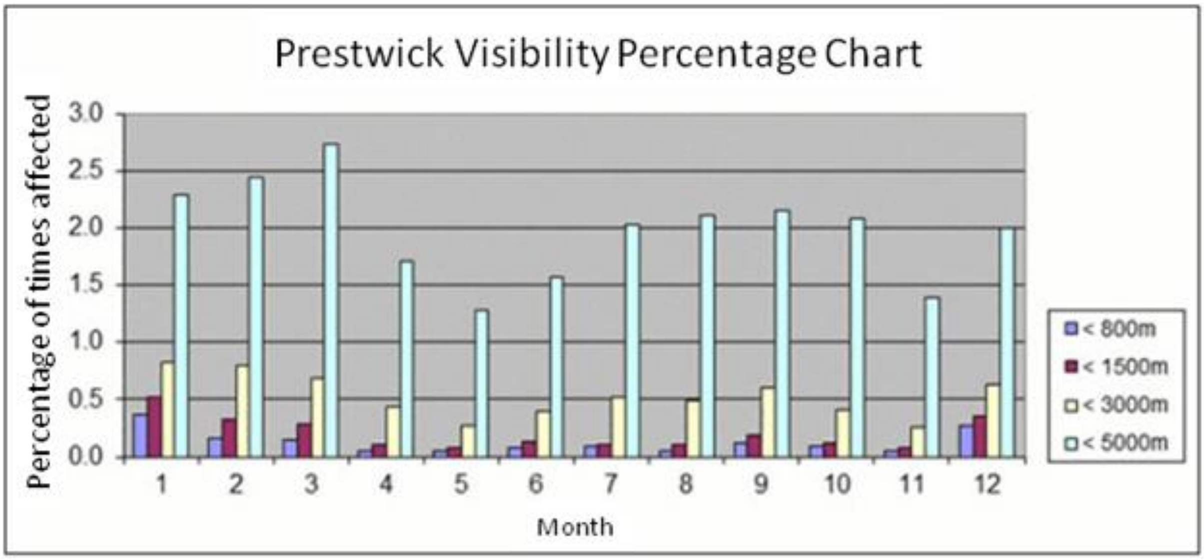

Figure 9 Met Office Historic Visibility Records for Prestwick

Analysis of the table in Table 9

27. The Prestwick Met Office tables show us that the visibility is historically below 5km (light blue) 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**.

28. Whilst Prestwick is not Knockcronal, 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 Knockcronal visibility would be better than that at Prestwick.

Weather (Cloud) Obscuration of Turbine Lighting.

29. On occasion, the visibility in the area of Knockcronal will reduce significantly due to the presence of cloud on the hills. If the Knockcronal 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.

30. The average height at the base of the Knockcronal turbines is around 900-1000ft above mean sea level (amsl). The hub heights will be around 1300-1400ft amsl. (Note: the obstruction lights are turbine hub mounted and all the turbines are sited on similar height terrain).

31. It is now possible to compare these two heights: **turbine base average 950ft** amsl and **turbine hub average 1350ft** amsl with the actual cloud bases recorded by the Met Office at Prestwick airport, again, over a 30-year period, shown in Table 10.

32. 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 (950ft). The lights will be completely obscured and not be seen.

33. The burgundy columns (600-1000ft) indicate that the cloud base will range from approximately 350ft to 750ft 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 350ft below the hub mounted light.

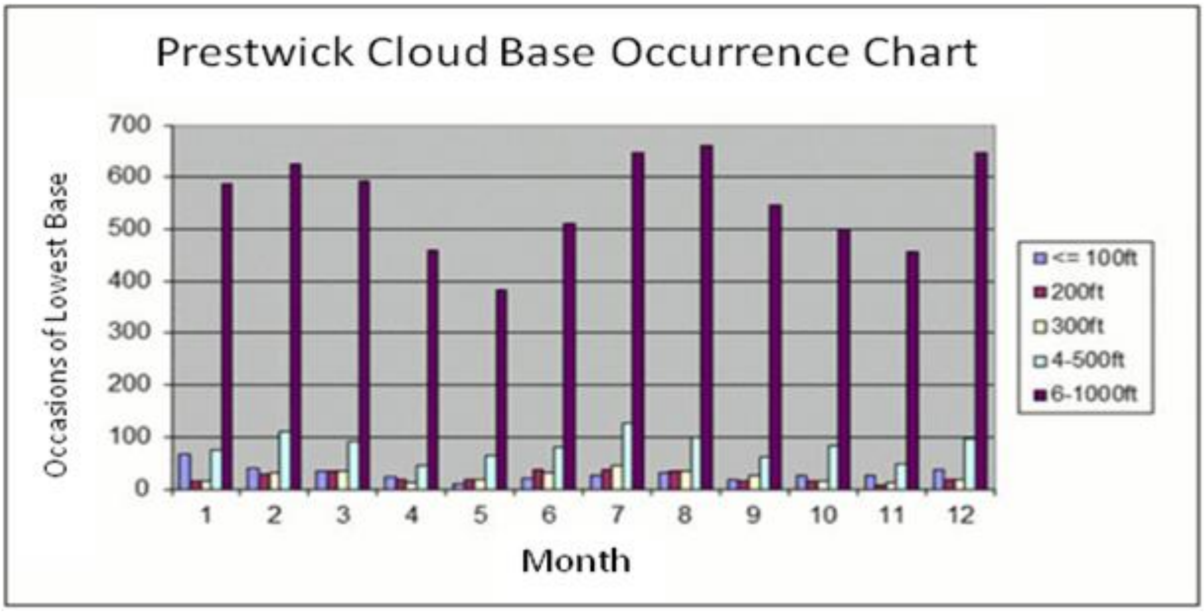

Figure 10

34. Whilst Prestwick is not Knockcronal, met office statistics show that height of the cloud-bases reduce in the region of hills. It could be argued that at Knockcronal 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.

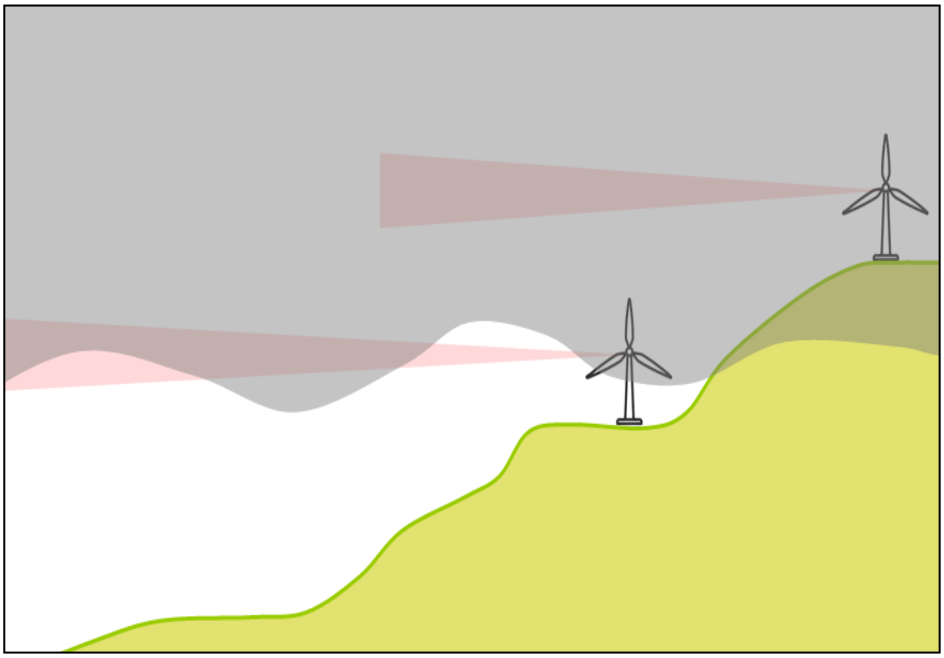

Figure 11 Turbine Visible Light Obscuration by Cloud – Full and Partial

Conclusion/Notes

35. The Knockcronal site does benefit 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.

<u>Accordingly, the 9-turbine site requires 6 visible-red and 8 infra-red hub mounted obstruction lights.</u>

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

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

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. 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 electro-magnetic 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 aerials, 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 12 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 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 as simple a process as one might imagine. This issue has been running for at least 20 years so far, however some progress is now being made. In the same response to a recent planning inquiry paper the CAA responded stating: *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 ADSL 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.

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 13 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 Knockcronal, with very little, if any night low level civilian traffic, the number of times the lights will activate is likely to be so small as to be statistically insignificant. The 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.

Conclusion

43. This report has assessed the requirements for both visible, CAA approved aviation lighting and MOD approved Infra-Red lighting for the Knockcronal Wind Farm. The resulting layout is set out in Figure 6 and makes use of both CAA/ANO Red lights and MOD IR lights. The proposed layouts will be sent to the CAA and MOD DIO for approval.

44. 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.

45. 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 will enable the future lighting effects to be mitigated to the extent of becoming almost non-existent.

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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Appendix A – 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 B Mid Mast Lighting Results

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	3.562	-0.4	50	3.9	X
4	2.456	-4.4	16	2.7	X
6	2.575	-1	47	7.1	X
9	3.7	-1.7	43	3.1	X

VP1

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	3.381	-3.2	26	2.3	
4	2.674	-4.7	16	2.2	
6	3.38	-3.9	20	1.8	
9	3.764	-3.3	23	1.6	

VP2

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	5.027	0.4	53	2.1	
4	4.765	0.1	52	2.3	
6	3.896	0	52	3.4	
9	4.602	0.1	52	2.5	

VP3

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	4.901	0	52	2.2	
4	4.211	-0.4	50	2.8	
6	4.886	-0.4	50	2.1	
9	5.298	-0.3	50	1.8	

VP4

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	3.79	-0.1	52	3.6	
4	4.821	-0.5	50	2.2	
6	5.309	-0.5	50	1.8	
9	3.967	-0.5	50	3.2	

VP5

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	5.259	-0.6	50	1.8	X
4	4.773	-2.7	26	1.1	X
6	5.542	-2.6	33	1.1	
9	5.703	-1	47	1.4	X

VP6

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	5.533	-1	47	1.5	X
4	5.119	-1.3	43	1.6	X
6	5.911	-1.5	43	1.2	X
9	5.989	-1.2	47	1.3	X

VP7

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	9.677	2.6	60	0.6	
4	9.585	2.4	60	0.7	
6	8.726	2.6	60	0.8	
9	9.212	2.6	60	0.7	

VP8

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	10.752	0	52	0.4	X
4	9.648	-0.4	50	0.5	X
6	9.659	-0.5	50	0.5	X
9	10.885	-0.3	50	0.4	X

VP9

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	9.634	1.3	56	0.6	X
4	9.793	-1.7	43	0.4	
6	10.662	-1.6	43	0.4	
9	10.107	0.2	52	0.5	X

VP10

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	11.552	3	60	0.4	X
4	12.646	1.1	54	0.3	X
6	12.669	-0.1	52	0.3	X
9	11.405	1.8	58	0.4	X

VP11

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	12.142	2.6	60	0.4	X
4	12.565	-0.8	47	0.3	X
6	13.409	-0.8	47	0.3	X
9	12.574	1.4	56	0.4	X

VP12

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	14.964	0.7	53	0.2	X
4	13.883	-0.2	52	0.3	X
6	13.542	0.2	52	0.3	X
9	14.92	0.2	52	0.2	X

VP13

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	15.965	0.2	52	0.2	X
4	14.89	-0.2	52	0.2	X
6	15.001	-0.4	50	0.2	
9	16.152	-0.1	52	0.2	X

VP14

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	15.319	2.5	60	0.3	X
4	15.195	2.2	58	0.3	X
6	14.33	2.3	60	0.3	X
9	14.855	2.5	60	0.3	X

VP15

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	17.13	-0.6	50	0.2	X
4	16.812	-0.9	47	0.2	M
6	17.604	-0.9	47	0.2	
9	17.604	-0.8	47	0.2	X

VP16

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	18.342	1.8	58	0.2	X
4	18.619	-0.3	50	0.1	
6	19.485	-0.3	50	0.1	
9	18.796	1.2	54	0.2	X

VP17

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	22.747	1.1	54	0.1	
4	21.694	1.1	54	0.1	
6	21.275	1.1	54	0.1	
9	22.656	1.1	54	0.1	

VP18

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	23.292	-0.1	52	0.1	X
4	23.04	-0.8	47	0.1	X
6	23.848	-0.8	47	0.1	X
9	23.771	-0.8	47	0.1	X

VP19

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	6.303	1.2	54	1.4	
4	6.027	0.9	54	1.5	
6	5.158	1	54	2	
9	5.874	1	54	1.6	

VP20

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	5.894	-1.3	43	1.2	X
4	5.358	-2.3	33	1.1	
6	6.1	-2.1	39	1	
9	6.33	-1.7	43	1.1	X

VP21

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	9.144	1.9	58	0.7	X
4	9.489	-1.2	47	0.5	X
6	10.344	-0.9	47	0.4	X
9	9.593	1.4	56	0.6	X

VP22

Turbine	Distance (km)	Elevation Angle	Candela	Microlumens	Obscured
1	8.179	1.1	54	0.8	X
4	7.917	0.9	54	0.9	X
6	7.047	1	54	1.1	X
9	7.743	0.9	54	0.9	M

VP23

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