Obstacle Lighting of Onshore Wind Turbines

Balancing aviation safety and environmental impact

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### Abbreviations

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<th>ACRONYM</th>
<th>DESCRIPTION</th>
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<tr>
<td>ICAO</td>
<td>International Civil Aviation Organization</td>
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<tr>
<td>LED</td>
<td>Light-Emitting Diode</td>
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<td>NLR</td>
<td>Netherlands Aerospace Centre</td>
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<td>NVG</td>
<td>Night Vision Goggle</td>
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<td>SERA</td>
<td>Standardised European Rules of the Air</td>
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<td>TMA</td>
<td>Terminal Control Area</td>
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<td>VFR</td>
<td>Visual Flight Rules</td>
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1 Introduction

To ensure the safety of air traffic, aviation authorities require wind turbines over a certain height (typically a tip height of 150 meter) to be fitted with obstacle lights. Although essential for air traffic flying at low altitudes, these lights cause significant residential annoyance, especially at night, reducing public support for wind energy. As next generation wind turbines have become increasingly higher over the years, the majority of newly planned wind farms will require obstacle lights. As a result, these plans encounter more and more resistance from local communities. Especially in populated states, this public resistance forms a serious challenge for wind farm developers and national wind energy ambitions.

This paper aims to provide wind farm developers and operators with a basic understanding of the international regulations regarding obstacle lighting and an overview of means to reduce the residential annoyance posed by these lights.
2 The Need for Obstacle Lighting

Obstacle lights are intended to alert a pilot flying at low altitude to the presence of an obstacle allowing the pilot to safely navigate around it. The low-level airspace around a wind farm is typically uncontrolled. This means that flights are not separated from each other by air traffic control; the pilot is responsible for avoiding other traffic and obstacles based on the principle of see-and-avoid. It is therefore imperative that obstacles penetrating this airspace (which starts at the minimum flight altitude of 150m above ground level) are equipped with obstacle lights, especially in low-visibility conditions and at night.

Air traffic in uncontrolled airspace normally operates under Visual Flight Rules (VFR), which requires the pilot to remain below the clouds and adhere to visibility minima. European standards, as laid down in the Standardised European Rules of the Air (SERA [[1]]), prescribe a minimum visibility of 1,500m in daylight\(^1\) and 5,000m at night\(^2\). Note that helicopters may be permitted to operate in 800m visibility\(^3\) and that further exemptions may apply to special cases such as military, search and rescue, medical emergency and fire-fighting flights.

Unless the wind farm is located near an airport, the wind turbines will normally not pose a threat to commercial airlines. The kind of air traffic that is usually encountered at low altitude in the vicinity of a wind farm encompasses smaller aircraft (private operators, flight schools) and helicopters (military, police, medical emergency services). Obstacle lights are therefore designed at providing this kind of traffic with a timely alert under any circumstances in which this traffic is allowed to operate (day/night, minimum visibility). This means that the intensity of the obstacle lights is such that the acquisition distance\(^4\) is sufficient for the pilot to recognize the danger, take evasive action and avoid the obstacle by a safe margin.

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\(^1\) When so prescribed by the national authority, 1,500m visibility may be permitted for flight operating at speeds of 140kts or less or in circumstances in which the probability of encounters with other traffic would normally be low. Otherwise the minimum visibility is 5,000m [SERA.5001].

\(^2\) when VFR-flights at night are permitted by the national authority [SERA.5005].

\(^3\) if manoeuvred at a speed that will give adequate opportunity to observe other traffic or any obstacles in time to avoid collision [SERA.5001].

\(^4\) The acquisition distance, or luminous range, is the maximum distance at which a light can be seen.
3 International Regulations and Guidelines

3.1 Regulatory Framework

The International Civil Aviation Organization (ICAO), part of the UN, publishes international regulations for civil aviation in Annexes to the 1944 Chicago Convention. The Annexes cover various aspects of aviation such as air navigation and its infrastructure, airport design and the rules of the air. They contain standards and recommended practices. Member states are obligated to adopt the ICAO standards and implement them into their national laws and regulations.

3.2 ICAO Recommendations

Volume I of Annex 14 [[2]] contains standards and recommended practices regarding the marking and lighting of obstacles. Generally, outside the vicinity of an airport, all objects which extend to a height of 150m or more above ground elevation are regarded as obstacles and should be marked and/or lighted.

Specific recommendations for the lighting of wind turbines are given in section 6.2.4. These recommendations specify the type of obstacle light to be used and on which turbines these lights should be installed in the case of a wind farm (a group of two or more wind turbines).

Regarding the type of obstacle light, ICAO specifies that medium-intensity lights should be used. Table 6.1 in Annex 14 lists three types of medium-intensity light:

- Type A: white, flashing lights with an intensity of 20,000cd in daylight and twilight conditions and 2,000cd at night;
- Type B: red, flashing lights with an intensity of 2,000cd at night;
- Type C: red, steady lights with an intensity of 2,000cd at night.

Although not explicitly stated, the fact that no daylight intensities are specified for Type B and C suggests that these types should only be used at night. Besides, an intensity of 2,000cd is typically not enough during the day to overcome the background lighting. Consequently, for the daylight period only Type A should be used. At night there is a choice between flashing (Type B) and steady (Type C) lights. In addition to the above, Annex 14 also specifies requirements regarding the horizontal and vertical beam spread.

Regarding the installation of lights throughout a wind farm, ICAO allows perimeter lighting, i.e. lighting only wind turbines on the perimeter (outer boundary) of the wind farm. In this case the obstacle lights should be installed such that:

- The maximum spacing between the lights along the perimeter is 900m or less;
- Flashing lights are synchronized;
- Wind turbines of significant higher elevation are also equipped with obstacle lights.

\[5\] unless a dedicated assessment shows that a greater spacing can be used
3.3 National Regulations in Europe and North America

Because the Annex 14 regulations on the lighting of wind farms are recommendations, states are not required to implement them in their national regulations. Besides that, the current Annex 14 recommendations are not comprehensive and leave room for interpretation by the national aviation authority. As a result, significant differences can be noticed between the national regulations of states in Northwest Europe (the Netherlands, Belgium, Germany, France, UK, Denmark, Norway, Sweden and Finland) and North America (Canada and the US) [[3]].

Some states, such as the US, UK, Belgium, Germany and Denmark, pose that the visibility of wind turbines during the daylight period is sufficiently guaranteed by the prescribed marking. In these states obstacle lights are not required during the daylight period. It should be noted however, that in Belgium and Germany the marking requirements are stricter. In addition to the white painting of the turbine, these states require orange or red bands on the turbine blades, mast and nacelle. Obstacle lights can be used as an alternative. On the contrary, other states, like France and the Scandinavian countries, prescribe high-intensity lights (100,000cd-200,000cd) for the daylight period.

There are also notable differences in the prescribed intensity at night. Requirements vary between 100cd (Belgium and Germany) and 100,000cd (Denmark). Belgium and Germany even allow the use of low-intensity lights (10cd) when installed at the blade tips.

On other aspects of the Annex 14 recommendations, there is more consensus. Most states require wind farms to be fitted with synchronously flashing lights. Perimeter lighting is also allowed in these states, provided the spacing does not exceed the ICAO norm of 900m. The option to deviate from this norm based on a dedicated study, as allowed by Annex 14, is generally not adopted. The exception to this is the UK, which allows the use of steady lights (ICAO Type C) to reduce residential annoyance. However, perimeter lighting is not permitted in the UK, i.e. all (onshore) wind turbines have to be fitted with obstacle lights.
4 LED & Night Vision Goggles

Because LEDs are more efficient and have a longer lifespan compared to traditional incandescent lights, LED-based obstacle lights have become the current standard. Although clearly visible to the naked eye, red LEDs may pose problems for pilots flying with Night Vision Goggles (NVGs), such as military, medical emergency and police helicopter flight crews. The reason for this is that LEDs, unlike incandescent lights, have a very narrow spectral output and do not emit infrared energy (heat). If the LED output falls outside the sensitivity range of the NVG, the light will be invisible through NVGs.

According to ICAO Annex 14 specifications aviation red lights should emit light with a wavelength between 610 and 700nm. NVGs approved for aviation are typically sensitive to light with a wavelength between 665 and 930nm. This means that a LED light may meet the international standards for red obstacle lights, yet be invisible through NVGs.

This problem was first noticed by the Canadian Airforce. In 2008 they issued a safety alert to their pilots warning them about the fact that some LED-based obstacle lights were not visible through NVGs. Subsequently, the Canadian and US aviation authorities issued similar warnings. Today, several states require obstacle lights to be NVG-friendly, either by including an infrared component or by ensuring the spectral output falls within the sensitivity range of an NVG. Examples include the UK, Norway and Finland. Other states (such as the Netherlands) are considering including this requirement in their regulations.
5 General Measures to Reduce Environmental Impact

5.1 Perimeter Lighting

To reduce the number of obstacle lights in a wind farm, Annex 14 allows for the option to only light turbines along the perimeter of the wind farm, as long as the spacing between the lights is not greater than 900m. When perimeter lighting is applied it is imperative that the contour of the wind farm is clearly visible to the pilot. The wind farm must appear as a group of obstacles forming an entity. If the wind turbines appear as isolated obstacles, the pilot may be tempted to fly through an unlit gap and potentially collide with an unlit turbine. This is why the spacing between the lights must be limited. The 900m norm for wind farms is adopted from the existing Annex 14 norm for an extensive object or group of closely spaced objects. Note that the use of synchronously flashing lights serves as an additional indication to the pilot that the obstacles form a group.

Most states permit perimeter lighting, albeit that the opportunity Annex 14 offers to deviate from the 900m norm based on a dedicated assessment is commonly not adopted.

5.2 Steady Burning Lights

Although Annex 14 allows the use of steady lights at night (Type C), most states have not adopted this option in their national regulations. They require the use of synchronously flashing lights in a wind farm to warn the pilot of a group of obstacles. Although this makes sense when some of the turbines are unlit, it seems unnecessary when all wind turbines are equipped with obstacle lights. In this case the integrity of the group appearance does not have to be maintained. Whether the wind farm appears as an entity or as isolated obstacles seems no longer relevant as there are no unlit obstacles to avoid.

The above reasoning may be of interest to wind farm developers trying to optimize the lighting of a wind farm. They could be offered the option to either use steady lights on all wind turbines or use flashing lights on some of the turbines along the perimeter. For a small wind farm of say three wind turbines, the most community-friendly option would probably be the use of three steady lights. On the other hand, for large wind farm perimeter lighting with flashing lights may be the way to go.

Currently most states do not permit the use of steady lights when all turbines are fitted with these lights. A recent aeronautical study [3] performed by NLR has recommended this option to the Dutch authorities. It is considered for the new version of the Dutch circular on obstacle lighting of onshore wind farms.

5.3 Intensity Regulation

Intensity regulation concerns the dimming of the obstacle lights when the visibility is good. The wind farm is equipped with visibility sensors that measure the local visibility. The light intensity is adjusted according to a fixed schedule;
typically the intensity is reduced to 30% of the maximum intensity when the visibility is 5km or more and to 10% when it is 10km or more. Intensity regulation is a common-sense solution to the fact that in good visibility the intensity of the lights is much more than required. Medium-intensity lights can be seen as far as 30-40km in good visibility conditions at night, because the lights are dimensioned to provide an adequate acquisition distance in poor visibility conditions.

Adjusting the intensity to the actual visibility conditions ensures that the lights do not cause unnecessary nuisance while the acquisition distance remains adequate for aviation safety.

To illustrate the above, Figure 1 shows the acquisition distance of medium intensity lights (2,000cd) in night and twilight conditions as a function of the visibility that is reported in aviation weather reports. The minimum acquisition distance required by a pilot flying at 165 knots to make an evasive manoeuvre (1.9km) is also shown in the figure. It can be seen that when intensity regulation is applied the acquisition distance remains sufficient.

Intensity regulation is an approved method to reduce the environmental impact in several states including Germany, Belgium, Denmark and Finland. It is currently being considered in France and Canada. In the Netherlands a recent pilot has been performed in which intensity regulation was one of the measures that were evaluated. In the aeronautical study \([3]\) that was part of this pilot NLR recommended the Dutch authorities to adopt it in their regulations.

![Figure 1: Acquisition distance of 2,000cd lights in night and twilight conditions as a function of visibility](image)
5.4 Aircraft Detection System

An aircraft detection system is a passive radar system that is designed to activate the obstacle lights only when an aircraft is detected in the vicinity of the wind farm. It does not require additional equipment in the aircraft. The system may include an optional voice/audio feature that transmits an audible warning message to provide pilots additional information on the obstruction they are approaching.

Several states have approved or are evaluating radar-activated lighting systems for installation on wind farms. Examples are the US, Canada, Germany, Norway and Sweden.

5.5 Shielding

Another way of minimizing the visual impact on the ground is by shielding the downward component of the obstacle light. Some manufacturers offer light fittings designed to reduce the light emitted below the horizontal. ICAO Annex 14 requires a minimum vertical elevation angle of -1° (i.e. 1° below the horizontal plane). Figure 2 illustrates the effect of shielding the beam spread below this minimum angle in good visibility (20km) at night using emission specifications of a typical obstacle light. It can be seen that the shielding decreases the footprint on the ground. In this case, the acquisition distance is increased from 600m to 5700m.

![Figure 1: Effect of shielding of 2,000cd lights installed at a height of 100m in 20km visibility at night](image-url)
6 Local Deviations based on an Aeronautical Study

An aeronautical study is a term used by ICAO for a dedicated safety assessment with the purpose of proving that a specific non-compliance to an ICAO standard or recommendation does not significantly affect the safety of aircraft operations. An aeronautical study can only be conducted when it is explicitly mentioned in national regulations.

Regarding the perimeter lighting of wind farms, ICAO Annex 14 offers the option to deviate from the maximum spacing of 900m between lighted turbines based on a dedicated assessment (aeronautical study). However, as already mentioned, most states have not adopted this specific option in their national regulations. Some of them do offer a more generic opportunity to deviate from the standards and tailor the lighting of the wind farm to the local needs. This will always require an aeronautical study, which can come in different forms but will generally need to include an assessment of the specific location of the wind farm, its geometry and characteristics, the surrounding terrain and other obstacles, and the local airspace structure and air traffic.

A promising opportunity for a successful aeronautical study was found during an obstacle lighting pilot at the Prinses Alexia wind farm in the Netherlands [[3]]. In this particular case it was argued that the current red flashing obstacle lights at night could be replaced by infrared lights, which would eliminate the residential nuisance at night. The argumentation behind this is that, because night-VFR is not allowed in the Netherlands, the only air traffic that is allowed there at night at low altitude are military, police and medical emergency helicopters that have an exemption. However, these operators all fly with NVGs and therefore would have more benefit from infrared lights. And even if night-VFR would be allowed in the Netherlands in the future, general aviation would not be flying near the wind farm because it is located under the restricted airspace (TMA) of Schiphol starting at an altitude of 1,500ft. The European rules of the air require VFR-traffic at night to fly at a minimum altitude of 1,000ft above any obstacle within 8km of the aircraft. Because the wind turbines have a tip height of 500ft, the airspace surrounding the wind farm will be off limits to regular air traffic. And even if by some odd chance a pilot accidentally overflies the wind farm at night, he/she would still be flying at 1,000ft clearing the turbines by a safe margin of 500ft.
Conclusions

Obstacle lights on wind turbines are increasingly causing residential annoyance. The regulations from aviation authorities, although based on the same international recommendations, vary significantly between states. Wind farm developers and operators potentially have two ways to tailor the required lighting. They can implement approved measures to reduce the environmental impact and they can conduct an aeronautical study to prove that a proposed deviation from the standards does not negatively affect flight safety.
8 References


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