INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems
ANNEX XI

46th IEA Topical Expert Meeting

Obstacle Marking of Wind Turbines

Stockholm, Sweden, October 2005
Organised by: FOI

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BASE TECHNOLOGY INFORMATION EXCHANGE

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The objective of this Task is to promote wind turbine technology through cooperative activities and information exchange on R&D topics of common interest. These cooperative activities have been part of the Agreement since 1978.

The task includes two subtasks. The objective of the first subtask is to develop recommended practices for wind turbine testing and evaluation by assembling an Experts Group for each topic needing recommended practices. For example, the Experts Group on wind speed measurements published the document titled "Wind Speed Measurement and Use of Cup Anemometry".

The objective of the second subtask is to conduct joint actions in research areas identified by the IEA R&D Wind Executive Committee. The Executive Committee designates Joint Actions in research areas of current interest, which requires an exchange of information. So far, Joint Actions have been initiated in *Aerodynamics of Wind Turbines, Wind Turbine Fatigue, Wind Characteristics, Offshore Wind Systems and Wind Forecasting Techniques.* Symposia and conferences have been held on designated topics in each of these areas.

In addition to Joint Action symposia, Topical Expert Meetings are arranged once or twice a year on topics decided by the IEA RD&D Wind Executive Committee. One such Expert Meeting gave background information for preparing the following strategy paper "Long-Term Research and Development Needs for Wind Energy for the Time Frame 2000 to 2020". This document can be downloaded from source 1 below.

Since these activities were initiated in 1978, more than 60 volumes of proceedings have been published. In the series of Recommended Practices 11 documents were published and five of these have revised editions.

All documents produced under Task XI and published by the Operating Agent are available to citizens of member countries from the Operating Agent, and from representatives of countries participating in Task XI.

More information can be obtained from:
1. www.ieawind.org
2. www.windenergy.foi.se/IEA_Annex_XI/ieaannex.html

INTRODUCTORY NOTE
IEA Topical Expert Meeting 46
on
Obstacle Marking of Wind Turbines

Björn Montgomerie FOI, Sven-Erik Thor Vattenfall, Sweden

1. INTRODUCTION

Wind turbines need obstacle warning aids to help the crew of airplanes, helicopters and ships to avoid collisions with the turbines. So far, the organizations performing the logistics of applying for building permits, site preparation and erection of wind turbines have generally handled each such activity as an isolated event. Thus, obstacle warning lights or markings has been applied as seen fit for the particular wind turbine or group of turbines. Although similar principles have emerged, there exists a recognition of a need for a general set of rules in this respect. The rules should preferably be international.

Accidents of airplanes colliding with wind turbines have not happened at all as far as this author is informed. It must be assumed that the natural visual signature and today's markings are adequate, although not uniform across the globe. The need for the proposed meeting emanates from a concern in the industry that investments made in obstacle marking must be appropriate for the different demands, from for example aviation and public perspectives. The number of wind turbines in the world, estimated to be of the order of magnitude 25 000, is increasing exponentially, with an annual growth of about 30% in terms of installed megawatts (MW), approaching 50 000 MW presently. Despite this fact there is still a lack of firm rules for the design and application of obstacle lights. The costs for lighting are thus becoming an issue of increasing importance. If new regulation will enforce a comprehensive and therefore expensive retrofit program, that regulation better be known as soon as possible. It seems strategically advantageous for the industry to pave the ground proactively for such regulation.

2. THE BASIC NEED

Over land the reason for markings is to guide only aviators to avoid collisions with the turbine. The visual information from any high object should be as clear and unambiguous as possible. It must be possible to interpret the lighting information as "wind turbine" as opposed to lighting for all other static high objects.

It is emphasized that ambiguous information from lights for aviation and those for ships must be avoided. Thus a marine light signal code must not mean a different thing to an aviator. It may be helpful to screen off regions to limit the lobes inside of which the lights will be visible. At a reasonably close range such screening would result in the aviation marking being seen by aviators only and the marine markings will be seen by mariners only. At a large distance both marking systems may be seen by both categories.

Although a proposed separation of light information, as proposed, is recommended the consequence for low flying operation is that the pilot must be able also to correctly interpret the sea marking. This has relevance for several civil flight services, including the need to fly at low heights, as well as for some military air operations. It is, however, strictly not necessary that the mariner is able to interpret the aviation signals for obvious reasons – airplanes may fly at low altitude but ships never fly at high altitude.

Obstacle markings have to be visible for aviators and seamen, this is obvious, but may be an annoyance to the public dwelling in the neighborhood. This will put demands on the functioning and intensity of the system. For example: an unsynchronized blinking of light may have an adverse effect of the public acceptance of a wind farm.

3. ITEMS FOR PRESENTATION AND DISCUSSION

Participants in the meeting will present their experience in the field. Topics can be chosen from, but must not be limited to, the items below.

- Visibility in variable natural light and haze/fog (physics)
- Attention attraction level (psychology and physics)
- Acceptance
- Safety issues (other than markings)
- Interaction between different interests and implication on the rules for obstacle marking
- Different methods for obstacle marking

4. INTENDED AUDIENCE

Participants will typically represent the following type of entities:

- Universities, research organizations
- Utilities, wind turbine owners
- Aviation and maritime organisations

5. OUTCOME OF MEETING

The outcome of the meeting is the proceedings and a plan for future information exchange / and work within this area.

Proposed rules for aviation marking in Sweden

Gunnar Fredriksson

IEA
Stockholm, Sept -05

DENMARK

- Windmills between 100 and 150 m total height should be equipped with low intensity red lights >10 candela.
- In some special cases, medium intensity lights should be used >2000 candela.
- The lights should be placed on the nacelle and be visible from all directions, from the horizon and upwards.
- To my knowledge nothing is so far said about windmills higher than 150 m or lower than100 m.
- The tower should be coloured as light as possible. Except from that, there are no rules of special markings on the blades or on the tower.

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Stockholm, Sept -05

SWEDEN

- As far as possible the rules should meet ICAO standards
  - the light placed on the highest point.
- It is however proposed that windmills could have the lights on top of the nacelle.
- Windmills below 150 m should be equipped with red, flashing light of medium intensity > 2000 Cd.
- Windmills higher than 150 m should have white flashing light of high intensity >100 000 Cd.
- These rules are in force until lights with good technical reliablity can be installed in the tips of the turbine wings.

SWEDEN

- The high-intensity light should be visible 1,5° below the horizon and 3° over the horizon.
- The light of medium intensity should be seen from the horizon and upwards.
  Nothing is officially said about the opening-angle

Why

- *Statens Luftfartsvæsen* in Denmark is closely associated to the Government. Therefore the recommendations have a political touch.
- The Civil Aviation Authority, *Luftfartsverket,* in Sweden is an independent authority and has only safety in mind.

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Stockholm, Sept -05

What do we want?

- We strive towards a global, or at least European, solution.
- The solution should be simple and acceptable for:
  The industry (cheap and easy to install)
  The citizens (not disturbing)
  The pilots (easily detectable)

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The solution – 1

- A marking that says “Hey, I’m a windmill, the light you see is therefore not necessarily on the highest point – take care”.
- A different colour maybe?
  - We do not think it is needed with the proposed, extremely high, intensity of >100000 Cd.

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The solution – 2

A number of systems could be involved, such as:

- Transponders
- Digital air-maps
- Floodlighted towers
- Variable light intensity
- Cleared areas
- Etc.

IEA
Stockholm, Sept -05

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Stockholm, Sept -05

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Aviation Marking of Wind Turbines
- in a Danish Perspective

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DANMARK – WIND POWER HUB

What are we talking about…

Issues

- Increasing obstacle for obtaining permits
  - Fear among neighbours & politicians
  - Environment: Visual pollution
- Regulatory framework
  - National – CAA & Air Forces
  - International – ICAO
- Technology – Lights, control & screening
- …

DANMARK – WIND POWER HUB

Denmark

- Ongoing repowering scheme where planning for larger turbines is essential
- Negotiations between:
  - Civil Aviation Authority
  - Air Force
  - Energy Authority
  - Wind Industry
- Result: New requirements for 100-150 m

DANMARK – WIND POWER HUB

Regulation - Onshore

- Below 100 m (total height)
  - – No requirements unless site is close to e.g. an airport
- 100 – 150 m
  - – New requirements announced in June 2005
- Above 150 m
  - – Follow international recommendations (ICAO Annex 14)

DANMARK – WIND POWER HUB

100 – 150 m

- Based on experience of +5,000 turbines in DK
- No painted markings required
- Three cases:
  1. No lighting required
  2. **Steady red light, low intensity minimum 10 cd (main case)**
  3. Special locations white flashing light, medium intensity minimum 2000 cd
- Lights should be placed on the nacelle visible 360 deg. horizontally
- Turbines should be painted in a light colour
- All lights follow ICAO Annex 14 specifications

DANMARK – WIND POWER HUB

Offshore Wind Power Plants

- The Danish CAA has evaluated experience from existing installations and adjusted the requirements
- 100 – 150 m:
  - All corners: Medium intensity light*
  - Marking in between is required if distance between corners is above 5 km
  - All inner turbines: Low intensity red light
- Above 150 m ???

*Follow ICAO, Annex 14, Vol. I Table 6-3. Characteristics of obstacle lights, Type A or Type B depending on the specific site e.g. is it a new or existing wind farm, is it located close to other farms etc.

DANMARK – WIND POWER HUB

’Technology’

- Examples:
  - Synchronisation (GPS)
  - Screen light to avoid light downwards
  - Visibility measurement and control system
- The industry can use these tools to reduce disturbance of neighbours
- Some degree of standardised requirement reduce cost
- Which other technological solutions exists?

DANMARK – WIND POWER HUB

The cost issue…

- Cost components:
  - Equipment
  - Maintenance – very costly offshore!
  - Redundancy requirements?
  - Maximum repair time allowed? (offshore)
- The goal is aviation safe solutions – without increasing cost-of-energy excessively

- Marking on nacelle – <u>No blade tip lights!</u>
  - Visually a mess!
  - Technologically an even bigger problem! (Lightning protection, O & M, Complexity etc.)

DANMARK – WIND POWER HUB

Above 150 m?

- This is traditionally ICAO territory
- We need to explain that wind turbines are different from other stationary obstacles
- Achieve 'wind power plant soultions' – not just single turbines
- Review high intensity light requirement
  - Can the intensity be reduced?
  - If not → Few onshore or near-shore turbines +150 m
- Can we use other 'tools' than light?
- …

DANMARK – WIND POWER HUB

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AISM Association of Internationale de Signalisation Maritime IALA

International Association of Marine Aids to Navigation

IALA Recommendation O-117

On

The Marking of Offshore Wind Farms

Edition 2

December 2004

(Edition 1 issued May 2000)

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Document Revisions

Revisions to the IALA Document are to be noted in the table prior to the issue of a revised document.

Date	Page / Section Revised	Requirement for Revision
Oct 2004	Overall Document revised for format and readability. Definitions added Details on marking requirements clarified	Introduction of large offshore wind farms has led to a requirement for more detailed guidance on their marking. Trials indicate interference problems with radars.

IALA Recommendation on the marking of offshore wind farms

THE COUNCIL

NOTING the function of the Association with respect to the safety of marine navigation, the efficiency of maritime traffic and the protection of the marine environment;

NOTING ALSO the provisions contained within the IALA Maritime Buoyage System (MBS), and other IALA Recommendations and IALA Guidelines;

RECOGNISING the increase in the number of areas with multiple wind generators (classed as wind farms) being established and the consequent increased danger posed to navigation;

RECOGNISING ALSO that it is a matter for National Authorities to assess the navigational requirements and the risks involved and decide on how wind farms need to be marked;

RECOGNISING FURTHER that marking of wind farms is intended to preserve the safety of navigation, the marine environment and to protect the wind generators themselves;

HAVING CONSIDERED the proposals by the IALA Aids to Navigation Management Committee, and taking into account the IALA Recommendation O-114 on the marking of Offshore Structures (May 1998);

RECOMMENDS that:

1 - Offshore Wind Generators should be marked so as to be conspicuous by day and night, with consideration given to prevailing conditions of visibility and vessel traffic;

2 - National Members take into consideration the Annex to this Recommendation when marking offshore wind farms.

Annex

The marking of offshore wind farms

1 Introduction

There are an increasing number of structures, which may affect shipping. IALA is monitoring the developments of these structures and will continue to create and update documentation as required to ensure clear and unambiguous marking of waterways for safe navigation, protection of the environment and protection of the structures themselves. Authorities facing problems in this field are invited to bring them to the attention of IALA to obtain advice on current practice.

1.1 Background

The initial recommendation on the Marking of Wind farms was published in May 2000. At this point offshore wind generators were comparatively rare and “farms” were comparatively small. In the intervening years many national authorities have made decisions to increase the percentage of renewable energy generators. This has resulted in many offshore banks and navigable waters being designated for wind farm installation. The number of generators in such farms has also increased and some farms have proposals for hundreds of wind generators.

1.2 General

Consultation between the stakeholders such as Developers, National Administrations, Lighthouse Authorities, Aviation Authorities, AtoN providers, Competent Authorities and wind farm contractors and developers should take place at an early stage. In general, development of offshore energy structures or wind farms should not prejudice the safe use of Traffic Separation Schemes, Inshore Traffic Zones, recognised sea lanes and safe access to anchorages, harbours and places of refuge. On a case-by-case basis, National Authorities may consider establishing Exclusion or Safety Zones, which would prohibit or restrict vessels from entering wind farms. Such information should be shown on the navigation chart, as appropriate.

In order to avoid confusion from a proliferation of Aids to Navigation in a high-density wind farm, full consideration should be given to the use of synchronised lighting, different light characters and varied light ranges.

Some IALA members have carried out trials on wind farms to identify if interference to radar, radio navigation and radio communications is experienced. Trials indicate that wind farm structures affects shipborne and shorebased radar systems. This interference returned radar responses strong enough to produce interfering side lobe, multiple and reflected echoes. Bearing discrimination was also reduced by the magnitude of the response. It has been determined that passage close to a wind farm boundary, or within the wind farm itself, could affect the vessel’s ability to fully comply with the International Regulations for the Prevention of Collisions at Sea. Administrations / developers should keep this information in mind when designing wind farms, and they may wish to carry out individual trials to verify the impact of the wind farm on navigation.

There has been some evidence that scouring at the bases of wind generators in areas of strong tides or currents has resulted in significant deposits of material in other locations. Some authorities have insisted on fitting depth monitoring devices to wind generators to measure scour. This may need to be considered when approving wind farm proposals/locations.

2 Scope

This recommendation is for the guidance of stakeholders such as Developers, National Administrations, Lighthouse Authorities, Aviation Authorities and other competent Authorities, AtoN providers, and wind farm contractors and developers.

3 Definitions & Acronyms

Wind Generator - any individual surface structure, usually consisting of an embedded mast or tower with rotating blades and incorporating a generator.

Wind Farm - a group of individual wind generators, which are located in one block and are considered to be a unit.

Significant Peripheral Structure (SPS) - the "corner" wind generator on a rectangular wind farm or other significant point on the periphery of a wind farm.

Transformer Station - a special structure within or outside the wind farm to which the individual wind generators are connected via power cable. Power is transferred ashore from the transformer station by submarine cable.

4 Considerations During Construction

During the construction of an offshore wind farm, working areas should be established and marked in accordance with the IALA Maritime Buoyage System (MBS). National Authorities should also consider the use of guard ships in areas of high traffic density.

Notices to Mariners, Radio Navigational Warnings and Notices to Airmen must be promulgated in advance of and during any offshore wind farm construction.

Power cables between wind generators, between wind generators and the transformer station, and between the transformer station and the shore should be sufficiently trenched to avoid exposure from scouring / sand migration or trawling activities.

5 Marking of Individual Structures (Wind Turbines)

The tower of every wind generator should be painted yellow all round from the level of Highest Astronomical Tide (HAT) to 15 metres or the height of the Aid to Navigation, if fitted, whichever is greater.

Alternative marking may include horizontal yellow bands of not less than 2 metres in height and separation.

Consideration may be given to the use of additional retro reflective material.

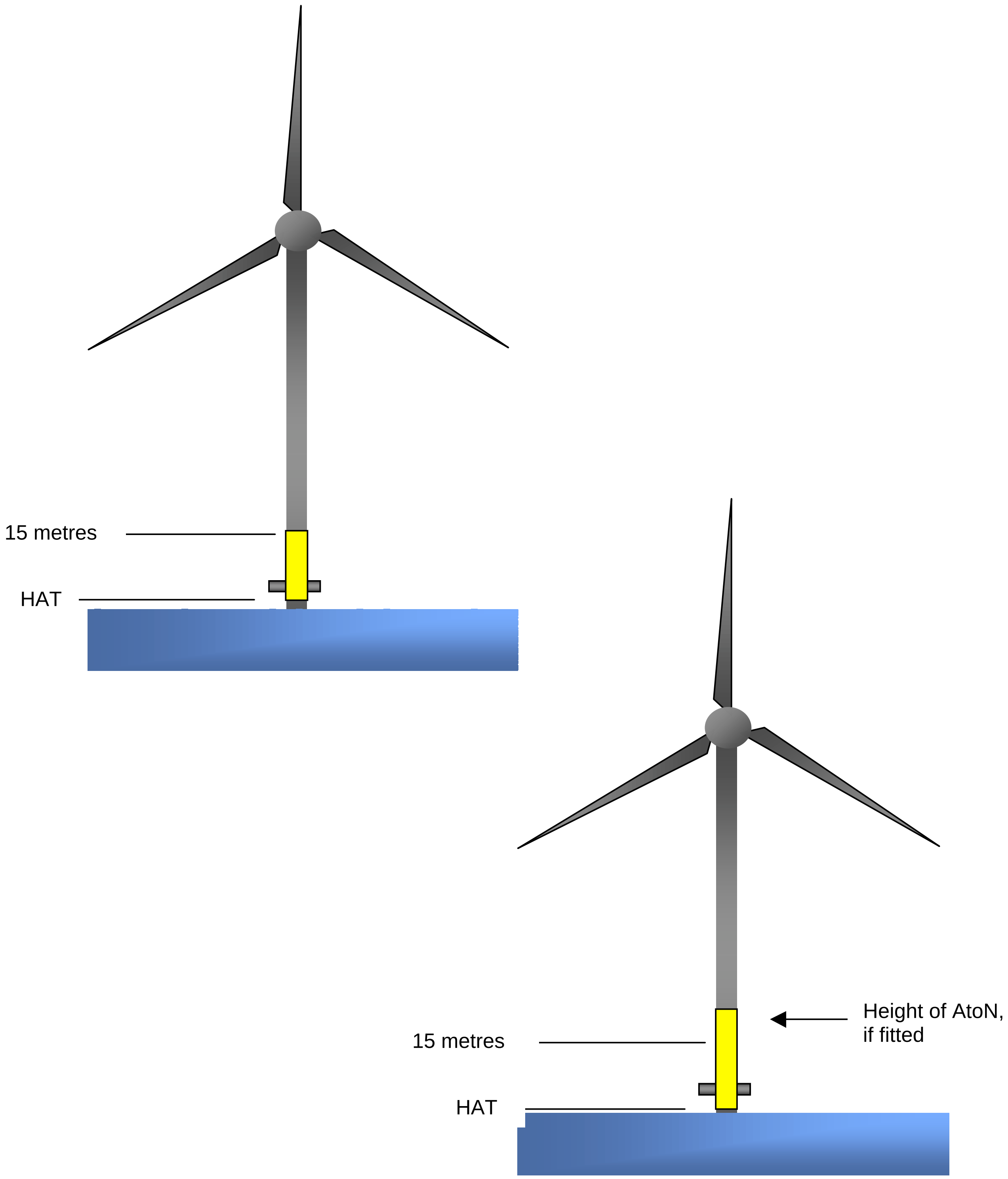
Due to the increased danger posed by an isolated structure, it should be lighted as per the IALA Recommendation on the marking of Offshore Structures(0-114) i.e. a white light flashing Morse code "U".

5.1 Aids to Navigation for marking Individual Structures

The Aids to Navigation on the structure of a wind generator should be mounted below the lowest point of the arc of the rotor blades. They should be exhibited at a height above the level of the Highest Astronomical Tide (HAT) of not less than 6 metres or more than 15 metres.

Aids to Navigation on wind turbines should comply with IALA Recommendations and have an availability of not less than 99.0% (IALA Category 2).

<u>Sample marking of individual wind turbines</u>



6 Marking Groups of Structures (Wind Farms)

A Significant Peripheral Structure (SPS) is the "corner" or other significant point on the periphery of the wind farm. Every individual SPS should be fitted with lights visible from all directions in the horizontal plane. These lights should be synchronized to display an IALA "special mark" characteristic, flashing yellow, with a range of not less than five (5) nautical miles.

As a minimum, lights on individual SPSs should exhibit synchronised flashing characteristics, however Administrations should consider the synchronisation of all SPSs. In the case of a large or extended wind farm, the distance between SPSs should not normally exceed three (3) nautical miles.

Selected intermediate structures on the periphery of a wind farm other than the SPSs, should be marked with flashing yellow lights which are visible to the mariner from all directions in the horizontal plane. The flash character of these lights should be distinctly different from those displayed on the SPSs, with a range of not less than two (2) nautical miles. The lateral distance between such lit structures or the nearest SPS should not exceed two (2) nautical miles.

6.1 Aids to Navigation for marking Wind Farms

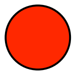
In addition to the use of lights for marking the SPSs and selected intermediate peripheral structures of a wind farm, further consideration should be given to the use of:

- Lighting all peripheral structures;
- Lighting all structures within the wind farm;
- Racons;
- Radar Reflectors and Radar Target Enhancers; and/or
- AIS as an Aid to Navigation (as per IALA Recommendation A-126).

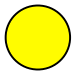
It is important that these AtoNs be used with care to mark the grouping of wind generators.

Consideration may be given to the provision of sound signals where appropriate, taking into account the prevailing visibility, topography and vessel traffic conditions. The typical range of such a sound signal should not be less than two (2) nautical miles.

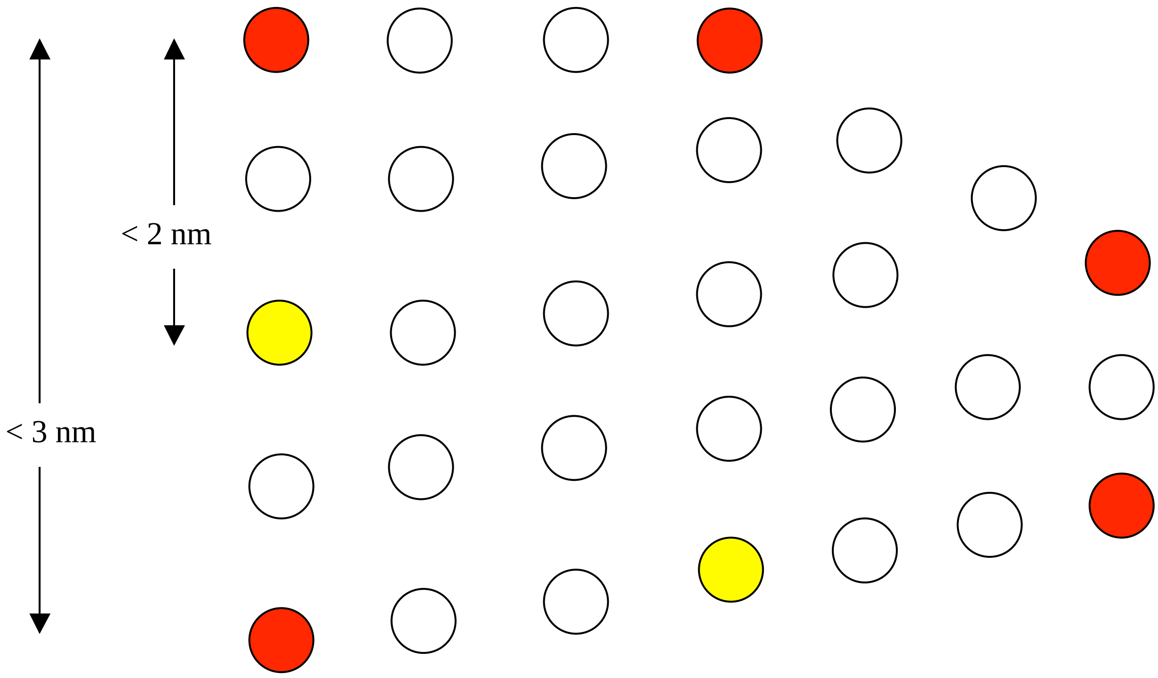
<u>Sample marking of wind farm</u>



SPS - lights visible from all directions in the horizontal plane. These lights should be synchronized to display an IALA “special mark” characteristic, flashing yellow, with a range of not less than five (5) nautical miles



Intermediate structures on the periphery of a wind farm other than the SPSs - marked with flashing yellow lights which are visible to the mariner from all directions in the horizontal plane with a flash character distinctly different from those displayed on the SPSs and with a range of not less than two (2) nautical miles



7 Additional Considerations

Depending on the marking, lighting and lateral separation of the peripheral structures, the additional marking of the individual structures within a wind farm may be considered as follows:

- Lighting of each structure
- Individual structures unlighted with retro-reflective areas.
- Individual structures illuminated with down-lights on ladders and access platforms.
- Use of flashing yellow lights with a range of not less than two (2) nautical miles.
- Identifying numbers on each individual structure, either lit or unlit.

An Electrical transformer station or a meteorological or wind measuring mast, if considered to be a composite part of the wind farm, should be included as part of the overall wind farm marking. If not considered to be within the wind farm block it should be marked as an offshore structure. (i.e. a white light flashing Morse code "U").

As far as practicable, Aeronautical obstruction warning lights fitted to the tops of wind generators should not be visible below the horizontal plane of these lights. Aviation Authorities should be consulted regarding the specification of such lights.

Examples of maritime marking

North Hoyle, UK

Utgrunden, Sweden

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IRISH AVIATION AUTHORITY

ÚDARÁS EITLÍOCHTA NA hÉIREANN

Aerodromes and Airspace Standards Department

Offshore Wind Farms Conspicuity Requirements
Advisory Material for the Protection of Air Navigation Safety

IRISH AVIATION AUTHORITY

ÚDARÁS EITLÍOCHTA NA hÉIREANN

- **OAM No. 09/02**

  Offshore Wind Farms Conspicuity Requirements Advisory Material for the Protection of Air Navigation Safety

- **History of Document**

  August 2001 - Internal IAA Meetings and Meeting between IAA and Office of the Commissioners of Irish Lights. Document developed in consultation with the Office of the Commissioners of Irish Lights in anticipation of planned offshore windfarms.
  October 2001 - Draft Produced for Consultation with Industry.

- **Consultation with the following:**
  - Irish Aer Corps (SAR)
  - CHC (SAR)
  - Commissioners of Irish Lights
  - Department of Public Enterprise
  - Irish Airline Pilots Association
- **OAM 09/02 Published August 2002**
- **Document is Guidance Material**
  - Document provides general guidance for lighting, marking and radar enhancement requirements as well as promulgation requirements.

- **Lighting Requirements to Protect Marine Navigation Safety**
  - Yellow lights on all turbines.
  - Higher intensity synchronised flashing yellow lights on Significant Peripheral Structures, spaced no more than 3 nautical miles apart.
- **Lighting Requirements to Protect Air Navigation Safety**
  - Marine lighting as above supplemented by white flashing high intensity lights on Significant Peripheral Structures $\geq$ 90m in height to highest point of structure.

- **Marking Requirements to Protect Marine Navigation**

  High visibility yellow from high water mark to the level of the marine navigation lights or double yellow bands.

- **Marking Requirements to Protect Air Navigation Safety**

  The marking required to protect air navigation is the marine navigation marking above.

- **Significant Peripheral Structures must be fitted with:**

  Radar Reflectors to protect Air Navigation Safety

and may also require the following:

Fog Signals
Radar Enhancers
Transponders
Reflectors and/or Marine Radar Automatic Identification Systems (AIS)
to protect Marine Navigation Safety

IRISH AVIATION AUTHORITY

➢ Information Required for promulgation

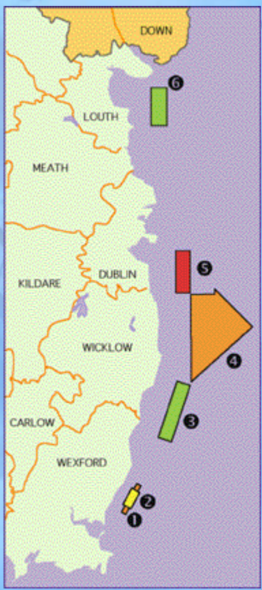
Information is required by the IAA and CIL at least three months in advance of the erection of wind machines or associated structures including:

- Positional Data in WGS-84 Co-ordinates
- Maximum Elevation of each structure
- Proposed Lighting and Marking details
- Proposed Radar Enhancer/Transponder/Reflector or Radar AIS to be fitted
- Spacing (min and max) between structures
- Planned date of erection

As-built information as above is also required after completion of the windfarm.

IRISH AVIATION AUTHORITY

IRISH AVIATION AUTHORITY



IRISH AVIATION AUTHORITY

Questions?

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IRISH AVIATION AUTHORITY ÚDARÁS EITLÍOCHTA NA hÉIREANN OPERATING STANDARDS DEPARTMENT	OPERATIONS ADVISORY MEMORANDUM (OAM)	OAM. No: 09/02 Re-Issue Date: 18/11/03
Title	Offshore Wind Farms Conspicuity Requirements Advisory Material for the Protection of Air Navigation Safety	

Contents

Offshore Wind Farms Conspicuity Requirements

Advisory Material for the Protection of Air Navigation Safety

1. General

1.1 Introduction

1.1.1 This document sets out certain minimum requirements for the lighting, marking, radar enhancing and supply of information for promulgation to ensure the conspicuity of offshore wind farm machines and associated structures.

1.1.2 The aircraft operations which have been considered in determining this guidance material include:

a) en-route instrument and visual flight between aerodromes;

b) local instrument and visual flight associated with an aerodrome;

c) search and rescue (SAR) activity;

d) helicopter operations in support of offshore installations, vessels and lighthouses.

1.1.3 Aircraft operations must comply with the Irish Aviation Authority (Rules of the Air) Order, 2001 (S.I. No. 568 of 2001) which provides that, generally, an aircraft shall not be flown:

a) at a height less than 500ft above the ground or water, or

b) closer than 500ft to any structure.

Flight at a height of 500ft requires a minimum flight visibility of 3kms.

1.1.4 There may be inaccuracies associated with aircraft altimetry. An aircraft attempting to fly at 500ft above the sea may, in certain circumstances, inadvertently be lower than 500ft above mean sea level.

1.1.5 SAR activity is exempted from the above specified minimum height and flight visibility requirements and can be anticipated to operate at 500ft or lower levels in adverse weather conditions for the purpose of saving life.

1.1.6 Helicopters supporting explorations rigs, vessels, lighthouses and offshore production platforms would not be subject to the above minimum height and flight visibility requirements while landing or taking off in accordance with normal aviation practice.

1.1.7 An object which is higher than 90m in height is considered to have significance for the en-route operations of aircraft in Irish airspace.

1.2 Purpose

The purpose of this document is to provide general guidance for lighting, marking and radar enhancement requirements and also on information required for promulgation to ensure the conspicuity of wind farm machines and associated structures, so as to protect air navigation safety.

1.3 Applicability

1.3.1 This guidance material is applicable, generally, for offshore wind farms and associated structures which are not located:

a) within 8 nautical miles of publicly licensed aerodromes; or

b) within 32 nautical miles of Air Navigation Services Radar and other radio navigation facilities; or

c) within 4 nautical miles of any permanent offshore helipads. (Note: some lighthouses, e.g. Kish Lighthouse, have helipads).

1.3.2 Within such areas specified at 1.3 (a) through (c) above, marking, lighting and radar enhancing requirements and information required for promulgation will require to be assessed on an individual basis.

1.3.3 Taking account of all the factors specified at 1.1 above, the lighting, marking and radar enhancing requirements and information required for promulgation to protect air navigation safety are outlined below.

2. Conspicuity Requirements

2.1 General

Lighting and marking requirements to protect air navigation safety consists of the same lighting and marking installed to protect marine navigation, supplemented as necessary for the protection of air navigation safety.

2.2 Lighting Requirements

2.2.1 Lighting Requirements to Protect Marine Navigation Safety

The following general minimum specification for lighting is assumed for application in the interests of safety of marine navigation, as determined by the Commissioners of Irish Lights[1]:

[1] Specification for Lighting Requirements to protect Marine Navigation Safety as outlined at 2.2.1 is provided by the Commissioners of Irish Lights.

a) Yellow lights will be fixed to all machines and shall be located appropriately at a point(s) on the structure above the Highest Astronomical Tide but below the lowest point of the arc of the structure's rotor blades. Such lights will be visible through 360° in azimuth and will have vertical divergence of 5° above and below the horizontal, 5 nautical miles visibility and a minimum of 99% availability.

b) Structures chosen as suitable for representing the periphery of wind farms are termed *Significant Peripheral Structures.* Such structures will be spaced along the periphery of wind farms at intervals of no more than 3 nautical miles, where practicable. Such structures will be lighted with flashing lights of distinctive navigational characteristic fitted above the Highest Astronomical Tide but below the lowest point of the arc of the structure's rotor blades. Such lights will be visible through 360° in azimuth and have a vertical divergence of 5° above and below the horizontal, 10 nautical miles visibility and a minimum of 99% availability.

2.2.2 Lighting Requirements to Protect Air Navigation Safety.

The lighting required to protect air navigation will be the lighting specified to protect marine navigation safety, as per 2.2.1 above, supplemented as follows[2].
All *Significant Peripheral Structures*, of height ≥ 90m, to the highest point of the structure including the top of blade spin where appropriate, above Mean Sea Level, will be fitted with high intensity warning lighting meeting the following requirements:

a) the lighting must be mounted on the highest point practicable of the fixed structure;

b) be in accordance with the International Civil Aviation Organisation (ICAO) Annex 14 standards, on a H24 basis, for High Intensity Type A lighting:-

- colour white with a flash rate of 40~60 fpm;
- have an effective intensity, with background luminance above 500cd/m², of 200,000 cd ± 25%;
- have an effective intensity, with background luminance 50~500cd/m², of 20,000 cd ± 25%;
- have an effective intensity, with background luminance below 50cd/m², of at least 2,000 cd;
- light fittings will be fully cut off so that practically no light will be emitted below the horizontal, or as otherwise agreed with the IAA;

[2] Specification for Lighting Requirements to protect Air Navigation Safety as outlined at 2.2.2 is provided by the Irish Aviation Authority.

- all lights across the farm should flash in synchronisation and reductions in light intensity should occur simultaneously, if practicable;
- be visible through 360° in azimuth.

c) any light which fails shall be repaired or replaced as soon as is reasonably practicable. An alerting system for light failure will be put in place, such as remote monitoring or other suitable method agreeable to the IAA.

2.3 Marking Requirements

2.3.1 Marking Requirements to Protect Marine Navigation.

The following general minimum specification is assumed for application to protect marine navigation safety, as determined by the Commissioners of Irish Lights[3]:

a) high visibility yellow from high water mark to the specified level of the marine navigation protection lights, or

b) double yellow bands as specified;

c) fog signals may be required to be fitted on *Significant Peripheral Structures* in wind farm developments.

2.3.2 Marking Requirements to Protect Air Navigation Safety.

The marking required to protect air navigation will be the marking required to protect marine navigation, as per 2.3.1 above.

2.4 Radar Enhancers/Reflectors.

2.4.1 Radar Enhancers Required to Protect Marine Navigation Safety

Significant Peripheral Structures may be required to be fitted with Radar Enhancers, Transponders, Reflectors and/or Marine Radar Automatic Identification Systems (AIS) as determined by the Commissioners of Irish Lights[4].

2.4.2 Radar Reflectors Required to Protect Air Navigation Safety

Significant Peripheral Structures must be fitted with Radar Reflectors[5].

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[3] Specification for Marking Requirements to protect Marine Navigation Safety as outlined at 2.3.1 is provided by the Commissioners of Irish Lights.
[4] Specification for Radar Enhancers required to protect Marine Navigation Safety as outlined at 2.4.1 is provided by the Commissioners of Irish Lights.
[5] Specification for Radar Reflectors required to protect Air Navigation Safety as outlined at 2.4.2 is provided by the Irish Aviation Authority.

3 Information Required for Promulgation

3.1 Information Required by IAA Prior to the Erection of Structures

At least three months in advance of the erection of wind machines or associated structures, the following information shall be supplied to the Irish Aviation Authority for promulgation in a manner considered appropriate by the Authority:

a) positional data representing the Estimated Position of each machine or structure to be erected. The geodetic datum to which all obstructions shall be referred is the World Geodetic System of 1984 (WGS-84). Co-ordinates should be provided in degrees, minutes, seconds and decimals of a second, as appropriate;

b) the estimated maximum elevation of each structure in feet and metres;

c) proposed lighting details for each structure;

d) proposed marking details for each structure;

e) whether it is proposed that a Radar Enhancer / Transponder / Reflector or Radar AIS be fitted;

f) minimum and maximum spacing between structures;

g) planned earliest date of erection, and

h) any other information considered relevant for air navigation.

Note: A template for supplying information required for promulgation is provided at attachment 2.

3.2 Information Required by C.I.L. Prior to the Erection of Structures

At least three months in advance of the erection of any structure, the information listed in 3.1 (a) to (h) shall be provided in an Application for Statutory Sanction, as required under the Merchant Shipping Acts, to the Commissioners of Irish Lights, with the proviso that the information referred to in (h) shall be that as pertains to marine navigation.

3.3 Information Required After Erection of Structures

Within three months of the completion of the development of a wind farm or part of a wind farm, updated information, as per 3.1 above, shall be supplied to the Irish Aviation Authority. The positional data will be derived by survey in accordance with the IAA specification for Obstruction Surveys (OAM 4/97), which is available on application from the Safety Regulation Division of the IAA.

The developer will thereafter be required to provide updated relevant information on any subsequent alterations to the wind farm.

This information shall also be supplied to the Commissioners of Irish Lights.

Note: A template for supplying information required for promulgation is provided at Attachment 2

4 Responsible Bodies

This guidance material has been developed by the Safety and Regulation Division (SRD) of the IAA in consultation with the Commissioners of Irish Lights. Any queries regarding the contents of this material, relating to air navigation safety, should be addressed in writing to:

Safety and Regulation Division,
Irish Aviation Authority,
Aviation House,
Hawkins Street,
Dublin 2.

Any queries regarding the contents of this material relating to the specification provided by the Commissioners of Irish Lights, to protect marine navigation, should be addressed in writing to:

The Inspector of Lights,
Commissioners of Irish Lights,
16 Lower Pembroke Street,
Dublin 2.

5 Future Revision of this Document

This document may be subject to future revision. Any interested party may propose an amendment to its provisions. Amendments will be agreed in consultations between the IAA, CIL, the Department of Communications, Marine and Natural Resources, and other interested parties.

Attachment 1.

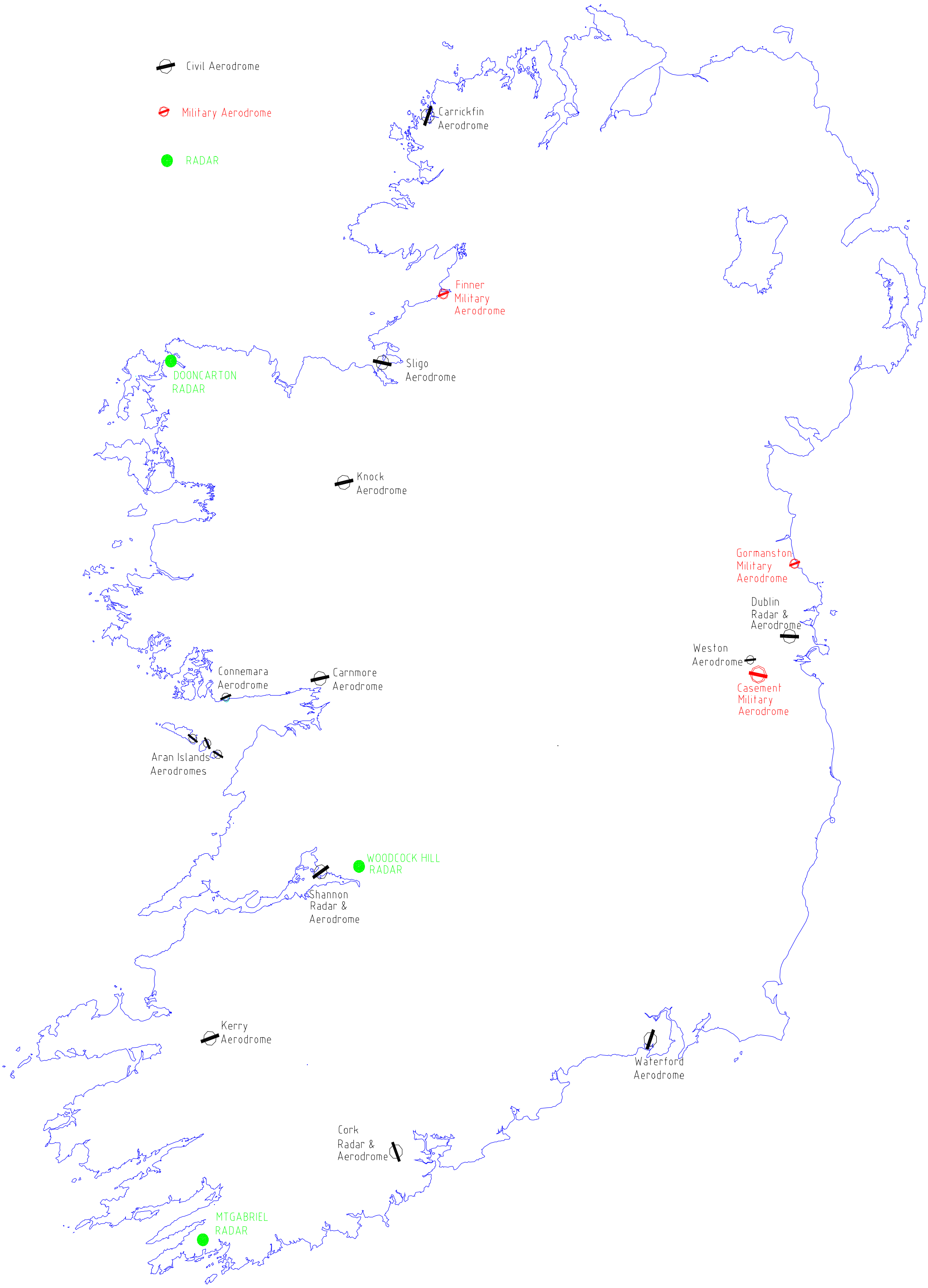
Diagram showing publicly licensed aerodromes, military aerodromes and radar facilities not located on aerodromes.

Attachment 2.

Template for supplying information required for promulgation – *Notification of Plan to Erect Wind Machines and Associated Structures.*

Attachment 1

Publicly Licensed Aerodromes, Military Aerodromes and Radar Facilities not located on Aerodromes



Attachment 2

Notification of Plan to Erect Wind Machines and Associated Structures

Obstacle Type *(e.g. Windfarm)* ______________________________

Structure Ident Number ______________________________

Obstacle Description *(e.g. Turbine 1)* ______________________________

Name *(e.g. Arklow Bank)* ______________________________

Owner ______________________________

Latitude ______________________ **Longitude** ______________________

Elevation (ft) ______________________ **Height (ft)** ______________________

Significant Peripheral Structure **Y/N** ☐

Lighting: Y/N ☐ Details ______________________________

____

Marking:

Day Mark Bands: **Y/N** ☐ Details: ______________________________

Radar Target Enhancer: **Y/N** ☐ Details: ______________________________

Radar Reflector: **Y/N** ☐ Details: ______________________________

AIS: **Y/N** ☐ Details: ______________________________

Status *(whether Permanent or Temporary)* ______________________________

Date of Erection: Earliest Date Planned ______________________________

Actual Date Constructed ______________________________

Planned Operational Period *(e.g. operation life)* ______________________________

Date of Removal ______________________

Comments ____

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Obstacle Marking

Björn Montgomerie
FOI, Sweden
Meeting at FOI, Kista, Stockholm
6 – 7 October, 2005

Possible ”Markings”

- Lights
- Paint schemes (deemed not necessary in Sweden)
- Transponder system (remote future)
- GPS system (remote future)

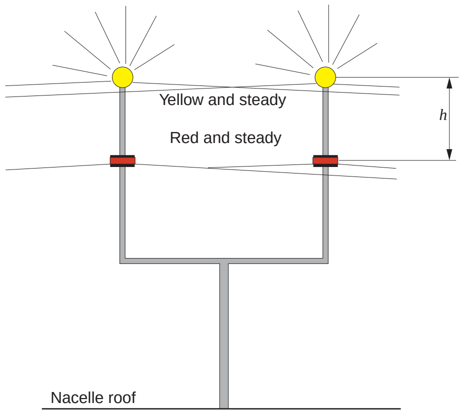
Basic requirement is **visibility**

- Visible at day and night
- Visible to the aviator
- Visible to the mariner

Markings proposed in Sweden

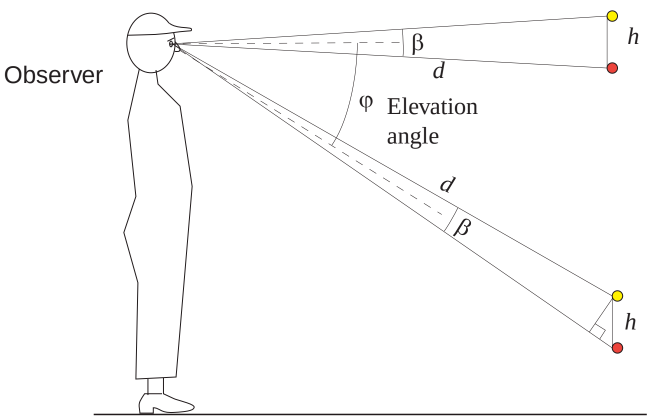
- Lights only
- Omnidirectional (blades must not cover light)
- Possible to interpret as **Wind Turbine**

Swedish proposal



Preliminary lighting proposal

Visibility



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Obstacle Markings on Wind Turbines for Safe Aviation and Marine Navigation

Björn Montgomerie, Swedish Defence Research Institute, FOI, Aeronautics Division, FFA
August 2004, meb@foi.se

1. Introduction

Wind turbines need obstacle warning aids to help the crew of airplanes, helicopters and ships to avoid collisions with the turbines. So far, the organizations performing the logistics of applying for building permits, site preparation and erection of wind turbines have generally handled each such activity as an isolated event. Thus, obstacle warning lights or markings have been applied as seen fit for the particular wind turbine or group of turbines. Although similar principles have emerged, there exists a recognition of a need for a general set of rules in this respect. The rules should preferably be international – at least valid within the European Union.

Accidents of airplanes colliding with wind turbines have not happened at all as far as this author is informed. It must be assumed that the natural visual signature and today's markings are adequate, although not uniform across the globe. Thus no response to any accident record forms part of the background for this document. The need for the present investigation rather emanates from a concern in the industry that investments made in obstacle marking may have to be protected. The number of wind turbines in the world, estimated to be of the order of magnitude 25 000, is increasing exponentially, with an annual growth of about 30% in terms of installed megawatts (MW), approaching 50 000 MW presently. This is power delivery equivalent to about 17 modern nuclear power blocks with 75% availability. Despite this fact there is still a lack of firm rules for the design and application of obstacle lights. The costs for lighting are thus becoming an issue of increasing importance. If new regulation will enforce a comprehensive and therefore expensive retrofit program, that regulation better be known as soon as possible. It seems strategically advantageous for the industry to pave the ground proactively for such regulation.

A Swedish trade organization recently took the initiative to organize the present thinking into a coherent text. The result is the present document, which is produced within a small project in an organization whose expressed work approach is to be free from business oriented influence from industry and other organizations. An existing Swedish reference group consists, however, of representatives from wind turbine manufacturers, representatives from trade and the Swedish government agencies for energy, civil aviation and marine administration. The viewpoints from the participants of the group have been merged by this author. Two meetings with the reference group have been held. This has caused two rewritings of the present text.

Thoughts and viewpoints presented in this text are to be thought of as an input to discussions about rules and regulation in Sweden as well as in an international context. The contents can be thought of as consisting of two groups of messages, i.e. partly possibilities and partly recommendations.

2.The Basic Need

Over land the reason for markings is to guide only aviators to avoid collisions with the turbine. The visual information from any high object should be as clear and unambiguous as possible. It must be possible to interpret the lighting information as "wind turbine" as opposed to all other static high objects.

At sea the visual markings must serve the need of both mariners and aviators. From the discussion in the reference group it was concluded that there seems to be no particular reason why any new markings on wind turbines should be devised for marine traffic. Thus, the present warning system in the form of lighting for marine traffic should be retained or possibly modified in accordance with the IALA text, see Ref. 1. The aviation markings at sea should be identical to those on land

It is emphasized that ambiguous information from lights for aviation and those for ships must be avoided. Thus a marine light signal code must not mean a different thing to an aviator. It may be helpful to screen off regions to limit the lobes inside of which the lights will be visible. At a reasonably close range such screening would result in the aviation marking being seen by aviators only and the marine markings will be seen by mariners only. At a large distance both marking systems may be seen by both categories.

Although a proposed separation of light information, as proposed, is recommended the consequence for low flying operation is that the pilot must be able also to correctly interpret the sea marking. This has relevance for several civil flight services, including the need to fly at low heights, as well as for some military air operations. It is, however, strictly not necessary that the mariner is able to interpret the aviation signals for obvious reasons – airplanes may fly at low altitude but ships never fly at high altitude.

3. Present Application of Safety Markings

Sweden

Swedish marking of the wind turbines consists of lights on top of the nacelle. This light is generally red and steady. The two early large machines at Maglarp (3MW) and still at Näsudden (2MW) had/has yellow light, which today can be seen as historical exceptions. Obstacles of 150m of height and higher have a certain status as far as marking requirements go. But, no distinction between turbines under 150m of total height and those over has been an issue yet since all operating turbines so far are below 150m. No particular paint scheme, for daytime attention elevation is required. It has been considered satisfactory without them. This is based on the tacit assumption that what is visible at night is certainly visible during the day, provided the lights are turned on around the clock.

Germany

In Germany a distinction between day and night is made. At daytime the markings of warning are painted patterns. Basically two orange stripes on white bottom is required at the blade tips. If, however, the turbine is located more than 5km away from an airport (size of airport is not specified) it may be provided by one orange stripe at the tip only, see Fig. 1. What happens when a new airport is to be built is not mentioned. It would logically mean that all wind turbines within 5km, having one stripe only, must have their blades repainted. The text seems to invite unnecessary complication to be avoided in future texts.

For nighttime warning purposes a steady red light on a turbine may be placed on the nacelle roof if *basically* the additional blade tip maximum height does not exceed 50m. The light may be turned on also during daylight. It is noteworthy that the German text has inserted the word basically (grundsätzlich) in the text, which will allow excesses of 50m perhaps with a special permit when required.

The exact design of these markings is defined in Ref 2.

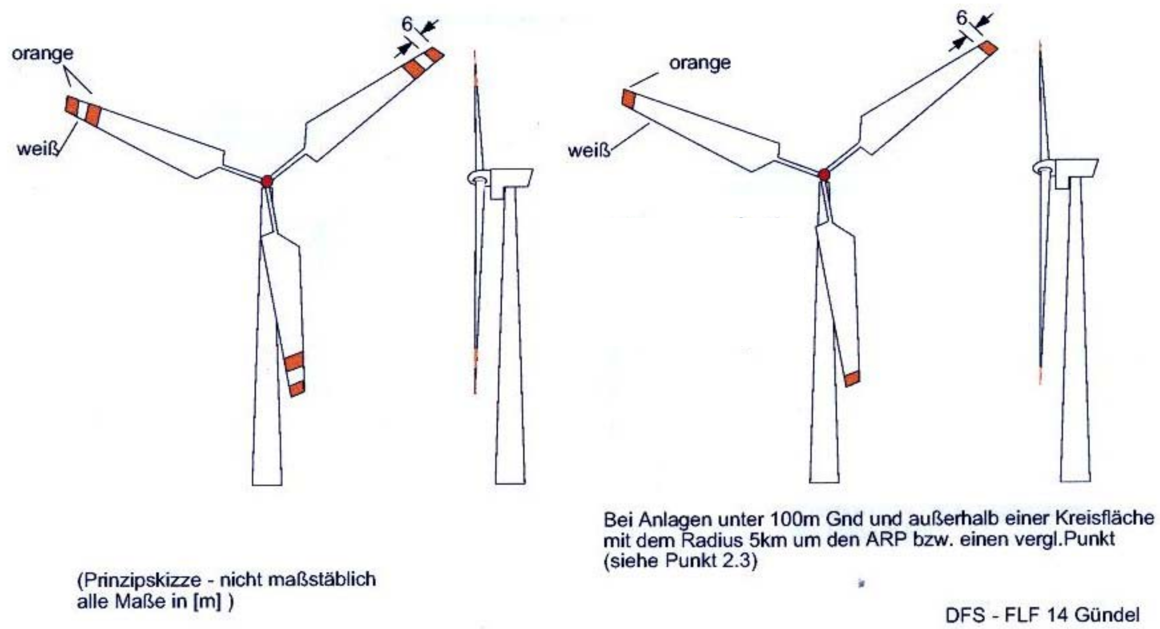


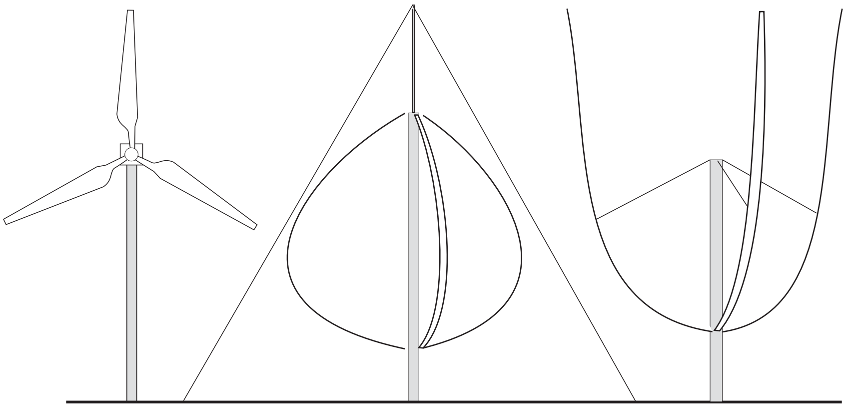
Figure 1 – Copy from Ref. 2

Denmark

In Denmark the present marking consists of two red and flashing lights on top of the nacelle. This is accepted for obstacles of heights up to 150m. If the blade tip in top position is lower than 100m no particular markings are required. The blades so far have not been required to be marked at all. But, in ongoing discussions requests have been voiced in favor of a paint scheme similar or equal to that of the German pattern. The Danish rules for markings on wind turbines are still a bit fluid (as in Sweden). Active discussions on the topic are presently taking place in Denmark as well.

4.Implementation of Future Wind-Turbine/Obstacle Warning Lighting

Several possibilities for markings exist. Some of these are discussed below. The basic view must include the fact that the highest point on a horizontal axis wind turbine is a mobile blade tip. For some, very unusual, vertical axis machines there may or may not be a highest point on the structure, which is not mobile. In the case of a fixed highest point it is simply proposed that the turbine be marked as a fixed tower, see b in the figure below. All arguments discussed below should therefore apply equally to turbines of horizontal axis and vertical axis with mobile highest points on the structure (a and c, see figure 2).



a b c

Figure 2 – Different types of wind turbines

4.1 Illumination at the Highest Point

It is possible to provide the blade tips with lights. One example of available lights comes from ENERTRAG, see Ref 3. The function for a three-bladed rotor, as proposed by the Enertrag company, is to turn on the horizontal axis light 60˚ before zenith and turn it off 120˚ later, while the lower blades are unlit. As soon as the upper blade has reached its 60˚ past zenith the light of the next blade repeats the on/off cycle etc. For a two-bladed rotor a similar on/off schedule can easily be imagined. How this scheme would apply to the type c vertical axis machine is not equally obvious.

Enertrag also provides variable light intensity depending on the intensity of the natural light. Typically the light intensity at night is one tenth of that of daylight.

The system would provide the aviator with maximum perception awareness while people on the ground, especially those unrelated to the turbine operation, would experience the mobile light as that coming from an amusement park with solid complaints as a consequence. Shielding this type of light from view is not possible.

It can be reasoned that turbines already in operation would be free from the obligation to carry blade tip lights, while new blades would be stipulated to have them. But, the weakness in such a proposal lies in the dual behavior of turbines, because, old blades may live for a number of decades. As a consequence the dualism in the light signals would linger on for quite some time. Moreover, the installation of tip lights require a relatively costly extra activity for inserting electrical wiring in the blade material during manufacturing and furthermore to shield these lines from lightning. When a failure occurs, perhaps because of a strike of lightning, the rotor would not rotate after the emergency stop procedure is finished. Thus, the blade that happens to be near vertical and up would probably be the one carrying the faulty light (Murphy’s law) such that the turbine would produce no light at all for the long time it takes to replace/mend the faulty blade. This must be compared with a light on top of the nacelle where repair can mostly be carried out promptly. The equipment has not been widely tested, which in itself would contribute to a certain reluctance to apply the technique.

It seems that tip lighting has many features detrimental to regular safe and inexpensive operation of wind turbines but it has only one advantage, although a strong one.

This discussion does not rule out the Enertrag system. It may find its place in certain specialized locations where its light signals certainly would be well understood by any aviator. Such locations could be in the proximity of airfields.

4.2Lighting at the Nacelle Top

a. Specifying the Need

Placing the warning light on the roof of the nacelle raises the question about sufficient pilot awareness. Since, during the dark hours, the pilot will not see the highest point on the turbine he must be able to ascertain that what he sees are the markings of a *wind turbine*. This information should be enough to estimate a safe flying height above the topmost blade position. Thus, it is critical that the pilot understands that the obstacle is truly a wind turbine. This insight can only be had if the light on the top of the nacelle signals this fact with distinction in relation to other ambient lights.

b. Lights must be visible from all directions of the compass

A fixed light at the top of the nacelle is easy to operate and repair. When a problem is identified with such a light an additional advantage might be that it probably has a "twin light" which still works. This gives continuous lighting while one is faulty. The reason for the possible need of two (almost) identical lights is that when there is no rotation, for whatever reason, the vertical up blade may obscure a singular light. The cure might be an adjacent "twin light". At least one of the two will then be visible from all directions of the compass (provided both are active).

Other schemes may be devised such as one light behind the nacelle and another at the hub (spinning with the rotor), although shielding downward will be practically impossible at the rotating light. But, any design that permits the light to be visible from all directions at all times should in principle be permissible.

c. Steady or Blinking Light

In order to be able to discriminate a wind turbine light from a fixed object light, two classes of lights can be discussed. Either a special blinking pattern or a steady light could be used. As indicated previously, blinking lights should be avoided for reasons of public tranquility, although they are superior for attracting the aviator's attention.

A steady light, which allows the knowledgeable observer to discriminate the turbine from any fixed obstacle, will also serve the need for safety. Blinking will, however, occur under all circumstances at every blade passage if the rotor is between the light and the observer. This is unavoidable. A few more aspects on blinking light, in relation to public annoyance, are presented under subsection *g* below.

d. Distinguishing Turbine Light from Other Lights

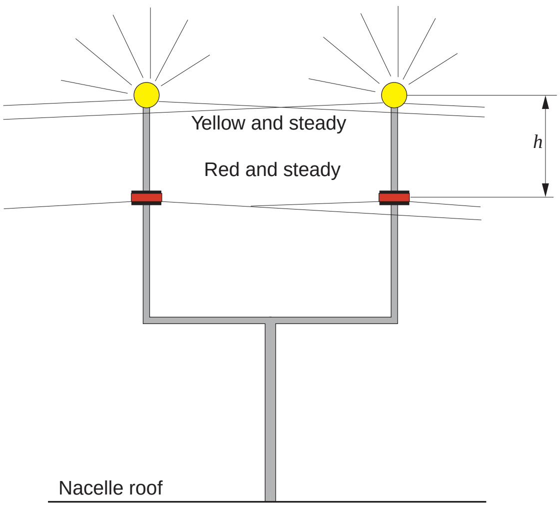
In order not to confuse the turbine light with all other visible light sources a two-color light seems to be an answer to this need. The following idea is offered.

The combination of red and yellow, both steady, should not have been reserved for any other purpose. Advantages are that yellow allows maximum penetration during hazy conditions and red provides maximum reception by the human eye during dusk and darkness.

Should dual and steady lighting be considered unacceptable for reasons of not attracting attention and/or technical complexity of four lights, only one yellow light could be used. If, after discussions, the light is required to flash, the IALA rules, for marine navigation, could be copied. IALA proposes that yellow flashing lights could be used for groups of sea based wind turbines. The flashing is furthermore suggested to signal a special "IALA mark", Morse code fashion. A question of the IALA implementation of the yellow light presents itself because that text proposes white light flashing the Morse code for "U" for singular turbines at sea while, for groups of turbines the yellow flashing light is to be used. It is not immediately clear to the novice reader why a distinction of light signals would be necessary, since one turbine would have one light and a group of turbines would have several. It should be easy to distinguish one from several, thus clarifying to the observer if he is approaching a single turbine or a group of turbines.

To have identically equal signal systems for sea and air would promote safety. But, the air safety signals would have to be equal on land and at sea which brings up the question of public acceptance again (flashing light). Speaking in favor of one flashing light is the fact that this light signal is universally understood to mean "danger – watch out". Another example is road construction block light, which is flashing yellow. The flashing light would not, however, distinguish the turbine from other objects.

People in the wind turbine industry tend to shy away from flashing light because of the stigma from the experience of civil court action caused by individuals who oppose what they perceive as visual pollution, which is largely generated by the flashing light. From discussions with the reference group application of two yellow and steady lights would be a probable industry stance in a negotiating role on this matter.



Preliminary lighting proposal

Figure 3 – Proposed lighting where the red lights may or may not be removed

e. Judging the Distance to a Turbine

If the two-light arrangement is applied it is important that the distance, indicated by the letter *h* in the sketch of Fig. 3, be specified to be equal at all installations in order for the interpreter to be able to judge the distance to the turbine. For a recommendation of the value of *h* the physics of light mixing with increasing distance will have to be penetrated first. Then also the maximum distance at which the red and the yellow will be perceived as two lights, rather than a mixed orange shade, must be specified.

f. Possibilities to Judge the Radius of the Rotor
At night the proposed lighting according to Fig. 3 will not convey any information of the added height above the light caused by the rotor blades. It is possible to use different flashing frequencies for different sizes of the rotor or alternatively more lights. Such arrangements are, however, more complicated. They might even invite misinterpretation in addition to the extra unavoidable unwanted visual pollution.

The Y arrangement of the poles holding the lights, in Fig. 3, is not meant to be an indication how to build the structure for the lights. The lights may be extended from the nacelle with individual arms or in any other way compliant with the basic requirement that the light must be visible from all directions.

g. Light Lobe Limitations
The light is proposed to be shielded from view at the ground. However, because of the need for wide visibility to aviators it is to be made visible on flat ground at a radial distance from the turbine of 5 km. This defines the limiting cone angle downward. Considering the remote possibility of a helicopter pilot descending from above a turbine, without having observed the turbine prior to the manoever, the limiting upward cone angle should be considerably higher than that defining the lower limit, preferably 90˚ but acceptably much lower. Helicopter flying procedures explicitly warns against such flying patterns, which is information to be analyzed carefully before an upward cone angle is to be defined. Therefore no such corresponding angle appears in the sketch above. During the discussions in the reference group 10° was mentioned as a very high angle. The number was compared with airplane landing procedures where the descent angle is typically 3° only.

The lower cone angle limit proposal is, however, directly taken from existing regulations valid for towers with heights in excess of 150m where a white blinking light is required. The proposed steady light is in itself non-obtrusive. Furthermore, if the light is hidden from view, within a radius of 5km from the turbine, the public complaint activity will be minimized. The remaining annoyance, because of lighting, consists of blinking because of blade passage, especially in hazy conditions where the flashing will be observable at much closer range.

h. Remote Monitoring
To make prompt repair possible, when a light ceases to function, positive remote light status signaling must probably be a requirement in the regulatory text on the matter. This can be used to alert the repair team to the need for action. This is a standard feature already today and it should meet with no objections in future discussions.

i. Intensity of Light
In daylight conditions the turbine should be visible even without lights. But, because of very variable daylight conditions, it will be desirable to keep the lights operational 24 hours per diurnal. Presently the lights on top of fixed towers are adapted to the ambient light by variation of the intensity of the light emission such that the highest intensity occurs at daytime and the lowest at night. This practice should probably be retained in a proposed future lighting system as well. But argumentation has been put forth in favor of having the same intensity based on the thought that what can be seen at night certainly can be seen in daylight. If such an argument is accepted a low constant intensity light would be chosen. But, the existence of mist degrades this argument.

The light intensity arises, as the compound physical effect, from the light source power and the size of the stereometric angle defining the lobe within which the light is visible. It is therefore important to investigate the human perception characteristics connected with reception intensity and level of haziness in the atmosphere together with a specified distance required for first perception. These parametrical relationships should be readily available from the literature, in support of such an effort.

4.3Clusters
Each turbine in a cluster may carry its own lighting as any isolated wind turbine. But, a group of wind turbines should not need individual lights. If the applicant company so wishes an investigation to reduce the number of lights may be conducted. As a guide for such an investigation only the turbines that constitute the corners of the group need be provided with lighting. If the highest turbines, or any other highest object, happen to be located inside the perimeter, defined by the corner turbines, they may need their own lighting if their height exceeds that of the corner machines by a certain differential height, say 40m.

The logics of reduction of the number of lights hinges upon the important definition of which turbines that belong to the “group”. If e.g. five wind turbines are configured with two of the turbines located ten rotor diameters away from the three and the three are five diameters away from each other, it can hardly be said that the outlying two are part of the cluster of five. In brevity, the internal distance between turbines determines what should be considered a group.

5.Alternate Obstacle Warnings

5.1 Paint Schemes

In order to attract attention German rules stipulate that the blade tips be marked orange and white in tangential stripes.

From observation of several wind turbines over the years mostly it appears as an unnecessary measure to provide the blades with the German paint scheme. This statement holds for times of the year when there is no snow on the ground. For a pilot with a view of the turbine from the air the contrast between the white blades and tower against the darker ground is clear enough for identification of the turbine. Orange markings, at the tips only, adds only marginally to the pilot’s attention. When the ground is covered with snow the paint markings will possibly have a place. But, if warning lights are turned on also during the day they will have the effect of attracting attention. This should eliminate the need for paint marks. Thus, it is recommended that no particular paint schemes be required in a future regulatory text on this matter.

5.2 Transponder

One possibility that has been mentioned is to exploit the transponder technique. In aviation this is standard even for small airplanes. The area control sends out a radar pulse/message in a narrow lobe, which rotates covering the 360 degrees in a certain amount of time. Any airplane within this lobe, with a transponder active, will respond to the control radar pulse. The receiving electronics at the control station will then interpret the response and present the distance and also mostly the altitude of the airplane to the air traffic control personnel. The very same technique could be utilized to alert a pilot to the proximity of a wind turbine. If so, the airplane would have to carry the radar equipment while the wind turbine would contain a transponder. By means of adjustment the airplane receiving electronics could filter out any responses from wind turbines being too far away to merit attention, thus providing warning only for those that are of interest. The exclusive application of the transponder technique for this purpose has not seriously been proposed. Not even one experiment known to the author has been carried out.

5.3 GPS

It would be possible to set up and maintain a database of high obstacles. Each obstacle could be characterized by at least geographical position coordinates and the height above ground. On board the air plane the computer would contain this database and logics to utilize it. Two difficulties emerge when this idea is pondered. The coordinates will be erroneously given for some high objects and there is a known difficulty in updating such a database. Recently FOI, Aeronautics Div., FFA has been looking into the status of the Swedish database of wind turbines locations thereby gaining insight into the shortcomings of system and procedures. A rigorous and well functioning system for this purpose would be costly, and yet, probably not completely dependable anyway.

For the future, however, it is highly desirable to develop legislation such that channels for information flow, of coordinates and other elements of relevant information, to a continuously updated database can be a reality. It would most likely be a simple matter to first organize a database for wind farms at sea. But, it is clearly desirable to also include the land based turbines in this database. Then the step toward a complete database for all high obstacles, of any kind, is not a remote thought. Once the dependable database is set up there is no clash of interest between lighting and GPS coordinate information utilization by the low flying aviators. A reporting system for identified errors in the database must also be part of the overall database system.

5.4 Night Vision Goggles

For specially trained rescue teams, performing flights at low altitude, infrared radiation from the ground and the turbines usually provide adequate contrast to be utilized by the infrared technique. Thus, night vision goggles could be used alone or in combination with lighting on wind turbines.

5.5 Radar Reflectors.

Radar 90 degree corner reflectors will increase the radar reflection intensity. However, wind turbine tower and rotor combinations are already powerful reflectors. Radar reflectors are therefore presently not seen as necessary.

6.Balancing Safety against Aesthetics

The German warning paint scheme on the blades is considered an eye sore to many people. In a discussion of these matters the value of the paint will have to be pitched against the freedom from visual pollution. No paint scheme is presently used in Sweden or Denmark.

Since it is considered by some that light markings are unaesthetic and therefore disturbing, how ever discrete, there is a technique available to keep the lights off most of the time. This is accomplished by radio communication from the particular airplane that is being used for low level flight. The wind turbine is equipped with a radio receiver, which identifies this message from the airplane and switches on the warning lights. The very same technique is being used in aviation at unattended airports where the radio is set at the particular airport frequency. By holding the sender button for typically 10 seconds the runway lights are turned on. Although this is a well proven technique it inevitably invites problems with reliability, which in the balance makes the value of the application of radio/light control doubtful.

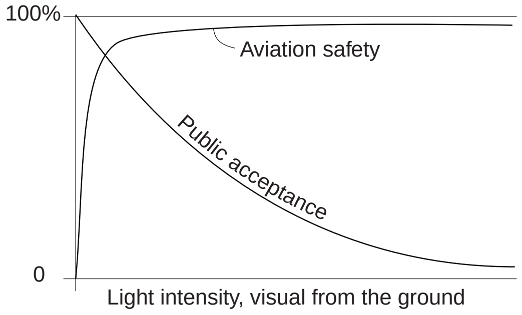


Figure 4

The conflicting requirements from safety and visual aesthetics may be described with the aid of a simple intuitive diagram. Light intensity on the x axis signifies intensity of light as perceived by the public. Increasing intensity is caused by more powerful light emission and/or intensity of flashing, which is equivalent with increasing obtrusiveness. The public acceptance curve for this intensity is seen to drop relatively gently. The aviation safety curve rises rapidly and reaches the “knee” of diminishing return. Thus even modest lighting reaches a high level of safety while public acceptance is still at a high level. The guidance from this exercise in overview is teaching us that low level lights are probably good enough. As pointed out previously no accidents involving the combination of wind turbines and airplanes have occurred so far. Since there should be a certain coupling between “light intensity” and investment in lighting, the lower intensity on the x scale will, furthermore, promote a modest beneficial lower cost of energy production.

This way of reasoning does not give any exact numbers. But, this conclusion merely reflects the “softness” of this issue. There are certainly complicating factors attached to this issue, such as e.g. light lobe control. Despite the need to weigh many small issues the writers of recommendations, and later rules, should not loose sight of a few important points. They are:

a) The light must be interpretable as *beware of wind turbine*
b) Modest lighting can be made to promote aviation safety
c) Equality of signaling across national borders promotes safety

7. Some Manufacturers of Lighting Equipment and their Products

ENERTRAG, See Ref. 3. - Products include LED lights for wind turbines. Light control boxes with different logics for switching with time or ambient light are part of the assortment. Some inventive features are presented in their prospectus available from the web.

HONEYWELL, with various addresses in different countries, has a variety of lights including those for wind turbines.

Brøndberg &Tandrup International A/S (BTI) of Copenhagen, Denmark has an assortment of lights some of which are suited for wind turbines.

8.References

1. The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), Recommendation AISM O-117, first issued in May 2000. A revised issue is planned to appear during 2004.

2. Nachrichen für Luftfahrer, Teil 1, 48. Jahrgang – Richtlinien für die kennzeichnung von Luftfahrthindernissen des Bundesministeriums für Verkehr, Bau- und Wohnungswesen, 22 Dezember 1999

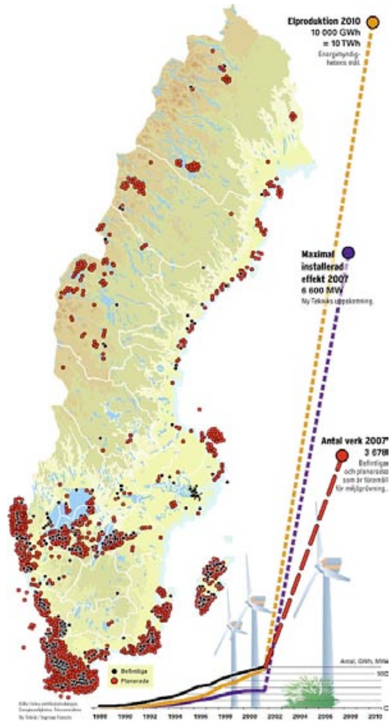
3. ENERTRAG, Windfeld Systemtechnik GmbH, Nechlin 7, 17337 Nechlin (Uckerland) in Germany - An information package can be found on the web (www.enertrag.de).

The Swedish aviation obstacle database

This map of planned and existent wind turbines was published in “Ny Teknik” early 2002. The planned part contains a significant share of outdated information.

There is a need to eliminate outdated wind turbine projects in this and other military databases as new projects can be turned down due to an area being considered “saturated” in one way or another.

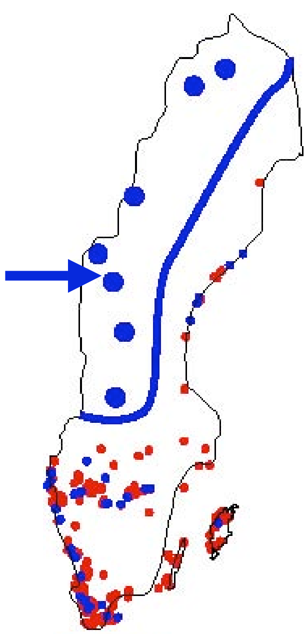
Who is responsible for deleting invalid data? An occasional survey showed that some planned projects actually had been built.

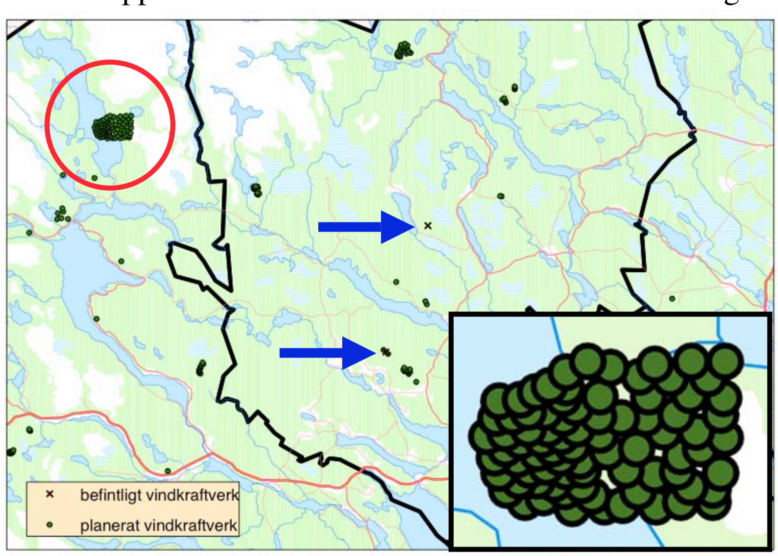


Vallrun V-52/850, Almåsa V-52/850

Q: What is going on?

A: Applications to the armed forces are free of charge





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Summary of IEA R&D Wind – 46^{th} Topical Expert Meeting on

OBSTACLE MARKING OF WIND TURBINES

October 2005, Stockholm, Sweden

Background

Wind turbines need obstacle warning aids to help the crew of airplanes, helicopters and ships to avoid collisions with the turbines. So far, the organizations performing the logistics of applying for building permits, site preparation and erection of wind turbines have generally handled each such activity as an isolated event. Thus, obstacle warning lights or markings have been applied as seen fit for the particular wind turbine or group of turbines.

Obstacle markings have to be visible for aviators and seamen, this is obvious, but may be an annoyance to the public dwelling in the neighbourhood. This will put demands on the functioning and intensity of the system. For example: an unsynchronized blinking of light may have an adverse effect on the public acceptance of a wind farm.

Two international organisations, ICAO[1] and IALA[2] work with recommendations for marking of wind turbines. ICAO is currently working on producing requirements specifically for marking and lighting wind turbines but have not yet completed these deliberations. The ICAO requirements for marking and lighting obstacles apply to all obstacles including wind turbines at present. But, there is still not a unifying agreement on the aviation warning marking lights.

From a few meetings in Sweden on this topic it appears that the present sea markings, for fixed obstacles, will be accepted in their present IALA forms without modifications.

Participants/Presentations

A total of eight participants attended this meeting with representatives from Denmark, Ireland and Sweden. The participants represented both maritime and aviation interests as well as manufacturers and developers.

Five presentations were given on the following topics:
1. Proposed rules for aviation marking in Sweden
2. Aviation Marking of Wind Turbines - in a Danish Perspective
3. IALA Recommendation O-117 on the Marking of Offshore Wind Farms
4. Offshore Wind Farms Conspicuity Requirements
5. Proposed lighting configuration for wind turbines

Discussion

The two different recommendations from ICAO and IALA, for obstacle marking were discussed and evaluated. It was concluded that aviation marking recommendations are far more demanding than the corresponding rules for maritime markings. However, the aviation recommendation does not cover every detail in how the actual marking is to be implemented.

All participants agreed that a holistic approach must be applied in this area, where many interests have to be dealt with.

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[1] International Civil Aviation Organization, www.icao.org
[2] The International Association of Marine Aids to Navigation and Lighthouse Authorities, www.iala-aism.org/web/index.html

The holistic approach should include:

- Safety
- Public acceptance
- Cost within reason
- International standards and harmonization

Structures considered to be an obstacle are associated with two categories of information:

1. Indication on a map and database showing position, extent and elevation above sea level as well as over ground
2. Lighting and painted marking

Adequate promulgation (Category number 1) is the main means to announce the presence of an obstacle. All pilots and seamen should make themselves aware of the most up to date information. Because of this it is of the utmost importance that relevant data on all obstacles, including windturbines, are kept updated in Aviation Information Publications (AIP) and Notices to Mariners (NtM). The visual marking is only to inform about the presence of an obstacle that already should be known. The Irish participant emphasized that the role of marking is to give visual information to aviators and seamen, in addition to what they already are supposed to know. This caused the remark that, if written information were to be considered sufficient, no markings whatsoever would be needed. The comments reflect the interest to go to the fundamental basics of markings.

A discussion was held on ways to mark wind turbines in order to try to find an outline of how the rules should be implemented in real world turbines. E.g. any new rules should preferably apply to new turbines only, thus allowing older turbines to retain their old markings (unless these old markings can be suspected to invite a collision hazard).

Aviation

Attached to this document, in Appendix B, is table 6-3 from ICAO “characteristics of obstacle lights”, which summarizes the light requirements for obstacles.

Single turbines

Light if the wind turbine is an obstacle. For guidance as to what is defined as an obstacle see ICAO Annex 14 volume 1. H below denotes highest point, to top of blade spin. If it is not an obstacle no lighting is needed, (only in case of offshore turbines, wind turbines onshore will normally require obstacle lighting as the majority will be above 90m in height). Note that even if the highest point (blade in its uppermost position) is higher than 150 m, the nacelle is rarely at that height. Only in those cases that the nacelle-top is higher than the 150 m the light should be visible slightly below the horizon. All lights should be visible 360 degrees in azimuth.

Given the present ICAO regulations the following is proposed if the object is considered an obstacle. All lighting shall be on the nacelle, thus not on the highest point. Definitions on intensity levels can be found Appendix B of this document.

H < 90m (100)	No marking or lighting if offshore, low intensity (LI) fixed red obstacle lighting may be required if onshore.
90 (100) < H< 150	Onshore: Low intensity steady red light, normally not visible below the horizon (except at tower bending and low clouds). Medium intensity (MI) fixed red lights may be required in certain circumstances near aerodromes. Offshore: high intensity type A flashing white light. Normally not visible below the horizon. Vertical beam spread should be 3 degrees up and zero down.

H > 150	High intensity (HI) type A flashing white light. Not visible below the horizon if the nacelle-top is at 150 m or lower. Vertical beam spread should be 3 degrees up and zero down.

Wind Farms

Light if the wind turbine is an obstacle. For guidance as to what is defined as an obstacle see ICAO Annex 14 volume 1.

General principles:

- A small wind farm, (onshore), say <10, may be lit on one of the highest points (nacelle), depending on the shape of the farm (minimum number of lights consistent with safety). For offshore windfarms light the peripheral turbines and suitable significant points!
- Large wind farm: Clearly indicate the periphery and significant points, based on a 3 nautical mile visibility. The other turbines do not have to be lit.

Some attendants noted that in no case does it seem necessary to use lights of medium intensity. The reason is that the high intensity light varies between 200 000 Cd at daytime, to 20 000 Cd at twilight conditions and 2 000 Cd at night, while the medium intensity light has an intensity of 2 000 Cd in all conditions. As the high intensity light is white it is believed to be less offensive to the public than the red from the medium intensity light. However, the cost if lighting equipment is however higher for the HI lights.

An Alternative Marking Option

One Swedish proposal was to adopt a principal that the wind turbine markings be specific to wind turbines and other structures where the highest point, such as the upper tip of a blade, can not be lit. The simple idea behind this proposal can be understood if e.g. an emergency pick-up mission for a pilot of an ambulance helicopter is considered. If markings on top of fixed objects and wind turbines are the same, in low visibility this pilot will have to assume that all lights are markings on wind turbines! Therefore he must pass above the light with a generous margin for a rotor radius. This may force him either to ascend into low clouds or go around the obstacle at a “safe” rotor radial distance + a margin. Indiscriminate obstacle lighting thus eliminates the option to pass close and above future fixed obstacles in marginal visibility circumstances. A discriminating light for non-fixed obstacles would preserve this option. However, the group, gathered at the 46th Topical Expert Meeting, voted down this proposal.

Maritime

Maritime marking according to IALA O-117 was considered to be relevant, see also documentation O-117 in presentation No4.

Miscellaneous

Below are a number of items commonly agreed on, regarding aviation lighting:

- Blade tip lights are considered to be too complicated and visually polluting. All lighting should be located on the nacelle
- White is more acceptable than red
- All flashing lights are to be synchronized if possible
- As little as possible should be seen below the horizontal plane. Under normal circumstances this means that no light is visible from the ground
- All wind turbines should have as light a colour as possible, preferably white

- Along with lights there could be one or more systems giving additional safety. Such systems include:
  - Up-to-date flight maps
  - Transponders
  - Radar-reflectors
  - Paint schemes
- New marking rules should only apply to new turbines

Other information

Preliminary Danish plans for lighting offshore below 150m are as follows:

- Outline of perimeter with medium intensity lighting
- Rest of turbine with low intensity lighting

Price examples of lighting devices.

LI	700 - 5000€
MI	5000 - 12500€
HI	5000 - ?€

Information obtained after the meeting

UK Aviation Authority has implemented recommendations for lighting wind turbines in territorial waters. The lighting principle states that the wind turbines on the periphery of a wind farm need to be fitted with at least steady red medium intensity light. The other turbines do not need to be lighted. The text describing the lighting principle is attached to this document in Appendix A. (Editor's note: "Territorial waters" must certainly even include waters in the UK economic zone.)

Continuation

The intention of the group is to continue informing about these topics. An E-mail list of interested people is anticipated and will be set up by the Operating agent.

References

1. International Civil Aviation Organization, (ICAO), Annex 14 to the Convention on International Civil Aviation, Aerodromes, Volume 1, Aerodrome Design and Operations, Fourth Edition July 2004.
2. IALA Recommendation O-117, On The Marking of Offshore Wind Farms Edition 2, December 2004

Definitions/Links

- IALA = The International Association of Marine Aids to Navigation and Lighthouse Authorities, www.iala-aism.org/web/index.html
- ICAO = International Civil Aviation Organization, www.icao.org/

Appendix A

The following information was obtained from Smailes Baggy[3] (MarkS.Smailes@dap.caa.co.uk) after the meeting.

"*Given the lack of international guidance, the UK has developed a statutory (legal) requirement to light offshore wind turbines. Article 134 of the UK Air Navigation Order, which came into effect during January of this year (editors comment, 2005), requires that turbines of 60m or more must be lit. A copy of the article is attached*."

[3] UK Civil Aviation Authority, Directorate of Airspace Policy

Lighting of Wind Turbine Generators in United Kingdom Territorial Waters

1.—(1) This article shall apply to any wind turbine generator which is situated in waters within or adjacent to the United Kingdom up to the seaward limits of the territorial sea and the height of which is 60 metres or more above the level of the sea at the highest astronomical tide.

Subject to paragraph (3) the person in charge of a wind turbine generator shall ensure that it is fitted with at least one medium intensity steady red light positioned as close as reasonably practicable to the top of the fixed structure.

Where four or more wind turbine generators are located together in the same group, with the permission of the CAA only those on the periphery of the group need be fitted with a light in accordance with paragraph (2).

The light or lights required by paragraph (2) shall, subject to paragraph (5), be so fitted as to show when displayed in all directions without interruption.

When displayed –

(a) the angle of the plane of the beam of peak intensity emitted by the light shall be elevated to between 3 and 4 degrees above the horizontal plane;

(b) not more than 45% or less than 20% of the minimum peak intensity specified for a light of this type shall be visible at the horizontal plane;

(c) not more than 10% of the minimum peak intensity specified for a light of this type shall be visible at a depression of 1.5 degrees or more below the horizontal plane.

The person in charge of a wind turbine generator shall –

(d) subject to sub-paragraph (b) ensure that by night, any light required to be fitted by this article shall be displayed;

(e) in the event of the failure of the light which is required by this article to be displayed by night, repair or replace the light as soon as is reasonably practicable.

When visibility in all directions from every wind turbine generator in a group is more than 5km the light intensity for any light required by this article to be fitted to any generator in the group and displayed may be reduced to not less than 10% of the minimum peak intensity specified for a light of this type.

In any particular case the CAA may direct that a wind turbine generator shall be fitted with and shall display such additional lights in such positions and at such times as it may specify.

This article shall not apply to any wind turbine generator in respect of which the CAA has granted a permission under this paragraph to the person in charge.

A permission may be granted for the purposes of this article in respect of a particular case or class of cases or generally.

In this article –

(f) 'wind turbine generator' is a generating station which is wholly or mainly driven by wind;

(g) the height of a wind turbine generator is the height of the fixed structure or if greater the maximum vertical extent of any blade attached to that structure; and

(h) a wind turbine generator is in the same group as another wind turbine generator if the same person is in charge of both and –

(i) it is within 2 km of that other wind turbine generator; or

(ii) it is within 2 km of a wind turbine generator which is in the same group as that other wind turbine generator.

Appendix B - ICAO

Chapter 6 of Annex 14 which defines Type A, B and C obstacle lighting in the Low, Medium and High Intensity variations.

CHAPTER 6. VISUAL AIDS FOR DENOTING OBSTACLES

6.1 Objects to be marked and/or lighted

Note.— The marking and/or lighting of obstacles is intended to reduce hazards to aircraft by indicating the presence of the obstacles. It does not necessarily reduce operating limitations which may be imposed by an obstacle.

6.1.1 **Recommendation.—** *A fixed obstacle that extends above a take-off climb surface within 3 000 m of the inner edge of the take-off climb surface should be marked and, if the runway is used at night, lighted, except that:*

a) such marking and lighting may be omitted when the obstacle is shielded by another fixed obstacle;

b) the marking may be omitted when the obstacle is lighted by medium-intensity obstacle lights, Type A, by day and its height above the level of the surrounding ground does not exceed 150 m;

c) the marking may be omitted when the obstacle is lighted by high-intensity obstacle lights by day; and

d) the lighting may be omitted where the obstacle is a lighthouse and an aeronautical study indicates the lighthouse light to be sufficient.

6.1.2 **Recommendation.—** *A fixed object, other than an obstacle, adjacent to a take-off climb surface should be marked and, if the runway is used at night, lighted if such marking and lighting is considered necessary to ensure its avoidance, except that the marking may be omitted when:*

a) the object is lighted by medium-intensity obstacle lights, Type A, by day and its height above the level of the surrounding ground does not exceed 150 m; or

b) the object is lighted by high-intensity obstacle lights by day.

6.1.3 A fixed obstacle that extends above an approach or transitional surface within 3 000 m of the inner edge of the approach surface shall be marked and, if the runway is used at night, lighted, except that:

a) such marking and lighting may be omitted when the obstacle is shielded by another fixed obstacle;

b) the marking may be omitted when the obstacle is lighted by medium-intensity obstacle lights, Type A, by day and its height above the level of the surrounding ground does not exceed 150 m;

c) the marking may be omitted when the obstacle is lighted by high-intensity obstacle lights by day; and

d) the lighting may be omitted where the obstacle is a lighthouse and an aeronautical study indicates the lighthouse light to be sufficient.

6.1.4 **Recommendation.—** *A fixed obstacle above a horizontal surface should be marked and, if the aerodrome is used at night, lighted except that:*

a) such marking and lighting may be omitted when:

1) the obstacle is shielded by another fixed obstacle; or

2) for a circuit extensively obstructed by immovable objects or terrain, procedures have been established to ensure safe vertical clearance below prescribed flight paths; or

3) an aeronautical study shows the obstacle not to be of operational significance;

b) the marking may be omitted when the obstacle is lighted by medium-intensity obstacle lights, Type A, by day and its height above the level of the surrounding ground does not exceed 150 m;

c) the marking may be omitted when the obstacle is lighted by high-intensity obstacle lights by day; and

d) the lighting may be omitted where the obstacle is a lighthouse and an aeronautical study indicates the lighthouse light to be sufficient.

6.1.5 A fixed object that extends above an obstacle protection surface shall be marked and, if the runway is used at night, lighted.

Note.— See 5.3.5 for information on the obstacle protection surface.

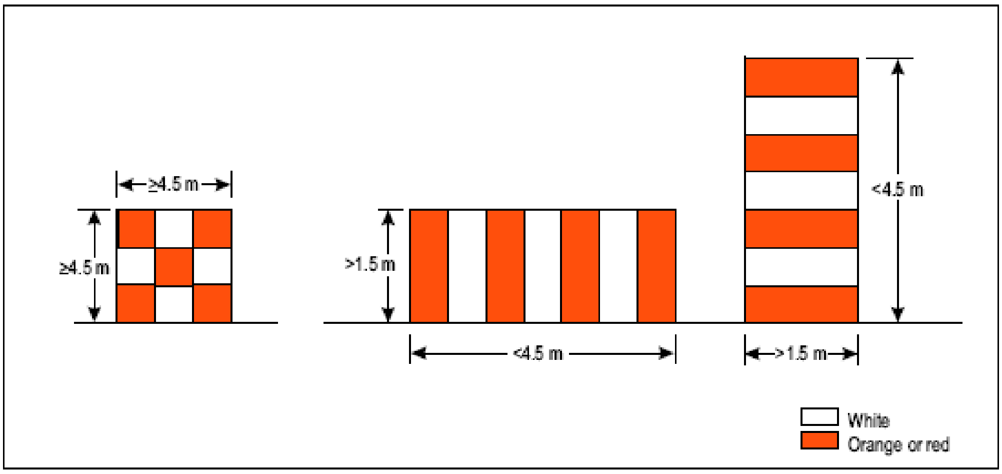

Figure 6-1. Basic marking patterns

6.1.6 Vehicles and other mobile objects, excluding aircraft, on the movement area of an aerodrome are obstacles and shall be marked and, if the vehicles and aerodrome are used at night or in conditions of low visibility, lighted, except that aircraft servicing equipment and vehicles used only on aprons may be exempt.

6.1.7 Elevated aeronautical ground lights within the movement area shall be marked so as to be conspicuous by day. Obstacle lights shall not be installed on elevated ground lights or signs in the movement area.

6.1.8 All obstacles within the distance specified in Table 3-1, column 11 or 12, from the centre line of a taxiway, an apron taxiway or aircraft stand taxilane shall be marked and, if the taxiway, apron taxiway or aircraft stand taxilane is used at night, lighted.

6.1.9 **Recommendation.—** *Obstacles in accordance with 4.3.2 should be marked and lighted, except that the marking may be omitted when the obstacle is lighted by high-intensity obstacle lights by day.*

6.1.10 **Recommendation.—** *Overhead wires, cables, etc., crossing a river, valley or highway should be marked and their supporting towers marked and lighted if an aeronautical study indicates that the wires or cables could constitute a hazard to aircraft, except that the marking of the supporting towers may be omitted when they are lighted by high-intensity obstacle lights by day.*

6.1.11 **Recommendation.—** *When it has been determined that an overhead wire, cable, etc., needs to be marked but it is not practicable to install markers on the wire, cable, etc., then high-intensity obstacle lights, Type B, should be provided on their supporting towers.*

6.2 Marking of objects

General

6.2.1 All fixed objects to be marked shall, whenever practicable, be coloured, but if this is not practicable, markers or flags shall be displayed on or above them, except that objects that are sufficiently conspicuous by their shape, size or colour need not be otherwise marked.

6.2.2 All mobile objects to be marked shall be coloured or display flags.

Use of colours

6.2.3 **Recommendation.—** *An object should be coloured to show a chequered pattern if it has essentially unbroken surfaces and its projection on any vertical plane equals or exceeds 4.5 m in both dimensions. The pattern should consist of rectangles of not less than 1.5 m and not more than 3 m on a side, the corners being of the darker colour. The colours of the pattern should contrast each with the other and with the background against which they will be seen. Orange and white or alternatively red and white should be used, except where such colours merge with the background. (See Figure 6-1.)*

6.2.4 **Recommendation.—** *An object should be coloured to show alternating contrasting bands if:*

a) it has essentially unbroken surfaces and has one dimension, horizontal or vertical, greater than 1.5 m, and the other dimension, horizontal or vertical, less than 4.5 m; or *b) it is of skeletal type with either a vertical or a horizontal dimension greater than 1.5 m.*

The bands should be perpendicular to the longest dimension and have a width approximately 1/7 of the longest dimension or 30 m, whichever is less. The colours of the bands should contrast with the background against which they will be seen. Orange and white should be used, except where such colours are not conspicuous when viewed against the background. The bands on the extremities of the object should be of the darker colour. (See Figures 6-1 and 6-2.)

Note.— Table 6-1 shows a formula for determining band widths and for having an odd number of bands, thus permitting both the top and bottom bands to be of the darker colour.

6.2.5 **Recommendation.—** *An object should be coloured in a single conspicuous colour if its projection on any vertical plane has both dimensions less than 1.5 m. Orange or red should be used, except where such colours merge with the background.*

Note.— Against some backgrounds it may be found necessary to use a different colour from orange or red to obtain sufficient contrast.

6.2.6 **Recommendation.—** *When mobile objects are marked by colour, a single conspicuous colour, preferably red or yellowish green for emergency vehicles and yellow for service vehicles should be used.*

Table 6-1. Marking band widths

Longest dimension		
Greater than	Not exceeding	Band width
1.5 m	210 m	1/7 of longest dimension
210 m	270 m	1/9 " " "
270 m	330 m	1/11 " " "
330 m	390 m	1/13 " " "
390 m	450 m	1/15 " " "
450 m	510 m	1/17 " " "
510 m	570 m	1/19 " " "
570 m	630 m	1/21 " " "

Use of markers

6.2.7 Markers displayed on or adjacent to objects shall be located in conspicuous positions so as to retain the general definition of the object and shall be recognizable in clear weather from a distance of at least 1 000 m for an object to be viewed from the air and 300 m for an object to be viewed from the ground in all directions in which an aircraft is likely to approach the object. The shape of markers shall be distinctive to the extent necessary to ensure that they are not mistaken for markers employed to convey other information, and they shall be such that the hazard presented by the object they mark is not increased.

6.2.8 **Recommendation.—** *A marker displayed on an overhead wire, cable, etc., should be spherical and have a diameter of not less than 60 cm.*

6.2.9 **Recommendation.—** *The spacing between two consecutive markers or between a marker and a supporting tower should be appropriate to the diameter of the marker, but in no case should the spacing exceed:*

a) 30 m where the marker diameter is 60 cm progressively increasing with the diameter of the marker to

b) 35 m where the marker diameter is 80 cm and further progressively increasing to a maximum of

c) 40 m where the marker diameter is of at least 130 cm.

Where multiple wires, cables, etc. are involved, a marker should be located not lower than the level of the highest wire at the point marked.

6.2.10 **Recommendation.—** *A marker should be of one colour. When installed, white and red, or white and orange markers should be displayed alternately. The colour selected should contrast with the background against which it will be seen.*

Use of flags

6.2.11 Flags used to mark objects shall be displayed around, on top of, or around the highest edge of, the object. When flags are used to mark extensive objects or groups of closely spaced objects, they shall be displayed at least every 15 m. Flags shall not increase the hazard presented by the object they mark.

6.2.12 Flags used to mark fixed objects shall not be less than 0.6 m square and flags used to mark mobile objects, not less than 0.9 m square.

6.2.13 **Recommendation.—** *Flags used to mark fixed objects should be orange in colour or a combination of two triangular sections, one orange and the other white, or one red and the other white, except that where such colours merge with the background, other conspicuous colours should be used.*

6.2.14 Flags used to mark mobile objects shall consist of a chequered pattern, each square having sides of not less than 0.3 m. The colours of the pattern shall contrast each with the other and with the background against which they will be seen. Orange and white or alternatively red and white shall be used, except where such colours merge with the background.

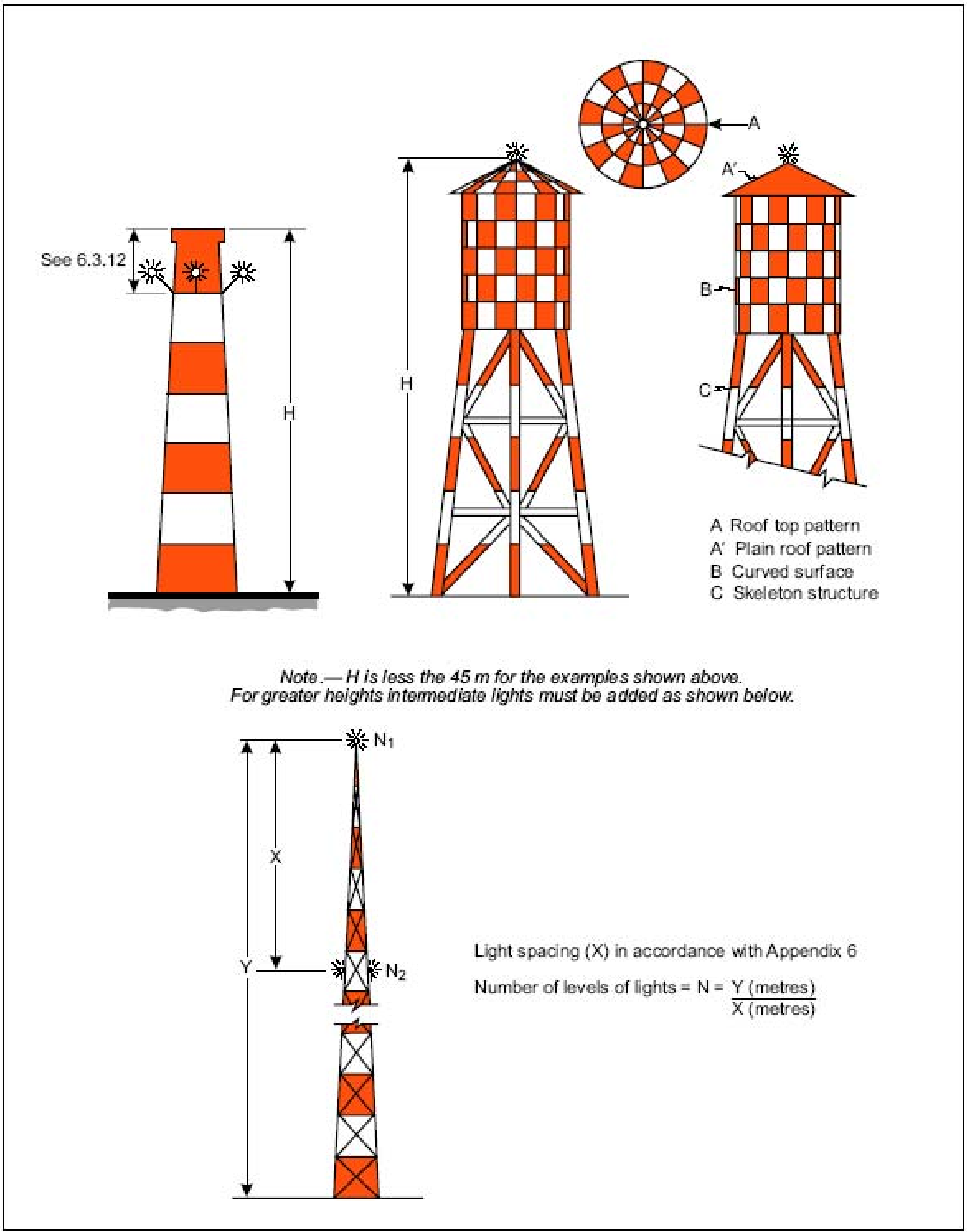

Figure 6-2. Examples of marking and lighting of tall structures

6.3 Lighting of objects

Use of obstacle lights

6.3.1 The presence of objects which must be lighted, as specified in 6.1, shall be indicated by low-, medium- or high-intensity obstacle lights, or a combination of such lights.

Note.— High-intensity obstacle lights are intended for day use as well as night use. Care is needed to ensure that these lights do not create disconcerting dazzle. Guidance on the design, location and operation of high-intensity obstacle lights is given in the Aerodrome Design Manual, *Part 4.*

6.3.2 **Recommendation.—** *Low-intensity obstacle lights, Type A or B, should be used where the object is a less extensive one and its height above the surrounding ground is less than 45 m.*

6.3.3 **Recommendation.—** *Where the use of low-intensity obstacle lights, Type A or B, would be inadequate or an early special warning is required, then medium- or high-intensity obstacle lights should be used.*

6.3.4 Low-intensity obstacle lights, Type C, shall be displayed on vehicles and other mobile objects excluding aircraft.

6.3.5 Low-intensity obstacle lights, Type D, shall be displayed on follow-me vehicles.

6.3.6 **Recommendation.—** *Low-intensity obstacle lights, Type B, should be used either alone or in combination with medium-intensity obstacle lights, Type B, in accordance with 6.3.7.*

6.3.7 **Recommendation.—** *Medium-intensity obstacle lights, Type A, B or C, should be used where the object is an extensive one or its height above the level of the surrounding ground is greater than 45 m. Medium-intensity obstacle lights, Types A and C, should be used alone, whereas medium-intensity obstacle lights, Type B, should be used either alone or in combination with low-intensity obstacle lights, Type B.*

Note.— A group of trees or buildings is regarded as an extensive object.

6.3.8 **Recommendation.—** *High-intensity obstacle lights, Type A, should be used to indicate the presence of an object if its height above the level of the surrounding ground exceeds 150 m and an aeronautical study indicates such lights to be essential for the recognition of the object by day.*

6.3.9 **Recommendation.—** *High-intensity obstacle lights, Type B, should be used to indicate the presence of a tower supporting overhead wires, cables, etc., where:*

a) an aeronautical study indicates such lights to be essential for the recognition of the presence of wires, cables, etc.; or

b) it has not been found practicable to install markers on the wires, cables, etc.

6.3.10 **Recommendation.—** *Where, in the opinion of the appropriate authority, the use of high-intensity obstacle lights, Type A or B, or medium-intensity obstacle lights, Type A, at night may dazzle pilots in the vicinity of an aerodrome (within approximately 10 000 m radius) or cause significant environmental concerns, a dual obstacle lighting system should be provided. This system should be composed of high-intensity obstacle lights, Type A or B, or medium-intensity obstacle lights, Type A, as appropriate, for daytime and twilight use and medium-intensity obstacle lights, Type B or C, for night-time use.*

Location of obstacle lights

Note.— Recommendations on how a combination of low-, medium-, and/or high-intensity lights on obstacles should be displayed are given in Appendix 6.

6.3.11 One or more low-, medium- or high-intensity obstacle lights shall be located as close as practicable to the top of the object. The top lights shall be so arranged as to at least indicate the points or edges of the object highest in relation to the obstacle limitation surface.

6.3.12 **Recommendation.—** *In the case of chimney or other structure of like function, the top lights should be placed sufficiently below the top so as to minimize contamination by smoke etc. (see Figures 6-2 and 6-3).*

6.3.13 In the case of a tower or antenna structure indicated by high-intensity obstacle lights by day with an appurtenance, such as a rod or an antenna, greater than 12 m where it is not practicable to locate a high-intensity obstacle light on the top of the appurtenance, such a light shall be located at the highest practicable point and, if practicable, a medium-intensity obstacle light, Type A, mounted on the top.

6.3.14 In the case of an extensive object or of a group of closely spaced objects, top lights shall be displayed at least on the points or edges of the objects highest in relation to the obstacle limitation surface, so as to indicate the general definition and the extent of the objects. If two or more edges are of the same height, the edge nearest the landing area shall be marked. Where low-intensity lights are used, they shall be spaced at longitudinal intervals not exceeding 45 m. Where medium-intensity lights are used, they shall be spaced at longitudinal intervals not exceeding 900 m.

6.3.15 **Recommendation.—** *When the obstacle limitation surface concerned is sloping and the highest point above the* *obstacle limitation surface is not the highest point of the object, additional obstacle lights should be placed on the highest point of the object.*

6.3.16 Where an object is indicated by medium-intensity obstacle lights, Type A, and the top of the object is more than 105 m above the level of the surrounding ground or the elevation of tops of nearby buildings (when the object to be marked is surrounded by buildings), additional lights shall be provided at intermediate levels. These additional intermediate lights shall be spaced as equally as practicable, between the top lights and ground level or the level of tops of nearby buildings, as appropriate, with the spacing not exceeding 105 m (see 6.3.7).

6.3.17 Where an object is indicated by medium-intensity obstacle lights, Type B, and the top of the object is more than 45 m above the level of the surrounding ground or the elevation of tops of nearby buildings (when the object to be marked is surrounded by buildings), additional lights shall be provided at intermediate levels. These additional intermediate lights shall be alternately low-intensity obstacle lights, Type B, and medium-intensity obstacle lights, Type B, and shall be spaced as equally as practicable between the top lights and ground level or the level of tops of nearby buildings, as appropriate, with the spacing not exceeding 52 m.

6.3.18 Where an object is indicated by medium-intensity obstacle lights, Type C, and the top of the object is more than 45 m above the level of the surrounding ground or the elevation of tops of nearby buildings (when the object to be marked is surrounded by buildings), additional lights shall be provided at intermediate levels. These additional intermediate lights shall be spaced as equally as practicable, between the top lights and ground level or the level of tops of nearby buildings, as appropriate, with the spacing not exceeding 52 m.

6.3.19 Where high-intensity obstacle lights, Type A, are used, they shall be spaced at uniform intervals not exceeding 105 m between the ground level and the top light(s) specified in 6.3.11 except that where an object to be marked is surrounded by buildings, the elevation of the tops of the buildings may be used as the equivalent of the ground level when determining the number of light levels.

6.3.20 Where high-intensity obstacle lights, Type B, are used, they shall be located at three levels:

— at the top of the tower;
— at the lowest level of the catenary of the wires or cables; and
— at approximately midway between these two levels.

Note.— In some cases, this may require locating the lights off the tower.

6.3.21 **Recommendation.—** *The installation setting angles for high-intensity obstacle lights, Types A and B, should be in accordance with Table 6-2.*

6.3.22 The number and arrangement of low-, medium- or high-intensity obstacle lights at each level to be marked shall be such that the object is indicated from every angle in azimuth. Where a light is shielded in any direction by another part of the object, or by an adjacent object, additional lights shall be provided on that object in such a way as to retain the

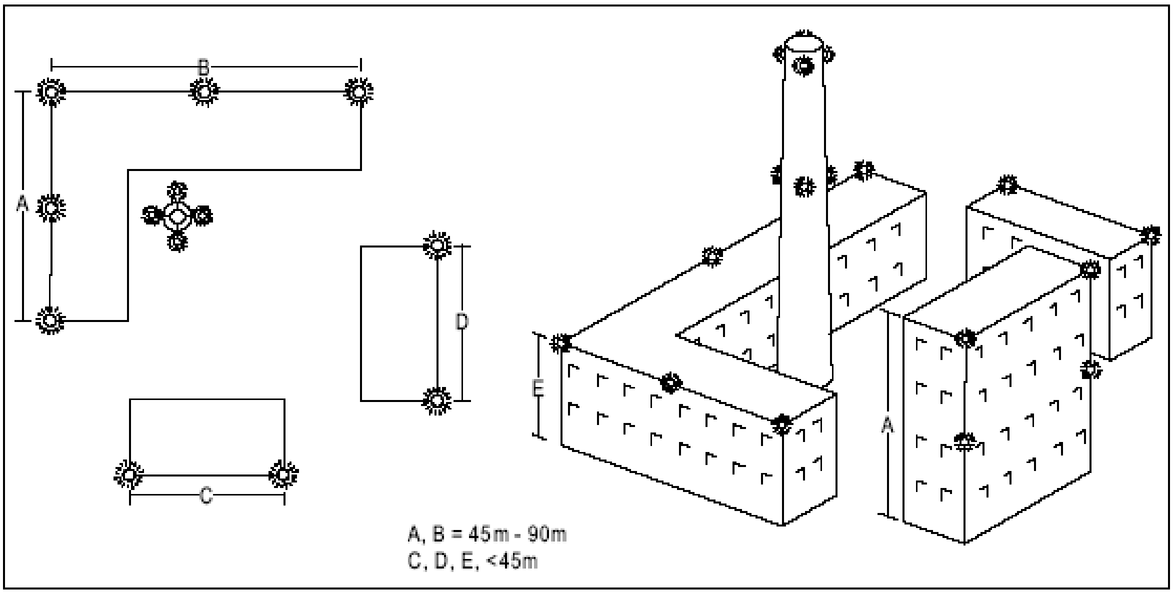

Figure 6-3. Lighting of buildings

general definition of the object to be lighted. If the shielded light does not contribute to the definition of the object to be lighted, it may be omitted.

Table 6-2. Installation setting angles for high-intensity obstacle lights

Height of light unit above terrain	*Angle of the peak of the beam above the horizontal*
greater than 151 m AGL	0°
122 m to 151 m AGL	1°
92 m to 122 m AGL	2°
less than 92 m AGL	3°

Low-intensity obstacle light — Characteristics

6.3.23 Low-intensity obstacle lights on fixed objects, Types A and B, shall be fixed-red lights.

6.3.24 Low-intensity obstacle lights, Types A and B, shall be in accordance with the specifications in Table 6-3.

6.3.25 Low-intensity obstacle lights, Type C, displayed on vehicles associated with emergency or security shall be flashing-blue and those displayed on other vehicles shall be flashing-yellow.

6.3.26 Low-intensity obstacle lights, Type D, displayed on follow-me vehicles shall be flashing-yellow.

6.3.27 Low-intensity obstacle lights, Types C and D, shall be in accordance with the specifications in Table 6-3.

6.3.28 Low-intensity obstacle lights on objects with limited mobility such as aerobridges shall be fixed-red. The intensity of the lights shall be sufficient to ensure conspicuity considering the intensity of the adjacent lights and the general levels of illumination against which they would normally be viewed.

Note.— See Annex 2 for lights to be displayed by aircraft.

6.3.29 Low-intensity obstacle lights on objects with limited mobility shall as a minimum be in accordance with the specifications for low-intensity obstacle lights, Type A, in Table 6-3.

Medium-intensity obstacle light — Characteristics

6.3.30 Medium-intensity obstacle lights, Type A, shall be flashing-white lights, Type B shall be flashing-red lights and Type C shall be fixed-red lights.

6.3.31 Medium-intensity obstacle lights, Types A, B and C, shall be in accordance with the specifications in Table 6-3.

6.3.32 Medium-intensity obstacle lights, Types A and B, located on an object shall flash simultaneously.

High-intensity obstacle light — Characteristics

6.3.33 High-intensity obstacle lights, Types A and B, shall be flashing-white lights.

6.3.34 High-intensity obstacle lights, Types A and B, shall be in accordance with the specifications in Table 6-3.

6.3.35 High-intensity obstacle lights, Type A, located on an object shall flash simultaneously.

6.3.36 **Recommendation.—** *High-intensity obstacle lights, Type B, indicating the presence of a tower supporting overhead wires, cables, etc., should flash sequentially; first the middle light, second the top light and last, the bottom light. The intervals between flashes of the lights should approximate the following ratios:*

Flash interval between	*Ratio of cycle time*
middle and top light	*1/13*
top and bottom light	*2/13*
bottom and middle light	*10/13.*

Table 6-3. Characteristics of obstacle lights

1	2	3	4	5	6	7	8	9	10	11	12
			Peak intensity (cd) at given Background Luminance			Vertical Beam Spread (c)	Intensity (cd) at given Elevation Angles when the light unit is levelled (d)				
Light Type	Colour	Signal type/ (flash rate)	Above 500 cd/m^2	50-500 cd/m^2	Below 50 cd/m^2		−10° (e)	−1° (f)	±0° (f)	+6°	+10°
Low-intensity, Type A (fixed obstacle)	Red	Fixed	N/A	10 mnm	10 mnm	10°	—	—	—	10 mnm (g)	10 mnm (g)
Low-intensity, Type B (fixed obstacle)	Red	Fixed	N/A	32 mnm	32 mnm	10°	—	—	—	32 mnm (g)	32 mnm (g)
Low-intensity, Type C (mobile obstacle)	Yellow/Blue (a)	Flashing (60-90 fpm)	N/A	40 mnm (b) 400 max	40 mnm (b) 400 max	12° (h)	—	—	—	—	—
Low-intensity, Type D Follow-me Vehicle	Yellow	Flashing (60-90 fpm)	N/A	200 mnm (b) 400 max	200 mnm (b) 400 max	12° (i)	—	—	—	—	—
Medium-intensity, Type A	White	Flashing (20-60 fpm)	20 000 (b) ± 25%	20 000 (b) ± 25%	2 000 (b) ± 25%	3° mnm	3% max	50% mnm 75% max	100% mnm	—	—
Medium-intensity, Type B	Red	Flashing (20-60 fpm)	N/A	N/A	2 000 (b) ± 25%	3° mnm	—	50% mnm 75% max	100% mnm	—	—
Medium-intensity, Type C	Red	Fixed	N/A	N/A	2 000 (b) ± 25%	3° mnm	—	50% mnm 75% max	100% mnm	—	—
High-intensity, Type A	White	Flashing (40-60 fpm)	200 000 (b) ± 25%	20 000 (b) ± 25%	2 000 (b) ± 25%	3°-7°	3% max	50% mnm 75% max	100% mnm	—	—
High-intensity, Type B	White	Flashing (40-60 fpm)	100 000 (b) ± 25%	20 000 (b) ± 25%	2 000 (b) ± 25%	3°-7°	3% max	50% mnm 75% max	100% mnm	—	—

Note.— This table does not include recommended horizontal beam spreads. 6.3.22 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.

a) See 6.3.25
b) Effective intensity, as determined in accordance with the *Aerodrome Design Manual*, Part 4.
c) Beam spread is defined as the angle between two directions in a plane for which the intensity is equal to 50% of the lower tolerance value of the intensity shown in columns 4, 5 and 6. The beam pattern is not necessarily symmetrical about the elevation angle at which the peak intensity occurs.
d) Elevation (vertical) angles are referenced to the horizontal.
e) Intensity at any specified horizontal radial as a percentage of the actual peak intensity at the same radial when operated at each of the intensities shown in columns 4, 5 and 6.
f) Intensity at any specified horizontal radial as a percentage of the lower tolerance value of the intensity shown in columns 4, 5 and 6.
g) In addition to specified values, lights shall have sufficient intensity to ensure conspicuity at elevation angles between ± 0° and 50°.
h) Peak intensity should be located at approximately 2.5° vertical.
i) Peak intensity should be located at approximately 17° vertical.

fpm — flashes per minute; N/A — not applicable

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IEA R&D Wind Annex XI, Topical Expert Meeting
OBSTACLE MARKING OF WIND TURBINES
6:th of October 2005

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