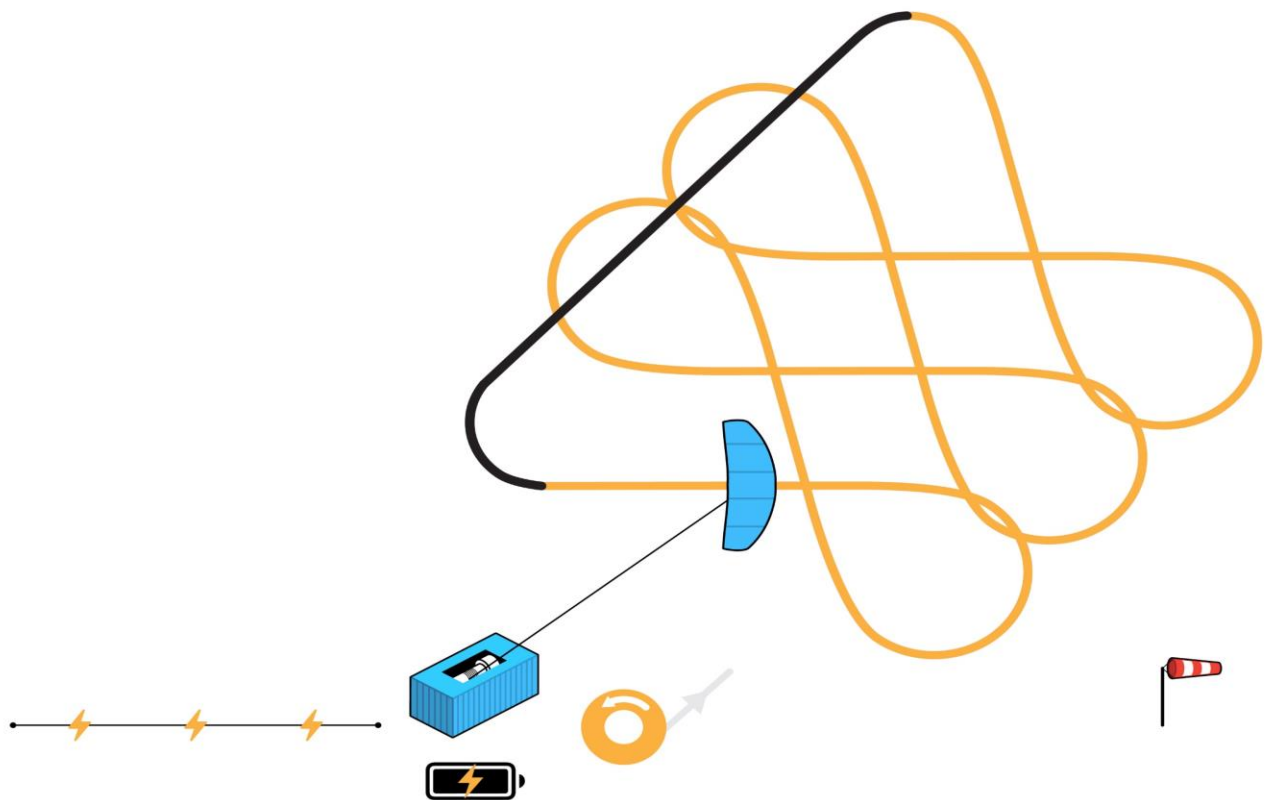


# Standardisation and Certification of Airborne Wind Energy



## GENERIC REPORT

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## Introduction

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Certification entails defining and establishing operational and technical parameters that must govern the operation of Airborne Wind Energy (AWE) systems. It encompasses the rigorous technical evaluation of the product, service, or organization culminating in the formal acknowledgment of their compliance with relevant requirements through the issuance of certificates, licenses, approvals, or other requisite documents in accordance with applicable regulations. Commercialisation can be achieved without rigorous certification to standards. For example, Skysails, an AWE company, have launched their products. However, as the industry grows, certification reduces the need to perform costly qualification testing with each purchaser and identifies the product as having an acceptable level of quality and safety for investors and regulatory bodies.

In various jurisdictions, AWE systems are currently regulated under unmanned aircraft systems (UAS) frameworks. Consequently, the AWE sector assumes that, at a minimum, fixed-wing AWE systems are subject to EU Delegated Regulation 2019/945 on unmanned aircraft systems and EU Implementing Regulation 2019/947 on the rules and procedures for the operation of unmanned aircraft. However, in specific jurisdictions, AWE systems are classified as obstacles. Under these circumstances, certifying AWE systems under obstacle standards, such as the International Electrotechnical Commission (IEC) 61400 series within the wind industry, presents a significantly more resource-efficient approach. Obstacle certification may necessitate certain modifications and mitigations, such as the introduction of lighting or transponders to enhance visibility within airspace management.

In summary, it is advantageous for AWE systems to primarily adhere to obstacle standards, supplemented by relevant industry standards like aviation regulations to address any gaps. The IEA Task 48 white paper, conducted in March 2023, surveyed eleven AWE system developers representing most of the industry [1]. The survey aimed to assess the status and future vision of AWE, offering insights that can guide the certification process to ensure that AWE systems are operated safely and economically.

Most developers expressed agreement with the approach of categorizing AWE systems as obstacles from an aerial risk perspective and as UAS from a ground risk perspective. To achieve widespread market acceptance, AWES must be designed and approved for operation over sparsely populated ground areas, as highlighted in the BVG White Paper [1]. Presently, smaller AWE systems, such as soft-kite variants, have obtained approvals for operation in uncontrolled ground areas, occasionally with third parties like farmers present. At their current scale and when operated in these controlled settings during the initial commercial stages, full certification is not an immediate necessity. However, as AWE evolves into a fully commercialized industry, type certification will become imperative.

This report aims to streamline AWE certification strategies, promoting operational safety and maximizing economic benefits. It contributes to the development of a new standard, drawing from both wind energy and aviation regulations and widely applied across the AWE sector. Rather than

providing specific guidance for systems or locations, the report offers general recommendations for standardization within the AWE industry.

The report's objectives include:

- Outlining a certification pathway for AWE system developers to follow
- Examining the regulatory landscape of 'obstacle' wind energy standards and discussing their applicability to AWE
- Providing guidance on the creation of a new AWE standard, including recommendations for engaging with relevant committees to support the standard's development, hearings, and the establishment of a technical committee
- Offering insights into the creation of a design document and the certification application process

## 1 Certification Route

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Certifying an AWES for safe operation is a complex process that involves various steps and considerations. Safety is paramount when dealing with any airborne technology, and regulatory bodies, both in aviation and wind energy typically have stringent requirements for certification. Table 1 displays an overview of the steps typically followed:

- Normal – Can be done by AWES developer internally
- **Bold** – Requires external support

*Table 1. Certification route*

### Pre-Certification Application

1. **Understand the Regulatory Landscape:** Research and understand the regulations specific to the operation region and the type of airborne wind energy system design in development. Regulations may differ between countries and may depend on factors such as the kite's size, altitude, and intended use. This stage may require external expertise from the standard committee that AWE desires to reference parts from. However, it is recommended to take this stage internally as far as possible, as to be prepared when reaching out to external committees so it is known exactly what is required from them.
  2. **Design and Development:** Commercially develop the AWES according to established engineering and safety standards such as the BS EN ISO 9001 and standards explored in the previous stage. This includes designing the kite's structure, control systems, safety mechanisms, and power generation components.
  3. **Risk Assessment:** Conduct a thorough risk assessment such as the aviation industries specific operating risk assessment (SORA) to identify potential hazards associated with the kite's operation. Assess risks related to mechanical failure, control system malfunction, weather conditions, and other factors. This can be carried out by the kite developer.
-

Table 1. Certification route

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4. **Testing and Prototyping:** Build prototypes and conduct extensive testing, both in controlled environments and field tests for validation of simulations. Gather data on the kite's performance and safety features.
  5. **Documentation:** Prepare comprehensive documentation (according to the IEC 61400-22 this is called the design document) that includes design specifications, test results, safety analyses, and maintenance procedures. This documentation will be critical during the certification process.
  6. **Compliance with Standards:** Ensure that the AWES complies with relevant safety and performance standards set out in stage 1, such as those set by wind turbine authorities, aviation authorities or other industry-specific organizations.
  7. **Risk Mitigation:** Implement safety features and risk mitigation measures to minimize the impact of potential failures whilst maintaining economic viability. This might include redundancy in critical systems such as the tether, emergency shutdown procedures, and fail-safes.

### During Certification Application

8. **Certification Application:** Preparation of an application for certification, which typically involves submitting your documentation, test results, and a detailed safety analysis to the appropriate regulatory authority or approved certification body. Be prepared for an inspection or audit of your operations. The appropriate authority will depend on the outcomes of stage 1.
9. **Review and Evaluation:** A certification body will review the application and conduct its own assessments and evaluations. They may also request additional tests or data to ensure compliance with safety standards.
10. **Compliance Modifications:** If any deficiencies or safety concerns are identified during the review process, necessary modifications should be made to the AWES and documentation to address these issues.
11. **Certification:** Once the AWES meets all safety and performance requirements, and the certification body is satisfied with compliance, certification for safe flight and operation will be granted.

### Post Certification Application

12. **Ongoing Compliance:** After certification, continued monitoring and maintenance should ensure it remains in compliance with applicable industry standards. Periodic inspections, maintenance, and reporting may be required.
- 

It's important to note that the certification process can be time-consuming and costly, but it is essential for ensuring the safety of an airborne wind energy kite and gaining the necessary approvals for commercial operation. Engaging with experts in aviation, wind and regulatory compliance can be invaluable in navigating this process successfully. Additionally, collaborating with relevant regulatory authorities and seeking their guidance early in the development process can help streamline certification efforts.

## 2 Understanding The Regulatory Landscape – Wind Standards

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Progress has already been made in the field of Airborne Wind Energy (AWE) during this phase, including the scoping of technical guidelines for the prospective AWE IEC standard, as well as the formulation of an advanced specific operations risk assessment (SORA) and measures to mitigate airspace risks. Consequently, this section will further elaborate on the wind power standards tailored specifically for AWE, mirroring the structure of the IEC 61400-1 standard, which outlines design requirements for wind turbines [2]. It's worth noting that the wind industry has reached a higher level of maturity compared to the UAS industry. Therefore, any certification aligned with these wind power standards will be more comprehensive and applicable on an international scale rather than being limited to specific regions. Nevertheless, it's important to acknowledge that certain sections of the proposed AWE standard, such as design requirements, may intersect with existing aviation standards or necessitate other standards such as cables.

### 2.1 Categories of AWES

**R&D Airborne Wind Energy Systems** are in the experimental and research phase, primarily used for testing and development purposes before commercial deployment. These systems serve as a foundation for understanding the technology's potential and limitations, relating to stage 2, 3 and 4 of the certification route. Typically, they consist of small-scale prototypes that validate the technology's feasibility. Researchers and engineers primarily focus on refining design, control algorithms, and safety measures. However, the electricity generated by R&D AWES is minimal and is not intended for widespread energy production. Instead, it plays a crucial role in data collection and analysis for evidence towards certification.

**Early commercial Airborne Wind Energy Systems** represent an intermediate stage between research and full commercial deployment. These systems are more advanced than the experimental prototypes and may have limited commercial applications. They are typically larger and more powerful, designed for specific industrial or remote power generation needs, testing compliance with grid connection and power generation rather alongside larger design. Early commercial AWES have demonstrated their technical feasibility and ability to generate significant amounts of electricity, often validated through successful pilot projects or prototype testing. However, they are often deployed in niche markets, such as off-grid power supply for remote communities, maritime applications, or research facilities in isolated locations.

**Fully commercial Airborne Wind Energy Systems** have achieved a level of maturity and reliability suitable for widespread deployment in the global energy market. These systems are designed for consistent and effective power generation and can compete with traditional wind turbines. They have a proven track record of reliable operation, meeting rigorous safety and performance standards after extensive testing and type certification processes. With a high capacity for generating substantial electricity, comparable to or exceeding conventional wind turbines, they can feed the grid and meet the energy needs of a broad range of consumers. Fully commercial AWES are now integrated into the

energy market, with established business models and partnerships with energy providers. They are considered a viable alternative to traditional wind energy solutions and are deployed in various locations worldwide, including both onshore and offshore installations. As technology continues to advance and become more cost-effective, the transition from the AWE R&D state to fully commercial is expected to accelerate. Figure 1 from the Airborne Wind Europe whitepaper on the needs and requirements of the AWE industry [1], highlights the specification definitions within each category, similarly Figure 2 shows the concept of operations of AWE.

	Current <sup>1</sup>	Early Commercial	Fully commercial
Wingspan	3-8 m	8-20 m	20-40 m <sup>3</sup>
Mass	<25 kg	25 – 600 kg	600 – 5670 kg
Airspeed	25 - 50 m/s	25 – 75 m/s	25 – 75 m/s
Config	Rigid <sup>1</sup> , GBG <sup>2</sup> , single tether	Rigid, GBG, single tether	Rigid, GBG, single tether
Power	<50 kW	50 – 100 kW	100 – 2000 kW

<sup>1</sup> First commercial operations are already underway based on soft kites with larger dimensions. <sup>2</sup> Ground Based Generation. <sup>3</sup> >40m for soft kites.

Figure 1. Design specifications for AWES in each category [1]

	Current	Early Commercial	Fully commercial
LOA <sup>1</sup>	2: Partially Automated	4: Fully Automated	5: System Only
Observer	VLOS <sup>2</sup>	BVLOS <sup>3</sup>	BVLOS <sup>3</sup>
Duration <sup>4</sup>	< 1 hour	Where? On-shore	On and off-shore
Number <sup>4</sup>	< 100	When? 2024 / 2025	

<sup>1</sup> Level of Automation. <sup>2</sup> Visual Line of Sight. <sup>3</sup> Beyond Visual Line of Sight. <sup>4</sup> Typical duration / number of flights with current systems. Note that much longer and more frequent flights are already being conducted by soft kite developers.

Figure 2. Concept of operations of AWES [1]

## 2.2 External Conditions for Defining Design Loads

It is recommended that AWES developers gather external condition data for documentation that can be used to define the external conditions class. If high altitude data is not available, it can be gathered with a vertical facing lidar scanning high altitude horizontal wind speed data. ORE Catapult currently have plans to install this configuration at Levenmouth in Scotland, data will be made open source

through the AIRE Horizon Europe project and can be used in the AWE industry. Figure 3 shows the wind shear profile for data collected by Svensson et al both offshore and onshore in the Baltic Sea [3].

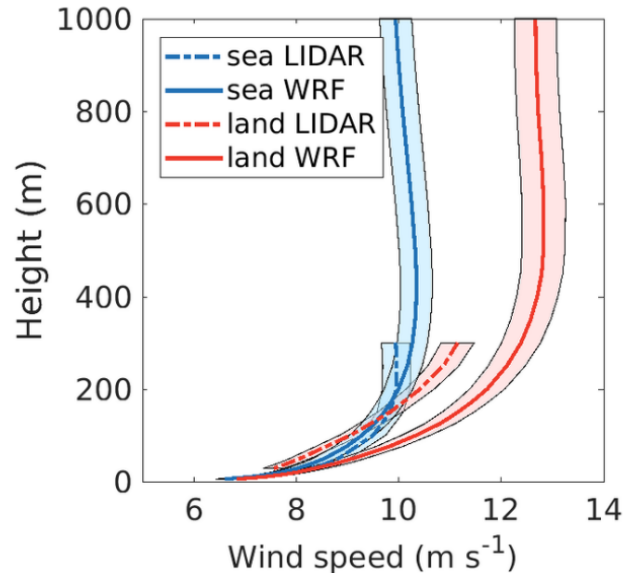


Figure 3. Wind shear profile onshore and offshore at a Baltic Sea location for one year with fitted standard deviation of the mean shaded [3]

This high-altitude wind shear profile sourced from a lidar or literature such as Svensson et al can be compared and validated to the power law given in IEC 61400-1, 6.3.2.2 for a chosen wind turbine with known hub height wind speed at hub height [2]:

$$V(z) = V_{hub} \left( \frac{z}{z_{hub}} \right)^\alpha \quad (1)$$

The wind profile  $V(z)$ , denotes the average wind speed as a function of height,  $z$ . The power law exponent,  $\alpha$ , shall be assumed to be 0.2.

High altitude wind speed distribution data should also be compared against IEC 61400-1, 6.3.2.1, the wind speed probability distribution for a chosen wind turbine, described by the Rayleigh distribution [2]:

$$P_R(V_{hub}) = 1 - \exp \left( -\pi \frac{V_{hub}^2}{2V_{Ave}^2} \right) \quad (2)$$

Where  $P_R$  is the Rayleigh probability function and  $V_{Ave}$  is the average wind speed.

Doing so would support either, the decision for use of the IEC 61400-1, 6 for defining external conditions and certification using this standard, or the development of altered external conditions classes for AWE [2]. Furthermore, simulation data gained from software such as kiteFAST can be used to further support this certification process.

If the IEC 61400-1, 6 is determined to be suitable for AWE, then design load calculations should use turbulence models in annex C, the Mann uniform shear model. Extreme wind conditions shall be

considered from IEC 61400-1 6.3.3 and other environmental conditions listed below should be considered and stated within design documentation [2]:

- Temperature – Cold climate and icing conditions should be considered, if the site is determined to be susceptible then the use of anti icing technology should be investigated
- Humidity
- Air density
- Solar radiation – Intensity will be significantly more due to reduced cloud cover at AWE altitude, testing and documentation should reflect this consideration
- Rain, hail snow and ice
- Chemically active substances
- Mechanically active particles –Less rigorous standards than wind turbines can be used, due to lower PM10 particles and salinity at AWE altitude
- Salinity
- Lightning - Definition of detailed requirements in IEC 61400-24. It is recommended to carry out lightning strike testing and adequate measures should be put in place depending on the system. The intensity difference of lightening at wind turbine level against AWE level should be investigated and the test loads should be altered accordingly with tether tests included. Strike intensity is likely to increase with height and the return stroke is likely to be more damaging. Tethers would need to include earthing cables which account for losses over the greater distance compared to turbines otherwise temperature rises will occur
- Earthquakes

Note that offshore and cold climate sites will require further consideration as per IEC 61400-3 and IEC 61400-1 clause 14 [2], [4]. Additionally, this level of standardisation within the whole of section 2 applies largely to fully commercial AWE, neither R&D or early commercial should follow such rigorous standards and should operate within a regulatory sandbox with reduced certification scope such as prototype certification discussed in section 4.4.

## 2.3 Power generation

Power generation is an area of overlap only between AWE and wind power since there is no power generation involved within aviation. The purpose of AWES characteristic testing is to establish performance-related characteristics of the AWE. The measurement of power performance is mandatory for type testing according to IEC 61400-22; however, the following measurements should also be considered [5]:

- Power quality tests – should conform with IEC 61400-21 [6]
- Low voltage ride through tests– should conform with IEC 61400-21 [6]
- Acoustic noise measurements – should conform with IEC 61400-11 [7]

In cases where the IEC 61400 standards are not applicable within AWE, the measurement procedure shall be agreed between applicant and certification body.

## 2.4 Design Loads

In AWE there are mechanical and structural loads created by external conditions and electrical loads created by power production. Most of the AWES design loads can be calculated according to the IEC 61400 series, however, those that cannot be defined under these standards such as tether loads should be put under higher scrutinization according to other standards. It is recommended to use simulation tools such as ASWING, CSIM, STAR-CCM+, NASTRAN, RCAS, Kite-fast, in-house MATLAB codes, XFOIL, MSES, VSAERO to perform aeroelastic simulations. Validation of in-house codes is required with reference to suitable verification studies and the descriptions of the calculation method shall be provided in the design document. Loads must correspond with external conditions defined in section 2.2 and with the appropriate safety factor within IEC 61400-1, 7, table 3 [2], which is itself taken from ISO 2394, general principles on reliability for structures [8]. This is applicable to certain aspects of the AWES however further work should determine component by component safety factors with their corresponding standard. This will depend on their risk, i.e., is there significant redundancy to guarantee safe or no failure on critical parts. The validation of some simulation tools can be achieved following IEC 61400-11 (noise) [7], -12-1 (electrical loads) [9], -13 (mechanical loads) [10], -21 (power quality).

There is considerable concern made around the AWES tether strength and ability to remain attached to the ground station in adverse weather. The following is taken from the AWES policy statement during the industries meeting with the federal administration association (FAA), there are already adequate systems in place for safe operation in extreme conditions within the industry [11]:

*“Altaeros commented that they rely on established aerostat practices and that their device has a valve to quickly and safely lower the device during an emergency, e.g., tether failure. EnerKite stated that its system has weak links, a pyrotechnical cutter, and soft wings to minimize any safety risk. Highest Wind commented that their system’s “anti-collision lights and on-board alarm” comprise their safety considerations. Makani commented that their system is unique from other obstructions and its aloft portion can transition to a stationary hover and land within minutes in case of an emergency or, in case of a tether failure, land the aloft portion at a pre-determined point. SkySails commented that it intends to mark and light its system and, if the aloft system escapes its mooring, the aloft portion will sink to the ground. Additionally, SkySails’ system has internal systems to monitor performance and recover the aloft portion as needed due to an emergency and suggested charting AWES to enhance safety. Windlift commented that their system can either quickly retrieve the aloft portion (reel in at 10 meters per second) or fly the aloft portion toward the ground (30 meters per second) to bring the aloft device below 500 feet AGL in less than 6 seconds.”*

Note that these systems still require documented testing to an agreed upon standard likely out with the IEC 61400 series and perhaps found within cable standards such as those used for floating offshore wind. Comments likely to come from the certification body will include how the tether has been tested to deal with snatch loads produced during high turbulence.

## 2.5 Mechanical and Electrical Systems

In Makani’s report 3, there has been significant work achieved with the support of DNVGL towards a certification scheme according to DNVGL-SE-0441 [12]. The DNVGL-SE-0441 is a further extension of IEC 61400-22, it allows for assessment of new technology. Their work on the Makani M600 is summarised in appendix A of the DNVGL report [13]. The Makani M600 is an FG AWES however it maintains the general principle of AWE and hence contains much of the same componentry, making their reported work useful for the certification of mechanical and electrical systems to the IEC 61400 series. In general, their findings revealed that the IEC 61400 series are applicable or partly applicable for some components and aspects including those in Table 2.

*Table 2. Summary of applicable standards of Makani M600 done by DNVGL in 2017 [13]*

Component	Applicable Standard
Motor/generators	IEC 60034
MV bus	IEC 62271
MV to LV converter	IEC 62477
LV system	IEC 60364
LV bus	
Servos	IEC 61800
Battery	
Inverter	IEC 62477
Switchgear	IEC 61439 and IEC 62271
Gimbal parts	IEC 61400-1
Winch parts	IEC 61400-1
Drum	IEC 61400-1
Brake	IEC 61400-1
Azimuth bearing	IEC 61400-1
Ground frame	IEC 61400-1
Ground tower	IEC 61400-1
Ground perch	IEC 61400-1
Data acquisition	IEC 61400-25

Note that most of these components are situated within the ground station, the kite components are likely to require standardisation to aviation standards. All other components not listed above will require further discussions for their applicable standard.

Within the IEC 61400 series, quality assurance is achieved according to the BS EN ISO 9001:2015 standard which specifies requirements for a quality management system suitable for all types of organizations irrespective of size, location, or sector and should hence be used within the AWE industry [14].

## 2.6 Operation Management

Neither aviation nor the AWE industry is at a steady state, and both can be expected to evolve in ways that may impact the other. Combining the current drive for AWE with the finite land resource in areas of feasibility, means that AWE and aviation are being required to operate closer and closer together. However, providing a suitable environment that allows the co-existence of AWES and aviation is not easy but possible, also because new or improved mitigation solutions are being developed all the time. Furthermore, AWE is expected to operate over sparsely populated ground area at one point in time to achieve significant market uptake [1]. Therefore, any standardization in these areas should act as a living document, updated periodically to reflect changes in interaction.

Makani utilised a regulatory sandbox to develop certification using their FAA issue of temporary determination of no hazard (DNH). This has allowed them to gather documentation, test results, and detailed safety analysis aiding in the eventual planned achievement of permanent obstacle certification [15]. In the UK, this is the same adherence that wind turbines have which follows CAP 764 [16]. If the AWE industry can follow this same process and it can demonstrate reliable operation, then it can take a further step in the direction of obstacle certification and utilise regional operational management guidelines such as the CAP 764.

CAP 764, a publication by the Civil Aviation Authority (CAA) in the UK, provides comprehensive policy and guidance pertaining to wind turbines and their impact on aviation. Of relevance, the guidelines in CAP 764, 3.8 regarding obstruction, marking, and lighting offer valuable insights that can be adapted for AWES design. Furthermore, ICAO annex 14 chapter 6 provides international standards and recommended practices, CAP 764 3.8 references ICAO directly. It's essential to note that not all AWES may feasibly adhere to aviation authorities' marking guidelines, necessitating discussions with the relevant authorities to explore alternative approaches. RenewableUK oversees the Aviation Management Board in the UK, which collaborates closely with aviation authorities to identify solutions for mitigating radar interference and flight obstruction arising from wind energy projects. It is advisable to establish contact with this organization to delve deeper into the regulations and gain a comprehensive understanding of their applicability in other countries that contain similar regulations under a different body.

Due to the industries current early state, it is likely that, more documentation will be required on the potential impacts to the navigable airspace in stage 5 before certification application in stage 8 of Table 1. Below is a range of questions likely to be asked by the certification committee as stated by the FAA [11]:

- What type(s) of mechanical devices is the individual or organisation employing to keep the system aloft?
- What are the physical dimensions of the device(s) with relation to the above?
- What kind of materials will comprise these devices?
- What are the operational dimensions (requirement for airspace) for the system?
- Is there a requirement to operate more than one device in the air?
- What are the long-term plans for this system?

- Marking and lighting.
- Can the individual or organisation comply with marking and lighting requirements?
- Can they identify any impacts to the system when complying with current guidance for marking and lighting standards?
- What are their plans or how is the system designed to make it conspicuous to the flying public?
  - Safety to other airspace users and persons and property on the ground.
- What safety redundancy mechanisms, devices and mitigation strategies have been designed into the system to ensure all aspects of aviation safety?
- What safety mechanisms or devices have been designed into the system to minimise or mitigate hazards to persons or property on the ground?
- What are the failure probabilities of critical components?
- How much autonomy is involved during operation and can this increase safety?

### 3 Proposed AWE Standard

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At the fully commercial level, it is desired within the AWE industry to have one overarching standard that applies to AWE and refers to different standards within. The creation process for this standard is described within this section.

IEC is a global organization, whose work in international standardisation underpins quality infrastructure and international trade in electrical and electronic goods. It administers four Conformity assessment systems whose members certify that devices, systems, installations, services, and people work as required. It is therefore relevant to the power system, tether, and kite for AWES unless agreement is reached between IEC and aviation authorities that IEC is only responsible for power generation aspects and aviation authorities responsible for design aspects.

It is proposed that if the AWES can largely be classified as an obstacle, then IEC will be the standardisation body with certain requirements written into the standardisation from the aviation authorities such as done for lighting and airspace management in CAP 764 on wind farms for aviation. However, if the AWES can't largely be classified as an obstacle, such as from not meeting safety redundancy requirements on the tether, from having intelligent flying control systems or from the potential to interact with other airspace users, then both IEC and aviation certification will be required with agreement on requirements gained between both parties. In either case, joint discussions will be required which can be achieved through technical committees and certification bodies.

IEC has several technical committees which could be relevant to AWES as shown in Table 3. The full list can be found here: [Technical committees and subcommittees | IEC](#). An important consideration is that solar energy, wind energy and tidal & wave energy all have their own Technical Committee (TC) and suite of standards suggesting that AWES would be in the same position. It is likely that volunteers steering the IEC 61400 wind turbine standards committee will not support the necessary changes needed within the series to write another standard for AWE. Therefore, AWE should look to create their own technical committee such as those in Table 3 have done, referring to other standards such as the IEC 61400 series.

Table 3. List of technical committees

Committee Number	Committee Description
TC2	Rotating machinery
TC8	System aspects of electrical energy supply
TC13	Electrical energy measurement and control
TC14	Power transformers
TC17	High voltage switchgear and control gear
TC18	Electrical installations of ships and of mobile and fixed offshore units
TC20	Electric cables
TC22	Power electronics systems and equipment
TC56	Dependability
TC81	Lightning Protection
TC88	Wind Energy generation systems
TC104	Environmental conditions, classification, and methods of test
TC114	Marine energy – Wave, tidal and other water current converters

To create a new TC anyone can propose a requirement through their National Body either to the Chair or Secretary of the relevant Committee. This is BSI (British Standards Institution) for the UK, DIN in Germany and CEN in Europe. The National Body will review the requirement and submit it for review to other National Bodies. The National Bodies then submit it for review to their expert members in relevant TCs such as TC88 and TC114. If the members are in agreement that a new TC need created then a leader is sought. It is important at this stage to note that if there is insufficient interest within the industry and there are not enough countries globally with expertise then the TC will not be created. A leader can come from within other committees and existing experts or by approaching experts from the technical field. Once a leader is organized a call for members is sent out to the National committees who are responsible for identifying members from existing committees and from active organizations in the field within their country. It is highly recommended that some members are liaisons with other committees such as aviation or marine energy to make referencing easier.

If there is insufficient interest shown in creation of the TC and standard, then there are alternative routes. The creation of an international energy agency (IEA) task can be done through the UK delegate contact. The IEA wind task creates its own technical guidelines and standards, critically with the support of both industry and academia to build up design documentation. AWE currently has its own IEA wind task 48, next steps in this task should ensure that further traction in the technology is gained globally so that the IEA task 48 can propose a TC to IEC. Within OREC, this methodology was followed for the eventual standardisation of floating wind lidars. This method is more financially feasible however it requires a strong core group of experts likely voluntarily. Other costs associated with the creation of a TC, include TC membership fees and national committee fees, varying depending on the

organisation. Most of the cost associated with standardisation is associated with design documentation, and the time spent at this stage.

Alternatively, to an IEA wind task, joint industry partnership with a certification body such as DNV or Lloyds can achieve the industry traction and documentation required to approach IEC. Lloyd's support marine energy due to their experience in standardisation within marine vehicles and vessels. Similarly, a company that has experience both within aviation and wind energy could be a good option for AWE. Note that this method requires a large amount of coordination and finances. Both approaches to the creation of the TC are shown in Figure 4.

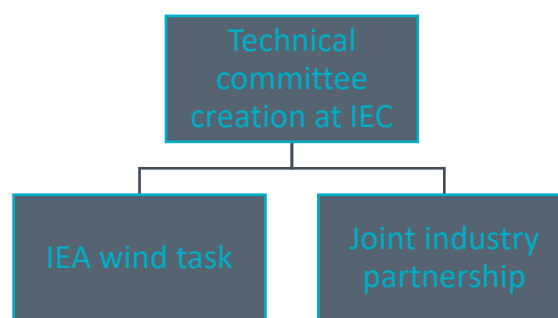


Figure 4. Flow chart of approaches to TC creation

During standard development after a TC has been created, there is encouragement to use the existing knowledge from other committees and other international standard organisations (defined during TC creation) to prevent duplication of work. Where similar or overlapping work is ongoing with other committees or standards, expert liaisons are created who attend and report in both committees. A recent example of this is within floating offshore wind, in which moorings and cables adhere to different standards, not defined within the IEC 61400 series. IEC standards thus often refer to other standards created by other international standardisation bodies which may also need alterations or new standards created for AWE. IEC and ISO (International Organisation for Standardisation) collaborate with each other, with individual technical committees, but also with members who sit on both technical committee boards for ISO/IEC Directives. ISO develop standards for product manufacture, managing processes, delivering services, and supplying materials. ISO collaborate with CEN, the European Committee for Standardisation who develop standardisation in air, defence and security, energy, ICT, machinery, materials which may be relevant to AWE with some overlap with ISO standards. CENELEC, the European Committee for Electrotechnical Standardisation collaborate with IEC under the Frankfurt Agreement. CENELEC supports standardization activities in Electromagnetic compatibility, Accumulators, primary cells and primary batteries, Insulated wire and cable, Electrical equipment, and apparatus, Electronic, electromechanical and electrotechnical supplies, Electric motors and transformers, Lighting equipment and electric lamps, Low Voltage electrical installations material, smart grid, smart metering, solar (photovoltaic) electricity systems, etc.

Furthermore, during this process it is important to consider the type of terminology used and what outcomes are desired. If it is more desirable to standardise AWE in the obstacle category and use wind

industry standards such as the IEC 61400 series, then it would be recommended to minimise the use of language associated with aviation.

## 4 Certification Application

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Once an AWE IEC standard – i.e. an amalgamation of different applicable standards and new standards – has been created and agreed upon, AWE developers will subsequently be able to achieve certification according to this standard and thus be able to show compliant operation. This represents stages 8 to 11 from Table 1. For certification according largely to the IEC 61400 series, the IEC 61400-22 can be used as guidance for design document creation [5]. It serves as a standard that certification bodies should adhere to but can be used as guidance for the certification application too. If standardisation is done under a different IEC series, then the following content is still highly transferrable and should still be considered during all stages of certification. Once created, the design documentation will be submitted to an accredited certification body.

According to IEC 61400-22, 7.1 there are four certificates at the following levels applying to AWE [5]:

- A type certificate – covers the whole AWES from kite to ground station
- A project certificate – covers one or more AWES. A project certificate presumes a type certificate and includes site conditions assessment and foundation design evaluation
- A component certificate – covers a major AWES component
- A prototype certificate – covers an AWES that is not yet fully commercial, likely will be this certification used for the R&D category of AWES in Figure 1

### 4.1 Type Certificate

Type certification consists of three mandatory modules shown in IEC 61400-22; design basis evaluation, design evaluation and manufacturing evaluation. The design basis evaluation ensures that all the design basis such as load cases and external conditions are properly defined. The design evaluation ensures that the design documentation is properly carried out, an example design documentation is shown in IEC 61400-22 annex A [5]. This includes conformity to all elements of the chosen standards such as component simulation/testing and evaluation of operation. Manufacturing evaluation is to ensure that the AWES is manufactured in conformity with the design documentation verified during the design evaluation. Combined, all this type testing feeds into the final evaluation which documents the findings that the certification body has made. Based on a satisfactory evaluation, the type certificate will be issued.

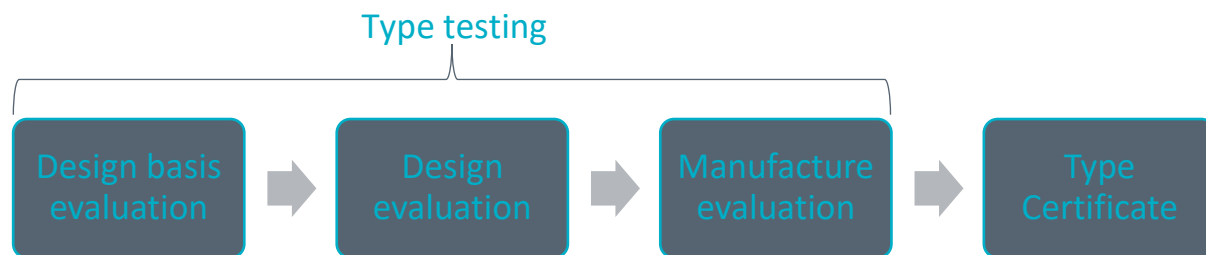


Figure 5. Type certificate process flow

## 4.2 Project Certificate

Project certification becomes notably more intricate and should only be contemplated once Airborne Wind Energy (AWE) has advanced to the early commercial stage. This entails the prerequisite of obtaining type certification for the Airborne Wind Energy Systems (AWES), encompassing a comprehensive array of assessments encompassing site suitability, integration, transportation, and commissioning.

## 4.3 Component Certificate

Component certification follows closely the same process in section 4.1. However, instead of ‘design’ basis evaluation, it works at a sub level known as ‘component’ design basis evaluation. Each of the three mandatory modules for component certification integrate directly into the type certification modules when the AWES is ready for type certification.

## 4.4 Prototype certificate

Prototype certification holds significant importance within the R&D category of Airborne Wind Energy Systems (AWES). It plays a pivotal role in the establishment of regulatory sandboxes, which are essential for collecting invaluable flight data necessary to construct the design documentation required for eventual type certification during the early or fully commercial stages. This certification process comprises three mandatory modules:

- Basic Design Evaluation; This encompasses both the basis design evaluation and the design assessment detailed in section 4.1 for type certification. However, it is limited to critical areas, including the control and protection system, loads and load cases, main structural and electrical components, as well as aspects related to personal safety. For AWES kites, additional areas may be required based on discussions with the certification body.
- Prototype Test Plan Evaluation; This module outlines the specific aspects of the AWES that will undergo testing. It serves as a comprehensive plan detailing the testing procedures and parameters.
- Safety and Function Tests; These tests are conducted to validate that the AWES performs in accordance with the design specifications. They ensure that the AWES functions safely and effectively, aligning with its intended performance standards.

## Conclusion

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This report has worked largely on the underlying assumption that obstacle certification is significantly less resource intensive than aviation certification and furthermore, is applicable on an international scale rather than being limited to specific regions. Nevertheless, it's important to acknowledge that certain aspects of AWE, such as design requirements, may intersect with existing aviation standards or necessitate other standards such as cables. This report has primarily laid out a route for AWE certification and standard creation within sections 1, 3 and 4. Furthermore, it has reviewed the IEC 61400 standard for wind turbines in section 2, investigating its applicability to AWE and providing specific recommendations and questions aiming to bridge gaps and initiate conversations for AWE developers in the required areas. There are many specific notes within this section, and it should be noted that these are for the certification of early and fully commercial AWES categories, prototype certification is limited to only some of these technicalities discussed in section 4.4. In conclusion, there are many areas of potential overlap between the IEC 61400 series and AWE, however, there must be testing and design documentation verifying assumptions made. Further work must be done to understand the regulatory landscape of other applicable standards such as those in aviation.

The following recommendations for the standardisation and certification roadmap are listed below:

- **Engage in Regulatory Talks:** Collaborative discussions with authorities linked to AWE such as aviation and wind are essential to establish a regulatory sandbox that facilitates AWE prototype or similar certifications. This enables the testing that builds into the design document required for type or component certification. It also provides the design data needed to approach existing standards desired for reference within the overarching AWE standard, such as those discussed within the IEC 61400 series.
- **Operational Management:** Once the regulatory sandbox is successfully implemented and AWES proves its design capability and reliability in all areas, it then needs to demonstrate its operational safety to operate largely within the obstacle category. CAP 764 and similar obstacle operation standards will play a pivotal role in this phase.
- **Design Documentation:** Building upon existing design documentation is crucial for informed discussions on selecting appropriate standards and certification towards those standards. Any variances in documentation or testing methods between AWE and the underlying standard should be identified and thoroughly investigated, particularly if certification aligns primarily with IEC 61400 standards.
- **Technical Committee:** For the creation of an AWE standard, it is crucial that a TC is created. This should be a mix of industry and academia with some liaisons that are members of the appropriate neighbouring TC such as wind or aviation.

- **Type Certification:** With well-defined AWE standards established through the preceding steps. Stages 8 to 12 in Table 1, the process of type certification can be further developed and implemented.

To enhance support in the standardization process, further work should conduct a comparative analysis of the design documentation generated during testing by AWES developers against the criteria outlined in the IEC 61400 standards. This effort includes addressing the questions raised within this report and conducting a data driven in-depth exploration of AWES applicability within the category of obstacle certification. Finally, it is important to understand that AWE has a broad range of companies all creating different AWES types at different technology stages. Rather than allowing this to cause paralysis, the industry should decide on the most common parts of design and operation that relate to most AWES types. Furthermore, processes such as materials testing requirements can be standardised alongside other minor design assessments, this will provide enough foundation for future certification of most design types. For different AWES types industry might then create sub-standards e.g. - rigid structural analysis, soft structural analysis for anything where there is a common interest between different developers. This would develop a comprehensive suite of standards over time. So the development is led by common need as it is identified and paid for by those companies in terms of providing time and information.

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