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Chapter 29
Current and Expected Airspace Regulations for Airborne Wind Energy Systems

Volkan Salma, Richard Ruiterkamp, Michiel Kruijff, M. M. (René) van Paassen and Roland Schmehl

Abstract Safety is a major factor in the permitting process for airborne wind energy systems. To successfully commercialize the technologies, safety and reliability have to be ensured by the design methodology and have to meet accepted standards. Current prototypes operate with special temporary permits, usually issued by local aviation authorities and based on ad-hoc assessments of safety. Neither at national nor at international level there is yet a common view on regulation. In this chapter, we investigate the role of airborne wind energy systems in the airspace and possible aviation-related risks. Within this scope, current operation permit details for several prototypes are presented. Even though these prototypes operate with local permits, the commercial end-products are expected to fully comply with international airspace regulations. We share the insights obtained by Ampyx Power as one of the early movers in this area. Current and expected international airspace regulations are reviewed that can be used to find a starting point to evidence the safety of airborne wind energy systems. In our view, certification is not an unnecessary burden but provides both a prudent and a necessary approach to large-scale commercial deployment near populated areas.

29.1 Introduction

Due to the emerging interest in airborne wind energy (AWE), a considerable number of prototype installations is approaching the stage of commercial development. As

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consequence, operational safety and system reliability are becoming crucially important aspects and it is evident that a certification framework addressing safety and reliability of airborne wind energy systems will be required for a successful market introduction and broad public acceptance.

Compared to conventional wind turbines, AWE systems operate at higher altitudes and for most concepts this operation is not stationary. Because of their substantially larger operational envelope the interaction with the aviation system is potentially stronger. For these reasons, AWE systems introduce risks to third parties in the air and objects on the ground. Thus, besides addressing the safety issues for wind turbines, such as the risk of lightning or fire within the equipment, additional considerations are required for managing the aviation-related risks.

The main system components are one or more flying devices, one or more tethers and the energy conversion system, which can be part of the flying device or part of a ground station. The flight control system can be either part of the flying device, a separate airborne device or part of the ground station. A thorough classification of implemented prototypes is provided in [2]. Although existing standards can be partially applied to some of the components, such as the low voltage directive (LVD) 2006/95/EC for electrical installation, and machine directives 2006/42/EC or IEC 61400 for wind turbines, there are no standards for the tether and the flying devices. This study investigates the applicability of existing rules and standards whose objective is to manage the aviation-related risks. In essence these standards define the acceptable risks to other airspace users or to people and property on the ground, often denominated as third-party risk. The aim of this chapter is to provide an overview of the current situation of AWE applications from the aviation perspective and to outline a permitting and certification approach for different types of AWE systems.

Ampyx Power is one of the early movers in this area and is currently pursuing with the European Aviation Safety Agency (EASA) the certification of an utility-scale, grid-connected rigid glider [33–35, 44]. It is the aim of this chapter to position the experience of Ampyx Power in the broader context of commercial-scale AWE systems of any design. We limit ourselves though to systems whose operation requires permitting by aviation authorities and takes place near populated areas and/or critical infrastructure. In other words, we consider only deployment scenarios which create an actual safety risk. We assume that the commercial operations for which a permit is sought take place initially over land restricted to qualified personnel. Our focus is on the European regulatory framework and on those AWE systems for which the current unmanned aerial vehicle (UAV) regulations seem most appropriate as a starting point. We merely provide the basic context for other cases.

At the Airborne Wind Energy Conference 2015, Glass mentioned the unique challenge of airborne wind turbine (AWT) certification because of the combined elements of wind turbine together with aircraft and the additional tether considerations [20]. In addition, he suggested a unified framework for the certification of AWTs. This framework starts with reviewing the existing standards in related sectors, including wind turbine standards and aviation standards. Then, identification of the AWT operation regime is required to see what must be addressed in the standards. Afterwards, a conservative gap analysis has to be performed for identifying the areas that are not adequately covered by the standards. Lastly, new requirements have to be developed to fill the gaps. Glass recommends collaboration with the standards developing organizations through the entire standard making process.

At the same conference, Ruiterkamp provided an overview of existing and expected rules and the standards for ensuring safe operation of AWE applications [44]. He further described possible risks introduced by AWE systems and supplemented his study with the expected legislation for a rigid wing concept.

Langley investigated AWE systems from a legal perspective [36]. In this study, he introduces the environmental impacts of AWE systems and the current legal landscape. An early mover in the US, Makani Power, which was acquired in 2013 by Google and is currently one of the "moonshot" projects of the Alphabet subsidiary X, has published a detailed document about the operation of an AWE system [21], responding to a "Notification for Airborne Wind Energy Systems (AWES)" issued by the Federal Aviation Authority (FAA) [17].

The chapter is structured as follows. Section 29.2 describes the commonly used terms in the study such as "regulation", "certification" and "flying permit". Section 29.3 provides an overview of the flying permit status of current prototypes to grasp the variety of architectures currently considered. The information has been collected by means of a survey and reveals that each architecture faces its own specific safety challenges requiring a tailoring of the mitigation measures. In Sect. 29.4, we start to explore the perspective for a large-scale deployment of such prototypes, and for this, the place of the AWE applications in the airspace is studied. Possible interference between AWE systems and current aviation activities is described. In Sect. 29.5 we introduce the civil aviation authorities which would most likely be important in the regulation making process. We then highlight in Sect. 29.6 three possible starting points to obtain operation permits for AWE prototypes. The first one is unmanned aerial vehicle (UAV) registration, the second one is air navigation obstacle registration, the third one is tethered gas balloon registration. Concerning UAV regulations, the current certification framework and future expectations are described, highlighting also different views of aviation authorities on tethered aircraft. Concerning air traffic obstacle regulation, ICAO rules for air traffic obstacles which might be applicable to AWE applications are referenced. Lastly, yet importantly, we assess in Sect. 29.7 different permitting and certification paths for AWE systems in the light of current regulations and future projections.

29.2 Concepts of Regulation, Certification and Flying Permit

As a starting point we describe how regulation, certification, permitting and standard relate to each other for the European context. The relevant overarching European laws are the Regulation (EC) No. 216/2008 [12], which distributes the responsibilities between EASA and the national aviation authorities (NAA), defines the mechanism of certification and lists the high-level airworthiness requirements, as well as Commission Regulation (EU) No. 748/2012 [10], which implements Part 21, the globally agreed requirements for certification in aviation. The Certification Specification (CS) and Special Conditions (SC) are type-specific soft regulations for airworthiness (incl. safety through the respective articles 1309), and suitable starting points for tailoring. Certification is done with respect to a certification basis agreed between applicant and aviation authority: a selection and tailoring of the appropriate CS/SC and definition of an acceptable means of compliance, using e.g. ARP/ED standards.[1] A Permit to Fly is given by the NAA for small, experimental or developmental systems. The necessary airworthiness and safety evidence shall be approved by a certification body or a qualified entity (this may be as part of a certification trajectory, but does not have to be). Key question addressed here is: can the system be flown safely? The NAA in addition considers local constraints and operational safety.

29.3 Current Operation Permit Status of AWE Systems

Airborne wind energy is currently in the development and testing phase. In this phase, companies and research groups conduct their tests with special permissions. Most of these permissions are issued by local civil aviation authorities. AWE application examples from different high-level architectures are shown in Table 29.1. Comprehensive information for each architecture and up-to-date implementation details for practically demonstrated AWE systems can be found in [2].

To understand the current status and extent of these exemptions, a survey was conducted in the context of the International Airborne Wind Energy Conference 2015 [45, p. 9]. Companies and research groups around the globe were invited to provide the technical specifications of their prototypes and information on the flight permit. The analysis of this data shows that current prototypes have a small airborne

	Ground generator, single tether	**Ground generator, multiple tether**	**Onboard generator, single tether**
Flexible Wing	TU Delft [47] Politecnico di Torino [13] SkySails Power [19] Kite Power Systems [30]	Kitenergy [38]	
Rigid Wing	Ampyx Power [46] Kitemill [31] eWind Solutions [32]	TwingTec [37] EnerKite [1]	Makani Power [52] Windlift [54]
Other	Omnidea [43]		Altaeros Energies [53]

Table 29.1 Selection of current AWE applications and architectures. System concepts with onboard generator (as a primary means for electricity generation) and multiple tethers are not known to the authors

[1] The acronym ARP stands for Aerospace Recommended Practices and the acronym ED stands for EUROCAE (European Organisation for Civil Aviation Equipment) Document.

Organization	Prototype category	Size[a]	Tether#	Weight (kg)
TU Delft	Flexible wing / generator on ground	25 m^2	1	20
Kontra Engineering	Flexible wing / generator on ground	2.5 m^2	2	0.5
Kitemill	Rigid wing / generator on ground	3.7 m	1	4.5
Windswept and Interesting Ltd	Flexible wing / generator on ground	~2 m^2 driving ~3 m^2 lifting	Many	1.6
FlygenKite	Flexible wing / generator on ground Flexible wing / airborne generation	2 m	Many	0.2
Kite Power Systems	Flexible wing / generator on ground	7 m	1	45
Kite Power Systems	Flexible wing / generator on ground	up to 40 m		450
EnerKite	Semi-rigid wing / generator on ground	11 m	3	20
Ampyx Power	Rigid wing / generator on ground	5.5 m	1	35
Federal University of Santa Catarina	Flexible wing / no electricity gen. (flight control purposes only)	3 m^2	1	2
kPower	Rigid wing / generator on ground Flexible wing / generator on ground Rigid wing / airborne generation Flexible wing / airborne generation	1–300 m^2	Many[b]	0.5–100
Altaeros Energies	Lighter than air / airborne generation	N/A	3	N/A
TwingTec	Rigid wing / generator on ground	3 m^2	2	15

[a] m^2 for projected wing area, m for wing span
[b] 3D lattices form for topological stability

Table 29.2 Reported AWE prototypes in the certification survey

mass, occupy only a small volume of the airspace and generally have human pilots in the loop or supervising the system. They are operating in a selected safe area to mitigate the risks to third parties. It is expected that the final commercial products will be significantly larger with higher airborne mass, will occupy larger volumes of the airspace and will ultimately have to comply with international airspace regulations. Conference participants were asked to fill out a web-based survey. Among the responses from 26 different organizations, 15 different AWE prototypes are reported. Table 29.2 shows the main properties of the reported prototypes. According to the responses, 10 out of 15 prototypes are formally registered with a civil certification authority. Three systems are registered as an air navigation obstacle, 6 systems are registered as unmanned glider or tethered kite. The remaining system holds an environmental permit (Dutch: "omgevingsvergunning") from the responsible local municipality. A selection of collected flying permit data is provided in Table 29.3. Results show that there is currently no consensus among the certification authorities. For technically similar concepts, some aviation authorities require personnel training, while others do not impose this requirement. Some prototypes need licensed personnel to operate. While most of the prototypes are allowed to operate at night, some can operate only during daylight hours.

Organization	Operation permit type	Issuing authority	Validity country code	Validity (Location)	Permitted altitude (m)	(P)ilot/op. Required (T)raining required (N)ight flight permitted Full (A)utonomy permitted	Other notes
TU Delft	Kite power system	ILT	NL	Valkenburg Airfield	500	N	–
Kitemill	Air traffic obstacle	CAA	NO	Lista	520	P – T – A – N	–
Ampyx Power	Unmanned glider	NAA	NL	Kraggenburg	300	P – T – A	*[a]
kPower	*[b]	FAA	US	*[c]	609	P – T – N	–
		FAA	US	*[d]	5486		NOTAM[f] req.
		FAA	US	*[e]	>10000		NOTAM[f] req.
QConcepts	*[g]	*[h]	NL	Doetinchem	300	P – A	–
Altaeros Energies	Air traffic obstacle	FAA	US	Confidential	240	Confidential	–
TwingTec	Tethered kite	BAZL	CH	Chasseral, Diegenstal, Silvaplana	150, 300[i]	A	*[j]

[a] 5000 meters of visibility required, off-cable flight below 450 m, not above people, 150 m horizontal distance from people, traffic and buildings, visual line-of-sight (VLOS)
[b] Legacy kite rules (FARs, part 101)
[c] Any place where legacy kites can be operated
[d] Warm Springs FAA UAS Test Range
[e] The Tillamook FAA UAS Test Range
[f] Notice to Airman
[g] Environmental permit (Dutch: "omgevingsvergunning")
[h] Local municipal
[i] Depending on location
[j] max 20 m^2, max 25kg

Table 29.3 Selection of flight permit data

29.4 AWE Systems in the Airspace

Aviation authorities divide the airspace into segments. These segments are called classes and labeled with the letters A through G. Each class has its own rules. For example, in Class A, all operations must be conducted under instrument flight rules (IFR) and air traffic control (ATC) clearance is required for flights. Even though most countries adhere to ICAOs standard rules for classes, individual nations can adapt the rules for their own needs. Current AWE system prototypes operate in Class G airspace, which is normally near to the ground. Figure 29.1 shows the airspace separation and Class G airspace. Class G is typically up to 1200 feet above ground level (AGL). However, Class G can be limited to 700 feet AGL if there is an airport close by, which requires Class B airspace in its vicinity as shown in Fig. 29.1. Class G is known as uncontrolled air space. There is no specific aircraft equipment or pilot specifications to enter Class G. Moreover, no ATC communication is required to fly in Class G. Although Class G is uncontrolled, civil aviation rules are still valid. There are visibility and cloud clearance requirements for flights in Class G, and most flights operate under visual flight rules, meaning that separa-

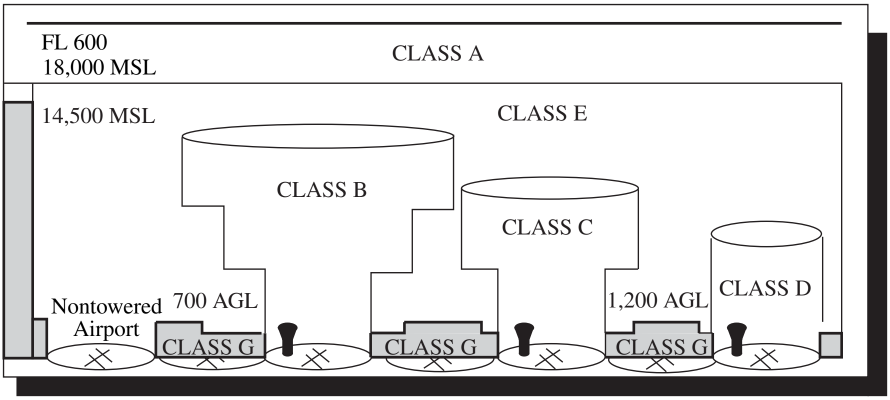

Fig. 29.1 Airspace separation and Class G airspace by FAA [14]

tion is based on the "see and avoid" principle. Since class G airspace is open to all users, interference between AWE systems and aircraft is possible.

In addition to interference risk, there are other aviation related risks posed by AWE systems. For example, uncontrolled crash (while the tether is attached or not) or uncontrolled departure from the designated flight area (with the tether partly attached or also detached) are the aviation risks which have to be managed.

29.5 Relevant Aviation Certification Bodies

This section discusses the regulatory bodies that provide rules for safe aviation and civil airspace. There are national aviation organizations as well as international aviation organizations that strive to harmonize aviation rules, in order to facilitate international air travel. These organizations all could have a role in the AWE relevant rule making process.

29.5.1 International Civil Aviation Organization (ICAO)

The ICAO was founded in 1944 upon the signing of the Convention on International Civil Aviation, commonly known as Chicago Convention. Since 1947, the organization works with the Convention's 191 Member States and with global aviation organizations as a specialized agency of the United Nations (UN). ICAO develops International Standards and Recommended Practices (SARPs) which are used by member states as a framework for their aviation law making processes.

29.5.2 Federal Aviation Authority (FAA)

The FAA is the civil aviation agency of United States Department of Transportation. The agency makes Federal Aviation Regulations (FARs) and puts them into practice to ensure the safety of civil aviation within the United States. The FAA is authorized to certify a civil aircraft for international use.

29.5.3 European Aviation Safety Agency (EASA)

The EASA was established in 2002 by the European Commission (EC) to ensure the safety of civil aviation operations. The agency advises the EC and member states of the European Union (EU) regarding new legislation. EASA is a second agency, next to the FAA, authorized to certify civil aircraft for international use.

29.5.4 National Aviation Authority (NAA)

The national regulatory body which is responsible for aviation is denoted as NAA or civil aviation authority (CAA). These authorities make national legislation in compliance with ICAO SARPs.

29.5.5 Joint Authorities for Rulemaking on Unmanned Systems (JARUS)

The JARUS is a group that consists of experts from national aviation authorities or regional aviation safety organizations which aims to define the certification requirements for UAVs to safely integrate them to the current aviation system. JARUS defines its objective for UAVs as follows [29]:

> ...to provide guidance material aiming to facilitate each authority to write their own requirements and to avoid duplicate efforts.

Working groups in JARUS publish recommended certification specifications for interested parties such as ICAO, EASA and NAAs.

29.6 Regulations for Airborne Wind Energy Systems

At the time of this study, there is no directly applicable regulation for AWE technologies. However, regulations for UAVs, air traffic obstacles or unmanned balloons are available as a starting point for tailoring to the specifics of a selected AWE architecture. In this section, current regulations for unmanned aerial vehicles from different regulatory bodies, air traffic obstacle regulations and tethered gas balloon regulations are summarized. Similar-looking AWE systems can be categorized differently depending on the modes of operation and the inherent safety measures and the proper starting point should be selected accordingly, together with the responsible aviation authority. Note that our focus is mostly on the developing UAV regulation since we expect that most tethered aircraft that will have the ability to (aerodynamically) leave their restricted safe area as a result of a single tether failure will be considered unmanned aircraft. Hence, for those systems, the UAV regulation seems the most appropriate starting point.

29.6.1 Regulations for the Unmanned Aerial Vehicle Category

Unmanned aerial vehicles were first used in the military sector. The technology then evolved also for civil applications and nowadays there are already many commercial products on the market, such as UAVs for high-quality aerial photography or 3D mapping. However, the increasing interest in UAVs has also led to a rise in safety concerns. As a consequence, national aviation agencies and international aviation organizations have directed their attention to developing certification processes, regulations and standards for UAVs including those related to airworthiness. One of the main challenging factors for UAV regulation is the wide variety of systems in the UAV domain. For instance, the UAV concept includes devices from micro UAVs which are extremely lightweight (e.g. 16 grams [3]) to High Altitude Long Endurance (HALE) class UAVs up to 14 tons [42]. Consequently, there is no consensus on a classification method which is able to cover this broad range yet. Several different classification approaches have been proposed for UAVs, such as classification according to aircraft weight, avionics complexity level, aircraft configuration (number and type of engines, etc.), aircraft speed, operation purpose (e.g., aerial work), operation airspace (segregated, non-segregated), overflown area, kinetic energy, operational failure consequence, and operation altitude.

The first publicly accepted standardization agreement, the STANAG 4671 [41] compiled by the North Atlantic Treaty Organization (NATO), was an important step forward in UAV registration, even though it is limited to military UAVs. The standard is based on EASA's CS-23 [6] civil airworthiness code. In addition to CS-23, STANAG 4671 includes subparts which are specific to UAVs such as ground control station and datalink. The standard provides a broad range of requirements for flight, aircraft structure, design, construction, power plant, equipment, command and control and the control station. However, the standard only addresses fixed-wing UAVs with a weight between 150 and 20,000 kg. As a result a considerable number of UAV types are not covered by the standard, among which the designs that are not structurally similar to conventional aircraft. With the following STANAG 4703 [40], the

NATO Standardization Agency (NSA) defined the airworthiness requirements also for lighter military UAVs whose take-off weight does not exceed 150 kg.

At the time of writing this chapter, required rules for integrating UAVs to civil airspace are still subject to change and different certification proposals from different certification authorities exist. In addition, it is known that a limited number of UAV applications are certified for civil operations by FAA and EASA with a case-by-case risk evaluation and only for specific operations. Depending on the definition of UAV in the upcoming regulations by different aviation authorities, some of the AWE applications may fall into the UAV category. In the following we will explore the possibilities in the light of current regulations, known regulatory views and the published regulatory proposals.

For AWE applications falling in the UAV category an airworthiness certificate would be sought for commercial operation. Currently, two types of airworthiness certificates are common for manned aviation. In contrast to the standard airworthiness certificate, the restricted airworthiness certificate has operational limitations such as restrictions on maneuvers, speed, activities undertaken or where the flights may be conducted. According to first drafts of UAV certification method proposals, a similar type scheme (standard and restricted airworthiness) will be used for UAVs. Considering that current AWE applications have very specific characteristics, such as being tethered to a ground station or operating in a specific area, it can be expected that the restricted type certificate will apply.

29.6.1.1 ICAO Regulations for Unmanned Aerial Vehicles

On 7 March 2012, ICAO adopted Amendment 6 to the International Standards and Recommended Practices, Aircraft Nationality and Registration Marks, which is identical to Annex 7 to the Convention on International Civil Aviation (also known as Chicago Convention). This revision included UAVs as remotely piloted aircraft (RPA), defining an RPA as “an unmanned aircraft which is piloted from a remote pilot station” [23]. At the same time Amendment 43 to Annex 2 “Rules of the Air” to the Chicago Convention was adopted. This amendment stipulates that an RPA shall be operated in such a manner as to minimize hazards to persons, property or other aircraft. Amendment 43 is the first regulation by ICAO that introduces the operation of remotely piloted aircraft systems (RPAS) in the Chicago Convention.

The current regulation [24] requires a certification of all types of aircraft that intend to fly in controlled and uncontrolled airspace, even though the certification framework for UAVs is not clear in Chicago Convention yet. In March 2011, ICAO published Circular 328 specifically addressing “Unmanned Aircraft Systems (UAS)” [28]. The aim of this circular is to establish a basis by properly defining the new technology, clarifying the differences between unmanned and manned aircraft. In March 2015, Circular 328 was superseded by the “Manual on Remotely Piloted Aircraft Systems (Doc 10019)” [27]. The following excerpts from this document are deemed representative of ICAO’s current perspective on UAVs [27, Chap. 1, Sect. 6]

> 1.6.3 These hazards relate to all RPAS operations irrespective of the purpose of the operation. Therefore, the recommendations in this manual, unless specified otherwise, apply equally to commercial air transport and general aviation, including aerial work, operations conducted by RPAS.
> 1.6.4 In order for RPAS to be widely accepted, they will have to be integrated into the existing aviation system without negatively affecting manned aviation (e.g. safety or capacity reduction). If this cannot be achieved (e.g. due to intrinsic limitations of RPAS design), the RPA may be accommodated by being restricted to specific conditions or areas (e.g. visual line-of-sight (VLOS), segregated airspace or away from heavily populated areas).

and further [27, Chap. 2, Sect. 2]

> 2.2.7 Categorization of RPA may be useful for the purpose of a proportionate application of safety risk management, certification, operational and licensing requirements. RPA may be categorized according to criteria such as: maximum take-off mass (MTOM), kinetic energy, various performance criteria, type/area of operations, capabilities. Work is underway in many forums to develop a categorization scheme.

Autonomous unmanned aircraft and their operations, including unmanned free balloons or other types of aircraft which cannot be managed on a real-time basis during flight, is not in the scope of the Doc 10019. At the time of writing, there are no rules for AWE applications or tethered aircraft in the ICAO regulations.

29.6.1.2 EASA Regulations for Unmanned Aerial Vehicles

EC-2008 is the European Union's law that converts the ICAO SARPs to the EU structure, describing the responsibilities of EASA and NAAs [12]. Annex II of EC-2008 defines the exceptional cases which are outside EASA's area of responsibility. For example, the following cases do not lie within the responsibility of EASA[2]:

> (b) aircraft, specifically **designed or modified for research**, experimental or **scientific purposes**, and likely **to be produced in very limited numbers**...
> ...(I) unmanned aircraft with an operational mass of **no more than 150 kg**

NAAs of member states are responsible for the regulation of these cases. Apart from the above mentioned exception cases, EASA makes the common European rules for UAV certification.

One of the important steps in civil UAV airworthiness certification is the interim Policy Statement EASA E.Y013-01 [4], which is still in use and aims at protecting people and property on the ground but not the UAV itself. The policy provides a kinetic energy-based classification method and a systematic certification guideline which suggests tailoring of fixed manned aircraft certification regulations. According to the tailoring principle, class determination has to be done as a first step using the kinetic energy evaluation method, which is defined in the regulation. Then, a tailoring process is required, adjusting an already existing certification specification for a conventional aircraft, which is in the same kinetic energy class with the new

[2] In this and the following quotations the emphasis is added by the authors

type that is intended to be certified. During this process, each requirement of the existing certification specification has to be reviewed and its applicability for new type has to be evaluated. Depending on the new type, special conditions may be added. This conditions may provide a starting point for the future applicants. It is further stated in the policy [4, Paragraph 21A.17]

> At an applicant's request, the Agency may accept USAR version 3, STANAG 4671, or later updates, as the reference airworthiness code used in setting the type certification basis

It should be noted that Ampyx Power and EASA have come to the conclusion that the tethered aircraft of Ampyx Power resembles more an unmanned glider than the typical tactical UAV that STANAG 4671 is templating. Therefore, the company has chosen to tailor CS-22 for its airworthiness baseline. These examples show EASA's willingness to accept the most suitable pre-existing airworthiness certification standard as a starting point for the tailoring process. The EASA E.Y013-01 has been amended regarding system safety to cover the class of very light aircraft (VLA) by Special Condition SC-RPAS.1309 [8], leaning on CS23.1309 [6]. This amendment was also adopted by Ampyx Power as a starting point for system safety.

The EASA E.Y013-01 provides guidance for restricted type certificates, as well as for standard type certificates for UAVs. However, it is not aimed at regulating public operations such as UAVs that are used by the military, police or firefighting department. Regarding mass criteria, EASA advises the NAAs of the member states to develop their own regulations for the UAVs which are lighter than 150 kg. As a consequence of this rule, current laws for light UAVs in the European countries are not harmonized and some of the countries do not yet have regulations.

EASA publishes the drafts of amendments on ICAO regulations as Notice of Proposed Amendment (NPA) in order to collect the comments of member states. In September 2014, the agency published the NPA-2014-09 with the first mention of operations of tethered aircraft [9]. In this notice, EASA identifies the tethering of the aircraft as a recognized mode of operation for remotely piloted aircraft

> **TAXONOMY OF OPERATIONS**
> RPA typical flight pattern may comprise a wide range of scenarios, which could be categorized in the following types of operations:
> (a) Very low level (VLL) operations below the minimum heights prescribed for normal IFR or VFR operations: for instance below 500 ft ($\approx$ 150 m) above ground level (AGL); they comprise:
> (1) **operations of tethered aircraft**;
> (2) Visual line of sight (VLOS) within a range from the remote pilot, in which the remote pilot maintains direct unaided visual contract with the RPA and which is not greater than 500 meters;
> (3) Extended visual line of sight (E-VLOS) where the remote pilot is supported by one or more observers and in which the remote crew maintains direct unaided visual contract with the RPA;
> (4) Beyond VLOS (B-VLOS) where neither the remote pilot nor the observer maintain direct unaided visual contract with the RPA.
> (b) **Operations of tethered aircraft**, above the minimum height in (a); ...

This statement can bring rigid wing AWE systems under Amendment 43 to Annex II of the Chicago Convention. Annex II covers other aspects related to RPAS besides their integration in airspace, namely the principles that RPAS shall be airworthy, the remote pilots licensed and the RPAS operator certified. However, specific ICAO standards and recommended practices—the SARPs—for the airworthiness and operation of RPAS as well as for licensing of the remote pilot have not been developed yet.

In addition to the EASA E.Y013-01 and NPA 2014-09, EASA has recently published a "Concept of Operations for Drones" [7]. This new proposal starts from the application rather than the aircraft used, applying a risk-based classification and regulation scheme for UAV operation. With this new scheme, EASA aims to cover a broad range of types and operations of UAVs, applying the three categories "Open", "Specific" and "Certified". Operations in the "Open" category would not require any certification as long as they operate in a defined boundary, for example not close to aerodromes, not in populated areas, being very small. The boundary conditions are not defined in the proposal but it is mentioned that conditions for the "Open" category are expected to be clarified in a collaboration with member states and industry. The "Specific" category is for UAVs whose conditions will not fit the "Open" category. These will require a risk assessment process specific to the planned operations. Depending on the output of the risk assessment process they might be certified case by case with specific limitations adapted to the operations. Permitting for the "Specific" category would be delegated to the NAAs. If the risk assessment shows that the UAV introduces a very high risk then the "Certified" category would be applicable. This requires multiple certificates similar to those for the manned aviation system, such as pilot licenses, approvals for design and manufacturer organizations. In addition to the certificates which are currently in use for manned aviation industry, the "Specific" category may also require new additional certifications that are specific to UAV operations, such as command and control link certification.

The operation-specific, case-by-case safety assessment method for the "Specific" category provides a mechanism to cover unconventional machines flying in civil airspace. If these machines have sufficient risk mitigation factors, such as being connected to the ground or being operated away from populated areas, an operation specific certificate could be sought. Current AWE applications would fall most likely into the "Specific" category, whereas utility-scale commercial systems would fall into the "Certified" category.

29.6.1.3 FAA Regulations for Unmanned Aerial Vehicles

The Title 14 of the Code of Federal Regulation [49] regulates the aeronautics and space operations conducted within the boundaries of USA. According to the current version [49, Part 91, Sect. 2031]

> ...every civil aircraft that operates in the US must have a valid airworthiness certificate.

Currently, unmanned aircraft systems can be certified by the FAA to operate in the national airspace (NAS) with a special airworthiness certificate in the experimental category [49, Part 21, Sect. 191]. However, FAA is regarding the aircraft as a part of a system, which includes command and control link, ground control systems and ground crew and accordingly, the entire system has to be certified. Nevertheless, the subsystems which do not exist in conventional aircraft, such as command and control links, ground control systems or sense and avoid systems, do not have any regulations yet. As a result, general use of commercial UAVs for civil use is highly restricted in US airspace at present.

The Title 14 of the Code of Federal Regulation (14 CFR) classifies the operation purpose of UAVs at a very high level [22]. In this classification, the first category is "Civil use", which refers to operation by a company or individual. The second category is "Public use", which includes the operations for scientific research and governmental purposes such as military operations. The last category is recreational use of model aircraft which is covered by FAA Advisory Circular 91-57 [16]. Currently, UAVs which are used for public operations require a Certificate of Waiver or Authorization (COA) from the FAA that permits public agencies and organizations to operate in a particular airspace. There are many COAs in use today by the several organizations, such as the Departments of Agriculture (USDA), Commerce (DOC), Defense (DOD), Energy (DOE), Homeland Security (DHS), Interior (DOI), Justice (DOJ) as well as NASA, State Universities and lastly State/Local Law Enforcement [51]. UAVs in the "Civil use" category can only operate with a special airworthiness certificate in the experimental category with limits on the operation to not create any risk for other airspace users or for people on the ground [49].

In February 2012, the United States Congress enacted the Federal Aviation Administration Reauthorization Legislation, which seeks to provide a framework for integrating UAVs safely into American airspace [48]. Following this action, the Next Generation Air Transportation System (NextGen) partner agencies, which are the Department of Transportation (DOT), DOD, DOC and DHS as well as NASA and FAA, started to work together to develop the Unmanned Aircraft Systems (UAS) Comprehensive Plan [50]. This report defines the interagency goals, objectives and approach to integrating UAS into the national airspace. Following the release of this report, FAA published a UAS roadmap [15] which includes a timeline for tasks required for integration of UAVs into the current aviation system. In accordance with this roadmap, FAA together with NexGen agencies established test sites for UAV research and development and studied new UAV-specific technologies such as detect-and-avoid systems.

While the FAA works on new regulations, the interim policy "Special Rules for Certain Unmanned Aircraft Systems" [48] has been enacted in 2012. Briefly, the Sect. 333 law authorizes the Secretary of Transportation to give a permit to civil operations of UAVs after an evaluation.

Regarding AWE applications, there is a discrepancy between EASA and FAA. On the one hand EASA recognizes the tethered aircraft as unmanned aircraft, on the other hand FAA clearly excludes the tethered aircraft from unmanned aircraft category [18, Appendix A];

> **41. Unmanned Aircraft (UA).** A device used or intended to be used for flight in the air that has no onboard pilot. This device excludes missiles, weapons, or exploding warheads, but includes all classes of aircraft, helicopters, airships, and powered-lift aircraft without

an onboard pilot. UA do not include traditional balloons (see 14 CFR part 101), rockets, tethered aircraft and un-powered gliders

In December 2011, the FAA had issued a "Notification for Airborne Wind Energy Systems" [17], according to which each deployment of an AWE system needs to be assessed on a case-by-case basis, accounting for the surrounding aviation environment to ensure aviation safety. Makani Power submitted a detailed response to this notification in February 2012 [21].

29.6.2 Regulations for Air Traffic Obstacle Category

Air navigation obstacles can be an impediment to civil air traffic. Some of the AWE companies registered their current AWE prototypes as air navigation obstacle (see Table 29.2). The aim of such a registration is to inform the aviation system to prevent incidents. For example, masts and wind turbines have to be registered as air traffic obstacles. This information is visualized in aviation charts and it is taken into account during flight route planning or emergency situations. If we consider the typical operation altitudes of AWE systems, obstacle registration might be sought in the future. ICAO defines "obstacle" in the Chicago Convention, Annex 4 [25] as follows

> All fixed (whether temporary or permanent) and mobile objects, or parts thereof, that:
> a) are located on an area intended for the surface movement of aircraft; or
> b) extend above a defined surface intended to protect aircraft in flight; or
> c) stand outside those defined surfaces and that have been assessed as being a hazard to air navigation.

According to this definition, air traffic obstacles can be mobile as many AWE systems are.

The Chicago Convention, Annex 14 [26] is about aerodromes and it includes the definition of the surrounding zones. Obstacle limitation surfaces are zones which have to be free of obstacles to permit regular civil use of the airspace. However, many AWE applications will potentially operate outside of these zones, about which the ICAO recommends to the civil aviation authorities the following in Annex 14 [26]

> 4.3 Objects outside the obstacle limitation surfaces
> 4.3.1 Recommendation.— Arrangements should be made to enable the appropriate authority to be consulted concerning proposed construction beyond the limits of the obstacle limitation surfaces that extend above a height established by that authority, in order to permit an aeronautical study of the effect of such construction on the operation of aeroplanes.
> 4.3.2 Recommendation.— In areas beyond the limits of the obstacle limitation surfaces, at least those objects which extend to **a height of 150 m or more above ground elevation** should be regarded as obstacles, unless a special aeronautical study indicates that they do not constitute a hazard to aeroplanes.

According to Annex 14, obstacles have to be conspicuous to air vehicles. Its Chap. 6 on "Visual aids for denoting obstacles" describes the required marking and lighting scheme for different types of obstacles. Regarding marking methods for increasing the visibility the following is recommended

> 6.1.2.2 Recommendation –Other objects outside the obstacle limitation surfaces should be marked and/or lighted if an aeronautical study indicates that the object could constitute a hazard to aircraft (this includes objects adjacent to visual routes e.g. waterway, highway).

Similarly, Article 6.2.2 defines marking requirements for mobile objects and Article 6.2.3 defines lighting requirements for objects with a height exceeding 150 m above ground. Article 6.2.4 addresses wind turbines separately, which is important because it defines the required marking for a wind farm setup. A similar or hybrid approach might be sought for future AWE farms.

29.6.3 Regulations for Tethered Gas Balloons Category

For static AWE systems that resemble the system developed by Altaeros Energies [53] a more applicable basis is the EASA certification specification for tethered gas balloons, CS-31TGB [5]. The lack of a complex control system which is required for the crosswind AWE systems, in conjunction with the self-stabilizing nature of a tethered lighter-than-air gas balloon will probably be sufficient to make CS-31TGB applicable.

We note here that the certification specification provides two more important inputs for the generic safety requirements and certification basis of AWE systems:

1. CS 31TGB.25 where the required tether safety factor of 3.5 is given.
2. AMC 31TGB.53(a) where it is stated that acceptable means of compliance to CS 31TGB.25(a) can be shown by a certificate of compliance to the Machinery Directive 2006/42/EC [11]. This means that a winch system can be certified to the Machinery Directive 2006/42/EC and thereby show compliance with an airspace certification specification. For AWE systems that use a winch as part of the ground station this can be important to limit the certification efforts for non-flying parts.

29.7 Discussion

Since no unified legal framework for AWE systems exists to the present day, the categories mentioned above are just starting points for a discussion with the authorities. They are a reference from which deviations can be defined systematically on a case-by-case basis. Nevertheless, we can derive some generally valid considerations.

AWE systems introduce potential hazards for other airspace users and people or critical infrastructure on the ground. These inherent risks have to be mitigated to successfully commercialize AWE technologies. It should be noted that this risk mitigation is not only sensible for saving lives, but also, from a commercial perspective, to reduce the costs resulting from accidents and crashes. It may well be a property of AWE that the commercial requirement for reliability is even more stringent than that coming from aviation regulations.[3]

If we define "normal operation" of the AWE system as the expected continuous operation within a limited airspace, with limited altitude and horizontal boundaries, we have to account for potential situations in which the AWE system interacts with the current civil aviation system. To prevent such undesirable interaction, regardless of the type of AWE system, some form of airspace segregation has to be arranged.

Furthermore, independent of the selected regulatory starting point, as UAV, obstacle or otherwise, and independent of the degree of permitting or certification sought, it will be fundamental that any risk of one or multiple fatalities as a result of a single functional failure is mitigated. The aviation approach to safe systems design is based on the presumptions that

- any single function can fail, so it must be assumed the tether can rupture, and
- any single failure with potential catastrophic consequence shall be demonstrably mitigated.[4]

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[3] Consider, as an example, a fully autonomous utility-scale system that has a design lifetime of 20 years and is in operation 5000 hours per year. Suppose that the airborne element replacement cost represents 10% of the levelized cost of energy (LCOE). As a complex system, the airborne element may have 100 failure conditions that would lead to loss of the aircraft ("hazardous"). If any of those failure conditions occurs during the design lifetime, the energy cost would be driven up by 10%, say 0.5 eurocent per kWh, which is more than significant and will negatively affect the commercial viability. It is commonly argued that the probability of a failure condition that might lead to death of someone from the general public ("catastrophic failure") must be at least 10 times less than a hazardous failure, leading to a required probability level per catastrophic failure condition of 10^{-8} per flight hour (pfh), which is once every $5000\times20\times100\times10$ flight hours. This number is two orders of magnitude more stringent than the 10^{-6} pfh requirement of Special Condition SC-RPAS.1309 [8] regarding UAVs or Certification Specification CS-23.1309 [6, Paragraph 23.1309] regarding general aviation.

To make the argument more vivid, one can also turn it around. For general aviation, a catastrophic incident is accepted every 10,000 flight hours. Yet, this number of flight hours is reached every other year by a single utility-scale AWE system and every week for a park of 100 systems. This is clearly something the general public would not accept. Note that utility-scale AWE cannot be installed too far away from the population, since they are supposed to provide the population with electricity, and long-distance cabling cost is forbiddingly expensive, so part of the solution has to come from additional design for safety. Still, even with the 10^{-8} pfh reliability level calculated above, in a park of 100 systems, nearly every 2 months an aircraft would be expected to crash within the park, which hardly seems economically viable. So, a further reduction of the number of hazardous failure conditions and/or a further improvement in reliability, and accordingly in design rigor, may be recommendable for this example.

What sets utility-scale AWE systems apart from general aviation aircraft and typical RPAS is the number of flight hours and the complexity, which determines the number of failure conditions. The challenge is that AWE systems are in this regard more in the direction of commercial airliners, albeit not quite as critical or complex, and an intermediate reliability approach and design rigor is to be pursued.

[4] The certification requirement for catastrophic failure probability applies to accidental death of someone from the general public during commercial operation. This is not to be confused with

Thus, assuming that the commercial AWE system is operated near a populated area—the consumer of the generated electricity—the risk of uncontrolled flight outside of the designated safe zone shall be mitigated in case of tether rupture or intentional release of the aircraft. Having a controlled flight following a mechanical disconnection is one possible option to mitigate such an event. Having a second, structurally independent tether is another option. Or one could otherwise demonstrate that the detached kite is not able to reach people or critical infrastructure on the ground.

It should be noted that if one aims to operate a kite with significant kinetic energy directly above people, the tether solution alone cannot act as sufficient mitigation, for example in case of a faulty flight controller that would lead to a crash onto the populated area. It shall then be shown that there are independent means of overcoming a single failure of any flight control function.

Factors that will affect the authorities' assessment of the overall risk posed by the system furthermore include the kinetic energy, the availability of onboard propulsion, which determines the flight range, and the complexity, including autonomy, with which AWE aims to enter new territory.

Ampyx Power interprets the above review in such a way, that single-tether AWE systems that can still (aerodynamically) reach populated areas after tether failure or release are likely to be considered to be UAVs. Therefore, the certification approach for UAVs seems to be a suitable starting point and the level of certification will depend on the risk factor which the system presents [7]. A different approach, such as obstacle registration, may arguably be followed, for example for kites that are steered from the ground above a restricted area using two structurally independent tethers.

In any case, certification of design and operation to some defined standard will, in our view, be a necessity for commercial deployment. Apart from the expected positive impact that the introduction of rigorous processes will have on system reliability and maintenance, design certification enables the concept of similarity as evidence for quality and safety. This is a proven way to cost-effectively deploy the large numbers of complex systems that the AWE industry aspires to. This means that also production and maintenance aspects shall be standardized. These further certifications are outside the scope of this study. It should be noted, that we only

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examples that may come to mind, such as the unfortunate recent SpaceshipTwo incident [39] that illustrate the higher level of acceptance for accidents during development affecting flight crew only. Secondly, the Certification Specification CS-23.1309 [6, Paragraph 23.1309] for mitigation of catastrophic failures applies to the functions of aviation systems, such as avionics, complex mechanisms, not to structures. For structures, it is recognized that redundancy could make the aircraft too heavy. The accepted approach there is to include the proper design safety factor and design for damage tolerance, for example, due to fatigue following barely visible tooling damage, hail, bird strike.

We argue that the tether is more than a structural element, but a functional part of a complex mechanism. It is used to control and restrict the dynamics of the airborne element, it is subject to wear during reeling, its integrity is affected by weather, subject to salt spray, dirt and lightning, it is subject to complex loading dynamics, such as jerks, shocks etc. At the same time, the tether is designed for minimal drag so the design safety factor may be limited. Hence we have to assume its incidental failure as part of a safety analysis.

considered so far the aviation-related risks and the regulation aspects of the AWE systems from an aviation perspective.

AWE systems are complex systems which consist of many components. There are additional regulations requirements, such as electric machinery regulations, grid connection regulations, noise emission regulations, environmental regulations and lighting regulations for the subcomponents which should be taken into consideration. It is noted here that those system elements and operations certified by an aviation authority are generally not required to comply also to machine standards, but these standards may be supporting guidance for the design or verification.

29.8 Conclusions

AWE systems have to be regulated for a successful commercial introduction and broad public acceptance. Ultimately, AWE systems are expected to be larger and heavier than current prototypes. They are expected to operate in Class G airspace where interaction with other airspace users is possible. In addition, AWE systems introduce risks to the people on ground. Therefore, it is expected that commercial AWE systems will have to comply with international airspace regulations.

The regulation framework for AWE systems is not yet mature. Current prototypes operate with special permits. These operation permits are issued by local aviation authorities and there is little commonality among the permits. Registration of the prototype as an air traffic obstacle or unmanned aerial vehicle (UAV) is the main approach followed by AWE companies and academic research groups. Classifying the AWE systems as UAV is a controversially discussed topic: on the one hand, current EASA view recognizes the tethered unmanned aircraft as UAV, on the other hand FAA excludes the tethered aircraft from the UAV category.

Each AWE system category has its own operation characteristics. The path for flight permitting and/or product certification goes through hazard analysis and mitigation independently from the category into which the system falls.

A regulation set which is specific to AWE systems will be built up over time, based on the specifically negotiated cases of first movers. As long as such a regulation is not in place, the most appropriate existing certification specifications and standards will have to be selected with authorities and tailored as necessary.

Lastly, yet importantly, AWE developers should accept the shared responsibility to avoid any incidents involving other airspace users, people on the ground or critical infrastructure. Such an incident, if no proper prevention or mitigation approach was in place, could well put the entire AWE industry under the most stringent aviation rules, which would jeopardize its commercial viability and eventual success.

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References

1. Bormann, A., Ranneberg, M., Kövesdi, P., Gebhardt, C., Skutnik, S.: Development of a Three-Line Ground-Actuated Airborne Wind Energy Converter. In: Ahrens, U., Diehl, M., Schmehl, R. (eds.) Airborne Wind Energy, Green Energy and Technology, Chap. 24, pp. 427–437. Springer, Berlin Heidelberg (2013). doi: 10.1007/978-3-642-39965-7_24
2. Cherubini, A., Papini, A., Vertechy, R., Fontana, M.: Airborne Wind Energy Systems: A review of the technologies. Renewable and Sustainable Energy Reviews **51**, 1461–1476 (2015). doi: 10.1016/j.rser.2015.07.053
3. Croon, G. C. H. E. de, Groen, M. A., De Wagter, C., Remes, B., Ruijsink, R., Oudheusden, B. W. van: Design, aerodynamics and autonomy of the DelFly. Bioinspiration & Biomimetics **7**(2), 025003 (2012). doi: 10.1088/1748-3182/7/2/025003
4. European Aviation Safety Agency: Airworthiness Certification of Unmanned Aircraft Systems (UAS), Policy Statement EASA E.Y013-01, 25 Aug 2009. https://www.easa.europa.eu/system/files/dfu/E.Y013-01_%20UAS_%20Policy.pdf
5. European Aviation Safety Agency: Certification Specifications and Acceptable Means of Compliance for Tethered Gas Balloons, EASA CS-31TGB, 1 July 2013. https://www.easa.europa.eu/system/files/dfu/Annex%20to%20ED%20Decision%202013-011-R.pdf
6. European Aviation Safety Agency: Certification Specifications for Normal, Utility, Aerobatic, and Commuter Category Aeroplanes, EASA CS-23, 14 Nov 2003. https://www.easa.europa.eu/system/files/dfu/decision_ED_2003_14_RM.pdf
7. European Aviation Safety Agency: Concept of Operations for Drones. https://www.easa.europa.eu/system/files/dfu/204696_EASA_concept_drone_brochure_web.pdf. Accessed 9 May 2016
8. European Aviation Safety Agency: Equipment, Systems and Installations in Small Remotely Piloted Unmanned Systems (RPAS), EASA SC-RPAS.1309-01, July 2015. https://www.easa.europa.eu/system/files/dfu/SC-RPAS.1309-01_Iss01-public%20consultation.pdf
9. European Aviation Safety Agency: Transposition of Amendment 43 to Annex 2 to the Chicago Convention on remotely piloted aircraft systems (RPAS) into common rules of the air, EASA NPA 2014-09, 3 Apr 2014. https://www.easa.europa.eu/system/files/dfu/NPA%202014-09.pdf
10. European Commission: Commission Regulation (EU) No 748/2012 of 3 Aug 2012 laying down implementing rules for the airworthiness and environmental certification of aircraft and related products, parts and appliances, as well as for the certification of design and production organisations, 3 Aug 2012. http://eur-lex.europa.eu/eli/reg/2012/748/oj
11. European Parliament and Council of the European Union: Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC, 17 May 2006. http://eur-lex.europa.eu/eli/dir/2006/42/oj
12. European Parliament and Council of the European Union: Regulation (EC) No 216/2008 of the European Parliament and of the Council of 20 Feb 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No 1592/2002 and Directive 2004/36/EC, 20 Feb 2008. http://eur-lex.europa.eu/eli/reg/2008/216/2013-01-29
13. Fagiano, L., Milanese, M., Piga, D.: High-altitude wind power generation. IEEE Transactions on Energy Conversion **25**(1), 168–180 (2010). doi: 10.1109/TEC.2009.2032582
14. Federal Aviation Administration: Aeronautical Information Manual. Official Guide to Basic Flight Information and ATC Procedures. (2015). http://www.faa.gov/air_traffic/publications/media/AIM.pdf
15. Federal Aviation Administration: Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap, 1st ed., 7 Nov 2013. https://www.faa.gov/uas/media/uas_roadmap_2013.pdf

16. Federal Aviation Administration: Model Aircraft Operating Standards, FAA Advisory Circular 91-57, 1 June 1981. https://www.faa.gov/documentLibrary/media/Advisory_Circular/91-57.pdf
17. Federal Aviation Administration: Notification for Airborne Wind Energy Systems (AWES), FAA-2011-1279, Dec 2011. https://www.gpo.gov/fdsys/pkg/FR-2011-12-07/pdf/2011-31430.pdf
18. Federal Aviation Administration: Unmanned Aircraft Systems (UAS) Operational Approval, FAA N 8900.227, 30 July 2013. https://www.faa.gov/documentLibrary/media/Notice/N_8900.227.pdf
19. Fritz, F.: Application of an Automated Kite System for Ship Propulsion and Power Generation. In: Ahrens, U., Diehl, M., Schmehl, R. (eds.) Airborne Wind Energy, Green Energy and Technology, Chap. 20, pp. 359–372. Springer, Berlin Heidelberg (2013). doi: 10.1007/978-3-642-39965-7_20
20. Glass, B.: A Review of Wind Standards as they Apply to Airborne Wind Turbines. In: Schmehl, R. (ed.). Book of Abstracts of the International Airborne Wind Energy Conference 2015, pp. 80–81, Delft, The Netherlands, 15–16 June 2015. doi: 10.4233/uuid:7df59b79-2c6b-4e30-bd58-8454f493bb09. Presentation video recording available from: https://collegerama.tudelft.nl/Mediasite/Play/90b60bc1e2bf44759ddc1b18185383791d
21. Hardham, C.: Response to the Federal Aviation Authority. Docket No.: FAA-2011-1279; Notice No. 11-07; Notification for Airborne Wind Energy Systems (AWES), Makani Power, 7 Feb 2012. https://www.regulations.gov/#!documentDetail;D=FAA-2011-1279-0014
22. Hayhurst, K. J., Maddalon, J. M., Morris, A. T., Neogi, N., Verstynen, H. A.: A Review of Current and Prospective Factors for Classification of Civil Unmanned Aircraft Systems. NASA TM-2014-218511, NASA Langley Research Center, Aug 2014. https://shemesh.larc.nasa.gov/people/jmm/NASA-TM-2014-218511.pdf
23. International Civil Aviation Organization: Adoption of Amendment 6 to Annex 7, ICAO State Letter AN 3/1-12/9, 4 Apr 2012. https://www.icao.int/Meetings/UAS/Documents/Adoption%20of%20Amendment%206%20to%20Annex%207.pdf
24. International Civil Aviation Organization: International Standards and Recommended Practices. Annex 2 – Rules of the Air, 10th ed., July 2005. https://www.icao.int/Meetings/anconf12/Document%20Archive/an02_cons%5B1%5D.pdf
25. International Civil Aviation Organization: International Standards and Recommended Practices. Annex 4 – Aeronautical Charts, 11th ed., July 2009
26. International Civil Aviation Organization: International Standards and Recommended Practices. Annex 14, Vol. 1 – Aerodrome Design and Operations, 6th ed., July 2013
27. International Civil Aviation Organization: Manual on Remotely Piloted Aircraft Systems (RPAS), ICAO 10019, Mar 2015
28. International Civil Aviation Organization: Unmanned Aircraft Systems (UAS), ICAO Circular 328-AN/190, Apr 2012. https://www.icao.int/Meetings/UAS/Documents/Circular%20328_en.pdf
29. Joint Authorities for Rulemaking on Unmanned Systems. http://jarus-rpas.org/ (2017). Accessed 1 Oct 2017
30. Kite Power Systems Ltd. http://www.kitepowersystems.com/. Accessed 4 Oct 2017
31. Kitemill AS. http://www.kitemill.no/. Accessed 16 July 2015
32. Kronborg, B., Schaefer, D.: eWind Solutions Company Overview and Major Design Choices. In: Schmehl, R. (ed.). Book of Abstracts of the International Airborne Wind Energy Conference 2015, pp. 32–33, Delft, The Netherlands, 15–16 June 2015. doi: 10.4233/uuid:7df59b79-2c6b-4e30-bd58-8454f493bb09. Presentation video recording available from: https://collegerama.tudelft.nl/Mediasite/Play/748f1290e610439dab221365c521bdfd1d
33. Kruijff, M.: The Technology of Airborne Wind Energy – Part I: Launch & Land. https://www.ampyxpower.com/2017/04/1002 (2017). Accessed 10 Oct 2017
34. Kruijff, M.: The Technology of Airborne Wind Energy – Part II: the Drone. https://www.ampyxpower.com/2017/04/the-technology-of-airborne-wind-energy-part-ii-the-drone (2017). Accessed 10 Oct 2017

35. Kruijff, M.: The Technology of Airborne Wind Energy – Part III: Safe Power. https://www.ampyxpower.com/2017/05/the-technology-of-airborne-wind-energy-part-iii-safe-power (2017). Accessed 10 Oct 2017
36. Langley, W. R.: Go, Fly a Kite: The Promises (and Perils) of Airborne Wind-Energy Systems. Texas Law Review **94**, 425–450 (2015). http://www.texaslrev.com
37. Luchsinger, R. H. et al.: Closing the Gap: Pumping Cycle Kite Power with Twings. In: Schmehl, R. (ed.). Book of Abstracts of the International Airborne Wind Energy Conference 2015, pp. 26–28, Delft, The Netherlands, 15–16 June 2015. doi: 10.4233/uuid:7df59b79-2c6b-4e30-bd58-8454f493bb09. Presentation video recording available from: https://collegerama.tudelft.nl/Mediasite/Play/646b794e7ac54320ba48ba9f41b41f811d
38. Milanese, M., Taddei, F., Milanese, S.: Design and Testing of a 60 kW Yo-Yo Airborne Wind Energy Generator. In: Ahrens, U., Diehl, M., Schmehl, R. (eds.) Airborne Wind Energy, Green Energy and Technology, Chap. 21, pp. 373–386. Springer, Berlin Heidelberg (2013). doi: 10.1007/978-3-642-39965-7_21
39. National Transportation Safety Board: In-Flight Breakup During Test Flight Scaled Composites SpaceShipTwo, N339SS, Near Koehn Dry Lake, California October 31, 2014. NTSB/AAR-15/02, Washington, DC, USA, 28 July 2015. https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR1502.pdf
40. North Atlantic Treaty Organization: Light Unmanned Aircraft Systems Airworthiness Requirements, NATO STANAG 4703 draft, 1st ed., Sept 2014
41. North Atlantic Treaty Organization: UAV Systems Airworthiness Requirements (USAR) for North Atlantic Treaty Organization (NATO) Military UAV Systems, NATO STANAG 4671 draft, 1st ed., Mar 2007
42. Northrop Grumman: RQ-4 Block 40 Global Hawk. http://www.northropgrumman.com/Capabilities/GlobalHawk/Documents/Datasheet_GH_Block_40.pdf. Accessed 16 July 2015
43. Pardal, T., Silva, P.: Analysis of Experimental Data of a Hybrid System Exploiting the Magnus Effect for Energy from High Altitude Wind. In: Schmehl, R. (ed.). Book of Abstracts of the International Airborne Wind Energy Conference 2015, pp. 30–31, Delft, The Netherlands, 15–16 June 2015. doi: 10.4233/uuid:7df59b79-2c6b-4e30-bd58-8454f493bb09. Presentation video recording available from: https://collegerama.tudelft.nl/Mediasite/Play/e51a679525fe491990de3a55a912f79d1d
44. Ruiterkamp, R., Salma, V., Kruijff, M.: Update on Certification and Regulations of Airborne Wind Energy Systems – The European Case for Rigid Wings. In: Schmehl, R. (ed.). Book of Abstracts of the International Airborne Wind Energy Conference 2015, pp. 78–79, Delft, The Netherlands, 15–16 June 2015. doi: 10.4233/uuid:7df59b79-2c6b-4e30-bd58-8454f493bb09. Presentation video recording available from: https://collegerama.tudelft.nl/Mediasite/Play/c8a9806aea024394a36cc35f9d6e98a81d
45. Schmehl, R. (ed.): Book of Abstracts of the International Airborne Wind Energy Conference 2015. Delft University of Technology, Delft, The Netherlands (2015). doi: 10.4233/uuid:7df59b79-2c6b-4e30-bd58-8454f493bb09
46. Sieberling, S., Ruiterkamp, R.: The PowerPlane an Airborne Wind Energy System. AIAA Paper 2011-6909. In: Proceedings of the 11th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Virginia Beach, VA, USA, 20–22 Sept 2011. doi: 10.2514/6.2011-6909
47. Terink, E. J., Breukels, J., Schmehl, R., Ockels, W. J.: Flight Dynamics and Stability of a Tethered Inflatable Kiteplane. AIAA Journal of Aircraft **48**(2), 503–513 (2011). doi: 10.2514/1.C031108
48. United States Congress: FAA Modernization and Reform Act of 2012. 112th Congress (2011–2012), House Resolution 658, Became Public Law No 112-95, Feb 2012. http://www.gpo.gov/fdsys/pkg/BILLS-112hr658enr/pdf/BILLS-112hr658enr.pdf
49. United States Government: Title 14 Code of Federal Regulations – Aeronautics and Space, http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title14/14tab%5C_02.tpl Accessed 29 May 2016

50. United States Next Generation Air Transportation System Joint Planning & Development Office: Unmanned Aircraft Systems (UAS) Comprehensive Plan, Washington, DC, USA, Sept 2013. http://purl.fdlp.gov/GPO/gpo42116
51. University of Washington Technology Law and Public Policy Clinic: Domestic Drones – Technical and Policy Issues. Clinic Policy Report, University of Washington, School of Law, 2013, pp. 1–20. https://www.law.washington.edu/clinics/technology/reports/droneslawandpolicy.pdf
52. Vander Lind, D.: Developing a 600 kW Airborne Wind Turbine. In: Schmehl, R. (ed.). Book of abstracts of the International Airborne Wind Energy Conference 2015, pp. 14–17, Delft, The Netherlands, 15–16 June 2015. doi: 10.4233/uuid:7df59b79-2c6b-4e30-bd58-8454f493bb09. Presentation video recording available from: https://collegerama.tudelft.nl/Mediasite/Play/639f1661d28e483cb75a9a8bdedce6f11d
53. Vermillion, C., Glass, B., Rein, A.: Lighter-Than-Air Wind Energy Systems. In: Ahrens, U., Diehl, M., Schmehl, R. (eds.) Airborne Wind Energy, Green Energy and Technology, Chap. 30, pp. 501–514. Springer, Berlin Heidelberg (2013). doi: 10.1007/978-3-642-39965-7_30
54. Windlift, Inc. http://www.windlift.com. Accessed 16 July 2015