An introduction to the Specific Operations Risk Assessment (SORA) for Airborne Wind Energy

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Document Version Control

Date	Version	Author	Description
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this information for the planning or execution of operational activities. This document has been prepared only for distribution within the AWEurope Working Group on Safety and is not intended for public distribution.

Contents

1. Definitions

AGL – Above Ground Level

ANSP – Air Navigation Service Provider

ARC – Air Risk Class

AWE – Airborne Wind Energy

BVLOS – Beyond Visual Line of Sight

CAA – Civil Aviation Authority

CONOPS – Concept of Operations

DAA – Detect and Avoid

ERP – Emergency Response Plan

FOCA – Federal Office of Civil Aviation

GRC – Ground Risk Class

GS – Ground Station

HRM – Holistic Risk Model

JARUS – Joint Authority on Rulemaking for Unmanned Systems

MAC – Mid Air Collision

NAA – National Aviation Authority

NOTAM – Notice to Airmen

OA – Operational Approval

OSO – Operational Safety Objective

SAIL – Specific Assurance and Integrity Level

SORA – Specific Operations Risk Assessment

TMPR – Tactical Mitigation Performance Requirements

UAS – Unmanned Aerial Systems

UTM – Unmanned Traffic Management

VLOS – Visual Line of Sight

2. Introduction and scope of document

This document on the topic of operational risk assessment has been prepared for review by the AWEurope working group on Safety as an input to the AWE Technical Guidelines which are currently being developed.

It contains a general overview of what is expected from a competent authority in the form of a National Aviation Authority (NAA) or Civil Aviation Authority (CAA) and the Air Navigation Service Provider (ANSP)[1] to be included in a Concept of Operations (CONOPS) for the testing of an Airborne Wind Energy (AWE) system as well as an overview of the operational risk assessment methodology proposed by the Joint Authority on Rulemaking for Unmanned Systems (JARUS) on specific operations. The overview is based on the Specific Operations Risk Assessment (SORA) V2.0 Guidelines recently published by JARUS [JARUS SORA v2.0 package] as well as the authors recent experience in applying this process to seek an Operational Approval (OA) for a AWE operation in the specific category.

The SORA process is based on a Holistic Risk Model (HRM) which provides a generic framework to identify the hazards, threats and the relevant harm and threat barriers applicable to any Unmanned Arial Systems (UAS) operation. A bow tie representation of this HRM is shown in Fehler: Referenz nicht gefunden below. A few key terms will now be defined:

- **Risk** – the combination of frequency (probability) of an occurrence and its associated level of severity
- **Threat** – an occurrence that in absence of appropriate threat barriers can potentially result in a hazard
- **Hazard** – a UAS operation that is out of control, which can potentially cause harm
- Three types of **harm** are considered:
    - Fatal injuries to third parties on the ground[2]

1 Examples: In Switzerland this would be SkyGuide, in Germany DFS.

2 AWE would clearly aim to mitigate all injuries, not only fatal ones.

- Fatal injuries to third parties in the air (i.e. Catastrophic Mid Air Collision (MAC) with a manned aircraft)
- Damage to critical infrastructure[3]

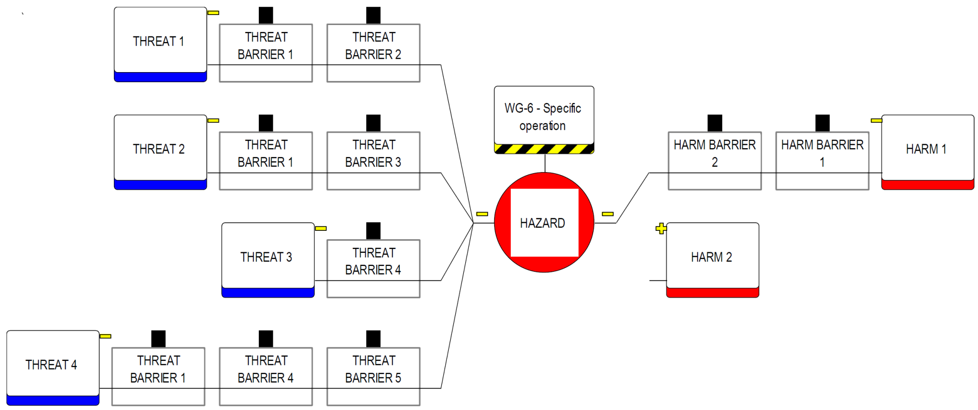

Figure 1: Bow tie representation of the Holistic Risk Model (HRM)

The basic approach of the SORA process is to define the requirements for the threat barriers which are considered proportional to the risk of the specific operation. With the risk being the likelihood that a hazard will occur, as well as the severity of the harm it will cause, considering the harm barriers that have been applied.

The result of the SORA process is to assign a Specific Integrity and Assurance Level (SAIL) to the operations, which is basically the level of confidence that an operation will stay in control. Depending on the resulting SAIL (value from 1 – 6), the operator must comply with a number of Operational Safety Objectives (OSOs) to varying levels of robustness. OSOs are the threat barriers shown in Fehler: Referenz nicht gefunden above. These OSOs are described in SORA Annex E [JARUS SORA v2.0 package]. The specific threats that the OSOs are attempting to mitigate are shown on the left side of Fehler: Referenz nicht gefunden below.

3 AWE would clearly aim to mitigate all damages, not only the ones to critical infrastructure.

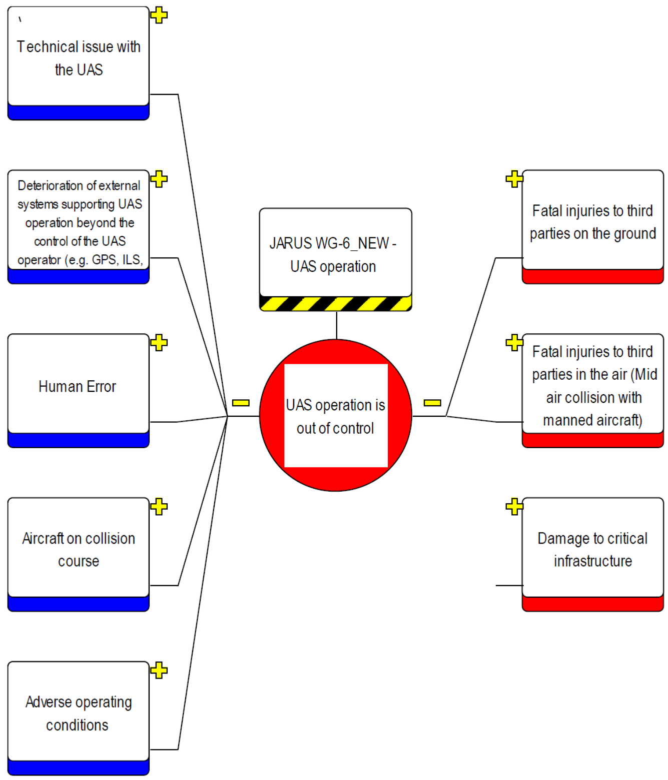

Figure 2: Threats and Harms considered by the SORA process

It is understood that not all AWE developers are currently required by their competent authorities to follow the SORA process as proposed by JARUS. However, it is believed that the principles applied within this process are helpful to ensure the safe operation of airborne wind energy systems, especially during the testing and development phase, which is in the interest of all AWE stakeholders. The basic goal of the process is to find a practical and proportional way to effectively mitigate the potential air and ground risks of the operation. The approach is general enough that it can be applied to any AWE operation, regardless of the system configuration, size or its location.

3. CONOPS and OSO Considerations for AWE

The first step in the SORA process is to develop a CONOPS description. This is a collection of the relevant technical, operational and system information needed to assess the risk associated with the intended operation. The SORA Annex A [JARUS SORA v2.0 package] provides a detailed framework for data collection and presentation. It consists of two main parts:

1. Operation relevant information
2. Technical relevant information

As the CONOPS structure has been proposed considering UAS applications, some adjustments need to be made for an AWE operation, but in general the structure of the document works well. As the CONOPS must include a description of how the required OSOs are met, the process of developing it is iterative, and the applicant should first get a good understanding of the likely SAIL requirement of their operation so that the CONOPS can be prepared appropriately.

For the testing and development of AWE prototypes, it is recommended that the applicant try and achieve a SAIL requirement of 3 or less, so that the number and robustness of the required OSO compliance is not so onerous. In total there are 24 OSOs, although only 18 of them are unique. A description of these OSOs as well as the compliance criteria for the three robustness levels are given in SORA Annex E. [JARUS SORA v2.0 package] Each OSO has at least one compliance criteria for both level of integrity and level of assurance. A few of the most important OSOs are listed below. These are considered to be quite important threat barriers as they each mitigate a number of different threats.

- Operational procedures are defined, validated and adhered to (OSO #08, #11, # 14 and # 21)
- Remote crew trained and current and able to control the abnormal and emergency situations (OSO #09, #15, #22)
- Safe recovery from technical issue (OSO #10, #12)

A few definitions will now be given which are needed to understand the implications of the resulting SAIL on the CONOPS in terms of OSO compliance.

- **Level of robustness** – a measure to describe a given risk mitigation or operational safety objective, designated by level of **integrity** and **assurance**.
- **Level of integrity** – the safety gain provided by each mitigation.
- **Level of assurance** – the method of proof that the claimed gain has been achieved.
    - low – self declaration.
    - medium – supporting evidence is provided.
    - high – third party validation.

The relationship between level of robustness, level of integrity and level of assurance is illustrated in Fehler: Referenz nicht gefunden below.

	Low Assurance	Medium Assurance	High Assurance
Low Integrity	Low robustness	Low robustness	Low robustness
Medium Integrity	Low robustness	Medium robustness	Medium robustness
High Integrity	Low robustness	Medium robustness	High robustness

Figure 3: Relationship between robustness, integrity and assurance

As seen in the tables on pages 27, 28 and 29 of the SORA V2.0 guidelines, for a SAIL of 4 and above, the operator must comply with all OSOs, and most of them to a medium or high level of robustness.

From the point of view of the author, SAIL = 2 seems to be a pretty good goal for AWE operations in the testing and development phase. Given the appropriate strategic mitigations, this allows the testing of prototypes with wing spans up to 8m with only 12 unique OSOs to comply with. In addition, only one of these (OSO #08) requires a medium level of robustness, which assuming the operator has a good track record of performing safe AWE operations should not be difficult to justify.

Based on the author's understanding of the SORA process (feedback on our application is still pending from the Swiss FOCA) there are a few specific ground and air risk strategic mitigations which can be relatively easily applied to AWE system operations in order to achieve a SAIL = 2. It is the authors opinion that these 'best practices' would be applicable to any AWE operation and can also be applied regardless if a formal SORA application must be submitted or not. Some basic concepts for the mitigation of ground and air risk will now be described.

3.1 Ground risk mitigation concept for AWE

As any AWE system in the testing and development phase has a non-zero chance of crashing to the ground, it is imperative that the area under which the airborne part of the system is operating is free from persons (third parties) or critical infrastructure. In an ideal case, the operator would have access to a test site with a restricted or controlled ground area (i.e. fenced off or otherwise controlled against entry from third parties). However, in practice such a test area is often difficult if not impossible to find. Based on the authors experience of operating AWE systems at a number of locations throughout Switzerland, it is possible to achieve an effectively controlled ground area through the careful selection of test site location as well as the use of ground risk observers who are in radio communication with the pilot or system operator.

The basic ground risk mitigation concept is illustrated in Figure 4: Strategic ground risk mitigation concept for AWE below. Although this was developed with a rigid wing AWE concept in mind, it can be applied to any system concept which can potentially crash under high tether load, resulting in an injury or fatality to the person in the affected area. Even though the low mass of a flexible wing (kite) is often cited as a safety advantage, based on the authors experience, the crash of a kite under high tether load is extremely dangerous and could be potentially fatal. For kite based system concepts using a control pod this is even more critical.

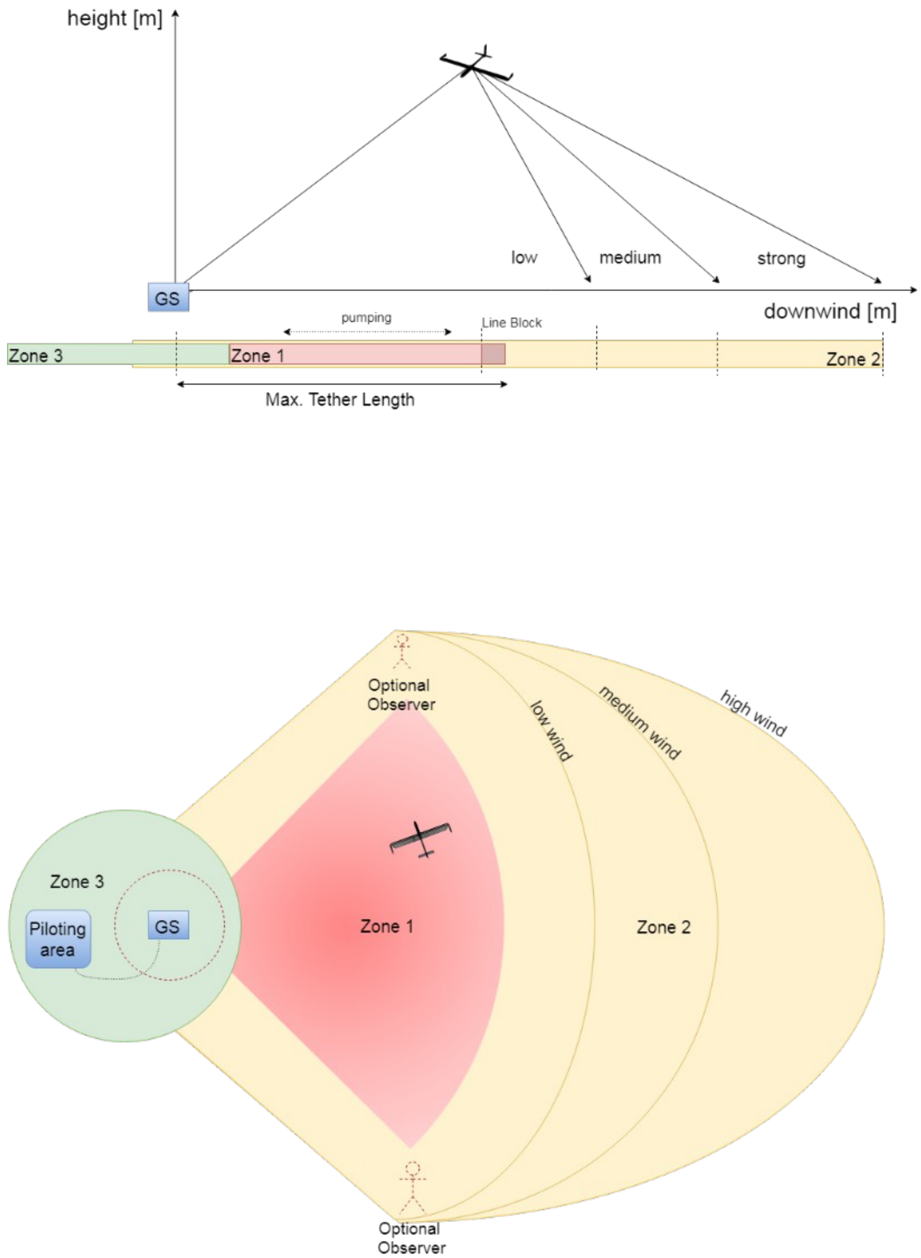

Figure 4: Strategic ground risk mitigation concept for AWE

The overall volume in which the system operates is defined as the 'operational zone', which has been sub-divided into three different areas (projected onto ground level) which will now be described.

Zone 1 is referred to as the 'restricted zone' and represents the area downwind from the ground station where the airborne part of the system could crash under high load on the tether. During operations, no persons (including test crew) are permitted in this zone. The Ground Station (GS) is located at a position where (for the given wind direction) the restricted zone does not include any active buildings or roads.[4]

Zone 2 is referred to as the 'danger zone' and represents an enlarged downwind area around the restricted zone which is normally kept free of persons during operations. In case of a tether break or a structural failure of the airborne part of the system, this zone represents the most probable area in which the parts of the system may land. Depending on the wind speed, the extension of this zone in the downwind direction is adapted.

Depending on the site and wind direction, the danger zone may include a street or a building, which are actively monitored by one or more 'observers' who are in constant radio communication with the pilot or system operator. In case a third party (typically a hiker or a biker in the authors experience) enters the zone, the pilot is notified and can use his judgement as to what evasive maneuvers (if any) should be taken. Typically the observers would be positioned at each end of any road which may pass through the 'danger zone' and they would notify any third parties passing through it of the test and to ensure that they pass through the zone quickly. In addition to the observers, warning signs should be placed at the appropriate locations around the test area.

Zone 3 is referred to as the 'piloting zone' and represents an area around the ground station in which staff or instructed third parties can be present during operations. This zone contains a safety shelter where persons should be located during launching and landing maneuvers. Also the area in front of the ground station (tether exit point) should be restricted.

With the application of the strategic ground risk mitigation concept described above, the intrinsic UAS ground risk class for any size of system can be reduced to a lowest possible value. The implication of this result on the SAIL determination will be described in section Operational risk assessment based on SORA V2.0 Guidelines below.

3.2 Air risk mitigation concepts for AWE

As with ground risk, the mitigation of air risk through strategic and tactical measures is highly dependent on the airspace conditions at the proposed test site. For the testing and development phases, the ideal situation is to have a restricted airspace around the test site, so that in theory no aircraft should enter the airspace and if they do then they are liable for any incidents which may occur. However, as is the case for a restricted ground area, a restricted airspace is probably even harder to find. A few potential air risk mitigation concepts for AWE system operations will now be proposed.

3.2.1 Maximize System Visibility

The first and potentially most important point which can help to minimize the chances of a Mid Air Collision (MAC) would be to make the airborne part of the system as visible as possible. This can be done through a combination of high visibility paint as well as the appropriate application of lighting.

4 Kitepower: This definition is adequate for the current test phase were we are in. In general, this is a very large area and the likelyhood that a crash occurs in a specific spot is not constant over the complete area. In the future Kitepower foresees dual use of this area with for example farmland, where the likelyhood that someone is present in this area is low.

Although no standards currently exist for the marking and lighting of AWE systems, the proposed concept from Makani (apparently developed in consultation with the FAA) is shown in Fehler: Referenz nicht gefunden below. These figures were taken from a description of their proposed offshore project which is available online. [Makani offshore project description and operational assessment] The document indicates that the 'kite' will be painted white, with a yellow area at the starboard wingtip and an orange area at the portside wingtip. The tether will be painted with white and orange bands each with 150 feet in length. It also indicates that there will be four white strobe lights on the 'kite', placed at the starboard wingtip (1x), portside wingtip (1x) and the tail (2x). The document claims that the intensity of these lights will be greater than 400 effective candela.[5]

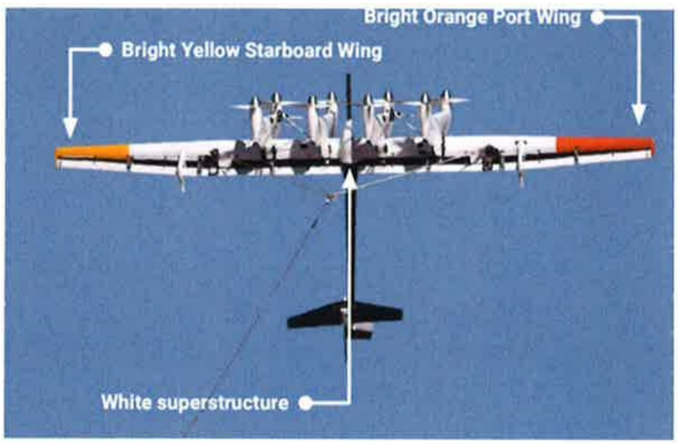

Figure 5: Makani concept for marking of the airborne system (left) and tether (right)

3.2.2 Danger Area w/ NOTAM

For extended AWE testing in the specific category (i.e. above 500 feet AGL), the publication of a 'Danger Area' and its activation through a Notice to Airmen (NOTAM) is a recommended practice.[6] Such a process should be possible to organize in consultation with the local authorities and should have a relatively low impact on the complexity of test operations. This would notify pilots who would be performing flights in the area that there might be some sort of dangerous tethered object flying around at a specific location and should (in theory) help reduce the chances of a MAC.

3.2.3 Dedicated Observer w/ FLARM

For the operation of AWE systems in airspace with a non-zero chance of encounters with manned aircraft, it is likely that the airspace authorities will require some sort of tactical mitigation of air risk. The legal background for this is to provide a means of compliance with the ICAO Annex 2 section 3.2

5 The criteria in CS 31TGB.65 Night lighting may be used. https://www.easa.europa.eu/sites/default/files/dfu/Annex%20to%20ED%20Decision%202013-011-R.pdf

6 For commercial applications this practice will need to be changed.

'See & Avoid' requirement. The most straightforward approach for meeting this requirement is to have a dedicated observer who is responsible for detecting incoming aircraft and initiating an emergency landing if an aircraft is on a collision course.

As the visual detection of an oncoming aircraft can be difficult and requires a very high degree of concentration and diligence from the observer, one option is to support the observer's ability to detect incoming aircraft through electronic means, such as FLARM. [PowerFLARM and Alert Zone firware update] FLARM is a traffic awareness and collision avoidance technology for general aviation, light aircraft and UAVs. Typically, the FLARM device is mounted on the aircraft or UAV, but for a tethered application like AWE, it is also feasible to have the device located on the ground station or piloting area. The specifications for the latest version of FLARM devices, called PowerFLARM, are shown in Fehler: Referenz nicht gefunden below. These new devices have a longer range compared to classic FLARM and also support incoming ADS-B and transponder data integration.

Although FLARM may not be the appropriate technology for all areas, at least in Switzerland almost all glider planes as well as many light aircraft and helicopters are equipped with them so it makes sense to take advantage of this.

Technical Specifications

	PowerFLARM Core	PowerFLARM Portable
Type	Installed	Portable
Display	Separate	Integrated Color LCD
Recommended for	All aircraft types	Personal use in all GA aircraft
Dimensions	41 x 80 x 120 mm	46 x 96 x 94 mm
Mass	245 g (Pure) / 285 g (ADS-B)	260 g w/o batteries
Power supply	12-32 V DC	8-23 V DC
Power consumption	165 mA @ 12 VDC	175 mA @ 12 VDC
Data ports, Storage	2 (D-sub DE-9 and RJ45), USB	1 (RJ45), Micro SD
Transponder/ADS-B 1090ES receiver	Optional	Included

Figure 6: Specifications for the PowerFLARM devices

With the latest PowerFLARM device, it is possible to use the 'Alert Zone' functionality which allows the user to setup a kind of danger area where incoming aircraft which are equipped with FLARM get a warning. It is also possible to set a warning limit for incoming traffic as well, so that the observer is able to detect incoming aircraft, even before they would be visible to the naked eye. An initial proposal for these warning limits as well as a Google Earth overlay showing their size in comparison to a typical operational volume of an AWE system are shown in Fehler: Referenz nicht gefunden below.

Alert Zone Configuration Parameters:	Radius (m)	Height (m)
Incoming warning limit	4,500	1,000
Warning limit for incoming	2,000	700

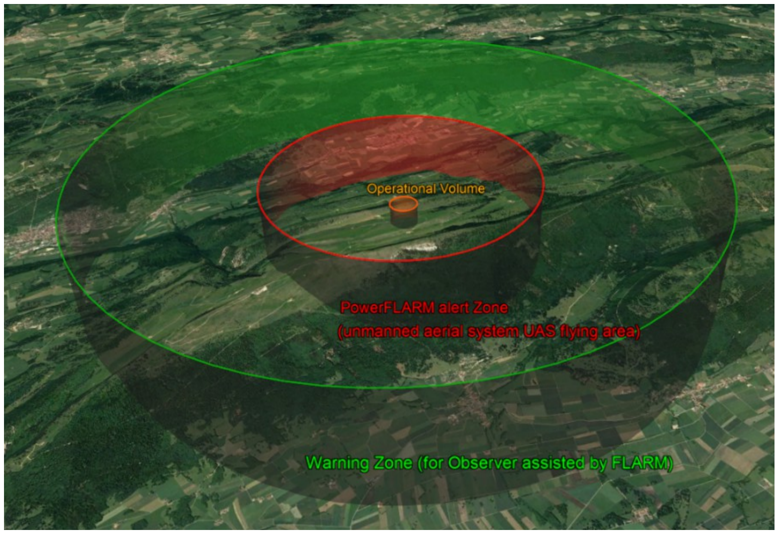

Figure 7: Alert zone parameters and visualization of the FLARM warning zones

4. Operational risk assessment based on SORA V2.0 Guidelines

The SORA V2.0 guidelines provide a detailed description of the steps that the applicant should follow in order to prepare the SORA application for submission to their competent authority. These 10 steps are visualized in Fehler: Referenz nicht gefunden below. For each of the steps, a few considerations and recommendations specific to AWE systems will now be given.

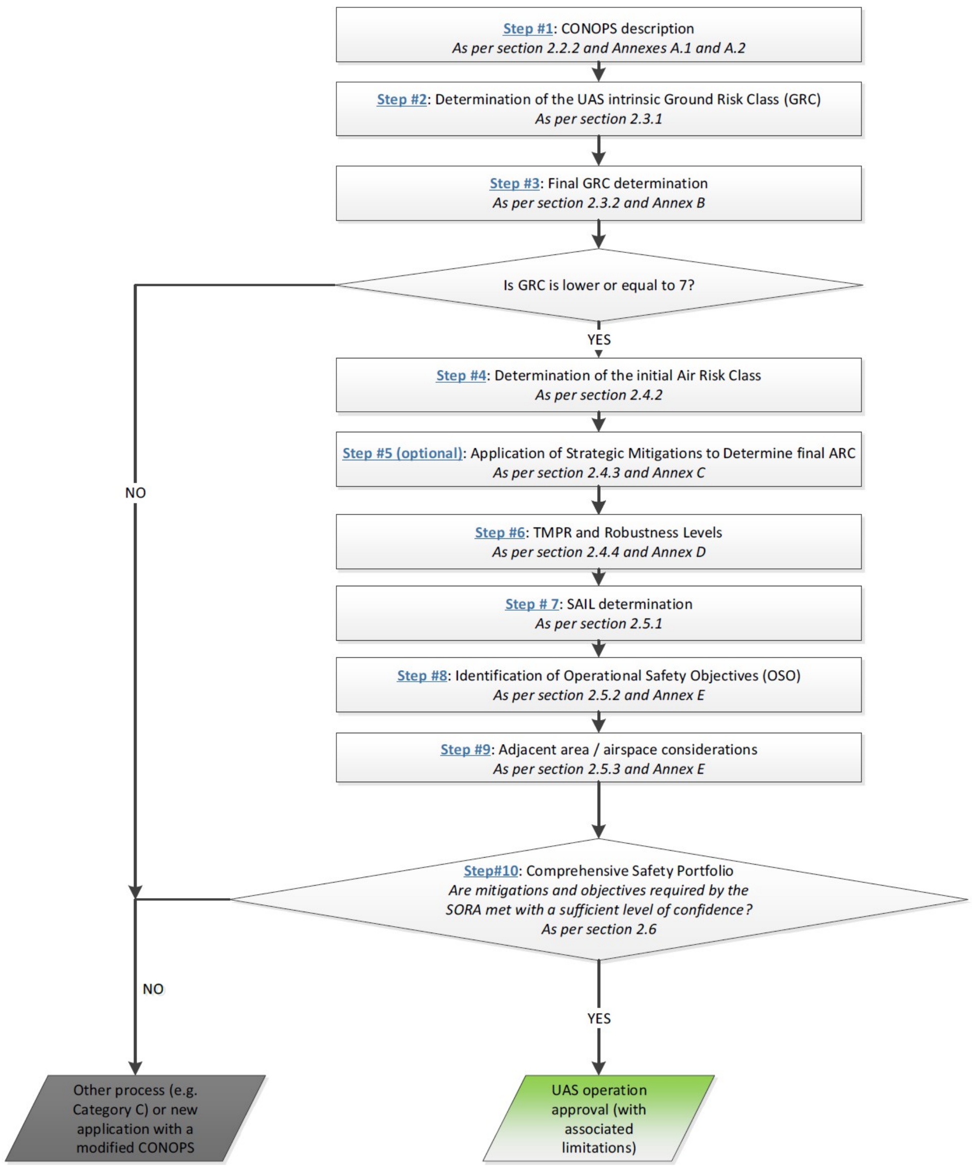

Figure 8: Process steps from SORA V2.0 Guidelines [JARUS SORA v2.0 package]

4.1 Step #1 – CONOPS description

The SORA Annex A [JARUS SORA v2.0 package] provides a detailed template on what operation and technical relevant information should be provided. Recommendations on potential ways of mitigating both air and ground risk, which should be included as part of the CONOPS, were given in section CONOPS and OSO Considerations for AWE above.

4.2 Step #2 – Initial GRC determination

Initial (or intrinsic) Ground Risk Class (GRC) is determined using the table in Fehler: Referenz nicht gefunden below.

Intrinsic UAS Ground Risk Class				
Max UAS characteristics dimension	1 m / approx. 3ft	3 m / approx. 10ft	8 m / approx. 25ft	>8 m / approx. 25ft
Typical kinetic energy expected	*< 700 J (approx. 529 Ft Lb)*	*< 34 KJ (approx. 25000 Ft Lb)*	*< 1084 KJ (approx. 800000 Ft Lb)*	*> 1084 KJ (approx. 800000 Ft Lb)*
Operational scenarios				
VLOS/BVLOS over controlled ground area	1	2	3	4
VLOS in sparsely populated environment	2	3	4	5
BVLOS in sparsely populated environment	3	4	5	6
VLOS in populated environment	4	5	6	8
BVLOS in populated environment	5	6	8	10
VLOS over gathering of people	7			
BVLOS over gathering of people	8			

Figure 9: Table 2 from SORA V2.0 Guidelines [JARUS SORA v2.0 package][7]

Based on preliminary feedback from the Swiss Federal Office of Civil Aviation (FOCA), the initial GRC is determined using only the maximum characteristic dimensions of the UAS, which for the case of an AWE system would be the wing span of the airborne part of the system. The justification for this is that regardless of the mass, and therefore the resulting kinetic energy dissipated in a ground impact, the lethality is considered to be high. In this case the most important factor is the effected area of the impact, which is roughly the square of the characteristic dimension. It could be that for very light airborne systems, such as fabric kites, the competent authority would allow for an adjustment of the initial GRC based on the kinetic energy factor, but this would have to be investigated further.

Once the appropriate column in the initial GRC table is determined, the next step is to classify the operational scenario in terms of being either Visual Line of Sight (VLOS) or Beyond Visual Line of Sight (BVLOS) and in terms of the type of environment over which the system is operating. For AWE systems in the testing and development phase it is recommended to operate over a controlled ground area, which would allow the initial GRC (and eventually the SAIL requirement) to be minimized. It is the authors understanding that in the context of the SORA process, a VLOS operation in terms of GRC would require the active monitoring of the ground area under which the airborne part of the system operations and the ability to react in case a third party enters that area. An approach to achieve this (and therefore minimize the initial GRC / SAIL determination) has been described in section Ground risk mitigation concept for AWE.

7 The definition of controlled/sparsely populated and populated environment should be checked for AWE.

4.3 Step #3 – Final GRC determination

The initial GRC is adapted using strategic mitigations (harm barriers) to obtain a final GRC. The three different types of strategic mitigations, their sequence and effect on the initial GRC is shown in Figure 10: Table 3 from SORA V2.0 Guidelines [JARUS SORA v2.0 package] below.

		Robustness		
Mitigation Sequence	**Mitigations for ground risk**	Low/None	Medium	High
1	M1 - Strategic mitigations for ground risk[e]	**0: None -1: Low**	**-2**	**-4**
2	M2 - Effects of ground impact are reduced[f]	**0**	**-1**	**-2**
3	M3 - An Emergency Response Plan (ERP) is in place, operator validated and effective	**1**	**0**	**-1**

Figure 10: Table 3 from SORA V2.0 Guidelines [JARUS SORA v2.0 package]

M1 mitigations are intended to reduce the number of people at risk on the ground. For an AWE system, the most obvious M1 mitigation is 'tethered operation'. This effectively 'geofences' the operational volume of the system, enabling a 'controlled ground area' to be claimed with a high degree of confidence. SORA Annex B [JARUS SORA v2.0 package] contains considerations for 'tether operation' and describes the integrity and assurance criteria which must be achieved to claim a certain degree of robustness.

M2 mitigations are intended to reduce the effect of ground impact once control of the operation is lost. The most obvious way to do this for a UAS would be the use of a parachute, although for an AWE system it is not clear if this is really effective due to the high flight speeds relatively close to the ground that are inherent with crosswind, tethered operations.[8] Another M2 mitigation could be a safety shelter.

The final mitigation (M3) is to have an Emergency Response Plan (ERP) in place. This is essentially a set of procedures that should be followed in case the operation becomes 'out of control' in order to avoid any escalating effects.

Once the mitigations and their robustness levels have been determined, the initial GRC can be adapted accordingly. One point to keep in mind is that M1 mitigations cannot reduce the GRC to a value lower than the lowest value in the applicable column in table 2 of the SORA V2.0 Guidelines [JARUS SORA v2.0 package]. For an AWE system this means that if the applicant is using the fact that the operation is tethered to justify a controlled ground area, as described in section Ground risk mitigation concept for AWE, then 'tethered operation' can not be used as an additional strategic mitigation.

8 In case of a "soft" wing, the canopy may be considered a parachute even in case where parts of the canopy are destroyed or collapsed.

4.4 Step #4 – Initial ARC determination

The Air Risk Class (ARC) is a qualitative classification of the rate at which a UAS would encounter a manned aircraft in a typical generalized civil airspace. The initial ARC is determined using the flow chart shown in Fehler: Referenz nicht gefunden below.

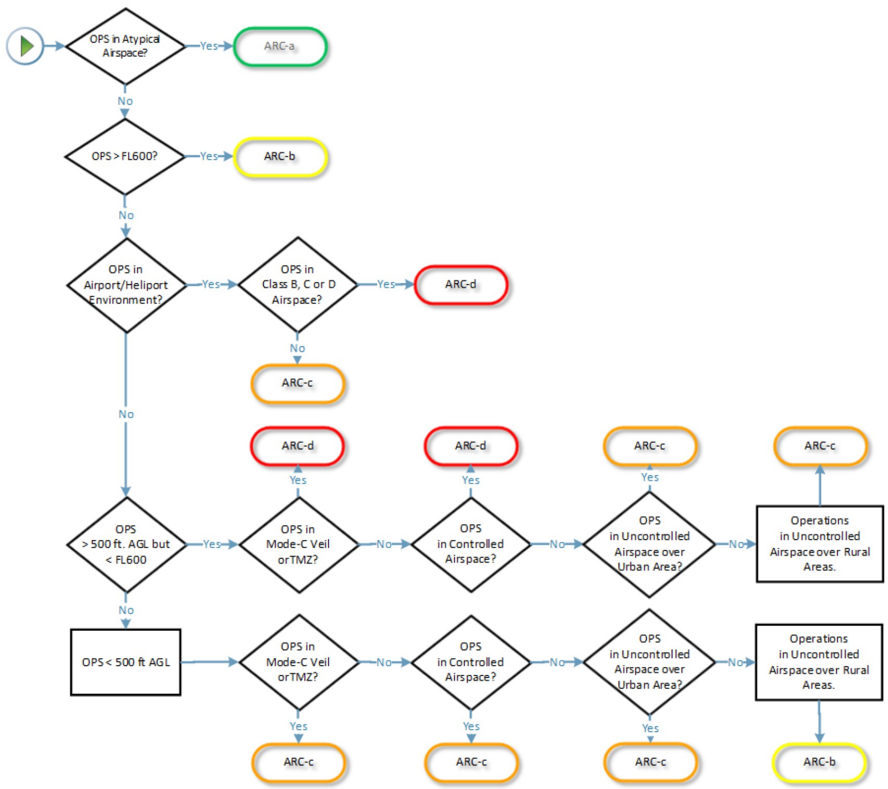

Figure 11: Figure 4 from SORA V2.0 Guidelines [JARUS SORA v2.0 package]

ARC for an AWE operation is highly dependent on the location of the proposed test site, and the type and frequency of air traffic that is operating in the area. The initial ARC classification should be discussed in advanced with the competent authority as it has a very strong impact on the SAIL determination.

It is expected that most AWE system operations in the testing and development phase (as well as for most commercial operations) will take place in uncontrolled airspace over rural areas, so ARC-c is probably the most appropriate classification. A reduction to ARC-b would require operations to stay under 500 ft. (~150m), which would be difficult for any system of reasonable size, or above FL600 (~18km), which is obviously not possible.

Operations within controlled airspace, such as a private or military airport which is inactive, has a low amount of traffic or fixed operating hours, could be a good opportunity for AWE in the testing and development phase. Assuming the applicant can get authorization from the airspace operator, this would be a good way to control air (and likely also ground) risk.[9]

4.5 Step #5 – Application of strategic mitigations to reduce ARC

The initial ARC can be (optionally) reduced through the application of strategic mitigations as described in SORA Annex C. [JARUS SORA v2.0 package] Mitigations are classified into three categories:

- 1 – Operational Restrictions
- 2 – Common Rules and Structures
- 3 – Tactical mitigations including separation provision and collision avoidance

The process of application of these mitigations and their effect on the residual ARC are shown in Fehler: Referenz nicht gefunden below.

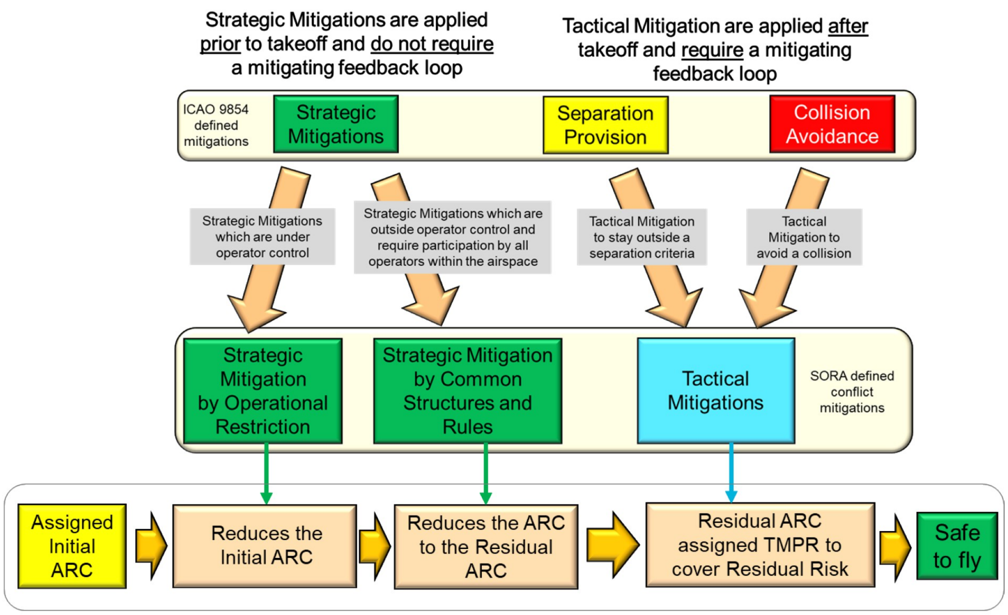

Figure 12: Figure 1 from SORA Annex C [JARUS SORA v2.0 package]

A number of potential strategic and tactical mitigations for air risk have been proposed in section Air risk mitigation concepts for AWE above[10]:

- Maximize system visibility

9 It needs to be discussed if for commercial systems the airspace above these sites should also be classified as "controlled", if it makes sense and what would be required.

10 Another option may be to park/hover or land the system in case other air traffic is detected or announced

- Danger area w/ NOTAM
- Observer w/ FLARM

For the testing and development of AWE systems, it is also reasonable to propose 'time of exposure' as an additional strategic mitigation. This considers the fact that a small number of short flights represent a much lower risk than continuous operation, and should be considered accordingly.[11] Operations during the night may also present an opportunity to justify a low ARC, as there are typically very few aircraft operating at that time and the application of lighting will be highly effective.

The SORA Annex C [JARUS SORA v2.0 package] proposes a method of justifying a reduction in ARC, which considers the density of manned aircraft in the area. However, it is recommended that the proposed mitigations as well as their impact on the residual ARC be discussed with the competent authority before finalizing the SORA application in order to make sure that the appropriate SAIL requirements in the form of OSO compliance have been considered in the CONOPS.

4.6 Step #6 – TMPR and robustness levels

Tactical mitigations are applied to mitigate any residual risk of a mid-air collision needed to achieve the applicable airspace safety objective. This takes the form of either 'see and avoid' (for VLOS operations) or may require a system which provides alternate means of achieving the safety objective, such as Detect and Avoid (DAA) systems. Tactical Mitigation Performance Requirements (TMPR) and their associated level of robustness are determined based on the residual ARC, as shown in Fehler: Referenz nicht gefunden below.

Residual ARC	Tactical Mitigation Performance Requirements (TMPR)	TMPR Level of Robustness
ARC-d	High	High
ARC-c	Medium	Medium
ARC-b	Low	Low
ARC-a	No requirement	No requirement

Figure 13: Table 4 from SORA V2.0 guidelines [JARUS SORA v2.0 package]

SORA Annex D [JARUS SORA v2.0 package] gives an overview of tactical mitigation, TMPR and the requirements which must be fulfilled in order to achieve a certain level of robustness. For AWE operations in the testing and development phase, which are most likely VLOS operations, there are no TMPR requirements. It is expected that this will be an important area of future development in order for commercial AWE systems to obtain operational approvals to operate at a high level of automation, where no human observer is required.

11 This is just about helping to reduce the SAIL and OSO requirements during the testing phase. For commercial operation, this measure must not be too important, otherwise 24/7 operation becomes difficult.

4.7 Step #7 – SAIL determination

The first step of the final part of the SORA process is to assign a SAIL to the operation. The SAIL parameter consolidates the ground and air risk analysis and drives the required activities. The SAIL represents the level of confidence that the UAS operation will stay under control. The SAIL is determined using the table shown in Fehler: Referenz nicht gefunden below.

What can be seen from the SAIL table below is that depending on the residual ARC, a reduction in the final GRC often has no impact on the SAIL determination. For example, there would be no point in applying additional mitigations to go from GRC 3 to 2, when the ARC is above ‘a’. However, GRC reductions would make sense down to 3 or even 2 for ARC’s ‘b’ or ‘a’ respectively.

As previously mentioned, for AWE operations in the testing and development stage, it is recommended to apply all possible mitigations in order to achieve a low as possible SAIL requirement. Although a SAIL = 1 is probably very difficult to achieve (unless maybe for operations at night or in a restricted / atypical airspace), a SAIL requirement of 2 or 3 would be a reasonable target, and should not add too many additional efforts compared to operations under the open category or some type of exemption.

For commercial operations, it is expected that higher SAIL requirements will be needed in order to allow AWE systems to operate in a wide range of environments (in order to maximize market size) and to minimize the tradeoffs (in terms of lost production capacity or operational costs) that many of the mitigation strategies would entail. For SAIL > 6, a certification process is envisioned.

At this point it is the authors opinion that it is not a foregone conclusion that a certification will be a hard requirement for all commercial AWE systems.[12] However, this decision will represent a trade off in terms of the costs of applying strategic and tactical mitigations (harm barriers) and those of complying with the operational safety objectives (threat barriers) or certification requirements needed for high SAIL or certified operations respectively.

12 For systems operating in locations with restricted airspace and controlled ground area, it can definitely be argued that a certification (at least from a safety perspective) may not be required. However, there are arguably also economic considerations which may actually be the driving factor here.

SAIL Determination				
	Residual ARC			
Final GRC	a	b	c	d
≤2	I	II	IV	VI
3	II	II	IV	VI
4	III	III	IV	VI
5	IV	IV	IV	VI
6	V	V	V	VI
7	VI	VI	VI	VI
>7	Category C operation			

Figure 14: Table 5 from the SORA V2.0 Guidelines [JARUS SORA v2.0 package]

4.8 Step #8 – Identification of OSOs

Once the SAIL requirement for the operation has been determined, it can be used to evaluate the defenses within the operation in the form of Operational Safety Objectives (OSOs) which must be applied and their associated level of robustness. As mentioned in section CONOPS and OSO Considerations for AWE, there are 24 OSOs, although only 18 of them are unique. A description of these OSOs as well as the compliance criteria for the three robustness levels are given in SORA Annex E [JARUS SORA v2.0 package]. Each OSO has at least one compliance criteria for both level of integrity and level of assurance. The OSOs and their robustness levels for each of the 6 SAIL levels are shown in Fehler: Referenz nicht gefunden below.[13]

OSO Number (in line with Annex E)		SAIL					
		I	II	III	IV	V	VI
	Technical issue with the UAS						
OSO#01	Ensure the operator is competent and/or proven	O	L	M	H	H	H
OSO#02	UAS manufactured by competent and/or proven entity	O	O	L	M	H	H

13 Twingtec has delivered a description for each of these points to the competent authority as part of the SORA document, which references back to the CONOPS where the compliance to these OSOs is described.

OSO Number (in line with Annex E)		SAIL					
		I	II	III	IV	V	VI
OSO#03	UAS maintained by competent and/or proven entity	L	L	M	M	H	H
OSO#04	UAS developed to authority recognized design standards[h]	O	O	O	L	M	H
OSO#05	UAS is designed considering system safety and reliability	O	O	L	M	H	H
OSO#06	C3 link performance is appropriate for the operation	O	L	L	M	H	H
OSO#07	Inspection of the UAS (product inspection) to ensure consistency to the ConOps	L	L	M	M	H	H
OSO#08	Operational procedures are defined, validated and adhered to	L	M	H	H	H	H
OSO#09	Remote crew trained and current and able to control the abnormal situation	L	L	M	M	H	H
OSO#10	Safe recovery from technical issue	L	L	M	M	H	H
	Deterioration of external systems supporting UAS operation						
OSO#11	Procedures are in-place to handle the deterioration of external systems supporting UAS operation	L	M	H	H	H	H
OSO#12	The UAS is designed to manage the deterioration of external systems supporting UAS operation	L	L	M	M	H	H
OSO#13	External services supporting UAS operations are adequate to the operation	L	L	M	H	H	H
	Human Error						
OSO#14	Operational procedures are defined, validated and adhered to	L	M	H	H	H	H
OSO#15	Remote crew trained and current and able to control the abnormal situation	L	L	M	M	H	H
OSO#16	Multi crew coordination	L	L	M	M	H	H
OSO#17	Remote crew is fit to operate	L	L	M	M	H	H
OSO#18	Automatic protection of the flight envelope from Human Error	O	O	L	M	H	H
OSO#19	Safe recovery from Human Error	O	O	L	M	M	H
OSO#20	A Human Factors evaluation has been performed and the HMI found appropriate for the mission	O	L	L	M	M	H

OSO Number (in line with Annex E)		SAIL					
		I	II	III	IV	V	VI
	Adverse operating conditions						
OSO#21	Operational procedures are defined, validated and adhered to	L	M	H	H	H	H
OSO#22	The remote crew is trained to identify critical environmental conditions and to avoid them	L	L	M	M	M	H
OSO#23	Environmental conditions for safe operations defined, measurable and adhered to	L	L	M	M	H	H
OSO#24	UAS designed and qualified for adverse environmental conditions	O	O	M	H	H	H

Figure 15: Table 6 in SORA V2.0 Guidelines [JARUS SORA v2.0 package]

The robustness of the OSOs have 4 possible levels, each of which is roughly categorized in terms of compliance requirements in the brackets below:

- O = Optional (not required)
- L = Low (self-declaration)
- M = Medium (supporting evidence provided)
- H = High (competent third party validation)

From this it can be seen that for SAIL >= 3, some aspects of the applicants CONOPS may require validation from a competent third party. At SAIL = 6, this is the case for all aspects of the CONOPS in order to be certain that the probability of the operational getting out of control (and creating a harm) is very low.

Regardless of the SAIL requirement, the application procedure is to describe the intended operations and for each OSO make a reference to the appropriate section of the CONOPS document in order to demonstrate compliance to the required level of robustness based on the guidance in SORA Annex E. [JARUS SORA v2.0 package]

4.9 Step #9 – Adjacent area / airspace considerations

In this step, the applicant should describe how they mitigate the risk posed by a loss of control of the operation resulting in an infringement of the adjacent areas on the ground and/or in the air. For an AWE system this is where the advantage of 'tethered operation' can be utilized to demonstrate first of all a very low probability that the airborne part of the system will leave the volume constrained by the maximum length of the tether (flight geography), and secondly that contingency procedures are in place to keep the airborne part of the system within the operational volume (flight geography + contingency volume) at all times.[14]

14 Mitigation of tether failure is very important here.

4.10 Step #10 – Comprehensive safety portfolio

This is a final step in which any additional requirements not identified by the SORA process can be addressed.

5. Outlook to Commercial Operations

When considering what insights can be taken from the SORA process as well as its relevance in general towards commercial AWE operations, a number of questions arise:

- How many countries (which are also interesting AWE markets) will adopt the SORA process?
- What would be the SAIL requirement for a typical commercial operation?
- Who will serve as the 'competent third party' who can validate that a certain mitigation meets a high level of robustness?
- At what point is the operation no longer under the specific category and certification is required?

Some general comments to these questions from the perspective of the author will now be given. Please keep in mind these are preliminary and may not take all relevant points into considerations. The feedback from the working group members is anticipated and highly appreciated.

5.1 Countries adopting the SORA process

This question has been posed to the Swiss FOCA, an employee of which (Lorenzo Murzilli) is the leader of JARUS WG-6, the working group which has developed the SORA process. Their feedback will be incorporated in a next version of this document. However, in the meantime, the competent authorities as well as their country of origin, who were involved in the core group of WG-6 or gave contributions are shown in the table below. It can be reasonably assumed that these countries are at least considering to adopt the SORA process at some point. In total the list contains 23 sovereign countries, 14 of which are currently part of the European Union.[15]

	Name:	Description:	Country:
Core Group			
1	Swiss FOCA	Swiss Federal Office for Civil Aviation	Switzerland
2	DTCA	Traffic, Building and Housing Agency	Denmark*
3	FAA	Federal Aviation Administration	USA
4	TRAFI	Finnish Transport Safety Agency	Finland*
5	CAA NZ	Civil Aviation Authority of New Zealand	New Zealand
6	DGAC	Directorate General for Civil Aviation	France*
7	UK CAA	Civil Aviation Authority of the UK	United Kingdom*

15 It still needs to be checked what the Netherlands, Norway, and Ireland are planning.

8	SACAA	South African Civil Aviation Authority	South Africa
9	German DOT	Department of Transportation	Germany*
10	CASA	Civil Aviation Safety Authority	Australia
11	AESA	Spanish Aviation Safety and Security Agency	Spain*
Contributing			
12	CAA Kenya	Civil Aviation Authority of Kenya	Kenya
13	ANAC Portugal	Portuguese Civil Aviation Authority	Portugal*
14	CAA Romania	Romanian Civil Aviation Authority	Romania*
15	ENAC Italy	Italian Civil Aviation Authority	Italy*
16	ANAC Brazil	National Civil Aviation Agency of Brazil	Brazil
17	CAA Czech Republic	Civil Aviation Authority of the Czech Republic	Czech Republic*
18	CAA Latvia	Latvian Civil Aviation Agency	Latvia*
19	Trans. Authority Slovakia	Transport Authority of Slovakia	Slovakia*
20	DGCA Indonesia	Directorate General of Civil Aviation	Indonesia
21	CAA Poland	Civil Aviation Authority of Poland	Poland*
22	Croatian CAA	Croatian Civil Aviation Authority	Croatia*
23	CAAC	Civil Aviation Administration of China	China
*EU Countries			

5.2 SAIL for commercial AWE operations

With reference to the table shown in Fehler: Referenz nicht gefunden, the initial GRC assessment of a commercial AWE operation is expected to be between 4 and 6. This assessment is based on a few main assumptions:

- Any commercial AWE system will have a wing span >8m in order to have a large enough power generation capacity to achieve economic viability, at least considering grid connected systems.
- The system will operate effectively BVLOS. This removes the requirement of having a pilot or observer on site who is responsible for monitoring ground and air risk and reacting to the situation.
- The system will operate either over a controlled ground area or in a sparsely populated environment (i.e. rural settings). It is expected that AWE operations in populated environments (i.e. urban settings) will be opposed by reasons other than just safety (noise, visual disturbance, permitting,…).

With reference to the table shown in Figure 10: Table 3 from SORA V2.0 Guidelines [JARUS SORA v2.0 package], the following strategic mitigations are foreseen:

- M1 – tethered operation. With a medium degree of robustness, this can reduce the initial GRC by -2, but to a minimum value of 4.
- M2 – none. A parachute or other means of reducing the ground impact are not foreseen, as described in section Step #3 – Final GRC determination.

- M3 – ERP in place, operator validated and effective. It is assumed that the ERP robustness is at least medium, which would have no effect on the initial GRC.

Although a reduction of initial GRC due to 'tethered operation' maybe be possible, it is expected that in most commercial operations that controlling the ground area underneath where the system is operating is not a practical or economically viable option. This would either significantly limit the suitable sites for AWE, and therefore the market potential, or would require expensive capital investments in fences or higher operational costs in the form of security personnel. Based on this it is concluded that the most likely residual GRC for most commercial AWE operations would be 6.

With reference to the flow chart shown in Fehler: Referenz nicht gefunden, commercial AWE operations are mostly expected to take place in environments with an initial ARC of 'c'. Basically these are operations above 150 meters Above Ground Level (AGL) which are taking place in uncontrolled (class G) airspace over rural areas.

In terms of strategic mitigations, it is expected that the AWE industry will work together to define a standardized set of guidelines for the lighting and marking of commercial AWE systems, which will be recognized by the competent authorities to help minimize the chances of a mid-air-collision with a manned aircraft. In addition to this it is expected that commercial AWE systems will be operating in a fixed location for many years, so that it will be feasible to have their location marked on airspace charts, so that general aviation pilots are aware of their existence, location and the potential danger that they impose. The systems can also be equipped with anti-collision devices, like FLARM, so that other equipped aircraft will be alerted to their presence, as described in section Dedicated Observer w/ FLARM. Going forwards, Unmanned Traffic Management (UTM) systems and U-space [UTM and U-space], which are currently being developed and demonstrated for commercial UAV applications, present a great opportunity to safely and economically integrate commercial AWE systems into the airspace.[16]

However, if we take a conservative approach, then the residual ARC may still be considered by the competent authority to be 'c'. Combined with a final GRC of 6, this would result in a SAIL = 5, with reference to the table shown in Fehler: Referenz nicht gefunden. With references to the tables shown in Fehler: Referenz nicht gefunden, this would require compliance with all 24 OSOs, mostly to a high degree of robustness. For AWE installations in controlled or class B, C or D airspace, the resulting SAIL might increase to 6, so that all OSOs would require a high degree of robustness.[17] An overview of the OSOs as well as the compliance criteria are described in SORA Annex E. [JARUS SORA v2.0 package]

16 This maybe a good topic for some masters studies.

17 The OSOs give a comprehensive set of 'guidelines' which should be followed in order to ensure safe operations of an AWE system. It should be left open as to what the final SAIL assessment for a specific operation is, which is actually the whole point of the exercise. However, coming up with an interpretation of each OSO from an AWE perspective, and what specifically is needed for each level of robustness, would be the important exercise. For instance, "soft" wings will have reduced ground impact which may lead to a SAIL of 3-4, even for commercial systems.

5.3 Competent Third Party Validation

For commercial AWE operations, which will most likely have a SAIL = 5 or 6 and therefore OSO compliance at a high level of robustness, will have to be verified by a competent third party, the next obvious question is: who is that competent third party?

For operations in the specific category, the competent authority will be the CAA or another entity which they have appointed to perform this function on their behalf. This brings up another interesting question: do the CAAs actually have the capacity, or the know-how, in order to perform the third party validation needed to prove that the OSOs are being met at a high level of robustness?

Another consideration (based on Regulation (EC) No 216/2008) is that in European countries (under the jurisdiction of EASA), the CAA's would only be responsible for systems with a maximum airborne mass up to 150kg, above which EASA would take over as the component authority. For 'experimental' systems, the CAAs can still serve as the competent authority, but at some point (i.e. once many systems are in operation) then it is expected that EASA will take over.

So in the long run, it seems that EASA will be the competent authority for commercial AWE operations in any European country where they have jurisdiction. In the USA, it is clear that the FAA will remain the competent authority and it is expected that CAAs in other countries will probably turn to EASA or the FAA for guidance.

5.4 When is Certification Needed?

From an operational safety perspective, it would seem like the SORA process could be used as a framework for mitigating air and ground risk and getting an OA from the appropriate CAA even for commercial AWE operations. Although this may be the case, certification may be embraced from a reliability or economic perspective, a position which Ampyx Power has been promoting for a number of years.

From a European perspective, where the current EASA view recognizes tethered unmanned aircraft as UAVs, the main question is around the maximum airborne mass of the systems and if for systems above 150kg, the systems to be regulated in a similar way as manned aircraft. Assuming this would entail certification, the question then comes down to a legal discussion if systems above 150kg can be operated under the specific category. An overview of the open, specific and certified category is given in the EASA document [EASA's A-NPA 2015-10: 'Introduction of a regulatory framework for the operation of drones'], but this question is not addressed directly.

It is the author's hope that others within the working group will be able to shed some additional light on this topic, so that a more complete understanding of the certification topic as it pertains to commercial AWE operations can be gained. The publication from Volkan et all. [Volkan, S., Ruiterkamp, R., Kruijff, M., van Paassen, R., Schmehl, R.: Current and Expected Airspace Regulations for Airborne Wind Energy Systems. In: Schmehl, R. Advances in Airborne Wind Energy, Chap. 29, pp. 703-725, Springer, Berlin Heidelberg (2015).] which gives an overview of the existing regulatory frameworks and their relevance as starting points to the certification of AWE systems serves as an excellent starting point for this discussion.

6. References

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