G+ Safe by Design workshop: Blades workshop summary report

G+ Global Offshore Wind
Health & Safety
Organisation

In partnership with
energy institute

G+ SAFE BY DESIGN WORKSHOP: BLADES
WORKSHOP SUMMARY REPORT

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DISCLAIMER

1 EXECUTIVE SUMMARY

The first G+ Safe by Design workshop in the 2021 G+ work programme was focused on the issues associated with wind turbine blades. More specifically, around routine internal access and egress, routine maintenance, and emergency rescue from personnel accessing a blade.

The workshop, comprising problem identification and potential solution exercises, was held virtually on 10 June 2021. The workshop format was developed to explore these blade-related issues and potential solutions with a focus on design solutions.

Across the workshop, many common and interrelated issues and associated recommendations were identified. These are shown in section 4.

1.1 RECOMMENDATIONS

Following the conclusion of the workshop, a number of perceived high-risk areas and potential design mitigations by the participants associated with routine internal access and egress, routine maintenance and emergency rescue from personnel accessing a blade were identified. These include:

- Improved design of floors/walking surfaces within the blades to increase grip for personnel to reduce slip risk.
- Consideration of access requirements for hatch location and size design, plus the addition of appropriate foot and hand holds to aid access and egress to reduce trip and fall risk.
- Consideration of manual handling requirements of hatch covers in design to improve ergonomics.
- Incorporation of hinges on hatch covers and/or handling features on the covers to aid manual handling of these items.
- Addition of netting at key locations in the blade to prevent dropped items from falling into difficult to access areas, reducing time and risk associated with retrieving these items.
- Incorporation of drop prevention for items which must be removed during access to the blade (e.g. retainers for hatch cover bolts, or tethers for hatch covers).
- Consideration of ventilation and temperature control solutions within the blade during O&M activities to reduce the risk of a hazardous breathing environment or heat exhaustion from prolonged working in confined space.
- Addition of designed anchor points or designated locations for temporary anchoring rated for the use by personnel accessing the blade to aid manoeuvring/fall arrest while operating within the blade or carrying out a rescue operation.

This list of recommendations is not exhaustive and is based on the opinion of the attendees who participated in the workshop.

2 BACKGROUND AND INTRODUCTION

2.1 BACKGROUND

The G+ Global Offshore Wind Health and Safety Organisation (G+) comprises the world's largest offshore wind developers who have come together to form a group that places health and safety at the forefront of all offshore wind activity and development. The primary aim of the G+ is to create and deliver world class health and safety performance across all its activities in the offshore wind industry. The G+ has partnered with the Energy Institute (EI) to develop materials including good practice guidelines to improve health and safety performance. Through sharing and analysis of incident data provided by G+ member companies, an evidence-based understanding of the risks encountered during the development, construction and operational phases of a wind farm project has been developed. This information has been used to identify the health and safety risk profile for the offshore wind industry.

In 2014, the Crown Estate asked the G+ to take over the running and delivery of their Safe by Design workshops. The Crown Estate had run a number of these previously, covering topics such as diving operations, lifting operations, wind turbine design and installation and the safe optimisation of marine operations.

By bringing the Safe by Design workshops into the G+ work programme, the G+ aims to explore industry operations and technologies with a focus on Safe by Design principles. The G+ workshops examine the current design controls relating to a topic, discuss where current design has potentially failed, identify opportunities for improvement and then seek to demonstrate the potential risk reduction to be gained from these new ways of thinking and operating.

To date, eight workshops have been held under the auspices of the G+ covering: Marine transfer/access systems; Escape from a nacelle in the event of a fire; Lifting operations; Service lifts; Davit cranes; WTG access/egress; WTG access below the airtight deck, and Hydraulic torquing and tensioning. The outputs from seven of these workshops have been made available in reports which can be downloaded from the G+ website, to be used as a reference by the industry.

Details of the workshops can be found at the following link: https://www.gplusoffshorewind.com/work-programme/workshops

2.2 INTRODUCTION

From incident data analysis and other feedback received by the G+, WTG blades was identified as an area that should be looked at further. Therefore, under the direction of the G+ Focal Group, a Safe by Design workshop on blades was held virtually on 10 June 2021.

The discussion points and outputs from this workshop are documented in this report.

3 METHOD, AGENDA AND ATTENDANCE

3.1 METHOD

A one-day virtual workshop was held on 10 June 2021, bringing together stakeholders from across the industry to consider the issues associated with blades, specifically around routine internal access and egress, routine maintenance, and emergency rescue from personnel accessing a blade.

After opening remarks from Marcus Peters, Head of HSE Offshore (Global) and Head of HSE Culture and Contractor Engagement (Global), RWE Renewables UK, a problem definition and data analytics presentation explored and explained the incident data from work in blades. To conclude the opening session, and allow a smooth transition to the workshop exercises, a short overview of these was provided, as shown here.

Exercise 1 – Issue/hazard identification (HAZID):

- Brainstorming techniques were used to identify the issues and hazards associated with blade work.
- Three main areas were covered, with each of the three workgroups covering one of these areas:
  - Group 1: routine internal access and egress.
  - Group 2: routine maintenance.
  - Group 3: emergency rescue from personnel accessing blade.

The most significant issues and hazards were explored further in exercise 2.

Exercise 2 – Hazard analysis and solution development:

- Analysis of the most significant issues/hazards identified in exercise 1 was conducted and solutions developed, with the emphasis on design solutions.
- Like in exercise 1, three main areas were covered, with each of the three workgroups covering one of these areas:
  - Group 1: routine internal access and egress.
  - Group 2: routine maintenance.
  - Group 3: emergency rescue from personnel accessing blade.

At the end of each exercise, a summary of the initial findings from each group was presented to the attendees. To conclude the workshop, the next steps were outlined, including the publication of a report from the workshop to further inform the industry.

Note: the full results and details of the workshop exercises are shown in annexes A and B of this report.

3.2 AGENDA

Table 1 presents the agenda from the workshop event.

Table 1: Workshop agenda

AGENDA
Welcome/introduction Marcus Peters, Head of HSE Offshore (Global) and Head of HSE Culture and Contractor Engagement (Global), RWE Renewables UK
Problem definition and data analytics Aissa Tebani, Technical Manager – Energy Institute
Workshop exercise's introduction and overview Gordon Stewart, SHEQ Manager, Offshore Renewable Energy Catapult
1st Breakout session Group 1: routine internal access and egress Group 2: routine maintenance Group 3: emergency rescue from personnel accessing blade Each exercise led by a Catapult facilitator: Lorna Bennet, Hamish MacDonald and Katharine York
Break
Summary of 1st breakout
2nd Breakout Group 1: routine internal access and egress Group 2: routine maintenance Group 3: emergency rescue from personnel accessing blade Each exercise led by a Catapult facilitator: Lorna Bennet, Hamish MacDonald and Katharine York
Summary of 2nd breakout
Summary and closure of workshop Marcus Peters, Head of HSE Offshore (Global) and Head of HSE Culture and Contractor Engagement (Global), RWE Renewables UK
End of workshop

3.3 ATTENDANCE

Table 2 presents a list of all persons and organisations who participated in the workshop.

Table 2: Attendees and organisations

Organisation
EDF Renewables
Equinor
Macquarie
MHI Vestas Offshore
MPI Offshore
Ocean Winds
ORE Catapult
Orsted
RWE Renewables UK
Scottish Power
Siemens Gamesa
Tempest Wind
Total Energies
Vattenfall
Vestas
Worley

4 CONCLUSIONS

A comprehensive workshop focusing on risks and mitigations for three key areas related to internal access O&M activities for wind turbine blades was carried out with a variety of stakeholders.

An analysis and summarised conclusion from the results of the workshop is provided in this section, highlighting the most prevalent discussions and the associated risks and mitigations perceived as being the highest in terms of risk (i.e. high impact and high probability of occurrence).

Key topics of risks identified across all workshop groups which were perceived as being high risk are summarised in Figure 1.

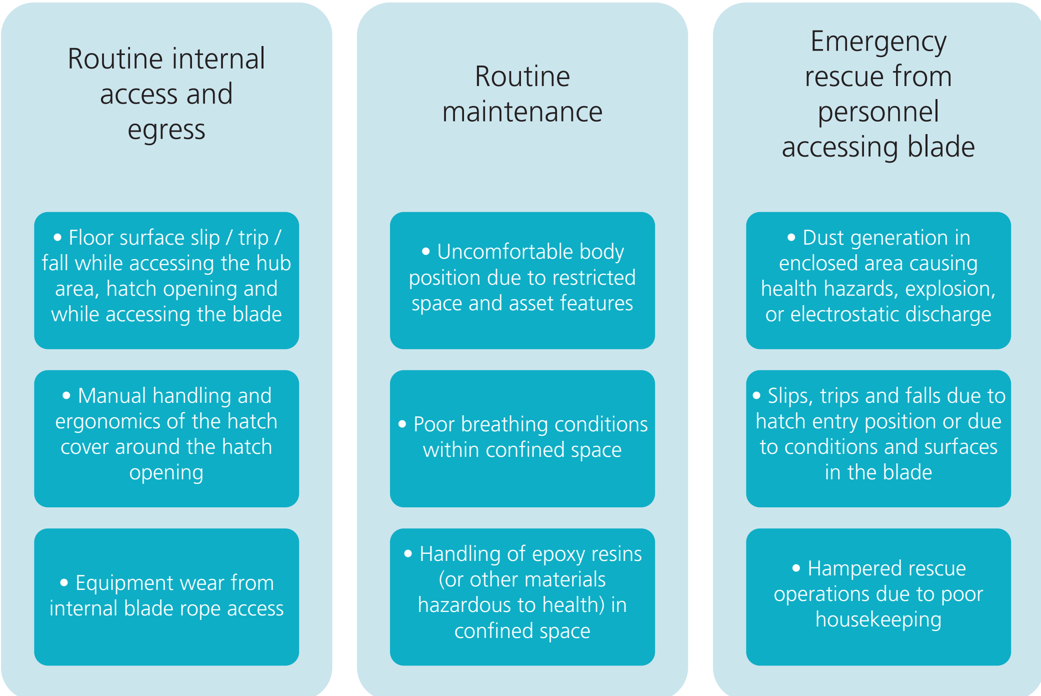

Figure 1: Risks with high impact and probability

Please refer to annexes A and B for a comprehensive list of all risks and mitigations identified during the workshop.

4.1 ROUTINE INTERNAL ACCESS AND EGRESS

The group was asked to discuss and identify any potential risks associated with wind turbine blade routine access and egress and to evaluate, where possible, the impact and probability that these risks could have on personnel safety and wellbeing.

Common themes arose during the workshop discussion with regard to:

- Floor surfaces and the access hatch into the blade.
- The position, size and shape of the access hatch.
- Manual handling of the hatch cover and its size and weight.
- Weight of equipment required to open and close the hatch.

The highest perceived risks by the workshop group and associated ideas for potential design changes to mitigate these risks are shown in Table 3.

Table 3: Highest perceived risks and identified design mitigations for routine internal access and egress

Risk		**Design mitigations**	
Slips/trips/ falls	Risk of injury due to slips/ trips/falls resulting from floor surfaces within the hub and blade not being designed to be walked on, i.e. surfaces can be smooth metal or laminates with little friction. Surfaces may also be rounded (not flat) making them more difficult to walk on. Risk is further increased where it is typical for oil/grease to be present in some locations.	**Alter floor design**	Design of surfaces for walking on to incorporate suitable surface finishes (i.e. PSV) to provide appropriate friction for the O&M life.
		Designated footholds/ steps	Incorporate specified safe step areas with appropriate surface finish, clearly marked with colour or signage.
	Risk of injury while entering the blade through a hatch which typically requires people to duck down or climb to enter. The rounded floor and limited head height can restrict movement around the entrance, increasing the chance of slips, trips or falls.	**Bulkhead design**	Design bulkheads with two hatches for access to both sides of the blade without the need for ladders or steps.
		Hatch shape and size	Increase the size of the hatch opening and/or alter shape to enable easier access. Also consider in conjunction with hatch handling risk.
		Designated holds/steps	Steps or proper footing and handholds up to the blade entrance.
		Anchor points	Design considerations and inclusion of suitable rated safety anchor points to support O&M requirements.

Table 3: Highest perceived risks and identified design mitigations for routine internal access and egress (continued)

Risk		Design mitigations	
Manual handling/ ergonomics of hatch covers	Risk of injury from manual handling of hatch covers during access/egress. Majority consist of flat plate bolted to bulkheads with no handles, handholes or hinges making them difficult to manoeuvre, lift and to hold in place as bolts are removed or replaced.	**Hatch hinges**	Addition of hinges to connect hatch to the bulkhead, making it easy to open without manual handling.
		Hatch handle/s	Addition of handles on hatch cover to improve grip while opening/ manoeuvring the hatch, reducing strain and risk of dropping.
	Risk of injury from working at height. Hatch positions usually require personnel to use a ladder and work at height to remove the hatch cover.	**Hatch designed for O&M**	Careful design considerations for O&M tasks when designing hatches, with specific thought to tools required to tighten hatch bolts in restricted space.
		Steps or footings to aid entry	Addition of steps or footings in the blade hatch entry to reduce the hazard of accessing and entering the blade through hatches.
Equipment wear from internal rope access	Risk of injury or damage to asset or equipment used for accessing the internal blade space. Limited, or a lack of appropriately located, anchor points for ropes access into a vertically positioned blade can create risks of overreaching for anchor points located within the blade root or pinch points for ropes that cross hard edges through the hatch.	**Anchor points**	Careful consideration of necessary anchor point locations to aid O&M requirements for rope access. These could be fixed or technician removable points.

4.2 ROUTINE MAINTENANCE

The group was asked to discuss and identify any potential risks associated with wind turbine blade routine maintenance and to evaluate, where possible, the impact and probability that these risks could have on personnel safety and wellbeing.

Common themes arose during the workshop discussion with regard to:

– Challenging ergonomics of working within confined spaces.
– Environmental conditions in confined space which lead to breathing/air quality risk.
– The handling of hazardous materials and chemicals in confined space with poor ventilation.
– Dropped objects increasing the risk to personnel.
– General welfare of technicians working for periods in confined space.

The highest perceived risks by the workshop group and associated ideas for potential design changes to mitigate these risks are shown in Table 4.

Table 4: Highest perceived risks and identified design mitigations for routine maintenance

Risk		**Design mitigations**	
Ergonomics working in confined space	Risk of injury due to the confined space and protruding structural features inside the blade. A technician may have to place themself in an undesirable position (e.g. kneeling, craning) to carry out a task in a certain location in the blade. Could cause injury in the short term or continuous exposure could lead to a long-term condition such as deep vein thrombosis (DVT).	**Altering internal blade design to accommodate for technicians**	Design of future blades considering technician O&M tasks and the positioning of structural features to enable improved ergonomics.
		Reduce amount of internal works using remote inspection and maintenance technologies	Design of blades to enable the implementation of remote technologies (e.g. remote inspection using cameras or maintenance using robotics).
Breathing conditions in confined space	The air quality inside the blade (i.e. oxygen availability, carbon monoxide exposure) is significant to technician health. There is also the risk posed by the dust caused from the blade materials, especially in tooling scenarios.	**Habitat zone with dust extraction**	Segregating the repair zone as a clean area using sheets, combined with suitable dust extraction.

Table 4: Highest perceived risks and identified design mitigations for routine maintenance (continued)

Risk		Design mitigations	
Handling of hazardous substances in confined space	The COSHH, slippage and environmental concerns were raised about the current methodology for handling of epoxy (or other composite matrix material) to carry out internal blade repairs. A large open-ended bucket is used that could tip over and spill.	**Qualification of alternative repair materials**	The use of (although none known currently) a different repair material that has reduced COSHH and environmental implications.
		Pre-mixing in access areas	Design for the use of pre-mixing of epoxy and hardener in open/ ventilated area before using in confined area to reduce impact of released gases/chemical.
		Design of new 'closed' design solution	Other design approaches to the mixing and application of epoxy resins, e.g. cartridge guns.
Dropped objects	Risk of injury from dropped objects due to impact or increased time in blade to resolve and retrieve loose objects.	**Netting**	Design for addition of netting which could be placed at a determined location to catch any falling objects before they fall too far down.

4.3 EMERGENCY RESCUE FROM PERSONNEL ACCESSING BLADE

The group was asked to discuss and identify any potential risks associated with emergency rescue from personnel accessing blades and to evaluate, where possible, the impact and probability that these risks could have on personnel safety and wellbeing.

Common themes arose during the workshop discussion with regard to:

- Presence of dust in the environment raising the risk of fire/explosion during emergency and rescue scenario.
- High temperatures within a blade increasing the risk of heat exhaustion during emergency and rescue scenario.
- Manual handling and ergonomics within the confined space increasing the difficulty to retrieve personnel.
- Risk of slips, trips and falls within the blade during rescue due to smooth surfaces and obstructing features within the blade.
- Poor housekeeping hindering the efforts of rescue operations.

The highest perceived risks by the workshop group and associated ideas for potential design changes to mitigate these risks are shown in Table 5.

Table 5: Highest perceived risks and identified design mitigations for emergency rescue from personnel accessing blade

Risk		**Design mitigations**	
Dust	Dust is generated by the repair activities. In the enclosed working environment of the blade this leads to risks during rescue: – Poor air quality. – Explosion risk. – Static shock.	**Reduce the risk of fire or explosion**	Incorporate ventilation or fire suppression systems as part of blade design.
		Improve the detection of conditions that could lead to fire or explosion	Particulate monitoring sensors built in.
Temperature exposure (heat exhaustion)	Risk of injury from effects of high temperatures experienced while operating within a confined blade space.	**Pre-installed cooling systems**	Incorporate the design of ventilation and cooling system for blade to improve temperatures for operating.
Manual handling/ ergonomics	Assist movement and security within the blade.	**Handhold positions within blade**	Design addition of handhold locations to assist with manoeuvring within the blade.
Slips/trips/ falls	The blade is accessed through a hatch. The position of the hatch may require people to duck down or climb up to enter.	**Alter access hatch position**	Design to incorporate 'walk in' access to greatly reduce the risk of slips, trips or falls during rescue.
	The rounded floor and the limited head height within the blade restrict the maneuvering area for a rescue.	**Steps and footholds**	Design in-steps or proper footings to aid the entrance into blades.
	The work activities within the blade contribute to the risk of slips. In particular, the humid atmosphere and the protective sheeting on the floor combine to create a slippery surface.	**Improve flooring/ surface finish within the blade**	Addition of anti-slip flooring or improve surface finish to aid grip on blade walking surfaces.
		Reduce humidity build-up	Integrate ventilation/ humidity reduction ducting in blade.

Table 5: Highest perceived risks and identified design mitigations for emergency rescue from personnel accessing blade (continued)

Risk		Design mitigations	
Poor housekeeping	Rescue attempts may be hampered by the tools and equipment within the blade for the normal work as there is no designated storage to keep the floor clear. This includes electrical hand tools such as grinders and COSHH materials.	**Designated storage of equipment**	Design places to put equipment so that it is stored off the floor of the blade.

4.4 OVERALL DESIGN MITIGATION

A review of the overall results from each of the workshops revealed a number of key themes of design mitigations identified by the group as being perceived to have a good potential to reduce risk. A summarised list of the perceived key mitigations from the workshops are shown in Figure 2.

Floor / walk areas

- Design of walking surfaces within blades to incorporate appropriate levels of grip and reduce risk of slipping.
- Design considerations of access / egress routes, minimising obstacles to reduce risk of trips and falls.

Manual handling features

- Addition of hinges to hatches or other large compents which require to be removed for access to reduce manual handling requirements.
- Addition of handles and design of components with handling in consideration for components which have to be removed for access (e.g. hatch covers).

Ergonomic design

- Hatches and openings size and shape designed with detailed consideration of O&M activities and requirements.
- Addition of hand- and foot-holds to aid entry and exit of confined spaces for O&M tasks as well as rescue.

Ventilation and temperature systems

- Inclusion of ventilation and temperature control systems for use during O&M.
- Systems should account for use of hazardous materials during O&M (e.g. vapour or dust extraction) as well as addressing potential hazards with dust build-up in an enclosed space.

Anchor points

- Addition of anchor points within the blade (e.g. use of physical hooks or areas for suction anchors) to enable the use of assistive or fall arest systems inside the blade.

Netting and object retention

- Addition of netting at specified locations within the blade to prevent droped objects from reaching difficult to access areas.
- Integrated retention features for items which require removal during access (e.g. hatch covers and associated bolts).
- Reducing risks associated with additional retrieval works.

Figure 2: Summarised key mitigation themes identified in workshops

ANNEX A
WORKSHOP EXERCISE 1

A.1 PURPOSE

The purpose of this exercise was to identify issues and hazards associated with working in wind turbine generator (WTG) blades. This was broken down into three areas:

1. Routine internal access and egress.
2. Routine maintenance.
3. Emergency rescue from personnel accessing blade.

These issue/hazards were captured and prioritised for solution development in exercise 2.

The objective supplied to the groups was to discuss and identify potential risks and evaluate, where possible, the probability and impact.

Out of scope within this exercise were solutions and mitigations to these risks, as these are covered within the next exercise.

A.2 METHODOLOGY

A structured collaborative workshop was designed by ORE Catapult in order to facilitate and engage with attendees of the workshops, promoting the identification of potential issues and hazards associated with each of the three focus areas. Three separate workshop groups were formulated to facilitate this for each of the focus areas. A spread of backgrounds and roles of attendees was planned prior to the session to ensure a diverse and appropriate audience was present at each workshop.

The interactive sessions were hosted on Microsoft Teams, where participants joined virtually and were dispersed into three separate breakout rooms, each with the different focus area. ORE Catapult provided two personnel to host these sessions:

– Facilitator – To host the session, encourage discussion, keep discussion on-topic, contribute to ideas and initiate conversations.
– Scribe – To capture discussion points and identify key themes in discussions for analysis and dissemination. An online collaboration board, Miro, was used to capture discussion points.

For this exercise, participants were asked to identify any potential hazards or risks from their experiences. These were captured on Miro using a high level 2x2 risk matrix to approximately capture the perceived probability and impact of the identified risks, as illustrated in Figure 3.

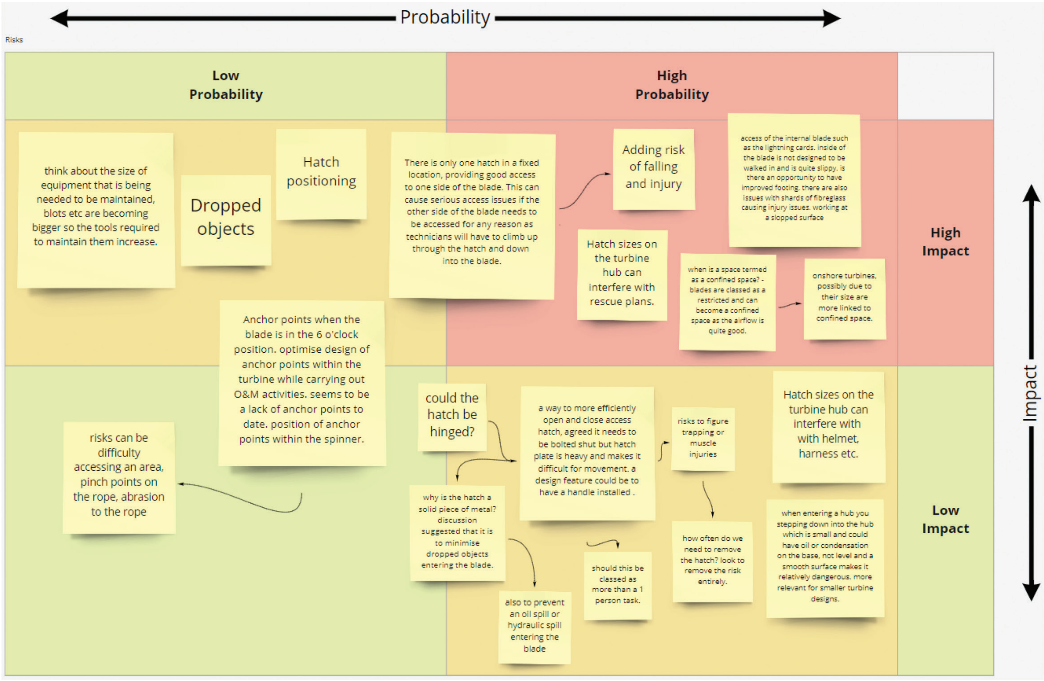

Figure 3: Miro risk identification workshop layout

The Miro board was presented live to workshop participants while the scribe made changes and additions. Comments and feedback were taken on board during the creation of the board content.

A.3 OUTPUTS

A.3.1 Routine internal access and egress

The group was asked to discuss and identify any potential risks associated with wind turbine blade routine access and egress and to evaluate, where possible, the impact and probability that these risks could have on personnel safety and wellbeing.

Common themes arose during the workshop discussion with regard to:

– Floor surfaces and the access hatch into the blade.
– The position, size and shape of the access hatch.
– Manual handling of the hatch cover and its size.
– Weight of equipment required to open and close the hatch.

It is important to emphasise that these risks are not exhaustive of all the risks posed by routine internal access and egress but what was covered in the sessions by the group of attendees. A summarised list of the points of discussions noted during the workshop are shown in Table 6.

Table 6: Identified risks – routine internal access and egress

Risk	Description	Impact	Probability
Floor surface slip/trip/fall – accessing the hub	Access to the internal blade is via the rotor hub. The floor surfaces within the hub have not been designed to be walked on, so are often smooth metal plates which can be slippery. This is often made worse by the common occurrence in many turbines of pitch system grease cups overflowing or leaking, causing a very serious slip hazard.	High	High
Dropped objects	The area around the hatch is usually narrow and opening the hatch is often a one-person task which includes loosening and removing the ring of bolts and storing them safely while holding the hatch cover in place. There is a risk of dropping and possibly misplacing the smaller bolt and washer components and a risk of injury to fingers, feet or legs if the hatch cover is dropped.	Low	High
Ergonomics and manual handling – hatch cover	As the majority of hatch covers consist of a flat plate bolted to the bulkhead with no handles, handholes or hinges, these can be incredibly difficult to manoeuvre, lift and hold in place as bolts are removed and replaced. This manual handling risk can result in back/muscle strain, trapped fingers and dropped heavy objects.	High	High
Ergonomics and manual handling – hatch cover	Consideration needs to be given to the size of equipment that is to be maintained; blots etc. are increasing in size and the tools required to maintain them also increase in both size and weight. With these increases comes the challenge of getting the necessary equipment up the turbine into the blade hub and operating it within a restricted space.	Low	High

Table 6: Identified risks – routine internal access and egress (continued)

Risk	Description	Impact	Probability
Ergonomics and manual handling – hatch position	There is usually only one hatch in a fixed location. This provides good access to one side of the blade. However, it can cause serious risks if the other side of the blade needs to be accessed. Personnel are required to use a ladder to climb up to remove the hatch cover, which is a challenging task on a level platform and adds the increased risk of falling from height in addition to the dropped objects mentioned earlier.	High	High
Ergonomics, slip/trip/fall – hatch opening	Hatch openings are often restricted to smaller sizes, usually round or square. These can be awkward to climb through, especially while wearing necessary PPE such as a climbing harness and helmet. There is a significant added risk of falling on the occasions that a ladder is required to climb through the hatch and drop down the other side of the bulkhead into the blade.	High	High
Slip/trip/fall – accessing the blade	The blade is accessed through a hatch. The position of the hatch may require people to duck down or climb up to enter. The rounded floor and the limited head height within the blade can restrict manoeuvring in and around the entrance increasing the risk of slips, trips and falling.	High	High
Floor surface slip/trip/fall – accessing blade	Access to the inside of the blade involves working on a slopped surface which has not been designed to be walked on and can be quite slippery, especially if grease has been transferred from the hub on the boots of personnel. There are also issues with shards of fibreglass which have caused injury when someone has slipped or fallen on these.	High	High
Slip/trip/fall and equipment wear – internal blade rope access	Limited, or a lack of, appropriately located anchor points for ropes access into a vertically positioned blade can create risks of overreaching for anchor points located within the blade root or pinch points for ropes that cross hard edges through the hatch.	High	High

A.3.2 Routine maintenance

The group was asked to consider the typical maintenance activities that occur internal to a wind turbine blade. To set the scene, the group had an initial discussion on the current requirements for such activities and the frequency of the routines carried out. Obviously, individual processes and procedures will be specific to different organisations, wind farms, and turbine models. Some initial considerations from these discussions included:

- Previously routine inspection and maintenance was adhoc or informed by other O&M activities. A more frequent rate of inspection is now commonplace, even annually.
- The blade root, sensors and access area would also be inspected separately as part of an overall turbine routine service (without rope technicians).
- Generally, an internal rope access team would consist of three personnel but could be slightly more/fewer depending on the region and scenario. Typically, one person would be based in the nacelle and two rope technicians can be required to be inside the blade at the same time.
- Technicians attending the inside of the blade could be from the turbine OEM, the owner/operator or a 3rd party service provider, depending on the warranty situation and other context.
- Repair tasks internal to the blade tend to be structural issues or related lightning protection systems (LPS) that require more complex intervention.

It is important to emphasise that these risks are not exhaustive of all the risks posed by routine maintenance activities but what was able to be covered in the sessions. There will certainly be other aspects included in a full risk assessment of activities inside a wind turbine blade. A summarised list of the points of discussions noted during the workshop are shown in Table 7.

Table 7: Identified risks – routine maintenance

Risk	Description	Impact	Probability
Electrocution risk	The increased carbon content of modern blades results in an electrocution risk if not grounded properly. This should be checked before entry.	High	Low
Uncomfortable body positioning	Due to the confined space and protruding structural features inside the blade, a technician may have to place themselves in an undesirable position (e.g. kneeling, craning) to carry out a task in a certain location in the blade. This could cause injury in the short term or continuous exposure could lead to a long-term condition such as DVT.	High	High

Table 7: Identified risks – routine maintenance (continued)

Risk	Description	Impact	Probability
General technician welfare	This covers a variety of different wellbeing considerations. Repair tasks internal to the blade can be complex and time-consuming. Concerns raised in the group session included stress levels, fatigue, and hydration levels.	High	Low
Breathing conditions in a confined space	The air quality inside the blade (i.e. oxygen availability, carbon monoxide exposure) are significant to technician health. There is also the risk posed by the dust caused from the blade materials, especially in tooling scenarios.	High	High
Use of corded power tools	For certain tasks, corded power tools (e.g. grinders and drills) are still preferred to battery-powered alternatives. The use of corded tools poses an entanglement and electrocution risk. The lighting required for the task should also be included.	High	Low
Dropped objects inside the blade	Dropped objects, particularly if the wind turbine blade is orientated in the vertical position, could cause injury to technicians or damage to the blade itself. The retrieval of objects down to the tip can be tricky and could cause further damage to the blade if not removed.	Low	High
Handling of epoxy	The COSHH, slippage and environmental concerns were raised about the current methodology for handling of epoxy (or other composite matrix material) to carry out internal blade repairs. A large open-ended bucket is typically used that could tip over and spill.	High	High
Use of heated blankets	Heated blankets are used to cure epoxy and hardener after composite repair. This poses a fire risk to the materials underneath. They typically require an electrical supply.	High	Low
Weather and climate conditions	The weather conditions outside still have a considerable influence on the risk posed to technicians inside the blade. This includes the potential blade oscillations in high winds and extreme temperatures inside the blade due to short-term weather or inherent to the climate.	High	Low

Table 7: Identified risks – routine maintenance (continued)

Risk	Description	Impact	Probability
Floating wind turbines	The specific risks relating floating offshore wind turbines was discussed. The attendees present did not have the experience to confirm, but the possibility of a more dynamic environment might pose more of a threat and could lead to more slips, trips and falls.	Low	Low

A.3.3 Emergency rescue from personnel accessing blade

The group considered plausible scenarios that could lead to injury and the difficulties of rescuing someone from inside a blade. While many of the risks discussed were likely to contribute to the need for an emergency rescue, they also had the potential to make a rescue more difficult.

It is important to emphasise that these risks are not exhaustive of all the risks posed by emergency rescue from personnel accessing blades, but what was able to be covered in the sessions by the attendees. A summarised list of the points of discussions noted during the workshop are shown in Table 8.

Table 8: Identified risks – emergency rescue from personnel accessing blade

Risk	Description	Impact	Probability
Dust	Dust is generated by the repair activities. In the enclosed working environment of the blade; this leads to: – Poor air quality. – Explosion risk. – Static shock.	High	High
Slips/trips/falls	The blade is accessed through a hatch. The position of the hatch may require people to duck down or climb up to enter. The rounded floor and the limited head height within the blade restrict the manoeuvring area for a rescue.	High	High
Slips/trips/falls	The work activities within the blade contribute to the risk of slips. In particular, the humid atmosphere and the protective sheeting on the floor combine to create a slippery surface.	High	High

Table 8: Identified risks – emergency rescue from personnel accessing blade (continued)

Risk	Description	Impact	Probability
Ergonomics and manual handling	The restricted working space creates hazards for rescuers handling a casualty. There is limited space for both the rescuer and the casualty within many blades and manoeuvring the casualty into a harness or onto a stretcher is difficult. Once on the stretcher, the casualty must be extracted from the blade and out of the hub.	High	Low
Housekeeping	Rescue attempts may be hampered by the tools and equipment within the blade for the normal work, as there is no designated storage to keep the floor clear. This includes electrical hand tools such as grinders and COSHH materials.	High	High

A.4 ANALYSIS AND FINDINGS

Many risks were identified across the three workshop groups. Of these risks a selection was perceived as being of high severity and high probability. These are shown in Figure 4.

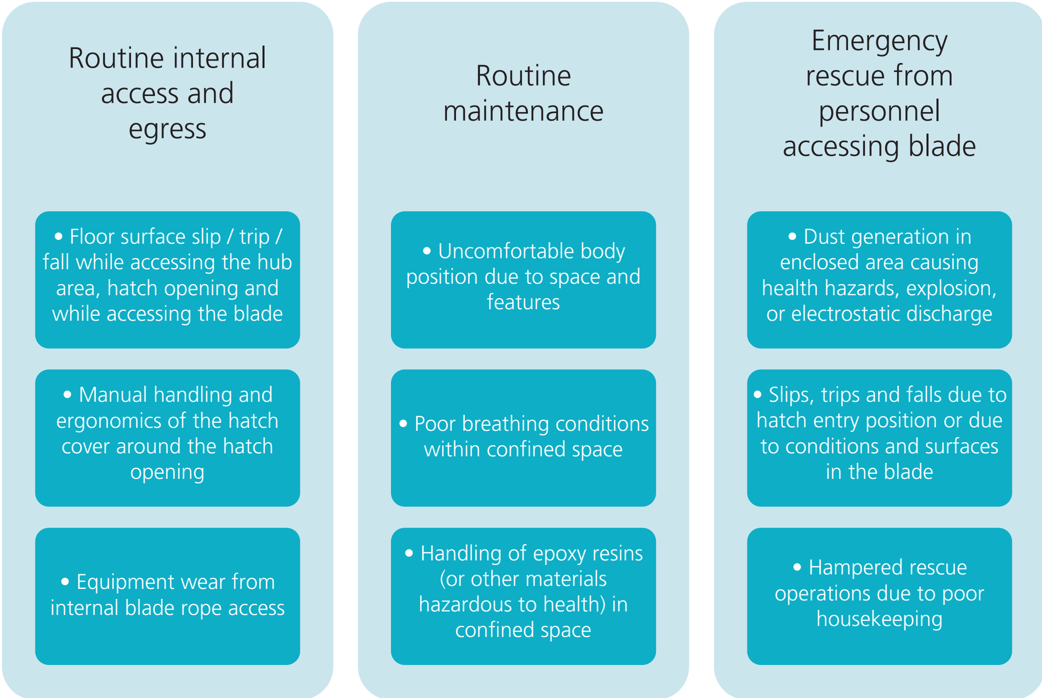

Figure 4: Risks with high impact and probability

ANNEX B
WORKSHOP EXERCISE 2

B.1 PURPOSE

The purpose of this exercise was to analyse the most significant issues/hazards identified in exercise 1 and develop solutions for these, with the emphasis on design solutions. Again, this was divided into three areas:

1. Routine internal access and egress.
2. Routine maintenance.
3. Emergency rescue from personnel accessing blade.

The objective supplied to the groups was to discuss and identify risk mitigations for risks identified from exercise 1.

B.2 METHODOLOGY

The same virtual workshop methodology was applied as in exercise 1. Participants were split into the same three groups and focus areas as before. However, in exercise 2 the focus of the topics was placed on potential mitigations for the identified risks in exercise 1, with an emphasis on design solutions.

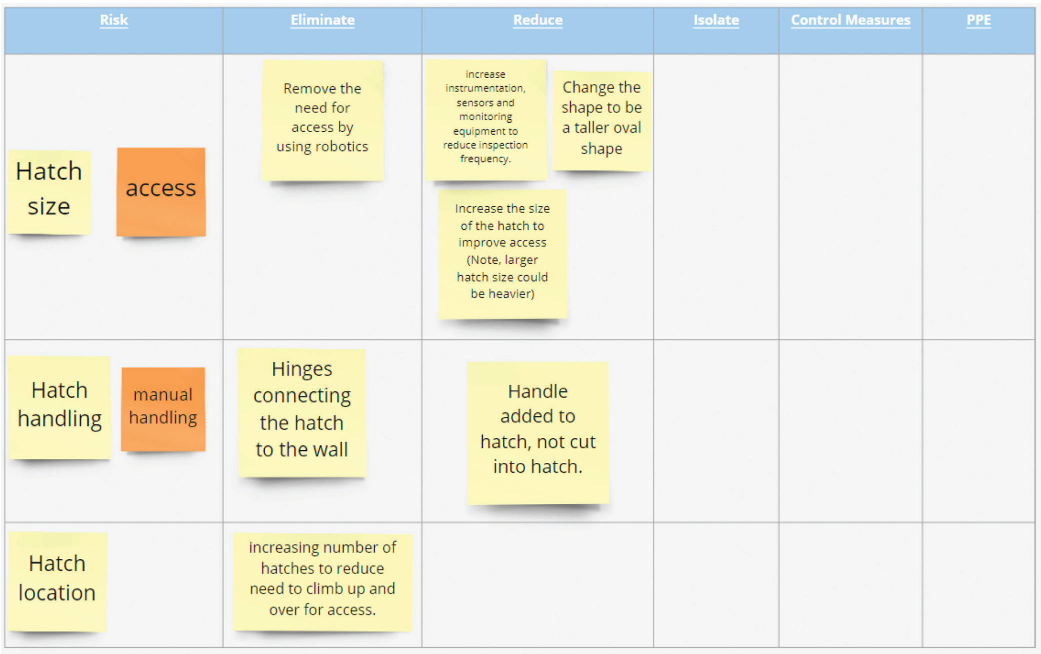

Figure 5: Miro mitigation workshop layout

The Miro board was preformatted with the key risks from those highlighted by the participants in exercise 1. Each risk was discussed, where participants were asked to identify potential mitigation solutions which could address the risk through reduction of impact and/or probability of occurrence, particularly with a focus on design solutions.

Mitigations which were identified were captured on the interactive board and approximately categorised by standard risk mitigation hierarchal type (eliminate risk, reduce risk, isolate risk, risk reduction control measures, personal protective equipment).

The layout of the Miro board used is illustrated in Figure 5.

B.3 OUTPUTS

B.3.1 Routine internal access and egress

The group was asked to discuss potential mitigations for the risks identified in the first workshop. Many of the solutions presented during the workshop related to reducing the need for access into the blade in the first instance and solutions for how to eliminate and reduce ergonomic and manual handling risks and slip, trip and fall hazards where access was unavoidable.

Table 9: Identified mitigations – routine internal access and egress

Risk	Mitigation	Description	Category	Residual risks
Floor surface slip/trip/ fall when accessing the hub and blade	Alter floor design	Design surface finishes of any surface that will be walked on with a suitable and necessary PSV value and provide a specification of the required and approved cleaner that will not degrade the PSV.	Reduce	
	Designated footholds/ steps	Incorporate specified safe step areas with an appropriate PSV as part of the design and clearly mark with signage or bright colours.	Reduce	
	Increase surface grip	Retrofitting grip tapes to surfaces.	Reduce	Adding coatings etc. can hide concerns that would be inspected in the laminate. Provides an additional item that requires regular inspection and maintenance. If grip tapes degrade, they can increase risks of slips/trips/falls.

Table 9: Identified mitigations – routine internal access and egress (continued)

Risk	Mitigation	Description	Category	Residual risks
Dropped objects	Retained bolts	Once unfastened, retained bolts remain connected to the hatch cover plate by a spring. System commonly used in the aerospace sector.	Eliminate	
	Netting	Netting could be placed at a determined location to catch any falling objects before they fall too far down.	Reduce	Suitable attachment and location for the netting so as not to interfere with, and add additional hazards, for access.
	Procedure	Ensuring that O&M procedures are adhered to for dealing with dropped objects.	Control measure	Procedures that are unclear, out of date, not appropriate or not followed.
Ergonomics and manual handling – tooling	Design	Careful design consideration to the necessary O&M tasks with specific thought to the tools required to tighten bolts in restricted spaces.	Reduce	
Ergonomics and manual handling – hatch cover	Hatch hinges	Connect the hatch to the bulkhead with hinges so that it can easily be opened without the need to manual handle the plate off and on to the bulkhead from the floor.	Eliminate	There may not be the space available within the bulkhead to allow the hatch cover to open sufficiently to permit access. May not be possible to retrofit to existing turbines.
	Hatch handle	Install a handle on the hatch cover to make it easier to grip and manoeuvre, reducing the risk of muscle strain and dropping.	Reduce	

Table 9: Identified mitigations – routine internal access and egress (continued)

Risk	Mitigation	Description	Category	Residual risks
Ergonomics, slip/trip/fall – hatch opening	Robotics	Remove the need for human access to the blades by utilising robotics inspection tools.	Reduce	Failure or loss of robotic vehicle that could damage the blade and require retrieval. Repair still required to be carried out by technician.
	Condition monitoring	Utilise instrumentation, sensors and monitoring equipment to reduce inspection frequency.	Reduce	Sensors can break and require inspection and recalibration.
	Improve access to the blade	Design bulkheads with two hatches for access to both sides of the blade without the need for ladders or steps.	Reduce	May not be possible to retrofit to existing turbines. Smaller models may not have the necessary area for two hatch openings.
	Improve access to the blade	Increase the size of the hatch opening to allow for easier access. Rectangular or oval shaped hatch openings to provide more height, enabling easier access.	Reduce	This could increase the weight, making handling of the hatch cover more difficult without additional mitigations. Hatch covers will need to be installed in a specific orientation and could therefore be misaligned if not replaced correctly.
	Improve access to the blade	Steps or proper footing up to the blade entrance.	Reduce	May introduce a further trip hazard or conflict with existing systems.

Risk	Mitigation	Description	Category	Residual risks
Slip/trip/ fall and equipment wear – internal blade rope access	Anchor point design	Careful design consideration to the necessary anchor point locations with specific thought as to the O&M requirements. Work positioning anchors within the blade.	Reduce	New anchors may introduce a further trip hazard or conflict with existing systems. Additional items to inspect during statutory inspections, increasing the frequency of access to hub/ blades.
	Improve access to the blade	Fully rated anchor points for removable/movable anchors that can be installed by technicians within the turbine when and where needed. Suction cup anchors (such as those used to lift panels or windows). Technicians can position anchors where they are needed as they work.	Reduce	Anchors could be left in the turbine after work is completed. Additional items to inspect during statutory inspections, increasing the frequency of access to hub/ blades.

B.3.2 Routine maintenance

As a number of risks were identified in the first session, it was not possible to collate a full range of potential solutions for all those risks, but several proposals are highlighted in Table 10. Some of these measures may already be utilised by certain organisations but may not be standard throughout the offshore wind industry.

Table 10: Identified mitigations – routine maintenance

Risk	Mitigation	Description	Category	Residual risks
Technicians conducting work inside blade	Use of robotic solutions	Robotic solutions, aerial drones, crawling or wheeled vehicles to carry out inspections. Internal repair tasks are complex and likely not capable to be carried out fully with today's state of technology. However, there may be possibilities for robotics to play an assistive role in the task.	Eliminate	Failure or loss of robotic vehicle that could damage the blade and require retrieval. Repair still required to be carried out by technician in the near future.
	Internal camera monitoring system	Use of either a permanent or temporary camera system on rails.	Eliminate	Maintenance of camera system. Dropped objects.
	Altering internal blade design to accommodate for technicians	Although probably not possible to change for existing turbines, new larger turbines could consider technician access in the placement or form of structural features.	Reduce	Still requires technicians to attend through rope access.
Uncomfortable body positioning	Knee and elbow protection	To mitigate against the effects of pressing joints against hard surfaces.	PPE	Confliction with other rope access equipment.

Table 10: Identified mitigations – routine maintenance (continued)

Risk	Mitigation	Description	Category	Residual risks
Handling of epoxy	Alternative materials for repairs	The use of (although none known currently) a different repair material that has less COSHH and environmental implications.	Replace	Spillages may still occur.
	Pre-mixing in access area	Pre-mixing of the epoxy and hardener could be performed in a more open and ventilated area e.g. in the nacelle near the blade root.	Control measures	Exposure to epoxy still possible. Transportation of curing mixture.
	A closed design solution or methodology to replace open bucket	Other design approaches are possible, such as cartridge guns.	Control measures	Exposure to epoxy still possible.
Dropped objects	Netting	Netting could be placed at a determined location to catch any falling objects before they fall too far down.	Reduce	Fixing of netting to composite surface. Determination of netting location as a separate task. Dropping of netting.
	Tethered tools and other objects	Some form of secondary retention or tethering.	Reduce	Injury to technician if dropped.
	Ensuring the minimum number of tools needed	Multi-tools may be an option for some tasks.	Control Measures	
Breathing conditions in a confined space	Habitat zone with dust extraction	Segregating the repair zone as a clean area using sheets, combined with suitable dust extraction.	Isolate	Communication channels.
	PPE	High spec breathing mask and other PPE whilst present in the habitat zone.	PPE	Interaction with other rope access equipment.

Table 10: Identified mitigations – routine maintenance (continued)

Risk	Mitigation	Description	Category	Residual risks
General technician welfare	Technician health monitoring	Certain sensors could be worn by the technician so their health could be monitored. This could consist of oxygen sensors, heart rate, breathing, body temperature or fall alerts.	Control measures	Personal data protection issues. Interaction with other rope access equipment. Comfort while trying to carry out task.
	Hands-free communication	Constant communication with supervisor without having to use a hand-held device.	Control measures	Interaction with other rope access equipment. Comfort while trying to carry out task.
	Hands-free hydration solution	Rather than carry a water bottle or travel up to the blade root to hydrate, a water pack could be included in rope access equipment. Could be crucial in hotter climates.	Control measures	Interaction with other rope access equipment. Risk of over-hydration and required use of welfare facilities.
	Consistent breaks	Simple time reminders to take breaks to offset fatigue.	Control measures	Ensuring that breaks are taken with time pressures of tasks.
	Selective technician clothing suitable for different weather conditions	This could be thermal or more breathable clothing that could be switched between or smarter clothing that would be suitable for a range of conditions.	PPE	Still has to be suitable and durable enough to handle maintenance tasks.

Risk	Mitigation	Description	Category	Residual risks
Power tools	Battery-powered tools	With advancing battery technology, cordless power tools could be sufficient to carry out lengthy repair tasks.	Eliminate	Battery tools can be heavier than their corded counterparts.
Use of heated blankets	Ultraviolet (UV) curing	UV curing would not pose such a fire risk.	Eliminate	Risks of UV.

B.3.3 Emergency rescue from personnel accessing blade

Many of the solutions presented during the workshop related to reducing the need for a rescue to take place. As these aspects were considered in more depth by other groups, where possible, this section relates the risks back to those experienced by a rescuer or a casualty.

Recurrent themes were the need to improve access, to increase the working space and to improve air flow.

Table 11: Identified mitigations – emergency rescue from personnel accessing blade

Risk	Mitigation	Description	Category	Residual risks
Harm to casualty or rescuer when recovering	Alter access hatch position	Next generation blades to incorporate walk-in access.	Eliminate	
	Improve housekeeping	Create places to put equipment so that it is stored off the floor of the blade.	Reduce	Potential obstruction at head/torso height. Items could drop Further cramps the space for manoeuvring a casualty.
	Enclose working environment	Canvas to stop things going deeper into the blade.	Control	
	Design with rescue in mind	Integrate clip-on points to blade for use with harness.	PPE	Additional items to inspect during statutory inspections, increasing the frequency of access to blades.
	Fit equipment to the task	Use a smaller harness for working in the blade.	PPE	Complexity of having multiple types of similar equipment.
	Reduce the need to access blades	Move lightning protection system out of the blade or provide a means to inspect without entering the blade.	Eliminate	Adds engineering complexity.

Table 11: Identified mitigations – emergency rescue from personnel accessing blade (continued)

Risk	Mitigation	Description	Category	Residual risks
Slip/trip/fall-related injury	Improve access to the blade	Steps or proper footing up to the blade entrance.	Reduce	May introduce a further trip hazard or conflict with existing systems.
	Improve flooring within the blade	Temporary flooring to give anti-slip surface.	Reduce	Manual handling to get the matting into the blade.
	Reduce build-up of humidity	Integrate ventilation/ humidity reduction ducting in blade.	Reduce	May get clogged. May interfere with blade integrity.
	Alter the inner finish	Keep flooring textured underfoot but smooth elsewhere for easier cleaning.	Reduce	
	Increase stability in high wind (floating wind turbines)	Keep flooring level and stable in wide range of sea states.	Reduce	
Casualty recovery after fire or explosion	Reduce the risk of fire or explosion	Ventilation or fire suppression built in.	Eliminate	
	Improve the detection of conditions that could lead to fire or explosion	Particulate monitoring sensors built in.	Reduce	
Cuts	Reduce risk of falling into or within the blade	Provide handles.	Reduce	May conflict with other uses of space.
	Rapid treatment	First aid kit in key places.	Control	
	Avoid harm from sharp edges	Wear gloves and kneepads.	PPE	

Table 11: Identified mitigations – emergency rescue from personnel accessing blade (continued)

Risk	Mitigation	Description	Category	Residual risks
Manual handling/ ergonomic injuries	Remove the need for human intervention in restricted workspaces	Sensors/ robotics to remove human interaction.	Eliminate	
	Assist movement and security within the blade	Places to hold onto inside blade.	Reduce	May conflict with other uses of space.
Rescuer welfare	Improve air quality	Improve the air exchange system.	Reduce	
	Reduce heat exhaustion	Pre-installed pipework for cooling.	Reduce	May reduce access space or interfere with carrying out tasks inside the blade.
	Keep cool	Active cooling in PPE.	PPE	

ANNEX C
ABBREVIATIONS

DVT	deep vein thrombosis
EI	Energy Institute
G+	G+ Global Offshore Wind Health and Safety Organisation
HAZID	hazard identification
HSE	Health and Safety Executive
H&S	health and safety
OEM	original equipment manufacturer
O&M	operation and maintenance
PPE	personal protective equipment
PSV	polished stone value
QC	quality control
RAMS	risk assessment and method statement
SbD	safety by design
WTG	wind turbine generator

Energy Institute
61 New Cavendish Street
London W1G 7AR, UK

t: +44 (0) 20 7467 7100
f: +44 (0) 20 7255 1472
e: pubs@energyinst.org
www.energyinst.org

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